Pumped Thermal Energy Storage (PTES)

Low-cost, safe and environmentally-responsible electrical energy storage anywhere

Echogen's Pumped Thermal Energy Storage (PTES)

Leveraging 15 years of power cycle development and IP in an energy storage system that is:

Low Cost

Efficient

Geographically Flexible

Scalable

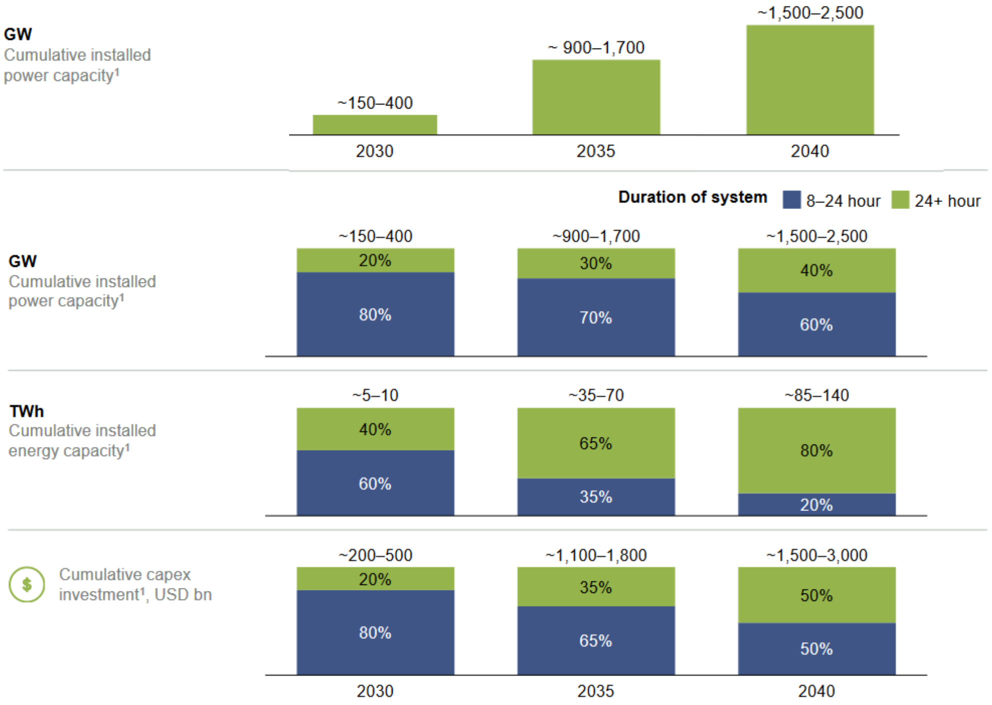
Safe

Sustainable

Long-Duration Energy Storage (LDES) Market Opportunity

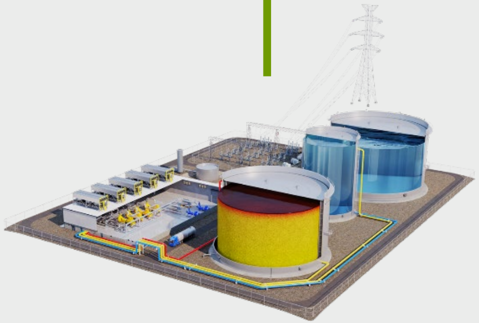
- Intermittent renewable generation drives
  - Wide deviations for grid supply/demand
  - Baseload plants operating in turndown
  - Tremendous growth in storage deployments
- Durations start at 8 hours, expected to increase to 24+ as market matures
- PTES incremental storage cost is very low and expandable, excellent fit for full range of durations

LDES total addressable market and cumulative capex investment by year



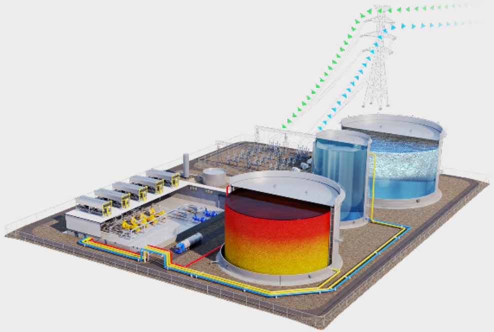
From: Net-zero power: Long duration energy storage for a renewable grid | LDES Council, McKinsey & Company

