HYDROSTOR

ADVANCED COMPRESSED AIR ENERGY STORAGE

**Thermal-Mechanical-Chemical Energy Storage Workshop**

August 2022

*Enabling the Energy Transition*

# A-CAES's Unique Long Duration Value Proposition

- How "A-CAES" differs from "Traditional-CAES"

- Technical basis for A-CAES value proposition:
  i. Adiabatic vs. diabatic or isothermal
  ii. Water for thermal storage
  iii. Hydrostatic compensation (isobaric) vs. fixed volume pressure vessel
  iv. Rock caverns vs. salt caverns
  v. Air as working gas/fluid
  vi. A-CAES (aka Pneumatic PHS) vs. PHS

- A-CAES performance specifications

- A-CAES commercial status

# Paradigm Shift from CAES to A-CAES

**Traditional CAES** → **A-CAES**

**Traditional CAES**

- ✓ Proven technology and established supply chain, O&M
- ✗ Heat loss during compression requires gas burners to re-heat air
- ✗ Siting dependent on salt cavern or mine to act as storage cavern
- ✗ Use of natural gas for reheating

*McIntosh CAES Plant in McIntosh, Alabama*

**A-CAES**

- ✓ Proven technology and established supply chain, O&M
- ✓ Adiabatic process increases system efficiency
- ✓ Hard rock caverns exponentially increase siting flexibility (in addition to salt caverns)
- ✓ Thermal storage eliminates the need for gas fired reheating

*Hydrostor Goderich, A-CAES Ontario facility*

**50+ year technology enhanced to meet 21st Century Energy Transition needs**

# A-CAES in a Nutshell

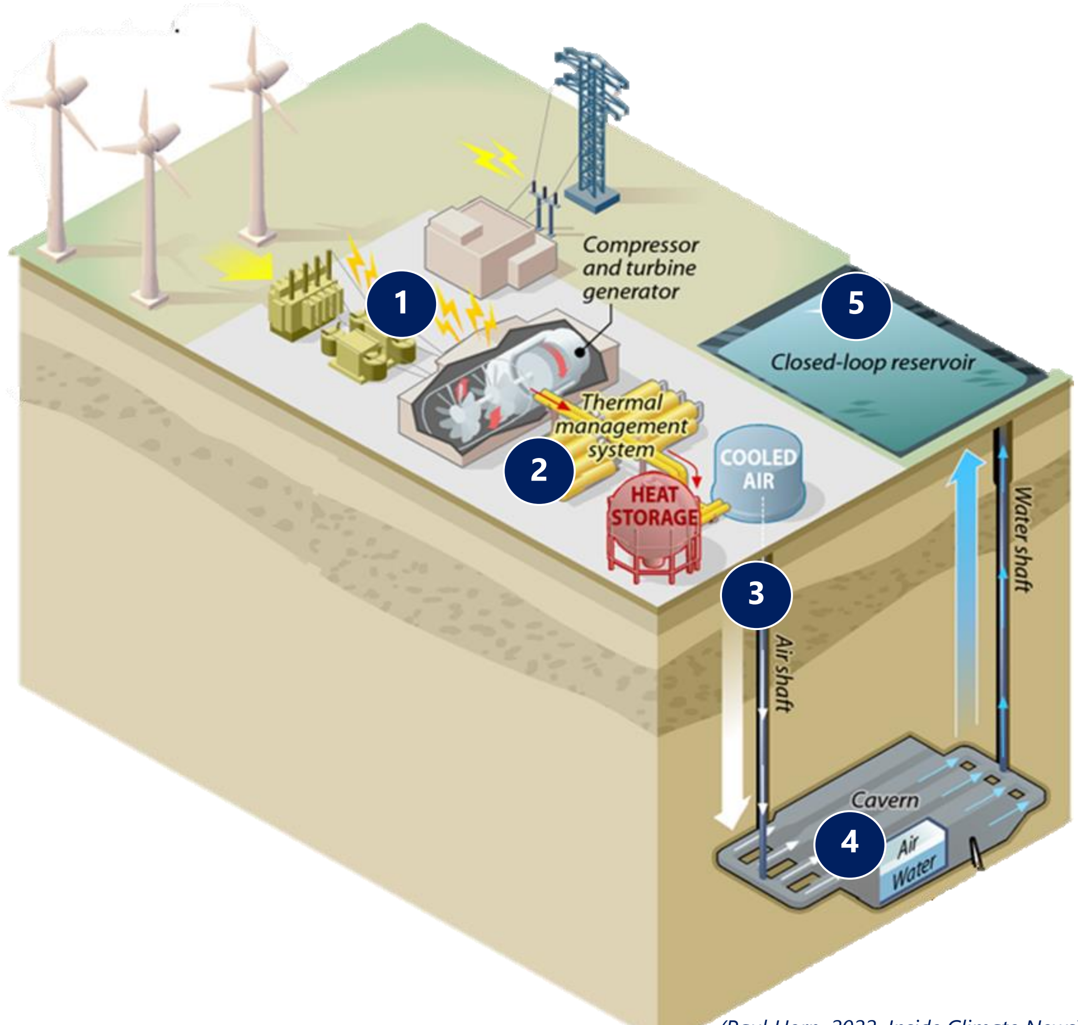
1 **Compression** Off-peak or renewable electricity powers a compressor, which produces heated, compressed air

