GTI STEP forward on sCO_2 Power

Supercritical Transformational Electric Power project

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gti

Working With Industry and Governments to Increase Access to Abundant, Affordable, and Acceptable Energy

FOR A BETTER ENVIRONMENT AND A BETTER ECONOMY

SUPPLY ▸ CONVERSION ▸ DELIVERY ▸ UTILIZATION

RESEARCH & DEVELOPMENT

PROGRAM MANAGEMENT

TECHNICAL/ ANALYTICAL

CONSULTING

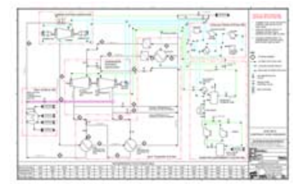
TRAINING

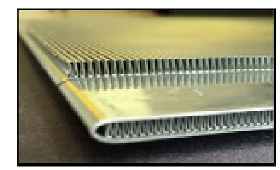
360+ EMPLOYEES

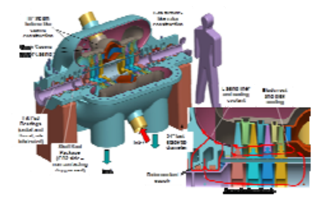
World-class piloting facilities headquartered in Chicago area

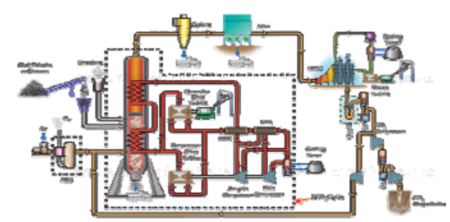
GTI Completed sCO_2 Projects

1. Applicability and system performance/benefit studies for large-scale nuclear (LMR), solar (CSP) and fossil applications
2. Oxy-fired natural gas combustor and turbo-expander for combustion product gas with recycled CO_2 – reference plant study of performance and LCOE assessment (direct-fired and cooled-turbine)
3. Costs and technology roadmap for recuperators
4. Advanced turbomachinery for indirect (T<760C) and direct (T>760C) sCO_2 power cycles
5. Oxy-fired pressurized fluidized bed combustor reference plant study of performance and LCOE (indirect-fired, un-cooled turbine)









