Techno-Economic Feasibility of Acid/Base Flow Batteries: A Long Duration Energy Storage Assessment for Behind-the-Meter Industrial and Commercial Customers in Alberta, Applying Arbitrage Opportunities and Value of Lost Load Considerations

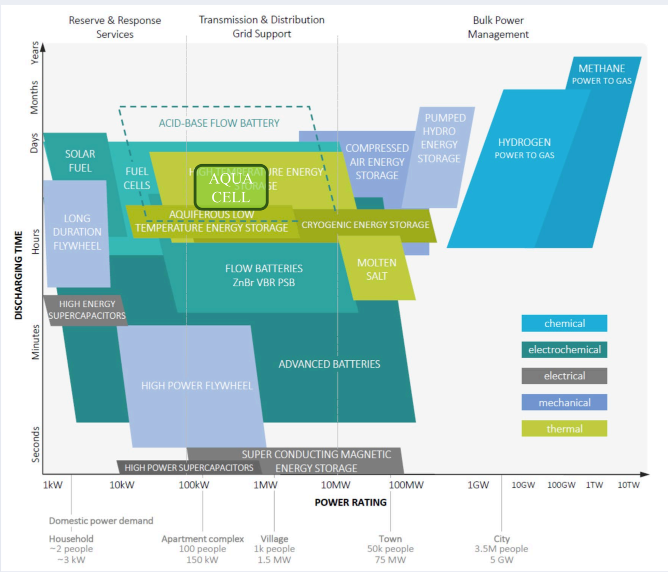
Hunter Jackson Brett

Academic Supervisor: Prof. David Brown, University of Alberta, Faculty of Arts, Department of Economics

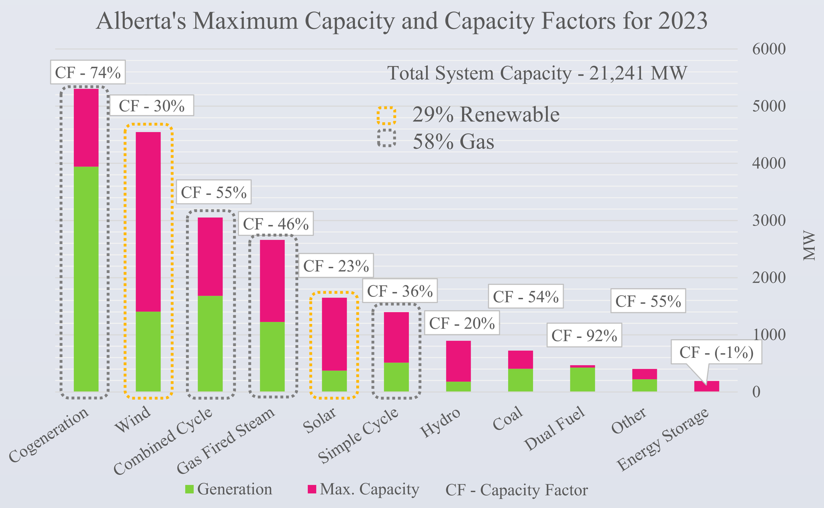
Industry Supervisor: Keith Cleland, Chief Executive Officer, Aqua-Cell Energy

ABSTRACT

The technological evolution of the Acid-Base Flow Battery (AB-FB) has led to a unique opportunity to utilize these batteries as a method for long-duration energy storage. Flow batteries are positioned to bridge the gap between traditional lithium-ion battery storage and storage technologies that reach days to months in storage, such as large-scale pumped-hydro storage. This has created a new opportunity for commercial and industrial-scale facilities to use AB-FBs as a behind-the-meter storage option. Recently, Alberta has seen increased market volatility, partially due to the increased presence of intermittent renewable electricity generators. This creates a potential environment for a battery to generate value for a customer through arbitrage opportunities and protection against potential periods of lost load. The paper assessed the techno-economic feasibility of implementing Aqua-Cell Energies AB-FB and exercising energy arbitrage opportunities and the value of lost load (VoLL), for behind-the-meter customers in Alberta.



