

Barracuda Virtual Reactor for Cement Related Applications: Calciner & Conditioning Tower

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CPFD Software

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Introduction to Cement Process Applications

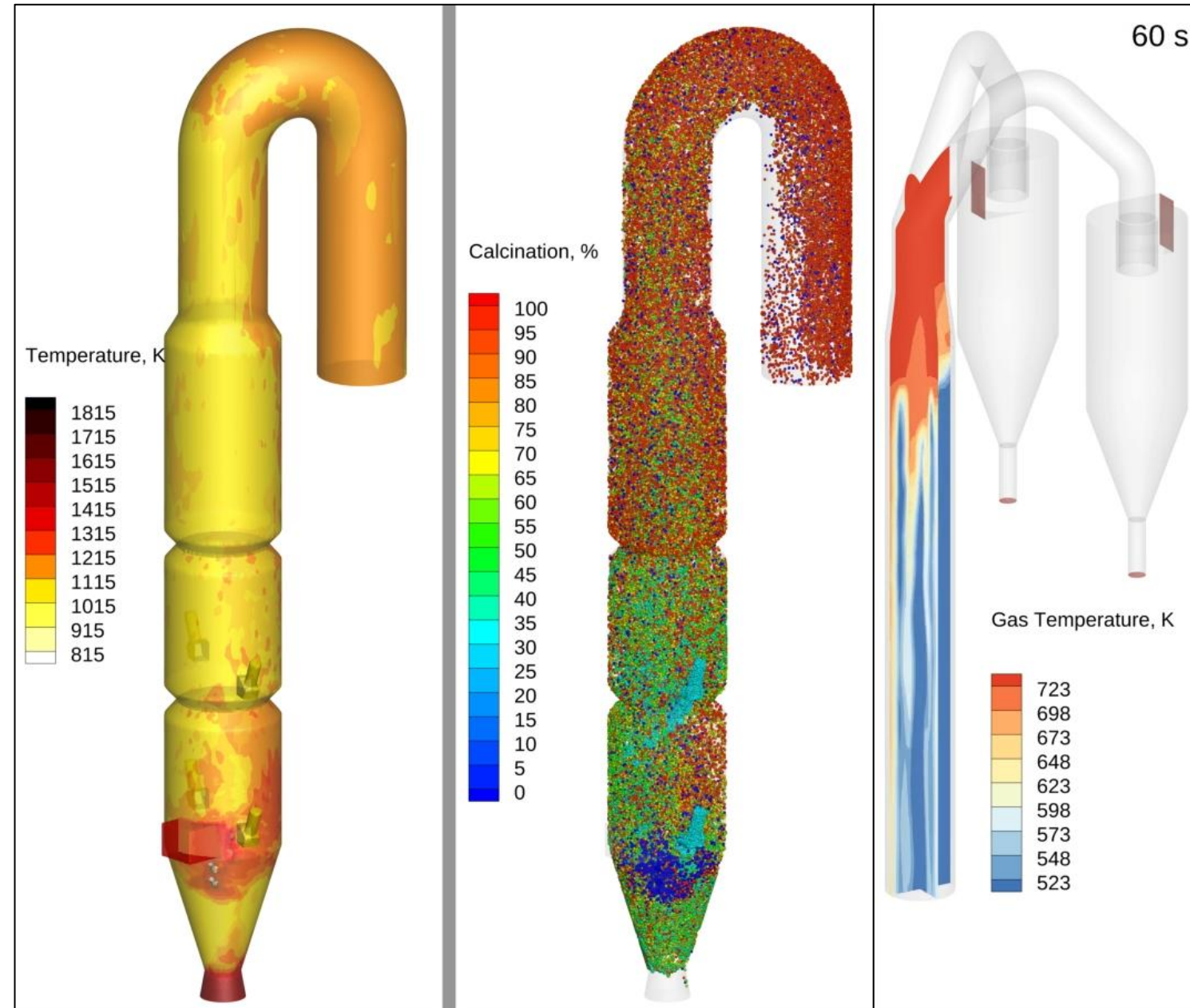
- Cement Manufacturing Overview
- Cement Calciners: Why they matter!
- Barracuda Virtual Reactor Solution

Application model: Calciner

- Model Scope & Domain
- Reaction Pathways & Kinetic Framework
- Validation: Temperature & Calcination
- Qualitative Distribution
- Extension: Coal & Sludge Cofiring Case

Application model: Conditioning Tower

- Model Scope & Domain.
- Qualitative Distribution
- Evaporation Quantification



Cement Manufacturing

What is Cement Manufacturing?

- Conversion of Raw Materials such as Limestone & Clay into Cement Clinker, which is finely ground into cement as we know it.

Main Process Stages

- Preheating of Raw Meal in the preheater cyclone stages
- Calcination in the calciner
- Clinker formation in the kiln
- Cooling & downstream grinding into Cement

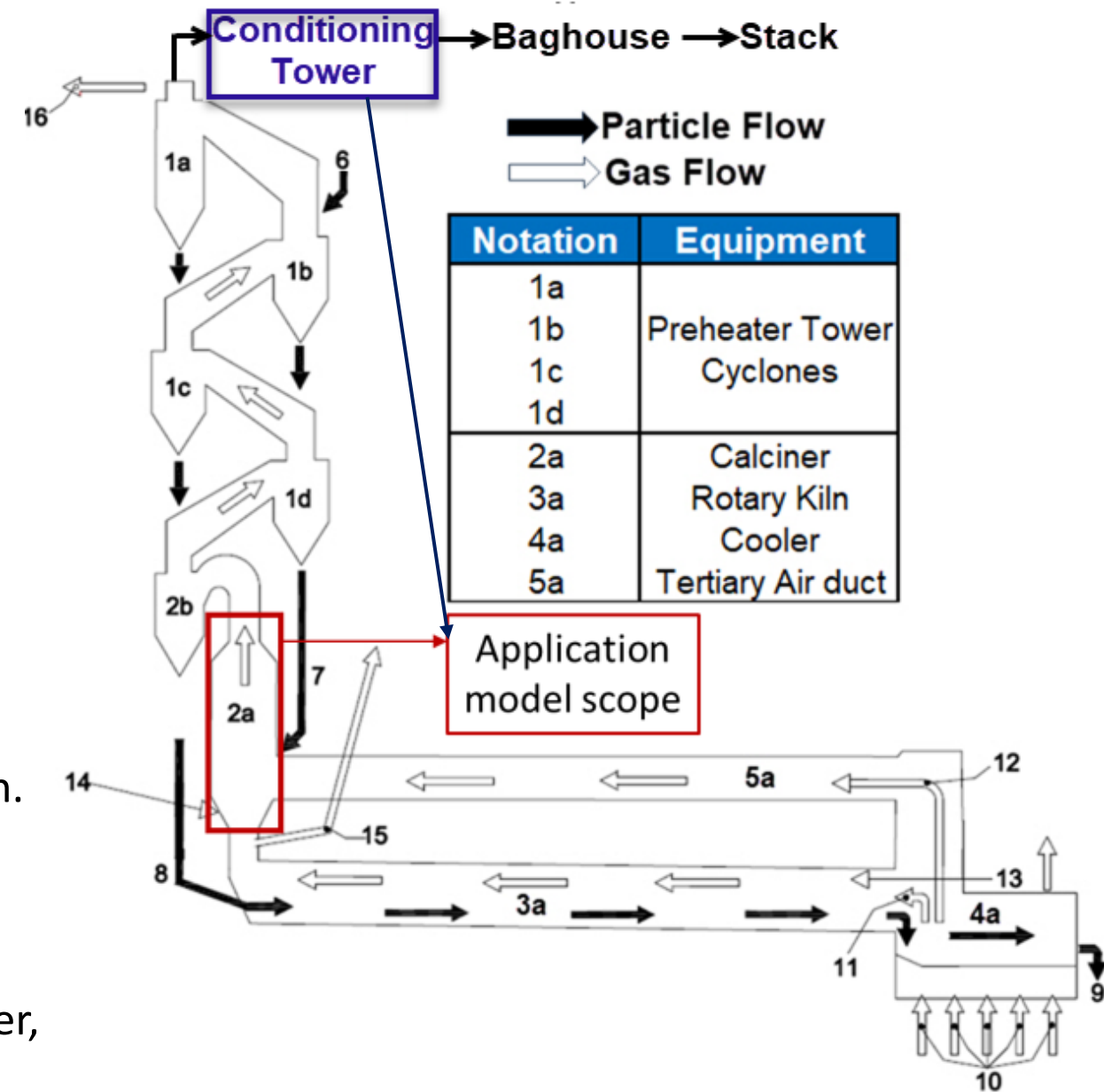
Where the Calciner & Conditioning Tower Fit

- Calciner located between the preheater cyclones & rotary kiln.
- Main reactor for raw material calcination.
- Conditioning Tower located downstream of the preheater system & upstream of dust collection equipment.
- Uses water injection to cool exhaust gas before downstream filtration.

