Direct Fired Oxy-Fuel Combustor for sCO2 Power Cycles

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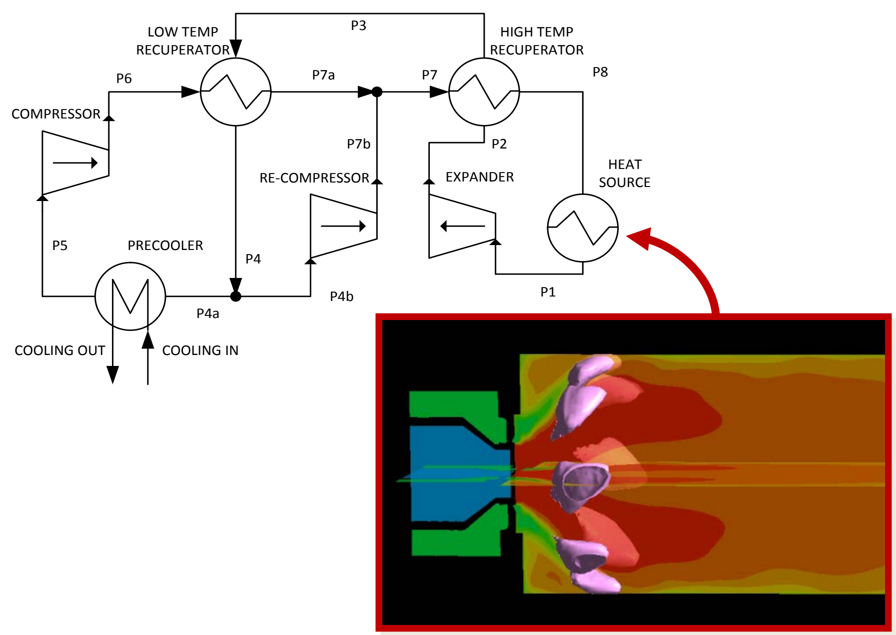


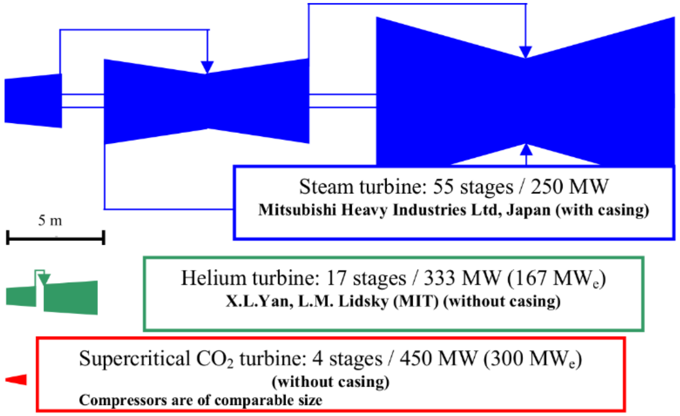
Work supported by US DOE under DE-FE002401

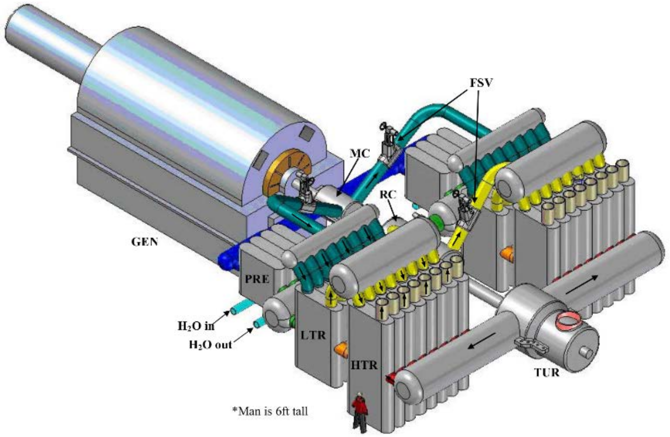
Outline

- Background
- Project Objectives
- Combustor Design
- Test Loop Design
- Future Work

Why sCO2 Power Cycles?

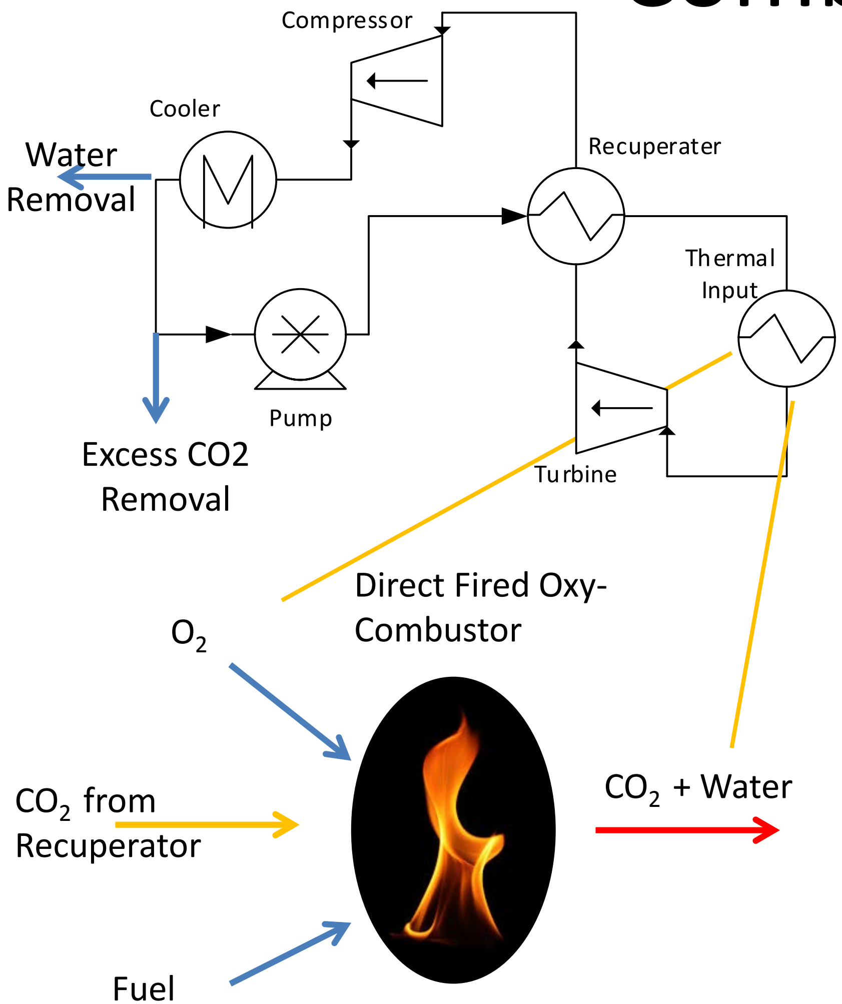
- Offer +3 to +5 percentage points over supercritical steam for indirect fossil applications
- High fluid densities lead to compact turbomachinery
- Efficient cycles require significant recuperation





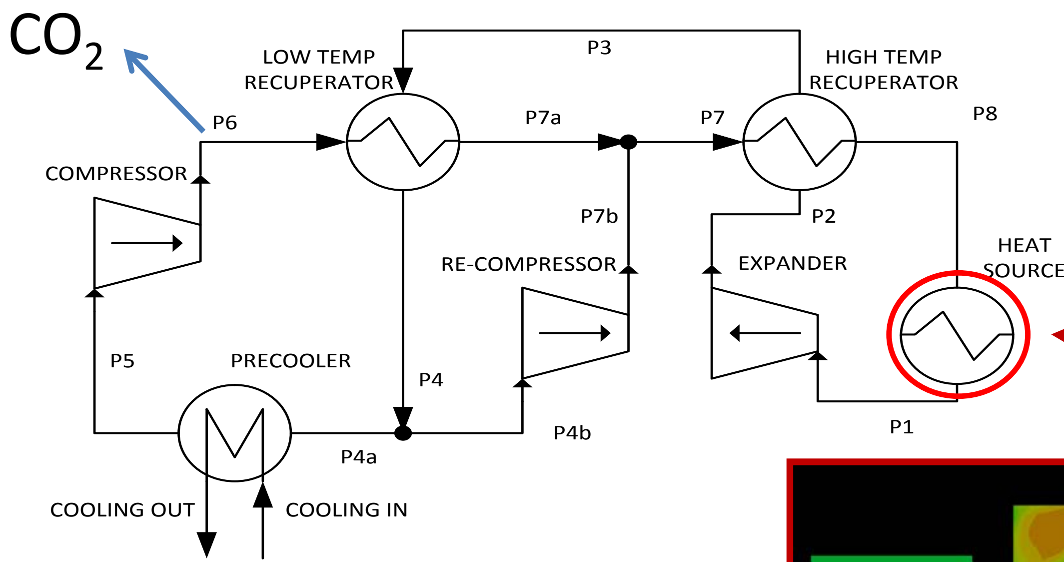
Third Generation 300 MWe S-CO2 Layout from Gibba, Hejzlar, and Driscoll, MIT-GFR-037, 2006

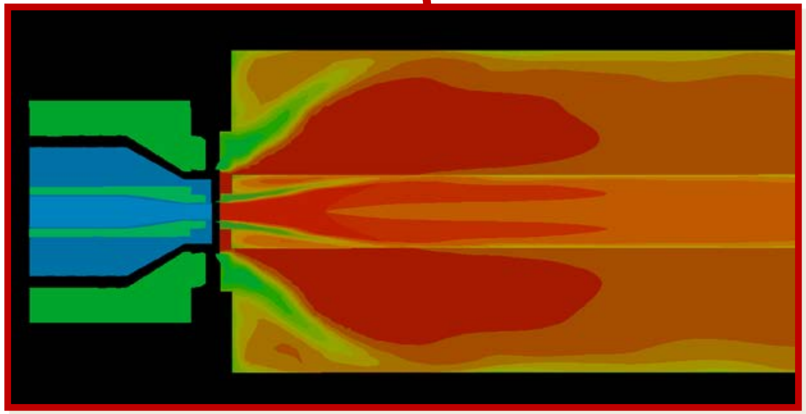
What is Direct Fired Oxy-Fuel Combustion?



