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sCO_2 Power and Heat Solutions

Timothy J. Held, Chief Technology Officer

Echogen has developed a platform sCO_2* technology to reduce industrial CO_2 emissions and enable the transition to 100% renewable energy

Waste Heat Recovery and primary cycle

Skid based solution to utilize high temperature heat (300+°C) to produce electricity or mechanical drive.

Industrial Heating

High efficiency heat pump technology to electrify low and medium temperature industrial applications

Long Duration Energy Storage

Pumped thermal energy storage (PTES) to enable baseloading renewable energy resources at the Utility scale

*sCO_2 – Supercritical CO_2

8 MW EPS100 Waste Heat Recovery System

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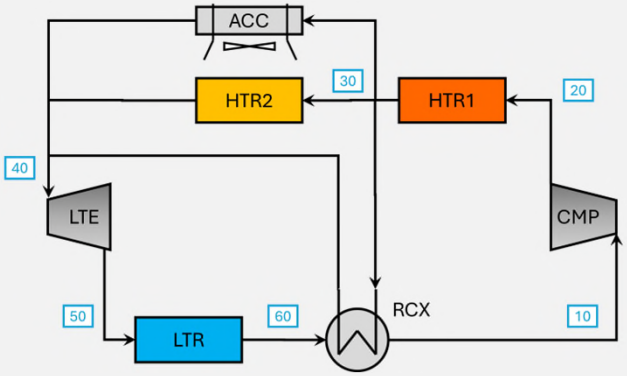
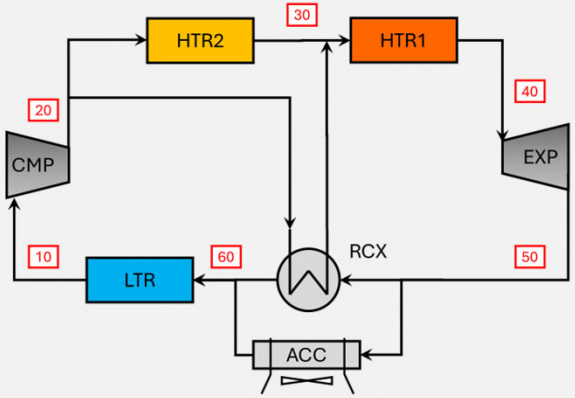
Pumped Thermal Energy Storage (PTES)

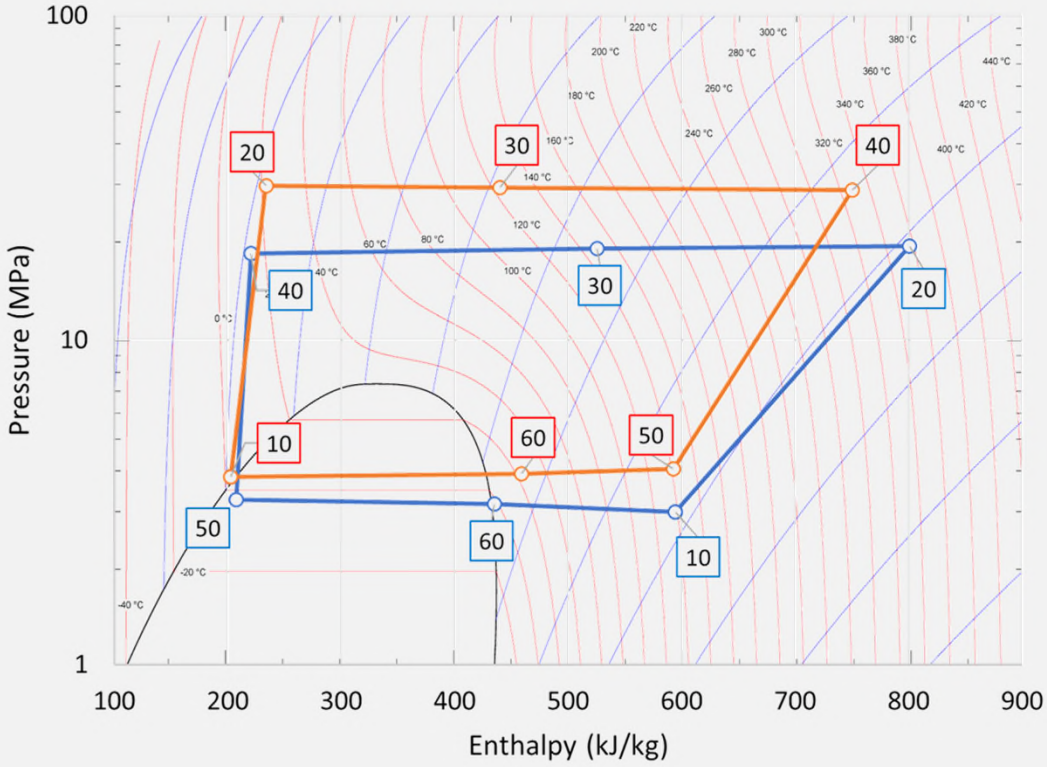
Pumped Thermal Energy Storage basics

Charging



Generating





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Combining Innovation and Proven Technology

