

# Industrial CFB Combustor Application Model

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CPFD Software

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# Outline

## Introduction to Circulating Fluidized Bed Combustors (CFBC's)

### Objective of Application Model

- Barracuda Virtual Reactor Solution
- CFD Value proposition

### From lab-scale to industrial – Modeling with Barracuda Virtual Reactor

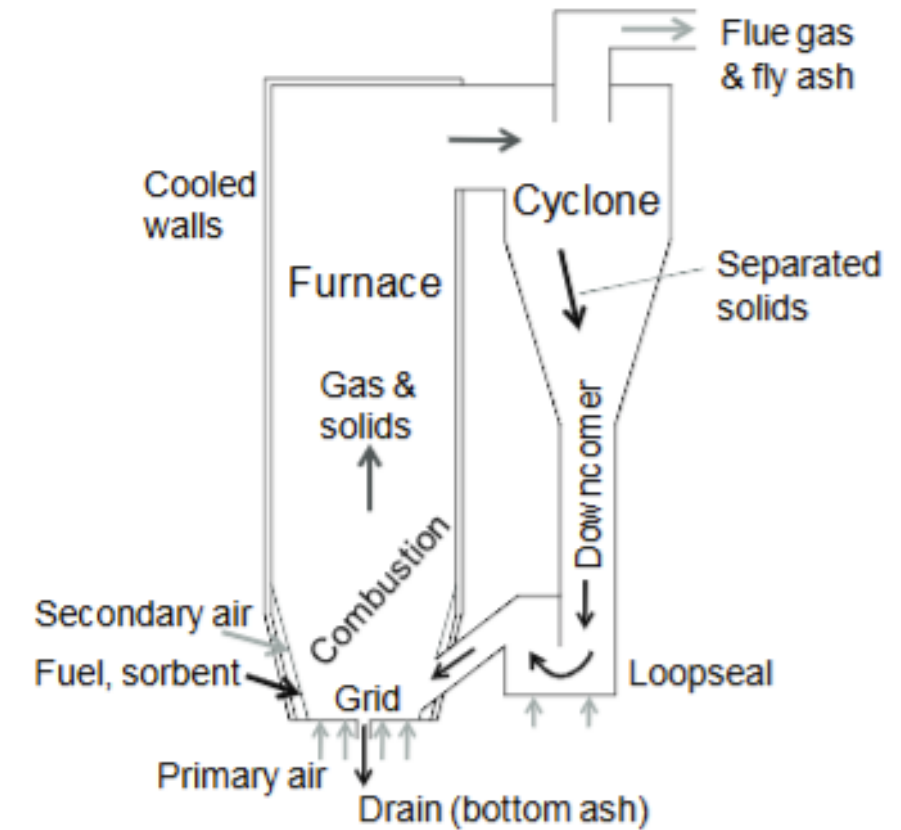
- Lab scale system
- Industrial system
- Extensions of work to emissions reductions

# Circulating Fluidized Bed Combustors (CFBC)

## What is a Circulating Fluidized Bed Combustor?

- An advanced furnace for efficient, low-emission combustion of solid fuels.
- Uses high-velocity air to suspend fuel and bed material (sand, ash, sorbent), creating a circulating, "fluidized" mixture that behaves like a liquid.
- High gas residence times and mixing improve process efficiency and temperature uniformity

Heat from combustion is recovered by various heat transfer surfaces, located in furnace, separator, return leg etc.

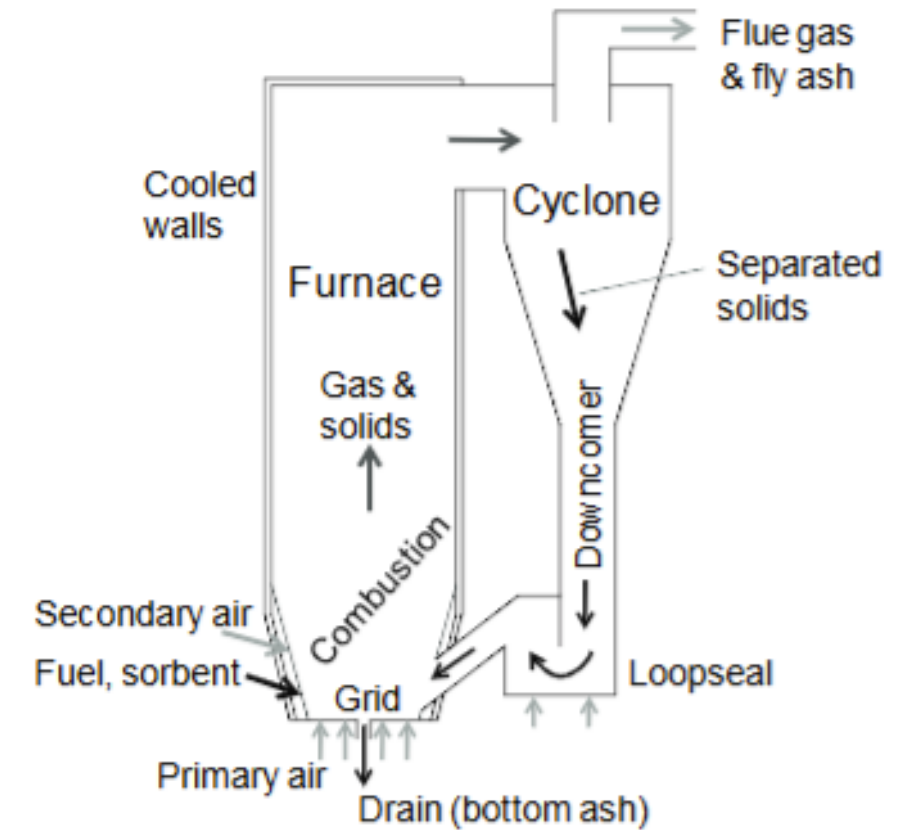


Ref: <https://urn.fi/URN:ISBN:978-952-265-161-7>

# Circulating Fluidized Bed Combustors (CFBC)

## Key Advantages Over Conventional Furnaces

- **Fuel Flexibility:** Burns diverse fuels including low-grade coals, biomass, industrial waste.
- **High Combustion Efficiency:** Efficient mixing and high residence time leads to complete combustion.
- **Environmental Performance:** Low combustion temperatures (~850-900°C) minimize NO<sub>x</sub> formation, while adding sorbents directly captures SO<sub>2</sub>.



