# Simulation of a Direct Fired Oxy-Fuel Combustor for sCO2 Power Cycles

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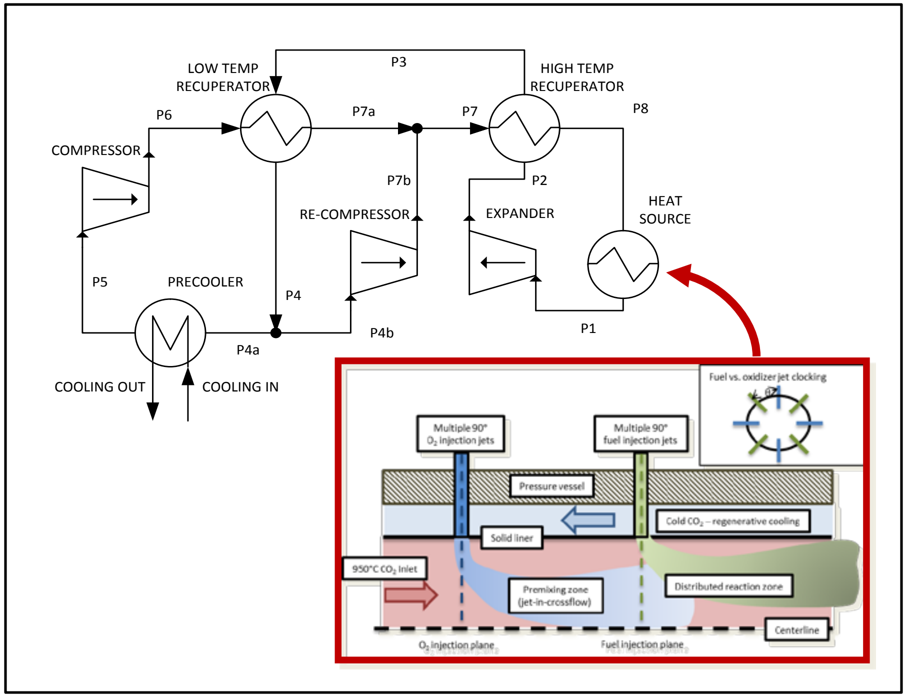
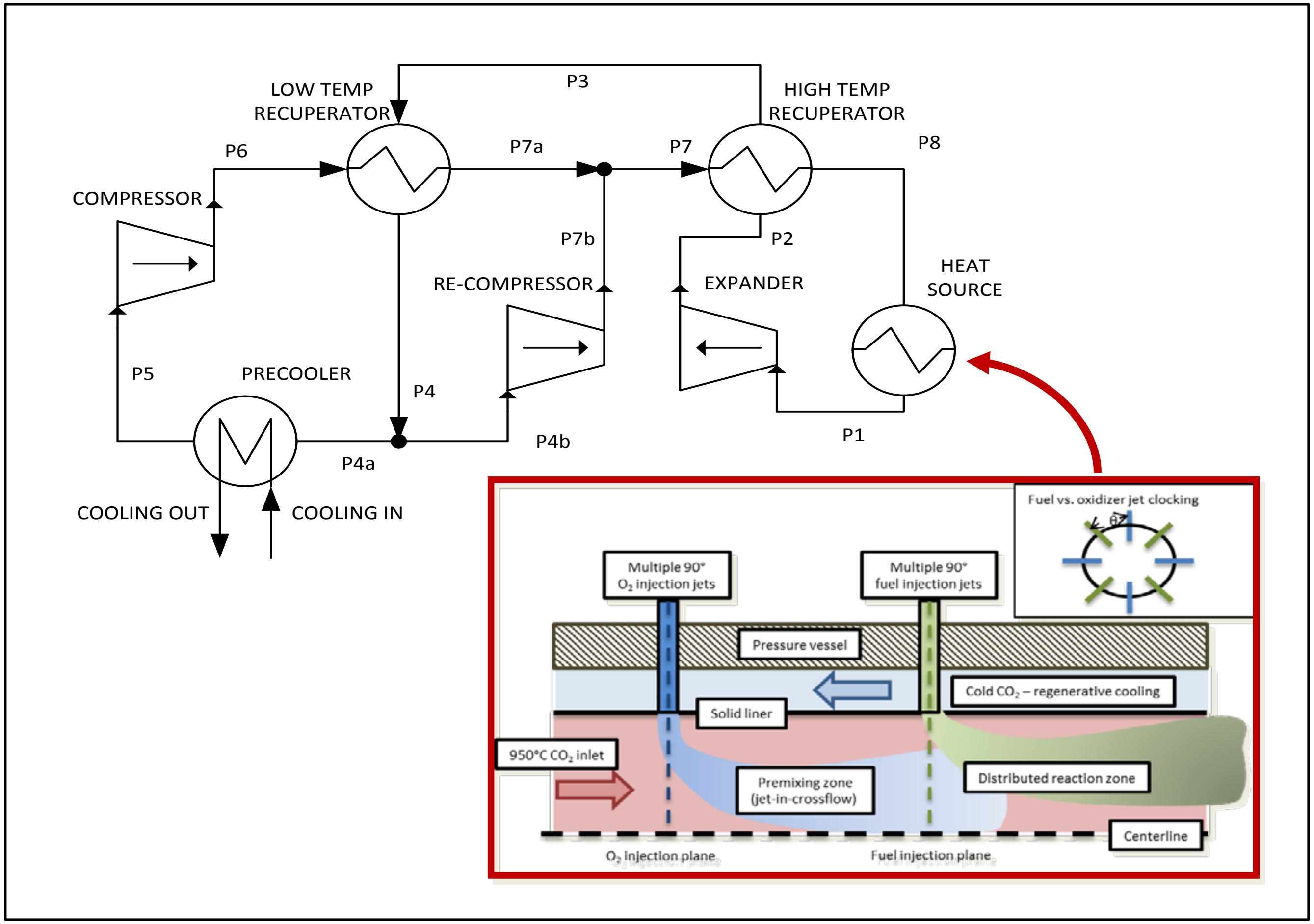
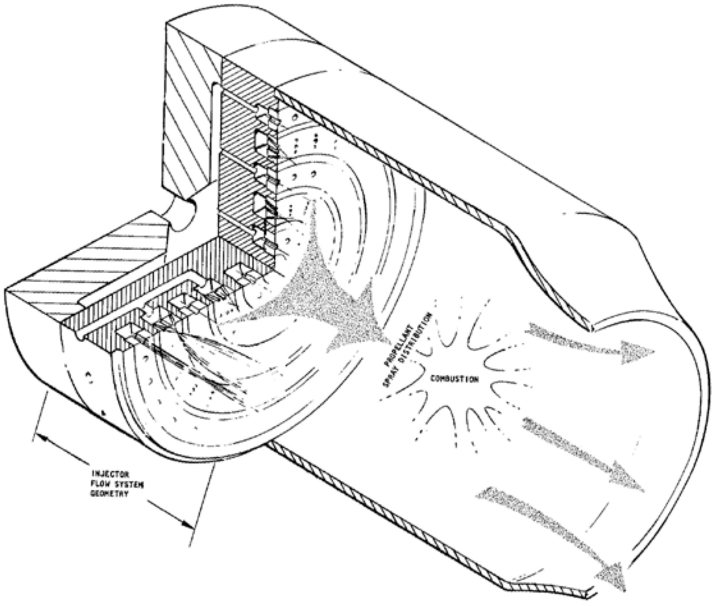