Westinghouse

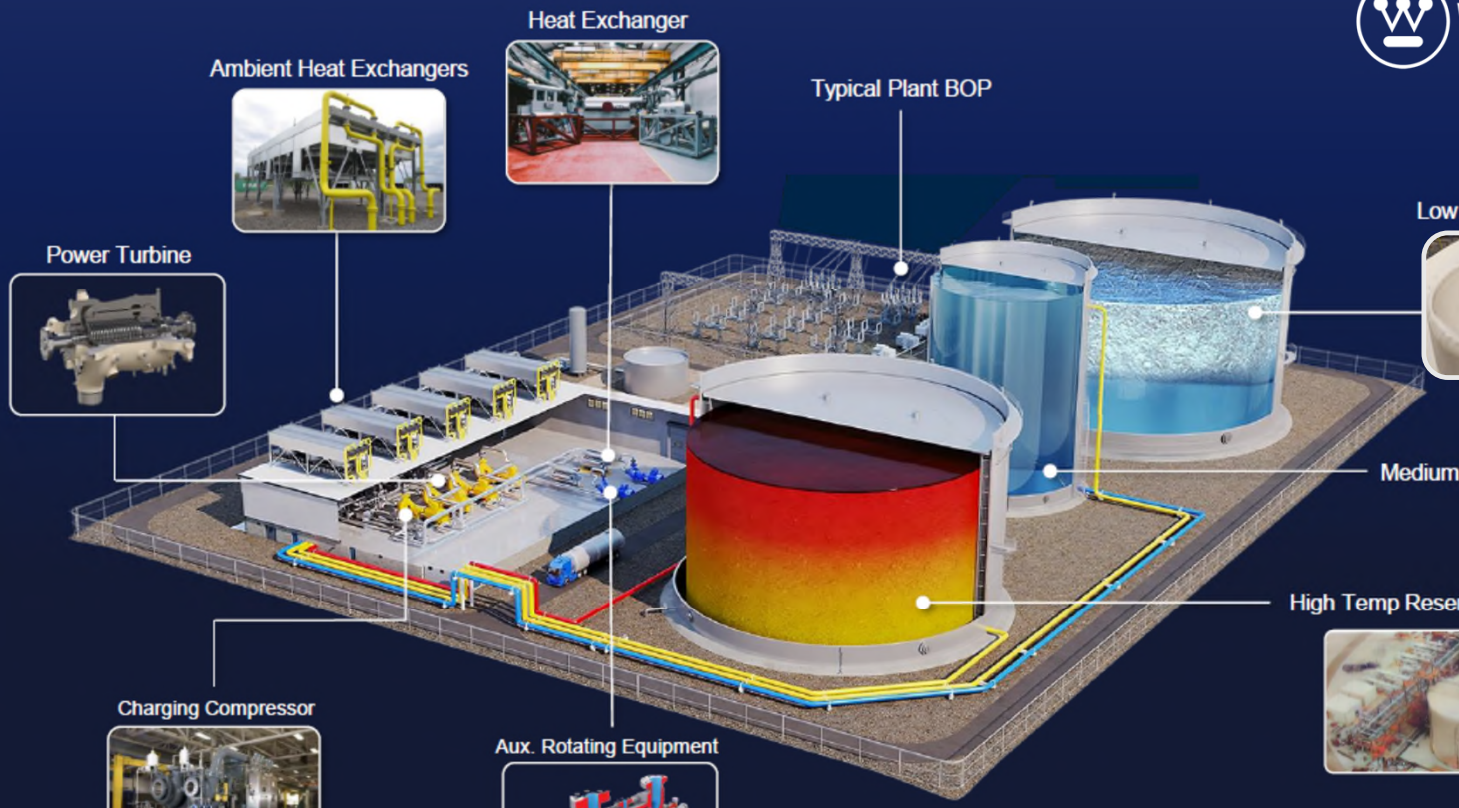
Systems

Generation

The EPS100 is a commercially available generating system with over 330 hours of operation

Heat Pump

Large pilot scale system used to validate models



Power generation turbine will be largest operational sCO_2 unit at time of deployment

