AN INTEGRATED APPROACH TO PREDICTING ASH DEPOSITION AND HEAT TRANSFER IN COAL-FIRED BOILERS

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August 24th, 2020
DOE FE R&D Project Review Meeting
University Coal Research

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National Energy Technology Laboratory

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Presentation Overview

- Project Objectives
- Background
- Solution
- Scope of Work
- Accomplishments
- Project Timeline
- Project Organization
- Acknowledgments
- Q&A

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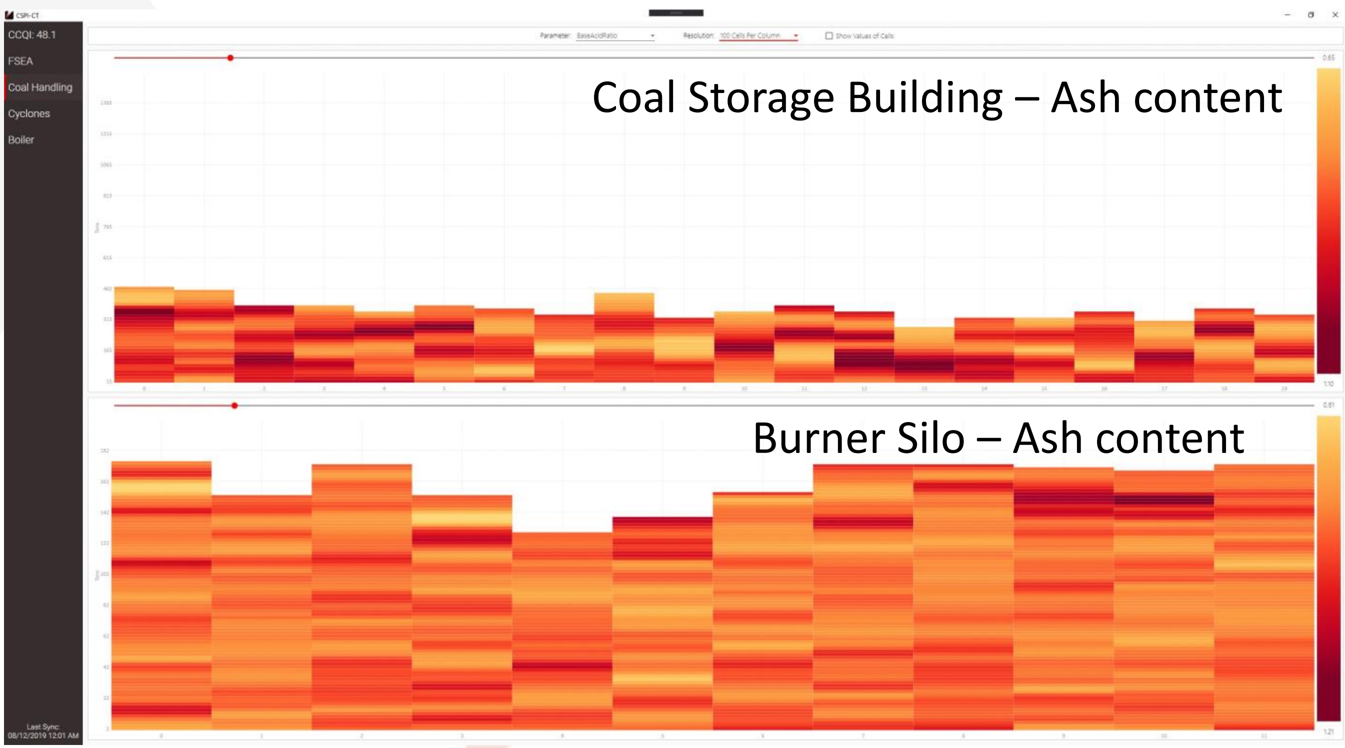
Objectives

Advance **on-line** technology to **predict**, **monitor** and **manage** fireside ash deposition allowing for more efficient operations under a range of **load** conditions and **fuel property** variability



Management Strategy

- Fuel sorting and blending can be done upstream
- Optimize operations to compensate for load and fuel properties
- Optimized composition of coal delivered to each burner

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Output Screen from CSPI-CT
Microbeam's Existing on-line Technology

