Alberta's Capacity Market Demand Curve

PREPARED FOR

Alberta Electricity System Operator

PREPARED BY

Kathleen Spees

David Luke Oates

Cathy Wang

John Imon Pedtke

Matthew Witkin

January 2019

THE Brattle GROUP

Notice

This report was prepared for the Alberta Electricity System Operator. The report reflects the analyses and opinions of the authors and does not necessarily reflect those of other employees or clients of The Brattle Group. There are no third party beneficiaries with respect to this report, and The Brattle Group does not accept any liability to any third party in respect of the contents of this report or any actions taken or decisions made as a consequence of the information set forth herein.

Table of Contents

Executive Summary

The Alberta Electric System Operator (AESO) commissioned The Brattle Group (Brattle) to provide analytical support for its development of a demand curve for Alberta's capacity market. We worked together with AESO staff, and through the AESO with stakeholders in the adequacy and demand curve working group ("Working Group"), from October 2017 through June 2018, evaluating the performance of a range of potential demand curves and responding to stakeholders' questions. This process culminated in the AESO's selection of its proposed demand curve, which was presented in the Comprehensive Market Design (CMD) Final Proposal and will be filed with the Alberta Utilities Commission (AUC).

This report summarizes the findings from the demand curve assessments conducted by Brattle during the course of the AESO's development of the demand curve for the Alberta capacity market. Iterations of our demand curve assessments were presented and consulted on within the Working Group from October 2017 through June 2018 and are presented as a compilation by the AESO as part of its capacity market design filing.[1]

The primary objective of the capacity market demand curve is to maintain the Government of Alberta's minimum resource adequacy standard. The standard requires that Expected Unserved Energy (EUE) in Alberta not exceed 0.0011% of load.[2] This objective will ensure that Alberta customers experience a similar level of resource adequacy under the new capacity market as under the historical energy-only market construct.

With our analytical support, the AESO has evaluated the performance of a range of demand curves capable of meeting the minimum resource adequacy standard and selected the curve shown in red in Figure 1 below. The AESO selected this proposed demand curve from among a range of curves. The curve has a price cap at the maximum of 1.75 × Net Cost of New Entry (CONE) or 0.5 × Gross CONE extending from 0 MW to the quantity corresponding to Alberta's minimum resource adequacy objective (*i.e.*, the "minimum acceptable quantity").[3] The curve has a convex shape with

---

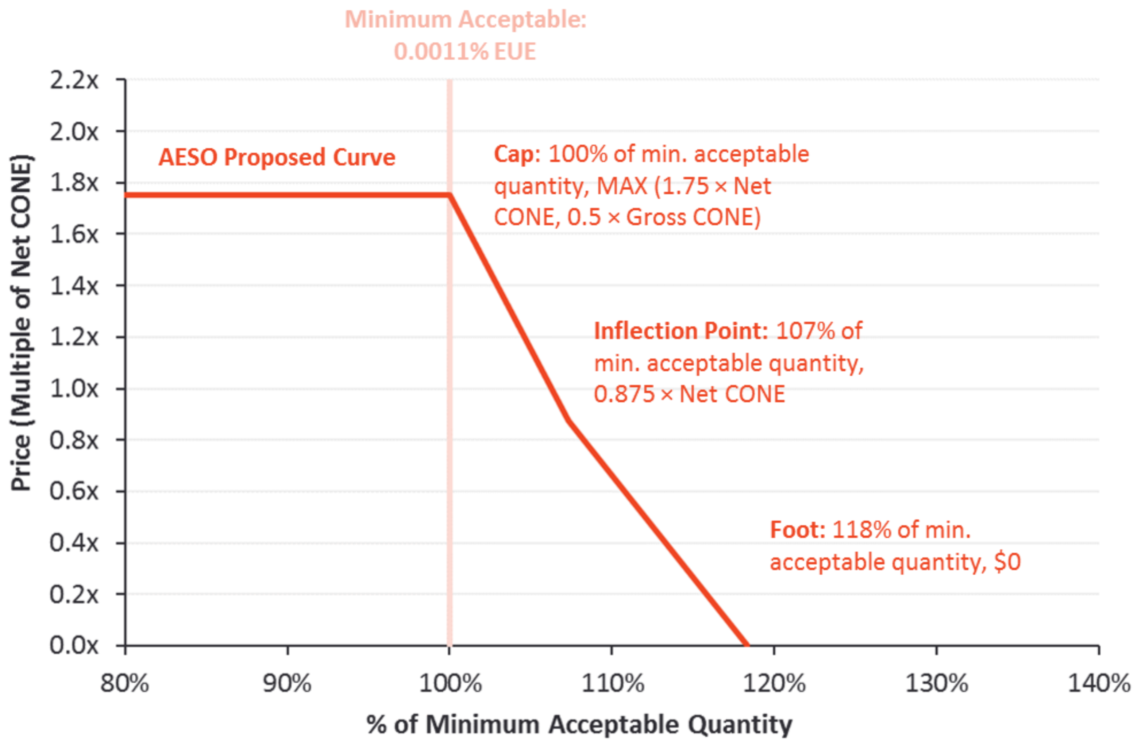
1 We show the history of these presentations in the Appendix.

2 We refer to the Government's objective as a *minimum resource adequacy objective* or *minimum acceptable quantity* because the system must be at least as reliable as the objective. A higher level of reliability would meet the objective. The AESO's capacity market rules refer to "minimum procurement volume" to denote the same volume.

3 Gross CONE represents the total annual net revenue (net of variable operating costs) that a new generation resource would need to recover its capital investment and fixed costs, given reasonable expectations about future cost recovery over its economic life. Net CONE represents the revenues that

an inflection point at 107% of the minimum acceptable quantity and a price of 0.875 × Net CONE. The curve's foot is at a price of $0 and a quantity 118% of the minimum acceptable quantity.

Figure 1
AESO's Proposed Demand Curve



Notes: The proposed curve achieves the Government's 0.0011% EUE minimum resource adequacy requirement under modeled Alberta conditions. The "Minimum Acceptable Quantity" is the quantity corresponding to this 0.0011% EUE minimum.

In addition to achieving the minimum resource adequacy objective, the AESO's proposed curve has several features that will support a sustainable capacity market design. The curve is near the minimum reliability requirement, but right-shifted (higher quantities at each price level) to control the risk of falling below the requirement. This means that the curve has quantities higher than the minimum acceptable level for any price below the price cap, which ensures that the minimum procurement volume will be secured in the auction in the large majority of all auctions.

It has a price cap high enough to attract and retain supply when the market is tight, with a price cap minimum (expressed as a percentage of Gross CONE) to prevent the curve from collapsing if estimated energy and ancillary services revenues would become very high. The curve's downward sloping, convex shape is consistent with the diminishing reliability benefits of incremental capacity at higher quantities. The curve is wide enough to control excessive price volatility and limit opportunities for the exercise of market power, but steep enough to limit over-procurement.

---

a new resource would need to earn in the capacity market, after subtracting energy and ancillary service market net revenues from Gross CONE and after considering the anticipated future revenues available over the future economic life of the asset.

This report summarizes our qualitative and quantitative assessment of the AESO's proposed demand curve performance relative to design objectives. The qualitative assessment draws on economic theory and our experience developing demand curves in other jurisdictions. The quantitative assessment leverages our Monte Carlo simulation model to evaluate the price, cost, and reliability implications of various demand curve design elements. After reviewing these assessments, we believe the AESO's proposed curve will cost-effectively support resource adequacy for Alberta while its market is in transition and extending into the future.

I. Background

In January 2017, the Government of Alberta directed the Alberta Electric System Operator (AESO) to design and implement a capacity market in Alberta.[4] The purpose of the Alberta capacity market is to meet the Government-defined resource adequacy standard, at reasonable cost to customers. The capacity market must work efficiently and effectively with the energy and ancillary services markets and be consistent with the transition to a lower-carbon electricity future.

The demand curve is one of the key elements of Alberta's capacity market design. The curve consists of a set of price and quantity points that define the market operator's willingness to pay for capacity. Since merchant suppliers of capacity will invest only if they expect to earn a competitive return on their invested capital, the demand curve provides an important signaling tool to the market. The demand curve must establish a capacity price high enough to attract entry when supply is needed (and low enough to discourage entry when that supply is not needed).

Together with offers from prospective capacity sellers, the demand curve determines the clearing prices and quantities of capacity in each auction. In the long run, the price levels signaled by the demand curve will trigger entry and exit decisions, establishing the average level of supply and reliability. Thus, the price levels on the demand curve must be consistent with supporting the estimated long-run marginal cost of supply, or the Net Cost of New Entry (Net CONE) while simultaneously supporting the reliability standard. The price and quantity outcomes in each auction consequently determine the costs borne by customers as well as year-to-year price volatility. The steepness of the demand curve affects price volatility and has implications for limiting opportunities for the exercise of market power. Thus from a customer perspective, a well-designed capacity demand curve can offer an appropriate balance among competing design principles.

A demand curve can also support a balance of principles relevant to capacity suppliers. A relatively flatter demand curve can provide more price stability and certainty. A relatively steeper demand curve will support more certainty in the total quantity of supply entry, thus rationalizing market entry and exit in ways that mitigate the potential for boom-bust investment cycles.

We were asked to provide analytical support to the AESO and stakeholders, and to assess the performance of the AESO's chosen capacity market demand curve. The purpose of this assessment is to determine the effectiveness of the proposed demand curve in maintaining resource adequacy consistent with the Government's minimum resource adequacy objective, and to assess the

[4] Government of Alberta (2017), *Letter of mandate*, January 2017.

tradeoffs among other performance principles such as mitigating price volatility and controlling customer costs.

This report documents our analysis and findings relating to the shape of the demand curve only. The Gross Cost of New Entry (CONE) for several candidate reference technologies was estimated in a separate study and the AESO will estimate the Energy & Ancillary Services (E&AS) offset and Net CONE closer to the first base auction.[5] The minimum procurement volume for the capacity auction will be filed separately by the AESO.[6]

II. Conceptual Approach to Developing Demand Curve Design Elements

We describe here the conceptual approach used to develop the downward-sloping capacity demand curve the AESO proposes to meet Alberta's resource adequacy objective in the capacity market. Since merchants will invest only if they expect to earn a return of and on capital through energy and ancillary service margins and capacity payments, the demand curve provides an important investment signal to the market. The demand curve design must provide a high enough capacity payment to attract and retain merchant investment when supply is needed, while avoiding over-investment when additional supply is not needed.

The AESO worked and consulted with stakeholders to construct a range of candidate demand curves, and to assess performance tradeoffs among these curves. The final proposed demand curve incorporates these various inputs and strikes a balance among sometimes competing design principles.

5 Pfeifenberger, J., Spees, K., Hagerty, J., Tolleth, M., Caulkins, M., Shorin, E., *AESO Cost of New Entry Analysis.* Prepared for the AESO, September 2018. This CONE study forms part of the AESO application (as does this Demand Curve report).

6 The analysis in this report uses preliminary values for Net CONE and the minimum procurement volume. However, our demand curve design recommendations will apply given any reasonable final value of Net CONE and the minimum procurement volume. Since the demand curve price and quantity points are expressed as multiples of Net CONE and the minimum procurement volume, respectively, the curve will adjust to accommodate the final values of these parameters. As we show in Section V.B, demand curve performance is insensitive to the specific value of Net CONE (assuming Net CONE is accurately estimated).

A. Design Criteria and Principles

The AESO worked with stakeholders to establish principles to guide the development of its capacity market demand curve.[7] These principles were designed to be consistent with the overall design criteria for the capacity market.[8] The primary demand curve principle is to deliver supply adequacy and reliability through the market, consistent with the government's resource adequacy objective. Below we describe this principle, as well as others developed by the AESO and stakeholders:

- **Deliver Supply Adequacy and Reliability (Primary Principle):** The AESO's demand curve should attract and retain sufficient supply to ensure system reliability and to meet the government's 0.0011% Expected Unserved Energy (EUE) standard.
- **Send Efficient Price Signals:** The demand curve should send efficient price signals, minimize capacity price volatility, and limit opportunities for the exercise of market power.
- **Minimize Customer Costs:** The demand curve should aim to minimize costs while ensuring reliability by avoiding over-procurement relative to the supply adequacy and reliability objectives.
- **Support Attracting and Retaining Investment:** The demand curve should provide sufficient incentive to retain existing supply and attract investment in new supply when needed to achieve the supply adequacy and reliability objective.
- **Ensure Robustness to Reasonably Foreseeable Changes in Market Conditions:** Recognizing the tradeoff between cost and supply adequacy, the demand curve should be reasonably robust to changes in market conditions in Alberta.
- **Reflect Lessons Learned in Other Jurisdictions:** The demand curve should reflect lessons learned in other jurisdictions that are applicable in Alberta's market.
- **Reflect Unique Aspects of Alberta's System:** The demand curve design should account for the unique characteristics of Alberta's power system.

