HYDROSTOR

ADVANCED COMPRESSED AIR ENERGY STORAGE

Australian Energy Market Operator
Via email: isp@aemo.com.au

21 February 2020

Subject: Written Submission on AEMO's 2020 Draft ISP

Dear Sir/Madam

Hydrostor appreciates the opportunity to provide comments on the AEMO's draft 2020 Integrated System Plan (ISP) and commends AEMO on its progress to date on this ambitious initiative. From our perspective as a developer of utility-scale energy-storage resources, we would suggest a few considerations and modifications to encourage the dynamic development of a least-cost solution for the NEM:

- **Storage Technologies:** In several locations the draft ISP mentions only pumped hydro storage and batteries as the possible options for energy storage. There is a broad, and growing, suite of alternative storage technologies that may be more suitable for many applications throughout the 20-year outlook period (e.g., compressed-air energy storage, thermoelectric energy storage). Given the significant siting-viability and environmental restrictions on pumped hydro, it would seem more appropriate to forecast the development of storage on a technology-neutral basis, categorized on the basis of the duration of storage required, rather than suggesting that pumped hydro, which has highly variable costs and viabilities depending on location is the likely candidate for development (as we assume these nuances and location-specific variations have not been accounted for in the analysis).

- **Compressed-Air Energy Storage:** Where specific technologies are contemplated, Hydrostor believes it is important that compressed-air energy storage, a 40-year-old technology, should be included for consideration. Included in the pages following this letter is information on Hydrostor and the performance and costing of Hydrostor's Advanced Compressed-Air Energy Storage (A-CAES), which is emission free and can be flexibly sited.

- **Non-Network Options:** While non-network options are mentioned in the draft ISP, these do not appear to be contemplated as viable options to offset any of the proposed network investment and appear to be more of an after-thought. While non-network options are now considered under all RIT-T processes (as mandated by the NER), it is incredibly important that the requirements of non-network options, including total power transfers and durations, are published as early as possible so as to allow time for viable non-network solutions to be developed. Ideally, this information would be published in the ISP. If insufficient notice is given, developers will be unable to provide non-network solutions that are more efficient than traditional network investments.

- **System Security Services:** The draft ISP contemplates the efficiencies of scale associated with developing large-scale infrastructure for the provision of power-system security services. We believe it is also important to consider potential *efficiencies of scope*, whereby participants in the energy market with synchronous loads and generation (e.g. compressed-air energy storage, certain types of pumped hydro, and GPG) are enabled to provide a broader range of services, including these critical security services, rather than building out specialized infrastructure, such as synchronous condensers, that cannot also participate in the energy market. Without adequate incentive structures, the NEM may miss out on these efficiencies and develop in a sub-optimal manner, resulting in higher costs for consumers. We commend the reference to this potential in D5.2 and support the call to pursue market reforms that will facilitate this. When contemplating system security in the ISP, a focussed consideration on these capabilities and the market structures required to facilitate them will be required to achieve least-cost outcomes for consumers.

Thank you for your consideration of our comments. Please contact the undersigned if you have any questions in relation to this submission.

Yours sincerely,

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About Hydrostor

Hydrostor, a private company founded in 2010 and based in Toronto, Canada, is a developer of utility-scale energy storage facilities using its proprietary A-CAES technology. Hydrostor A--CAES is uniquely situated to provide long-duration, non-emitting, cost effective energy storage capacity, enabling greater integration of renewable generation with the electrical grid, deferral of costly transmission investments and provision of grid stabilization services.

A description of Hydrostor A--CAES technology can be found in the appendix to this memo.

Hydrostor operated a pilot plan in Toronto for a number of years, has an operational project in Canada and another under construction in Australia that total more than 25 MWh, and numerous utility-scale projects (each at 50 – 500 MW) in various stages of development across the U.S., Australia, Canada and Chile, including 2 completed FEED Studies, 400 MW of commercially bid projects and a 1.5 GW+ project pipeline with projects ranging in size up to 500 MW / 5 GWh. See Figure 1 for more details.

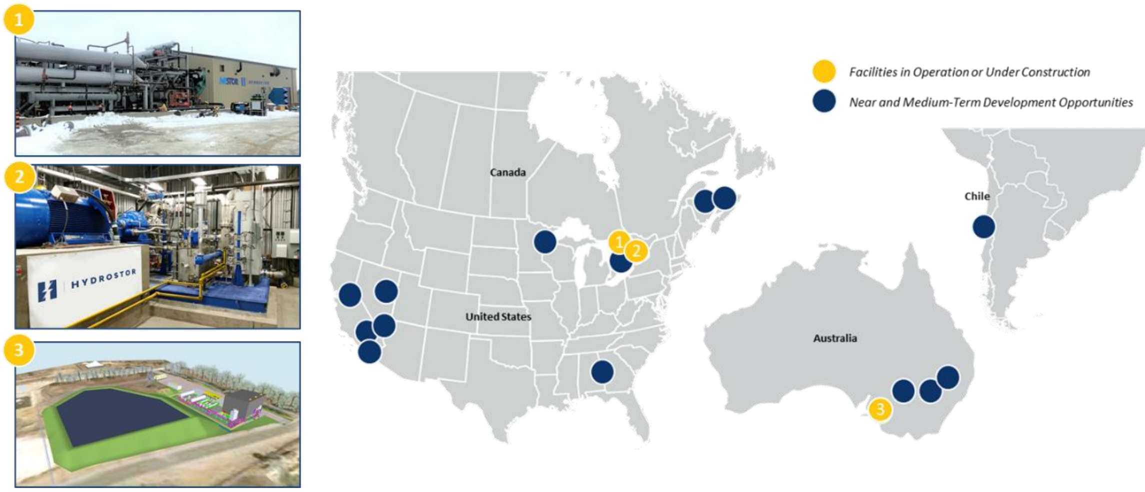


Figure 1: Hydrostor's Project Pipeline

Hydrostor offers a complete solution including financing and warranty options, working with leading Engineering Procurement and Construction (EPC) delivery partners like AECOM and SNC-Lavalin to deploy solutions globally. Export Development Canada (EDC) is also working with Hydrostor on its existing projects to provide bonding and reinsurance support as part of its overall cleantech assistance mandate. Hydrostor has a proven project delivery team with experience designing and building A-CAES projects globally, as well as a seasoned senior executive team with prior experience at leading firms including Brookfield, Deloitte, Bruce Power and Siemens. Hydrostor's development and construction relationships with AECOM and SNC-Lavalin bring a broad range of project management services and technical expertise to support Hydrostor A-CAES projects through feasibility and Front-End Engineering & Design (FEED) studies, permitting, EPC and commissioning activities.

Overview of Hydrostor A-CAES

Hydrostor A-CAES technology is uniquely suited to enable the transition to a cleaner, more reliable electricity grid. A-CAES provides grid services that are not readily replicated by other storage technologies, giving it unique market potential. It flexibly addresses bulk electricity system needs for dispatchable capacity, renewable integration and optimization, and ancillary services. The technology can also replace retired fossil fuel plants and leverage existing mining infrastructure, facilitating the modernization of these assets as part of the green energy economy.

Hydrostor's solution delivers low-cost, long-duration bulk energy storage (hundreds of MWs, 4-24+ hours) that is synchronous and emission-free and can be flexibly located where required by the grid. It does so with large-scale rotating generators that deliver traditional grid stability services sought by utilities such as reliable (long-duration) capacity, spinning reserves, voltage support, and synchronous inertia. Importantly, A-CAES can be constructed in places where other forms of large-scale synchronous storage cannot (like pumped hydro and traditional CAES) and provides grid benefits that other forms of non-synchronous storage cannot (like batteries). A-CAES uses no fossil fuels and is non-emitting, unlike gas-fired generation, facilitating permitting and emissions reductions.