Ref: <https://urn.fi/URN:ISBN:978-952-265-161-7>

# CFBC Applications, Challenges, and value of CFD

## Primary Applications

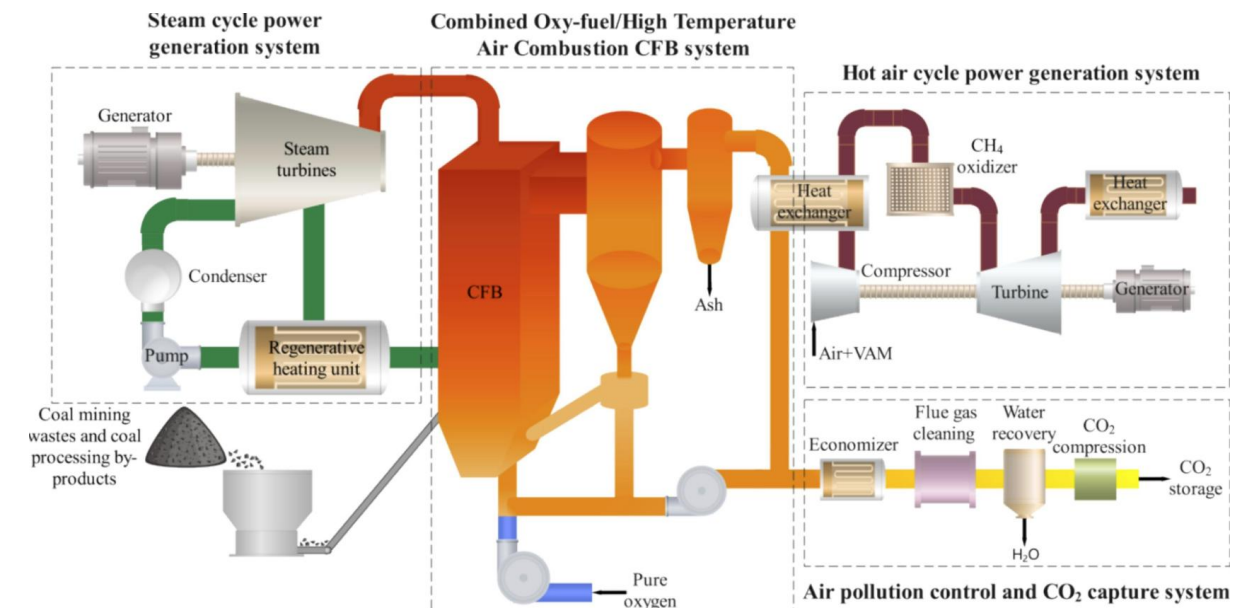
- Power Generation, Industrial Processes, Waste-to-Energy

## Key Operational Challenges

- Complex Physics
- Emissions Control: NO<sub>x</sub>, SO<sub>x</sub>, and CO
- Inefficiency: Poor mixing, temperature non-uniformity
- Erosion

## CFD value proposition

- Detailed Physical Insights: Optimize furnace design, troubleshoot operational problems, and de-risk scale-up for peak efficiency & minimal emissions.