In many cases, developing a demand curve involves tradeoffs among competing design principles. For example, steep capacity market supply and demand curves contribute to structurally volatile prices, with small changes in supply or demand sometimes causing large changes in price. Introducing a sloped demand curve will mitigate some of this price volatility, with flatter curves resulting in more stable prices. However, a very flat demand curve will introduce a greater quantity uncertainty, the risk of low-reliability outcomes, and the tendency to over-procuring

---

7 These demand curve principles were originally laid out in a September 2017 document: AESO, *Principles to Setting Demand Curve Parameters, Adequacy & Demand Curve Determination Design Stream*, September 2017. The principles were re-stated in Section 4 of the CMD 4.0 Rationale.

8 The capacity market design criteria were laid out early in 2017 in another stakeholder document: AESO, *Designing Alberta's Capacity Market: Desired end state, criteria and assumptions*, May 2017.

when the market is already long.[9] Minimizing costs according to the design principles will require limiting the quantity of procurement above the reliability standard to a modest level (while still avoiding frequent events below the minimum acceptable reliability). We further explain the tradeoffs among these design objectives as we compare the performance of the AESO's proposed demand curve and alternative demand curves.

B. Translating Government Reliability Objectives into a Demand Curve Shape

In March 2018, the Alberta government directed the AESO to move forward with a minimum resource adequacy standard of 0.0011% EUE.[10] This minimum standard requires that the AESO attempt to maintain Alberta EUE below 0.0011% of load in every year. It differs from standards in some other jurisdictions that require the market to deliver the target level of resource adequacy *on average over many years*.

The AESO, with our support, has translated this Government standard into the specifications of how a demand curve should be designed. One implication relates to the quantity of supply at the price cap. The AESO's capacity auction should never clear a quantity of supply lower than the quantity needed to achieve 0.0011% EUE at a price lower than the price cap. The other primary implication is that the demand curve should ensure that the market rarely clears a quantity below the minimum acceptable level (*i.e.*, if insufficient supply were offered into the auction, even at the price cap). The AESO built into the design of the demand curve a threshold for the capacity market to deliver cleared quantities below the minimum acceptable quantity (*i.e.*, deliver EUE *above* 0.0011%) no more than 5% of the time. In the 5% of years where resource adequacy may fall short of the minimum acceptable quantity based on base auction outcomes, the AESO could rely on the rebalancing auctions or take out-of-market measures to keep EUE below 0.0011%. The AESO's proposed demand curve, as well as the alternative "candidate" demand curves described in Section IV below, are designed to achieve this objective.

C. Demand Curve Design Elements

In working with the AESO and stakeholders to develop a proposed demand curve for Alberta, we evaluated a range of demand curves with different price cap and quantity points, overall shape, and width/steepness. These design elements come together collectively to determine the overall demand curve performance, resulting in different tradeoffs between reliability, price volatility, and customer cost. We discuss the significance of each of these design elements for demand curve performance below.

---

9 A "long" market describes a market that has an oversupply of capacity in comparison to its peak load and reliability needs. A "short" market describes a market that has an undersupply of capacity.

10 Alberta Energy, *Policy Direction for Alberta's Capacity Market*, March 2018.

Capacity Auction Price Cap

The price cap defines the AESO's maximum willingness to pay for in-market supply. When the market is short, reliability can improve meaningfully by adding only small amounts of incremental supply. As a result, market operators should be willing to pay considerably more than Net CONE to secure supply under these circumstances.[11] In U.S. jurisdictions, price caps range from 1.5 × Net CONE to around 2.0 × Net CONE. The price cap is often expressed as a percentage of the Net CONE parameter, or a combination of Net CONE and Gross CONE. For example, PJM uses the higher of 1.5 × Net CONE and 1.0 × Gross CONE.

Higher price caps improve reliability and reduce the risk of out-of-market intervention by attracting additional supply when the market is short. Higher price caps are also associated with higher price volatility. While a higher price cap increases customer costs in years when the market is short, it does not necessarily result in higher costs on average. A demand curve with a higher price cap can be steeper relative to a curve with a lower price cap, while maintaining the same level of reliability. The steeper curve with a higher cap typically also produces lower prices in years when the market is long (offsetting higher customer costs in the years when the market is short). Thus the price cap typically has little impact on average customer costs.

Quantity Corresponding to the Price Cap

The quantity at the cap determines the level of supply at which prices reach the cap. Increasing this quantity will attract more supply to the market, while decreasing it will result in less supply. The quantity at the cap should be no less than the minimum acceptable quantity in order to ensure that all in-market opportunities are exhausted before out-of-market actions are taken to secure supply. Generally, the quantity at the cap is set at or close to the minimum acceptable quantity, at least in those jurisdictions where a minimum acceptable quantity is explicitly defined.[12]

Demand Curve Shape

Demand curve shapes range in complexity from vertical curves (such as MISO's) to downward sloping straight-line curves (such as New York ISO), to two-part kinked curves (such as PJM), to smoothed multi-point curves (such as ISO New England). Downward-sloping, convex demand curves are more consistent with the diminishing reliability value of incremental supply (see Figure

---

11 Net CONE represents the capacity price that a new resource would need to earn in order to be attracted into the capacity market. It is calculated as Gross CONE minus expected energy and ancillary service (E&AS) margins. Gross CONE represents the total annual net revenue (net of variable operating costs) that a new generation resource would need to recover its capital investment and fixed costs, given reasonable expectations about future cost recovery over its economic life. E&AS margins represent the revenues (net of variable operating costs) that the resource can expect to earn from the energy and ancillary services markets.

12 NYISO's demand curve, which has a very low quantity at the cap, is an exception.

5) and tend to result in somewhat lower customer costs for the same level of average reliability, compared with linear or concave curves.

The AESO's proposed demand curve uses two linear segments with different slopes to achieve a convex demand curve shape (see Figure 1). This approach is currently used in PJM and was proposed for use in New England's original locational capacity market.[13] A range of price and quantity coordinates for the inflection, or "kink", point between the two linear segments can lead to acceptable convex curves. Both the curve in PJM and the proposed curve for ISO-NE use an inflection point price of 50% of the price cap. AESO's proposed curve adopts the same convention.

Demand Curve Width and Steepness

The width and steepness of the demand curve directly affect performance metrics relevant to the design principles, including average reliability, customer cost, price volatility, and opportunity for the exercise of market power. Generally, a demand curve needs to be wide enough so that the entry or exit of any one resource will not introduce excessive price volatility or susceptibility of market power. The curve should not be so wide that the price signals are muted and do not adequately reflect market conditions (which may drive the market to protracted periods with excess supply, and inadequately incentivize producers to quickly address shortages when they arise).

Wider and flatter demand curves generally display lower price volatility and reduced opportunity for the exercise of market power, but produce higher quantity uncertainty and may produce higher customer costs under some circumstances.[14] Tighter and steeper curves reverse these tradeoffs. When developing demand curves to achieve a reliability objective, price caps can be varied to allow for flatter or steeper curves (with associated advantages and disadvantages). For example, to achieve the same level of reliability, curves with a higher price cap will need to be tighter and steeper, while curves with a lower price cap will need to be wider and flatter. The intuition here is that a curve with a higher price cap can send stronger price signals when the reserve margin is low, so if the foot of the curve is not brought in (making the curve steeper), it would result in over-procurement and higher associated customer cost.

---

13 See: Pfeifenberger J., Newell, S., Spees, K., Murray, A., Karkatsouli, I., *Third Triennial Review of PJM's Variable Resource Requirement Curve*, May 15, 2014, Prepared for PJM Interconnection; Stoft, S., *Prepared Direct Testimony of Steven E. Stoft On Behalf of ISO New England Inc.*, August 31, 2004, Docket No. ER03-563-030

14 Wider curves would produce higher customer costs on average if the minimum quantity and the price at the cap were maintained at the same level, while right-shifting the foot point of the curve. If a wider curve were achieved by right-shifting the foot and reducing the price cap, then average customer costs may remain approximately similar.

D. Review Cycle

AESO is proposing to conduct comprehensive reviews of the demand curve parameters every four to five years. These reviews provide the opportunity to evaluate the performance of the demand curve relative to the design principles and make any changes necessary to improve its design. AESO could use these periodic reviews for a range of purposes, including:

- **Updating the Cost of New Entry Parameter:** Changes in technology costs, the cost of other inputs such as land and labour, tax rates and deductions, policy incentives and requirements, and the relative economics of different potential reference resource types, can all potentially affect CONE. The periodic review provides an opportunity to revise the parameter given observed and anticipated market conditions.
- **Updating the Energy and Ancillary Services Offset Methodology:** Changes in fuel prices, energy and ancillary service prices, the generation resource mix, demand for power, policy requirements, and the choice of reference technology can all potentially affect the approach to calculate the E&AS offset. The periodic review provides an opportunity to revise the calculation methodology to reflect the most up-to-date information.
- **Broadly Reviewing Performance of the Demand Curve:** Evaluating market pricing, customer costs, the types of investments occurring in the market, performance relative to the resource adequacy objective, and any observed or anticipated challenges to the market, would provide useful information about the performance of the demand curve. The results of this review could be used to inform a number of potential design refinements to the demand curve.

The AESO's proposal to conduct periodic reviews is consistent with current practices in the majority of existing capacity markets. Table 1 summarizes the frequency and scope of periodic reviews in PJM, ISO-NE, NYISO, and Great Britain. PJM's quadrennial reviews focus on the choice of reference technology, CONE estimate, energy and ancillary services offset estimation methodology, and the demand curve. NYISO's reviews have a similar scope. ISO-NE's review focuses less on the demand curve, but considers default offer mitigation thresholds for each resource type. Great Britain's review is potentially the broadest in scope and includes a general review of performance relative to objectives and the possibility of re-evaluating the objectives themselves.

Table 1
Capacity Market Review Cycles in a Selection of Other Jurisdictions

	PJM	ISO-NE	NYISO	Great Britain
Frequency	4 years	3 years	4 years	5 years
Scope	CONE estimate, E&AS offset methodology, demand curve	CONE estimate, E&AS offset, resource type mitigation levels	CONE estimate, demand curve performance	Assess market performance relative to objectives, review market objectives

Notes: PJM's major reviews were initially on a three-year cycle and included a broader scope. See, for example, Pfeifenberger, J., Newel, S., Spees, K., Hajos, A., Madjarov, K., *Second Performance Assessment of PJM's Reliability Pricing Model*, August 26, 2011. Great Britain's Energy Act of 2013 calls for a comprehensive review of the market 5 years from passage of the Act.

III. Probabilistic Simulation Approach

The price cap, quantity at the cap, shape, and width/steepness of the demand curve will affect the performance of Alberta's capacity market relative to its design objectives (as described in Section II). These demand curve parameters affect the expected distribution of price and quantity outcomes from the capacity auction. To quantify the scale of these effects and tradeoffs we have used a Monte Carlo model to simulate market clearing outcomes that can be expected under long-run equilibrium conditions with a variety of potential demand curves. Our modeling assessed the market on a *gross* supply and demand basis, meaning that suppliers are assumed to bid all of their capacity and buy all of their load from the market, rather than buy or sell only energy *net* of any load obligations. The model uses assumptions consistent with 2021/22 anticipated market conditions but we expect the results to be broadly relevant across a range of uncertainties that may be realized over a longer time horizon, given that both price and quantity points on the demand curve are defined to scale with market conditions. In this section, we describe the primary components of this model, including our characterization of supply, demand, and reliability. In subsequent sections of the report, we apply this simulation approach to evaluate the likely performance of candidate demand curves in Alberta.