Hydrostor utilizes standard, off-the-shelf equipment that has been rigorously deployed in a variety of other applications and industries (e.g. pipeline compressor stations) and is supplied by Tier 1 original equipment manufacturers (e.g. GE, Hanwha, MAN Turbo). Unlike short duration solutions (e.g. lithium-ion), Hydrostor's is a long-duration product that will be required to effectively integrate renewables, replace existing emitting coal and gas capacity, and optimize or defer investments in new transmission.

Capital investment for A-CAES is significantly lower per kWh for full-scale installations than other storage technologies, in part because of its significant economies-of-scale, and by combining the well-established expertise and supply chains of the mining sector with those of proven, bankable, industry-standard generating and process equipment to offer a compelling solution at scale.

A-CAES Benefits

The key benefits of Hydrostor's technology are summarized below:

Ability to Site Where Needed

- Proprietary purpose-built air caverns allow for flexible project siting
- No toxic materials, contaminants, or thermal impacts on environment; suitable for urban settings

Credible Cost Base

- Off the shelf equipment from Tier 1 original equipment manufacturers
- EPC delivery partners with well understood engineering principles and construction techniques
- Well-established expertise and supply chains from the mining sector for sub-surface elements

Low Cost

- Lowest installed cost per kWh for siteable large-scale, long-duration storage (100+MW)
- 50+ year system life, with no replacements required and nearly unlimited cycling
- Low operating costs, and increased efficiency over traditional CAES systems

Customized System Design

- System design optimized to match client requirements, with independent settings for charge, discharge and storage capacity
- Long duration of storage enables wide-scale provision of grid capacity

Proven, Reliable Equipment

- Well-proven mechanical equipment from Tier 1 OEM suppliers is matched with seasoned EPC engineering expertise, system warranty and delivery guarantees
- Traditional CAES been in operation at two large (110MW to 320MW) projects in Germany and North America since 1978.

Emission Free

- Adiabatic thermal storage system uses no fossil fuels and results in no emissions

Ancillary Services

- Synchronous motors and generators provide rotational inertia, system strength, and reactive voltage support, supporting grid stability.
- Full suite of ancillary services available including voltage support, spinning reserve, black start and frequency response / load following.

A-CAES Applications

As a long-duration, bulk energy storage technology that can be flexibly sited the Hydrostor A-CAES solution is uniquely positioned to address various evolving grid challenges. Its long duration means it can soak up over-generation in off-peak hours helping to avoid curtailment of renewable energy, it can provide significant synchronous generation and locatable flexible capacity crucial for system reliability as traditional fossil fuel assets retire, and it can cost effectively defer investments in transmission infrastructure by alleviating congestion issues. Compared to pumped hydro, another commercially viable bulk large-scale energy storage alternative, Hydrostor's solution comes at a lower cost per unit of capacity provided, has greater energy density (requiring a much smaller footprint), and offers unique siting flexibility to provide capacity where the grid requires it.

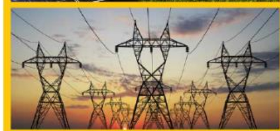
	**Renewable Integration**	▪ Provide dispatchable, baseload renewables ▪ Optimize solar/wind project economics through time-shifting ▪ Reduce curtailment
	**Transmission Deferral**	▪ Non-wires alternatives to defer grid network investment ▪ Alleviates grid congestion during peak periods ▪ Locatable reliable power for critical areas and infrastructure
	**Mines / Large Industrial**	▪ Reduces or eliminates fuel costs and logistics (off-grid) ▪ Improve reliability and reduce electricity grid charges (grid-connected) ▪ Can repurpose legacy mining infrastructure
	**Fossil Plant Replacement**	▪ Alternative to new thermal peaking capacity ▪ Repurpose decommissioned thermal plants, reuse infrastructure and defer remediation costs ▪ Synchronous generation for reliability, without emissions

Figure 2: A-CAES Applications

A-CAES Comparison vs. Other Bulk Energy Storage Alternatives

Although Hydrostor enjoys a relatively unique market niche for A-CAES given its flexible siting, large-scale and long storage duration, it generally competes with other long-duration storage technologies (e.g. pumped hydro and to a lesser extent lithium-ion or flow batteries), dispatchable capacity from single/combined-cycle natural gas, as well as new transmission investments.

Summary of Hydrostor's Competitive Positioning

- More cost-effective than li-ion or flow batteries at scale (even accounting for expected cost reductions), much longer lifespan (50+ years, nearly unlimited cycling)
- Provides synchronous inertia important for grid reliability, unlike batteries
- More flexible siting than pumped hydro storage (PHS)
- Non-emitting unlike natural gas-fired generation, facilitating permitting and eliminating need for fuel supply infrastructure
- Frequently lower cost and more rapid deployment relative to new transmission lines, and in many cases with ability to capture other value streams (capacity, ancillary services)

Table 1: A-CAES Competitive Comparison vs. Other Bulk Energy Storage Alternatives

	Hydrostor A-CAES	Gas Turbine	Traditional CAES	Pumped Hydro	Li-Ion Battery	Flow Battery
Size (MW)	50 – 500+	>100	150 – 500+	>200	1 – 100	1 – 20
Duration (hours)	>6	N/A	>6	>6	1–4	4–6
Efficiency	>60%	N/A	30 – 40%	70 – 85%	85%	70%
Emissions	None	Emitting	Emitting	None	None	None
Lifecycle (cycles)	>20,000	>20,000	>20,000	>20,000	5,000	10,000
CAPEX (US$/kW)	$1,000–$3,000	$1,000	$1,500–$2,500+	>$2,500	$3,000+	$5,000
CAPEX (US$/kWh)*	$150–$300*	N/A	$150–$250+	>$250	$300+**	$500
Operating Costs	Low-Medium	High (fuel costs)	High (fuel costs)	Low-Medium	Medium	Low-Medium
Siting Flexibility	Medium-High	Medium (emissions)	Low (salt, emissions)	Low (topography)	High	High

** Assumes 10-hour discharge for storage, fully-delivered system with BOP. Additional cost reductions possible where infrastructure can be repurposed.*
*** Li-ion costs based on Lazard LCOS v4.0 adjusted to 10-hour discharge using CPUC methodology in order to show equivalency with 10-hour A-CAES.*

The Indicative CAPEX / OPEX section later in this document provides more specific costings for A-CAES in the Australian market.

Comparison of Hydrostor A-CAES and Traditional CAES

Compressed Air Energy Storage (CAES) is a long-standing technology with proven operation history, as highlighted in the subsequent section of this document. By way of explanation, CAES (as opposed to A-CAES) is a method for storing electrical energy and providing it back on demand. A compressor is used to convert electrical energy into an increased internal energy state of an air stream, after which the air is stored in an accumulator at high pressure. When electricity is required, heat is added back to the compressed air before it is expanded through a turbine-generator, converting the stored energy back into electricity. It is a batched, open process, with the compressor and turbine drawing in and exhausting air to the environment.

The proprietary design of Hydrostor A-CAES has advantages over traditional CAES systems, which have been held back by two key limitations: (1) CAES requires expensive high-pressure vessels or suitable, very large, underground geological formations for siting, and (2) they rely on burning natural gas, or other fuels, to generate the heat needed during expansion of air to generate electricity, thus producing emissions.

Conventional "diabatic" CAES operations utilize the burning of fuels to heat the air prior to entering the turbine, thereby providing more energy to the generator and protecting equipment from extremely low temperatures. Similarly, the heat of compression is rejected in such operations, using waste-heat intercoolers throughout the compression cycle.

Responding to market demand, Hydrostor has developed fuel-free, adiabatic compressed air energy storage. The key to providing such a system is through recycling the heat by capturing the heat of compression, storing it, and then re-injecting it into the air before it enters the turbine. This makes the Hydrostor system truly emission-free and boosts the round-trip efficiency. Hydrostor uses a proprietary design that includes heat storage to achieve adiabatic operation.