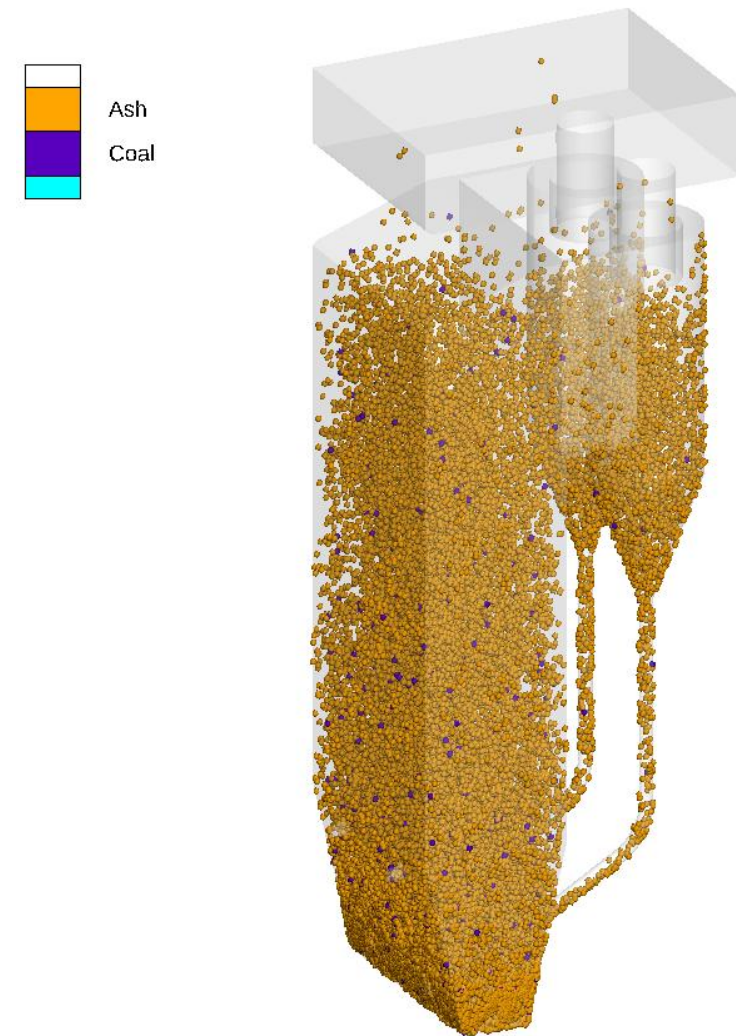


Ref: <https://doi.org/10.1016/j.fuel.2024.132341>

# Barracuda Virtual Reactor Solution

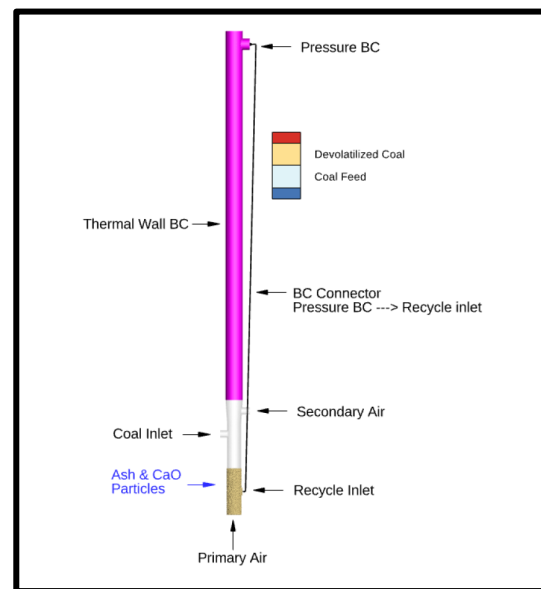
## Value of Barracuda Simulation

- **See the Unseen:** Provides a complete 3D view of internal flow, temperature, and chemical reactions.
- **Optimize Performance:** Reaction dynamics in dense, transition, and dilute zones will impact efficient and emissions (NO<sub>x</sub>, SO<sub>x</sub>, and CO)
- **Solve Problems:** Pinpoints the root cause of issues like poor combustion, temperature hot spots and erosion
- **Better Design:** Allows engineers to test and validate designs virtually, reducing risk and cost.

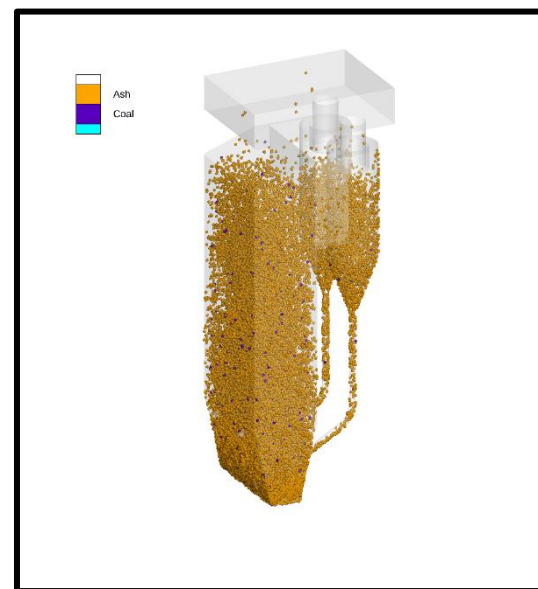


# CPFD Modeling workflow

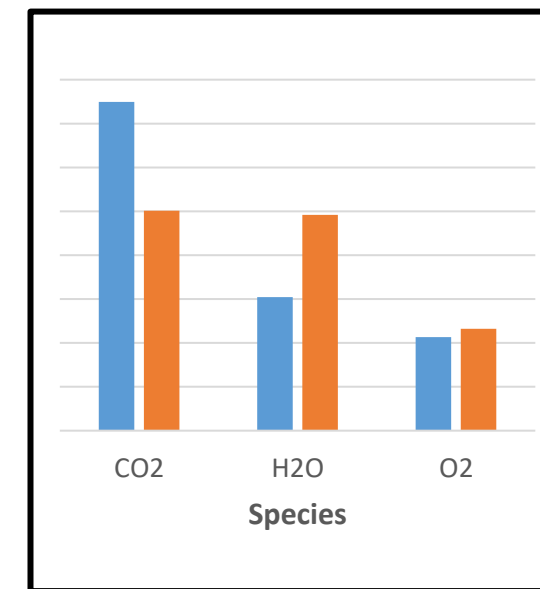
## Lab scale (50 kw)



## Industrial CFB



## Ammonia cofiring (emissions reduction)



Lab scale system (50 kW) was set up based on work of Wu et al. 2017

- 50 kW system consists of a 4.2 m tall riser

Industrial scale system

- 110 MW system consists of 28 m tall riser section

Emissions reduction

- Cofiring with ammonia (20%)

# Chemical reaction kinetics

Custom kinetic model of 28 homogeneous and heterogeneous reactions. Volatile composition derived from Wu 2017.

## Volatile Pyrolysis:

$$d[\text{CH}_4]/dt = -0.55165 * d[\text{Volatile(S)}]/dt$$

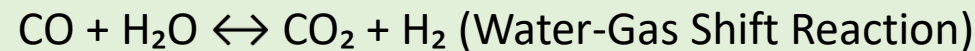
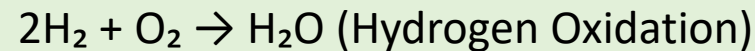
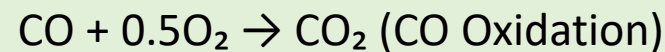
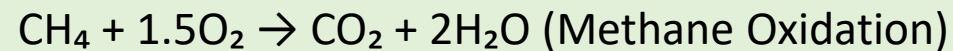
$$d[\text{CO}_2]/dt = -0.40096 * d[\text{Volatile(S)}]/dt$$