- Oxygen + fuel + CO2
- Designer can choose the O2/CO2 ratio, unlike typical gas turbine combustors
- ASU to produce oxygen

Why Direct Fired Oxy-Fuel Combustion?



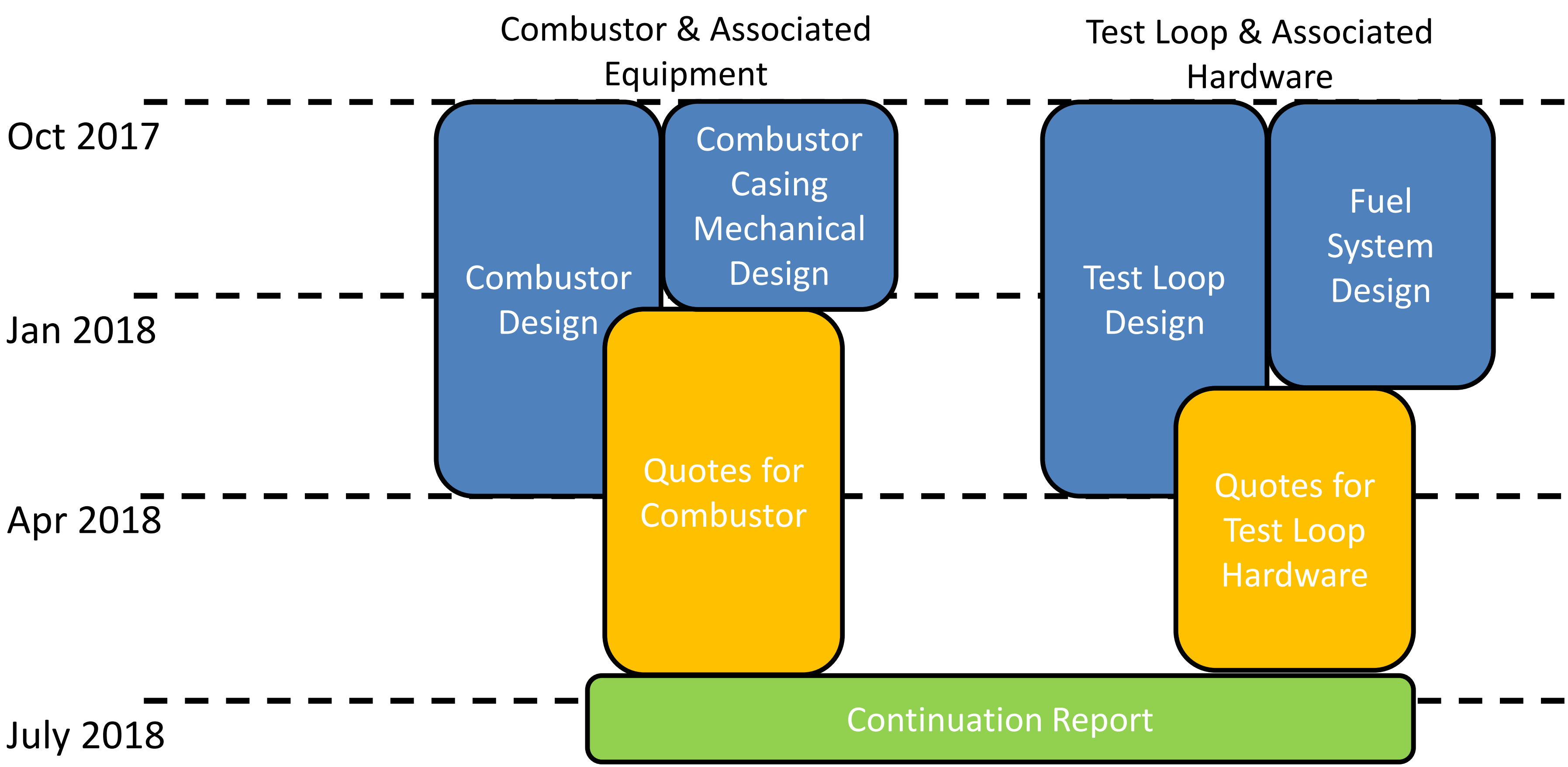


- Capture 99% of carbon dioxide
- Higher turbine inlet temperatures possible
- Limiting component is the recuperator, not the heater

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
  - Optical access for advanced diagnostics

Schedule



Combustor & Associated Equipment
Test Loop & Associated Hardware
Oct 2017
Jan 2018
Apr 2018
July 2018
Combustor Design
Combustor Casing Mechanical Design
Quotes for Combustor
Test Loop Design
Fuel System Design
Quotes for Test Loop Hardware
Continuation Report

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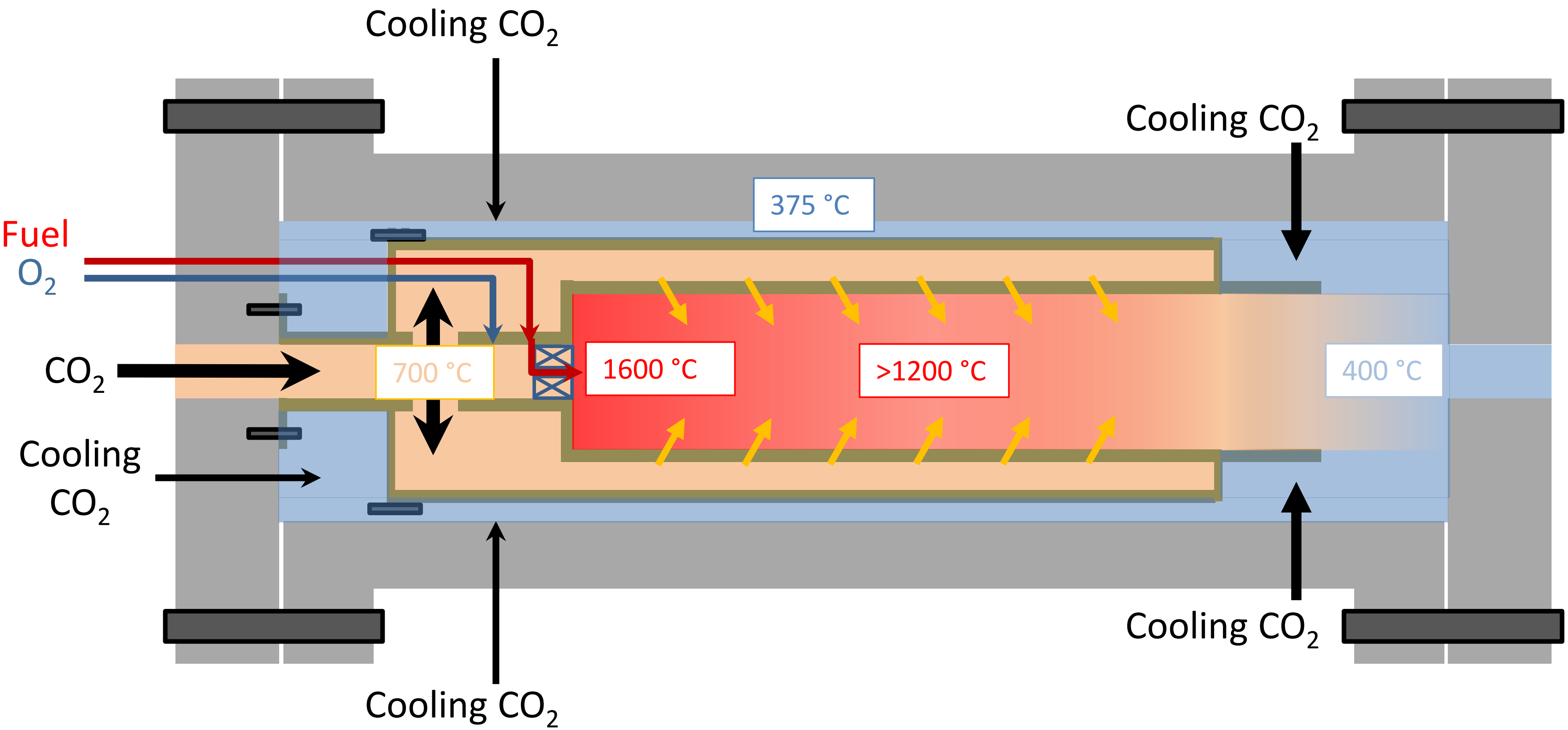
Combustor Design

