# Characterizing Impacts of High Temperature and Pressures in Oxy-Coal Combustion Systems

Department of Energy under Cooperative Agreement No. DE-FE0025168

For Energy and Environmental Solutions

REACTION ENGINEERING INTERNATIONAL

2017 NETL $CO_2$ Capture Technology Project Review Meeting

Omni William Penn Hotel; Pittsburgh, PA

August 25, 2017

# HTHP Program

## Enabling Technologies for Advanced Oxy-Coal Combustion Systems

**Characterizing Impacts of High Temperature and Pressures in Oxy-Coal Combustion Systems (HTHP)**

*September, 2015 – August 2018*

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THE UNIVERSITY OF UTAH

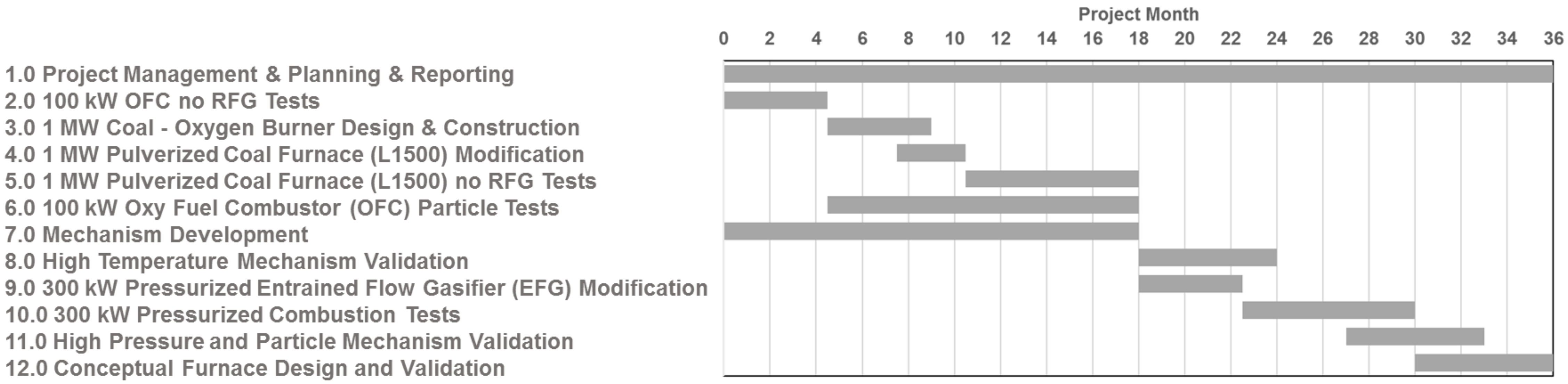
PRAXAIR

Jupiter Oxygen

- Key second generation candidates for $CO_2$ capture include high temperature and pressurized oxy-firing of coal
- Promising technologies because of potential to increase efficiency, lower capital costs, avoid air ingress and reduce oxygen requirements
- Unquantified challenges exist in the practical utilization of these technologies

# HTHP Timeline and Budget

## September 1, 2015 – August 31, 2018



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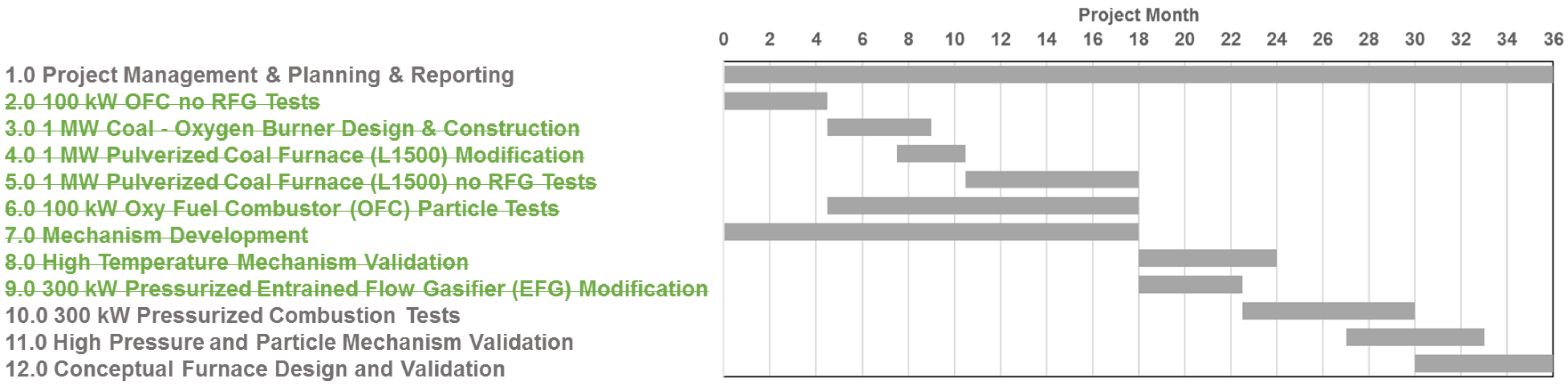
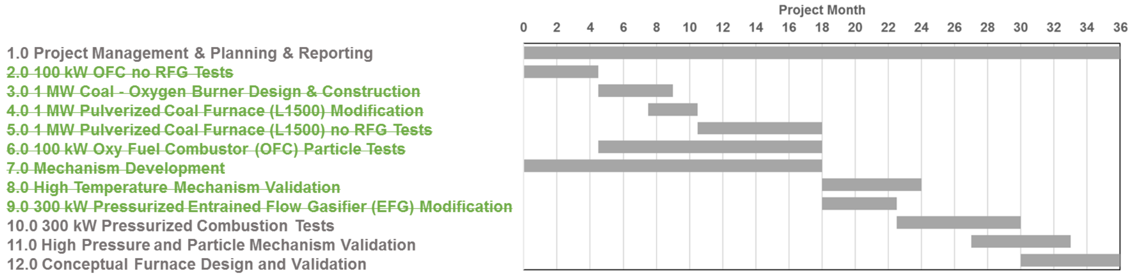
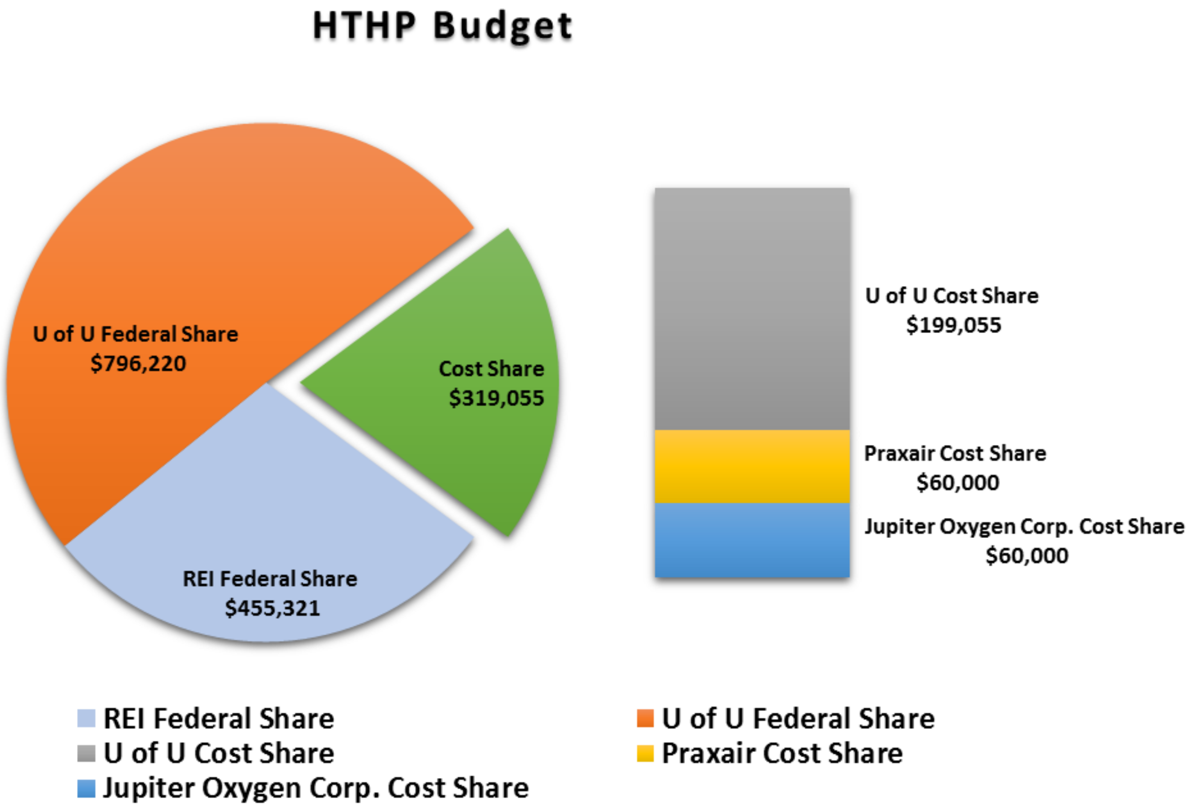