Pärnamäe et al. (2020) – Adapted



OBJECTIVES

The research in this paper is meant to provide industry and academia with an updated feasibility of Long Duration Energy Storage (LDES), in the form of an AB-FB, within a real power market. The research is focused on exploring the viability of an energy storage system that commercial and industrial customers can utilize as a behind-the-meter apparatus that can help shave power costs and provide reliability to those looking to save on power costs and reduce risks to their operations. The paper will outline the current technological advancements in AB-FBs, setting the stage for its use as a medium-duration LDES option within the unique power market of Alberta. Simulations of hypothetical behind-the-meter customer load profiles will be run to produce techno-economic assessments and assess their viability. Finally, introduce the valuation of lost load and create a quantitative assessment to showcase the holistic benefits of battery storage.

To align with the United Nations Sustainable Development Goals (SDGs) the research paper will highlight three of the seventeen goals. The three SDGs that will be identified are:

Goal 7 - Affordable and Clean Energy; will be assessed by examining the economics of battery storage implemented, assisting renewable energy generation intermittency to create a reliable and sustainable energy system.

Goal 9 - Industry, Innovation, and Infrastructure: will focus on AB-FBs and how they can be implemented in an Alberta context.

Goal 12 – Responsible Consumption and Production: investigates how best Alberta can generate and consume power, offering the most reliable solutions for grid stability through battery storage.

Achieving these 3 SDGs will propel sustainability in energy development, specifically, affordability, innovation, responsible production and consumption. Society must continue to strive towards all seventeen goals and the objectives for each goal in the efforts to create a sustainable civilization, allowing equal or better opportunities for future generations.

MATERIALS & METHODS

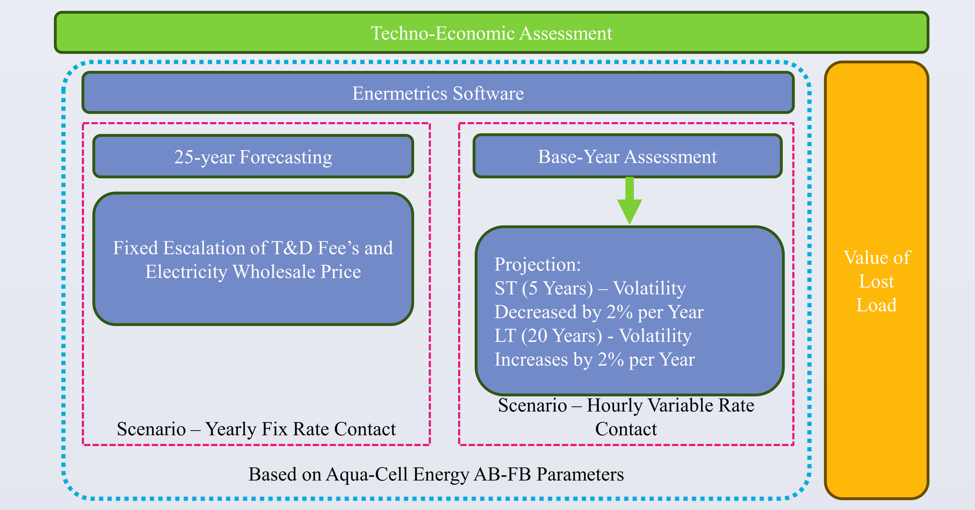
The methods used within the paper focus on utilizing the most recent data, policies, market structures, and technological advancements to feed into a techno-economic study. For the techno-economic assessment, financial modelling was completed on arbitrage pricing schemes. This was split into multiple customer load profiles and scenarios to test against the battery's sensitivity to pricing. The last consideration was an assessment of the VoLL for industrial and commercial customers.

