GTI step forward on sCO_2 Power

Supercritical Transformational Electric Power project

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

FOR A BETTER ENVIRONMENT AND A BETTER ECONOMY

RESEARCH & DEVELOPMENT

PROGRAM MANAGEMENT

TECHNICAL/ ANALYTICAL

CONSULTING

TRAINING

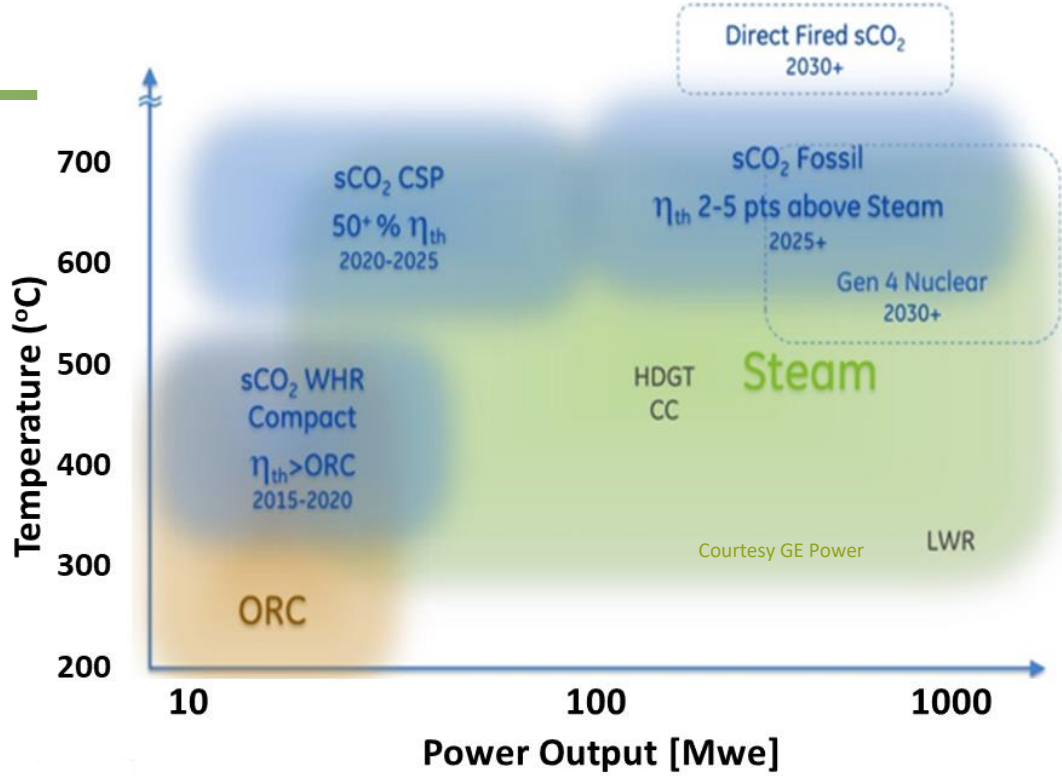
360+ EMPLOYEES

World-class piloting facilities headquartered in Chicago area

Benefits of sCO_2 Power Cycles

Supercritical CO_2 working fluid advantages:

- Heat source flexibility
- Higher efficiencies
- Compact turbo-machinery
- Economic scalability
- Lower emissions & water consumption
- Facilitates and economizes low-carbon power production



Versatile Technology – Broad Applicability:

Concentrated Solar

Fossil Fuel

Geothermal

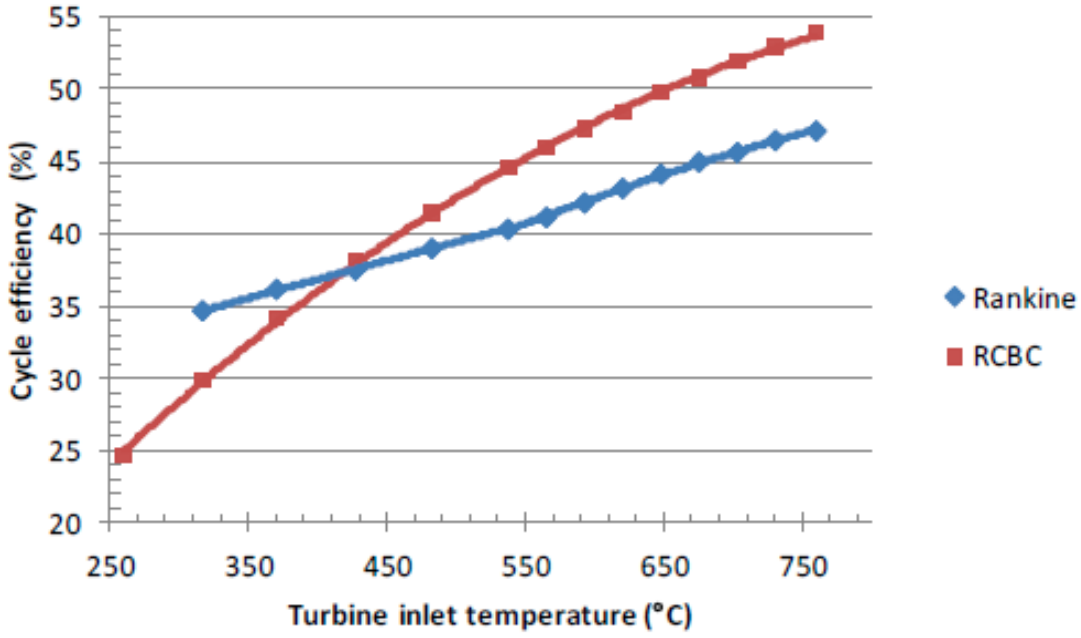
Nuclear

Ship-board Propulsion

Waste Heat Recovery

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
  - Power plant 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)
U.S. Department of Energy (NETL)

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

Cost: $119MM Total / $84MM 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.