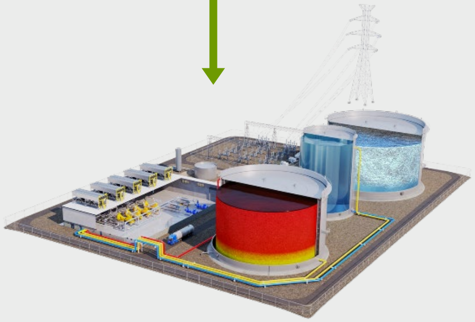
PTES - Storing electrical energy as thermal potential



Charging

sCO_2 heat pump cycle consumes grid power to move heat from freezing of water in LTR to heating oil/media in HTR.





Full Charge

System at a fully charged state where LTR has ice and HTR has hot oil/media.

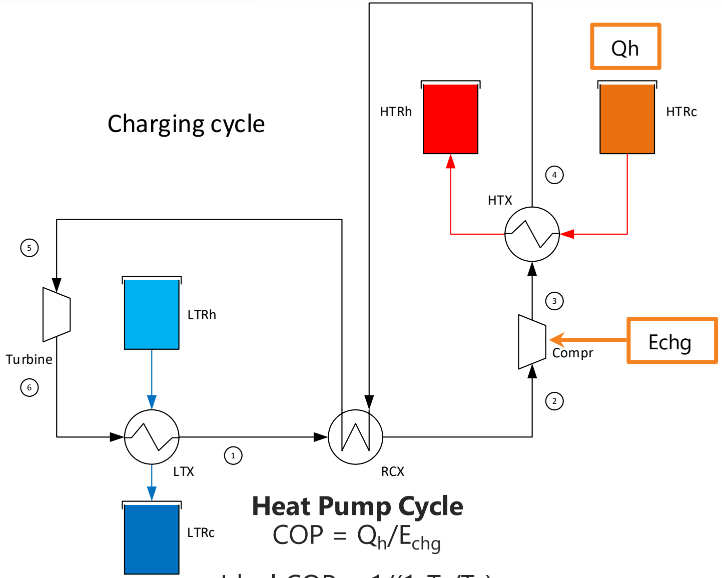
Discharging

sCO_2 heat engine cycle utilizes stored temperature difference to produce electricity, melting ice & cooling the oil/media.

Zero Charge

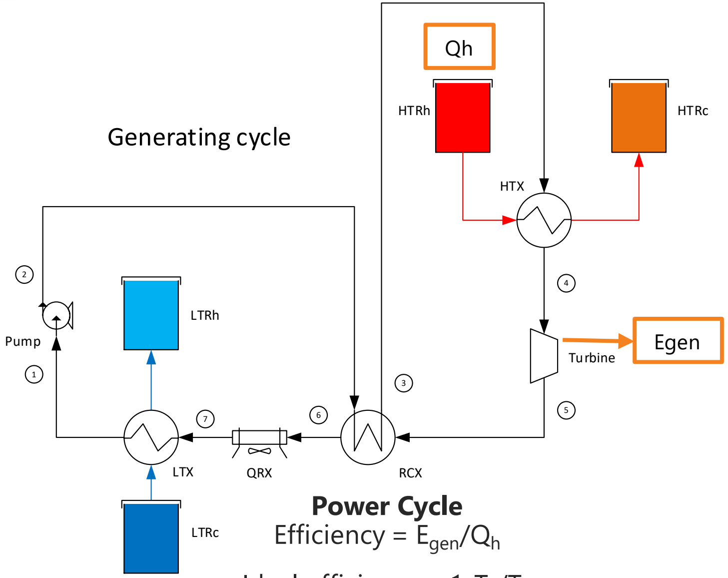
System at a fully discharged state where LTR has chilled water and HTR has warm oil/media.

