Computational Modeling of a Direct Fired Oxy-Fuel Combustor for sCO2 Power Cycles

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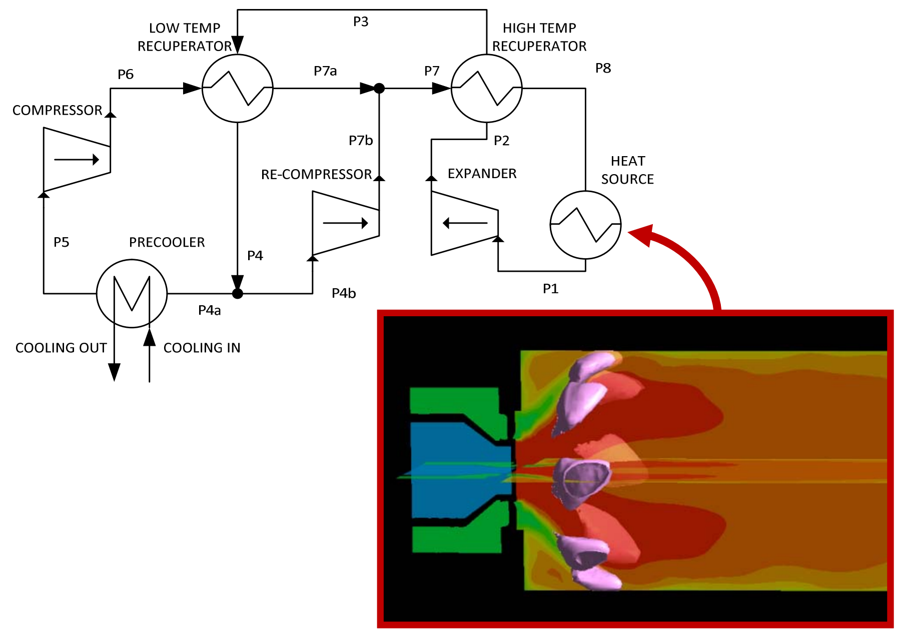

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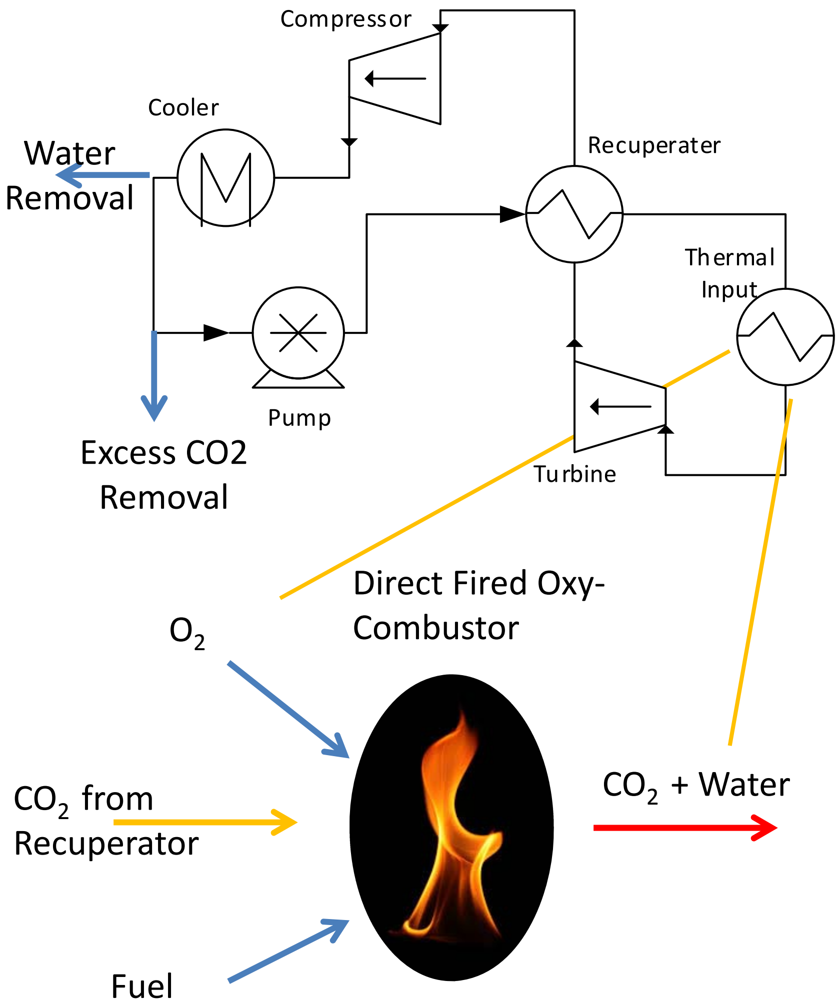
Outline

- Background and Project Objectives
- Geometry and Boundary Conditions
- Combustor CFD Results
- Conclusions

sCO_2 Oxy-Combustion



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

Current Objectives

- Design a 1 MW thermal oxy-fuel combustor capable of generating 1200°C outlet temperature
- Manufacture and assemble a combustor and test loop, and commission oxy-fuel combustor
- Evaluate and characterize combustor performance
  - Optical access for advanced diagnostics
- Paper Objective: Publish sample baseline geometry for others

