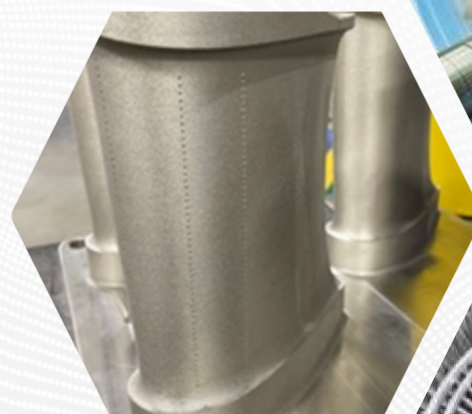
Oxy-Combustion and Turbine Design for Supercritical CO_2 Power Cycles






John Crane
Technology Manager, Advanced Turbines & Supercritical CO_2 Cycles

9th International Supercritical CO2 Energy Technologies Symposium

U.S. DEPARTMENT *of* ENERGY

March 3, 2026

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Advanced Turbines Program Areas

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Focused Research in Key Technology Areas

Developing advanced turbine technologies in pursuit of power generation with higher efficiency, flexibility, and lower costs

ADVANCED TURBINES

Advanced Combustion Turbines

- Combined cycle efficiency 67% (LHV, NG benchmark, turbine inlet temperature (TIT) of 3,100°F)
- Syngas, NG, H_2 Fuels (IGCC, NGCC)

Pressure Gain Combustion

- Alternate pathway to high efficiency
- TRL 2~3 (higher risk, long term, high payback)

Supercritical CO_2 Power Cycles

- sCO_2 indirect and direct power cycles for high efficiency and fuel flexibility

Advanced Turbines | netl.doe.gov

Advanced Turbines & STEP Program

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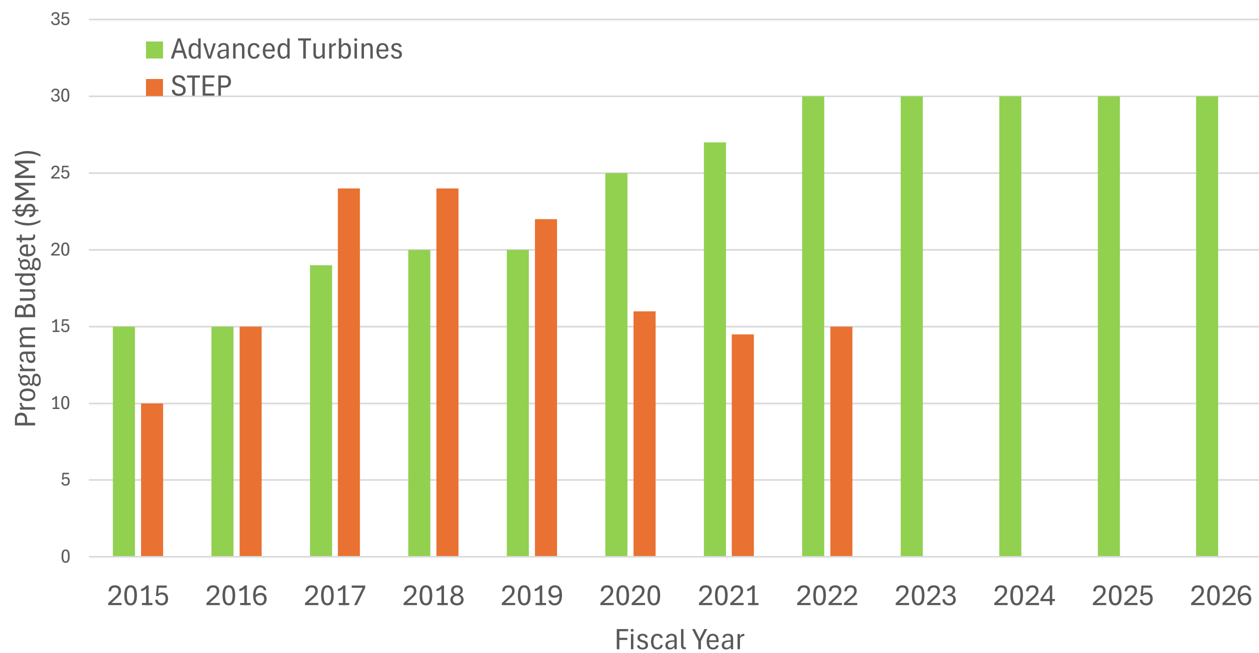
Budget History

