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THE ROLE OF STORAGE IN ALBERTA'S ELECTRICITY MARKET: SUMMARY OF A SCHOOL OF PUBLIC POLICY ROUNDTABLE EVENT*

Blake Shaffer[1]

SUMMARY

Alberta's electricity market is in transition. Coal, the long-dominant source of supply, is set to retire or be phased out by 2030. A combination of climate policies and rapidly declining renewable energy costs is changing Alberta's electricity generation mix to one that will contain a larger share of renewable energy.

A less emission-intensive grid will be the result, yet one that has a larger share of intermittent generation. To convert this raw energy into the on-demand power consumers want, the market has several options:

1. Supply side: Ensure sufficient peaking capacity is available
2. Demand side: Encourage responsive demand
3. Regional integration: Expand capacity to trade electricity with regional neighbours
4. Develop storage

This menu of options is not an either/or choice. In reality, a combination of supply- and demand-side efforts will likely be needed. Greater transmission interconnections – notably with British Columbia, whose flexible reservoir hydro resources are an excellent complement to Alberta's superior wind resources – are

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1 I wish to thank co-organizer Jennifer Winter, as well as Michelle Sadden for superb event co-ordination. I also acknowledge Jordan Neff and Mokhtar Tabari, who took detailed notes of the event.

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also an option worth exploring. However, it brings the added complexity of interprovincial negotiations amid very different market structures.

Storage is often seen as the holy grail in terms of solutions to the issue of intermittency. Transferring abundant clean energy during the times when nature is providing it to the times when consumers are demanding power offers an elegant and direct way to transfer raw energy to on-demand power.

In consideration of this possibility, the School of Public Policy convened a roundtable on March 18, 2019, bringing together experts in electricity markets and storage, to answer the following questions:

- What role will storage play in Alberta?
- How do the costs of storage compare to alternatives for managing intermittency?
- What, if any, regulatory impediments or market failures exist that may prevent storage from being developed in Alberta?
- What policy next steps are needed?

The event brought together industry representatives, regulators, grid operators and academics. The purpose of the roundtable was to facilitate open discussion among those with in-depth knowledge from multiple perspectives to discuss the role of storage from policy, engineering and system design perspectives. This paper provides a concise summary of the roundtable event, including the keynote address, all three panel discussions and key themes.

The event began with a keynote address by James Bushnell, an academic with over 20 years' experience in electricity markets. Bushnell provided lessons from California, where renewable growth has exceeded state targets, bringing considerable impetus for storage-based solutions to manage both intermittency as well as steep morning and afternoon ramps that coincide with sunrise and sunset.

The remainder of the event consisted of three panels, each discussing a different aspect of the role of storage. Panel 1 considered the bigger picture of where storage fits into the broader issue of decarbonization and climate policy. Panellists considered whether there was in fact a necessity for storage solutions and discussed alternatives.

Panel 2 went into depth on the engineering aspects of different storage solutions. Panellists discussed different storage technology options, highlighting the pros and cons of each. Specific attention was paid to the challenges faced in Alberta, with its strong seasonal swings in renewable generation and cold northern climate.

Panel 3 considered the detailed policy landscape, and any potential regulatory impediments to the efficient deployment of storage in Alberta. This panel focused on the role wholesale electricity market design plays in affected storage development and investment.

Overall, several key themes emerged from the event:

First, there was consensus that storage provides a valuable service in its ability to absorb energy in periods of abundance (i.e., when the wind is blowing or the sun is shining) while discharging during periods of scarcity. It was also noted that storage can play an important role in very short-term ancillary services for the electric grid to maintain reliability.

Second, despite the above-mentioned benefits, the general view of the participants was that Alberta's current renewables targets (30 per cent of generation by 2030) would be a low enough level to be manageable within Alberta's grid without the explicit need for new storage resources. Nevertheless, there was considerable interest in pursuing more storage research, in particular into compressed air energy storage (CAES),[2] given Alberta's ideal geology for cavern construction throughout much of the province and CAES's potential for longer duration discharge.

Third, alternatives to storage were discussed, including:

- Greater potential for automated demand response to shift flexible demand from periods of scarcity to times of abundance;
- Potential for increased interconnections across the western provinces to better integrate Alberta's strong wind and solar resources with B.C.'s and Manitoba's flexible hydro capacity; and
- Maintaining a fleet of natural gas power capacity that can operate infrequently but during critical periods of supply scarcity.

Fourth, despite the lack of immediate need for storage in Alberta, participants broadly agreed that consideration of how storage fits into the electricity market in Alberta needs to be incorporated into ongoing market design reforms.[3] It was noted that given the decarbonization and market transition underway in Alberta's electricity market, policy-makers and regulators need to take a longer and broader view of market design reform. They must ensure they design a market that will deliver the low-cost, reliable and low-carbon electricity system Albertans need for the future. If the event could be summed up in one statement, it is that we should design policy to properly value and compensate for the attributes we want, rather than to deliver any specific technology outcome.

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[2] CAES is a family of technologies that store energy by compressing ambient air to higher pressure and regenerating electricity when desired by expanding the air back to atmospheric pressure. CAES uses conventional equipment, is suitable for multi-day energy storage with a similar asset life and electrical operating characteristics to the thermal generation that is currently on the grid.

[3] At the time of the event, Alberta was about to transition from an energy-only wholesale generation market to one that includes a forward capacity market. As of July 2019, the capacity market has been rescinded. Additional related policies in flux include coal phase-out, renewables targets, renewable procurement auctions, and details of carbon pricing as applied to the electricity sector.