# HTHP Timeline and Budget

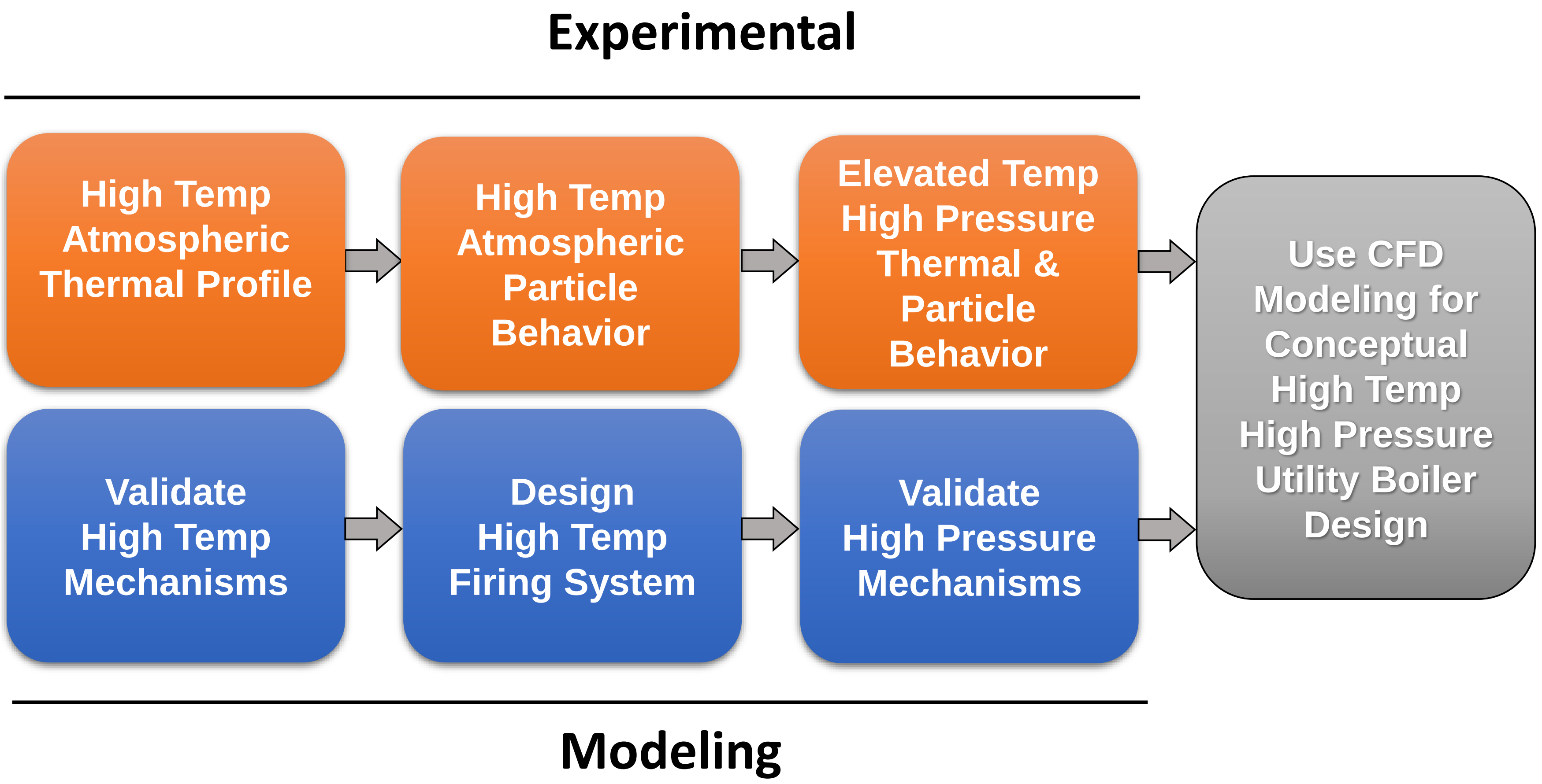



**Total Budget**
**$1,570,596**

**Total Federal**
**$1,251,541**



# Program Approach



# Technical Approach

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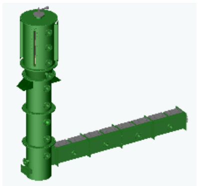
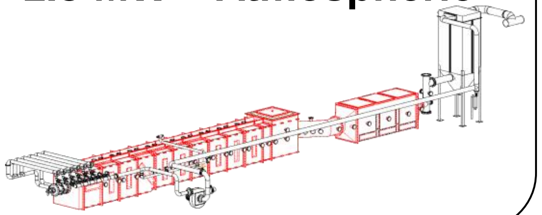
**Experimental**

**High Temp (Minimum Recycle)**

**Oxy-fuel Combustor**
**100 kW – Atmospheric**



**L1500 Multi-fuel Furnace**
**1.5 MW – Atmospheric**



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**Modeling**

**Design High Temp Firing System**

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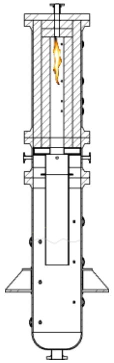
**Experimental**

**Elevated Temperature & Pressurized (17 bar)**

**300 kW <u>Pressurized</u>**
**Entrained Flow Reactor**



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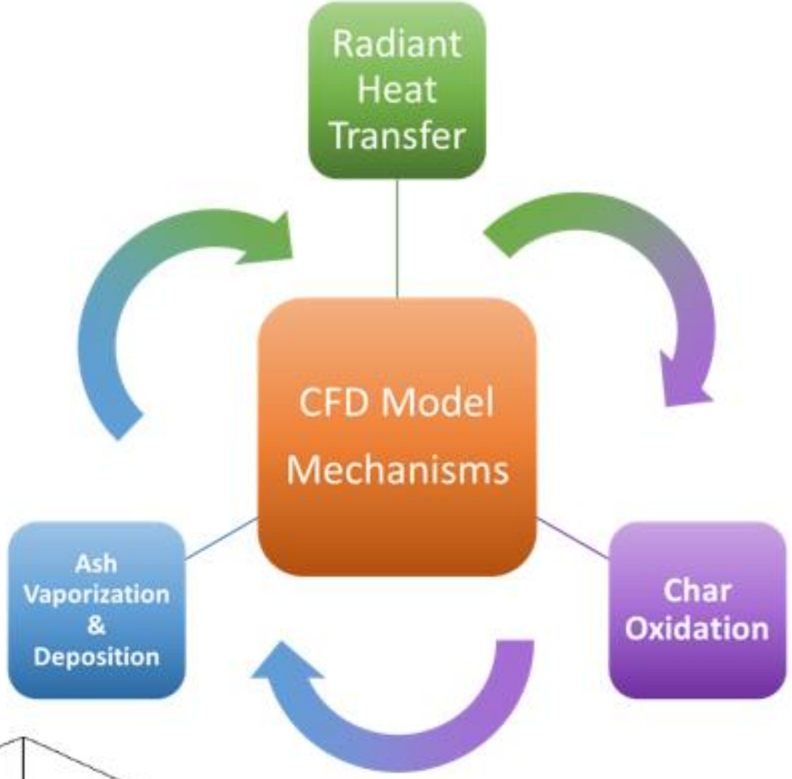
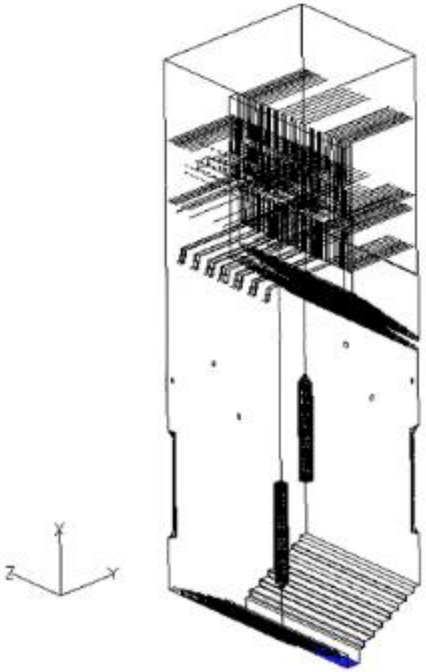
**Modeling**

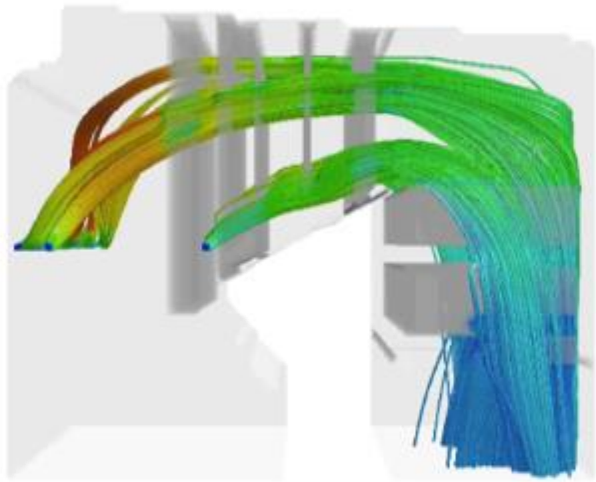
**Design Pressurized Firing System**

# CFD Tools: GLACIER

- REI's in-house CFD software
- Developed specifically for application to solid fuel fired furnaces and boilers
- 3D, steady-state, turbulent flows
- Coupling between turbulent fluid mechanics, radiative and convective heat transfer, homogeneous and heterogeneous reactions
- Statistical description of particles including particle dispersion
- Pollutant formation kinetics for NOx, SOx, CO, Hg and fine particles
- Continually evolving including recent developments for atmospheric pressure and pressurized oxy-coal applications