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STEP Program Objectives

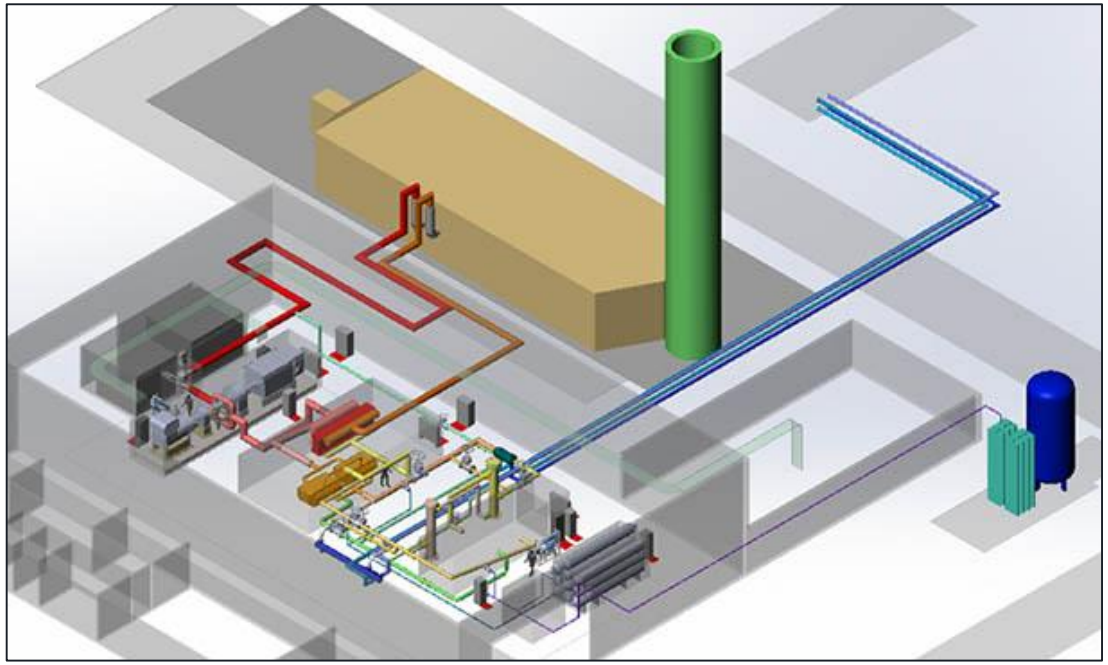
Demonstrate pathway to RCBC cycle efficiency > 50%

Demonstrate cycle operability up to 700°C turbine inlet temperature and 10 MWe net power generation

Quantify performance benefits:

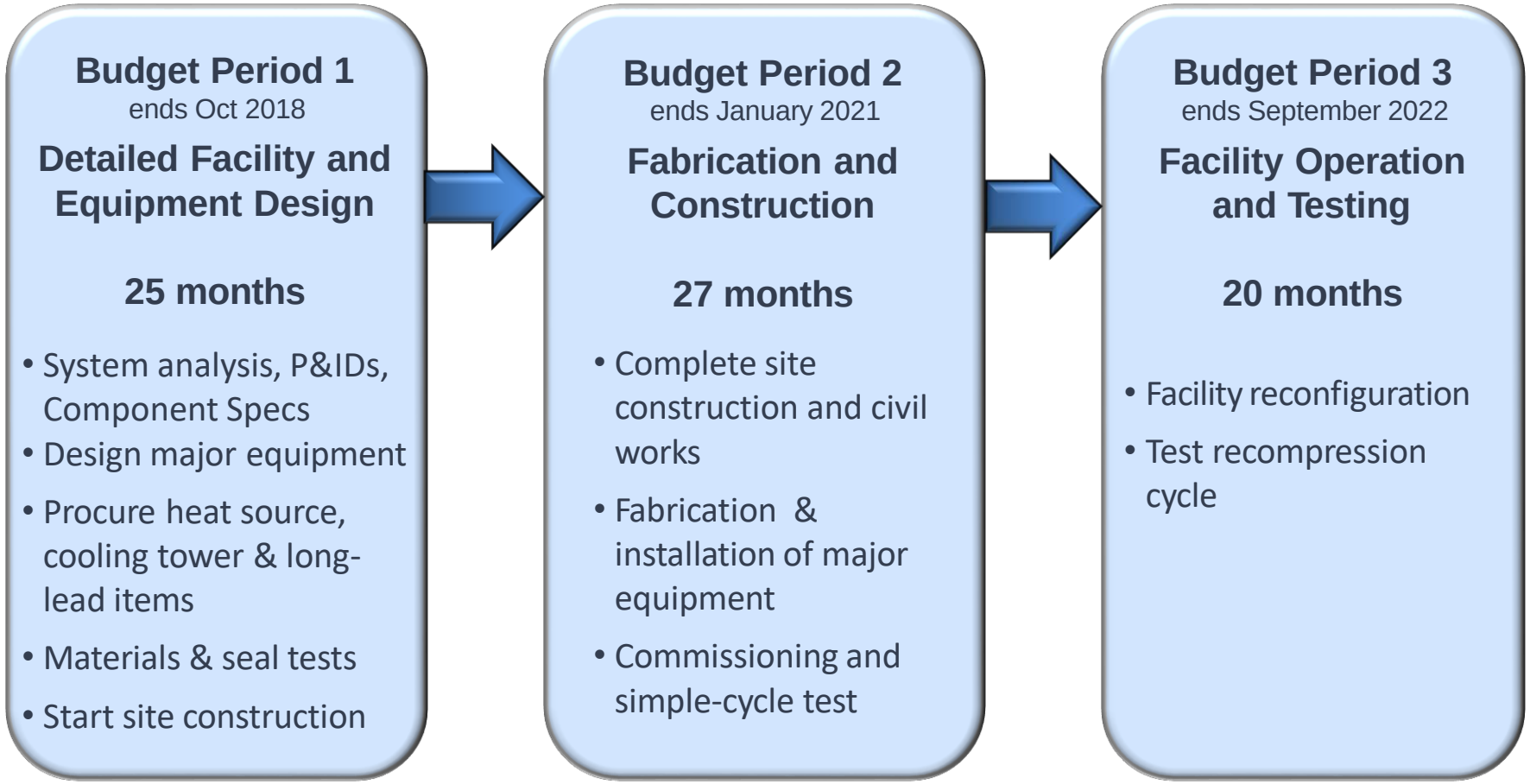
- 2-5% point net plant efficiency improvement
- 3-4% reduction in LCOE
- Reduced emissions, fuel, and water usage