A. Monte Carlo Simulation Modeling Approach

We used Brattle's proprietary Monte Carlo simulation model to evaluate the performance of capacity market demand curves in Alberta. At its core, the model represents the capacity auction, determining market clearing prices and quantities by intersecting supply and demand curves. The model simulates a large number of auction clearing outcomes, representing a realistic range of supply and demand conditions for Alberta's market.[15] By simulating the capacity auction many times, we developed distributions of cleared prices and quantities. These price and quantity distributions can be used to calculate expected values and ranges for Alberta's cleared quantity, EUE, and customer cost. A stylized depiction of the price and quantity distributions resulting from our Monte Carlo model is shown in Figure 2, with the intersection of supply and demand curves determining price and quantity distributions.

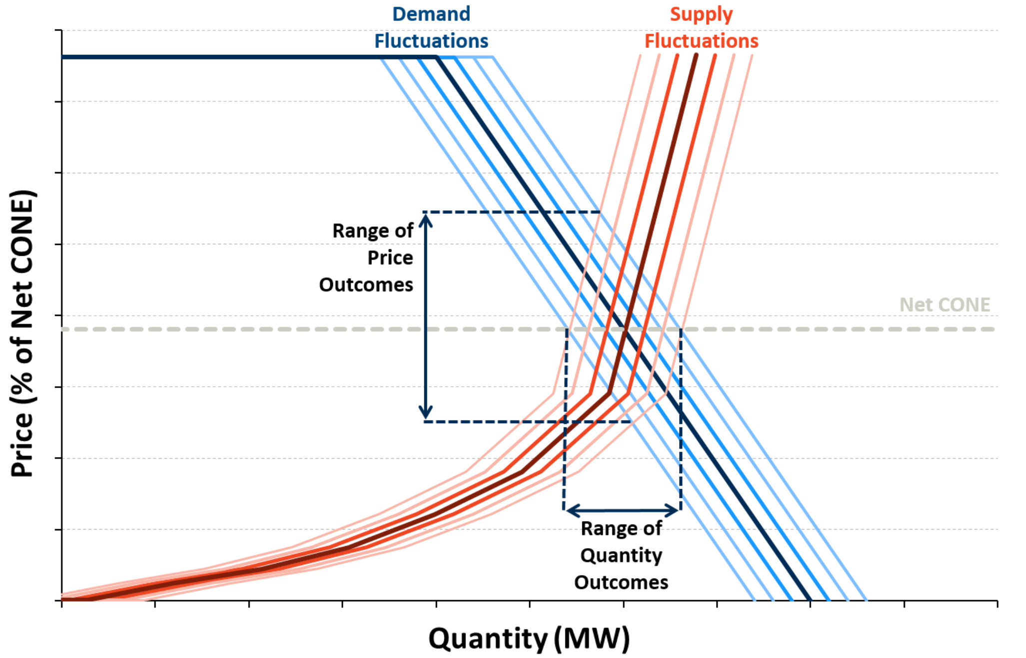
Our model assumes economically rational new entry, with supply entering or exiting the market infra-marginally until the long-term average price equals Net CONE. Due to this convergence towards Net CONE on average, our simulations reflect long-term economic equilibrium conditions, and do not reflect a forecast of outcomes over the next several years or any other particular year. We implement this convergence by increasing or decreasing the quantity of modeled supply so that the average clearing price across all draws is equal to Net CONE. Too much zero-priced supply would result in an average price below Net CONE, while too little supply would result in an average price above Net CONE. This model feature simulates the action of economically rational investors, who are expected to enter the market when prices are above their Net CONE, and not to enter (and possibly exit) when prices are below Net CONE.

The model provides meaningful indicators of Alberta's capacity market performance because its mechanics and inputs were informed by Alberta-specific data and analysis. We used Alberta-specific inputs provided by the AESO to determine the required level of demand in the capacity market, the EUE vs. procured volume relationship, capacity import characteristics, and the expected sizes of fluctuations in demand and supply. In the absence of historical capacity supply offers in Alberta, we supplemented the Alberta-specific data with a range of capacity supply curve shapes based on eight years of offers into PJM's Base Residual Auction (BRA). These supply curves reflect the full range of resources that might offer into Alberta's capacity market under a variety of potential future market conditions.

---

15 The model runs 10,000 Monte Carlo simulation draws. The first 9,000 draws are used to calibrate the "Smart Block" (described in more depth in Section III.B), and the last 1,000 are used to evaluate the performance of the demand curve.

Figure 2
Stylized Depiction of Supply and Demand Fluctuations in the Monte Carlo Analysis



Notes: Illustrative only, fluctuation magnitudes are not intended to exactly reflect model inputs. We evaluated both linear and kinked candidate demand curves.

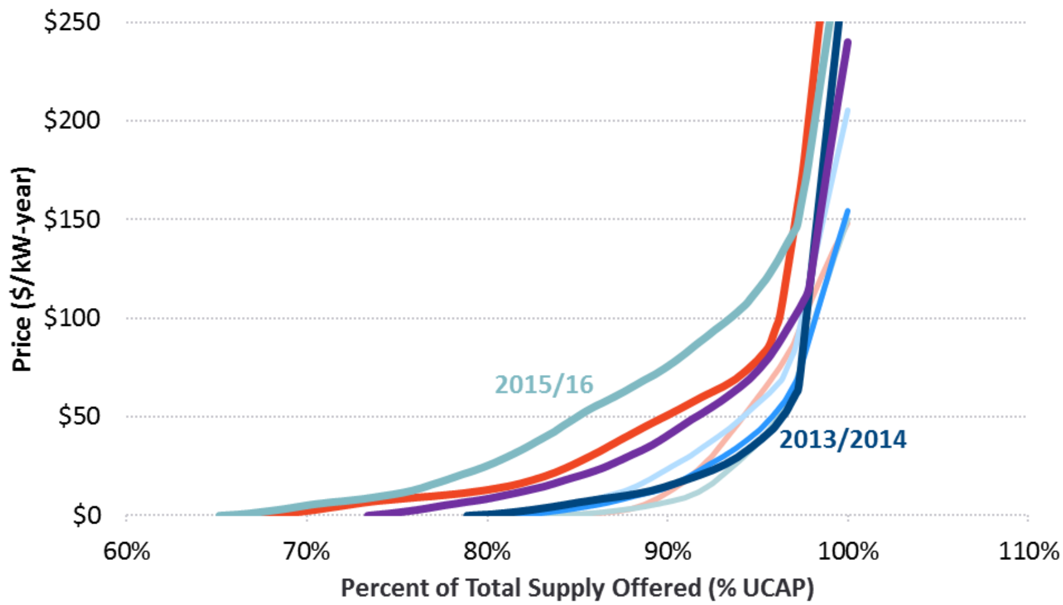
B. Supply Curves and Market Entry

The shape of the capacity market supply curve is one driver of market outcomes, affecting distributions of prices, quantities, and reliability. Given fluctuating supply and demand conditions, a gradually-increasing, elastic supply curve would result in relatively stable prices and quantities near the resource adequacy requirement, while a steeper supply curve would result in greater price and quantity volatility. Unlike the demand curve, the capacity market supply curve is not under the control of the AESO and is determined collectively by market participants based on their offers. For our modeling, we aim to use supply curves and a representation of market entry that realistically reflect resource participation in Alberta's future market.

Since there are not yet any Alberta market data that could be used directly to develop a capacity supply curve, we developed realistic supply curve shapes by adapting data from PJM's capacity market into the Alberta context. We developed eight Alberta supply curves using offers into PJM's capacity market for delivery years 2009/10 through 2016/17 as presented in Figure 3. We adapted these curves to apply in Alberta by adjusting for system size, inflation, and exchange rate.

The resulting supply curve shape is consistent with the expected fleet-wide resource economics in Alberta, given the cost structure of highly capital-intensive resources with long economic lives. With this cost structure, we anticipate that the majority of resources (65-80% of the fleet) is likely to offer at zero or low prices, consistent with the offer of a resource whose investment costs are sunk and fixed going-forward costs are more than offset by anticipated energy and ancillary service net revenues. These resources would not be likely to retire or mothball even if capacity prices were zero. The remaining fleet would be made up of aging resources, demand response, imports, and new resources that would offer at higher prices, and that may enter or exit the market based on that specific year's capacity prices. This range of supply curves also reflects the realistic wide range of market conditions that may affect a capacity market over multiple years. For example, it should be expected that broader market conditions could occasionally induce significant reinvestment costs across the fleet that may periodically prove necessary to keep resources online, as they did in 2015/16 in PJM.

Figure 3
Supply Curve Shapes used in Monte Carlo Analysis



Sources and Notes: Supply curve shapes based on PJM data, adjusted for inflation and exchange rate. We did not use the supply curve shapes from PJM's more recent auctions, because they have a different shape due to the introduction of the Capacity Performance product. See Newell, *et al.* PJM VRR Curve report (2018) for further details.

These shapes are then used as one component of our overall representation of short-term and long-term supplier decisions. In our model, we represent supplier curves with three components, shown in a stylized depiction in Figure 4. The first component, the "Smart Block," represents long-term entry and exit from the market and is used to converge on the total quantity of supply in the market at equilibrium. As we described in Section III.A, if average prices exceed Net CONE on average over many years, supply will enter the market. If prices fall below Net CONE on average, supply will exit. The exact size of the Smart Block is calibrated during the first 9,000 runs of the model to achieve a level of supply that results in a long-run average clearing price equal to Net CONE. The size of the Smart Block reflects this rational entry or exit from the market, consistent with reaching a long-run equilibrium quantity where average prices equal Net CONE.[16]

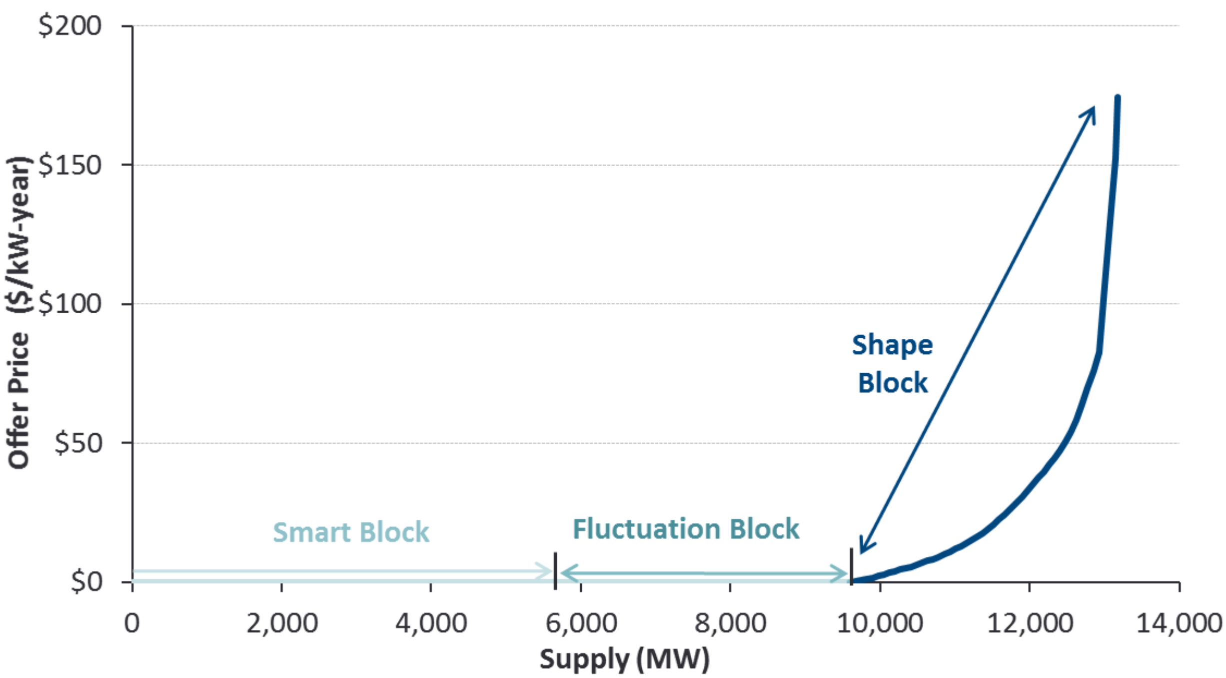
---

16 While the Smart Block is represented as zero priced supply, we are not suggesting that new supply will enter the market at a price of $0. The Smart Block simply determines the total quantity of supply in the

In the long-run equilibrium condition, the Smart Block is held constant even as market conditions fluctuate in our Monte Carlo model, but the size of the Smart Block may be different between demand curves. In contrast, the second component, the "Fluctuation Block", reflects the lumpy and uncertain portion of market entry and exit that is not necessarily driven by rational economic decision-making. The Fluctuation Block reflects uncertain construction timelines for new plants (leading to earlier or later online dates than anticipated), policy drivers of investment or retirement, the impact of investment cycles, the occasional over-sizing or under-sizing of lumpy investments compared to market-wide needs, and lags between price signals and market reaction.

