GTI ENERGY

solutions that transform

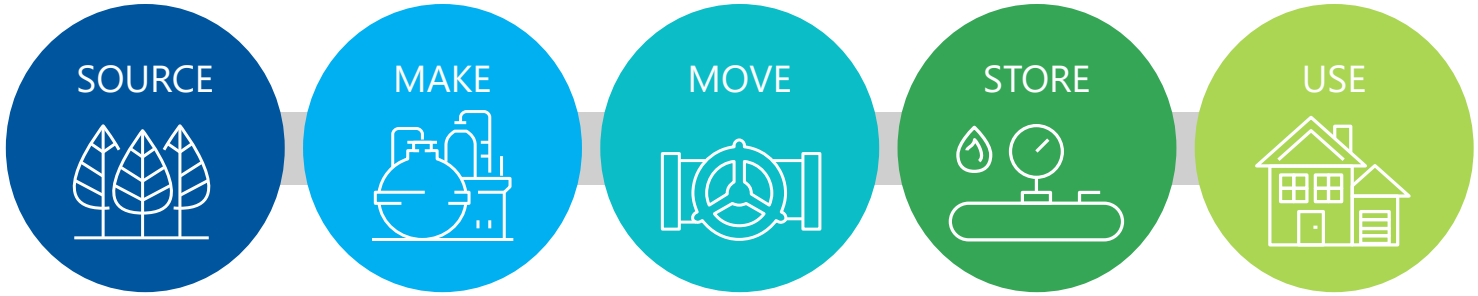
9th sCO2 Energy Technologies Symposium:

Updates on the STEP Demo Project and its Role in Supporting sCO2 Commercialization

Daniel M. Dodd
Program Director for Adv. Power Cycles
3rd March 2026

Who we are

With an 80-year history, GTI Energy is a technology development and training organization, with a trusted team of scientists, engineers, and partners, delivering impactful innovations — from concept to market — for low-emission, low-cost, and resilient energy systems.



Enterprise Employees

500+

Partners in Active Collaborations

175+

80+ years of experience and leadership in energy production, storage, delivery and use

Research & Development

$1B+

In the past decade

Leading and convening collaborative R&D

Innovation & Commercialization

1,300+ Patents

500 Products

750+ Licensing Agreements

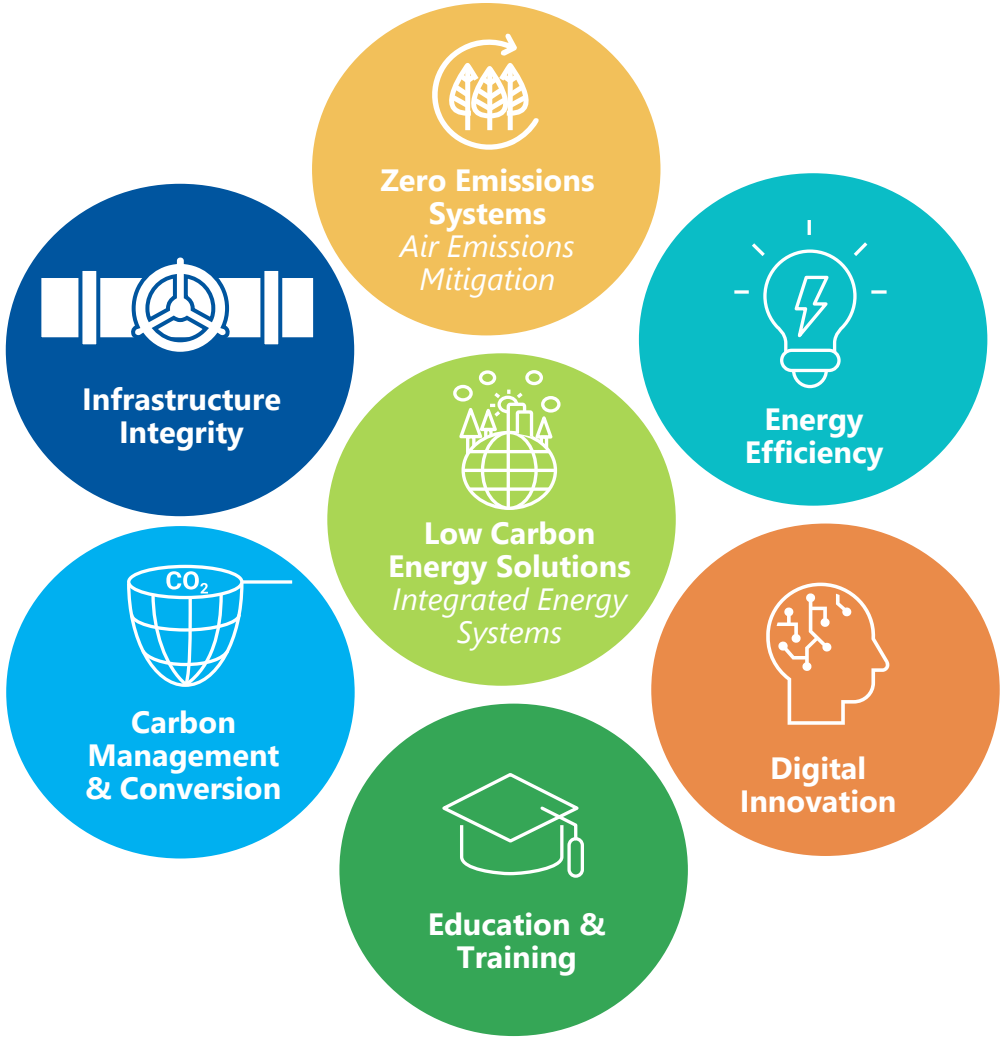
10+ Industry Collaboratives

What we focus on

Our mission is to progress energy systems to benefit the people they serve

Within our business areas, we also focus on:

- Advancing the H2 economy
- Emissions accounting
- Power generation
- Reliability of essential infrastructure
- Subsurface technology
- Next generation workforce
- Operational resilience at federal facilities
- Collaborative, investment-focused platforms for energy transitions



And we are guided by our core values:

- Prioritize safety
- Empower people
- Act with Integrity
- Impact a greater good
- Drive innovation
- Collaborate to accelerate progress