- Mechanical casing
- Fluid flow path
- Fuel injector
- Oxygen injection
- Combustor liner thermal management
- Optical access
- Instrumentation
- Design for additive manufacturing

Conceptual Combustor Design



Design Pressure: 250 bar
Temperature: 375-700 °C

Computational Modeling

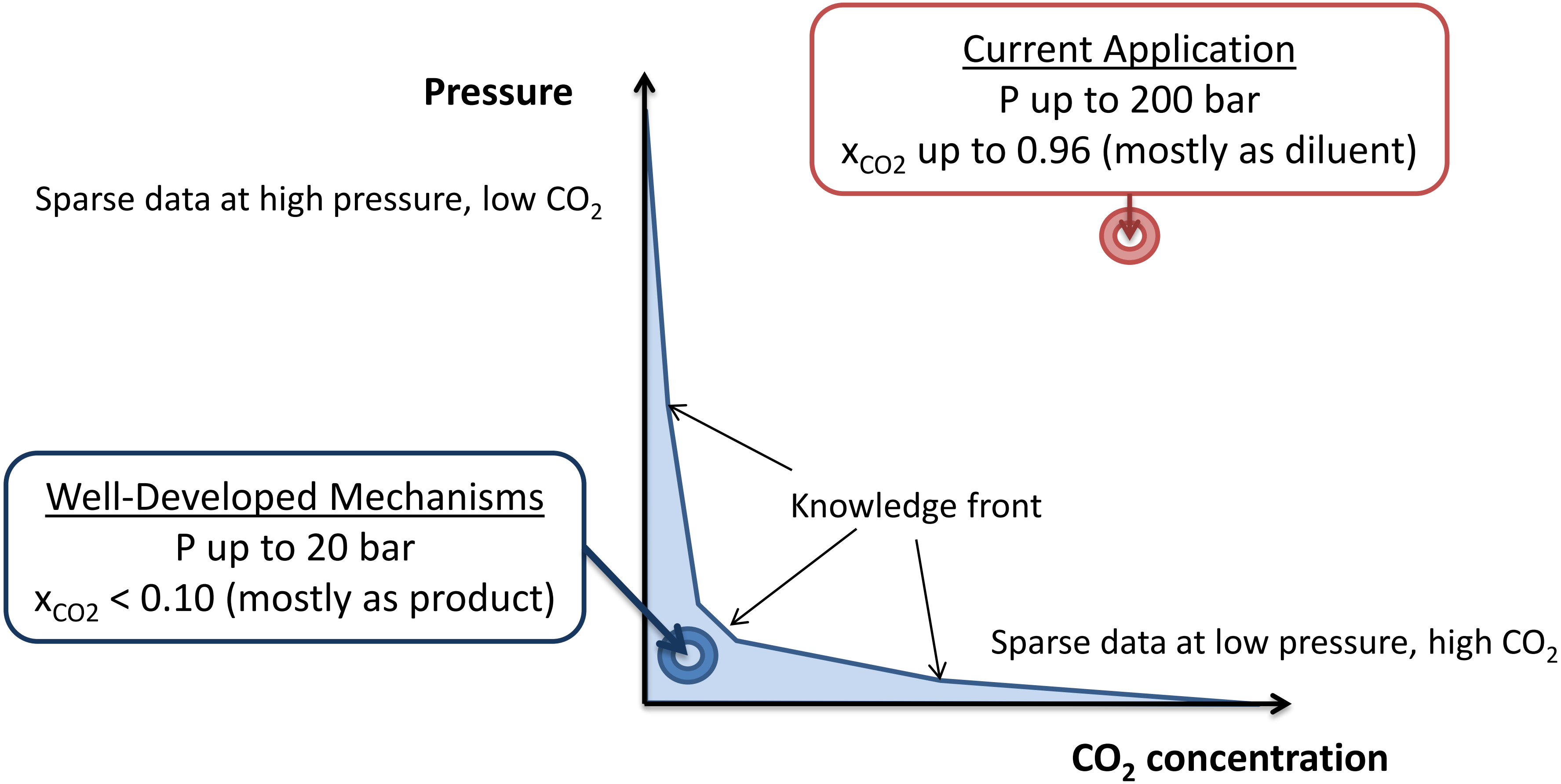
Goals

- Rapid solution times
- Iterate on geometry
- Inform liner thermal model
- Reduce risks in a variety of areas prior to combustor manufacturing

Modeling

- RANS simulations by SwRI
- Relatively course mesh
- Variety of reduced chemical mechanisms
- LES simulations performed by others
- Well over 100 cases run

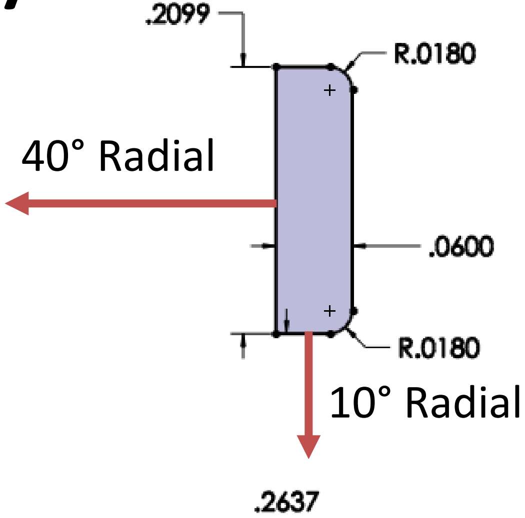
Knowledge Base

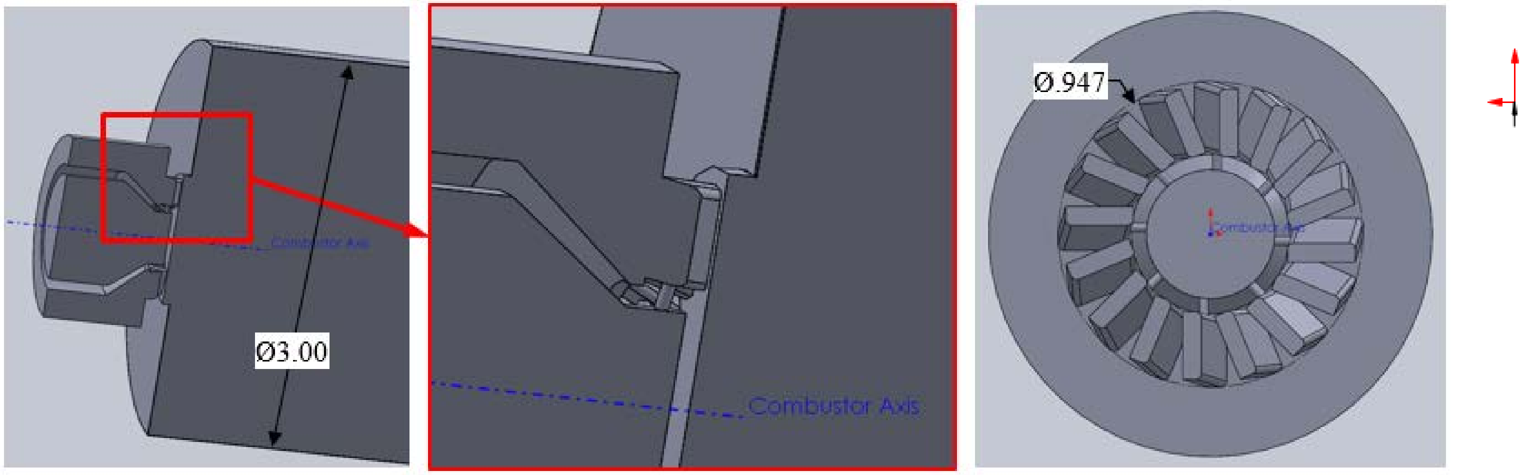


Limited data available – Current UCF and Georgia Tech projects

Injector Geometry

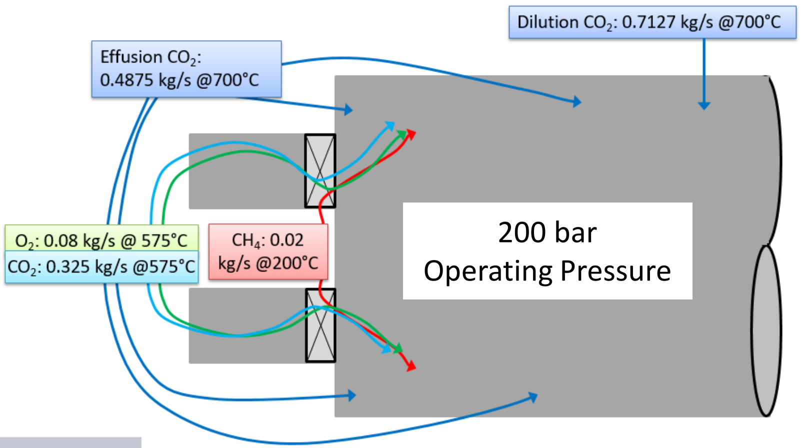
- 16 straight swirler passages, 40° radial swirl w/ 10°down angle
- 8 fuel injectors inject fuel midway through swirler passage