Pumped Thermal Energy Storage basics



Heat Pump Cycle
COP = Q_h/E_{chg}

Ideal COP = $1/(1-T_c/T_h)$



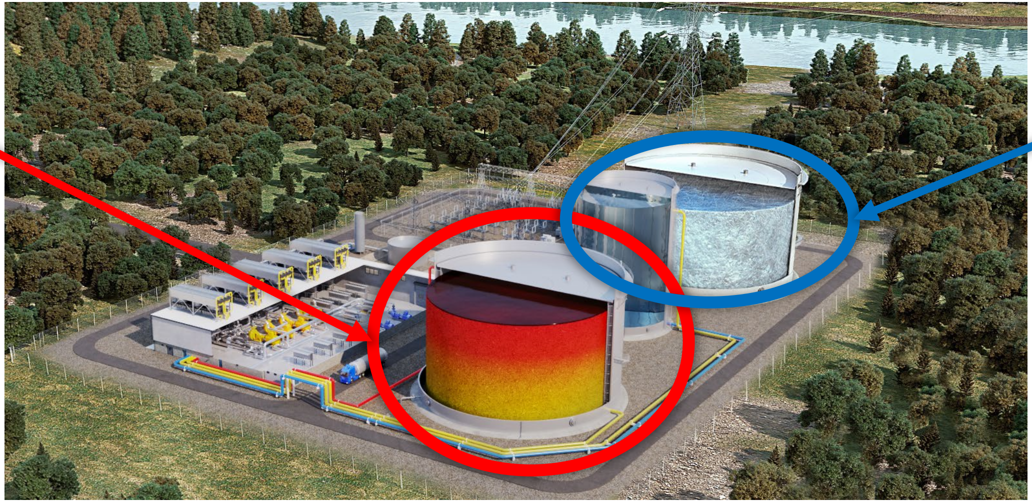
Power Cycle
Efficiency = E_{gen}/Q_h

Ideal efficiency = $1-T_c/T_h$

RTE = E_{gen}/E_{chg} = **COP x Efficiency**

Material selection key to cost, sustainability, strategic goals

Hot reservoir = concrete + HTF



Cold reservoir = water/ice mixture

Moderate operating temperatures = carbon steel, concrete

Echogen CO_2-based PTES system design uses materials that are: safe, low cost, environmentally sustainable, recyclable, readily available

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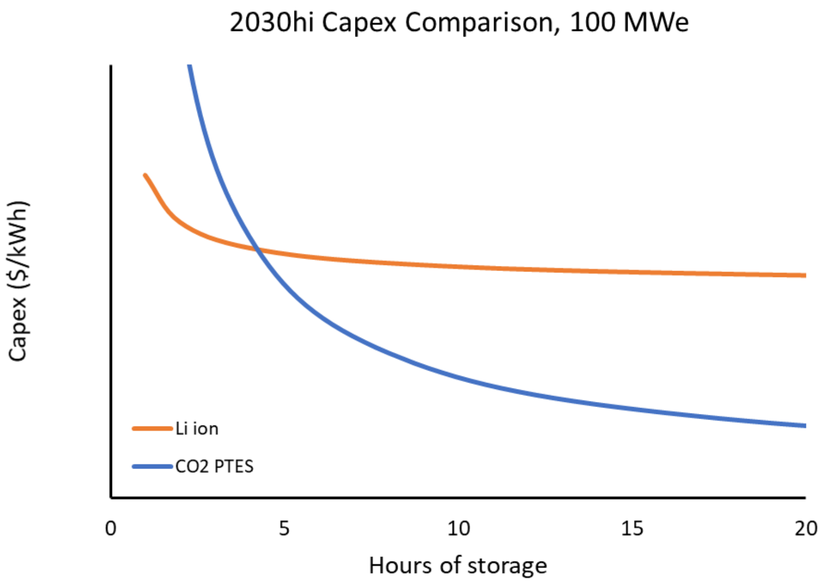
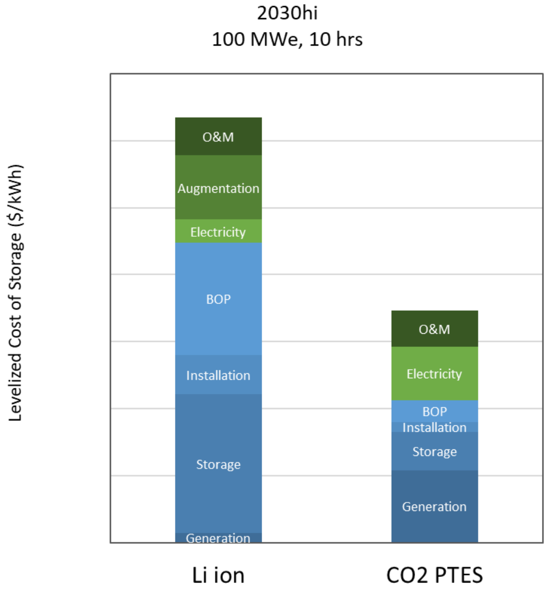
Longer Duration = Lower Capex/kWh = Lower LCOS