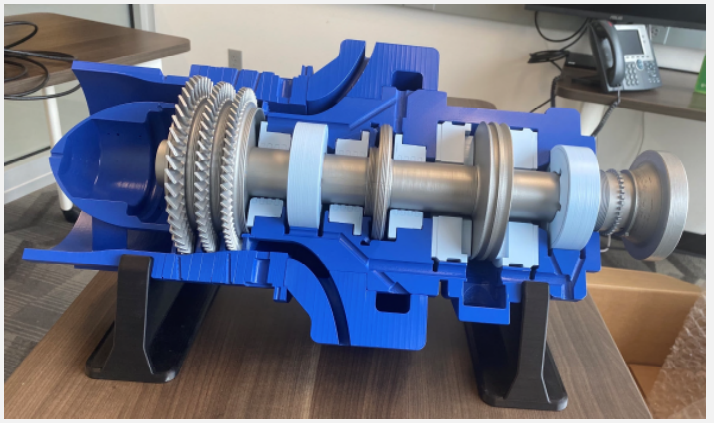
~62 MW net output

HP steam turbine derivative

Multi-stage axial design, synchronous generator

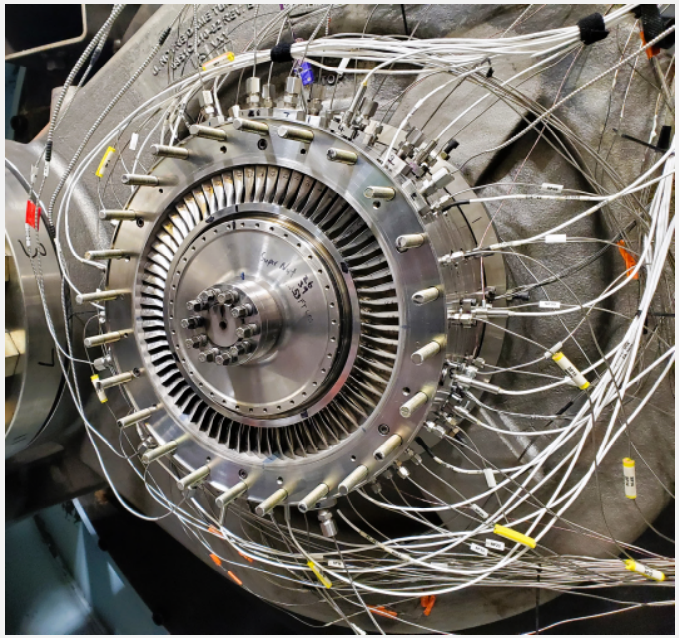
Large-scale axial compressor development program

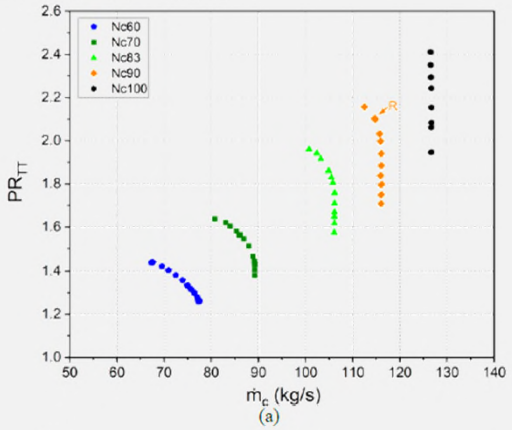
- Initial deployments are multiple centrifugal compressors in parallel
- Pumped thermal energy storage requires grid-scale compression - >100 MW – better served by axial design

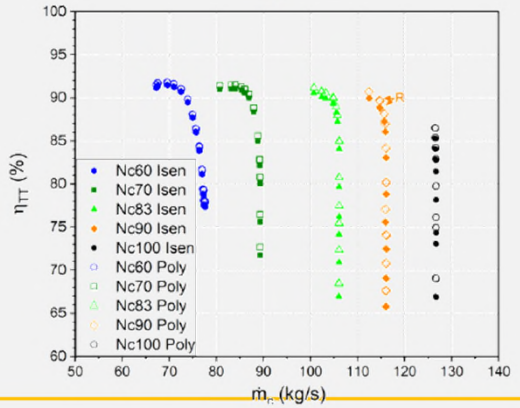


- DOE/EERE funding
- Univ. Cincinnati optimized blade aero
- Univ. Notre Dame Turbolab design/test

