Fifth Review of PJM's Variable Resource Requirement Curve

FOR PLANNING YEARS BEGINNING 2026/27

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Executive Summary

We have been commissioned by PJM Interconnection (PJM) to evaluate the parameters and shape of the administrative Variable Resource Requirement (VRR) curve used to procure capacity under the Reliability Pricing Model (RPM), as required periodically under the PJM Tariff.[1] For this Fifth Quadrennial Review, we have had more substantial opportunities to gather stakeholder feedback than in past reviews, including several rounds of stakeholder presentations and feedback sessions on preliminary analysis, in addition to individual meetings with stakeholder groups and the Independent Market Monitor (IMM).

Additionally we conducted this Fifth Quadrennial Review with special attention to PJM's Board and stakeholder stated priorities, which have emphasized three specific focus areas:[2]

- **Appropriate levels of procurement** needed to support the PJM's one-event-in-ten-years ("1-in-10"), or 0.1 loss of load events (LOLE) per year reliability standard;
- **Uncertainty in Net CONE** and the reference technology used for anchoring the VRR Curve; and
- **Changing resource mix in PJM and impact of potential reforms** that may materialize from the Resource Adequacy Senior Taskforce (RASTF).

We have conducted the entirety of this Quadrennial Review in light of the overarching design objectives of the RPM, with a particular emphasis on these focus areas.

RECOMMENDED CANDIDATE VRR CURVE AND WORKABLE RANGE

To assess the performance of the current VRR Curve and alternative curves, we have conducted both qualitative analyses and probabilistic simulation analyses, as required in the Tariff. In Figure 1 we summarize our recommended "Candidate Curve" (orange) to replace the current VRR Curve. The recommended Candidate Curve has a similar conceptual basis and similar simulated performance as compared to the current curve, but we recommend several adjustments as

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[1] PJM Interconnection, L.L.C. (2022). PJM Open Access Transmission Tariff. Effective January 1, 2022, ("PJM 2022 OATT"), Section 5.10 a.iii.

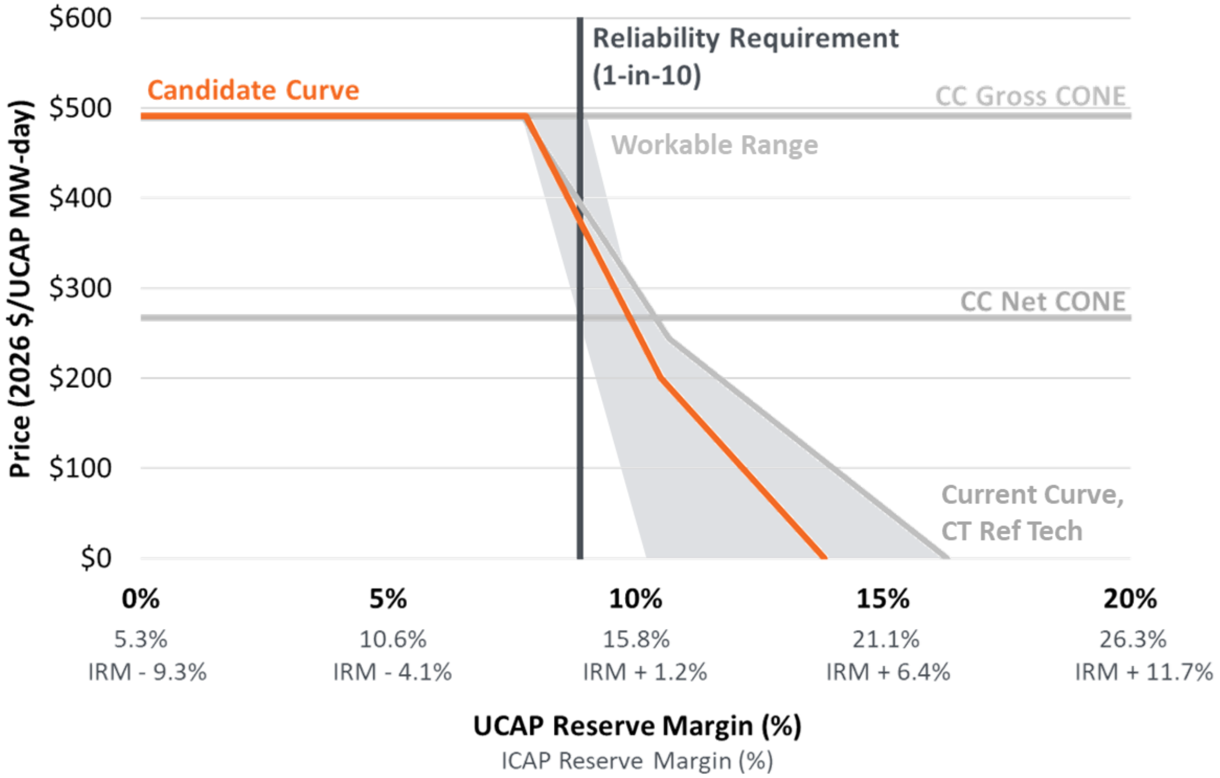
[2] PJM, Board Letter Regarding Capacity Market Minimum Offer Price Rule and Initiation of the Critical Issue Fast Path Process, April 6, 2021; PJM, Resource Adequacy Senior Task Force, 2022.

compared to the current VRR Curve (grey) to balance among competing objectives in the RPM. Relative to the current VRR Curve, we recommend that the updated curve should:

- Adopt a combined cycle gas turbine (CC) as the reference technology, as documented in our separate study PJM CONE 2026/2027 Report*,* "2022 Net CONE Study."
- Maintain a medium-to-high price cap in the system-wide demand curve. We suggest raising the price cap formula to be the maximum of either 1.75 × Net CONE or Gross CONE. This would change the current Net CONE multiple from 1.5 to 1.75 and would ensure that the VRR price cap remains sufficiently high in the face of Net CONE uncertainty, even if future conditions differ from current Energy and Ancillary Service (E&AS) revenue offsets.
- Update the formula for the quantity points of the VRR Curve in unforced capacity (UCAP) MW terms, without reference to the Installed Reserve Margin (IRM), which is an ICAP metric.
- Maintain a quantity at the price cap equal or greater than 99% of the Reliability Requirement.
- Adjust the current curve shape to be slightly steeper to mitigate Net CONE uncertainty and reduce the curve foot to mitigate the potential for over-procurement. The specific quantity parameters in our Candidate Curve are 99%, 101.5%, and 104.5% of the Reliability Requirement for points A, B, and C respectively).

While we suggest one Candidate Curve as illustrated in the following figure, we acknowledge that there is a "workable range" of curves (shown approximately as the grey shaded area) which all would offer sufficient system reliability but with a differing balance of performance trade-offs.

FIGURE 1: RECOMMENDED "CANDIDATE" VRR CURVE
AND WORKABLE RANGE OF POTENTIAL VRR CURVE PARAMETERS



Sources/Notes: Candidate Curve price cap at Max(1.75 × CC Net CONE, **CC CONE**); Current Curve, CT Ref Tech price cap at Max(**1.5 × CT Net CONE**, CT CONE), bolded text indicates which parameter sets the price cap for each curve.

RECOMMENDATIONS RELATED TO VRR CURVE IMPLEMENTATION

Throughout this Quadrennial Review, we have identified a number of opportunities to improve the performance of the VRR Curve. These recommendations are driven by the overarching design objectives of the RPM and VRR Curve, which are to procure the volume of capacity needed to meet the 1-in-10 reliability standard in expectation while managing variability and uncertainty around that expectation, in addition to ensuring acceptable performance with respect to reliability outcomes, clearing price volatility, and mitigating the impacts from Net CONE uncertainty. Several of our recommendations related to our assessment of VRR Curve performance in light of the PJM Board and stakeholders' identified focus areas of achieving appropriate levels of procurement, managing uncertainties in Net CONE, and aligning with the changing resource mix and parallel market reforms.

Our recommendations are as follows:

1. **Eliminate over-forecast bias in the load forecast.** While acknowledging that the RPM must be robust to managing some unavoidable (but unbiased) load forecast error, we recommend

that PJM should eliminate the over-forecast bias historically seen in the load forecast. We understand that PJM has committed to and is in progress of addressing this issue. Changes adopted since approximately 2016 have indeed reduced the level of over-forecasting; however, we cannot conclude that PJM has fully eliminated the over-forecast bias based on evidence available to date. Though it is out of our scope to conduct a complete assessment of the load forecast methodology, we suggest the following adjustments to enhance the accuracy of the PJM load forecast and the ability of the RPM to manage the remaining unavoidable forecast error:

- In each load forecast report, explicitly estimate and report the uncertainty bands around the weather-normal peak load forecast by forward year (total error including model error and error in the independent variables), so as to better inform investment decisions, stakeholders, and future Quadrennial Reviews.

- Adopt a continuous improvement process for enhancing the load forecast over time, including: (1) retrospective annual reviews by PJM staff to diagnose the causes of realized forecast error (both weather-normalized and actual); and (2) periodic independent reviews of load forecast accuracy to identify opportunities for improvement. With continued changes to how electricity will be used by consumers, we anticipate that regular updates to the load forecast may be necessary to achieve the greatest possible load forecast accuracy.

- Align the Energy Efficiency (EE) resource participation model with the load forecast. Acknowledge that a centralized load forecast cannot realistically predict all EE activity across the PJM footprint. Therefore, we suggest that PJM reverts to the original concept for EE, namely, that supply-side EE can participate in the RPM if it demonstratively displaces the need for capacity that would otherwise be procured. Under this approach, PJM could develop the most accurate possible load forecast based on historical data, projected technology penetration rates, laws/regulations, and other predictors. This forecast would determine baseline assumptions with respect to the anticipated level of EE. At the same time, market participants could qualify energy efficiency as supply-side resources in the capacity market if they demonstrate that the EE measures are not already accounted for in the load forecast. EE resource UCAP ratings would decline over time as the baseline level of EE incorporated into the load forecast increases (declining to zero at the earlier of the EE measure life or when the load forecast is able to fully incorporate the measure). The EE add-back would then be eliminated from explicit consideration the VRR Curve, thus simplifying the VRR Curve and eliminating the need for iterative auction clearing associated with the EE add-back.

2. **Improve accuracy, transparency and consistency in capacity supply and demand accounting.** The need for enhanced accuracy in resource accounting has already been acknowledged by PJM and stakeholders as a priority to address in ongoing RASTF efforts. Through our assessment of historical levels of procurement, we have identified several opportunities to enhance resource accounting and reporting:

   - Transition to exclusive use of unforced capacity (UCAP) and forecast pool requirement (FPR) for all reliability and resource adequacy purposes. UCAP/FPR are a more accurate measure of capacity needs and commitments and are therefore already used for many purposes in the RPM including resource accounting and settlements. However, the less precise installed capacity (ICAP) and the Installed Reliability Margin (IRM) are still the primary (or intermediary) metrics presented for the purposes of: (a) setting the reliability standard (before converting to UCAP); (b) defining the quantity points on the VRR Curve (before converting to UCAP); and (c) issuing seasonal reliability assessments. We recommend PJM to utilize UCAP/FPR as the primary basis of measurement for all of these purposes.

   - Consider explicitly tracking reliability needs and supply commitments in the winter season. Our assessment of procurement levels has been inconclusive with respect to the winter season, given that supply and demand accounting within RPM is primarily associated with the summer season.

   - Consider updating other reliability and resource adequacy accounting reports (such as in seasonal reliability assessments) with the more accurate UCAP-based accounting approach utilized within the RPM. A portion of the stakeholder concerns about over-procurement may stem from a lack of consistency between RPM-based resource commitments and how seasonal reliability assessments are reported. Clarified reliability assessment reports can also clarify the distinction between resources that have RPM capacity commitments versus those that do not, given that non-committed resources may not be available to contribute to system reliability needs (e.g. due to export commitments or retirement).

3. **Adopt a gas-fired CC plant as the reference technology, while maintaining readiness to adopt a "clean" reference technology when needed.** The details of our recommendations related to the reference technology and Net CONE estimation are provided in our separate

2022 Net CONE Study. The pertinent subset of these recommendations relevant to this VRR Curve Study report are to:

- Adopt a gas CC as the reference technology to utilize in the system VRR Curve, as discussed in our 2022 Net CONE Study.
- Monitor States' environmental and clean energy policies across the PJM footprint to determine whether at any point it becomes clear that new fossil resources may not be feasible to develop in certain Locational Deliverability Areas (LDAs), particularly in the Commonwealth Edison (ComEd) and Public Service Electric & Gas (PSEG) regions of Illinois and New Jersey, respectively. If it becomes infeasible to develop fossil resources in these locations, adopt a clean reference technology in the affected LDAs.
- Continue to improve the ability to accurately estimate the Net CONE of one or more clean energy technologies such as batteries, solar, wind, and hybrid resources to enable the adoption of a clean reference technology if needed.

4. **Defer consideration of any additional left-shifting in the Base Residual Auction (BRA) VRR Curve.** Some stakeholders have suggested that the three-year forward BRA VRR Curve should be left-shifted to address over-procurement, with any remaining needs procured in the shorter-term Incremental Auctions (IAs). We agree that the best measurement of procurement relative to the reliability standard is the measurement immediately prior to the Planning Year. However, we do not recommend reducing procurement in the BRA below what is expected to achieve the 1-in-10 standard as of the time of the BRA because: (a) the above-recommended reforms will largely address the potential for over-procurement; and (b) there is little evidence that sufficient supply would be consistently offered in the short-term IAs to meet reliability needs in the case of a shortfall in the BRA. If the above-recommended reforms do not sufficiently achieve appropriate levels of procurement, we recommend that shifting some procurement into the shorter-term IAs should be studied and considered again in the next Quadrennial Review.

5. **Consider further adjustments to locational demand curves and associated auction clearing to moderate price volatility and manage reliability needs.** Consistent with our findings in prior Quadrennial Review, we anticipate that using one formula for VRR Curves across all sizes of LDAs will not provide a uniformly strong balance of RPM objectives. Particularly in small LDAs that are more susceptible to disproportionately large swings in supply, demand, and transmission constraints, prices can be more volatile, and reliability may be more severely affected by a shortfall. To address this concern, consider a transition to a Marginal Reliability

Impact (MRI)-based approach to setting locational VRR Curve and locational market clearing, similar to what is used in New England (or to what we have recommended in prior Quadrennial Reviews). Under the New England MRI-based curve approach, the locational VRR Curve would represent not the absolute price but the price premium (above parent LDA or system price) that would be paid to resources located in an import-constrained LDA. This demand curve approach has the potential to moderate price spikes in smaller LDAs, offer a more stable and moderated local price premium, and one that is more aligned with reliability value.

6. **As part of the ongoing RASTF, adopt conforming changes to improve performance of the VRR Curve.** Though the outcomes of the ongoing RASTF are not determined, we note several interactions among the VRR Curve and other design elements that should be updated on a joint basis to ensure consistency. Specifically:

    - Update the administrative Net CONE estimate to align with any changes to resource UCAP accounting, performance obligations, penalties, carbon pricing, or other factors that could materially affect the cost of developing new supply.

    - If PJM and stakeholders pursue a seasonal capacity market, take a fresh look at the VRR Curve shape and parameters. A seasonal capacity market may require different quantity points, reference technology, pricing parameters, and shape.

    - Simplify auction clearing by: (a) eliminating the iterative and heuristic steps associated with seasonal matching, locational clearing, and EE add-back, replacing these steps with a one-step optimized clearing; and (b) simplifying IA clearing based on a gross (rather than net) clearing optimization approach. These simplifications will improve market transparency, price formation, efficiency, and allow for other complexities that may be considered.

7. **Consider broadening the scope of future Quadrennial Reviews to the original, more comprehensive scope, as a full review of the RPM.** If there is a prospect that substantial ongoing refinements will be needed to RPM to continue supporting reliability throughout ongoing fleet transition, consider utilizing future Quadrennial Reviews as an opportunity for a regularized review and refinements.

I. Demand Curve Design Objectives

PJM's capacity market, called the Reliability Pricing Model (RPM), ensures long-term grid reliability by securing the required volume of capacity resources needed to meet predicted electricity demand in the future.[3] The RPM functions through an auction mechanism and consists of the Base Residual Auction (BRA), which procures capacity on a three-year forward basis, and three Incremental Auctions (IA), which serve to procure or release capacity closer to the Planning Year to right-size supply relative to reliability needs.[4]

The RPM employs a downward sloping demand curve, the Variable Resource Requirement (VRR) Curve, which is designed to fulfill the objectives summarized in Table 1. Some objectives such as meeting the 1-in-10 LOLE system-wide reliability standard and the 1-in to 25 conditional LOLE standard for the Locational Deliverability Areas (LDA) are codified in the PJM Tariff and PJM Manual, while others are our own interpretation of RPM's overarching role to support reliability and economic efficiency in a financially sustainable merchant investment context. These design objectives drive our assessment of VRR Curve performance, consistent with our approach in past Quadrennial Reviews.[5] We emphasize that there are inherent performance trade-offs between reliability outcomes, price volatility, procurement cost, and potential for over-procurement with a given VRR Curve shape and that any workable VRR Curve must ensure adequate performance while reasonably balancing these competing objectives.

We note that in addition to these design objectives, we conduct this Quadrennial Review while taking account of the three focus areas identified by PJM's Board and stakeholders, namely: appropriate levels of procurement, Net CONE and reference technology uncertainty, and interactions with ongoing reform efforts in the RASTF.

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[3] PJM, Capacity Market (RPM), 2022.

[4] The forward period for the first IA is 20 months, the second IA 10 months, and the third and final IA is 3 months prior to the Planning Year.

[5] See PJM 2022 OATT, Section VI, Attachment C, Section 16; PJM, Manual 18, Section 2.2; Newell, *et. al.*, Fourth Review of PJM's Variable Resource Requirement Curve, Section IV.A, April 19, 2018; and Pfeifenberger, *et. al.*, Third Triennial Review of PJM's Variable Resource Requirement Curve, Section V.A.1, May 15, 2014.

TABLE 1: SUMMARY OF DESIGN OBJECTIVES OF VRR CURVE

Demand Curve Design Objectives	
Reliability	• Maintain 1-in-10 LOLE system-wide target on a long-term average basis; maintain 1-in to 25 conditional LOLE in each locational deliverability area. Reliability as measured immediately prior to the Planning Year • Avoid market clearing outcomes that result in insufficient capacity and out-of-market intervention • Maintain reliability across a range of potential market conditions, while mitigating the potential for over-procurement
Prices	• Prices high enough to attract entry when needed for reliability; prices low enough to enable efficient exit and retirements during surplus • Manage price volatility due to small changes in supply and demand • Mitigate susceptibility to exercise of market power • Allow prices to move sufficiently to reflect changes in market conditions • Few outcomes at the administrative price cap
Other	• Strike a balance among competing objectives • Aim for simplicity, stability, transparency, and consensus

Source/Notes: PJM, Manual 20, Section 1.4 PJM Installed reserve Margin (IRM), 2021; Section 4.1 Overview; Newell *et. al.*, Fourth Review of PJM's Variable Resource Requirement Curve, April 19, 2018.

II. Target and Realized Procurement Levels

The RPM has consistently procured capacity volumes beyond the Reliability Requirement, an outcome that produces high reliability but also higher consumer and societal costs than needed to meet the market's design objectives. The PJM Board has identified the need for "appropriate levels of capacity procurement" as a focus area for this Quadrennial Review.[6] To that end, we document the magnitude and reasons for the current levels of procurement in the RPM, and suggest RPM reforms to address stakeholder concerns of over-procurement, as summarized in Table 2.[7]

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[6] PJM, Board Letter Regarding Capacity Market Minimum Offer Price Rule and Initiation of the Critical Issue Fast Path Process, April 6, 2021.

[7] See Consumer Advocates & Environmental Organizations, Letter Regarding Long-Term Load Forecasting, December 2, 2021; Environmental Stakeholders, Letter Regarding Phase II Capacity Market Reforms, August 8, 2021.

The largest reason for the current procurement levels has historically been an upward bias in the load forecast that has resulted in procuring excess capacity in the three-year forward auction compared to what has been needed in the Planning Year. The most appropriate response to this issue is to eliminate the upward bias in the load forecast and engage in a process of continuous improvement to the forecast; PJM has already committed to improving the accuracy of its load forecast.

We have also identified several other factors contributing to historical procurement levels. Some of these are drivers that PJM has already addressed, including eliminating the prior 1% right-shift of the VRR Curve and preventing the EE gross-up to inflate procured quantities beyond the offsetting EE resource commitments. Other drivers for procurement in excess of reliability requirements could be addressed within the scope of the RASTF, including improving the accuracy of reliability modeling and Reliability Requirement, improving capacity resource accounting, improving resource obligations and performance incentives, and explicitly accounting for winter capacity needs. We note that the effort to enhance capacity resource accounting and performance may or may not materially change the apparent volumes of capacity procurement, but will improve reliability and economic performance regardless. Further, we note that our assessment of procurement levels in the winter season remains inconclusive as to whether the winter season has excess or deficient capacity supply; we therefore highlight the importance of formalizing winter capacity accounting.

The VRR Curve can be adjusted to better achieve appropriate levels of procurement by adopting a lower and more accurate estimate of Net CONE and adjusting the shape of the curve to limit the potential for over-procurement in capacity long conditions. We see additional opportunities to right-size capacity procurement by updating the framework for supply-side EE participation to align with the load forecast and by improving transparency and consistency in reliability accounting.