Low reservoir cost / kWh

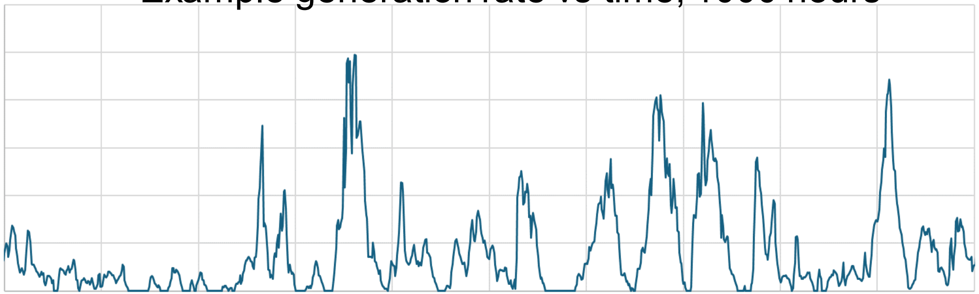


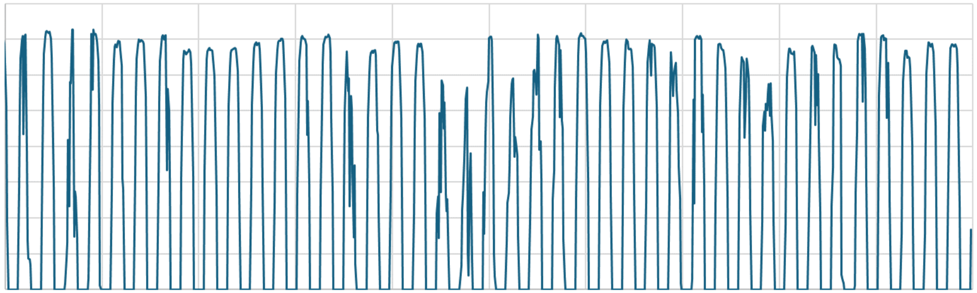
Lower Capex, no augmentation costs => Lower LCOS

PTES Use Case Flexibility

- Decoupled charge/generate equipment and storage capacity = wide application range
  - Wind applications – Highly variable charging rate, long storage duration needed
  - Solar applications – High charging rate, medium duration needed

Example generation rate vs time, 1000 hours





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PTES Advantages

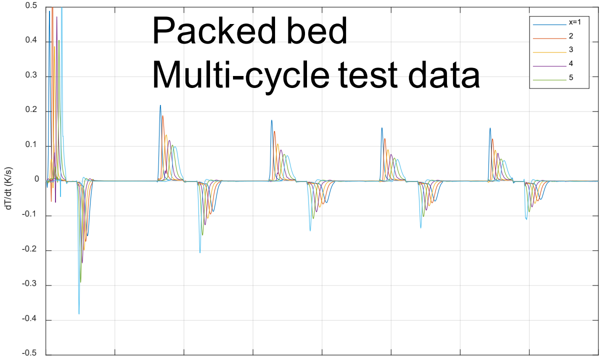
- Echogen CO_2–based PTES offers significant advantages vs other storage technologies
- Safety – Very low fire risk. Moderate storage temperatures = lower hazard. Small CO_2 inventory required in closed-loop system
- Operator familiarity – Power plant equipment & controls
- Grid support – Synchronous generators and motors provide VAR support, natural inertia
- Low CAPEX – Moderate storage temperatures = low-cost materials
- No strategic or costly materials needed – Carbon steel, concrete are primary materials of construction
- High storage density - > 1 GWh in 5-acre site
- No significant geographical restrictions
- Long system life without degradation – 60-year anticipated plant life, no augmentation required