$$d[\text{NH}_3]/dt = -0.00337 * d[\text{Volatile(S)}]/dt$$

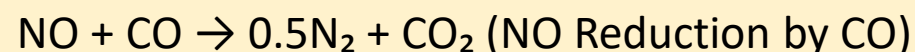
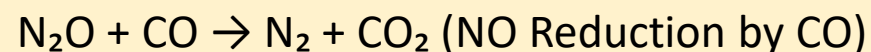
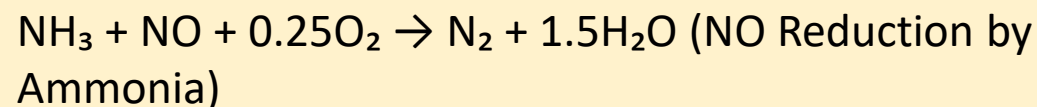
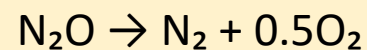
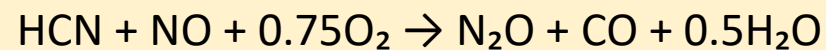
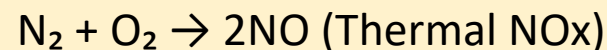
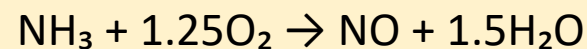
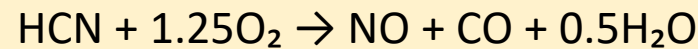
$$d[\text{HCN}]/dt = -0.0125 * d[\text{Volatile(S)}]/dt$$

$$d[\text{H}_2\text{S}]/dt = -0.02585 * d[\text{Volatile(S)}]/dt$$

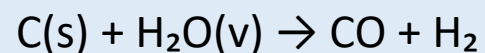
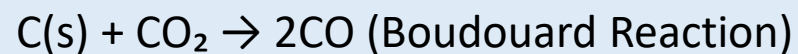
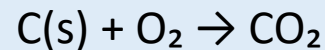
## Fuel & Volatile Combustion:



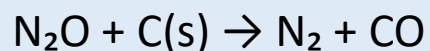
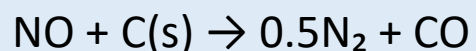
## Nitrogen Chemistry (NO<sub>x</sub> Formation & Reduction):



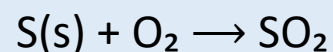
## Char Combustion & Gasification:



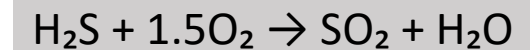
## Nitrogen Chemistry (NO<sub>x</sub> Reduction by Char):



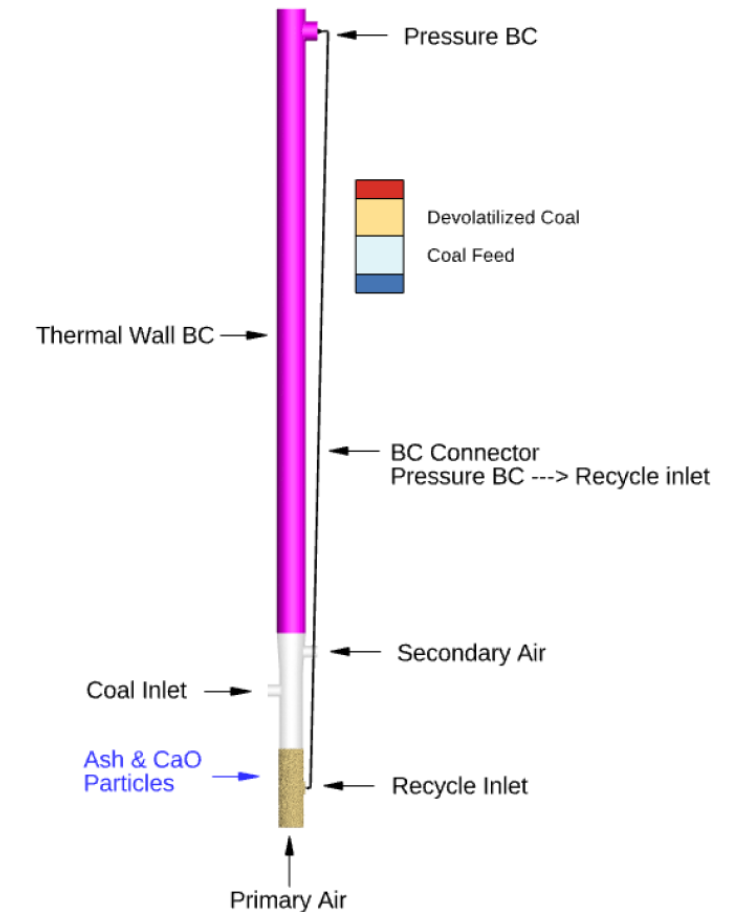
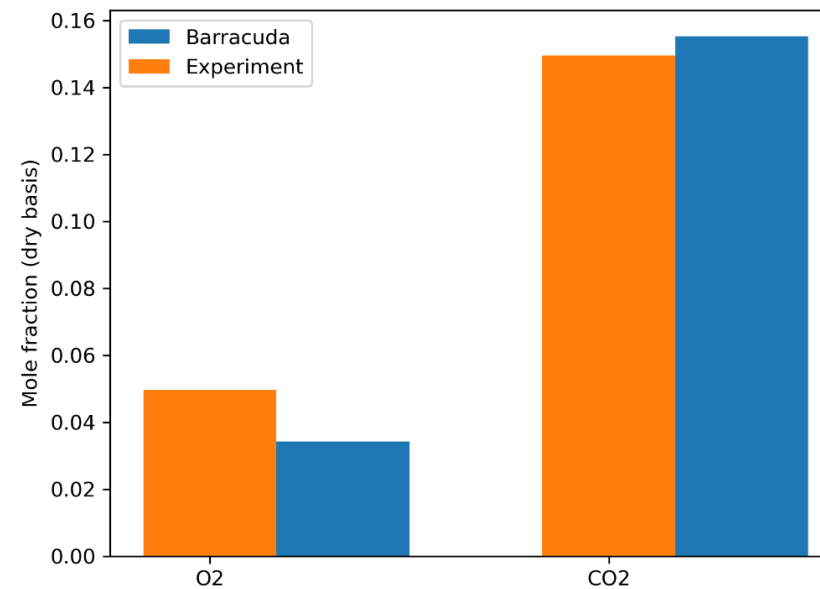
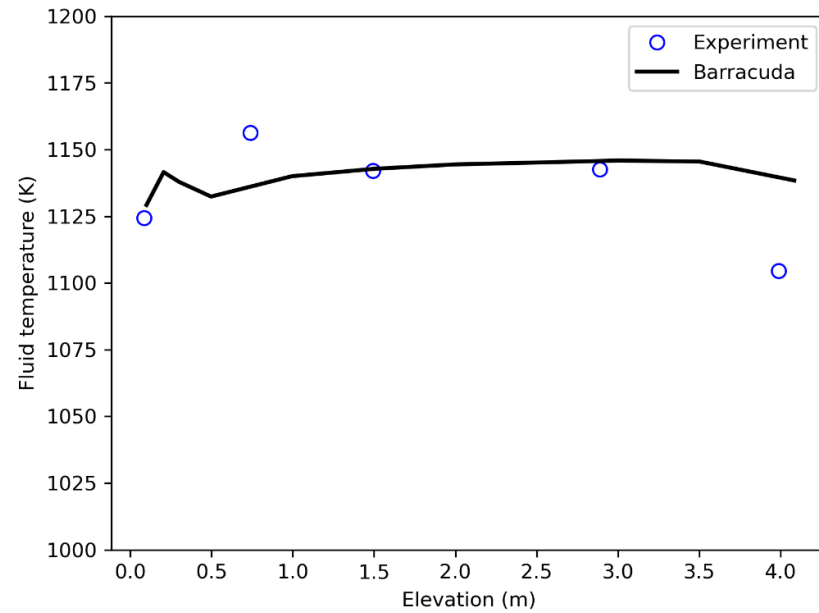
## Char Component Oxidation:



## Sulfur Capture:



# Lab-scale model validation



Fluid temperature, as well as CO<sub>2</sub> and O<sub>2</sub> mole fraction (dry basis) compared between the experiment and simulation

Lab-scale model results provide confidence in reaction kinetics used for this system

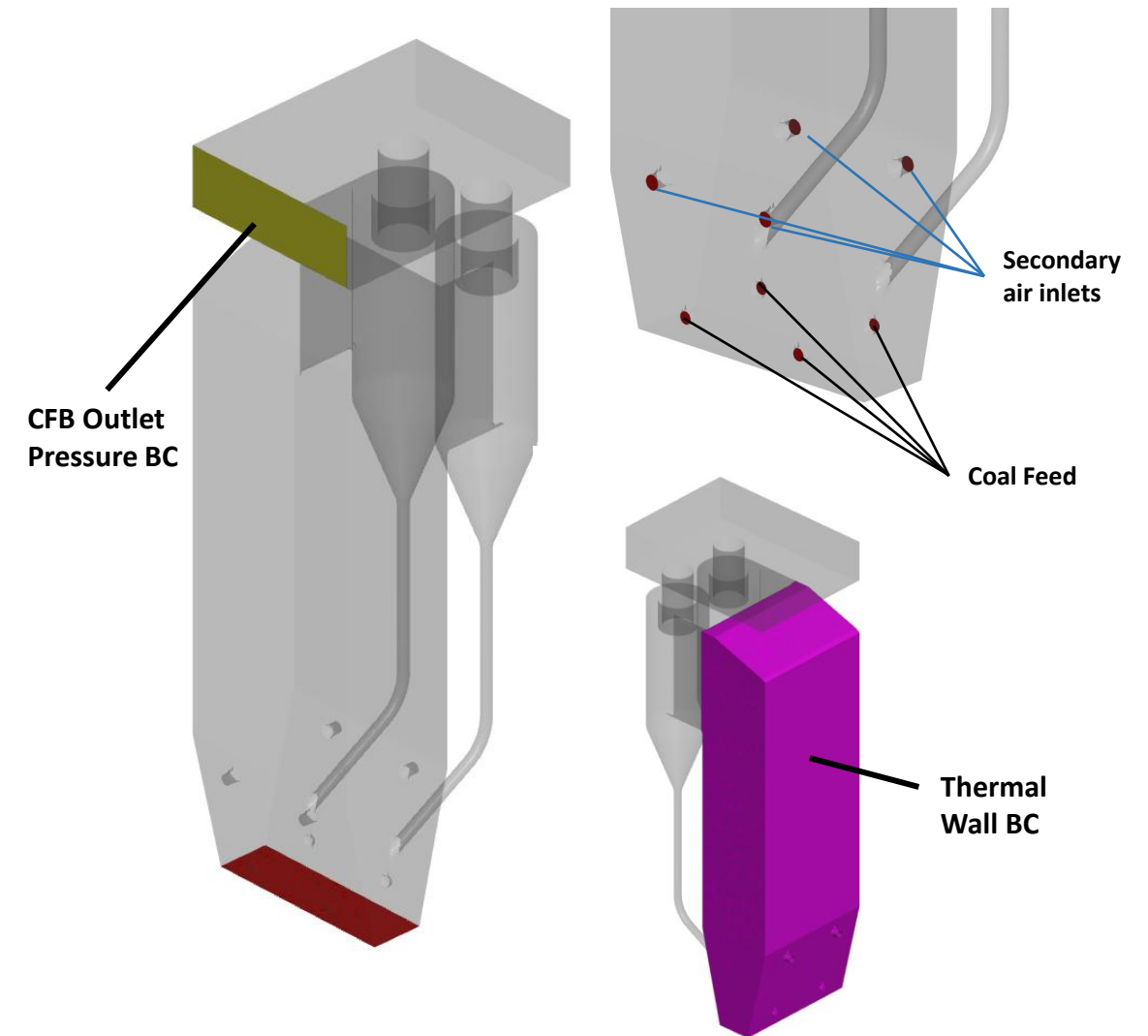
# Industrial CFB system

## Domain & Physics

- 28 m tall riser section. Width: 2.4 m - 5.4 m
- Compressible flow simulation with volumetric and discrete chemical reactions

