Characterizing Impacts of Dry Coal Feeding in High Pressure Oxy-Coal Combustion Systems

Department of Energy under Cooperative Agreement No. DE-FE0029162

For Energy and Environmental Solutions

REACTION ENGINEERING INTERNATIONAL

Transformative Power Generation

Project Review Meeting

September 28, 2020

Motivation

Relevance

- Key second generation candidates for CO_2 capture include high temperature and pressurized oxy-firing of coal
- Application of these technologies to steam generation have potential to increase efficiency, reduce capital costs, avoid air ingress and reduce oxygen requirements
- Compared to first-generation oxy-coal combustion, high pressure oxy-coal is thermodynamically more efficient and reduces equipment size requirements
- Fuel feeding and firing system flexibility are challenges for high pressure coal and biomass fed combustion and gasification equipment
- Slurry-fed systems often have atomization and burnout problems exacerbated at high pressure
- Slurry atomization processes may be difficult to scale up
- Dry feeding has the potential to yield efficiency gains, provide better control over flame aerodynamics, improve flexibility and facilitate scale up

Program Objective

- Develop data and validate mechanisms describing heat transfer, ash deposition and corrosion in a high temperature, high pressure oxy-coal combustion system with dry coal feeding

Technical Approach

1. Design, construction and installation of a pressurized feeding system for dry pulverized coal in an entrained flow pressurized combustor
2. CFD-based guidance of burner design and pilot-scale operation of pressurized oxy-coal combustion with a dry feed system
3. Detailed measurements of heat flux and flame and material temperatures at high temperatures while firing at 300 kW and 17 bar
4. Ash aerosol measurements at 17 bar pressure experimental conditions to determine slagging and fouling propensity of the ash, and its deposition rates as a function of high pressure
5. Characterize corrosion propensity under high temperature and high pressure conditions using real time corrosion sensors
6. Refinement of CFD modeling tools to ensure accurate prediction of the impacts of high temperature and high pressure oxy-coal combustion on heat flux, ash deposition and corrosion in a commercial boiler implementation

Program Overview

Enabling Technologies for Advanced Oxy-Coal Combustion Systems

Characterizing Impacts of Dry Coal Feeding in High Pressure Oxy-Coal Combustion Systems (DFHP)

October, 2016 – September 2021

REACTION ENGINEERING INTERNATIONAL

THE UNIVERSITY OF UTAH

EPRI

PRAXAIR

SOUTHEAST UNIVERSITY 東南大學

Program Elements

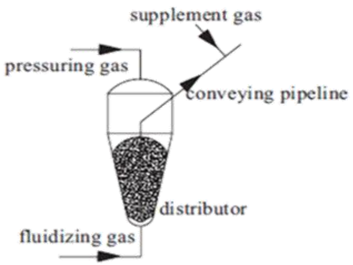
Design, construct and install pressurized dry feed system

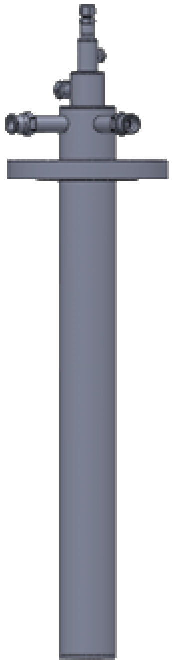
Design, construct and install pressurized burner system

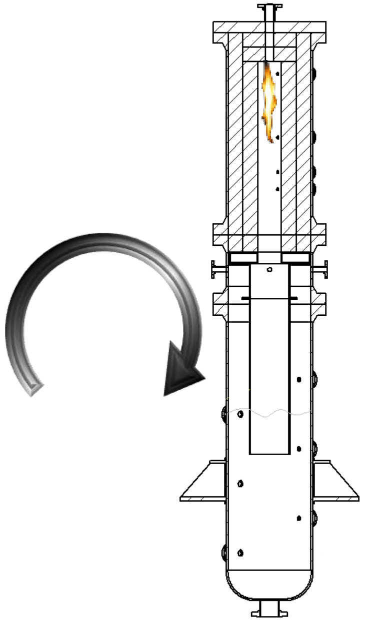
Conduct experiments at University of Utah's Entrained Flow Pressurized Reactor (EFPR)

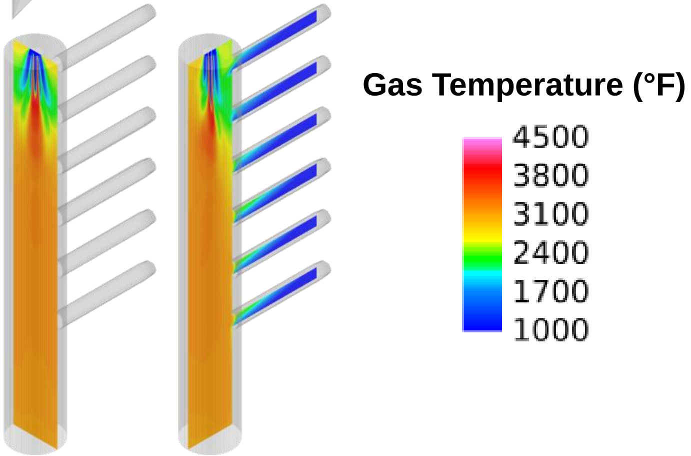
Validate simulations of high pressure oxy-coal combustion

Economic analysis and full-scale boiler scoping



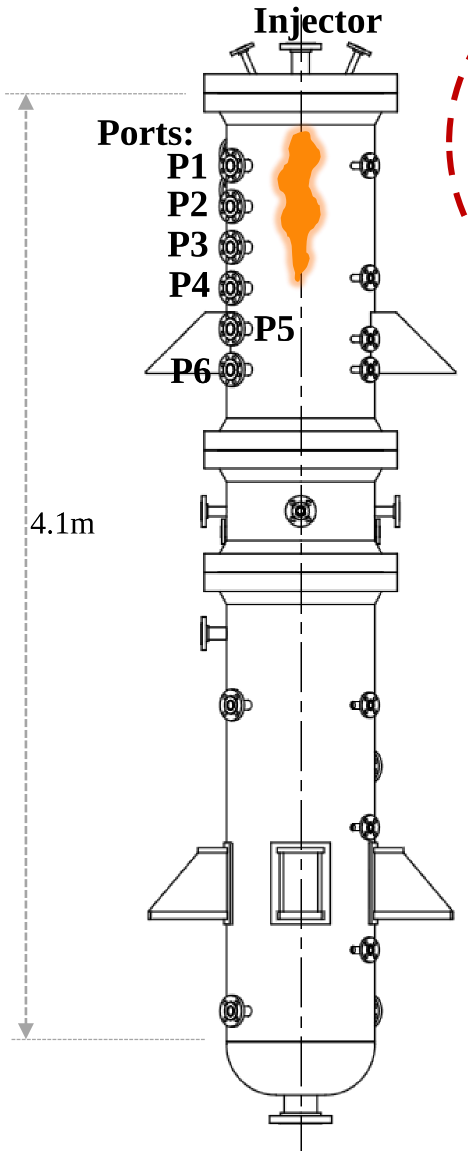


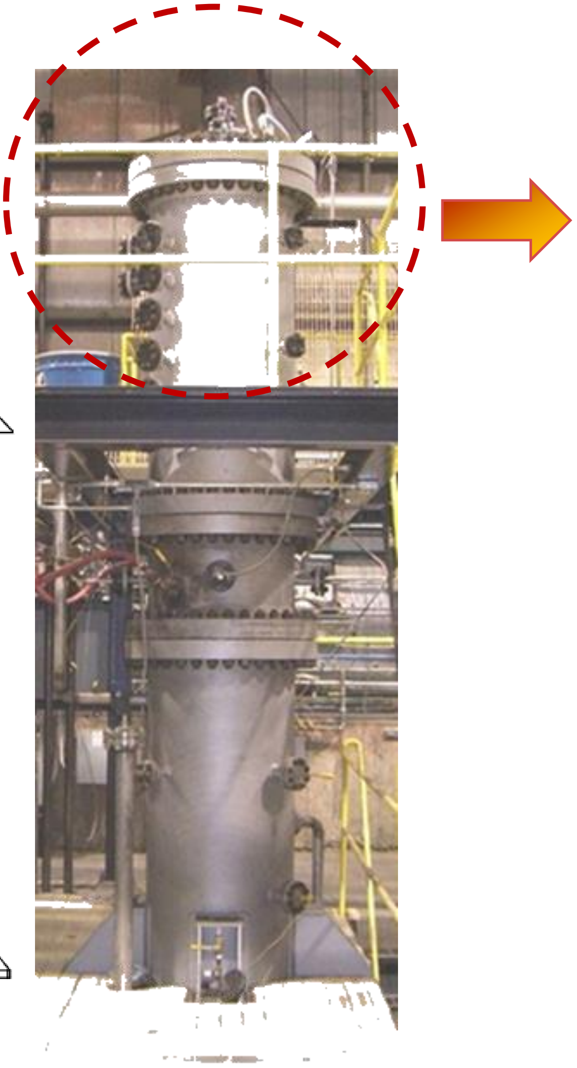


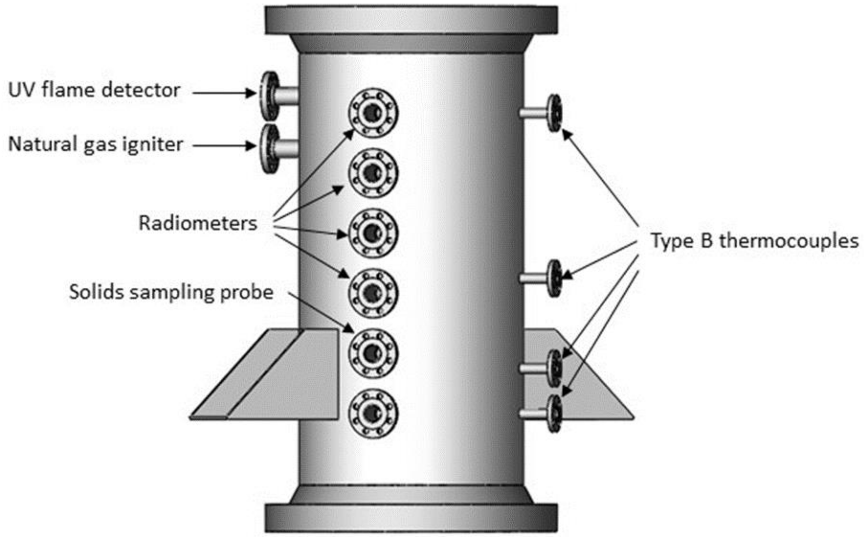


300 kW Entrained Flow Pressurized Reactor (EFPR)

