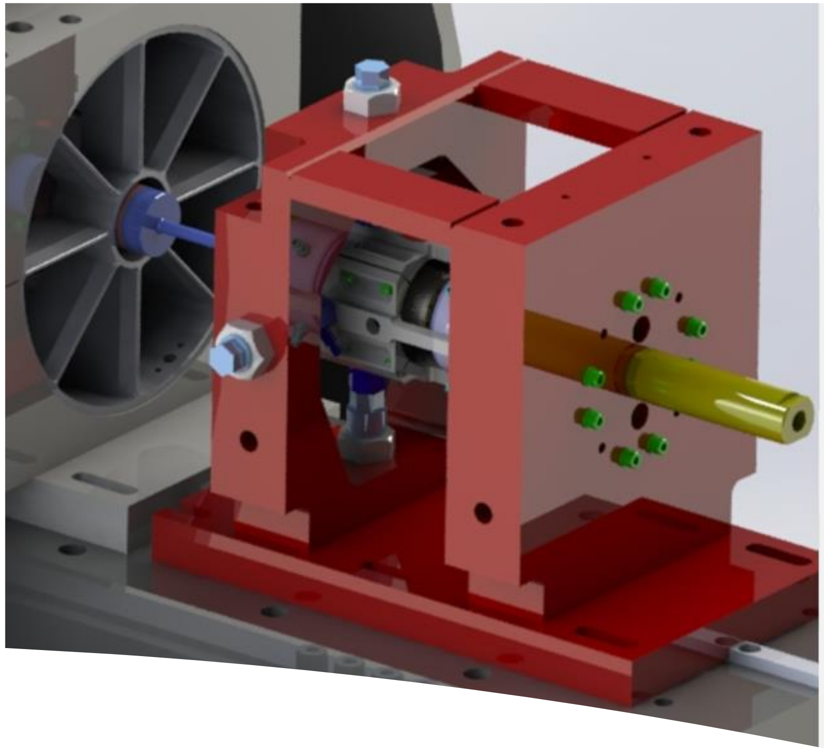
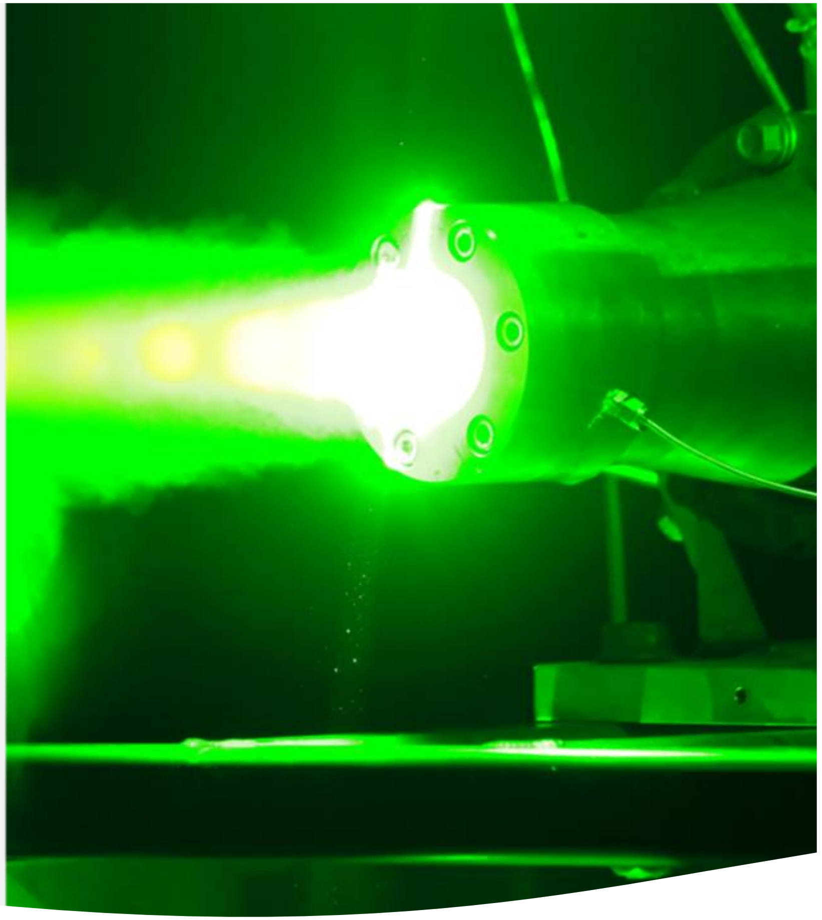




Design of a 1 MW Direct Fired Oxy-Fuel Combustor for sCO_2 Power Cycles

SwRI

SOUTHWEST RESEARCH INSTITUTE

Introduction

Advantages of a direct-fired sCO_2 power cycle

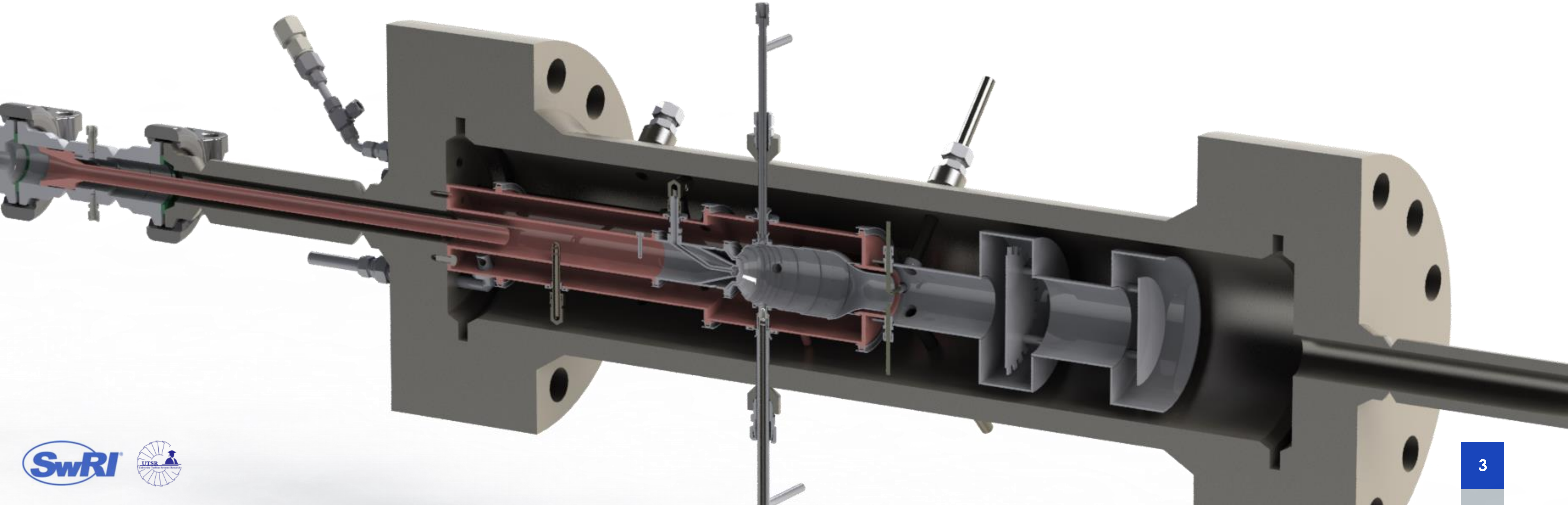
- Compact hardware
- Greater heat-addition efficiency
- Nearly 100% carbon capture

Challenges

- Lack of validated combustion modeling techniques
- High pressure and temperature