The advancements to A-CAES enable an important paradigm shift in CAES technology at a large utility-scale, capable of full replacement of fossil generating infrastructure and major transmission investment deferral. There are two successful large-scale (110–320 MW) conventional CAES facilities operating in Alabama, USA and in Huntorf, Germany. The improved technology, A-

CAES, can be deployed using salt caverns, remnant underground mine workings or engineered underground storage caverns, enabling A-CAES to be sited where the grid requires it.

Hydrostor's A-CAES has a number of advantages, as outlined below:

	Traditional CAES	Hydrostor A-CAES
Mechanical	✗ *Air processing equipment is forced to operate with drastic pressure variations, substantially reducing system performance and reliability*	✓ *The near constant pressure afforded by hydrostatic compensation ensures highly efficient equipment operation over the entire state of charge range*
Thermal	✗ *Proven, but requires natural gas (infrastructure, fuel costs, permitting challenges), and significant GHG emissions over life of facility*	✓ *Proven, fuel free and GHG free (no gas infrastructure, no fuel costs, easier permitting)*
Air Storage	✗ *Requires highly specific geologic formations (salt caverns) that are typically in areas with limited grid needs or connection potential* ✗ *Requires large cavern volumes and very high pressures to be feasible*	✓ *Can be sited in a variety of geological formations, close to load centers or areas where grid needs are greatest* ✓ *Stored under hydrostatic compensation drastically reducing the volume requirements*

Existing CAES Plants

Hydrostor's A-CAES technology builds upon traditional CAES and its over 40 years of successful operation as demonstrated by the successful ongoing performance of the 320 MW Huntorf CAES Plant, and the 110 MW McIntosh CAES Plant. Both facilities have demonstrated excellent availability, reliability and start-up reliability of over 90%. However, importantly, A-CAES is emissions-free (adiabatic) and the use of a compensated, purpose-built hard-rock cavern allows for the facilities to be flexibly sited where needed. A CAES leverages systems proven in the oil-and-gas, mining, and power-generation sectors to deliver an energy storage solution with two key advancements beyond traditional CAES systems: purpose-built, hydrostatically compensated air storage caverns (allowing for flexible siting); and an innovative thermal-management system (enabling emission-free operation).

Table 1: Existing CAES Plants

	Existing CAES Plants[1]	
	Huntorf (1978) Germany	**McIntosh (1991) USA**
		
CAES Type	Diabatic 1st Generation	Diabatic 1st Generation
Compression Power / Charging time	60 MW / 8 hrs	50 MW / 38 hrs
Turbine Power / Discharge time	320 MW / ~3 hrs	110 MW / 24 hrs
Compressor OEM	MDT-CH *(former Sulzer Turbo)*	Dresser Rand
Turbine OEM	ALSTOM *(former BBC)*	Dresser Rand
Charge / Discharge duration ratio	2.7	1.6

[1] MAN Turbo 2018 Presentation on CAES

Cavern Pressure	46 – 72 bar(a)	45 – 74 bar(a)
Efficiency **Heat Rate**	42% (without heat recuperator)	54% (with heat recuperator)
Availability **Reliability** **Start-up Reliability**	90% 97% 95%	90% 97% 95%
Cavern	2 x 150,000 m^3 (Salt Cavern)	538,000 m^3 (Salt Cavern)

Information on the operating and technical parameters of Hydrostor's A-CAES technology can be found later in the "A-CAES Technical and Performance Specifications" section of this document.

Comparison of Pumped Hydro vs. Hydrostor A-CAES

A-CAES shares many positive characteristics with pumped hydro storage, including a long lifespan (50+ years), long storage durations, and the provision of synchronous generation (including rotational inertia) to the grid (including similar performance characteristics). However, while PHS has higher efficiencies by running water directly through a turbine, A-CAES has a number of advantages over pumped hydro in particular the ability to be flexibly sited by being far less space intensive. These advantages are outlined below:

	Pumped Hydro	Hydrostor A-CAES
Cost	✘ *Generally very capital intensive, with turnkey CAPEX typically exceeding US$2,500/kW, and size feasibility typically >300MW* ✘ *Cannot readily be sited to take advantage of infrastructure synergies*	✓ *Less capital intensive and more scalable, with greenfield applications at scale <$1,500/kW with increments of 50MW or less readily available.* ✓ *Siting capability enables reuse of existing infrastructure (e.g. decommissioning coal plants) and mining infrastructure to reduce costs*
Siting Flexibility	✘ *Requires specific geographic features (e.g. surface elevation differentials, and viable reservoirs) that are not often located in areas close to load centers or with significant grid need*	✓ *Flexible siting in areas where grid capacity and/or storage need exists* ✓ *Ability to construct underground cavern in a variety of geological conditions and no specific pre-existing topological requirements to construct*
Land Intensity	✘ *Requires much larger reservoirs and cannot cost-effectively construct lower reservoir underground, resulting in very large property requirements to develop and construct a project*	✓ *Smaller reservoir and land footprint, coupled with project modularity, enables projects to be easier to site on grid without compromising the application requirement*
System Flexibility	✘ *Limited flexibility to size projects below 200 MW due to high costs* ✘ *Projects typically larger than 300 MW*	✓ *Flexibility to tailor system to utility requirements* ✓ *Project size can range from 50 MW to 500 MW+ depending on site conditions and proposed application, with smaller projects possible on a brownfield basis* ✓ *Similar operating characteristics to gas-fired plants*

Comparison of Lithium-Ion Batteries vs. Hydrostor A-CAES

Hydrostor's A-CAES solution shares some positive characteristics with battery-based energy storage, including ancillary service provision, relatively small surface footprint (though for large-scale storage applications battery footprint is much larger than that of A-CAES), and fuel-free generation. However, Hydrostor A-CAES is in a different energy storage category than battery energy storage: it is a bulk, long-duration energy storage that is designed to deliver capacity at >50-500+ MW scale and energy discharge capabilities of 4-24+ hours, as essential long-term grid infrastructure. As a mechanical storage technology, A-CAES performance is not significantly impacted by time, amount of cycling, or environmental factors like temperature. It is therefore, a very reliable long-term, long duration storage that is highly cost-effective at scale, and able to directly replace synchronous generation with similar operating characteristics.

Battery energy storage on the other hand is typically much shorter duration, lower capacity energy storage, but one that is highly modular and rapidly responding. However, batteries are significantly limited by a lifespan that is roughly 20% that of A-CAES and exhibits significant performance degradation starting early in its lifespan and declining nearly linearly thereafter. Their performance is also materially impacted by environmental factors like temperature, which could be a significant restriction for hot-weather applications like Australia (while this can be adjusted for with auxiliary HVAC, it brings total efficiency down far below levels touted by battery manufacturers). Batteries therefore serve an important distributed, smaller-scale role with excellent frequency response applicability, but claims of useful applicability to long-duration utility-scale applications we believe are highly exaggerated in cost claims and ignoring many critical performance factors.

In summary, lithium-ion batteries and A-CAES are providing very different grid services, with batteries primarily focused on distributed, behind-the-meter applications and frequency response, whereas A-CAES can deliver grid services like capacity, voltage support and synchronous inertia much like conventional generating sources.