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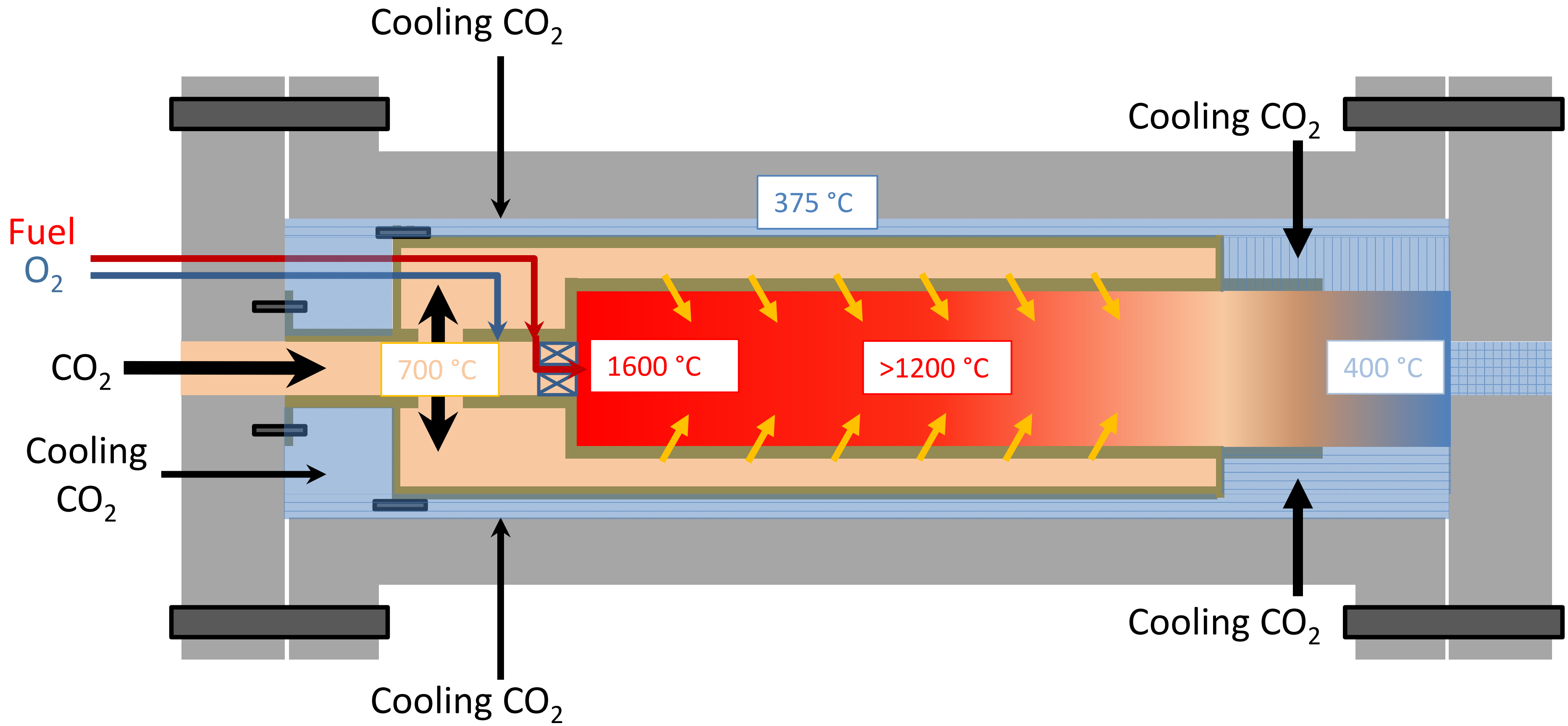
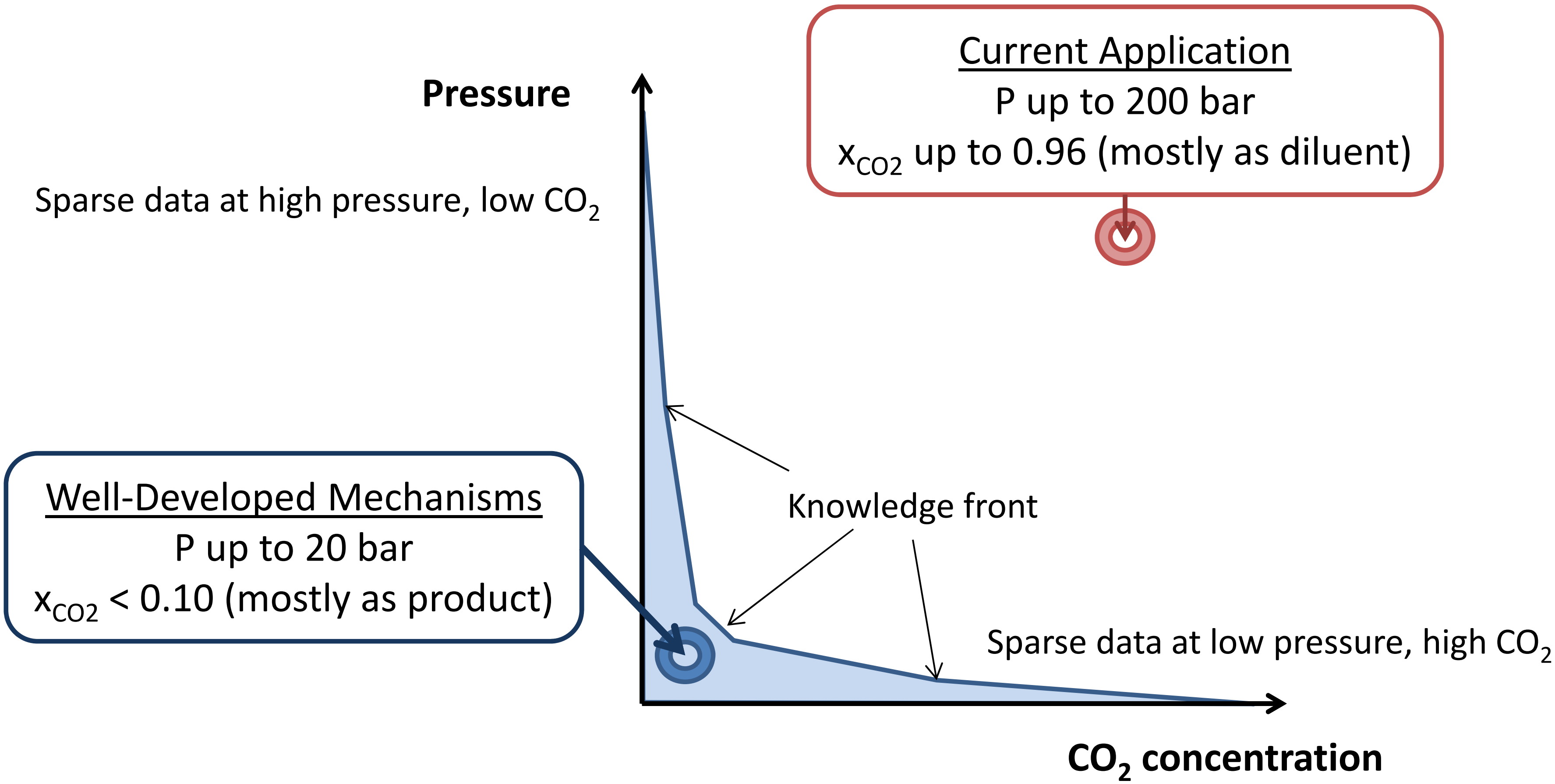
- Future Work