TABLE 2: OPPORTUNITIES TO ACHIEVE APPROPRIATE LEVELS OF PROCUREMENT

Changes already implemented or being pursued by PJM	• Improve load forecast accuracy and eliminate over-forecast bias • Eliminate 1% right-shift of VRR Curve • Eliminate discrepancy between EE gross-up and cleared quantities
Areas in scope in the RASTF	• Determine the appropriate level of capacity procurement • Explicitly measure capacity requirements and supply commitments in winter season and more fully integrate seasonal resources • Improve capacity qualification methods and performance requirements for capacity resources
Other opportunities for improvement	• Change reference technology from CT to CC • Adopt forward-looking estimate of E&AS revenues • Adjust the VRR Curve shape to mitigate potential for excess procurement in long capacity conditions (reduce the x-axis quantity at point "C") • Explore possibility of qualifying EE as supply-side resources in the capacity market if suppliers demonstrate that the EE measures are not already accounted for in the load forecast, thereby eliminating the EE add back • Improve accounting consistency and clarity by using UCAP accounting for all purposes in RPM and seasonal reliability assessments; distinguish between supply MW with and without capacity commitments in seasonal assessments

A. Historical RPM Procurement Levels

The RPM has consistently procured capacity above the Installed Reserve Margin (IRM) requirement, which has resulted in excess capacity between 9,500 MW – 11,912 ICAP MW over the most recent five Planning Years (2018/19 through 2022/23) years according to the Independent Market Monitor (IMM).[8] As illustrated in Figure 2, however, we understand that stakeholders may have multiple potential definitions of the reserve margin in mind, depending on when procured supply is measured (either as of the BRA or after the final IA) and which load forecast this supply is compared to (either the three-year forward BRA Load Forecast or the Final Load Forecast as of the Final IA). For example, the measurement of procurement levels reported

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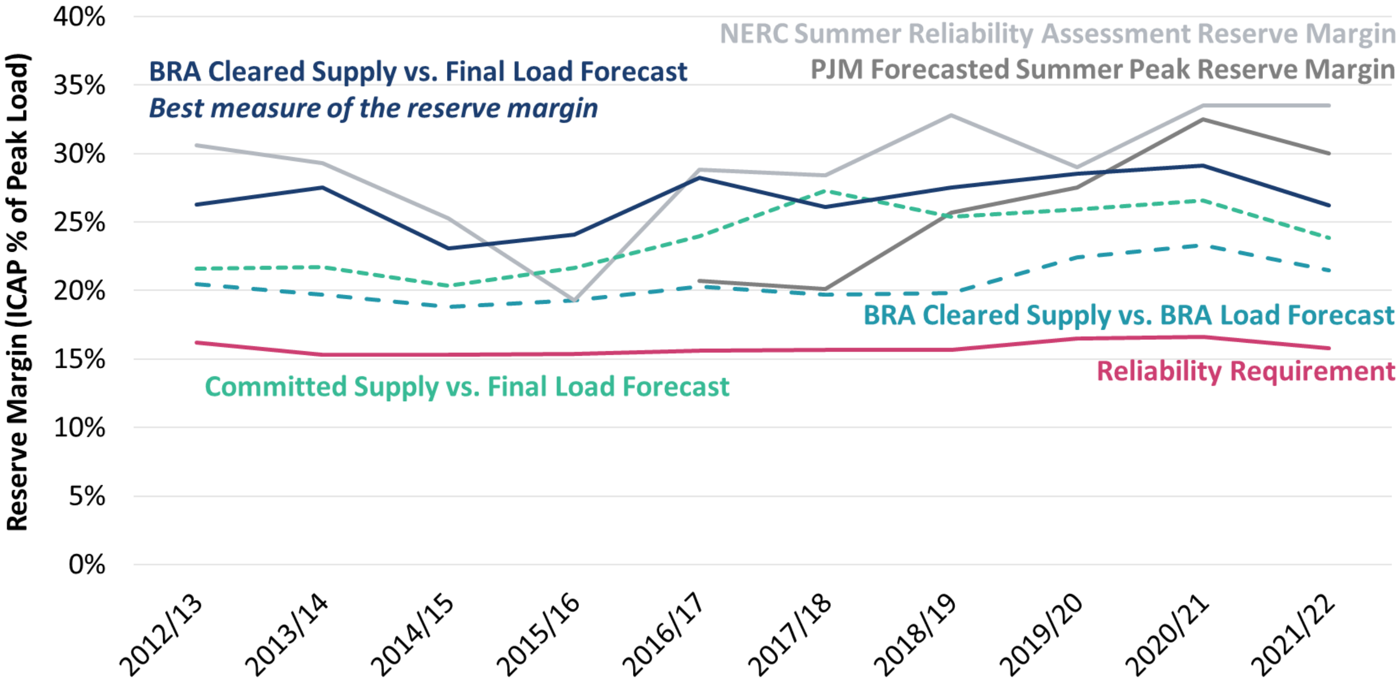
[8] Monitoring Analytics LLC, 2021 Quarterly State of the Market Report for PJM: January through September, Section 5: Capacity, November 11, 2021, Table 5-7, p. 303.

within the BRA auction results indicates reserve margins in the range of 19%-23% (compared to a 15%-16% target IRM); however the realized reserve margin prior to delivery has been higher at 23%-29% given that load growth has not been as high as was expected at the time of the BRA.

In our view, the best measure of the reserve margin is the BRA cleared supply compared to the final load forecast (the dark blue line in Figure 2) since this compares what was initially procured to the final load forecast developed three months before the Planning Year. This measures the volume of capacity paid for by consumers relative to what is needed after load forecast uncertainty has resolved.

FIGURE 2: PJM INSTALLED RESERVE MARGIN AND PROCURED AMOUNTS



Source/Notes: Reliability Requirement and BRA Load Forecast from PJM, 2012/13 to 2021/22 RPM Base Residual Auction Planning Period Parameters; BRA Cleared Supply from PJM, PJM 2022/2023 RPM Base Residual Auction Results, Table 1; Final Load Forecast from PJM, 2012/13 to 2021/22 3rd Incremental Auction Planning Period Parameters; PJM Forecasted Summer Peak Reserve Margin uses Forecasted Summer Demand from Load Forecast Report as of the Planning Year, from PJM, 2015 to 2021 Forecast Reserve Margin Graphs; NERC Summer Reliability Assessment Reserve Margin from NERC, 2012 to 2022 Summer Reliability Assessments.

An additional point of confusion is introduced by the reserve margins reported in PJM's Summer Reliability Assessment and NERC Summer Reliability Assessment reports (grey lines above), which indicate even higher reserve margins on the order of 20%-34%.[9] These Summer Reliability

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[9] See PJM, 2015–2022 Forecast Reserve Margin Graphs; NERC Summer Reliability Assessment Reserve Margin from NERC, 2012–2022 Summer Reliability Assessments.

Assessment reports tend to indicate higher levels of supply availability because they include all supply on the PJM system, even if that supply does not have a capacity obligation, may retire within the Planning Year, or has capacity export obligations. Further, the accounting methods used in ICAP-based summer assessment reports are different from and less formalized than the accounting methods used for settlement purposes in the UCAP-based capacity market. To improve transparency and consistency between these approaches, we recommend that PJM adopt a unified approach to reliability accounting between the capacity market and these summer assessment reports. We recommend relying on UCAP accounting methods that are intended to offer the most accurate reflection of resources' reliability value. We further recommend clarifying the status of resources with and without capacity commitments in the reliability assessment reports.

A critical, but missing, component of our assessment relates to winter reliability. The PJM capacity market does not explicitly determine a Reliability Requirement for the winter season, and resources' UCAP MW ratings do not consider winter-specific reliability drivers (such as cold-weather-driven fuel supply and thermal outages). It is possible that the winter season may have ample supply and even higher procurement levels than summer (i.e. if the current annual resource commitments can be considered firm even in winter, which has lower peak demand). It is also possible that higher outage rates as observed in the 2014 Polar Vortex are a great concern that makes winter reliability a more substantial concern than summer.[10] PJM and stakeholders have assessed this issue in the past and implemented the current capacity performance regime as at least a partial solution. However, the RPM and reliability accounting mechanisms have not been updated to explicitly track winter needs and supply commitments. We recommend that winter capacity supply and demand should be explicitly tracked so as to clarify whether winter reliability is a substantial concern and support evaluation of updating RPM to become a seasonal construct within the parallel RASTF process.

B. Diagnosis of Capacity Procurement Beyond the Reliability Requirement

In Figure 3 we summarize the scale of impact from distinct drivers of procurement beyond the reliability requirement. We present these results for the most recent auction at the time of

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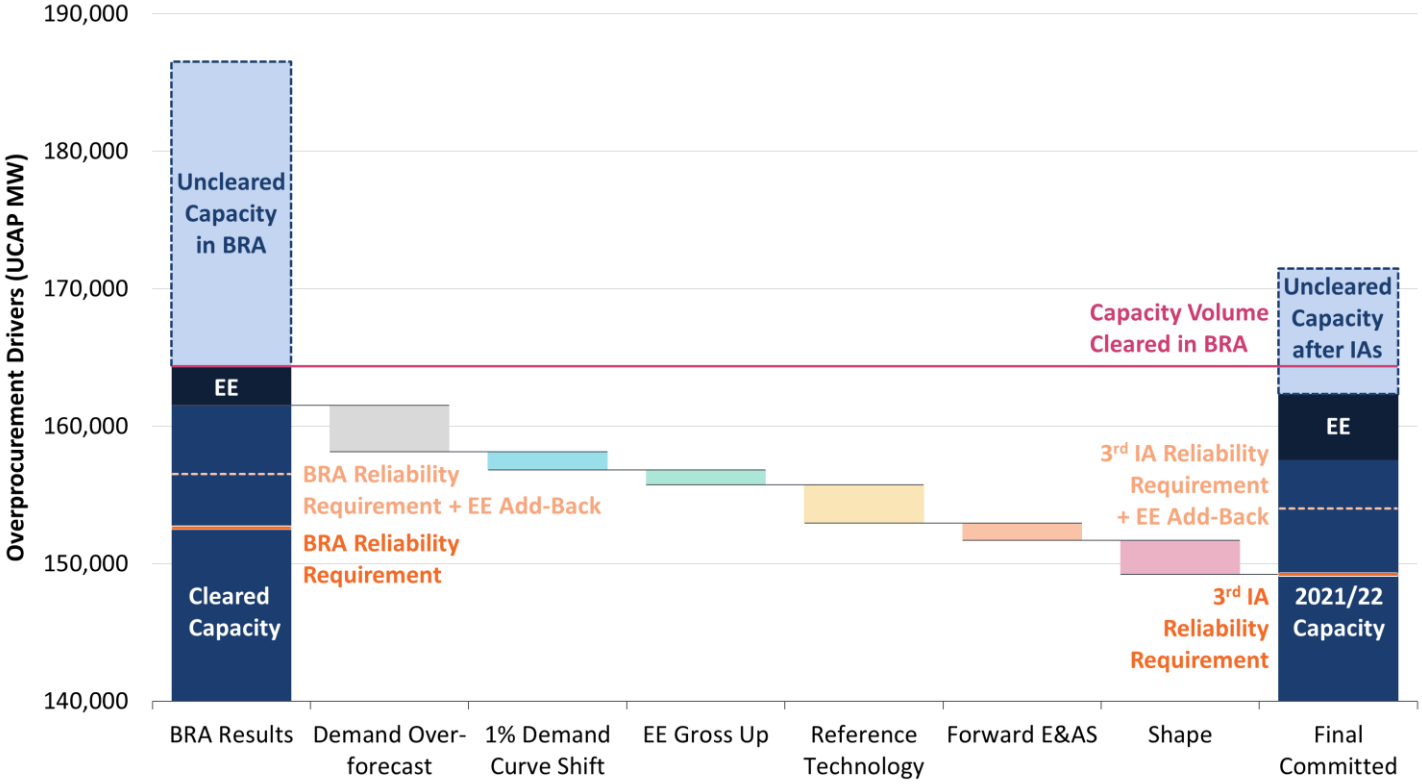
[10] During the 2014 Polar Vortex PJM faced outages of 40,200 MW or 22% of total PJM capacity. See PJM, Strengthening Reliability: An Analysis of Capacity Performance, June 20, 2018, pg. 15.

publication (2021/2022 Planning Year) noting that the relative impact of each driver has differed for each auction. The largest factor contributing to procurement beyond the reliability requirement has been a consistent over-forecasting in the load forecast.[11] However, many other factors have contributed to excess procurement within the RPM; each of these drivers will need to be addressed in a different fashion (and some have already been addressed).

FIGURE 3: DRIVERS OF OVER-PROCUREMENT (2021/22 PLANNING YEAR)



Source/Notes: Cleared Capacity, Final Committed Capacity, Uncleared Capacity, BRA and Final Reliability Requirement (adjusted for FRR), Cleared EE, Final Cleared EE from data provided by PJM; Impact of 1% Demand Curve Shift, Reference Technology, and Forward E&AS from PJM, 2021/22 BRA Planning Period Parameters, May 3, 2018 and data provided by PJM; EE Gross Up from PJM, 2021/22 RPM Base Residual Auction Results, May 23, 2018, Table 6.

The left-hand side of the chart shows BRA Cleared Capacity (blue), the Cleared EE (dark blue), and Uncleared Capacity (light blue). The far right-hand side shows the same three components of the supply stack after the final Incremental Auction. Any capacity procured above the final IA Reliability Requirement is excess relative to what is needed to meet the 1-in-10 standard. In the

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[11] Our findings in this respect are generally consistent with prior work on this topic. See Public Interest and Environmental Organizations User Group (PIEOUG), Posted Meeting Materials, January 17, 2020 and James F. Wilson, Over-Procurement of Generating Capacity in PJM: Causes and Consequences, Wilson Energy Economics, prepared for Sierra Club and Natural Resources Defense Council, February 2020.

colored boxes in between, we show the impact of each factor contributing to excess procurement.

Our assessment of each driver and recommendations for how to address each contributing factor are as follows:

- **Demand Over-Forecast (grey, partially addressed):** Demand over-forecasting has been the largest single contributor to over-procurement. Beginning with the 2016 load forecast, PJM has taken measures to improve their load forecast model and address over-forecasting bias. Since then, the size of the bias has been substantially reduced.[12] However, we cannot confirm whether the bias has been eliminated, given that to date there has not been a Planning Year in which weather-normalized peak load has been under-forecasted. PJM has committed to address load forecast error and improve the forecast within the Load Analysis Subcommittee.[13] We recommend that PJM continue to address this issue though periodic load forecast improvements and independent reviews until all bias is eliminated. We also recommend to place particular focus on aligning the treatment of EE between the load forecast with the supply-side EE RPM participation model. We also recommend to re-examine the topic of forward and prompt procurement levels in light of load forecast uncertainties in future Quadrennial Reviews (see additional discussion in the following section).

- **1% Demand Curve Shift (blue, already addressed):** For several years, the VRR Curve had been implemented with a 1% right-shift compared to what we had recommended in the latest Quadrennial Review. This right-shift applied in the 2021/22 BRA depicted in this figure, but has since been eliminated. No further changes are needed to address the 1% right-shift.

- **EE Gross Up (green, partially addressed):** Under the RPM's participation model for EE, the underlying assumption is that PJM's load forecast is already accounting for all EE in the footprint. In order for EE to be incorporated as a supply-side resource in the capacity market, the demand curve is also right-shifted by the "EE add-back" or the expected UCAP MW volume of EE that is expected to clear in the auction. In the 2021/22 capacity auction however, the EE add-back was larger than the volume of EE that cleared, resulting in over-procurement. PJM has since updated its treatment of the EE add-back however, so as to iteratively adjust

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[12] PJM, Load Forecast Report, January 2016; average over-forecast bias between the BRA and Third IA was 9,518 UCAP MW from 2012/13 to 2016/17 but 6,681 UCAP MW between the 2017/18 to 2021/22 Planning Years; data provided by PJM.

[13] PJM, Load Analysis Subcommittee.

the EE add-back and until it exactly matches and cancels out the volume of EE cleared.[14] This change will prevent one component of over-procurement as associated with the EE add-back. There is an additional concern (not pictured in the above chart) related to the EE participation model however, which is the underlying assumption that the load forecast has already accounted for all EE in the footprint. While it is not in the scope of the Quadrennial Review to conduct a comprehensive review of the load forecast, we do not believe it is a realistic expectation to require the market operator to accurately predict all EE investments that could occur throughout the PJM footprint (particularly those EE investments that may be incrementally driven by the prices and clearing results of the RPM). If the forecast under-predicts EE, this could be a contributing factor to the historical over-forecasting bias. A more realistic and self-consistent approach would be to clarify the EE assumptions within the load forecast; qualify EE measures as supply-side resources within the RPM if they will reduce consumption relative to the load forecast; maintain EE measures' capacity eligibility for the greater of the measure life or the timeframe needed to fully incorporate EE trends into the load forecast; and clear EE in the RPM in competition with other capacity supply options. This participation model would offer greater accuracy and consistency between RPM and the load forecast, allow for the elimination of the EE add-back, and eliminate the need for iterative steps in auction clearing.

- **Reference Technology (yellow, not yet addressed):** This item shows the difference in the cleared volume of capacity the VRR Curve procured (based on the current gas CT reference technology), compared to the VRR Curve if it were based on a gas CC reference technology. A CC-based curve would reduce the price parameters of the VRR curve, resulting in lower procurement volumes at a given price compared to the current CT-based curve. To improve the accuracy of the Net CONE parameter and address this driver of over-procurement, we recommend to adopt a gas CC as the system-wide reference technology, as documented in our separate Net CONE Study.[15]

- **Forward E&AS (orange, not yet implemented):** As also documented in our Net CONE Study and prior Quadrennial Reviews, we recommend to adopt a forward-looking estimation of the E&AS offset to more accurately estimate Net CONE. If a forward-looking E&AS offset had been used as of the 2021/22 BRA it would have further reduced the Net CONE, VRR Curve pricing points, and resulting procurement volumes. A forward E&AS offset will not always reduce Net

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[14] PJM Resource Adequacy Planning Department, PJM Load Forecast Report, January 2016, pg. 1.

[15] We offered the same recommendation in the last Quadrennial Review. See Newell *et.al,* Fourth Review of PJM's Variable Resource Requirement Curve, p. vii, April 19, 2018.

CONE and procurement levels; however, it can result in a higher or lower value than the current backward-looking approach. Rather, the reason to adopt a forward-looking estimate is that it is likely to be more stable and accurate. PJM has previously proposed to adopt a forward-looking approach, but FERC did not approve it for unrelated reasons. We recommend a forward-looking E&AS offset should be adopted.[16]

- **Shape (pink, not yet addressed):** A portion of the reason for procurement beyond the Reliability Requirement is associated with the downward-sloping shape of the VRR Curve, an outcome that may or may not be viewed as over-procurement depending on one's perspective. As we discuss in the remainder of this report, we assess that the potential for over-procurement under long-capacity conditions can be reduced by reducing the quantity point at point "C" in the demand curve without materially sacrificing overall VRR Curve performance. See additional discussion in Section III below.

C. Addressing Impacts of Over-Forecasting Bias

We recognize, and the RPM as a construct must anticipate, that some level of load forecast error is unavoidable. However, the construct can and should aim to eliminate any systematic bias in the load forecast. Historically in RPM, there has been an over-forecast bias, meaning that forecasted load has consistently been higher than realized demand, which has contributed to over-procurement.

Figure 4 shows the historical excess procurement for the past ten years. The dark blue is the capacity procured in excess of the Reliability Requirement of the Final IA; the light blue is the additional excess capacity that was procured in the BRA. Over-procurement has increased in recent years (as evidenced by the sum of the two bars); however, the BRA and final IA capacity procurement levels are converging (evidenced by the smaller light blue bars indicating less additional procurement in the BRA versus the final IA). This convergence is due to improved load forecasting that PJM has actively pursued. Between these improvements to the load forecast and other adjustments that PJM has made to partly address over-procurement issues (discussed in the prior section), we anticipate that the level of over-procurement will decline in coming years even if none of our additional recommendations are adopted. The three-year forward nature of

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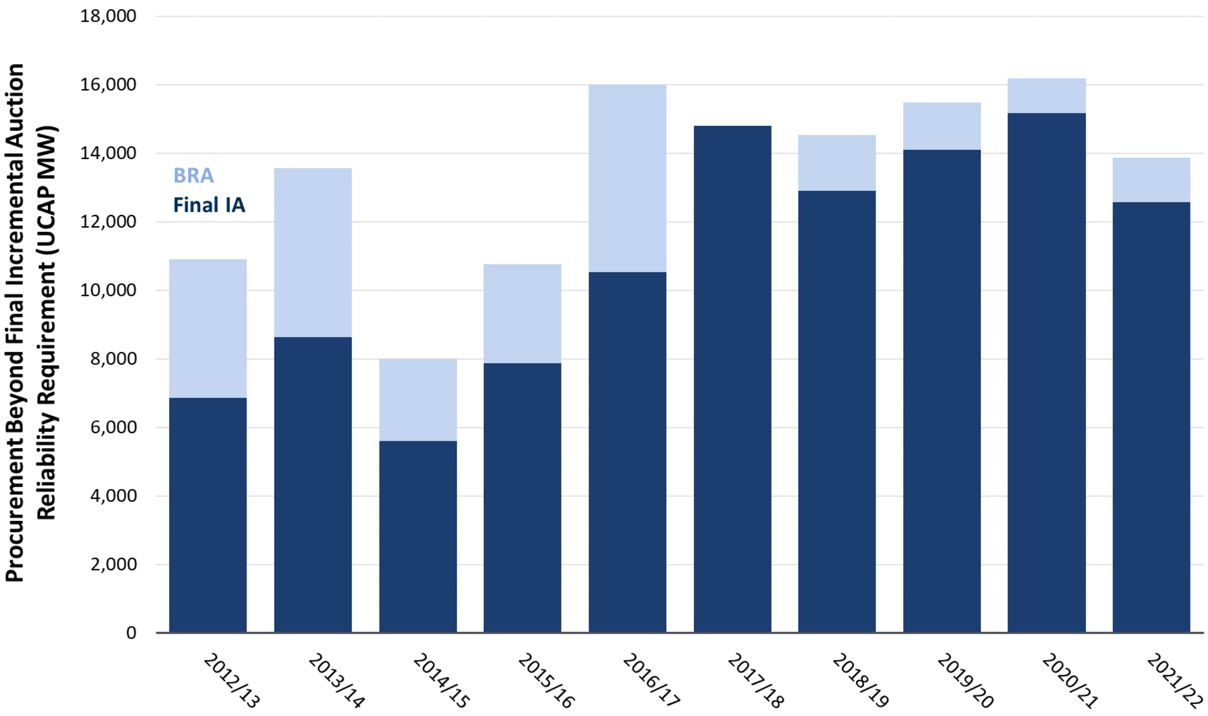
[16] The FERC identified deficiencies with portions of PJM's Operating Reserve Demand Curve filing, which had the collateral effect preventing implementation of the forward-looking E&AS offset, though the concept of the forward E&AS offset itself was not found deficient. FERC emphasizes this point in the remand order: "*As discussed below*, ***we are not determining that a forward-looking E&AS Offset is unjust and unreasonable***." Federal Energy Regulatory Commission, 177 FERC ¶ 61,209, Order on Voluntary Remand, Issued December 22, 2021, pg. 13.

the RPM and BRA creates a lag period before these improvements can materialize in the historical record.

FIGURE 4: EXCESS CLEARED CAPACITY IN BRA AND FINAL IA, ABOVE RELIABILITY REQUIREMENT AS OF THE FINAL IA



Source/Notes: BRA Cleared Capacity from PJM, 2022/23 RPM Base Residual Auction Results, Table 6, January 6, 2022; Final Incremental Auction Reliability Requirement and Final Cleared Quantity data provided by PJM.

Some stakeholders have suggested to reduce procurement levels in the BRA by the amount of historical over-forecast. This would result in buying less capacity in the forward auction and instead planning to buy more in the short-term IAs. We do not recommend to adopt this approach. If the load forecast is corrected to fully eliminate the over-forecast bias, a forecast-adjusted BRA would under-procure compared to the Reliability Requirement.[17] The more direct approach is to eliminate any bias in the load forecast, as we recommend.