Reconfigurable facility to accommodate future testing



Pilot Site: SwRI in San Antonio, TX

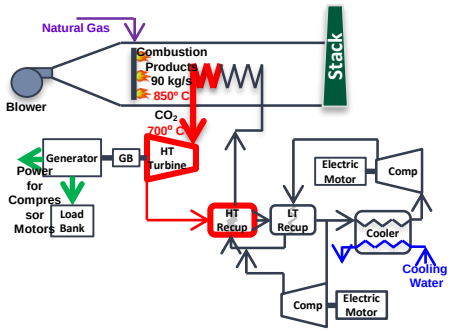
STEP Project Plan

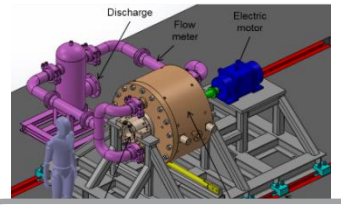


Transitioning from Component and Cycle Design to Integrated System Demonstration

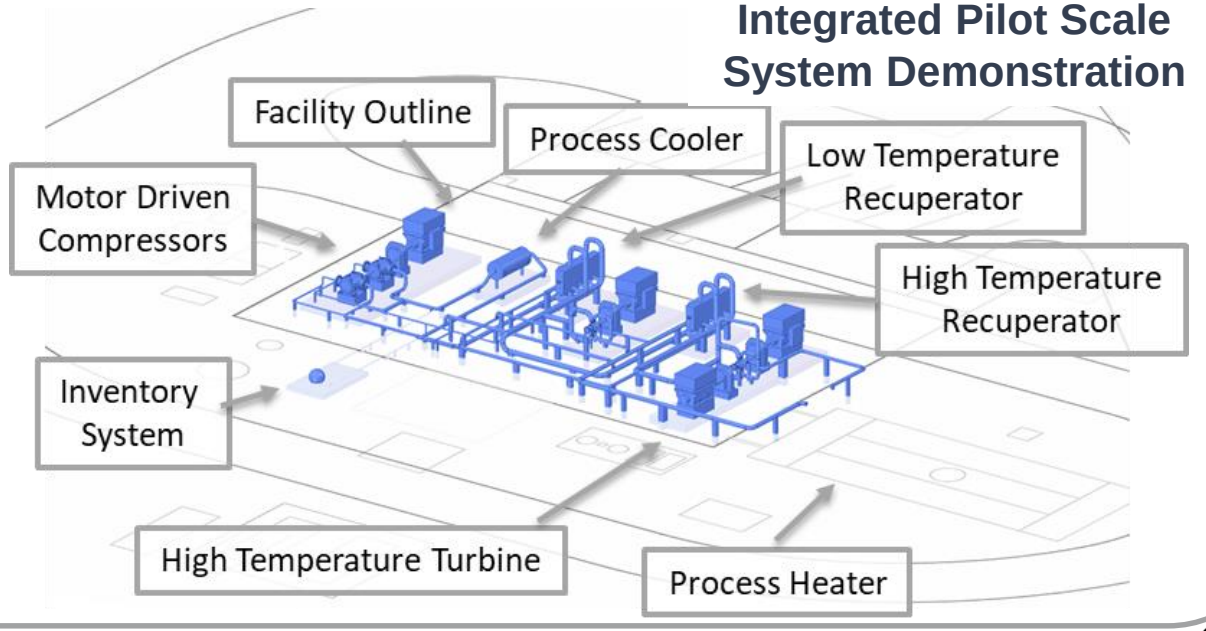
STEP DEMO

Individual Cycle and Component Development Efforts





Integrated Pilot Scale System Demonstration