Conceptual Combustor Design



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

Kinetics Knowledge Base

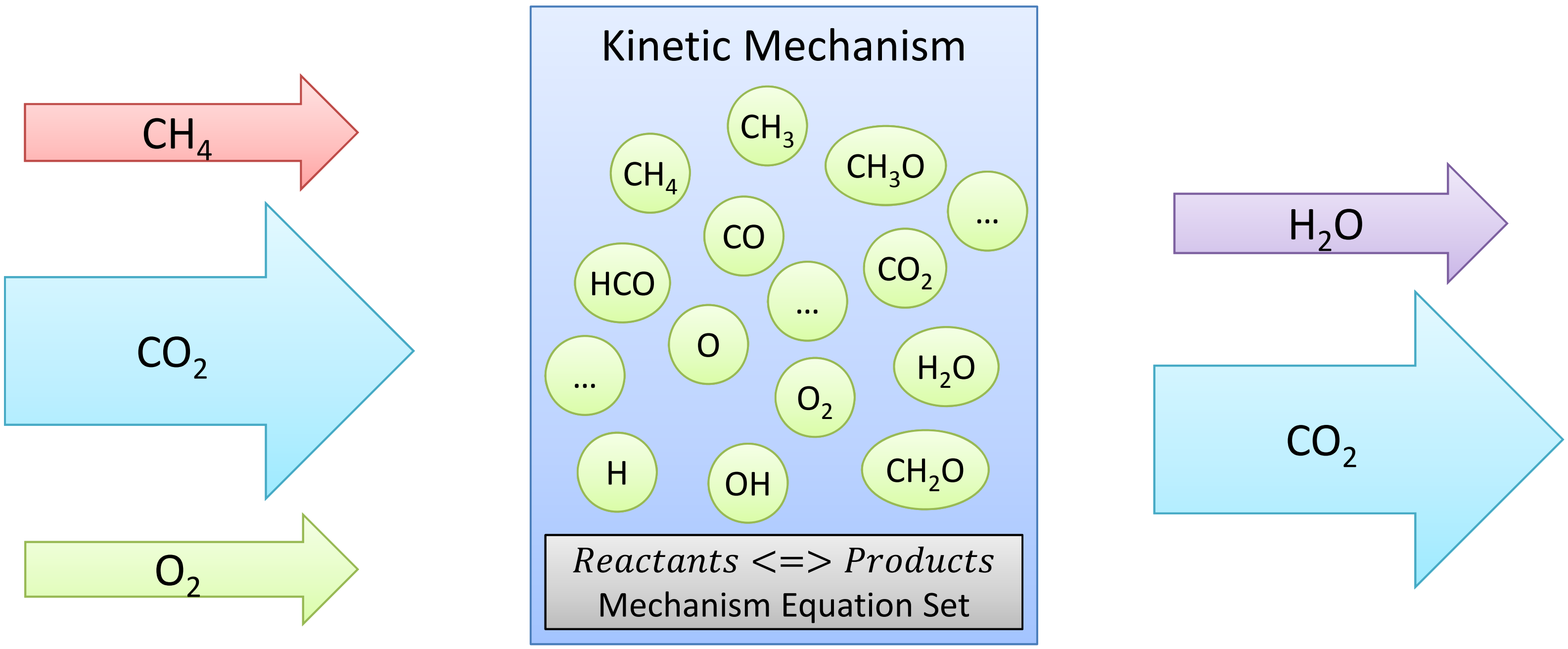


Limited data available – Current UCF and Georgia Tech projects

Chemical Reaction Kinetics

Overall Reaction: $CH_4 + 2O_2 \rightarrow 2H_2O + CO_2$

Actual reaction is made of hundreds of intermediate chemical reactions with dozens of intermediate chemical species.



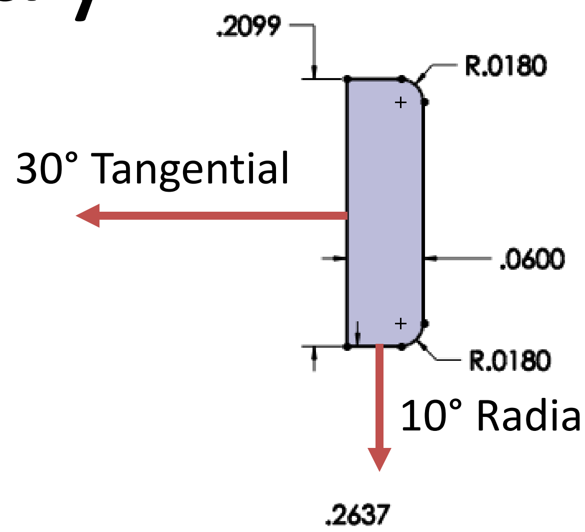
Current simulations employ reduced mechanism created by Georgia Tech.
Leverages 12 chemical species and 25 reactions.

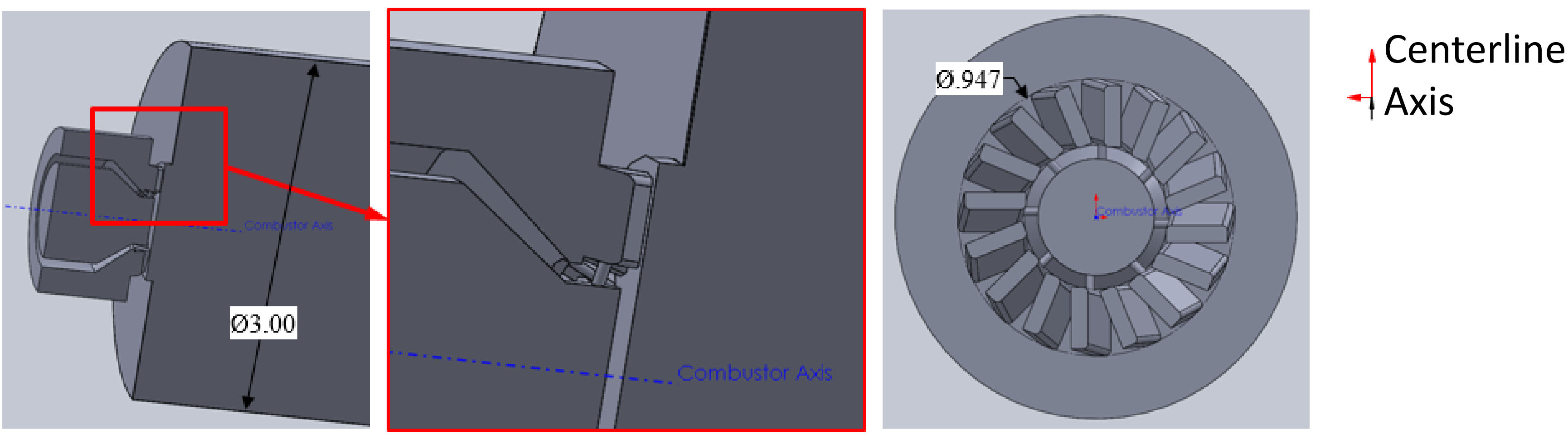
Computational Design

- Early design efforts constrained by high inlet temperatures needed to operate in a recompression cycle ~900°C combustor inlet
- Recuperator technology unlikely to be able to support those temperature in the near future
- Lower inlet temperature allow for easier design of submerged aerodynamic components
- Auto-ignition, sudden expansion, trapped vortex and swirl type injection explored

Injector Geometry

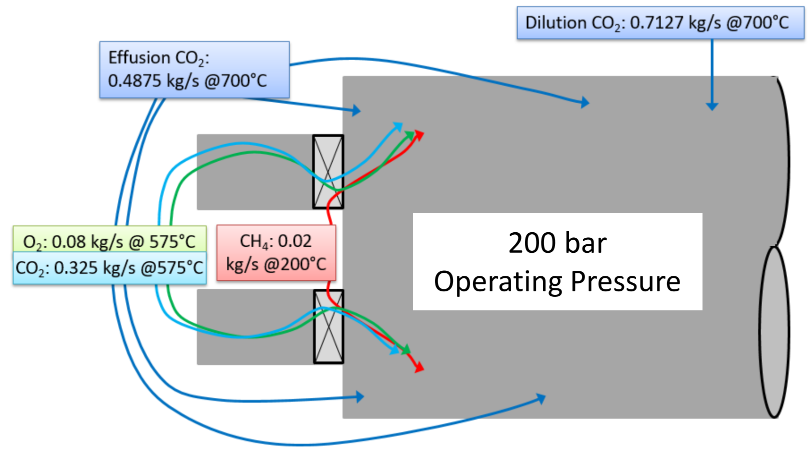
- 16 straight swirler passages, 30° radial swirl w/ 10°down angle
- Swirl passage area remains constant when angle is changed
- 8 fuel injectors inject fuel midway through swirler passage