Given its long durations and flexible-siting capability, A-CAES is much better suited to the provision of electrical generating capacity than battery alternatives. Utilities and ISOs globally are increasingly reluctant to use the shorter duration and non-synchronous lithium-ion batteries, and several Independent System Operators (ISOs) / Electricity Market Operators have indicated the importance of >8-10 hour storage durations to be able to provide reliable capacity to grid when it is required.[2] Further, research on California gas plant operations by Wood Mackenzie showed that a 4-hour energy storage system would "miss most of the peaks that the gas peakers met in 2017" whereas "eight-hour storage hits 90 percent".[3] Other markets such as in the UK are "derating" the capacity value of <4-hour duration assets up to 80%. UK policymakers determined this action was necessary because these short-duration assets were shown to be insufficient to meet capacity needs during stress events.[4]

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[2] NYISO: Expanding Capacity Eligibility: DER Market Design (Oct 2018); PJM: Order 841: Updated Straw Proposal (Sep 2018)

[3] Energy Storage for Peaker Plant Replacement: Economics and Opportunity in the U.S. by Ravi Manghani, GTM Research

[4] National Grid Capacity Market Auction Guidelines. Section 1.3. (https://www.emrdeliverybody.com/Lists/Latest News/Attachments/197/Auction Guidelines 2018 v2.0.pdf)

As a result, A-CAES has a number of advantages over lithium ion batteries as outlined below:

	Li-Ion Battery	Hydrostor A-CAES
Cost	✗ *Cost of capacity when deployed at grid scale, long duration currently >US$3,000+ / kW* ✗ *Cost of storage currently >US$300+ / kWh; 50% of costs associated with BOP that cannot significantly decrease despite anticipated cell cost reductions* ✗ *Marginal cost of storage does not decrease with scale*	✓ *Cost effective solution with turnkey delivered costs ranging from US$1,000 to US$3,000/ kW* ✓ *Cost of storage currently <$150 to $300 / kWh delivered including contingency and warranties, and all BOP, with 20-30% reduction expected* ✓ *Marginal cost of storage significantly decreases with scale (e.g. less than $50 / kWh on a marginal basis from 4 to 12+ hours)*
Lifespan	✗ *Undergoes performance degradation in both power and storage duration after first cycle, worsening significantly with ongoing use* ✗ *Unusual for applications to last longer than 10 years, with many credible developers planning swap-outs at 5-7 year intervals*	✓ *50+ year useful life of all mechanical equipment, with no performance degradation* ✓ *Underground air storage caverns (approximately 50% of cost) designed to last much longer*
System Flexibility	✗ *While very modular for smaller-scale applications, charge/discharge ratings cannot be fine-tuned for specific application requirements* ✗ *Environmental changes (e.g. temperature) severely impact lithium-ion batteries*	✓ *Design allows for the charge power rating, discharge power rating, and storage duration all to be set independently allowing utilities to right size projects for grid needs* ✓ *Environmental changes have minimal impact, and systems can operate at any state of charge*
Grid Service Delivery	✗ *Unable to provide rotational inertia, important for grid stability and increasingly valued as renewable penetrations on the grid increase* ✗ *Cannot generate power without harmonics, diminishing power quality*	✓ *Provides synchronous motors and generation and naturally provides system inertia, softening the impact of fluctuations on the grid* ✓ *Delivers power without harmonics*
Other	✗ *Significant disposal costs* ✗ *Significant energy and greenhouse gas intensity on a life-cycle basis*	✓ *Long lifespan with little-to-no disposal considerations and minimal life-cycle emissions* ✓ *Broad global supply chain with existing capacity to absorb growth*

Hydrostor Projects

Hydrostor has implemented a series of operational or soon-to-be operational facilities ranging in size from 1 MW to 5 MW, as well as an active development pipeline of several 10 MW to 300 MW+ projects across North America, Australia and Chile. The smaller-scale operating facilities form the basis of Hydrostor's recent implementation track record in core markets, commercial-market integration, and operational performance. It is important to recognize that the deployment of large-scale A-CAES systems involves two basic scale-up considerations:

- **Construction/Implementation Scale-up:** Construction of A-CAES facilities differs at different system scales – Hydrostor's existing projects typically utilize brownfield infrastructure such as pre-existing salt formations and mining infrastructure to reduce construction costs (necessitated by their smaller-scale). However, Hydrostor's large-scale projects have well-established and proven implementation approaches to its top-side rotating and thermal management systems, as well as cavern construction, including FEED precedent and highly experienced global partners.

- **Operational Scale-up:** Operation of A-CAES facilities under its adiabatic process and hydrostatic compensation are directly analogous at all system sizes, and therefore operational history at Hydrostor's existing and near-term commercial operations date (COD) facilities are directly scalable to large-scale system operation.

Project Delivery

Through the delivery of two A-CAES projects to date (Toronto Island and Goderich) and the pre-construction development and engineering on a third (Angas project in South Australia), as well as through consultation with leading experts and EPC delivery partners experienced on analogous large-scale aboveground and subsurface projects, Hydrostor has developed a deep understanding of how best to deploy full-scale A-CAES projects over a range of sizes.

Hydrostor has developed project schedule estimates for greenfield, hard-rock cavern A-CAES systems ranging from 100 MW to 500 MW of discharge power capacity, with discharge durations from 4 to 12 hours. For reference, the indicative delivery timeline for a target system size (250 MW, 6-8 hours) ranges between approximately 2.5 – 3.5 years. This delivery timeline represents the post-financial-close construction schedule at which Hydrostor anticipates the project will be deliverable in average geological conditions. Hydrostor anticipates improvements in delivery timeline in above-average geological conditions and, in future, accounting for technological and project-delivery improvements. Delivery timeline under a brownfield scenario (e.g. reuse of existing mine) is a function of highly site-specific mining infrastructure and must be assessed on a site-by-site basis, with material reductions in schedule possible.

Given the above, and the timeframe required for large-scale power project development and construction, Hydrostor is developing its large-scale (100 MW to 300 MW+) projects in parallel to the deployment of its smaller-scale projects in order to meet market needs in the mid-2020's for long duration, flexibly-located storage. Hydrostor has significant financial backing to deliver on these projects today, including:

- Development partnership with major international infrastructure asset management fund.
- Supply partnership and equity sponsorship with top-tier global equipment supplier for major top-side components.
- Well-established vendor relationships with EPC partners for delivery of both the top-side mechanical/electrical infrastructure and subsurface cavern construction delivery.
- Construction bonding through EPC relationships and through Export Development Canada (credit support agency of the Canadian government).
- Performance insurance for large-scale system operations to meet specified client needs provided through global reinsurance providers.

Detailed descriptions of Hydrostor's existing and near-term COD facilities are included below.

A-CAES Reference Facility – Toronto Island A-CAES

With the completion of the Toronto Island Demonstration Facility in 2015, Hydrostor developed the world's first, grid connected adiabatic-CAES facility with utility host Toronto Hydro. The purpose of the facility was to demonstrate the technology and provide an ongoing testbed, with a potential long-term role as reserve power for Toronto Island. The facility demonstrated A-CAES' ability to play a significant role in the long-duration energy storage market globally.

The Toronto Island facility achieved its primary objectives, including:

1. The viability and benefits of a hydrostatically compensated air storage, which includes a near-constant pressure regardless of charge state and a reduced storage volume. For this purpose, the air was stored in underwater air storage vessels approximately 180 feet below the surface of Lake Ontario.
2. The ability to use standard, off-the-shelf compressors and turbines in a constant pressure compressed air energy storage process.
3. The performance of an adiabatic process in terms of round-trip efficiency, response time, ramp rate, and cycle life.
4. The cost and permitting baselines of the technology compare very favourably to other storage technologies (e.g. pumped hydro, cavern-CAES, li-ion batteries, flow batteries)

During the first 2 years of testing, Hydrostor optimized the facility through calibration, adding a new thermal storage system, and installing an enhanced control system. The facility has performed as expected during testing and the remaining optimization activities are well understood and viable. The testing of the system and new components proved out several of Hydrostor's advancements to the technology—specifically, the recycling of the heat of compression (adiabatic) and the hydrostatically compensated (and thus constant-pressure) operation. This design and operational approach is analogous to the approach in Hydrostor's A-CAES system, and thus, the Toronto Island facility proved the technical readiness of A-CAES.

