Supercritical CO_2 Power Cycle Projects at GTI

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Presented at Third European Conference on sCO2 Power Systems

Paris, France

20 September 2019

Agenda

1. STEP 10 MWe Indirect sCO_2 Pilot Plant
2. Oxy-PFBC Power Cycle for solid fuels
3. Combustor development for direct sCO_2 cycles

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

Promise & Challenges of sCO_2 Power Cycles

Promise:

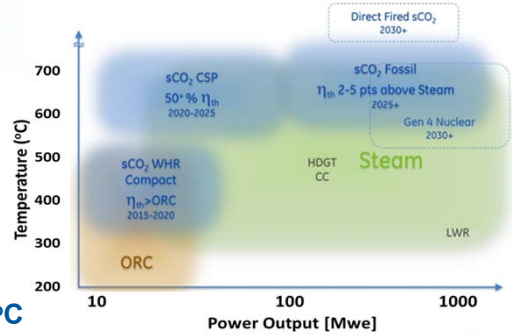
- Efficient, Compact, Scalable, low water, low-carbon power generation

Challenges:

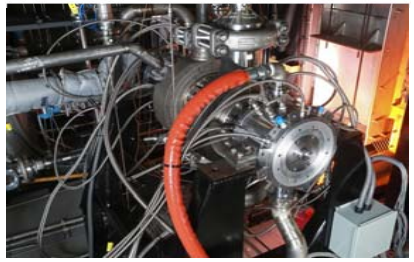
- Operability, Transients, Turbomachinery areo performance, seals, recuperator size & durability, materials, corrosion, cost

STATE OF DEVELOPMENT

EPS100 Echogen ~3.1 MWe, ~270°C



NetPower LaPorte TX, 25 MWe, 1150°C – in start-up



Sunshot SwRI/GE 1 MWe ~715°C

Versatile Technology – Broad Applicability:

Concentrated Solar

Fossil Fuel

Geothermal

Nuclear

Ship-board Propulsion

Waste Heat Recovery

Supercritical Transformational Electric Power (STEP) Project

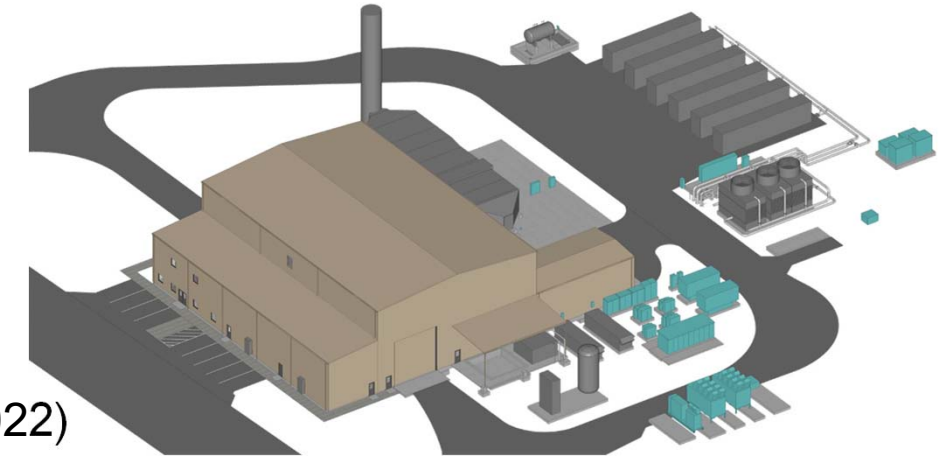
Scope: Design, construct, commission, and operate a **10 MWe sCO_2 Pilot Plant Test Facility** - reconfigurable to accommodate other testing

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 (**DOE NETL**)

Joint Industrial Partners:

KEPCO Korea Electric Power Corporation
Natural Resources Canada / Ressources naturelles Canada
Southern Company
American Electric Power – Boundless Energy



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

Cost: $122MM Total / $84MM Federal Funding

STEP Program Objectives

Demonstrate pathway to efficiency **> 50%**

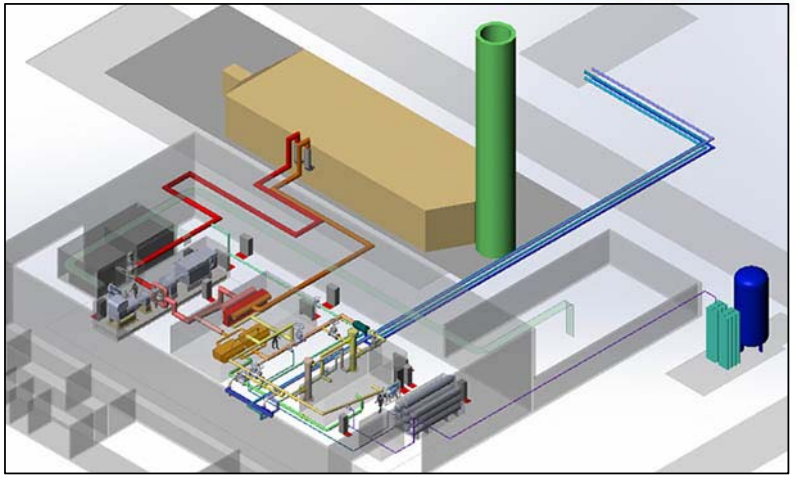
Demonstrate cycle operability up to **700°C** turbine inlet temperature and 10 MWe net power generation

