sCO2 Power Cycle Development and STEP Demo Pilot Project

STEP DEMO

The 4th European sCO2 Conference for Energy Systems
March 22-26, 2021
Prague, Czech Republic

2021-sCO2.eu-1060

Brian Lariviere
GTI, Program Director, STEP Project

NATIONAL ENERGY TECHNOLOGY LABORATORY gti SwRI

Agenda

- Project Overview & Objectives
- Facility and Test System Equipment Status
- Commissioning, Start Up, and Test Plan
- Summary

Cooperative Project Execution Organization

STEP DEMO

Don Stevenson (GTI)
John Marion (GTI)
Tim Allison (SwRI)
Darren Hallman (GE-R)

Project Steering Committee

- DOE
- Project team (GTI, SwRI, GE)
- JIP (Joint Industry Program) Cost-sharing organizations (national & international)

Project guidance/ recommendations

NATIONAL ENERGY TECHNOLOGY LABORATORY

Project Coordination
Seth Lawson
Project Manager

KEPCO, Natural Resources Canada, American Electric Power, Southern Company, ENGIE, CSIRO, EGAT

STEP Project Team

SwRI
Aaron McClung
Program Manager

gti
Brian Lariviere
Program Director

GE
Jason Mortzheim
Program Manager

Co-PI's for Project Execution with GTI lead

Texas Commission on Environmental Quality, University of Houston Cullen College of Engineering, Natural Resources Canada, University of Wisconsin-Madison

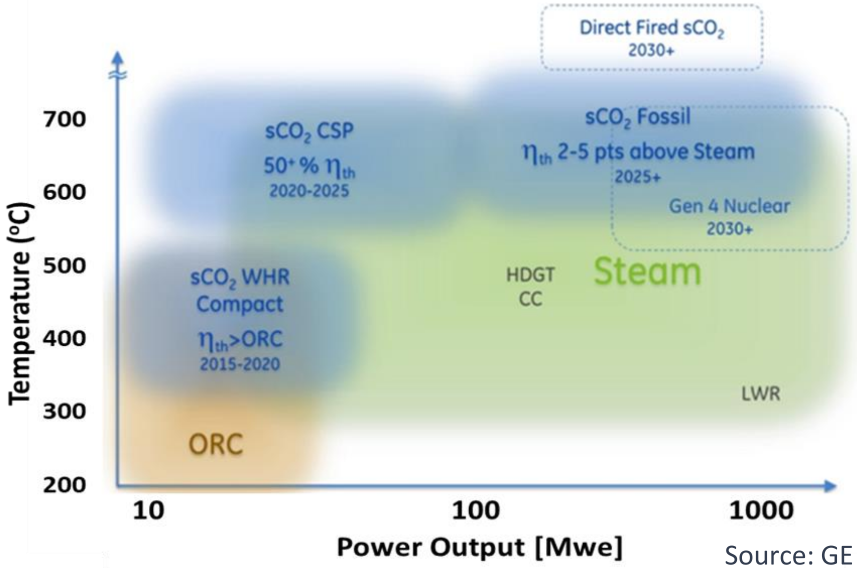
Promise of sCO_2 Power Cycles

Promise:

> Efficient, Compact, Scalable, low water, low-carbon power generation

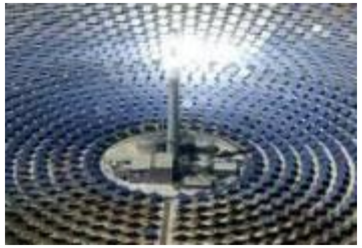
STEP Demo will demonstrate:

> Operability, Turbomachinery, Seals, Heat Exchangers, Durability, Materials, Corrosion, Cost



Source: GE

Versatile Technology – Broad Applicability:



Concentrated Solar

Fossil Fuel

Geothermal

Nuclear

Ship-board Propulsion

Waste Heat Recovery

Supercritical Transformational Electric Power (STEP) Project DE-FE0028979

STEP DEMO

Scope: Design, construct, commission, and operate **10 MWe sCO_2 Pilot Test Facility**
Reconfigurable to test new technologies in the future

Goal: Advance state of the art for high temperature sCO_2 power cycle performance
Evolve Proof of Concept (TRL3) to operational System Prototype (TRL7)

Schedule: Three budget phases over six years (2016-2022)
Currently in Budget Phase 2 – Fabrication & Construction

Team: U.S. Department of Energy (**DOE NETL**)
Gas Technology Institute (**GTI®**)
Southwest Research Institute (**SwRI®**)
General Electric Global Research (**GE-GR**)

Industry Partners:

KEPCO, Natural Resources Canada, Southern Company, American Electric Power, ENGIE, CSIRO, Texas Commission on Environmental Quality, EGAT Power for Thai Happiness

DOE, National Energy Technology Laboratory, gti, SwRI, GE

STEP Program Objectives

STEP Demo will demonstrate a fully integrated functional electricity generating power plant using transformational sCO2-based power cycle technology

- Turbomachinery (aerodynamics, seals, durability)
- Recuperators (design, size, fab, durability)
- Materials (corrosion, creep, fatigue)
- System Integration & Operability (start, transients, load following)