Why This Process Matters

- Thermally intensive, multi-phase reacting system.
- Process performance depends on how effectively mixing, heat transfer, reaction kinetics, & residence time are controlled.

Cement Manufacturing Pyro-Processing



Cement Calciners: Why They Matter

What is a Calciner?

- High Temperature reactor located between the preheater & rotary kiln in Cement manufacturing.

Where the Calciner Fits:

- Shifts roughly 90–95% of calcination out of the rotary kiln.
- Helps increase throughput & lowers kiln fuel demand.

Why It is Critical:

- Calcination alone contributes about 5% of global fossil CO₂ emissions. With combustion included, cement production is responsible for roughly 7–8% of global CO₂

What Happens Inside the Calciner

- Gas–solid mixing & residence time control
- Fuel staging & combustion (Coal / Municipal Solid Waste)
- Raw meal heating & limestone decomposition
- CO₂ generation

A credible cement calciner CFD model must capture:

- Staged gas & solids injection.
- Compressible coupled-reacting flow behavior.
 - Limestone Decomposition.
- Fuel Conversion: Devolatilization & Char burn-out
 - Fluid-particle heat transfer & radiation
 - Emissions-relevant pathways (Ex., NO_x)

Cement Calciner -> Long residence times & mixing -> opportunity for alternative fuels substitution & emission control.

Barracuda Virtual Reactor Solution

Core Technology (Industry-proven MP-PIC Framework):

- Resolves industrial-scale dynamic transient gas–solid hydrodynamics within a fully coupled thermally reactive framework.

High-Fidelity Physics & Chemistry:

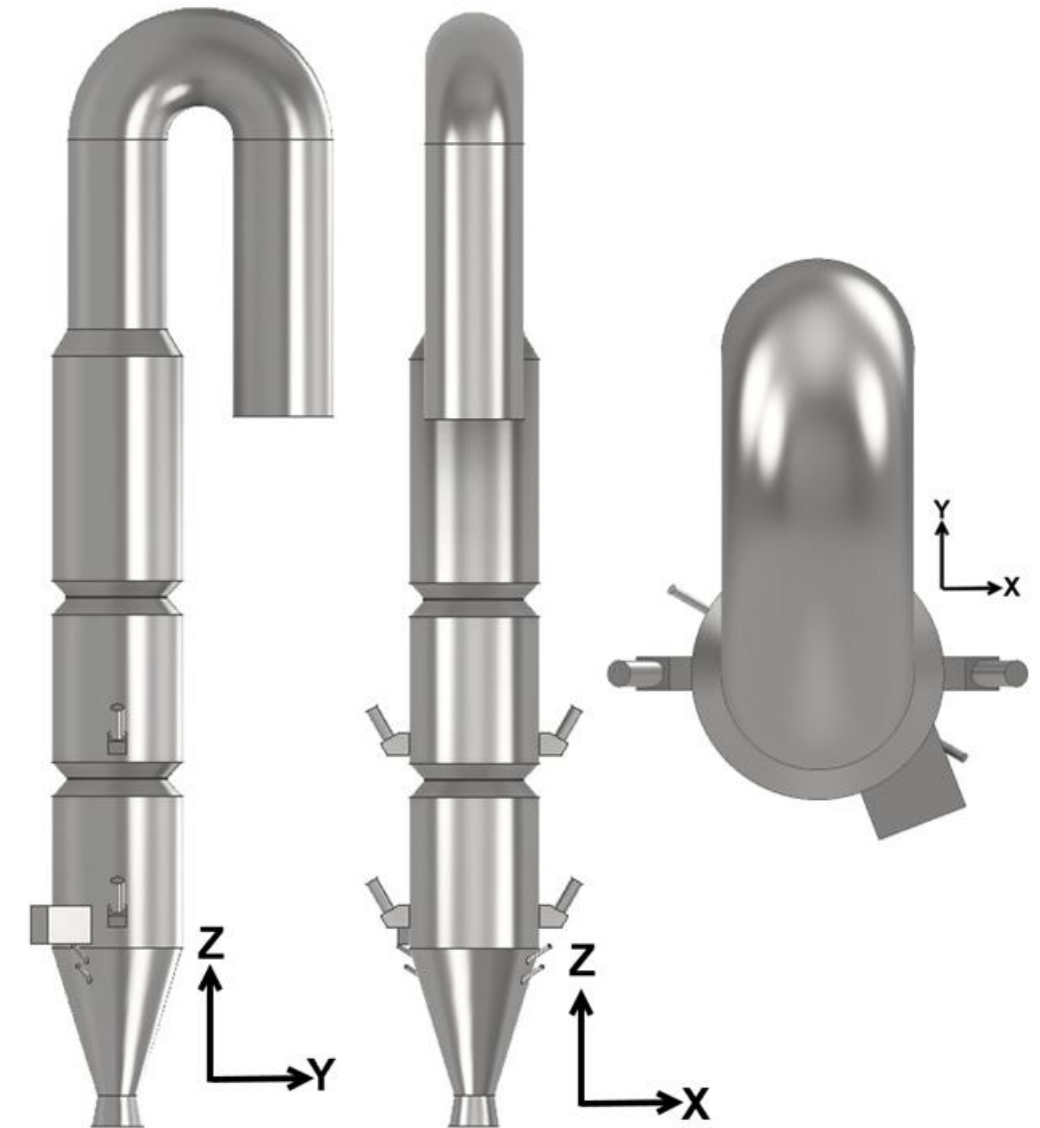
- Captures 3D hydrodynamics, temperature fields, & gas distribution.
- Models coupled thermochemistry between flue gas, tertiary air, fuel, & raw meal staging.

Scalability & Performance:

- Supports **large industrial reactor simulations** with **GPU-accelerated computation** for practical turnaround times.

Value of Simulation:

- **Resolve Internal Reactor Behavior:** Understand existing operation.
- **Support Design & Operational Changes**
- **Enable Process Development:** Alternative fuels feasibility & emissions reduction.
- **Solve Problems:** Identify root causes of existing issues with Calciner.



Barracuda Model
(Fluid Domain)

Cement Calciner Model



Model Scope & Domain

- Industrial-scale model setup derived primarily from **Zhu et al. (2024)**, with supplemental open literature used where needed.
- Model is **64.2m** tall, with a maximum diameter of **7.6m**.
- **Four** narrow inclined pipes for coal feed.
- Raw material staging through **four** chutes at **two** elevations.
- Inlets for tertiary air & kiln exhaust gas, & a single outlet for gas & particle exit.

