# Direct Fired Oxy-Fuel Combustor for sCO2 Power Cycles

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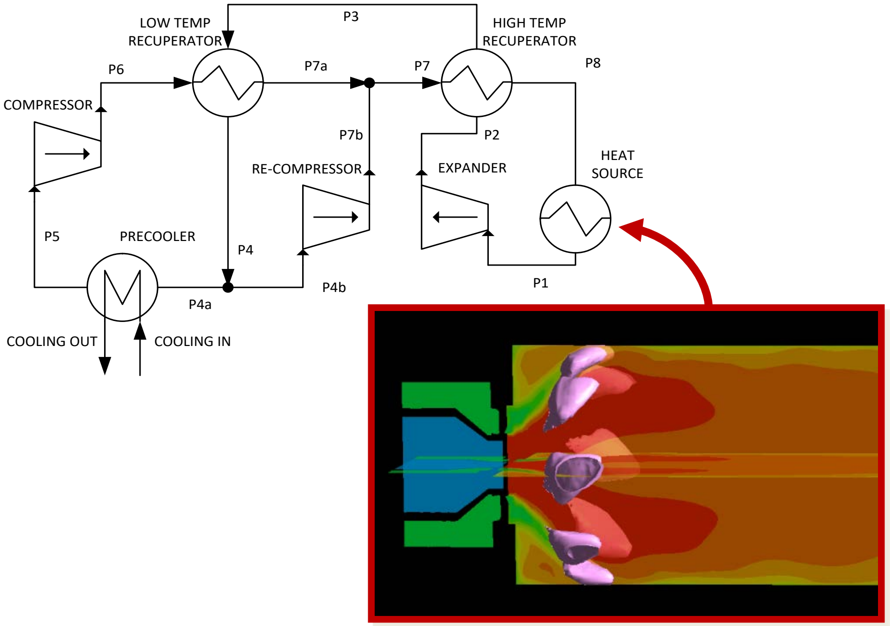


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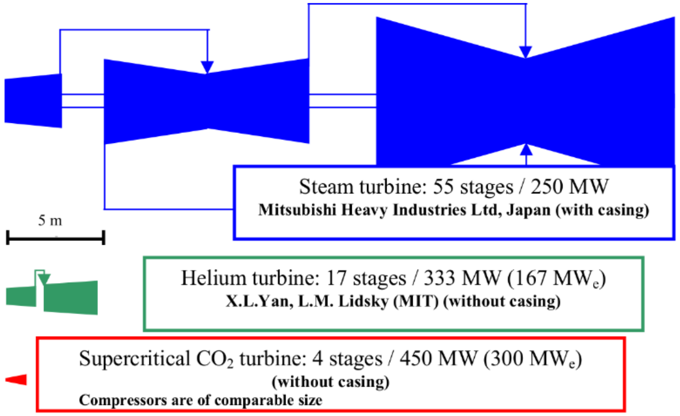
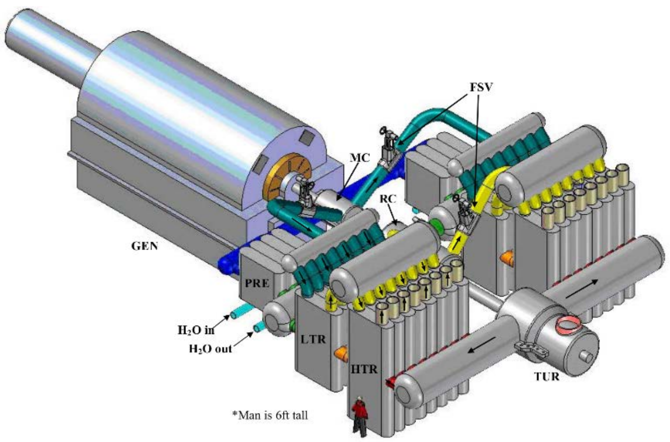
# Outline

- Background
- Project Objectives
- Combustor Design
- Optical Diagnostics
- Future Work