Advanced 3-stage axial CO_2 compressor design & demonstration





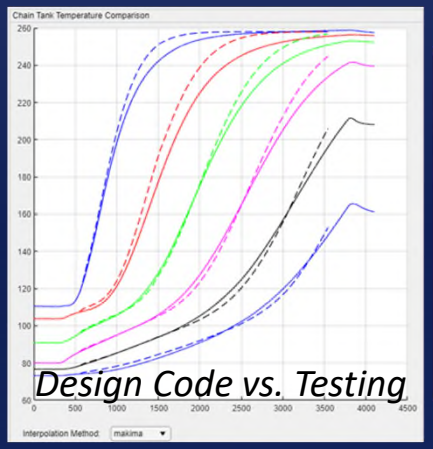


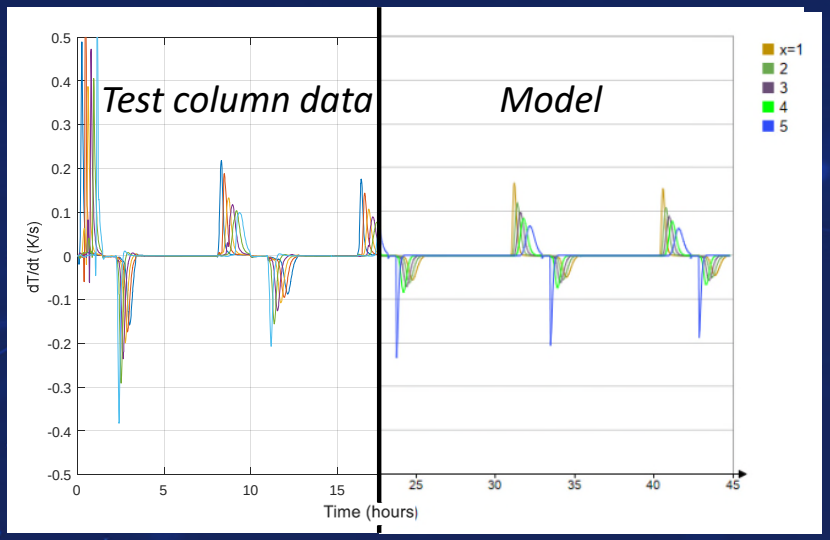
- Advanced blade aero design & optimization
- Met projected performance (pressure ratio and isentropic efficiency)
- Highest sCO_2 isentropic compressor efficiency to date
- In discussions with OEMs for potential commercialization
- 2 ASME IGTI Best Paper awards (2024 and 2025)

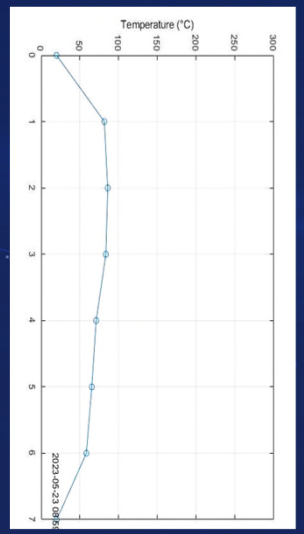
Thermal Reservoirs

Packed Bed + Heat Transfer Fluid

- Westinghouse proprietary engineered concrete fill
- Testing of thermal column
  - Multiple fill materials tested
  - Simulation tools validated against data
- Active test & simulation programs
  - Packing fraction + DEM* simulation program
  - Durability (cycle) testing
  - Manufacturing automation
  - Integrated effects (large-scale) test





