ECHOGEN

Experts in CO_2 Power Equipment and Systems

Echogen background

- Founded in 2007 in Akron, OH
- Mission: To develop and commercialize better heat recovery, primary power and energy storage systems using CO_2 as the working fluid

Commercialization progress

- Key partnerships – Siemens (Oil & Gas), GE (Marine)
- First commercial article (EPS100 – 7.5 MWe) designed and built by Echogen, tested at Siemens
- First commercial sale (EPS120 – 9.5 MWe) announced in March 2019 to TransCanada
- FEED study underway for Petrobras

TransCanada

SIEMENS

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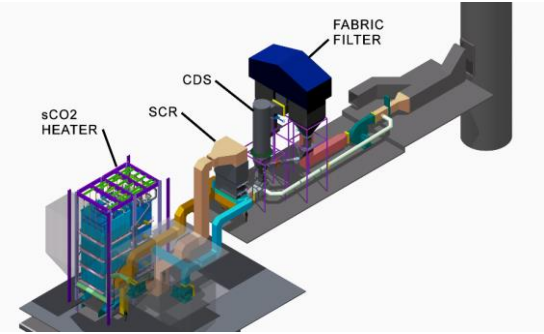
TransCanada / Siemens project

- Announced by TransCanada in March 2019
- EPS120 (uprated EPS100) on an RB211
- Partially-funded by ER Alberta
- TC investigating potential for 25-30 additional WHRUs in Western Canada

https://www.tcenergy.com/stories/2019/2019-02-28-capturing-the-power-of-hot-air/

Ongoing R&D and commercialization

- Leading multiple DOE- and industry-funded projects in:
  - Nuclear – Micro-reactor power plant, others
  - Fossil – 10 MWe indirectly-fired power plant (pre-FEED)



  - Solar – thermochemical energy storage
  - Electro Thermal Energy Storage – ARPA-E DAYS program
  - Thermal power plant integration with ETES

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Capabilities

- System design and optimization
  - Stage-gated design processes based on well-established industrial practices
  - Sophisticated thermodynamic models coupled with detailed, data-based component and system cost models
- Operation and controls expertise
  - 1000's of hours operating closed-loop CO_2 systems
  - Detailed transient modeling and control simulations
- World-class testing facilities
  - Lab-scale system: 700°C/200 bar (upgrading to 250 bar for ARPA-E HITEMMP) or 800°C / 80 bar, 0.3 kg/s CO_2 flow
  - Mid-scale system: 300°C/200 bar at 5 kg/s, upgrading to 600°C for CCCF program
  - 200 kWth-scale Electrothermal Energy Storage system in commissioning

Echogen EPS100 – System Design and Operation

EPS100 process skid

EPS100 power skid

- 7.5 MWe net power output
- Gas turbine combined cycle application (22 MWe target application)
- Tested > 300 hours at Siemens facility

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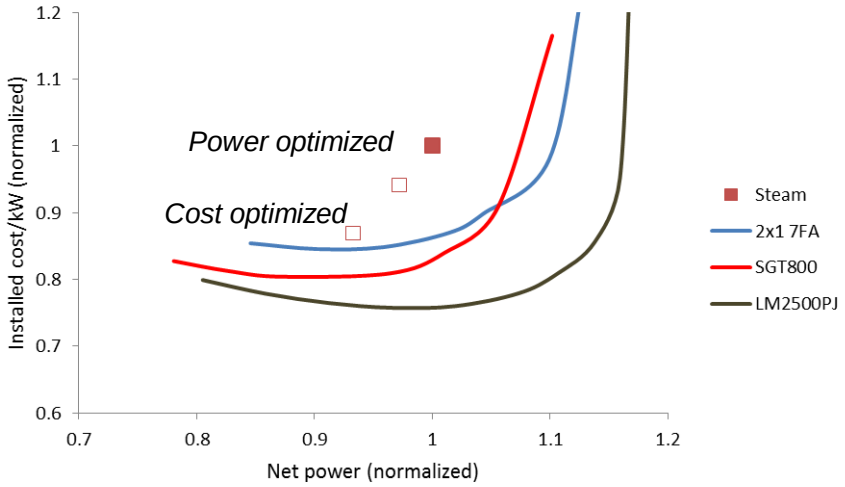
Techno-Economic Analysis and Optimization Example



- Normalized to steam power & cost from GT-Pro, “power-optimized” solutions (“cost-optimized” point shown for reference)
- Same exhaust and boundary conditions used for sCO_2
- 10-20% lower cost for same power
- 7-14% higher power for same cost