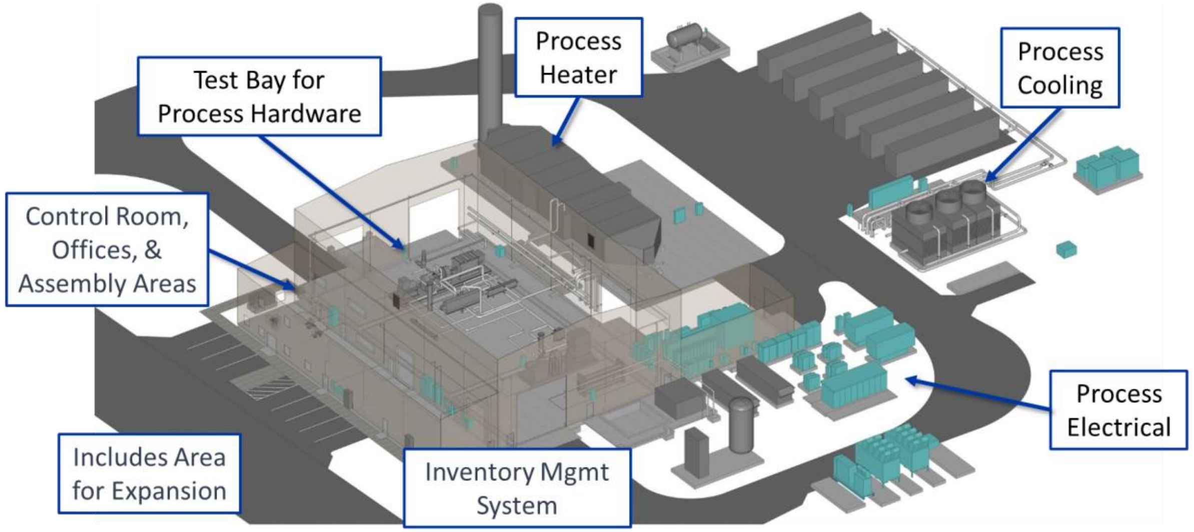
Demonstrate pathway to efficiency **> 50%**

Demonstrate cycle operability **>700°C** turbine inlet temperature and 10 MWe net power generation

Quantify performance benefits:

- 2-5% point net plant efficiency improvement, 3-4% reduction in LCOE, Reduced emissions, fuel, and water usage

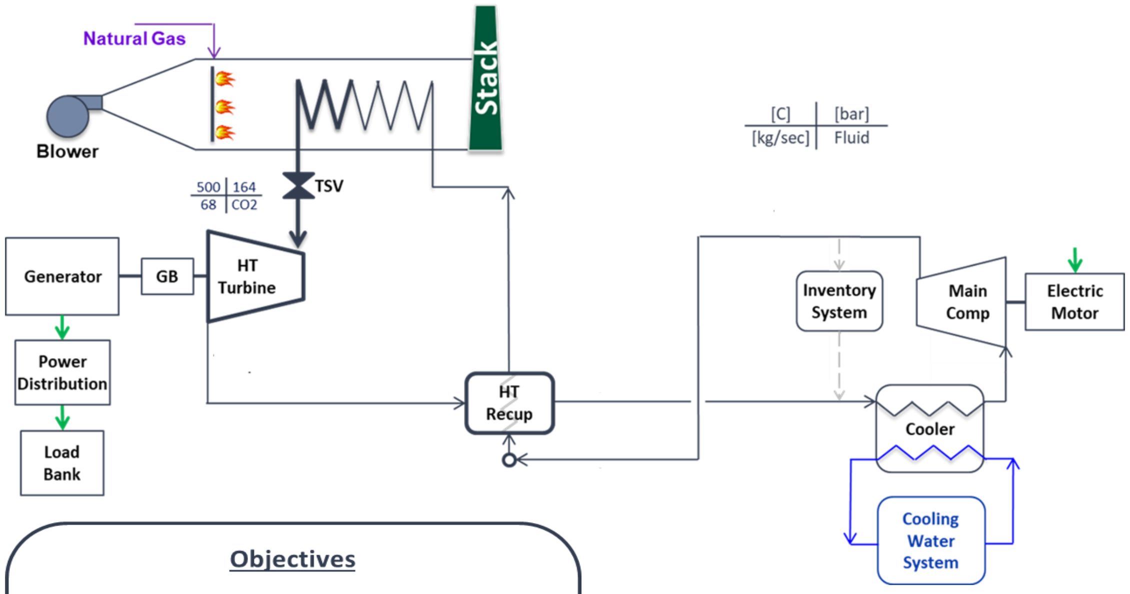
Demonstrate Reconfigurable flexible test facility - Available for Testing future sCO2 equipment & systems



STEP will be among the largest demonstration facilities for sCO2 technology in the world

Simple and Recompression Brayton Cycle test configurations planned to achieve project objectives