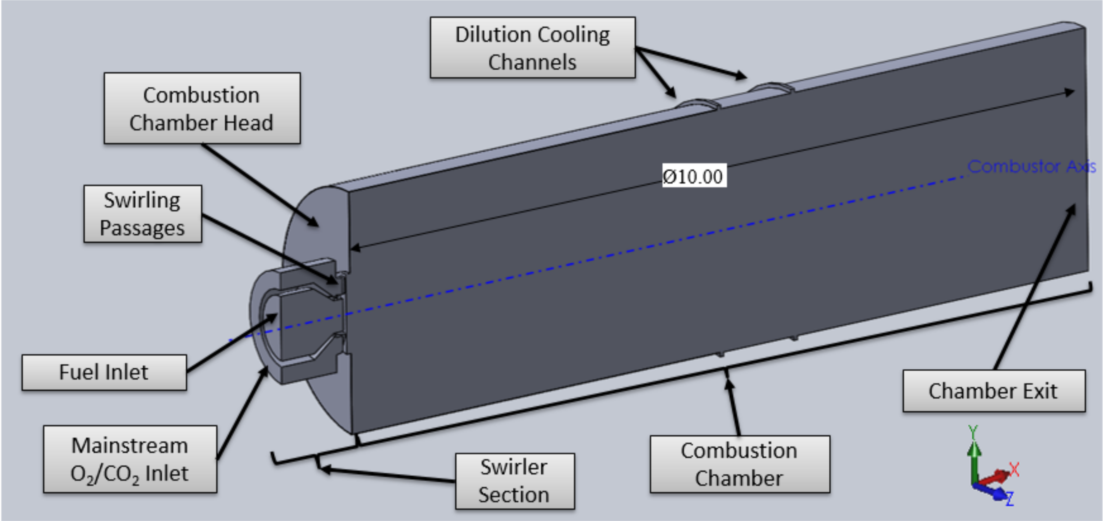




Combustor Geometry

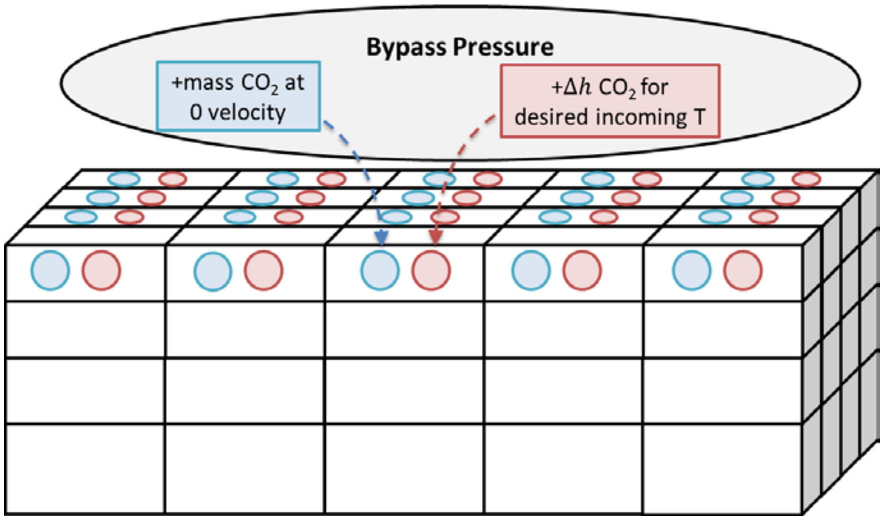
- Effusion cooling on combustor head and liner between head and dilution holes
- 0.05” wide dilution cooling slots, 1” apart

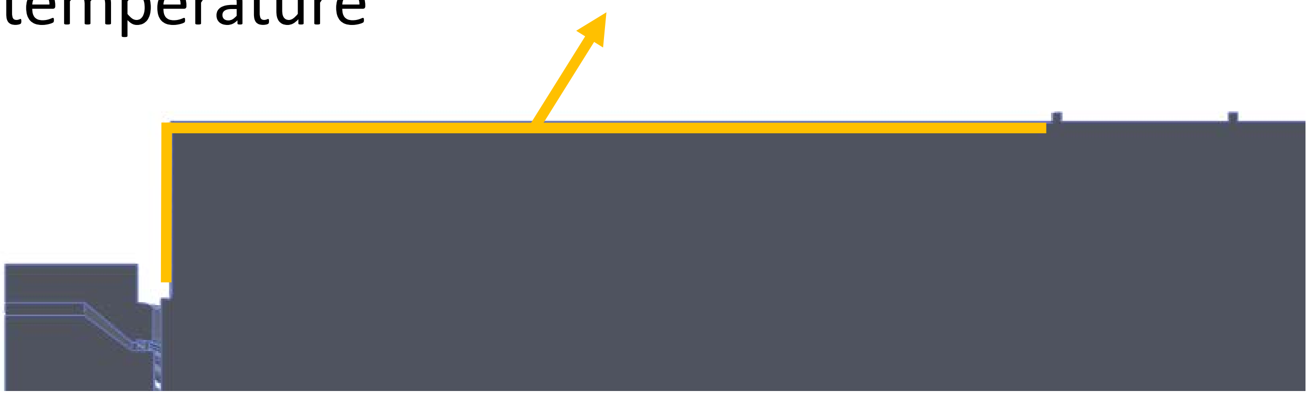




Effusion Type Boundary Condition

- Effusion boundary condition created by mass source in first near wall element
- Energy source also used to make fluid injection temperature



