November 1, 2023

White Paper
Compressed Air Energy Storage (CAES) in Saskatchewan

Commissioned by the PTRC

Brian Brunskill, P.Geo
and
Robert Stewart, Ph.D., P. Eng

White Paper
Saskatchewan's Transition to a Low-Carbon Energy Future
Our Geological Advantage: Compressed Air Energy Storage in Salt Caverns

Overview

The geology of Saskatchewan and the resources it provides has generated great wealth for our province. For generations, the production of oil, gas, potash, coal, uranium, gold and several other minerals has provided jobs and revenue to the province, and now, as we invest in a low-carbon energy generation future, our geology will continue to play a significant role.

Saskatchewan's geology supports the development of three utility-scale, zero or low-carbon generation technologies, those being: 1) Small Modular (nuclear) Reactors (SMRs); 2) Natural gas generation with Carbon Capture Utilization & Storage (CCUS); and 3) Variable Renewables generation with Compressed Air Energy Storage (CAES). While SMRs and CCUS facilities can provide base-load power, it is widely recognized that to fully integrate renewables like wind and solar generation into the grid, utility-scale, long duration energy storage systems are also required. Compressed air storage can provide this service and is an option that is particularly suitable for development in Saskatchewan.

A perceived barrier to the wider adoption of wind and solar energy as sources for electrical generation is the fact that these sources are intermittent in nature, suggesting that they cannot be relied on to provide firm-capacity power. This intermittency can largely be overcome by storing surplus, low-cost, renewable energy at times when it is abundant and drawing on this stored energy when required.

While lithium-ion batteries are useful for short term storage (several minutes to hours), to *bridge-the-gap* over periods of non-generation, Saskatchewan's advantageous geological conditions and expertise in utilizing rock-salt caverns for natural gas storage warrant consideration of using CAES technology. CAES can provide much higher storage capacities over longer duration periods than batteries and it is a cost-effective method of converting intermittent renewable generation to firm capacity that is safe, well understood and produces no toxic waste.

CAES assets utilize the electricity generated from renewable sources to compress and store atmospheric air in purpose-built salt caverns. During this process, intermittent wind and solar energy is converted to firm capacity by *charging* the cavern while the sun is shining or the wind is blowing and allowing the compressed air to be controllably released later into an electricity-generating turbine. This process is illustrated in Figure 1.

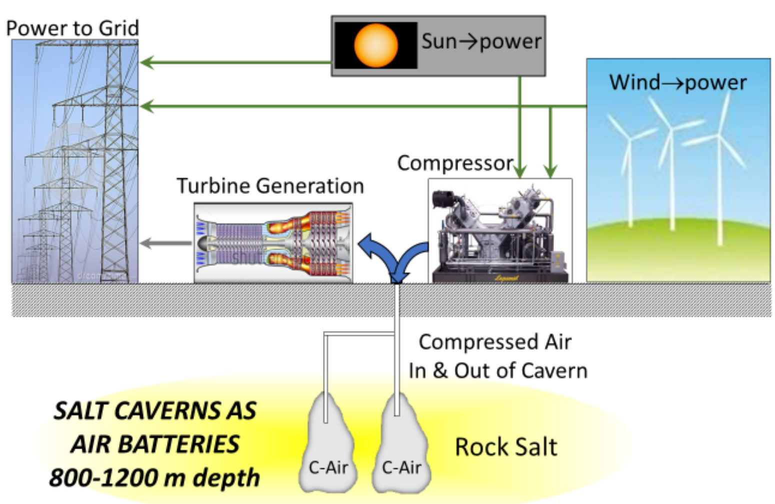

Figure 1. Compressed Air Energy Storage System.

Saskatchewan's Geological Advantage

Saskatchewan has highly favourable geological conditions for the deployment of CAES technology due to a layer of rock salt, primarily sodium chloride, which is over 200 metres thick in some southern Saskatchewan areas. The geological make-up of the *Prairie Salt Formation* is well-understood from the drilling of over 170,000 oil and gas wells and from potash mining operations. Since the 1950s, Saskatchewan has also successfully mined and operated caverns over 140,000 m^3 (five million ft^3) in size within this rock salt to store natural gas, other hydrocarbons and industrial waste. Saskatchewan also has the means to safely dispose of the salt *brine* that is created into deep saline aquifers during the cavern-mining processes. These conditions give Saskatchewan a significant *geological advantage* over most other jurisdictions globally.