# Why Oxy Combustion?

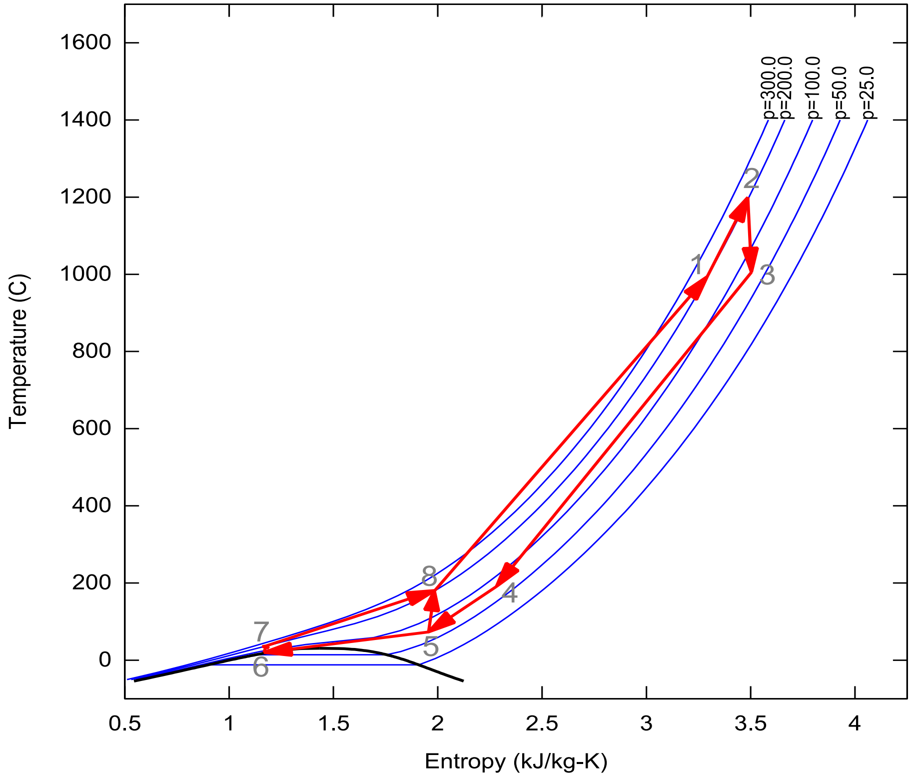


# Oxy-Combustion




- Oxygen + fuel
- Direct fired sCO2 combustors have a third inert stream
- Challenge:
  - Mix and combust fuel with out damaging combustor

# Combustor Conditions




- Narrow thermal input window
- High inlet temperature sCO2
- High inlet pressure sCO2

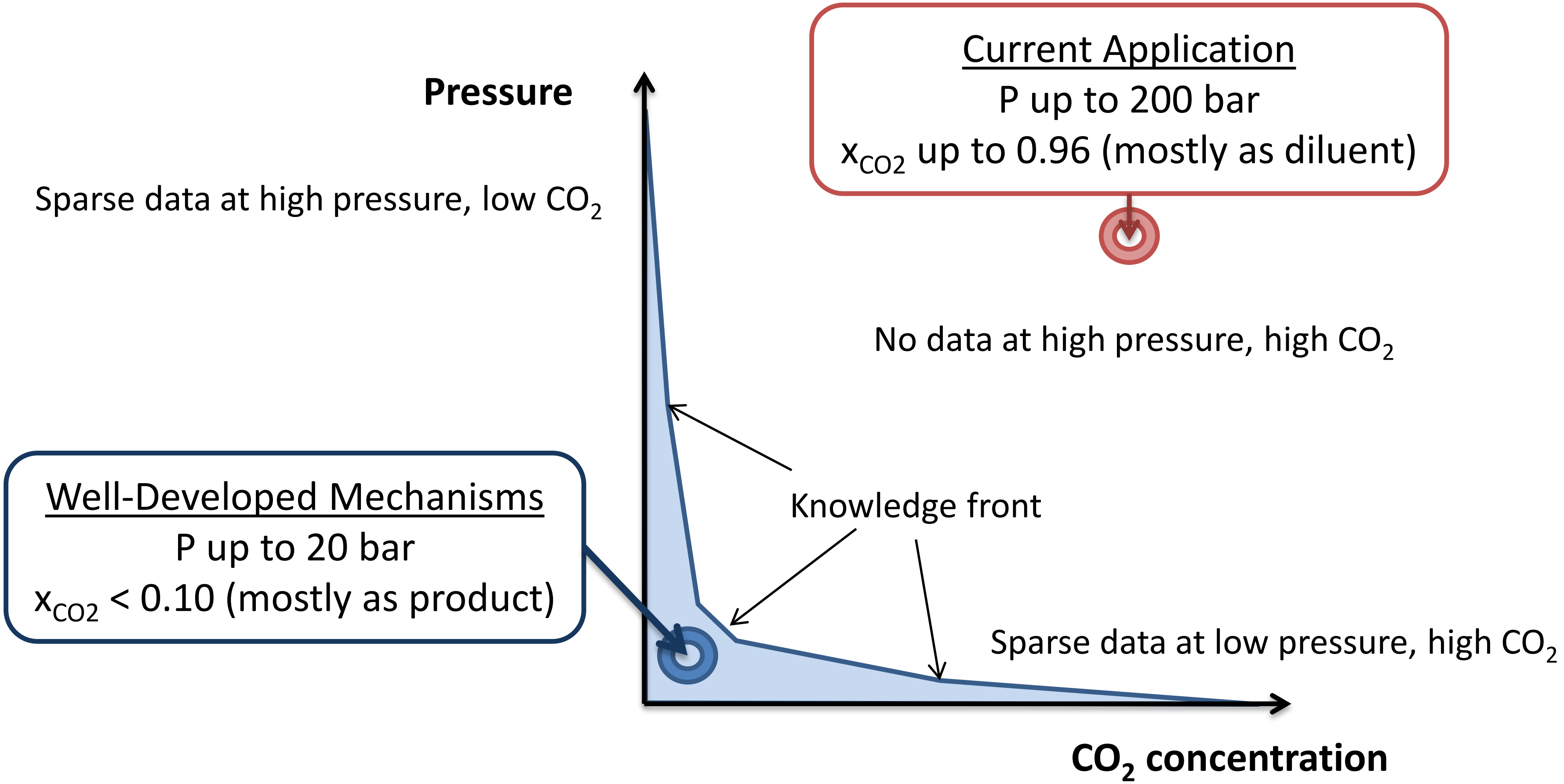
# Oxy-combustion

- Supercritical Oxy-combustion
  - Combustion occurs at supercritical pressures (>74 bar)
  - Required for direct fired $sCO_2$ cycles, compatible with indirect cycles
  - Flue gas cleanup and de-watering at pressure may be challenging
  - Effects of residual water on other system components unknown

# Direct Fired Supercritical Oxy-Combustion

- Cycle analysis and optimization for large scale, direct fired supercritical oxy-combustion for power generation
  - Based on engineering development and technology assessment
  - *Target 52% plant efficiency to compete with NGCC*
  - Requires 64% cycle efficiency + balance of the plant losses
  - *Turbine inlet near 1200°C*
- All cycle configurations are compatible with an *auto-ignition* style combustor for 1200°C Turbine inlet temperatures.