Boundary Conditions & Model Inputs

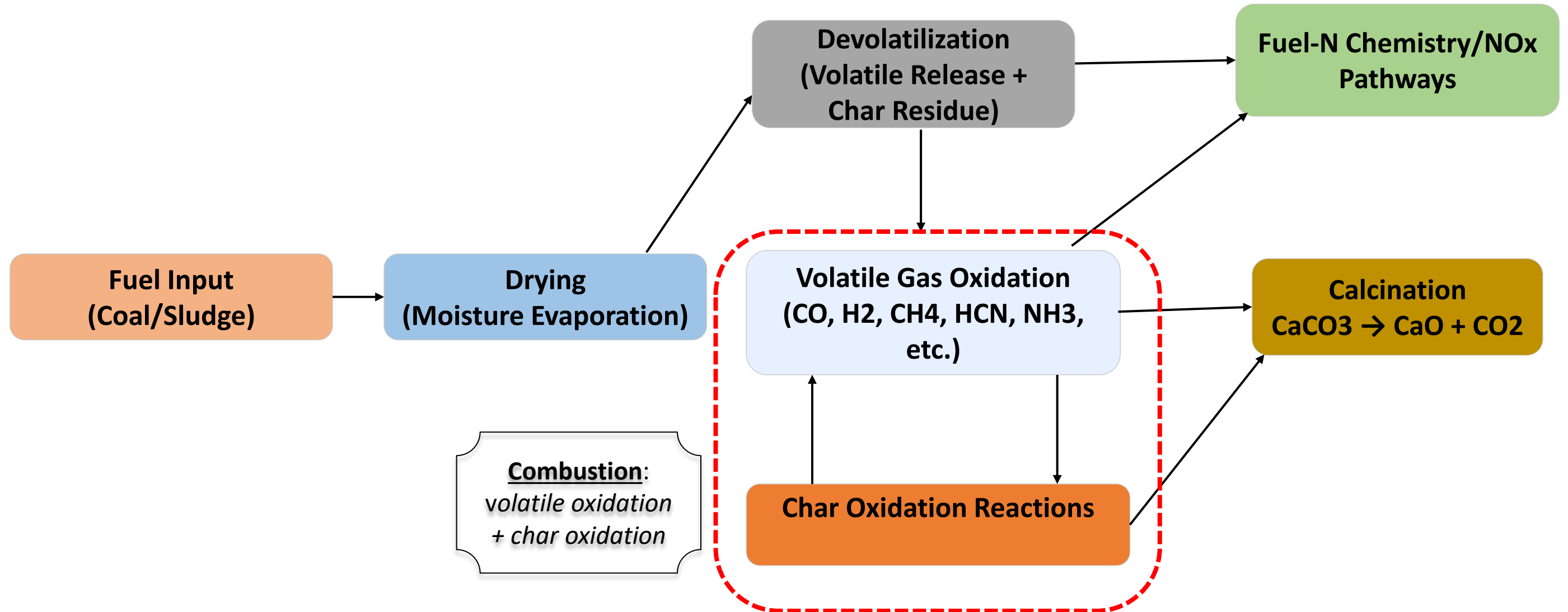
- Thermal wall resistance & emissivity capture heat loss through the calciner shell & refractory.
- **Raw material, coal, & sludge waste** are solid species with full Particle Size Distributions (PSDs) & compositions.
- **Included Heat transfer mechanisms:** Convection, particle-particle conduction, & radiation.



You Can Download This App. Model:
<https://cpfd-software.com/application-model-cement-calciner/>

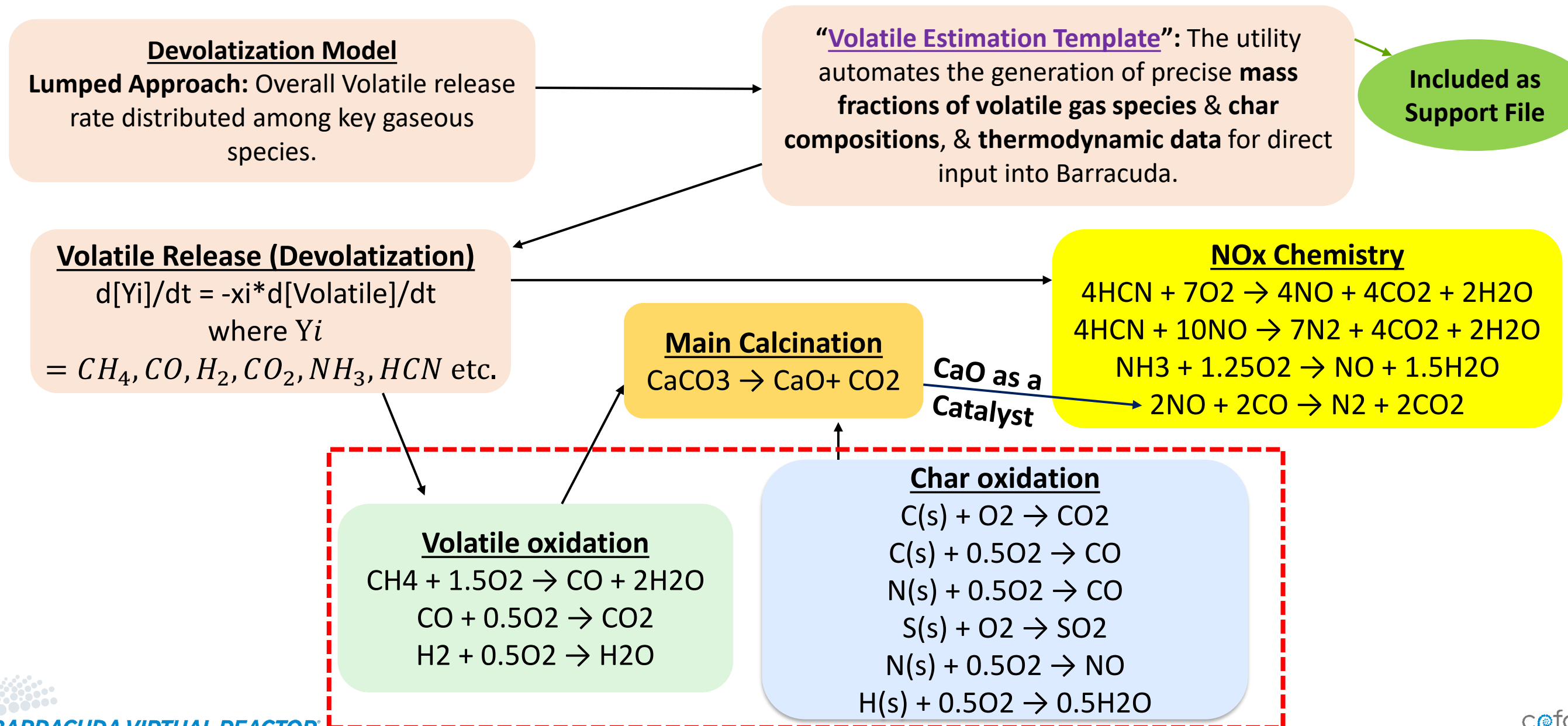
Primary Literature for Model Development
"Zhu et al. (2024)"
"The Co-Processing Combustion Characteristics of Municipal Sludge within an Industrial Cement Decomposition Furnace via CFD"

Cement Calciner Reaction Pathways



Cement Calciner Reactions & Kinetics

A custom kinetic model comprising 15 reactions was developed from open-source literature to capture the relevant chemistry.



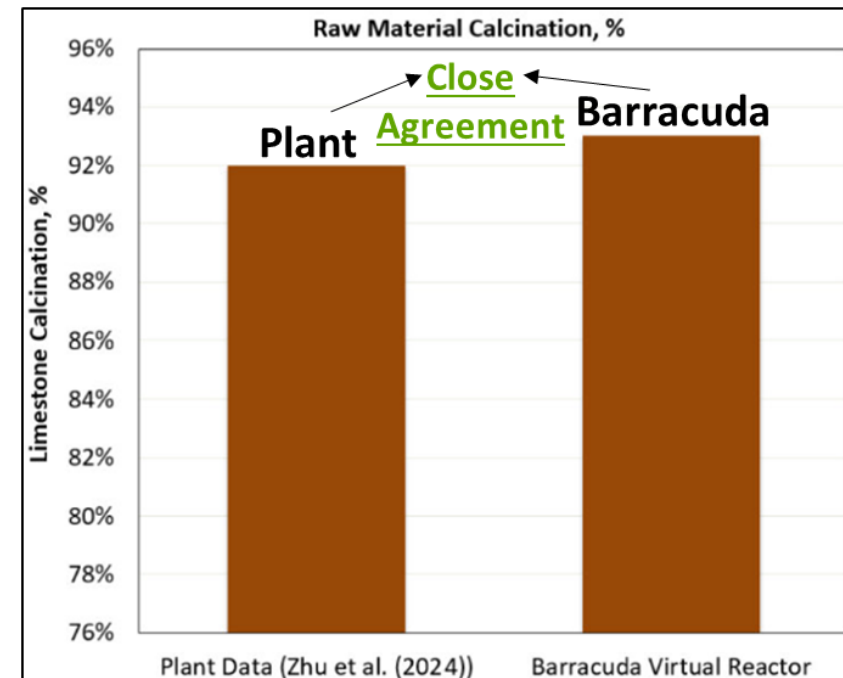
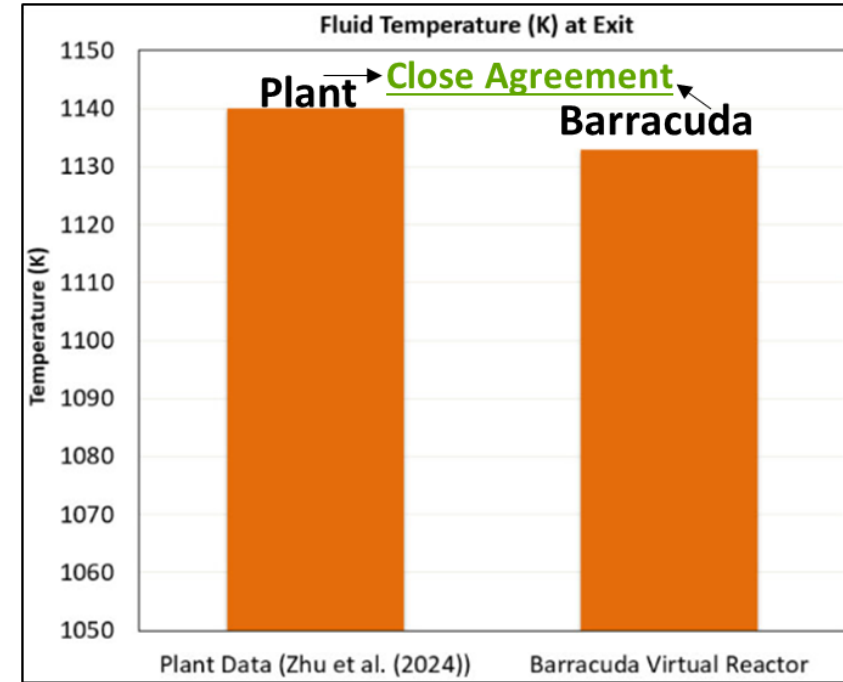
Cement Calciner Validation