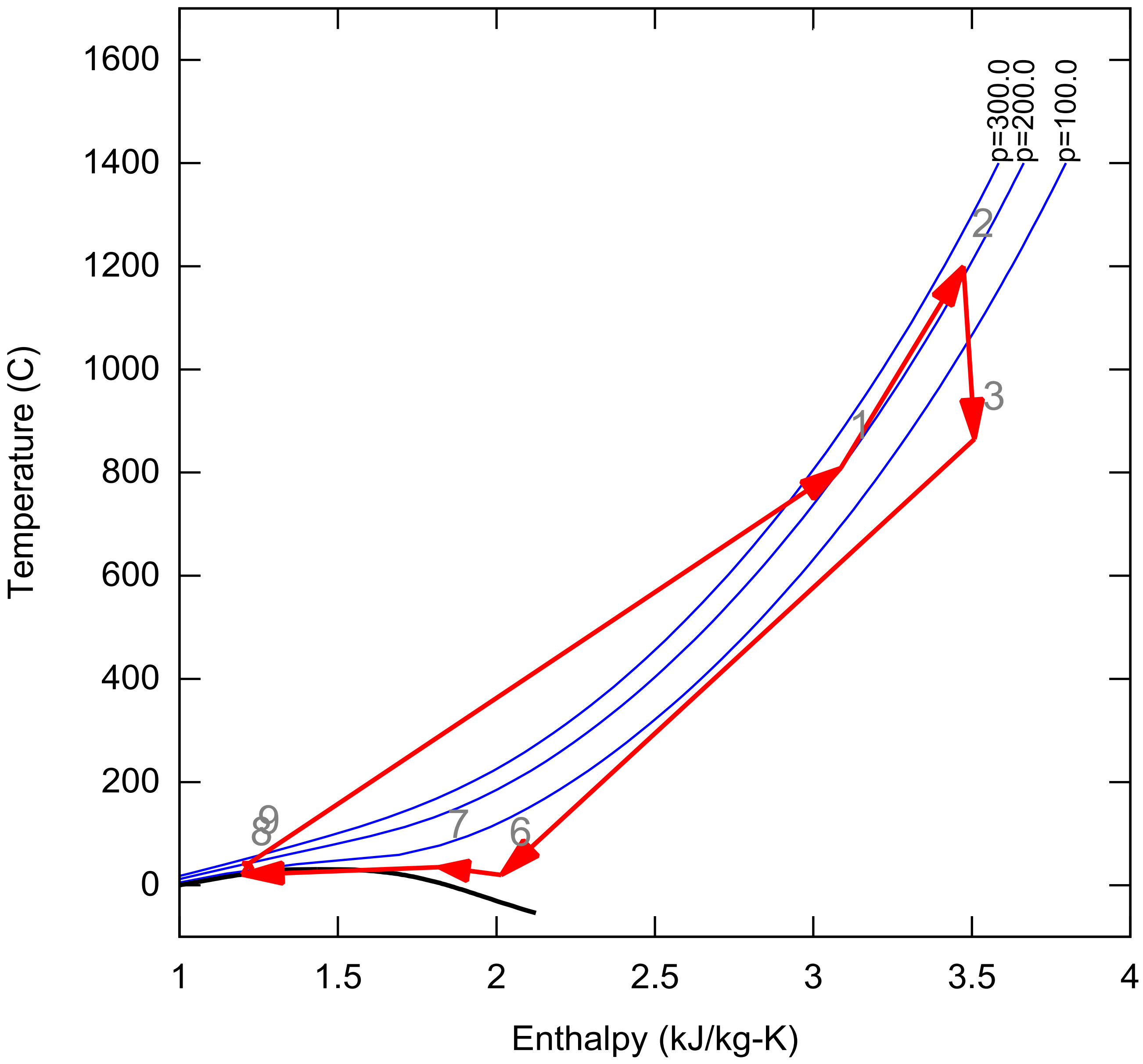
Project Objectives

- Design a 1 MW thermal oxy-fuel combustor capable of generating 1200°C outlet temperature
- Manufacture combustor, assemble test loop, and commission oxy-fuel combustor
- Evaluate and characterize combustor performance using optical access for advanced diagnostics



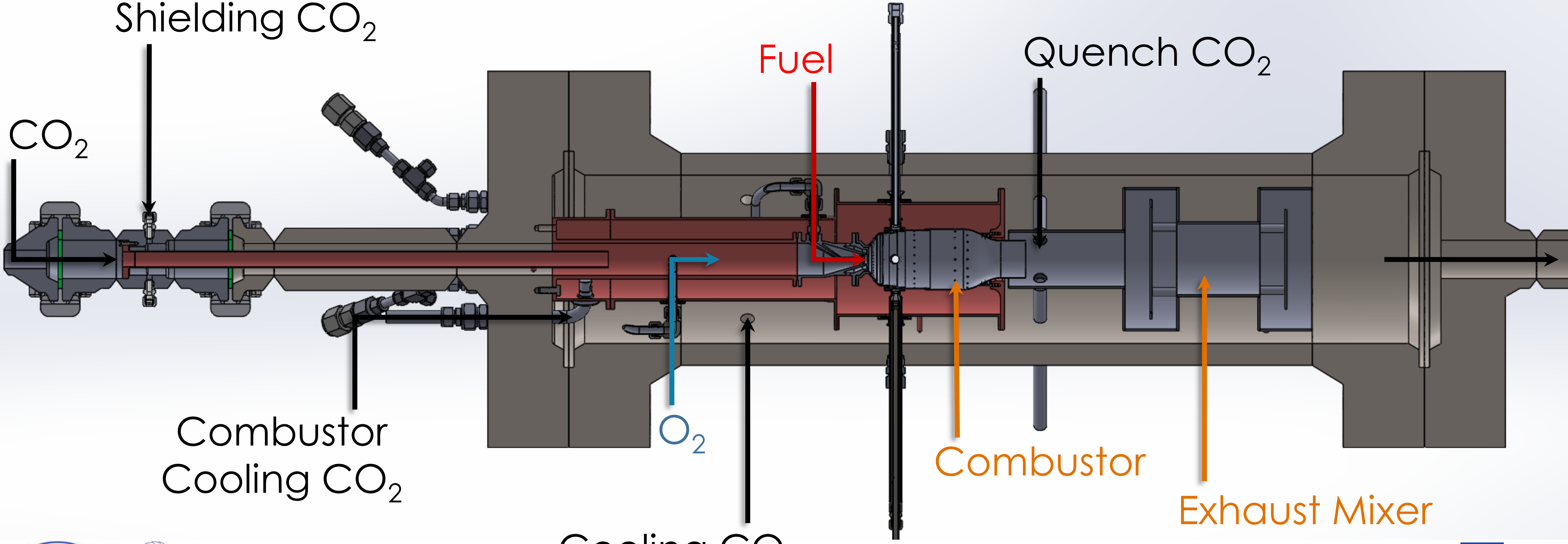
Cycle Conditions

- Combustor Inlet and Outlet temperatures dictated by reviewing previous cycle modeling work done at SwRI
- Combustor inlet temperature: 700°C at 200 bar
- Combustor outlet temperature: 1200°C
- Achieves a plant efficiency comparable to a NGCC power plant

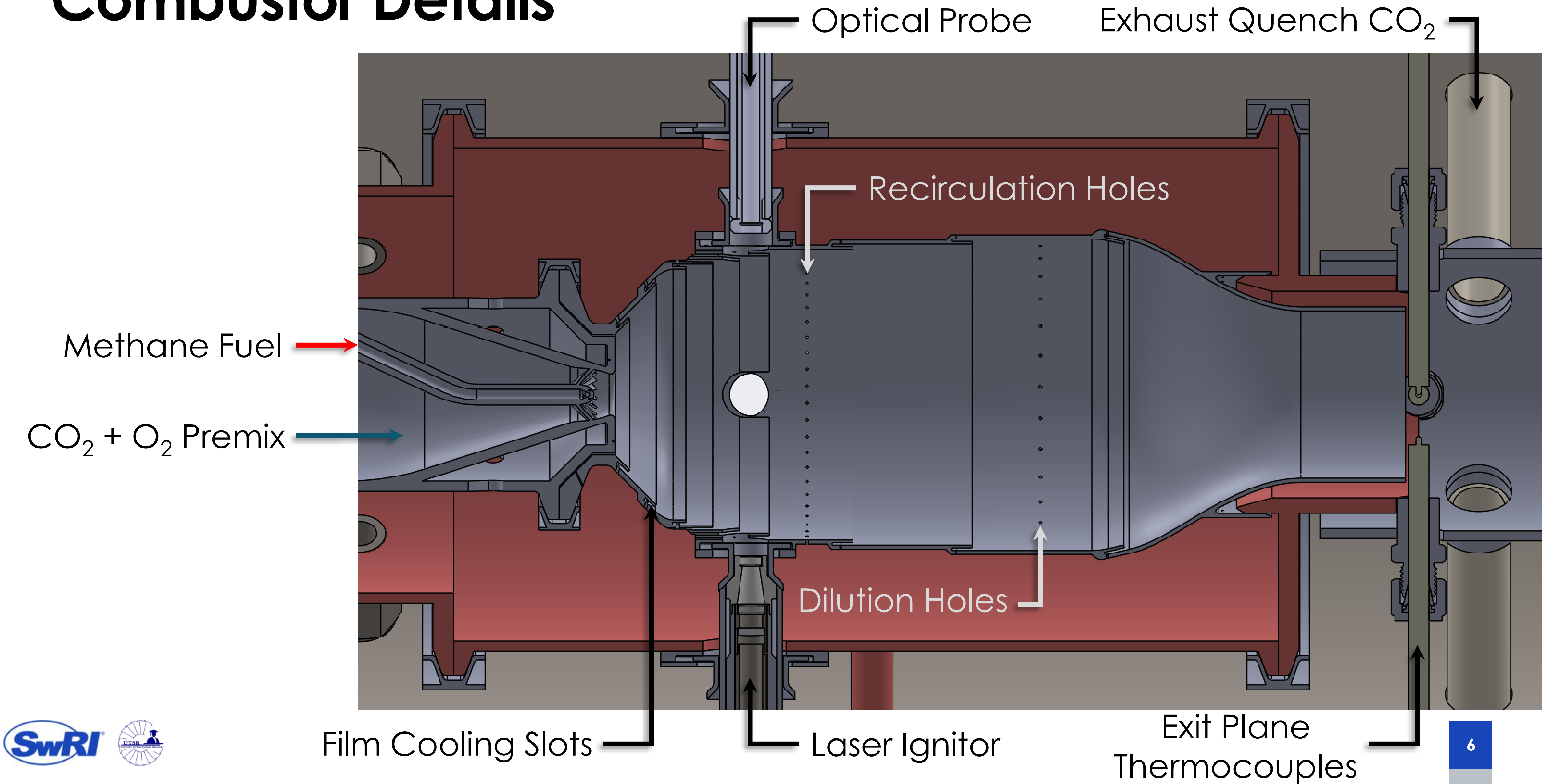


Combustor Schematic

Line	Temp (°C)
Main CO_2 Line	700
Shielding/Quench CO_2	90
Combustor Cooling CO_2	350
Fuel/Oxygen	ambient
Combustor Exit	1200
Casing Exit	415