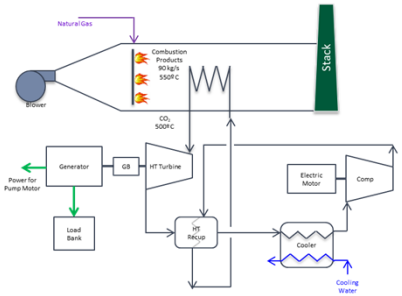
Quantify performance benefits:

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

Reconfigurable facility:

- accommodate future testing

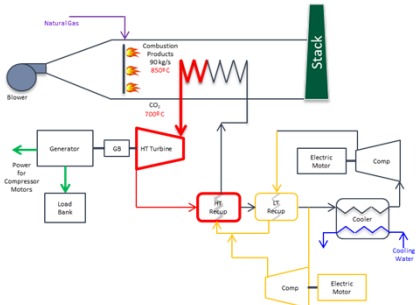




Simple Cycle

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

T_{iT} 500°C, 250 bar



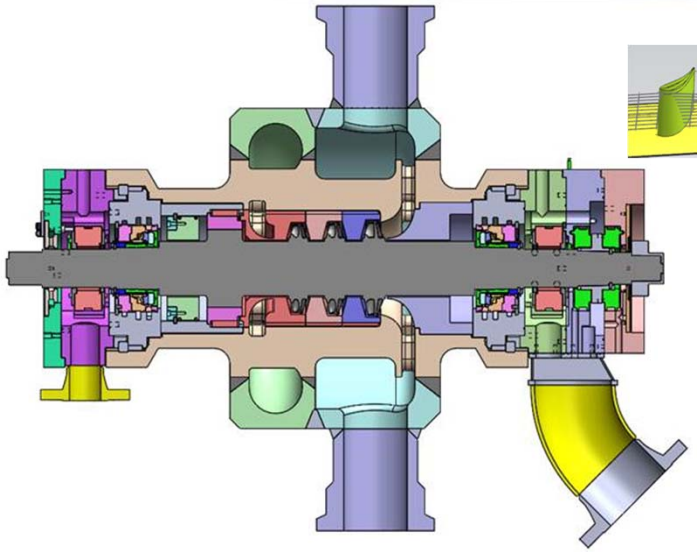
Recompression Cycle

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

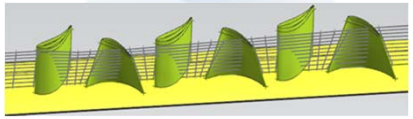
T_{iT} 715°C, 250 bar

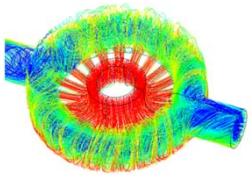
STEP Turbine

- Three stage gas path
- Enhanced thermal gradient region
- Increased performance inlet/exit volutes
- Builds on successful SunShot 1 MWe demonstration [700°C]
- Preliminary design review completed



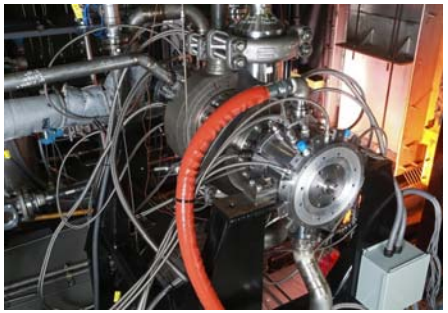
Turbine side view

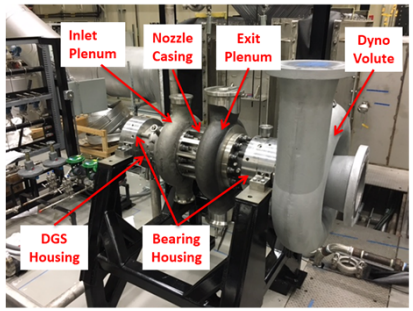




Aero analysis

Design basis from successful SunShot 1 MWe pilot [715°C, 27,000 rpm]