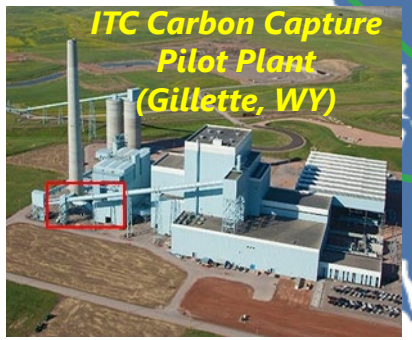
Diverse customers from industry and government

Pilots & Demos


Dry Solids Pilot Plant, (Grand Forks, ND)


IH2 Pilot Plant, (Des Plaines, IL)


Oxy-PFBC Pilot (Ottawa, CN)


ITC Carbon Capture Pilot Plant (Gillette, WY)


Renugas Pilot Plant (Tampere, Finland)


CHG Pilot Plant (Cranfield, UK)


R-GAS Demo Plant (Taiyuan, China)

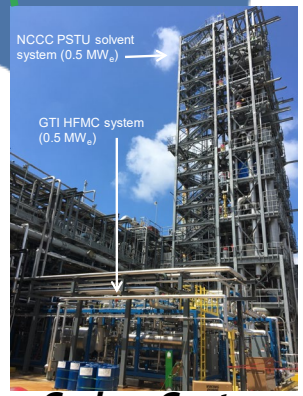

Field Test Sites (Permian Basin, TX)


Gasification Pilot Facilities (Chicago, IL)


CHG Pilot Plant (Des Plaines, IL)

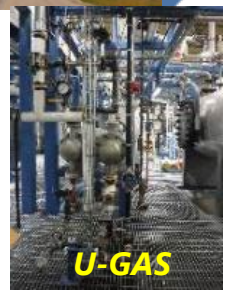

U-GAS Demo Plant (Zaozhuang, China)


10MW sCO2 Demonstration Plant (San Antonio, TX)



Carbon Capture Pilot Plants (Wilsonville, AL)


R-GAS


U-GAS


IH2 Demonstration Plant (Bangalore, India)

Heat & Power
Industrial Technology Landscape

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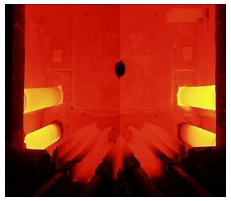
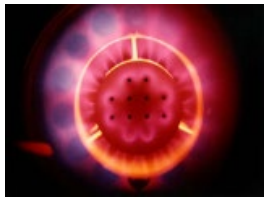
Decades of Experience in Research, Innovation, Field Demonstration and Commercialization

Environment/ Emissions


Advanced Radiant Tubes


3D Printed Burner


O2-Enriched-Combustion

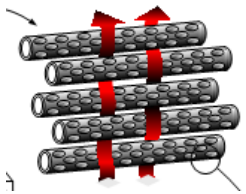



Ultra Low NOx Burners

Heat and Water Recovery

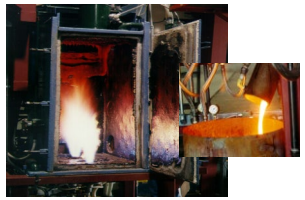

Transport Membrane Condenser


Water Recovery


Waste Heat Recovery

Efficiency


Superboiler


Submerged Combustion Melting


POGT for CHP

Oxy-Fuel (PrimefFre, Honeywell)


Flex CHP

Sensors


Low-Cost O2-NOx Sensor


Gas Quality Sensor

Multiple technologies in different industrial sub-sectors

Heat & Power
Commercial & Industrial – RD&D Capabilities

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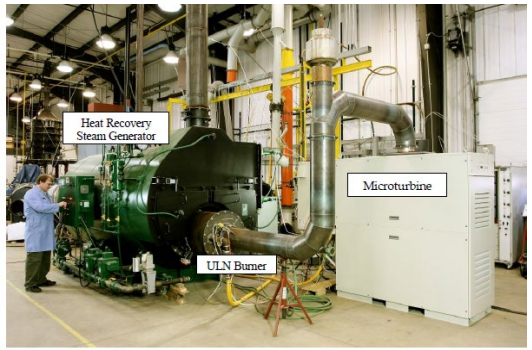
Test platforms for Advanced Thermal Energy Storage & Heat Recovery, simulating boilers, onsite generation, and C&I facilities





Custom multi-fuel test furnaces / heaters for high temp. industries (glass, metals, etc.)




Multi-fuel test platforms at kW-to-MW scale for CHP & Microgrid R&D, including storage integration (H_2, BESS), PV / EV integration, and digital twins

Wide Range of Capabilities for At-Scale Experimentation in Heat & Power

Heat & Power
Commercial & Industrial – RD&D Capabilities

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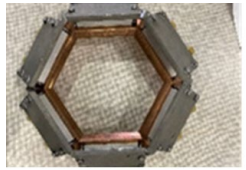
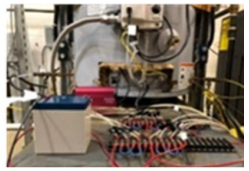
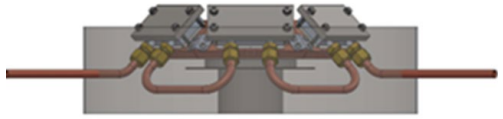
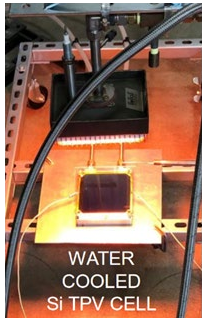
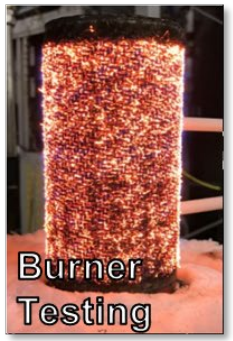
Integration R&D of Energy Storage / Novel Working Fluids

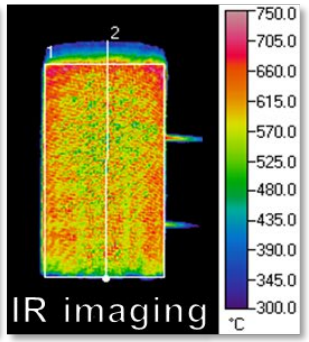

Liquid Desiccant Cooling (L) and sCO2-based Stirling Heat Pumps (R)