- Converted from an entrained flow gasifier
- 300 kW (rated) pilot scale
- Originally coal-water slurry feeding with pure O_2
- Down-fired, self-sustained with no external heating
- Operation pressure up to 30 bar



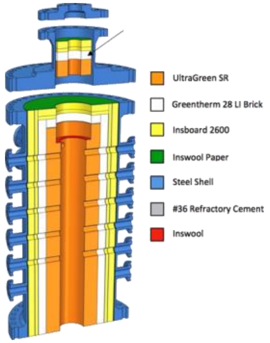


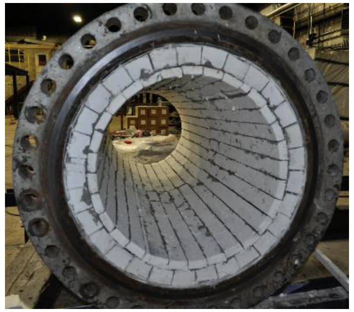


Conversion from Gasifier to Combustor

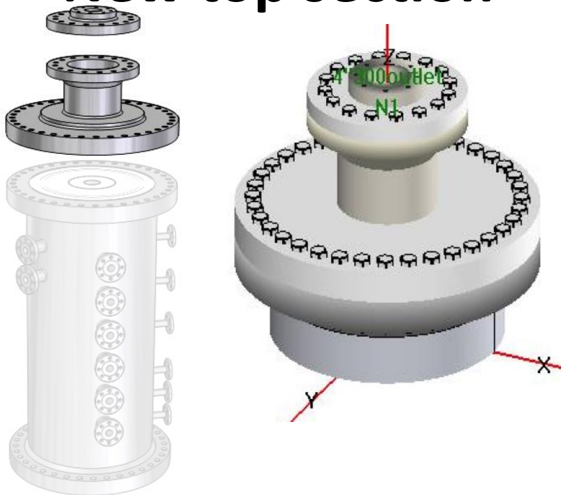
Hardware and Instrumentation

Refractory overhaul

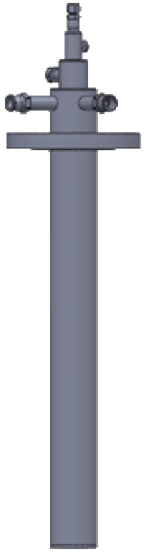




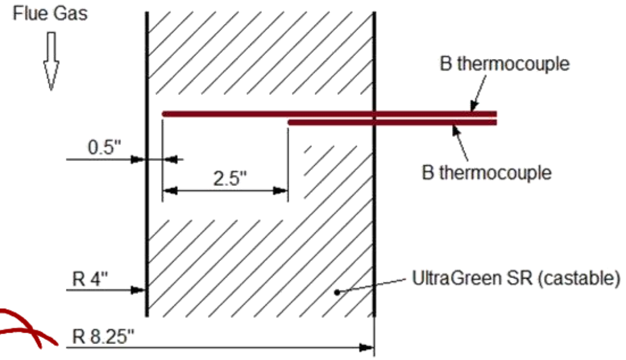
New top section



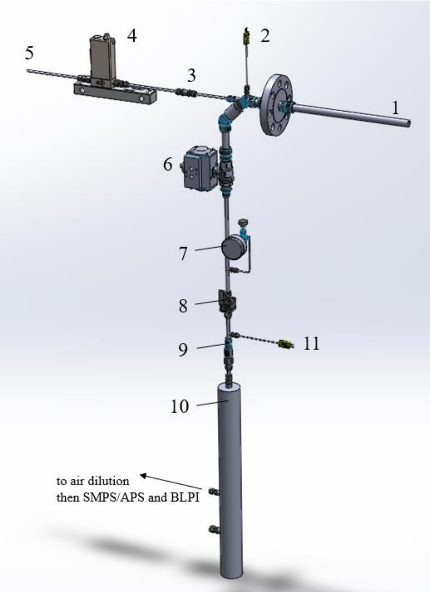
New burner



New radiometers & Multi-depth thermocouples



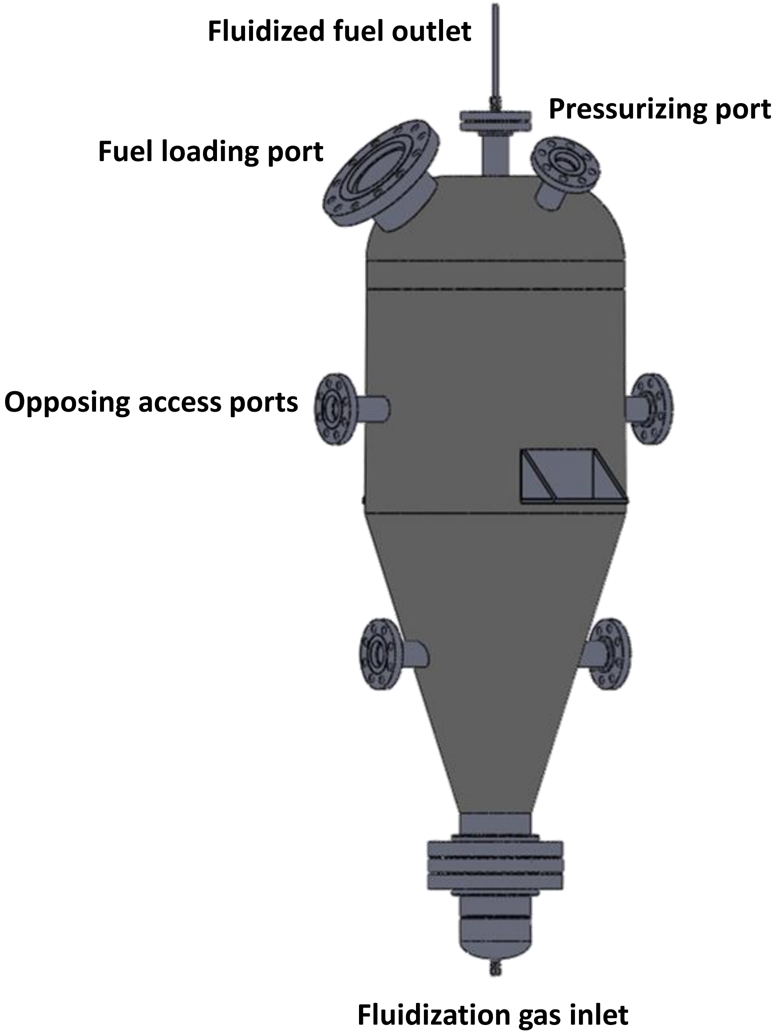
Particle sampling system designed and constructed