Even if the load forecast is unbiased, we do see some conceptual rationale to consider incrementally shifting a portion of RPM procurement volumes from the BRA to the shorter-term

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[17] An additional issue to contend with in a partial forward auction is how to update market monitoring and mitigation provisions. Requiring all supply or nearly all supply to offer into the market with a must-offer and offer cap, while incorporating only a portion of the demand in the forward auction has the potential to cause price suppression. Though this issue likely could be addressed in a mixed forward-and-prompt construct, it would require robust analysis and likely a meaningful update to the monitoring and mitigation framework.

IAs, as a possible avenue to manage the potential for over-procurement. To date, the BRA VRR Curve has been slightly right-shifted relative to the Reliability Requirement under the concept that RPM should procure enough supply to achieve a system-wide Loss of Load Event (LOLE) standard of 1-in-10 as measured at the time of the BRA. A revised approach could be to develop the VRR Curve in the BRA considering the possibility that additional capacity may be available for purchase in the subsequent IAs. The IAs would be relied upon to procure any remaining capacity needs. This approach would reduce forward procurement volumes, thereby reducing the potential cost of over-procurements in the event that the three-year foreword forecast is high. The risk of this approach however, arises in a tight capacity supply scenario in which forward procurements are low and the load forecast increases between the forward and prompt auctions. In that scenario, the IAs would need to attract additional supply offers beyond what was offered in the BRA or else the system would face a capacity shortfall.

To assess the merits of shifting demand from the BRA to subsequent IAs, we have reviewed both historical market data and model simulations. Table 3 summarizes the offered volumes in RPM BRA and IA auctions, with the far right column tabulating the Net Supply increases (or decreases, where negative) that have been offered into the IAs as compared to the BRA. If the volume of supply offered in the IA is lower than the uncleared supply from the BRA, this shows up as a negative number and indicates that supply available for purchase is contracting as the forward timeframe becomes short. Historically the IAs have shown a consistent pattern of uncleared supply from the BRA dropping out between the three-year forward BRA and the non-forward Final IA. This is logical since RPM has historically over-procured in the BRA relative to reliability needs, and uncleared resources may retire (or not build) such that they can no longer make themselves available in the non-forward auctions. Prices in the IAs have also been low and generally unattractive, likely contributing to the contraction of available supply in the IAs. Recent history shows however that approximately 53.8% of BRA Uncleared Supply has been retained and continued to offer as of the final IA.[18]

We do not yet have evidence regarding whether incremental supply would be available in the IAs under shortage conditions when the BRA has cleared with short supply and the near-term load forecast has increased. This is the primary scenario of interest however, when considering whether the RPM could shift procurement volumes from the BRA to the IA without introducing reliability risks. To maintain reliability, the prospect of increasing load forecast and a potential

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[18] Here we refer to the average since the 2017/18 Planning Year after PJM implemented notable improvements in the load forecast, excluding 2018/19, which was an outlier. With the exception of the 1st IA Auction for the 2014/15 Planning Year, all Incremental Auctions since 2012/13 have resulted in negative Net Supply. See also Table 3 and the Appendix Section D.

shortfall in the IAs would need to be communicated to prospective sellers. Anticipating high prices in the IAs, sellers could then mobilize incremental supply offers that they had not offered into the BRA. If sufficient supply offers are made available in the IAs, prices may be high but reliability can be maintained. If insufficient supply offers are made available in the IAs, prices will be high but the market will clear with a shortage. We are optimistic that incremental supply could be attracted into the IAs under such a scenario, but there are no market data available to date to demonstrate this.

TABLE 3: SUPPLY OFFERED, CLEARED, AND NET SUPPLY INCREASE (DECREASE)

Year	**Auction**	**Supply Offered**			**Supply Cleared**			**Uncleared Supply**		**Cumulative Uncleared Supply**	**Net Supply Increase (Decrease)**
		Sell Offers (MW) [A] See notes	PJM Buy Bids (MW) [B] See notes	Net (MW) [C] [A]-[B]	Sell Offers (MW) [D] See notes	PJM Buy Bids (MW) [E] See notes	Net (MW) [F] [D]-[E]	Sell Offers (MW) [G] [A]-[D]	PJM Buy Bids (MW) [H] [B]-[E]	(MW) [I] [I][t-1] - [F]	(MW) [J] [A] - [I][t-1]
2017/18	BRA	178,839	n/a	178,839	167,004	n/a	167,004	11,835	n/a	11,835	n/a
	Transition	10,408	0	10,408	10,017	0	10,017	391	0	1,818	(1,426)
	1st IA	1,705	10,880	(9,175)	605	4,184	(3,579)	1,100	6,696	5,397	(113)
	2nd IA	2,842	12,223	(9,381)	1,448	4,211	(2,763)	1,394	8,012	8,160	(2,556)
	3rd IA	2,533	13,786	(11,253)	1,452	4,019	(2,567)	1,081	9,767	10,728	(5,627)
2018/19	BRA	179,891	n/a	179,891	166,837	n/a	166,837	13,054	n/a	13,054	n/a
	1st IA	16,487	9,602	6,885	2,545	2,366	180	13,942	7,236	12,875	3,433
	2nd IA	13,061	12,996	65	2,378	4,888	(2,510)	10,683	8,108	15,385	186
	3rd IA	13,109	15,712	(2,604)	4,197	4,199	(2)	8,912	11,513	15,387	(2,276)
2019/20	BRA	185,540	n/a	185,540	167,306	n/a	167,306	18,234	n/a	18,234	n/a
	1st IA	17,914	18,274	(361)	2,295	3,992	(1,697)	15,619	14,282	19,931	(320)
	2nd IA	16,891	15,329	1,562	1,613	2,294	(681)	15,279	13,036	20,612	(3,039)
	3rd IA	13,097	15,944	(2,847)	5,827	5,962	(135)	7,270	9,982	20,747	(7,514)
2020/21	BRA	183,352	n/a	183,352	165,109	n/a	165,109	18,242	n/a	18,242	n/a
	1st IA	16,413	13,372	3,041	3,554	4,326	(772)	12,859	9,046	19,014	(1,829)
	2nd IA	12,525	8,499	4,027	1,909	1,964	(55)	10,617	6,535	19,069	(6,489)
	3rd IA	10,478	11,401	(923)	3,503	4,547	(1,044)	6,975	6,854	20,114	(8,591)
2021/22	BRA	186,505	n/a	186,505	163,627	n/a	163,627	22,878	n/a	22,878	n/a
	1st IA	17,748	8,966	8,782	2,143	2,029	114	15,605	6,937	22,763	(5,129)
	2nd IA	16,755	18,021	(1,267)	3,708	6,485	(2,777)	13,047	11,537	25,541	(6,009)
	3rd IA	14,337	12,232	2,106	5,236	4,516	720	9,102	7,716	24,821	(11,203)

Sources/Notes: The 2017/18 auction cycle features a Transition Auction due to the introduction of Capacity Performance products. A negative Net Supply Increase (Decrease) [J] value indicates that the Sell Offers [A] in the current auction have decreased relative to the Cumulative Uncleared Supply from the previous auction [I][t-1], while a positive Net Supply value indicates an addition of new incremental capacity, [t -1] refers to previous auction year. Results from 2019/2020 auctions contain a mix of Base and Capacity Performance products. [A], [B], [D], & [E] from PJM, 2019/20 to 2021/22 BRA and IA Results Reports. Average Final IA Total Supply as a percent of BRA Uncleared Supply = 53.8% from years 2017/18 to 2021/22, excluding 2018/19. Calculated as: ([I][BRA] + [J][3rd IA]) / [I][BRA].

We have also conducted a simulation analysis of the potential reliability outcomes under RPM when considering the opportunity to procure capacity first from the BRA, and later through the IAs (see Appendix Section E, Table 17). In that simulation we examine reliability in a scenario with an unbiased load forecast, subject to three-year-ahead forecast error. We further assume that 53.8% of supply that was uncleared as of the BRA will remain available and offer into the IAs consistent with recent historical data. We find that our estimate of reliability is improved by accounting for the effect of the IA procurements, but this improvement is immaterial, changing from 0.73 LOLE in the BRA to 0.71 LOLE as of the final IA for the Candidate Curve. If more supply can be attracted into the IAs under shortage conditions, there could be a more notable improvement to reliability than we have estimated.

Based on this assessment, we recommend to defer until the next Quadrennial Review any further consideration of shifting procurements volumes from the BRA to the IAs. Between the changes PJM has already made and others that we recommend, we anticipate that the challenges associated with the potential for over-procurement should be largely addressed. As a result, we anticipate that the IAs will no longer be systematically oversupplied, pricing in the IAs could become more attractive, and we will have the opportunity to observe whether incremental supply can be attracted to participate in the IAs. At that time, we recommend to reconsider the question of whether and how much demand should be shifted from the BRA to the IAs to address any remaining over-procurement risks.

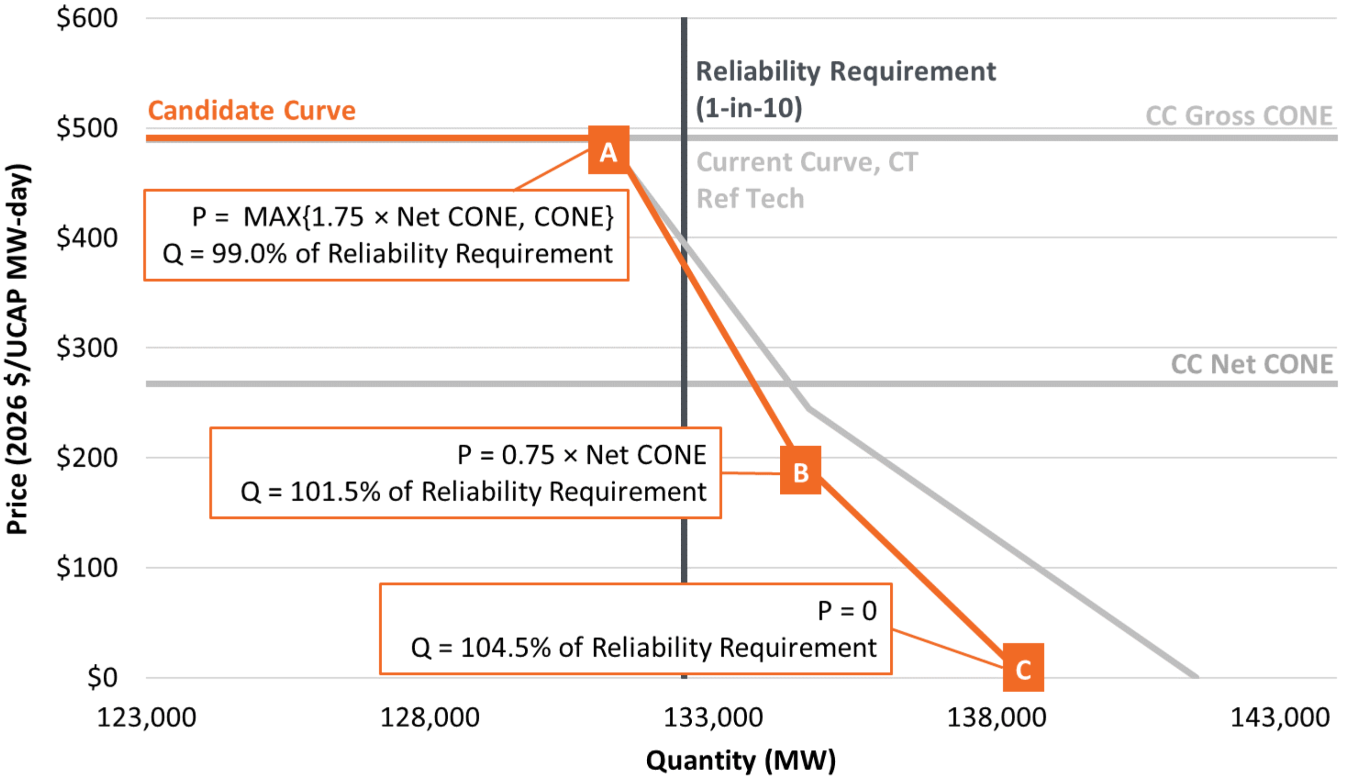
III. Evaluation of Candidate VRR Curve and Recommended Adjustments

Based on a combination of qualitative analysis and probabilistic simulations, we recommend that PJM should adopt a Candidate Curve that incorporates several adjustments relative to the current VRR curve. The Candidate Curve is a steeper kinked curve based on a gas CC reference technology with a reduced foot compared to the current VRR Curve. While we suggest a specific formula for each defined point in the Candidate Curve, we believe there is a “workable range” of curves that all would offer sufficient system reliability but with a differing balance of performance trade-offs.

A. Candidate VRR Curve

In Figure 5 we show our suggested Candidate Curve (orange) along with the formulas for creating each defined point, in comparison to the Current Curve (grey). The updated Candidate Curve would be defined based on a gas CC as the reference technology (rather than a gas CT); incorporate an adjusted formula for setting the price cap based on the greater of CONE or 1.75 × Net CONE (rather than the greater of CONE and 1.5 × Net CONE); produce a steeper kinked shape by reducing the quantity definition of Point C; and simplify the calculation of the other quantity points by referencing the UCAP-based Reliability Requirement (rather than referencing the ICAP-based IRM).

FIGURE 5: CANDIDATE VRR CURVE RECCOMMENDED TO REPLACE THE CURRENT VRR CURVE



Sources/Notes: Reliability Requirement is calculated based on UCAP Reserve Margin provided by PJM and BRA Peak Load (adjusted for FRR) from PJM, 2022/2023 RPM Base Residual Auction Planning Period Parameters, February 8, 2021; Net CONE estimates from the Brattle 2022 Net CONE Study.

The rationale for these proposed adjustments to the VRR Curve is as follows:

- **Reference Technology:** As discussed at length in our separate Net CONE Study and prior Quadrennial Reviews, we recommend to update the reference technology based on a gas CC.

- **Price Cap:** The price cap in the current VRR Curve is already defined as the maximum of Gross CONE and 1.5 × Net CONE, with the maximum serving to prevent the possibility of the demand curve collapsing to zero if administrative Net CONE would be estimated as very low or zero. We recommend to adjust the formula to the greater of Gross CONE and 1.75 × Net CONE in consideration of the substantial uncertainty in Net CONE that we perceive at the present moment.[19] As a practical matter, this change is unlikely to materially affect the VRR curve given that Gross CONE and 1.75 × Net CONE happen to be nearly identical under our current estimates. Still, the change may provide some incremental protection against the possibility of too-low pricing during short supply conditions.

- **Steeper Shape:** As seen in Figure 5, the Candidate Curve is steeper and slightly left-shifted compared to the Current Curve, achieved primarily by adjusting the foot position (Point C) to 4.5% above the Reliability Requirement. We offer this recommended adjustment to Point C based on several observations. First, we observe that under recent market conditions, the RPM has experienced a sustained long-market condition associated in part with a large turnover of the resource mix. Prices even in the "foot" region of the VRR curve have been high enough to retain existing supply and attract new supply. Reducing administrative Net CONE to a more accurate level based on a CC we expect will prevent the market from continuing to attract additional supply into an already-long market, but this may not sufficiently discipline continued going-forward investments to retain aging supply that could be allowed to retire without posing reliability problems. Put differently, the RPM has attracted large volumes of supply offers beyond what is needed for reliability and across a highly elastic supply stack; under these market conditions a relatively steep demand curve can more effectively "right-size" capacity procurements without introducing large problems with price volatility. A flatter curve is more susceptible to exacerbating current surpluses, particularly if Net CONE would be over-estimated. Our simulation results confirm these same observations (see below).

- **Simpler, UCAP-Based Quantity Formulas:** Consistent with our recommendation to simplify and improve capacity and reliability accounting by relying exclusively on a UCAP-based accounting system, we recommend to implement a simpler formula for calculating the

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[19] As an example, consider a stress test scenario in which the "True" Net CONE needed to attract supply into the market is 1.4 × the administrative Net CONE used to set the demand curve. There would then be an insufficient small "buffer" of only 0.1 × Net CONE between the price cap and the long-run average price needed to attract entry. The only way to produce average prices near the long-run cost of supply would be to clear at the price cap (*i.e.*, in shortfall) approximately half of the time. This would be an unsustainable outcome and would result in administrative intervention, though we acknowledge that the scenario assumes a large error in Net CONE.

quantity points of the VRR Curve based on a straightforward percentage of the Reliability Requirement (99%, 101.5%, and 104.5% of the Reliability Requirement for Points A, B, and C, respectively).

To examine the likely performance of the Candidate Curve compared to the Current Curve, and other alternative VRR Curves, we have conducted a probabilistic simulation analysis of potential market outcomes under long-run equilibrium conditions. As described more fully in Appendix and similar to the approach used in prior Quadrennial Reviews, we conduct a Monte Carlo analysis to simulate the estimated range of price, quantity, and reliability outcomes under each VRR curve considered.

We summarize the results of this simulation analysis Table 4 and Figure 6, comparing the estimated performance of the Candidate Curve and the Current Curve. The Candidate Curve has a slightly steeper slope to mitigate over-procurement risks in the face of Net CONE uncertainty.[20] A tradeoff of a steeper slope is the slight increase in price volatility (measured in Table 4 as the standard deviation of clearing prices).

Because the Candidate Curve reduces procurement volumes, it will also produce slightly poorer reliability compared to the Current Curve. However, we estimate that both curves would outperform the 0.1 LOLE reliability standard on average, at least under our base simulation assumptions. We do see some rationale for further left-shifting the curve toward one that exactly supports the 1-in-10 standard (rather than exceeding the standard), but this would introduce other trade-offs as we discuss further in Sections III.C and III.E below.

TABLE 4: BASE CASE RESULTS OF CANDIDATE CURVE COMPARED TO CURRENT CURVE

	Price			**Reliability**					**Cost**
	Average	Standard Deviation	Frequency at Cap	Average LOLE	Average Excess (Deficit)	Average Excess (Deficit)	Frequency Below Target	Frequency Below IRM - 1%	Average Procurement Cost
	($/MW-d)	*($/MW-d)*	*(%)*	*(events/yr)*	*(MW)*	*(IRM + X %)*	*(%)*	*(%)*	*($ mln/yr)*
Candidate Curve	$267	$85	2.7%	0.073	1,221	1.1%	10.9%	3.3%	$13,104
Current Curve, CT	$267	$74	1.5%	0.059	2,026	1.8%	7.5%	2.0%	$13,169

Source/Notes: All prices in 2026$/UCAP MW-Day and all quantities in UCAP MW; The Base Case results assesses curve performance when Administrative Net CONE is equal to the True Net CONE, whereby both are the CC Net CONE ($267/UCAP MW-Day) estimate from the Brattle 2022 Net CONE Study.

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[20] We note that the Net CONE values used in our simulation analysis are slightly different from the final numbers in the 2022 Brattle Net CONE study; however, this does not materially impact our conclusions of the simulation analyses.

Figure 6 summarizes our estimated distributions of simulated clearing quantities and prices of the Candidate Curve and the Current Curve, CT under equilibrium market conditions. As seen on the left-hand side (Cleared Quantity Above/Below Reliability Requirement) the Current Curve, CT would over-procure by a greater volume and with a slightly greater frequency than the Candidate Curve. Furthermore, the quantity distribution of the Current Curve, CT is slightly wider, meaning that a greater window of clearing quantities would be experienced more frequently; this results in higher quantity uncertainty, as expected from a flatter curve. By comparison, the Candidate Curve has a slightly tighter quantity distribution since it is a steeper curve, thereby reducing clearing quantity uncertainty. Additionally, the Candidate Curve reduces expected procurement beyond the Reliability Requirement by 805 UCAP MW on average compared to the Current Curve, CT under our base assumptions.

On the right-hand side of Figure 6 (Clearing Price) we see the opposite effect, the Candidate Curve has a wider distribution meaning that clearing price volatility is slightly greater than the Current Curve, CT. However as seen in the figure and confirmed by the results in Table 4, the increase in price volatility for the Candidate Curve is modest, on the order of $11/UCAP MW-day. Furthermore, as we show in Figure 6 (in Section III.E below) the Candidate Curve is approximately in the middle of the range of tested curves in terms of key performance trade-offs, specifically, the clearing price volatility and expected excess procurement.

Overall, both curves produce price and quantity outcomes that are generally “workable”, and without substantial concerns.[21] Overall, we view the Candidate Curve as offering improved performance compared to the Current Curve given that it reduces total procurement levels and associated costs, while still exceeding the 1-in-10 standard and offering otherwise similar performance.

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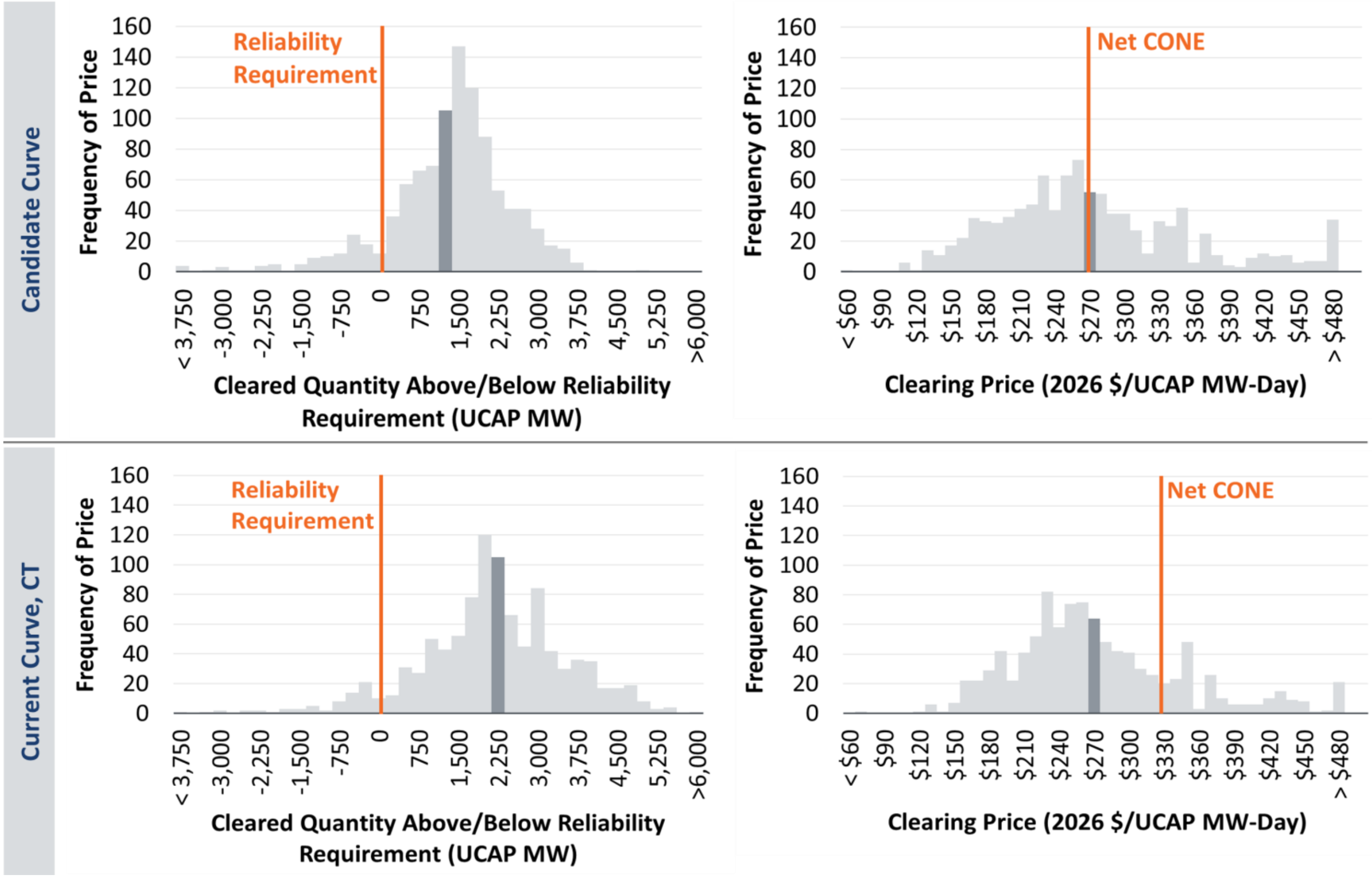
[21] The problematic outcomes that we would be concerned about with a poorly performing curve include average quantities below the Reliability Requirement, high frequency of outcomes far below the Reliability Requirement, average quantities far above the Reliability Requirement, a bimodal distribution of prices, and/or a high frequency of outcomes at the price cap. Such problematic outcomes can occur with curves that are too flat, too steep, have a too-low price cap, or quantity points that far above or far below the Reliability Requirement. None of these features is present within the Current Curve or the Candidate Curve.