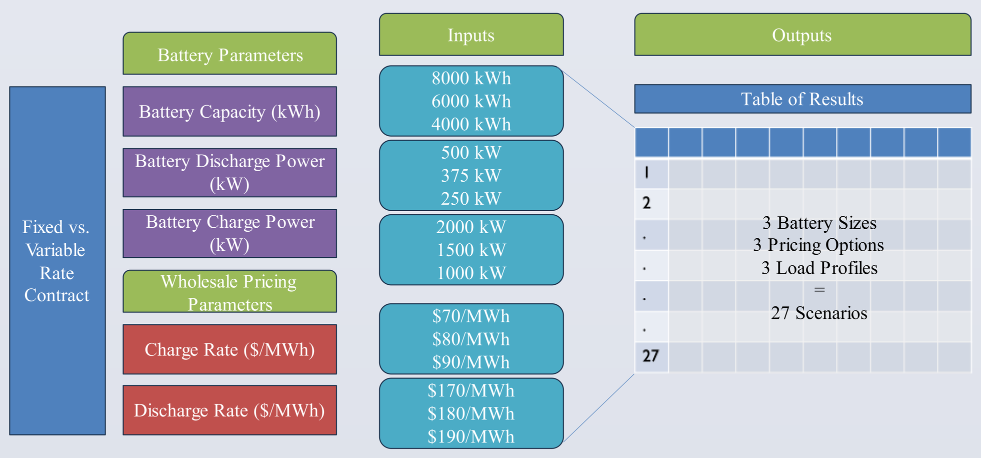
Materials:

- Primary data: Aqua-Cell Energy on AB-FB, AESO wholesale market data, AESO energy emergency alert data, NREL 2021 load profile dataset
- Secondary Data (Literature Review): AB-FB, LDES, Alberta market structure, economic advantages of battery storage, and VoLL

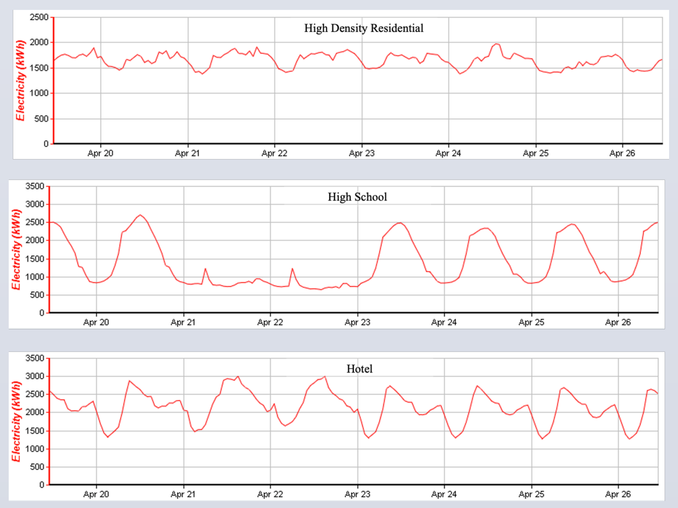
Method:

The below diagrams showcase the methods used to carry out a techno-economic assessment of the AB-FBs.

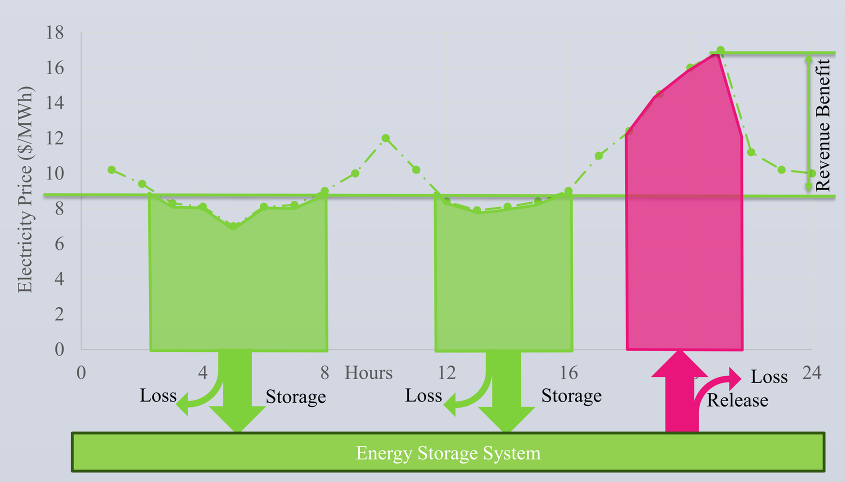




The three load profiles used in the assessment were high-density residential, high school, and hotel with varying profiles to test the battery's sensitivities to load.