Finally, the third component, the "Shape Block", represents offers at above-zero prices that represent the short-term economics of existing and new resources that may enter or exit the market depending on whether it clears a particular auction. For each run of our simulation model, the Shape Block reflects one of the eight supply curve shapes shown in Figure 3 at prices above zero.

Figure 4
Stylized Depiction of Simulated Basic Supply Curve Components



Note: Smart block and fluctuation blocks both represent supply offered at zero-price.

Based on input from stakeholders, we also considered a different approach to modeling supply curves in the Alberta capacity market that would be developed from Alberta-specific, bottom-up estimates of individual resources' economics. Although we did not ultimately adopt this approach

market at equilibrium. In any given year, the supply curve is expected to consist of a) existing supply with no net going-forward costs offering at $0 (likely the largest portion of the market) and b) new and existing supply with positive net going forward costs. This basic structure is reflected in all of the modeled supply curves, regardless of the Smart Block value.

in our modeling assessment of the demand curve, we did review the indicative curves developed by the AESO staff and validated that the general shape of the supply curves we use are generally consistent with the economics of Alberta's current fleet. We did not attempt to adopt such an approach for the purposes of this demand curve assessment however, primarily because our objective is to review the likely performance of the demand curve under long-term equilibrium conditions (rather than to evaluate the near-term implications for the existing resource mix).

C. Resource Adequacy Outcomes

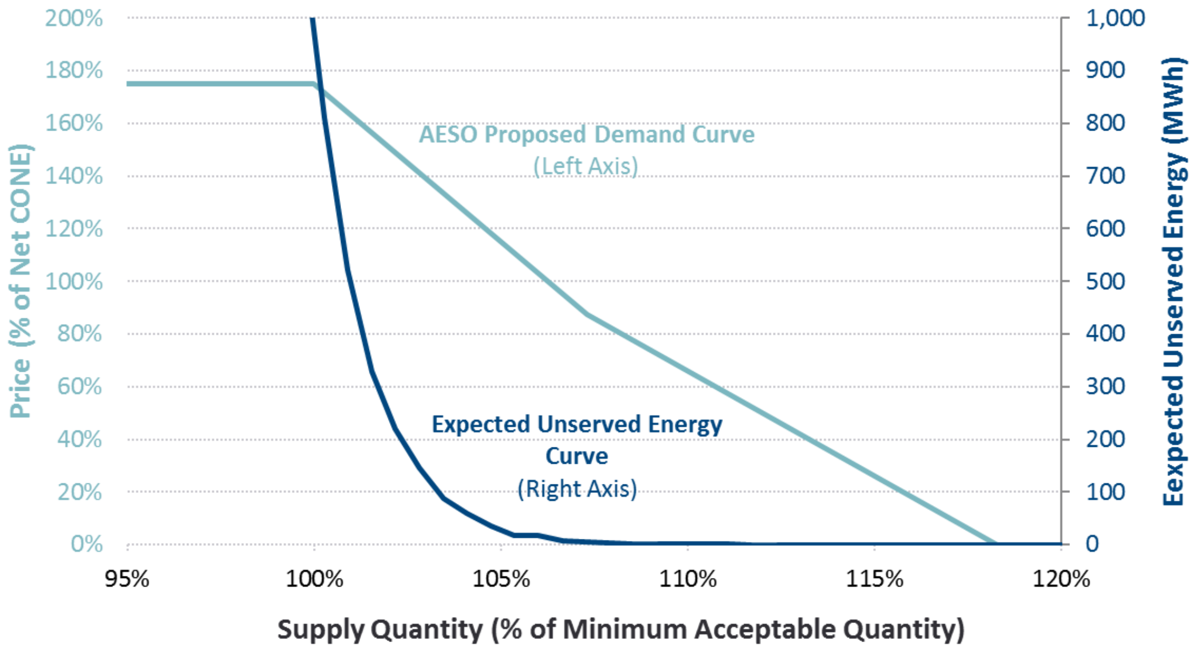
In March 2018, the Government of Alberta announced a minimum resource adequacy standard of 0.0011% EUE (approximately 964 MWh at the load level anticipated in 2022). The AESO has determined that it will aim to procure a level of supply consistent with or above this objective through the capacity market base auctions at least 95% of the time, i.e., requiring out-of-market interventions being required only 5% of the time. We have developed capacity market demand curves consistent with this resource adequacy objective.

In order to evaluate the resource adequacy implications of different levels of cleared capacity, we drew on reliability simulations conducted by the AESO.[17] Figure 5 shows the relationship between the supply quantity and EUE, as well as the AESO's proposed demand curve. The EUE curve is downward sloping and convex. Increasing supply causes the EUE curve to decline rapidly at lower supply levels, but decline only gradually once above the minimum acceptable level.

As shown in Figure 5, the AESO's Proposed Demand Curve is downward sloping and convex, as is the EUE curve (or any other representation of marginal EUE avoided by incremental capacity). However, the demand curve is not nearly as steep at low quantities nor as flat at high quantities. It would be possible to develop a demand curve whose shape more closely matches EUE. To meet the minimum reliability standard, the curve would need to be significantly right-shifted (resulting in a greater quantity at the price cap) from its current position on the chart, or else the price cap would need to be significantly higher.

17 AESO's estimate of reliability at different quantities of capacity is based on a model operated by AESO staff. The data used in our simulation model are from a simulation date in April 2018. We understand that AESO has continued to revise the model since this time, but that the shape of the EUE vs capacity curve has remained relatively unchanged.

Figure 5
EUE vs. Supply Quantity Relationship Based on AESO Modeling



Source: EUE data provided by the AESO.

D. Fluctuations in Supply and Demand

We also simulate realistic distributions of price, quantity, and reliability outcomes that may be observed over many years in the capacity auction, with the magnitude of the fluctuations based on Alberta-specific historical data. Year-to-year variability in supply and demand result in distributions of clearing prices, quantities, and delivered resource adequacy. We used historical and modeled data from the AESO to inform the expected size of these "fluctuations".[18] The estimated sizes of these fluctuations were refined over the course of our work with the stakeholders.[19] Table 2 summarizes the supply and demand fluctuation sizes used in our modeling.

These fluctuations are an important driver of demand curve design. The most practical implication of net supply fluctuations is that it is not possible to ensure that procured capacity will land exactly at the Government's minimum acceptable reliability in every year. Instead there will necessarily be a distribution of reserve margins produced by the capacity market. The introduction of a

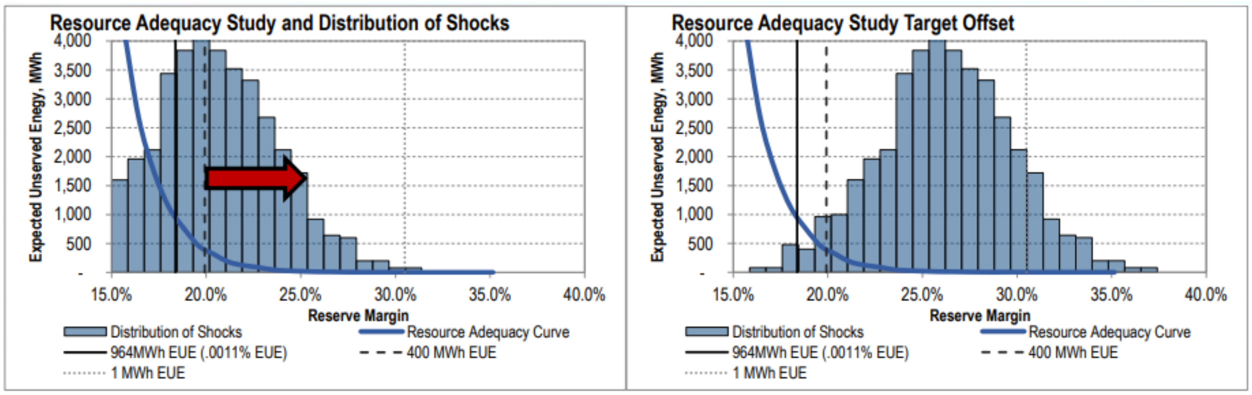
---

18 Fluctuation sizes in our analysis were based on supply and load forecast data available when analysis was being conducted with stakeholders. While these fluctuation sizes could evolve over time, the AESO's periodic reviews of the capacity demand curve will provide an opportunity to update the fluctuation size estimate to account for any changes.

19 Due to a lack of historical market data in Alberta, we did not attempt to empirically determine the likely distribution of fluctuations in supply and demand. We made the simple assumption that fluctuations are normally distributed. This assumption is consistent with our assessments of demand curve performance in PJM and New England.

capacity market can be expected to significantly reduce the realized variability in reserve margins across years compared to Alberta's historical energy-only market (by mitigating the potential for boom-bust cycles from uncoordinated entry and exit). However, this variability cannot be eliminated. The demand curve must be wide enough to manage the year-to-year supply and demand variability inherent in the market, given the many market players, non-uniform infrastructure decisions, and uncertain loads. Because EUE increases at an increasing rate when supply is scarce, a demand curve with the target set around the minimum acceptable reliability level will not achieve the minimum acceptable reliability on average. Thus, the curve will need to be right-shifted (higher quantities at each price level), as seen in Figure 6, such that the auction is expected to fall short of that requirement no more than 5% of the time.

Figure 6
Right-Shifting the Demand Curve to Achieve Minimum Acceptable Reliability Level



Sources and Notes: AESO, *Technical Working Group #3: Demand Curve Shape Analysis*, May 2018, p. 7. The figure shows that reliability would be below the target with a demand curve with the target set around 400 MWh EUE (a previous tuning concept). The same principles would still hold if we were to center the target on the minimum acceptable quantity.

Demand

Recognizing that the AESO recently updated its load forecasting methodology, we estimated the size of demand fluctuations based on a back-cast developed using the updated methodology.[20] We evaluated expected variability from the new load forecast methodology using back-casted data

[20] During our discussions with stakeholders, we developed an earlier preliminary estimate of demand fluctuation size using historical Alberta load forecast data. The objective of that historical analysis was the same as that of the analysis discussed here: to capture the variability in load forecasts between auctions, rather than the load forecast uncertainty between the auction and delivery year (which is captured in the EUE curve provided by the AESO and reflected in the minimum procurement volume). We iterated on the historical approach with stakeholders in an effort to avoid any double-counting between the demand fluctuations used in our Monte Carlo model and the load forecast uncertainty reflected in the EUE curve. The final demand fluctuation size developed based on this methodology was 3.2% of the expected procurement volume, or similar to the 3.3% estimated based on the AESO's new load forecast methodology. See AESO, *Demand Curve Shape*, Presented to the Technical (Demand Curve) Workgroup #4, June 14, 2018.

provided by the AESO for delivery years 2010 through 2016. The back-casts for each historical delivery year rely only on data that would have been available at the time (for example, the 4-year ahead forecast for 2016 would have been conducted in 2012 and would have relied only on data available in 2012). We evaluated the variability in these back-casts around the load growth trend in order to estimate the expected variability in demand between consecutive base auctions, arriving at a standard deviation of 3.2% of the procurement volume.[21] We note that this estimate of demand fluctuation size is within the 1.6% to 3.8% range of demand fluctuation sizes in other jurisdictions for capacity market regions of similar size to Alberta's.