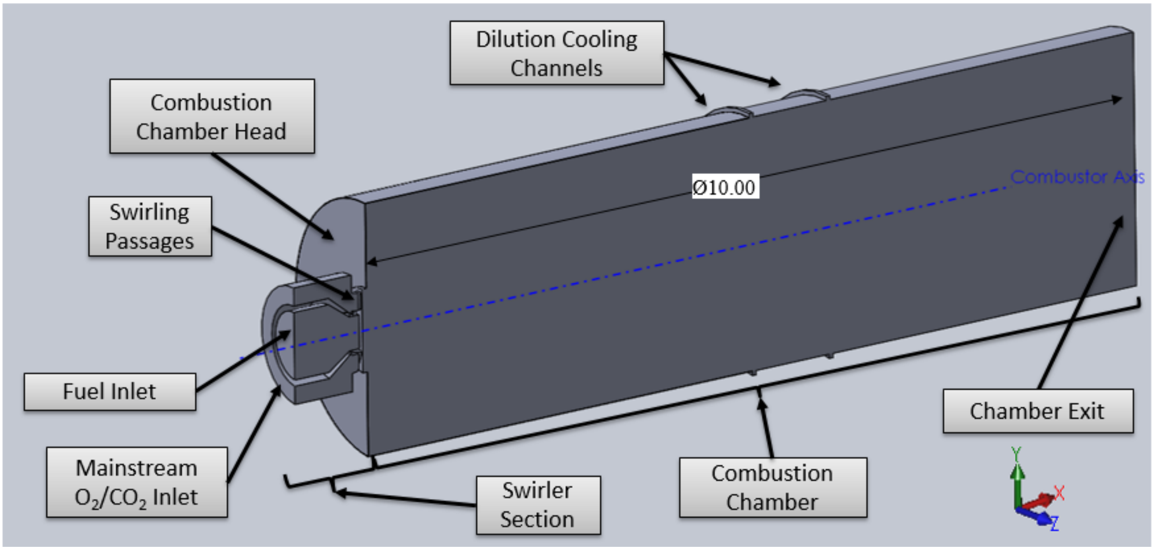




Combustor Geometry

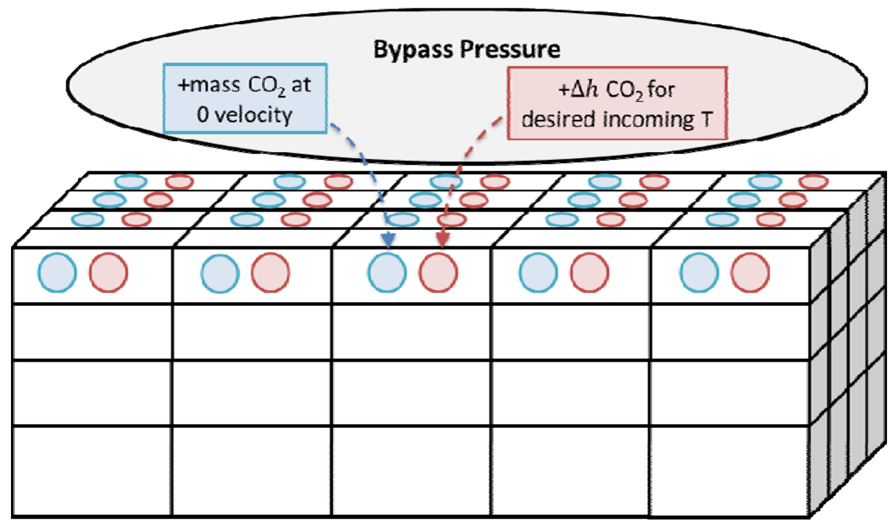
- Effusion cooling on combustor head and liner between head and dilution holes
- 0.05" wide dilution cooling slots, 1" apart

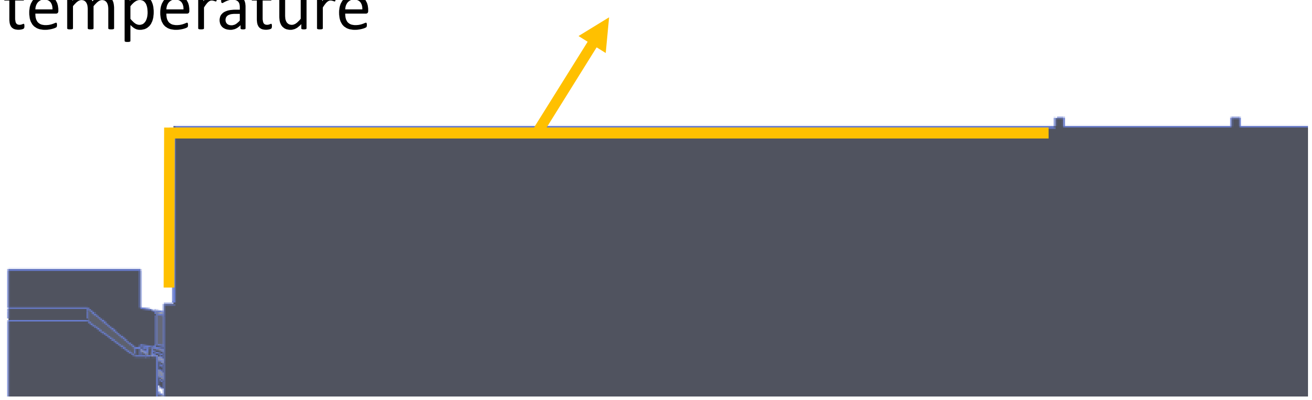




Effusion Type Boundary Condition

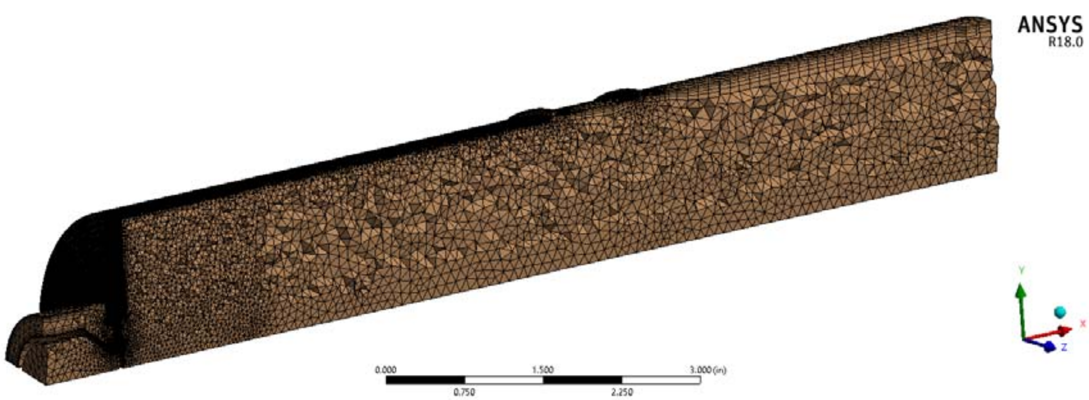
- Effusion boundary condition created by mass source in first near wall element
- Energy source also used to make fluid injection temperature





CFD Domain and Setup

- Computational domain:
  - ¼ Domain w/ periodic boundaries
  - 1.125 MM elements
  - 5-6 Wall inflation layers
- CFD Modeling Setup:
  - Pseudo Steady State RANS, Realizable k-ϵ model, Standard wall function
  - Compressibility, Ideal Gas EOS, C_p polynomials, gas mixture rules
  - Pressure outlet @ 2% total pressure loss
  - Mass flow inlets