# Kinetics Knowledge Base




No data available at conditions relevant to this application.

# Reduced Order Model

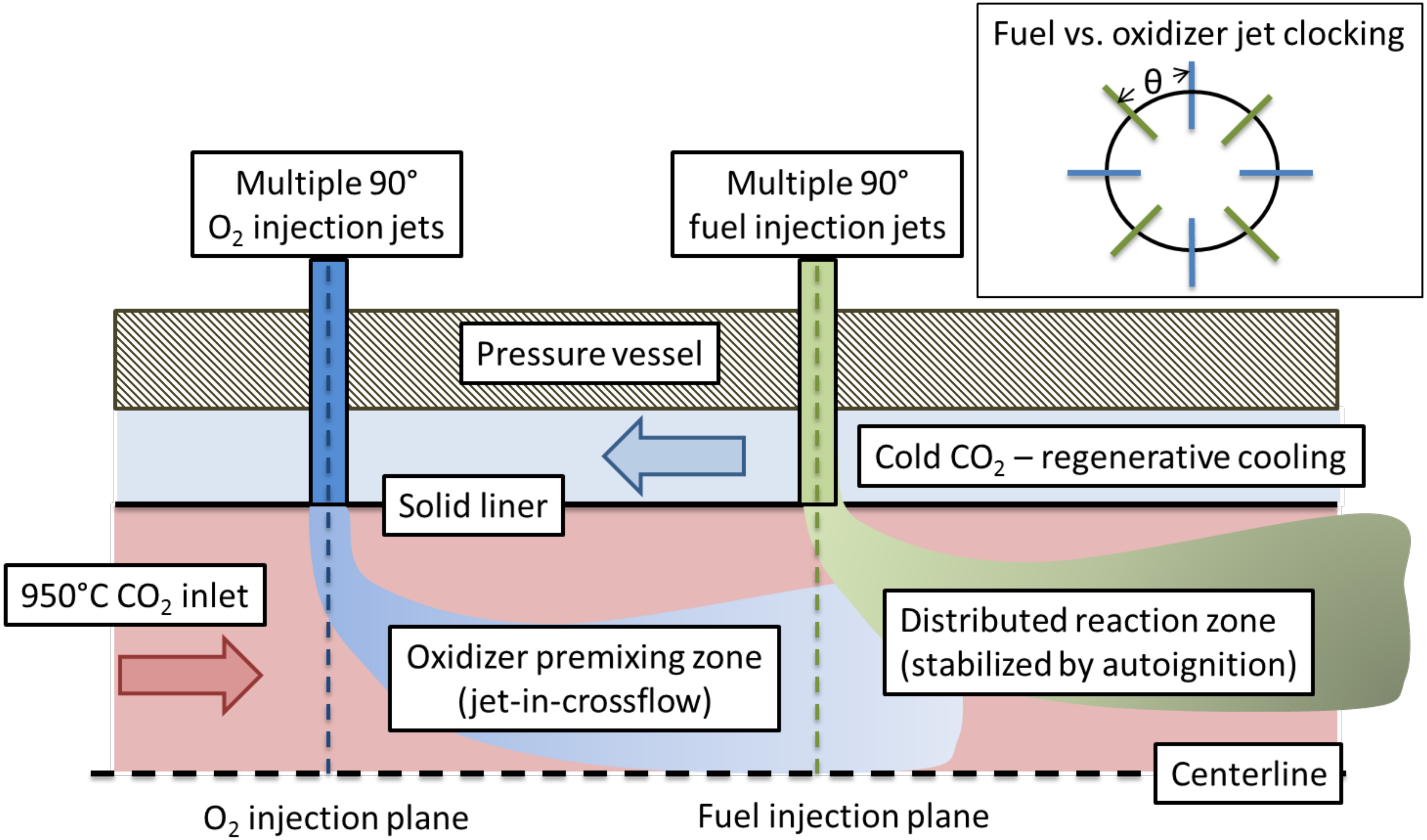
- Equations based on Arrhenius rate equation were tuned to match USC-II model predictions
  - Match auto-ignition delay
  - Match residual CO levels
  - Overall time to complete reaction

Species: 5 Reactions: 2

$CH_4 + 1.5\ O_2 \rightarrow 2\ H_2O + CO$  $r_1 = A_1 T^{n1} e^{-\frac{E_{a_1}}{RT}} [CH_4]^{a1} [O_2]^{b1}$

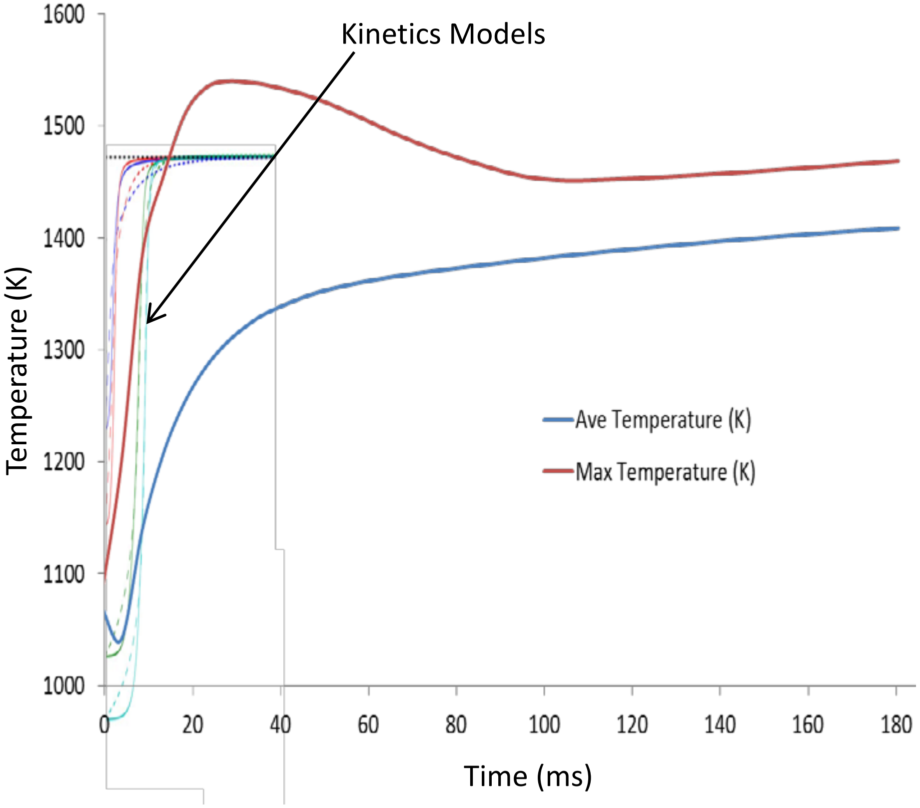
$CO + 0.5\ O_2 \rightarrow CO_2$  $r_2 = A_2 T^{n2} e^{-\frac{E_{a_2}}{RT}} [CO]^{a2} [O_2]^{b2}$