Supply Offers

We estimated the size of fluctuations in supply offers based on historical variability in Alberta's installed capacity around the long-term trend in supply growth, arriving at a standard deviation of 3.7% of total supply. The historical record of installed capacity provides an indication of how supply offers into Alberta's capacity market might vary as market conditions change over time. Note that one of the key functions of the capacity market is to reduce the boom and bust cycle by better coordinating entry and exit decisions and we therefore expect installed capacity variability to decrease going forward. Our modeling captures this effect. While we used historical installed capacity as a basis for our estimate of the variability in supply *offered into the auction*, the effect of the sloped demand curve in our model results in a reduction in the variability of supply cleared in the market.

[21] The forecasts for 2010–2016 included the impact of the 2008 recession, which resulted in a very low 4-year ahead forecast for 2013. Recessions of this magnitude happen occasionally, but are likely over-represented in our limited data sample. We therefore weighted the recession-driven 2013 residual by 50% in calculating the standard deviation of the load forecast about the trend. Including the 2013 year at 100% weight would have resulted in a standard deviation of 4.9% and excluding it altogether would have resulted in a standard deviation of 2.1%.

Table 2
Modeled Fluctuation Sizes (Standard Deviation)

Fluctuation Type	MW Size	% of Procurement Volume
Demand	358	3.1%
Supply Offers	419	3.6%

Notes: Sample percentages of procurement volume vary slightly from what is described in the text (*population* standard deviation) due to statistical noise over the 1,000 draws used in the Monte Carlo model. MW sizes are based on a procurement volume of 11,470 MW, calculated based on EUE data provided by the AESO.

IV. Performance of the Proposed Demand Curve Under Base Case Assumptions

In this section, we discuss the performance of the AESO's proposed demand curve relative to several alternative curves with different price caps, shapes, and steepness. We first compare to demand curves from several other capacity markets. These curves are helpful reference points and illustrate the main design elements shared by all demand curves. However, due to Alberta's small size and larger fluctuation sizes on a percentage basis, we expect that none of these demand curves would attract enough supply to achieve the resource adequacy objective in Alberta.

During the stakeholder process, a range of demand curve designs were suggested and discussed. This section summarizes our analysis and conclusions developed for AESO and stakeholders during the stakeholder process, though some of the specific demand curves have been adjusted to allow for an easier comparison of the impact of key demand curve design elements and modeling assumptions have been updated over this timeframe.[22] Not all demand curves that we have examined are consistent with the market's primary design principle of achieving the government's minimum resource adequacy standard. We therefore developed a set of "candidate" demand curves, all meeting the minimum resource adequacy objective. These demand curves combine different design elements in such a way as to achieve performance consistent with the resource adequacy objective, but represent different tradeoffs among other design principles. We leveraged the probabilistic modeling approach described in Section III to estimate distributions of price,

[22] The Appendix summarizes the individual stakeholder materials in which each of these analyses were originally presented.

quantity, and reliability outcomes for the proposed curve and these candidate curves under the long-run equilibrium conditions represented in our model.

Figure 7 shows the AESO's proposed demand curve along with each of the candidate demand curves developed for Alberta.[23] We describe each of the candidate demand curves below:

- **Proposed Curve** (shown in red). The Proposed Curve has a price cap at MAX(1.75 × Net CONE, 0.5 × Gross CONE), at the quantity corresponding to the minimum acceptable resource adequacy objective. Its foot is located at a price of $0 and 118% of the minimum acceptable quantity. It has an inflection point at a price of 0.875 × Net CONE and a quantity of 107% of the minimum acceptable quantity.
- **High Price Cap** (shown in blue). The High Price Cap curve has a price cap at MAX(2.0 × Net CONE, 0.5 × Gross CONE), an inflection point at 1.0 × Net CONE, a foot at 114% of the minimum acceptable quantity, and is otherwise defined in the same way as the Proposed Curve. With a higher price cap, the demand curve can be steeper and still achieve the minimum resource adequacy objective.
- **Low Price Cap** (shown in yellow). The Low Price Cap curve has a price cap at MAX(1.5 × Net CONE, 0.5 × Gross CONE), an inflection point at 0.75 × Net CONE, a foot at 126% of the minimum acceptable quantity, and is otherwise defined in the same way as the Proposed Curve. With a lower price cap, the demand curve must be wider in order to achieve the minimum Resource Adequacy objective.
- **Linear** (shown in teal). The linear curve shares almost all design elements with the Proposed Curve, except that it has no inflection point. With a linear shape, the curve can be slightly steeper and still achieve the minimum resource adequacy objective.
- **More Convex** (shown in purple). The More Convex curve has an inflection point at Net CONE and the quantity corresponding to 100 MWh EUE. It has a higher price cap at 1.9 × Net CONE and a foot at 132% of the minimum acceptable quantity. Even with its higher price cap, the More Convex curve's leftward- and downward-shifted inflection point means the curve's foot point must be shifted considerably to the right in order to achieve the minimum resource adequacy objective.

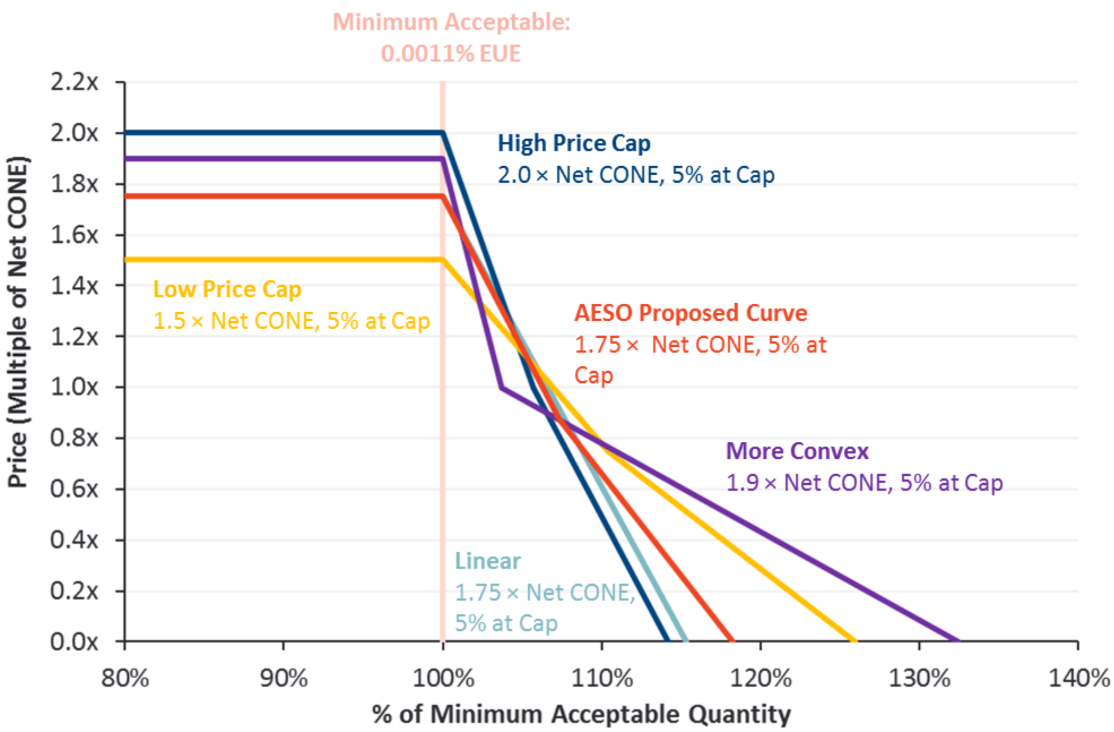
Each of the candidate demand curves in Figure 7 was "tuned" to achieve the minimum resource adequacy objective, leveraging the simulation model described in Section III. In general, demand curves with lower price caps need to be wider in order to achieve the same EUE. Demand curves with higher price caps can be steeper and achieve the same EUE. In developing the demand curves, we adjusted the steepness of each demand curve until the resource adequacy objective was met, but not exceeded. Exceeding the resource adequacy objective could result in greater costs to customers than necessary.

---

23 While all candidate curves were introduced during the stakeholder process, the exact definitions of the curves that we present here are slightly different than what was presented during the stakeholder process due to updated data and changing reliability objectives. That being said, the same conclusions that we can draw about the demand curve characteristics from the candidate curves are still applicable.

For all of the candidate demand curves in Figure 7, prices reach the price cap at a quantity corresponding to the 0.0011% EUE minimum resource adequacy objective. If the capacity market were to clear less than the quantity corresponding to 0.0011% EUE, the AESO might initiate out-of-market intervention to ensure resource adequacy. Ensuring that the price reaches the cap at or above this minimum acceptable quantity is consistent with the fundamental principle that all in-market supply options should be exhausted before out-of-market actions are initiated. It helps ensure confidence in the market by minimizing collateral impacts on other market participants should any out-of-market intervention be necessary.

Figure 7
Candidate Demand Curves Meeting Alberta's Minimum Resource Adequacy Objective



Sources and Notes: All candidate demand curves were designed to achieve the Government's 0.0011% minimum resource adequacy requirement under modeled Alberta conditions. Each curve represents a different tradeoff between other design criteria, including customer cost and price volatility.

In the remainder of this section, we compare the AESO's curves to demand curves from other jurisdictions, discuss how each of the key demand curve design elements represented in the candidate demand curves affect performance across design objectives, and discuss the significance of the 0.5 × Gross CONE price cap minimum. This section summarizes analysis and conclusions developed for AESO and stakeholders during the stakeholder process, though some of the specific demand curves have been adjusted for easier comparison of the impact of key demand curve design elements.

A. Comparison with Demand Curves Used in Other Markets

Figure 8 shows the AESO's proposed demand curve compared to demand curves in other North American capacity markets and zones. The AESO's proposed curve width is 18% of total capacity. This is wider, on a percentage basis, than the 8% in PJM and 12% width in ISO-NE, but smaller than the 19% width in NYISO and 23% width in New York City.[24]

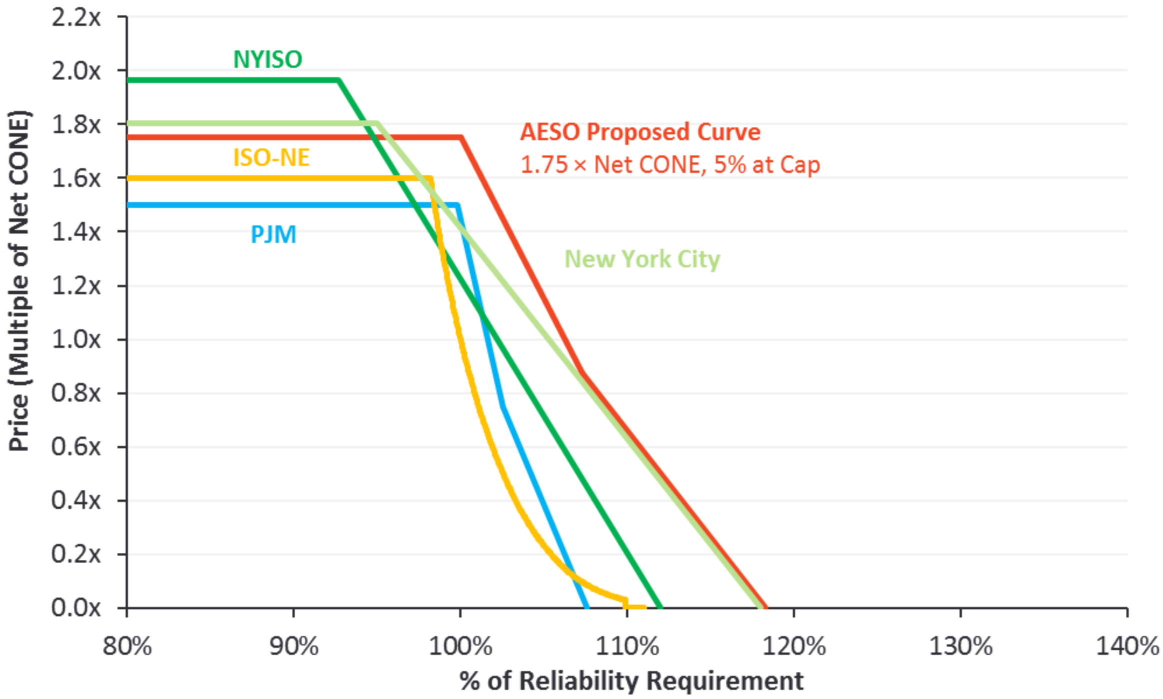
The AESO's proposed curve is wider on a percentage basis than demand curves in PJM and ISO-NE, because the additional width is needed to manage entry and exit of lumpy supply in Alberta's relatively smaller market. On a percentage basis, variability in supply and demand would produce greater price impacts in Alberta's relatively smaller market (while on a MW basis variability would be smaller). This is the same reason that a somewhat higher high price cap is also justifiable. The higher price cap helps maintain reliability when the market is short and the curve can be steeper than it would be with a lower cap, for the same level of reliability.