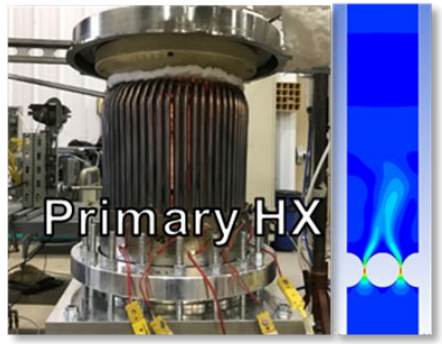





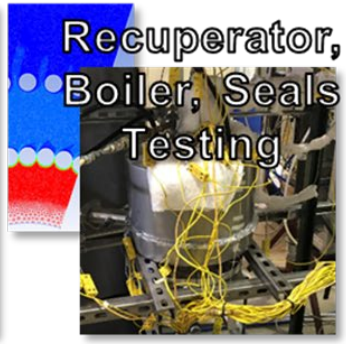
Solid-state Heat-to-Power (L/C) and Novel ORCs (R)

Bench-scale Combustion R&D Examples

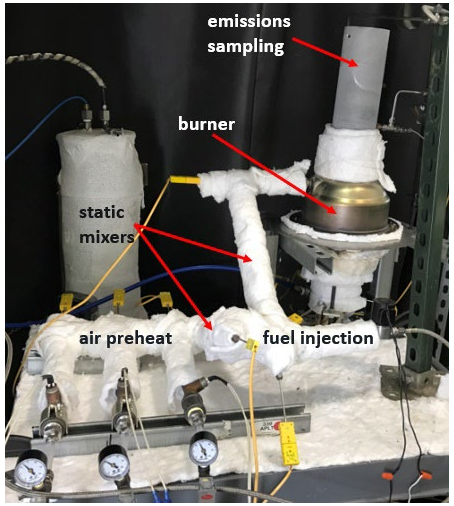








"Hot Side" Development for Stirling Engine




High-Temp. Recuperator (L), Porous Matrix Burner Development (C), Direct-fired Desorber Tests at –30°C (R)

Heat & Power
Commercial & Industrial – RD&D Capabilities

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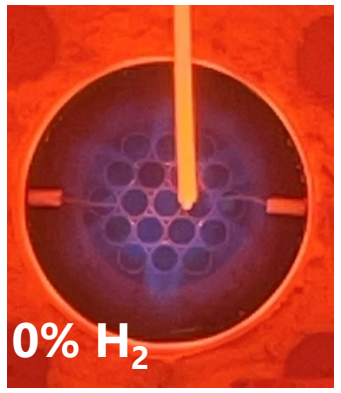
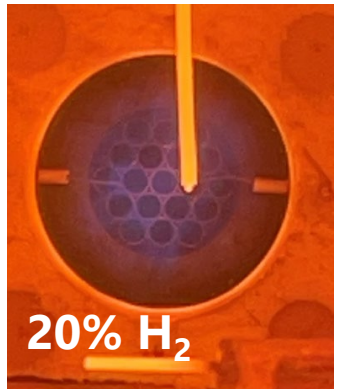
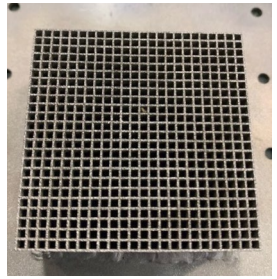
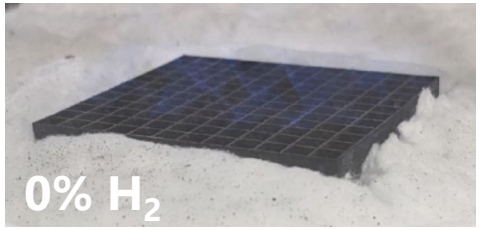
Metals Industry Solutions: Advanced Aluminum Melter demonstrated with low NOx performance and recuperative heat transfer with significant energy savings (16%)

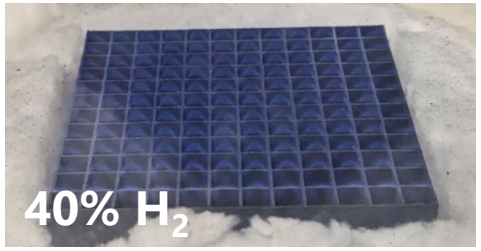
Asphalt Plant Converted for H_2 Utilization: Process underway at CA asphalt to convert ~1.0 MW process heater to safely operate with 30%+ H_2 blend, quantifying emissions impacts











3D-Printed Burners: Working with ORNL, 3D-printed burners with metals at pilot-scale (left, ~1.0 MW) and at test-scale (right, ~2 kW) are being developed for H_2-ready in-situ conversions

Emerging Technologies Program

GTI ENERGY

GTI ENERGY
EMERGING TECHNOLOGY PROGRAM (ETP)

ETP helps companies assess the benefits of new energy efficiency products and integrated solutions for use in near- to mid-term energy efficiency program implementation.

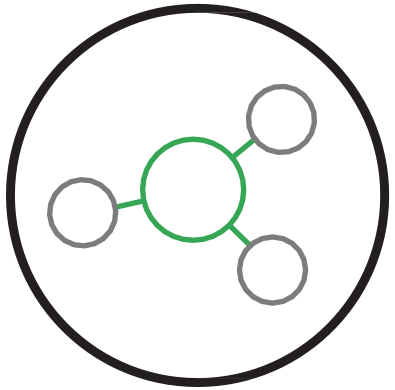
Emerging Technology Program

- GTI Energy-led, utility-supported, North American collaborative targeting residential, commercial, and industrial solutions
- ETP's goal is to accelerate the market acceptance of emerging energy efficient technologies

Low Carbon Resources Initiative

The **Low Carbon Resources Initiative** is accelerating a safe, affordable, reliable, and environmentally responsible energy transition by advancing production, distribution, and application of low-carbon, alternative energy carriers and the cross-cutting technologies that enable integration at scale

