HYDROSTOR

ADVANCED COMPRESSED AIR ENERGY STORAGE

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Hydrostor Advanced Compressed Air Energy Storage (A-CAES) is a cost effective, fuel-free storage solution that can be sited where needed to deliver hundreds of megawatts (MW) and 4 to 24+ hours of storage.

Low Cost

- Lowest installed cost per kilowatt hour (kWh) for large-scale, long duration energy storage (100+ MW).
- 50+ year system life, with unlimited cycling and no replacement required.

Emission-free

- Increased efficiency, lower operating costs, and no hazardous chemicals or fossil fuels with Hydrostor's patented adiabatic thermal management system.

Flexible Siting

- Sites where grid requires it using proprietary, purpose-built air storage cavern.
- No toxic materials, contaminants, or thermal impacts on environment.
- Suitable for urban environments, with low noise and minimal surface footprint.

Customized System Design

- System design optimized to match client requirements, with independent settings for charge, discharge, and storage capacity.

Ancillary Services

- Supports electrical grid stability and resiliency, with the system's synchronous generation providing rotational inertia.
- Delivers volt-ampere reactive (VAR) support, spinning reserve, black start, and frequency response.

Proven Solution

- Warrantied and guaranteed systems using industry-proven mechanical equipment from tier one OEM suppliers paired with well-tested planning and engineering expertise derived from analogous projects.

How A-CAES Works

Step 1
Compress air using electricity

- Off-peak or surplus electricity from the grid or a renewable source is used to operate a compressor that produces heated compressed air.

Step 2
Capture heat in thermal store

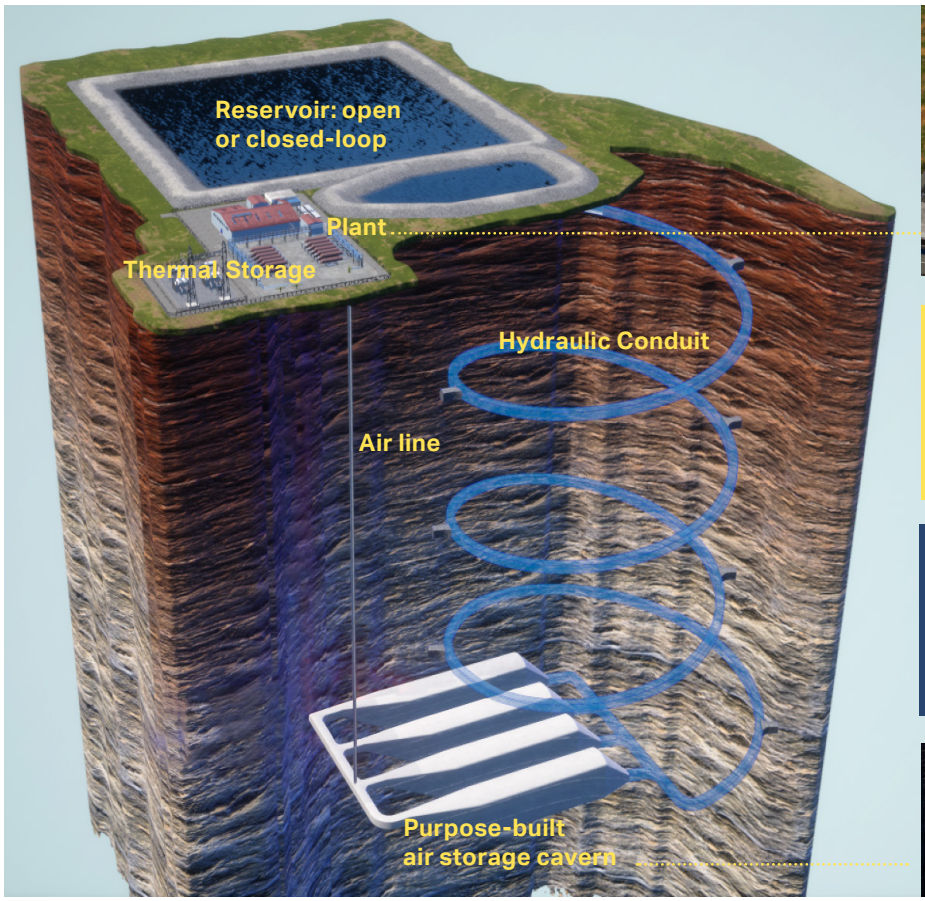
- Heat is extracted from air stream and stored inside proprietary thermal store.
- This adiabatic process increases overall efficiency and eliminates the need for fossil fuels during operation.