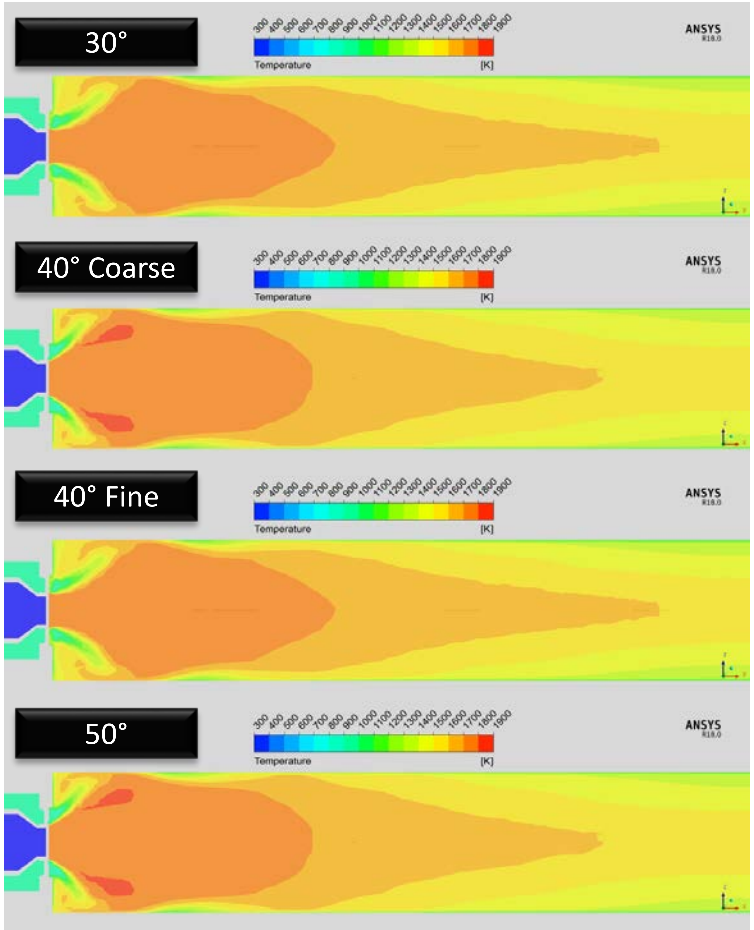


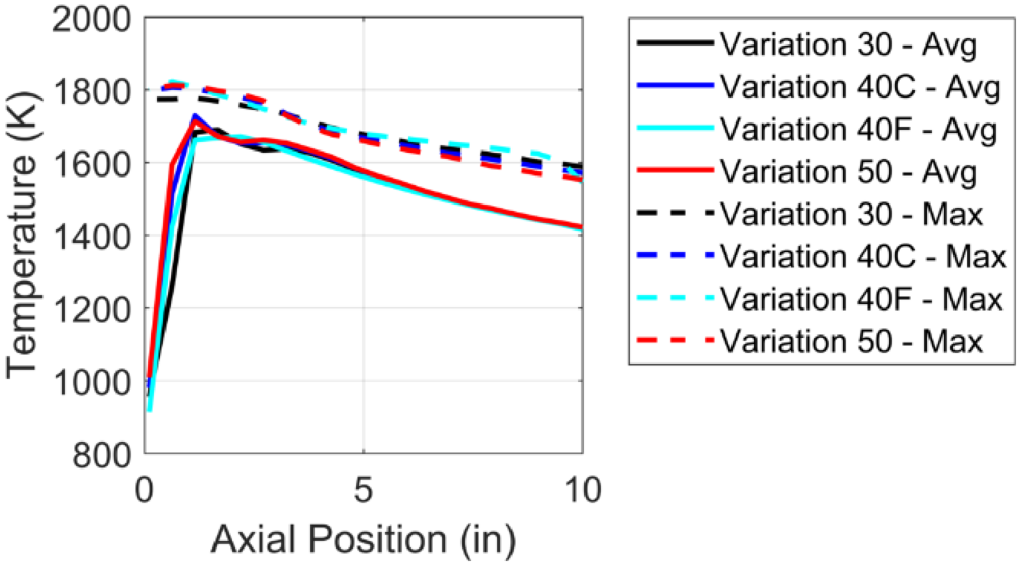
Design and Off-design CFD Boundary Conditions

- Design point simulations
- Off-Design: Unique problem of sCO2 oxy-fuel combustion is the cold startup case
  - Roughly order magnitude change in density

	Design Point	Cold Start	Fast Start Ramp
CO_2 Mass Flow (kg/s)	1.53	1.02	1.02
Pressure (bar)	200.00	133.33	133.33
CO_2 Inlet Temp (°C)	700	50	150
CO_2 Density (kg/m^3)	104.2	649.4	203.5
O_2 Mass Flow (kg/s)	0.0806	0.0806	0.1360
CH_4 Mass Flow (kg/s)	0.0200	0.0200	0.0338