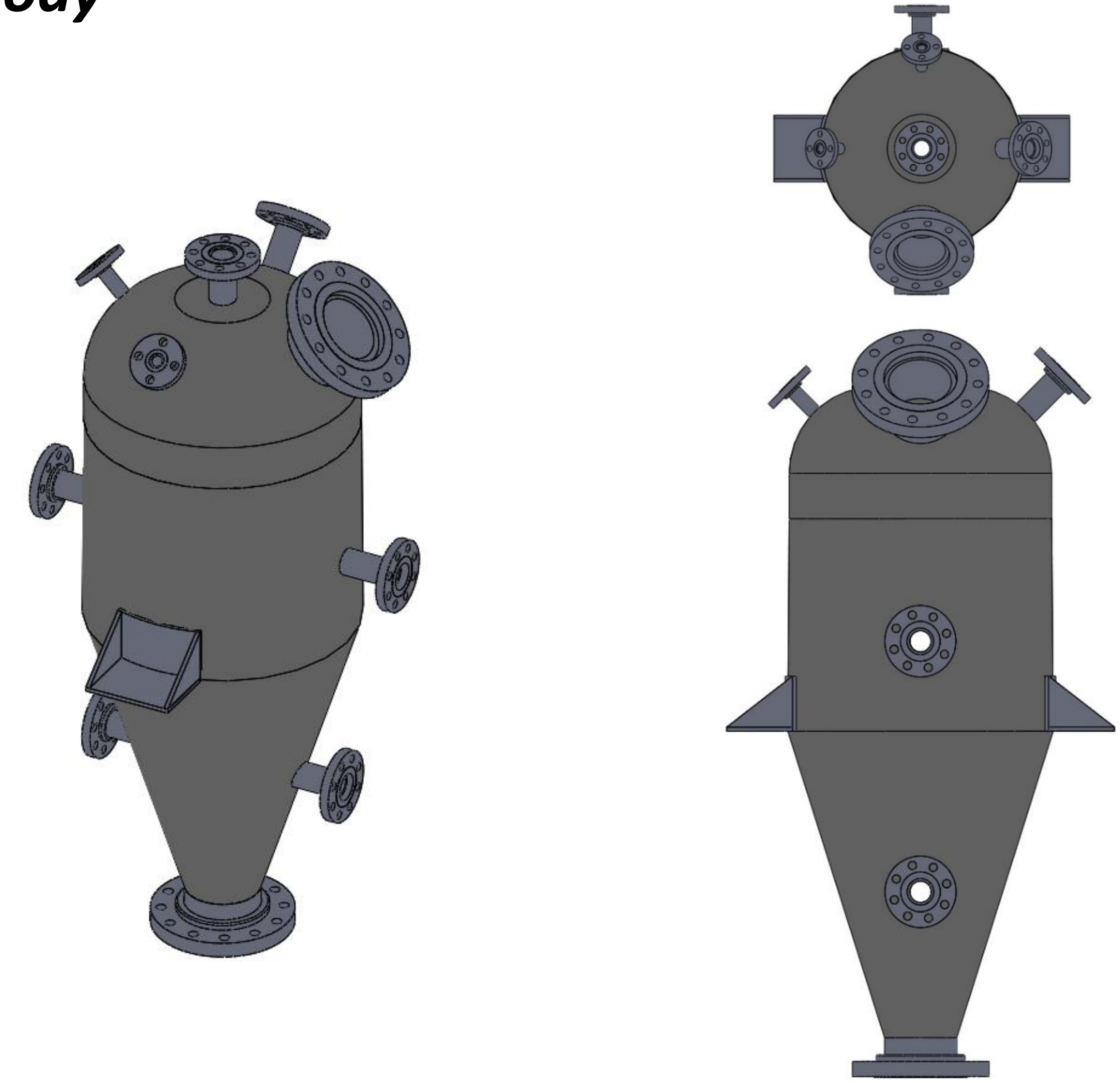


Corrosion probe designed and constructed

Pulverized Coal Feeder Design

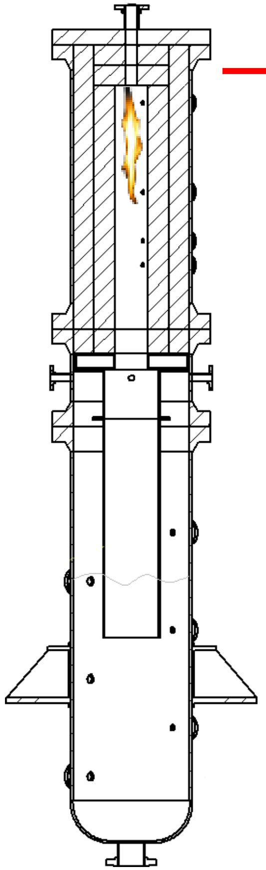
Final design of fluidized feeder body

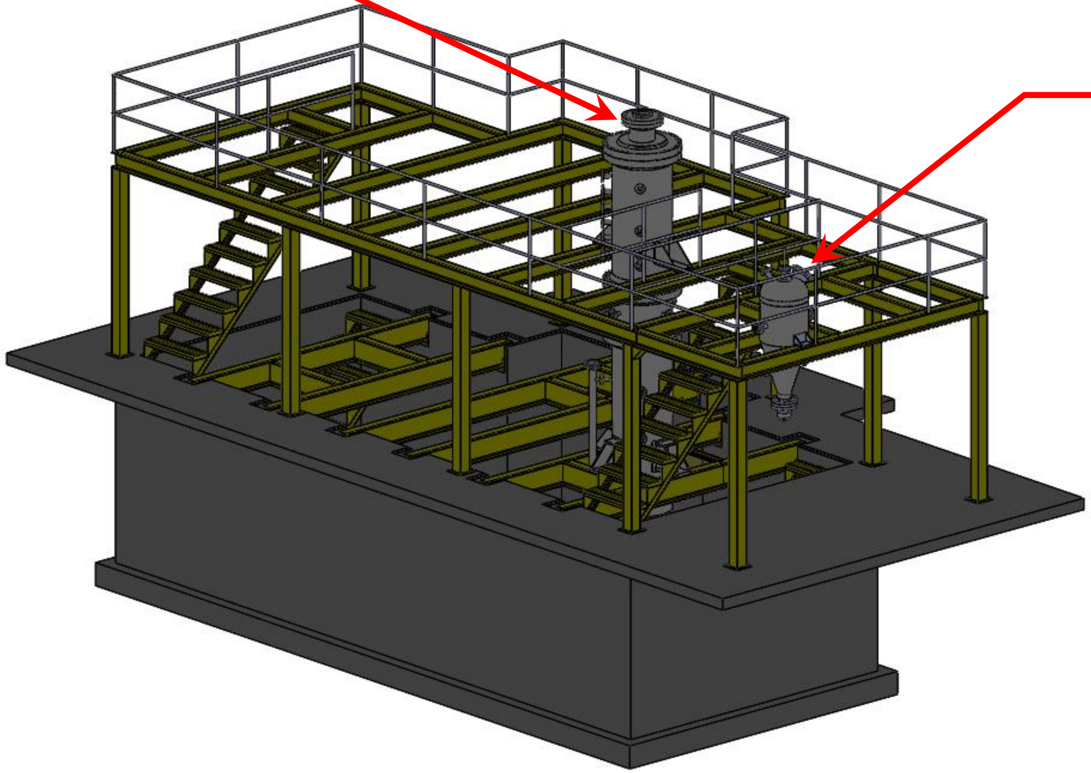


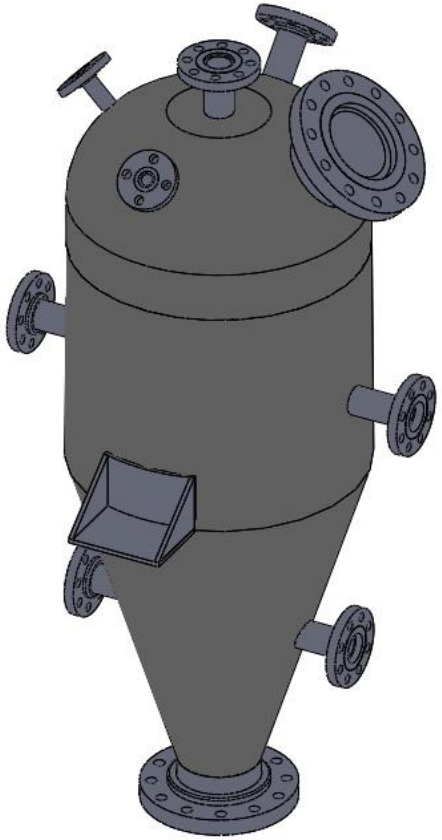