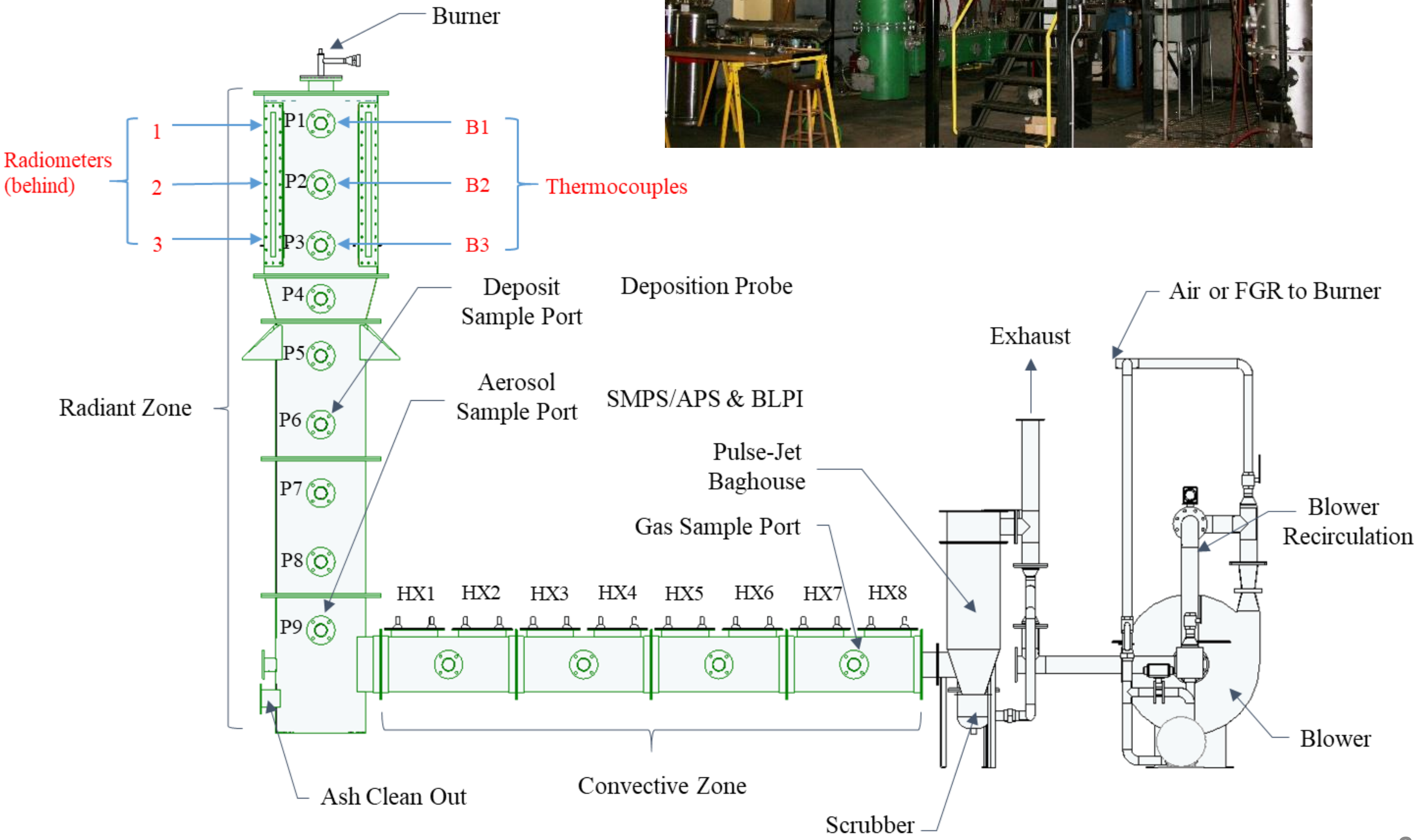
# 100 kW Oxy-Fuel Combustor

**Specifications**

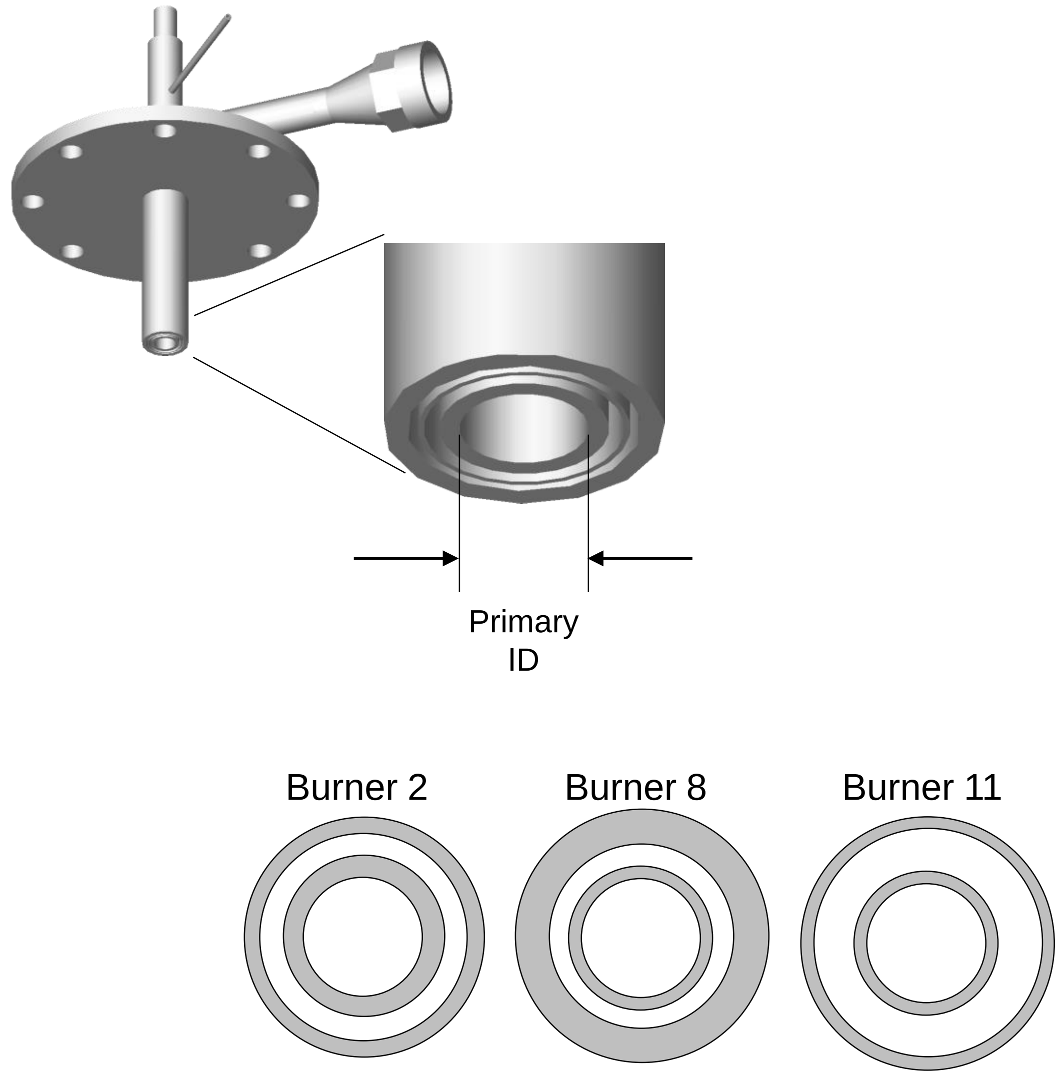
- 100 kW (0.25 MBtu/hr) Firing Rate
- Main Burner Zone 20 in x 48 in
- Quartz Windows for Optical Access of Flame
- Vertical Height 12.5 ft
- Horizontal Convective Section 12 ft