Barracuda Model vs Plant Data

- Barracuda predictions show good agreement with plant data for:
 - Outlet gas temperature (1140K vs 1133K)
 - Degree of calcination (92% vs 93%)
- The agreement indicates that the model captures:
 - the coupled gas–solid heat transfer
 - Fuel conversion & energy release
 - Calcination kinetics under industrial conditions

Key Takeaway: The implemented kinetics are adequate in capturing the heat-transfer characteristics & the overall energy balance of the calciner, as evidenced by the strong agreement with plant data.

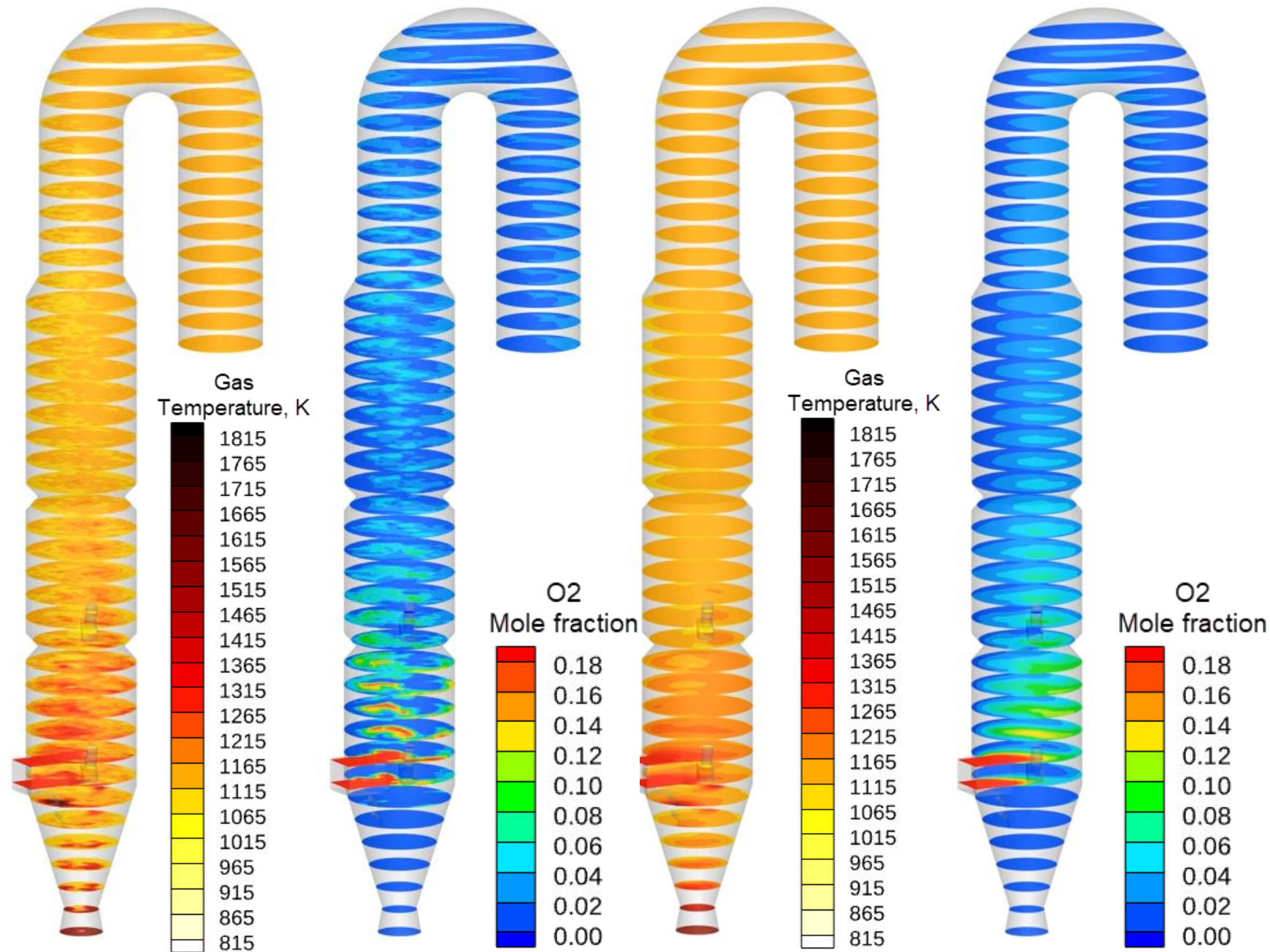
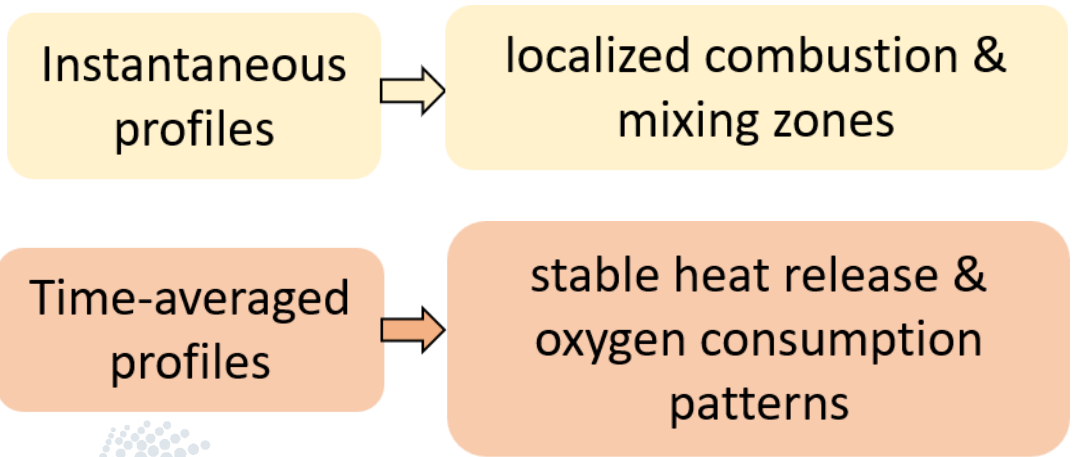
The reaction kinetic set from the application model can be reused, if desired, to model similar systems, with appropriate adjustments to the kinetic parameters to reflect material and process-specific conditions.



Plant data are provided in the primary literature (Zhu et al., 2024) & come from an actual 6000 t/d cement plant in China.

Cement Calciner – Temperature + O₂

- High temperature + low O₂ identify the primary combustion zone near fuel injection
- O₂ shows a progressive depletion along the calciner, indicating continuous consumption due to exothermic combustion & oxidation reactions.
- A progressive decrease in gas temperature with increasing elevation, primarily driven by heat transfer from flue gases to colder raw material.
- At higher elevations, a local thermal equilibrium is established between the gas & solids.