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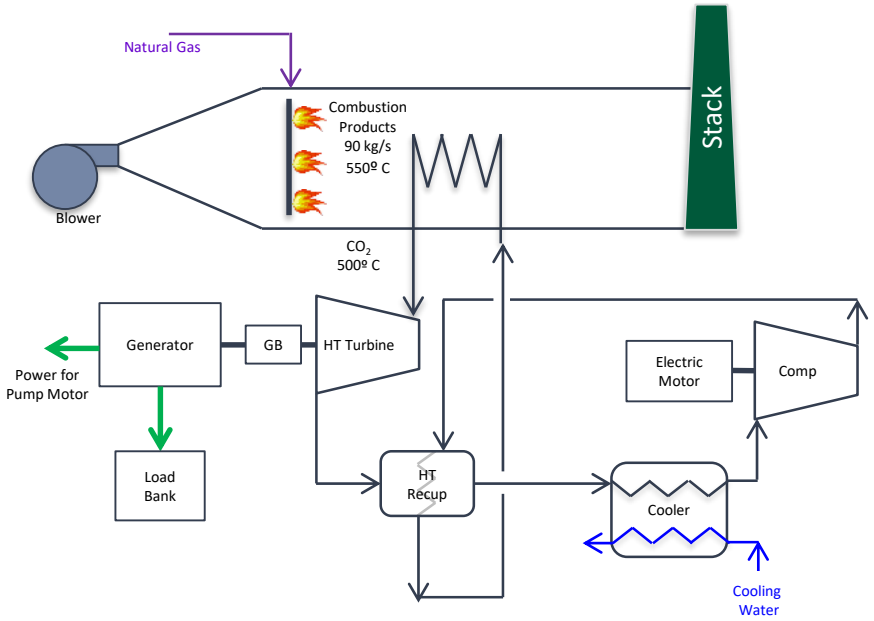
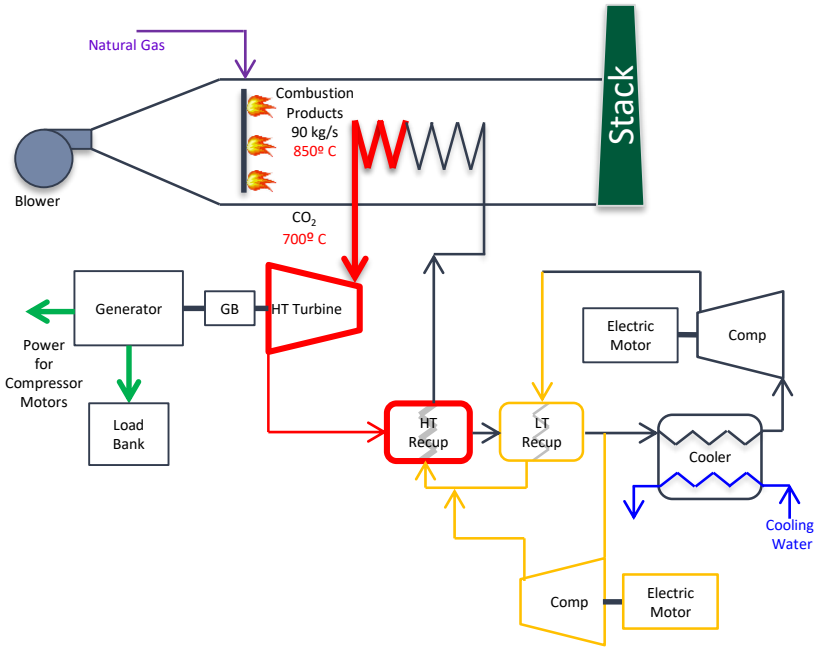
Flexible Test Facility Designed with Alternate Indirect Cycle Configurations



Simple Cycle

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

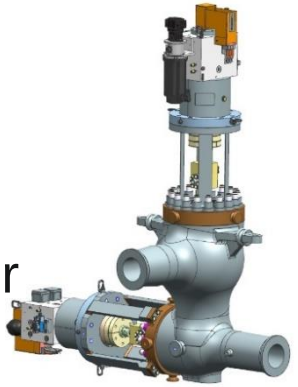


Recompression Cycle

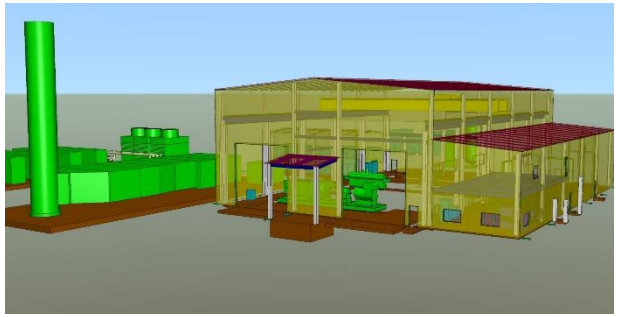
- Inventory management
- Starting transients
- Parallel compressor control
- SOA component efficiencies
- Cycle efficiency > 50%