## IC & BC Conditions

- Primary air injected from bottom (11.91 kg/s) and 4 secondary air inlets (5.96 kg/s)
- Two 4 m I.D. cyclones with returning solids via two diplegs
- Pressure outlet on the top
- Coal flow rate = 2.254 kg/s; bed of ash+CaO is initialized.
- Thermal wall BC: Constant at 298 K for the riser section



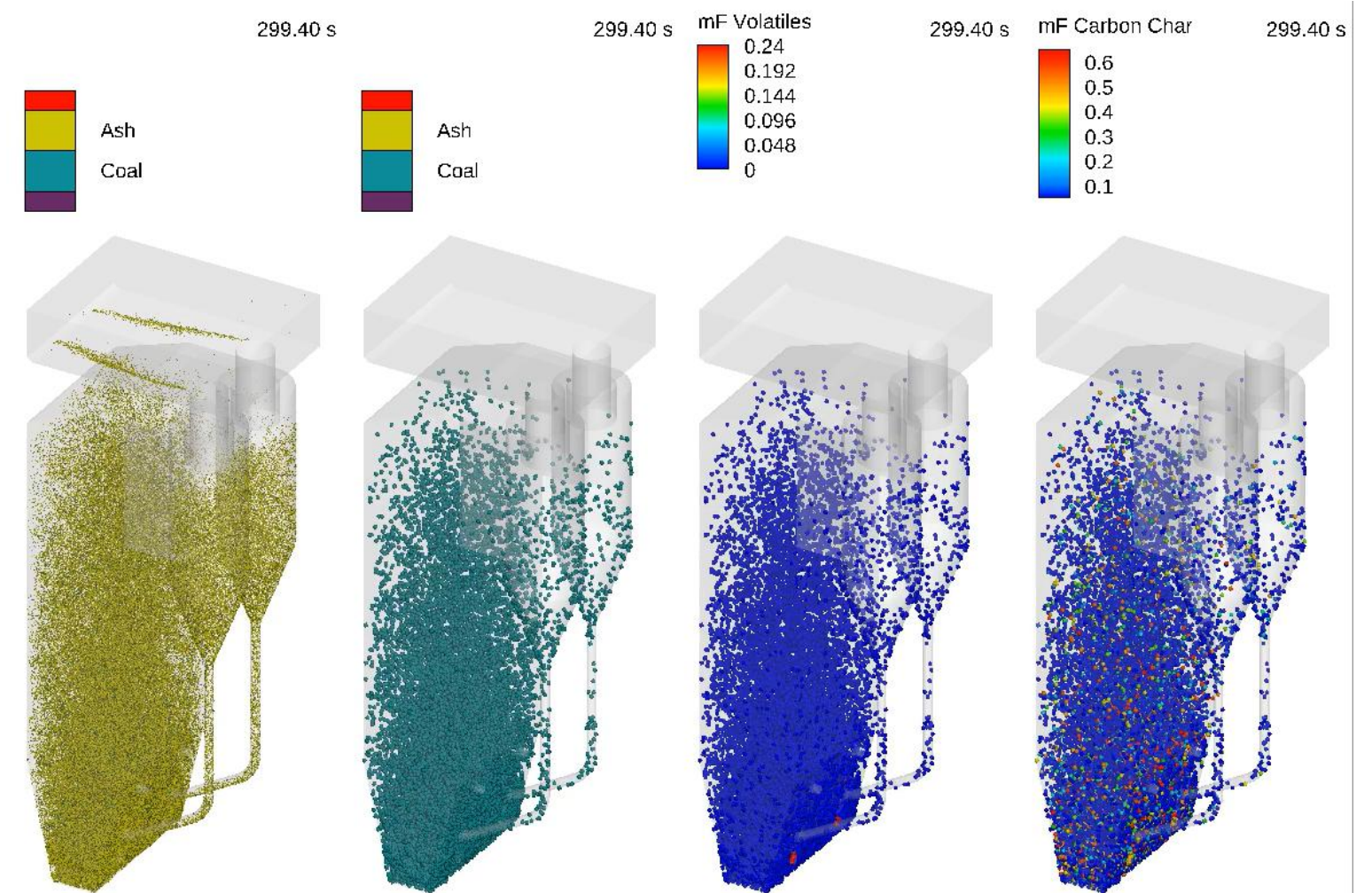
Modeled CFB Domain

# Industrial CFB Results

Circulation of devolatilized coal/ash key to achieving efficient heat transfer.