Versatile Technology - Broad Applicability

Concentrating Solar

Fossil Fuel

Geothermal

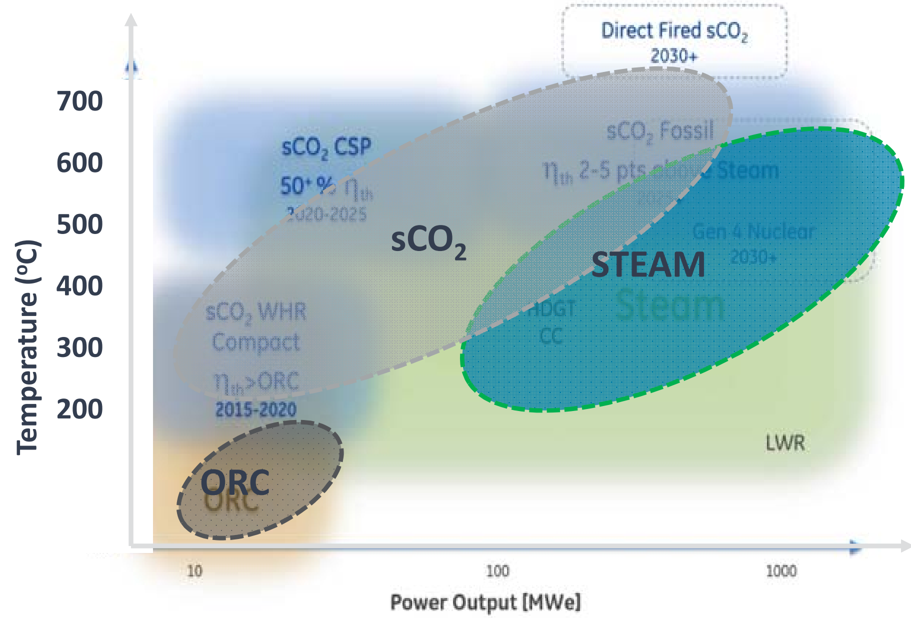
Nuclear

Ship-board Propulsion

Waste Heat Recovery

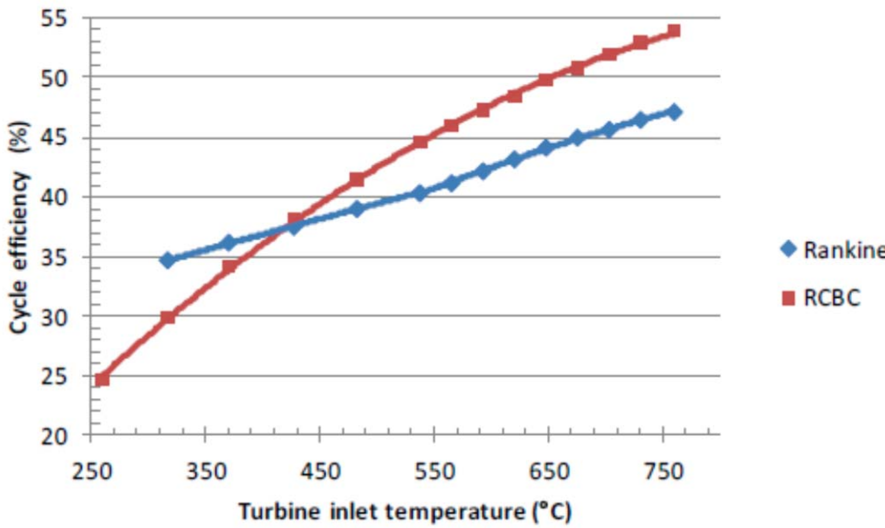
Promise of sCO_2 Power Cycles

- Heat-to-power conversion cycles with supercritical CO_2 working fluid promise several advantages
  - Heat source flexibility
  - Higher efficiencies
  - Compact turbo-machinery
  - Economic scalability
  - Lower emissions & water consumption
  - Facilitates and economizes low-carbon power production



Challenges of Advanced sCO_2 Power Cycles

- Technology and process development to confirm advantages
  - Materials: corrosion, creep, fatigue
  - Turbomachinery: life, aero performance, seals
  - Recuperators: design, size, fabrication, durability
  - Cycle operability: startup, transients, load following



Source: NETL

Supercritical Transformational Electric Power (STEP) Program

Scope: Design, construct, commission, and operate a 10 MWe sCO_2 Pilot Plant Test Facility

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

Team: Gas Technology Institute (GTI)
Southwest Research Institute® (SwRI®)
General Electric Global Research (GE-GR)

Schedule: Three budget phases over six years (2016-2022)

Cost: $113MM Total / $80MM Federal Funding

Building a flexible platform for long-term use to validate component performance, quantify cycle efficiency, and study plant operability in an integrated, grid-connected system.

STEP Program Objectives

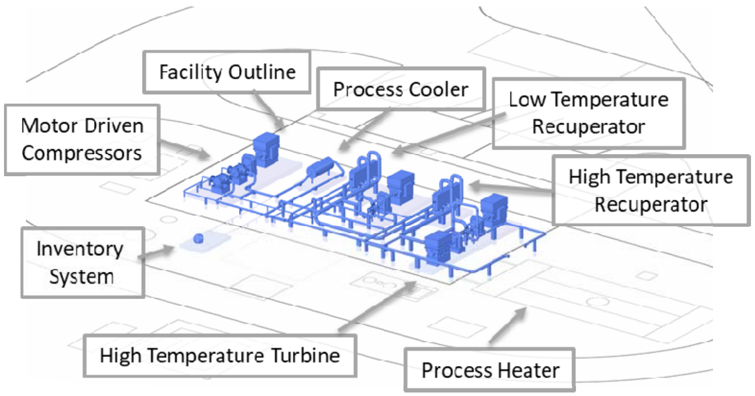
Demonstrate pathway to RCBC cycle efficiency > 50%

Demonstrate cycle operability up to 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

Reconfigurable facility to accommodate future testing



Pilot Site: SwRI in San Antonio, TX

STEP Project Plan

Budget Period 1
ends Oct 2018

Detailed Facility and Equipment Design

25 months

- System analysis, P&IDs, Component Specs
- Design major equipment
- Procure heat source, cooling tower & long-lead items
- Materials & seal tests
- Start site construction

Budget Period 2
ends January 2021

Fabrication and Construction

27 months

- Complete site construction and civil works
- Fabrication & installation of major equipment
- Commissioning and simple-cycle test