The AESO's proposed curve is not as wide as the NYISO and New York City demand curves, even though Alberta's market is smaller than NYISO system and about the same size as New York City. NYISO's market may require a wider curve partly to manage the additional volatility that would otherwise be expected in that non-forward market, and is partly related to the relatively left-shifted price cap chosen there.

---

24 We define the demand curve width as the quantity from the end of the price cap to the foot as a percent of the reliability standard in each jurisdiction.

Figure 8
Comparison with Other Markets



Sources and Notes: Curves represent: NYISO and NYC's 2018 summer period curves, ISO-NE's FCA11 MRI curve, and PJM's 2021/22 BRA VRR curve. The curves are expressed as a percentage of the reliability requirement (or the minimum acceptable level in Alberta's case).

B. Comparison with Curves with Higher or Lower Price Caps

The price cap is a key determinant of demand curve performance. A high price cap reduces reliability risks when the market is tight by attracting as much supply as possible when it is most needed. In so doing, a high price cap reduces the need for out-of-market backstop procurement. High price caps mitigate the risk that the true Net CONE faced by developers is higher than the administrative price cap. If the price cap is well above the administrative estimate of Net CONE, the market will be able to attract supply in shortage conditions, even if the administrative Net CONE parameter is too low.

At the same time, demand curves with higher price caps result in higher price volatility and increased potential for the exercise of market power. For demand curves achieving the same level of average reliability, the price cap and demand curve steepness are closely linked, with higher price caps associated with steeper curves. For such "tuned" demand curves, a high price cap implies a steeper demand curve.

Table 3 compares the performance of the AESO's proposed curve to alternative demand curves with higher and lower price caps, drawing on results from our probabilistic simulation model. The table reports price, cost, and reliability metrics for market simulations conducted with each demand curve. In all cases, average prices converge to true Net CONE as market-based supply enters and exits the market across all demand curves. The frequency of events at the price cap also represents the frequency with which the cleared quantity is equal to or below the minimum acceptable quantity. The average cost column reports price times quantity in each simulated market year.[25]

We estimated the standard deviation of prices across simulated market years, a measure of price volatility and a key driver of market performance. While it is expected that cleared prices will vary year-to-year, lower price volatility is preferred to avoid the uncertainty for investors and customers. However, attempting to reduce or eliminate price volatility entirely would produce overly muted price signals that do not align with market conditions, which could potentially result in protracted periods of surplus or shortage. Thus, a demand curve should balance the competing objectives to mitigate price volatility and mitigate quantity uncertainties.

We report two types of average EUE metrics. *Before* intervention refers to the level of reliability delivered by the Base auction, without considering any actions outside of this auction. *After* intervention refers to the level of reliability achieved, assuming the AESO would procure backstop supply up to the minimum acceptable quantity in the event market-based supply does not reach that level. Averaged cleared and uncleared supply illustrate the amount of supply in the simulated market on average using the developed supply curves.

As shown in Table 3 the AESO's proposed curve with its price cap of 1.75 × Net CONE, represents a reasonable tradeoff among the various design principles. Under the High Price Cap (2.0 × Net CONE) and the Low Price Cap (1.5 × Net CONE) candidate demand curves, some performance metrics improve, while others deteriorate. With the High Price Cap curve, the largest change is the 25% increase in price volatility to $65/kW-yr. The higher price volatility can be seen graphically in Figure 9's left-hand panel, where the price distribution is more spread out with a high frequency at the extremely high prices (> 172% of Net CONE). Conversely, the Low Price Cap curves achieves 28% less price volatility, with the price distribution centered more narrowly on the long-term average price (Net CONE).

The price cap has a secondary impact on average customer costs. As Table 3 shows, customer costs are somewhat (~1%) lower with the High Price Cap, reflecting the reduced need for a supply "buffer" during all years, since the market is able to attract additional supply only when the market is short and the additional supply is needed. Conversely, customer costs under the Low Price Cap curve are somewhat higher (though less than 1%).

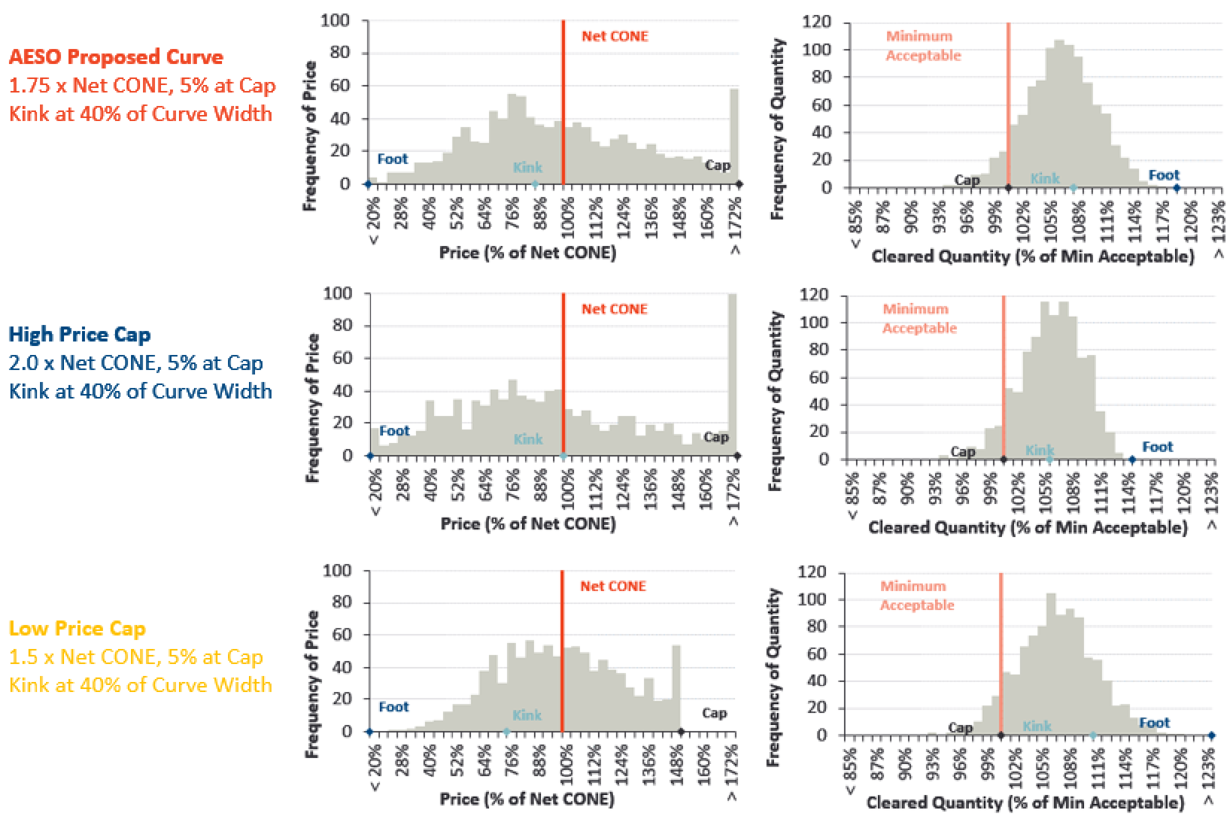
---

[25] This metric provides an indication of long run average costs in the capacity market, although self-suppliers and retailers with financial hedges will not be fully exposed to the capacity auction price.

Table 3
Simulated Performance of Proposed Curve vs. Curves with High/Low Price Caps

	Price and Cost				Reliability			
Demand Curve	Average Price *($/kW-yr)*	Standard Deviation of Price *($/kW-yr)*	Frequency at Cap *(%)*	Average Cost *($mil/yr)*	Average EUE (Before Intervention) *(MWh)*	Average EUE (After Intervention) *(MWh)*	Average Cleared Quantity *(MW)*	Average Uncleared Supply *(MW)*
Simulated Performance								
Proposed Curve	$139	$53	5%	$1,665	266	118	12,042	247
High Price Cap	$139	$65	5%	$1,655	264	119	11,994	276
Low Price Cap	$139	$38	5%	$1,670	268	117	12,092	223
Percent Difference from the Proposed Curve								
High Price Cap	0%	25%	0%	-1%	-1%	1%	0%	12%
Low Price Cap	0%	-28%	0%	0%	1%	-1%	0%	-10%

Figure 9
Price and Quantity Distributions of Proposed Curve vs. Curves with High/Low Price Caps



C. Comparison with a Linear Curve

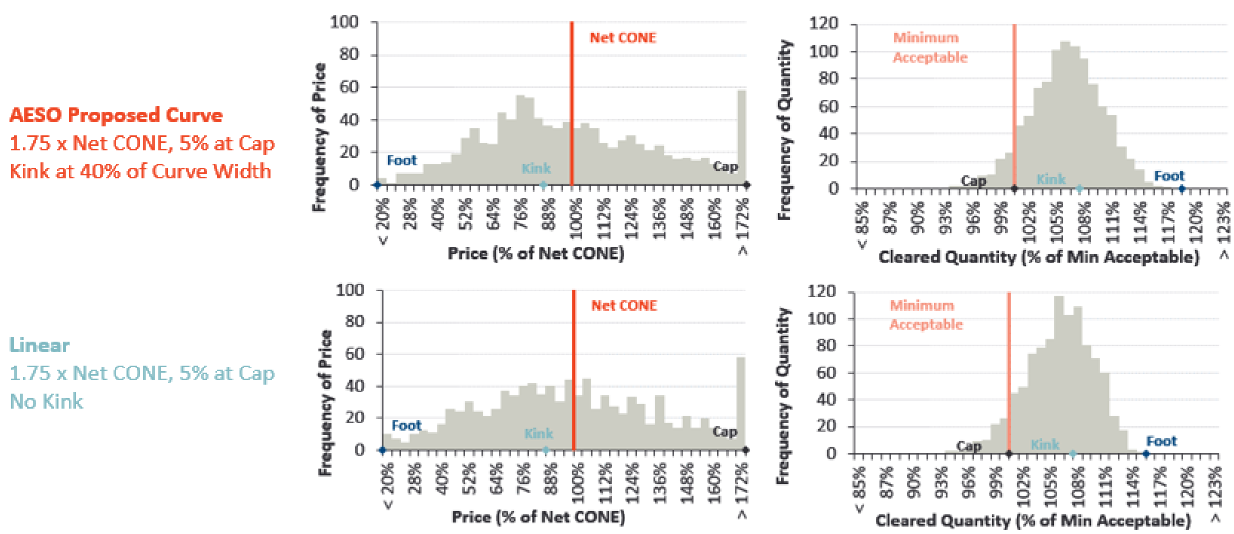
As discussed in Section II, the demand curve shape has important implications for several design principles. The most important aspect of demand curve shape is that it is downward sloping, consistent with the declining reliability value of incremental supply. A straight-line demand curve is the simplest way to achieve a downward-sloping demand curve and captures many of the efficiency, cost effectiveness, and price volatility benefits of adopting a downward-sloping curve. The convex demand curve proposed by the AESO is somewhat more consistent with the shape of the incremental reliability curve.

As Table 4 and Figure 10 illustrate, the quantitative results for the linear curve are very similar to the AESO's proposed curve. The most significant quantitative difference between the two curves is in the resulting price volatility. As shown in Table 4 and Figure 10, price volatility is slightly higher with a linear curve. This is likely due to the linear curve's steeper slope compared to the bottom portion of the convex curve. Other performance metrics, such as reliability and customer costs, are almost identical between the two demand curves.