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RÔLE DU STOCKAGE D'ÉNERGIE SUR LE MARCHÉ DE L'ÉLECTRICITÉ EN ALBERTA : RÉSUMÉ D'UNE TABLE RONDE ORGANISÉE PAR L'ÉCOLE DE POLITIQUES PUBLIQUES*

Blake Shaffer[1]

RÉSUMÉ

Le marché de l'électricité de l'Alberta est en transition. Le charbon, principale source d'approvisionnement depuis longtemps, sera sans doute remplacé d'ici 2030. Un ensemble de politiques climatiques ainsi que la baisse rapide du coût des énergies renouvelables viennent transformer les modes de production d'électricité en Alberta, qui comprendront au fil du temps une plus grande part d'énergie renouvelable.

Il en résultera un réseau moins émetteur d'émissions, mais qui connaîtra de plus grandes fluctuations de production. Pour convertir cette énergie brute en énergie disponible en fonction de la demande des consommateurs, le marché dispose de plusieurs possibilités :

1. Du côté de l'alimentation : s'assurer qu'une capacité de pointe suffisante est disponible
2. Du côté de la demande : encourager la demande réactive
3. Intégration régionale : accroître la capacité de faire commerce de l'électricité avec les voisins régionaux
4. Développer le stockage

Il ne s'agit pas une liste de choix qui s'excluent les uns les autres, car il faudra probablement une combinaison d'efforts du côté de l'offre et du côté de la demande. Il convient aussi d'explorer l'idée de meilleures interconnexions de transport, notamment avec la Colombie-Britannique, dont les ressources

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1 Je tiens à remercier la coorganisatrice Jennifer Winter ainsi que Michelle Sadden pour la coordination de l'événement. Je remercie également Jordan Neff et Mokhtar Tabari, qui ont pris des notes détaillées de l'événement.

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hydroélectriques flexibles constituent un excellent complément aux ressources éoliennes supérieures de l'Alberta. Cependant, cela apporte la complexité des négociations interprovinciales au sein de structures de marché très différentes.

Le stockage est souvent considéré comme le Saint Graal des solutions au problème des fluctuations. En effet, de grandes quantités d'énergie propre produite au moment où la nature est généreuse peuvent être stockées puis redistribuées en fonction de la demande des consommateurs. C'est là une façon élégante et directe de transformer une énergie brute en énergie sur demande.

Dans cette optique, l'École des politiques publiques a organisé, le 18 mars 2019, une table ronde où se sont réunis des experts du marché et du stockage de l'électricité, pour répondre aux questions suivantes :

- Quel rôle le stockage jouera-t-il en Alberta?
- Comment les coûts de stockage se comparent-ils aux autres méthodes de gestion de l'intermittence?
- Quels obstacles réglementaires ou quelles défaillances du marché pourraient empêcher le développement du stockage en Alberta?
- Quelles sont les prochaines étapes politiques?

L'événement réunissait des représentants de l'industrie et d'organismes de réglementation ainsi que des exploitants de réseau et des universitaires. Le but de la table ronde était de favoriser la discussion entre personnes d'horizons variés qui possèdent des connaissances approfondies sur le sujet. Le rôle du stockage y a été abordé sous l'angle des politiques, de l'ingénierie et de la conception de systèmes. Ce document fournit un résumé concis de la table ronde, notamment le discours principal, les trois tables rondes et les thèmes clés.

L'événement a débuté par le discours principal de James Bushnell, un universitaire qui possède plus de 20 ans d'expérience sur le marché de l'électricité. M. Bushnell a présenté des leçons tirée de la Californie, où la croissance de l'énergie renouvelable a dépassé les objectifs de l'État, ce qui a donné un fort élan aux solutions de stockage pour gérer les fluctuations ainsi que les fortes demandes du matin et de l'après-midi qui coïncident avec le lever et le coucher du soleil.

Le reste de l'événement se composait de trois panels, chacun abordant un aspect du rôle du stockage. Le premier panel a examiné le tableau d'ensemble de la place du stockage dans le contexte de la décarbonisation et des politiques climatiques. Les panélistes ont d'abord examiné s'il y avait un besoin de solutions de stockage, puis ils ont envisagé les diverses possibilités.

Le deuxième panel a approfondi les aspects techniques des solutions de stockage. Les panélistes ont discuté des diverses technologies de stockage, soulignant les avantages et inconvénients de chacune. Une attention particulière a été accordée aux défis auxquels fait face l'Alberta, avec ses fortes fluctuations saisonnières de production d'énergie renouvelable et son climat nordique froid.

Le troisième panel s'est penché sur le paysage politique et sur les obstacles réglementaires potentiels au développement efficace du stockage en Alberta. Ce panel s'est concentré sur le rôle que joue le marché de gros de l'électricité dans le développement du stockage et dans les investissements connexes.

Plusieurs thèmes clés se sont dégagés :

Premièrement, il y a consensus sur le fait que le stockage fournit un service précieux par sa capacité d'absorber l'énergie en période d'abondance (c'est-à-dire lorsque le vent souffle ou que le soleil brille) pour la distribuer pendant les périodes de pénurie. On a également noté que le stockage peut jouer un rôle important dans les services auxiliaires à très court terme du réseau électrique afin d'en maintenir la fiabilité.

Deuxièmement, malgré les avantages susmentionnés, les participants ont convenu que les objectifs actuels de l'Alberta en matière d'énergies renouvelables (30 % de la production d'ici 2030) sont à un niveau suffisamment bas pour être gérable dans le réseau de l'Alberta, sans besoin explicite de nouvelles ressources de stockage. Néanmoins, il y a un grand intérêt à poursuivre les recherche sur le stockage, en particulier sous la forme de stockage par air comprimé (SPAC), étant donné la géologie idéale de l'Alberta pour la construction de galeries sous-terraines dans une grande partie de la province et le potentiel du SPAC pour un déchargement sur une plus longue durée.[2]

Troisièmement, on s'est penché sur des alternatives au stockage, notamment les suivantes :

- Un plus grand potentiel de réponse automatisée à la demande pour faire passer la demande flexible des périodes de pénurie aux périodes d'abondance
- Possibilité d'augmenter les interconnexions entre les provinces de l'Ouest afin de mieux intégrer les puissantes ressources éoliennes et solaires de l'Alberta à la capacité hydroélectrique flexible de la Colombie-Britannique et du Manitoba
- Maintenir une flotte de capacité de production d'électricité au gaz naturel qui peut fonctionner sporadiquement, mais surtout pendant les périodes critiques de pénurie d'approvisionnement.