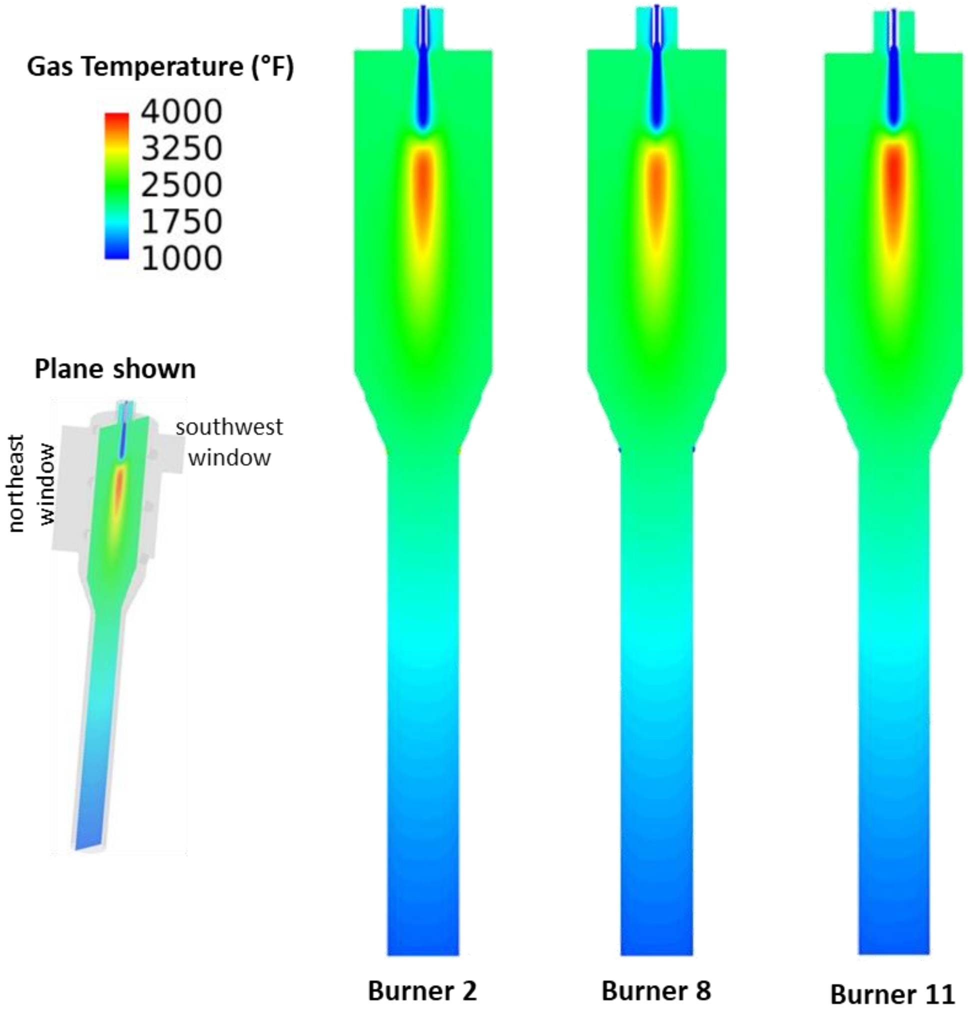
**Research**

- Ash Formation
  - Aerosols
  - Deposition
  - Trace Elements
- Sorbent Development
- Optical Diagnostics
  - Flame, Radiation & Flow Field