# Why sCO2 Power Cycles?

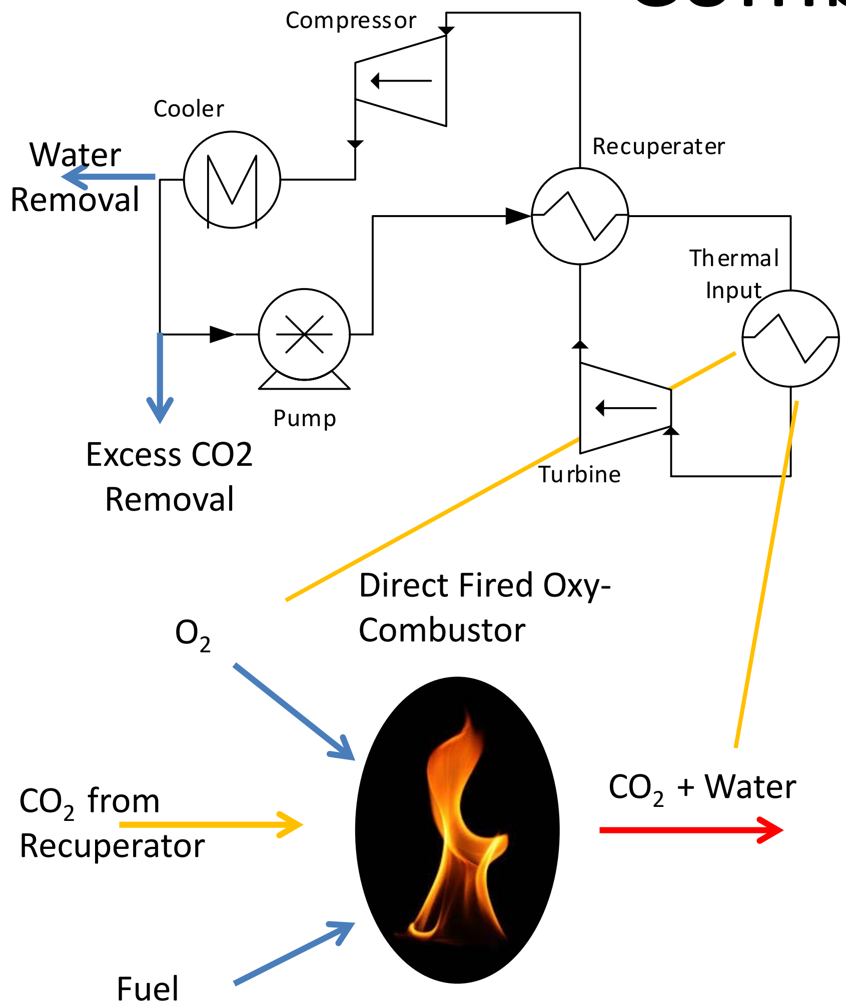
- Offer +3 to +5 percentage points over supercritical steam for indirect fossil applications
- High fluid densities lead to compact turbomachinery
- Efficient cycles require significant recuperation



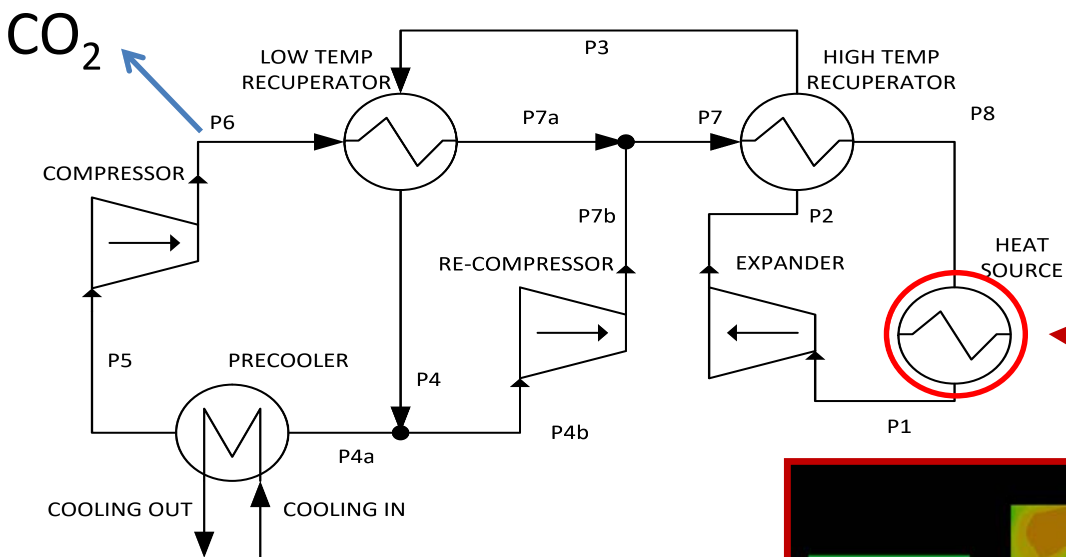

Third Generation 300 MWe S-CO2 Layout from Gibba, Hejzlar, and Driscoll, MIT-GFR-037, 2006