Temperature Predictions





CO Concentrations

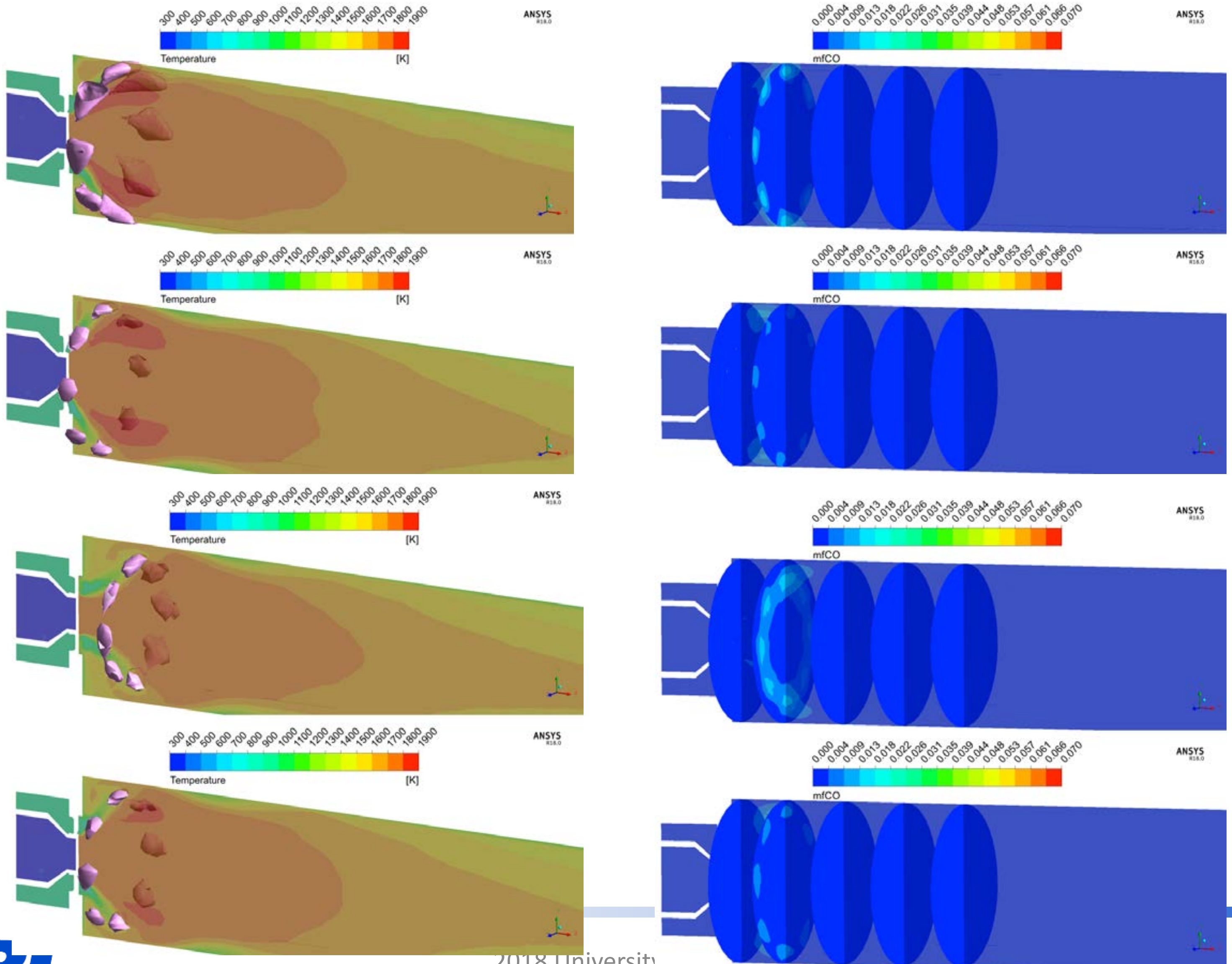
30°

40° Coarse

Light Purple zones are for mole fraction CO=0.008

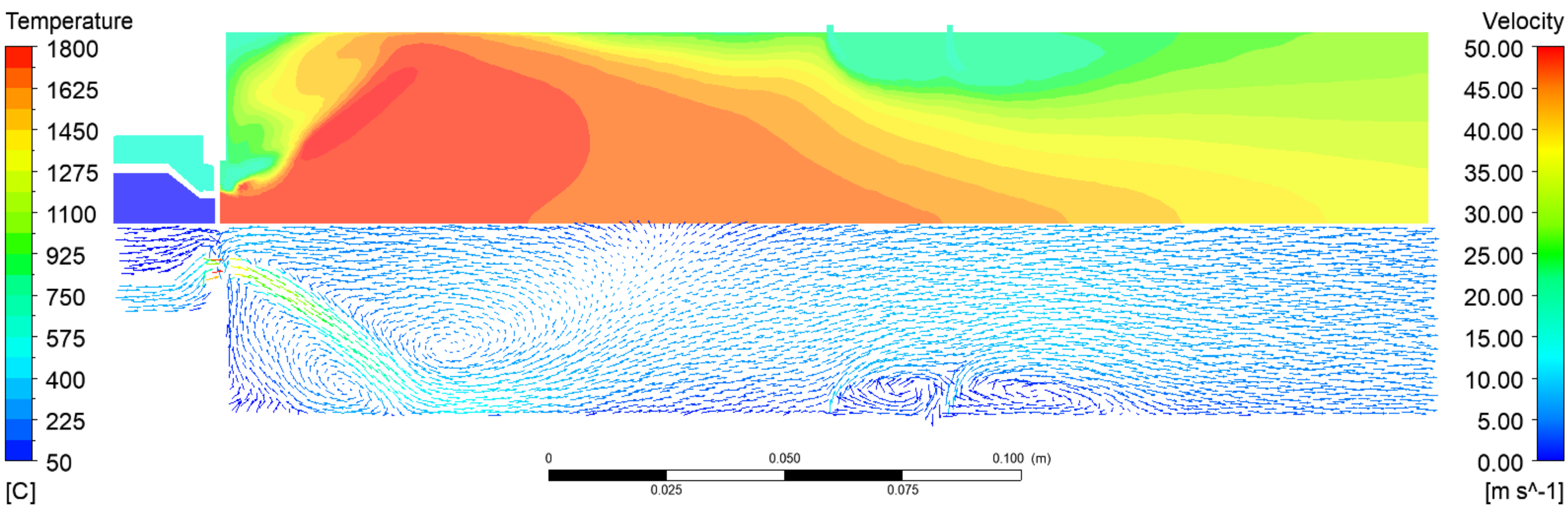
40° Fine

50°

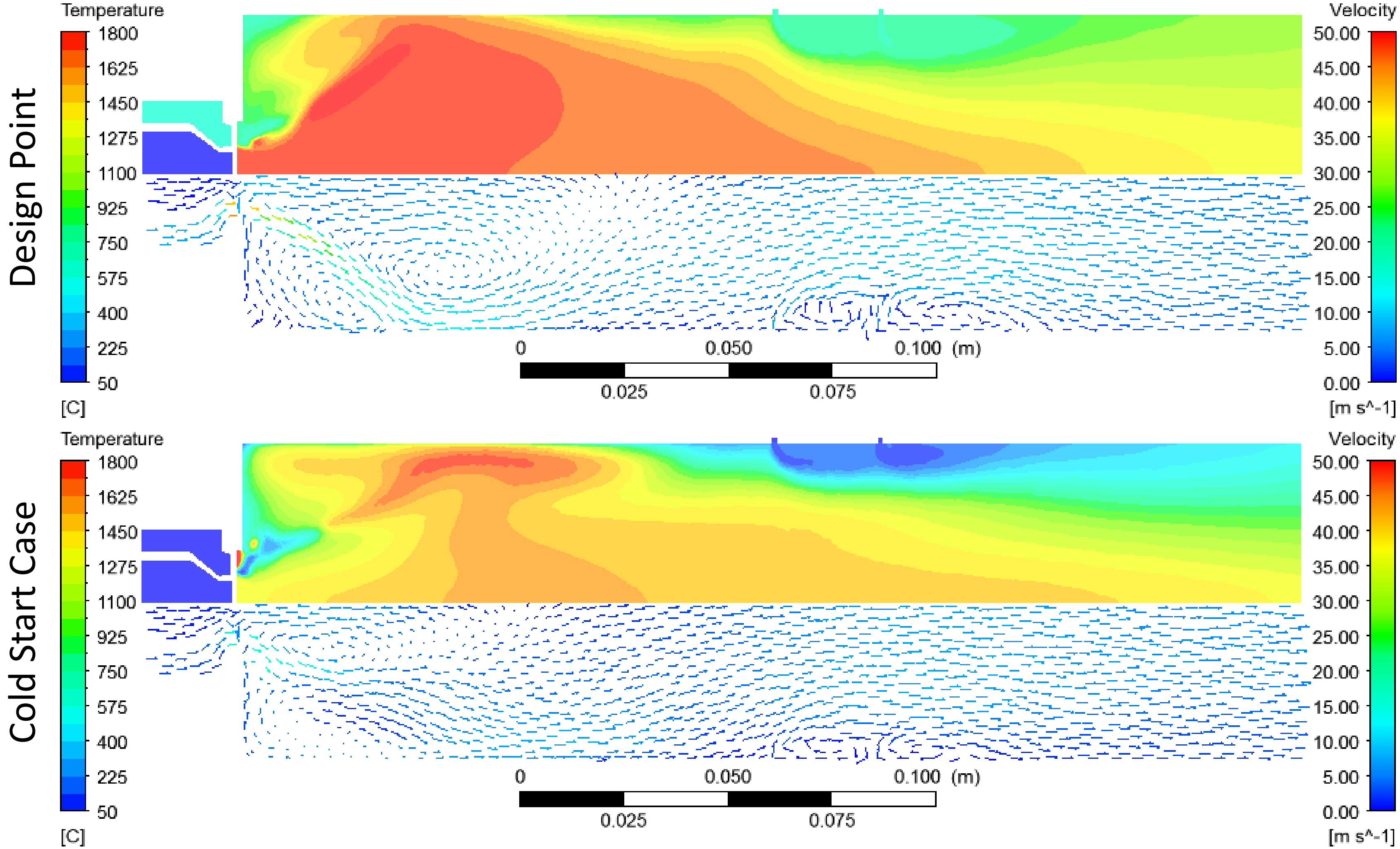


Selected Results with Dilution

- Fairly strong recirculation zone
- High temperature near walls
  - Adiabatic wall boundary conditions
  - Additional cooling

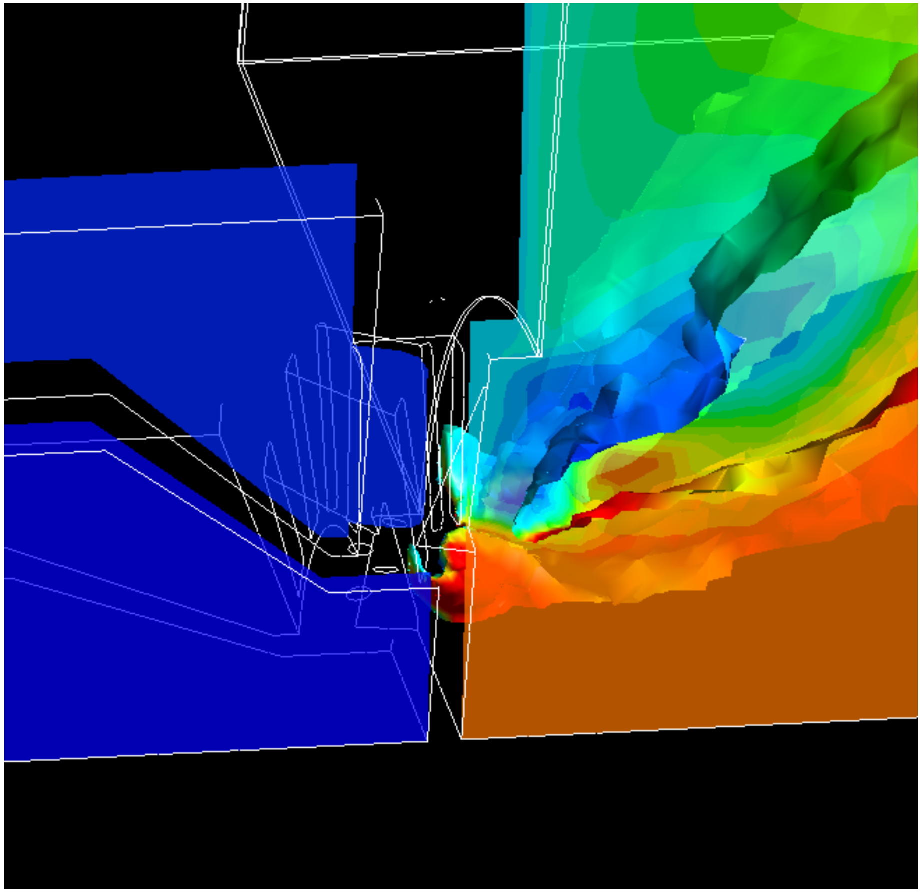


Cold Start Case



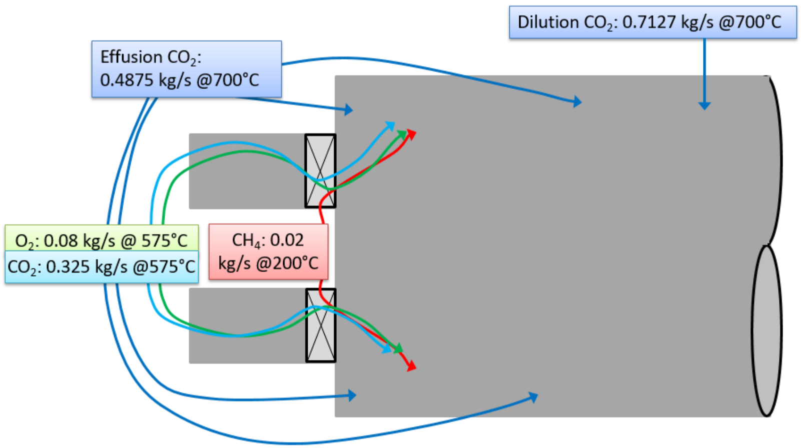
Possible Flame Holding Concerns

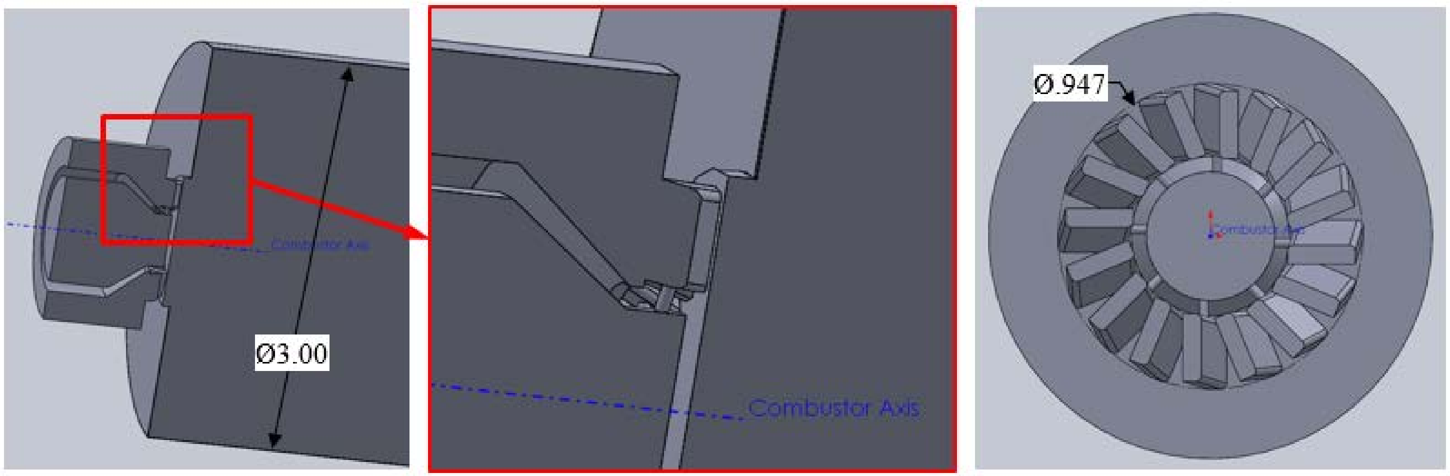
- Fuel injected within swirler passage
- Startup case where velocity is much lower than design point