SUPERCRITICAL CO_2 POWER CYCLES

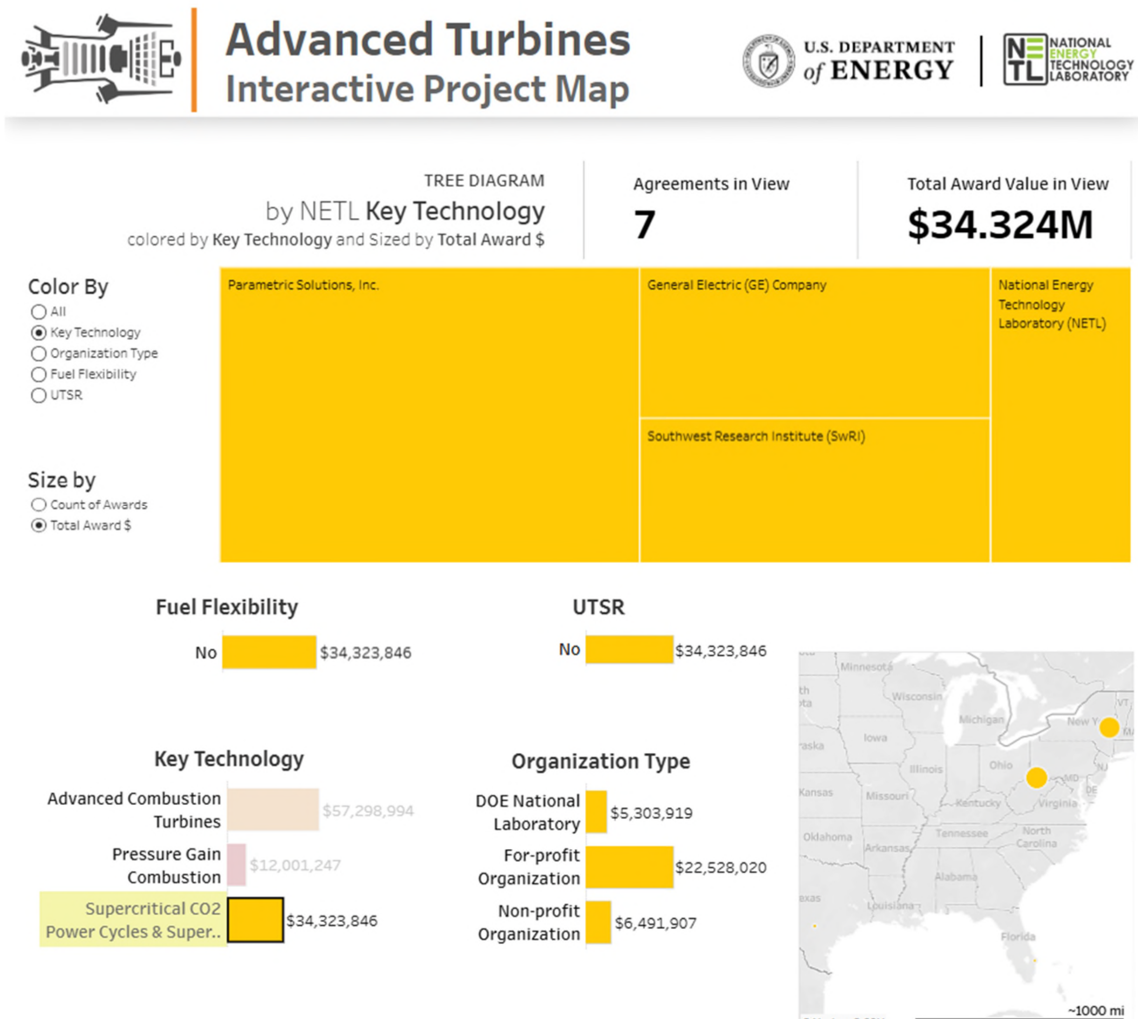
ADVANCED COMBUSTION TURBINES



DOE HQ Program Manager:
- Robert Schrecengost

NETL Technology Manager:
- John Crane

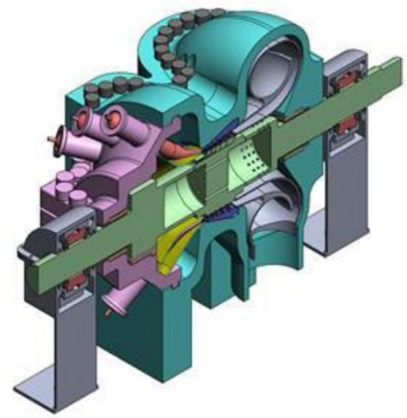
Advanced Turbines Supercritical CO_2 Portfolio



FECM sCO_2 Development Activity

Key Projects for Direct sCO_2 Power Cycles

- External Projects
  - *[Development of Coal Syngas Oxy-Combustion Turbine for use in Advanced Supercritical Carbon Dioxide (sCO_2) Power Cycles – SwRI]*
  - *[Testing of a zero-emission sCO_2 oxy-combustor – Parametric Solutions]*
- NETL RIC R&D/Systems Analyses



Preliminary design of a 300 MWe Oxy-fuel sCO2 turbine

Development of Coal Syngas Oxy-Combustion Turbine for use in Advanced Supercritical Carbon Dioxide Power Cycles

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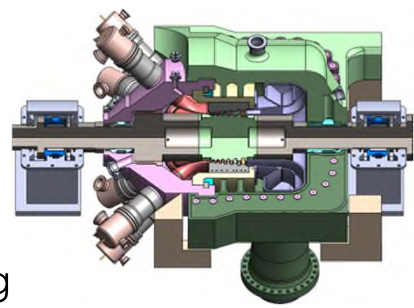
FE0031929 – Southwest Research Institute

Goal: Develop detailed design for sCO_2 direct fired oxy-fuel turbine for utility scale (300 MWe Net, 450 MW turbine power) utilizing a coal syngas fuel, with the ability to be co-fired with natural gas.