Devolatilization happens rapidly near the fuel feed inlets

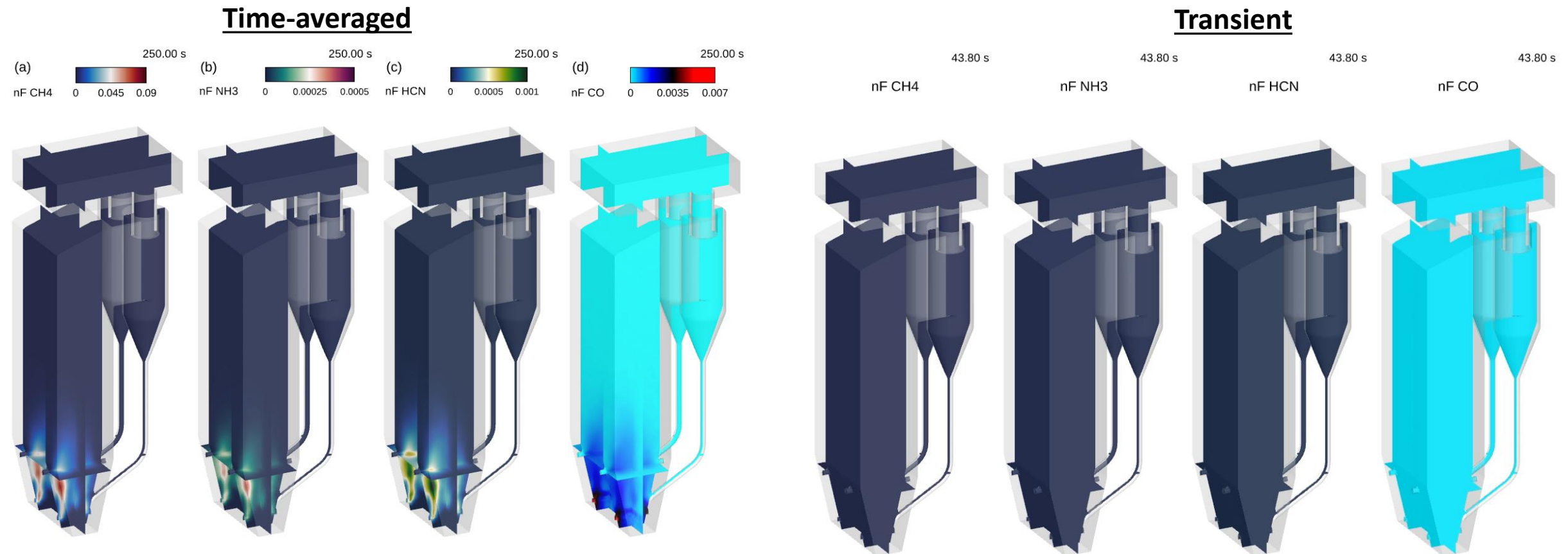
Solid carbon reacts through a series of char reactions



# Industrial CFB Results

## Volatiles release

- Consumed quickly – not present in appreciable quantities above secondary air inlets

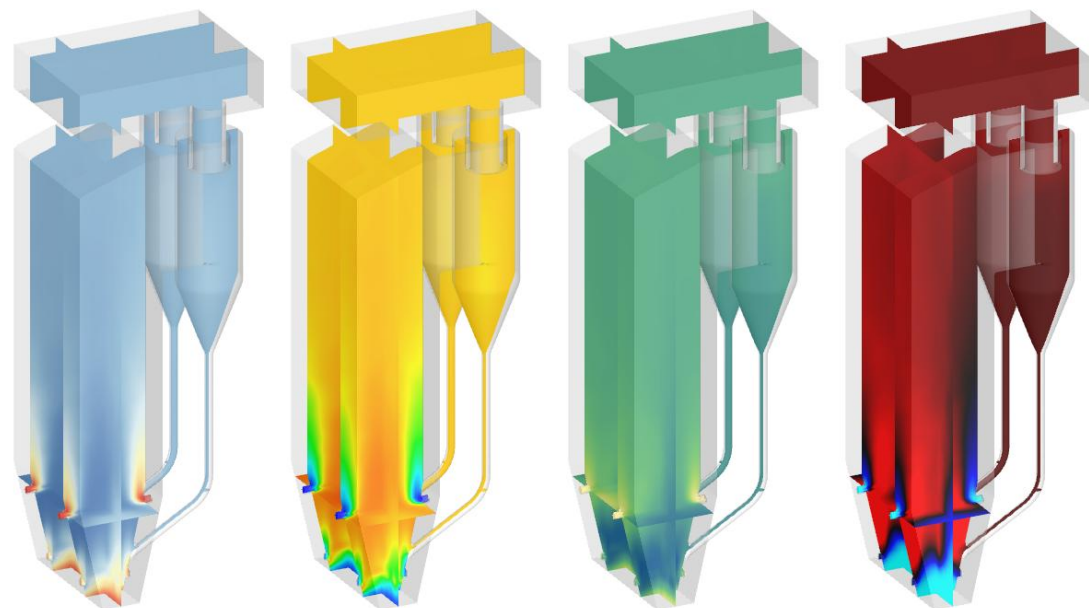
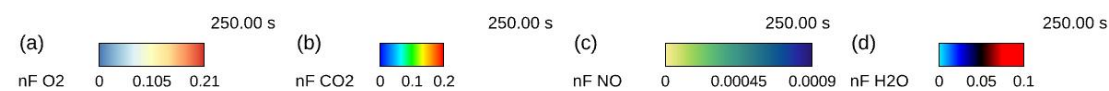


# Industrial CFB Results

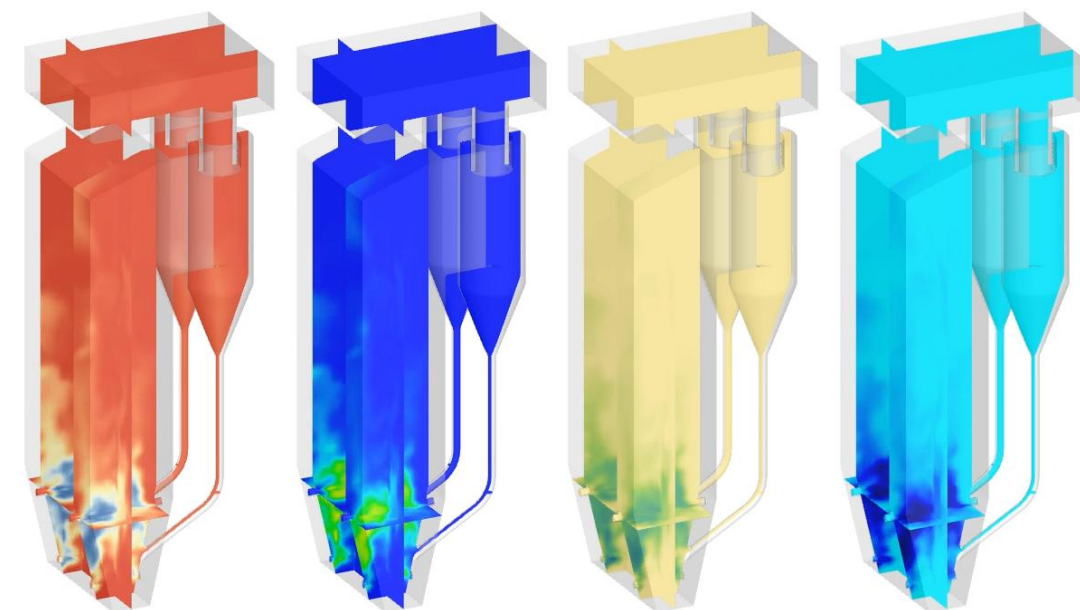
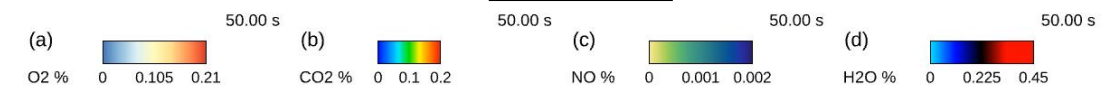
## CO<sub>2</sub>, H<sub>2</sub>O and NO production