Quatrièmement, malgré l'absence de besoin immédiat en matière de stockage, les participants ont convenu dans l'ensemble que la façon dont le stockage s'intègre au marché de l'électricité en Alberta doit être prise en compte dans les réformes en cours concernant la conception du marché.[3] On a noté qu'en raison de la décarbonisation et de la transition en cours sur le marché de l'électricité en l'Alberta, les décideurs et les organismes de réglementation doivent avoir une vision plus vaste de la réforme du marché. Ils doivent prévoir un marché qui fournira un système électrique à faible coût, fiable et à faible émission de carbone, ce qui est essentiel pour l'avenir des Albertains. Si l'événement pouvait être résumé en un seul énoncé, ça serait que nous devons concevoir les politiques adéquates pour mettre en place les caractéristiques que nous souhaitons, plutôt que pour fournir un résultat technologique spécifique.

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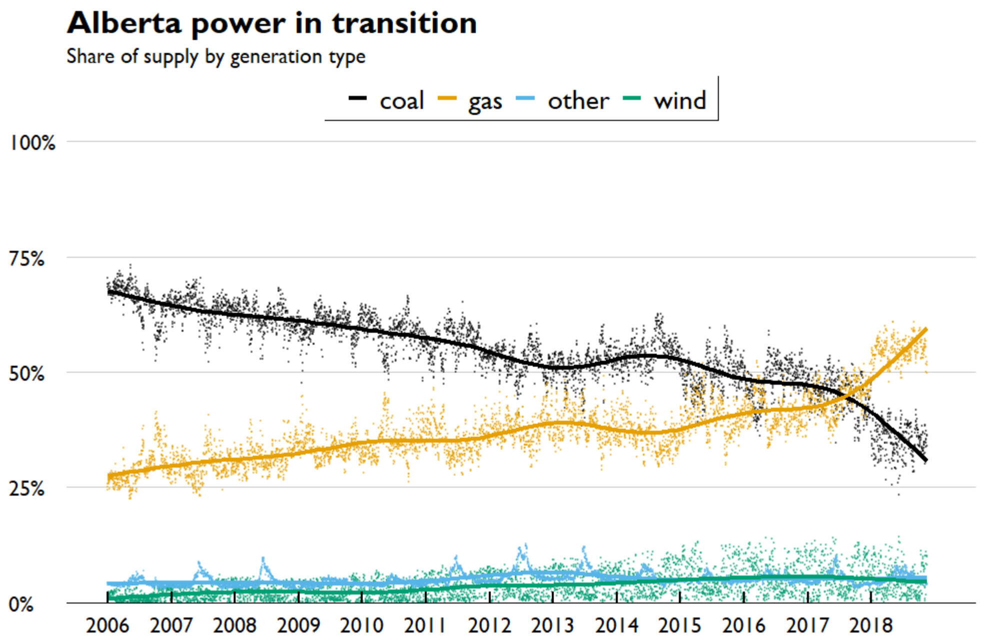
[2] Le SPAC est un ensemble de technologies qui stockent de l'énergie en comprimant l'air ambiant à une pression plus élevée et en régénérant l'électricité au moment souhaité en ramenant cet air à la pression atmosphérique. Le SPAC fait appel à des équipements conventionnels, convient au stockage d'énergie pendant plusieurs jours avec une durée de vie des actifs et des caractéristiques de fonctionnement électrique similaires à ceux de la production thermique actuellement sur le réseau.

[3] Au moment de l'événement, l'Alberta était sur le point de passer d'un marché de production de gros à un marché axé sur la capacité à venir. Depuis juillet 2019, ce marché axé sur la capacité a été annulé. D'autres politiques connexes en évolution comprennent l'élimination progressive du charbon, les objectifs en matière d'énergies renouvelables, les enchères d'achat d'énergies renouvelables et les spécificités de la tarification du carbone appliquées au secteur de l'électricité.

CONTEXT: ALBERTA'S POWER MARKET IN TRANSITION

Historically, coal has made up most of Alberta's power supply. This share, however, is on the decline. A combination of policies encouraging lower greenhouse gas emissions, aging coal plants, cheap natural gas and rapidly lowering renewable costs is changing the supply mix in Alberta (Figure 1).