# Initial Combustor Concept



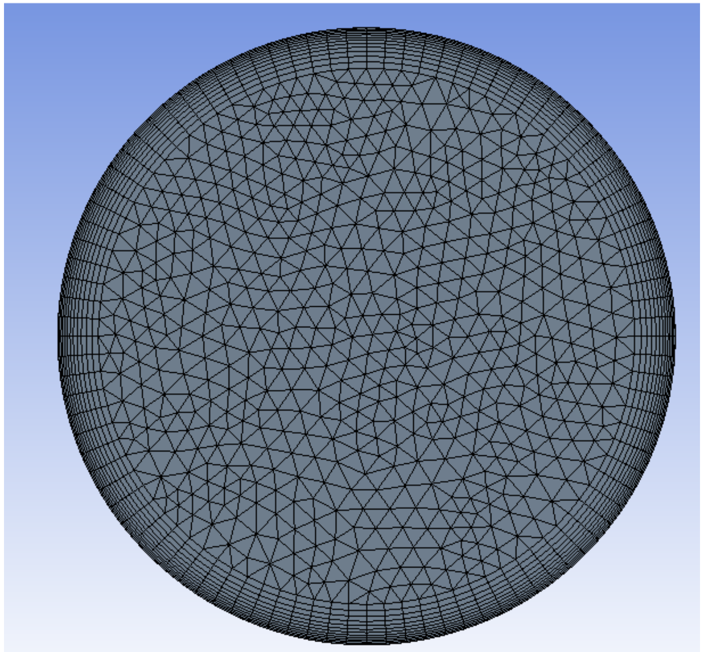
# Mixing vs. Kinetics Time Scales

- Kinetic time scales are much smaller than physical mixing time scales
- This means that domain must be much longer than kinetics alone dictate
- Use of CFD with finite rate chemistry captures both these effects



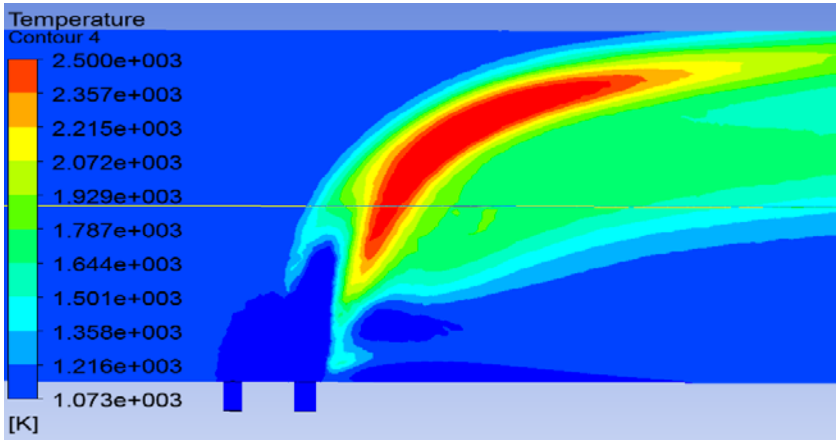
# CFD Setup

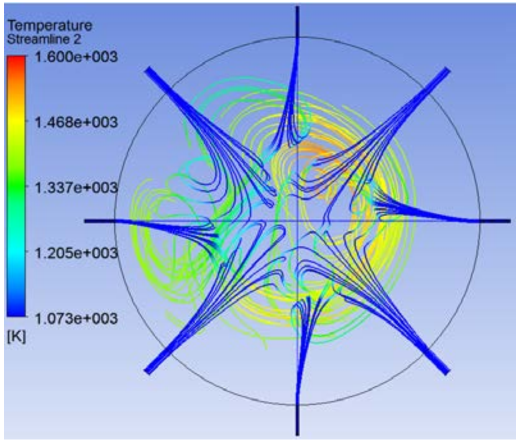
- Ansys CFX 16.2
- Unstructured mesh
  - Boundary layer and injection region refinement
  - 4 million elements
  - Mesh sizes from 2 to 17 million elements for independence study

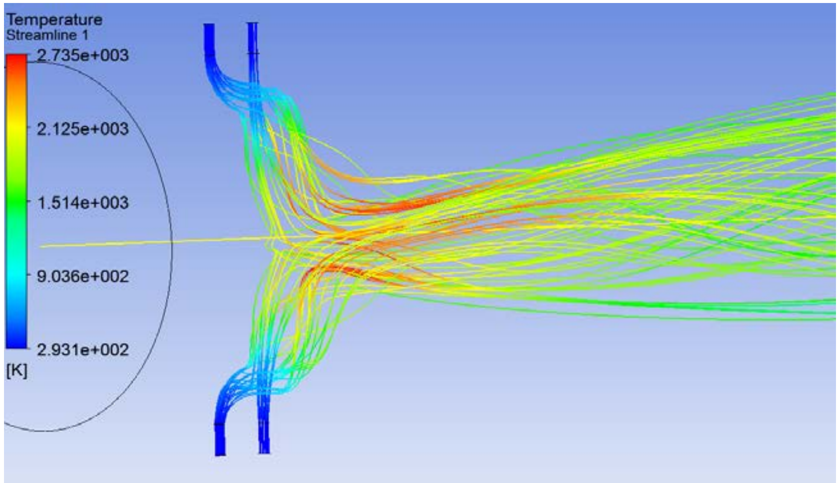


# Injector Hole Sizing

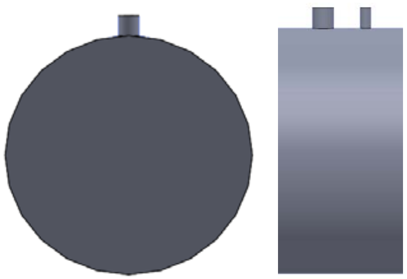
- Simple correlations based on same density fluids
- Informed iterative sizing