Pulverized Coal Feeder Design & Construction

Dry feed system pressure vessel



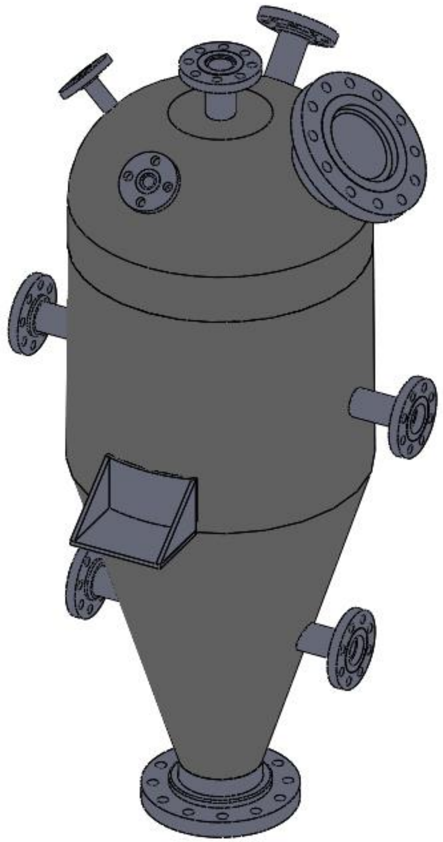




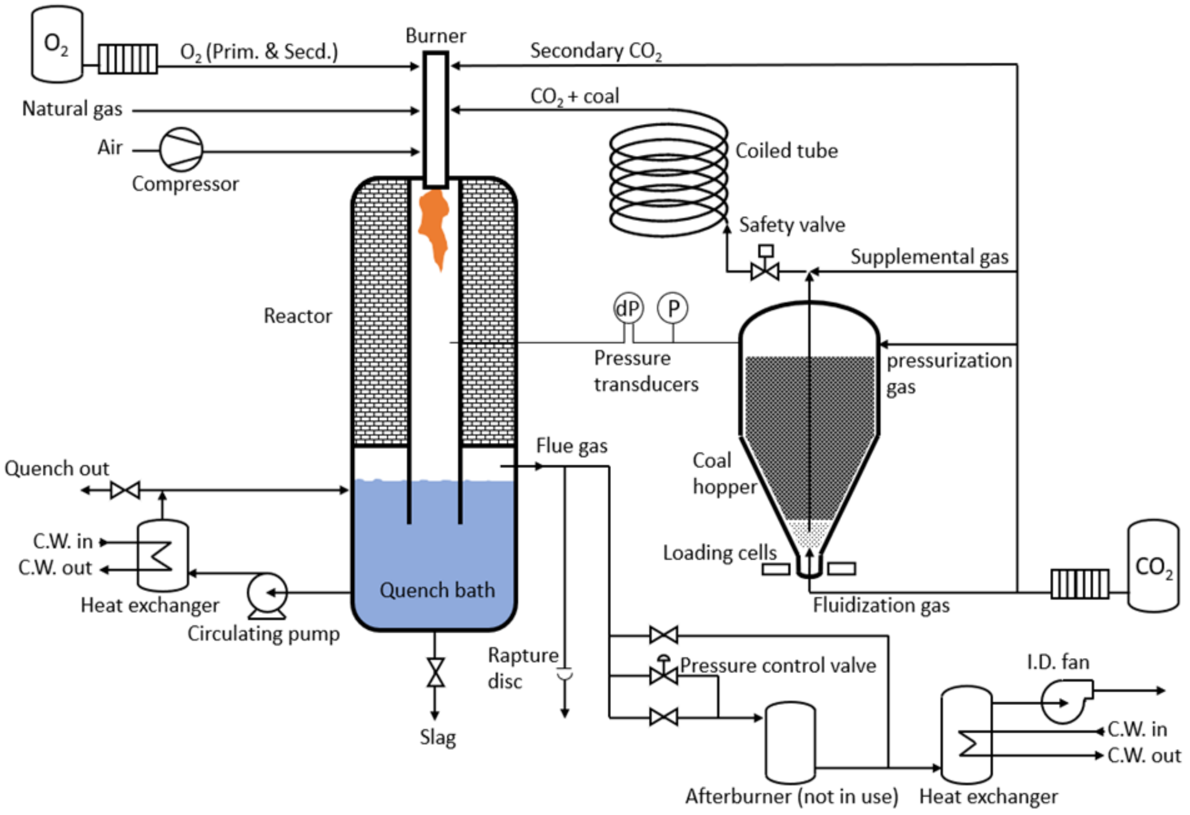
Entrained flow pressurized reactor

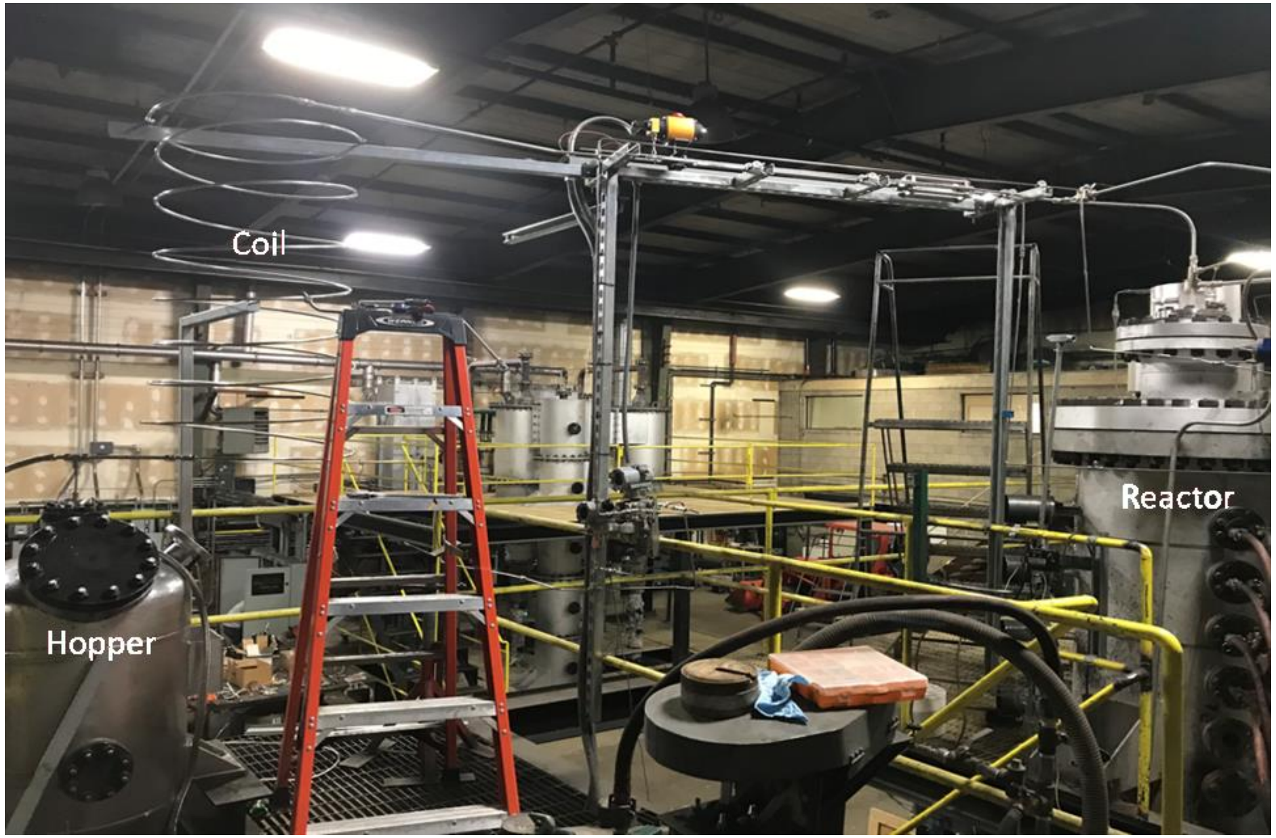
Pulverized Coal Feeder Design & Construction