FIGURE 6: DISTRIBUTIONS OF CLEARED QUANTITY AND PRICE FROM THE CANDIDATE CURVE (TOP) AND THE CURRENT CURVE (BOTTOM)

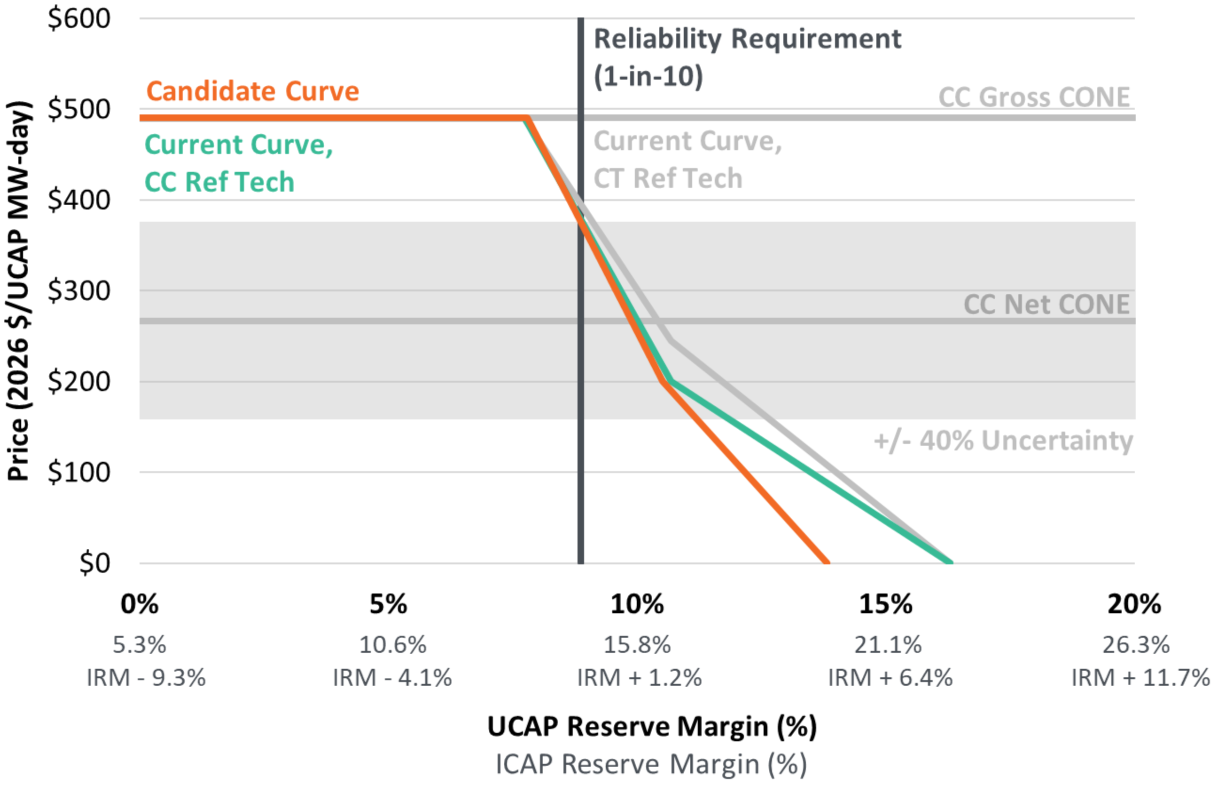


Sources/Notes: All results are generated from Base Case model run where True Net CONE is equal to CC Net CONE ($267/UCAP MW-Day); Top results are for Candidate Curve where Administrative Net CONE is equal to CC Net CONE; Bottom results are for Current Curve, CT, where Administrative Net CONE = CT Net CONE ($326/UCAP MW-Day); Histograms are reflective of results after the BRA, created from the last 1,000 model draws; Historical 2009/10 to 2022/23 RTO clearing price volatility is $48.59, calculated from PJM, 2009/10 to 2022/23 Base Residual Auction Results.

B. Performance in the Context of Net CONE Uncertainties

As discussed in our separate Net CONE Study, we perceive substantial uncertainties in administrative Net CONE under present market conditions. To evaluate the robustness of the Candidate Curve to Net CONE uncertainty, we perform stress testing equivalent to a window of ± 40% of CC Net CONE. We additionally test scenarios where the True Net CONE is a CC as we expect (the Base Case) and if the True Net CONE is instead a CT. Therefore, our stress test encompasses four scenarios in total where True Net CONE is: (1) -40% of CC Net CONE, (2) CC Net CONE, (3) CT Net CONE, and (4) +40% CC Net CONE. Figure 7 illustrates this uncertainty band in Net CONE as compared to the Candidate Curve, Current Curve with a CT as the Reference Technology, and the Current Curve with a CC as the Reference Technology.

FIGURE 7: CURRENT CURVE BASED ON CT VS CC REFERENCE TECHNOLOGY



Sources/Notes: Candidate Curve price cap at Max(1.75 × CC Net CONE, **CC CONE**); Current Curve, CC Ref Tech price cap at Max(1.5 × CC Net CONE, **CC CONE**); Current Curve, CT Ref Tech price cap at Max(**1.5 × CT Net CONE**, CT CONE), **bolded text** indicates which parameter sets the price cap for each curve.

Table 5 shows the simulated performance of these three curves across the stress test range. For the CC-based Current Curve, Gross CONE is higher than 1.5 × Net CONE meaning that the price cap (Point A) is higher relative to the target point (Point B where the kink begins). Therefore by only changing the reference technology (i.e. the Current Curve, CC Ref Tech), the resulting curve is slightly steeper. As seen in the simulation results, a consequence of changing the reference technology is a reduction in over-procurement compared to the Current Curve, CT Ref Tech. However, since the foot position would still be in the same wide position, changing the reference technology alone would not fully mitigate the potential for over-procurement. Therefore, to further address the potential for over-procurement, our recommended Candidate Curve has a reduced foot and is a slight departure from the Current Curve, CC Ref Tech. The Candidate Curve would be expected to reduce average procurement levels by 805 MW compared to the Current Curve, CT Ref Tech and by 210 MW compared to the Current Curve, CC Ref Tech in the Base Case, while still exceeding the 0.1 LOLE standard. If True Net CONE is substantially lower than the administrative estimate, the potential for over-procurement can become larger with both the CC-based and CT-based Current Curve (estimated at 3,716 MW and 4,548 MW respectively). The Candidate Curve would also produce excess procurement, but by a smaller estimated 2,026 MW.

In the event that True Net CONE is substantially higher than the administrative estimate, all curves perform worse from the perspective of estimated reliability outcomes and all produce reliability that would not meet the 1-in-10 reliability standard. That being said, all of the three curves produce reliability in the range of 0.117-0.128 LOLE (translating to a range of 1-in-8.5 to 1-in-7.8 LOLE). This level of reliability would be unacceptably poor if it were anticipated under base assumptions, but we view this as an acceptable level of risk under a stress test scenario. The curves perform similarly in this scenario due primarily to the similar placement of the price cap across the three curves (in prior Quadrennial Reviews, we have identified proper placement of the price cap as the most important factor for preventing extreme poor reliability outcomes).

TABLE 5: CANDIDATE CURVE VS CURRENT CURVE WITH CC AND CT REFERENCE TECHNOLOGIES

	Price			**Reliability**					**Cost**
	Average *($/MW-d)*	Standard Deviation *($/MW-d)*	Frequency at Cap *(%)*	Average LOLE *(events/yr)*	Average Excess (Deficit) *(MW)*	Average Excess (Deficit) *(IRM + X %)*	Frequency Below Target *(%)*	Frequency Below IRM - 1% *(%)*	Average Procurement Cost *($ mln/yr)*
Candidate Curve									
True Net CONE = 0.6 x CC	$160	$57	0.0%	0.043	2,861	2.5%	0.0%	0.0%	$7,939
True Net CONE = CC	**$267**	**$85**	**2.7%**	**0.073**	**1,221**	**1.1%**	**10.9%**	**3.3%**	**$13,104**
True Net CONE = CT	$326	$94	9.8%	0.098	388	0.4%	31.0%	11.5%	$15,889
True Net CONE = 1.4 x CC	$374	$94	21.2%	0.128	-393	-0.3%	50.0%	24.8%	$18,092
Current Curve, CT									
True Net CONE = 0.6 x CC	$160	$52	0.0%	0.026	4,548	4.0%	0.0%	0.0%	$8,029
True Net CONE = CC	**$267**	**$74**	**1.5%**	**0.059**	**2,026**	**1.8%**	**7.5%**	**2.0%**	**$13,169**
True Net CONE = CT	$326	$86	7.8%	0.085	922	0.8%	23.2%	9.0%	$15,941
True Net CONE = 1.4 x CC	$374	$87	17.9%	0.117	-25	0.0%	43.2%	20.0%	$18,133
Current Curve, CC									
True Net CONE = 0.6 x CC	$160	$52	0.0%	0.034	3,716	3.2%	0.0%	0.0%	$7,978
True Net CONE = CC	**$267**	**$81**	**2.1%**	**0.069**	**1,431**	**1.3%**	**10.0%**	**2.9%**	**$13,119**
True Net CONE = CT	$326	$92	9.3%	0.095	510	0.5%	28.8%	10.8%	$15,900
True Net CONE = 1.4 x CC	$374	$92	19.6%	0.126	-318	-0.2%	48.4%	24.4%	$18,100

Source/Notes: All prices in 2026$/UCAP MW-Day and all quantities in UCAP MW; Administrative Net CONE is equal to CC Net CONE ($267/UCAP MW-Day) for Candidate Curve, and Current Curve, CC runs above; Administrative Net CONE is equal to CT Net CONE ($326/UCAP MW-Day) for Current Curve, CT runs above.

C. Comparison to Curves “Tuned” to 1-in-10 Reliability Standard

The Current VRR Curve is anchored to the RPM Reliability Requirement and the 1-in-10 reliability standard. In prior Quadrennial Reviews, we have recommended curves (including the Current VRR curve) based on parameters that were “tuned” to achieve a 1-in-10 LOLE on average in the BRA given observed supply and demand variability. Under this approach, we have previously recommended a VRR curve that is slightly right-shifted compared to the Reliability Requirement due to: (1) the asymmetry of the LOLE curve, which means the market must remain above the Reliability Requirement more often than it falls below the Reliability Requirement in order to produce LOLE at 1-in-10 on average; (2) a price cap defined at 1.5 × Net CONE, which also would tend to require a flatter and more right-shifted curve (compared to a steeper curve with a higher price cap) in order to support reliability at 1-in-10; and (3) prior market conditions that indicated low supply elasticity around prices near Net CONE, which tended to produce more price volatility and hence a wider curve to achieve 1-in-10 and long-run equilibrium prices at estimated Net CONE.[22]

In the present Quadrennial Review, we have conducted a similar analysis to identify potential VRR curves that exactly support the 1-in-10 standard under our base assumptions. Figure 8 shows two such curves, straight line (no kink) curves with a price cap at the reliability backstop threshold and a foot at Point C that is adjusted until the curve produces an estimated LOLE of 0.1 in simulation modeling under base assumptions. In both cases, we define the price cap quantity as being fixed at near the reliability backstop threshold, which is currently defined as IRM-1%. As we have discussed in prior Quadrennial Reviews, the price cap quantity should be set at or above IRM-1%, as it represents the threshold below which PJM would consider corrective actions to ensure sufficient system capacity.[23] A well-functioning VRR Curve should limit or eliminate any need for out-of-market or corrective actions to maintain reliability, and procure all in-market capacity that has been offered before any out-of-market or backstop actions would be triggered. The curves have price caps at prices of 1.5 × Net CONE up to 1 × Gross CONE respectively, and illustrate the shape of a tuned curve would need to vary to maintain capacity procurement at the

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[22] Newell, *et. al.*, Fourth Review of PJM’s Variable Resource Requirement Curve, Section IV.A, April 19, 2018; and Pfeifenberger, *et. al.*, Third Triennial Review of PJM’s Variable Resource Requirement Curve, Section II.C, May 15, 2014.

[23] As per PJM’s tariff, if the RPM clears below the reliability backstop threshold three years consecutively, this would trigger a Reliability Backstop Auction; PJM, 2022 OATT, Attachment DD, Section 16.3.a.i.

1-in-10 LOLE reliability level on average. As seen in Figure 8, as the price cap increases, the demand curve foot moves to the left and the overall curve becomes steeper. Stated differently, a higher price cap allows for a steeper curve.

The 1-in-10 "turned" curves that we estimate in this Quadrennial review are substantially left-shifted compared to our findings in prior Quadrennial reviews primarily due to changes in prevailing market conditions.[24] Specifically, our updated estimate of Net CONE based on a gas CC power plant is a lower number than we have used in prior Quadrennial Reviews, and is at a price level that is within a range of the capacity supply curve with substantially greater supply elasticity. This update is consistent with observed reality that many new gas CC plants have offered into and entered into the RPM market at price levels that are intermixed with other sources of capacity supply including demand response, aging resources that may retire if they do not clear, energy efficiency, etc. Under these observed market conditions, a relatively steeper demand curve can "right-size" capacity supply every year (rather than procuring more excess in some years, so as to ensure adequate supply on average after considering yearly variability in the supply-demand balance). If these conditions persist, with ample new supply available and offering at price levels that are intermixed in a competitive fashion with existing supply, it suggests that a steeper demand curve can be adopted that will align more closely with the Reliability Requirement.

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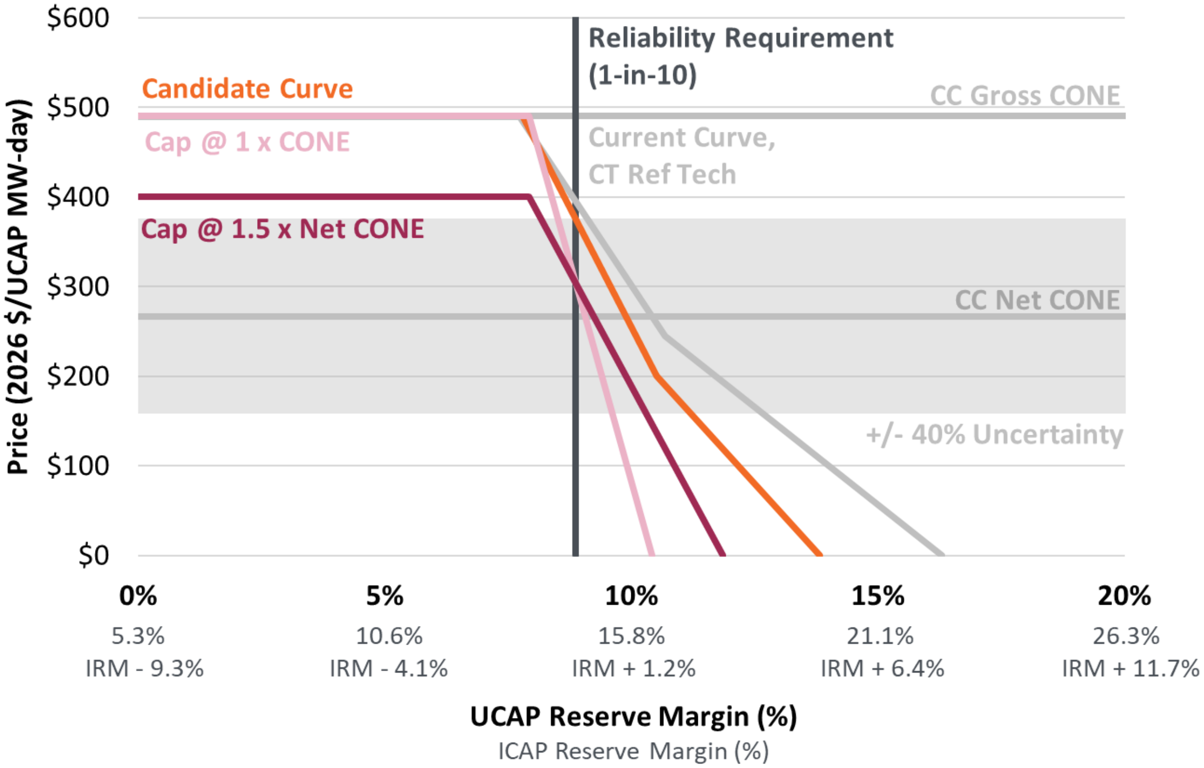
[24] The changes we discuss as driving this result all relate to the availability and cost of capacity supply. Other factors that can similarly influence this result (supply variability, demand variability, PJM's estimate of reliability vs. reserve quantity), have not materially affected the shape and placement of a tuned VRR curve as compared to prior Quadrennial Reviews.

FIGURE 8: CURVES "TUNED" TO ACHIEVE 1-IN-10 LOLE IN THE BRA



Source/Notes: Candidate Curve price cap at Max(1.75 × CC Net CONE, **CC CONE**), **bolded text** indicates which parameter sets the price cap; Cap @ 1 × CONE and Cap at 1.5 × Net CONE curves are both tuned to achieve 1-in-10 LOLE in the BRA.

Performance of these tuned curves as estimated in simulation results are shown in Table 6. Compared to the Candidate Curve, the steeper "tuned" curves reduce reliability to exactly support 0.1 LOLE, reduce average procurement levels, and reduce capacity procurement costs accordingly. The version with a higher price cap is steeper and produces higher price volatility than the Candidate Curve; the version with a lower price cap is wider produces lower price volatility. While the steeper "tuned" curve would modestly increase price volatility, the overall impact is substantially mitigated by high elasticity in the supply stack. A higher price cap is also more robust to Net CONE estimation uncertainty whereas a lower price cap is more susceptible, which could cause reliability concerns if the market clears too far below the Reliability Requirement.

Of these two tuned curves, we view the steeper curve as within the workable range of acceptable performance, particularly if recent market conditions with ample capacity supply offers remain available across a price range above and below Net CONE. However, we offer some hesitation against adopting the 1-in-10 tuned curve immediately, given that we are not confident as to whether recent market conditions (relatively lower Net CONE and greater fleet turnover than observed in prior Quadrennial Reviews) will persist indefinitely. Among other reasons, we have incorporated this analysis into our recommended Candidate Curve, which will incrementally adjust the Current VRR curve toward a curve that supports the 1-in-10 standard. In the next Quadrennial Review, we recommend revisiting this question again and considering the adoption of a curve that is exactly aligned with 1-in-10 as long as it sufficiently supports other performance objectives.

TABLE 6: PERFORMANCE OF CURVES "TUNED" TO ACHIEVE 1-IN-10 LOLE IN THE BRA

	Price			Reliability					Cost
	Average	Standard Deviation	Frequency at Cap	Average LOLE	Average Excess (Deficit)	Average Excess (Deficit)	Frequency Below Target	Frequency Below IRM - 1%	Average Procurement Cost
	($/MW-d)	*($/MW-d)*	*(%)*	*(events/yr)*	*(MW)*	*(IRM + X %)*	*(%)*	*(%)*	*($ mln/yr)*
Candidate Curve									
True Net CONE = 0.6 x CC	$160	$57	0.0%	0.043	2,861	2.5%	0.0%	0.0%	$7,939
True Net CONE = CC	**$267**	**$85**	**2.7%**	**0.073**	**1,221**	**1.1%**	**10.9%**	**3.3%**	**$13,104**
True Net CONE = CT	$326	$94	9.8%	0.098	388	0.4%	31.0%	11.5%	$15,889
True Net CONE = 1.4 x CC	$374	$94	21.2%	0.128	-393	-0.3%	50.0%	24.8%	$18,092
Current Curve, CT									
True Net CONE = 0.6 x CC	$160	$52	0.0%	0.026	4,548	4.0%	0.0%	0.0%	$8,029
True Net CONE = CC	**$267**	**$74**	**1.5%**	**0.059**	**2,026**	**1.8%**	**7.5%**	**2.0%**	**$13,169**
True Net CONE = CT	$326	$86	7.8%	0.085	922	0.8%	23.2%	9.0%	$15,941
True Net CONE = 1.4 x CC	$374	$87	17.9%	0.117	-25	0.0%	43.2%	20.0%	$18,133
Cap @ 1 x CONE									
True Net CONE = 0.6 x CC	$160	$65	0.0%	0.078	876	0.8%	1.5%	0.0%	$7,840
True Net CONE = CC	**$267**	**$98**	**5.6%**	**0.100**	**126**	**0.1%**	**29.5%**	**5.6%**	**$13,017**
True Net CONE = CT	$326	$106	14.8%	0.121	-417	-0.3%	52.2%	14.8%	$15,810
True Net CONE = 1.4 x CC	$374	$105	29.1%	0.150	-1,003	-0.8%	70.6%	29.1%	$18,024
Cap @ 1.5 x Net CONE									
True Net CONE = 0.6 x CC	$160	$60	0.0%	0.061	1,701	1.5%	0.6%	0.0%	$7,879
True Net CONE = CC	**$267**	**$75**	**9.9%**	**0.100**	**248**	**0.2%**	**31.1%**	**9.9%**	**$13,000**
True Net CONE = CT	$326	$71	32.4%	0.151	-914	-0.8%	62.0%	32.4%	$15,710
True Net CONE = 1.4 x CC	$374	$49	62.8%	0.258	-2,625	-2.2%	88.0%	62.8%	$17,746

Source/Notes: All prices in 2026$/UCAP MW-Day and all quantities in UCAP MW; Administrative Net CONE is equal to CC Net CONE ($267/UCAP MW-Day) for Candidate Curve, Cap @ 1 × CONE, and Cap @ 1.5 × Net CONE runs above; Administrative Net CONE is equal to CT Net CONE ($326/UCAP MW-Day) for Current Curve, CT runs above.