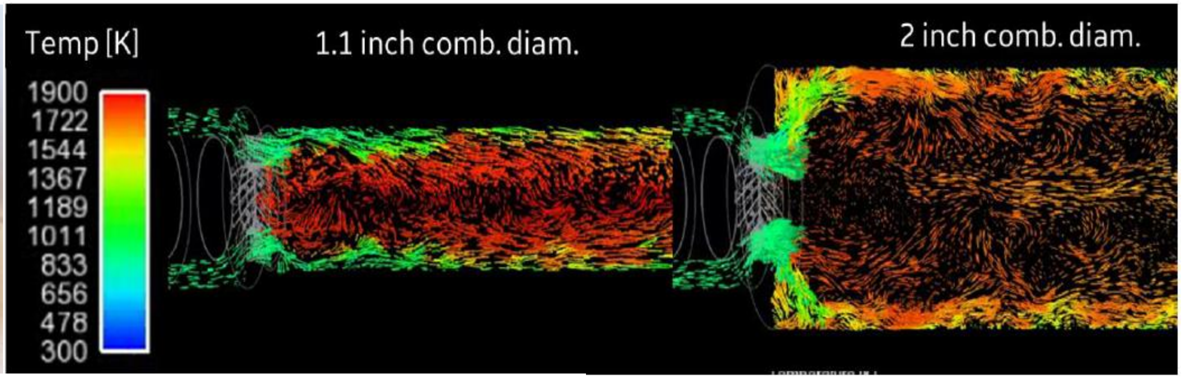


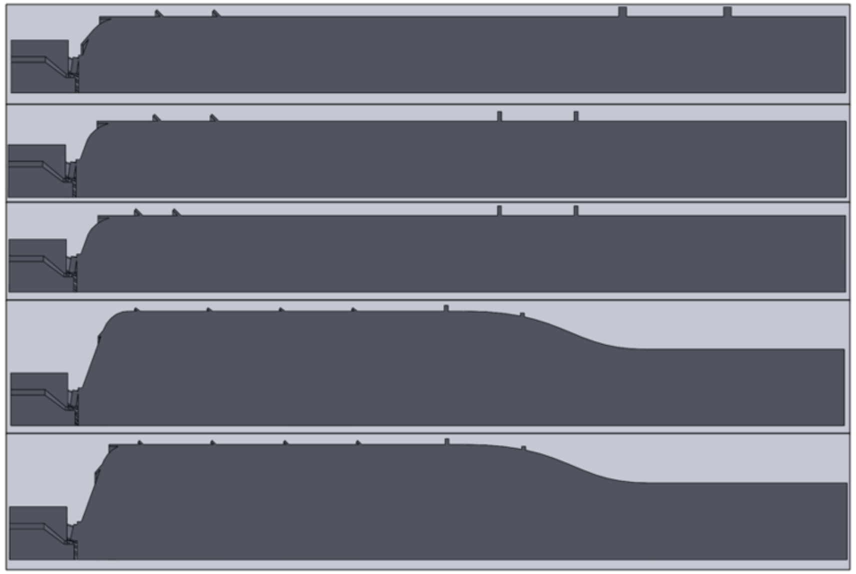
Combustor Details

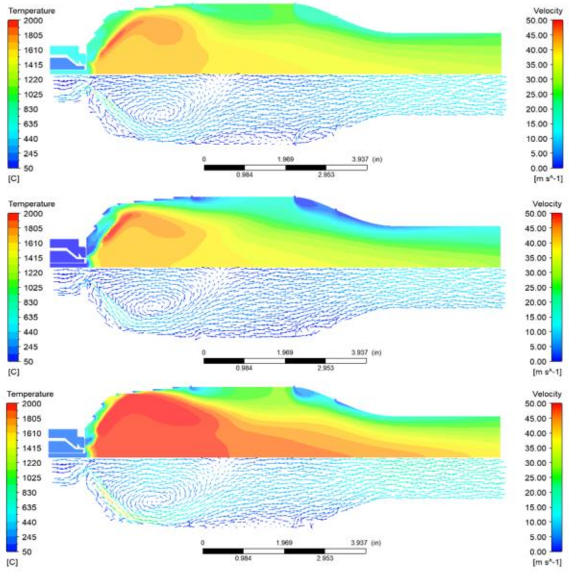


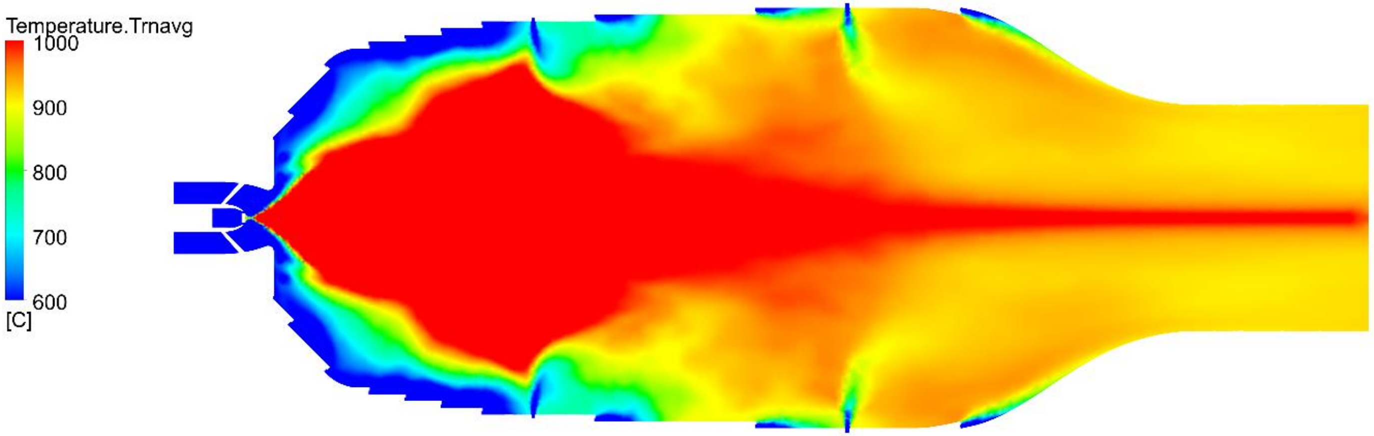
Combustor Design

- Design work began in conjunction with GE-GRC using a heritage swirler
- Design maturation focused on flame holding and film cooling
- Final combustor design uses film cooling slots, recirculation holes and dilution holes



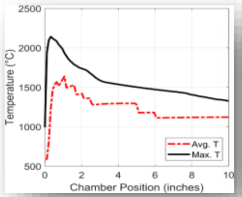


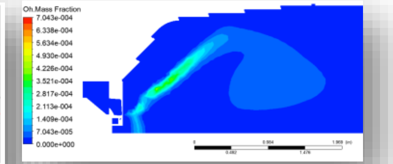




CFD Design

Heat Release And Flame Holding





Cooling/Recirculation Schemes

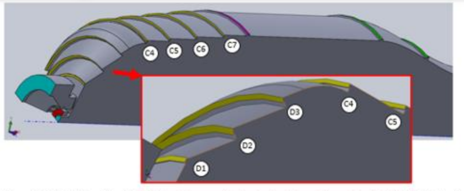


Figure 1-7. Details of the Fluid Inlets, Purposed Indicated by Face Color: CO_2+O_2 Inlet (Teal), Fuel Inlet (Red), Wall Cooling (Yellow), Recirculation Control (Magenta), and Dilution (Bright Green)

Injection and Swirl

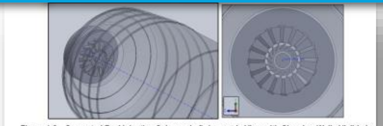


Figure 1-8. Separated Fuel Injection Scheme. Left: Isometric View with Chamber Walls Visible in Wireframe. Right: View of Injection Plane from Combustor Exit

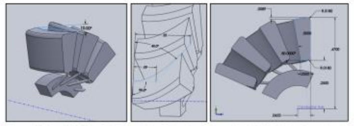


Figure 1-9. Details of the Swirling and Fuel Injection Schemes. Left: 10° Swirling Down Angle; Center: 40° Swirl Angle and Facial Sweep; Right: Swirler Inlet Facial Features

Startup Conditions

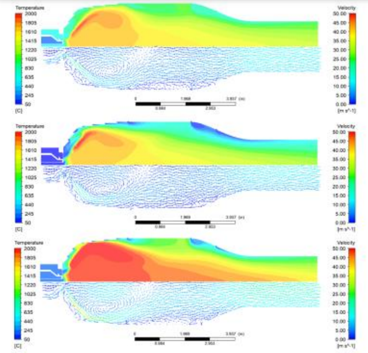
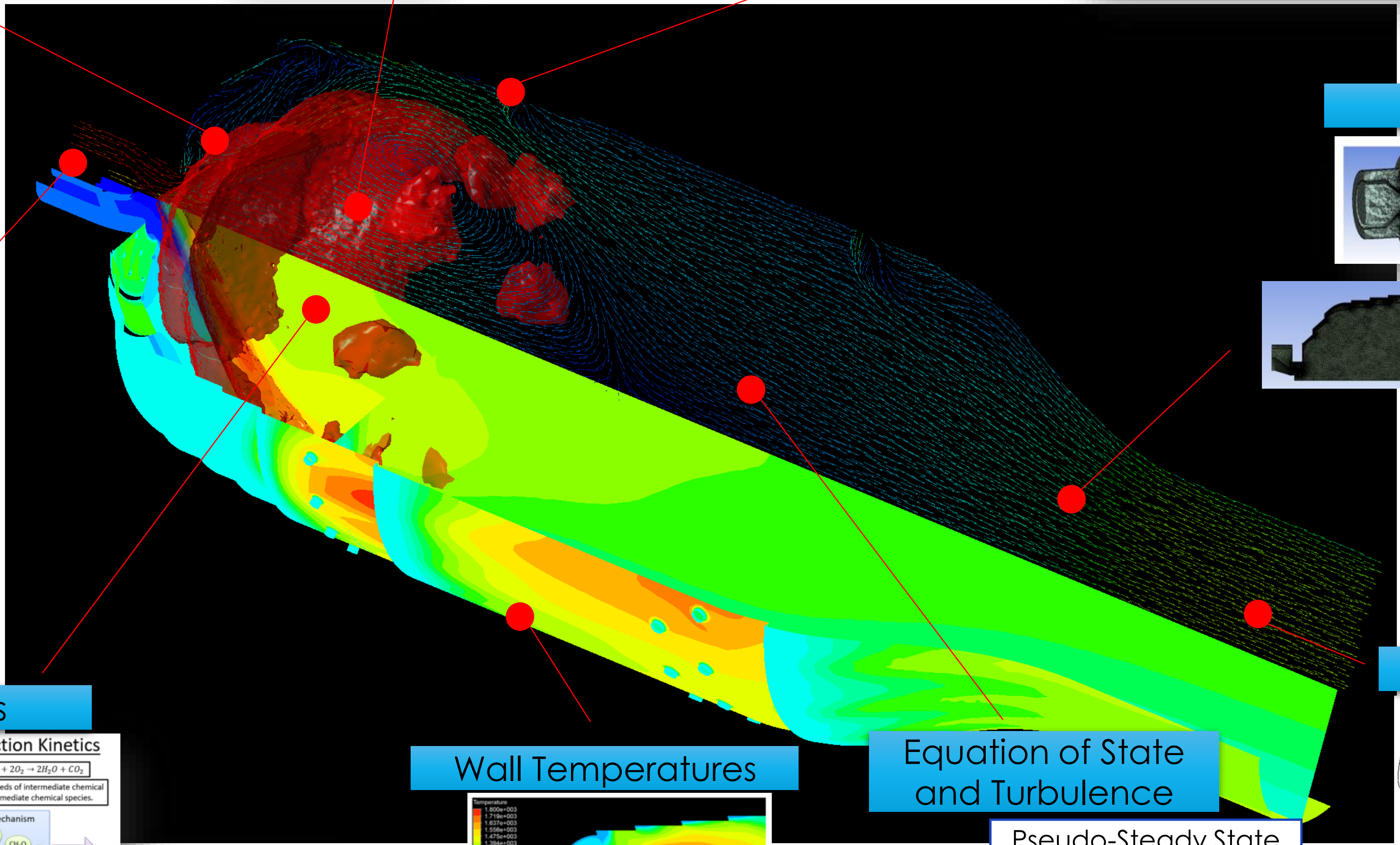
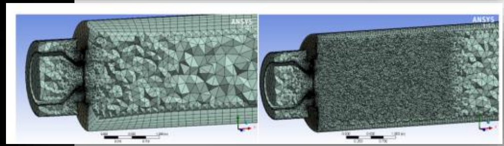