Figure 2 shows the distribution of and depth to the top of the Prairie Salt Formation and where 58 salt caverns are located[1]. The warmer colours represent greater depth to the top of salt, being approximately 1050 m deep near Saskatoon and 1650 m near Regina. Ideal cavern depths range from 800-1200 m but depths up to 1800 m are possible.

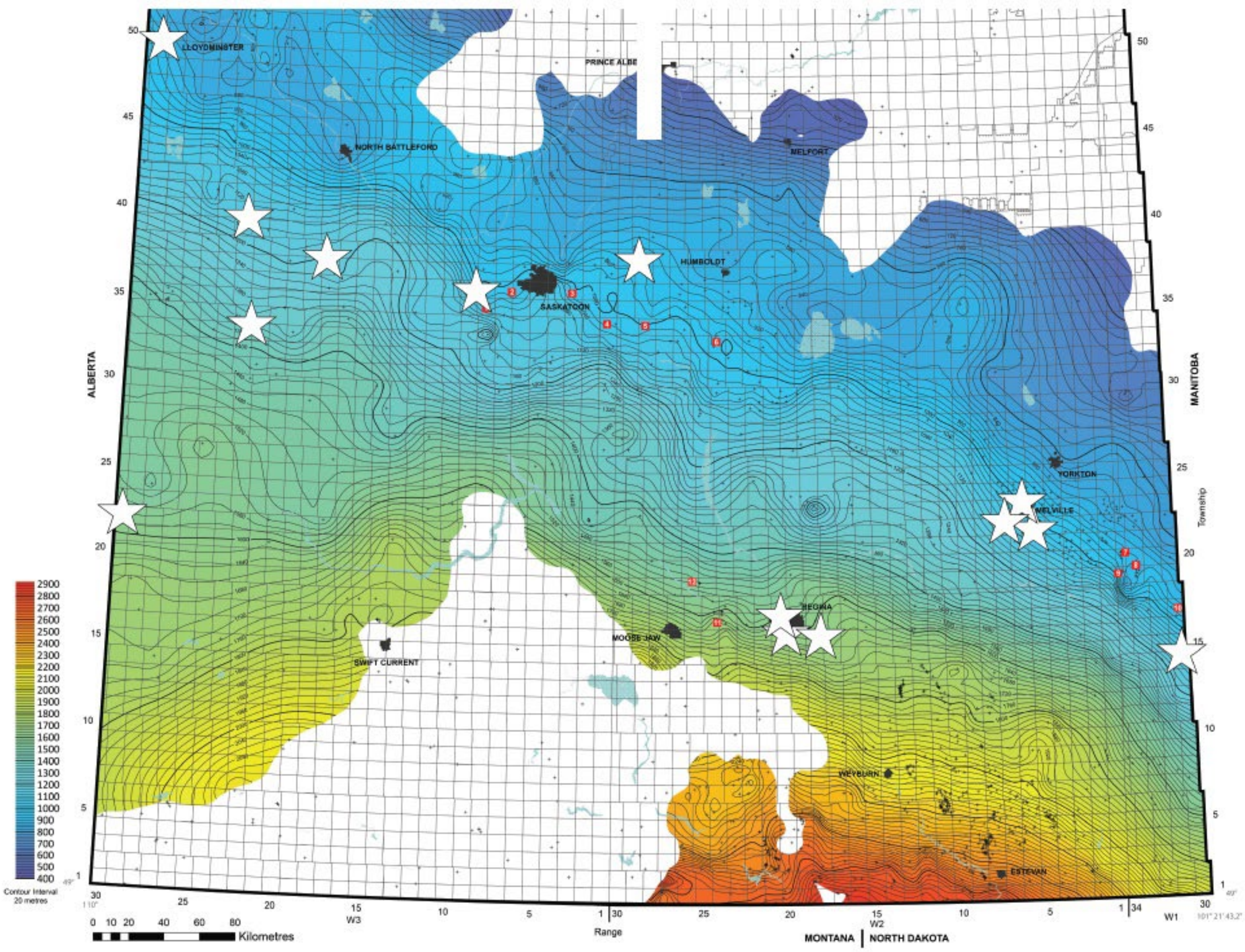

Figure 2. Map of salt distribution and existing caverns in Saskatchewan (cavern locations indicated by stars).