Hard-to-decarbonize applications



Alternative energy carriers as solutions to deep decarbonization

Additional research, development, and demonstration

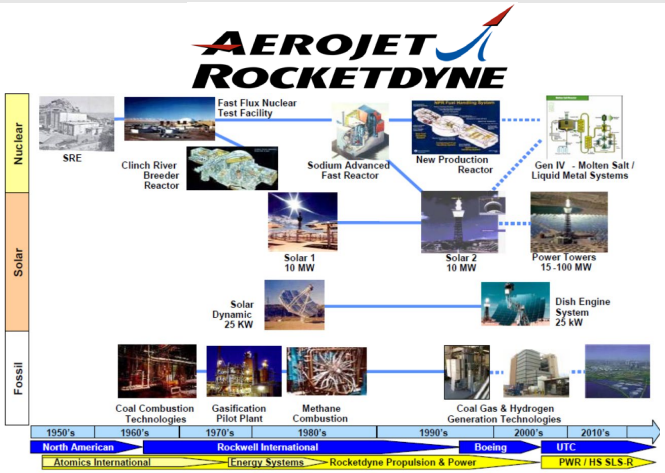
$136MM funding

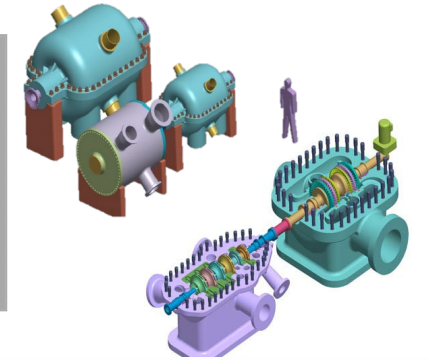
55 global partners

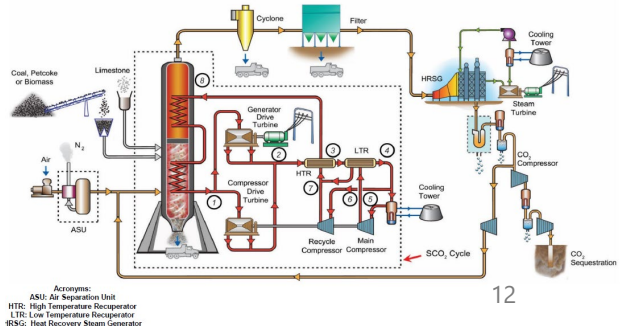
GTI Energy's Heritage in Advanced Power Cycles

- In **2015, GTI acquired Rocketdyne's Energy Transition technology and personnel**
- Since 1950s, Rocketdyne (and predecessors) lead development of: **next-gen nuclear, solar concentration and thermal storage, and fossil combustion and gasification**. That, combined w/ **high-speed and high-power turbomachinery from rocket engine business units** lead to **Rocketdyne becoming a leader in emerging sCO2 space**.

- 2006 – Rocketdyne completed sCO2 IR&D, and separately work for Sandia NL
- 2007 – Rocketdyne completed power cycle study for French adv. Nuclear plant 500MWe+
- 2011 – 1GWe sCO2 power cycle for 550°C LMR nuclear facility. For Argonne NL and DOE NE.
- 2011 – Direct-fired sCO2 for coal conversion. For DOE FE.
- 2012 – sCO2 retrofit to solar tower facilities. For DOE EERE.
- 2014 – sCO2 key equipment studies, with focus on 500MWe ZEPS (coal conversion). For DOE FE.
- 2014 – Patent awarded on RCBC sCO2 cycle.
- 2015 – Completed conceptual design for 10MWe indirect-heated pilot. For DOE NE.
- 2016 – Awarded prime contract for STEP Demo 10MWe pilot plant, from DOE FE.
- 2017 – Patent awarded on ZEPS cycle that inc. sCO2 power cycle.
- 2018–present. STEP Demo project is the main focus, while continuing to complete ~10 studies and engineering work for OEMs, project developers and end-users.







sCO_2 Cycles – Unleashing Energy Innovation

Potential USA Electric and Energy Impacts by 2050

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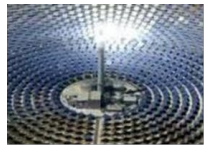
GTI's meta analysis on Net-Zero pathways:
All studies showed 3X more electricity required by 2050 in all scenarios!


Waste Heat Recovery


Concentrated Solar


Energy Storage


Geothermal


Fossil Fuel & Biomass


Nuclear

Total Potential
232 GW, 1.4 TWh/yr
~18% of Current US Electric Capacity

Next Gen Nuclear
10% of Total Nuclear
8 GW_e 62,500 GWh_e/yr
Increased power, compact

Adv Geothermal
10% of Geothermal
8.5 GW_e 60,000 GWh_e/yr
Resilient, anywhere

OxyFuel with CCS
10% of NG fueled generation
13.3 GW_e 93,100 GWh_e/yr
Next-generation gas-fired power

Improving Energy Output and Resilience

Electro-Thermal Energy Storage
25% of Total Storage
40.9 GW_e 89,500 GWh_e/yr
Resilience, distributed grids

Industrial Heat Pumps
10% of Industrial Heat
138 GW_{th} 970,000 GWh_{th}/yr
Multiplying electrified heat

Concentrated Solar
5% of Total Solar
14 GW_e 98,500 GWh_e/yr
Grid/Industrial heat resilience

WHR
25% of SCGT Installed Base
9.3 GW_e 10,700 GWh_e/yr
Increased power >30%

SwRI 2025

% = Assumed market penetration
GW_e or GW_{th} = installed capacity
GWh_e /yr or GWh_{th}/yr = energy delivered
Primary data source: eia annual energy outlook

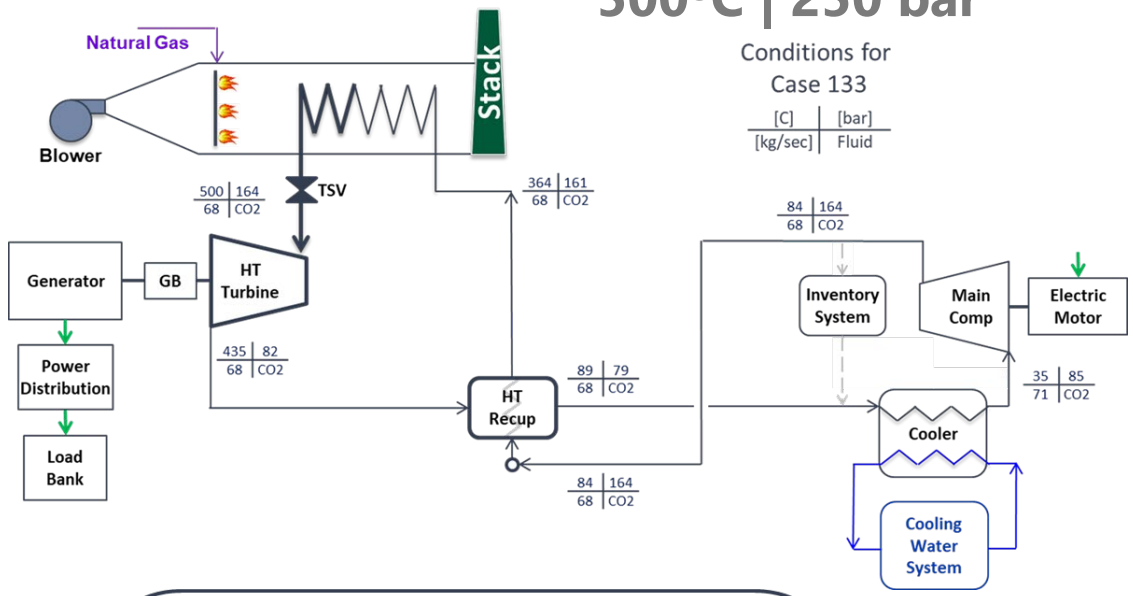
Supercritical Transformational Electric Power (STEP) Demo Project