# CFD Model Predictions (Validation)



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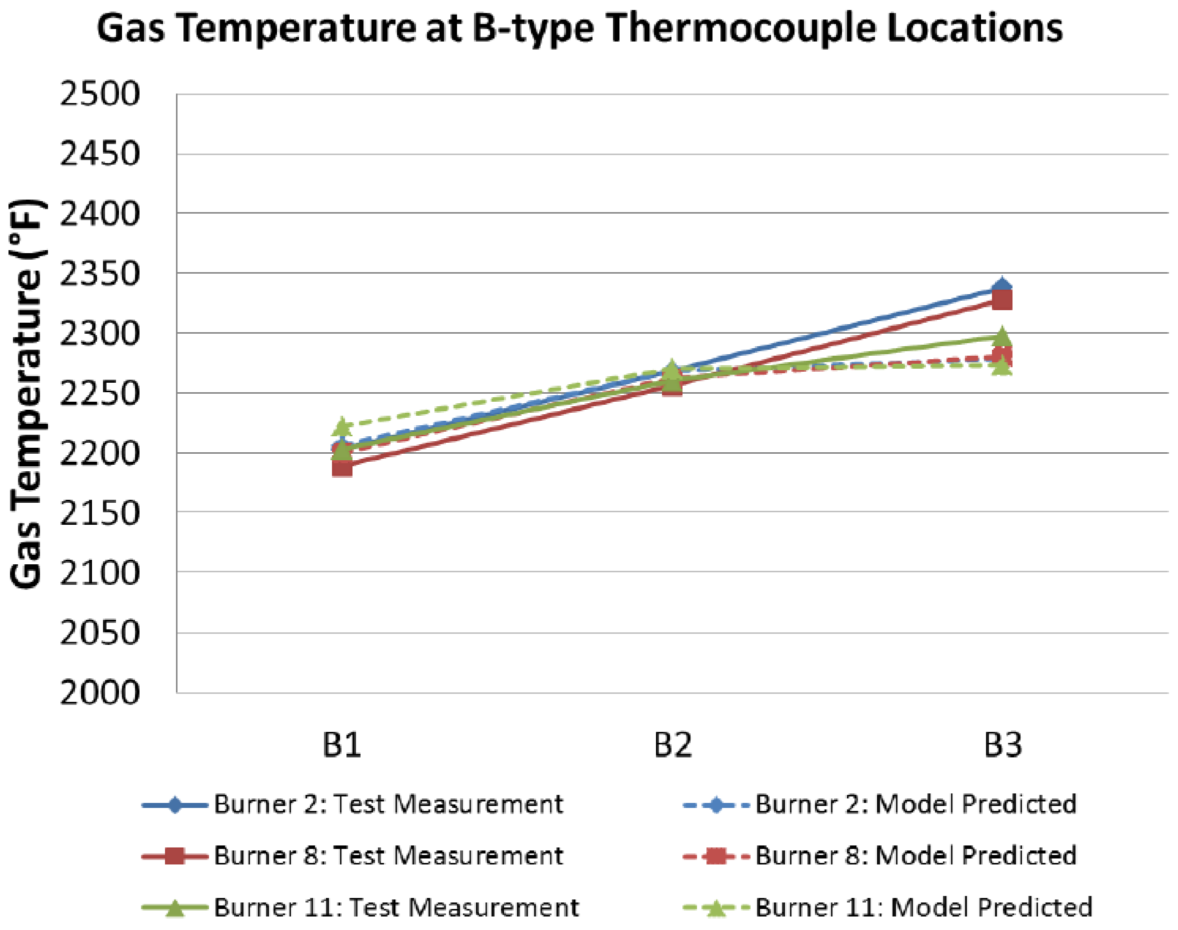
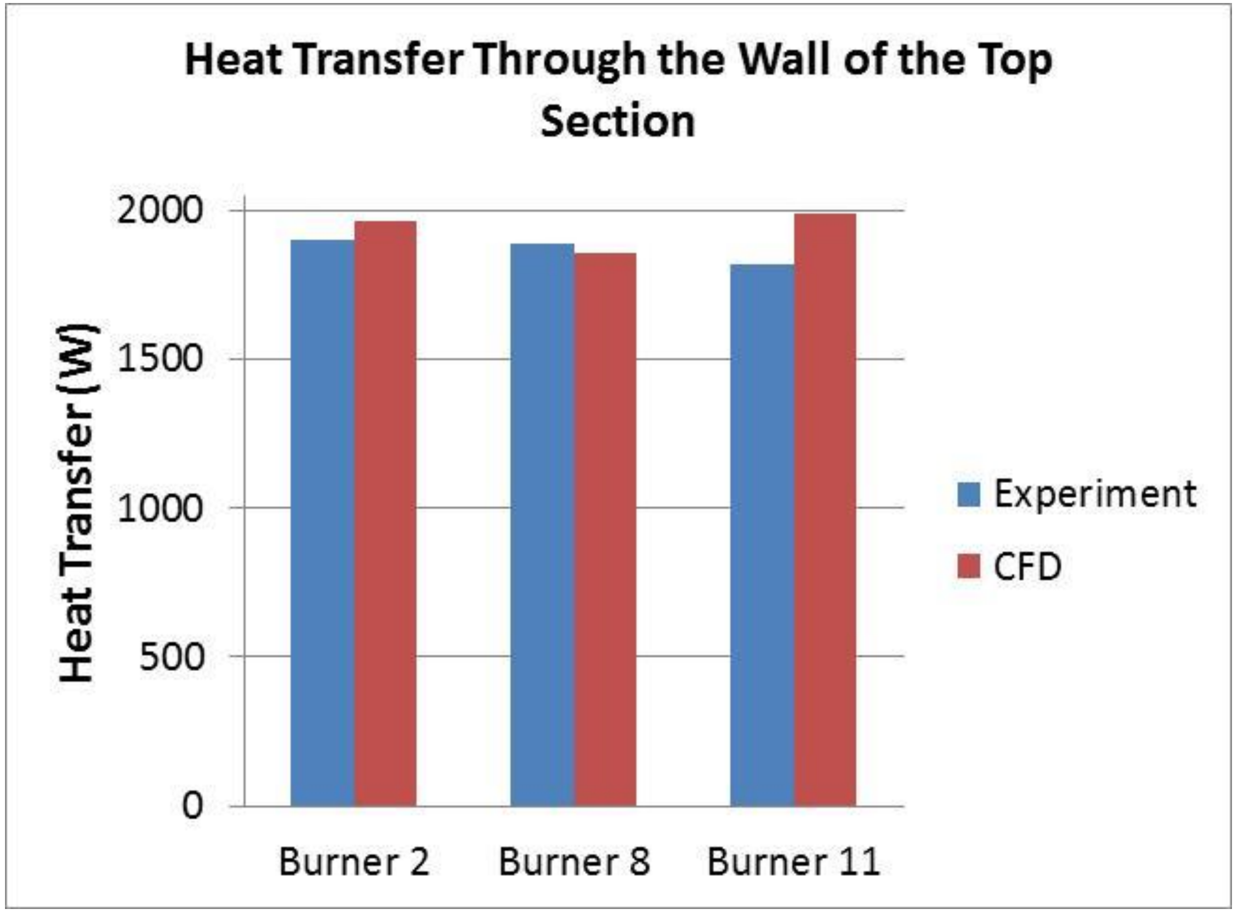
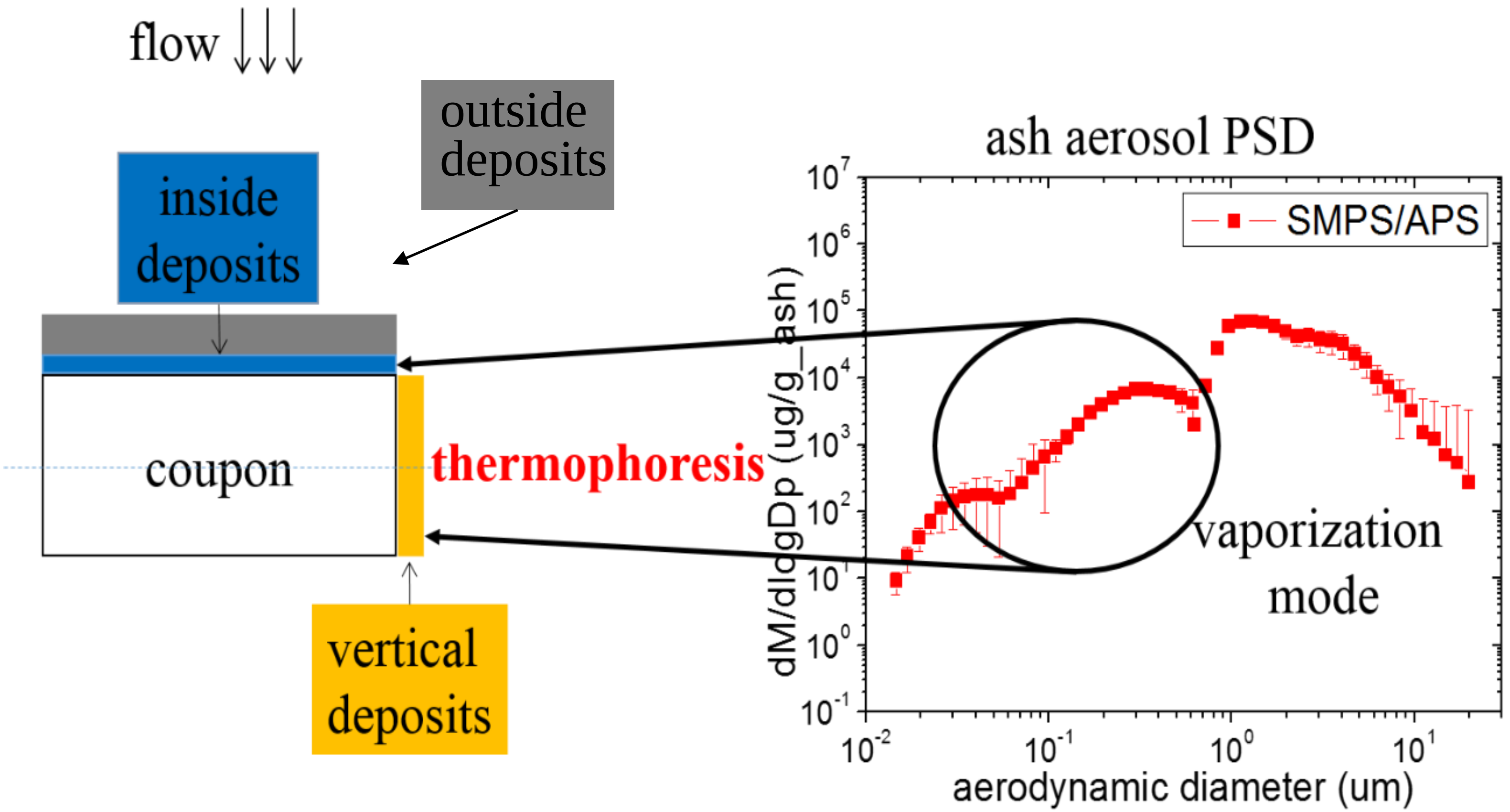
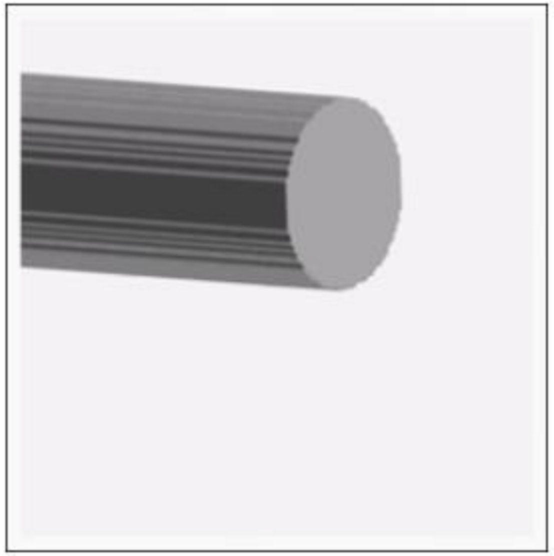