Dry feed system pressure vessel



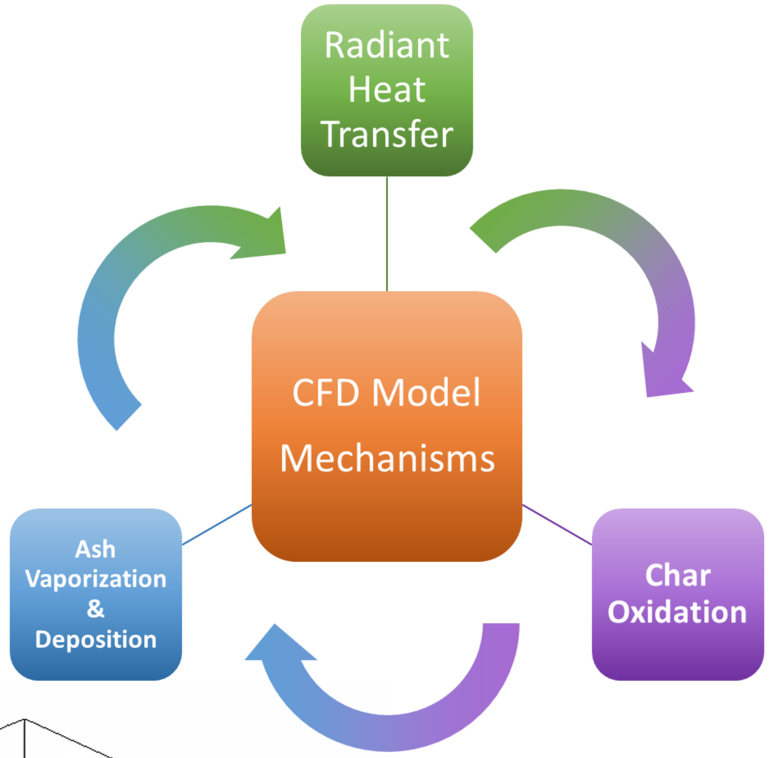
Integration of Dry Feed System

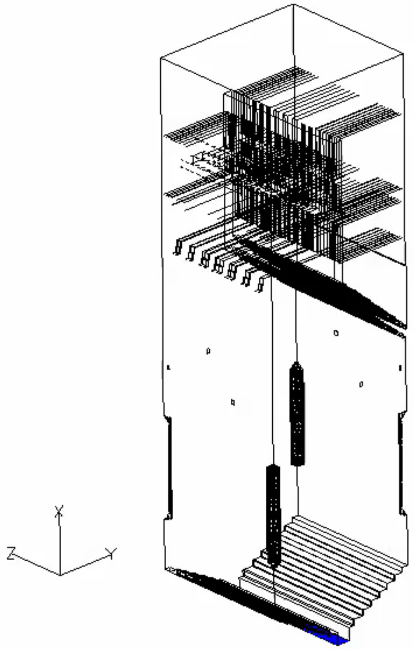


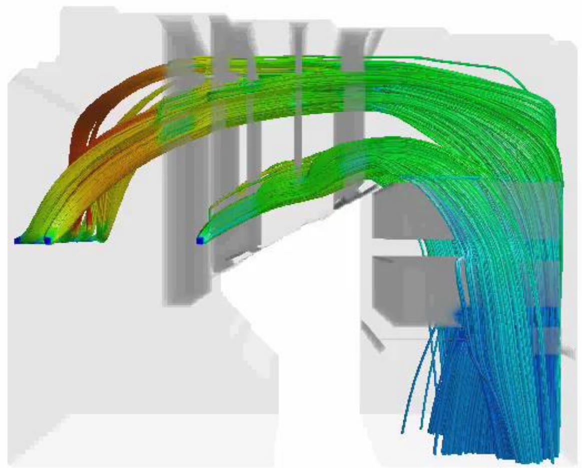


CFD Tools: GLACIER

- 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

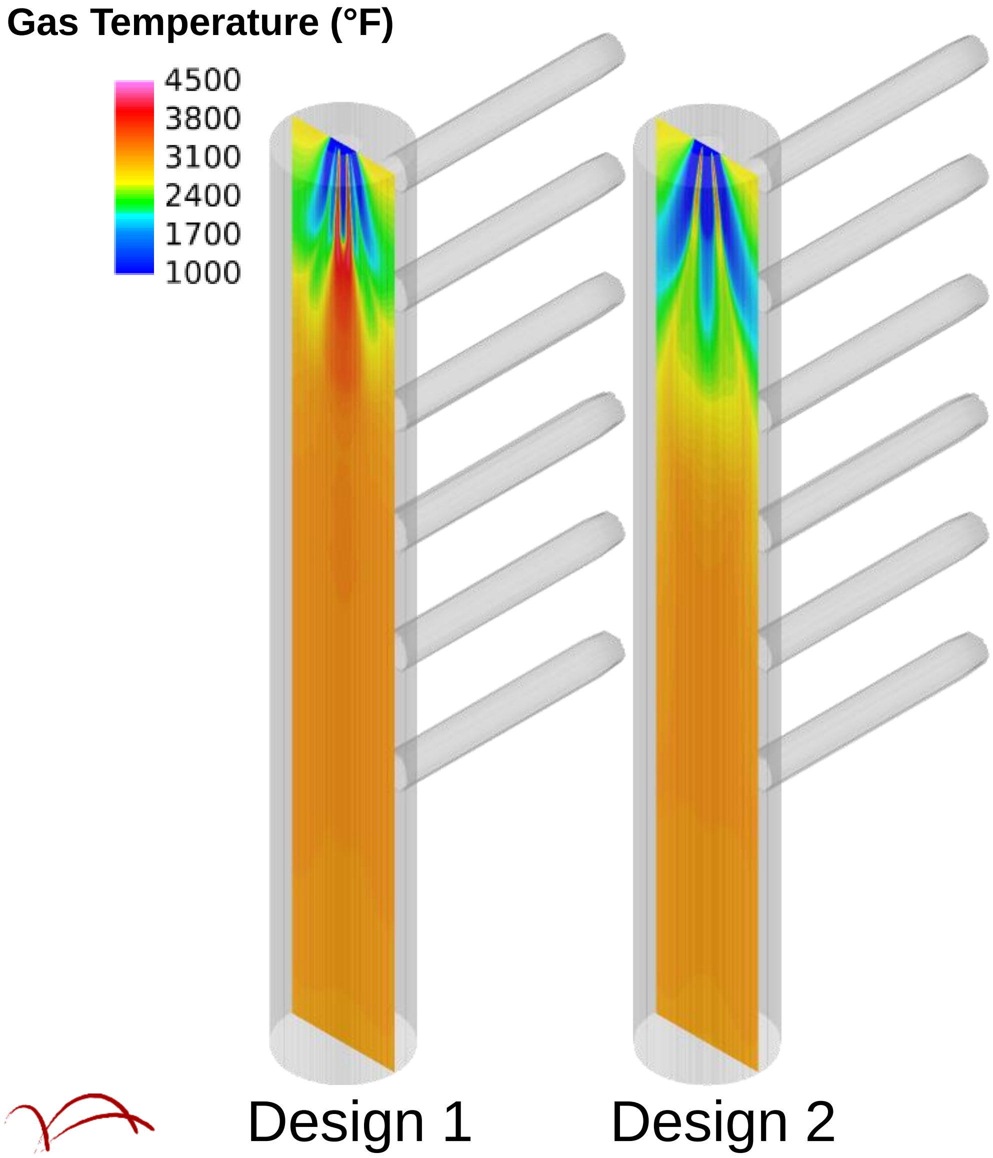


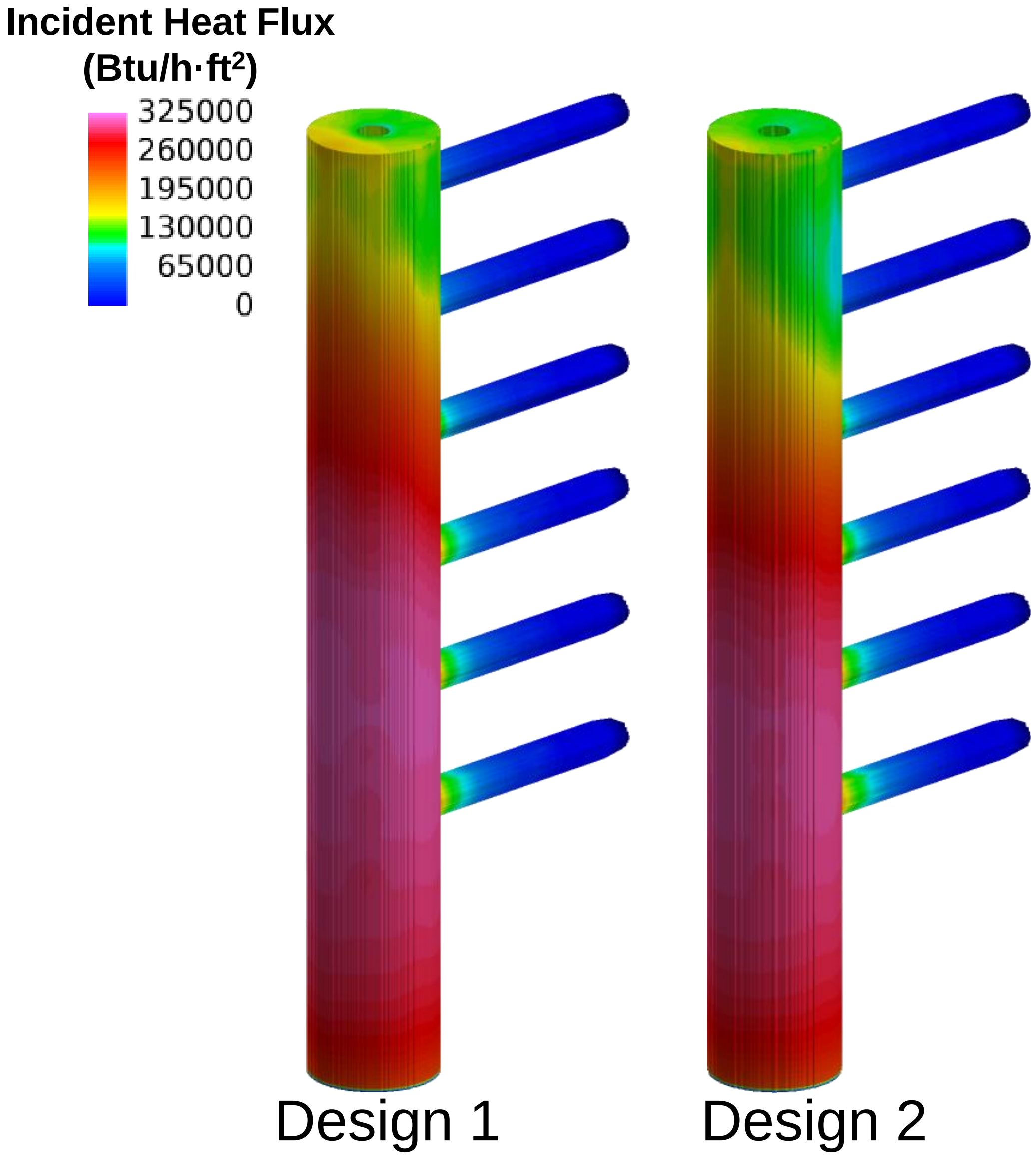




EFPR Dry Pulverized Coal Burner Design Concepts

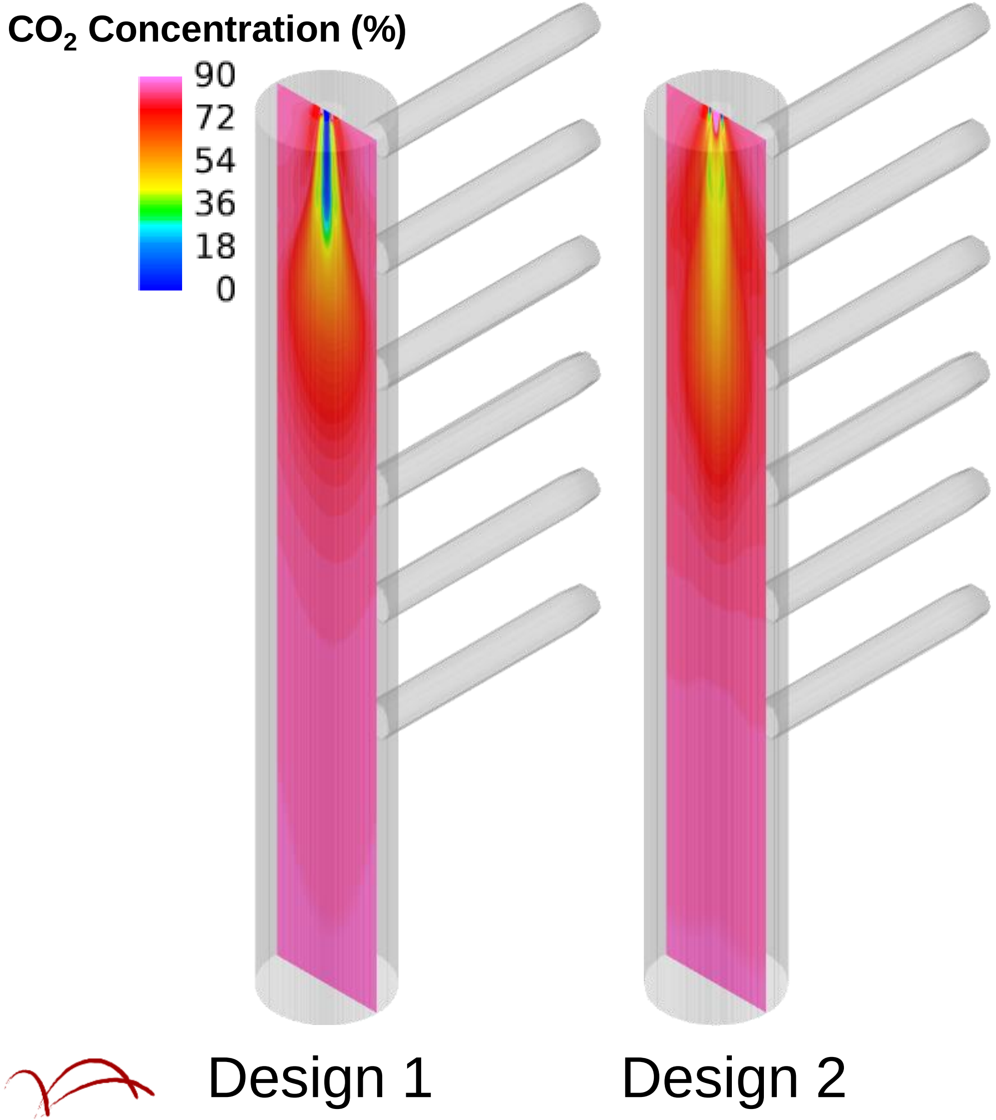
CFD Model Predicted Gas Temperature and Heat Flux Profiles