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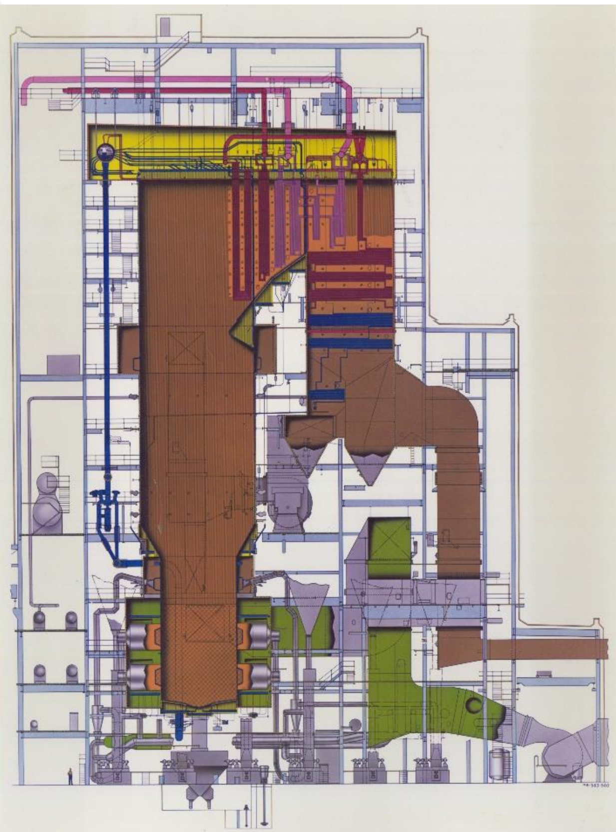
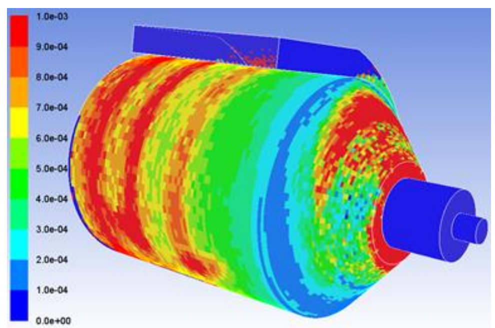
Background Information

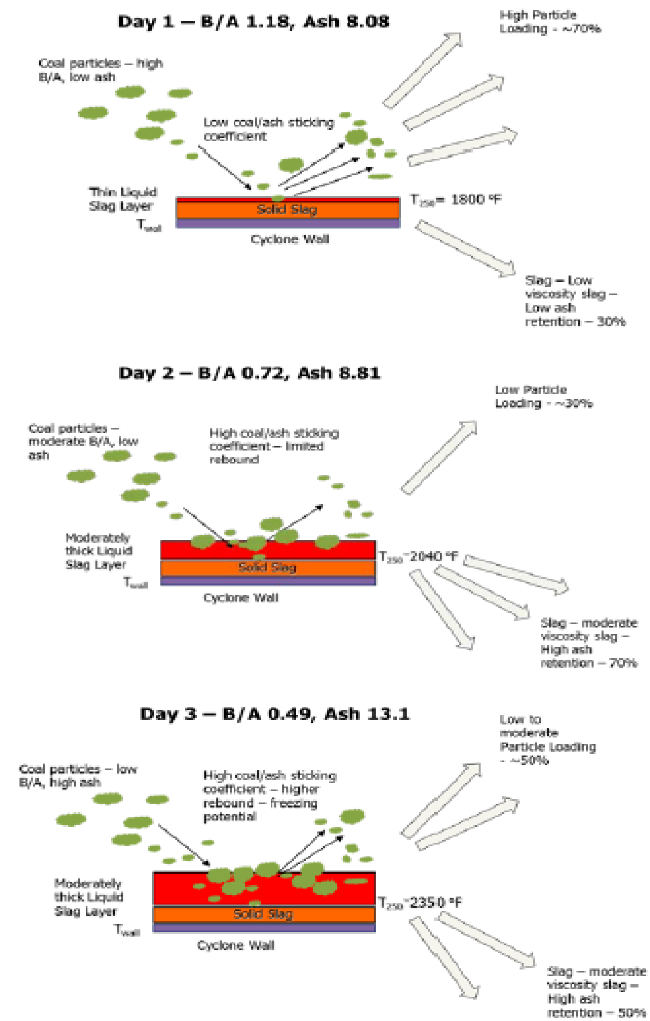
- Inorganic transformations to form vapors, liquids and solids
- Partitioning in burner
- Vapor phase and particle transport mechanisms
- Ash sticking and deposit growth
- Sintering and strength development
- Heat transfer

Inorganic Transformations and Partitioning in Burner

$(B/A = (Na_2O+CaO+MgO+K_2O+FeO)/(SiO_2+Al_2O_3+TiO_2))$







Slag layer thickness as a function of fuel properties.