Simple Recuperated Brayton Cycle

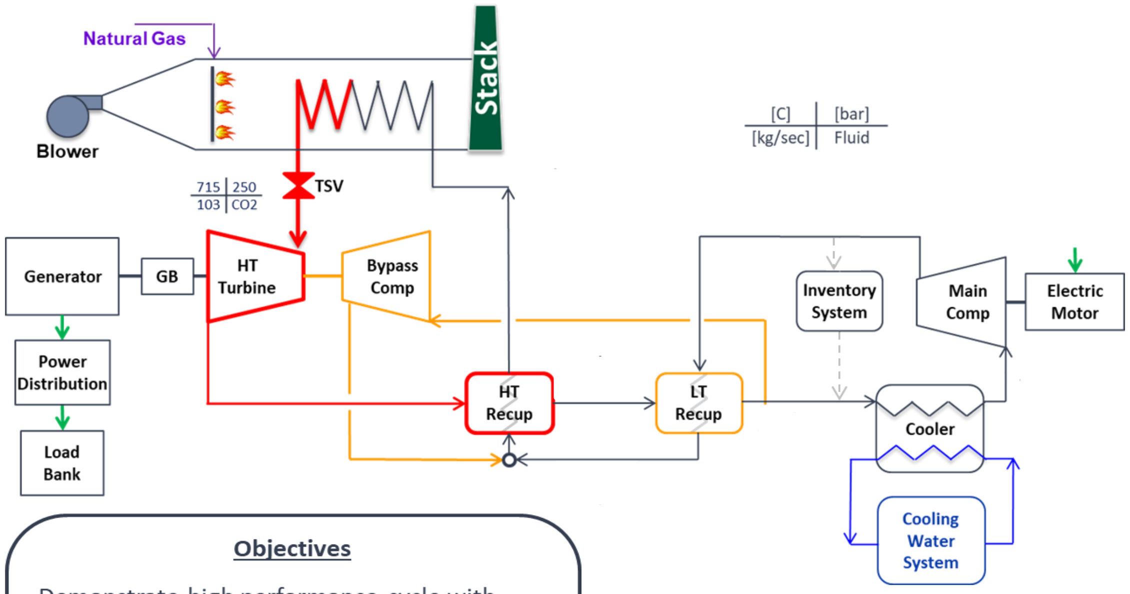


Objectives

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)



Objectives

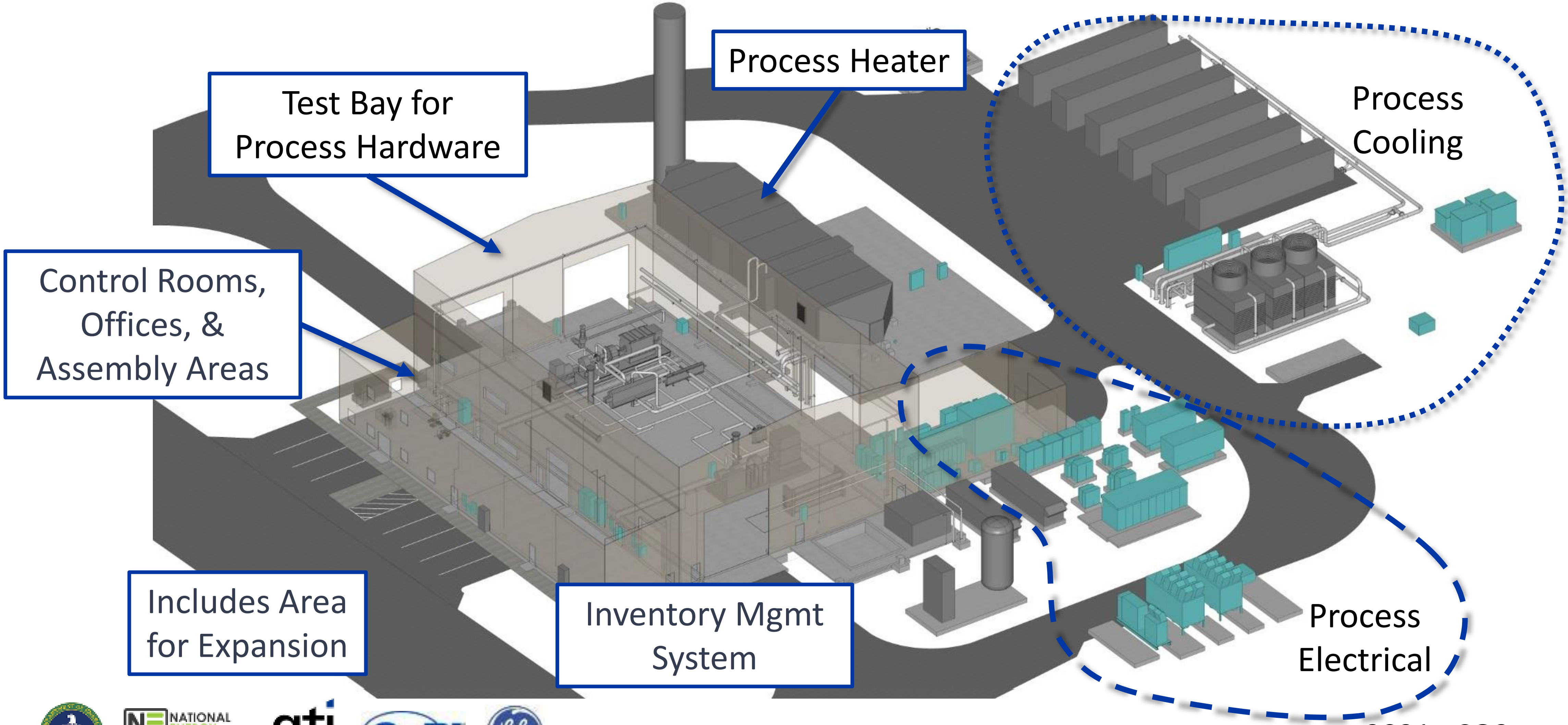
Demonstrate high performance cycle with parallel compressors & multiple HEX

- 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 Facility and Test Equipment Status