FIGURE 1 ALBERTA'S CHANGING POWER SUPPLY

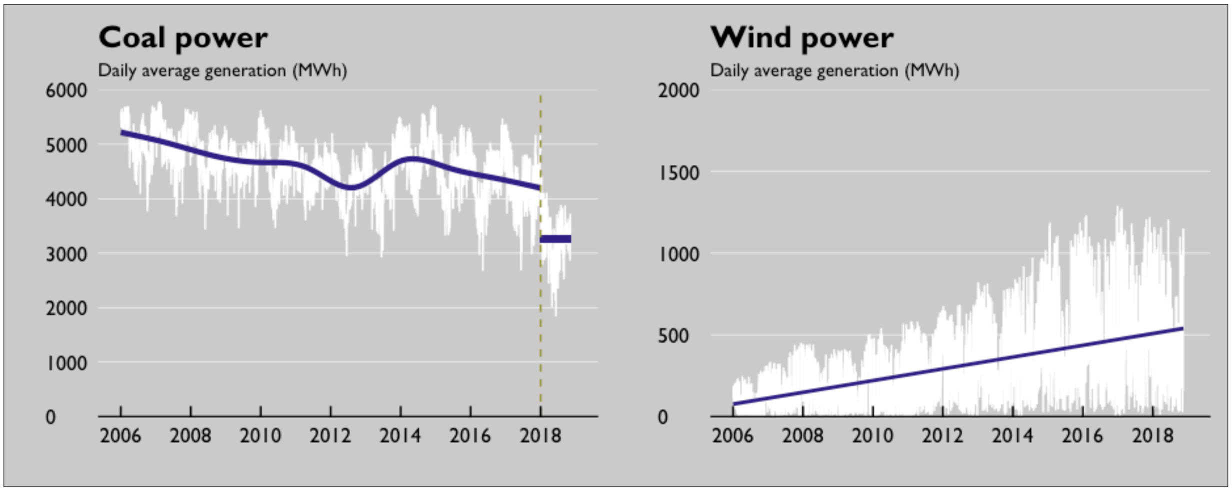


Source: AESO Metered Volumes report (accessed via NRGstream); share calculations by author.

In 2018, coincident with the introduction of a new large emitter program in Alberta – the Carbon Competitiveness Incentive Regulation (CCIR) – coal generation fell by roughly 1,000 average MW (Figure 2). The reasons for this fall are twofold. First, several coal units chose early retirement or temporary mothballing at the start of 2018. This was partly due to a more stringent carbon pricing policy (as compared to the previous Specified Gas Emitters Regulation), and partly due to low market prices for electricity. Second, the higher carbon costs raised the marginal cost of generating from coal, and thus remaining coal plants are being run less frequently.

At the same time, wind power is on the rise, though not yet to the same degree. From roughly 50 MW 10 years ago, wind generation has increased tenfold, now adding roughly 500 MW of average generation (current installed capacity is over 1400 MW). Of course, the scale of wind generation in the province does not yet compete with the level of coal generation; however, at the time of the roundtable event, the province had legislated a target of 30 per cent of all generation to be from wind power by 2030. Subsequent to the roundtable event, the new UCP government rescinded the 30% renewables target, however, continued renewable development is expected in the province despite the lack of legislated target given renewables' rapidly declining cost.

FIGURE 2 CHANGING FORTUNES: COAL AND WIND POWER (NOTE: DIFFERENT Y-AXIS SCALES)



Source: AESO Metered Volumes report (accessed via NRGSTREAM).

THE KEYNOTE ADDRESS

James Bushnell, co-director of the energy economics program at the University of California-Davis, delivered the keynote address. Bushnell's talk highlighted four key trends driving storage in California:

1. Wholesale price impacts
2. Regulatory arbitrage
3. Potential for storage as a rate-based asset
4. 100 per cent renewable energy goals

Bushnell immediately drew the connection between more renewables and wholesale price impacts. Citing recent research, he noted that the large growth in solar power is increasing the range of prices within a day by depressing prices to near zero (or at times negative) prices during the middle of the day. It is simultaneously increasing prices during the morning and evening ramps when demand is strong but solar generation is limited (Bushnell and Novan 2019). These larger price swings create an environment conducive for storage.

Storage can increase the ability of electricity demand to respond to swings in intermittent demand, improving the electricity system's overall efficiency. However, storage can have minimal (or negative) system cost savings when it is simply used to shift infrastructure costs from one set of customers to another, rather than reduce the need for new or upgraded infrastructure. Regulatory arbitrage and those seeking to "cut the cord" to avoid fixed charges can create balkanized networks with adverse efficiency and distributional implications. This issue highlighted the potential tension between storage developers motivated by their private economics, who are at odds with actions that are welfare enhancing for society.

Bushnell raised the issue of whether storage, which can provide similar services as transmission and distribution assets, should be eligible for rate-based treatment.[4] This is a complex area of discussion, as storage operates in many areas of the electricity system, and there will inevitably be interactions between storage operations and both rate-based and competitive assets. On the one hand, there is an argument for including storage in utility rate bases to level the playing field and allowing it to delay or obviate the need for alternative, more costly, rate-based assets. On the other hand, rate-basing storage poses a problem when it is competing directly in the wholesale energy markets with market-based assets, as its operations will depress price spreads, harming exposed market participants while itself remaining immune via rate-based treatment.

Bushnell noted California needs more flexibility in its system in large part due to the rapid growth in renewables, but also due to the natural gas fleet's aging infrastructure. These older plants are unable to provide the type of flexibility California needs, and from an owner's perspective are unable to recoup the costs of operation and sustaining capital. As a result, the California Independent System Operator (CAISO) has relied on out-of-market contracts to keep some gas plants in service for reliability.

To better respond to the need for more flexibility, especially around the morning and evening ramps, which have been exacerbated by the growing share of solar generation, California is adding more products that price needed attributes in its market. These include flexibility products that reflect the ability of generators to respond within specific time parameters, and moving energy settlements to a finer five-minute market.

On the retail side, Bushnell noted that as rates change, so too do the private benefits of storage. Dynamic (time-varying) pricing could better encourage the efficient use of storage by reflecting the true location-specific time-varying system marginal cost of supply to the demand side. Currently, California has high variable rates and very low fixed rates. This encourages a lot of distributed energy (such as rooftop solar) without actually reducing system costs, especially at the distribution level. This results in creating incentives to shift sunk costs to those unable or unwilling to install distributed generation. This has adverse distributional impacts as it tends to shift system costs onto poorer households (which is offset somewhat in California by a low-income electricity subsidy program known as CARE).