The chosen battery advantage was arbitrage opportunities within the market, simply taking advantage of stored energy at times of increased wholesale pricing to reduce the costs on purchasing electricity.



Adapted from Zhang et al. (2021)

The VoLL calculation is based on the likelihood of Energy Emergency Alerts (EEA) turning into lost load situations.

Lost Load Likelihood Factor	EEA Level	Hours of Lost Load Likelihood (h)
0.01	EEA1	0.05
0.15	EEA2	0.43
0.55	EEA3	1.76

Annual VoLL

$$= \text{Hourly Average Facility Load (kWh) x Average Lost Load} \left(\frac{\text{h}}{\text{year}}\right) \text{x Gorman (2022) VoLL} \left(\frac{\$}{\text{kWh}}\right)$$

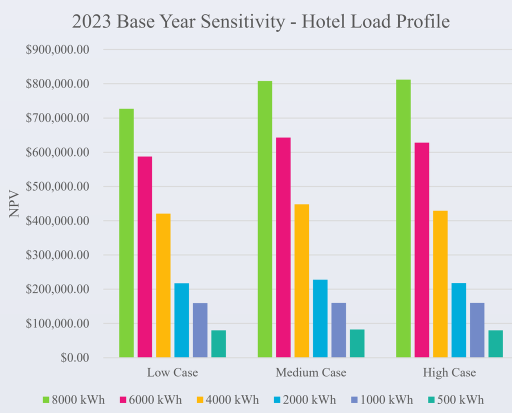
RESULTS

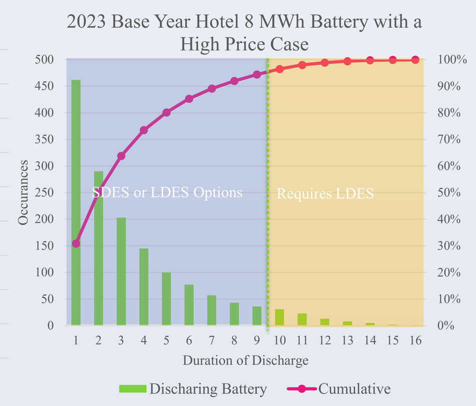
The results showcase variable net present values based on the sizing of the battery, and for the purpose of the poster, the load profile of the hotel will be used.

Battery Pricing is based on battery capacity and discharge rates, which are used as a capital cost throughout the modelling.

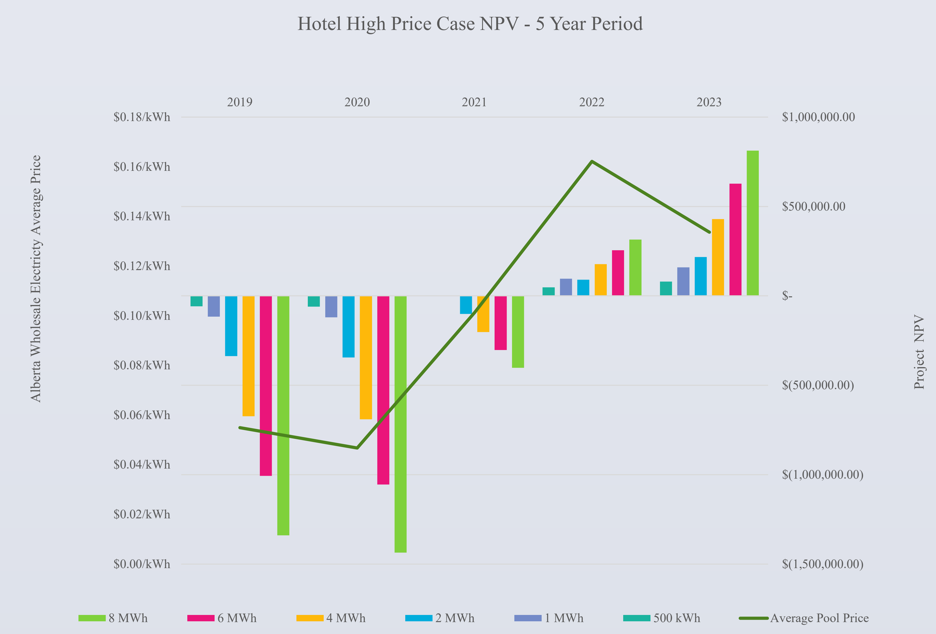
Battery Capacity (kWh)	Discharge Rate (kW)	Duration of Discharge (h)	Capital Cost
32000	500	60.8	$ 2,080,000
16000	500	30.4	$ 1,560,000
8000	500	15.2	$ 1,300,000
4000	500	7.6	$ 1,170,000
2000	500	3.8	$ 1,105,000