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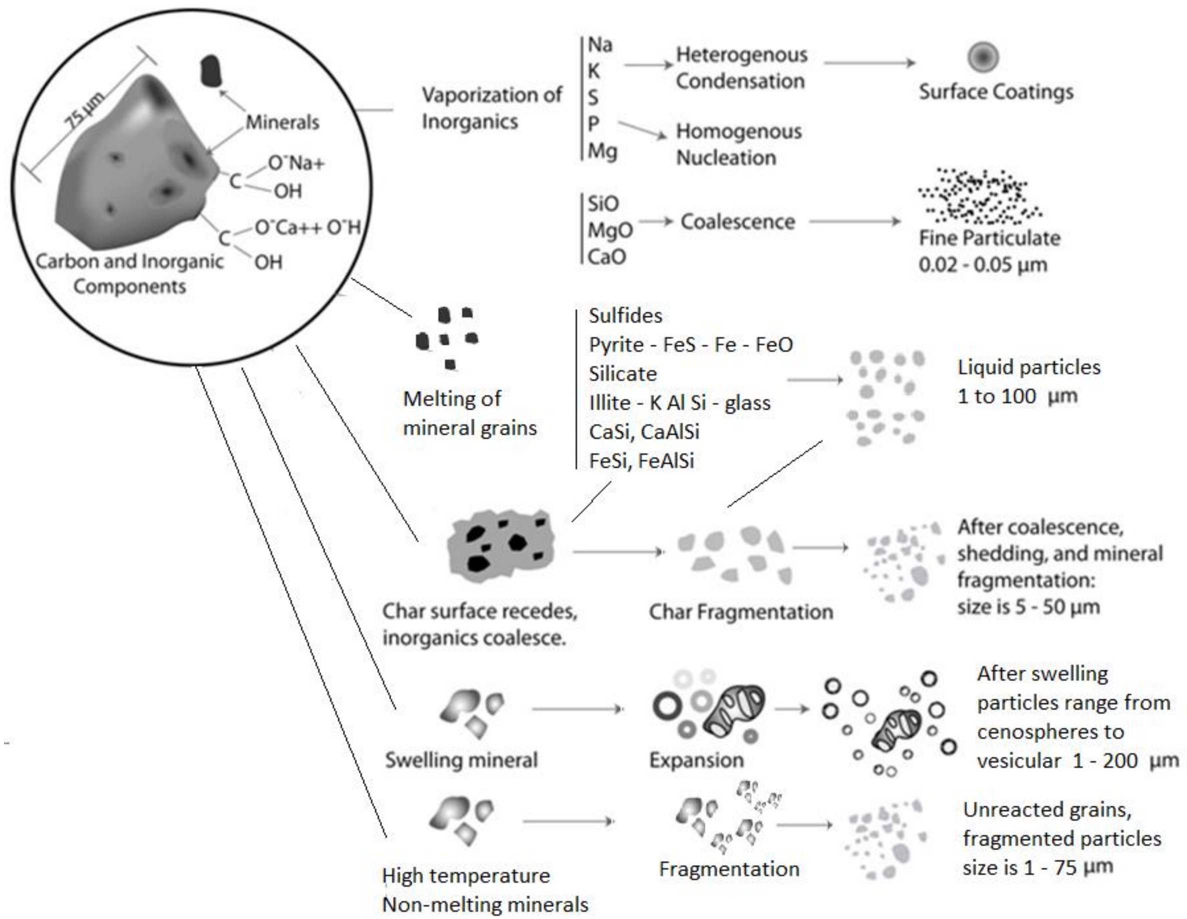
Ash formation during coal combustion