- $170M project to design, construct, commission, and operate a 10 MWe sCO_2 demonstration power plant
- **Objectives:**
  - Advance sCO_2 power from TRL-3 to TRL-6/7
  - Demonstrate pathway to plant efficiency > 50%
  - Demonstrate control and operability at **500°C** and **715°C** turbine inlet temperature with **10 MWe** power generation
- **Project Partners:**
- **Industry Co-Funders:**

www.STEPdemo.us

STEP Demo will test two indirectly-heated sCO2 Cycle configurations:

Simple Recuperated Brayton Cycle
500ºC | 250 bar

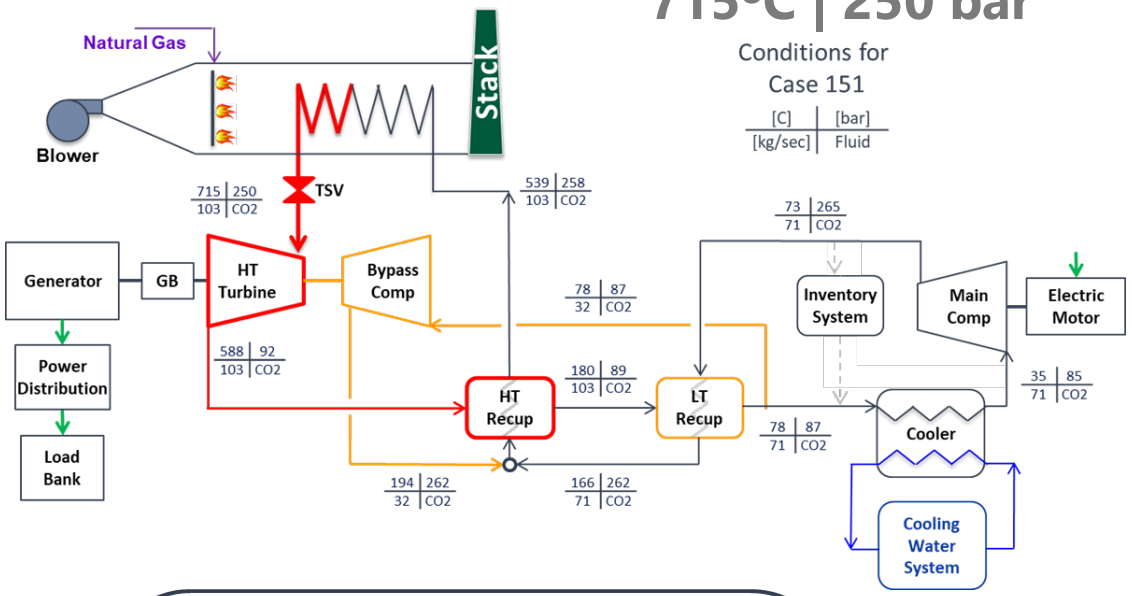


Objectives

Demonstrate initial cycle performance with reduced risk configuration

- Reduced Turbine inlet at 500°C similar to Waste Heat Recovery applications
- Single compressor configuration
- Provides Steady & Transient Cycle Performance Data used to predict RCBC performance and operations

Recompression Brayton Cycle (RCBC)
715ºC | 250 bar



Objectives

Demonstrate high performance cycle with parallel compressors & multiple HEX

- Increase Turbine inlet to 715°C
- Measure Steady & Transient Cycle Performance Data, evaluate operability
- Demonstrate pathway to 50% thermal efficiency
- Supports application to in-direct coal, HT WHR Industrial sources, and CSP plants