2 **Heat Exchanger** Heat is extracted from the air and captured by the thermal management system for reuse

3 **Air Pump** Air is pumped down the shaft into a water filled cavern

4 **Water Displacement** Compressed air forces water up the shaft to the surface reservoir

5 **Fully Charged State** Once reservoir is filled the plant is ready to provide electricity on demand for up to 10 hours at a time




*(Paul Horn, 2022, Inside Climate News)*
*Not to scale*



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# i Adiabatic vs. diabatic or isothermal

**A turbine requires a temperature change in order to extract work.**
**Hydrostor's view is adiabatic best balances cost/performance/risk.**

Diabatic:

- Traditional-CAES has used natural gas to generate this heat. Adiabatic-CAES instead captures and reuses the heat of compression. This heat is produced either way, traditional-CAES plants simply reject it to atmosphere, as an energy loss in the system.

- Adiabatic-CAES thus eliminates the need for fossil fuel combustion and emissions while significantly increasing the efficiency of the process. Due to the reduction in cooling load and lack of further input energy, A-CAES is ~2.5x more efficient than traditional-CAES when the input fuel energy is accounted for (net RTE from 25-30% to +60%).

Isothermal:

- Adiabatic-CAES leverages existing turbo-machinery unlike isothermal concepts, which unsuccessfully attempted to create new isothermal turbo-machinery (SustainX, General Compression, LightSail) in pursuit of slightly higher RTE.

# ii Water for thermal storage

**An economic analysis was performed for various storage mediums and water was found to be the lowest cost and most bankable option.**

- Engineered fluids were considered, but the increased cost of these engineered fluids makes them a more expensive option despite the reduced costs of tanks. This is especially true when looking at lifecycle costs.
- Higher temperature limits may change the result, but turbo-machinery (compressors) are not readily available at higher outlet temperatures.
- Water thermal storage offers several advantages:
  - Small footprint due to high heat capacity. Only ammonia is comparable.
  - Stable in ambient temperatures. No need for difficult-to-commission-and-maintain cryogenic systems, or exotic metallurgies. This saves cost and increases reliability.
  - Liquid at useful temperatures (with some pressurization). Easy to pump and efficient at transferring heat. This allows the system to use proven, bankable components.
  - Cheap, abundant, and poses no environmental or toxicity risk. This saves cost and makes the system easier to permit.
  - Pressures required for hot storage can be accomplished in large tanks.

# iii Hydrostatic compensation (isobaric) vs. fixed volume pressure vessel

**Hydrostor's A-CAES technology utilizes hydrostatically compensated caverns to significantly reduce the cavern volume requirement and improves system performance.**

- Hydrostatic compensated caverns require ~4-6X less volume than a non-compensated cavern operating at the same maximum pressure (the range depends on allowable pressure swing in the fixed volume cavern; ~4X larger for 30% swing, ~6X larger for 20% swing).
- Hydrostatic compensation allows the cavern to operate a near constant pressure, this improves system efficiency by providing consistent operating conditions during the complete system cycle.
- Enables use of hard rock caverns for CAES and reduces cyclic loading on the host rock and facility components as a secondary benefit (reduced maintenance/ longer life).
- Salt caverns have cycling limits for hydrostatic compensation due to deformation.