Looking to the future, Bushnell questioned the cost-effectiveness of achieving a 100 per cent renewable target, noting the high cost to the last 10 per cent of carbon-free energy. It may be more cost effective, even with a high carbon price, to retain some natural gas capacity running infrequently to manage occasional scarcity events.

PANEL 1: STORAGE AS A SOLUTION

The ability to integrate larger shares of intermittent renewables may be new to Alberta, but it is not a novel problem. Denmark has demonstrated the ability to integrate over 50 per cent of wind energy. California now reaches upwards of 40 per cent renewable energy at

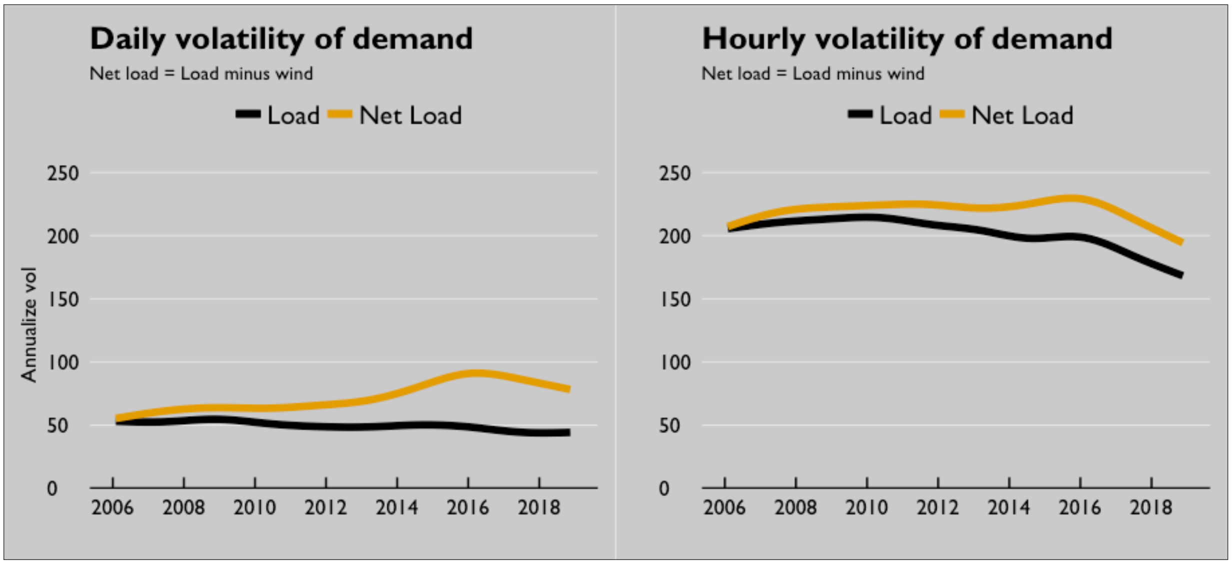
[4] Under rate-based treatment, utilities must justify their costs to a regulator, and they are then allowed to set a service rate to recoup their declared costs plus a prescribed rate of return. This differs from market-based treatment where utilities take the risk of recouping costs and earning a rate of return via market prices.

certain times of the year. Neither faces reliability concerns nor large cost shocks as a result, for the most part.

But both these jurisdictions have advantages over Alberta in terms of integrating intermittency; namely, large interconnections as a share of their load, and access to flexible resources, such as hydroelectricity. Alberta, relatively speaking, is an electric island, with interconnections totalling little more than 1,000 MW, or roughly 10 per cent of peak load. California, by comparison, counts on nearly a third of its supply on the interties, and is capable of exporting during periods of excess solar as well.

In the absence of increased interconnections and large hydroelectric reservoirs, storage may play a larger role in Alberta. A look at daily volatility suggests there is a need for resources that can balance the variability of demand. Figure 3 compares the volatility of demand (load) against the same measure for net demand (load minus wind generation). The graph demonstrates several features. First, hourly volatility of demand is higher than daily volatility. This is due to large intra-day differences in demand. Second, the increase in wind generation in the last 10 years can be seen clearly by an expanding gap between load and net load, suggesting that wind intermittency is more volatile than extant demand. Third, and interestingly, the gap between load and net load is larger for daily volatility than hourly. This suggests as wind is added, the larger challenge is in dealing with day-to-day variability in net load, rather than hourly intermittency.

FIGURE 3 VOLATILITY OF NET DEMAND IS INCREASING WITH MORE WIND ON THE SYSTEM



Source: AESO Metered Volumes report (accessed via NRGSTREAM); calculations by author.

Looking further into the future, new research by Rivers and Shaffer (2019) considers how rising temperatures will affect both the level and shape of electricity demand. They find that the intra-day minimum to maximum range expands, leading to larger ramping requirements. This finding, coming from the demand side, exacerbates known issues coming from the supply side; hence they describe this as “stretching the duck’s neck”. By mid-century, the intra-day range will double across some provinces in Canada.

The first panel of the day considered the role storage can play in facilitating the decarbonization of Alberta's electricity grid. While everyone acknowledged that storage provides services that assist in the challenges posed by renewable variability, the general question was whether storage would actually be needed in Alberta. "We may not need storage, but storage does bring benefits," was a commonly cited line.

A consensus emerged that rather than specifically targeting storage technologies, the focus should be on the attributes the system needs. These attributes include the ability to balance supply and demand at every instant, the ability to respond to sudden events quickly and accurately, and ways to supply electricity when the renewable supply is scarce. Further, due to extreme weather events, such as the cold spell in February 2019 when wind generation failed to materialize for multiple days, it was noted that Alberta requires longer duration storage, with the ability to shift supply and demand over many days and potentially across seasons.