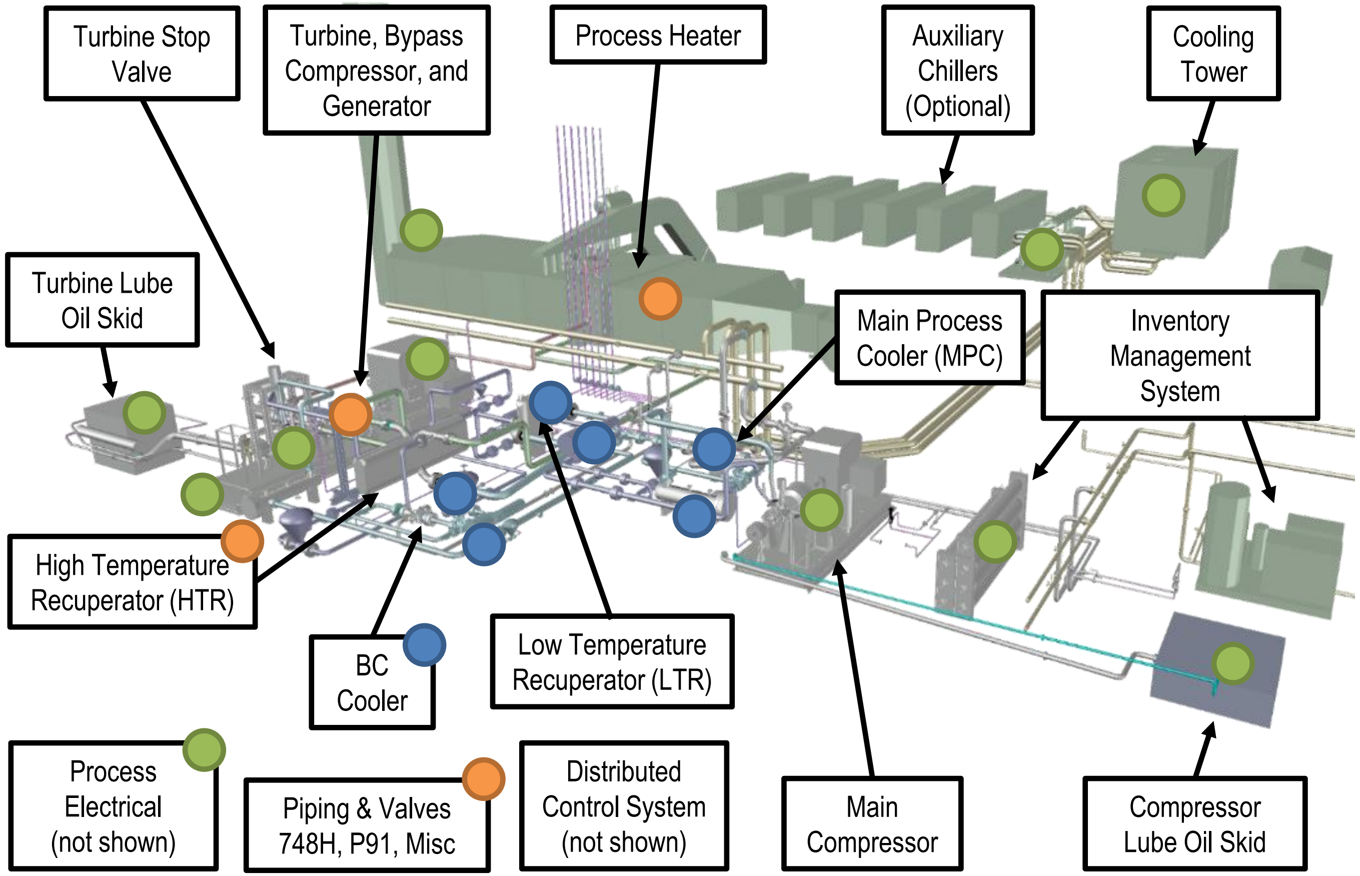
- **Site Construction Progress Excellent**
  - Building Occupancy received in early June 2020 on schedule
  - Process Electrical, Heater, Cooling Water, Compressor Installation progressing
- **Significant Achievements on Major Equipment Design & Fabrication**
  - Most Major Equipment delivered or near completion
  - Remaining Major Equipment delivery by Summer
- **Challenges with ‘first of a kind’ equipment impacted schedule**
  - Design: High Temperature Recuperator
  - Fabrication: Turbomachinery
  - Fab Adv Ni-Alloys: Primary Heater (740H), and Turbine Stop Valve (H282)
  - Resolved most technical issues and progressing with final equipment manufacture and delivery
- **Industry efficiencies impacted schedule during COVID pandemic**