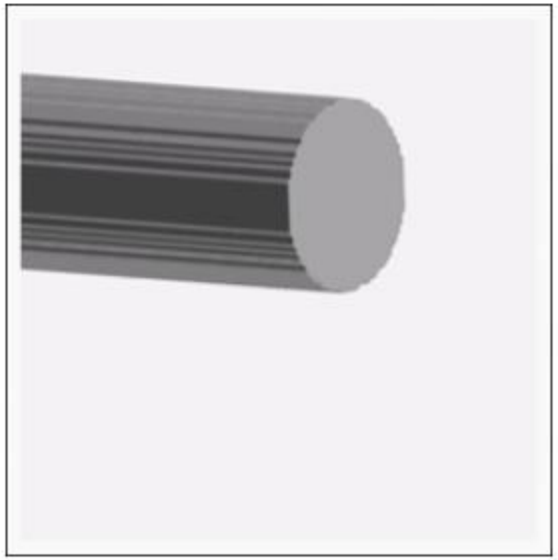




K-type thermocouples located in the top section (3 flush with the inside wall, 3 at the midpoint between the inside wall and outside shell).

# Ash aerosol PSD and deposits (vertical, inside and outside)



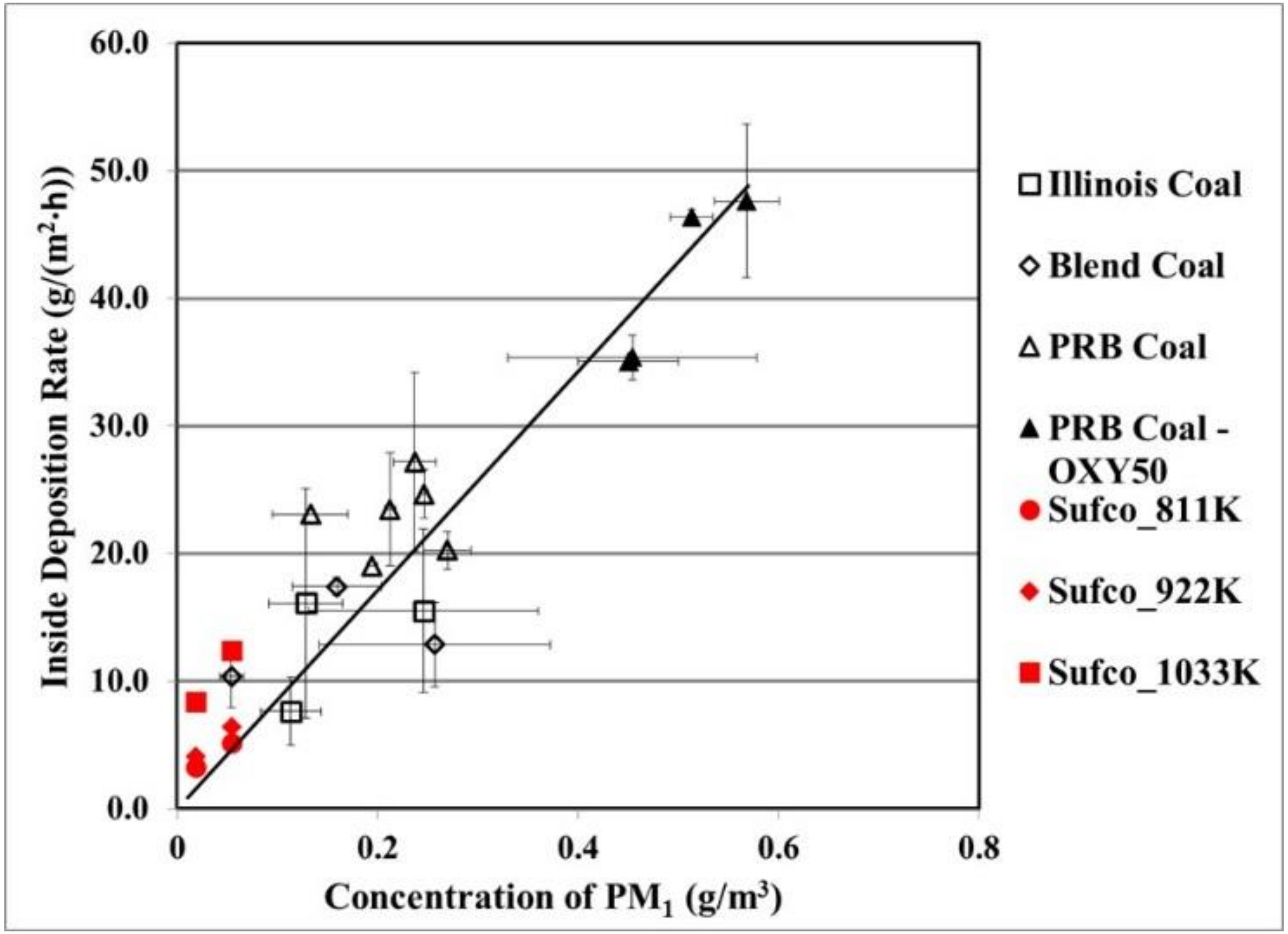


Horizontal deposits:

Outside deposits: loosely bound, easily removed by vigorous shaking.

Inside deposits: tightly bound, removed only by scraping.

# Sample ash deposition rate results from DOE Cooperative Agreement No: DE-FE0025168




*Ref.*
*Z. Zhan and J. O. L. Wendt, "Role of Sodium in Coal in Determining Deposition Rates," Energy & Fuels, 2017.*

# 1.5 MW CFD-Based Burner Design

*Pulverized Coal Combustor (L1500)*

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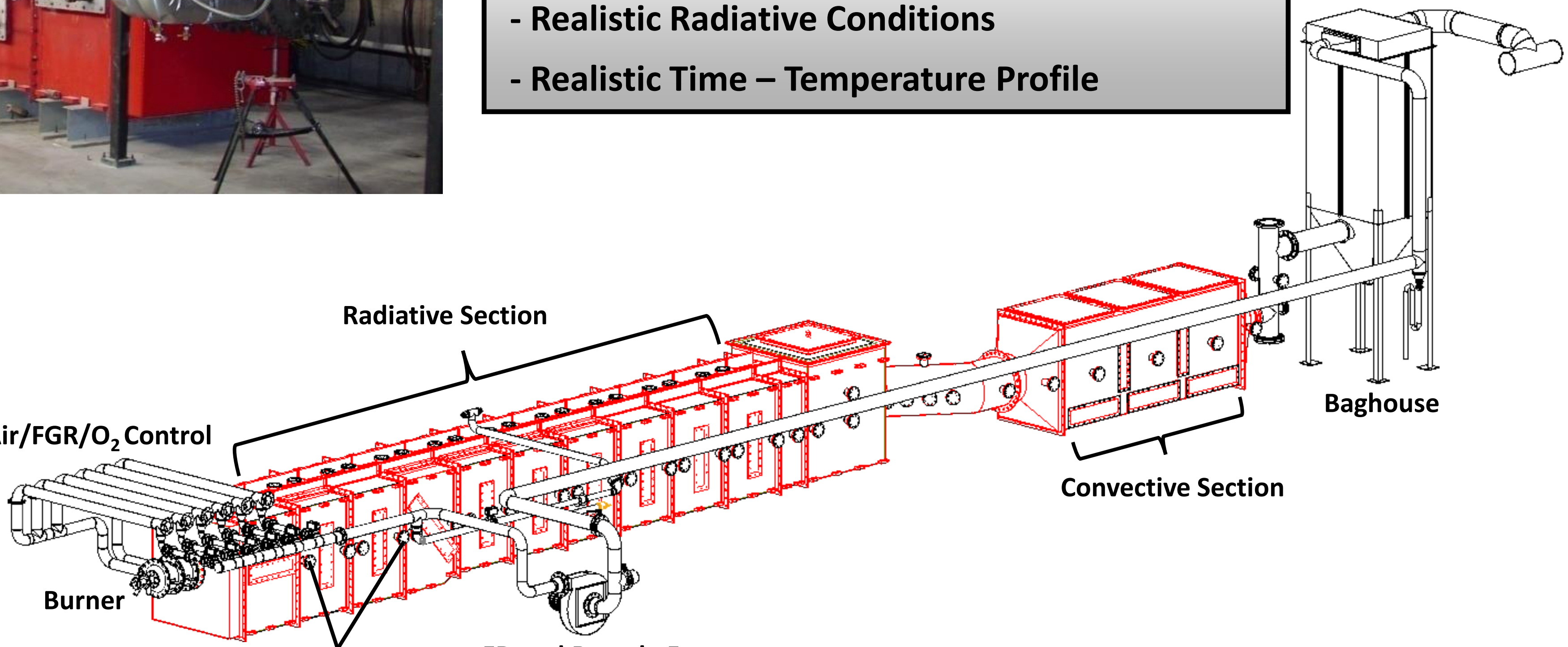
**Unique L1500 Capabilities:**

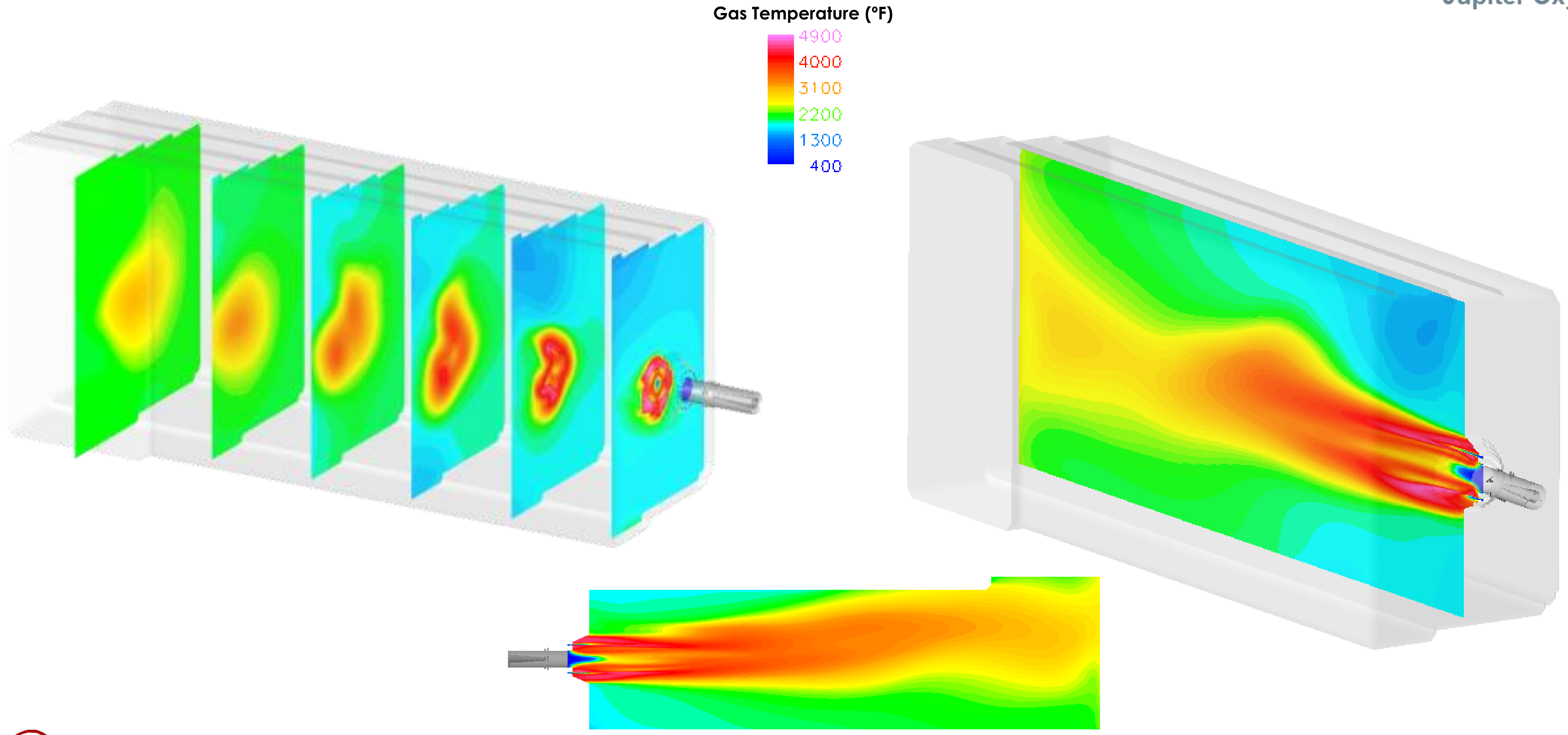
- Realistic Burner Turbulent Mixing Scale
- Realistic Radiative Conditions
- Realistic Time – Temperature Profile