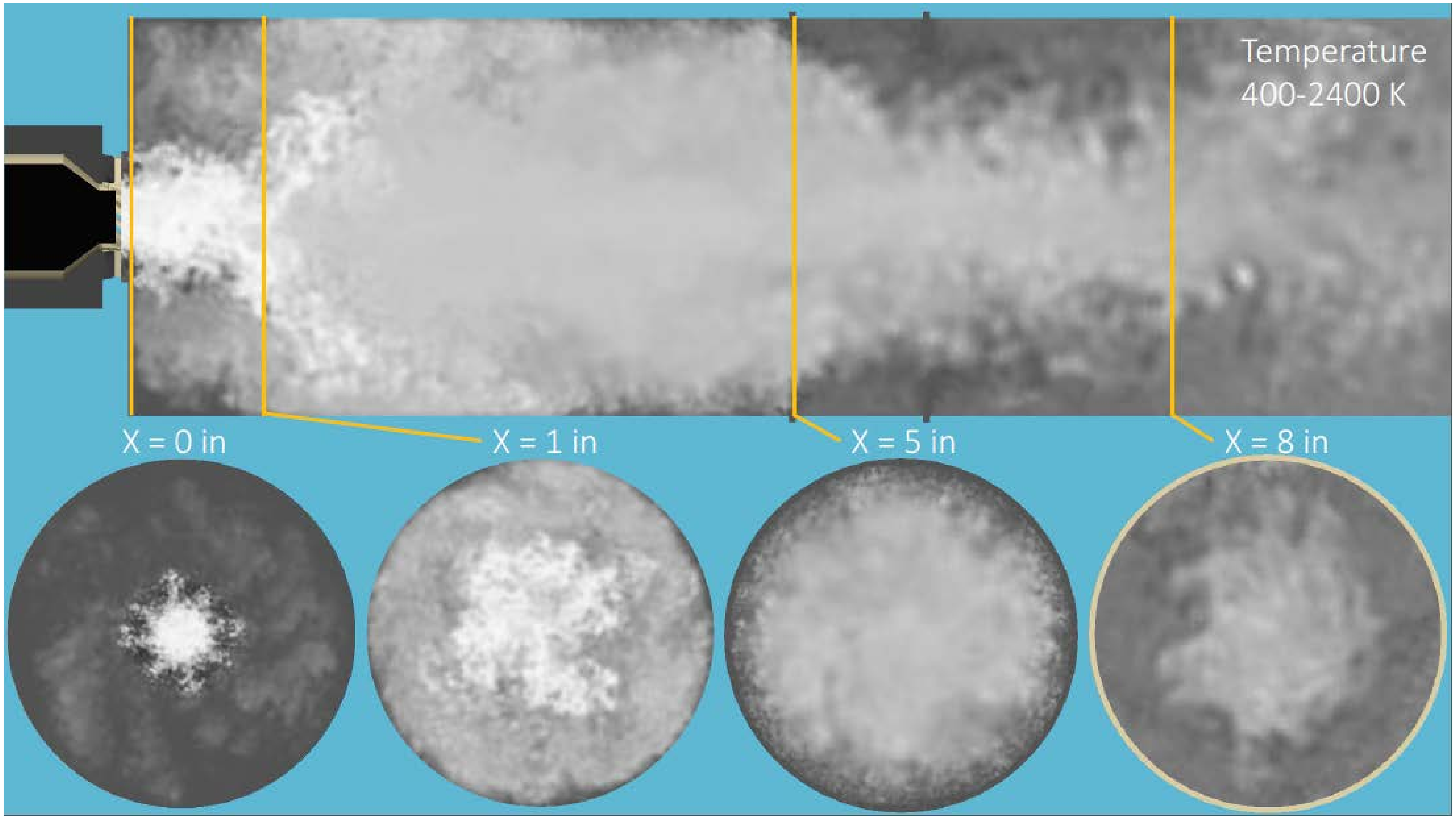
Collaboration on Combustor Modeling with Others

- Work with several small companies interested in modeling direct fired sCO2 combustion
- Universities interested in geometry