STEP Project Milestones

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BP1

2016 - Oct Project Start

BP2

2018 – Oct Ground-breaking

2019 - Jan Facility design complete

2020 - May Building Completed

2023 - Oct Mechanical Completion

2023 - Dec 1st Turbine Spin

2024 – Jan 1st Closed-Loop Test

2024 - Oct Simple Cycle Testing completed

BP3 & 4

2025-26+ RCBC Testing to be completed

STEP groundbreaking – Oct 2018

STEP site construction – Oct 2019

Building Foundation – Dec 2019

Certificate of Occupancy – May 2020

Mechanical Completion & Start of Commissioning – Oct 2023

Turbine & compressor install – Sep 2021

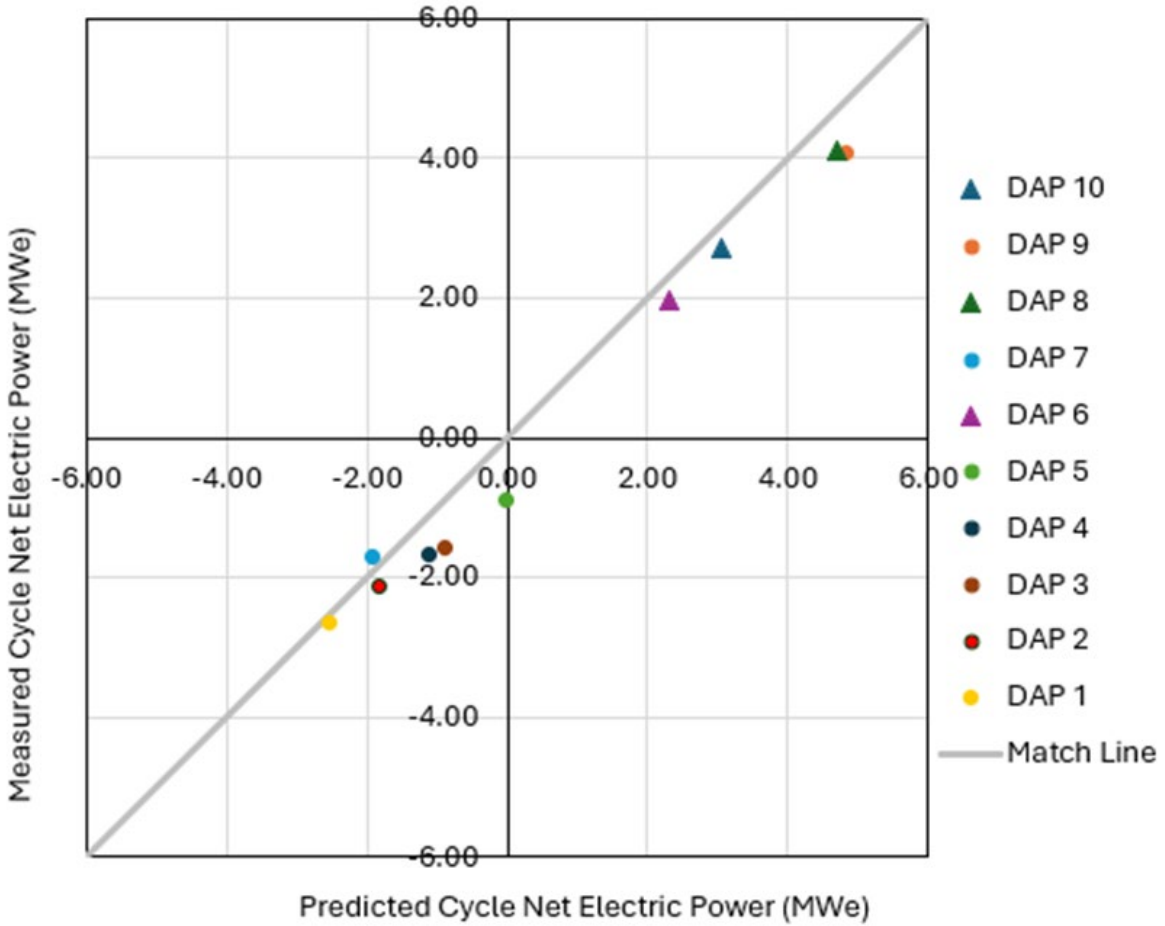
Compressor Commissioning

Completed in 2024

Turbine Test

STEP Demo Simple Cycle Testing

- Successful and robust operations and control
- Performance of components and system in line with expectations and our steady & dynamic models
- ~390 hrs of compressor and loop testing culminating in first hot fire tests in Jan 2024
- Achieved full turbine speed (26,620 rpm) in May 2024 with TIT of 250°C
- Test program followed increasing speed, temperature, and power
- Seven test campaigns in Fall 2024 conducted reaching TIT of 500°C culminating in 7.4MWe generator power and 3.9MWe net to grid



"DAP" = Data Acquisition Point

STEP Team @ sCO2 Symposium

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Tuesday

Modeling & Control 1 [1:30–3:00 PM]

- **Darryl Hino (GTI) – Paper #057** – *Validation of the STEP Demo Dynamic Model with Simple Cycle Test Data*
- **Josh Warren (SwRI) – Paper #061** – *Operational Transients in Supercritical CO_2 Systems: A Case Study on a 10 MWe Cycle*
- **Wade Mao (GTI) – Paper #067** – *Steady State Model Update for the 10 MWe sCO2 Test Facility Program*

Testing 1 [3:00–4:00 PM]

- **Dr. Henry Saari (Carleton University) – Paper #030** – *Analysis of Gas Samples Collected from the 10 MWe Supercritical Transformational Electric Power (STEP) Demonstration Plant*

Wednesday

Compressors 2 [11:00–12:30 PM]

- **CJ Nolen (SwRI) – Paper #053** – *Comparison of sCO2 Compressor Performance Test Results Using Temperature-, Density-, Or Torque-based Measurements*

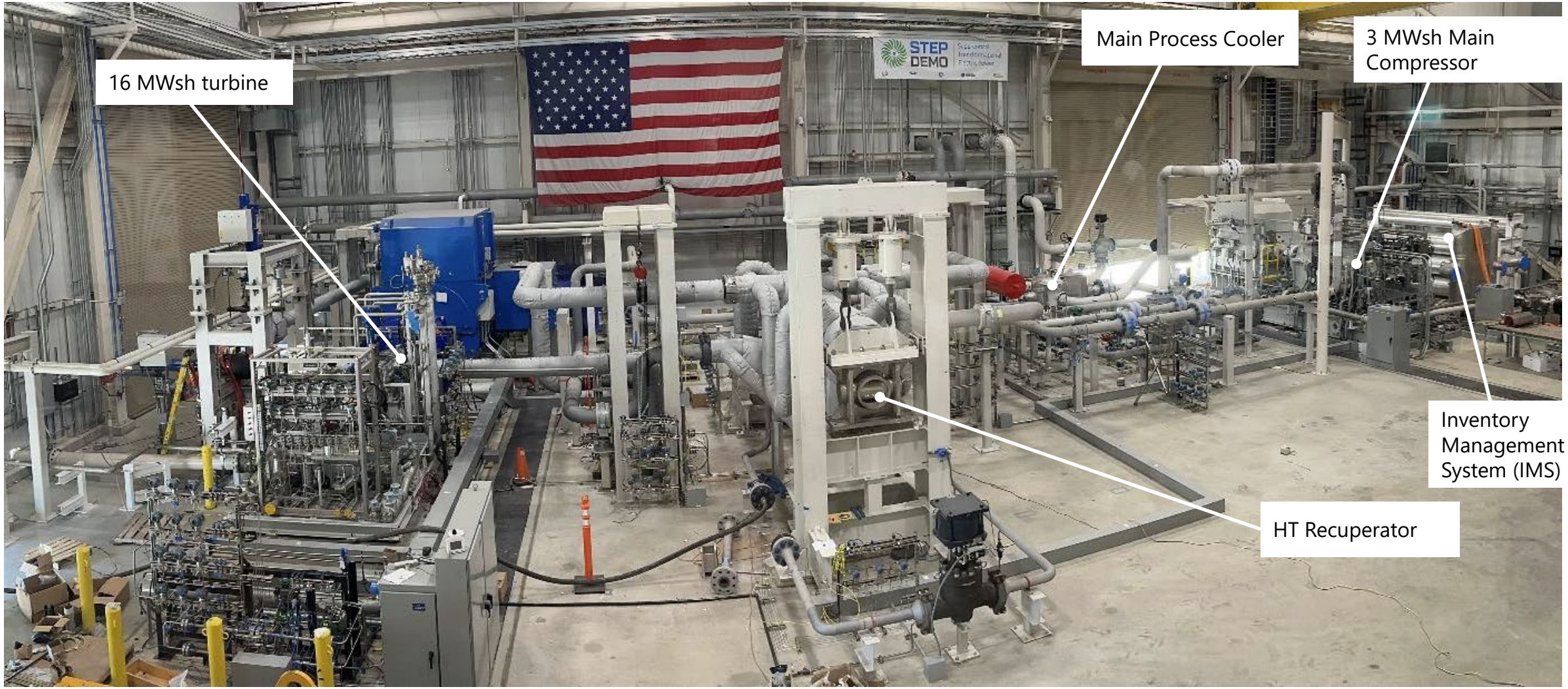
Testing 2 [2:00–3:30 PM]