D. Comparison to Marginal Reliability Value-Based Curves

The Marginal Reliability Impact (MRI) of capacity reflects the expected improvement in reliability associated with adding incremental capacity. A demand curve constructed from the MRI would consist of price/quantity pairs such that the price at each volume of capacity is proportional to its MRI value. Under an MRI-based demand curve, prices would rise at an increasing rate as reserve margins decline to provide an increasingly strong price signal to avoid very low reliability outcomes. In a similar manner, prices decrease slowly at higher levels of reliability as reserve margins increase to reflect the diminishing, but non-zero, value of additional capacity beyond the Reliability Requirement. The primary conceptual advantage of an MRI-based curve is that all quantities on the demand curve are defined according to a consistent willingness-to-pay to avoid outage events. The MRI curve can be updated each year and used directly to calculate the parameters of a capacity demand curve, as is done in New England, or can be used more indirectly to inform the shape of the demand curve.

As shown in Figure 9, we have defined and tested two potential MRI curves, defined as: (1) an MRI curve that passes through the intersection of Net CONE and the Reliability Requirement, and at a price cap just below 1.5 × Net CONE; and (2) an MRI curve that has the price cap at Gross CONE.[25] The price cap of both curves begins where the curve quantity intersects with a quantity equivalent to the PJM reliability backstop threshold.

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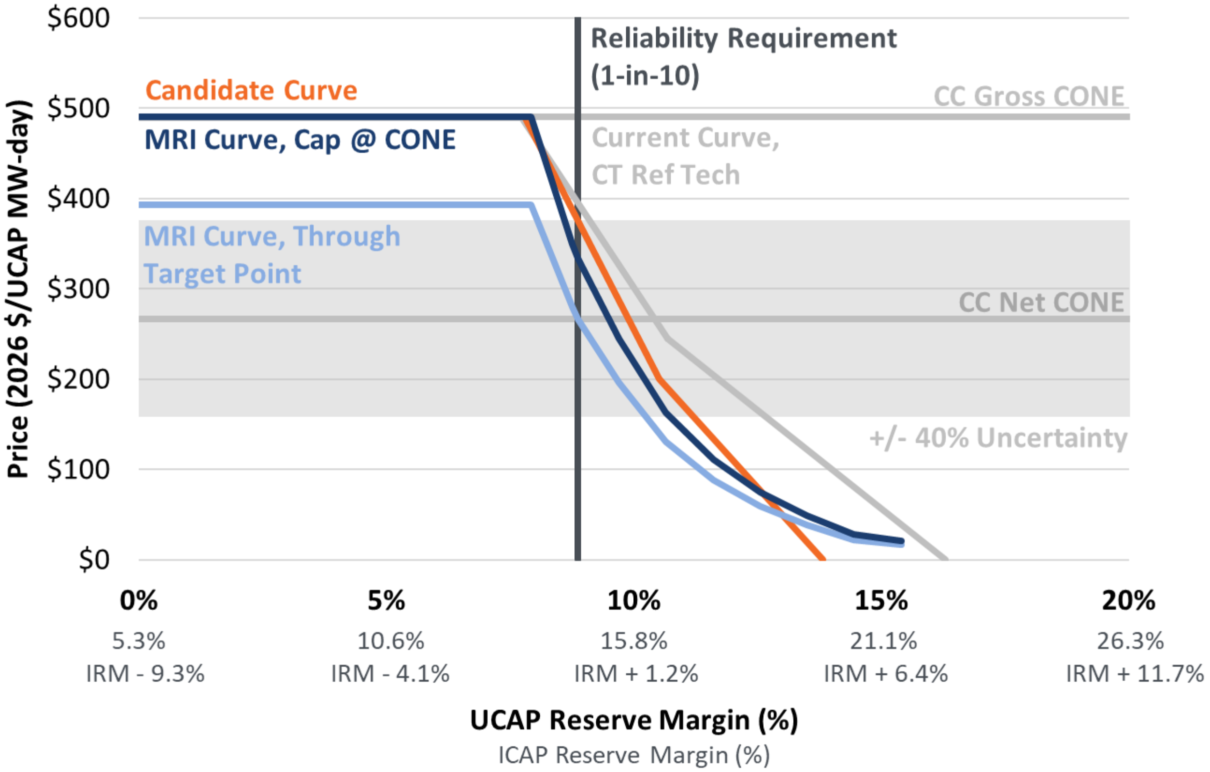
[25] To create these MRI-based VRR curves, we first begin with the Loss of Load Hours (LOLH) (in units of hours per year), which is one of the reliability metrics produced in PJM's annual reliability modeling study, and that is produced at each quantity of capacity (UCAP MW along the x-axis). We then adopt the assumption that 1 MW of UCAP at each quantity point, would incrementally displace the estimated LOLH times 1 MW across the year. The result is a calculation of avoided Expected Unserved Energy (EUE) per each 1 UCAP MW of capacity added to the market (in units of MWh/UCAP MW). This incremental avoided EUE can be translated into a willingness-to-pay unit for capacity ($/MW-day) via a penalty factor or value of reliability metric in units of ($/MWh). The two MRI-based curves illustrated here have two different penalty factor values, but are otherwise identical.

FIGURE 9: MARGINAL RELIABILITY IMPACT BASED CURVES



Source/Notes: Candidate Curve price cap at Max(1.75 × CC Net CONE, **CC CONE**), **bolded text** indicates which parameter sets the price cap; MRI Curve, Through Target Point passes through CC Net CONE at the Reliability Requirement and has price cap at 1.47 × CC Net CONE. Both curves have price caps where the quantity intersects with IRM-1%.

As shown in the numerical simulation results in Table 7, the MRI Curve, Through Target Point would slightly under-procure capacity relative to the 0.1 LOLE standard under the Base Case due to the lower price cap. The MRI Curve Cap @ CONE however would reduce procurement quantities while still achieving the 0.1 LOLE standard in the Base Case and result in less procurement cost on average but with an increased price volatility compared to the Candidate Curve.

Overall, we view a demand curve based on the MRI curve has a sound theoretical basis and could be a workable option that performs similarly to (or arguably better than) our recommended Candidate Curve. However, the MRI curve is based on the simulated PJM EUE reliability metric and therefore is dependent on the accuracy of the underlying reliability modeling. Given that PJM's reliability model is currently under review in the RASTF due to known deficiencies, we at the present time have only used the MRI-based curve to inform the parameters and shape of recommended Candidate Curve. We do not yet recommend to utilize these results directly in setting future VRR curves until PJM's ongoing review and enhancements to the reliability modeling are completed. Once completed within the RASTF or in future Quadrennial Reviews, we recommend that an MRI-based curve should be reviewed again and possibly considered for adoption as the basis for future VRR curves.

TABLE 7: PERFORMANCE OF CURVES BASED ON MARGINAL RELIABILITY IMPACT

	Price			Reliability					Cost
	Average	Standard Deviation	Frequency at Cap	Average LOLE	Average Excess (Deficit)	Average Excess (Deficit)	Frequency Below Target	Frequency Below IRM - 1%	Average Procurement Cost
	($/MW-d)	*($/MW-d)*	*(%)*	*(events/yr)*	*(MW)*	*(IRM + X %)*	*(%)*	*(%)*	*($ mln/yr)*
Candidate Curve									
True Net CONE = 0.6 x CC	$160	$57	0.0%	0.043	2,861	2.5%	0.0%	0.0%	$7,939
True Net CONE = CC	**$267**	**$85**	**2.7%**	**0.073**	**1,221**	**1.1%**	**10.9%**	**3.3%**	**$13,104**
True Net CONE = CT	$326	$94	9.8%	0.098	388	0.4%	31.0%	11.5%	$15,889
True Net CONE = 1.4 x CC	$374	$94	21.2%	0.128	-393	-0.3%	50.0%	24.8%	$18,092
Current Curve, CT									
True Net CONE = 0.6 x CC	$160	$52	0.0%	0.026	4,548	4.0%	0.0%	0.0%	$8,029
True Net CONE = CC	**$267**	**$74**	**1.5%**	**0.059**	**2,026**	**1.8%**	**7.5%**	**2.0%**	**$13,169**
True Net CONE = CT	$326	$86	7.8%	0.085	922	0.8%	23.2%	9.0%	$15,941
True Net CONE = 1.4 x CC	$374	$87	17.9%	0.117	-25	0.0%	43.2%	20.0%	$18,133
MRI Curve, Cap @ CONE									
True Net CONE = 0.6 x CC	$160	$56	0.0%	0.050	2,449	2.1%	0.1%	0.0%	$7,913
True Net CONE = CC	**$267**	**$88**	**4.5%**	**0.083**	**802**	**0.7%**	**18.7%**	**4.5%**	**$13,065**
True Net CONE = CT	$326	$98	12.8%	0.108	27	0.1%	42.1%	12.8%	$15,849
True Net CONE = 1.4 x CC	$374	$99	26.3%	0.139	-696	-0.6%	60.7%	26.3%	$18,056
MRI Curve, Through Target Point									
True Net CONE = 0.6 x CC	$160	$56	0.0%	0.061	1,788	1.6%	2.3%	0.0%	$7,873
True Net CONE = CC	**$267**	**$74**	**11.3%**	**0.110**	**-52**	**0.0%**	**44.0%**	**11.3%**	**$12,968**
True Net CONE = CT	$326	$69	37.0%	0.167	-1,274	-1.1%	75.9%	37.0%	$15,665
True Net CONE = 1.4 x CC	$374	$47	67.3%	0.279	-2,930	-2.5%	93.9%	67.3%	$17,699

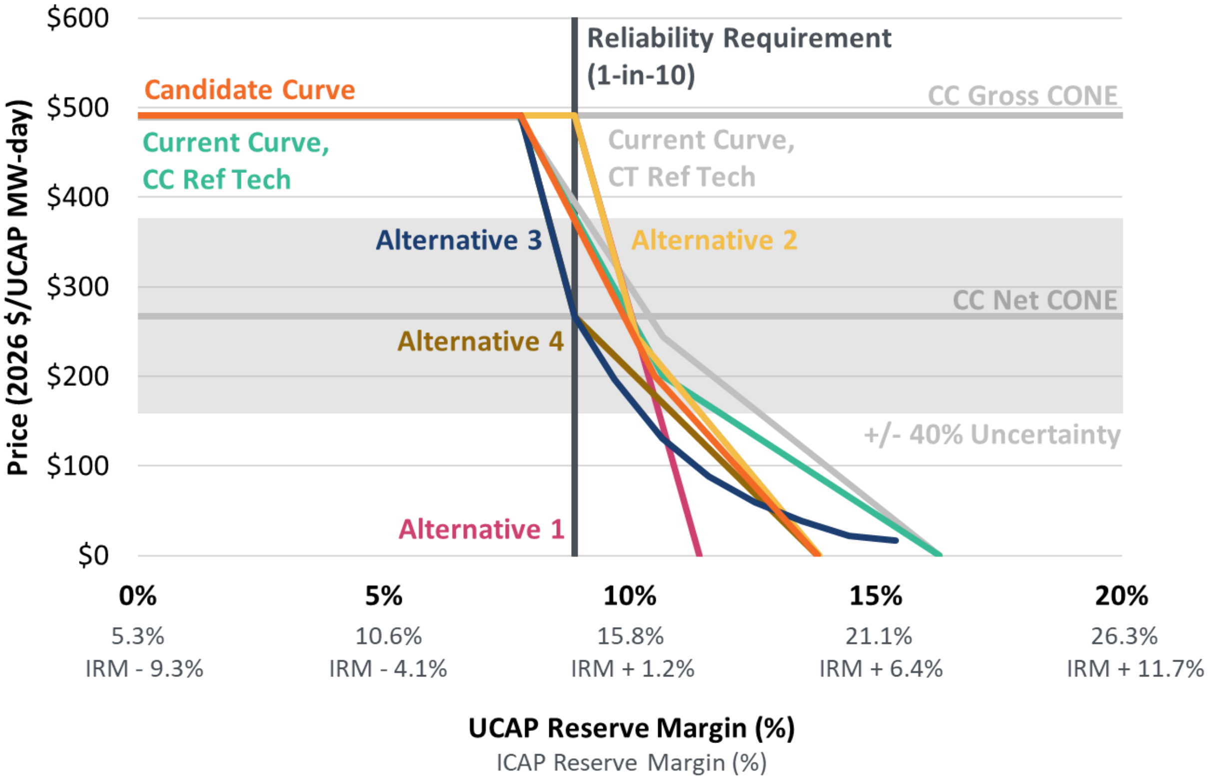
Sources/Notes: All prices in 2026$/UCAP MW-Day and all quantities in UCAP MW; Administrative Net CONE is equal to CC Net CONE ($267/UCAP MW-Day) for Candidate Curve, MRI Curve, Cap @ CONE, and MRI Curve, Through Target Point runs above; Administrative Net CONE is equal to CT Net CONE ($326/UCAP MW-Day) for Current Curve, CT runs above.

E. Comparison to Alternative VRR Curves in the Workable Range

In addition to the curves examined in the previous sections, we have also considered four Alternative Curves. Each of these curves contains features derived from one of the tested curves listed above. Additionally, the prices at the price cap for the Alterative Curves all follow the same formula for the price cap at the maximum of Gross CONE or 1.75 × Net CONE. Along with the Current Curve CT and the Current Curve, CC these Alternative Curves illustrate what we view as the "workable range" of curves (gray shaded area) previously shown in Figure 1.

In Figure 10 we show the alternative curves alongside a +/-40% Net CONE uncertainty range. Due to the inherent performance trade-offs present in designing the VRR Curve, the Alternative Curves result in a range of outcomes in terms of reliability, procurement volumes, and clearing price volatility.

FIGURE 10: ALTERNATIVE CURVES



Sources/Notes: See above for details on Alternative Curves; Current Curve, CT Ref Tech price cap at Max(**1.5 × CT Net CONE**, CT CONE), Candidate Curve, Current Curve, CC Ref Tech, and all Alternative Curve price caps at Max(1.75 × CC Net CONE, **CC CONE**); Alternatives 1 and 2 pass through CC Gross CONE at the Reliability Requirement; Alternative 3 and Alternative 4 pass through CC Net CONE at the Reliability Requirement; **bolded text** indicates which parameter sets the price cap.

Figure 11 shows the average price volatility and average excess (or deficit) across the stress test range +/-40% Net CONE uncertainty for all assessed curves. Each curve was constructed under a different concept and offers a different balance of performance trade-offs, as follows:

- **Alternative 1,** (steeper straight curve): Alternative 1 is constructed based on the tuned Curve with the Cap @ CONE (see Figure 8). As shown in Table 6 the tuned curve results in an expected reliability of exactly 0.1 LOLE when True Net CONE is equal to Administrative Net CONE, by design. However, when True Net CONE is greater than Administrative Net CONE, this curve falls short of the Reliability Requirement on average. To address this shortcoming, we move Point A to intersect with the Reliability Requirement, so the cleared quantity will only fall below the Reliability Requirement when clearing at the price cap. Point B is set so that Alternative 1 has the same slope as the tuned curve, Cap @ CONE which results in a foot position at 102.3% of the Reliability Requirement.

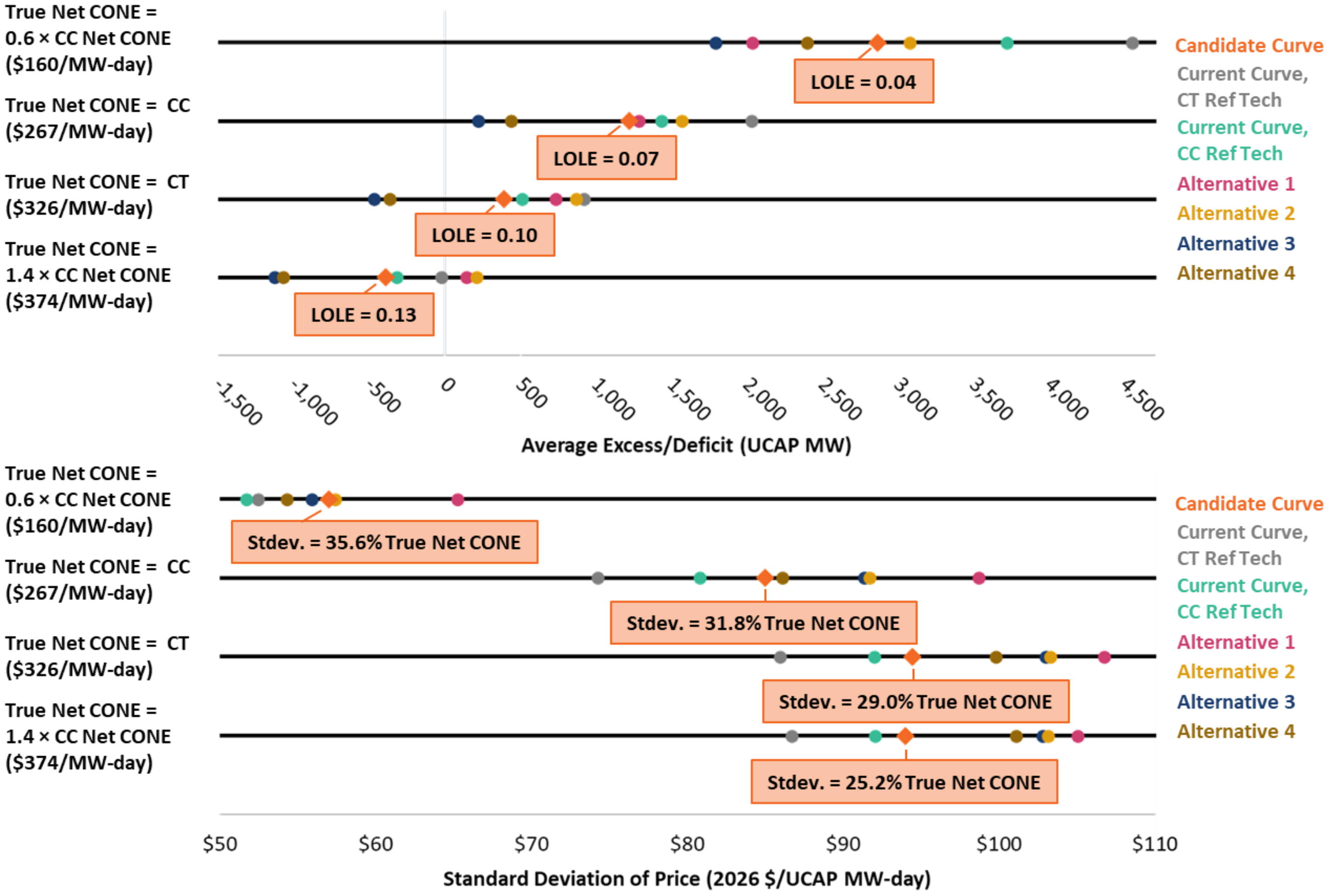
- **Alternative 2,** (steeper kinked curve): Alternative 2 has the same price cap and the same slope between point A and point B as Alternative 1. Point B is set at the same price, in $ UCAP/MW-Day, as Point B from the Current Curve, CT Ref Tech. However, Alternative 2 has a right-shifted foot compared Alternative 1 to result in a kinked curve. The foot position is set halfway between the foot position of the Current Curve, CT and Alternative 1 to result in a zero intercept at 104.6% of the Reliability Requirement. Therefore, the Alternative Curve 2 provides better protection against quantity shortfalls when Net CONE is underestimated, though it tends to over-procure more than Alternative 1 due to the kinked construction with a right-shifted foot.

- **Alternative 3,** (based on the MRI curve): Alternative 3 is straight from Point A (set at 99% of the Reliability Requirement) to Point B, which is set at the intersection of CC Net CONE and the Reliability Requirement. To the right of the target point, Alternative 3 is the MRI curve with a penalty factor chosen so that the curve passes through the target point (see "MRI curve, Through Target Point" in Figure 9). Alternative 3 results in the least excess procurement when Net CONE estimation is accurate and therefore is the closest curve to achieving an 0.1 LOLE in the Base Case. However, when Net CONE is underestimated Alternative 3 will tend to under-procure leading to potential reliability shortfalls.

- **Alternative 4,** (straight-line MRI curve): Alternative 4 is a linear approximation of Alternative 3. Points A and B are the same as Alternative 3 however the foot position is chosen to approximate the MRI curve's downward slope. This makes Alternative 4 steeper than the Candidate Curve from Point A to Point B, so it has greater price volatility but tends to over-procure less when Net CONE is overestimated. However when Net CONE is underestimated, Alternative 4 would be expected to under-procure relative to the Reliability Requirement.

The Candidate Curve falls in the middle of this range at each of the Net CONE scenarios, which is one of the reasons that we have opted to recommend the Candidate Curve as compared to these other workable alternatives. Though we do recommend the Candidate Curve as offering robust performance across a range of stress tests, we also acknowledge that these and likely other curves within the workable range could be adopted with a somewhat different balance of competing objectives. For more information on the estimated performance of the Alternative Curves, see Appendix F, Table 19.

FIGURE 11: COMPARISON OF PERFORMANCE OF ALTERNATIVE CURVES, CLEARED QUANTITY (TOP) AND PRICE VOLATILITY (BOTTOM)



Sources/Notes: 2009/10 to 2022/23 RTO clearing price volatility is $48.59, calculated from PJM, 2009/10 to 2022/23 Base Residual Auction Results.

F. Additional Considerations within Constrained LDAs

The VRR Curves for the LDAs presently use the same formula as the system-wide curve, even though LDAs are subject to distinct environments. Locational Net CONE estimation is subject to greater uncertainty and administrative error, partly driven by the use of localized E&AS revenue offsets that can be more volatile (especially under a backward-looking estimation approach). LDAs also tend to face other reliability and economic challenges that are different from the system as a whole in that they can be subject to greater capacity price volatility due to small changes in supply, demand, and transmission parameters; this volatility manifests as periodic price spikes (given that downward price volatility is buffered by parent LDAs' pricing). We have identified these same challenges in prior Quadrennial Reviews.