Figure 1-16. Comparison of Temperature Contours and Velocity Vectors for the Three Operating Condition Cases: Design Conditions (Top), Cold Start (Middle), Fast Start (Bottom)



Mesh Sensitivity



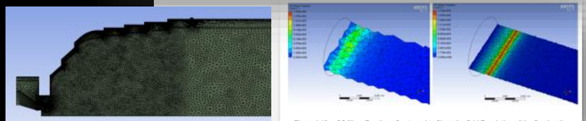


Figure 1-13. CO Mass Fractions Contoured to Show the Grid Resolution of the Combustion Reaction. Coarse Grid (left) and Fine Grid (right)

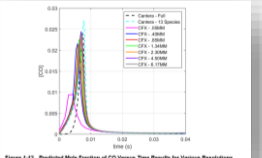
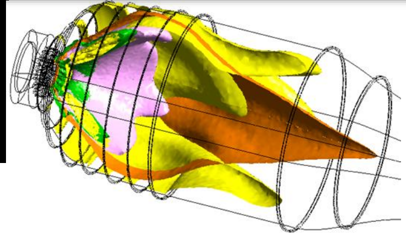


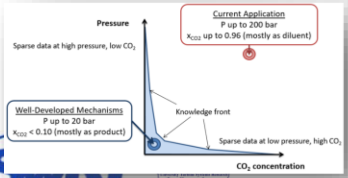
Figure 1-12. Predicted Mole Fraction of CO Versus Time Results for Various Resolutions

Unreacted Products



Chemical Kinetics

Kinetics Knowledge Base



Georgia Tech

Chemical Reaction Kinetics

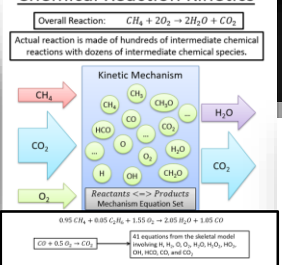


Figure 1-2. The Conversion of the 6-Species Kinetic Model to a 13-Species Kinetic Model

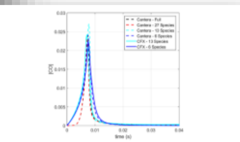
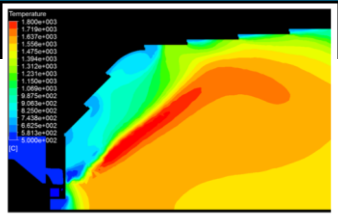


Figure 1-7. Predicted Mole Fraction CO Versus Time Results

Wall Temperatures



Equation of State and Turbulence

Pseudo-Steady State

$k-\omega$ RANS

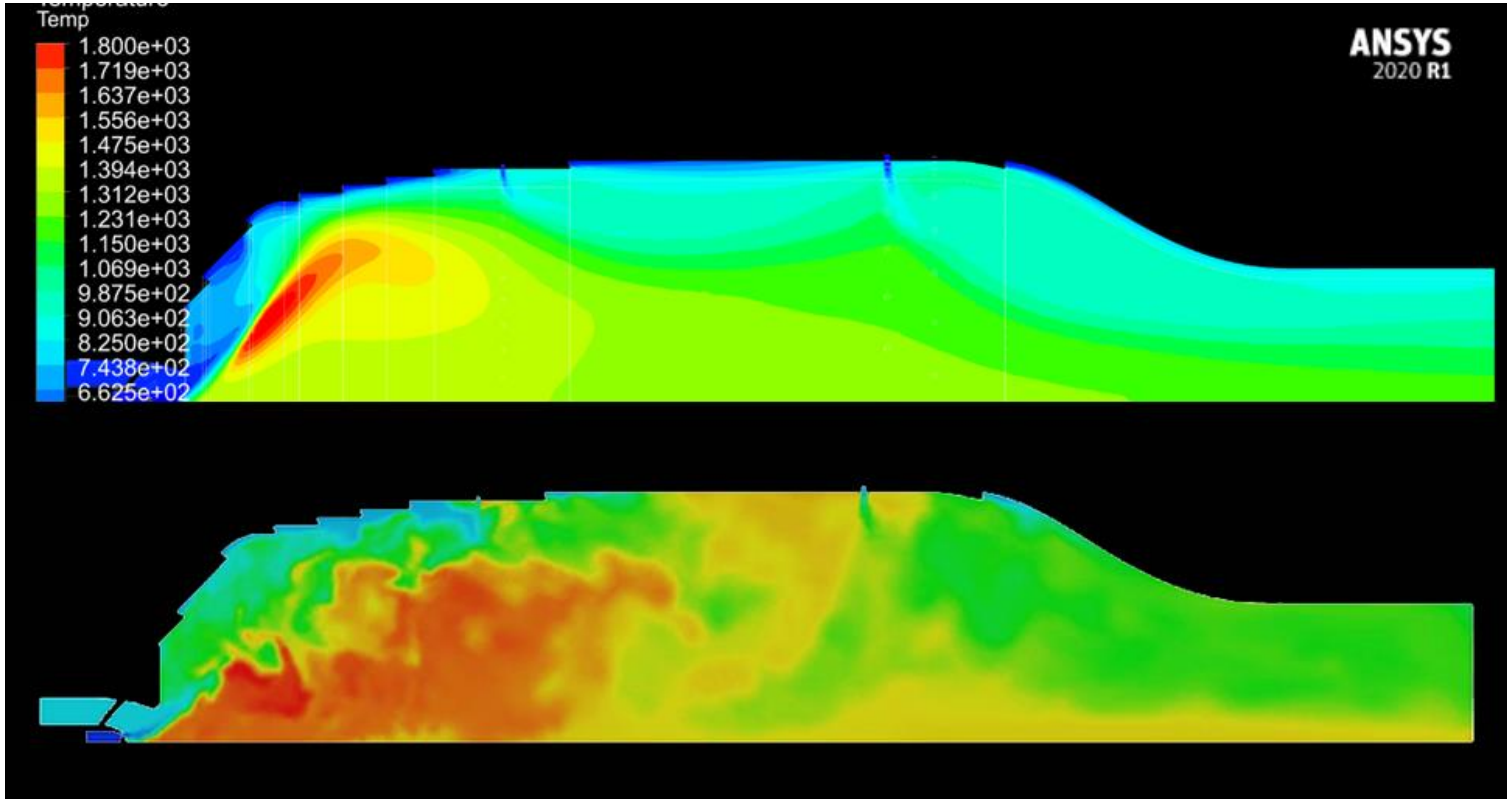
ANSYS FLUENT

Ideal Gas vs Cubic EOS

Combustor Design

The design process to this point has employed pseudo steady-state analysis using RANS simulations and realizable k-ε turbulence modeling. In an effort to improve the prediction of combustor hot spots, unsteady analysis was performed using the Delayed Detached Eddy Simulation (DDES) model