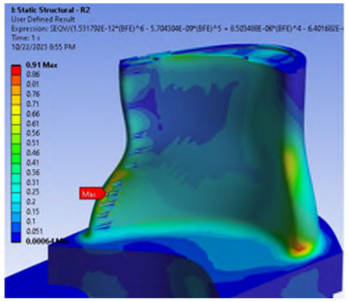
Turbine Design

Case Design and Manufacturing Process

- FEA at nominal loads used to verify sealing pressure is maintained for split case.
- Limit load analysis converged
- Turbine case manufacturing process includes casting, welding, and final machining
- Engineering drawings include sealing surfaces and keyway features

Combustor Housing Design

- Combustor housing materials include high-strength cast steels (J42045), with Haynes 230 used for combustor nozzles due to localized high temperature region
- Limit load and local failure analyses completed and converged



FEA

FEA

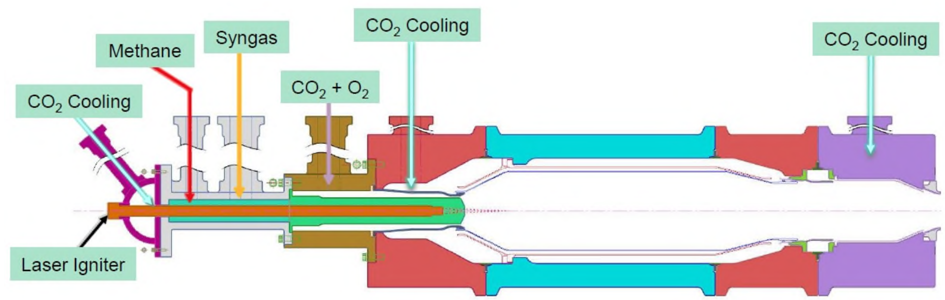
- Pressure loading, centrifugal loading, thermal expansion effects with updated geometry and unsteady CFD for more accurate external load
- Localized regions remain with function value over 1, signifying life prediction < 30k hrs
- Final iterations being completed to achieve 30k hr. life.
- Validation of testing completed at SwRI facility reusing existing BP2 test rig