STEP Program Achievement Status

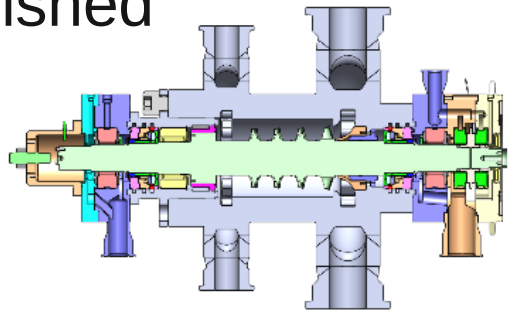
- Ground Breaking – October 15th, 2018
- Purchase orders issued for major hardware
  - Process Heater, Compressor, HTR, Cooling Tower
- Facility bid package release in November
- Turbine design complete in December
- Joint Industry Program (JIP) – established



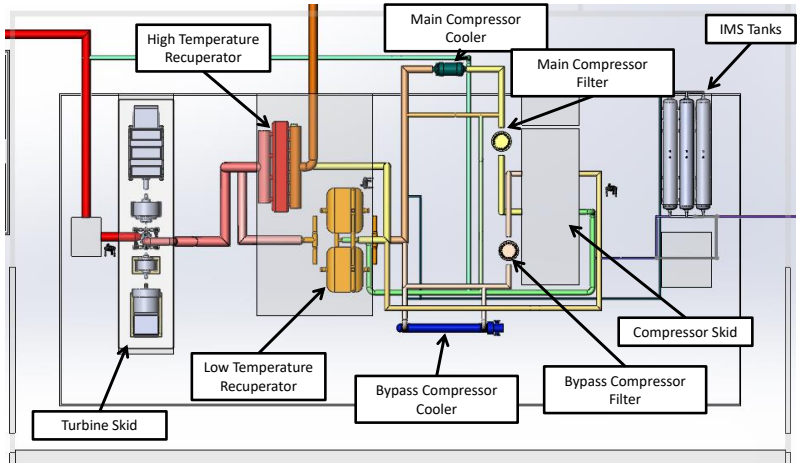
Seal development testing nearing completion



Process heater and building



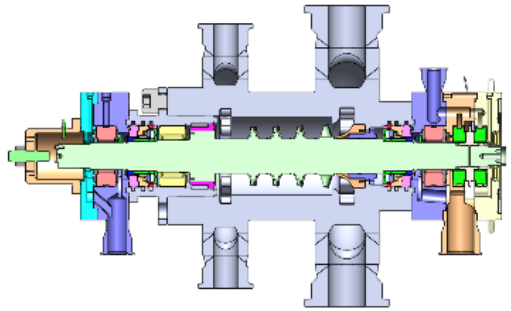
Turbine



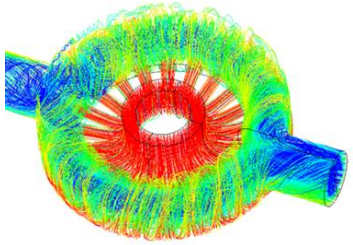
Arrangement inside building

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

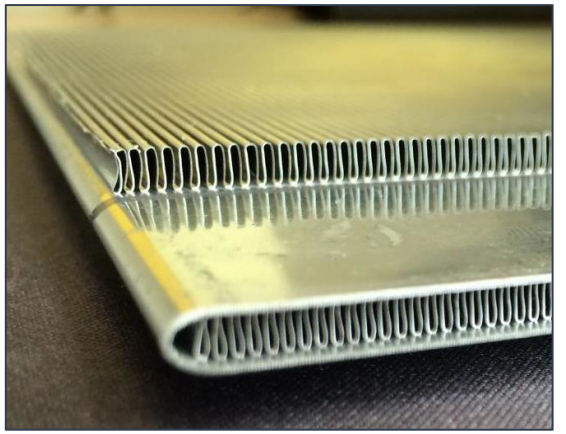


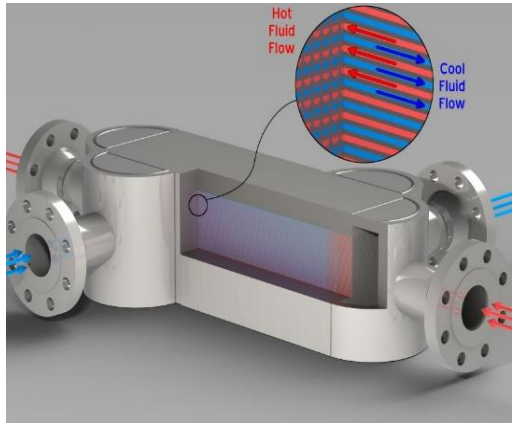
- Current activities
  - Design to be completed in December
  - Long lead material being ordered