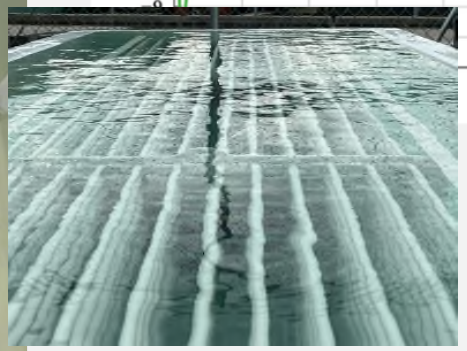


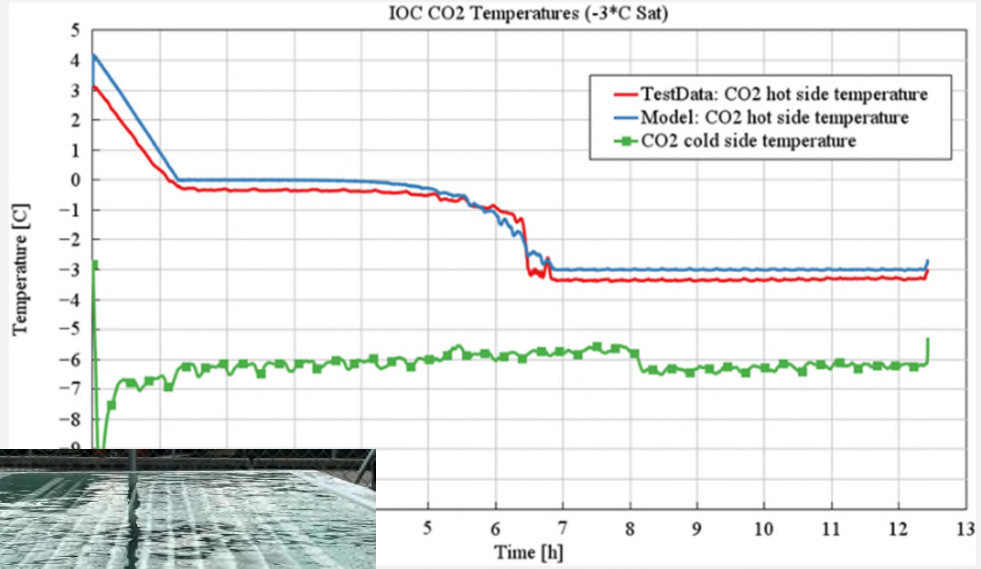
*Discrete Element Modeling

Low temperature reservoir - IOC

a. IOC with tube bundle

f. Ice formation on IOC tubes





Commercial Scale IOC Installation

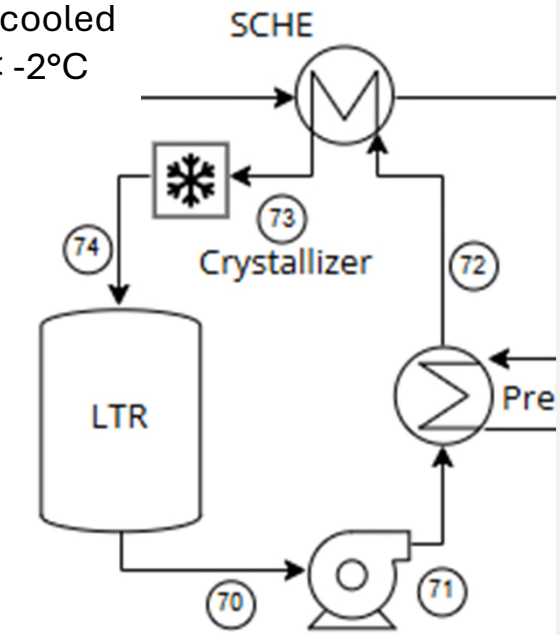
> 5000 miles of tubing for 1 GWh

Low temperature reservoir – Supercooled water Ice Water Slurry (IWS) generation

Liquid water cooled with CO_2 to < -2°C

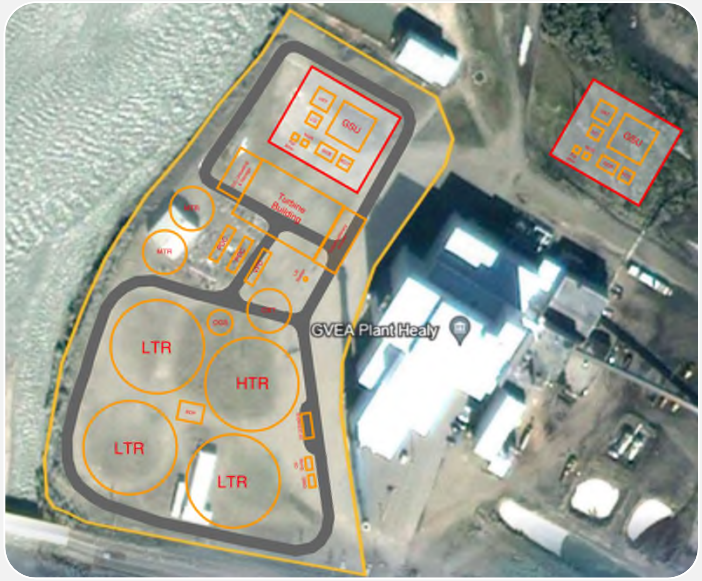
Triggered to convert to ice/water mixture

Liquid water extracted from LTR



Low cost, highly scalable storage solution

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



- Prime recipient: Westinghouse Electric Company
- US DOE awards project to deploy 50MW, 24-hour (1.2 GWh) long-duration energy storage
- Bolsters energy security for the region
- Mitigates transmission system limitations, balances load
- Enables future integration of renewable energy
- Air quality and electricity pricing benefits to community
- Leverages existing utility staff skillsets

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 · Westinghouse · ECHOGEN · ASRC ENERGY SERVICES a subsidiary of Arctic Slope Regional Corporation · GVEA

Project status

- FEED study completed on time (Dec 2025), awaiting BP1/BP2 transition
- Preliminary P&IDs, equipment specs transmitted to potential suppliers, quotes received
- No component show-stoppers
- Steady-state and quasi-steady-state modeling near completion –
  - Design point
  - Turndown
  - Ambient temperature
  - Reservoir capacity imbalance recovery
  - Reservoir temperature variation
- Transient model and control simulation underway

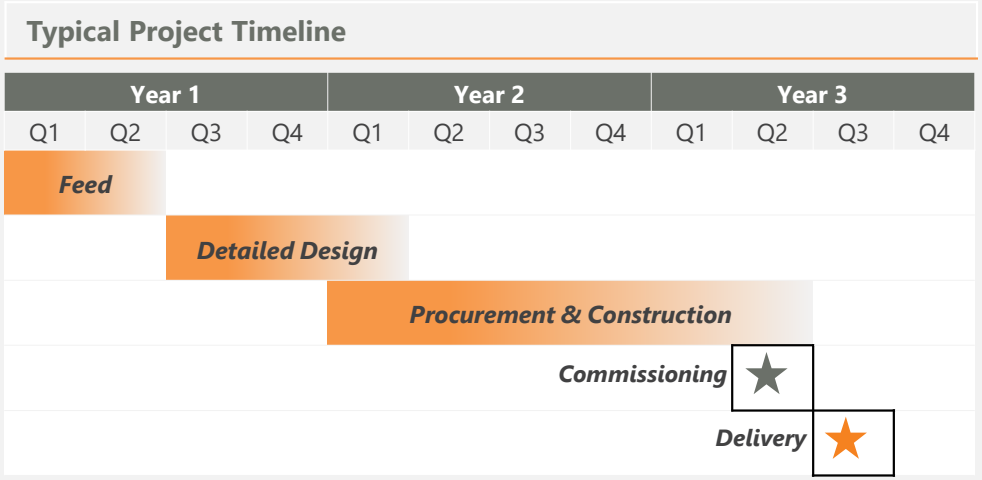
International PTES Deployment

Vodohospodárska Výstavba (VVB)