# What is Direct Fired Oxy-Fuel Combustion?

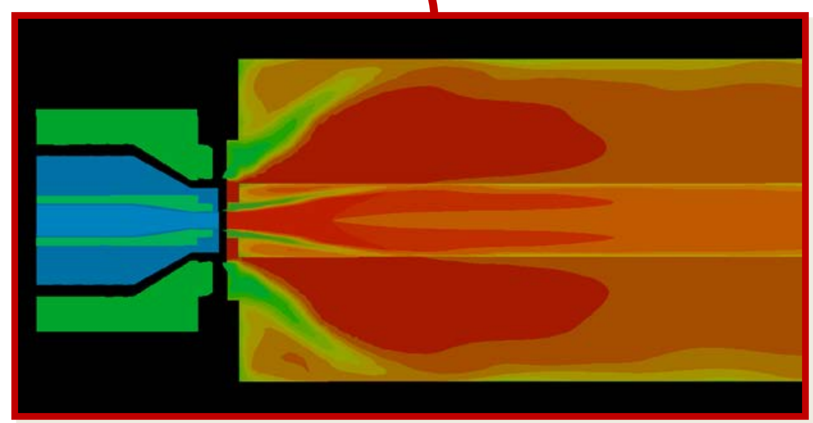



- Replace indirect heat source in a sCO2 power cycle
- Oxygen + fuel + CO2
- CO2 and water produced by the combustion separated
- ASU to produce oxygen

# 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

# Programmatic Changes in 2019

- Major cost sharing partner no long participating in project
- Much of 2019 has been spent in resolution of this and programmatic changes involved with changing cost share providers
- Path forward with same level of funding has been identified and submitted to DOE for approval
- This has caused a significant project delay

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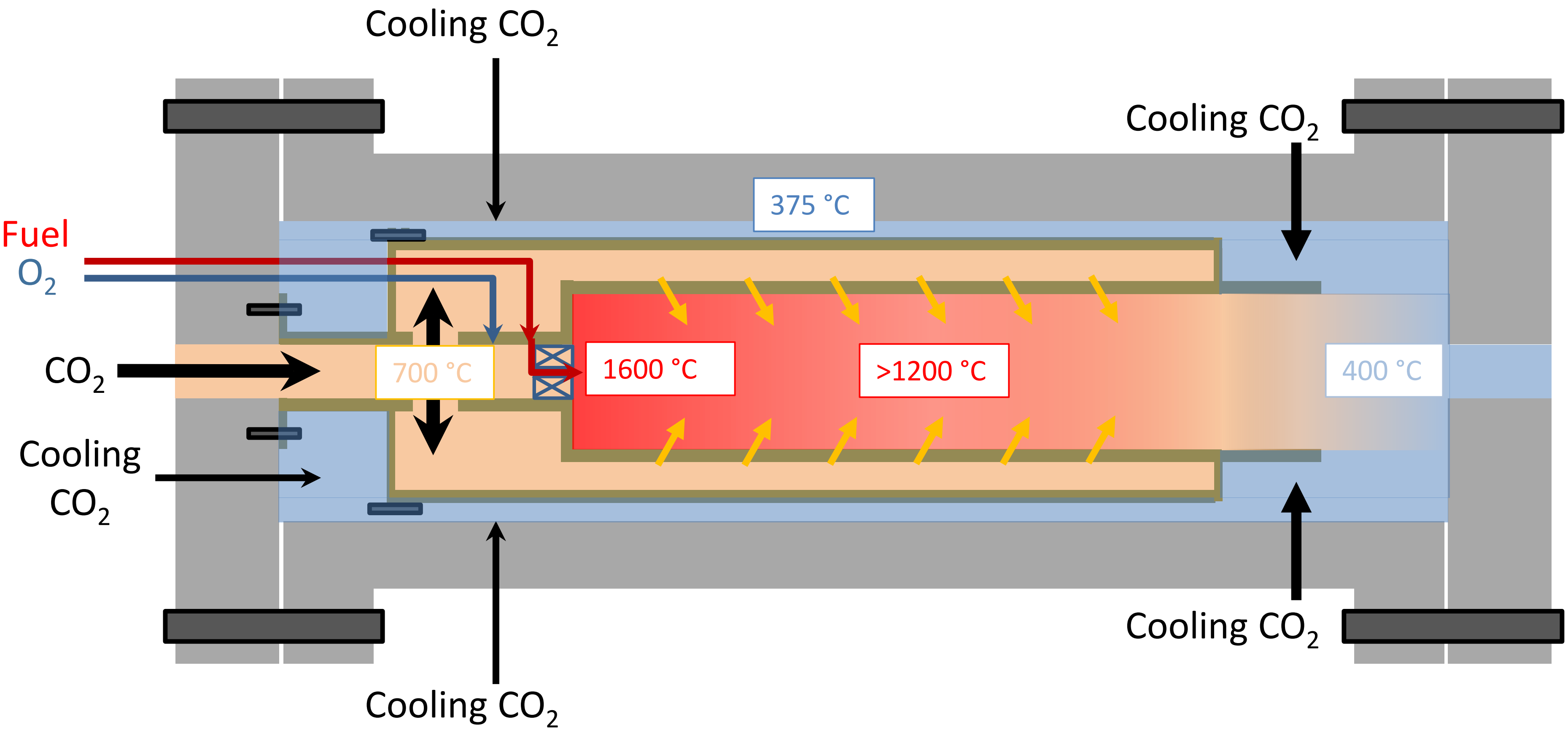
# Combustor Design