Location	Toronto Island, Ontario, Canada
Utility Host	Toronto Hydro
Owner	Hydrostor Inc.
Application	Technical demonstration, R&D
Rating	660 kW / ~1 MWh
Type	Marine air cavity
In-Service Date	Nov. 15, 2015

Figure 3: Toronto Island A-CAES Demonstration Facility

Commercial Demonstration of A-CAES Technology – Goderich A-CAES Facility

The Goderich A-CAES Facility is a commercial storage plant located in Goderich, Ontario. Unlike the Toronto Island facility that uses water to keep air at constant pressure, the Goderich A-CAES facility stores air in an existing salt deposit formation. Hydrostor is in the process of commissioning the 1.75 MW peak output, 2.20 MW charge rating, and 15 MWh storage capacity A-CAES facility which is expected to be in service Q3-2019. The facility is contracted by Ontario's Independent Electricity System Operator (IESO) for peaking capacity, ancillary services, and full participation in the merchant energy market. The new facility is contracted for a charge time of 7.5 – 8 hours and a discharge time of 4 hours; however, the project includes the ability to operate for longer durations and the attached cavern contains substantial expansion opportunity for the future.

The facility is a utility-scale commercial application of the technology and the largest fuel-free (adiabatic) CAES system in the world, conforming to all interconnection, uptime, performance and dispatch requirements / standards as set out by the IESO. The Goderich project proves the ability of A-CAES to participate in an advanced electricity market and to provide a range of grid services.

Figure 4: Goderich A-CAES Commercial Demonstration Facility

Location	Goderich, Ontario, Canada
Offtaker	IESO (10-yr contract)
Application	Load leveling
Rating	1.75 MW / up to 15 MWh (contracted to 7 MWh)
Type	Salt Deposit Formation
In-Service Date	Commissioning; COD Expected Q3-2019

Goderich A-CAES Commercial Demonstration Facility

Full Demonstration of Integrated A-CAES Platform – Angas A-CAES Project

Through late 2017, Hydrostor undertook a site identification process to identify preferred sites to demonstrate hard rock mine air cavern storage technology and open-up the Australian market. From that process, Hydrostor selected the Angas Zinc Mine near Strathalbyn in South Australia. The mine, owned by Terramin Australia Limited, is currently in care-and-maintenance. The 5 MW, 10 MWh Angas A-CAES project will leverage the existing non-operational mine infrastructure for development of the A-CAES purpose-built, air storage cavern using a closed-loop water reservoir system (surface pond) for hydrostatic compensation. This project demonstrates the hard rock mine air storage cavern capability of A-CAES, while acting as a vehicle to open the Australian market to A-CAES technology.

As a market participant in the Australian National Energy Market (NEM), the project increases the value delivered by renewable energy by addressing the issues of reserve capacity, peak demand, and integration of renewables. During off-peak hours, electricity from the grid will be used to compress air into the mined air storage cavern. During charge, the heat of compression will be stripped out of the air stream and stored in sensible thermal storage using pressurized water, similar to the process proven at Toronto Island and Goderich. During peak hours, the stored air will be re-heated as it enters a turbine to generate electricity when the grid needs it.

The Angas A-CAES project will consist of a 5 MW turbine-generator and a 3 MW compressor and includes 10 MWh of storage capacity (2-hour storage duration). The project sizing was based on:

- **Turbine size:** Maximizing project capacity while remaining below the 5 MW threshold that results in additional regulatory requirements and a more costly interconnection process.
- **Compressor size:** Optimizing compressor power to reduce demand charges yet increase flexibility on charge times. The compressor size is also optimized to enable the addition of a future solar PV facility.
- **Storage duration:** Sized to utilize the full underground space available at the Angas Zinc Mine at sufficient depth requirement for A-CAES operating pressures, without additional mining, with the potential for expansion later.

The FEED Study for the Angas A-CAES Project is complete and construction has commenced. The project is expected to be commercially operational in Q4 2020.

Location	Near Strathalbyn, South Australia
Offtaker	Merchant and R&D Tax Rebates
Owner	Hydrostor Inc.
Application	Load leveling, voltage support, inertia
Rating	5 MW / +10 MWh
In-Service Date	Under construction; COD expected 2020

Figure 5: Angas A-CAES Project

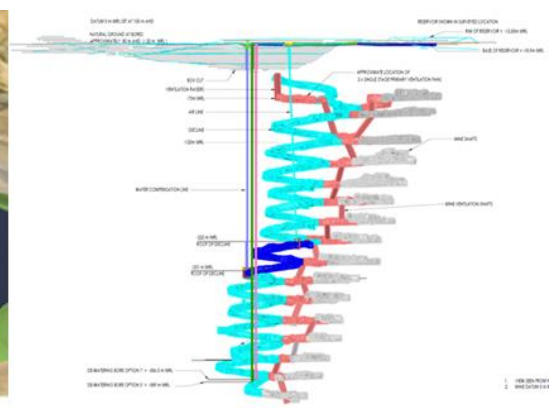

Figure 6: Angas A-CAES Project - 3D Model of Aboveground Infrastructure and Underground Schematic

A-CAES Technical and Performance Specifications

Hydrostor A-CAES performance overall is similar to other rotating power generation equipment such as natural gas-fired facilities. Specific performance metrics for a typical full-scale (100+ MW) A-CAES project are shown below.

Metric	Performance Specifications	Performance [1]
Response Time	Time from signal to charge (electrical power consumption)	5 min
	Time from signal to discharge (electrical power generation)	5 min [2]
Response Time with Hybrid Battery	A short-duration (5–10 min) battery system can provide rapid power consumption or delivery during charge and discharge response	500 ms
Spinning Mode	Auxiliary power draw to operate the system as a synchronous condenser for continuous voltage support and to provide faster response times	0.5–2% of power rating
Ramp Rate	Maximum rate of change on electrical consumption / generation	25% / min [2]
Reactive Power Delivery	Maximum reactive power during charge / discharge [3]	1.6 MVA_r/MW
	Maximum reactive power during standby in spinning mode [3]	1.75 MVA_r/MW
Efficiency	Steady-state round-trip efficiency (AC-to-AC), including all auxiliary loads, assuming daily cycling	60%
Lifetime	Cycle life	20,000 cycles
	Equipment useful life	30–50+ years
Real Inertia	Provided by compressor and turbine while charging, discharging, or in spinning mode	
Metric	**System and Site Specifications**	
System Configuration	Charge, discharge, and storage capacity are sized independently	
Surface Equipment	Compressor & turbine trains available in 5 MW to 100 MW increments, scaled to meet project needs	
Footprint	Closed loop: 20 acres (250 MW, 4-hour facility) to 60 acres (500 MW, 10-hour facility)	
	Open loop: significantly smaller where open-loop systems possible (40 – 50% smaller)	
Water	No source water limitations (fresh, salt or recycled); negligible temperature impact on water	
	Water requirement of 170 m^3/MWh	
Noise	Noise from facility approximately 55 dB at site perimeter	

(1) Metrics can be optimized to meet project requirements
(2) Response time and ramp rate can be improved according to customer needs
(3) Based on machines with a power factor of 0.8; reactive power delivery per machine of ~0.75 MVAr/MW during operation and ~0.88 MVAr/MW while acting as a synchronous condenser

If any additional information is required on the technology for this purpose, or if there are any questions about A-CAES technical or performance specifications, please don't hesitate to contact us.

Hydrostor A-CAES Indicative CAPEX / OPEX

When built under greenfield conditions, Hydrostor's A-CAES technology is most cost effectively deployed at larger-scale system sizes (200 – 500+ MW) where significant economies of scale are realized. Indicative CAPEX costs are shown in Figures 7 and 8 below on a $AUD/kWh and $AUD/kW basis for a range of system sizes and storage durations.[5]

Costs are based on a range of factors such as geological conditions, project delivery options and item costing variability. The low ends of the ranges, for example, are based on the assumption of more-favourable geological conditions, technology and project delivery optimizations and bulk costing on certain components.