The question of how much storage might be needed in Alberta focused on the potential for alternatives in providing the attributes noted above. In Alberta, the largest competitor to storage was deemed to be natural gas. Given the extremely low cost of Alberta natural gas, the panel viewed it as likely to remain a critical part of the province's power grid long after it has been phased out in other jurisdictions with higher delivered natural gas costs. A counter-argument was raised that storage provides more certainty in energy prices by better managing peaks, whereas a reliance on natural gas peaking supply comes with uncertainty over potential volatility of underlying natural gas prices.

This competition with natural gas is reflected in the profitability of storage providers. While storage costs have declined in recent years, the coincident decline in natural gas prices has lowered revenue opportunities in power markets at the same time. However, it was noted that storage can participate beyond simply energy markets, as it can provide rapid and accurate frequency response and other valuable ancillary services.

Other alternatives to storage discussed included:

- Demand response
- Electric vehicles (both timing of charging and potential for discharge)
- Building more transmission lines to connect with hydroelectric provinces
- Overbuilding renewables and allowing for more curtailment

Questions covered a wide range of topics and challenges to storage development:

The need for longer duration storage in Alberta

Given the aforementioned early 2019 cold weather event in Alberta, much of the discussion focused on the ability of storage to provide a longer duration supply. This led to a discussion noting that installing the right type of storage asset is important. Also discussed was the potential for compressed air energy storage in Alberta, which can discharge for over 60 hours. Increasing transmission connection with B.C. can also provide long-duration storage, opening access to existing multi-year hydro reservoirs.

At what level of renewable penetration does storage become more important?

In academic modelling, one panellist noted that, as a rule of thumb, somewhere around 50 per cent renewable share it becomes more challenging to manage variable renewable energy due to the magnitude of swings in supply. A recent paper finds that at renewable penetrations above 90 per cent, the total system costs to integrate renewables rise significantly (Sepulveda et al. 2018). In the U.S.'s and Germany's experience, with most penetration levels below 30 per cent there has not been a pressing need for storage (yet). The panel generally agreed that Alberta's planned 30 per cent renewable generation target by 2030 did not pose a critical need for storage.

The interaction of regulated and unregulated assets in similar markets

A concern was raised that since storage provides similar attributes to transmission and distribution assets (in the case of storage, shifting power in time rather than space), it may not be on a level competitive playing field with those assets that fall under rate-based regulation. However, moving to allow rate-basing of storage assets then risks unfairly affecting non-regulated generation assets, if additional storage capacity depresses wholesale prices while rate-based storage remains immune from the lower prices. This remains a complex challenge, as storage falls somewhere in between the regulated and non-regulated pieces of Alberta's electricity system.

Is Alberta pricing flexibility properly?

The need for storage should ultimately be dictated by prices that reflect alternating periods of abundant generation (low prices) and scarcity events (extremely high prices). A lengthy discussion ensued as to whether Alberta's current and planned electricity market adequately allows prices to reflect these needs. The limitation of the current energy-only market in Alberta is that the price is both floored ($0 per MWh) and capped ($1,000 per MWh), despite the fact the value of lost load (and thus willingness to pay) is orders of magnitude higher. Under the proposed capacity market,[5] it is unclear whether flexibility will be properly compensated, or if the new market will simply promote an abundance of potentially unnecessary but less flexible capacity.

Incorporating flexibility classes into the capacity market was discussed as one potential solution. This would involve procuring subsets of capacity products based on their ability to respond to dispatch signals at varying levels of speed and accuracy. This would ensure that more flexible resources are better recognized for what they can provide.

Panellists also discussed the benefits of shortening the current 60-minute settlement period to have payments based on shorter (one-minute) dispatches. Shortening the settlement period would better reflect the ability of generators to quickly respond to system operator signals and properly value short-term scarcity periods.

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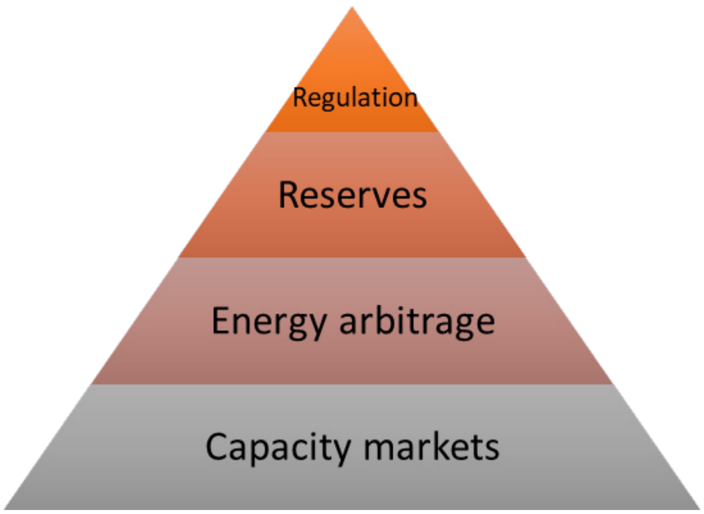
[5] At the time of the roundtable event, Alberta was in the final stages of implementing a new capacity market for the wholesale electricity market, to compensate generators for the ability to generate and ensure sufficient system reliability. As of July 2019, the new government had rescinded the capacity market.

PANEL 2: STORAGE COSTS AND TECHNOLOGY

Storage derives value from many components of the electricity market. The ability to produce on-demand power can replace capacity needs, with value collected in a capacity market (or via scarcity pricing in an energy-only market). The ability to shift energy from low-price periods of abundant renewables (or low load) to high-price periods can be captured via temporal arbitrage in the energy market. Storage can also provide ancillary services, such as reserves and frequency regulation that provide the very short-term needs to maintain a reliable grid (see Figure 4).