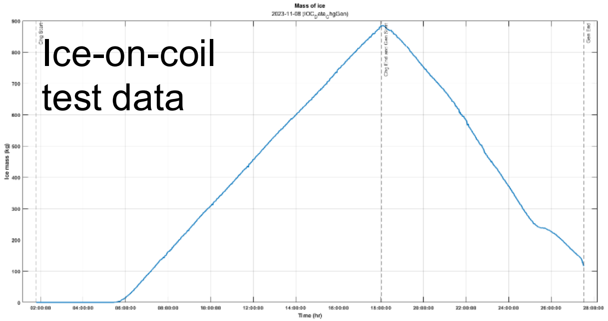
Leveraging Echogen CO_2 power cycle and heat pump experience

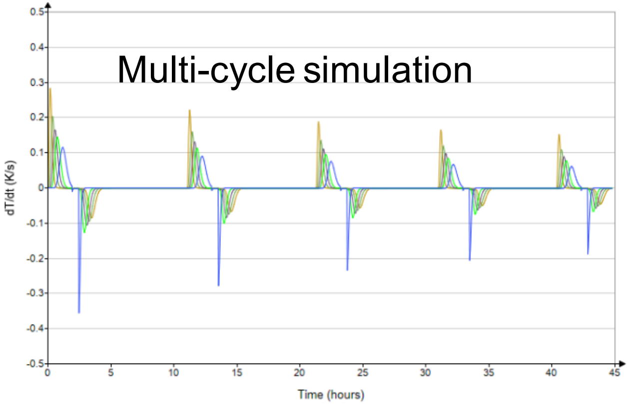
7.3 MW EPS100 during factory test

50 kW pilot scale steam generating heat pump

Thermal reservoir development test programs







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POLAR Project in Healy, AK - One of the largest planned installations of long-duration energy storage in the United States

- Prime recipient: Westinghouse
- US DOE awards project to deploy 50MW, 24-hour (1.2 GWh) long-duration energy storage
- Built to support new deployment wind to replace a baseload coal asset
- Minimizes challenges associated with transmission limitation & low-sulfur distillate fuel costs
- Provides significant benefits to local community in air quality and utility pricing
- Will employ portion of existing staff – similar skillset

Submission to DOE	Award Date	Contract Signed	Phase 1 Feed Study	Design Completed	Construction Started	COD
March 2023	Sept. 2023	July 2024	July 2024	Q4 2025	Q1 2026	Q1 2029