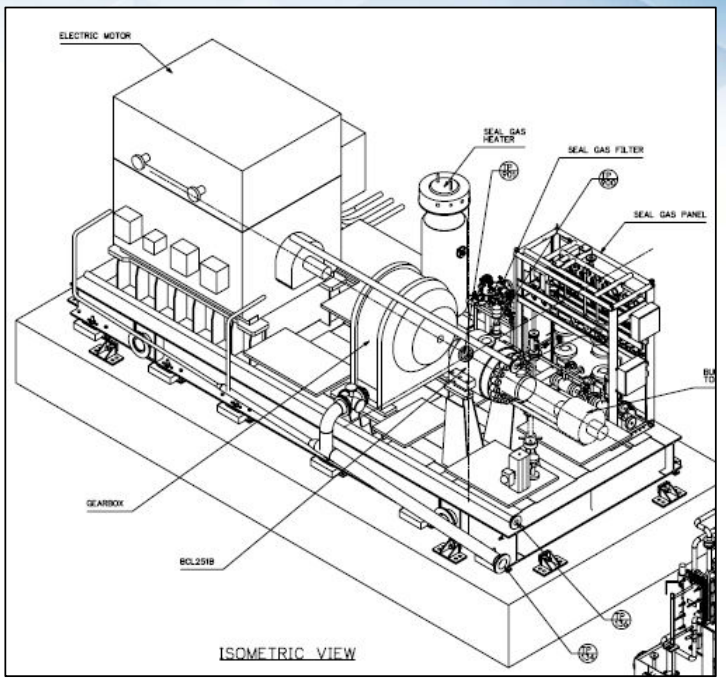


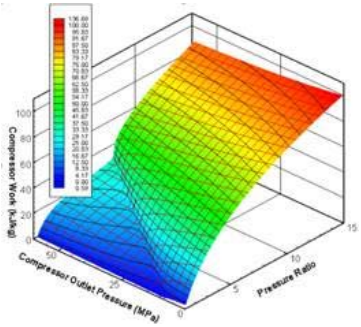
Sunshot Turbine

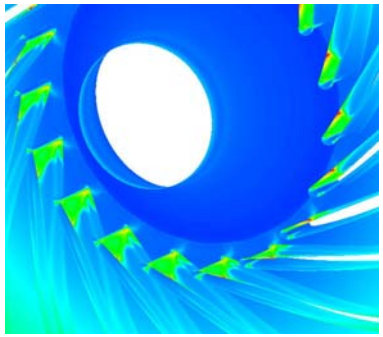
STEP Compression System

- Main Compressor driven by electric motor
- Bypass Compressor directly driven by STEP sCO2 turbine
- Real gas aerodynamics
- Compact Integral Guide Vanes (IGV) with large angle variation
- Smallest BGHE radial impeller of a similar class

Design basis from industrial CO2 compressors and DOE Apollo project DE-EE-0007109

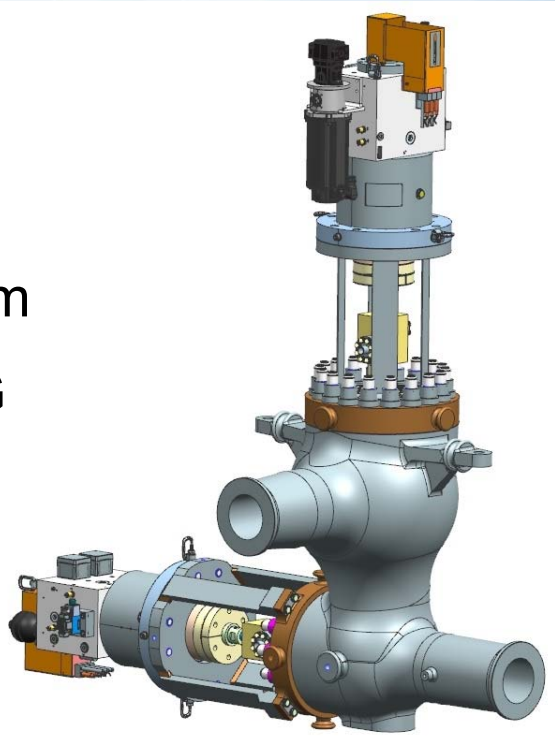


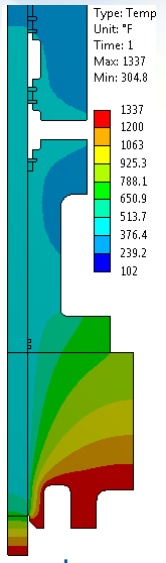




STEP Stop/Control Valve

- Leverages Haynes 282 material development under DOE AUSC program
- Advanced seals leveraging BHGE O&G capability
- Self-contained actuators leveraging BHGE O&G experience





Challenging thermal management

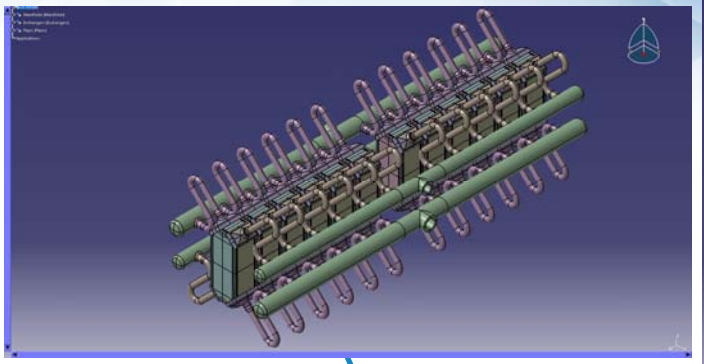
Seal & shaft testing at GE

Valve design similar to conventional steam valves with sCO_2 specific differences addressed with analysis and testing