Managing Net CONE variability by location has always been challenging, especially among the smaller LDAs that do not have location-specific Gross CONE or E&AS estimates. Smaller LDAs can have idiosyncratic siting and land costs, differing environmental policies, or infrastructure limitations that do not apply in the larger CONE Areas. Further, these locations are unlikely to have a substantial number of projects similar to the reference unit used to estimate the Area Net CONE, limiting the available evidence that can be used to inform the LDA Net CONE and reference resource assumptions. Going forward, we anticipate that locational differences in viable reference technologies and Net CONE can become even greater as more states and local governments pursue greater environmental policies. One question we have reviewed throughout this Quadrennial Review is whether there may already be some locations within PJM where the recommended gas CC reference technology cannot be built. At this time, we have not identified regulatory or statutory limits that will prevent new fossil resources from being developed, but we anticipate that such limits could be implemented over the coming years in some locations given the substantial greenhouse gas and clean energy policy mandates already in place across the PJM footprint. We therefore recommend that PJM monitor the regulatory and statutory developments across the footprint and transition to using a clean reference technology for those LDAs if it becomes clear that gas plants cannot be built.

Managing proportionally large supply-demand variability is another reality that is more challenging across the LDAs, particularly the smallest LDAs. Figure 12 and Table 8 illustrate the scale of year-to-year supply-demand variability experienced across capacity LDAs in relationship to the size of the VRR curve. Because the same VRR Curve shape as a percentage of the Reliability Requirement is used in all LDAs, the curve becomes steeper in absolute terms in the smallest LDAs. In these locations, small increases or decreases in supply can substantially impact clearing results, even the size of a single generation plant could result in price changes from the price cap to the price floor.[26] In fact, a single 700 MW power plant has a size greater than the entire width of the LDA VRR Curve in PS-N, DPL South, PEPCO, ATSI-Cleveland, BGE, Dayton, and DEOK under the current curve parameters. Together, these characteristics increase the susceptibility of smaller LDAs to price spikes, exercise of localized market power, and proportionately large reliability challenges (or out-of-market actions to prevent reliability shortfalls) when a single large resource retires.

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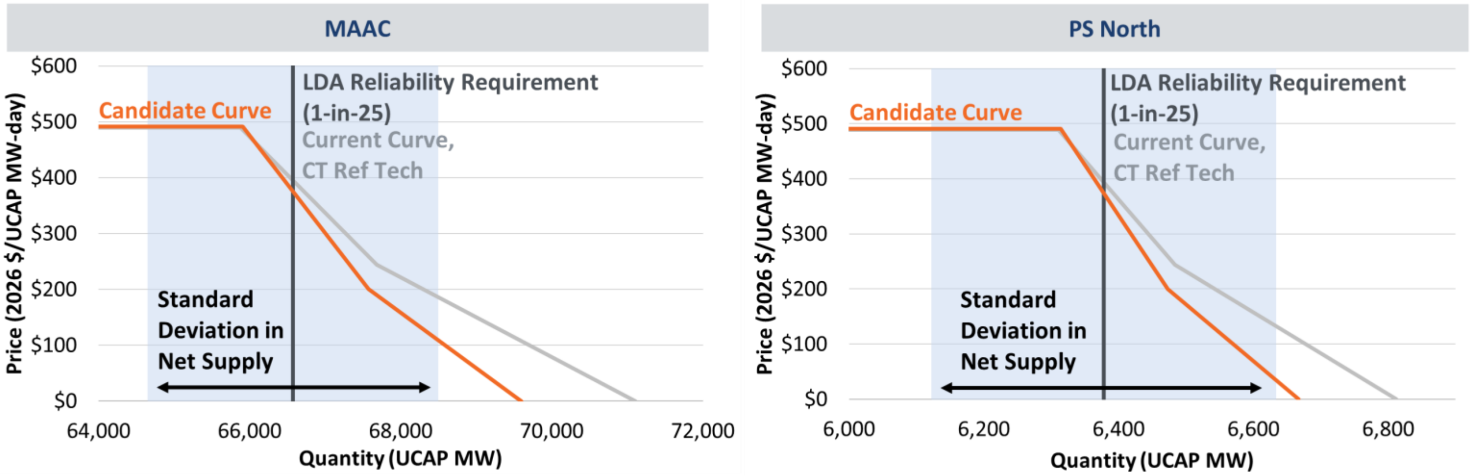
[26] LDAs can only clear prices at or above their parent LDA. The clearing price in the parent zone therefore acts as a soft price floor for the LDA, with the LDA price-separating above the parent only when import limits are binding.

FIGURE 12: COMPARISON OF NET SUPPLY VARIABILITY BETWEEN LARGE AND SMALL LDAS



Sources/Notes: Standard Deviation in Net Supply calculated over period 2013/14 to 2022/23; LDA Reliability Requirements from PJM, 2013/14 to 2022/23 RPM Planning Period Parameters; CONE values from 2022 Net CONE Study.

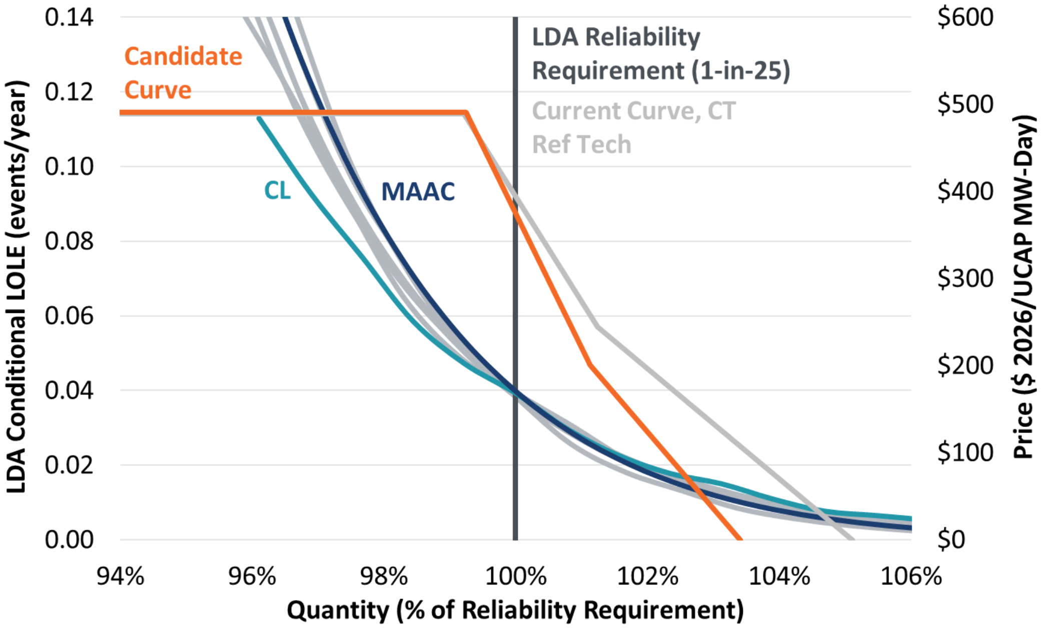
TABLE 8: LOCAL NET SUPPLY VARIABILITY COMPARED TO LOCATIONAL VRR CURVE WIDTH

	Net Supply Variability (Standard Deviation)					
LDA	Supply	CETL	Reliability Requirement	Net Supply	**Demand Curve Width**	**Net Supply Variability as Percentage of Width**
	(MW)	*(MW)*	*(MW)*	*(MW)*	*(MW)*	*(%)*
RTO	9,636	n/a	10,061	9,720	10,396	94%
MAAC	2,280	1,472	3,265	3,851	5,071	76%
EMAAC	2,260	662	1,667	2,467	2,821	87%
SWMAAC	796	985	1,030	1,958	1,174	167%
PSEG	1,351	1,001	643	864	919	94%
PS-N	611	703	215	506	486	104%
DPL-S	64	146	96	129	248	52%
PEPCO	603	959	577	1,772	605	293%
ATSI	769	1,375	410	1,481	1,180	126%
ATSI-C	202	351	329	543	453	120%
COMED	3,223	1,116	1,700	4,866	1,881	259%
BGE	435	283	384	362	615	59%
PPL	478	1,169	378	1,516	805	188%
DAYTON	200	287	39	137	311	44%
DEOK	128	266	15	242	558	43%

Sources/Notes: Standard Deviation in Net Supply calculated over period 2013/14 to 2022/23; LDA Reliability Requirements from PJM, 2013/14 to 2022/23 RPM Planning Period Parameters.

Another factor to consider when examining LDA VRR Curve is the relationship between reliability and quantity procured. PJM's local resource adequacy requirements are set based on a 1-in-25 or 0.04 *conditional* LOLE standard.[27] The LDA Reliability Standard reflects the reliability events that may be caused by location-specific shortages, which are additive to any events that may experienced due to system-wide shortages. As we show in Figure 13, the conditional LOLE curves in all currently modeled LDAs intersect with the price cap at a relatively high quantity before very poor reliability (*e.g.*, 0.1 locational LOLE) is observed, which will ensure that all in-market capacity is procured before extreme poor reliability events are observed. This relatively right-shifted price cap, combined with the 1 × CONE minimum on the price cap provide some protection against poor reliability outcomes in all of the LDAs. However, the shape of the VRR curve and pricing outcomes are otherwise disconnected from the reliability value of capacity resources in the LDAs. Capacity resources in the most constrained sub-zones have greater reliability value than capacity resources in the broader RPM footprint, but the usual outcome of RPM is that these LDAs do not produce higher prices consistent with incrementally higher reliability value (unless the LDA happens to be facing a temporary price spike and shortfall).

FIGURE 13: LDA CONDITIONAL LOLE CURVES VS THE SYSTEM-WIDE VRR CURVE



Sources/Notes: Candidate Curve price cap at Max(1.75 × CC Net CONE, **CC CONE**); Current Curve, CT Ref Tech price cap at Max(**1.5 × CT Net CONE**, CT CONE), bolded text indicates which parameter sets the price cap for each curve. Data provided by PJM.

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[27] See Newell, *et. al.*, Fourth Review of PJM's Variable Resource Requirement Curve, April 19, 2018, Section V.A for an in-depth description of the conditional LDA LOLE standard.

We recommend that PJM should consider locational VRR curves that are aligned with localized MRI in order to more meaningfully reflect local reliability value, manage locational supply-demand variability, reduce susceptibility to price spikes, and reduce the susceptibility to exercise of local market power. The most effective use of a local MRI curve would be combined with enhanced market clearing, following the model already in use in ISO-NE.[28] Under MRI-based VRR curves and locational clearing, an MRI curve would be calculated for the system and each LDA, reflecting the incremental value of avoided EUE achieved by adding 1 UCAP MW of capacity in each location. The system-wide MRI curve would reflect avoided EUE from reduced system-wide shortfall events, which can then be translated into units of capacity price using a value-of-reliability or penalty factor translation factor. The LDA MRI curves would be different since they would reflect the *additional* avoided EUE associated with locating capacity in a particular LDA, rather than locating that capacity elsewhere in the unconstrained system. The LDA MRI curves would then be translated into units of capacity price using the same penalty factor as used in the system curve. However, the LDA MRI curve would reflect the locational price adder to be awarded in addition to the system price, in recognition of the greater reliability value produced by resources in import-constrained locations.[29] This new MRI-based definition of local VRR would produce a flatter and lower demand curve in the LDAs, producing a more stable and modestly-sized pricing premium for locating capacity in an import-constrained region, reduced likelihood of price spikes, less susceptibility to exercise of localized market power, and pricing in alignment with differentiated reliability value. A side-benefit of redefining local VRR curves in this way is that it would simplify RPM auction clearing to eliminate the iterative steps currently required to establish LDA prices.

We recommend this approach to MRI-based LDA VRR Curves and auction clearing be reviewed for consideration in the RASTF, after PJM completes its review and enhancement to its reliability modeling framework. The enhancement of reliability modeling and MRI curves could be considered as an opportunity to align and enhance several features of the RPM including the establishment of separate summer and winter reliability requirements, separate seasonal VRR curves, LDA VRR curves, and enhanced auction clearing so as to consistently align procurement volumes and prices with reliability value.

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[28] ISO-NE, MRI Based System-wide and Zonal Sloped Demand Curves, August 25, 2016. We have also recommended similar changes in the past several Quadrennial Reviews, see Newell, *et. al.* Fourth Review of PJM's Variable Resource Requirement Curve, Section V.B.2, April 19, 2018; and Pfeifenberger, *et. al.*, Third Triennial Review of PJM's Variable Resource Requirement Curve, Section D.4 of Recommendations, May 15, 2014.

[29] This definition of the locational VRR curve pricing points is different from the definition in place in the RPM today. Local curves today reflect the absolute price that can be paid for local resources, rather than the price adder.

IV. Changing Resource Mix and Interactions with Potential RPM Reforms

The PJM Tariff identifies the scope of the Quadrennial Review as including a review of the Net CONE parameter and formula for the VRR Curve shape. In this Quadrennial Review, we have been tasked with a slightly broader scope so as to align with identified priorities and related ongoing activities of the PJM Board, OPSI, and related stakeholder initiatives, particularly those of the Resource Adequacy Senior Task Force (RASTF).[30] Though our recommendations remain mostly focused on the role of the VRR Curve within the PJM capacity market, we are acutely aware of the much more foundational transformation of the RPM that may come about as the outcome of ongoing parallel reform efforts. We also understand, and entirely agree, that foundational reforms such as those being considered in the RASTF will be necessary for the RPM to continue to maintain reliability levels, improve economic performance, align with a changing resource mix, and potentially to advance states' and consumers' resource preferences. The RPM cannot be viewed as a static construct, but rather one that must be updated over time to maintain relevance throughout industry transition.

Conducting this independent review of the VRR Curve has presented new challenges given the context of fleet transition and the large uncertainties regarding potential reforms to the broader PJM market. The VRR Curve that PJM adopts upon conclusion of this review is scheduled to be implemented in the market for Planning Years 2026/27 to 2029/30, a timeframe over which nearly every aspect of the RPM has the potential to be at least adjusted and in some cases substantially reformed. Table 9 provides a summary of the key work activities currently underway within the RASTF and scheduled for completion throughout 2023 (a timeframe that extends beyond the Fall 2022 deadline for PJM to file any VRR Curve updates with the FERC). Many of the potential RPM reforms may have limited interactions with the demand curve shape, and would require nothing more than a double-check to ensure alignment or a refinement to the administrative Net CONE estimate. Other reforms, such as adopting a seasonal capacity market, likely would require revisiting the question of the VRR Curve shape entirely. We summarize our initial sense of these potential interactions below, but note that we are unable to provide a complete assessment without having a clearer picture of the specific reforms that will be implemented.

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[30] See PJM, PJM Board of Managers; Organization of PJM States (OPSI); and Resource Adequacy Senior Task Force.

TABLE 9: INTERACTIONS BETWEEN VRR CURVE AND KEY WORK ACTIVITIES OF THE ONGOING PJM RESOURCE ADEQUACY SENIOR TASK FORCE

Key Work Activity	Potential Interactions with VRR Curve
1. Determine whether a forward procurement of clean resource attributes should be pursued, and investigate the inclusion of the Social Cost of Carbon in PJM	• Incorporating the Social Cost of Carbon would pose **modest interactions** and would require updating the Net CONE estimate • Forward clean energy or capacity attribute procurements could pose anywhere from **modest to large interactions** depending on the scope of reforms. An entirely separate clean energy attributes market may pose minimal interactions with the current VRR Curve; but a fully integrated clean energy/capacity market could introduce substantial interactions and may require a new demand curve or constraint to be defined for the new product(s)
2. Determine the types of reliability risks and risk drivers the capacty market should consider and how they should be accounted for	• Improved reliability assessments can more accurately determine the quantity placement of the VRR Curve and can inform the VRR Curve shape in future reviews, but will have otherwise **minimal interactions** • If a seasonal capacity market is adopted, the **VRR Curve likely would need to be considered afresh** with the possibility of different interpretations of the Reliability Requirement reference technologies, Net CONE values, and parameters in each season. Similarly, other new/segmented capacity products could also require a fresh look at the VRR Curve
3. Determine the desired procurement metric and level to maintain the desired level of reliability	• Similar to #2, **minimal interactions** unless this also introduces changes to the number of distinct capacity products (e.g. seasonal capacity commitments)
4. Determine the performance expected from a capacity resource	• May require an update to the Net CONE estimate, otherwise **modest interactions**
5. Determine the qualification and accreditation of capacity resources	• May require an update to the Net CONE estimate, otherwise **modest interactions**
6. Determine the desired obligations of capacity resources	• Seasonal market would require **a fresh VRR Curve review** (see #2). May require an update to the Net CONE estimate
7. Determine if there are needed enhancements to the capacity procurement process	• **Unclear interactions** until potential reforms are more fully specified • To enhance performance with VRR Curve we recommend updating optimized auction clearing to remove iterative and heuristic steps, and to incorporate MRI concepts into locational clearing and price formation
8. As applicable, determine any remaining design details for a seasonal capacity market construct not addressed in other key work activities	• If a seasonal market is implemented, **a fresh look at the VRR Curve** likely would be required for each defined season
9. Determine if supply-side market power mitigation rules in the capacity market need to be enhanced	• Based on sensitivity testing reported in the Appendix, we anticipate **modest interactions** between VRR Curve performance and adjustments to the mitigation framework
10. Determine if the FRR rules need to be synchronized with any changes made	• **Modest interactions** unless the scale of implications for year-to-year changes in RPM cleared market size becomes much larger

Among these reforms, we highlight the possibility of a seasonal capacity market (key work activities 2, 3, 6, and 8) as having a large interaction with the VRR Curve, and likely requiring a fresh look at the VRR Curve shape once the basic construct for the seasonal market (number of seasons, nature of procurement) is identified. One variation of a seasonal capacity market would require a demand curve to be determined for each defined season, which would have its own capacity product and supply/demand accounting. Under such a seasonal design, it may be necessary to define separate reference technologies, separate Net CONE parameters, separate Reliability Requirements, and otherwise examine the VRR Curve parameters for each season.

Related to clean resource attributes procurement (key work activity 1), we note that there is the potential to require substantial VRR Curve reforms, but the topic is not sufficiently explored to evaluate the scope of interactions. We do offer a recommendation to continue developing PJM's capability to accurately estimate the Net CONE of clean resources, denominated in both clean energy attribute (e.g. $/MWh and/or $/REC terms) and in capacity (e.g. $/MW-day) terms in order to improve the accuracy of the parameters. A clean resource Net CONE parameter may be required in any case if there are LDAs where new fossil supply will eventually not be possible to be developed and may eventually be needed for use in a regional clean energy/capacity market construct.

Related to procurement processes (key work activity 7), again the activity is not yet sufficiently defined to evaluate the scope of interactions. That being said, we offer several recommendations here for how the RPM procurement process could be enhanced to improve the relevance and performance of the system and locational VRR Curves (also touched on in prior sections of this report). We recommend to eliminate all iterative and heuristic steps from capacity market clearing, and replace them with optimized clearing. As of now, iterative/heuristic steps are used for seasonal resource matching, locational clearing, and matching cleared EE with the volume of the EE gross up. Each of these iterative clearing processes can be improved by replacing them with a simpler one-step optimization; as relevant examples for how this can be done we point to Ontario's seasonal two-season optimized capacity market clearing, ISO-NE's MRI-aligned locational market clearing approach (see Section III.D above), and recommend using an entirely supply-side EE accounting approach (see Section II.C above).[31] Auction clearing in the Incremental Auctions can also be simplified and clarified by using a "gross clearing" rather than a "net clearing" approach, with all existing capacity commitments pre-scheduled into the auction

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[31] See Ontario's two season (summer/winter) capacity market IESO, Capacity Auction, and ISO-NE's MRI locational clearing approach, ISO-NE, MRI Based System-wide and Zonal Sloped Demand Curves, August 25, 2016.

clearing.[32] Simplifying auction clearing will improve transparency, enhance optimized resource selection, and refine pricing signals, especially for signalling seasonal and locational capacity needs. A simpler auction clearing platform that eliminates iterative/heuristic steps will also create a more robust framework that can be used to layer on new products or constraints should the need be identified.

As a final observation related to the ongoing fleet transformation and RPM reform efforts, we note that the scope of the Quadrennial Review is relatively limited compared to the scope of reforms that could be needed over the coming decades. Some of the challenges and issues that have been identified by stakeholders in the QER process cannot be meaningfully addressed via changes to the VRR Curve shape or parameters. The scope of the RASTF, on the other hand, is quite broad and therefore has the potential to produce the range of enhancements needed to improve the performance and sustainability of the capacity market. Even after the present RASTF process is concluded, there is a possibility that additional ongoing refinements could be needed over the coming date throughout fleet transition. If it is determined that a regularized process for RPM reform updates would be helpful, one option would be to broaden the scope of future Quadrennial Reviews (e.g. starting with Planning Years 2030/31 to 2033/34).

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[32] The current approach to incremental auction clearing uses a "net clearing" approach that aims to clear only residual capacity needs (or release excess capacity), recognizing only a limited portion of the system and locational VRR Curves; the IAs also recognize only a portion of the system's capacity transmission capability. This approach to IA clearing has the potential to under-utilize the transmission system, and (at least in our view) reduces the transparency of the IAs. A simplified gross IA clearing approach would account for all supply (including supply already committed and not yet committed), all portions of all demand curves as updated with the latest load forecast, and all transmission capability. Any capacity supplies already committed would be pre-scheduled into the clearing so that the volumes could be accounted for in auction clearing, but these resources would not have any financial implications. Incremental and decremental supply/demand bids would then be determined to clear optimally against the IA price and in full use of the transmission system. This gross clearing model would be more analogous to how the real-time energy market is cleared, and is largely the same as the model that the Midcontinent ISO uses to clear its locational capacity auction in consideration of the capacity obligation commitments that are made largely in advance of the auction (and that therefore are accounted for in auction clearing even though they do not "clear" that auction). See MISO, Business Practices Manual: Resource Adequacy (BPM 011: Resource Adequacy), Sections 5.3 and 5.5.

List of Abbreviations

A/S	Ancillary Service
ATSI-Cleveland	American Transmission Systems, Inc.-Cleveland
BGE	Baltimore Gas and Electric
BRA	Base Residual Auction
CC	Combined Cycle
CETL	Capacity Emergency Transfer Limit
ComEd	Commonwealth Edison, Exelon Corporation
CONE	Cost of New Entry
CT	Combustion Turbine
CP	Capacity Performance
Dayton	Dayton Power and Light Company
DEOK	Duke Energy Ohio/Kentucky
DPL South	South Delmarva Power and Light-South
DR	Demand Response
E&AS	Energy and Ancillary Services
EE	Energy Efficiency
EUE	Expected Unserved Energy
FERC	Federal Energy Regulatory Commission
FPR	Forecast Pool Requirement
FRR	Fixed Resource Requirement
IA	Incremental Auction
ICAP	Installed Capacity
IMM	Independent Market Monitor
IRM	Installed Reserve Margin
ISO	Independent System Operator
ISO-NE	ISO New England
kW	Kilowatt
kWh	Kilowatt Hours
LDA	Locational Deliverability Area
LOLE	Loss of Load Event
MAAC	Mid-Atlantic Area Council
MISO	Midcontinent Independent System Operator
MOPR	Minimum Offer Price Rule
MRI	Marginal Reliability Impact
MW	Megawatts

MWh	Megawatt Hours
NERC	North American Electric Reliability Corporation
OATT	Open Access Transmission Tariff
PEPCO	Potomac Electric Power Company
PJM	PJM Interconnection, LLC
PPL	Pennsylvania Power and Light Company
PS-N	North Public Service Enterprise Group-North
PSEG	Public Service Enterprise Group
RASTF	Resource Adequacy Senior Taskforce
Ref Tech	Reference Technology
RPM	Reliability Pricing Model
RTO	Regional Transmission Organization
UCAP	Unforced Capacity
VOM	Variable Operations and Maintenance
VRR	Variable Resource Requirement

Appendix: Detailed Modeling Assumptions and Approach

In this Appendix we provide additional detail on the structure and input assumptions for the probabilistic Monte Carlo simulation modeling, utilized to examine performance of a range of VRR Curves. Additionally, we provide the results of additional sensitivity analyses to illustrate the sensitivity of model results to our input assumptions and modeling approach.