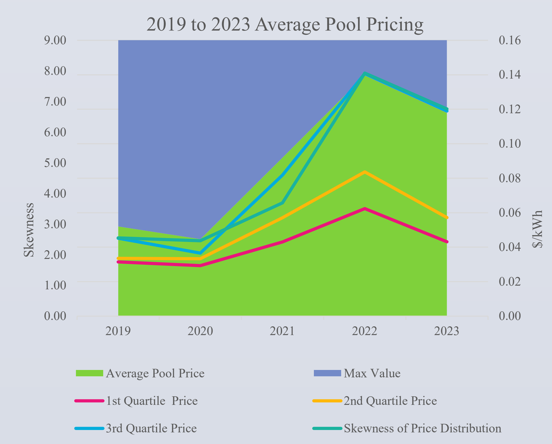
Using the 2023 base year case and forecasting 25 years ahead, a positive NPV was realized.



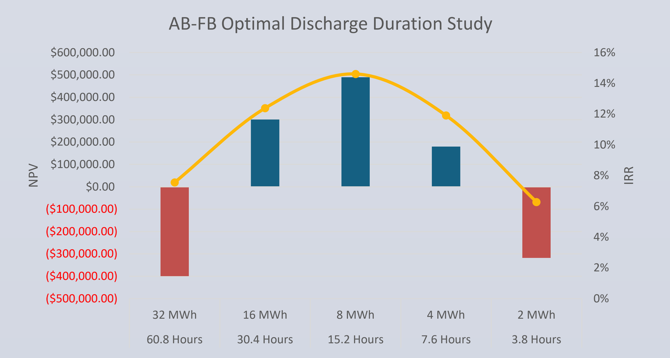


Assessing the 2023 AESO data against years the last 5 years of wholesale pricing showcases volatility within the wholesale pricing and the batteries arbitrage performance.

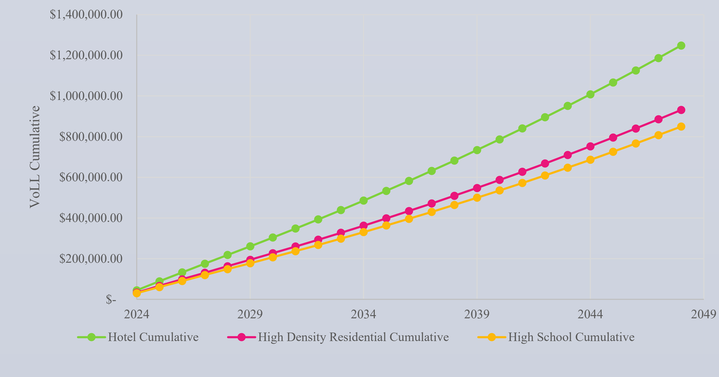




It was determined that the Aqua-Cell battery does have an optimal discharge duration against the Alberta 2023 base year wholesale market price for a Hotel load profile in a high price case.