EPRI ELECTRIC POWER RESEARCH INSTITUTE
Shell
ASRC ENERGY SERVICES a subsidiary of Arctic Slope Regional Corporation
GVEA
OCED Office of Clean Energy Demonstrations
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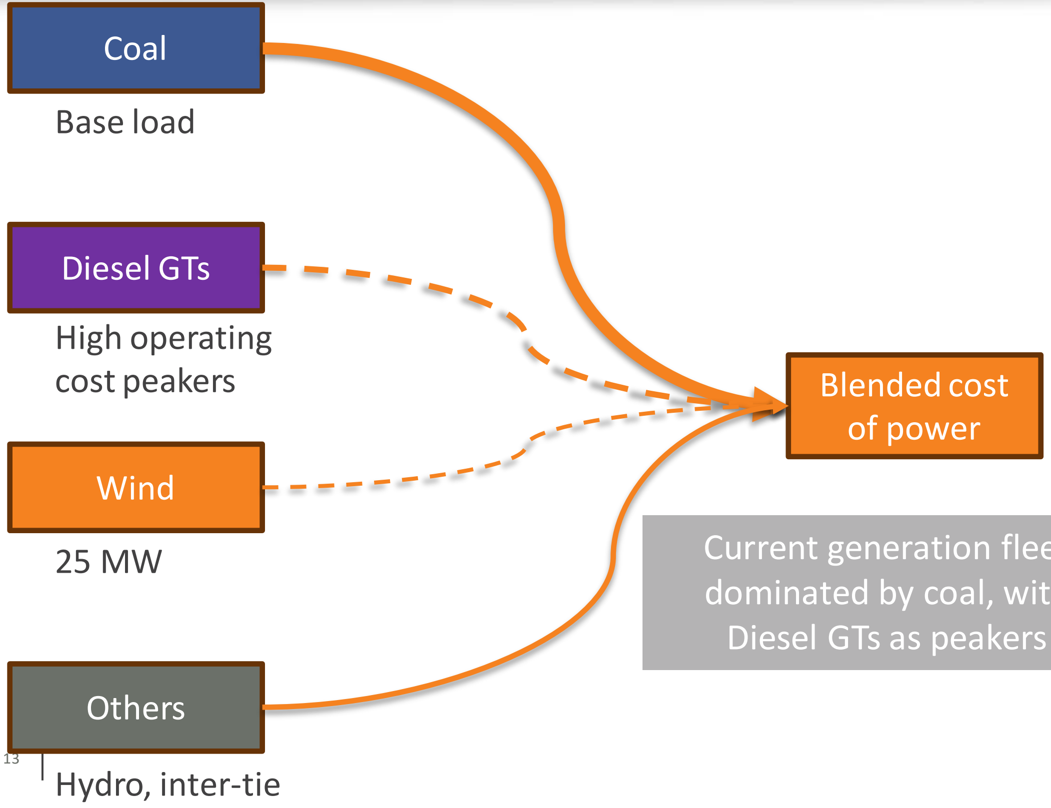
Understanding the Healy use case – current generation mix



Current generation fleet dominated by coal, with Diesel GTs as peakers

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Understanding the Healy use case – future without LDES

Coal

2/3 of capacity retiring

Diesel GTs

High operating cost peakers

Wind

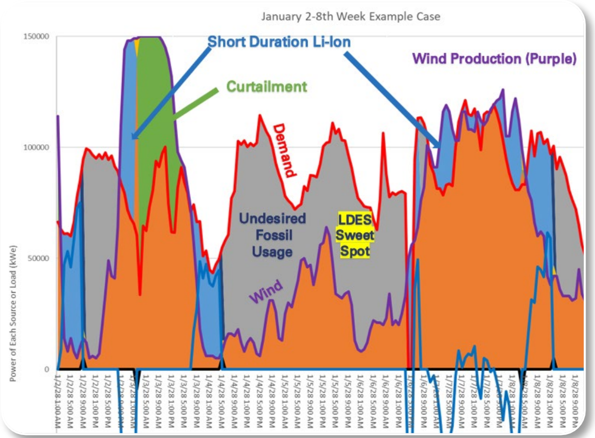
100+ MW

Others

Hydro, inter-tie

Blended cost of power

Significant increase in cost to customers, CO_2 and other emissions with increased Diesel firing



Understanding the Healy use case – future with LDES

Coal

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Wind → **PTES**

100+ MW

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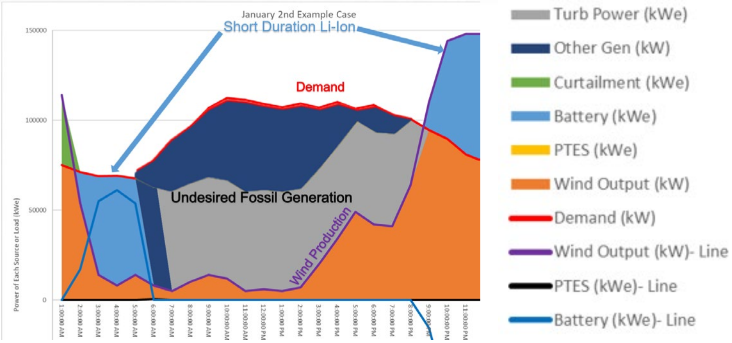
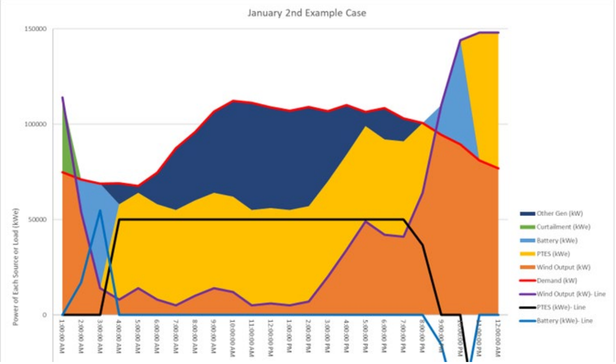
→ **Blended cost of power**