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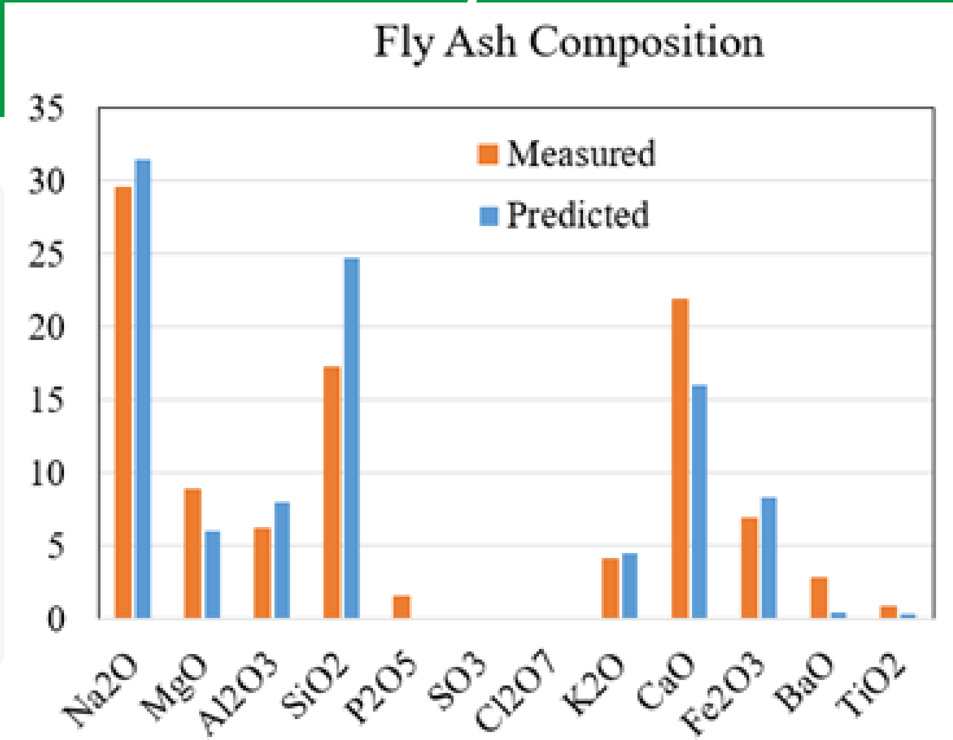
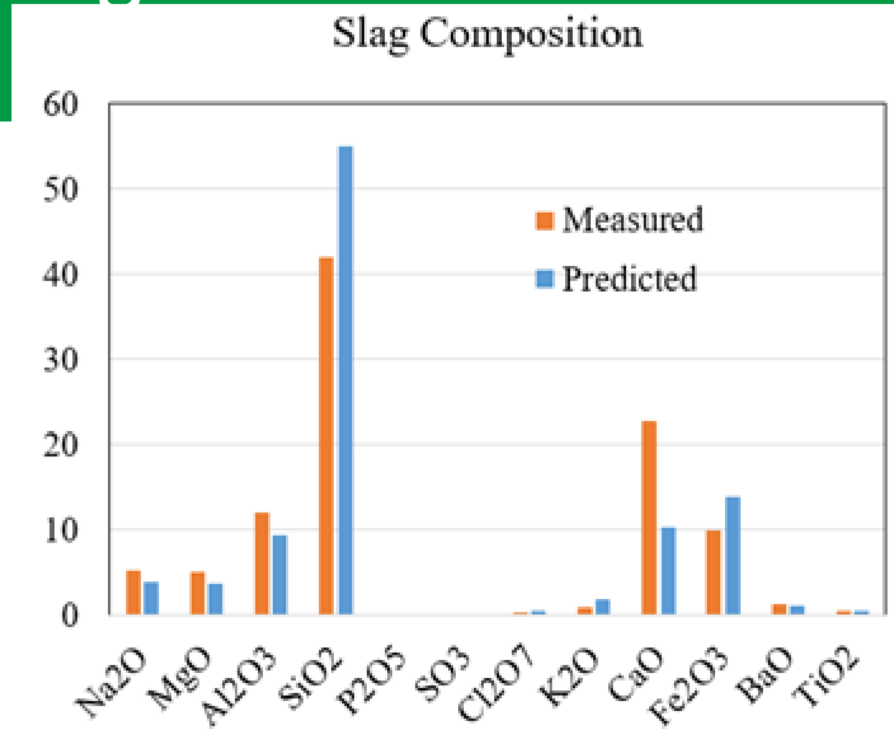
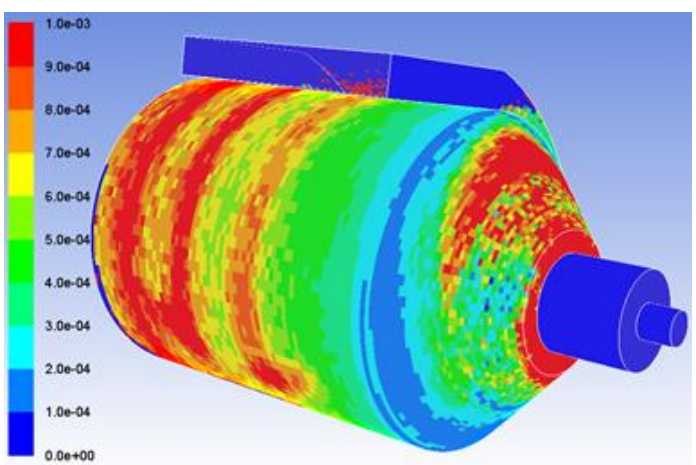
Cyclone Performance - Slag and Fly-Ash Partitioning