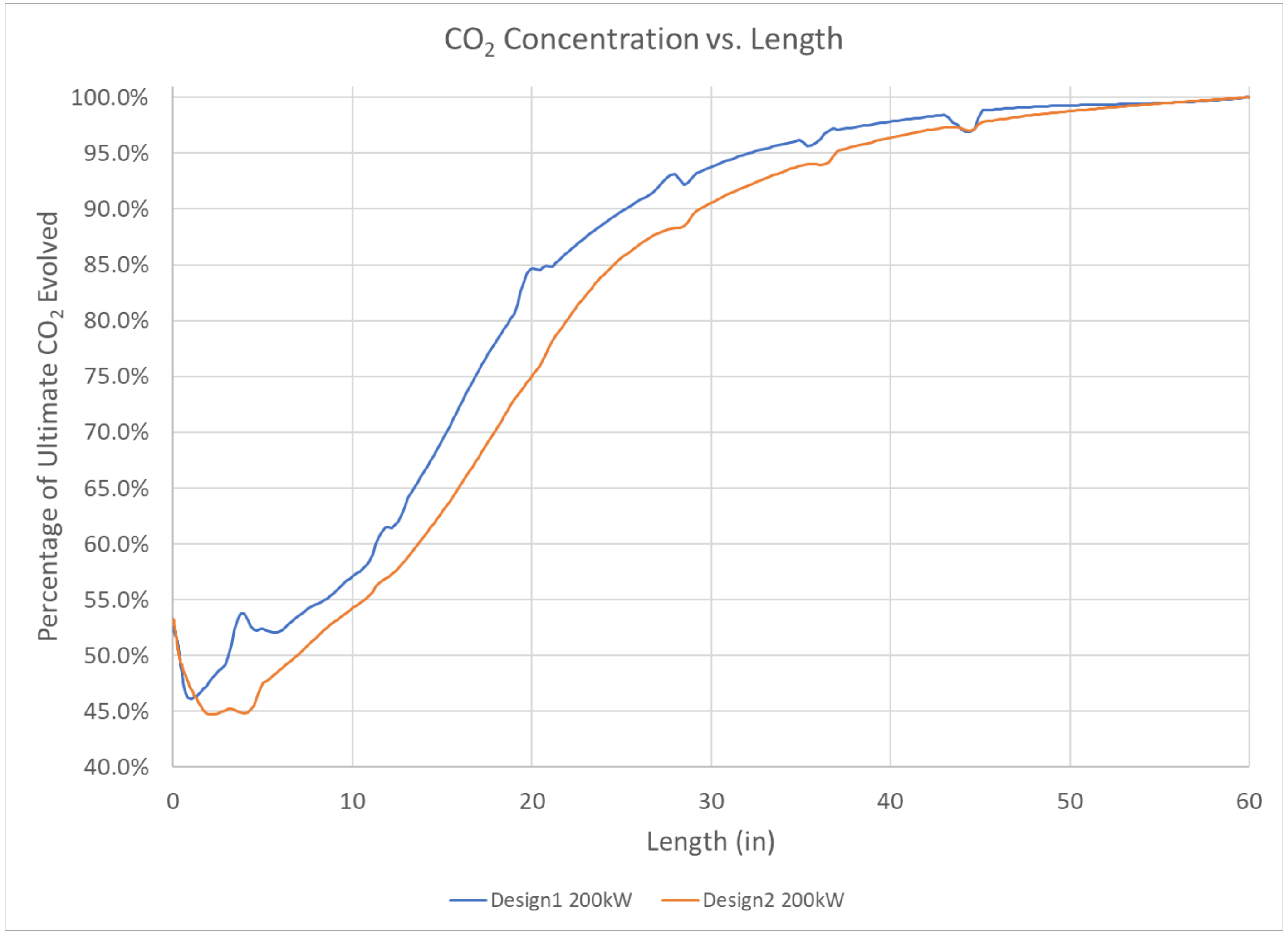




Controlling the Rate of Heat Release

Tracking CO_2 Formation in the Furnace

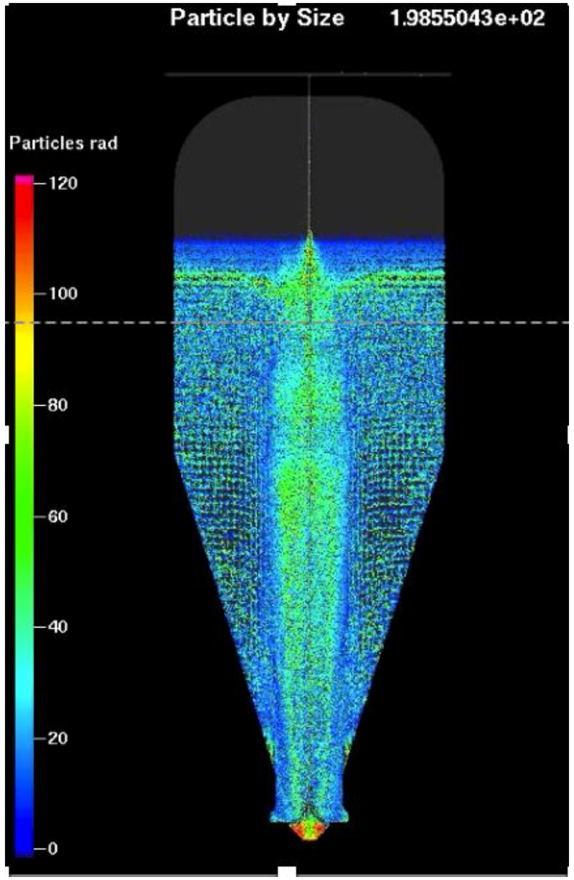




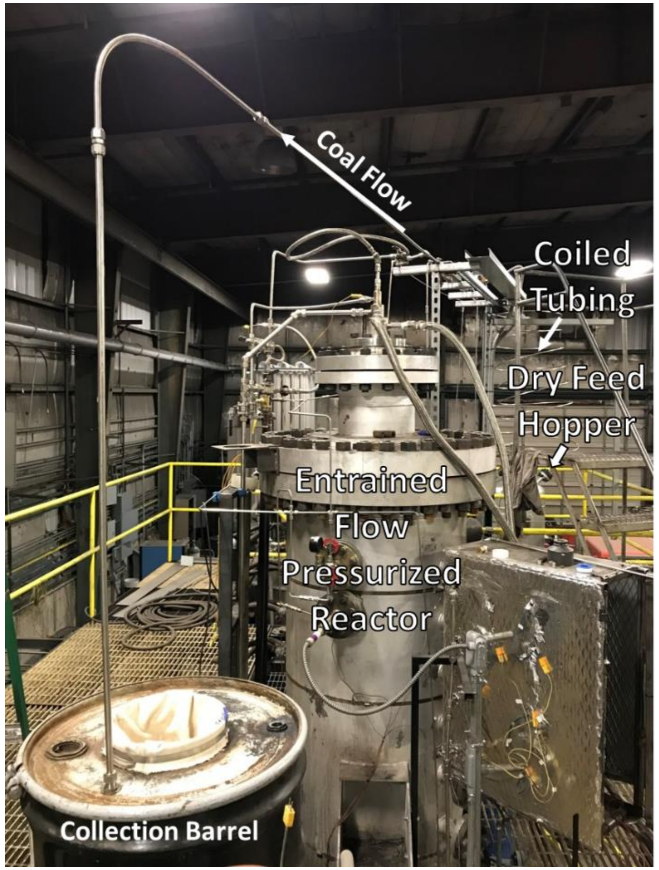
EFPR Dry Pulverized Coal Burner Design Concepts