- MOU signed in Washington, D.C. in 2025
- Feasibility study and use case analysis completed
- Use case to store and utilize significant unused hydroelectric power → 200MW PTES system
- Expected COD 2030

Africa

- Late-stage discussions to deploy first PTES project in Africa
- Expected 50MW PTES system with COD 2030



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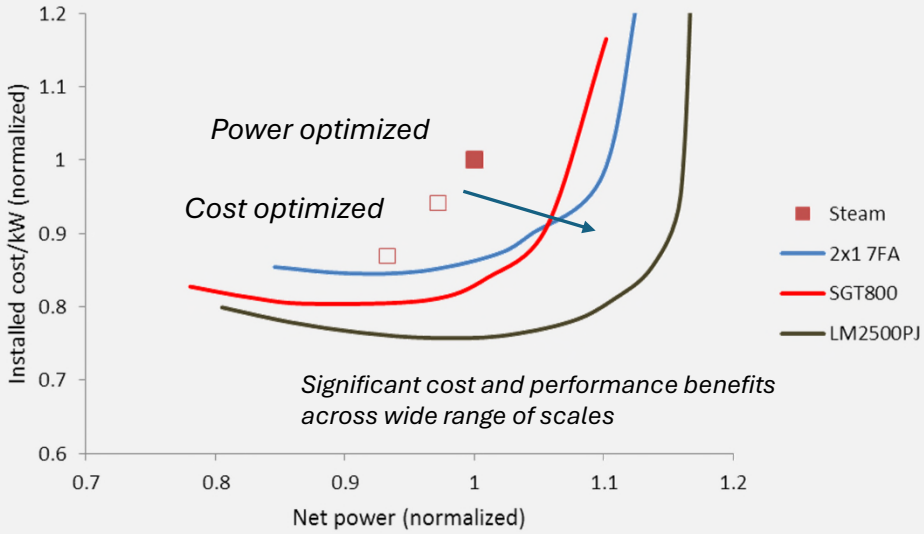
Other technology developments

Power cycle development and commercialization

EPS100 during factory test

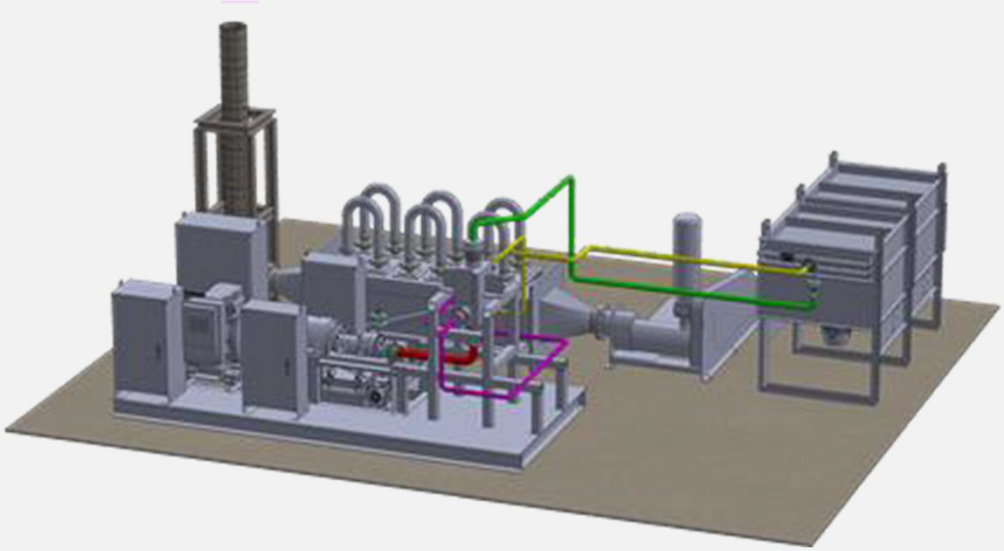
Held, T. J., 2015, "Supercritical CO_2 Cycles for Gas Turbine Combined Cycle Power Plants," Power Gen International, Las Vegas, NV.



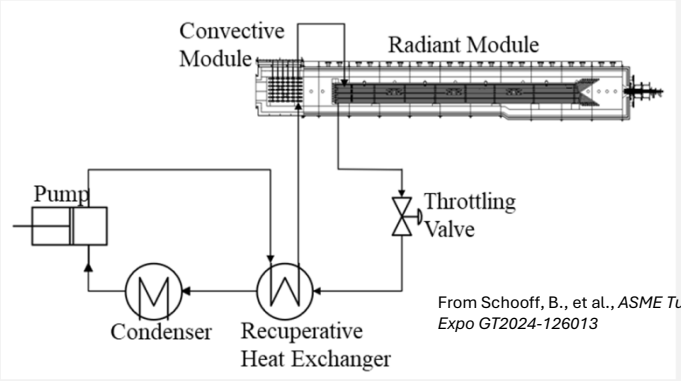
- Data center power demands pushing solutions that increase output from existing assets
- Large increase in interest for advanced nuclear cycles as well