$$T_{cv} = 1385.44 + 74.1(A/B) \text{ (K)}$$

$$A/B = \frac{SiO_2 + Al_2O_3 + TiO_2}{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}$$

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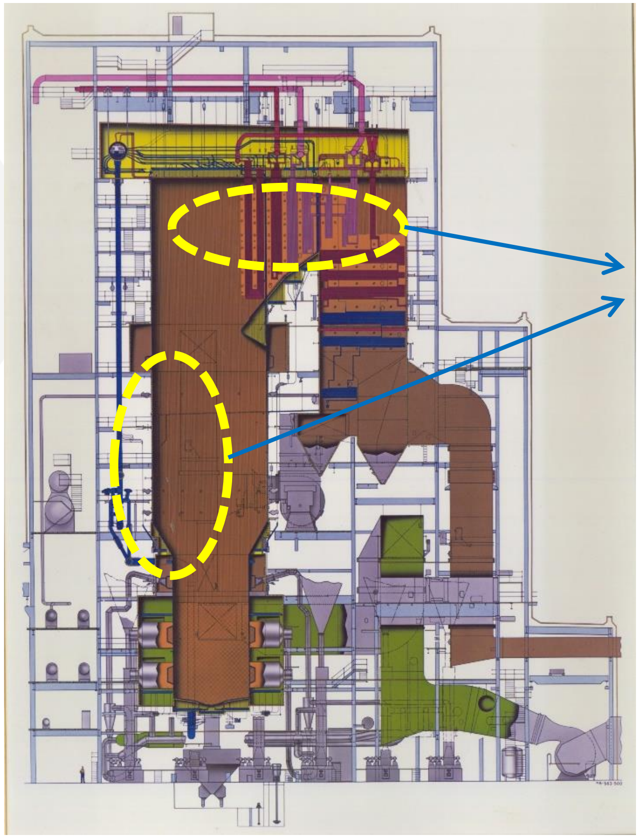
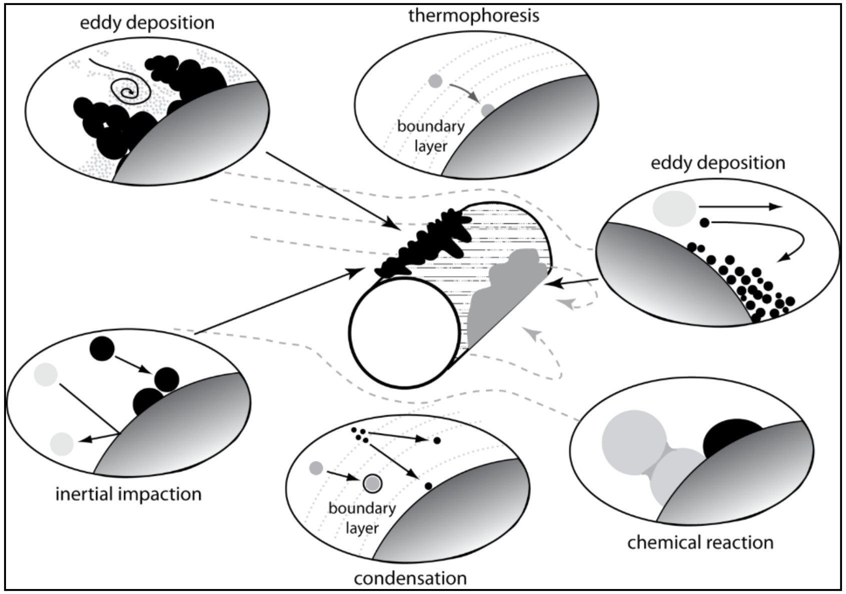
Deposit Formation – particle transport to walls and convective surfaces