A. Overview of Model Structure and Assumptions

To evaluate PJM's current VRR Curve and possible alternative curves, we conducted Monte Carlo simulations using an updated and enhanced version of the model used in the 2018 review.[33] This analysis allows us to estimate distributions of price, quantity, and reliability outcomes under a particular VRR Curve, and review these outcomes in light of the performance objectives of the VRR Curve and RPM. Though we continue to focus primarily on the estimated outcomes in the three-year-forward BRA, we have also updated the model to account for supply and demand uncertainties that unfold after the BRA and before the Planning Year begins.

The Monte Carlo simulation model we employ in this analysis evaluates capacity market outcomes probabilistically, given realistic variability in supply and demand in both the forward and prompt periods, and under the long-run equilibrium assumption that merchant generation will enter the market until average prices equal Net CONE. Due to unavoidable variability in supply-demand conditions, it is not possible to ensure that procured capacity will land exactly at the Reliability Requirement in every year. We therefore simulate a distribution of cleared reserve margins produced by the capacity market, and evaluate how a demand curve performs. Given our assumption of economically rational new entry, our simulations reflect long-term economic equilibrium conditions and average performance of tested curves, and do not reflect a forecast of outcomes over the next several years or any particular year.

We use historical market data to calibrate the size and standard deviations of supply and demand; every input parameter utilized in the model is derived directly from auction parameters, historical market data, and historical offer prices. By ensuring that all model inputs and parameters are derived directly from observable data, we aim to improve the accuracy and validity of modeling results and minimize the importance of subjective judgements.

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[33] See Newell, *et. al.*, Fourth Review of PJM's Variable Resource Requirement Curve, April 19, 2018.

Figure 14 shows a stylized depiction of how the model estimates a distribution of price and quantity distributions driven by supply and demand variability. We derive parameters causing supply and demand variability from the historical variation of supply and demand in the BRA and IA, using data from the 2013/14 to 2021/22 Planning Years. For each model draw, the model chooses one supply curve (with quantity represented as a percent of BRA total supply) from the range of normalized and smoothed supply curves. On the demand side, the VRR Curve is calculated relative to the Reliability Requirement, which is subject to variability in each model draw. The intersection of supply and demand determines the clearing price, quantity, and reliability in each draw. These clearing results as tabulated across many draws provide the estimated distribution of market clearing results. The shape of the demand curve under consideration will result in different price and quantity distributions compared to other tested curves. To simulate rational economic entry and exit, we modify the quantity of BRA total supply offered into the market such that average prices across 1,000 distinct simulated draws in the market converge to an equilibrium price at Net CONE.[34]

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[34] We utilize a "smart block" in the supply curve that grows or contracts as needed to achieve pricing convergence at Net CONE. Pricing convergence is achieved in the first 9,000 draws of the model. After the model converges, the model begins tabulating price, quantity, and reliability outcomes across another 1,000 draws. We report the results from these final 1,000 draws throughout this study. Differently-shaped demand curves will result in different average cleared quantities and average performance metrics. This Monte Carlo approach allows us to examine the performance of each candidate VRR Curve in a long-term equilibrium state under total expected variability in supply and demand.

FIGURE 14: ILLUSTRATION OF CLEARING OUTCOMES ACROSS MODELING DRAWS

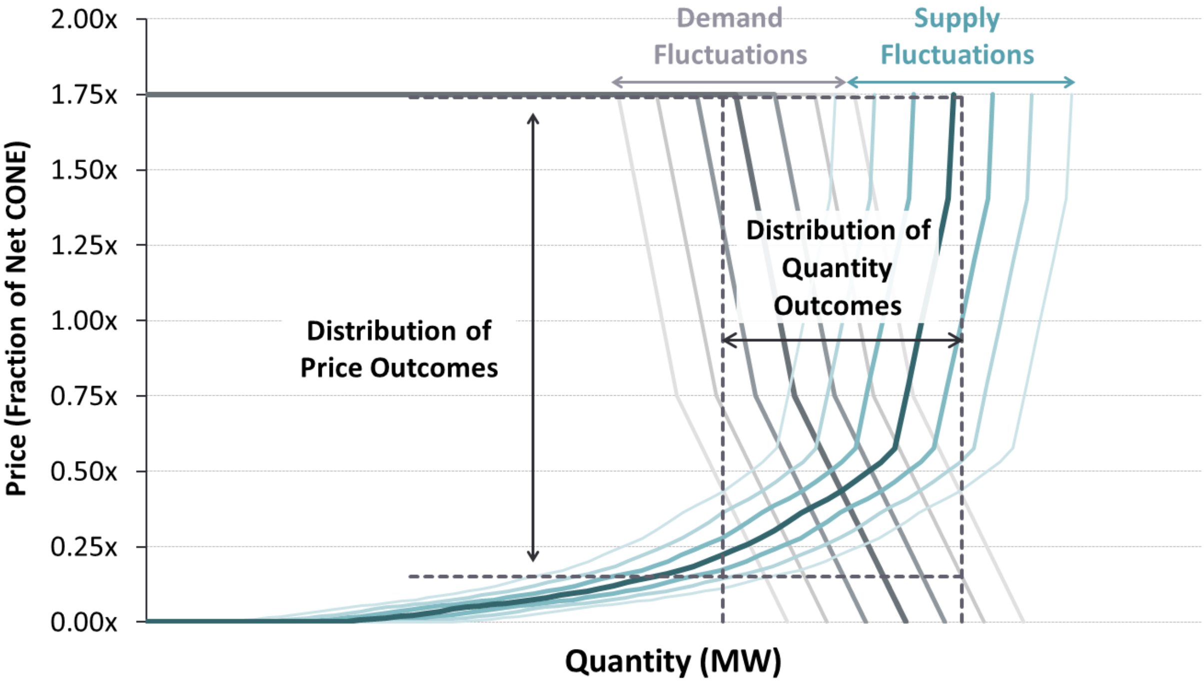

Table 10 summarizes the Base Case input assumptions. We detail the derivation of each parameter in its respective sub-sections in the Appendix. Most modeling inputs such as system peak load are consistent with the 2022/23 BRA Planning Period Parameters, whereas Gross and Net CONE values are from the concurrently released 2022 Net CONE Study.[35]

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[35] There are slight differences in Gross and Net CONE parameters between this study and the Net CONE Study due to ongoing refinements of the Net CONE parameters. We anticipate these refinements may continue throughout an ongoing PJM and stakeholder engagement process; however, we have recommended a Candidate VRR Curve that will offer strong performance over a large uncertainty range in Net CONE and Gross CONE parameters.

TABLE 10: BASE CASE INPUT ASSUMPTIONS

Parameter	Unit	Value
PJM System Parameters		
Peak Load	(MW)	121,693
Forecast Pool Requirement	(UCAP %)	8.9%
Reliability Requirement	(UCAP MW)	132,495
Net CONE		
CC Net CONE	($2026/MW-day)	$267
CC Gross CONE	($2026/MW-day)	$491
CT Net CONE	($2026/MW-day)	$326
CT Gross CONE	($2026/MW-day)	$408
Supply and Demand Variability		
BRA Total Supply	(Std. Dev as % of BRA Total Supply)	3.2%
BRA Reliability Requirement	(Std. Dev as % of BRA Reliability Requirement)	4.1%
Forward-to-Prompt Supply	(Std. Dev as % of BRA Total Supply)	1.0%
Forward-to-Prompt Reliability Requirement	(Std. Dev as % of Final IA Reliability Requirement)	1.7%
Incremental Auction		
IA Available Supply	(% of BRA Uncleared Supply)	53.8%
Capacity Released in IA	(% of Target Quantity)	50.0%
Minimum Supply Offered in IA	(MW)	1,000

Sources/Notes: BRA Reliability Requirement and Peak Load are adjusted for FRR; Peak Load from PJM, 2022/23 Base Residual Auction Planning Period Parameters; UCAP Reserve Margin provided by PJM; CONE values from Brattle 2022 Net CONE Study; IA data and Variability calculations based on historical deviation from trend, data from PJM, 2013/14 to 2021/22 Base Residual Auction Planning Parameters, PJM, 2013/14 to 2021/22 Base Residual Auction Results, and PJM, 2013/14 to 2021/22 RPM Incremental Auction Results.

B. Demand and Reliability

Demand parameters summarized in Table 10 are consistent with the 2022/23 Base Residual Auction, and exclude demand associated with FRR entities.[36] We estimate reliability outcomes from the cleared UCAP reserve margin in each draw.[37] Figure 15 shows the relationship between LOLE and cleared quantity as estimated by PJM staff in the most recent reliability study. This relationship is asymmetrical, with LOLE increasing more steeply (indicating worsening reliability outcomes) below the Reliability Requirement but with LOLE decreasing more gradually (meaning improving reliability) at reserve margins above the Reliability Requirement. An implication of this

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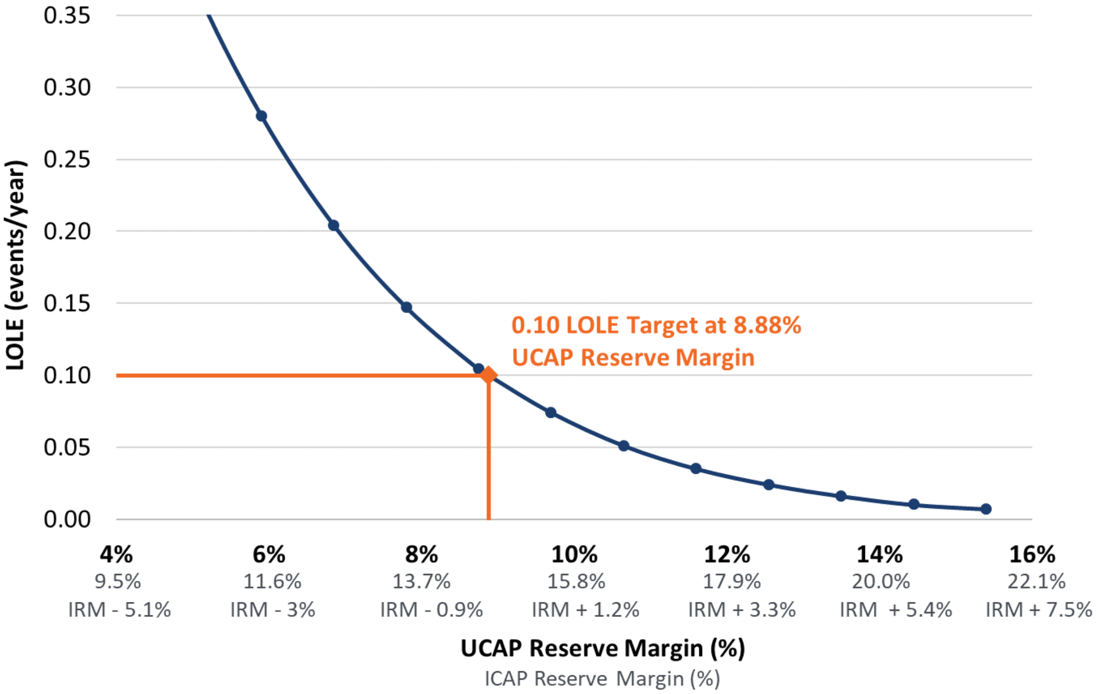
[36] PJM, 2022/23 Base Residual Auction Planning Period Parameters, February 8, 2021.

[37] In our analyses, the average LOLE reported for a given demand curve is calculated as the average of the LOLE at the cleared reserve margin in each individual draw, rather than the LOLE at the average cleared reserve margin across all draws.

asymmetry is that a demand curve that results in a distribution of clearing outcomes centered on the Target Point (i.e. the Reliability Requirement) with equal variance above and below the target will fall short of the 0.1 LOLE target on an average basis.

FIGURE 15: LOSS OF LOAD EVENTS VS UCAP RESERVE MARGIN



Sources/notes: LOLE at each quantity point were estimated by PJM reliability modeling staff.

In each model draw, the Reliability Requirement is updated after applying normally-distributed randomized variability. The magnitude of this variability parameter is based on historical variation in the RTO Reliability Requirement relative to a linear trend. Table 11 shows the historical Reliability Requirement values, as well as the linear prediction and the deviation from the trend, which sets the BRA Reliability Requirement variability. The average historical deviation from the trend is 6,467 UCAP MW, or 4.1% of the average BRA Reliability Requirement.[38]

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[38] The 2022/23 BRA was a notable outlier due to the exit of Dominion Energy Virginia, which extracted over 18 GW of resources and load from RPM by switching to the FRR option. Therefore, we excluded the 2022/23 when calculating historical variation in both supply and demand. FRR-based entry and exit have the effect of simultaneously decreasing (or increasing) supply and demand, and so the net effect on the remaining RPM market is mitigated as compared to a large withdrawal of supply (e.g. a large amount of retirements) which would still leave demand in RPM or vice versa. Nevertheless FRR-based exits or entry can have the effect of increasing supply-demand uncertainties as experienced in the remaining RPM market because the size of supply and demand that exit (or enter) RPM will not be exactly balanced. To ensure that our modeling accurately reflects realized supply-demand variability *including* accounting for the impact of FRR exit/entry, we have also confirmed that the Net Supply variability in our modeling is consistent with magnitudes realized in the market by applying a correlation factor between supply and demand (as discussed further in the following section).

TABLE 11: HISTORICAL VARIABILITY IN BRA RELIABILITY REQUIREMENT

Year	Historical BRA Reliability Requirement [A] *(UCAP MW)*	Linearized BRA Reliability Requirement [B] *(UCAP MW)*	Residual Above (Below) Linear Trend [C] *(UCAP MW)*
2013	149,989	156,567	(6,578)
2014	148,323	156,799	(8,475)
2015	162,777	157,030	5,747
2016	166,128	157,262	8,866
2017	165,007	157,493	7,514
2018	160,607	157,725	2,883
2019	157,092	157,956	(864)
2020	154,355	158,188	(3,833)
2021	153,161	158,420	(5,259)
Average BRA Reliability Requirement	[1]	Average [A]	157,493
Standard Deviation of Residuals	[2]	Std. Dev. [C]	6,467
BRA Reliability Requirement Variability	[3]	[2]/[1]	4.1%

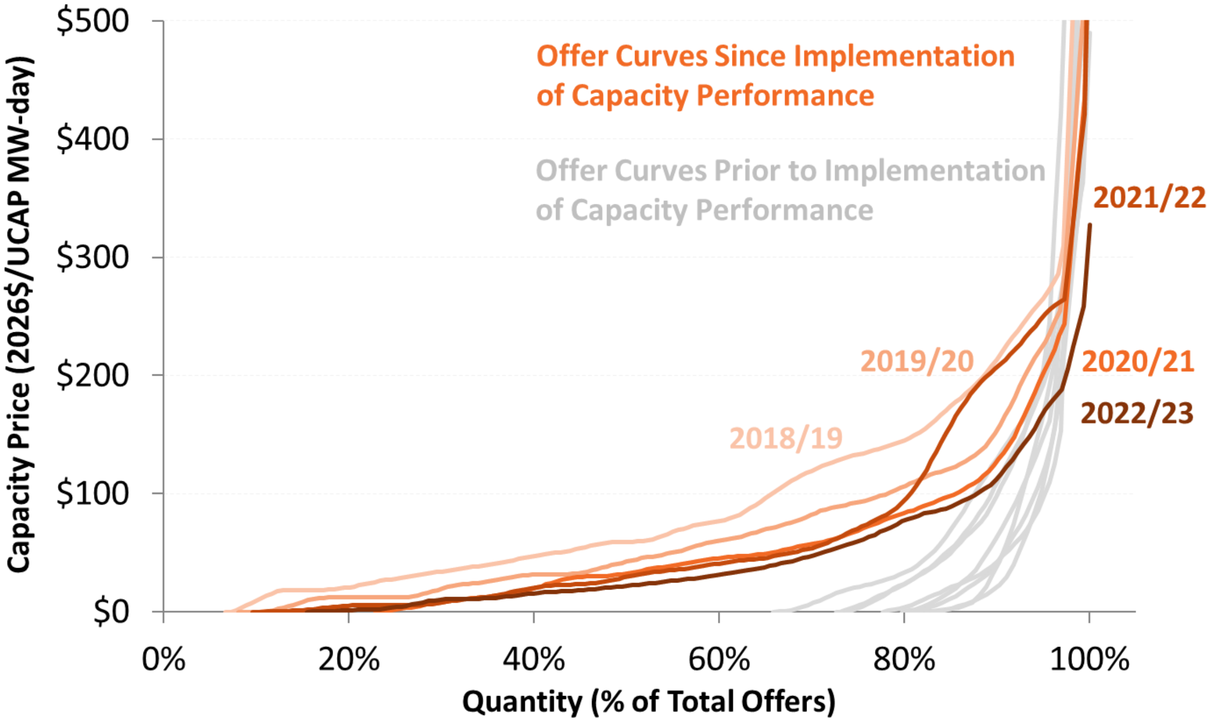
Sources/Notes: All quantities in UCAP MW; [A]: From PJM, 2013/14–2021/22 Base Residual Auction Planning Parameters; [B]: Expected value of [A] based on linear trend; [C]: [A] – [B].

C. Capacity Supply

Unlike the demand curve, the capacity market supply curve is not administratively determined and under the control of PJM. Instead, it is constructed from price-quantity pair supply offers by market participants. For our modeling, we use supply curve shapes derived from historical RPM offers from the 2009/10 to 2022/23 Planning Years. These supply curves reflect a wide range of capacity resources offered into the market and account for participant bidding behavior changes in response to rule changes and market conditions over time.

To prepare these curves for our model, we construct smoothed and normalized supply curves from the 2009/10 to 2022/23 Base Residual Auction offer data. We smooth price-quantity pairs into 1,000-MW standard blocks, adjust prices for inflation so that all prices are in 2026$, and normalize MW quantity bids so that the final supply curves quantities are represented as a percentage of BRA Total Supply for each year. Figure 16 shows these normalized curves.

FIGURE 16: NORMALIZED SUPPLY CURVES



Sources/Notes: BRA supply offer data provided by PJM.

We highlight that auctions from 2009/10 to 2017/2018 are from before PJM introduced the "Capacity Performance" measures.[39] Under Capacity Performance, resources that fail to fulfill their capacity obligation during emergency events are penalized, while resources that do fulfill their obligation are awarded bonus payments.[40] At the same time that Capacity Performance was implemented, sellers' offer caps were also increased and the resulting RPM supply curves have increased to a more elastic shape (orange lines). Upcoming changes to seller offer caps and performance regimes within the ongoing RASTF may have the potential to once again cause somewhat different characteristics in future supply curve shapes. To examine the impact of steeper and flatter supply curves on our conclusions, we have conducted additional sensitivity analysis and found relatively modest impacts as shown later in Table 17.

The total volume of supply incorporated into each draw of BRA clearing results is subject to normally-distributed random variability. Table 12 contains data from 2013/14 to 2021/22 and shows that the historical deviation of BRA Total Supply from the linear trend is 5,683 UCAP MW.

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[39] PJM replaced the pre to 2018/19 capacity products with interim capacity products (with lower performance expectation than Capacity Performance resources) for the 2018/19 and 2019/20 Planning Years; 2020/21 was the first year in which exclusively Capacity Performance resources were offered in the BRA and IAs; Federal Energy Regulatory Commission, 151 FERC ¶ 61,208, Order on Proposed Tariff Revisions, Issued June 9, 2015,.

[40] PJM, PJM Manual 18: PJM Capacity Market, Section 8.4A, October 20, 2021.

This value is equivalent to 3.2% of the average BRA Total Supply from 2013/14 to 2021/22, setting the supply variability we utilize in our modeling.

TABLE 12: HISTORICAL VARIABILITY IN BRA TOTAL SUPPLY

Year		Historical BRA Total Supply [A] *(UCAP MW)*	Linearized BRA Total Supply [B] *(UCAP MW)*	Residual Above (Below) Linear Trend [C] *(UCAP MW)*
2013		160,898	165,580	(4,682)
2014		160,486	168,587	(8,101)
2015		178,588	171,594	6,994
2016		184,380	174,601	9,779
2017		178,839	177,608	1,230
2018		179,891	180,615	(724)
2019		185,540	183,623	1,917
2020		183,352	186,630	(3,278)
2021		186,502	189,637	(3,135)
Average BRA Total Supply	[1]		Average [A]	177,608
Standard Deviation of Residuals	[2]		Std. Dev. [C]	5,683
BRA Total Supply Variability	[3]		[2]/[1]	3.2%

Sources/Notes: [A]: From auction data provided by PJM; [B]: Expected value of [A] based on linear trend; [C]: [A] – [B].

In the RPM, there is a partial correlation between supply and demand. This correlation can be explained by changes in the size of PJM, as PJM's footprint has increased and demand growth proceeds, supply and demand typically both increase at comparable rates. Conversely, when a substantial volume of demand exits the market under FRR, it will exit along with a similarly-sized share of the total supply mix. Separately estimating supply and demand variability without accounting for this correlation would overstate resulting variability in net supply (i.e. offered supply minus Reliability Requirement) that produces the effect of market price volatility. We therefore apply a correlation factor between supply and demand variability parameters to ensure that net supply variability produced by our simulation model exactly matches historically observed net supply variability.

We estimate the deviation of Net Supply from a linear trend in the same manner as with the other variability calculations. The historical deviation of Net Supply from the linear trend is 2,983 UCAP MW, as shown in Table 13. This value is equivalent to 1.9% of the average BRA Reliability

Requirement from 2013/14 to 2021/22, which sets the BRA Net Supply variability size as implemented in our model.