STEP - Flexible Test Facility



Facility Construction Completed at Test Site in San Antonio, TX

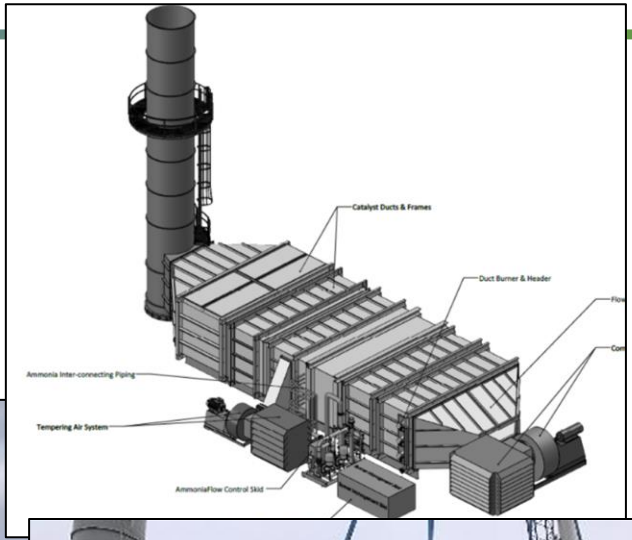
New Facility Occupancy on Time



Received and Set   Received in Storage   Critical Delivery

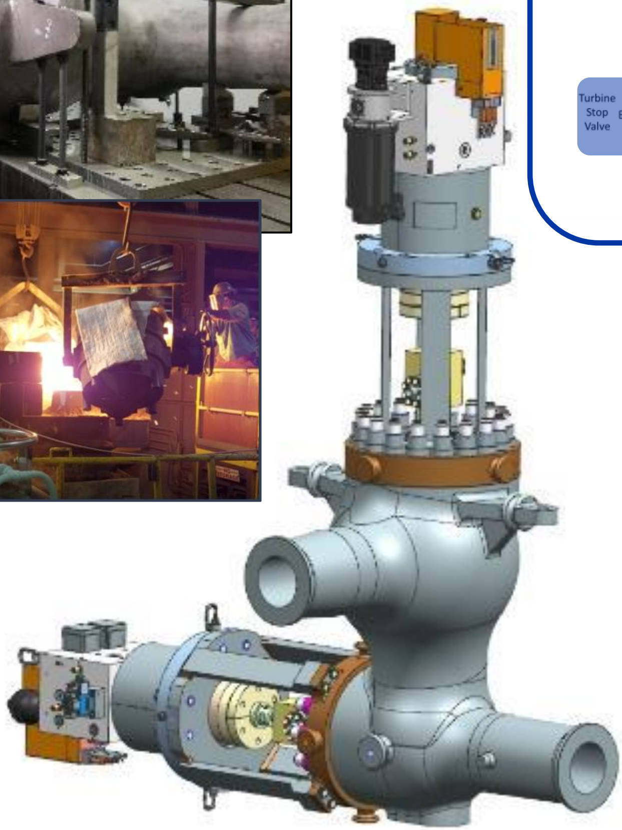
Process Heater construction on going

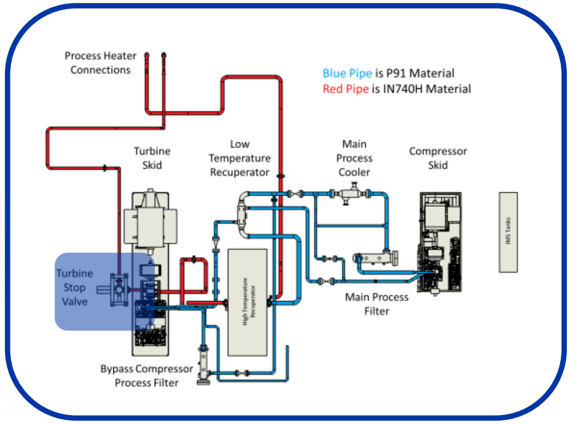
- Heat Recovery Steam Gen (HRSG) style “boiler”
  - Duct NG burner ~ 50 MWth
  - Designed to ASME BPV Section 1
  - Size: 14’W x 133’L x 18’H
- Optimus Industries, LLC



STEP Turbine Stop/Control Valve (TSV)

> Turbine Control and Stop Function
  - Provided by GE Power
  - Based on conventional steam valves with sCO2 specific features
  - Leverages Haynes 282 material development under DOE AUSC program
  - Stem Seal Design Tests Completed
  - **First production Haynes 282 Valve**

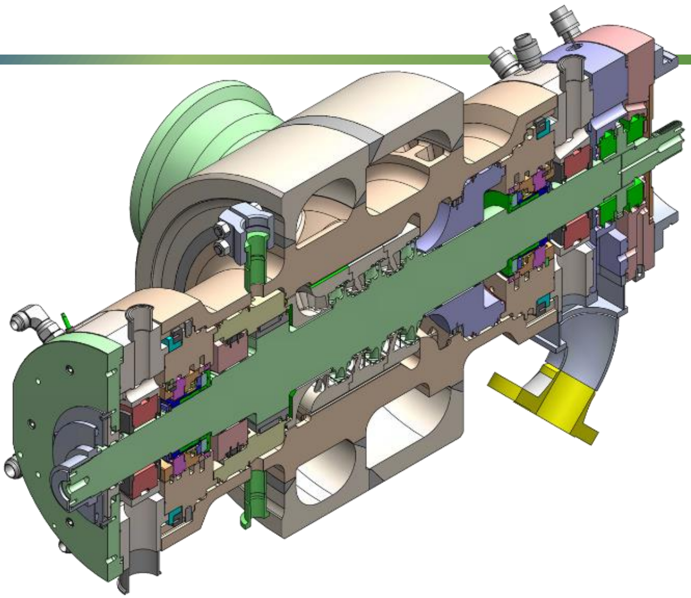




Testing Completed On sCO2 Stem Seals

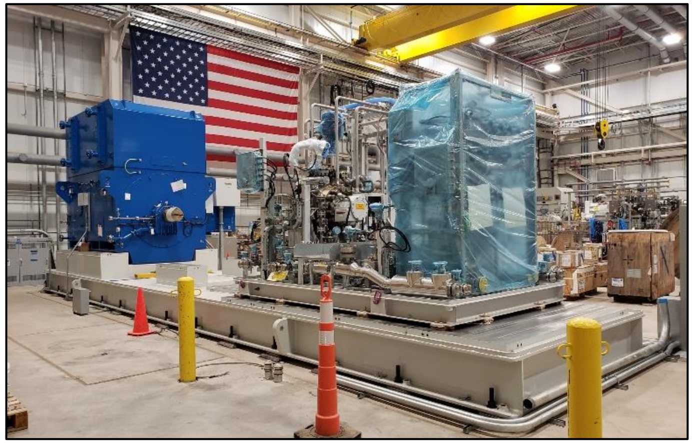
STEP Turbine - Builds on SunShot success