Budget Period 3
ends September 2022

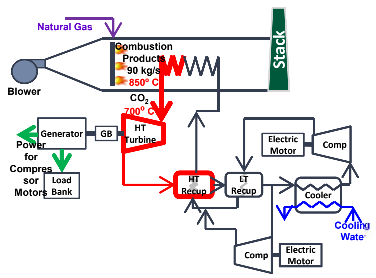
Facility Operation and Testing

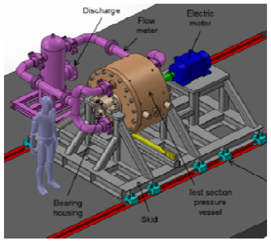
20 months

- Facility reconfiguration
- Test recompression cycle

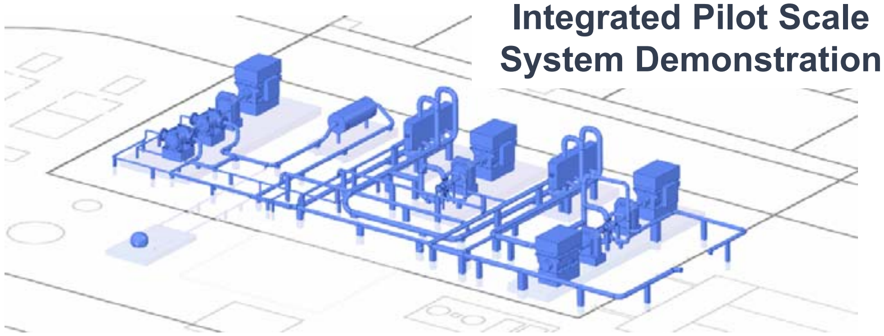
Transitioning from Component and Cycle Design to Integrated System Demonstration

Individual Cycle and Component Development Efforts

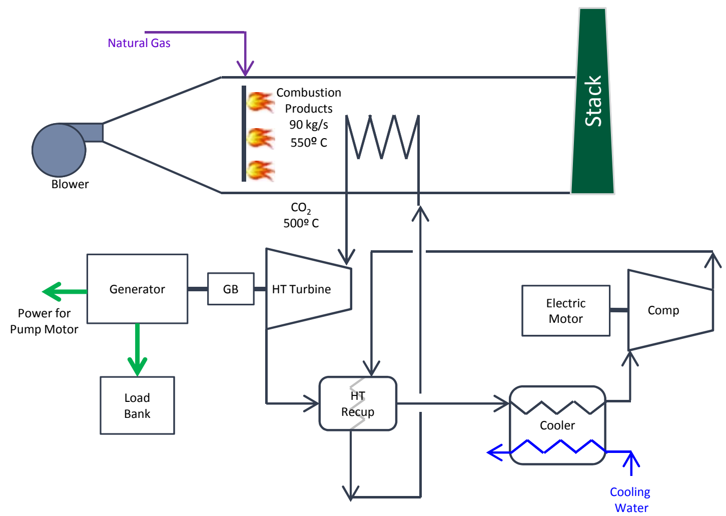




Integrated Pilot Scale System Demonstration

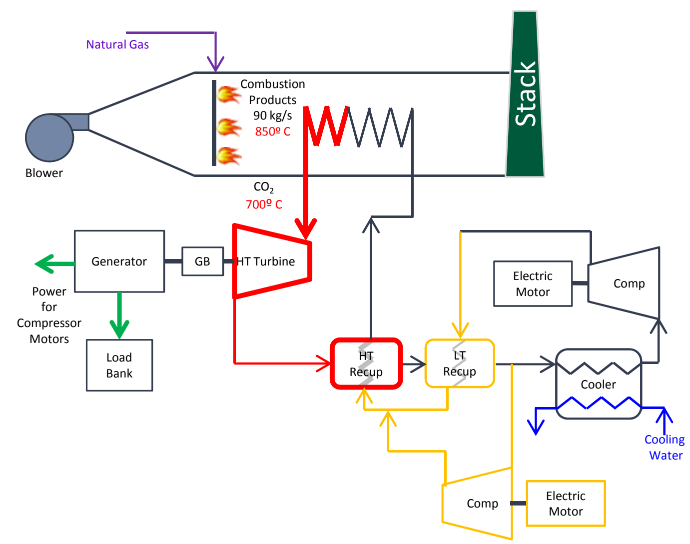


Flexible Test Facility Designed with Alternate Indirect Cycle Configurations



Simple Cycle

- Shortest time to initial data
- Controls & safety
- Component performance
- Steady & transient cycle data