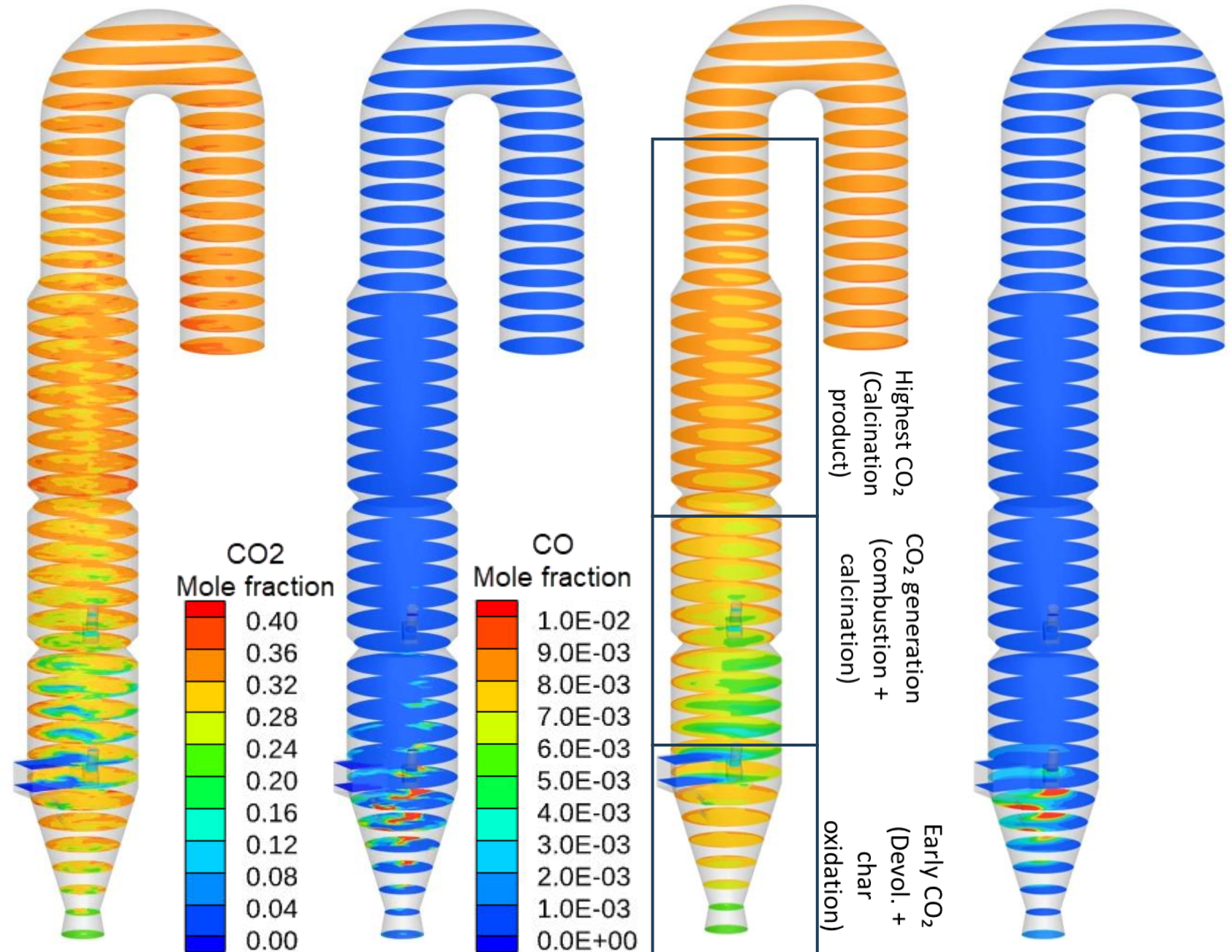
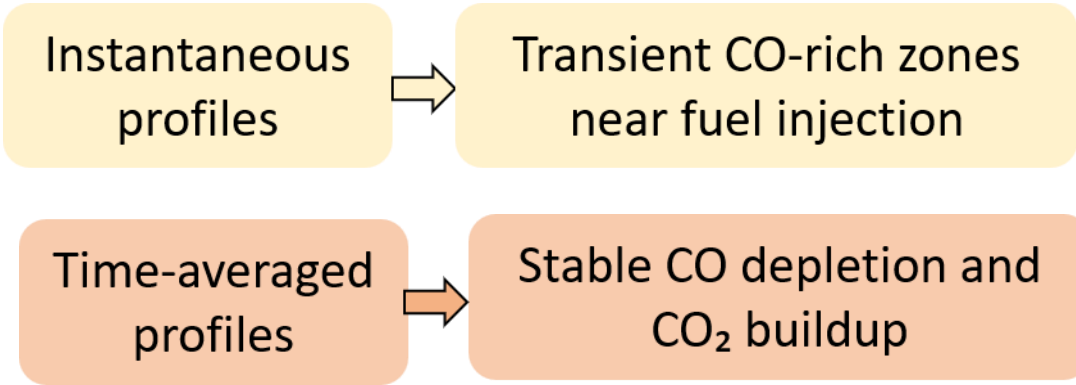
Instantaneous Profiles

Time-averaged Profiles

Cement Calciner – Species Distribution



- CO₂ increases along the calciner, reflecting:
 - fuel combustion
 - calcination ($\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$)
- CO is concentrated near the fuel injection region, indicating:
 - Localized incomplete combustion
 - Active reaction zones.
- CO is rapidly consumed along the riser, showing:
 - Oxidation to CO₂
 - Progression towards complete combustion.