- Collaboration between GE-R and SwRI
- Design challenges include high blade loading and large temperature gradients
- Based on frame design demonstrated under the EERE SunShot program
- **Incorporates updated flowpath for higher performance**
- **Revised casing design incorporates lessons learned from EERE SunShot**
- **Fabrication of components on going**



Turbine Rotor First and 2nd Stage Completed

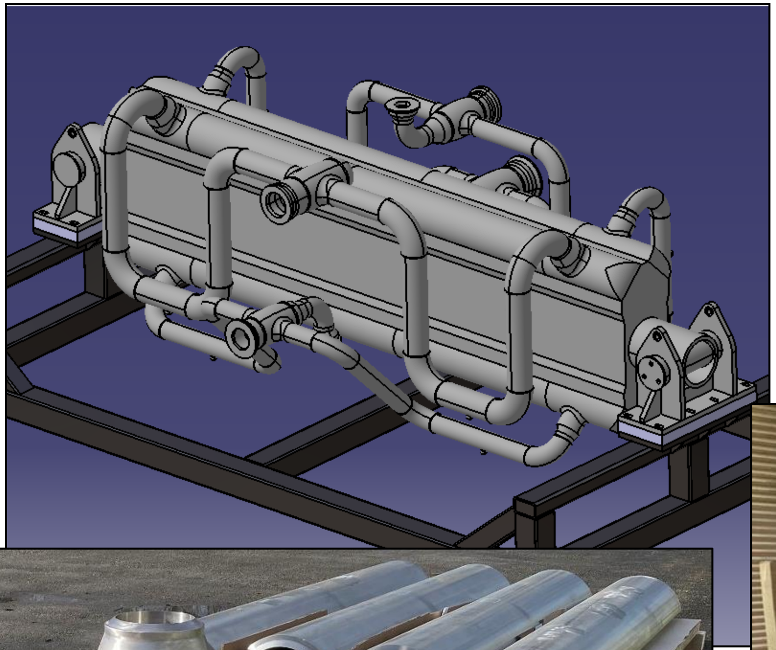
Turbine Skid in the High Bay with Generator in place and Bypass Compressor Sub-Skid

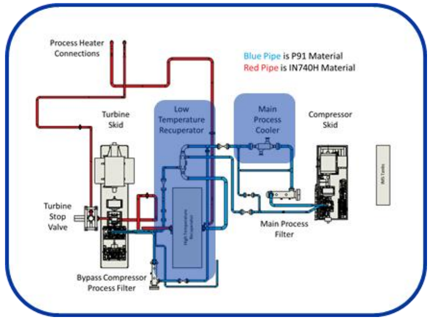


Turbine Stator Nozzle Machining

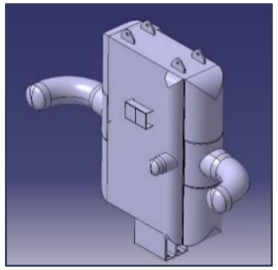
High Temp Recuperator fabrication continues

- HTR (High Temp Recuperator)
  - sCO2/sCO2 service
  - 49 MWth duty, 600ºC design temp
- Heatric, Inc.
  - PCHE Fabrication
  - Design life/structural issues delayed fabrication
  - Design Completed, Material Ordered
  - All HEX Cores Fabricated & Bonded
  - Core to Core Welds Initiated
- Delivery Planned for August 2021

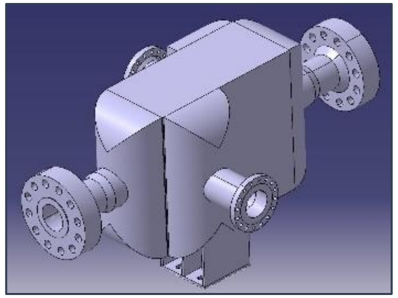




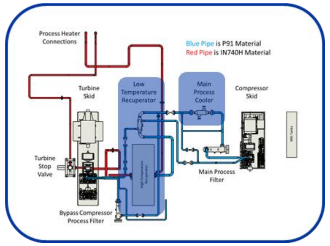
All Low Temperature Recuperators and Coolers delivered awaiting installation at SwRI

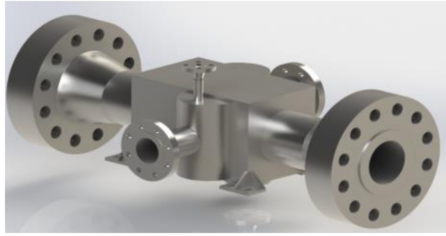


Low Temp Recuperator
13 MWth duty @ 250°C



Main Process Cooler
16MWt duty @ 150°C





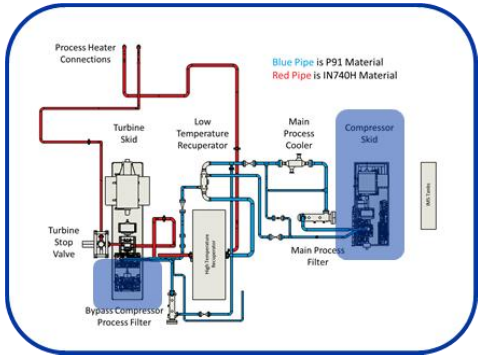
Low Temperature Recuperator
Heatric, Inc.