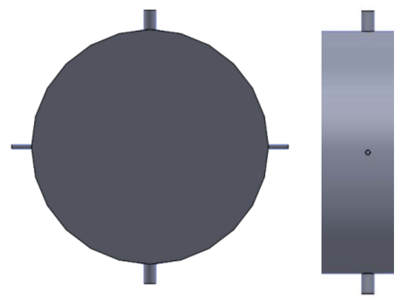


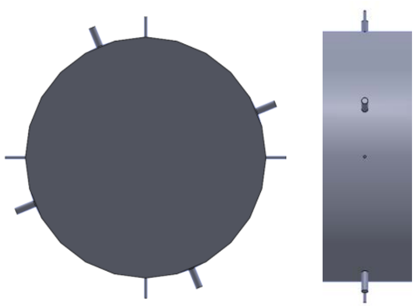



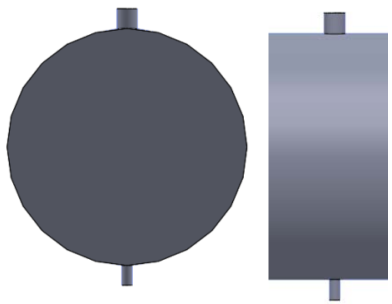



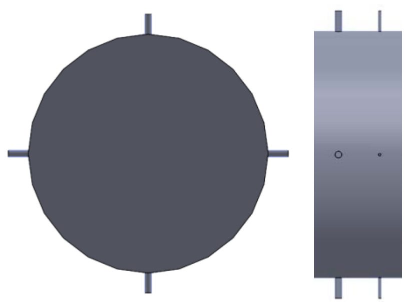
# Inlet Geometries

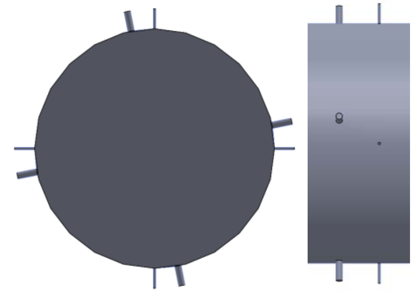

1 Hole Aligned

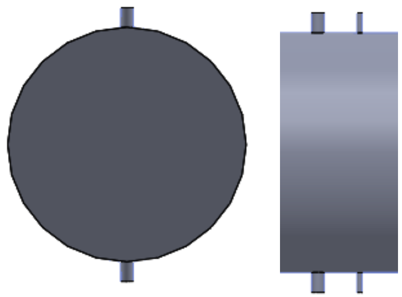

2 Hole Clocked

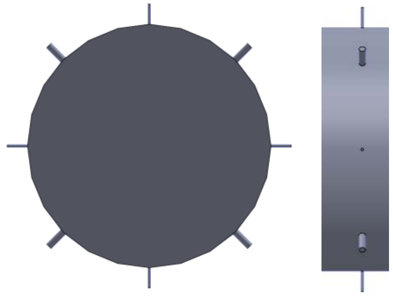

4 Hole 22.5° Clocked