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

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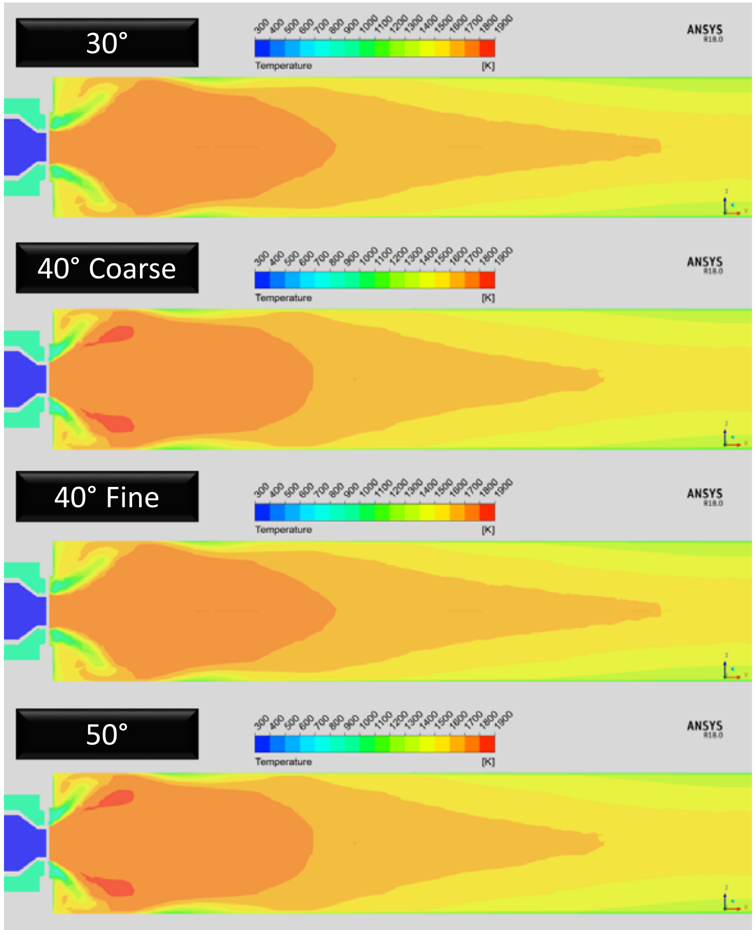
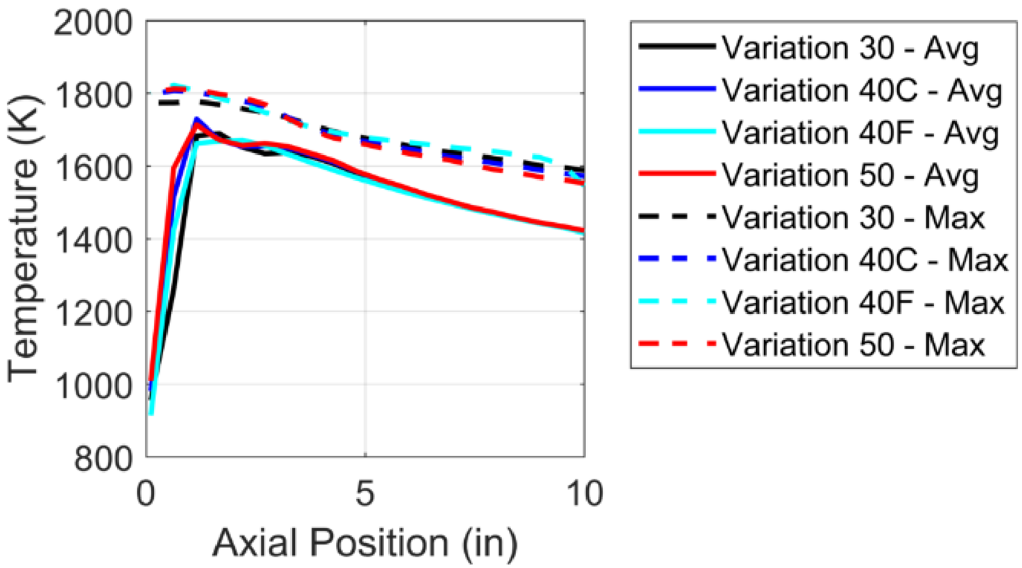
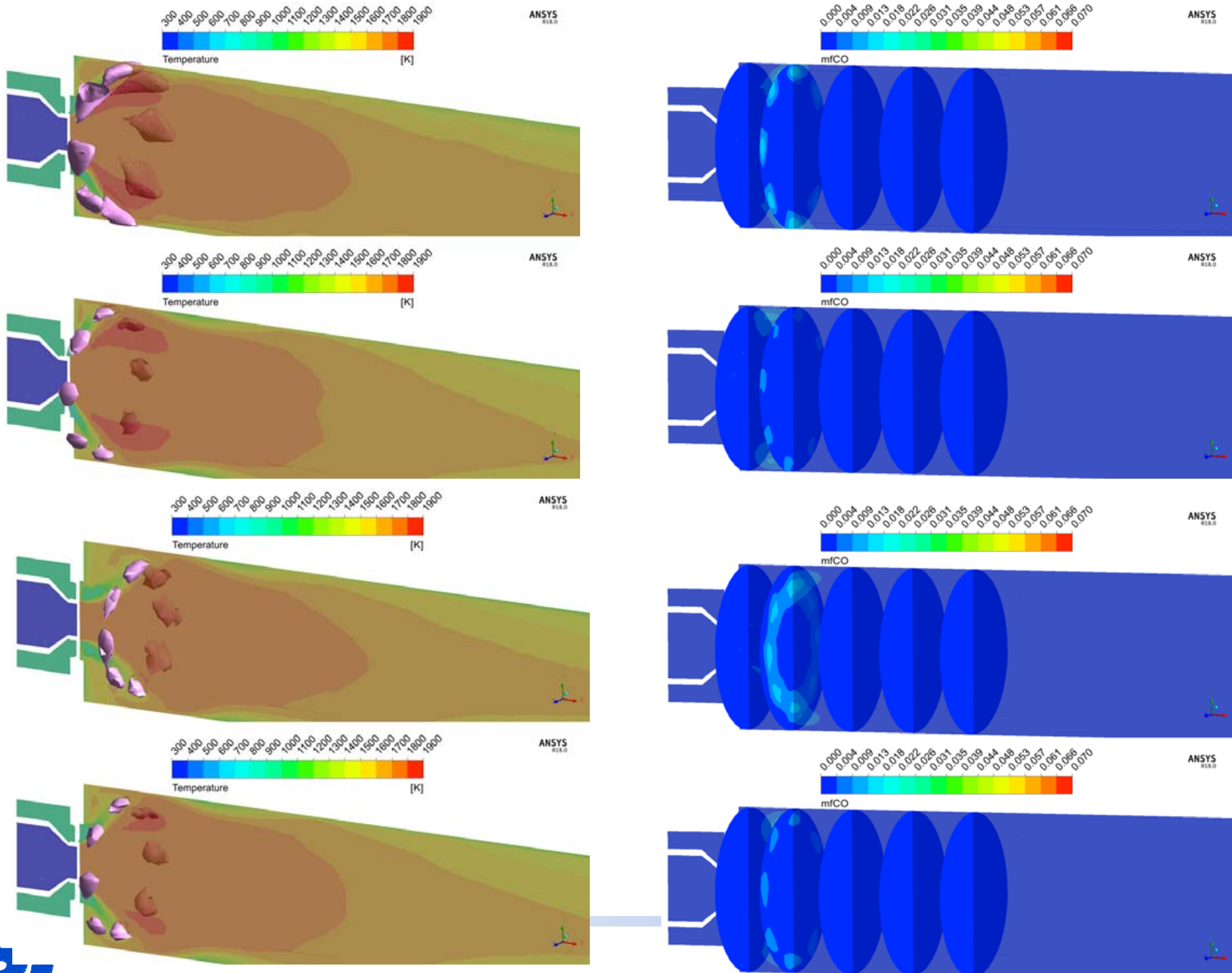
Temperature Predictions