# iv Rock caverns vs. salt caverns

**The major benefit of hydrostatic compensation is that it allows the construction of hard rock caverns to be economical (less space required), whereas previously CAES caverns have been confined to salt caverns.**

- Hydrostatically compensated hard rock caverns offer similar costs to isobaric salt caverns for CAES applications.

- This breakthrough enables Hydrostor to construct caverns wherever suitable hard rock geology is present. This provides orders of magnitude more project opportunities. Hard rock caverns can be developed in most locations where igneous or metamorphic formations are present at 400-600m bellow surface.

- Hard rock caverns are already constructed around the world for hydrocarbon storage in a variety of geologies. Hydrostor's caverns use the same construction approaches and containment principles as these hydrocarbon storage caverns.

# v Air as working gas/fluid

**Air is non-toxic and non-flammable.  This leads to easy permitting and cost savings due to the use of simpler (not bubble-tight) components.**

- The system can be drained to atmosphere when discharging (i.e. the atmosphere is the low-pressure storage for the working gas). This greatly reduces capital cost as the working gas only needs to be stored in its high-pressure state, as well as simplifies commissioning and maintenance.
- Furthermore, since atmospheric air is used there is no cost associated with procuring or maintaining the actual working fluid.
- Other thermo-mechanical energy storage concepts require higher costs, complexity, and/or technology step-outs to maintain/store their working gas (e.g. low-pressure CO2 storage, supercritical gas, liquefaction of air).

# vi A-CAES (aka pneumatic PHS) vs. PHS

**The main benefit of A-CAES over PHS is the siting flexibility, density, and speed of construction/permitting. The disadvantage is ~10% lower RTE.**

Density:

- The land footprint for PHS depends on the reservoir depth and head of the system. Since both the low elevation and the high elevation reservoirs will be above ground it greatly increases the footprint (up to 40X) compared to A-CAES which only has one surface reservoir.

Water:

- With the same head as the A-CAES system (600m), pumped hydro requires ~5X more water than A-CAES ($150m^3$/MWh vs. $770m^3$/MWh). At a more conservative head of 150m, Pumped Hydro requires ~20X more water than A-CAES ($150m^3$).

- A-CAES can achieve net negative or neutral water consumption during operation in most climates since water is produced during charging.

- In arid climates, a floating reservoir cover can be added to drastically reduce evaporation and keep the net water consumption at or near net neutral. The volume of pumped hydro reservoir typically makes them unsuitable for covering and the drastically larger surface area results in significantly higher evaporation rates.

# A-CAES Performance Specifications

A-CAES performance can provide compelling system benefits with performance similar to or better than other rotating power generation equipment such as natural gas–fired facilities. Key performance metrics include a 60%+ RTE, a start-up time of less than 5-minutes, and an operating ramp rate of 5%/second

| Performance Metric | Metric Detail | Performance |
|---|---|---|
| Efficiency | Round-trip efficiency (AC-to-AC) at grid connection point, including all auxiliary loads, assuming daily cycling at full power rating | 60%+ |
| Response Time | Discharge start-up time (signal to minimum load point) | <5 minutes |
| | Discharge full-power response time (signal to full power generation) | 10 minutes |
| | Charge full-power response time (signal to full power load) | 10 minutes |
| Ramp Rate | Ramp rate of power generation during operation | 5%/second |
| | Ramp rate of power generation during start-up (average) | 15 %/min |
| Minimum Load Point (MLP) | Minimum discharge level that can be sustained per turbine | 10 MW |
| | Minimum charge level that can be sustained per compressor | 90 MW |
| Minimum Run Time | Though not a technical limit, minimum amount of time to discharge/charge recommended to maintain efficiency | 1 hour* |
| Minimum Down Time | Minimum amount of time to stay offline after any shut down of charge or discharge | 5 min |
| Reactive Power Delivery | Voltage support provided with reactive power during charge / discharge | 0.5 MVAr/MW |
| Lifetime | Equipment service life with recommended maintenance | 30–50+ years |
| | Cycle-life of rotating equipment between refurbishments | 7,000 cycles |
| Degradation | Degradation over useful life of the project | 0% |