- NO production limited due to O<sub>2</sub> consumption
- Reaction of NO with volatiles and oxygen supplied by the secondary air inlets produces steam

### Time-averaged



### Transient

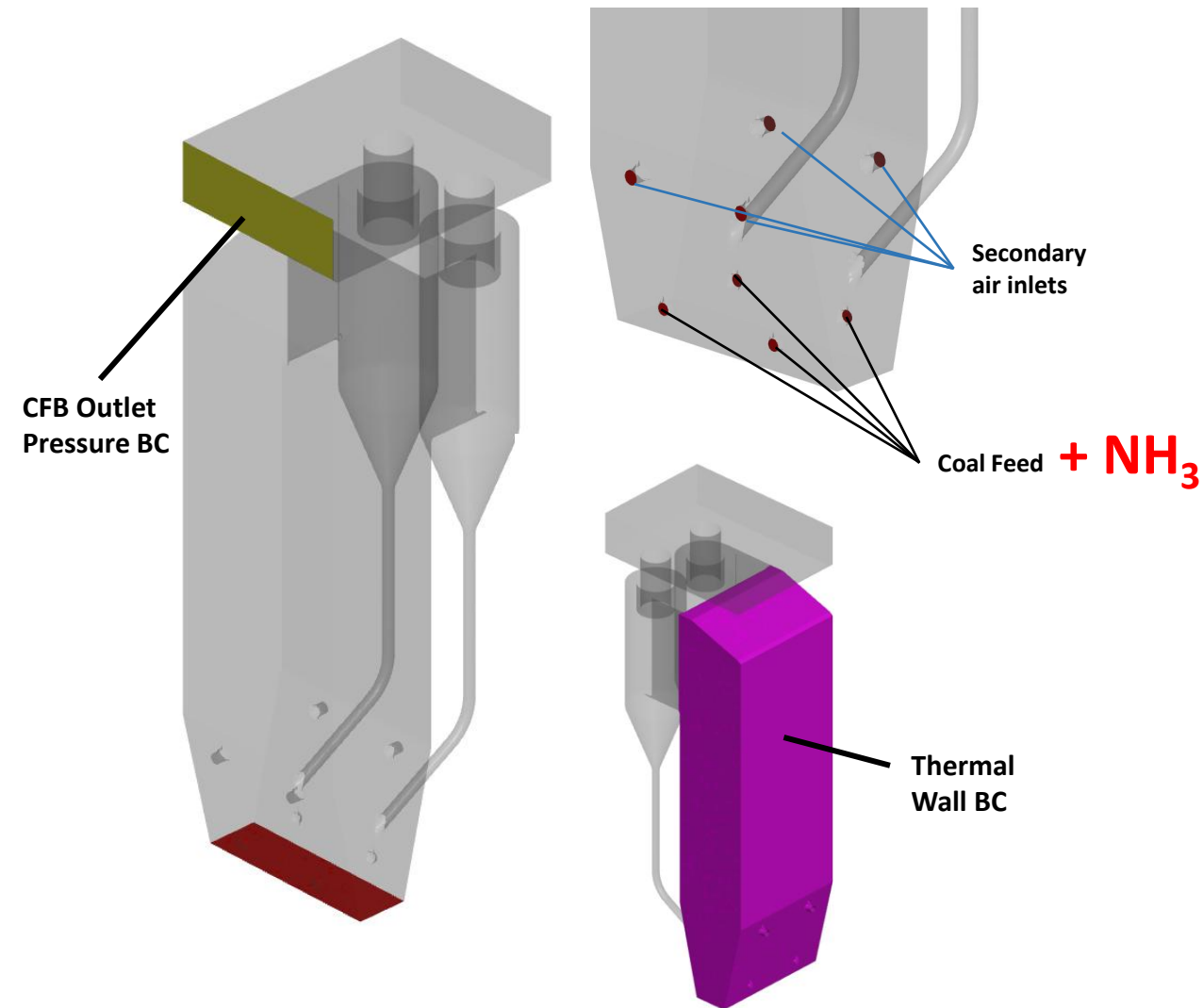


# Ammonia co-firing example

Ammonia is fed along with coal at a 20% mass fraction to keep the same thermal mass as conventional operation

Air flow rate is adjusted to accommodate new fuel composition

Reduces emission of CO<sub>2</sub> through replacement of coal feed



# Ammonia co-firing

Ammonia cofiring case includes a replacement of the coal feed with 20%  $\text{NH}_3$

Significant reduction in  $\text{CO}_2$  emissions

Increase in production of  $\text{H}_2\text{O}$  due to the stoichiometry of ammonia