CO Concentrations



30°

40° Coarse

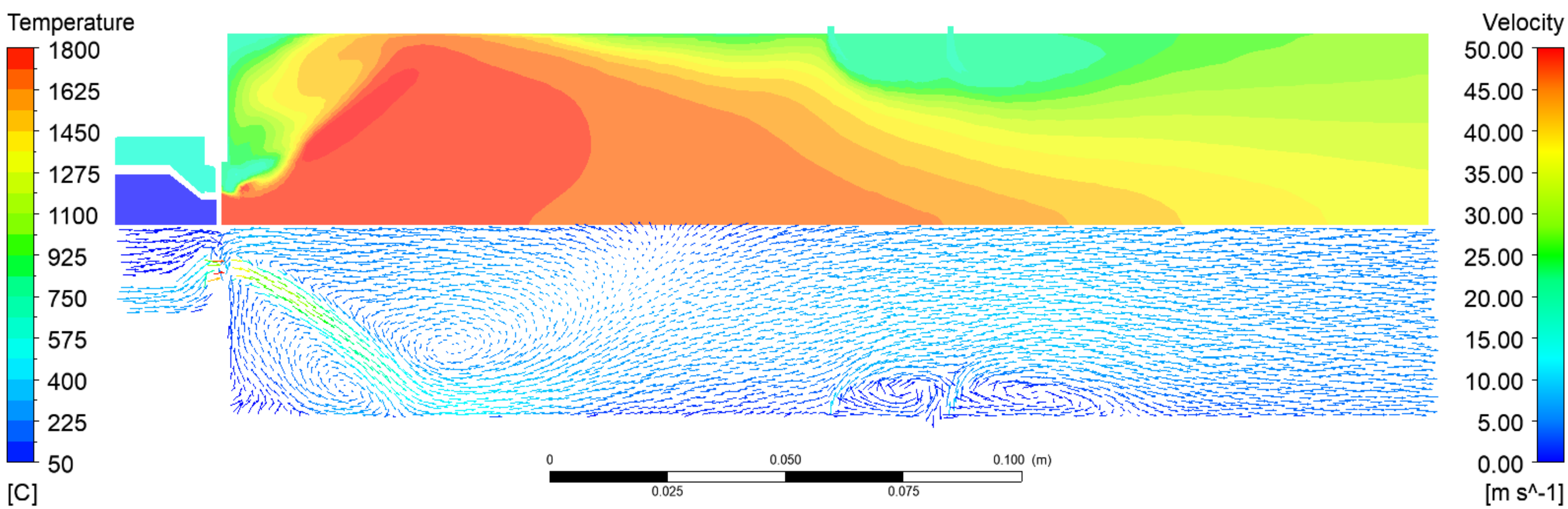
Light Purple zones are for mole fraction CO=0.008