TABLE 13: HISTORICAL VARIABILITY IN BRA NET SUPPLY

Year	Historical BRA Reliability Requirement [A] *(UCAP MW)*	Historical BRA Total Supply [B] *(UCAP MW)*	Historical BRA Net Supply [C] *(UCAP MW)*	Linearized BRA Net Supply [D] *(UCAP MW)*	Residual Above (Below) Linear Trend [E] *(UCAP MW)*
2013	149,989	160,898	10,909	9,013	1,896
2014	148,323	160,486	12,163	11,788	375
2015	162,777	178,588	15,810	14,564	1,246
2016	166,128	184,380	18,253	17,339	913
2017	165,007	178,839	13,831	20,115	(6,284)
2018	160,607	179,891	19,284	22,891	(3,607)
2019	157,092	185,540	28,447	25,666	2,781
2020	154,355	183,352	28,996	28,442	555
2021	153,161	186,502	33,341	31,217	2,124
Average BRA Reliability Requirement			[1]	Average [A]	157,493
Standard Deviation of Residuals			[2]	Std. Dev. [E]	2,983
BRA Net Supply Variability			[3]	[2]/[1]	1.9%

Sources/Notes: All quantities in UCAP MW; [A]: From PJM, 2013/14 to 2021/22 Base Residual Auction Planning Parameters; [B]: From auction data provided by PJM; [C]: [B]-[A]; [D]: Expected value of [C] based on linear trend; [E]: [C] – [D]. If we would have included the year 2022/23 that included a large exit of both supply and demand from RPM, the net supply variability would be 1.8% and would not materially impact our conclusions. In our simulation sensitivity analyses we test a large range of parameters to illustrate the implications to our estimated results if net supply variability is substantially larger or smaller than under our base assumptions.

D.Modeling the Incremental Auctions

We have updated our probabilistic simulation model in this Quadrennial Review to account for supply-demand uncertainties that unfold after the three-year BRA and before the Planning Year. The modeling accounts for load forecast uncertainty that can cause increases or decreases in the reliability requirement between the BRA and the final IA, as well as changes to supply availability that can be offered into the IAs. If the load forecast decreases, then excess supply will remain available beyond what was anticipated at the time of the BRA. If the load forecast increases, the IA will aim to procure more capacity to meet the increase in demand.

We model these forward-to-prompt adjustments as time-sequential changes between the BRA and IA within a single modeling draw:[41]

1. **Model the BRA** and determine the resulting quantity of cleared and uncleared capacity
2. **Determine IA Reliability Requirement** as of the time of the last IA, after accounting for three years of load forecast uncertainty between the BRA and the last IA. Starting with the BRA Reliability Requirement, we apply a normally distributed random variable of 1.7% to determine the IA Reliability Requirement. Under base assumptions we assume no bias to the load forecast, but we test the implications of potential load forecast bias in a sensitivity analysis.
3. **Determine IA Available Supply Offers** that can be procured. We begin with the BRA capacity that was offered but remained uncleared, under the assumption that some of these resources will remain available for purchase in the subsequent IAs (others may retire or cease development efforts and become unavailable for procurement in the IAs). We assume that 53.8% of BRA uncleared supply will remain available for procurement as of the last IA, consistent with historical market data (see Table 3).[42] We also apply a normally-distributed random variable to represent variability in the total volume of IA supply offered, the size of which is 1.0% of total BRA supply quantities, as shown in Table 15. We also assume that a minimum quantity of 1,000 MW will always be offered into the IAs.[43]
4. **Estimate Final Quantity Procured (or Released) as of the Final IA.** We utilize a simplified representation of IA auctions in our modeling, treating the auctions in a combined fashion (rather than as three separate auctions) and calculating only the final resulting quantity rather than aiming to estimate pricing outcomes in the IAs. If the Reliability Requirement increases between the BRA and the final IA, we assume that PJM will procure 100% of the

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[41] Each of the 1,000 draws from the BRA results are randomized draws that we do not attempt to capture in a time-sequential fashion; however, within each draw the BRA and IA are treated in a time-sequential fashion.

[42] This is the average Net Supply available as of the Final Incremental Auction as a percentage of BRA Uncleared Supply from the 2017/18 to 2021/22 auction cycles. We exclude 2018/19 however, due to the idiosyncratic effects of Capacity Performance transition auctions. See Table 3.

[43] See Table 3 for data on final IA total supply; 2,533 MW was offered in 2017/18 Third Incremental Auction, which was the minimum supply offered in any auction over 2012/13 and 2021/22. The volume of capacity offered in these historical auctions has been larger than the minimum 1,000 MW that we assume, because of historical supply excesses. We do not have sufficient historical data to determine the volume of capacity that might be offered in a scenario of short supply in the forward auction combined with load forecast increases. In our modeling we assume that at least 1,000 MW of incremental supply can become available in that scenario, but we acknowledge that this assumption is speculative.Table 3: Supply Offered, cleared, and Net Supply

increase, subject to limitations in IA Available Supply.[44] IA if the Reliability Requirement decreases, the model releases 50% of the reduction (in line with historically observed levels of released capacity).[45] We then estimate the final achieved level of reliability based on the final committed volume after the last IA.

Consistent with our modeling approach for the other variability calculations, we calculate historical variability in IA Reliability Requirement relative to the BRA Reliability Requirement, after removing the historical load forecast bias (see Table 14). The IA Reliability Requirement deviates from the linear trend by an average of 2,495 UCAP MW. This is equal to 1.7% of the average final IA Reliability Requirement from 2013/14 to 2021/22, and we define this percentage as the forward-to-prompt Reliability Requirement variability in our model.

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[44] We note that PJM's current approach pursues IA procurements based primarily on changes to the Reliability Requirement, rather than on the absolute need for capacity after accounting for the volumes that have already cleared in prior auctions. Our modeling aims to reflect PJM's current IA procurement practice, even though we believe that conducting IA procurements relative to residual needs would be a simpler and more straightforward approach. The current approach to determining IA procurement volumes is described in Manual 18, Section 3.5, October 20, 2021. Under current rules, if the Reliability Requirement decreases by an amount greater than the lesser of 500 UCAP MW or 1% of the prior auction's Reliability Requirement, then PJM seeks to release capacity in the IA, and vice versa if the Reliability Requirement increases.

[45] This approach aims to reflect the current market rules and historically observed levels of capacity released by PJM in the IAs. PJM currently determines the volume of capacity released based on changes in the Reliability Requirement between auctions, rather than the remaining need (or excess supply) at the time of the IAs. In each auction cycle between 2012/13 and 2021/22, the Reliability Requirement has decreased from the BRA to the Final IA. Consequently, the net effect of the IAs has been to release capacity. Therefore, we model capacity release in the IA based on historical data. The volume of capacity released in prior auctions has never been enough to fully reduce excess system capacity so that the final committed quantity is equal to the final IA Reliability Requirement. From 2013/14 to 2021/22, on average 44% of the Target Quantity (difference between BRA Reliability Requirement and IA Reliability Requirement) was released as of the Final IA. We round this to 50% for our modeling purposes. We do not have historical data to confirm how IA supply would respond if the BRA clears short. Therefore, we model IA procurement assuming PJM would acquire sufficient capacity to cover any deficit to meet the 1-in-10 LOLE target in the case of a shortfall, subject to the IA available supply.

TABLE 14: HISTORICAL VARIABILITY IN FINAL IA RELIABILITY REQUIREMENT

Year	Historical BRA Reliability Requirement [A] *(UCAP MW)*	Historical Final IA Reliability Requirement [B] *(UCAP MW)*	Delta of IA Above (Below) BRA Requirement [C] *(UCAP MW)*	Linearized Delta [D] *(UCAP MW)*	Residual Above (Below) Linear Trend [E] *(UCAP MW)*
2013	149,989	139,184	(10,805)	(10,073)	(732)
2014	148,323	141,983	(6,340)	(9,509)	3,169
2015	162,777	153,800	(8,977)	(8,945)	(32)
2016	166,128	153,158	(12,969)	(8,381)	(4,588)
2017	165,007	153,969	(11,039)	(7,818)	(3,221)
2018	160,607	152,316	(8,292)	(7,254)	(1,038)
2019	157,092	151,832	(5,260)	(6,690)	1,429
2020	154,355	148,939	(5,417)	(6,126)	709
2021	153,161	149,765	(3,396)	(5,562)	2,166
Average Final IA Reliability Requirement			[1]	Average [B]	149,438
Standard Deviation of Residuals			[2]	Std. Dev. [E]	2,495
Final IA Reliability Requirement Variability			[3]	[2]/[1]	1.7%

Sources/Notes: All quantities in UCAP MW; [A] & [B]: From auction data provided by PJM; [C]: Historical difference between Final IA Reliability Requirement [B] and BRA Reliability Requirement [A]; [D]: Expected difference between Final IA Reliability Requirement [B] and BRA Reliability Requirement [C] based on linear trend; [E]: [C] – [D].

We estimate forward-to-prompt supply variability based on historical data as shown in Table 15. Consistent with our modeling approach for other variability calculations, we calculate historical variability in final IA available supply relative to a linear trend. Final IA available supply deviates from the linear trend by an average of 1,698 MW or 1.0% of the average BRA Total Supply from 2013/14 to 2021/22, as seen in Table 15. This percentage is the forward-to-prompt supply variability assumption in our simulation modeling.

TABLE 15: HISTORICAL VARIABILITY IN IA AVAILABLE SUPPLY

Year	Historical BRA Total Supply [A] *(UCAP MW)*	Historical Final IA Total Supply [B] *(UCAP MW)*	Linearized Final IA Total Supply [C] *(UCAP MW)*	Residual Above (Below) Linear Trend [D] *(UCAP MW)*
2013	160,898	(571)	933	(1,504)
2014	160,486	1,293	2,311	(1,019)
2015	178,588	992	3,690	(2,698)
2016	184,380	3,697	5,068	(1,371)
2017	178,839	6,208	6,447	(239)
2018	179,891	10,778	7,825	2,953
2019	185,540	10,719	9,203	1,516
2020	183,352	9,651	10,582	(931)
2021	186,505	11,674	11,960	(286)

Average BRA Total Supply	[1]	Average [A]	177,609
Standard Deviation of Residuals	[2]	Std. Dev. [D]	1,698
Final IA Supply Variability	[3]	[2]/[1]	1.0%

Sources/Notes: All quantities in UCAP MW; [A] & [B]: From data provided by PJM; [C]: Expected value of [B] based on linear trend; [D]: [B] – [C].

E. Additional Sensitivity Analysis of Candidate Curve

To understand the impact of modeling assumptions on our results, we conduct various sensitivity analyses to understand how these assumptions change our estimates of VRR Curve performance. We summarize here the impact of alternative assumptions with respect to: (a) larger or smaller assumed supply and demand variability; (b) supply curve shape; and (c) the impact in the IA of load forecast bias in the three-year ahead BRA load forecast.

SENSITIVITY TO SUPPLY AND DEMAND VARIABILITY

We report here simulated performance of the Candidate Curve to alternative assumptions about the size of the variability in supply and demand. Table 16 summarizes estimated performance if variability is 33% larger and 33% smaller than base assumptions. The Candidate Curve offers comparable reliability to the Base Case when supply and demand variability is 33% smaller or larger than history. As expected, greater supply-demand variability would produce greater price volatility, lower supply-demand variability would reduce price volatility.

TABLE 16: SENSITIVITY ANALYSIS OF SUPPLY AND DEMAND VARIABILITY

	Measured After the BRA								
	Price			Reliability					Cost
	Average ($/MW-d)	Standard Deviation ($/MW-d)	Frequency at Cap (%)	Average LOLE (events/yr)	Average Excess (Deficit) (MW)	Average Excess (Deficit) (IRM + X %)	Frequency Below Target (%)	Frequency Below IRM - 1% (%)	Average Procurement Cost ($ mln/yr)
Candidate Curve									
33% Smaller Variability	$267	$68	0.6%	0.071	1,230	1.1%	7.2%	0.9%	$13,066
Base	**$267**	**$85**	**2.7%**	**0.073**	**1,221**	**1.1%**	**10.9%**	**3.3%**	**$13,104**
33% Larger Variability	$267	$99	5.6%	0.078	1,183	1.1%	14.4%	6.3%	$13,147

Sources/Notes: All prices in 2026$ and all quantities in UCAP MW; Both BRA Total Supply variability and BRA Reliability Requirement variability were modified to be 33% larger/smaller than their base values reported in Table 10.

SENSITIVITY TO SUPPLY CURVE SHAPE

As explained above, we use smoothed, inflation-adjusted, normalized supply curves from 2009/10 to 2022/23 to reflect the shape of the capacity supply curve. After introduction of Capacity Performance in 2018/19 auction cycle, capacity supply curves have been higher and relatively more elastic than previously. To test the impact of the supply curve shape on our simulated results, we evaluate how the Candidate Curve performs under the steeper curve shapes that existed prior to 2018/19, the more elastic curves observed since 2018/19, and compared these results to our base assumptions (incorporating all curves both before and after 2018/19).

We find that the shape of the supply curves does not have a substantial impact on the performance of the Candidate Curve. Table 17 shows that while the steeper pre-Capacity Performance supply curves would result in somewhat greater price volatility than the flatter Capacity Performance supply curves, estimated LOLE is virtually unchanged.

TABLE 17: SENSITIVITY ANALYSIS OF SUPPLY CURVE SHAPE

	Measured After the BRA								
	Price			Reliability					Cost
	Average ($/MW-d)	Standard Deviation ($/MW-d)	Frequency at Cap (%)	Average LOLE (events/yr)	Average Excess (Deficit) (MW)	Average Excess (Deficit) (IRM + X %)	Frequency Below Target (%)	Frequency Below IRM - 1% (%)	Average Procurement Cost ($ mln/yr)
Candidate Curve									
Pre-CP Supply Curves	$267	$91	2.8%	0.074	1,246	1.1%	12.0%	3.3%	$13,109
Base	**$267**	**$85**	**2.7%**	**0.073**	**1,221**	**1.1%**	**10.9%**	**3.3%**	**$13,104**
CP Supply Curves	$267	$67	1.4%	0.071	1,231	1.1%	8.4%	1.7%	$13,090

Sources/Notes: All prices in 2026$ and all quantities in UCAP MW; All results use Candidate Curve, with Net CONE = $267/UCAP MW-Day; Pre- Capacity Performance Supply Curves are smoothed, inflation-adjusted, normalized curves from 2009/10 to 2017/18 auctions; Capacity Performance Supply Curves are smoothed, inflation-adjusted, normalized curves from 2018/19 to 2022/23 auctions; Base run is Candidate Curve, with all supply curves from 2009/10 to 2022/23.

SENSITIVITY TO LOAD FORECAST BIAS

We analyze the performance impact of load forecast bias as a sensitivity. Despite improvements to the load forecast accuracy in recent auction years, the Reliability Requirement for the 2021/22 Third Incremental Auction was 2.2% lower compared to the Reliability Requirement from the BRA.[46] For this sensitivity, we considered the impact of a 2% and 4% over-forecast bias (when IA Reliability Requirement is smaller than the BRA Reliability Requirement), as well as a 2% under-forecast bias (when IA Reliability Requirement is greater than the BRA Reliability Requirement). Results from this sensitivity analysis are shown in Table 18. The forecast bias only affects the results of the IA, so BRA results will be equivalent for each run.

As expected, greater over-forecast bias causes greater over-procurement after the IA. Even a 2% over-forecast bias (which is close to the bias in the most recent auction cycle) has a substantial impact on over-procurement. In this scenario, the average excess grows from 1,221 UCAP MW in the BRA to 2,560 UCAP MW after the IA, an increase of 1,339 UCAP MW. In the case of the 2% under-forecast bias, the opportunity to procure additional capacity in the incremental auctions provides a modest boost in reliability to protect against capacity shortfalls. However, since we base our model on market evidence, our representation of the ability of the IA to address shortfalls is limited given the historically observed short-term supply when the RPM has been

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[46] For recent Capacity Performance auction cycles (2018/19 to 2021/22), the average over-forecast bias as a percent of the BRA Reliability Requirement (adjusted for FRR) is 3.6%; Data from 2018/19 to 2021/22 RPM Base Residual Auction Planning Period Parameters and 2018/19 to 2021/22 3rd Incremental Auction Planning Period Parameters.

exclusively in long market conditions. We conclude that load forecast bias does have a significant impact on curve performance, see Section II.B for additional discussion of how this issue could be addressed.

TABLE 18: SENSITIVITY ANALYSIS OF LOAD FORECAST BIAS

	Measured After the BRA				Measured After the Final Incremental Auction			
	Reliability				Reliability			
	Average LOLE *(events/yr)*	Average Excess (Deficit) *(MW)*	Average Excess (Deficit) *(IRM + X %)*	Frequency Below Target *(%)*	Average LOLE *(events/yr)*	Average Excess (Deficit) *(MW)*	Average Excess (Deficit) *(IRM + X %)*	Frequency Below Target *(%)*
Candidate Curve								
Over-forecast bias = 4%	0.073	1,221	1.1%	10.9%	0.033	3,828	3.5%	1.3%
Over-forecast bias = 2%	0.073	1,221	1.1%	10.9%	0.050	2,560	2.3%	4.0%
Base	**0.073**	**1,221**	**1.1%**	**10.9%**	**0.071**	**1,459**	**1.3%**	**11.9%**
Under-forecast bias = 2%	0.073	1,221	1.1%	10.9%	0.110	282	0.3%	34.2%

Sources/Notes: Since Base Case run assumes no load forecast bias between the BRA and the Final IA, the full Base Case results presented elsewhere (see Table 4) are the same as the Base Case run here; Therefore we do not report the full results in the table (Base Case run has Standard Deviation of Price of $85/MW-d, not shown here); All prices in 2026$ and all quantities in UCAP MW; All results use Candidate Curve, with Net CONE = $267/UCAP MW-day; Over-forecast bias indicates the BRA Reliability Requirement is greater than the Incremental Auction Reliability Requirement (and vice versa for under-forecast bias).

F. Additional Sensitivity Analysis of Alternative Curves

Table 19 provides detailed simulation results regarding the estimated performance of the alternative VRR curves developed and evaluated in Section III.E, as well as comparing these curves to the Candidate Curve and the Current VRR Curve with either a CT or CC Reference Technology.

TABLE 19: SIMULATED PERFORMANCE OF ALTERNATIVE CURVES

	Price			**Reliability**					**Cost**
	Average *($/MW-d)*	Standard Deviation *($/MW-d)*	Frequency at Cap *(%)*	Average LOLE *(events/yr)*	Average Excess (Deficit) *(MW)*	Average Excess (Deficit) *(IRM + X %)*	Frequency Below Target *(%)*	Frequency Below IRM - 1% *(%)*	Average Procurement Cost *($ mln/yr)*
Candidate Curve									
True Net CONE = 0.6 x CC	$160	$57	0.0%	0.043	2,861	2.5%	0.0%	0.0%	$7,939
True Net CONE = CC	**$267**	**$85**	**2.7%**	**0.073**	**1,221**	**1.1%**	**10.9%**	**3.3%**	**$13,104**
True Net CONE = CT	$326	$94	9.8%	0.098	388	0.4%	31.0%	11.5%	$15,889
True Net CONE = 1.4 x CC	$374	$94	21.2%	0.128	-393	-0.3%	50.0%	24.8%	$18,092
Current Curve, CT									
True Net CONE = 0.6 x CC	$160	$52	0.0%	0.026	4,548	4.0%	0.0%	0.0%	$8,029
True Net CONE = CC	**$267**	**$74**	**1.5%**	**0.059**	**2,026**	**1.8%**	**7.5%**	**2.0%**	**$13,169**
True Net CONE = CT	$326	$86	7.8%	0.085	922	0.8%	23.2%	9.0%	$15,941
True Net CONE = 1.4 x CC	$374	$87	17.9%	0.117	-25	0.0%	43.2%	20.0%	$18,133
Current Curve, CC									
True Net CONE = 0.6 x CC	$160	$52	0.0%	0.034	3,716	3.2%	0.0%	0.0%	$7,978
True Net CONE = CC	**$267**	**$81**	**2.1%**	**0.069**	**1,431**	**1.3%**	**10.0%**	**2.9%**	**$13,119**
True Net CONE = CT	$326	$92	9.3%	0.095	510	0.5%	28.8%	10.8%	$15,900
True Net CONE = 1.4 x CC	$374	$92	19.6%	0.126	-318	-0.2%	48.4%	24.4%	$18,100
Alternative 1									
True Net CONE = 0.6 x CC	$160	$65	0.0%	0.054	2,032	1.8%	0.0%	0.0%	$7,909
True Net CONE = CC	**$267**	**$99**	**5.7%**	**0.071**	**1,280**	**1.1%**	**5.7%**	**2.6%**	**$13,132**
True Net CONE = CT	$326	$107	15.1%	0.087	732	0.7%	15.1%	8.2%	$15,949
True Net CONE = 1.4 x CC	$374	$105	29.3%	0.108	141	0.2%	29.3%	16.9%	$18,182
Alternative 2									
True Net CONE = 0.6 x CC	$160	$57	0.0%	0.040	3,077	2.7%	0.0%	0.0%	$7,953
True Net CONE = CC	**$267**	**$92**	**5.2%**	**0.066**	**1,566**	**1.4%**	**5.2%**	**2.1%**	**$13,146**
True Net CONE = CT	$326	$103	14.3%	0.084	867	0.8%	14.3%	7.6%	$15,958
True Net CONE = 1.4 x CC	$374	$103	28.8%	0.107	208	0.2%	28.8%	16.4%	$18,187
Alternative 3									
True Net CONE = 0.6 x CC	$160	$56	0.0%	0.061	1,789	1.6%	2.3%	0.0%	$7,873
True Net CONE = CC	**$267**	**$91**	**5.1%**	**0.098**	**220**	**0.2%**	**38.2%**	**6.5%**	**$13,012**
True Net CONE = CT	$326	$103	14.3%	0.124	-471	-0.4%	63.5%	16.7%	$15,796
True Net CONE = 1.4 x CC	$374	$103	28.9%	0.156	-1,126	-0.9%	79.5%	33.8%	$18,003
Alternative 4									
True Net CONE = 0.6 x CC	$160	$54	0.0%	0.051	2,397	2.1%	1.7%	0.0%	$7,907
True Net CONE = CC	**$267**	**$86**	**4.8%**	**0.093**	**440**	**0.4%**	**36.3%**	**6.0%**	**$13,025**
True Net CONE = CT	$326	$100	13.8%	0.121	-365	-0.3%	62.5%	15.9%	$15,803
True Net CONE = 1.4 x CC	$374	$101	28.4%	0.154	-1,068	-0.9%	79.2%	33.5%	$18,008

Sources/Notes: All prices in 2026$ and all quantities in UCAP MW; For Current Curve, CT, Administrative Net CONE = $326/UCAP MW-Day and price cap is Max(**1.5 × CT Net CONE**, CT CONE), for all other curves Administrative Net CONE = $267/UCAP MW-Day and price cap is Max(1.75 × CC Net CONE, **CC CONE**); **bolded text** indicates which parameter sets the price cap for each curve; All CONE values from 2022 Net CONE Study.

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