Table 4
Simulated Performance of Proposed Curve vs. Linear Curve

	Price and Cost				Reliability			
Demand Curve	Average Price *($/kW-yr)*	Standard Deviation of Price *($/kW-yr)*	Frequency at Cap *(%)*	Average Cost *($mil/yr)*	Average EUE (Before Intervention) *(MWh)*	Average EUE (After Intervention) *(MWh)*	Average Cleared Quantity *(MW)*	Average Uncleared Supply *(MW)*
Simulated Performance								
Proposed Curve	$139	$53	5%	$1,665	266	118	12,042	247
Linear	$139	$55	5%	$1,663	265	117	12,033	256
Percent Difference from the Proposed Curve								
Linear	0%	5%	0%	0%	0%	-1%	0%	4%

Figure 10
Price and Quantity Distributions of Proposed Curve vs. Linear Curve



D. Performance Relative to Curve Anchored at 100 MWh EUE

In many jurisdictions, capacity market demand curves produce prices well above Net CONE at the reliability target (see Figure 8) and could be described as "right-shifted" relative to this target.[26] Though Alberta does not have an average reliability target, most of the candidate demand curves we evaluated could still be described as "right shifted" compared to the minimum reliability standard. The AESO's proposed demand curve, for example, results in a price of approximately 1.3 × Net CONE at the quantity corresponding to 100 MWh EUE (which is approximately aligned with historically realized reliability in Alberta).[27]

Alberta stakeholders requested that we evaluate a demand curve that was not right-shifted. In response, we developed the "More Convex" curve shown in Figure 7, which passes through Net CONE at a quantity corresponding to 100 MWh EUE. In isolation, this change would reduce long-run supply in the market because at quantities above the quantity corresponding to 100 MWh EUE, this new curve would have a flatter slope compared to the Proposed Demand Curve. This would result in Alberta falling short of the minimum resource adequacy objective. In order to meet the resource adequacy objective, we increased prices at other points in the More Convex curve by increasing the price cap to 1.9 × Net CONE and right-shifting the foot point to 132% of the minimum acceptable quantity.

Table 5 and Figure 11 show how the More Convex demand curve performs compared to the AESO's proposed curve. By design, the frequency of clearing at the cap (*i.e.*, at or below the minimum acceptable quantity) is 5% for both curves. However, the More Convex curve achieves somewhat lower average reliability (*i.e.*, higher average EUE) as it does not attract as much supply at mid to low quantities compared to the AESO's proposed curve. Since the More Convex curve is very flat, it results in considerably lower price volatility than the AESO's proposed curve.

The major drawback of the More Convex demand curve is that it is too wide—nearly 80% wider than the AESO's proposed curve. At high supply quantities where EUE is zero, it establishes higher prices than all of the other candidate demand curves. While average customer costs in the long run are only very slightly higher relative to the AESO's proposed curve, there could be several years in the short run where market prices and quantities are significantly higher (if the Alberta market is long on capacity during transition). It would be difficult to justify such high prices to customers when the market is long.

---

26 One exception is ISO-NE's demand curve, which passes through Net CONE at the Reliability Requirement.

27 AESO, *Resource Adequacy Criteria Overview and Alberta Historical Performance*, Prepared for Adequacy & Demand Curve Workgroup. July 2017, Slide 11.

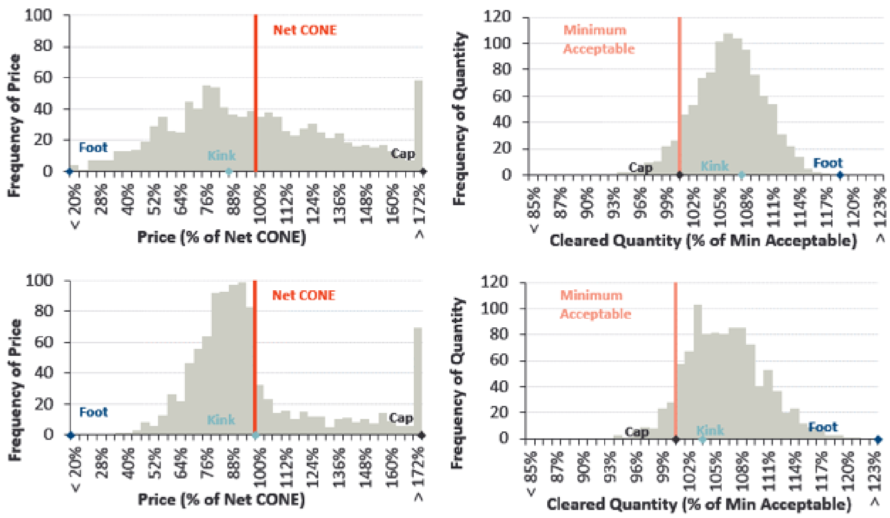
Table 5
Simulated Performance of Proposed Curve vs. More Convex Curve

	Price and Cost				Reliability			
Demand Curve	Average Price *($/kW-yr)*	Standard Deviation of Price *($/kW-yr)*	Frequency at Cap *(%)*	Average Cost *($mil/yr)*	Average EUE (Before Intervention) *(MWh)*	Average EUE (After Intervention) *(MWh)*	Average Cleared Quantity *(MW)*	Average Uncleared Supply *(MW)*
Simulated Performance								
Proposed Curve	$139	$53	5%	$1,665	266	118	12,042	247
More Convex	$139	$46	5%	$1,666	276	128	12,047	229
Percent Difference from the Proposed Curve								
More Convex	0%	-12%	0%	0%	4%	8%	0%	-7%

Figure 11
Price and Quantity Distributions of Proposed Curve vs. More Convex Curve

AESO Proposed Curve
1.75 x Net CONE, 5% at Cap
Kink at 40% of Curve Width

More Convex
1.9 x Net CONE, 5% at Cap
Kink at 100 MWh EUE and Net CONE



E. Performance Impacts of the Minimum Price Cap at 0.5 × Gross CONE

A price cap minimum anchored to Gross CONE aims to reduce reliability risks in the event there is a very low Net CONE estimate. Such an estimate could be due to real market conditions, or could be due in part to estimation error in Net CONE. Since E&AS margins vary substantially from year to year, they represent a key driver of under-estimation risk for Net CONE. If the true Net CONE faced by capacity developers is actually very low, then the demand curve would not need to send a strong price signal to attract capacity. However, if Net CONE is substantially under-estimated due to E&AS margins being over-estimated, this could pose a significant reliability concern. In that case, demand curve prices would fall to very low levels, collapsing down to zero or close to zero, though the true cost of developing incremental capacity is higher. As a result the demand curve may not attract or retain enough supply to keep the market above the minimum resource adequacy objective. A price cap minimum at a multiple of Gross CONE will prevent the demand curve from collapsing and ensuring reliability even if Net CONE were to become low in the future.[28] Further, imposing a minimum on the price cap is consistent with expressing that there is always a minimum value to avoiding a shortfall relative to the Government's reliability standard (which does not disappear even if estimated Net CONE becomes small).

In order to prevent the collapse of the demand curve, the price cap minimum could be set at Gross CONE, or some multiple of Gross CONE. The key tradeoff in choosing a multiple of Gross CONE is between reliability and cost. In the event Net CONE has been underestimated, a price cap minimum at a higher multiple of Gross CONE will result in better reliability. In the event Net CONE has not been underestimated and is simply very low, a price cap minimum at a higher multiple of Gross CONE will result in higher cost to customers with little improvement in reliability.

PJM uses a price cap minimum of 1.0 × Gross CONE, but the Net CONE parameter in PJM has very different components compared to Alberta. For example, in PJM's 2021–22 Base Residual Auction parameters, Net CONE represented 82% of Gross CONE.[29] In contrast, AESO's illustrative Net CONE values show Net CONE ranging from only 17% of Gross CONE for a Combined Cycle (CC) reference unit to 54% for an Aeroderivative Combustion Turbine (CT).[30] Either of these reference resources would immediately trigger a price cap minimum at 1.0 × Gross CONE in the first auction.[31]

The proposed price cap minimum at 0.5 × Gross CONE would avoid triggering the price cap minimum under our modeling assumptions for a CT reference resource.[32] However, it would still provide backstop reliability in the event that Net CONE becomes small. Given the very large E&AS margins currently estimated in Alberta for a CC, this feature could provide additional confidence to potential investors that the market will deliver a reliable supply mix across a range

---

[28] An alternative formulation would be to establish both a minimum price cap *and* minimum inflection point that would apply when Net CONE falls below a threshold value. Such a mechanism would likely achieve the desired effect of providing some support to reliability in case Net CONE is under-estimated, but may be more prone to over-procurement. The recommended formulation (with minimum price cap only) is a more targeted way to address the problem, as it tends to set higher prices only when Net CONE is low *and* the market is relatively short, whereas the alternative formulation would set higher prices at all quantities when Net CONE is low.

[29] PJM, *2021-2022 RPM Base Residual Auction Planning Parameters*, May 2018.

[30] See AESO, *CONE Update, EAS Offset Methodology, CONE Reference Technology Selection*, August 2018, slide 38.

[31] With a price cap at Max(1.75 × Net CONE, 1.0 × Gross CONE), the price cap minimum is triggered if Net CONE is less than 1.0/1.75 = 57% of Gross CONE.

[32] With a price cap at Max(1.75 × Net CONE, 0.5 × Gross CONE), the price cap minimum is triggered if Net CONE is less than 0.5/1.75 = 29% of Gross CONE.

of market conditions, even if E&AS offset becomes high and even if administrative Net CONE would happen to be under-estimated.

V. Sensitivity to System Conditions and Modeling Uncertainties

We conducted a sensitivity analysis to assess the performance of the AESO's proposed demand curve under adverse conditions and to account for uncertainty in modeling assumptions. The primary objective of the sensitivity analysis is to ensure that the AESO's proposed curve performs accounting for unavoidable uncertainty in model parameters and is robust under a reasonable set of adverse conditions. We provided some sensitivity cases to clarify issues of concern to stakeholders and to help explain some of the key dynamics of our probabilistic simulation model. In the sections below, we evaluate the following sensitivities:

- **Fluctuation Sizes:** The size of fluctuations in supply and demand are key drivers of EUE and price volatility. These parameters are estimated based on market data and are not known with perfect certainty. We test fluctuation sizes of ±25% relative to our base case assumptions.
- **True Net CONE:** Assuming it is accurately estimated, true Net CONE has very minimal impact on demand curve performance. We test Net CONE values ±25% relative to our base case assumptions to demonstrate that changes in the AESO's estimate of the Net CONE parameter would likely not have a substantial impact on the proposed demand curve.
- **Administrative Net CONE Estimation Error:** Administrative Net CONE under-estimates (*e.g.*, developing a Net CONE parameter of $140/kW-year when the actual cost of entry is $160/kW-year) and over-estimates both have a substantial impact on performance. We evaluate ±25% administrative error *in long-run equilibrium* to evaluate reliability and cost impacts. These results assume that the AESO never acts to correct its Net CONE estimation error in order to provide a bounding case for the impact of such estimation errors.
- **Offer Behaviour:** The Alberta market will incorporate a default offer cap of 80% of Net CONE for resources failing the market power screen. Stakeholders requested that we evaluate the performance of the market if all supply resources offer at or above this level. While we expect competitive pressures to cause most resources to offer below 80% of Net CONE, this sensitivity provides a bounding case for the impact of the offer behaviour.

In the remainder of this section, we describe the sensitivity cases in more detail, report the performance of the proposed demand curve under these sensitivity cases, and discuss implications.

A. Fluctuation Sizes Larger and Smaller than Expected

The size of fluctuations in supply and demand are key drivers of EUE and price volatility results in our simulation model. With larger fluctuations, there is a greater risk of the market falling short and failing to achieve the minimum resource adequacy objective. Larger fluctuations therefore drive higher frequency at the cap (*i.e.*, frequency at or below the minimum acceptable quantity) and higher average EUE.[33] In a similar way, smaller fluctuations result in a lower risk of the market falling short and greater reliability.

As discussed in Section III.D above, we estimated the size of fluctuations in supply and demand using available data from Alberta and informed by the experience of other markets. However, there is unavoidable uncertainty in our estimates. We therefore evaluated the performance of AESO's proposed demand curve if actual fluctuations were 25% larger or 25% smaller than our estimate. This corresponds to standard deviations ranging 314 MW to 523 MW on the supply side and 268 MW to 447 MW on the demand side. These results are summarized in Table 6.