40° Fine

50°

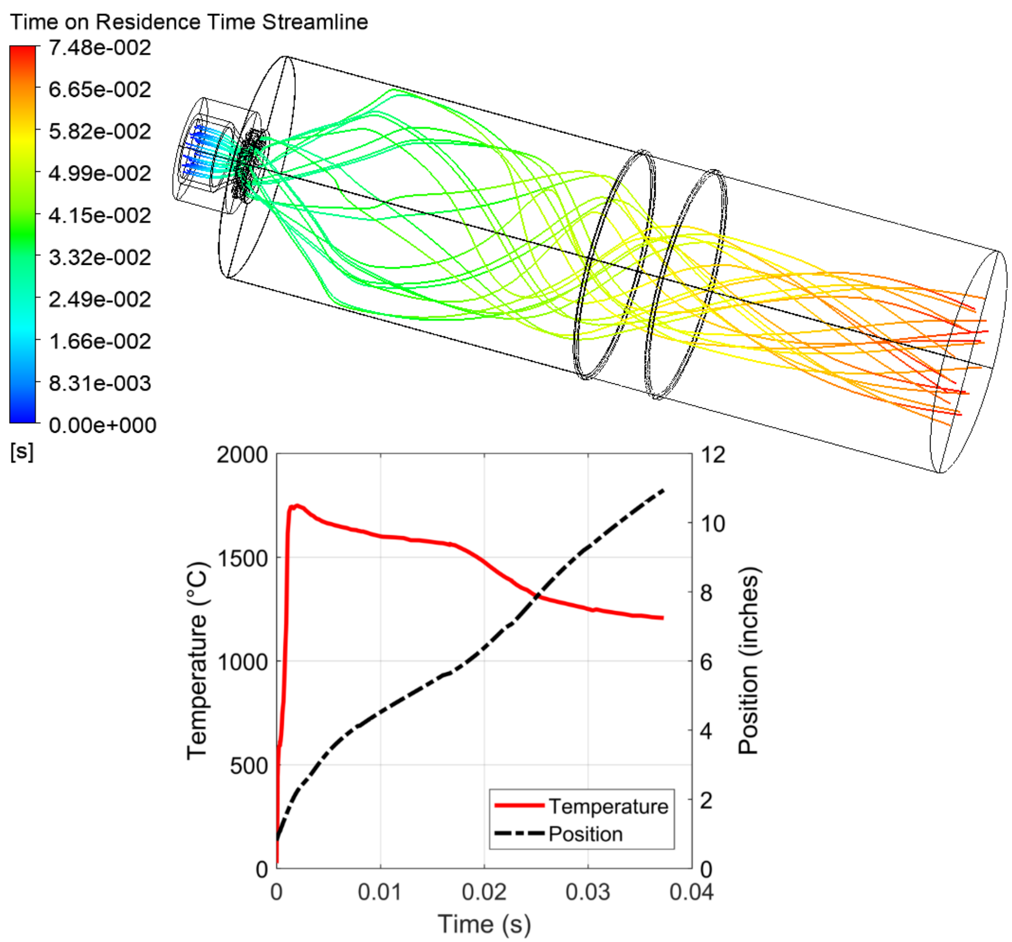
Selected Results with Dilution

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

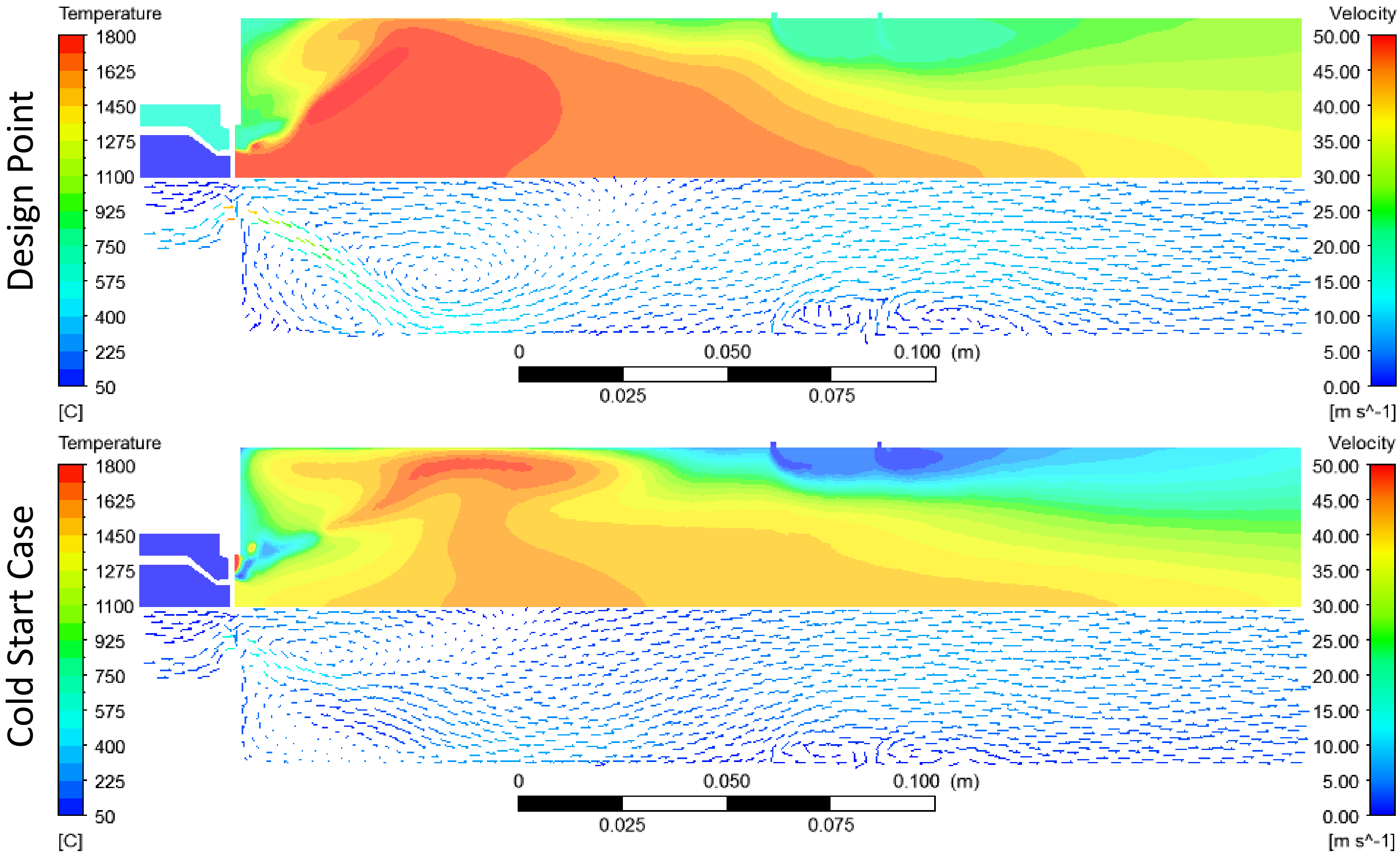


Residence Time

- Combustor is designed to allow for a fairly long residence time
- For fluid not trapped in recirculation – ~0.02s in primary zone