High temperature sCO_2 heat pump

- 500 kW, 300°C air-source heat pump pilot project awarded by DOE/IEDO last year
- Awaiting DOE project approvals
- Commercialization discussions in process with food/beverage potential customers



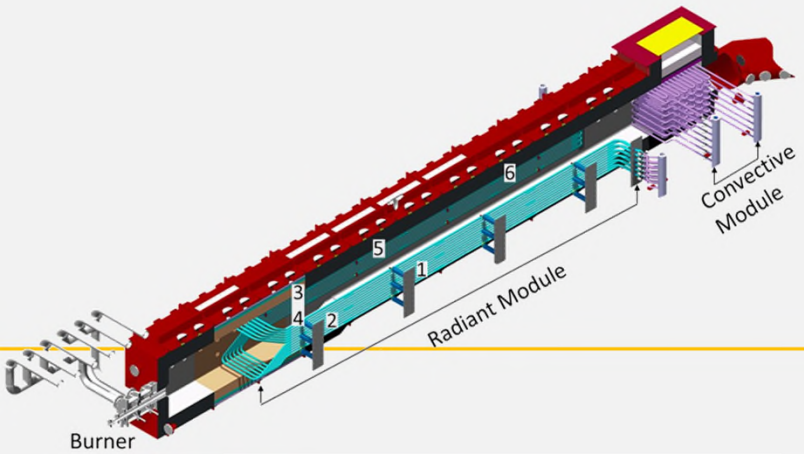
Solid fuel combustor and primary heat exchanger



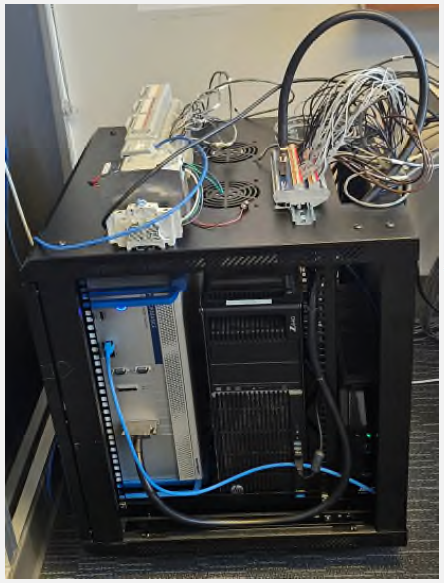
From Schooff, B., et al., *ASME Turbo Expo GT2024-126013*

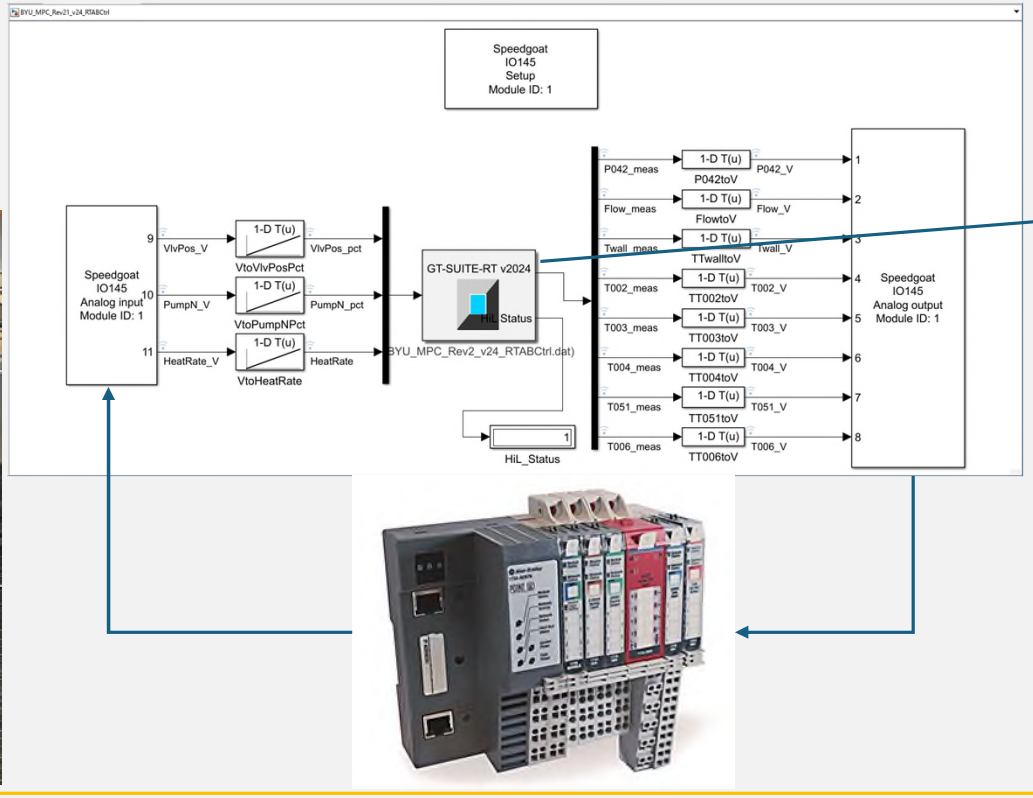
- L1500 solid fuel combustor (BYU) – coal & biomass
- Super 304H primary heat exchanger by Riley Power
- > 200 hours operation