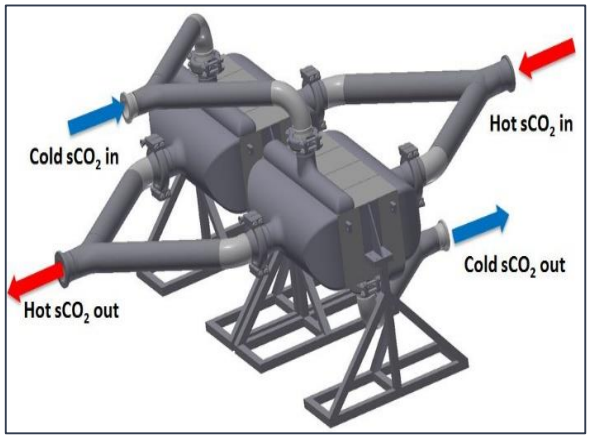


STEP Current Status: Recuperators

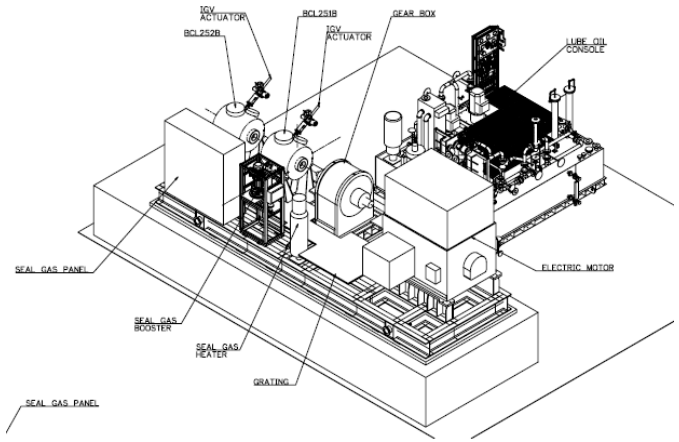
- Heatric under contract for HTR vendor
- Evaluating suppliers for other units (3)
- Alternate compact technologies
  - heat transfer surface vs. volume
- STEP is a significant scale-up
- Evaluating performance vs. cost and plant integration



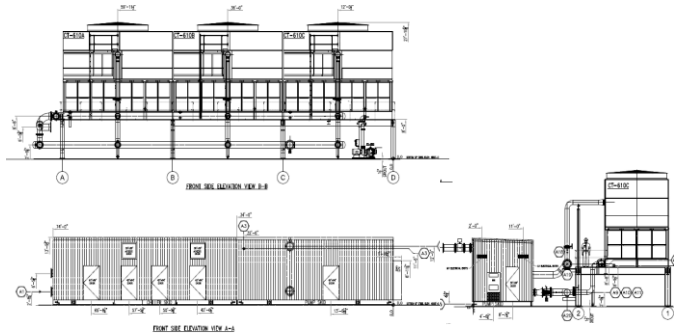




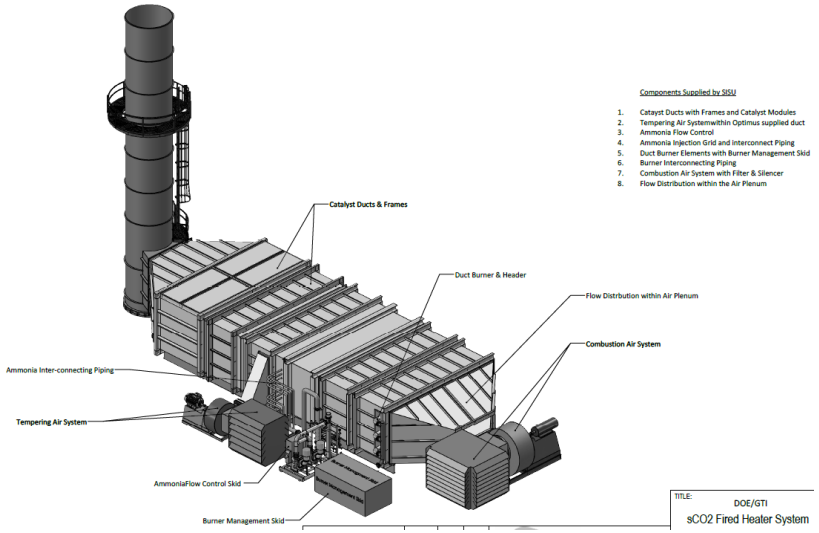
STEP Current Status:
Other Major Components