FIGURE 4 VALUE PYRAMID FOR STORAGE



In terms of broad categories, storage facilities can be classified based on the timespan over which they can store. Thus lithium-ion batteries would fall into the category of fast-acting short duration, while hydro-pumped storage would fall into the category of slower acting long-duration storage.

Short-duration storage provides value to deal with hour-to-hour (and in fact minute-to-minute) variability. Remuneration can come from energy markets, but also ancillary reserve markets, which explicitly value the fast-acting capability of quick response resources. However, ancillary service markets are notoriously thin, in that the introduction of new supply quickly depresses prices (see, for example, the effect of the Tesla 100 MW battery in South Australia). Thus while storage provides excellent value in managing short-term variability, this opportunity's market size is small.

Long-duration storage deals with multi-day seasonal variability. The cost to cover such timeframes with battery technology is seen as too high, given the large installed capacity required and relatively low cycling factor. Longer duration storage tends toward reservoir or pumped-hydro storage.

Determining appropriate solutions to deal with both short- and long-run variability, and considering their costs and benefits, was Panel 2's focus. The various technologies were classified according to metrics, including power duration, useful life, and operation and maintenance expenses.

The relative pros and cons of each technology are summarized in Table 1, and rough estimates of costs for varying levels of storage duration are provided in Table 2.

TABLE 1 PROS AND CONS OF DIFFERENT STORAGE TECHNOLOGIES

Technology	Pros	Cons
Pumped hydro	• Longer duration • Long useful life (20+ years) • Good efficiency (~85%)	• Location-limited
Lithium-ion batteries	• Energy dense • Future costs falling towards material costs • Current research: reducing balance of cell components and using low-cost materials to reduce Li-ion costs	• Short duration • Energy and power are coupled (can't benefit from scaling up storage capacity while keeping power-related costs fixed)
Flow batteries	• Longer duration than Li-ion	• Issues with membrane replacement • Lower efficiency than other electrochemical options (~60-70% efficient)
Compressed air energy storage	• Longer duration	• Lower efficiency (42%) with gas turbine • Location-limited (need naturally occurring caverns for low-cost storage)
Thermal storage	• Longer duration than Li-ion	• Lower efficiency

TABLE 2 COST ESTIMATES FOR DIFFERENT STORAGE TECHNOLOGIES

Technology	Efficiency	O+M Costs	Installed Costs	4-hour System	8-hour System	24-hour System
Pumped Hydro	85%	1-2.5%	$1000 – 2500/kW	$250-625/kWh	$125-315/kWh	$40-$100/kWh
Li-ion (today)	81%+	1%	$200/kWh $250-$500/kW	$260-$325/kWh	$230-$260/kWh	$210-$220/kWh
Flow Batteries	60-70%	2%	$30-$80/kWh $250-350/kW	$90-$170/kWh	$60-120/kWh	$40-$100/kWh
Compressed Air	42% (gas turbine)	1-2%	$1000-$1500/kW	$250-$375/kWh	$125-$190/kWh	$40-$60/kWh
Thermal	33%	2%	$1250-$1500/kW $20-$30/kWh	$330-$400/kWh	$180-$220/kWh	$70-90/kWh

A discussion ensued regarding the growing technical and engineering challenges of today's electricity systems that are raising the prospects for more storage on the grid. These challenges were broadly classified into three categories:

1. Infrastructure challenges

- Supply shortages
- Stressed transmission system
- Constrained distribution system
- *Dealt with using generation, transmission and distribution expansion*

2. Conventional flexibility challenges

- Demand variability
- Power plant outages
- Grid outages
- *Dealt with using reserves, energy trading and curtailments (storage is possible, but unlikely to be needed)*

3. Non-conventional flexibility challenges

- Oversupply of renewable energy
- Variability of renewable energy
- *Dealt with as above plus storage*

While storage can play a role in meeting all of these challenges, it was noted that the impetus for its potential need is largely coming from the increased share of renewables (challenge #3) in today's electric grids, not simply in Alberta, but in most systems around the world where renewable shares are rising.

Discussion and questions from roundtable participants included the value of specific location decisions, the potential value chain for storage, and challenges to investment:

What are the co-location benefits of energy storage with renewable generation sites?

In some cases, panellists saw the benefits of co-location in terms of savings on transmission and distribution upgrade costs. It was also noted that co-location has the potential to allow load to go "behind-the-fence" (i.e., to decouple from the electricity grid in an effort to save on transmission and distribution costs by serving their own demand). In this case, the savings are largely private in the form of avoided fixed costs and do not necessarily improve the system's overall efficiency.

What are the components of the value chain from which storage stands to benefit?

In terms of potential uses for storage, several areas of the value chain were identified:

1. Avoidance of transmission and distribution infrastructure costs (rate-based)
2. System operations and supply adequacy (typically non-regulated energy space)
3. Enabling emissions reductions through increased renewables penetration
4. Real options value

Panellists noted that providing fair and proper compensation for the services that storage can provide is a critical piece of market design reform. Participants pointed to recent Federal Energy Regulatory Commission (FERC) orders in the U.S. that require power markets to provide compensation based on performance and accuracy, which better reflects storage assets' value.

Storage investment as a "hold-up problem"?

Last, panellists noted that investment in storage presents as a classic hold-up problem in that once large capital is sunk, storage owners lose significant bargaining power. Further, storage deployment and utilization can have a large effect of shrinking the very price spreads that support their economic rationale. For both reasons, there may be a compelling case for vertical integration of storage (as is done with transmission and distribution assets) or long-term contracts.

PANEL 3: STORAGE IN ALBERTA: REGULATORY IMPEDIMENTS AND MARKET FAILURES

This panel began with a timely summary of the recent AESO paper assessing the need for dispatchable renewables and storage.[6] In short, the report did not find that there was an immediate need for storage even in the 30-per-cent-renewables-by-2030 scenario. There was, however, a recognition that the regulation and market treatment of storage, in some situations treated as load (demand) and other situations as supply, required some tariff reform.