* Not a technical limit

# A-CAES Commercial Status

**Patented Improvements to Proven CAES Asset Class**

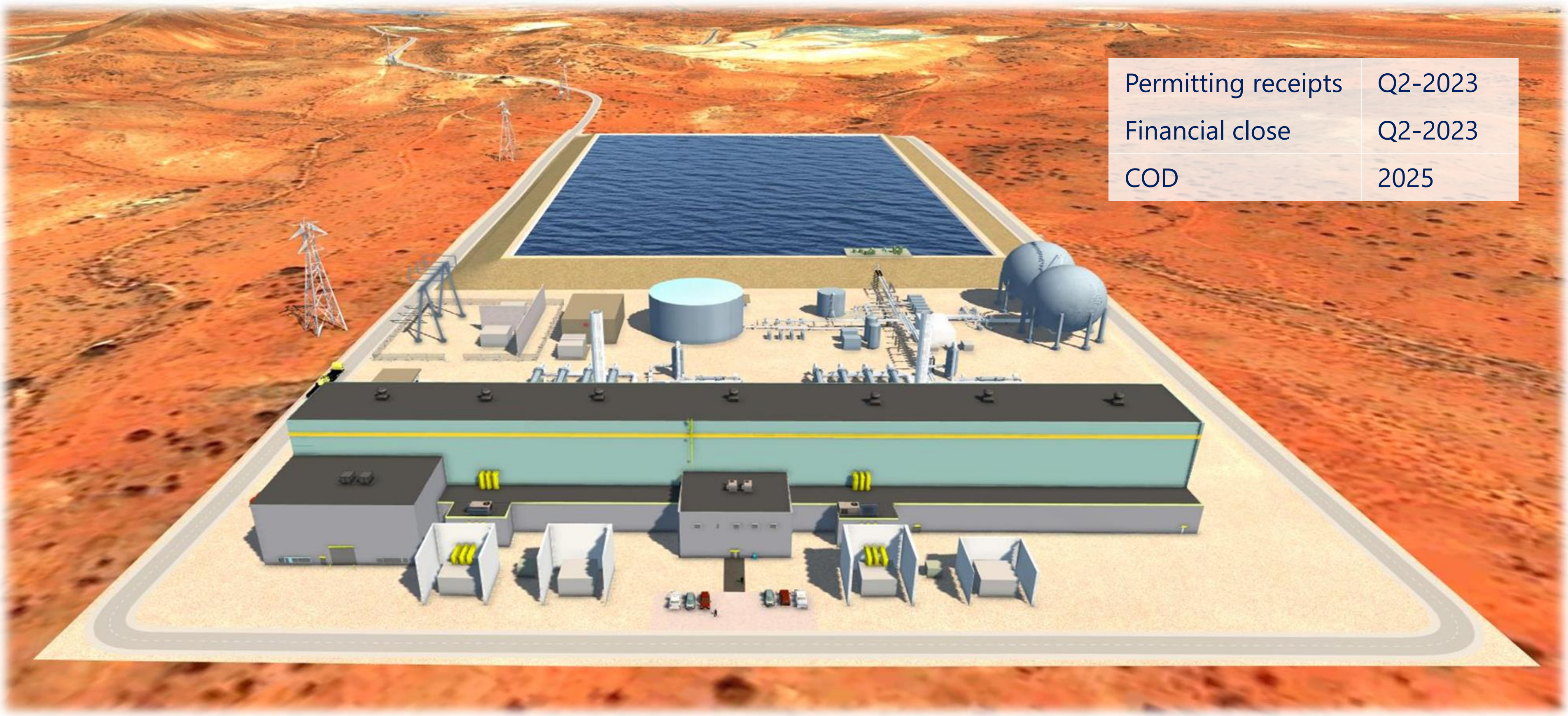
**Two Demonstration Systems Operating for Years, including Commercial Facility**

**Performance Insurance, Bonding, Project Financing, and EPC Wraps**

**Scale Projects Contracted and Approaching Financial Close in 2023**

# Project: Silver City (NSW, Australia)

**200 MW** A-CAES facility being developed by Hydrostor.  The project will provide **8 hours (1,600 MWh)** at full capacity. This project is the only long-duration energy storage project in Australia that has been selected as the preferred option under a Regulatory Investment Test for Transmission (RIT-T).



| | |
|---|---|
| Permitting receipts | Q2-2023 |
| Financial close | Q2-2023 |
| COD | 2025 |