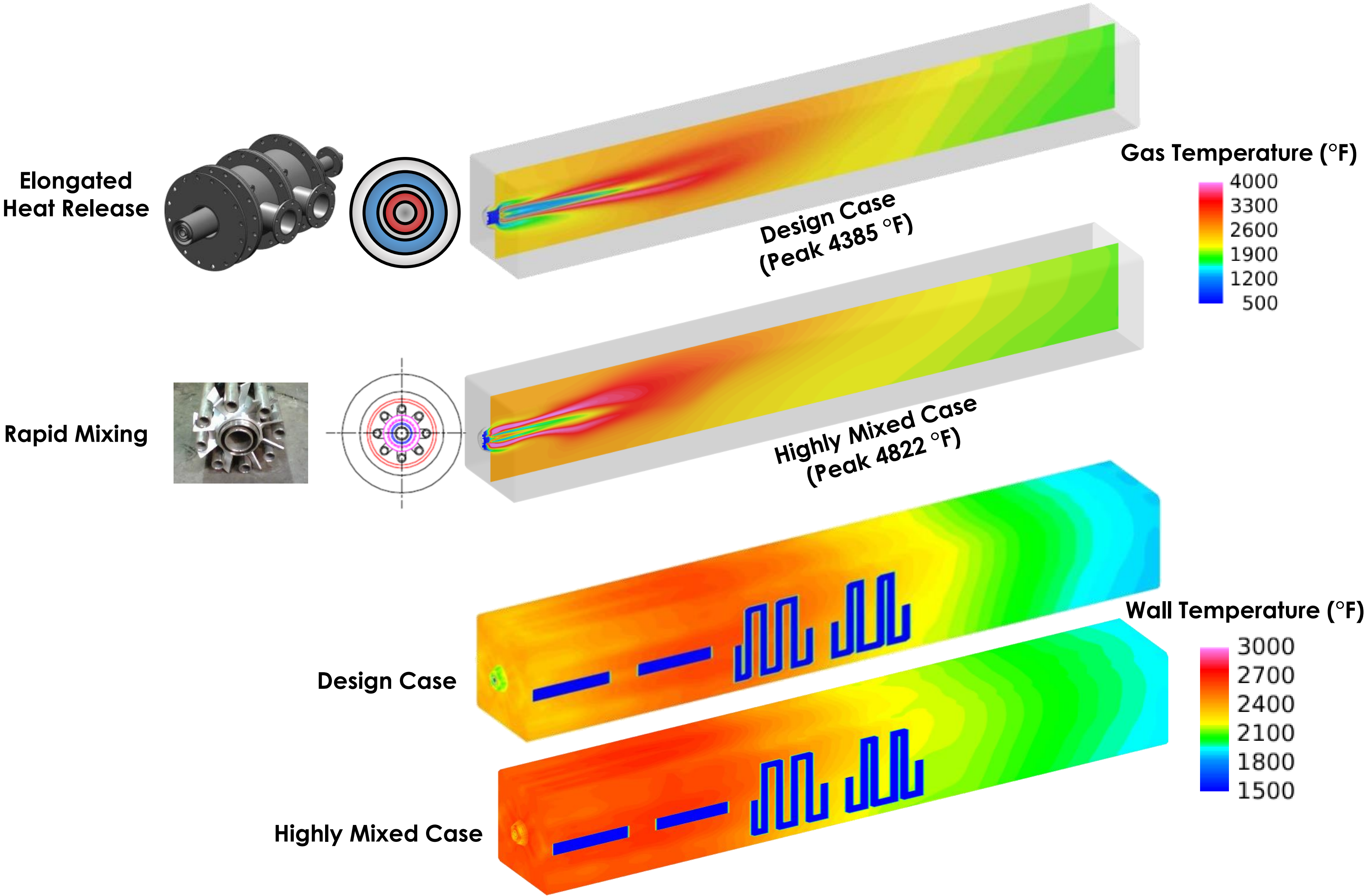
# Leveraging Strengths of Project Partners