> 25% reduction in blended cost of power with LDES by reducing peaker usage





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PTES Roadmap

PTES Design & Technical Modeling

2015– 2026

- Basis in commercial EPS100 product
- Over $90M invested in the core technology
- Conceptual designs & trade-off studies explored
- Performance modeled

Small Scale Testing

2021– 2025

- 120kW CO_2 test loop
- Thermal test column
- Direct ice on coil test
- Concrete durability

Testing, Grid Modeling & Commercialization

2024 – 2026

- FEED studies
- Early site feasibilities & economic modelling
- Large scale HTR demonstration
- Full scale ice demonstration

Initial Commercial Projects

2026 – 2029

- Two > 1 GWh projects
- DOE award
- 1st commercial developer, site & financing

PTES Mass Deployment

2030 and beyond

50 MW, 24-hour PTES system in AK – design underway
100 MW, 10-hour system in NY – Expect project start before end of 2024

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Contact: Timothy Held, Ph.D. (CTO) theld@echogen.com

Pumped Thermal Energy Storage: Electricity stored as heat & cold

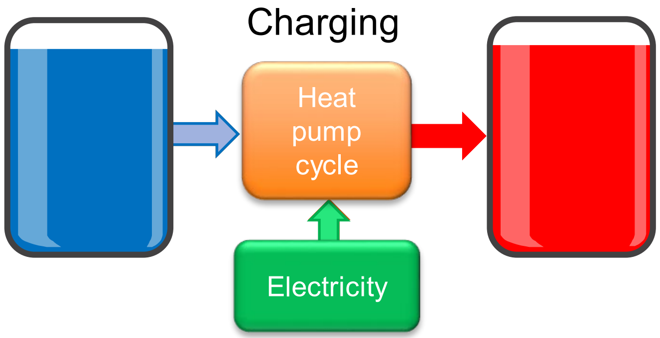
Thermodynamic cycles transform energy between electricity and heat

Charging cycle

- Heat pump cycle
- Uses electrical power to move heat from a cold reservoir to a hot reservoir
- Creates stored energy as "thermal potential"

Generating cycle

- Heat engine cycle
- Uses heat stored in hot reservoir to generate electrical power



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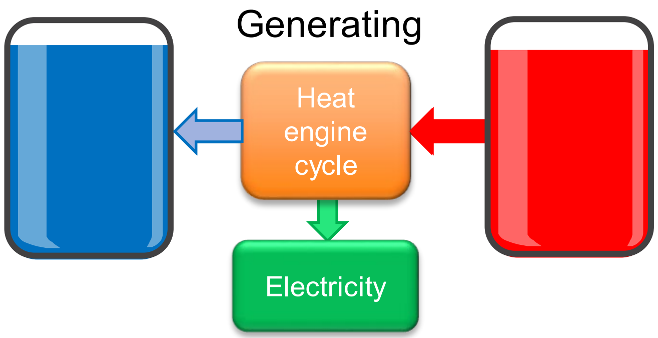