- 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

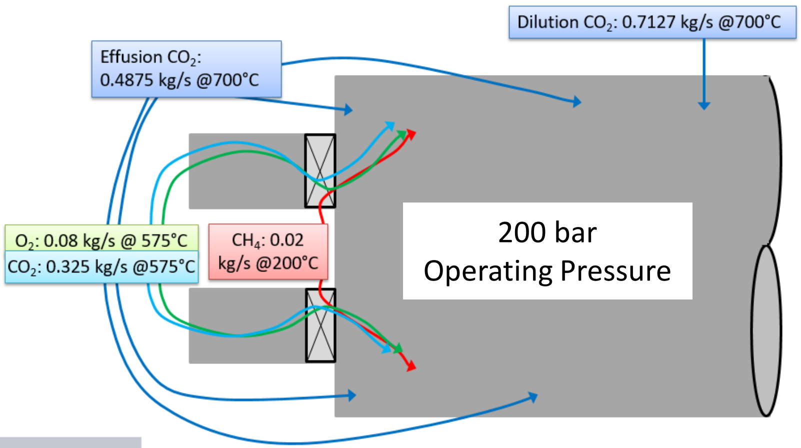
- Rapid solution times
- Iterate on geometry
- Inform liner thermal model
- Reduce risks in a variety of areas prior to combustor manufacturing

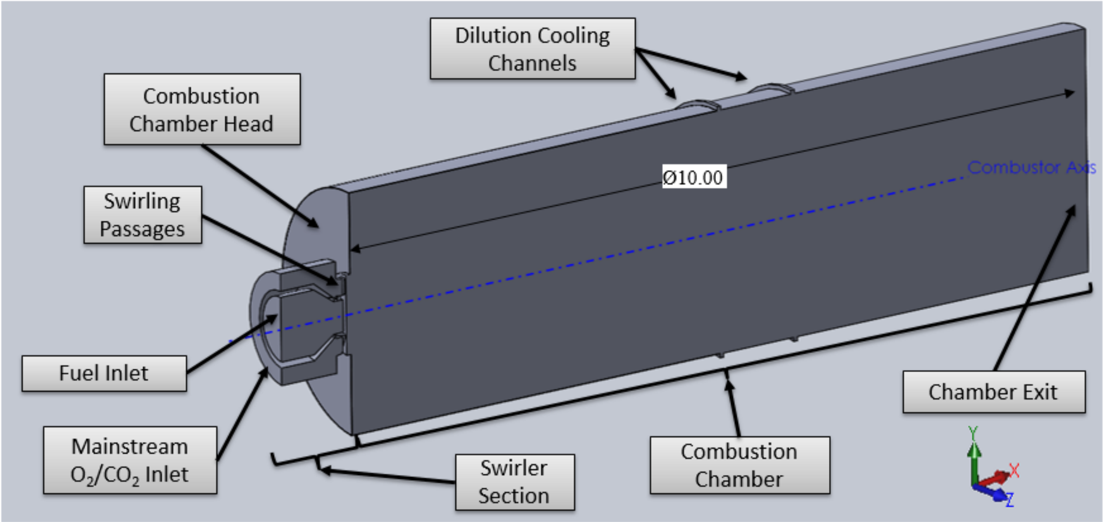
Modeling

- RANS simulations by SwRI
- Relatively course mesh
- Variety of reduced chemical mechanisms