1 Hole Clocked


4 Hole Aligned

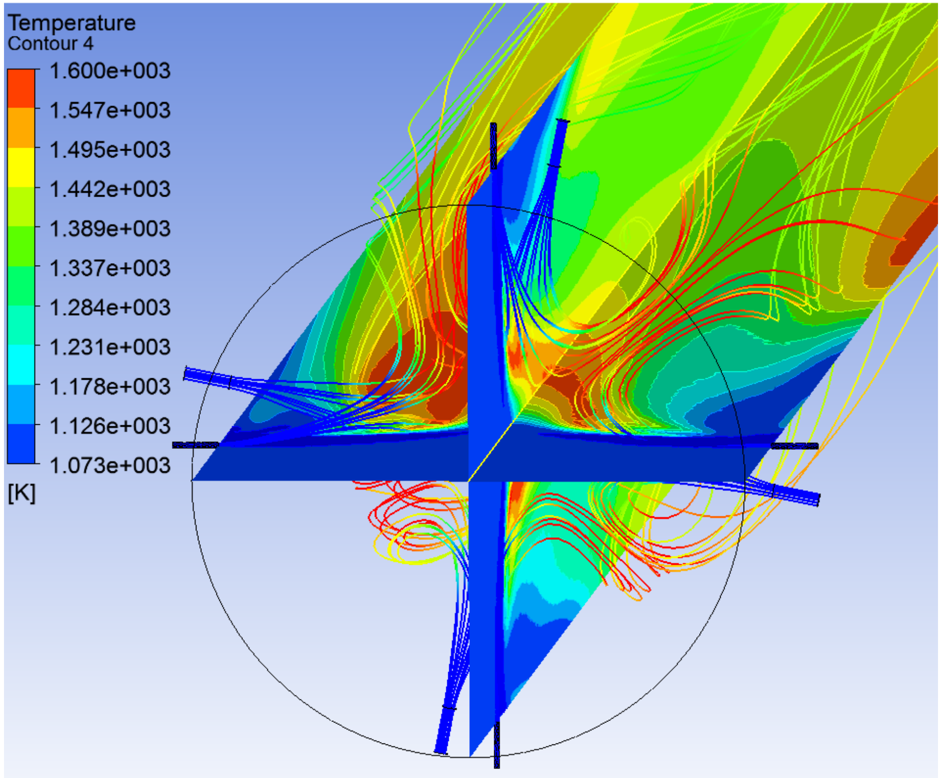

4 Hole 11.25° Clocked

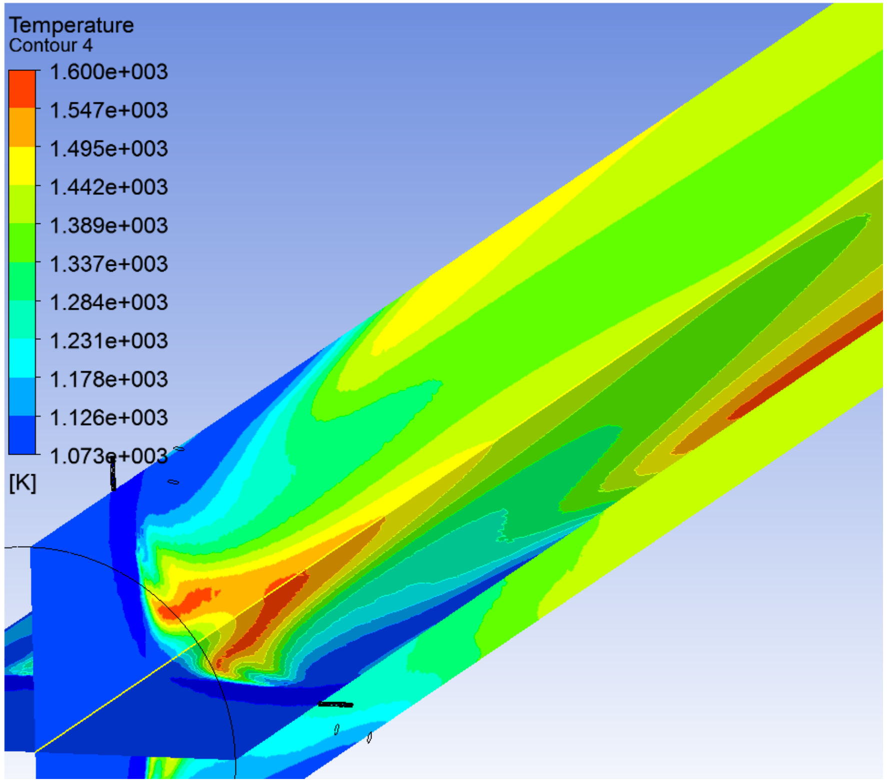

2 Hole Aligned

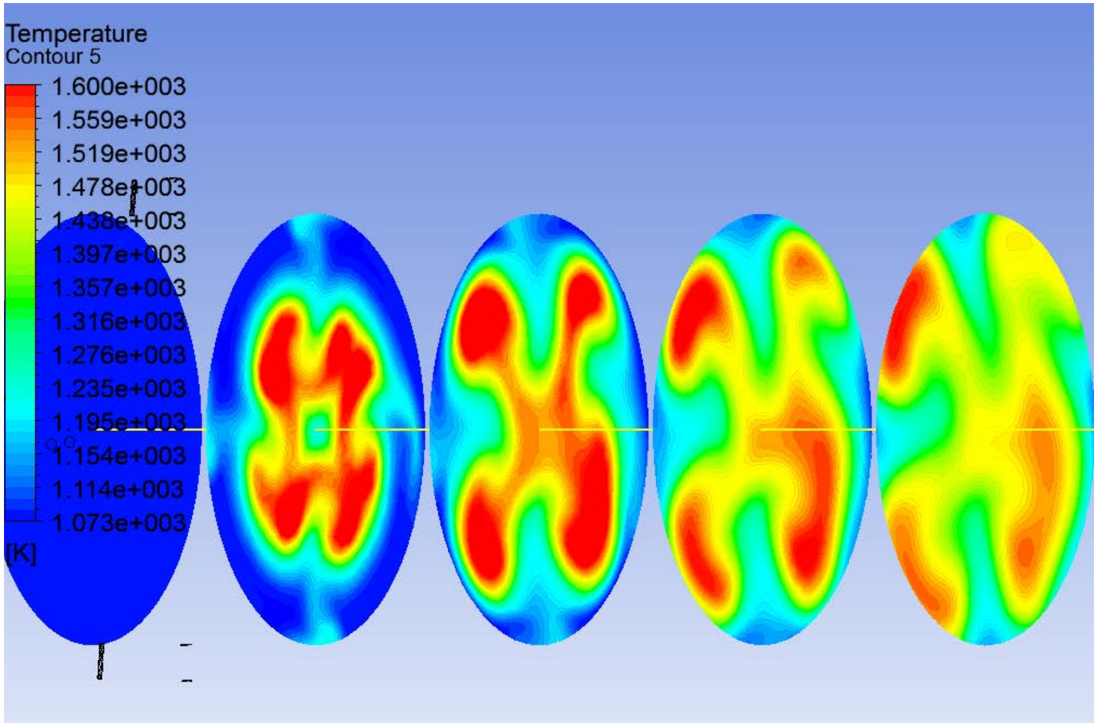

4 Hole 45° Clocked

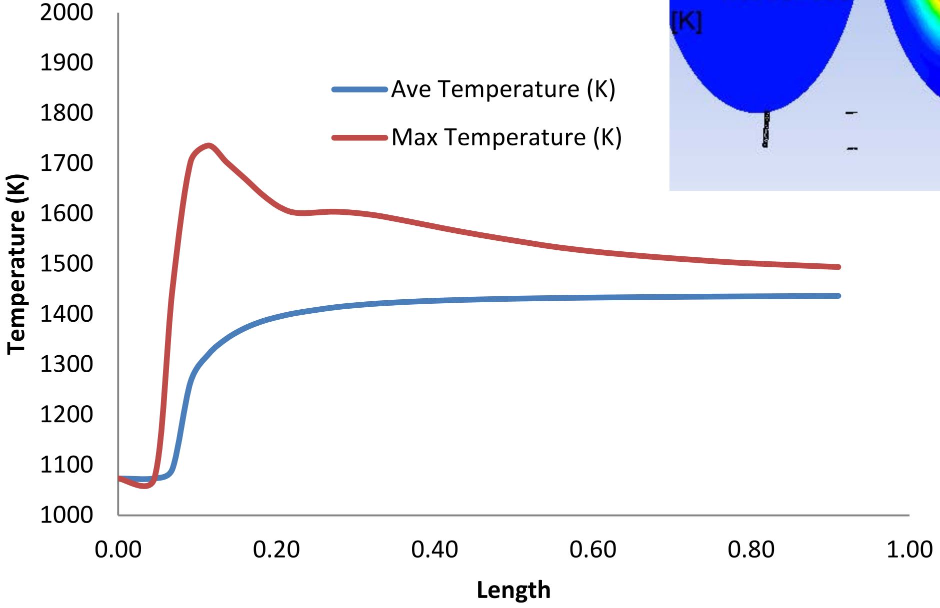
In all cases the smaller hole is the fuel delivery port and the larger is the hole is the oxygen port.