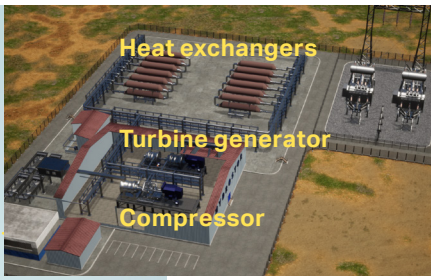
Step 3
Store compressed air

- Air is stored in purpose-built air storage cavern where hydrostatic compensation is used to maintain the system at a constant pressure during operation.

Step 4
Convert compressed air to electricity

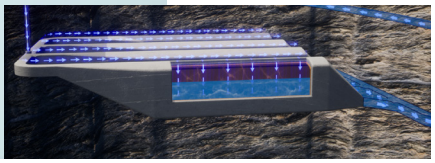
- Hydrostatic pressure forces air to the surface where it is recombined with the stored heat and expanded through a turbine to generate electricity on demand.





Charge
As compressed air is sent into the air storage cavern, water is displaced via a flooded decline or shaft.

Discharge
As water enters the air storage cavern, hydrostatic pressure forces air to the surface.



- Industry-tested mechanical equipment with decades of operational history in oil and gas sector.
- Well-established mining techniques for air storage cavern construction based on identical precedents for cavern construction globally.
- Well-proven application of hydrostatic compensation and thermal storage systems.

A-CAES cleanly and cost effectively solves today's most difficult energy challenges.

Fossil Plant Replacement

- Provides identical synchronous generation on the grid, improving reliability without emissions
- Repurposes decommissioned thermal plants and defers remediation costs
- Reduces costs for construction by reusing existing interconnection, buildings, water intakes, permits, and more

Renewable Integration

- Provides baseload wind and solar
- Optimizes solar/ wind project economics through time shifting
- Reduces curtailment

Transmission Deferral

- Serves as non-wires alternative to defer network infrastructure investment
- Alleviates grid congestion during peak periods
- Locatable, reliable power for critical areas and infrastructure

Mines and Large Industrial

- Improves reliability and reduces electricity grid charges (on-grid)
- Reduces or eliminates fuel costs and logistics (off-grid)
- Repurposes legacy mining infrastructure

A-CAES specifically targets very high-value grid and customer applications that are not easily accessible by other storage technologies.

Hydrostor's A-CAES is the best-in-class solution for long duration, bulk energy storage.

▲ *Hydrostor's A-CAES technical demonstration facility in Toronto, Ontario, Canada, is the world's first operational commercial-scale adiabatic A-CAES plant, in partnership with utility host Toronto Hydro.*

▼ *Hydrostor's A-CAES commercial demonstration plant in Goderich, Ontario, Canada, is contracted by Ontario's Independent Electricity System Operator (IESO) for peaking capacity.*

Total installed turnkey cost estimates of Hydrostor A-CAES technology, including all balance of plant, typically range from USD $1,500 to $3,000 per kW, depending on such factors as site location and system design.

Capital investment for Hydrostor A-CAES can be significantly lower than other storage technologies while offering several important advantages. The technology combines established mining expertise and techniques with proven, bankable, industry-standard equipment to offer a compelling solution at scale.

Hydrostor A-CAES provides long-duration, emission-free energy storage that also delivers synchronous generation and inertia. The technology provides more flexible siting options than pumped hydro or conventional CAES, and its variable capacity provides dispatchable load and generation services. It is also right-sized to meet your project requirements, including charge, discharge, and storage capacity.

Compared to competing technologies, Hydrostor A-CAES has many distinct advantages that lower life cycle costs.