# Simplified Combustor Geometry

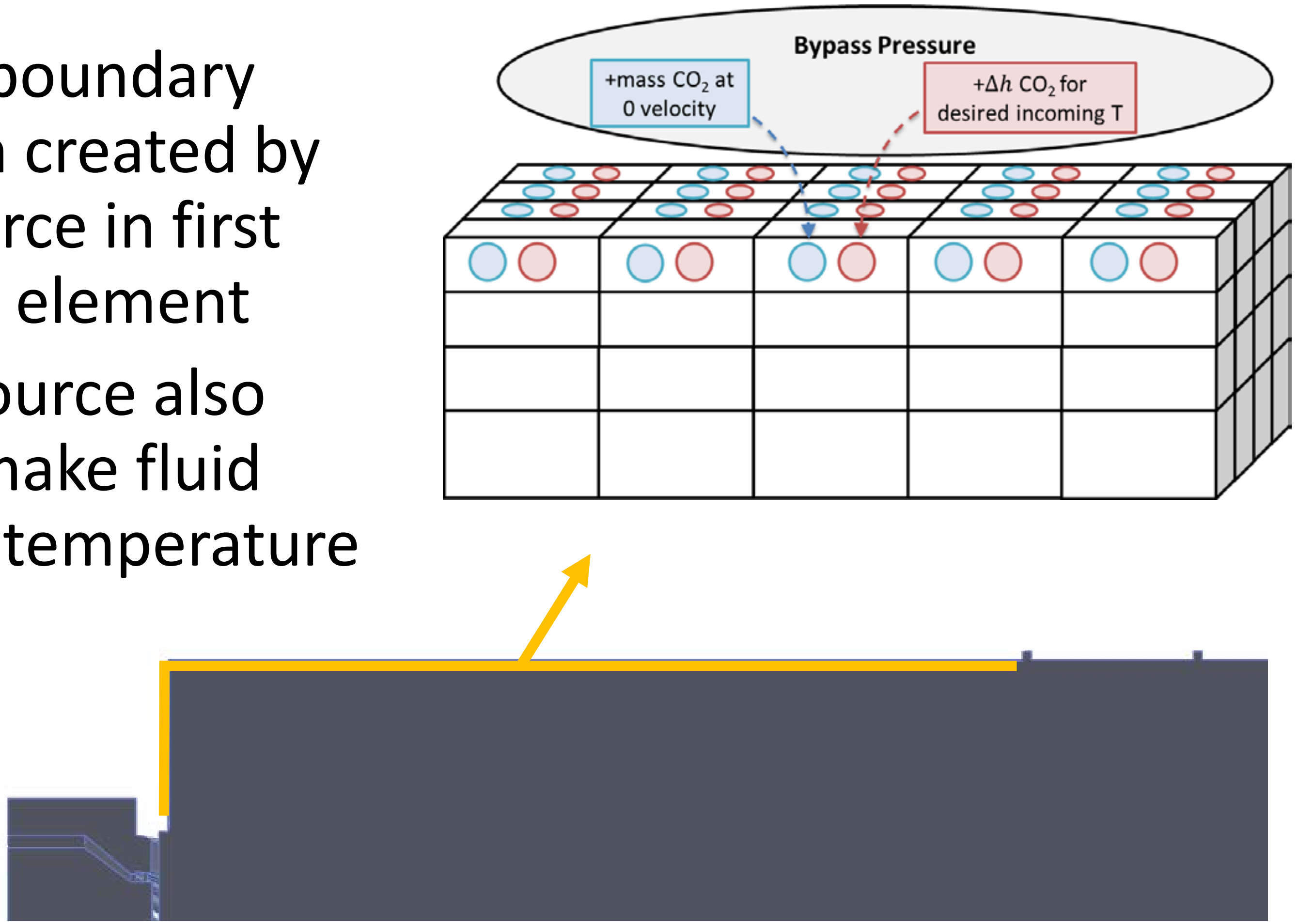
- Modelled effusion cooling on combustor head and liner between head and dilution holes
- Dilution slots