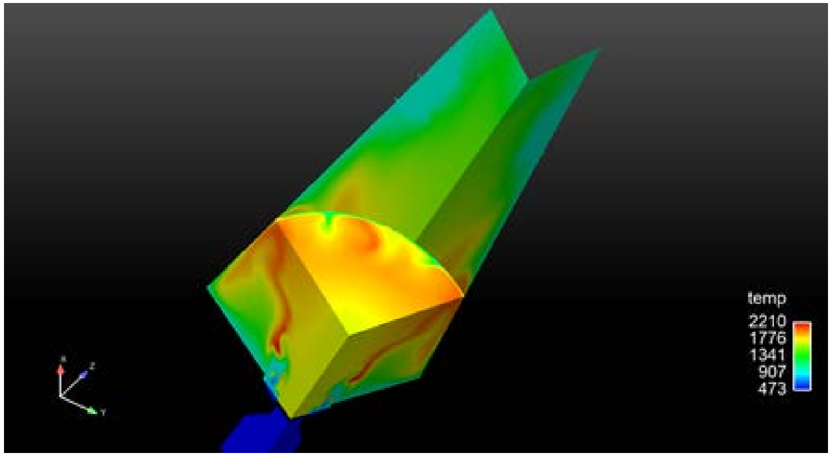


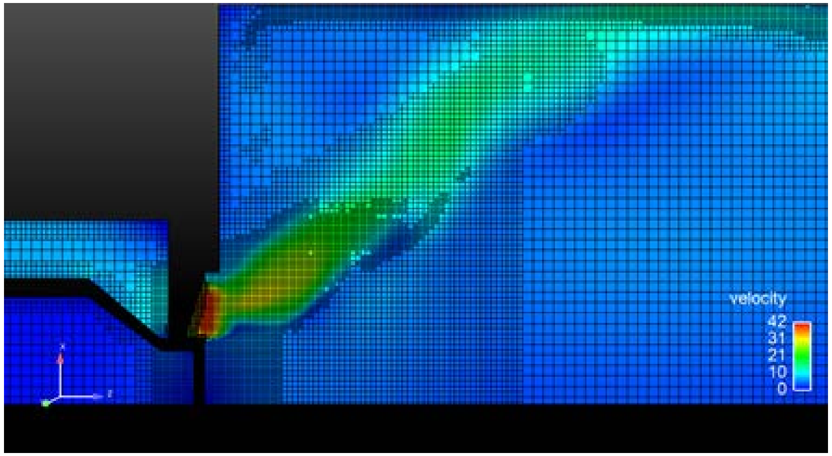
Cascade Technologies



Shunn, sCO2 Oxy-combustion Working Group, Aug 2018

Convergent Science





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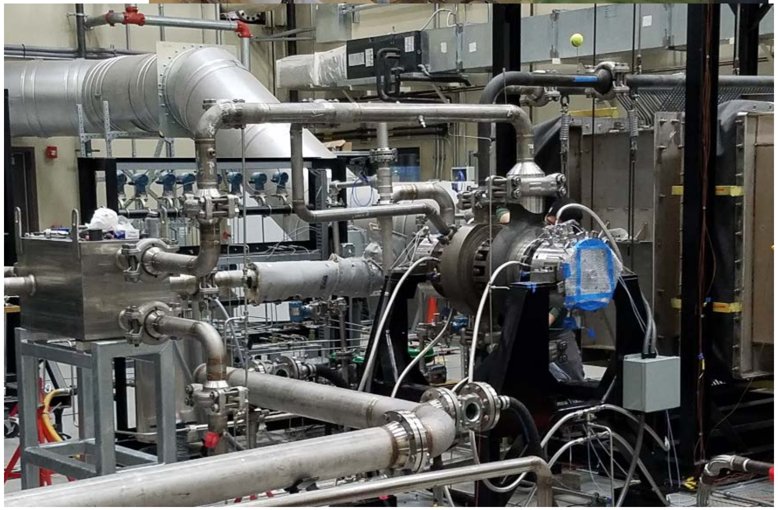
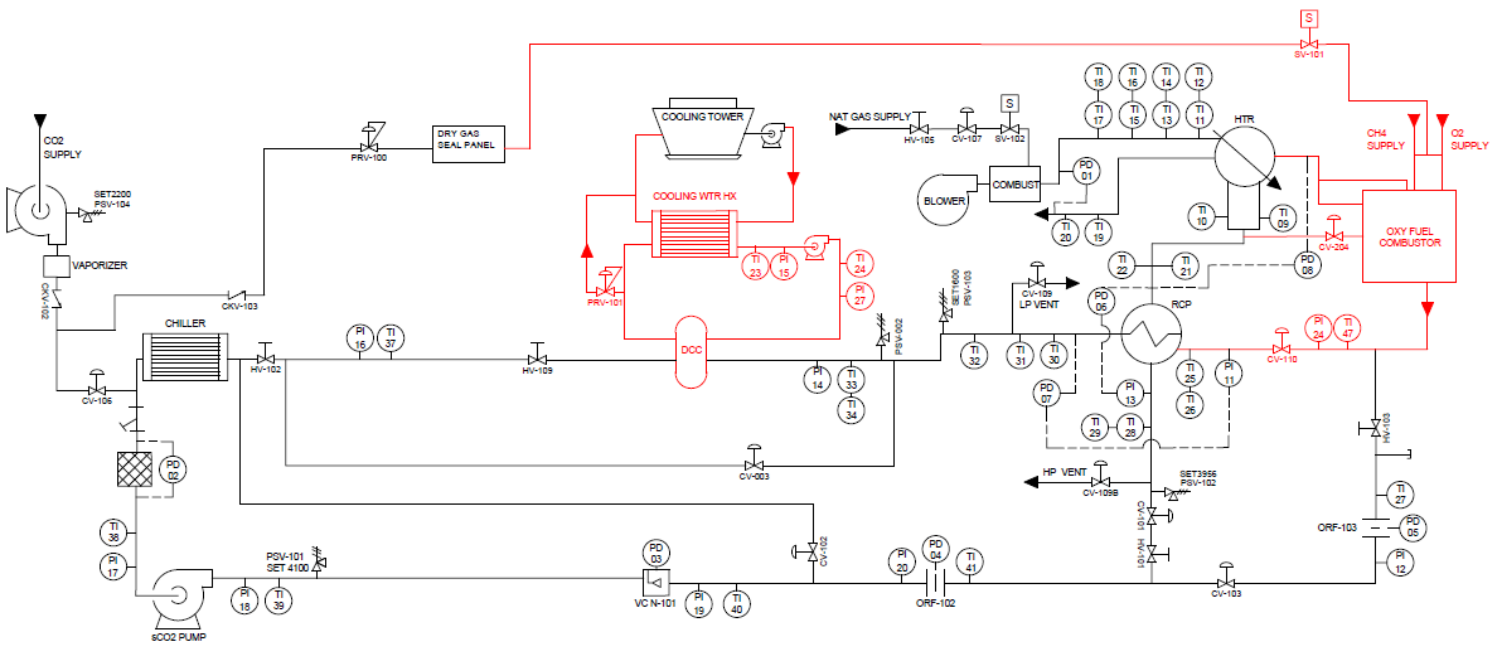
Sunshot Test Loop

- The project will use the "Sunshot" loop currently being commissioned at SwRI
- Sunshot turbine will be replaced with letdown valve

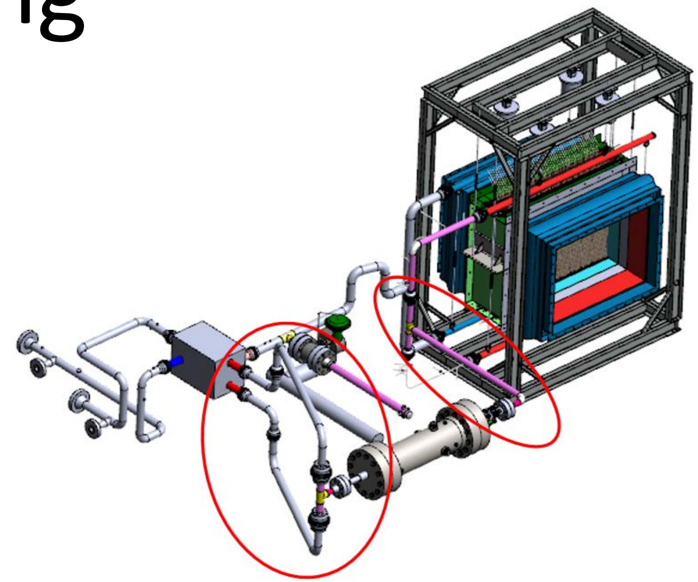


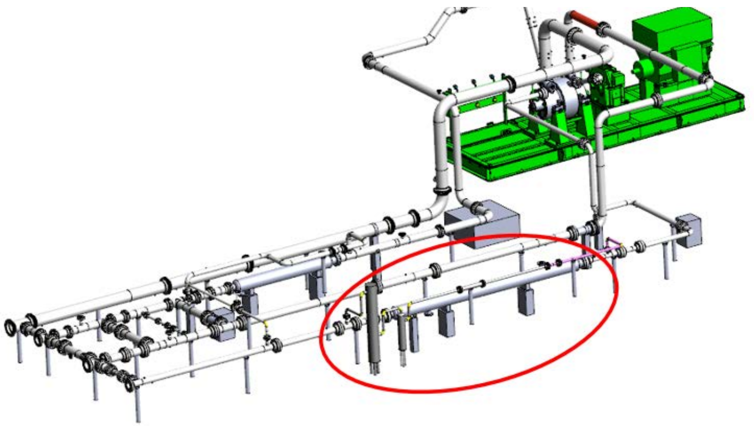
Combustion Loop P&ID



Closed Test Loop Built to Minimize New Piping

- Combustor to be closely coupled with existing “Sunshot heater”
- Connecting pipes made from Inconel 740H
- Addition of water separation in the heat rejection portion of the loop
- Quotes obtained for all major and minor hardware and fixtures needed for testing





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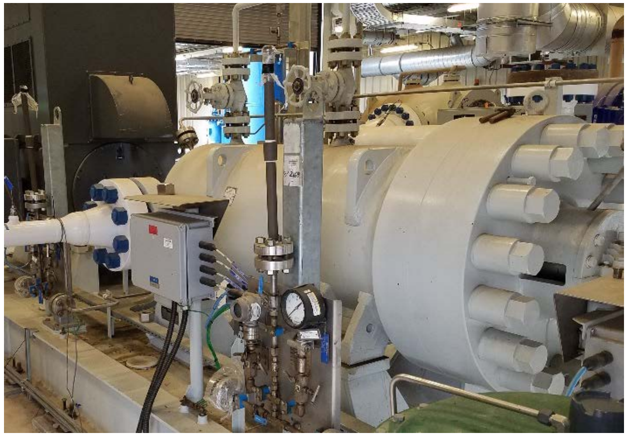
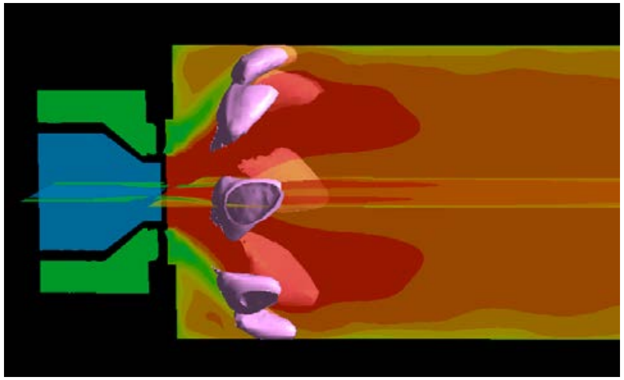
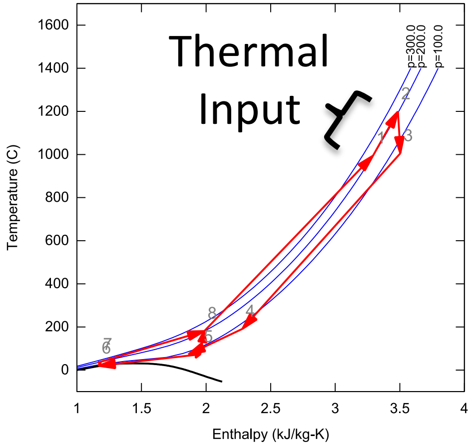
Next Steps

- Place major component orders
- Assemble test loop
- Assemble combustor
- Instrumentation and DAQ
- Commissioning – End 2019, Early 2020
- Test Campaign – 2020

QUESTIONS?






Thermal
Input
p=300.0
p=200.0
p=100.0
Temperature (C)
Enthalpy (kJ/kg-K)
1600
1400
1200
1000
800
600
400
200
0
1
1.5
2
2.5
3
3.5
4