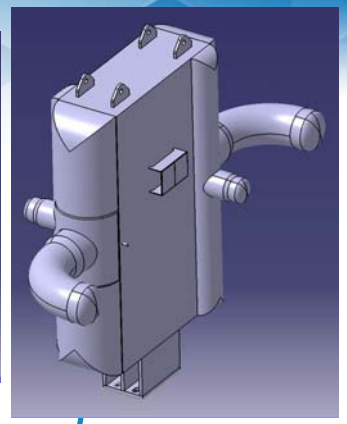
STEP Heat Exchangers

- **HTR** (High Temp Recuperator)
  - sCO_2/sCO_2 service
  - 49 MW_{th} duty, 600ºC design temp
- **LTR** (Low Temp Recuperator)
  - sCO_2/sCO_2 service
  - 13 MW_{th} duty, 250ºC design temp
- **Main Process Cooler**
  - sCO_2/clean water service
  - 16 MW_{th} duty, 150ºC design temp
- Materials of construction – SS316
- Supplier – Heatric

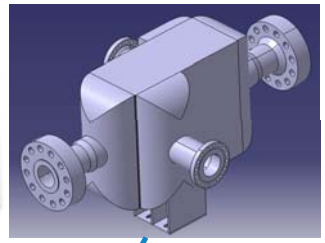
All STEP heat exchangers are compact Printed Circuit Heat Exchangers (PCHEs)



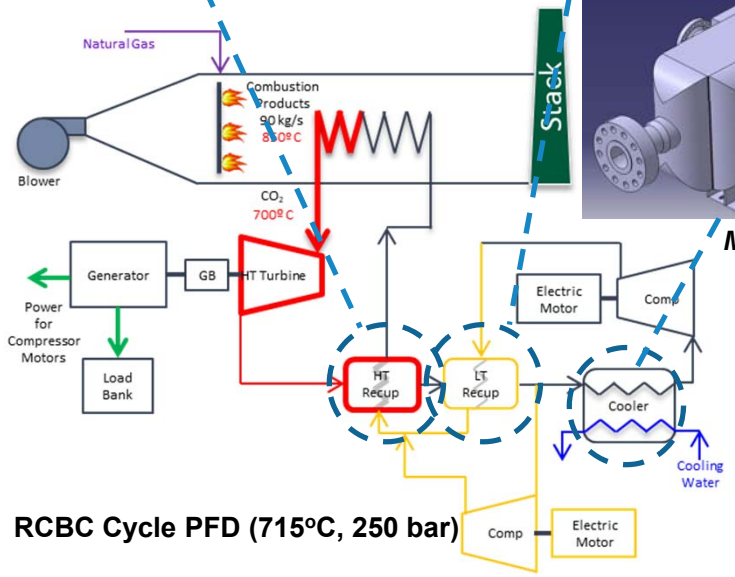
HTR (preliminary)



LTR



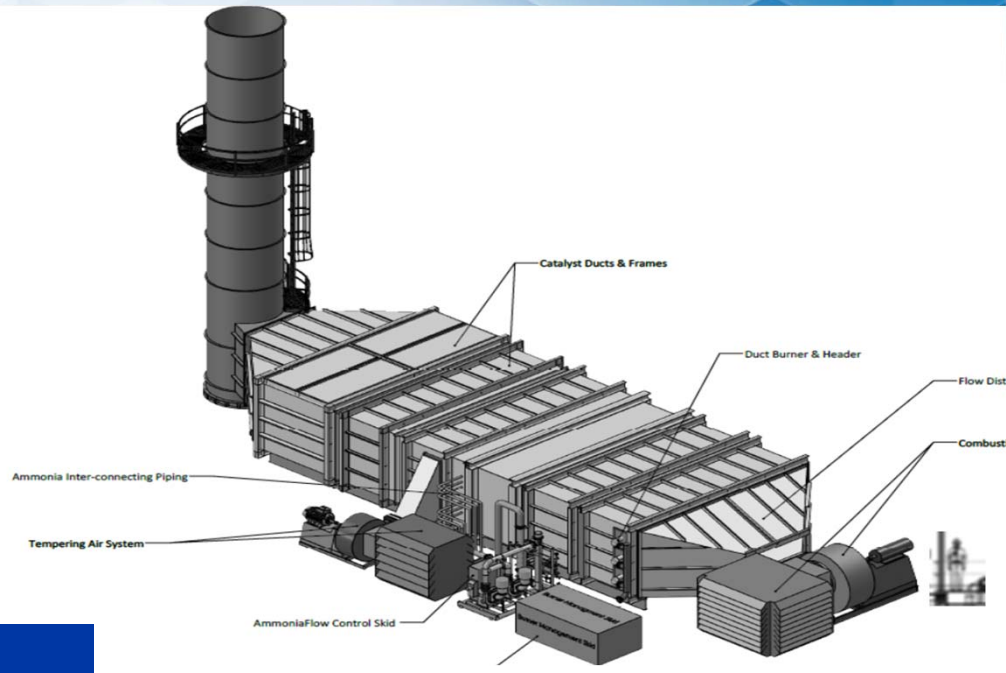
Main Cooler



RCBC Cycle PFD (715ºC, 250 bar)

STEP Process Heater

- HSRG style “boiler”
  - Duct NG burner ~ 50 MW_{th}
  - Multi-pass IN740H heat exchanger
  - Designed to ASME BPV Section 1
  - Designed for 100 kg/s at 255 bar, 715°C
  - Size: 14’W x 133’L x 18’H (Stack 70’H)
- Provided by Optimus Industries, LLC