Zero Emission Supercritical Carbon Dioxide Oxy-Combustor Development and Testing

FE0031922 – Parametric Solutions

Project Goal:

- Design, build, and test the world's first syngas-fueled supercritical carbon dioxide (sCO_2) combustor for the Allam-Fetvedt Cycle. This cycle has the potential to produce electricity at a lower cost than conventional fossil generation with high flexibility, inherent carbon capture, and near-zero air emissions and water use. PSI will build and operate two commercial-scale 50 MW_{th} syngas combustors at up to 12-20 MW_{th} load, moving the combustor up to Technology Readiness Level (TRL) 6.
- Provide the data needed to commercialize a 200-300 MWe Allam-Fetvedt coal plant, which would be built utilizing a radial array of ten to twelve 50 MWth syngas combustors or with one or two large silo-type combustors



Syngas Oxy-combustor Concept Design

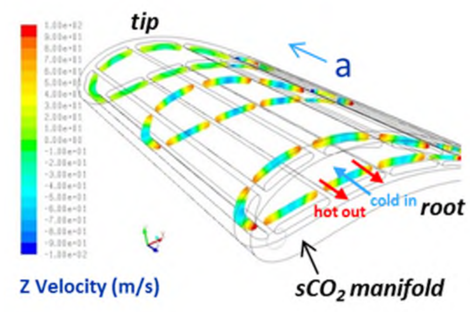
Current Status:

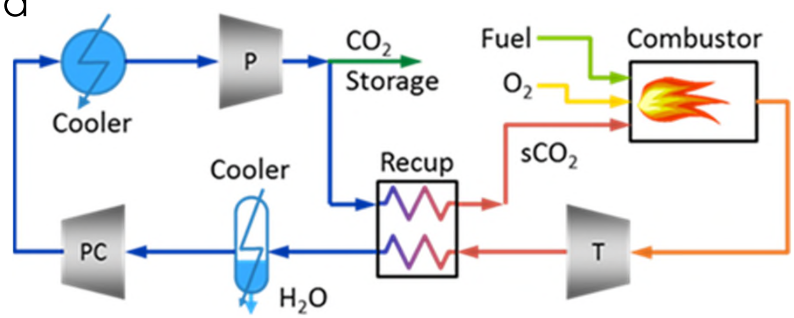
- Final Design in manufacturing for high pressure combustor test articles
- Testing was scheduled for late 2025

NETL Research & Innovation Center R&D—Supercritical Carbon Dioxide Technology

Systems Analysis —

- Optimized "exemplar" sCO_2 power cycle system configurations with respect to DOE goals
- Techno-economic analysis of low to negative emissions processes leveraging direct- and indirect-sCO_2 cycles

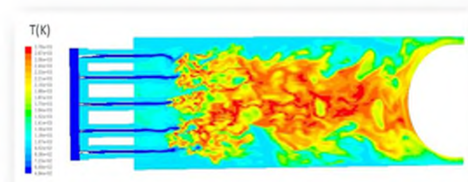




Direct-Fired Supercritical CO_2 power cycle for zero CO_2 Emissions

R&D to Support Cycle Development —

- sCO_2 heat transfer in recuperators and turbine blades
- High-pressure sCO_2 oxy-combustion fundamental testing and modeling



Combustion Model Validation Issues

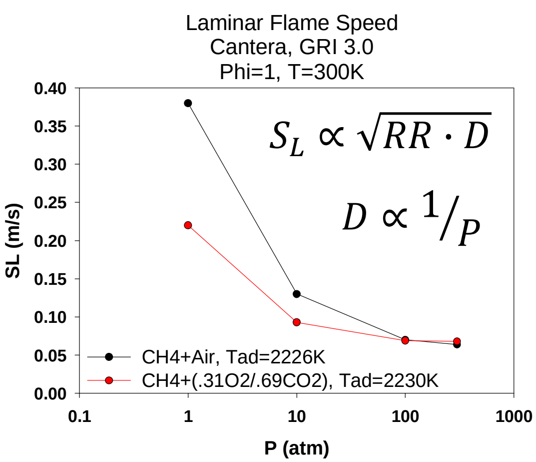
- Three cases shown for 300 bar oxy-combustion define a range of conditions (O2 mass fraction from 7-25%) spanning the thickened, corrugated flame regime and stirred
- Significantly outside the range of gas turbine and IC engine operation.
- Requires assessment of appropriate turbulent combustion models.