Compressor
BHGE



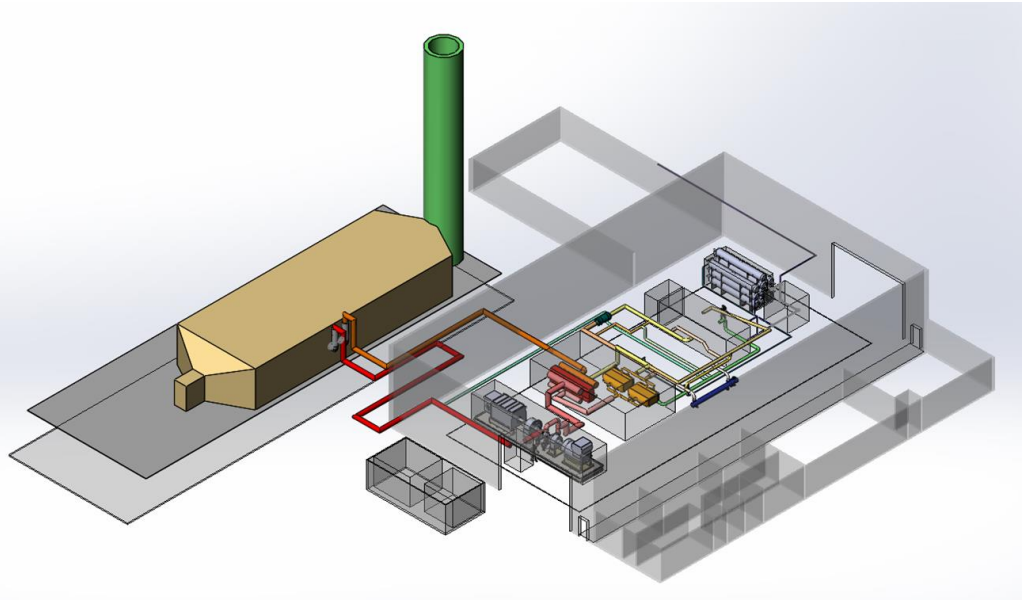
Cooling Tower
TAS

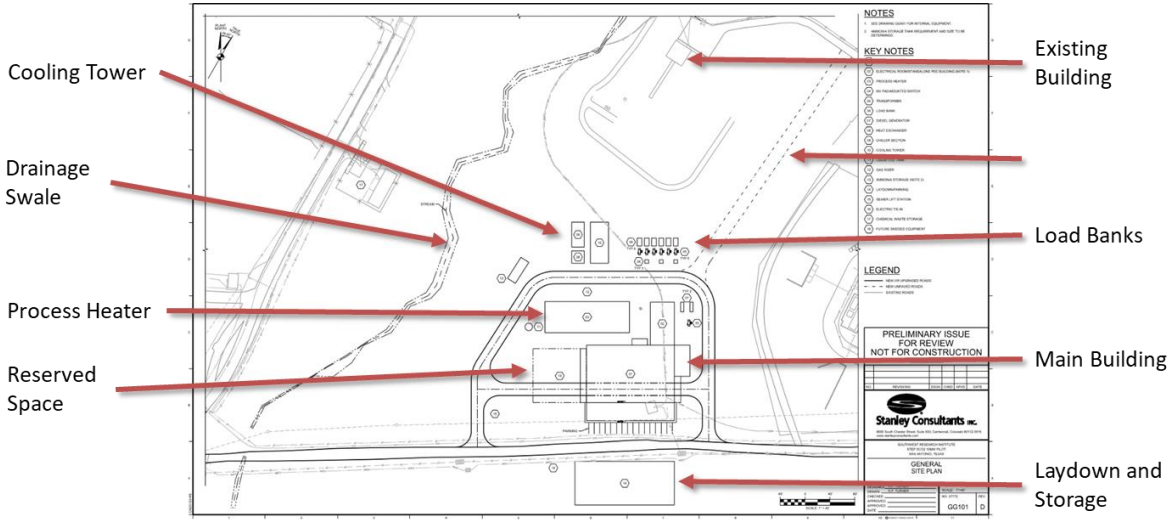


Process Heater
Optimus

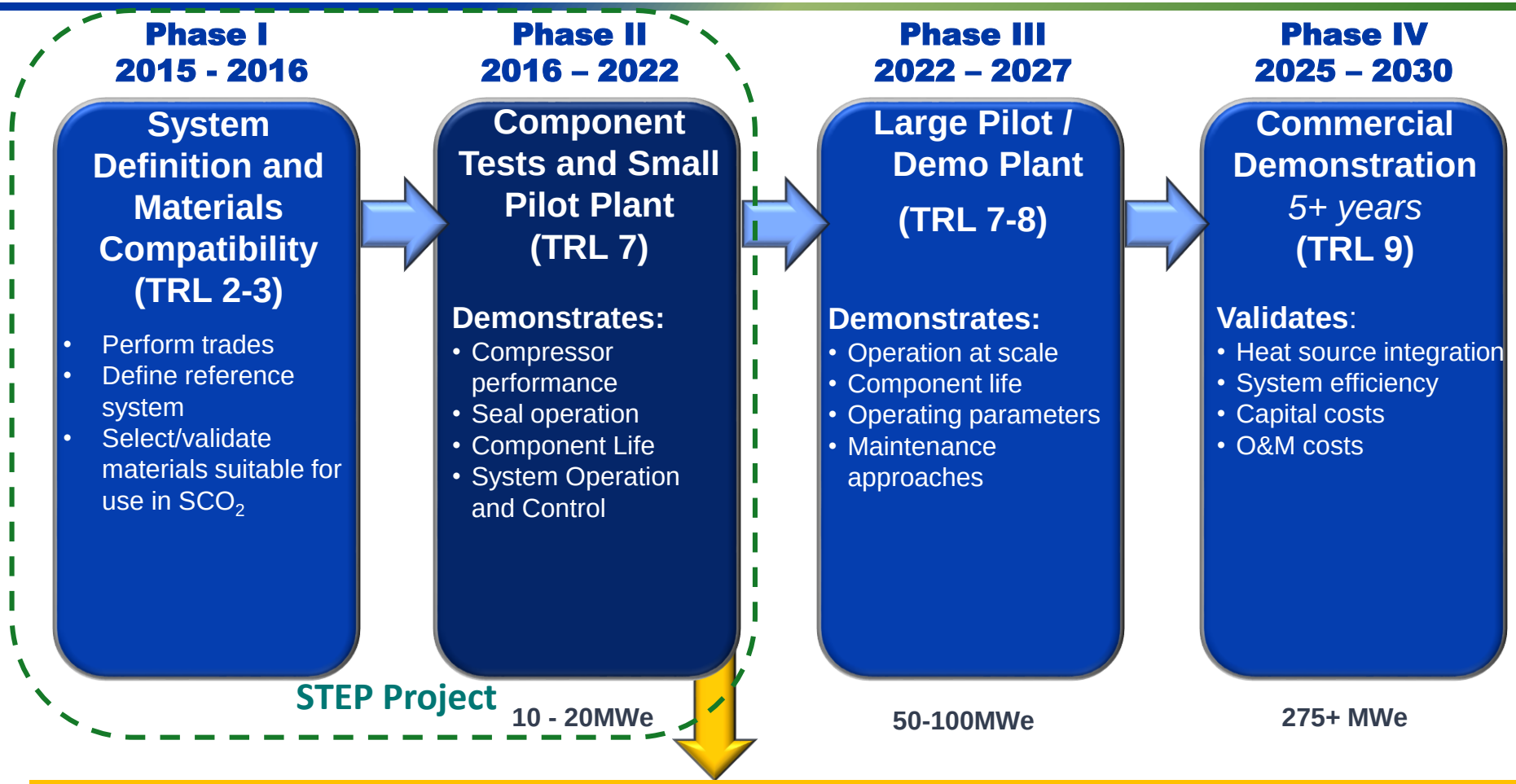
STEP Current Status: Facility and Site

- Facility design in review
- Bid package to be issued in November
- Ground breaking next week
- Construction scheduled to start in spring 2019





sCO_2 Step-by-Step Commercialization



Joint Industry Program (JIP)

Leverage $84 MM in US DOE funding and $35+ MM in industry funding to determine how this technology fits into your plans and influence project direction

1. Steering Committee Level - $250k/year for 6 years (or equivalent)
   - 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
   - Opportunity for facility visits and training in system operations
   - Period of exclusive access to license system IP
2. Associate Membership - $100k/year for 6 years (or equivalent)