The panellists took a big-picture view of these reforms by asking: "How would we design Alberta's electricity market rules and regulations to handle storage if we were starting from scratch?" What would Alberta's market design and regulatory environment look like in that case? The answer reflected a theme of the event: a focus on attributes, rather than specific technologies. The speed and accuracy with which power plants respond to dispatch signals would be recognized, not simply the quantum of energy and capacity. As a useful example, one panellist noted that current markets have set requirements for physical inertia to maintain grid stability during losses of supply as well as sudden

[6] The AESO report can be found here: https://www.aeso.ca/assets/Uploads/AESO-Dispatchable-Renewables-Storage-Report-May2018.pdf

changes in demand.[7] However, the need for inertia may now be questionable given the advent of intra-second communication and responsive-power electronics technology. Virtual inertia can deliver all the necessary attributes of physical inertia at lower cost in a renewables-heavy system. Tariffs should be modernized to reflect current technology that allows for desired attributes (e.g., reliability) to be met in the most cost-effective manner, including via newer technologies.

The point was also made how path dependency applies to tariff design. Panellists agreed that if policy-makers and regulators continue to simply think about the next step rather than 10 steps down the road, we may go down the wrong path for the long run. Hence, it is imperative to take a longer view of future electricity system needs in current market design.

In terms of specific storage needs, there were no clear technology winners. Most panellists viewed a portfolio approach of solutions as the best way to integrate a larger share of renewables at low cost. This includes storage solutions, as well as natural gas capacity in the medium term and potentially greater transmission interconnection with other regions in the longer term. In terms of market design, most panellists favoured an energy-only market to provide clear price signals for the need, if any, for storage or other solutions. It was recognized that this likely involved modifications to Alberta's existing energy-only market, such as higher price caps and potential lower (negative) price floors, as well as shorter settlement periods to better value short-term flexibility.

Questions focused on how to bridge the gap between where market design is today, and where it needs to be. Specifically, some raised the potential political challenges of increasing the price cap, noting that the salience of the visible price cap could attract negative public attention, despite the potential efficiency gains and infrequency of prices being at or near the higher cap. Alternatives such as shortening the settlement period draw less attention, and thus less potential negative scrutiny, while also increasing efficiency and better compensating flexible resources for the services they provide. Another option discussed, along the lines of what ERCOT (Texas' electric grid) has chosen, was to create an administratively determined demand curve for operating reserves, allowing the price to rise as reserve margins get narrower. This method values energy during times of need while avoiding the potential adversity of higher energy price caps. It also explicitly controls for market power during scarcity events through the use of the administratively set demand curve.

Concerns were raised regarding the possibility of long-term contracts. Specifically, locking in to long-term contracts today means locking in to today's technology (and today's costs) despite rapidly changing technology and falling costs. Panellists agreed with the goal of remaining technology-neutral and focusing on attributes over specific technologies if any long-term contracts were used in Alberta, and for market design more generally.

Some panellists were less optimistic that storage would play a significant role in Alberta and pointed to Alberta's large and low-cost supply of natural gas as a cost-effective

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7 Physical inertia comes from large rotating masses, such as power-generating units, which can be used to maintain electric grid reliability by correcting imbalances between power supply and demand using the mechanical energy of inertia (i.e., slowing down or speeding up the spinning equipment). An alternative, virtual inertia, uses power electronics and direct current equipment to send signals to power generation units to instantaneously increase or decrease generation to manage imbalances.

alternative to grid-scale storage. Again, more panellists agreed that if Alberta's power market is properly pricing attributes – including carbon dioxide emissions – and regulating other difficult-to-price externalities, then gas running at low-capacity factors (i.e., running infrequently) may be a viable solution.

Ultimately, however, while participants debated various alternative market designs, the consensus was that whichever way is chosen, electricity market participants and investors require certainty over rules for the foreseeable future. From an end-user perspective, wholesale market design is unlikely to be a hot-button topic for the everyday consumer. Rather, consumers are more interested in reliable and affordable – and for some, green – power rather than the specific mechanisms regulators and market designers use to deliver such a product.

CONCLUSIONS

The roundtable event provided an opportunity for those with in-depth knowledge of Alberta's electricity system, and storage technology more generally, to assess the role for storage in Alberta's electricity future.

Overall, most participants concluded that attributes such as flexibility will be more highly valued in an Alberta electricity grid with a greater share of renewables, and that storage can provide such flexibility. However, there was no sense in which storage needed to be targeted for implementation through explicit policy design. Rather, participants emphasized the need to reform current market design and tariffs to reflect the value of desirable attributes for the electric system, and compensate resources accordingly.

There were important implications from the event relevant to the current market design reform process. While opinions varied as to the merits of particular market designs, all participants stressed considering the longer run vision of where Alberta's electricity grid is headed when designing policies today. There remains a role for storage in that future.

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About the Author

Blake Shaffer is an energy and environmental economist working at the intersection of electricity markets and climate policy. He uses empirical methods to evaluate policy effectiveness and better understand consumer and firm behaviour.

Prior to returning to academia, Shaffer had a 15 year career in energy trading, specializing in electricity, natural gas and emissions markets. He holds a PhD in economics from the University of Calgary, Master of Philosophy in economics from the University of Cambridge and a bachelor's degree in environmental science from Queen's University.

Shaffer has served as a policy advisor on energy and environmental policy matters for the governments of Alberta and Canada. He is currently a postdoctoral fellow and Fulbright scholar at Stanford University, an adjunct professor at the University of Calgary's department of economics, Energy Policy Fellow at the C.D. Howe Institute, and Research Fellow at The School of Public Policy.

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