$$Ka = \frac{\tau_{chem}}{\tau_K} = \frac{\delta_L^2}{l_K^2}$$

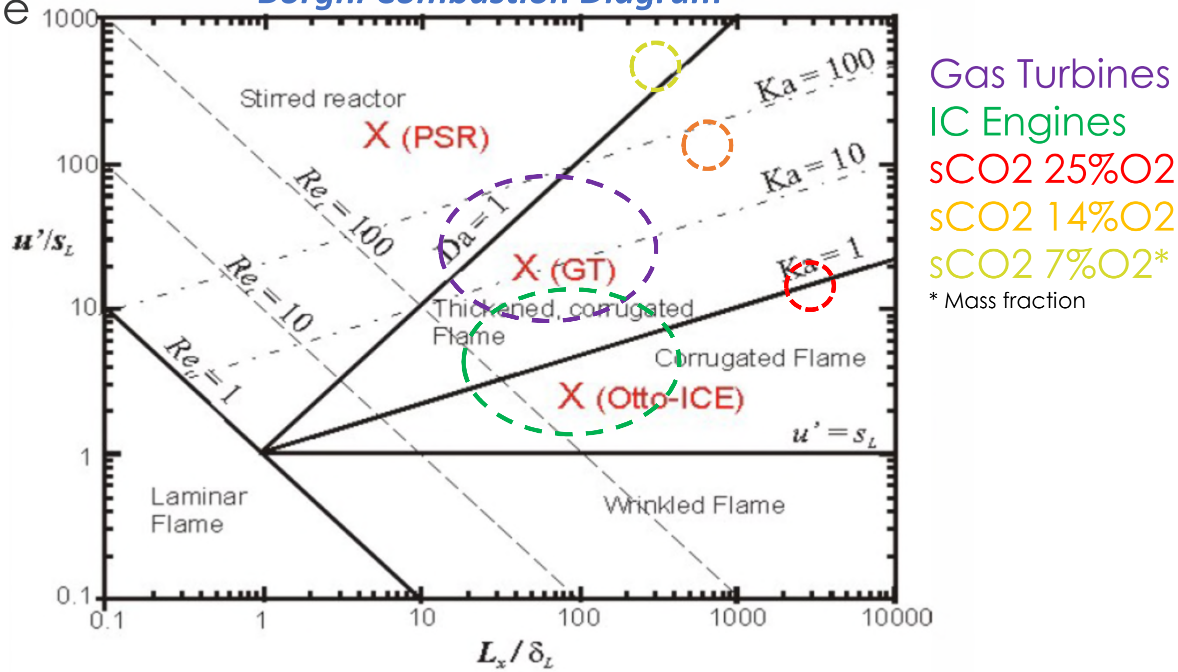
Laminar Flame Thickness

$$\delta_L = \frac{\alpha}{S_L}$$

$$\alpha = k/\rho C_P$$



Borghi Combustion Diagram



Effect of O_2 Concentration

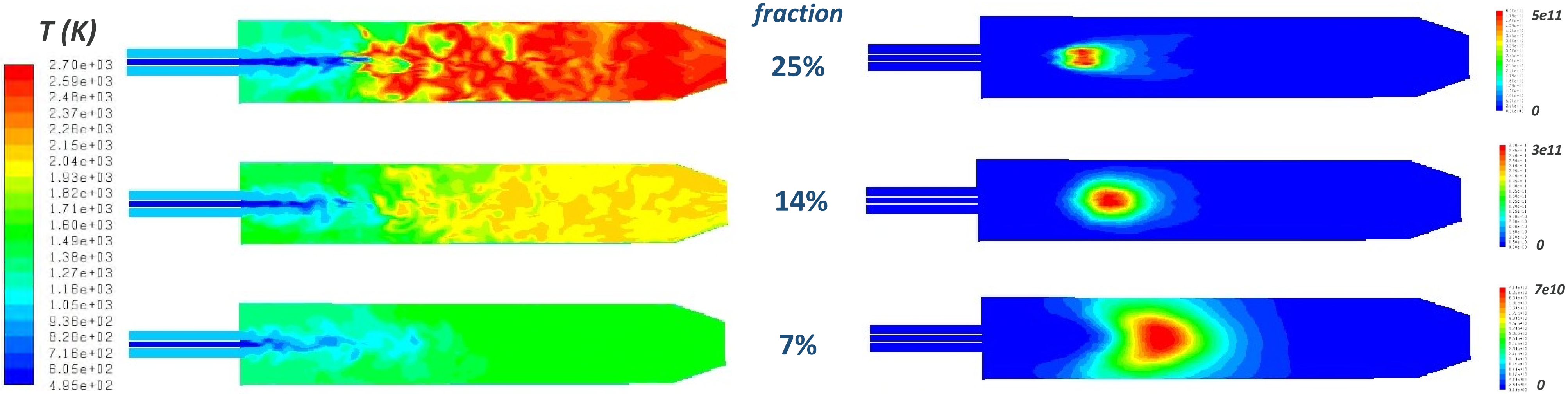
Laminar Model

Lifted flame at 25% O_2 transitions to autoignition reaction at 7% O_2.