Instantaneous Profiles

Time-averaged Profiles

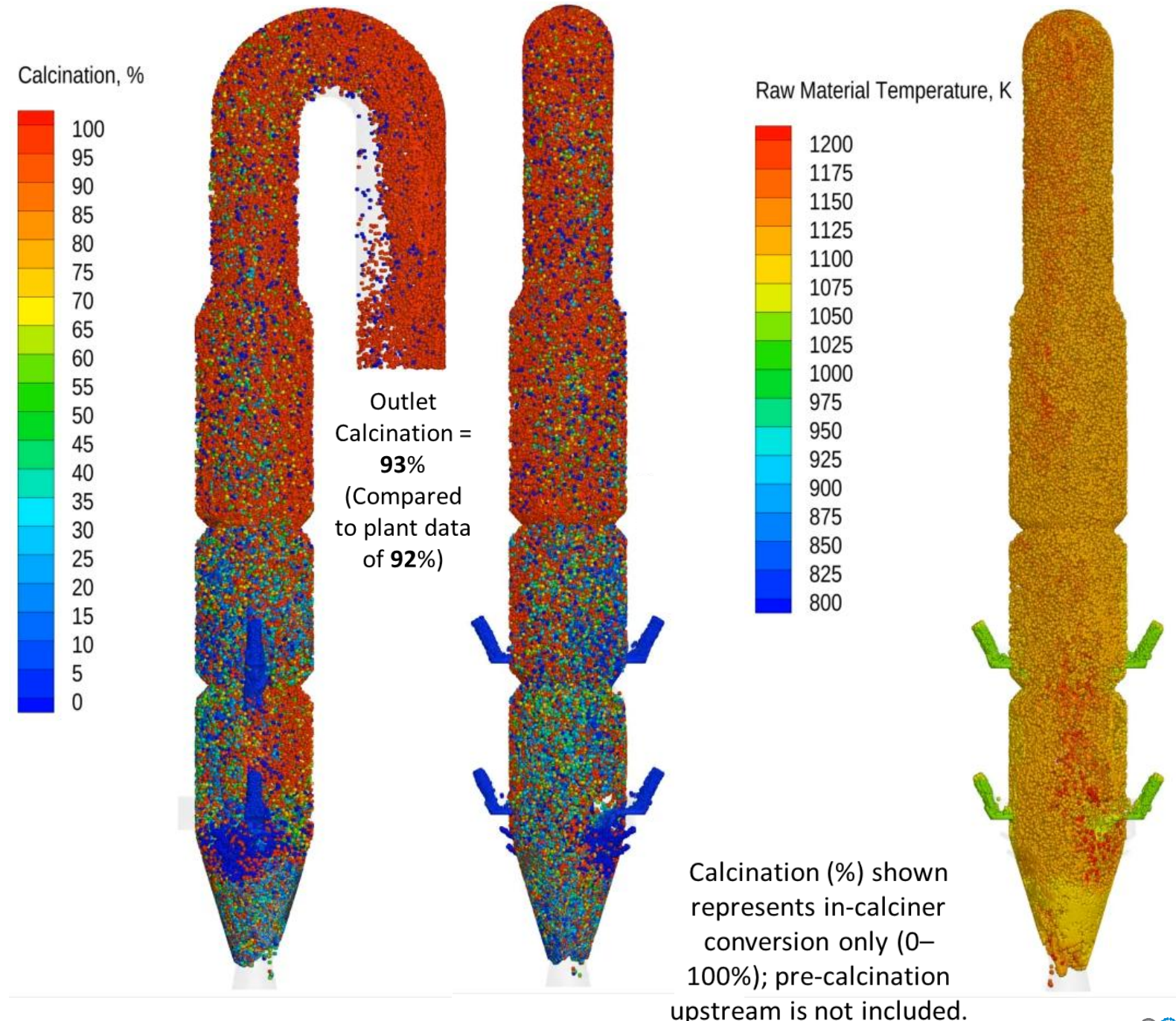
Cement Calciner – Calcination

Calcination Behavior

- Calcination initiates in the lower calciner as raw meal particles heat up due to fuel combustion.
- Conversion progresses with increasing particle temperature & thermal exposure.
- Near-complete calcination is achieved in the upper calciner region.

Key Observations:

- Calcination strongly correlates with particle temperature distribution.
- The lower region is dominated by raw material heating & reaction initiation, while the upper region shows high conversion of $\text{CaCO}_3 \rightarrow \text{CaO}$.

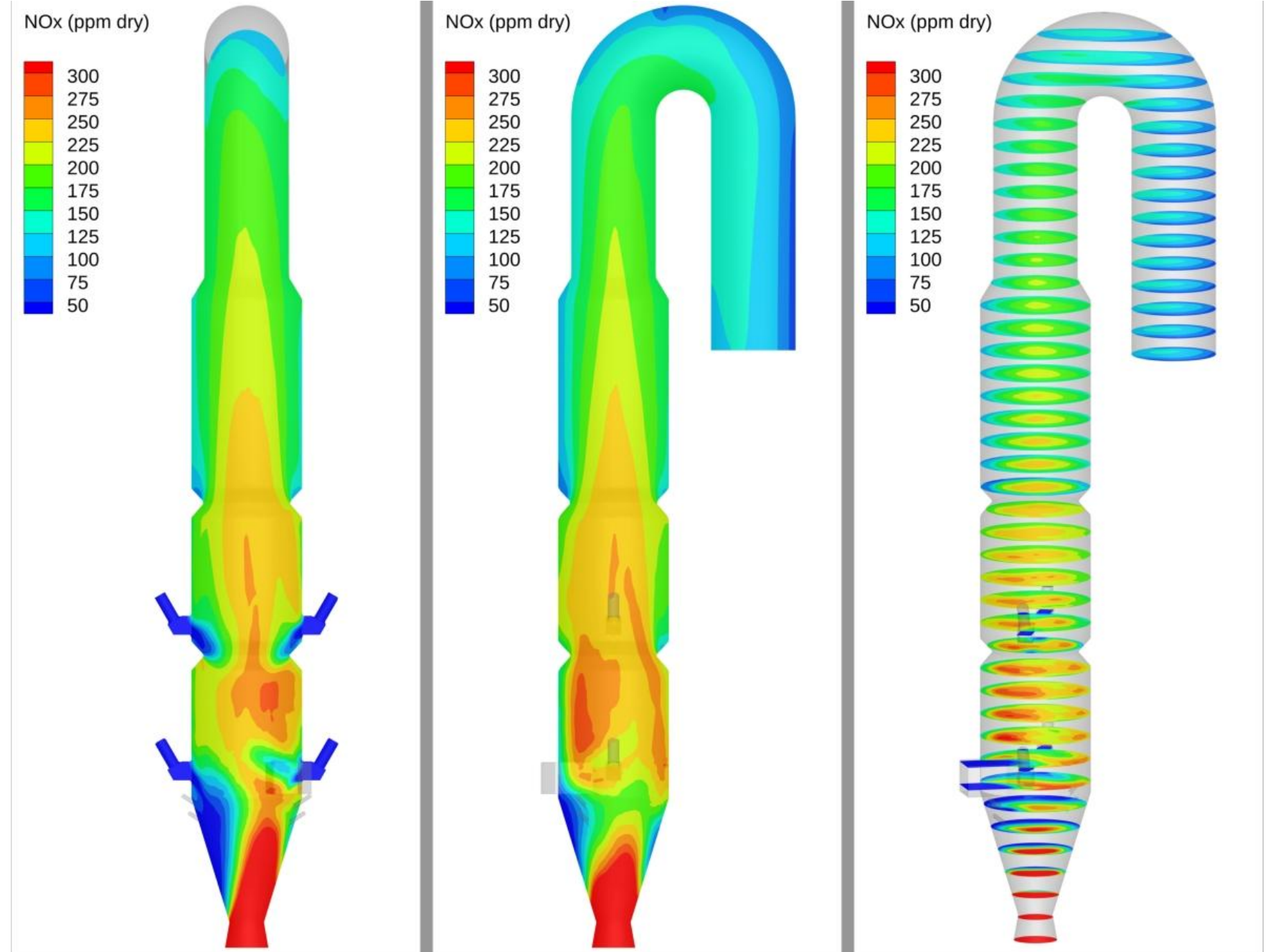


Cement Calciner – NO_x Distribution

- Fuel-based NO_x is the primary source of NO_x.
- Oxidation of Nitrogen compounds present in the fuel & flue gas.
- Peak NO_x formation dominates in the lower combustion-dominated region (High O₂ + 1000–1300 °C temperatures)
- The spatial pattern reflects the balance between fuel-N oxidation & reduction pathways as local reaction conditions evolve through the calciner.

Key Takeaway:

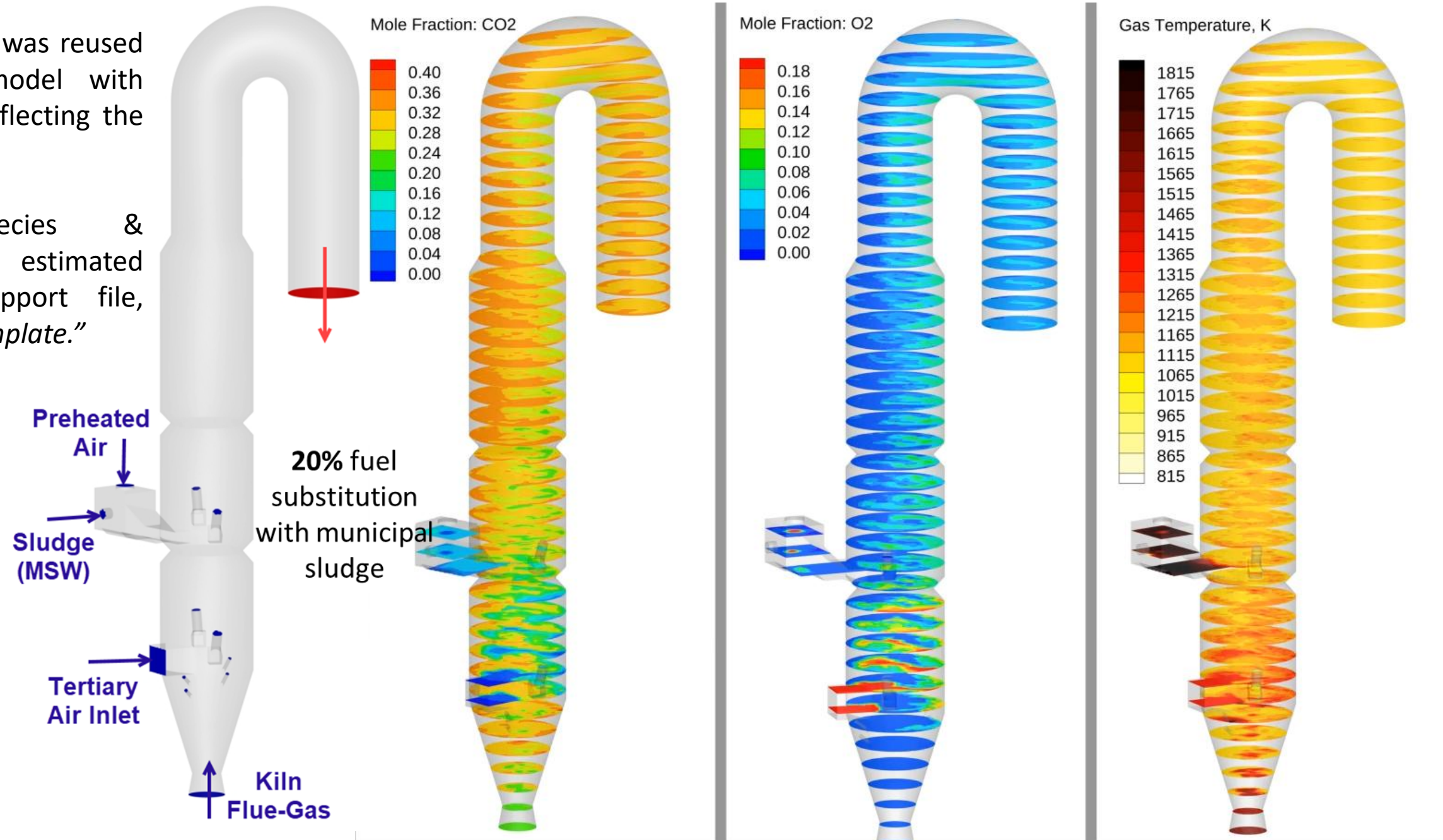
The model determines where NO_x forms & how its distribution changes through the calciner under coupled combustion & mixing conditions.