[1] Yang, C. and Love, M. (2021): Depth at the top of the Prairie Evaporite Salt in Saskatchewan; MER, Sask. Geological Survey. https://publications.saskatchewan.ca/#/products/111909 (accessed June 15, 2021).

Technology Maturity and Reliability

CAES is a mature and proven technology that has been used at Huntorf, Germany, since 1978 and at McIntosh, Alabama, since 1991, providing industry over 70 years of combined operational experience. These facilities use a ***diabatic*** process where a small amount of natural gas is used during the generation stage. Installing a new diabatic system could potentially be cost competitive with new-build, best-in-class Combined-Cycle Gas Turbine (CCGT) generation while providing an 80% reduction in GHG emissions. Additionally, all the components of CAES systems are proven in numerous stand-alone applications and are available from top tier suppliers. Next generation CAES systems could use an ***adiabatic*** process where the heat from compression is stored and reused during generation resulting in zero GHG emissions.

CAES technology is being advanced in several jurisdictions: the Hydrostor 1.75 MW capacity[2] facility in Goderich, Ontario came into service in 2019 and they are currently planning or developing projects in California and Australia; Corre Energy is a European CAES developer involved in projects in The Netherlands and Denmark[3]; Magnum Development operates several salt caverns for liquid fuel storage and is planning to develop new caverns in central Utah for an advanced clean energy storage project that could provide up to 1000 MW of storage capacity[4]; Apex Clean Energy is planning to develop a 324 MW/16,000 MWh CAES facility at the Bethel Energy Centre in Texas[5] and Federation Engineering will be developing a 320 MW facility near Marguerite Lake in Alberta[6]. China's first 60 MW/300 MWh CAES facility came online in May, 2022 with a second 350 MW/1.4 GWh system being under construction[7].

Levelized Generation and Capital Cost

According to RMP Energy Storage – a storage developer from Calgary – the Levelized Cost of Electricity (LCOE) for a full time, wind-supported 300 MW (36 GWh), zero-emission *adiabatic* CAES electricity is approximately $91 - $114 per MWh (6% discount rate), assuming a contracted wind price of $30 - $45/MWh respectively and 65% round trip efficiency[8]. RMP notes that adiabatic technology with this duration and efficiency requires some additional technological development for thermal storage, estimating that the capital cost to construct a 300 MW adiabatic CAES facility will range from $900 - $1200 million. For comparison, the LCOE for a 300 MW (36 GWh) diabatic system ranges from $72-94 per MWh with an average capital cost of $775 M.

The *Economic and Finance Working Group – SMR Roadmap (EFWG)* [9] (2018) provides a broad LCOE range from ~$52-$110 per MWh (6% discount rate) with an average capital cost of $3.06 billion for an SMR built in 2034. On March 28, 2022 the Minister for SaskPower was reported to have said a small reactor would cost in the range of $5 billion[10]. The document also provides a broad LCOE range from ~$82-140 per MWh for CCGT generation with Carbon Capture (CC; not including storage costs).

Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies (EIA 2020) provides an extrapolated CCUS capital cost estimate between $0.90-$1.00 billion[11]. The CCS Knowledge Centre in Regina estimates adding carbon capture infrastructure to the new 353 MW Chinook CCGT unit located near Swift Current would cost approximately $1 B[12]. Due to the load required to operate the CC unit, power output could be reduced approximately 13% to 307 MW.

---

[2] https://www.hydrostor.ca/company/ (accessed October 22, 2021).
[3] https://corre.energy/about-us/ (accessed October 15, 2023).
[4] https://magnumdev.com/ (accessed September 7, 2021).
[5] http://www.apexcaes.com/bethel-energy-center (accessed September 7, 2021).
[6] https://federationengineering.com/media/documents/Project%20Profile_CAES.pdf (accessed October 15, 2023).
[7] https://www.energy-storage.news/construction-starts-on-1-4gwh-compressed-air-energy-storage-unit-in-china/ (accessed October 12, 2023).
[8] https://www.rmpenergystorage.com/_files/ugd/2a9f23_7222f0ddf5d9404bbc32696c1c3b76a3.pdf (accessed October 28, 2021)
[9] https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf (accessed April 5, 2022)
[10] https://leaderpost.com/business/energy/saskatchewan-maps-out-plan-for-small-nuclear-power-reactors (accessed April 2, 2022)
[11] https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capital_cost_AEO2020.pdf (Accessed April 28, 2022)
[12] CCS Knowledge Centre, Regina, *pers comm* May 30, 2023.