# Temperature in 11.25° Clocked Case

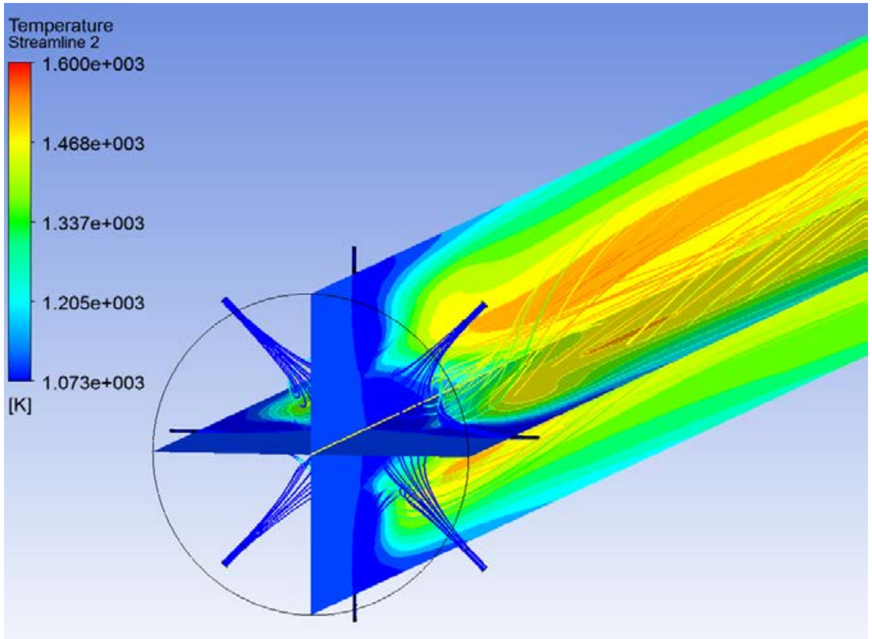


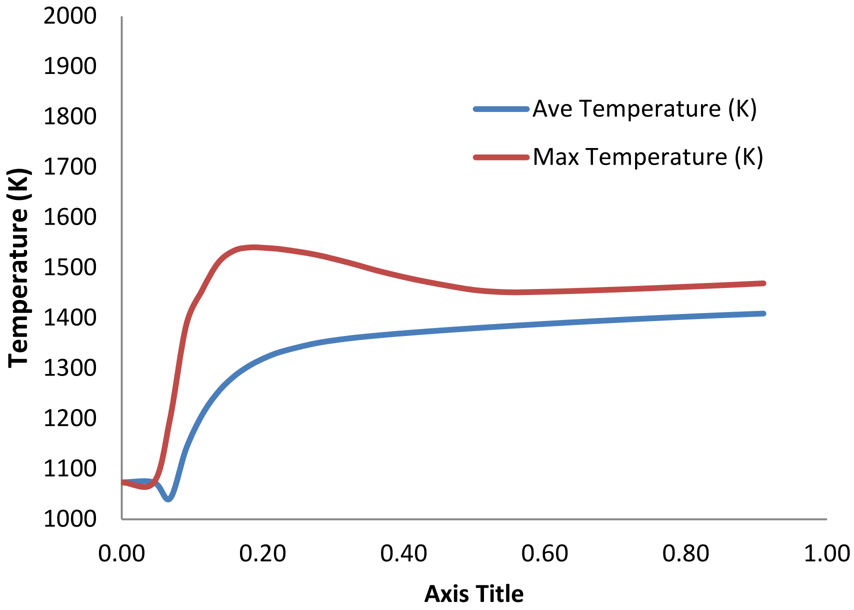



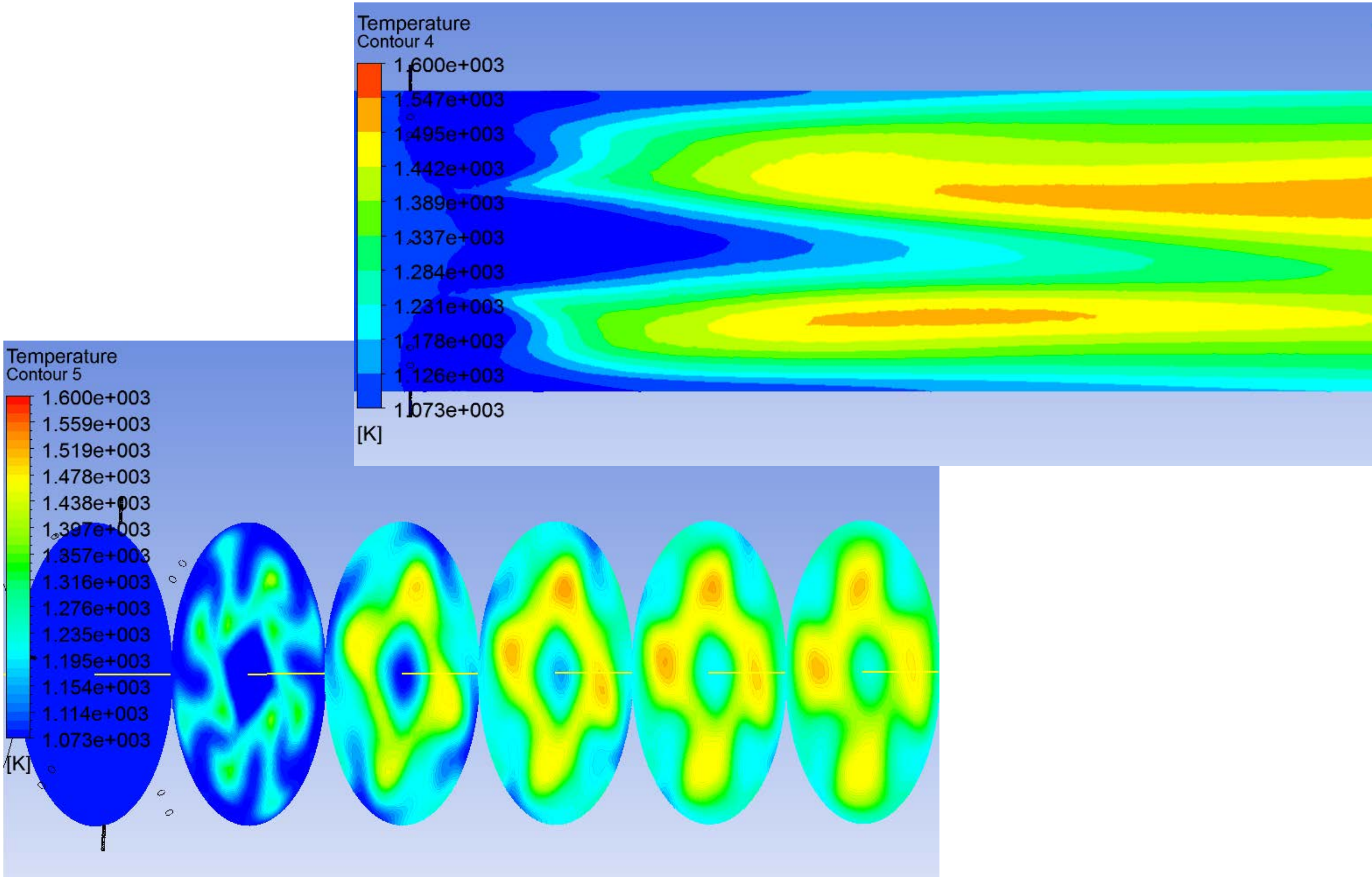

Temperature
Contour 5
1.600e+003
1.559e+003
1.519e+003
1.478e+003
1.438e+003
1.397e+003
1.357e+003
1.316e+003
1.276e+003
1.235e+003
1.195e+003
1.154e+003
1.114e+003
1.073e+003
[K]


Ave Temperature (K)
Max Temperature (K)
Temperature (K)
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
0.00
0.20
0.40
0.60
0.80
1.00
Length

# Temperature in 45° Clocked Case

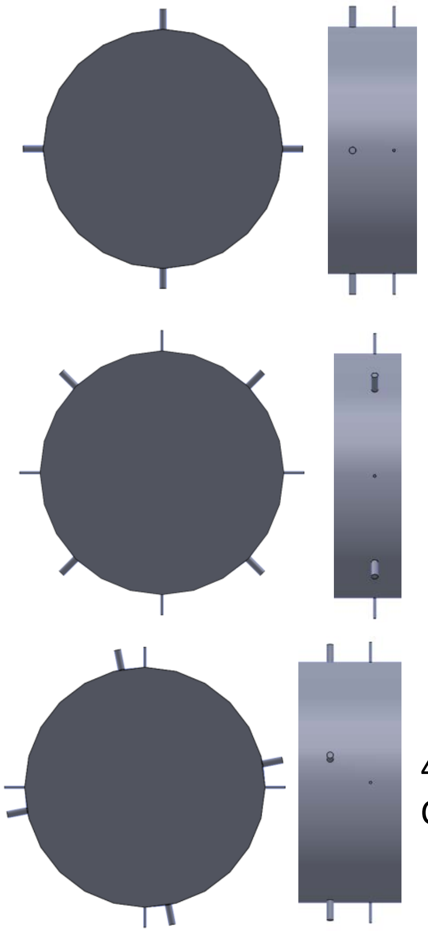




Temperature
Contour 4
1.600e+003
1.547e+003
1.495e+003
1.442e+003
1.389e+003
1.337e+003
1.284e+003
1.231e+003
1.178e+003
1.126e+003
1.073e+003
[K]
Temperature
Contour 5
1.600e+003
1.559e+003
1.519e+003
1.478e+003
1.438e+003
1.397e+003
1.357e+003
1.316e+003
1.276e+003
1.235e+003
1.195e+003
1.154e+003
1.114e+003
1.073e+003
[K]