Time-averaged Profiles

Calciner Model: Sludge & Coal Co-firing

- The **kinetic framework** was reused from the Baseline model with appropriate changes reflecting the sludge properties.
- Volatile gas species & thermodynamic inputs estimated by the provided support file, "*Volatile Estimation Template.*"



Cement Conditioning Tower

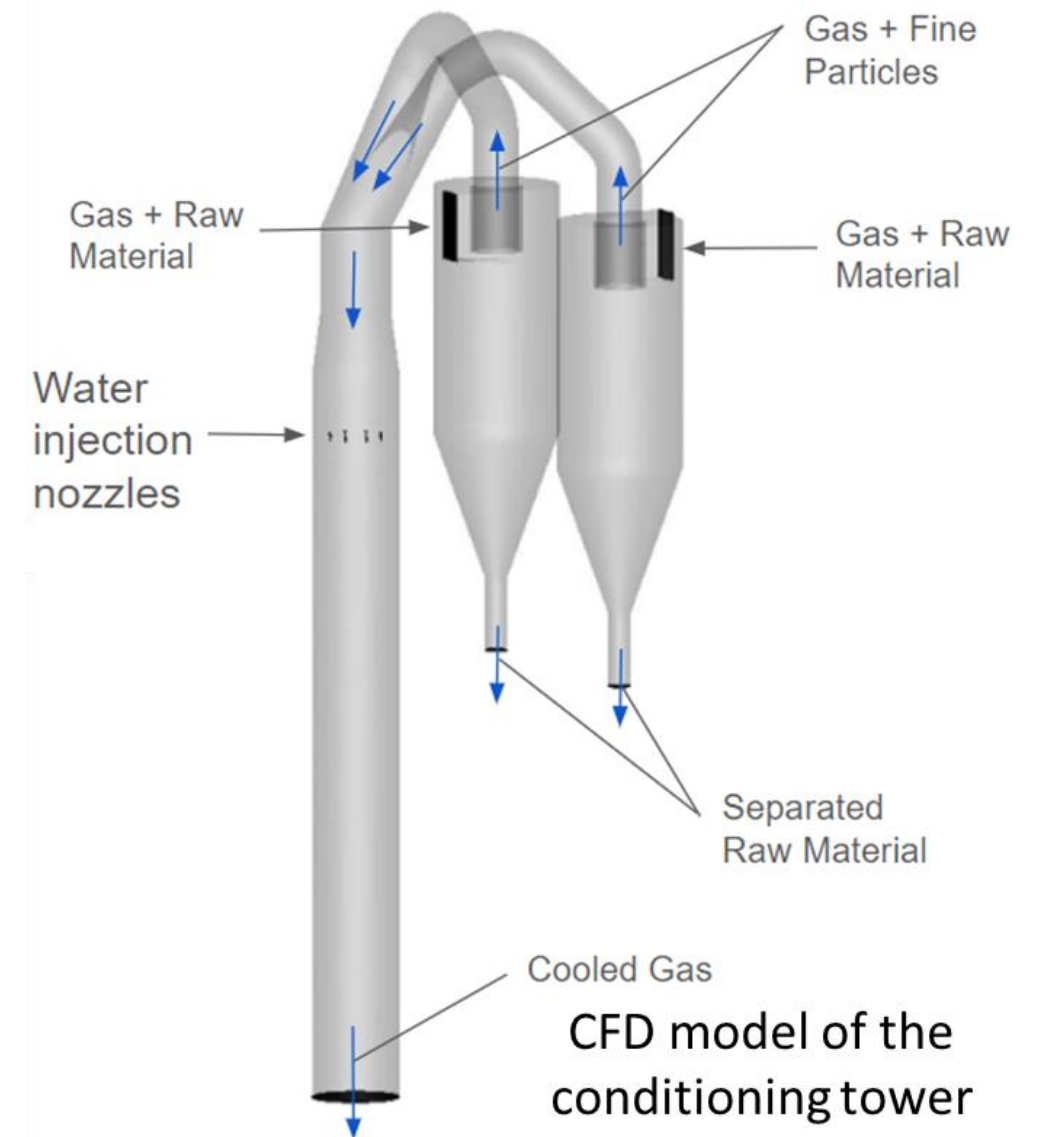
Objective: Simulate evaporative gas cooling in a Cement Conditioning Tower to improve operation & protect downstream equipment.

Value of Simulation

- **Full-Physics Insight:** Visualizes cyclone separation efficiency, gas cooling zones, & thermal hot spots to drive design decisions.
- **Asset Protection:** Validates cooling effectiveness to safeguard downstream Baghouses or ESPs.
- **System Optimization:** Optimizes nozzle design, placement, quantity, & cooling rates to achieve the desirable maximum evaporation height.

Conditioning Tower Domain

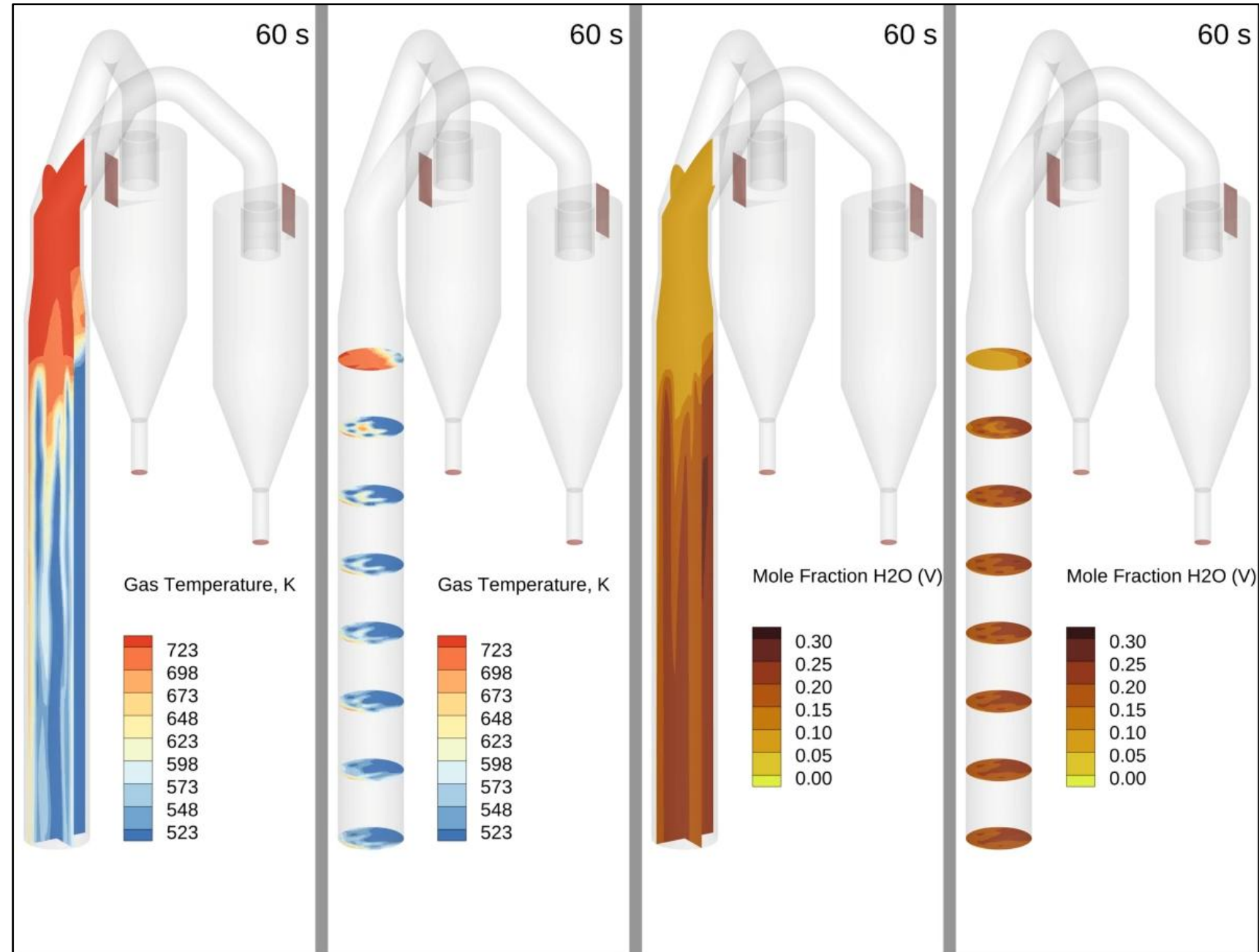
- **Geometry**
 - Tower: 40 m height × 5 m diameter.
 - Cyclones: 7.9 m height × 4.3 m diameter (each)
- **Operating Conditions**
 - Inlet Feed: 300 kpph exhaust gas + 240 kpph solids @ 450°C
 - Cooling Injection: 115 GPM water + 400 SCFM air @ 20°C
- **Utilizes the built-in evaporation model**
- **Nozzles are modeled with point source injections.**