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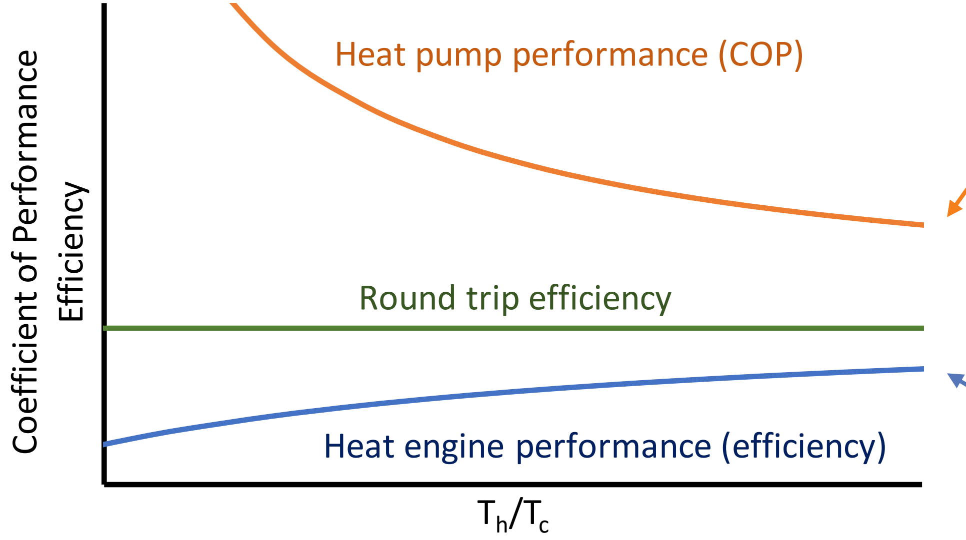
PTES provides good round-trip efficiency (RTE) at modest temperatures



Heat pumps get more efficient at low temperature ratio (T_h/T_c)

RTE is mathematical product of heat pump and heat engine performance

Heat engines get more efficient at high temperature ratio

… so good RTE (~60%) can be obtained at moderate temperature ratio

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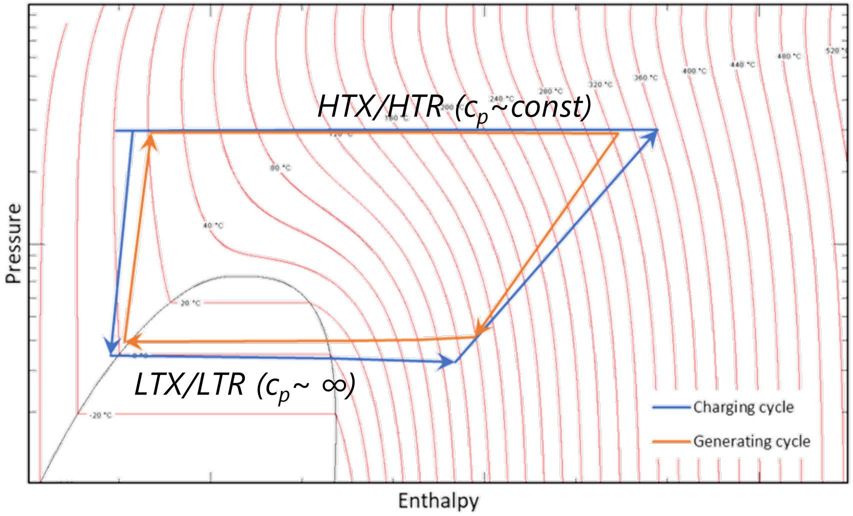
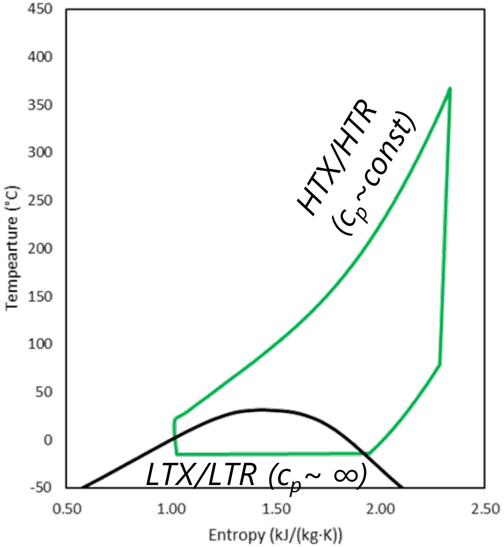
Thermodynamic properties and operating state drive reservoir selection

HTX heat transfer is supercritical - sensible enthalpy transfer interaction with HTR

LTX is subcritical – condensation and evaporation - ~ constant temperature interaction with LTR





Ice/water equilibrium and sand reservoir materials = low cost, low impact

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