# Change Injection Spacing

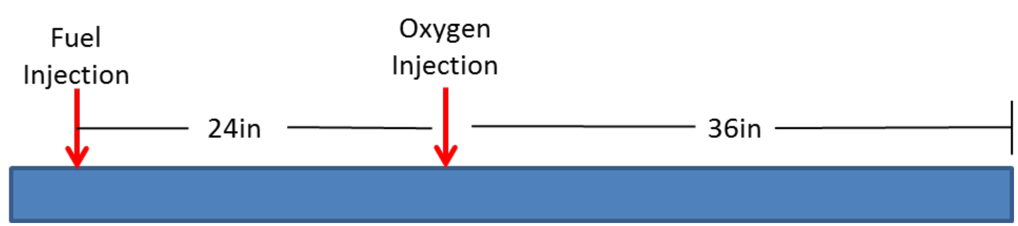


4 Hole Aligned

4 Hole 45° Clocked

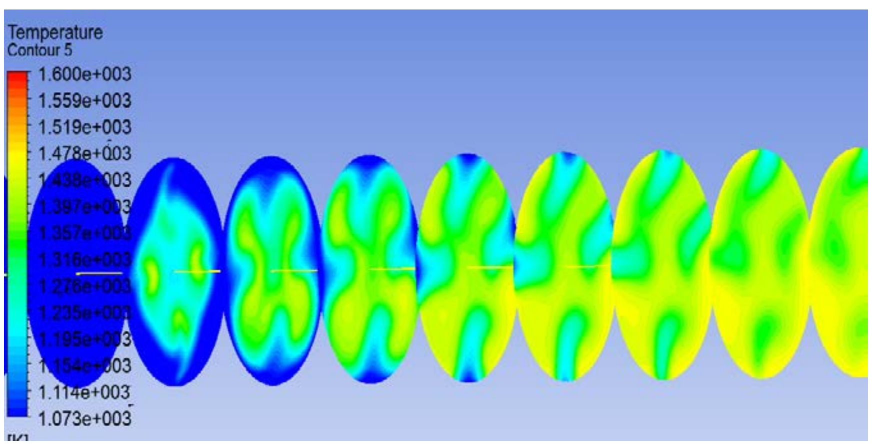
4 Hole 11.25° Clocked

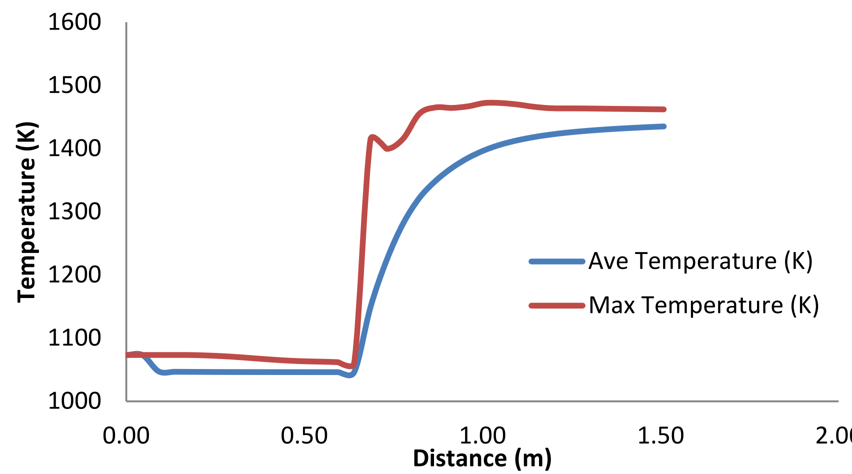
- Realization that we don't need to inject oxygen and fuel at same location
- Auto-ignition allows even small concentrations of fuel+oxidizer to react



# Fuel Injection 24in Upstream

- Fuel well mixed throughout combustor before oxygen
- Allows hydrocarbon “cracking” before oxygen injection
- Cooler max temperatures
- Very good mixing at outlet
- Very low unburnt fuel percentage



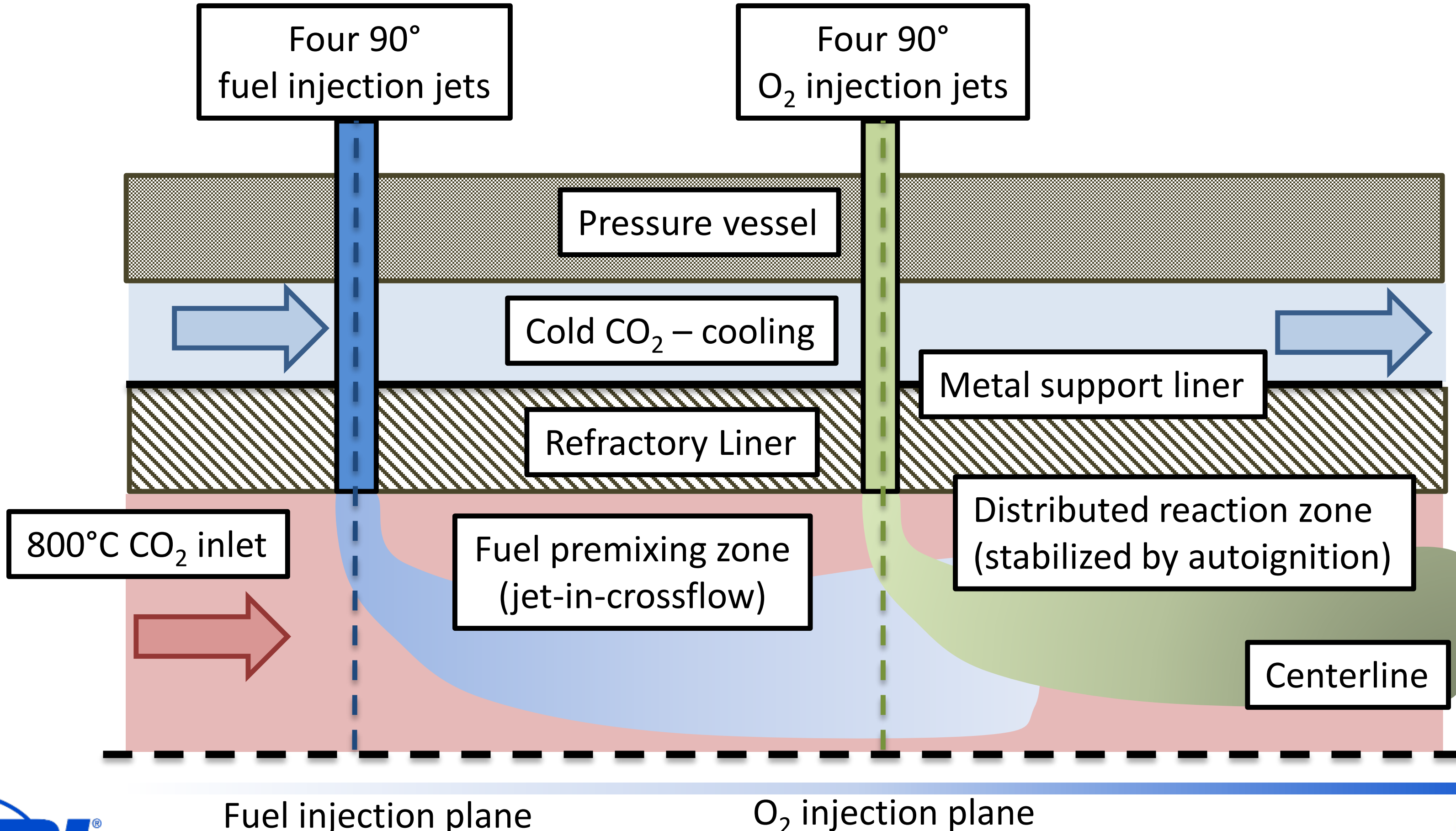



# Comparison of Results

| | Max. Wall Temperature (K) | Max. Temperature (K) | Temperature Spread at Outlet | Percent Unburnt Fuel |
|---|---|---|---|---|
| 1-Hole Aligned | 1,821 | 2,942 | - | 2.49 |
| 1-Hole Clocked | 1,849 | 1,866 | - | 5.41 |
| 2-Hole Aligned | 1,549 | 3,000 | - | 5.64 |
| 2-Hole Clocked | 1,653 | 1,653 | - | 11.13 |
| 4-Hole 45° Clocked | 1,468 | 1,541 | 123 | 6.25 |
| 4-Hole 22.5° Clocked | 1,613 | 1,724 | 110 | 1.80 |
| 4-Hole 11.25° Clocked | 1,604 | 1,740 | 98 | 2.68 |
| 4-Hole Aligned | 1,593 | 1,885 | 134 | 2.27 |
| 4-Hole 45° Clocked (Modified Hole Size) | 1,440 | 1,547 | 158 | 6.82 |
| 4-Hole 24" Upstream $CH_4$ Injection | 1,474 | 1,474 | 78 | 2.77 |
| 4-Hole 12" Upstream $CH_4$ Injection | 1,546 | 1,546 | 197 | 4.19 |
| 4-Hole 24" Upstream $CH_4$ Injection 3% $O_2$ | 1,476 | 1,476 | 66 | 1.92 |

- Four fuel ports located 24in upstream of oxygen injection was the best design

# Refined Design Concept



# QUESTIONS?