Preparing for Dry Feed System Operation

Bench-scale cold flow model of dry feed system hopper

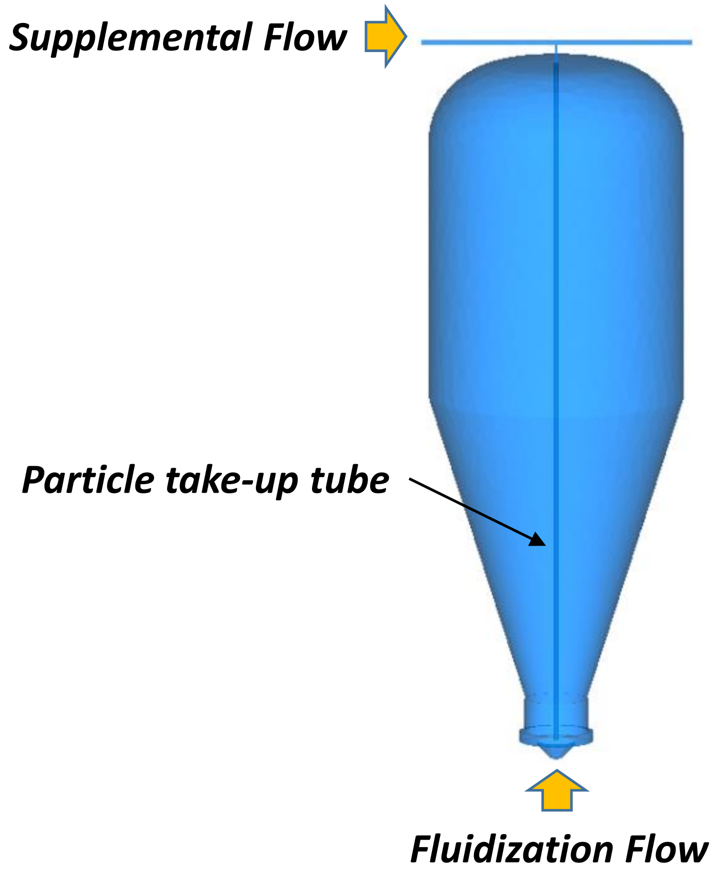


CFD modeling of lab-scale dry feed system hopper

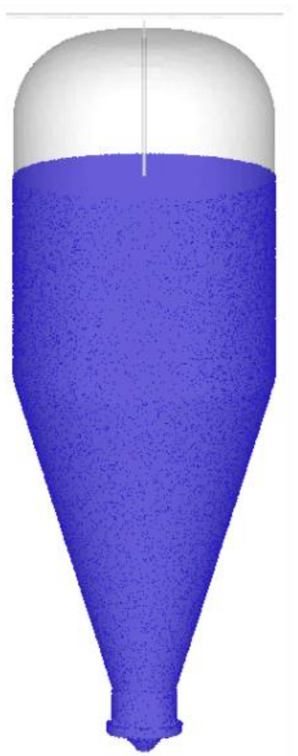


Non-reacting coal transport with the dry feed system

CFD Modeling of Dry Feed Operation

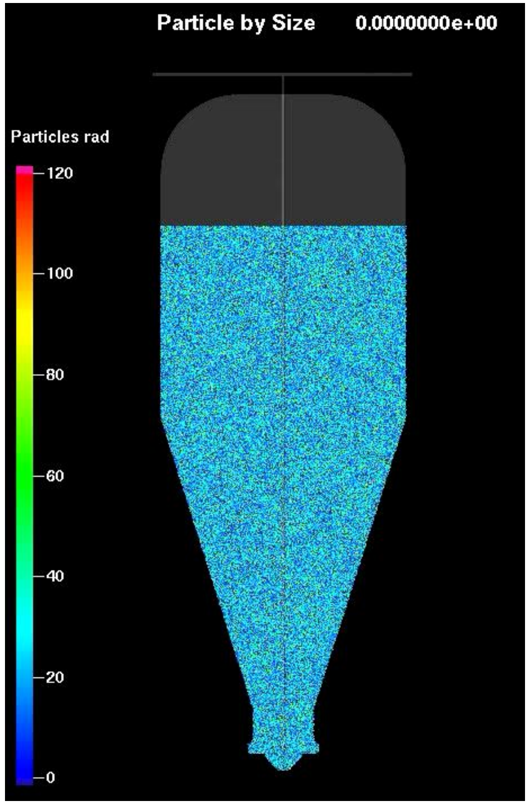


Initial Condition



Initial Condition

Simulation



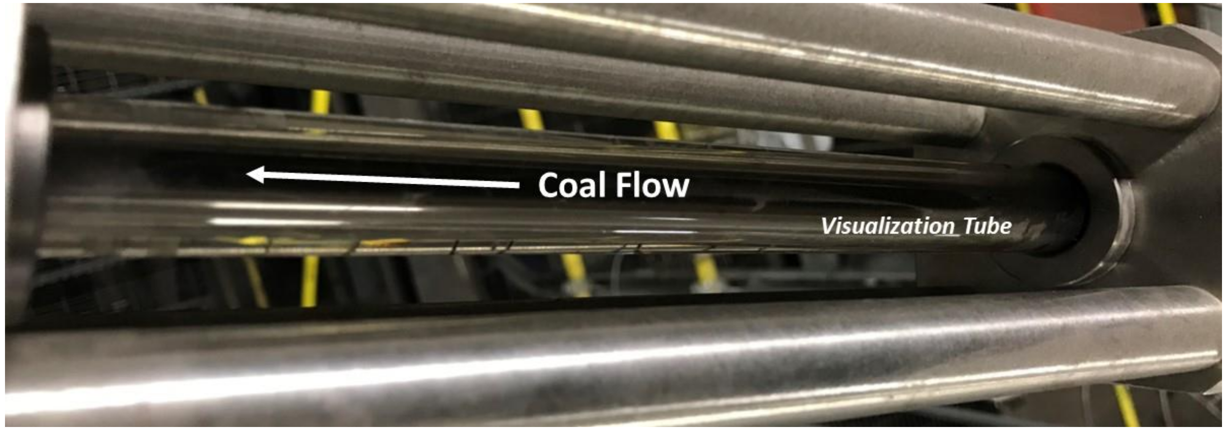
Simulation*

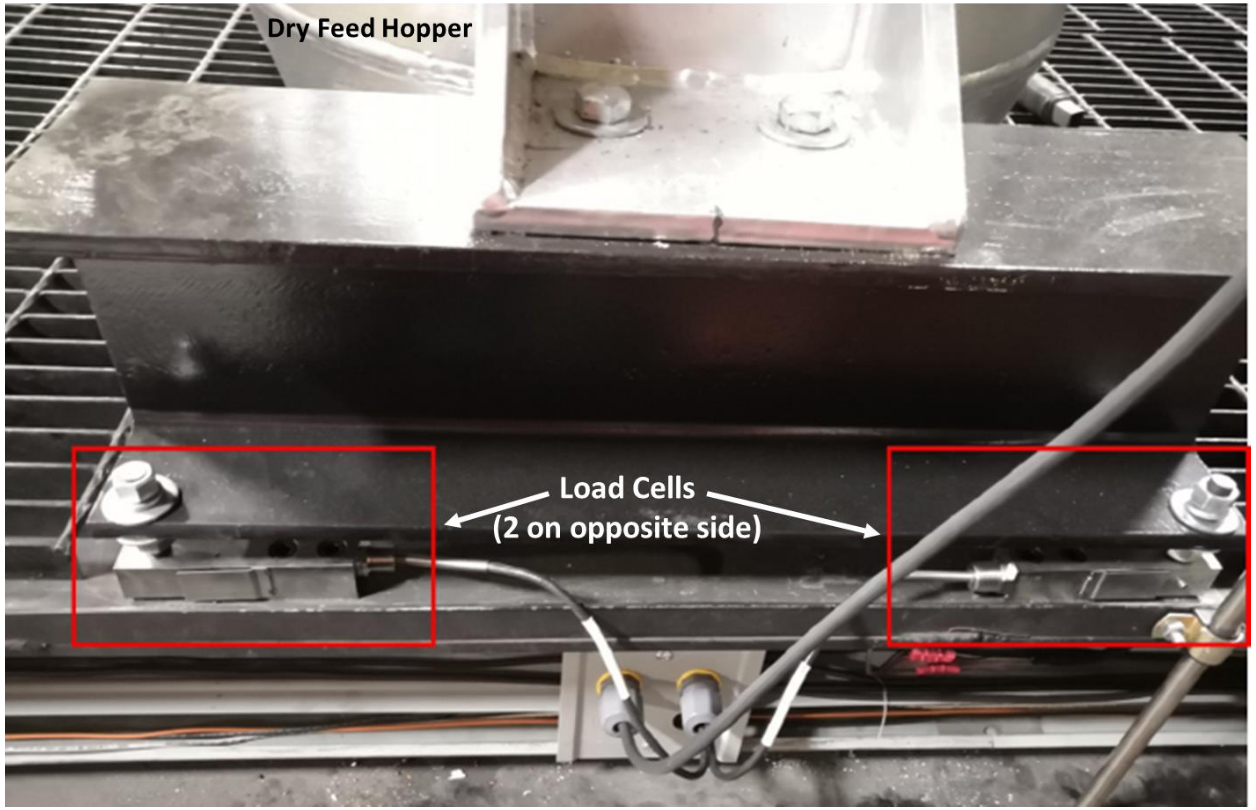
*Simulation performed using CPFD's Barracuda