Application of AUSC technology

Burner Section module being fabricated

IN740H header pipe 11.25” OD, 7.5” ID with holes for tubing drilled

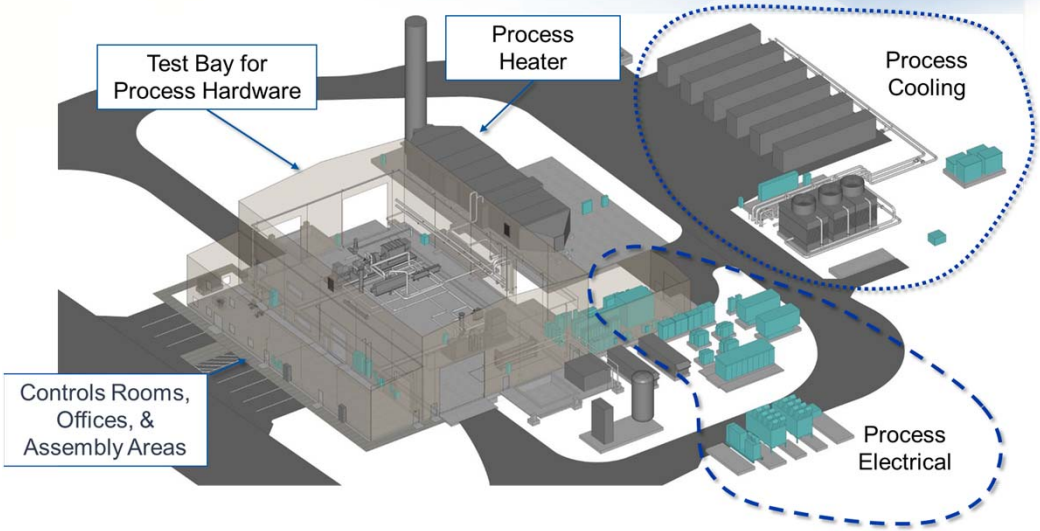
Cast tube sheet

IN740H tubing bends

IN740H tubing with 304S fins

STEP Facility Construction

- Site cleared
- Natural gas pipeline installed
- General Contractor progressing on schedule
- Building Occupancy - May 27, 2020
- Process hardware installation continues with building occupancy
- Mechanical Completion – October 20, 2020