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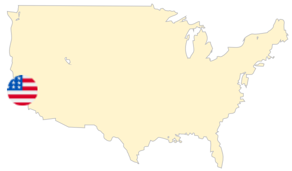
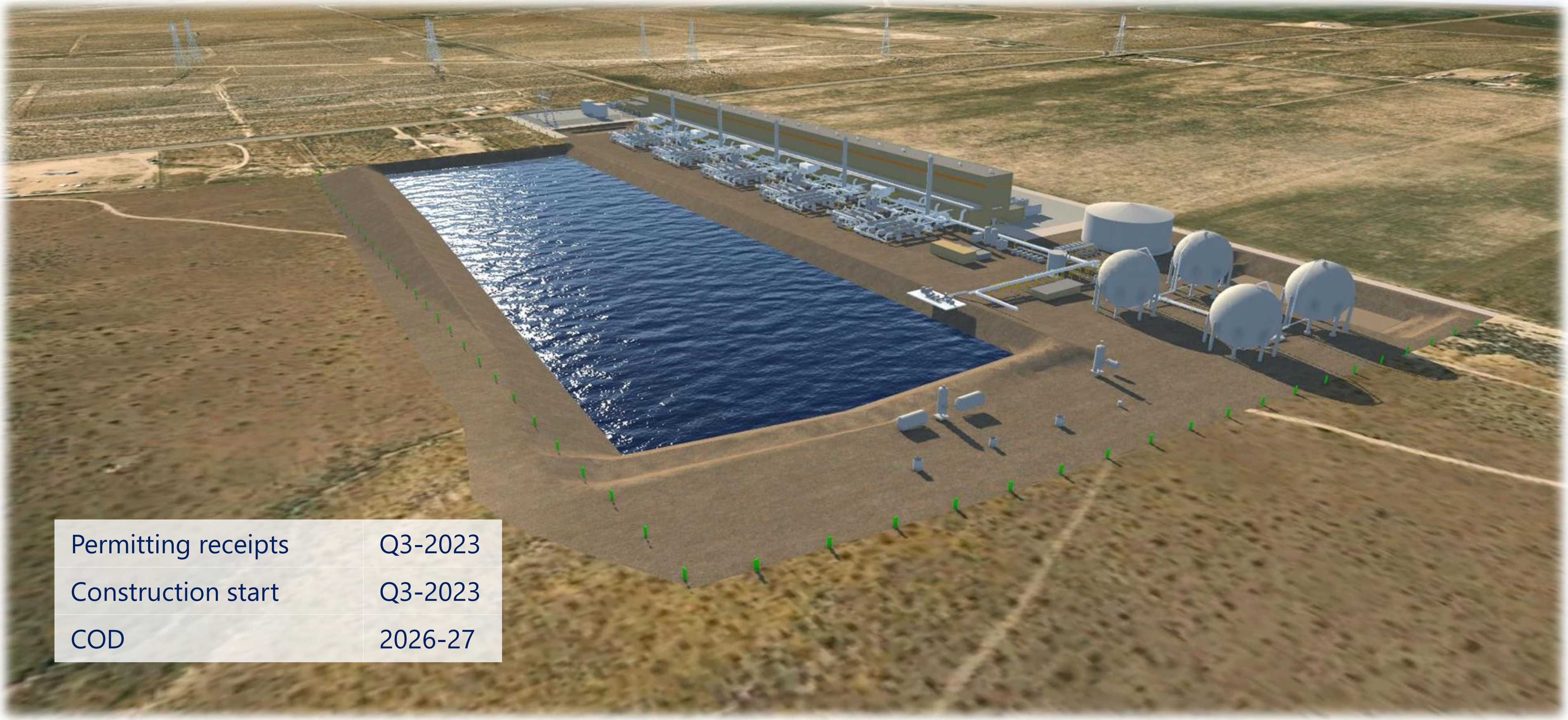
# Project: Willow Rock, California



**500 MW**, **8 hour long-duration (4,000 MWh)** project located in the high desert area, northwest of the Los Angeles basin. The project has confirmed full interconnection deliverability (500 MW), achieved CEC data adequacy for permitting, and has been contracted/short-listed for majority of offtake.



| | |
|---|---|
| Permitting receipts | Q3-2023 |
| Construction start | Q3-2023 |
| COD | 2026-27 |



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# Contact Information

**Curtis VanWalleghem**
Chief Executive Officer, Co-Founder
curtis.vanwalleghem@hydrostor.ca
+1-416-567-2695

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