RANS Simulation



DDES Simulation

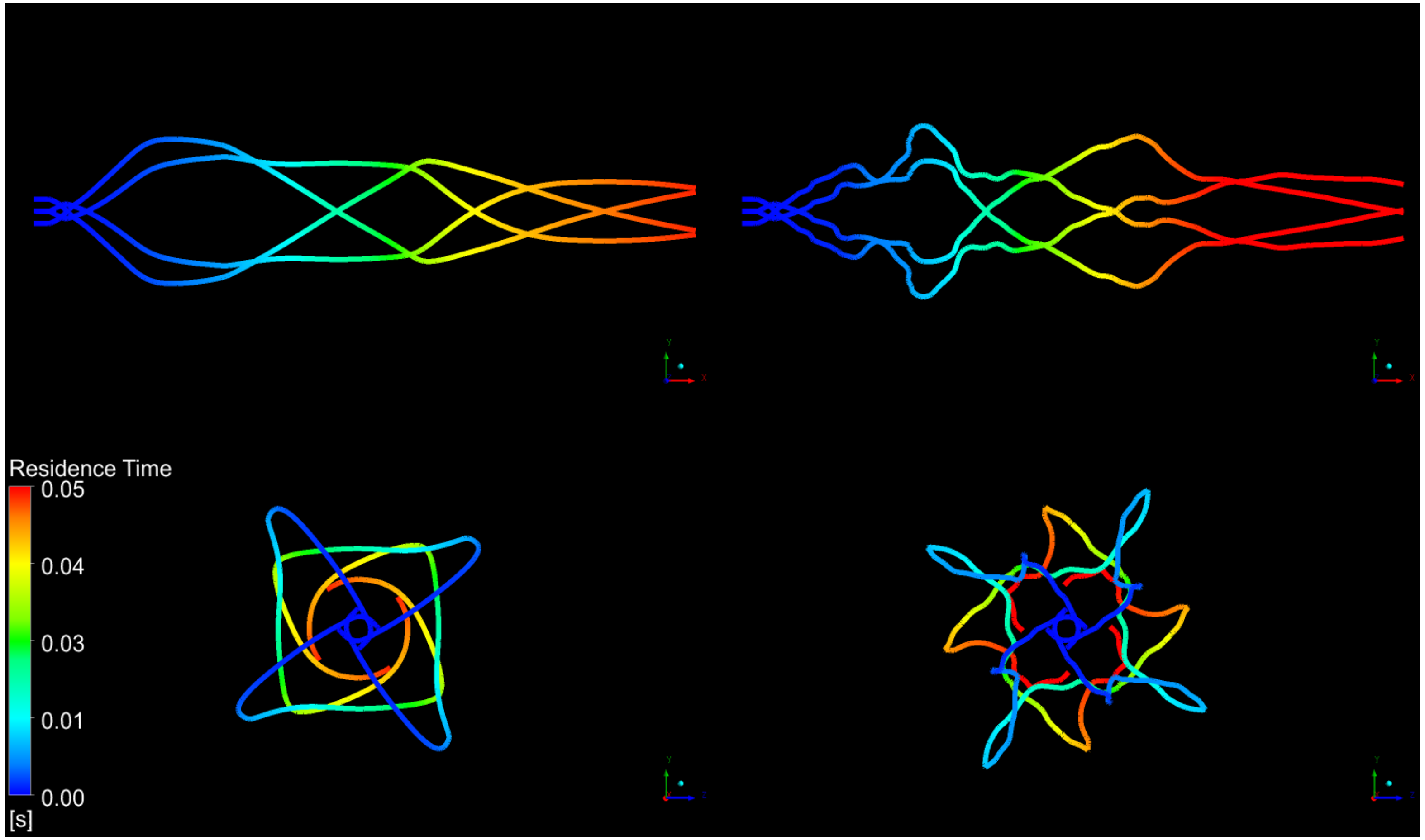
Flowfield Comparison

Combustor Design

The design process to this point has employed pseudo steady-state analysis using RANS simulations and realizable k-ε turbulence modeling. In an effort to improve the prediction of combustor hot spots, unsteady analysis was performed using the Delayed Detached Eddy Simulation (DDES) model

RANS Simulation

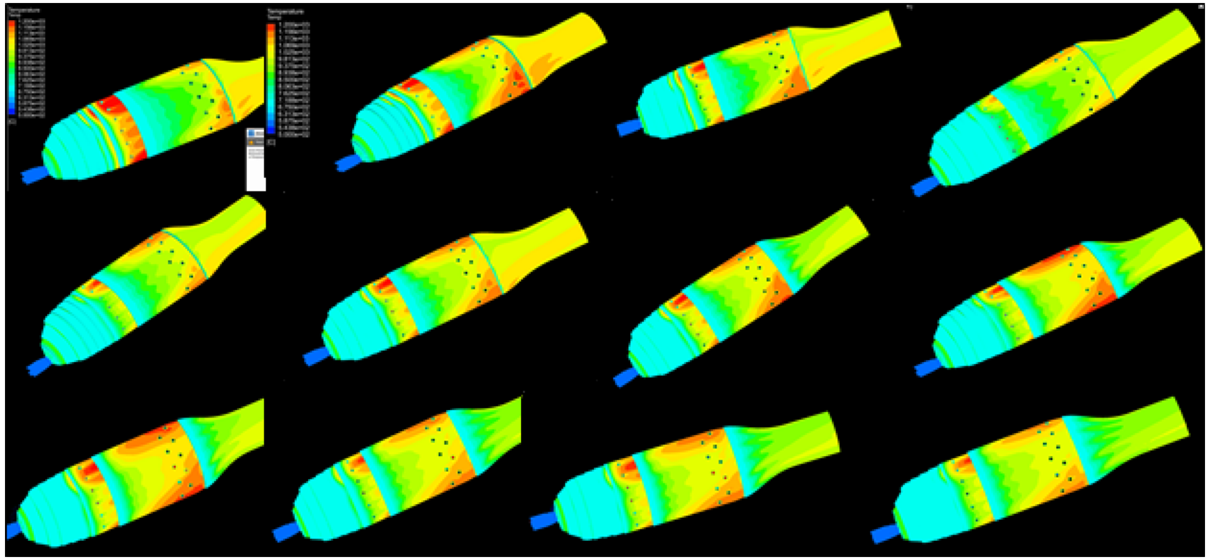
DDES Simulation

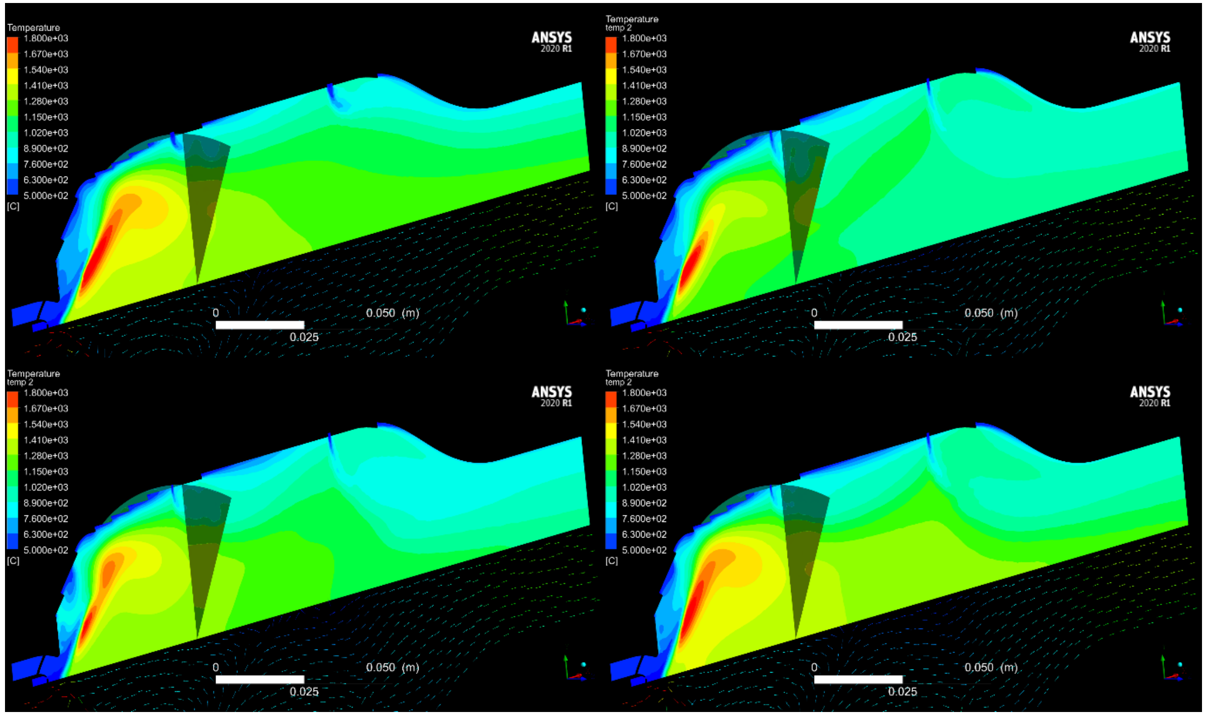


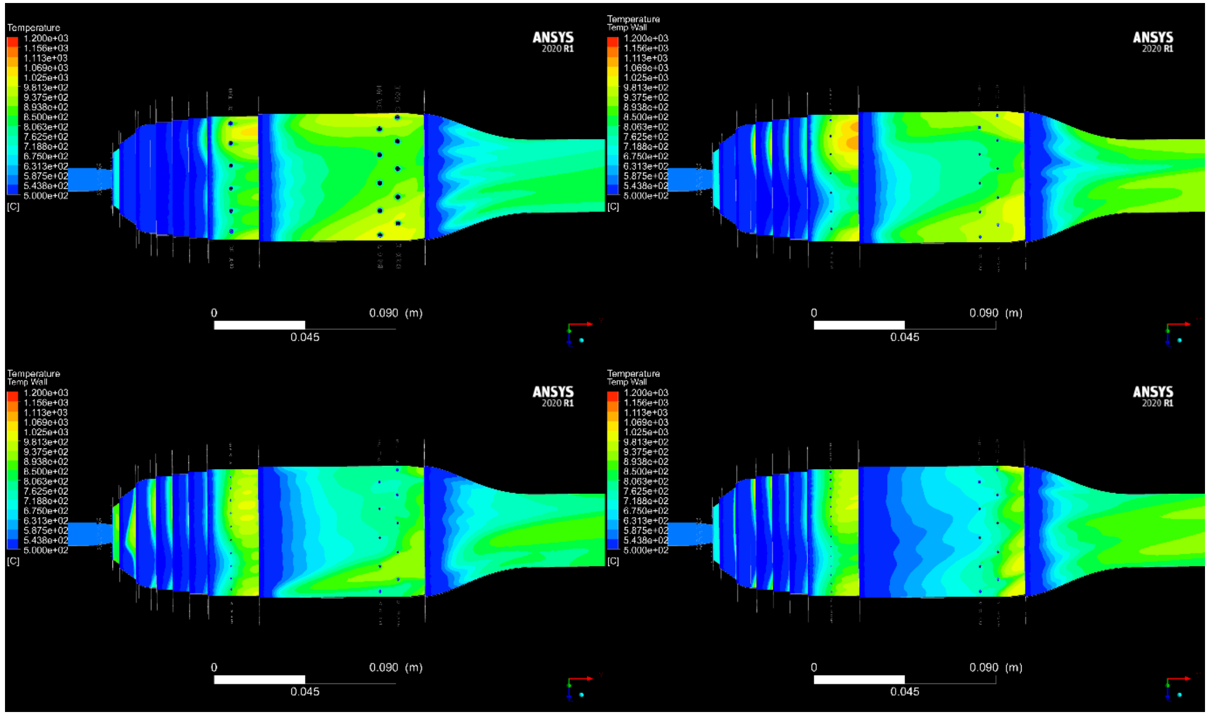
Streamlines Comparison

Combustor Design

- Recent work includes dozens of iterations to film cooling geometry to minimize hot spots