STEP facility arrangement

Reconfigurable facility to accommodate future testing

10 MW_E SUPERCRITICAL CO_2 PILOT POWER PLANT

STEP DEMO

Improve power plant efficiency

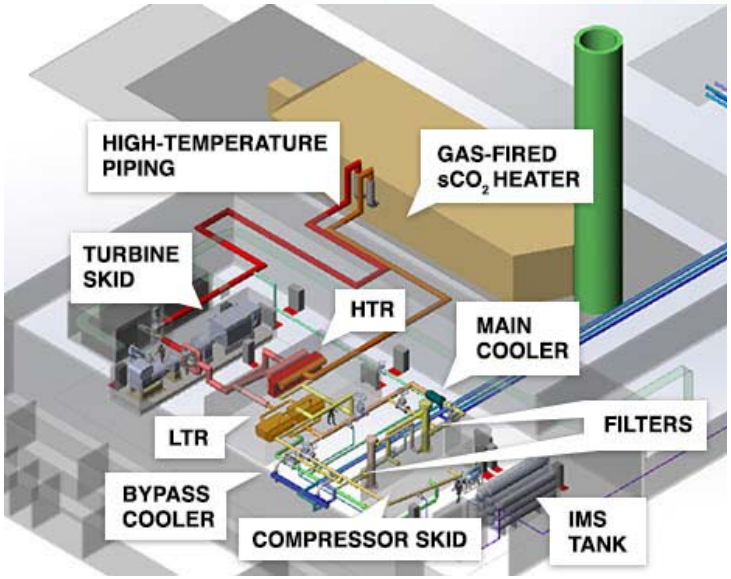
Zero emissions configurations

Reduce costs, emissions, water use

Quick response time

Versatile technology with many applications

Compact: small size turbomachinery



NATIONAL ENERGY TECHNOLOGY LABORATORY

gti

SwRI

KEPCO

Natural Resources Canada / Ressources naturelles Canada

Canada

Southern Company

AMERICAN ELECTRIC POWER

BOUNDLESS ENERGY

STEPDemo is meant to be an open program: Inviting Additional Project Partners

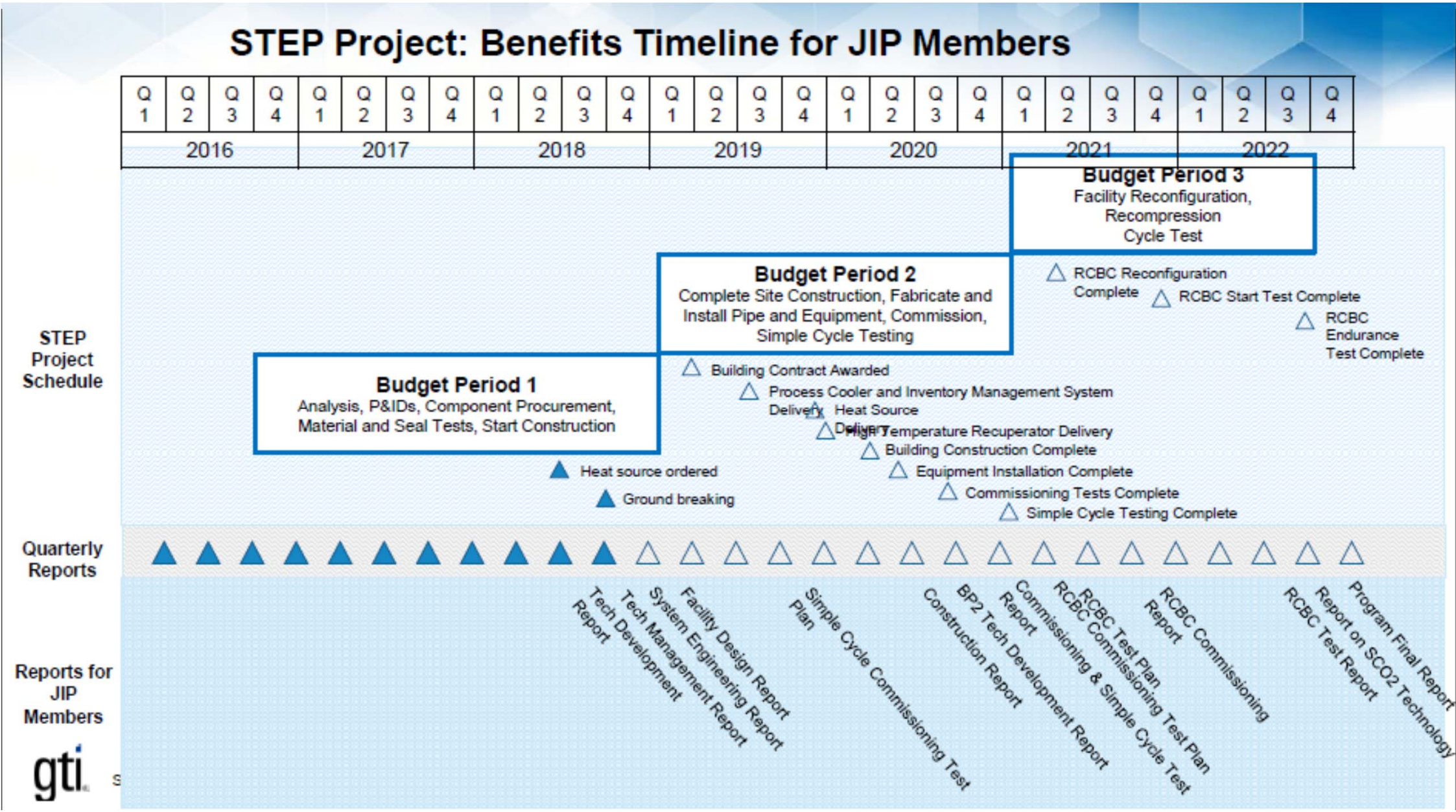
Joint Industry Program [JIP]

Leverage $84 MM in US DOE funding and $20+ MM in Industry funding to determine how this technology fits into your power generation plans and influence the project direction

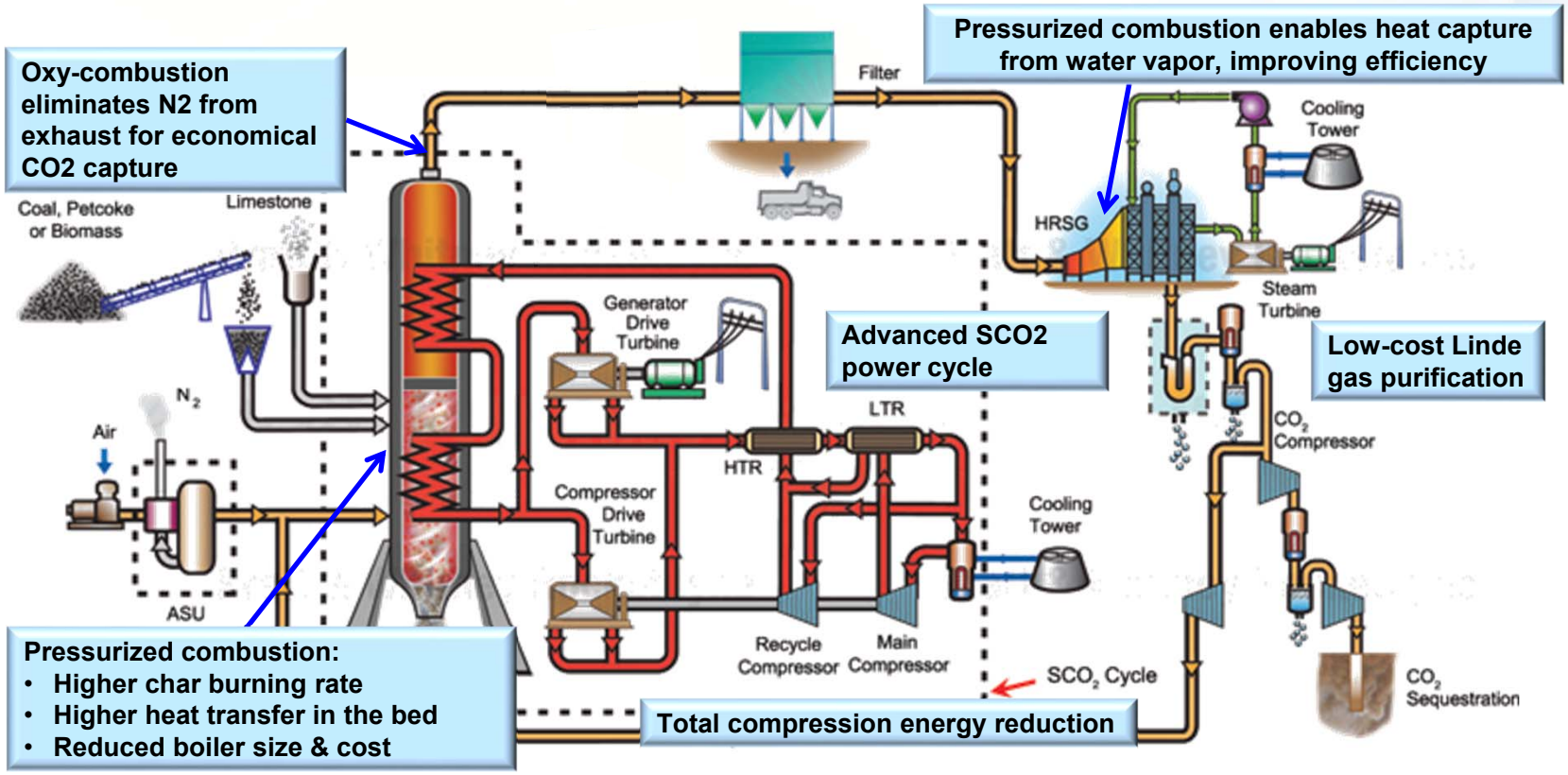
Two levels of participation available to Industry:

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
    - Opportunity for facility visits and training in system operations
    - Period of exclusive access to license system IP
2. Associate Membership
    - Attendance at bi-annual technical interchange meetings
    - Receipt of quarterly technical status reports
    - Opportunity for 2 site visits per year

STEP Project: Benefits Timeline for JIP Members



Oxy-PFBC / sCO_2 Plant Vision



High Coal Power efficiency and near zero emissions

- Initial product Oxy-PFBC with steam-Rankine cycle
- Final vision Oxy-PFBC with Supercritical CO2 Brayton for highest efficiency

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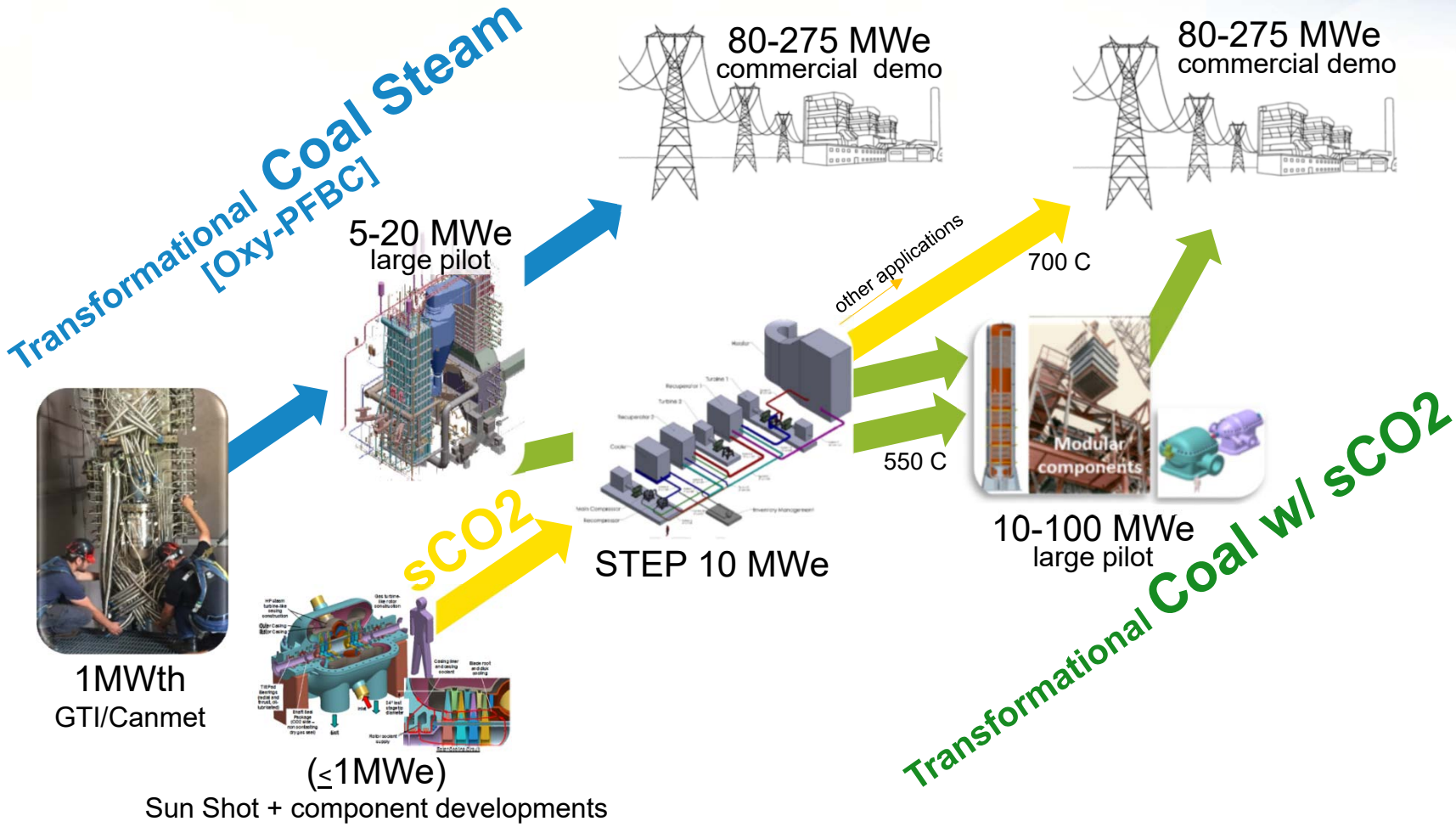
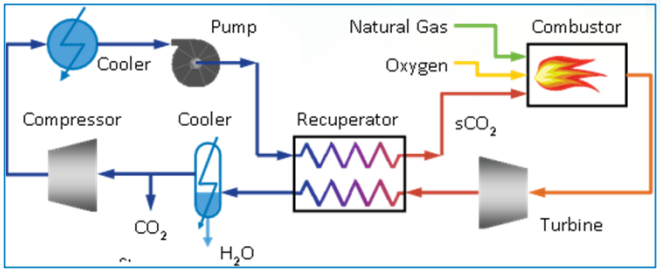
Oxy-PFBC Development Path with sCO2