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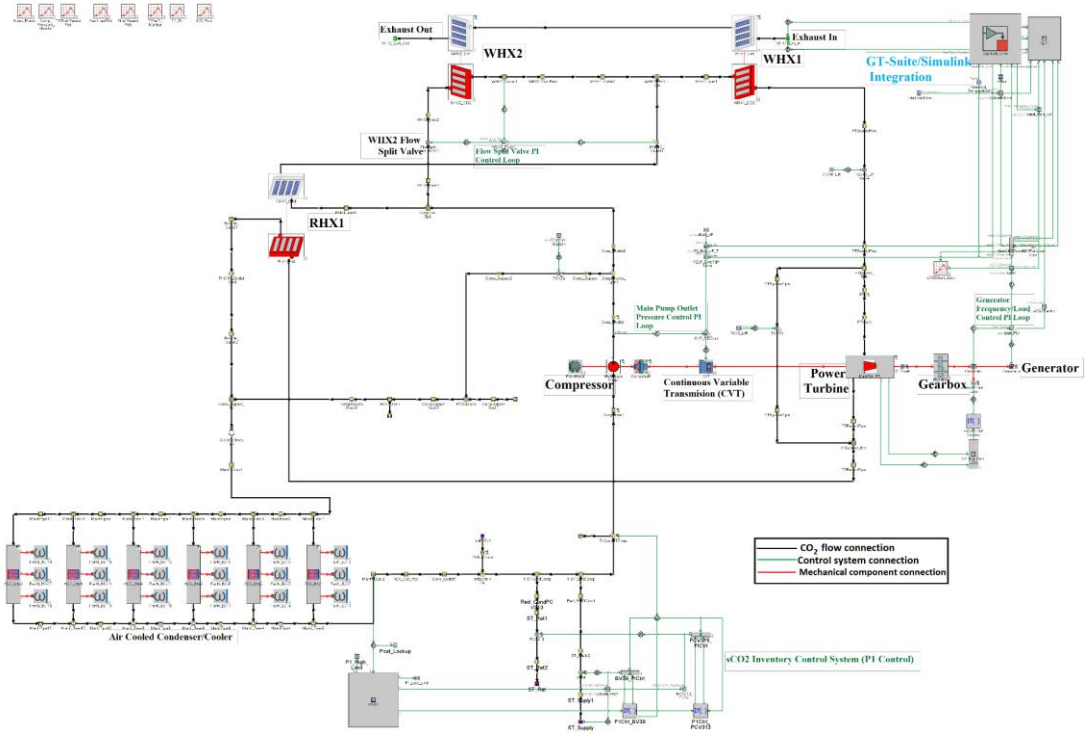
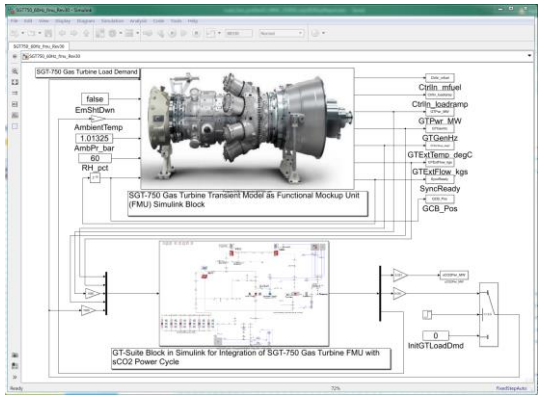
Transient Modeling and Control



- Detailed component and system modeling with integrated control system simulation
- Co-simulation with external heat source (e.g. gas turbine exhaust, reactor core) demonstrated



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High-temperature and Pressure Lab System

- 700°C at 200 bar continuous operation demonstrated
- Upgrades to 250 bar planned
- Both air- and water-cooling available
- Heat exchanger testing
- Operation and control development