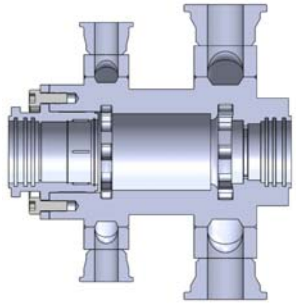
Recompression Cycle

- Inventory management
- Starting transients
- Parallel compressor control
- SOA component efficiencies
- Cycle efficiency > 50%

STEP Current Status: Turbine

> Turbine improvements over SunShot

- Increased casing and rotor life, 100,000 hrs vs 20,000 hrs
- Increase bolt retightening schedule to 30,000 hr vs 1,000 hrs
- Design for couplings on both shaft ends
- Improved aero performance with increased volute flow area

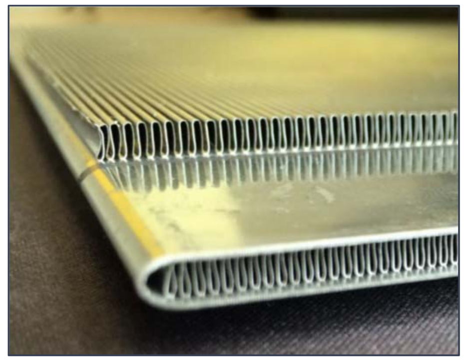


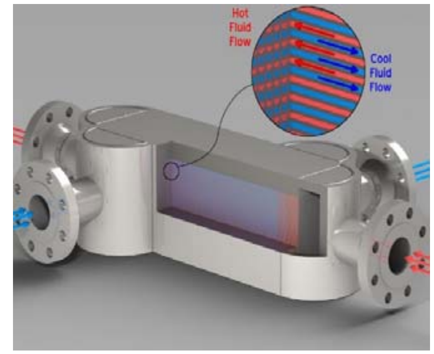
> Current design activities

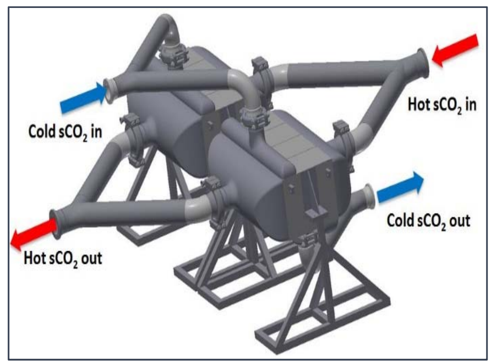
- Torsional train dynamics
- Rotor flowpath preliminary design
- Flowpath mechanical and aeromechanical integrity

STEP Current Status: Recuperators

- Evaluating replies to RFQ from several suppliers
- Alternate compact technologies
  - heat transfer surface vs. volume
- STEP is a significant scale-up
- Evaluating performance vs. cost and plant integration