- Broadening of reaction zone.
- Lower flame temperatures.

Large Eddy Simulation Modeling of Oxy-Combustion

Instantaneous Temperature (K) ***Mean RR (W/m^3)***



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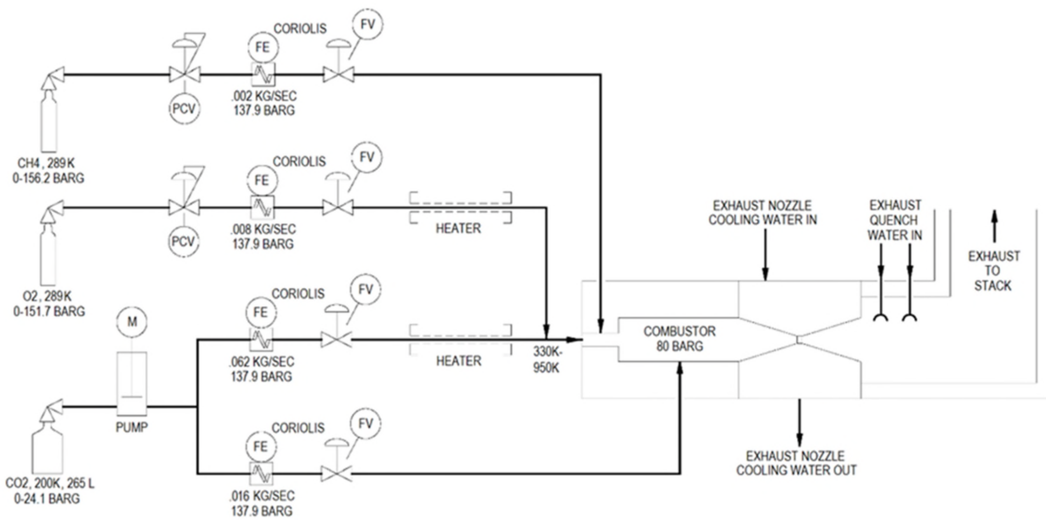
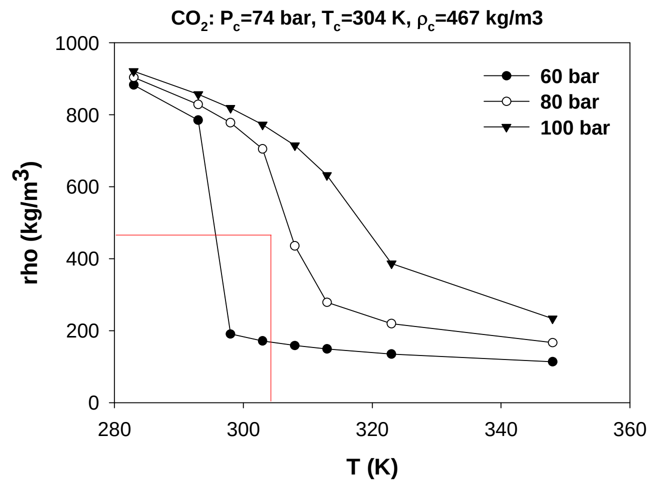
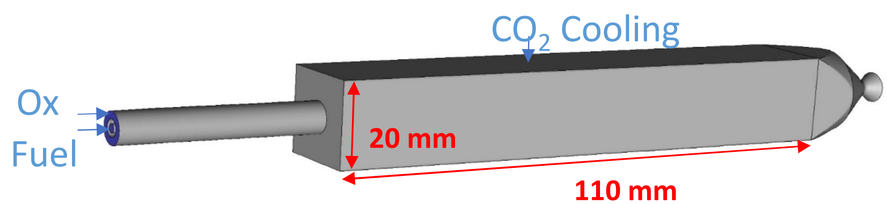
Experimental Layout and CO_2 Properties