Average capital and LCOE values for SMR, CCGT with CC and CAES facilities are summarized in the Table 1. Discretion is advised when comparing values because of inconsistencies in generation capacity, the year the values were determined, the discount rates applied, impact of inflation and use of different data sources. Further detailed investigation is required.

Technology	Av Capital Cost	LCOE/ MWh
300 MW SMR (first of a kind in 2034)[9]	$3.06 B	$52-110
Leader-Post - Mar 28, 2022[10]	$5.0 B	?
300 MW CCGT with CC (90% GHG reduction, no storage)	$950 M [11]	$82-140[9]
353 MW SaskPower Chinook CCGT[13]	$605 M	?
Add Carbon Capture to Chinook (excludes storage) Net output reduced to ~307 MW[12]	$1 B	?
300 MW CAES diabatic[8] (80% GHG reduction)	$775 M	$72-94
300 MW CAES adiabatic[8] (100% GHG reduction)	$1050 M	$91-114

Table 1. Comparison of capital and LCOE values for SMRs, CCGT with CC and CAES.

Saskatchewan's Economic Opportunity

Significant investment will be required to replace coal and potentially natural gas power generation by 2035. Developing renewable sources in conjunction with CAES technology have the potential to keep most of this investment in Saskatchewan. By building our wind and solar generating infrastructure (secure, cheap Saskatchewan feedstocks) along with CAES (abundant subsurface salt resources), Saskatchewan will be less dependent on importing power from Manitoba or North Dakota, or natural gas from Alberta and B.C. (Saskatchewan currently imports over 50% of natural gas consumed[14]). In addition, we can leverage our highly trained and experienced oilfield and power plant workforce to build and operate this new infrastructure.

Developing our own renewable resources will help keep capital investment and jobs in Saskatchewan, unlocking regional growth opportunities and supporting the tax base of several Saskatchewan rural municipalities. Developing CAES infrastructure will support significant investments in the wind and solar energy sectors. For example, to emulate base load generation, each 300 MW CAES facility would require the third-party investment and construction of up to 1100 MW of wind generating capacity valued at over $1.76 Billion[15]. Indigenous groups, farmers, ranchers, cooperatives, municipalities and communities could become power generators, harvesting the energy of sunshine and wind. Developing CAES facilities could advance the economic potential of our renewables' generation – being some of the best in Canada.

Summary

Compressed Air Energy Storage is a mature technology that can be implemented in Saskatchewan, utilizing our abundant and well-understood geological resources for cavern development and our abundant wind and solar resources for power generation. Billions of dollars would be invested in Saskatchewan-based businesses and communities if this technology is developed.

SMR, CCUS and wind+CAES are complimentary technologies that can provide power with low-to-zero GHG emissions, however, further investigation may show that CAES technology is the most cost-effective generation option. In addition to direct power generation, CAES technology can also provide utility-scale energy storage and

[13] https://www.saskpower.com/Our-Power-Future/Our-Electricity/Electrical-System/System-Map/Chinook-Power-Station
[14] Sask. Ministry of Energy & Resources (*pers. comm.* January 8, 2021).
[15] https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2018/market-snapshot-cost-install-wind-solar-power-in-canada-is-projected-significantly-fall-over-long-term.html (accessed January 12, 2021).

power balancing services to SMR and CCUS facilities, maximizing the market value of zero-carbon electricity and renewable power export opportunities. Our expanded understanding of salt cavern use will also support the eventual inclusion of green hydrogen generation and cavern storage.

Next Steps

The next step is to investigate the potential development of a diabatic CAES pilot project that would be expandable in capacity and duration and able to eventually include a demonstration of adiabatic geothermal heat storage technology. This work would also include a broad assessment of the suitability of subsurface salt for cavern development contiguous with power transmission constraints and significant load locations.

Brian Brunskill P.Geo.
Regina, Sask.
brianbrunskill@sasktel.net

Robert Stewart Ph.D. P.Eng
Calgary, Alberta.
rastewar@gmail.com

Short Bios

Brian Brunskill has worked in Saskatchewan's oil and potash industries since 1985. Since 2010, this work has included the assessment and development of Saskatchewan's geothermal and energy storage resources.

Robert Stewart has worked on energy storage technology and project developments with a focus on CAES in Western Canada for over 10 years.