## *Jupiter Oxygen Corporation High Temperature Oxy-Combustion*

Jupiter Oxygen



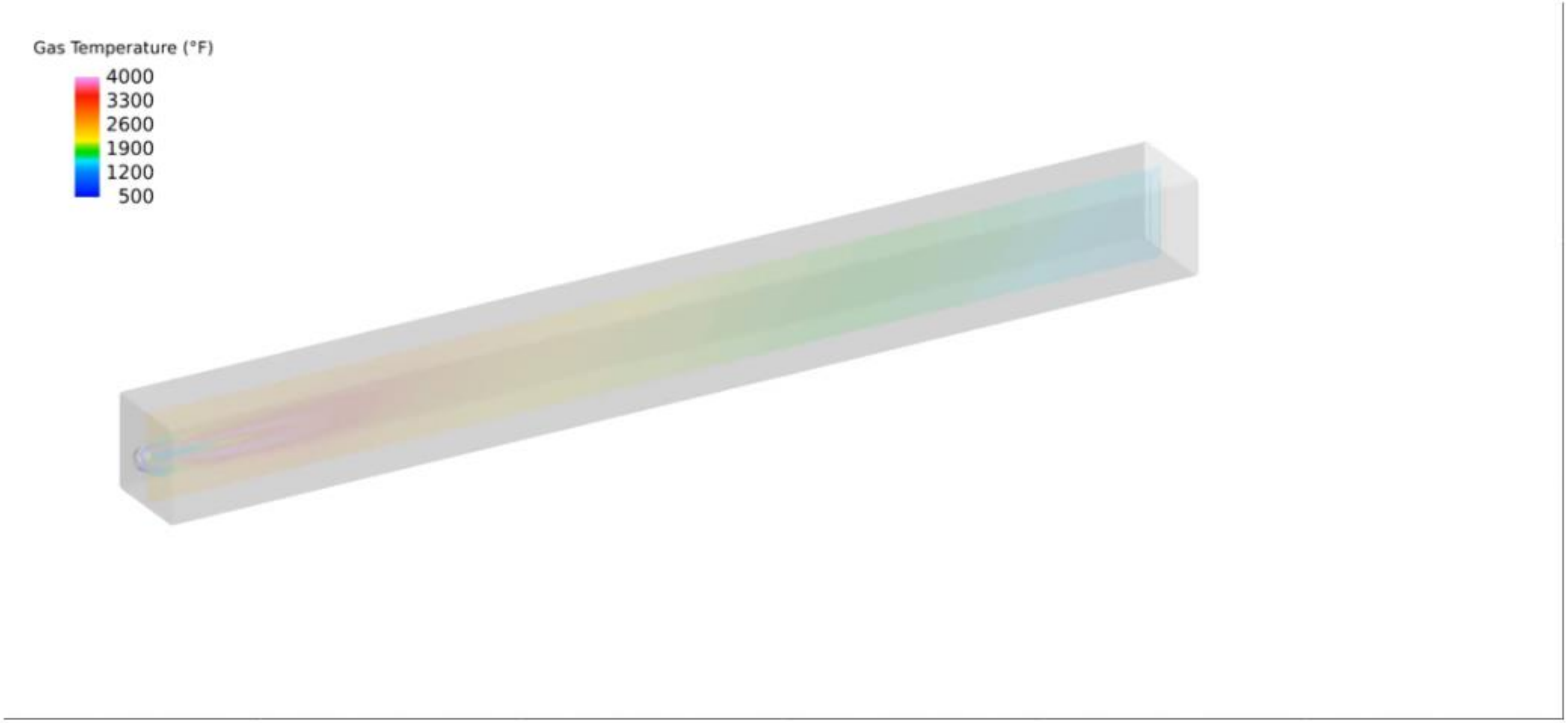
# 1.5 MW CFD-Based Burner Design



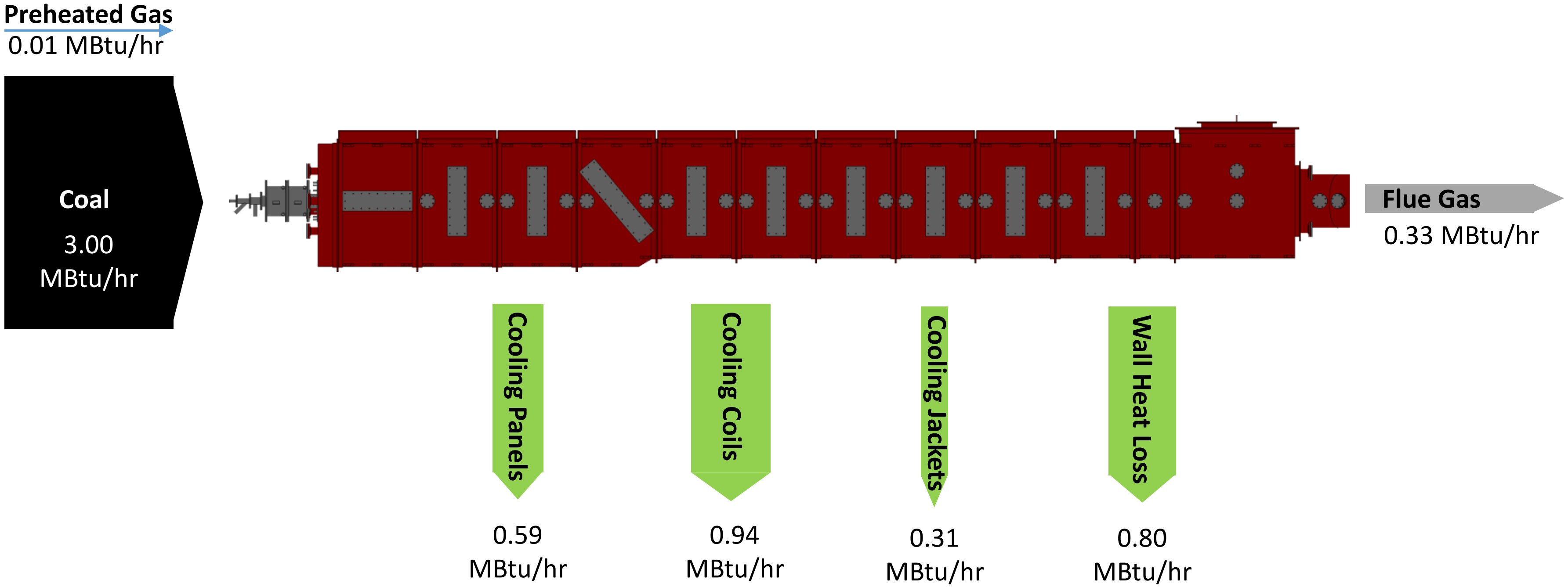
# Results: Air-Fired Flame

# 1.5 MW CFD Model Predictions

## July, 2016 High Temperature Oxy-Coal Tests



# Experimental Results: Furnace Heat Balance




Heat Loss From Furnace

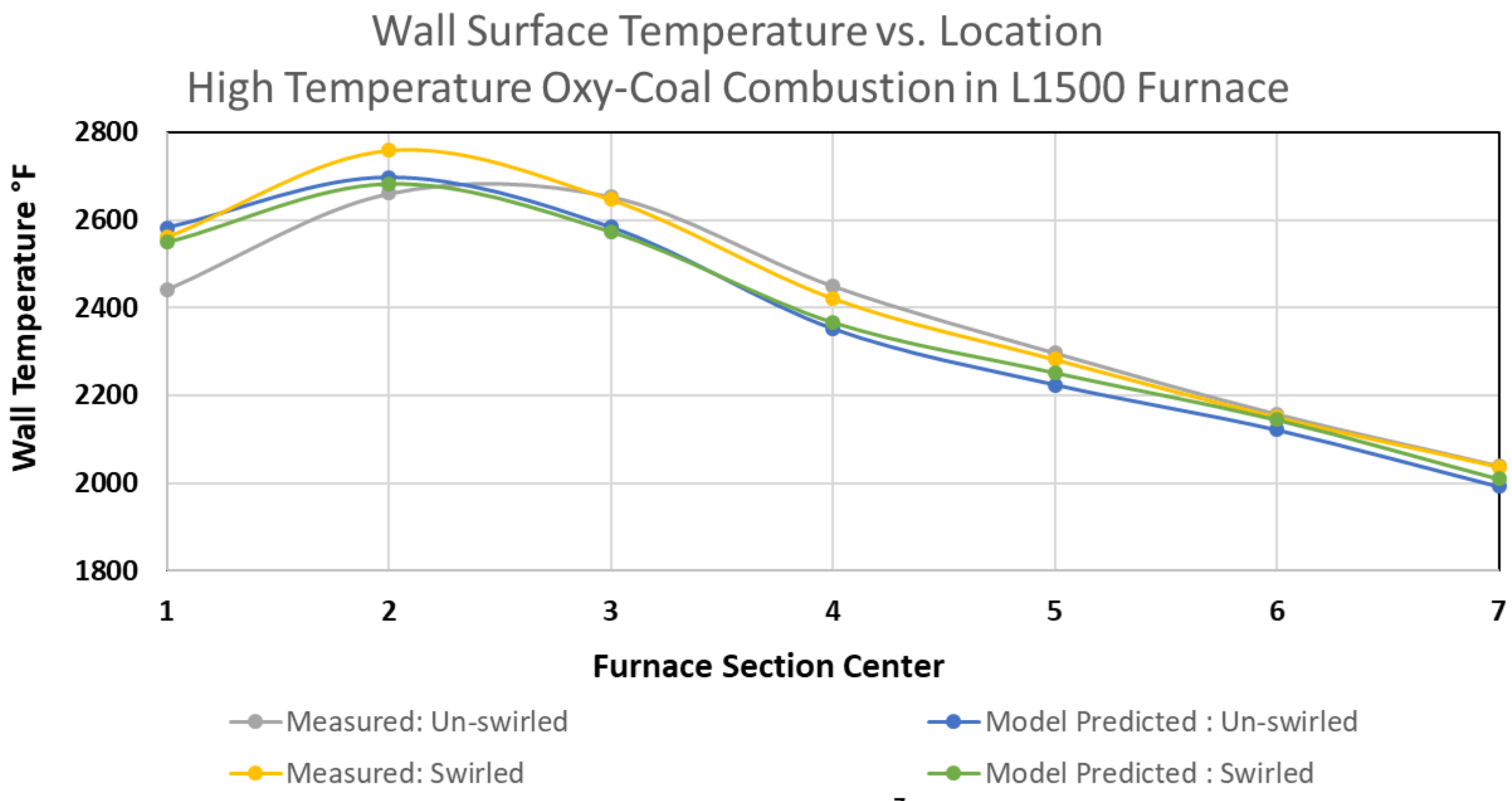
**2.69 MBtu/hr**

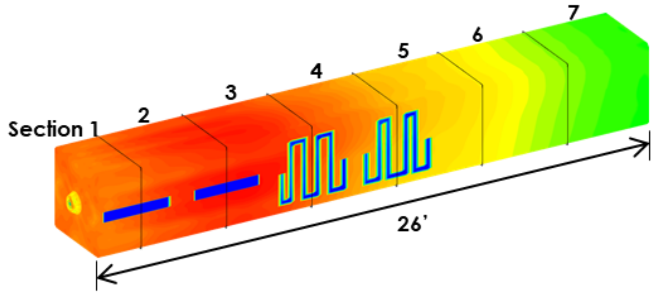
1.3 % Difference

Measured Heat Removal

**2.64 MBtu/hr**

# CFD Model Predictions (Validation)




- Wall surface temperature was an important determining factor for burner design
- CFD model predictions of wall temperature are in good agreement for the un-swirled and swirled conditions through Section 7 of the furnace

# Next Steps

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**Conduct experiments at University of Utah's Entrained Flow Pressurized Reactor**

**Validate simulations of high pressure**

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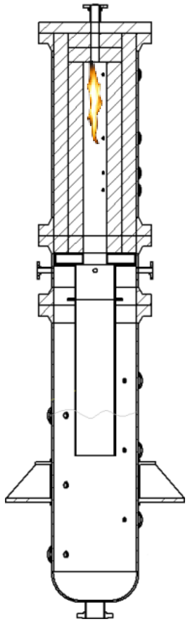
**300 kW Entrained Flow Pressurized Reactor (EFPR)**



# Summary

- Two years into the program: eight of eleven technical tasks have been completed
- 100 kW simulations provide a good representation of the thermocouple data and wall heat flux as measured by multi-depth thermocouples in the wall
- Submicron particle concentration is directly correlated with formation rates of the initial deposit layer, which subsequently facilitates the capture of larger particles
- A model-based approach was used to represent the physical and thermochemical phenomena associated with ash transformation
- The predicted mass of the submicron particles is comparable to the experimental data in both absolute value and relative value
- CFD model predictions of deposition of the submicron particles are consistent with the experimental data in terms of trend and magnitude
- 1.5 MW simulations for multiple parameter variations based on a simple burner concept in the L1500 have been completed
- Burner design efforts to increase peak flame temperatures are typically counter to efforts to distribute heat axially
- Extended heat release correlated to particulate burnout and the percentage of exit $CO_2$ evolved indicate best performance for protecting combustion components
- CFD model predictions of wall temperature are in good agreement for the un-swirled and swirled conditions through Section 7 of the furnace
- Experimental campaign for elevated temperature and high pressure oxy-coal combustion has begun

# Acknowledgment

This material is based upon work supported by the Department of Energy under Cooperative Agreement No. DE-FE0025168.

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# Thank You