- **Darryl Hino (GTI) – Paper #058** – *Hydraulic Shock Event and Analysis During Simple Cycle Testing at STEP Demo Facility*
- **Josh Warren (SwRI) – Paper #069** – *Experimental Operation and Future Design Considerations of a sCO2 Turbine Stop and Control Valve*

Poster

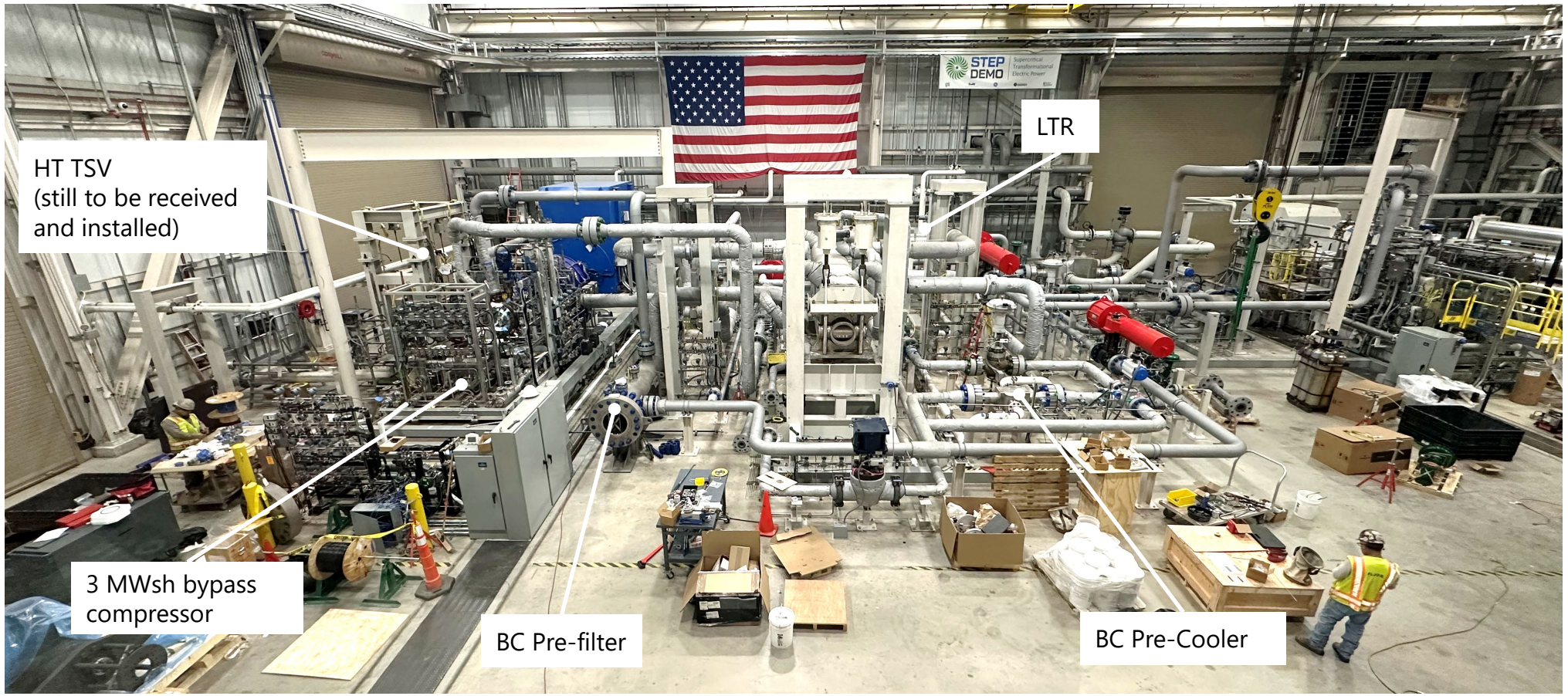
- **Jon Wade (SwRI) – Poster #056** – *Verification of Settle Out Condition Prediction Methods for STEP Pilot*

STEP Demo During Simple Cycle Testing



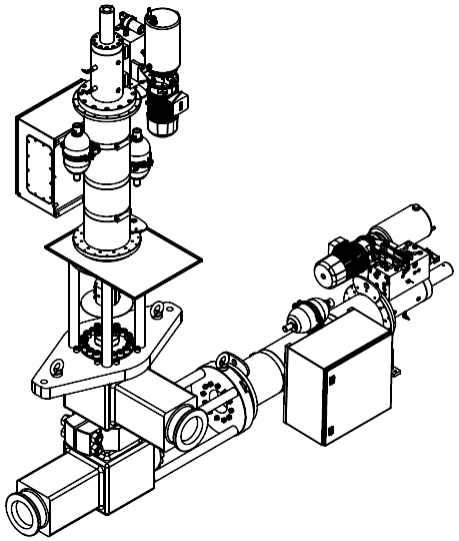
STEP Demo During Reconfiguration to RCBC

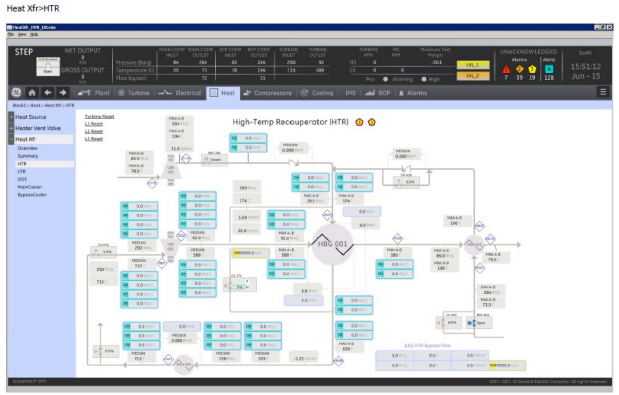
Since Fall 2024: LTR; BC, BC PC, BC PF; and related PVF and EI&C additions. Extensive compressor modification. HT TSV manufacturing. Improvements to subsystems, and final HAZOP (and mods).