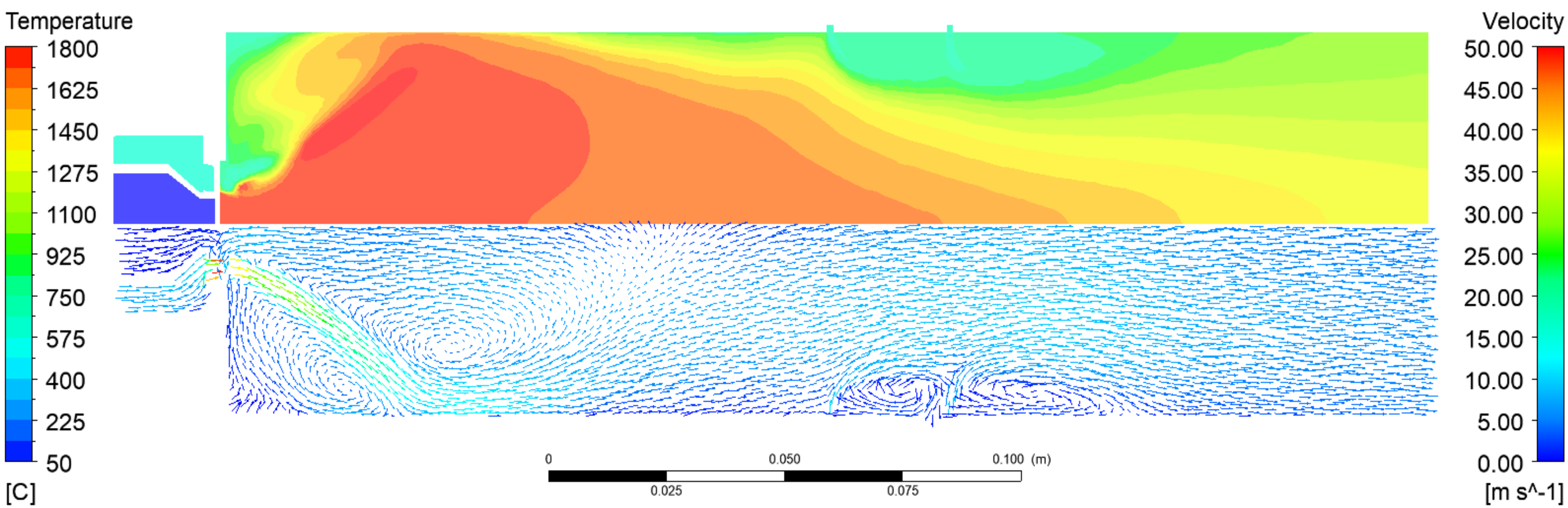
# Effusion Type Boundary Condition

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



# Results from Simple Simulation

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

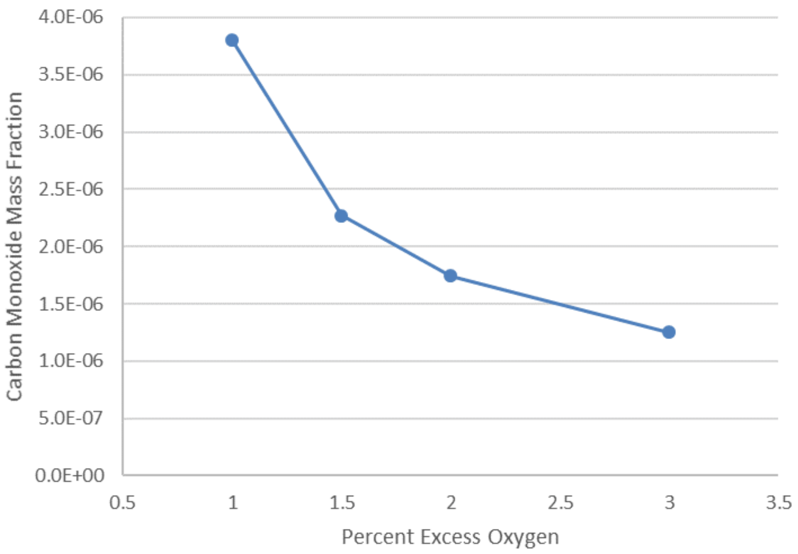


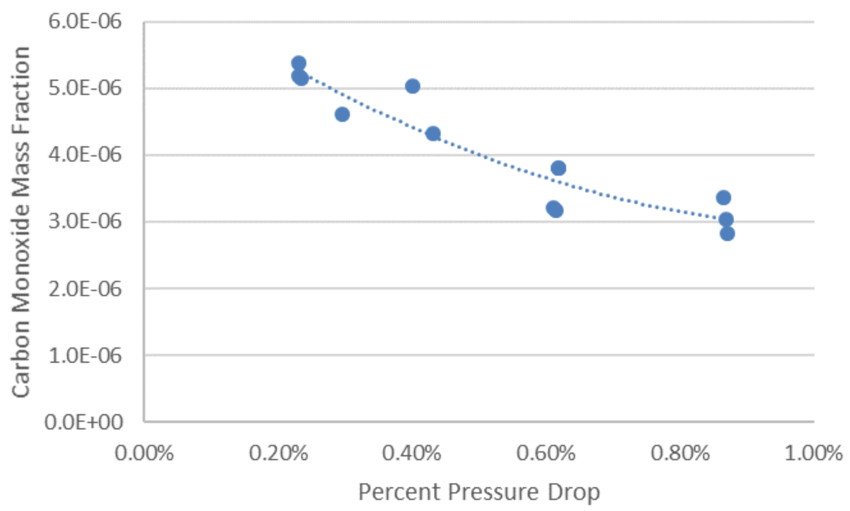
# Additional Considerations

- Typical combustor pressure drops of ~2% result in significant ΔP across the combustor liner at 200bar
  - This may result in need for a more robust mechanical design
- Carbon Monoxide production is a concern
  - Insuring good quality mixing, while maintaining relatively low pressure drop dictates longer residence times

# Carbon Monoxide Production

- Possible to mitigate with excess oxygen
- Increase mixing, typically requires more pressure drop
- Longer combustor residence time