An additional attribute to installing a behind-the-meter battery is the VoLL, which can generate economic value dependent on battery size and capital cost incurred.



CONCLUSION

The techno-economic assessment of AB-FBs for behind-the-meter commercial and industrial customers in Alberta showcases variable opportunities for economic conditions that would allow a customer to implement battery storage. An Aqua Cell AB-FB at an 8 MWh battery capacity can perform for 15.2 hours, offering arbitrage and VoLL opportunities. The pricing sensitivity of the AESO wholesale market pricing causes considerable variation in scenarios and appropriate batteries to use in each price case. The optimized scenarios using a hotel load profile and high price case arbitrage with an 8 MWh battery, produce a positive NPV of $812,213. A range of scenarios were used and showcased varying NPVs and IRRs, with some scenarios not being economical. This attests to the importance of techno-economic properly choosing forecasting parameters around future markets and selecting the best AB-FB battery capacity to optimize savings through arbitrage and VoLL. Insights were gained on the implications of market pricing distribution and skewness, with historic Alberta markets changing year-to-year shifting the ability to take advantage of arbitrage opportunities within the market. The assessment of VoLL should not be lost in the larger discussion of arbitrage, as the valuation alone offers economic considerations for industrial and commercial customers to use batteries as solutions to reducing the potential hours of lost production or activity through lost load from the grid. The paper provides positive sentiment to utilizing LDES AB-FBs for arbitrage and VoLL. The battery's opportunities are not limited to these advantages, which promotes future considerations. This situates companies like Aqua Cell in a strong position to implement their batteries into today's Alberta market and potentially future restructured energy market designs.

LIMITATIONS

Due to the nature of this high-level techno-economic assessment, multiple assumptions were made:

- Forecasting was assumed to reach 100% accuracy in tracking the wholesale market price
- If energy arbitrage reduced energy maximum demand, the transportation and distribution costs were not reduced due to software limitations, which potentially would be additional cost savings
- The software did not allow for co-optimization of peak shaving and arbitrage

FUTURE WORK

The work in this paper pre-dates the Alberta full implementation of a market redesign and AB-FBs commercial deployment and as such, much is to be considered in future work. Some points to consider are:

- **Assessment of the AESO market redesign outcomes**
- **Co-optimization and Value Streams of the AB-FB -** Introduce multiple battery advantages together such as assessing the stacking ability of peak shaving and arbitrage opportunities of a battery to test their value streams
- **AB-FBs LDES Applications in Alberta** – Assess Alberta's LDES potential and what would be required to implement AB-FBs
- **Reserve Option** – Assess the economics of LDES batteries as reserve options to the AESO

REFERENCES

AESO. (n.d.). AESO Annual Hourly Market Report from 2019-2023 (Version 2019-2023) [Csv]. AESO ETS. Retrieved June 23, 2024, from http://ets.aeso.ca/

AESO. (2024). AESO 2023 Annual Market Statistics. https://www.aeso.ca/assets/Uploads/market-and-system-reporting/Annual-Market-Stats-2023_Final.pdf

Gorman, W. (2022). The quest to quantify the value of lost load: A critical review of the economics of power outages. The Electricity Journal, 35(8), 107187. https://doi.org/10.1016/j.tej.2022.107187

Pärnamäe, R., Gurreri, L., Post, J., Van Egmond, W. J., Culcasi, A., Saakes, M., Cen, J., Goosen, E., Tamburini, A., Vermaas, D. A., & Tedesco, M. (2020). The Acid–Base Flow Battery: Sustainable Energy Storage via Reversible Water Dissociation with Bipolar Membranes. Membranes, 10(12), 409. https://doi.org/10.3390/membranes10120409

Zhang, X., Qin, C. (Chris), Loth, E., Xu, Y., Zhou, X., & Chen, H. (2021). Arbitrage analysis for different energy storage technologies and strategies. Energy Reports, 7, 8198–8206. https://doi.org/10.1016/j.egyr.2021.09.009

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Contact: Hjbrett@ucalgary.ca