Coal Flow Monitoring and Control

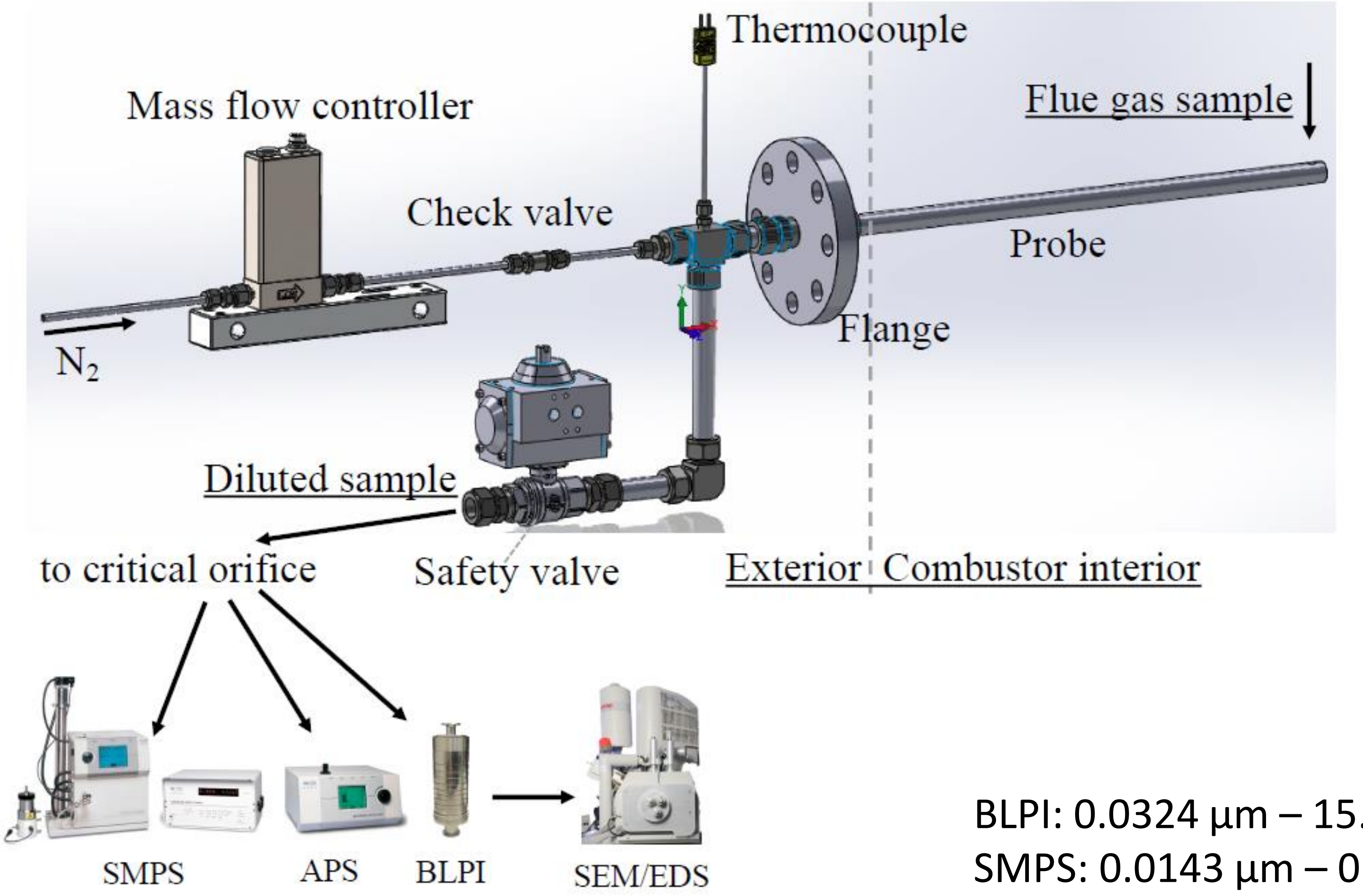
No Coal Flow

With Coal Flow

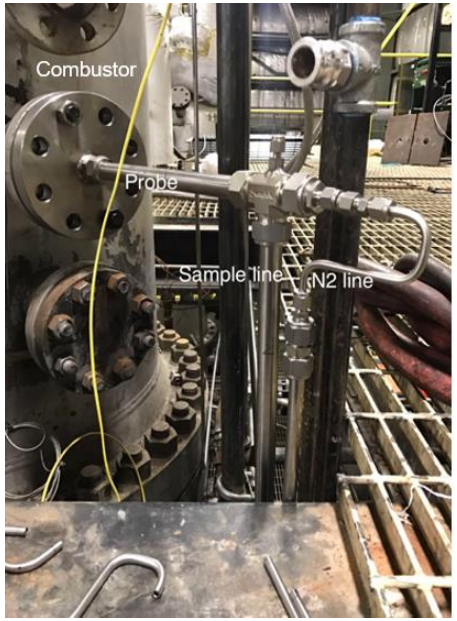




High Pressure Aerosol Sampling System

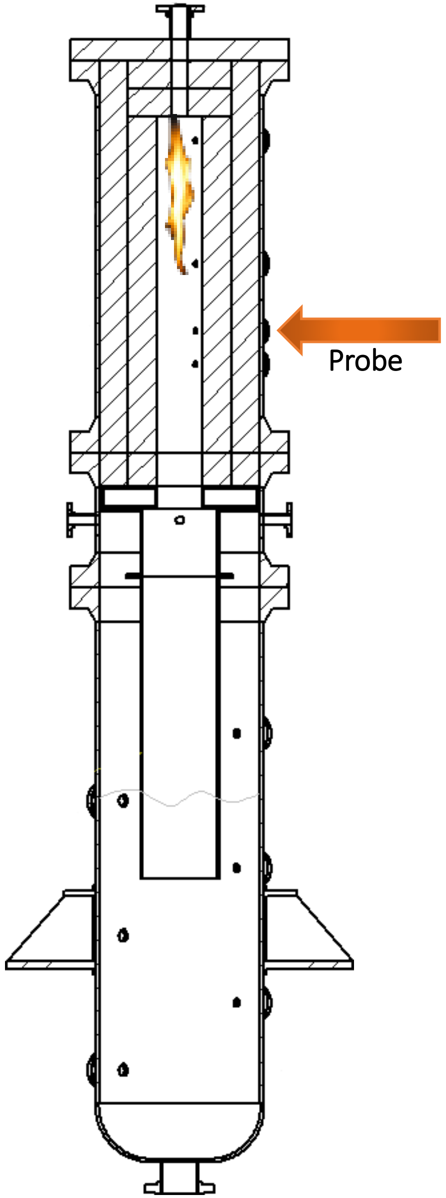


System Schematic



BLPI: 0.0324 µm – 15.7 µm
SMPS: 0.0143 µm – 0.6732 µm
APS: 0.532 µm – 20 µm

EFPR Corrosion Propensity Characterization



- Three alloys of interest
- T22, P91, and 347H
- T22: Low carbon, low chromium alloy commonly used in sub-critical boilers
- P91: Commonly used in supercritical boilers
- 347H: Advanced high-Ni, high-Cr alloy targeted for advanced power plants
- The corrosion studies will primarily focus on the extremes, T22 and 347H, with some limited data from P91

Next Steps

Market Benefits/Assessment

- Demand for the proposed technology has significant promise in the U.S. as power producers seek technologies for CO_2 capture, utilization (e.g., enhanced oil recovery) and storage
- Certain U.S. utilities are actively pursuing collaboration with academia and industry experts to explore strategic alternatives for effective utilization of coal
- Immense demand for coal overseas along with viable technologies to address CO_2 emissions

Technology-to-Market Path

- Efficiency gains, fuel flexibility, and opportunities for scale up present a great value proposition for U.S. utilities
- REI is seeking to leverage its relationships with U.S. utilities, international clients, project partners, and industry stakeholders to actively pursue commercial opportunities within the U.S. and internationally
- Upcoming pilot-scale experiments will seek to demonstrate the technical feasibility of integrating a batch dry feed system into a pressurized oxy-coal system
- Continued research is necessary to address challenges associated with:
  1. Continuous steady operation vs. batch
  2. Design of a steam generator incorporated into a pressurized oxy-coal combustor with dry feed
  3. Application at larger scales

Summary

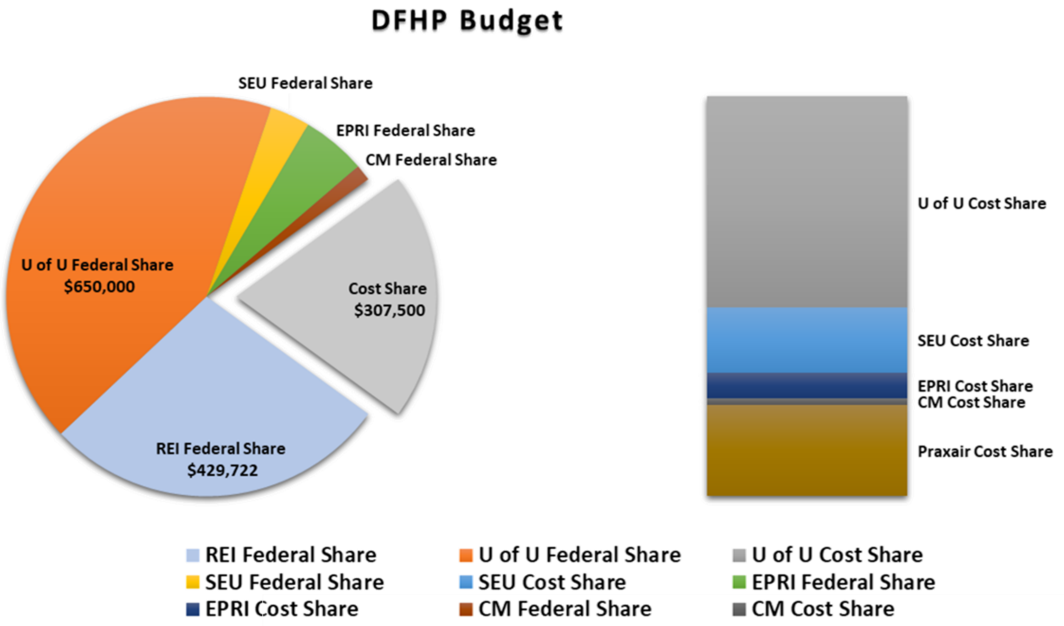
- High pressure oxy-coal combustion is thermodynamically more efficient and has the potential for smaller builds than atmospheric oxy-coal combustion
- Slurry feeding is the approach used by most commercial high pressure pulverized coal conversion systems
- Dry pressurized coal combustion systems have the potential to yield efficiency gains, improve flexibility and facilitate scale up compared to slurry-fed systems
- Design and fabrication of the pilot-scale dry feeding system has been completed to address the key technical challenge of consistently feeding dry coal in a pressurized reactor
- CFD-guided design of burner for the EFPR with dry feeding completed and burner fabricated and tested
- Operational parameters of the dry feed system evaluated using bench-scale apparatus, CFD modeling, and non-reacting coal flow with the pilot-scale system
- Advanced aerosol characterization in EFPR successfully applied in preceding coal slurry-fed operation and readied for dry-fed experiments
- Design and fabrication of corrosion monitoring equipment for use in the EFPR completed
- Full integration of dry feeder with high pressure EFPR and subsequent shakedown testing scheduled for Q4 2020 and Q1 2021

Acknowledgment & Disclaimer

This material is based upon work supported by the Department of Energy under Award Number DE-FE0029162 under Program Manager Steven Markovich.

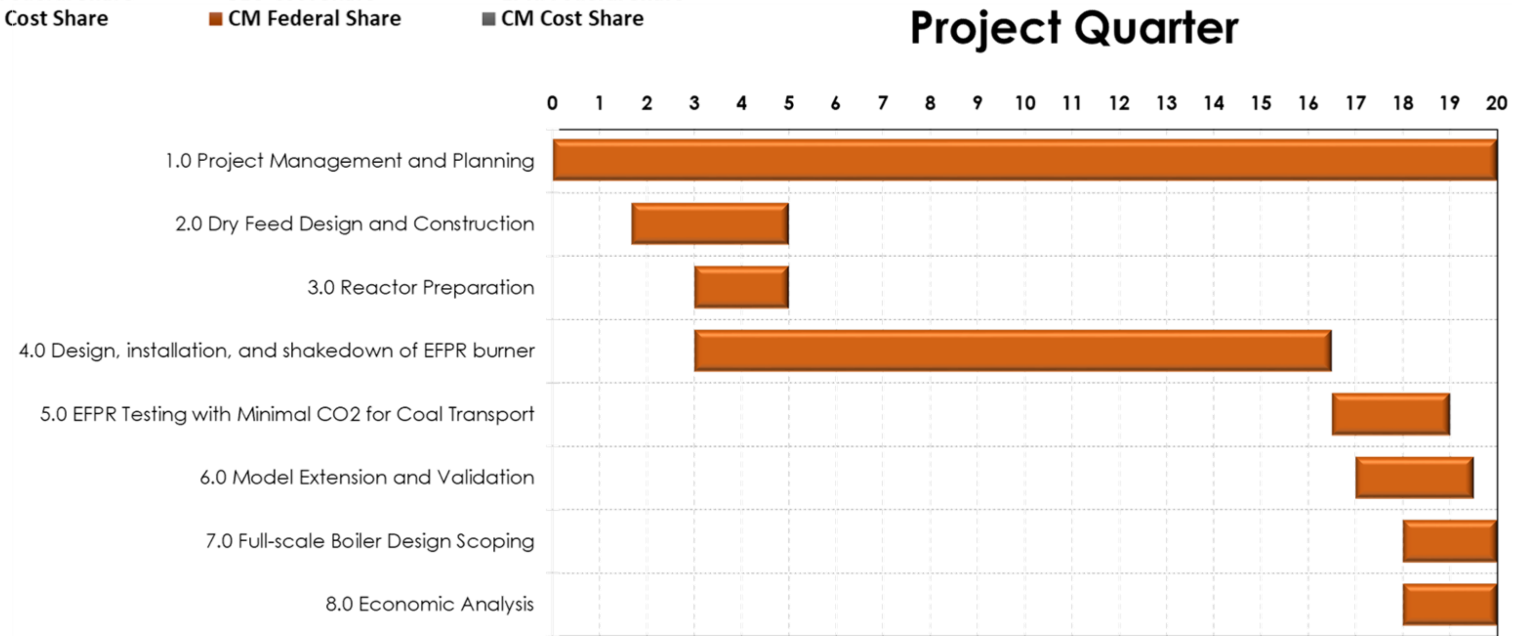
Thank You

Project Timeline and Budget



Total Budget
$1,537,220

Total Federal
$1,229,720



Initial Testing

Transport of Coal at Atmospheric Pressure