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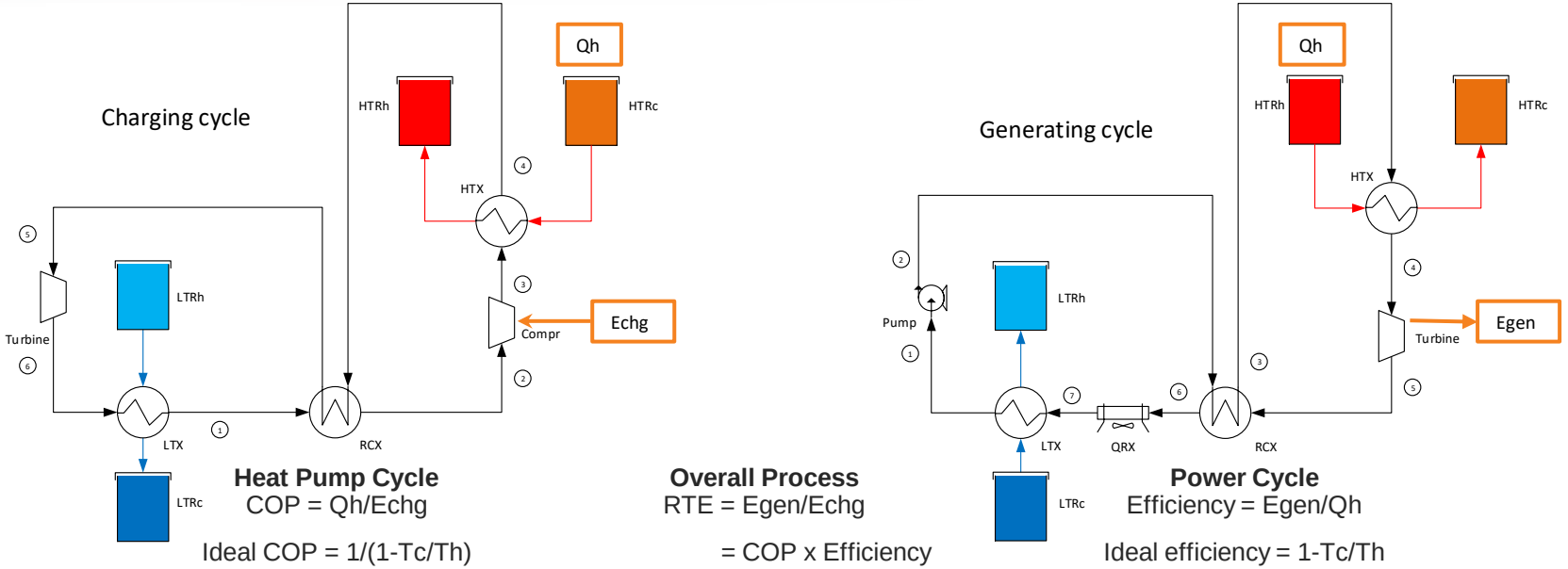
ETES Process flow diagram (simplified)



Ideal cycle RTE = COP_{Carnot} x η_{Carnot} = 100%

Non-ideal processes result in RTE ~60%, even at modest temperature ratio

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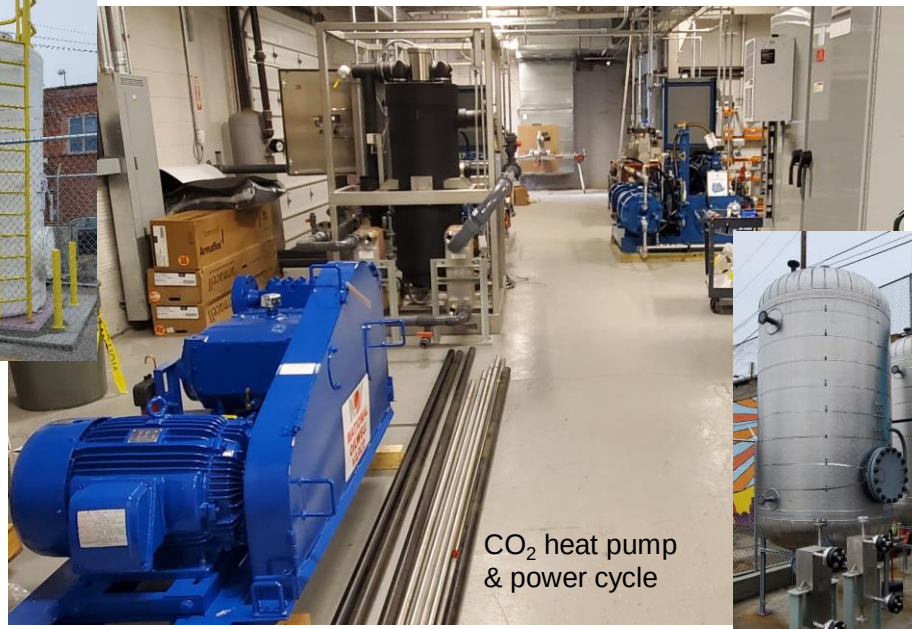
ARPA-E DAYS Program – ETES Proof of Concept

~200 kWth system, including both charging and generating cycles



Initial build
- 2-tank heat transfer fluid HTR
- Ice slurry LTR
- Commissioning end of Sept 2020
- Complete testing October 2020

BP 2
- Build and test sand or concrete HTR system
- Complete July 2021

Primary developmental focus:
- HTR and heat exchanger (TRL 4)
- LTR performance (TRL 4)
- Operation and controls

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