# Acoustic Modeling

- Acoustic modeling using CFD flow field
- Modeling shows modes that might be excited
- Modeling conducted to insure sufficient space was available to install dampers for most likely frequencies
- Combustor design has a fairly large amount of damping, which will most likely suppress the acoustic modes

| Mode # | Frequency | Description |
|---|---|---|
| 1 | 420 Hz | 1st longitudinal shroud mode |
| **2** | **530 Hz** | **Helmholtz (bulk) combustor mode** |
| 3 | 1,600 Hz | Mixed longitudinal-transverse shroud mode |
| **4** | **1,600 Hz** | **1st Longitudinal (1L) combustor mode** |
| 5 | 2,200 Hz | Mixed longitudinal-transverse shroud mode |
| **6** | **2,500 Hz** | **Coupled shroud-combustor mode** |
| 7 | 2,600 Hz | Mixed longitudinal-transverse shroud mode |
| 8 | 2,900 Hz | Mixed longitudinal-transverse shroud mode |
| 9 | 3,100 Hz | 1R shroud (1st radial shroud mode) |
| 10 | 3200 Hz | Mixed shroud mode |
| 11 | 3,300 Hz | Mixed shroud mode |
| **12** | **3,400 Hz** | **Coupled shroud-combustor mode** |
| 13 | 3,400 Hz | Mixed shroud mode |
| **14** | **3,500 Hz** | **Coupled shroud-combustor mode** |
| 15 | 4,000 Hz | Longitudinal shroud mode |
| **16** | **4,000 Hz** | **Mixed (1L1T) combustor mode** |

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# Optical Diagnostics Effort

- Observe combustion process in an effort to generate validation data
- Explore validity of traditional diagnostic techniques in a high pressure $CO_2$ environment
- Challenges with optical measurements direct-fired combustor with $sCO_2$
  - Optical probe design for 200bar pressure and high temperature
  - $CO_2$* emissions
  - $CO_2$ absorptivity

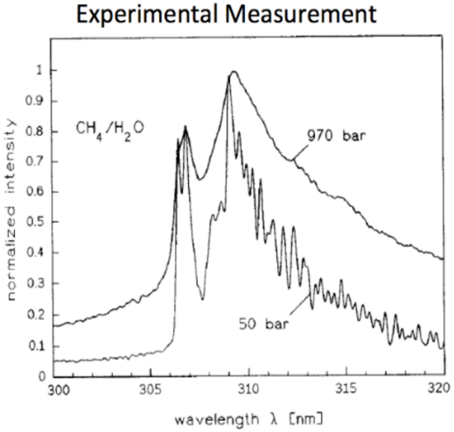
# Optical Test Plan

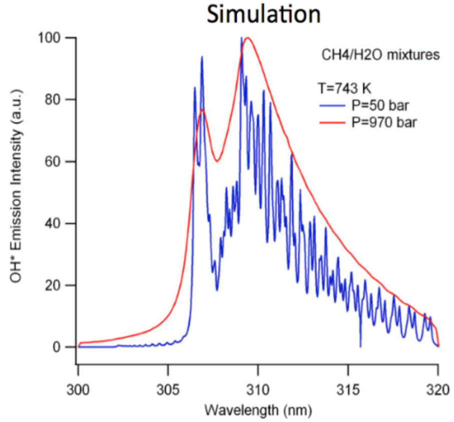
- Plan developed to allow flexibility depending on the spectral conditions encountered
- Hyperspectral imaging
- OH* measurements
- CH* will also be considered
- Wide range of optical filters will be available during testing to allow for flexibility

# OH* measurements

- No experimental data available at the time for OH*
- Broadband $CO_2$* emissions and thermal emissions may pose a problem for the OH*
- Modeling of OH* emissions in $CO_2$ was inconclusive

Left: Emission spectra from OH* at 50 and 970 bar in supercritical 70/30 water–methane mixture at 470˚C [1]. No significant optical interference from other species was observed in the experimental data. Right: Modeled OH* emission spectra at 50 and 970 bar.