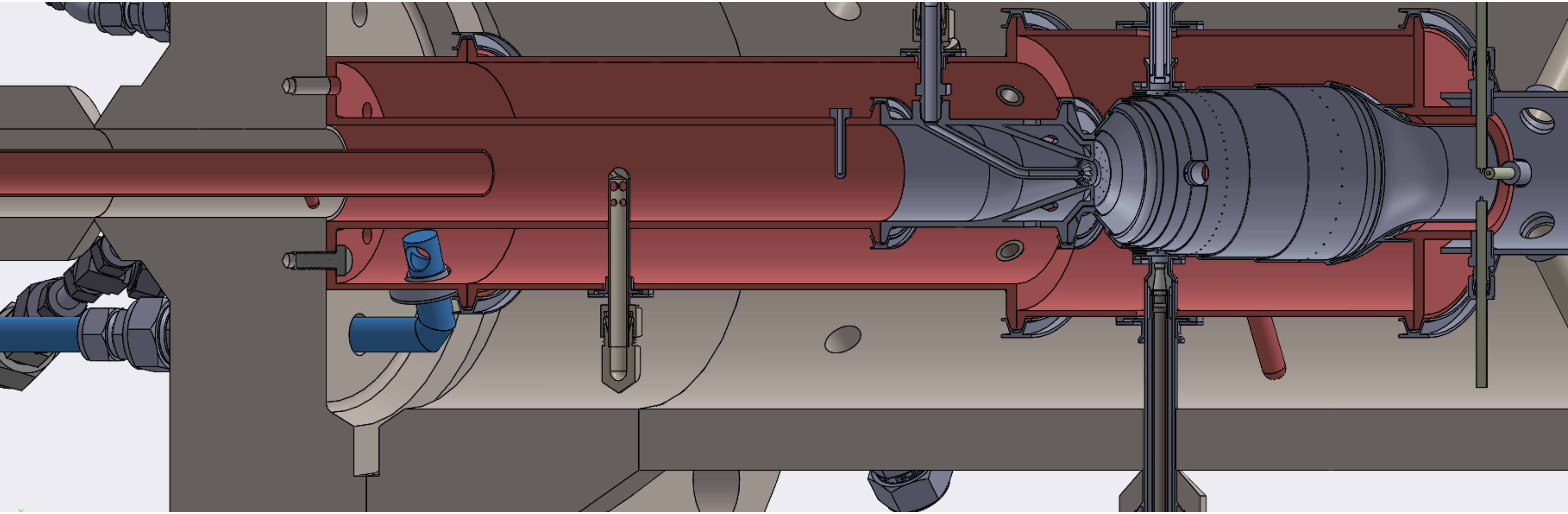






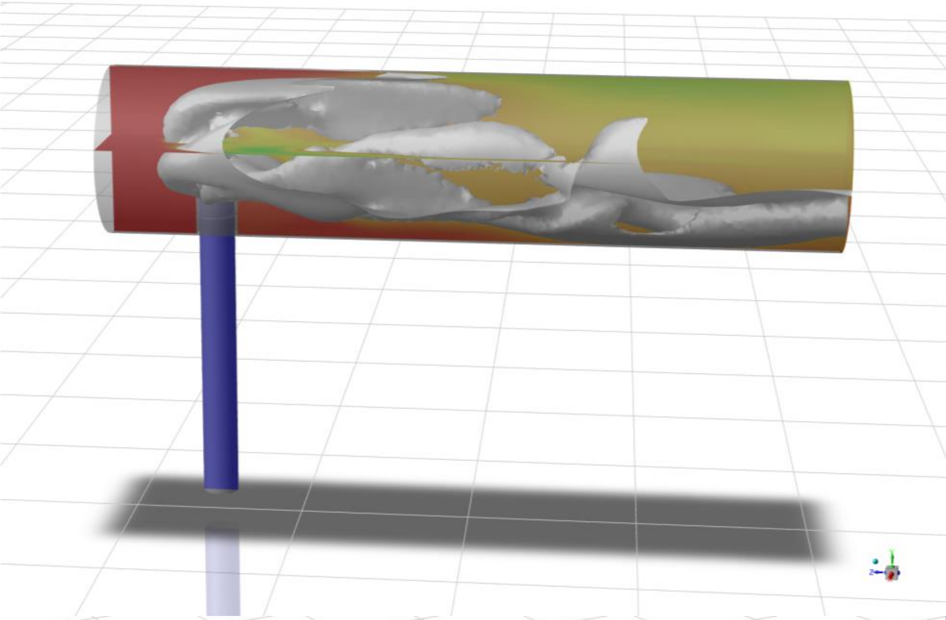
Combustor Cooling

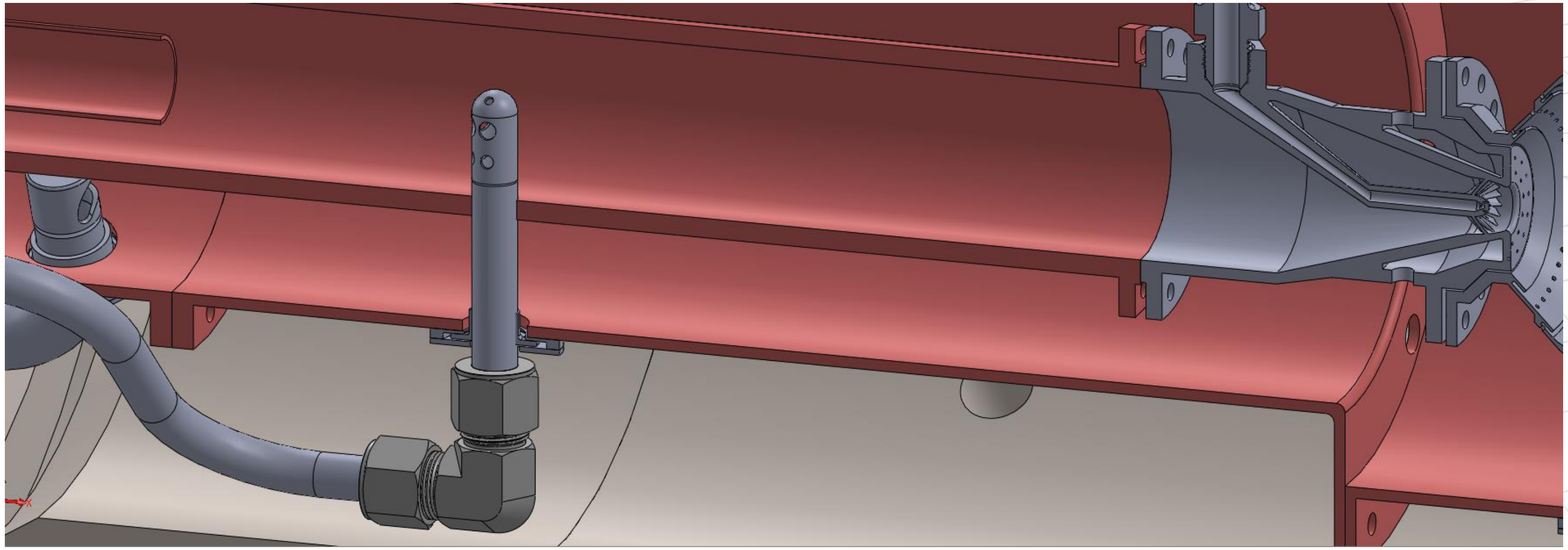
CO_2 bypass gas enters annulus from a dedicated line (highlighted in blue) with flow control, allowing remote manipulation of combustor liner temperatures