   - Attendance at bi-annual technical interchange meetings
   - Receipt of quarterly technical status reports
   - Opportunity for 2 site visits per year

Summary

- sCO_2 power cycles promise substantial cost and emissions benefits
- Applicable to coal, natural gas, solar, geothermal, nuclear, waste heat
- STEP Demo will demonstrate $10MW_e$ grid-connected sCO_2 power plant
  - Reconfigurable facility to accommodate future testing
- Groundbreaking at SwRI in October 2018
- Joint Industry Program allows for international industry participation
  - Additional partners welcome

Acknowledgment and Disclaimer

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Contact

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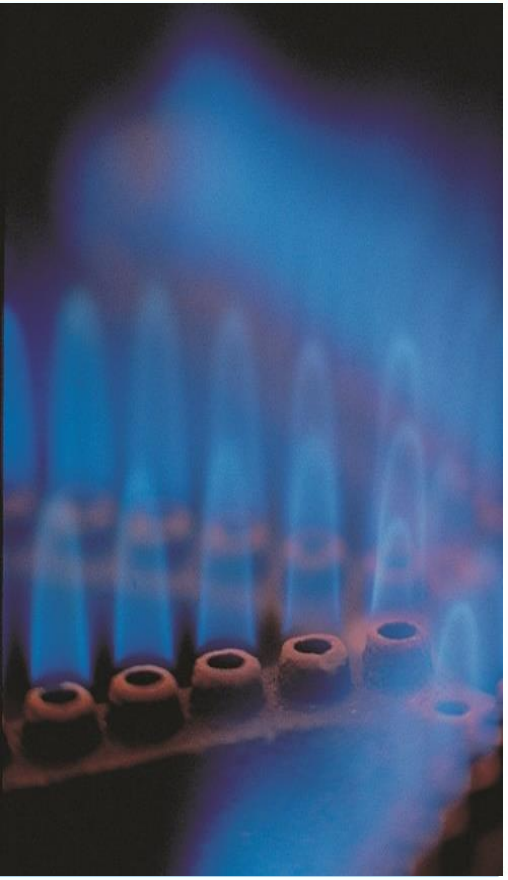
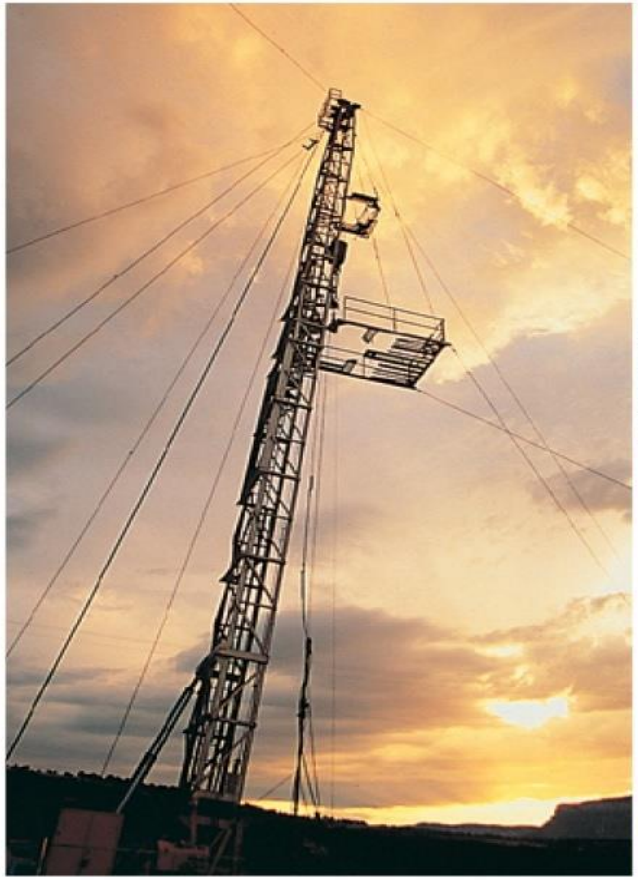
Turning Raw Technology into Practical Solutions





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