All AUD capital costs as outlined are for turnkey Hydrostor A-CAES systems fully installed and delivered to the high-voltage grid, including all balance-of-plant. Capital costs also include contingency, bonding and insurance provisions for above ground and subsurface infrastructure, aligned with industry-standard best practices.

For planning and modelling purposes, A-CAES can be sited where it is required on the grid in locations where bedrock is available at cavern depth (~400 – 600 metres). Hydrostor would be happy to collaborate with the PUO in support of its planning and modelling work to identify areas of grid need and confirm the availability of bedrock at cavern depth for A-CAES deployment.

Depending on the additional availability of subsurface void space (e.g., existing mining workings), the figures below would see cost reductions in the range of ~20–25% (250 MW) and ~15–20% (500 MW), depending on duration. Also note that with existing mining workings, A-CAES can be highly cost effective at even smaller system sizes, which can be assessed on a site-specific basis.

Costing Basis for A-CAES in Australia

The indicative cost curves provided are based on several recent estimates for commercially backed proposals of A-CAES systems in the United States. In collaboration with its delivery partners, Hydrostor's estimates are based on independently verified engineering estimates for all top-side and thermal management equipment requirements, as well as independent expert subsurface costing for Hydrostor's A-CAES applications building directly on the decades of experience with analogous mined storage caverns used for the underground storage of hydrocarbons.

As outlined above, all AUD capital costs shown in the figures below are for turnkey Hydrostor A-CAES systems fully installed and delivered to the high-voltage grid, including all balance-of-plant. Capital costs also include contingency, bonding and insurance provisions for above ground and subsurface infrastructure, aligned with industry-standard best practices.

Figure 7: A-CAES Cost Profile (AUD $/kWh) for delivery in Australia

[5] Assuming a 1:1 charge to discharge ratio. Hydrostor's A-CAES technology has significant flexibility to customize a solution which can include sizing charge, discharge and energy storage duration independently.

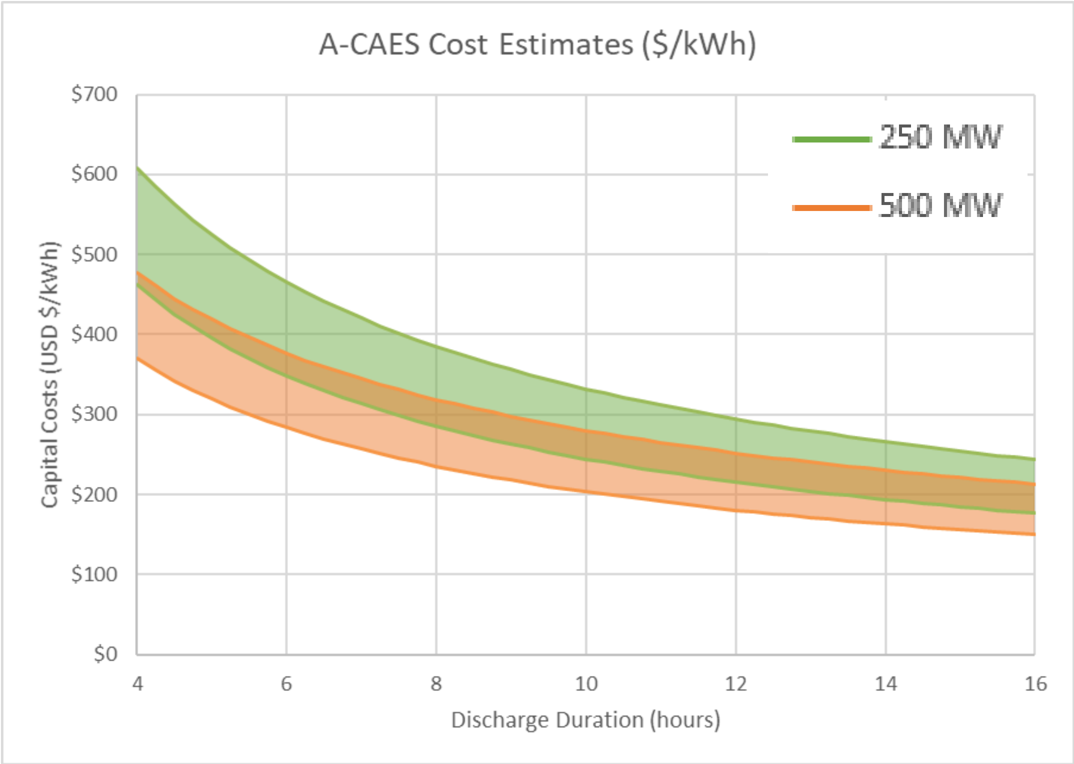

Figure 7: A-CAES Cost Profile (AUD $/kWh) for delivery in Australia

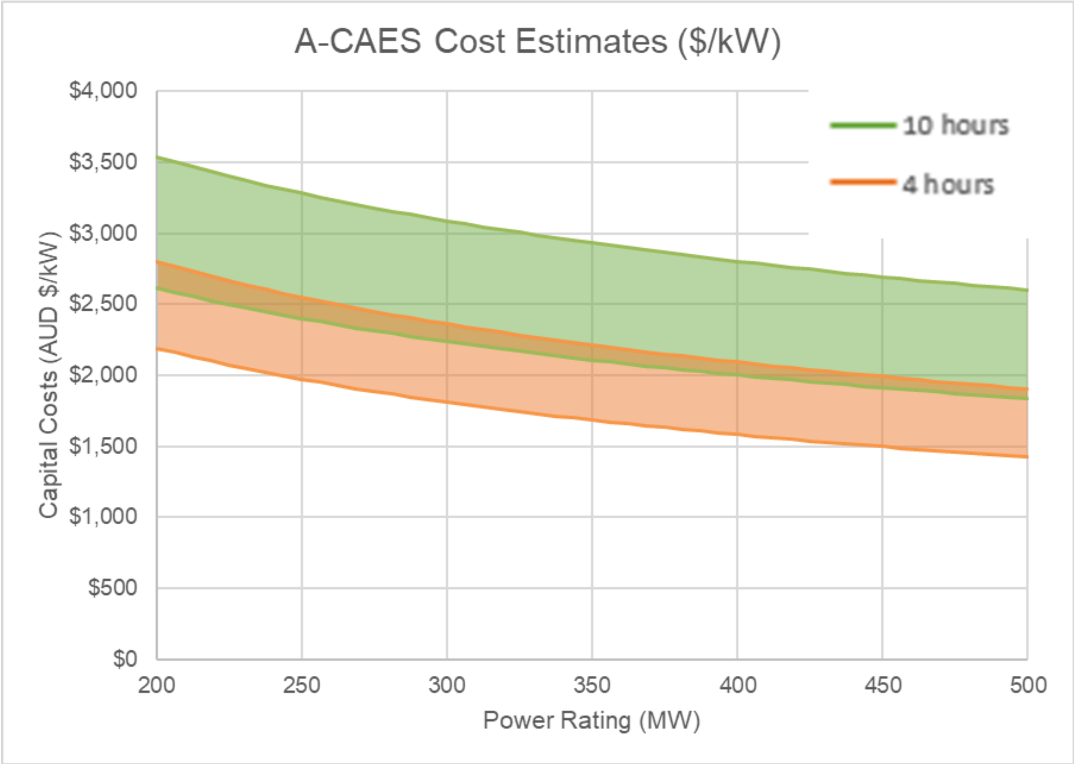

Figure 8: A-CAES Cost Profile (AUD $/kW) for delivery in Australia

Revenue Requirement

While overnight CAPEX is one metric to consider, the revenue requirement for A-CAES at scale is considerably lower than competing technologies such as lithium-ion, resulting in a material cost advantage for A-CAES over its +50-year asset life. This advantage only grows with increasing system size and duration given A-CAES' ability to leverage significant economies of scale. To illustrate this, note that lithium-ion batteries see an approximate doubling of revenue required when going from a 4-hour duration to an 8-hour duration. In contrast, the equivalent jump in duration for an A-CAES system results in an increased revenue requirement of only 15–30% depending on the system size.