STEP Demo Upcoming Activities

- Project Award Reinstatement (planned)
- Completion of RCBC System Readiness
- Facilitate JIP member test and validation input, and requests that would support their sCO2 cycle acquisition efforts
- Receipt and install of HT TSV
- Accrue approx. 160+ hours of operations (LT and HT RCBC)
- Materials corrosion testing (6,000+hr), and working fluid impurity monitoring
- Production of CBO HMI (GE Mark VI) simulator anchored with empirical data, and provide training to STEP Demo team and 3rd parties
- TMP (inc. gaps analysis) and TEA (focus on (a) retrofitting SCGT peaker plants, (b) SMRs; though many other use cases possible)





STEP Demo Joint Industry Consortium

Leverage $170+million program to determine how this technology fits into your power generation plans and influence the project direction

Two levels of participation available to Industry:

1. Steering Committee Level

- Input and advisory recommendations to the project team
- Direct participation in bi-monthly advisory meetings
- Attendance at bi-annual technical interchange meetings
- Receipt of quarterly technical status reports
- Real time access and use of Project System Data
- Copies of Government technical reports (upon publication)
- Opportunity for facility visits and training in system operations
- Period of exclusive access to license system IP

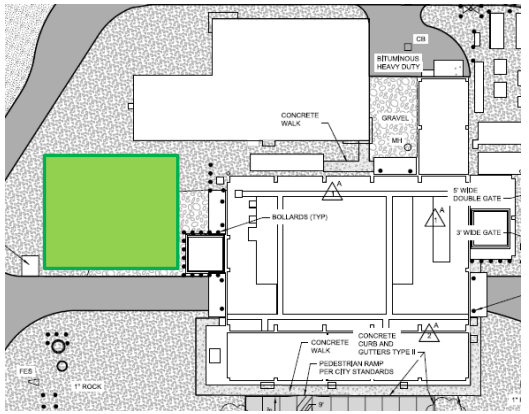
2. Associate Membership

- Copies of Government technical reports (upon publication)
- Attendance at bi-annual technical interchange meetings
- Receipt of quarterly technical status reports
- Opportunity for 2 site visits per year

Project team welcomes new individual or joint participants to the Joint Industry Program!

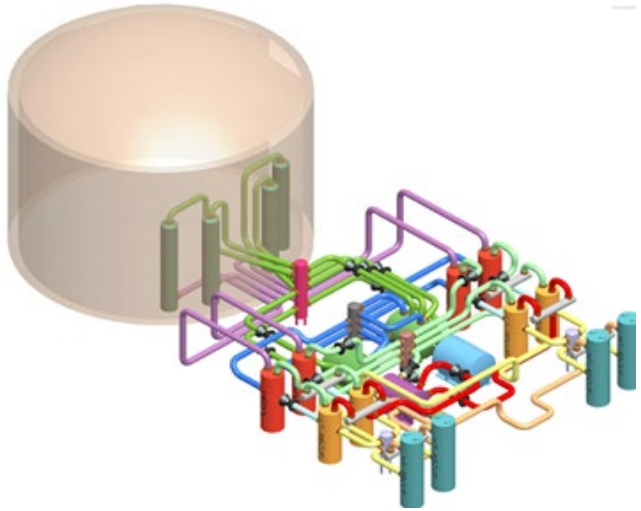
STEP Demo 2.0 and Other Initiatives

- Prospects to utilize STEP Demo 10MWe facility
  - 1,000-hr (6-wk) endurance testing inc. real-world dispatch/transient operations
  - Installation and validation of components or complete packaged systems
    - Next-generation low-leakage rotating equipment install and testing
    - FAT for commercial orders
    - **opportunity** to participate in consortium that's forming
  - Continued materials corrosion testing
  - Incorporation of additional heat sources (e.g. energy storage) into sCO2 power cycle, and especially the integration with the complex Primary HX.
  - Potential for incorporation of additional cycle configurations (e.g. cascade etc.)
- **opportunity** Assembling consortium for install of TRL-8 system at customer's site (likely 500°C TIT system attached to SCGT peaker). Through multiple years of operations, drive this technology to TRL-9.



Other Initiatives and Recent Work Completed

- Need to explore strategies for cost-down of equipment (demand aggregation; standardization), while increasing robustness of **supply chains**…
  - **ASME Turbo Expo 2026 panel on this very topic**.
- Space-based small-scale micro-nuclear
- WHR from steel and cement processes
- WHR from simple-cycle gas turbines
- Nuclear fusion at the 600 MWe gross scale
- CSP and thermal storage
- Thermal storage w/in sCO2 power cycle for more-rapid load-following
- SMRs for land-based applications 20–80 MWe
- Oxy-Fuel coal to power integrated with sCO2
- Materials for sCO2 power combined with Nuclear Fusion
  - Heat Exchangers 2 [Thu 9:30–10:30 AM]. **Chris Clements (AtkinsRéalis and GTI) – Paper #020** – *Considerations of Primary Heat Exchanger Materials for Fusion Reactors Utilizing sCO2 for Power Conversion*



Example of GTI prior work: Pre-FEED for DOE/NE (sCO_2 Cycle for LMR)

Summary and Outlook

- Compelling indirectly-heated cycle with broad scalability (100s kWs to 100s MWs) and temperature ranges (220°C for geothermal up to 700°C++ for HTGRs, CSP etc.)
- Strong opportunity to retrofit existing SCGTs to generate additional power from existing assets, providing an additional option for utilities struggling to support significant demand increases from datacenters etc.
- Everllence/MAN and EnergyDome help, but need significantly more operating hours at real-world installations for actual power cycles and at higher-temperatures for the overall industry's credibility
- Cycle even listed by DOE's Fusion Science & Technology roadmap with need to "Validate closed Brayton / Rankine power cycles." DOE Offices of FE, NE and SE had laid-out a robust, sensible long-term roadmap covering a 10+ year period.
- Has the US Government ceded our lead in this emerging sector to China and others?
- If you're an OEM, EPC, end user, utility – we'd like to talk (how sCO2 can support your medium-term goals; solidifying supply chains; demonstration consortiums etc.)

Gratefully Acknowledging the Support from U.S. DOE-NETL and Project Partners

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