80 bar Max Combustor Pressure







- 80 bar chosen as a compromise between cost and relevancy
- Blow-down from standard k-bottles for CH_4 and O_2
- CO_2 from liquid dewar with pump and heater (330K initially, 950K later)

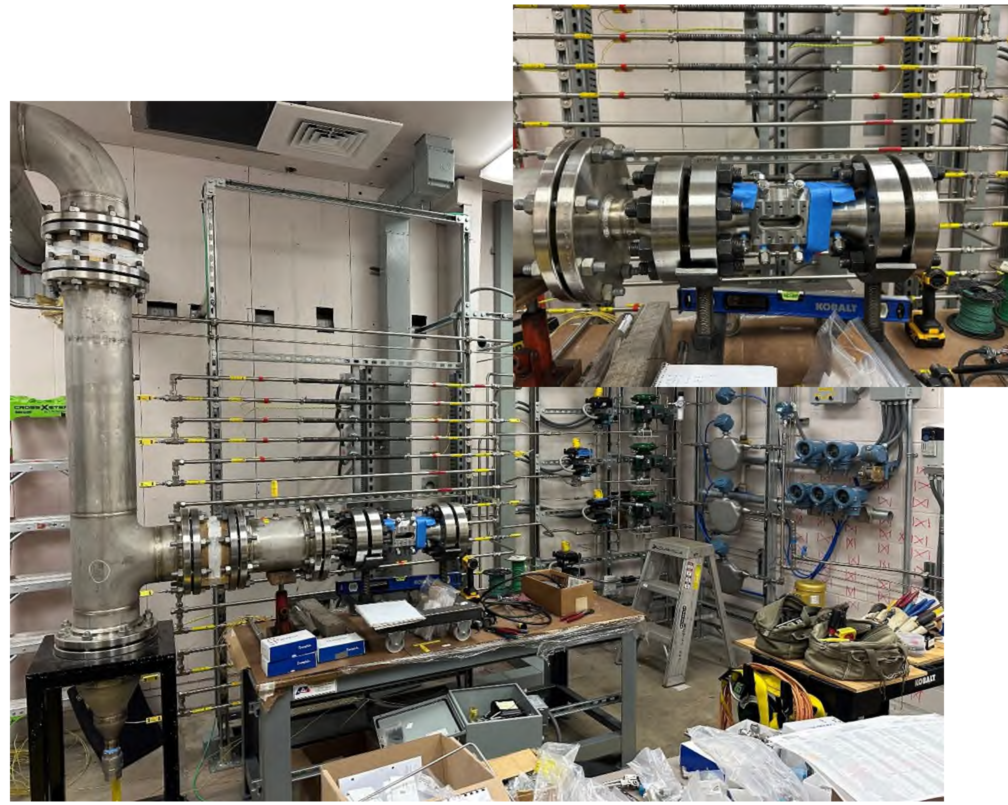
Morgantown B13 Oxy-Combustion Facility

80 Bar Research Combustor

- Construction mostly completed. Shakedown testing scheduled for March 2026.

- Combustor designed for 80 bar and 100 kW.
- 30 second blow-down test duration.
- Maximum of 20 tests per CO_2 dewar fill.

- O_2/CO_2 Mixture Preheat Temperature
  - 50°C (planned upgrade to 650°C)
- O2 ~ 7% to 25% by mass with CO_2 balance.
- Bottled CH_4 fuel.
- 4 combustor access windows for imaging and laser diagnostics.



Questions?

Thank You!

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Additional information can be found at:
https://netl.doe.gov/carbon-management/turbines