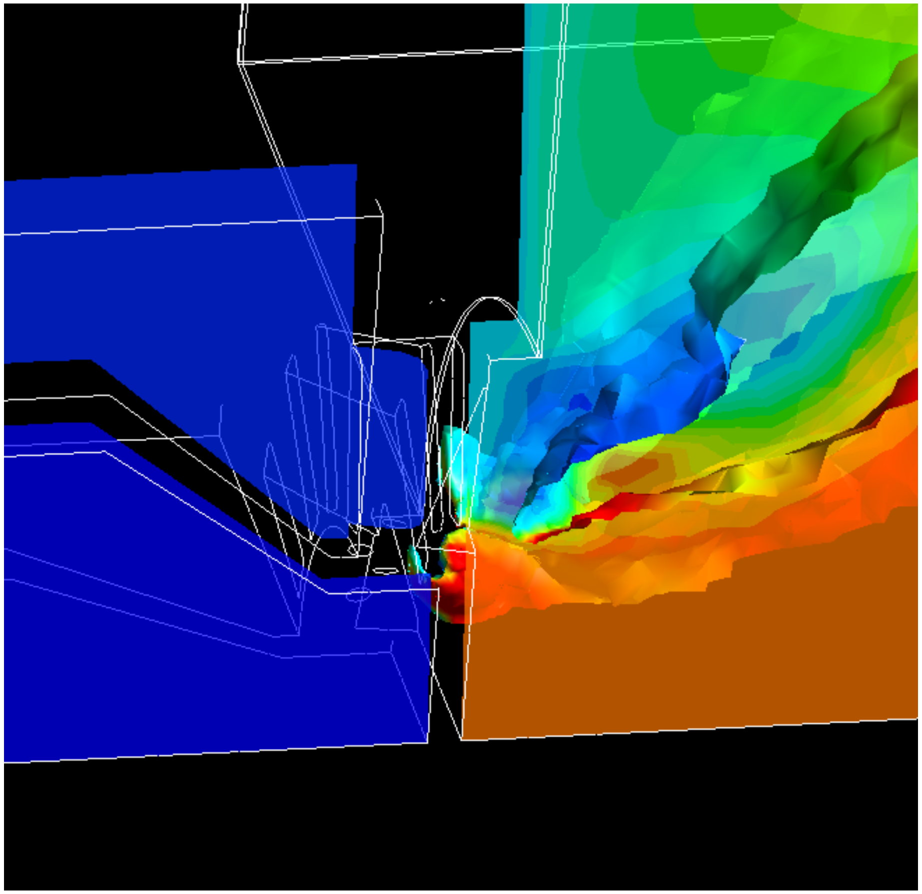


Cold Start Case



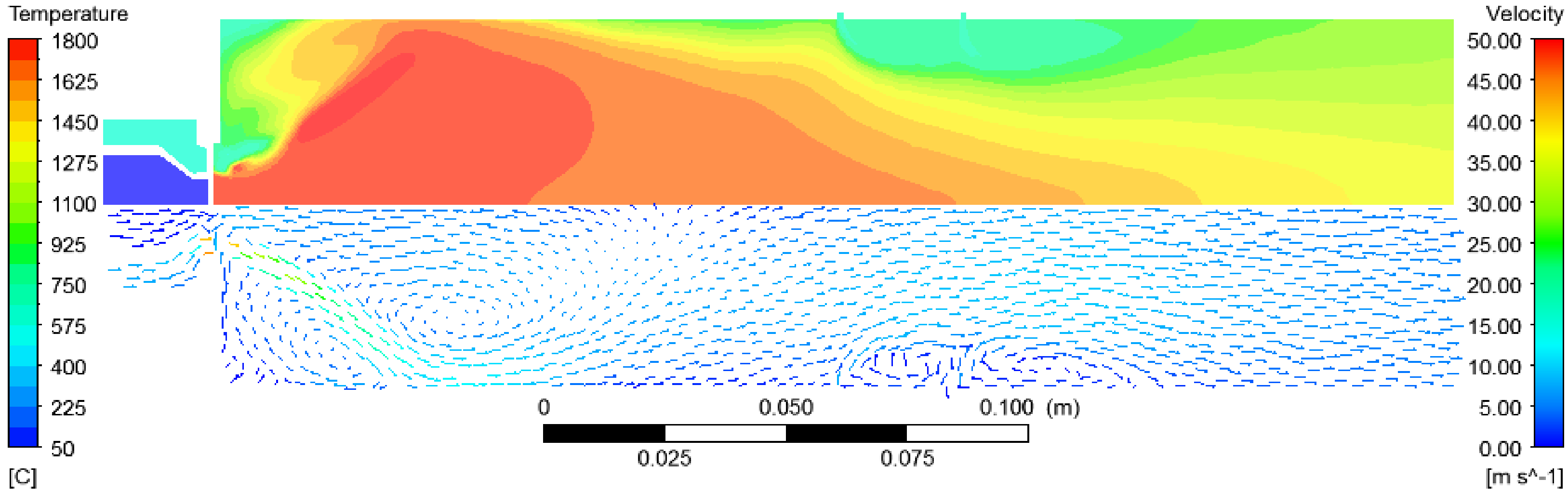
Possible Flame Holding Concerns

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

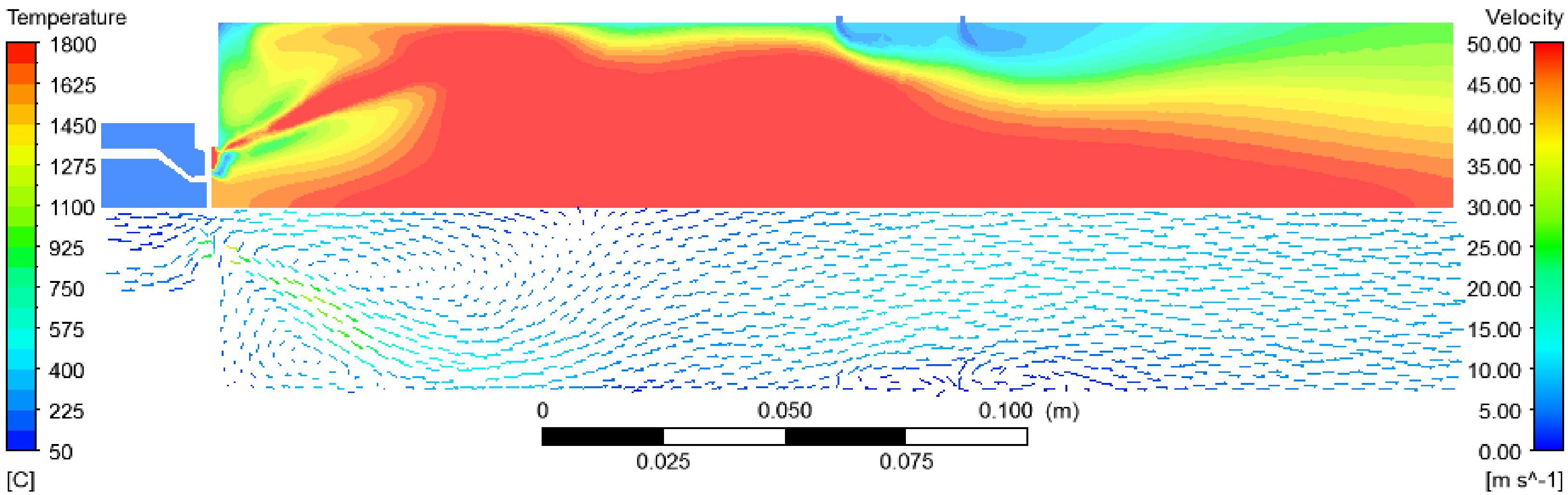


Fast Start Loop Ramp

Design Point



Fast Start



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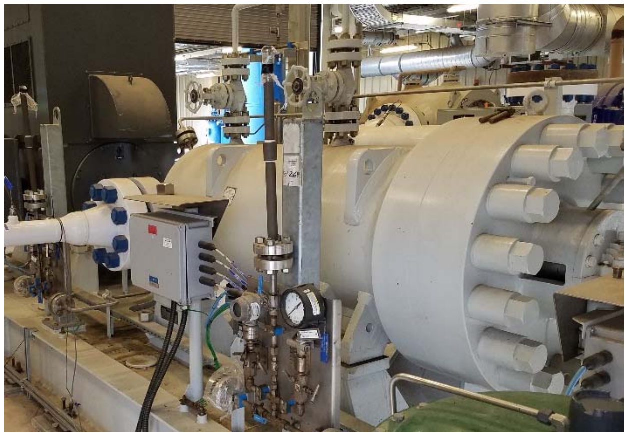
Simulations Summary

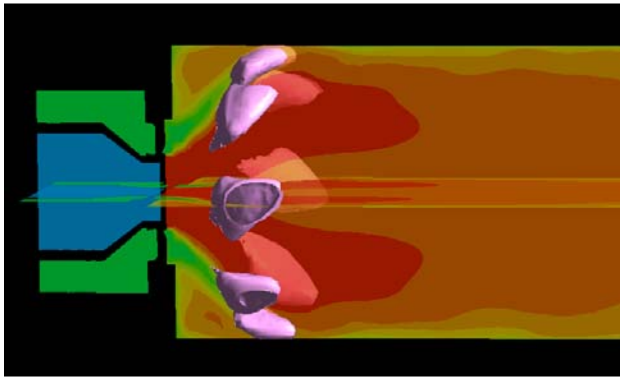
- Rapid iteration on geometry variations
  - RANS
  - Relatively course Tet meshes
  - Reduced mechanism
- Design and off-design cases considered
- Effort to develop a functional 1MWth scale oxy-fuel combustor

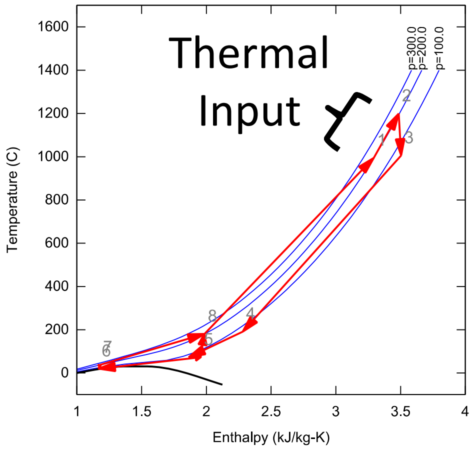
Conclusions

- Simplified combustor geometry presented
  - Not exact geometry which will be manufactured
  - Very useful geometry for trending changes to geometry
- Design appears to work well at design point
- Fast loop ramping case may be too aggressive
- Cold state case needs real gas properties

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