Direct sCO2 Cycles

- **Growing interest in direct-fired supercritical CO2 cycles**
  - High cycle efficiencies
  - CO2 capture capability
  - Natural gas and syngas options
- **Unique Cycle Requirements**
  - Turbine inlet conditions of 1150-1200°C and 300 bar
  - High-pressure, high-temperature oxy-combustion
  - Recuperator inlet temperatures >700°C
  - Working fluid impurities (H_2O, O_2, CO, N_2, Ar)



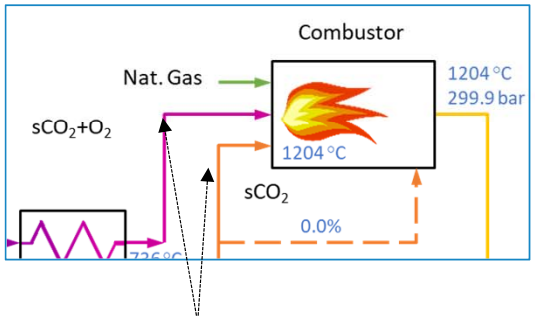
Simplified Direct-fired sCO2 Cycle

NetPower Plant (LaPorte, Texas)

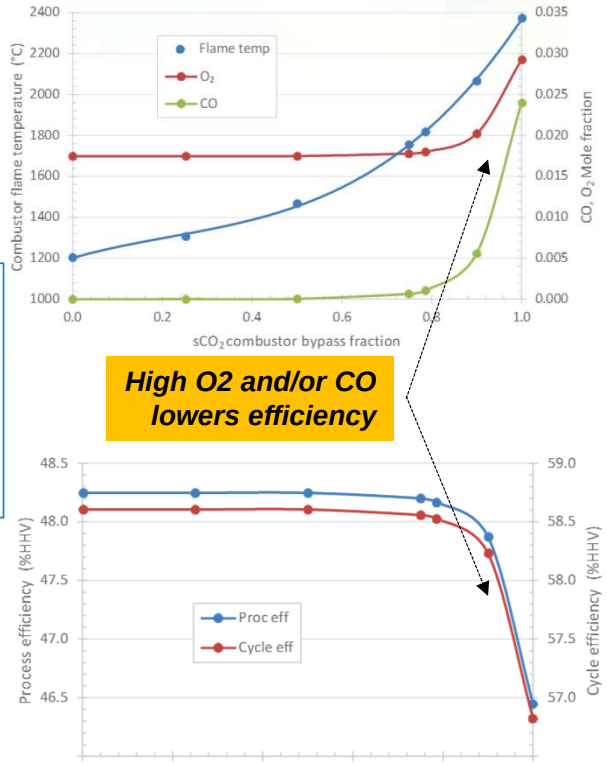
Combustor Requirements

- **Combustor Requirements**
  - Directly heat sCO2 from 700-800°C to 1150-1200°C
  - Operate at 200-300 bar
  - Interface with sCO2 turbine
  - Minimize excess O2 and CO levels

- **Combustor Concepts**
  - Gas turbine-derived
  - Rocket engine-derived (multi-element)
  - GTI developing unique combustor, leveraging rocket engine heritage



sCO2 split into two streams



High O2 and/or CO lowers efficiency

Source: Weiland et al

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