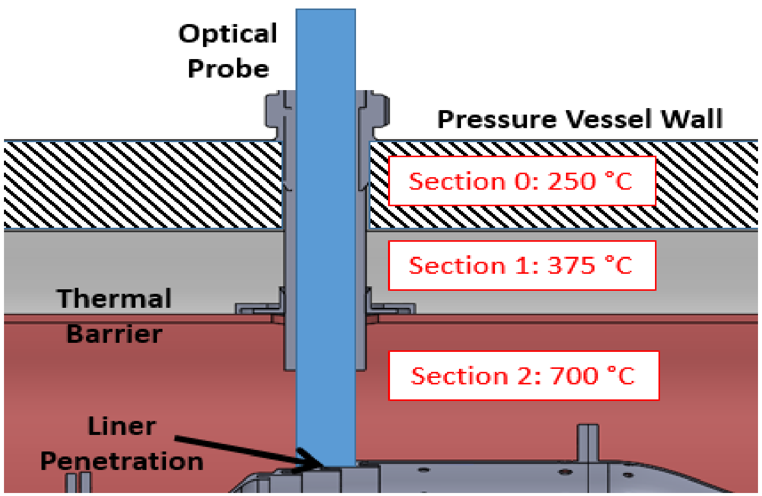


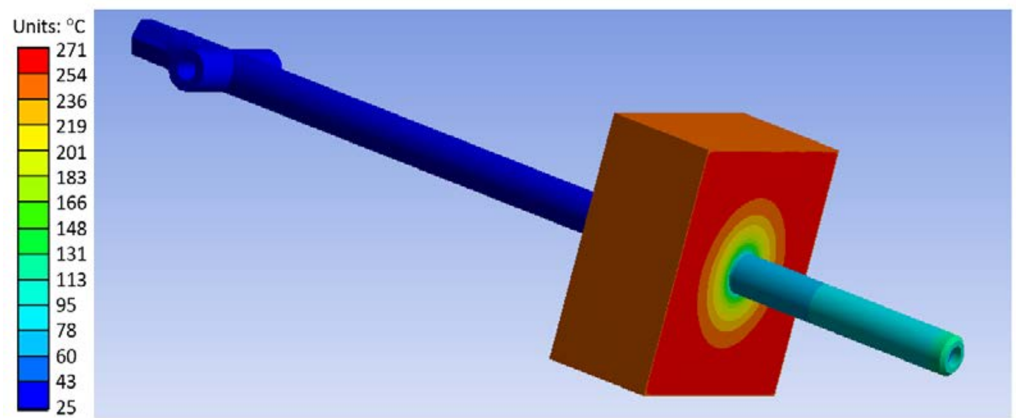




[1] G. M. Poshner and E. U. Franck, "Spectra and Temperature of Diffusion Flames at High Pressures to 1000 bar," Bunsenges Chem. Phys., vol. 98, pp. 1082-1090, 1994.

# Optical Probe Design

- Existing Spectral Energies design was modified by Spectral and SwRI to accommodate higher pressures and temperatures



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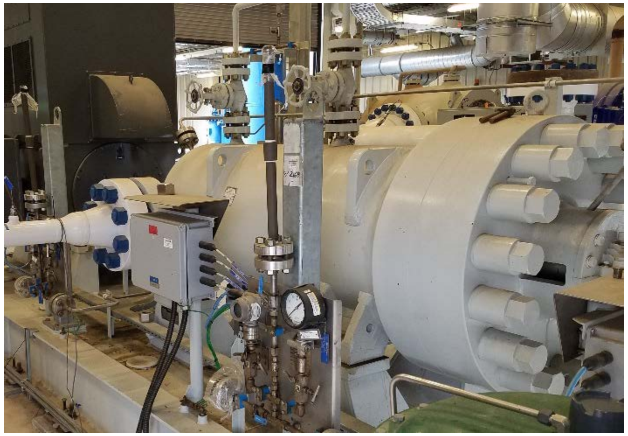
# Topics in Need of Additional Study

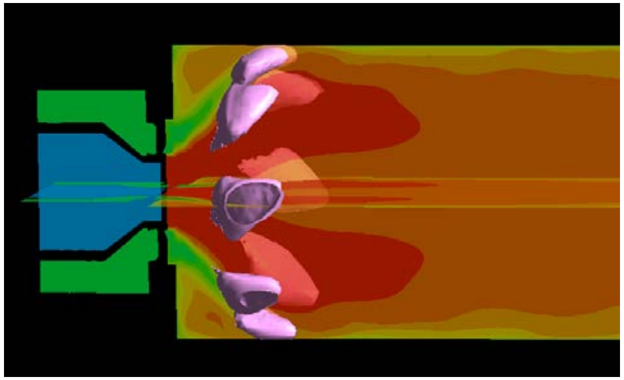
- Nitrogen will be present in any oxygen stream from an ASU
  - How does the presence of $N_2$ alter the combustion?
  - Do we need to worry about $NO_x$?
- Formation of soot and CO in combustion process
- Light off: How to manage this? Light off at lower pressure -> CO2 inventory management
- Part load operation: System level thermodynamic studies to look at reduced mass flow, reduced pressure, and/or reduced firing temperature

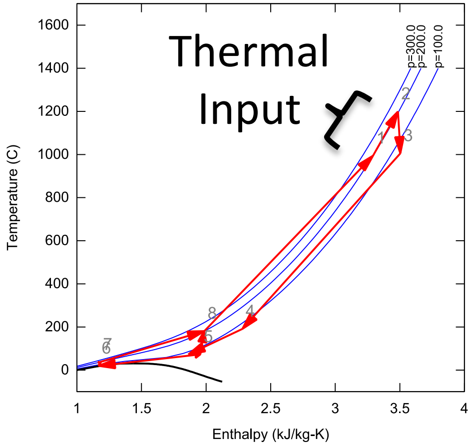
# Next Steps

- Place major component orders
- Assemble test loop
- Assemble combustor
- Instrumentation and DAQ
- Commissioning – End 2020, Early 2021
- Test Campaign – 2021

# QUESTIONS?






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