The advantage A-CAES enjoys over competing technologies with respect to revenue requirement is particularly relevant when considering the longer durations required (i.e. 8+ hours) to enable the effective replacement of thermal / peaker plants, integration of higher penetrations of renewable energy, and the deferral of transmission investments. The use of batteries in these applications is not cost effective, as they fail to deliver economies of scale and have a much shorter life requiring significant augmentation costs, i.e. capital replacement required to maintain the full usable energy storage capacity (MWh) over the life of the unit due to degradation.

Operating Costs

Due to the similarities between the configuration of an A-CAES process plant and that of a simple-cycle gas-turbine plant ("SCGT"), the annual operations and maintenance ("O&M") costs of the two are comparable. While non-fuel annual O&M costs for an SCGT vary between 1% and 2% of the plant's capital cost, depending on factors such as the local labour costs and the plant's capacity factor[6], the equivalent costs for an A-CAES plant are expected to differ for two primary reasons: a lack of combustion in the process and a large portion of capital cost being related to subsurface infrastructure with negligible maintenance costs.

Because no combustion occurs in the A-CAES process, the system's equipment cycles through a much lower temperature range when alternating between operating states. Whereas SCGTs experience internal temperatures up to 1,200°C, A-CAES infrastructure is never exposed to temperatures greater than 250°C. Additionally, because no combustion occurs in the process, no combustion by-products accumulate in the system's turbine, significantly reducing maintenance requirements.

The capital costs to develop the subsurface infrastructure of an A-CAES plant are on the order of 50% of the overall system capital cost, depending on the system parameters. The O&M costs for this subsurface infrastructure are negligible, so, as a percentage of overall system capital costs, the O&M costs of an A-CAES plant is projected to be substantially lower than those for an SCGT. The all-in O&M costs for an A-CAES plant are thus estimated at approximately 1% of the full-system capital costs (equivalent to roughly 2% of the capital cost for the aboveground infrastructure) per annum. This estimate has been verified in collaboration with Hydrostor's delivery partners through itemized O&M budgets for larger-scale system sizes, available upon request.

End of Memo.

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[6] 2017 PSE Integrated Resource Plan – Gas-Fired Resource Costs; Fuel and Technology Cost Review Report, ACIL Allen, June 2014; Lazard's Levelized Cost of Energy – Version 12.0, November 2018;

Appendix: Hydrostor A-CAES Supplemental Information

How A-CAES Works

Figure 9 illustrates how A-CAES works. As the A-CAES system is charged, off-peak or surplus electricity from the grid or a renewable source is used to power an air compressor, which converts the electrical energy into potential energy and heat in the form of heated compressed air. The heat generated during compression is captured by a set of heat exchangers and stored separately for later use. The air stream is compressed to match the pressure needed to inject it into the underground storage cavern. Once in the cavern, the air can be stored until electricity is required.

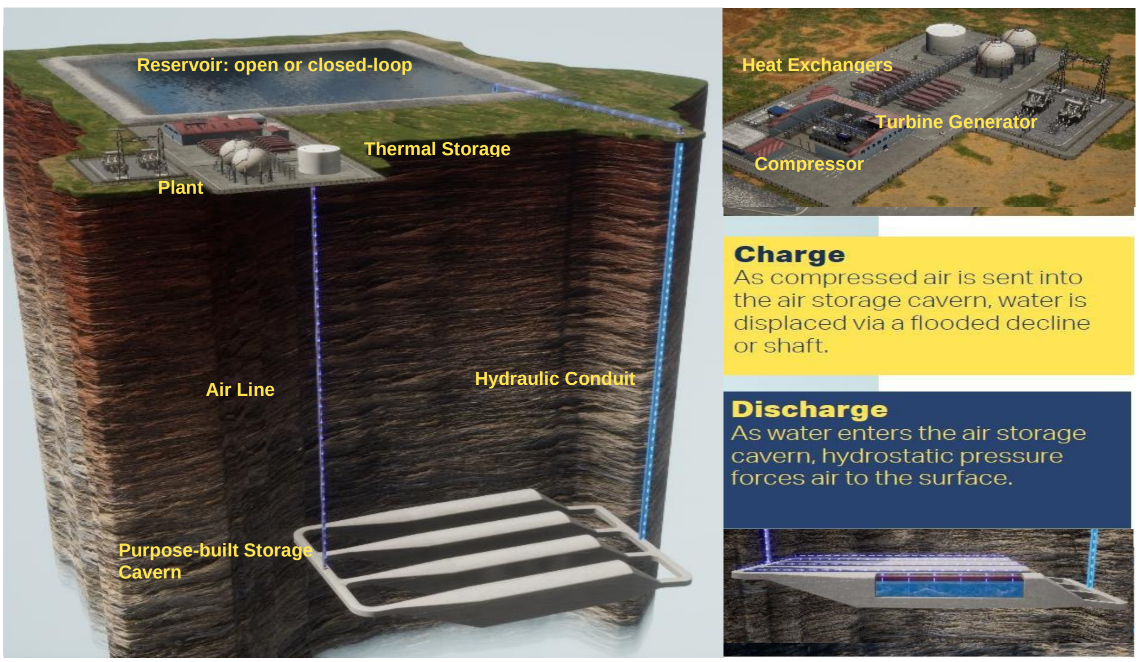
Hydrostatic compensation is provided by a surface reservoir of water, connected to the cavern through the construction access facilities (either a shaft or a helical decline, depending on geology). As air is charged into the storage cavern, water is displaced up the access decline or shaft and into the surface reservoir, storing substantial potential energy in the large elevation difference. Since the elevation of the water surfaces in the reservoir and cavern change by only a slight fraction of the distance between the two, the air pressure within the cavern is maintained at a near constant level. This is essential for the efficient performance of the air handling equipment for both pressure variation and pressure regulation (in traditional CAES the storage pressure varies significantly, which limits system effectiveness).

When energy is required, the compressed air is permitted to flow back to surface, which it does so under the process of the compensation water re-flooding the cavern. The stored heat is reinjected through the same heat exchangers before the compressed air is used to drive a turbine, generating electricity and supplying it back to the grid. As turbines require heat for both adequate power production and thermal protection, it is only through the use of the thermal storage system that Hydrostor's A-CAES can be fossil fuel and emissions free.

As the cavern can be fully flooded, all of the stored air is recoverable; unlike traditional CAES which requires a substantial portion of the air to maintain a minimum storage pressure for either cavern protection or turbine operation. This drastically reduces storage volume requirements. It is only through the use of hydrostatic compensation that Hydrostor's A-CAES can economically utilize mined storage caverns and benefit from the ability to be constructed in most geologies.

How Advanced Compressed Air Energy Storage (A-CAES) Works

1. Compress Air Using Electricity	2. Capture Heat in Thermal System	3. Store Compressed Air	4. Convert Compressed Air to Electricity
Off-peak or surplus electricity from the grid or a renewable source is used to operate a compressor that produces heated compressed air.	*Heat is extracted from the air stream and stored inside proprietary thermal store. This adiabatic process increases overall efficiency and eliminates the need for burning fossil fuels during expansion.*	*Air is stored in purpose-built storage caverns where hydrostatic compensation is used to maintain the system at a constant pressure during operation.*	*Hydrostatic pressure forces air to the surface where it is recombined with the stored heat and expanded through a turbine to generate electricity on demand.*



Industry-proven air and heat processing equipment with decades of operational history in power and oil & gas sectors.	*Well-established mining techniques for storage cavern construction based on precedents of more than 150 analogous storage caverns globally.*	*Proven application of hydrostatic compensation and thermal management systems.*

Figure 9: How A-CAES Works

An animation illustrating how Hydrostor's A-CAES system works can be found at hydrostor.ca.