- Fuel, chemical, and emission-free.
- Long lifespan (50+ years of unlimited cycling).
- Less storage volume needed versus conventional CAES or pumped hydro.
- Low-pressure, bankable surface equipment.
- Small surface footprint, making it ideal for high-value grid applications near load.
- Existing site infrastructure, such as retired fossil plants and legacy mine sites, can be repurposed to lower capital costs.

A-CAES Competitive Comparison:

	Hydrostor A-CAES	Gas Turbine	Traditional CAES	Pumped Hydro	Li-Ion Battery	Flow Battery
Size (MW)	50-500+	>100	150-500+	>100	1-100	1-20
Duration (hours)	>6	N/A	>6	>6	1-4	4-6
Round-Trip Efficiency	>60%	N/A	30-40%	70-85%	85%	70%
Emissions	None	Emitting	Emitting	None	None	None
Life cycle (cycles)	>20,000	>20,000	>20,000	>20,000	5,000	10,000
CAPEX ($/kW)	$1,500-$3,000	$1,000	$1,500-$2,500+	>$2,500	$3,000+	$5,000
CAPEX ($/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.*

A-CAES Experience

Hydrostor has multiple projects in operation/under construction in Canada and Australia that total more than 25 MWh. Hydrostor also has numerous projects in advanced development across the United States, Australia, and Canada, ranging in size up to 500 MW, 5 gigawatt hours (GWh).

Toronto A-CAES Facility

Location:
Toronto Island, Ontario, Canada

Utility Host:
Toronto Hydro

Application:
Technical demonstration, R&D

In-Service:
2015

Goderich A-CAES Facility

Location:
Goderich, Ontario, Canada

Owner:
NRStor, Inc., contracted by Ontario's Independent Electricity System Operator (IESO)

Application:
Commercial demonstration, peaking capacity

In-Service:
2019

Angas A-CAES Project

Location:
Strathalbyn, South Australia, Australia

Owner:
Hydrostor, dispatched into the National Electricity Market (NEM)

Application:
Load leveling, frequency response, inertia

In-Service:
2020

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 Warm Start	Time from signal to full electrical power consumption (charge)	3–5 min
	Time from signal to full electrical power generation (discharge)[2]	~5 min
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	<2% of output capacity
Ramp Rate	Maximum rate of change on electrical consumption / generation	65 MW/min
Reactive Power Delivery	Maximum reactive power during charge or discharge[3]	1.5 MVA_r/MVA
	Maximum reactive power during standby in spinning mode[3]	2.2 MVA_r/MVA
System Inertia	Provided by compressor and turbine regardless of operating condition	~2.2 MWs/MVA
Efficiency	Steady-state round-trip Efficiency (AC-to-AC), including all auxiliary loads, assuming daily cycle	>60% of input electricity
Lifetime	Cycle life[4]	>20,000 cycles
	Equipment useful life	>50 years

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 250 MW increments, scaled to meet project needs
Location	15 acres (100 MW – 4 hr facility) to 70 acres (300–500 MW – 12 hr facility); smaller where open-loop systems possible
Water	No source water limitations (fresh, salt or recycled); no temperature impact on water
	Total water requirement of 300,000 m^3 for a 250 MW 8-hour system
Noise	Noise from facility approximately 55 decibels at site perimeter
Electrical	Interconnection voltage available across low, medium or high ranges, standard is 115 kV
	Option to charge and/or discharge in DC

(1) Metrics can be optimized to meet project requirements
(2) Response time for long idle durations may be longer (+~2 mins), but system can be optimized according to customer needs
(3) Based on reactive power delivery per machine of 0.48-0.75 MVAr/MVA during operation; 0.48-1.25 MVAr/MVA while acting as a synchronous condenser
(4) Cycle life estimate is conservative and expected to be much higher for most applications

About Hydrostor

Hydrostor, a private company founded in 2010 and based in Toronto, Canada, is a leader in Advanced Compressed Air Energy Storage (A-CAES), a technology 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, transmission deferral and ancillary services, and is ideal for use in behind-the-meter or remote applications for mines and large industrial operations. 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 located where the grid needs it, including the ability to replace retired fossil generating plants and the need for new transmission. Hydrostor has multiple projects in operation or under construction in Australia and Canada, as well as numerous projects in advanced development globally. Learn more at hydrostor.ca.

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