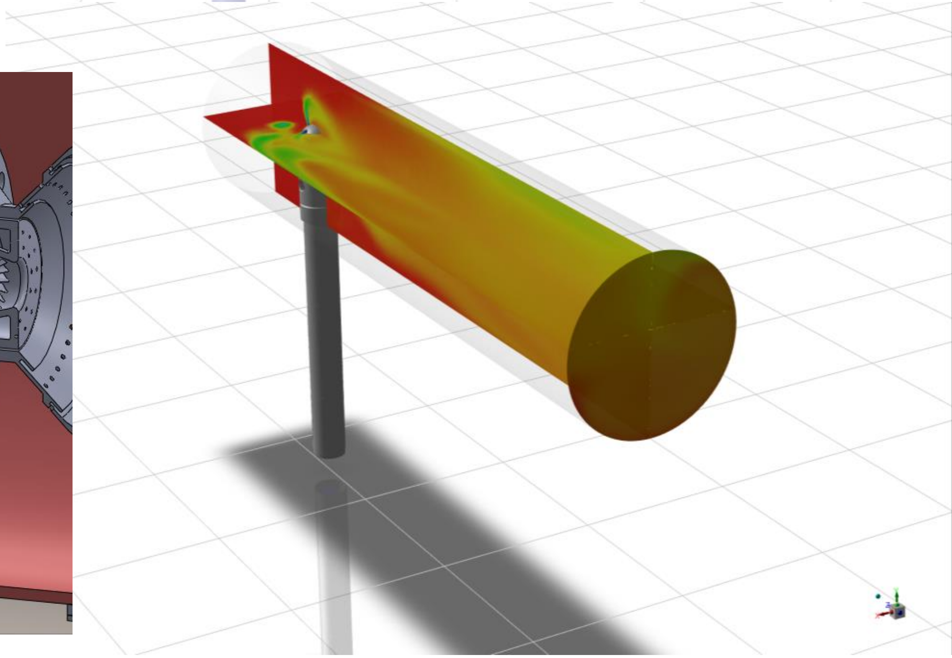


Oxygen System

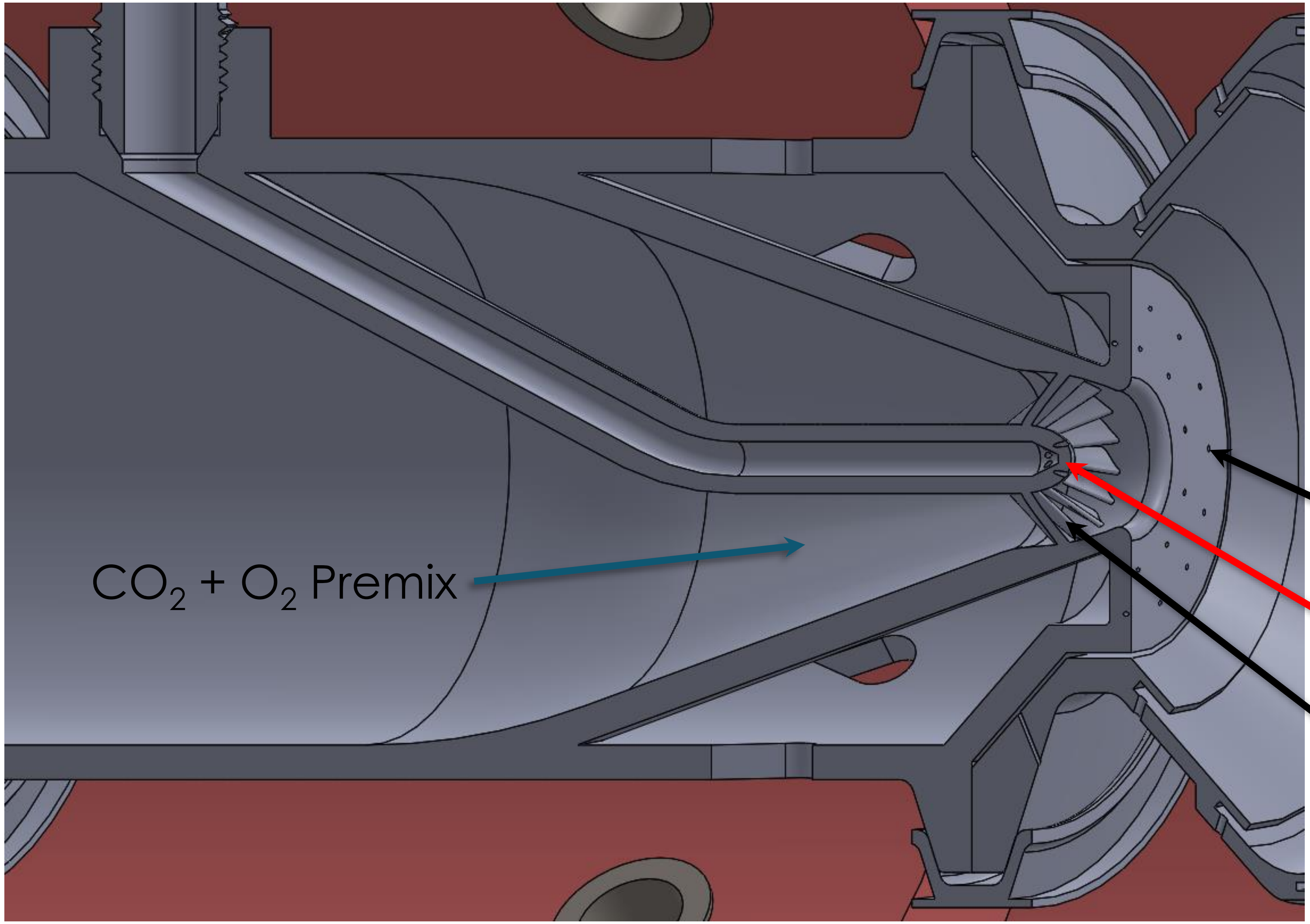
- Guidance from personnel at NASA Stennis and White Sands, review from project partner Air Liquide
- LOX tank with cryogenic pump and ambient vaporizer
- Oxygen injection upstream of fuel injector







Fuel Injector



- Additively manufactured Haynes 282
- 32° swirl angle of inlet vanes chosen after literature review and CFD simulations