The Three Subsystems of A-CAES

Large-scale deployment of energy storage technologies has been challenged by several factors, including total installed cost, scalability, and geographic constraints (such as topography and footprint), and in the case of traditional CAES, the reliance on burning fossil fuels. Each of the three subsystems of Hydrostor's A-CAES technology has been designed from the ground up to address these factors through the use of standard industrial equipment and two key innovations to traditional CAES technology: the development of a patented thermal storage system that eliminates the need for fuel and the use of hydrostatically compensated air storage caverns.

Electrical Conversion	▪ A-CAES uses standard electrically driven air processing equipment (compressors, motors, turbines, and generators) routinely used in power and oil & gas applications, where they offer exceptional reliability ▪ Tier 1 original equipment manufacturers (GE Oil & Gas, Man Energy Solutions, Hanwha Power Systems) offer best-in-class warranties and performance guarantees ▪ Established supply chains and global support services for this equipment mean that they can be deployed on any scale at a competitive cost
Thermal Management *Hydrostor Innovation*	▪ Hydrostor has developed an adiabatic process, enabling fossil fuel-free and emission-free CAES ▪ The thermal management subsystem captures heat developed as the air is compressed, stores it, and reinjects it into the air on generation, boosting electricity production and system efficiency ▪ While the system is proprietary, it relies on well-proven, industry-standard heat processing equipment available from Tier 1 original equipment manufacturers (Alfa Laval, Therco-Serck, Exchanger Industries)
Air Storage *Hydrostor Innovation*	▪ A-CAES stores air in mined caverns, analogous to those used for the storage of hydrocarbons, enabling siting flexibility in almost all common geologies ▪ Mined caverns are a mature storage solution with 150 deployments worldwide with design and construction by global experts (Geostock, Agapito Associates, Lane Power Solutions) ▪ Hydrostor's innovation to this storage solution is the use of a water flooded cavern, which drastically reduces the mined volume required and enables fully recoverable, near constant pressure air storage

Figure 10: Three Subsystems of A-CAES

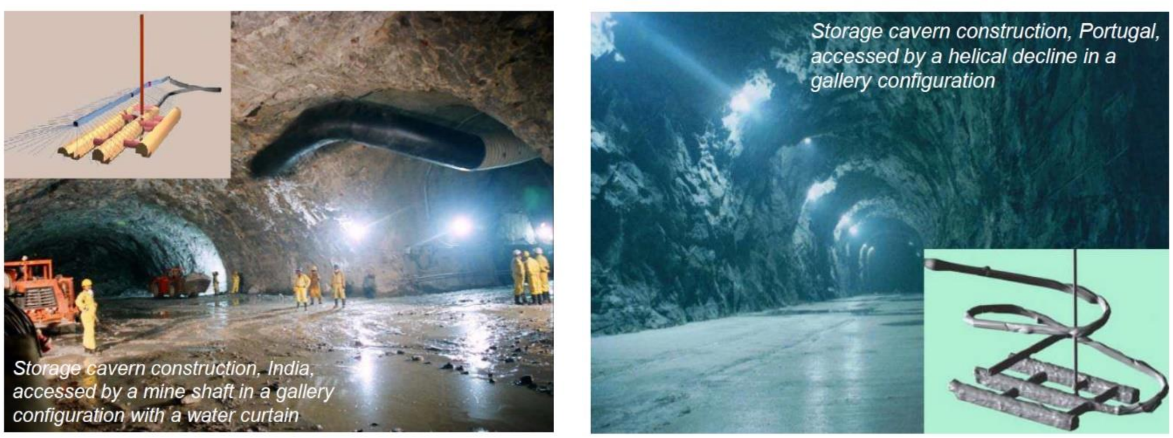


Figure 11: Hard-rock storage caverns are commonly used for the bulk storage of hydrocarbons

Hydrostor's innovations represent an important paradigm shift in CAES technology (a proven and deployed technology[7]), notably:

- By capturing and reusing heat developed during compression, the A-CAES process is adiabatic. This increases the system's efficiency, eliminating the need for burning of fossil fuels, as required for traditional CAES. Hydrostor's patented thermal storage subsystem has thereby unlocked adiabatic emissions-free CAES. This is all conducted using proven and reliable equipment with decades of operational experience in the oil and gas sectors, and has been demonstrated at Hydrostor's Toronto Island and Goderich facilities as the world's first grid-connected, adiabatic CAES facilities.
- By storing air under hydrostatic compensation, the air processing equipment can be run at a near constant operating pressure, essential for maximizing system efficiency, without the need for a massively oversized storage volume. This has enabled the use of flexibly sited engineered underground storage caverns, which can only be cost-effectively delivered for CAES with Hydrostor's approach to hydrostatic compensation. This innovation has thereby untethered CAES from the highly specific geology of salt caverns historically employed by CAES, and enabled A-CAES to be flexibly sited where required on the grid. At the same time, Hydrostor's A-CAES is still compatible with traditional salt cavern air storage, for projects which coincide with a salt deposit.

Geotechnical and Water Considerations

As hydrostatically compensated air storage offers a substantial improvement in energy density, Hydrostor can cost-effectively employ mined storage caverns for CAES. Because Hydrostor uses conventional mining techniques, it can construct hard-rock caverns in a majority of common geologies. A mine access—either a shaft or a decline—is constructed to provide access for personnel and equipment to the depth at which the cavern is to be developed. A series of interconnected cavities (drifts) are then excavated to create the storage volume.

Hydrostor has established relationships with cavern design and construction management experts Geostock Entrepose, Agapito Associates, and WSP, who have collectively designed and/or constructed approximately 190 hard-rock caverns globally. Hydrostor also has strong relationships with RESPEC, a consulting firm who led pioneering research and development of underground CAES technology in partnership with the US Department of Energy. Cavern development leverages typical mining techniques, with significant optimizations made possible due to the differing nature between storage caverns and extraction mining. Some crucial differences between extraction mining and hard-rock cavern development which lead to increased flexibility, lower development risk, or cost and schedule optimizations, are:

- Caverns can be flexibly situated to take advantage of the best geology for excavation at a site, while extraction mining must contend with the geology of and surrounding an ore body.
- Caverns are developed at single depth, enabling the use of rapid shaft development techniques, instead of conventional drill-and-blast shafts or declines, required for off-shoots at various depths.

[7] CAES has been deployed commercially at large scale at the Huntorf CAES facility in Germany (290 MW) and McIntosh CAES facility in Alabama, USA (110 MW).

- During service, caverns are partially supported by the internal storage pressure, supporting longer service lives with a similar ground support design than in extraction mines.

The similarities with mining enable hard-rock caverns to rely on a supply chain, a pool of expertise, and a series of techniques developed for a much larger industry, while the differences enable flexibility and optimization, by selecting the most cost-effective techniques developed for a more demanding industry.

A-CAES can use salt, non-potable or fresh water, including the use of groundwater where available, as compensation water to provide hydrostatic pressure. The system's operation has no temperature or chemical impact on the water. A-CAES can utilize a purpose-built reservoir i.e. "closed-loop" system, or an "open-loop" compensation system which uses water sourced from a natural body of water (e.g. ocean). The use of an open-loop system is considered on a project by project basis when there is a nearby body of water, as this approach reduces the cost of construction, and overall footprint of the system. A-CAES enjoys a distinct advantage over pumped hydro, requiring approximately 15 to 20 times less water (and a significantly smaller land footprint) to deliver the equivalent energy storage capacity. This is particularly relevant in regions where water is a scarce resource. Our approach to project development, delivery and operations includes proactive community engagement, environmental protection practices and sustainable management of natural resources, including water, working collaboratively with local partners and stakeholders.

End of Appendix.