You Can Download This App. Model:
<https://cpfd-software.com/application-model-conditioning-tower/>

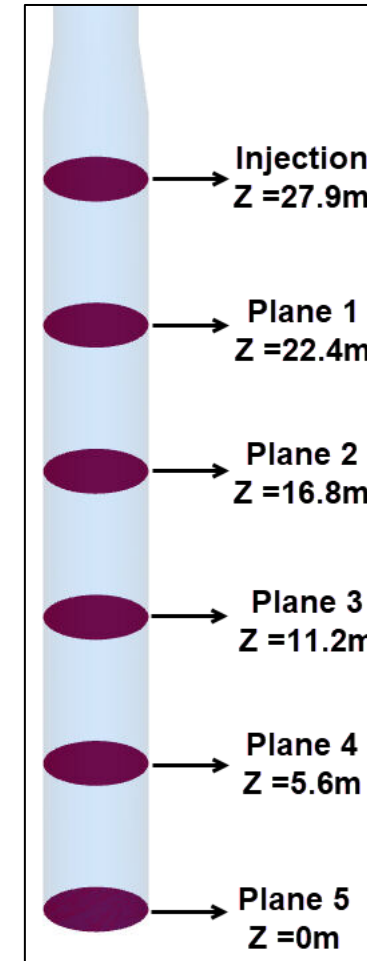
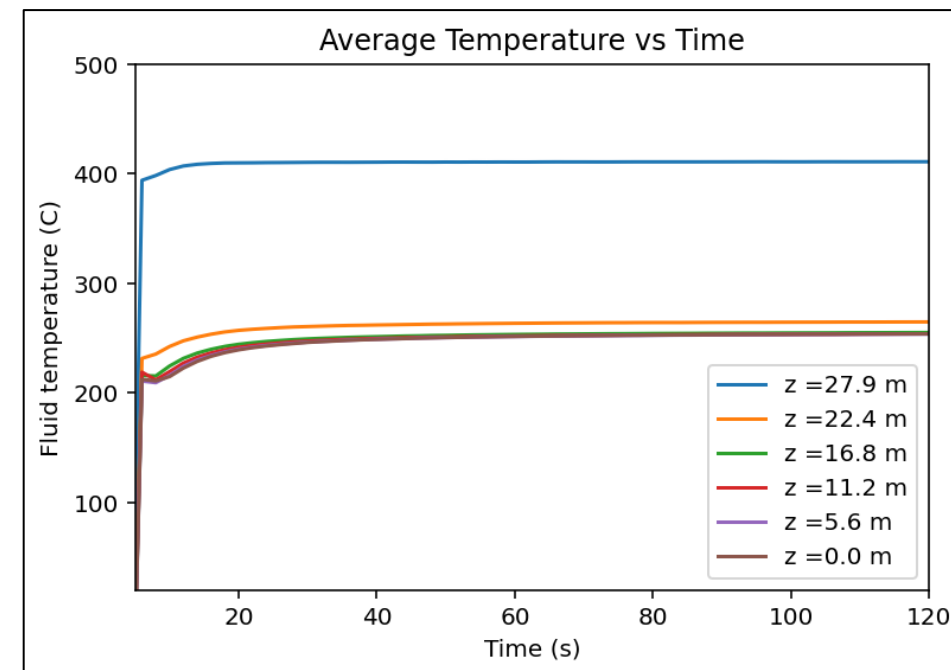
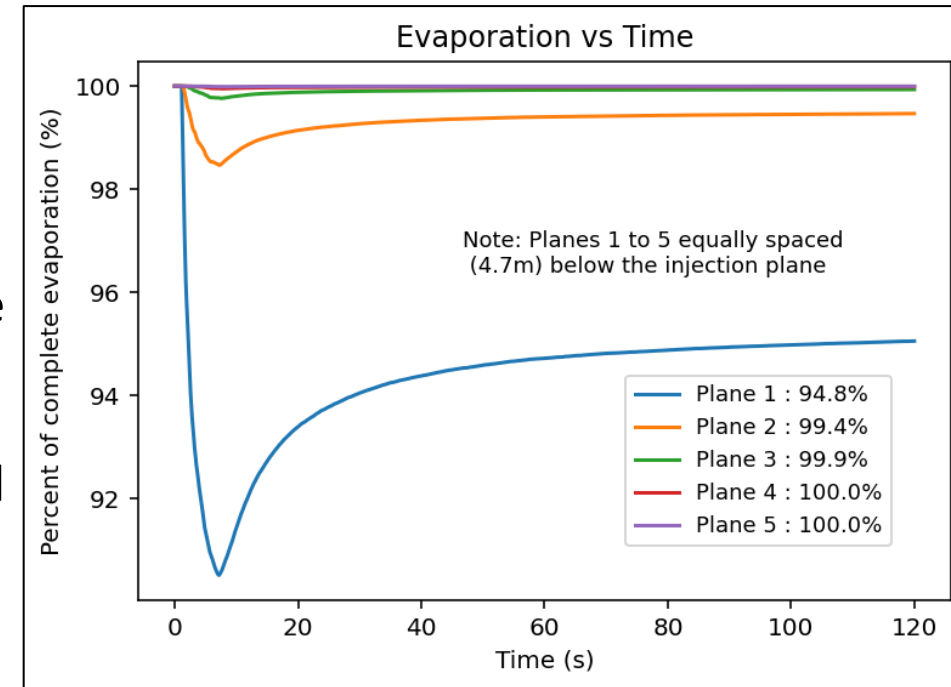
Conditioning Tower – Temperature & Steam

- Exhaust gas is cooled from 450°C to ~250°C.
- Temperature slices reveal a radial temperature distribution, showing non-uniform cooling & mixing.
- Water fully evaporates before the tower exit.
- H₂O vapor contours confirm evaporation & gas mixing.
- Raw material is separated in the cyclone section. Cyclone efficiency affects gas cooling efficiency.
- The model supports optimization of spray location, flow rate, & cooling performance.



Conditioning Tower–Evaporation Performance

- Exhaust gas cooled from 450°C to ~250°C.
- ~99% evaporation achieved within ~11 m below injection.
- Near-complete evaporation by ~16–17 m, with complete evaporation before the exit.
- Downstream gas temperature stabilizes near the desired cooling range.



Questions? Let's Continue the Conversation!

- Download and try today:
 - [Cement Conditioning Tower](#)
 - [Cement Calciner Decomposition Furnace](#)
- Schedule a meeting!
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