Overall, the AESO's proposed demand curve performs well even if fluctuation sizes are materially different from our estimate. With 25% larger fluctuations, reliability achieved by the market degrades slightly, but still remains within a reasonable range. The market falls below the minimum acceptable quantity 8% of the time, rather than the 5% the AESO is intending to achieve and average EUE (without intervention) rises to about 560 MWh. This would mean a slightly greater dependence on rebalancing auctions and a higher rate of out-of-market intervention. With 25% smaller fluctuations, reliability increases with the frequency at the cap falling to 2% and average EUE falling to about 100 MWh.

---

33 The impact of larger fluctuation sizes on *average* EUE merits some additional explanation. Larger fluctuations result in the market clearing low quantities, corresponding to high EUE, more frequently. At the same time, larger fluctuations also result in the market clearing very *large* quantities, corresponding to *low* EUE, more frequently. However, due to the non-linear shape of the EUE vs. supply quantity curve, reliability deteriorates quickly when the market is short. When fluctuations are larger, the lower EUE outcomes do not offset the higher EUE outcomes and average EUE is overall larger.

Table 6
Larger and Smaller Fluctuation Sizes Sensitivities

	Price and Cost				Reliability			
Demand Curve	Average Price *($/kW-yr)*	Standard Deviation of Price *($/kW-yr)*	Frequency at Cap *(%)*	Average Cost *($mil/yr)*	Average EUE (Before Intervention) *(MWh)*	Average EUE (After Intervention) *(MWh)*	Average Cleared Quantity *(MW)*	Average Uncleared Supply *(MW)*
Simulated Performance								
Proposed Curve	$139	$53	5%	$1,665	266	118	12,042	247
25% Larger Fluctuations	$139	$60	8%	$1,662	564	158	12,034	270
25% Smaller Fluctuations	$139	$43	2%	$1,667	101	78	12,041	227
Percent Difference from the Proposed Curve								
25% Larger Fluctuations	0%	15%	68%	0%	112%	34%	0%	9%
25% Smaller Fluctuations	0%	-18%	-62%	0%	-62%	-34%	0%	-8%

B. True Net CONE Larger and Smaller than Expected

An accurate estimate of Net CONE is important in ensuring the demand curve achieves its design principles (as discussed in Section V.C below). However, as long as Net CONE is estimated accurately, the *specific level* of Net CONE is less important for the curve's performance. In Table 7, we show performance metrics for the AESO's proposed demand curve if Net CONE is accurately estimated, but 25% higher or lower than the value we have assumed in our modeling.

The most obvious impacts of higher and lower Net CONE values are on average prices, price volatility, and cost. If Net CONE is 25% higher than estimated, prices must be 25% higher on average, in order to attract and retain supply. Average cost and price volatility must also be higher. Similarly, these price and cost metrics are all lower if Net CONE is lower. However, these results have little impact on the design of the capacity market, since the true value of Net CONE is not a parameter that the AESO selects, but rather a reflection of the actual cost of developing new supply.

Results in Table 7 demonstrate that the AESO's proposed demand curve achieves the resource adequacy objective across a wide range of Net CONE values. The frequency at the cap varies between 4% and 6%, despite the value of Net CONE varying across a very wide range. This level of variation is likely within the margin for error of our analysis. The results in Table 7 also demonstrate that the AESO's proposed demand curve is reasonable even though the value of Net CONE assumed in the analysis we have conducted over the past year may not be exactly what the market will clear in the future.

Table 7
True Net CONE Larger/Smaller than Expected Sensitivities

	Price and Cost				Reliability			
Demand Curve	Average Price *($/kW-yr)*	Standard Deviation of Price *($/kW-yr)*	Frequency at Cap *(%)*	Average Cost *($mil/yr)*	Average EUE (Before Intervention) *(MWh)*	Average EUE (After Intervention) *(MWh)*	Average Cleared Quantity *(MW)*	Average Uncleared Supply *(MW)*
Simulated Performance								
Proposed Curve	$139	$53	5%	$1,665	266	118	12,042	247
Actual Net CONE 25% Larger	$174	$68	6%	$2,081	299	125	12,042	174
Actual Net CONE 25% Smaller	$104	$38	4%	$1,249	212	107	12,044	363
Percent Difference from the Proposed Curve								
Actual Net CONE 25% Larger	25%	29%	10%	25%	12%	6%	0%	-30%
Actual Net CONE 25% Smaller	-25%	-27%	-24%	-25%	-20%	-10%	0%	47%

C. Administrative Net CONE Over- and Under-Estimation

In the analyses presented up to this point, we assume that the administrative Net CONE estimate accurately represents the true Net CONE that developers need to earn in order to enter. However, there are inherent uncertainties in administrative estimates.

If the administrative estimate of Net CONE understates true Net CONE, the demand curve would be lower than needed to meet the minimum resource adequacy objective. Supply would still enter and set prices at the true Net CONE in the long term, but the cleared quantity and reliability would be below the requirement. Conversely, overstated Net CONE would attract excess supply as suppliers continue entering until average prices equal the true Net CONE. Customers would not have to pay higher prices in the long term, but they would have to buy a greater quantity that has diminishing value.

We evaluated the performance of the AESO's proposed demand curve if Net CONE is over-estimated by 25% or under-estimated by 25%.[34] Table 8 shows these results. With a 25% under-estimate, too little supply is attracted and retained to the market and reliability degrades materially. The frequency at the cap reaches 23% and average EUE rises to 1,546 MWh. With a 25% over-estimate, too much supply is attracted and reliability exceeds the minimum resource adequacy objective. Customer costs increase by 2% to about $1.7 billion per year.

34 Note that all three sets of results in the table assume the same *true* Net CONE value of $139/kW-year. In the 25% Net CONE Over-Estimate case, the demand curve is based on a Net CONE value of 1.25 × $139/kW-year = $174/kW-year. In the 25% Net CONE Under-Estimate case, the demand curve is based on a Net CONE value of 0.75 × $139/kW-year = $104/kW-year.

Table 8
Administrative Net CONE Over-/Under-Estimation Sensitivities

	Price and Cost				Reliability			
Demand Curve	Average Price *($/kW-yr)*	Standard Deviation of Price *($/kW-yr)*	Frequency at Cap *(%)*	Average Cost *($mil/yr)*	Average EUE (Before Intervention) *(MWh)*	Average EUE (After Intervention) *(MWh)*	Average Cleared Quantity *(MW)*	Average Uncleared Supply *(MW)*
Simulated Performance								
Proposed Curve	$139	$53	5%	$1,665	266	118	12,042	247
25% Net CONE Over-Estimate	$140	$61	1%	$1,702	72	48	12,278	259
25% Net CONE Under-Estimate	$139	$38	23%	$1,609	1,546	351	11,633	224
Percent Difference from the Proposed Curve								
25% Net CONE Over-Estimate	0%	15%	-72%	2%	-73%	-59%	2%	5%
25% Net CONE Under-Estimate	0%	-28%	358%	-3%	481%	198%	-3%	-9%

The poor reliability associated with the 25% Net CONE under-estimate sensitivity illustrates the possibility and impact of under-performance, but a possibility that does not necessarily need to be prevented by widening the demand curve or otherwise adjusting the capacity market to make the market even more robust. The sensitivity reflects performance if the AESO *persistently* over- or under-estimates Net CONE in the long run over many years, making no adjustment to its estimate based on market performance. If the AESO corrected its Net CONE estimate after a few years—such as during the periodic reviews—or if its estimation errors resulted in over-estimates in some years and under-estimates in other years, the impact on performance would be much smaller. The takeaway from this sensitivity is therefore not that the demand curve needs to be changed, but that the AESO should take care in estimating Net CONE and adjust its estimate if the market is not performing as intended.

D. Offer Convergence at the Default Offer Price Cap

Stakeholders requested that we evaluate demand curve performance under the assumption that all suppliers offered at or above the default offer threshold of 80% of Net CONE. Under this scenario, the supply curve begins at 80% of Net CONE rather than at $0. As Table 9 shows, the AESO's proposed demand curve performs well with this alternate supply curve shape. The frequency at the cap decreases to 3% and average EUE (before intervention) falls to 144 MWh. Since prices never fall below 80% of Net CONE, price volatility decreases by 29% to $37/kW-yr. While the demand curve performs well with an offer convergence at 80% of Net CONE, we do not think this is a particularly realistic scenario, as competitive pressures should prevent all resources form offering up to 80% of Net CONE if their costs are below this level.

Table 9
Offer Convergence at 80% of Net CONE Sensitivities

Demand Curve	Price and Cost				Reliability			
	Average Price *($/kW-yr)*	Standard Deviation of Price *($/kW-yr)*	Frequency at Cap *(%)*	Average Cost *($mil/yr)*	Average EUE (Before Intervention) *(MWh)*	Average EUE (After Intervention) *(MWh)*	Average Cleared Quantity *(MW)*	Average Uncleared Supply *(MW)*
Simulated Performance								
Proposed Curve	$139	$53	5%	$1,665	266	118	12,042	247
Convergence at 80% of Net CONE	$139	$37	3%	$1,667	144	77	12,025	418
Percent Difference from the Proposed Curve								
Convergence at 80% of Net CONE	0%	-29%	-50%	0%	-46%	-34%	0%	69%

Appendix: Summary of Analyses Presented to Stakeholders

All of the candidate demand curve and sensitivity analyses presented in this report were discussed with stakeholders at various points in the last several months, although we have made some adjustments to those prior analyses based on updated data, assumptions, and design proposals. The results and takeaways of the analyses remain the same as when presented to stakeholders. Table 10 lists the public materials that were shared with stakeholders regarding each demand curve and sensitivity analysis.

Table 10
Reference to Stakeholder Presentations of Demand Curve and Sensitivity Analyses in This Report

	Demand Curve [A]	Presentation [B]	Slide # [C]
Demand Curve Analyses			
[1]	Proposed (Less Convex) Curve	(14 Jun 2018)	Slides 31-32
[2]	More Convex Curve	(14 Jun 2018)	Slides 31-32
[3]	High Price Cap (1.9x Net CONE)	(29 Nov 2017)	Slide 4
[4]	Low Price Cap (1.5x Net CONE)	(29 Nov 2017)	Slide 4
[5]	Linear Curve	(1 Nov 2017)	Slide 5
Sensitivity Analyses			
[6]	20% Larger/Smaller Fluctuations	(1 Nov 2017)	Slide 8
[7]	True Net CONE Smaller/Larger than Expected	(29 Nov 2017)	Slide 8
[8]	25% Admin Net CONE Over-/Under-Estimate	(14 Jun 2018)	Slide 39
[9]	Offer convergence at default price cap	(1 Nov 2017)	Slide 12

Sources and Notes:

The November 2017 presentations showed analyses of demand curves developed using different reliability objective (100MWh EUE instead of 5% frequency at cap) and different fluctuation sizes; however the key takeaways and the basis for takeaways remain the same.

We had previously analyzed 50% larger/smaller fluctuations.

14 Jun 2018: AESO, *Demand Curve Shape, Technical (Demand Curve) Workshop #4*.

29 Nov 2017: Spees *et al.*, *Demand Curve Shape, Candidate Curves and Performance*.

1 Nov 2017: Spees *et al.*, *Demand Curve Shape, Responses to Stakeholder Questions and Comments*.

List of Acronyms

AESO	Alberta Electric System Operator
AUC	Alberta Utilities Commission
BRA	Base Residual Auction
CMD	Comprehensive Market Design
CONE	Cost of New Entry
CT	Combustion Turbine
E&AS	Energy & Ancillary Service
EUE	Expected Unserved Energy
FCA	Forward Capacity Market
FOM	Fixed Operation and Maintenance
ISO	Independent System Operator
ISO-NE	Independent System Operator of New England
kW	Kilowatt
LOLE	Loss of Load Expectation
MISO	Midcontinent Independent System Operator
MRI	Marginal Reliability Impact
MW	Megawatt
MWh	Megawatt Hour
NYC	New York City
NYISO	New York Independent System Operator
PJM	PJM Interconnection
VRR	Variable Resource Requirement

BOSTON
NEW YORK
SAN FRANCISCO

WASHINGTON
TORONTO
LONDON

MADRID
ROME
SYDNEY

THE Brattle GROUP