Main Process Cooler
Heatric, Inc.

Bypass Cooler
VPE

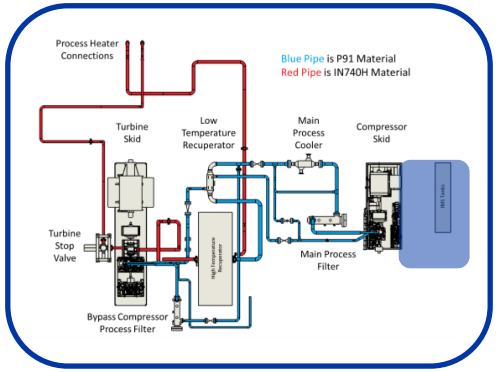
STEP Compressor Systems Delivered and Set Factory Performance Tests demonstrated

- Main Compressor driven by electric motor
- Bypass Compressor directly driven by STEP sCO2 turbine
- Baker-Hughes OEM of Main & Bypass Compressors
  - Design based on industrial CO2 compressors and DOE Apollo project DE-EE-0007109



Inventory Management System

- Dual functions
  - Manage system inventory
  - Provide for initial system fill and makeup
- System control
  - System inventory along with Heat Rate and Compressor IGVs influence overall system Pressure Ratio and Mass Flow (Power Output)
  - Optimal system control leverages inventory control to operate at peak thermodynamic efficiency across the load range
- Fill and Makeup
  - Supporting auxiliary supply flows for Dry Gas Seal supply, Turbine Stop Valve Stem Seals
  - Replenish inventory vented to atmosphere
- Status of the IMS System
  - Long lead equipment procurement is complete, working through short lead piping and valves



System Includes:

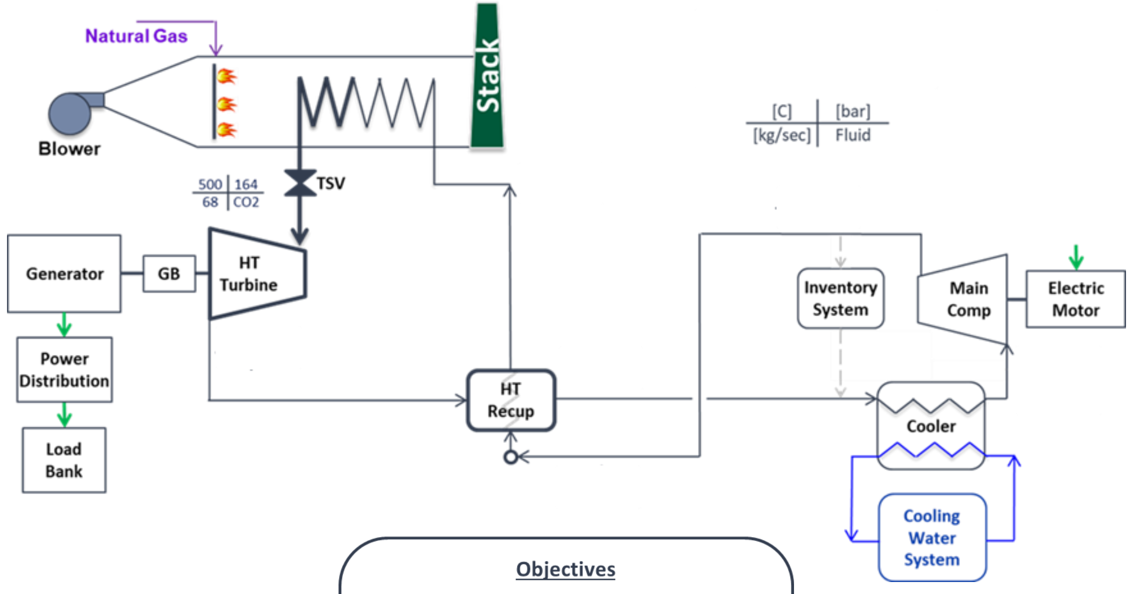
- Storage Tank
- Bulk Liquid Tanks
- Liquid Pumps
- Vaporizers
- Cooling/Heating

Simple Cycle Test Objectives Per SOPO

> Objectives:
  - Demonstrate basic operation and control of a simple recuperated sCO2 Brayton power cycle producing greater than 5 MWe.
  - Implement and test an automated control system for the safe and predictable operation of the simple recuperated Brayton cycle through normal operating transients and simulated emergency transients.
  - Obtain component performance validation data for sCO2 expander, recuperator, heat source, and compressor.
  - Obtain cycle performance data to validate steady state and dynamic models and performance predictions.

This (simple cycle test) plan will verify the facility and component performance at lower temperatures (500°C) and in a configuration with reduced technical risk.