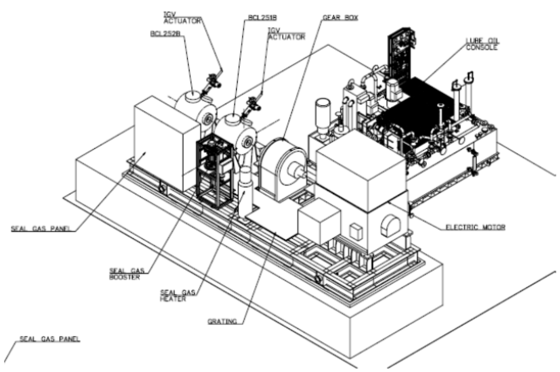




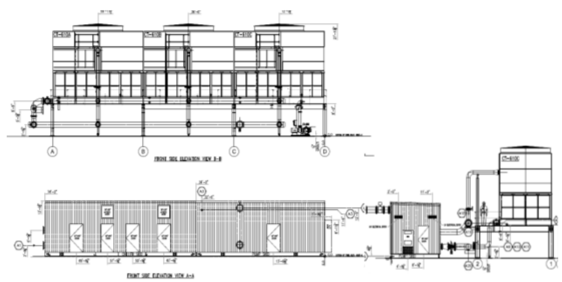


STEP Current Status: Other Major Components

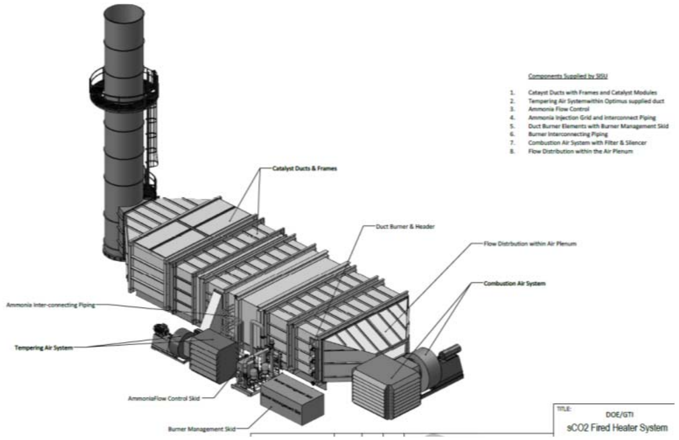
> Finalizing selections



Compressor



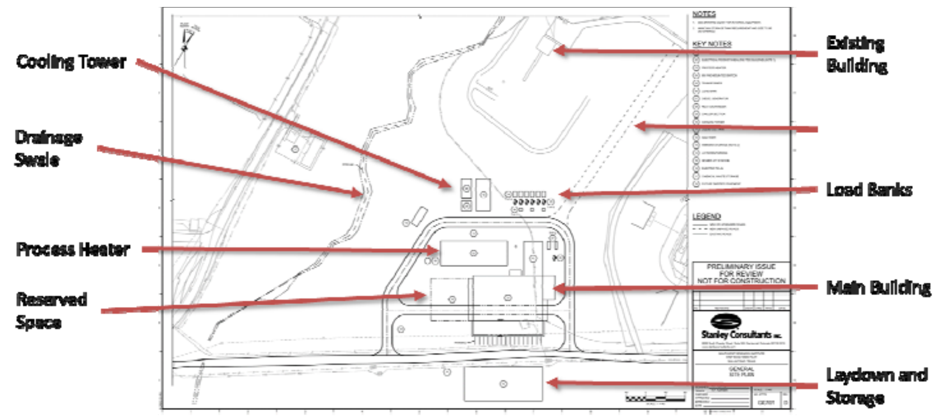
Cooling Tower

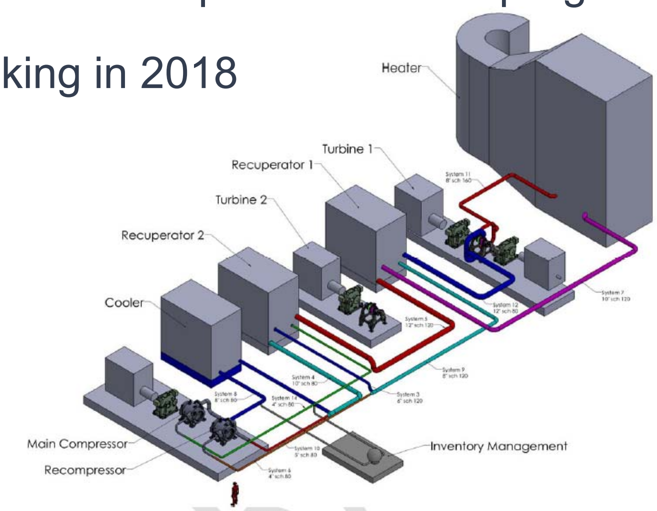


Process Heater

STEP Current Status: Facility and Site

- General arrangement defined
- EA ready for public review
- Building design being finalized
- Major BOP hardware specifications in progress
- Ground breaking in 2018





Summary

- sCO_2 power cycles promise substantial cost and emissions benefits
- Applicable to coal, natural gas, solar, geothermal, nuclear, waste heat
- STEP 10MW$_e$ program well underway – groundbreaking at SwRI site this year
- Strong team in place and executing smoothly
- Additional partners welcome

sCO_2 Step-by-Step Commercialization

Phase I
2015 - 2016

System Definition and Materials Compatibility (TRL 2-3)

- Perform trades
- Define reference system
- Select/validate materials suitable for use in SCO_2

Phase II
2016 – 2022

Component Tests and Small Pilot Plant (TRL 7)

Demonstrates:

- Compressor performance
- Seal operation
- Component Life
- System Operation and Control

10 - 20MWe

Phase III
2022 – 2027

Large Pilot / Demo Plant (TRL 7-8)

Demonstrates:

- Operation at scale
- Component life
- Operating parameters
- Maintenance approaches

50-100MWe

Phase IV
2025 – 2030

Commercial Demonstration ***5+ years*** **(TRL 9)**

Validates:

- Heat source integration
- System efficiency
- Capital costs
- O&M costs

275+ MWe

Early product off-ramp for 10-20 MWe distributed power generation systems

Turning Raw Technology into Practical Solutions

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STEP

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GTI • SwRI • GE Global

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