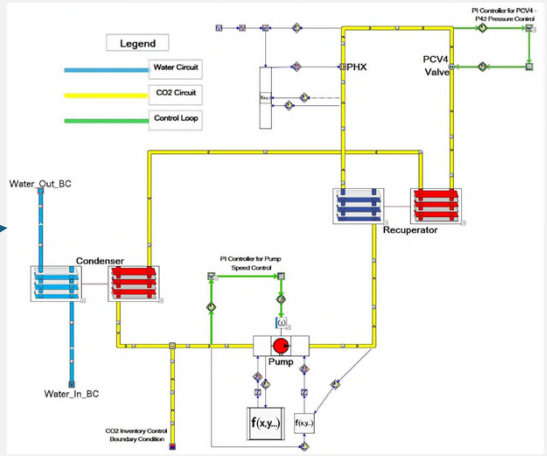
Installation at Utah San Rafael Energy Laboratory



Transient model and controls HIL (Hardware-In-the-Loop) demonstration

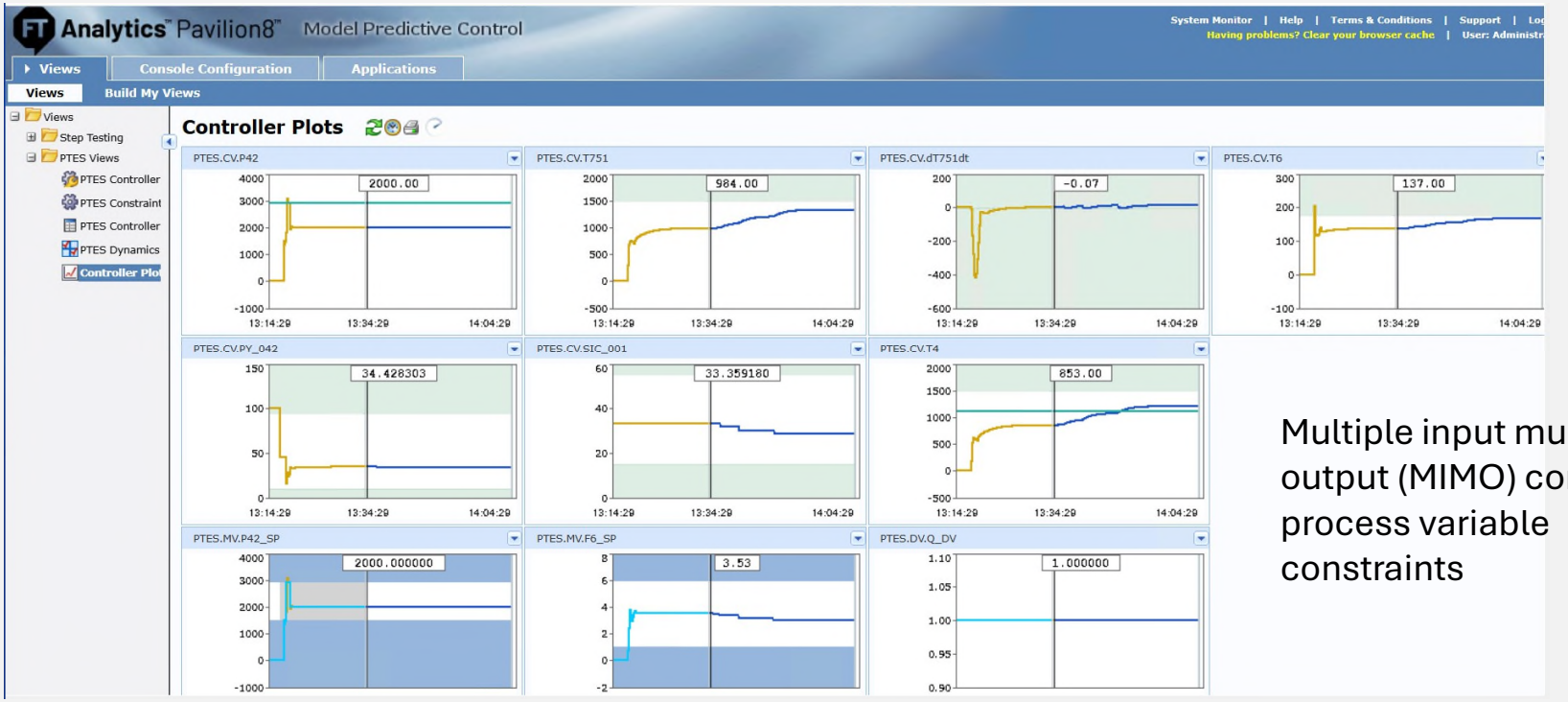






Real-time model simulation of the BYU “plant”

Transient model and controls MPC (Model Predictive Control) demonstration



Multiple input multiple output (MIMO) control with process variable constraints

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