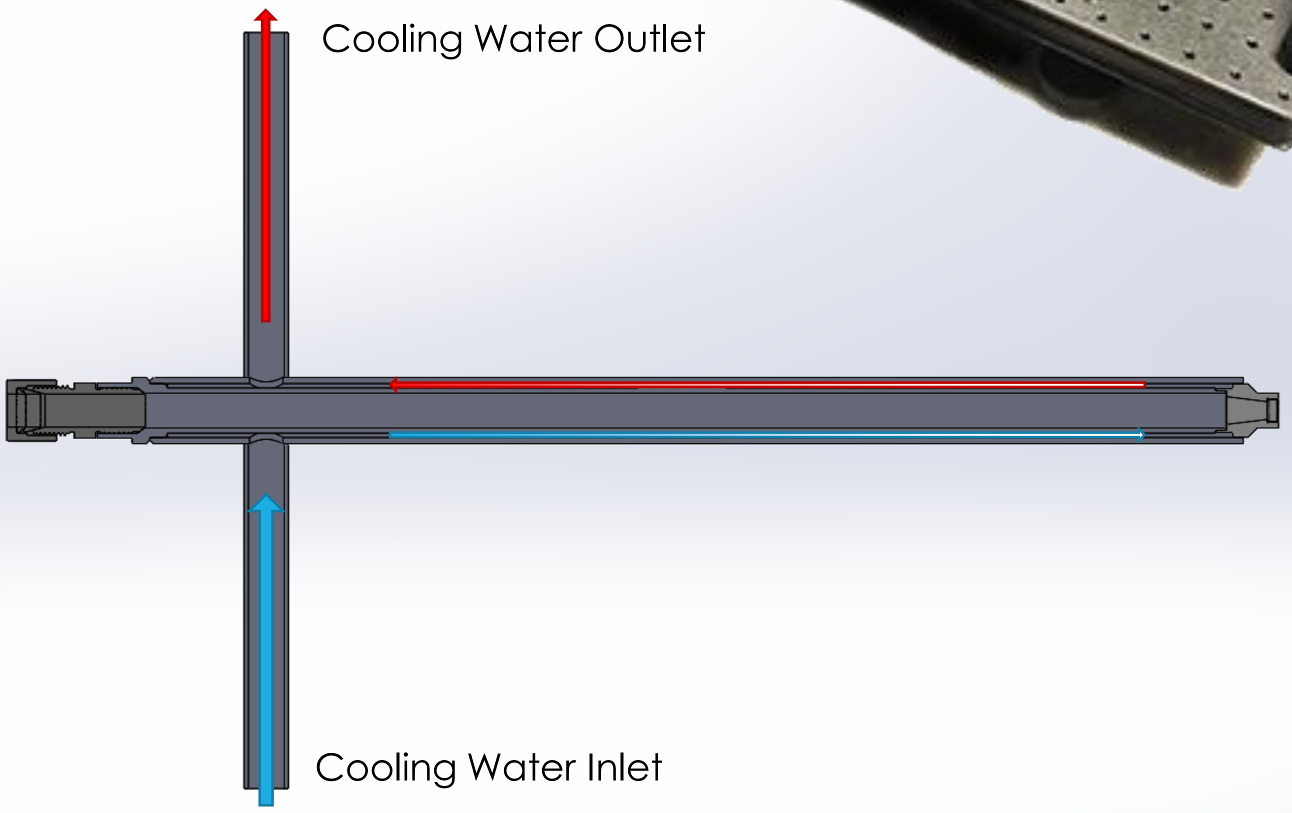
CO_2 Face Cooling

Methane Fuel Injection Point

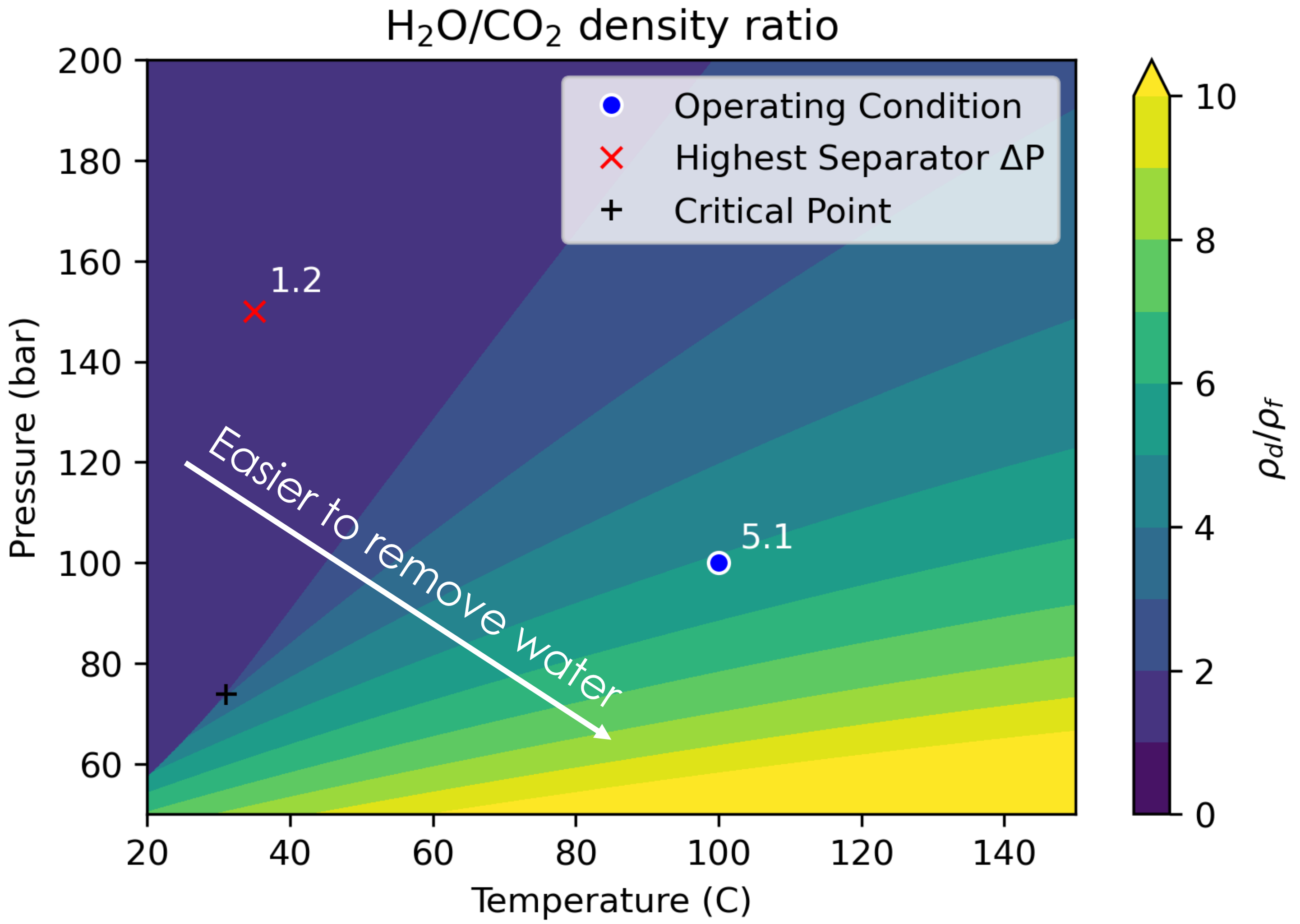
Swirling Vanes

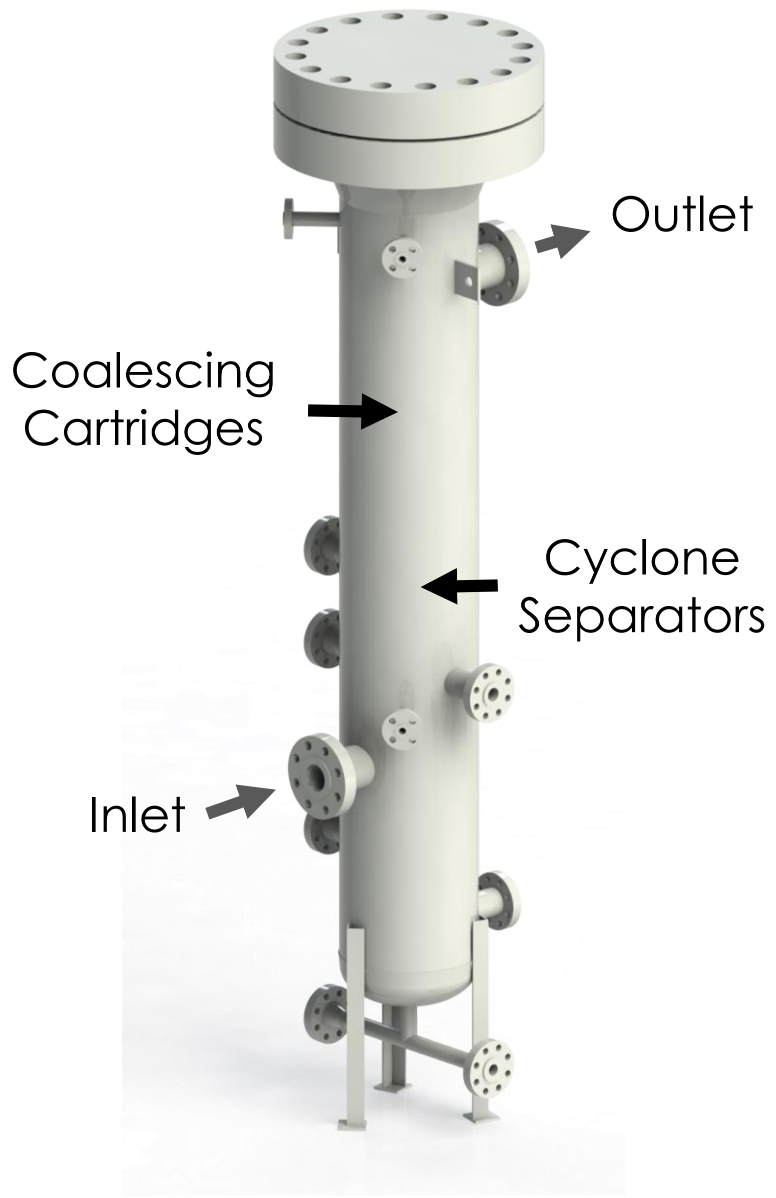
Laser Ignition System

- Class 4 Quantel Qsmart Twins
  - 2x380mJ @ 532nm, 10Hz
- Water cooled probe allows access to the combustor and keeps focal lens temperature low
- Laser system has been tested on a bench scale combustor rig



Water Separator





Project Status

- Laser Ignition system commissioned
- Water Separator fabricated and installed
- Combustor and Fuel Injector design complete and sent out for quote
- CO_2 piping design complete and sent out for quote
- Oxygen Supply system nearing final review

- CO_2 Loop and Combustor assembly expected to be complete in January 2022
- Commissioning to begin in February 2022
- Combustor Testing scheduled through December 2022

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Georgia Tech

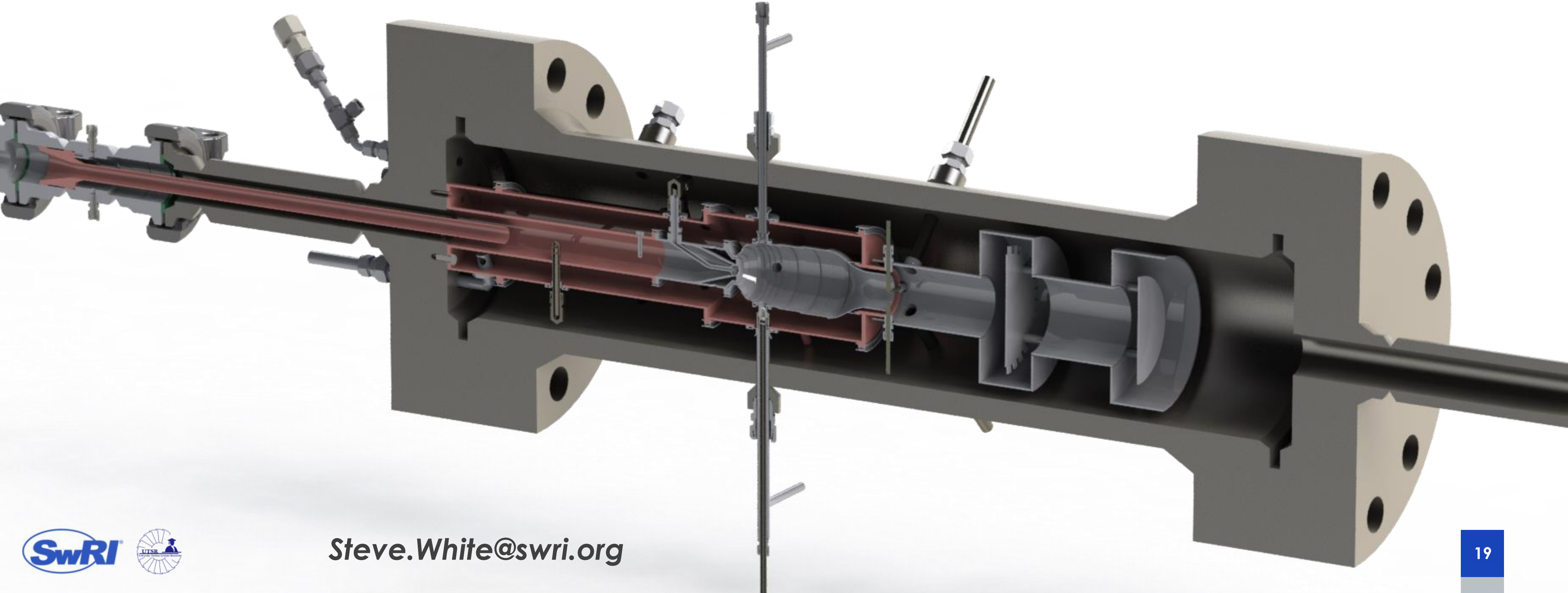
Air Liquide

Spectral Energies

UTSR
University Turbine Systems Research

NETL
NATIONAL ENERGY TECHNOLOGY LABORATORY

Questions



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