Simple Brayton Cycle



Objectives

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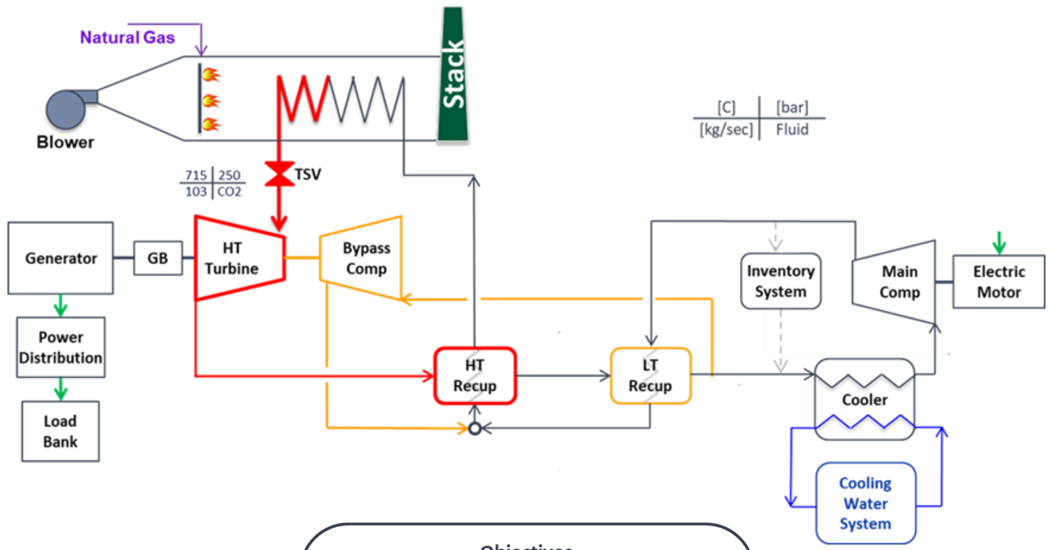
- Reduced Turbine inlet at 500°C similar to Waste Heat Recovery applications
- Single compressor configuration
- Provides Steady & Transient Cycle Performance Data used to predict RCBC performance and operations

Recompression Closed Brayton Cycle (RCBC) Test Objectives Per SOPO

> Objectives:
  - Demonstrate basic operation and control of a RCBC power cycle producing 10 MWe.
  - Implement and test an automated control system for the safe and predictable operation of the RCBC through normal operating transients and simulated emergency transients.
  - Obtain component performance validation data for new and updated components.
  - Obtain cycle performance data to validate steady state and dynamic models and performance predictions.

This (RCBC) plan will verify the performance capability of the technology temperatures (715°C) and in a configuration with reduced technical risk.

Recompression Brayton Cycle (RCBC)



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

Target Test Points
Start/Trips, Transients, and Load Following

Cycle Configuration	Description	Load %	Net Power Level (MWe)	Cooler Exit Temperature	Turbine Inlet Temperature	Cycle Efficiency
Simple	Simple cycle minimum load case	Min	2.5	35°C	500°C	22.6%
Simple	Simple cycle maximum load case	Max	6.4	35°C	500°C	28.3%
Recompression	Baseline case	100%	10.0	35°C	715°C	43.4%
Recompression	“Hot” Day Case	70%	6.6	50°C	675°C	37.4%
Recompression	“Cold” Day Case	100%	9.9	20°C	525°C	36.8%
Recompression	Partial load case using inventory control	40%	4.0	35°C	715°C	37.0%
Recompression	RCBC at 500°C turbine inlet temperature	70%	6.9	35°C	500°C	32.5%
Recompression	Partial load case using TSV throttling (transient condition)	40%	4.2	35°C	715°C	30.8%
Recompression	Partial load case using TSV throttling	40%	3.9	35°C	675°C	29.6%

Timeline to Test Operations

Aug. 2021	Complete Key Equipment deliveries
Feb. 2022	Mechanical Completion – Simple Cycle
July 2022	Complete Commissioning Simple Cycle
Oct. 2022	Complete Simple Cycle Tests (End BP2)
Dec. 2022	Complete RCBC Reconfiguration
Oct. 2023	Complete RCBC Tests (End BP3)

STEP Project Status

- **Excellent Team with the right experience in sCO2 system design & operations**
- **Site Construction Progress Excellent -** Building Occupancy received on schedule
- **Significant Progress on Major Equipment Fab/Installation**
- **Challenges with low TRL equipment impacted schedule**
  - Design: High Temperature Recuperator
  - Fabrication: Turbomachinery
  - Fab Adv Ni-Alloys: Primary Heater (740H), and Turbine Stop Valve (H282)
  - Resolved most technical issues and progressing with final equipment manufacture and delivery

- **Commissioning to Initiate in early 2021**

- **STEP Project Status can be followed at *www.STEPdemo.us***

Acknowledgement

> The authors would like to gratefully acknowledge and thank the U.S. Department of Energy, Office of Fossil Energy and the National Energy Technology Laboratory under Award Number DE-FE0028979 for their continued support of this work.

> Also thank you to the Joint Industry Program members for their critical support and guidance – American Electric Power, Southern Company, Korean Electric Power Company, Natural Resources Canada, Engie, CSIRO, Electricity Generating Authority of Thailand (EGAT), and the State of Texas, TCEQ.

> Also thank you to the STEP Team from GTI, SwRI, GE and our project participants for their dedication and effort.

Questions?

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