Laursen K, Frandsen F, Larsen OH. Ash deposition trials at three power stations in Denmark. Energy & Fuels 1998;12:429–42.

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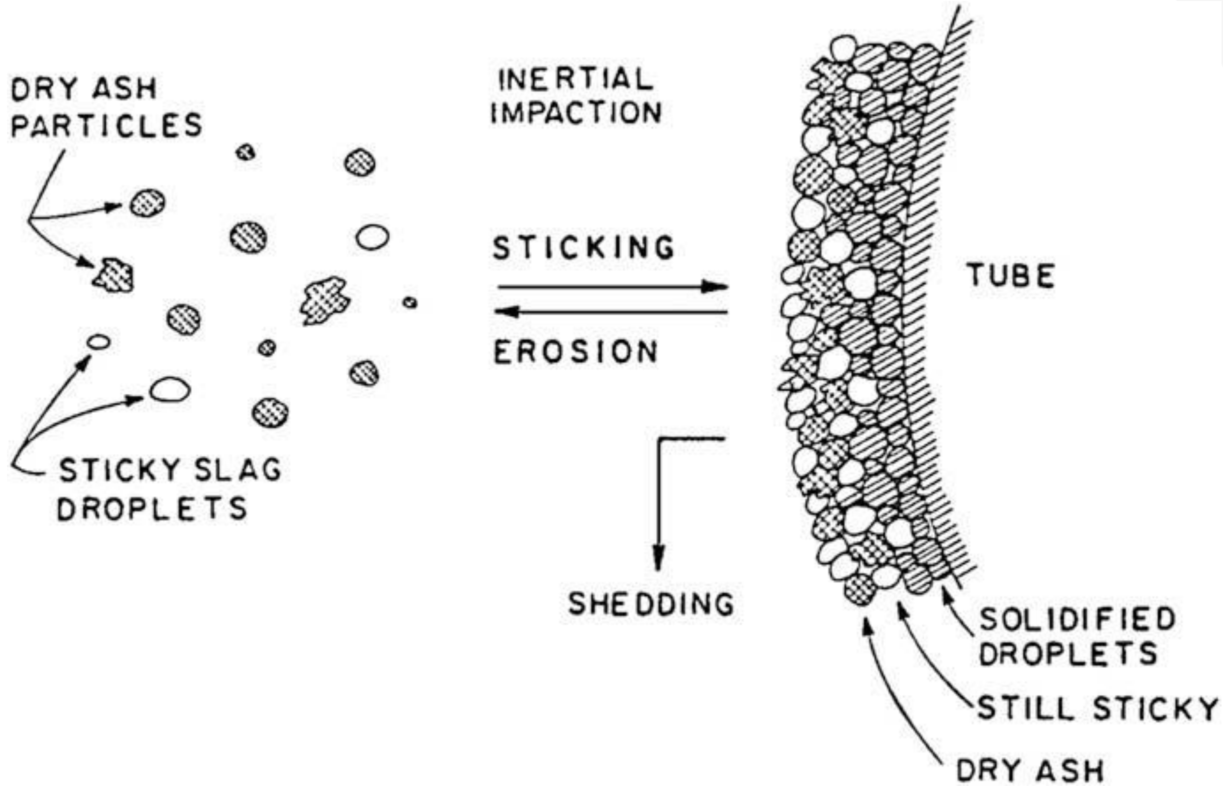
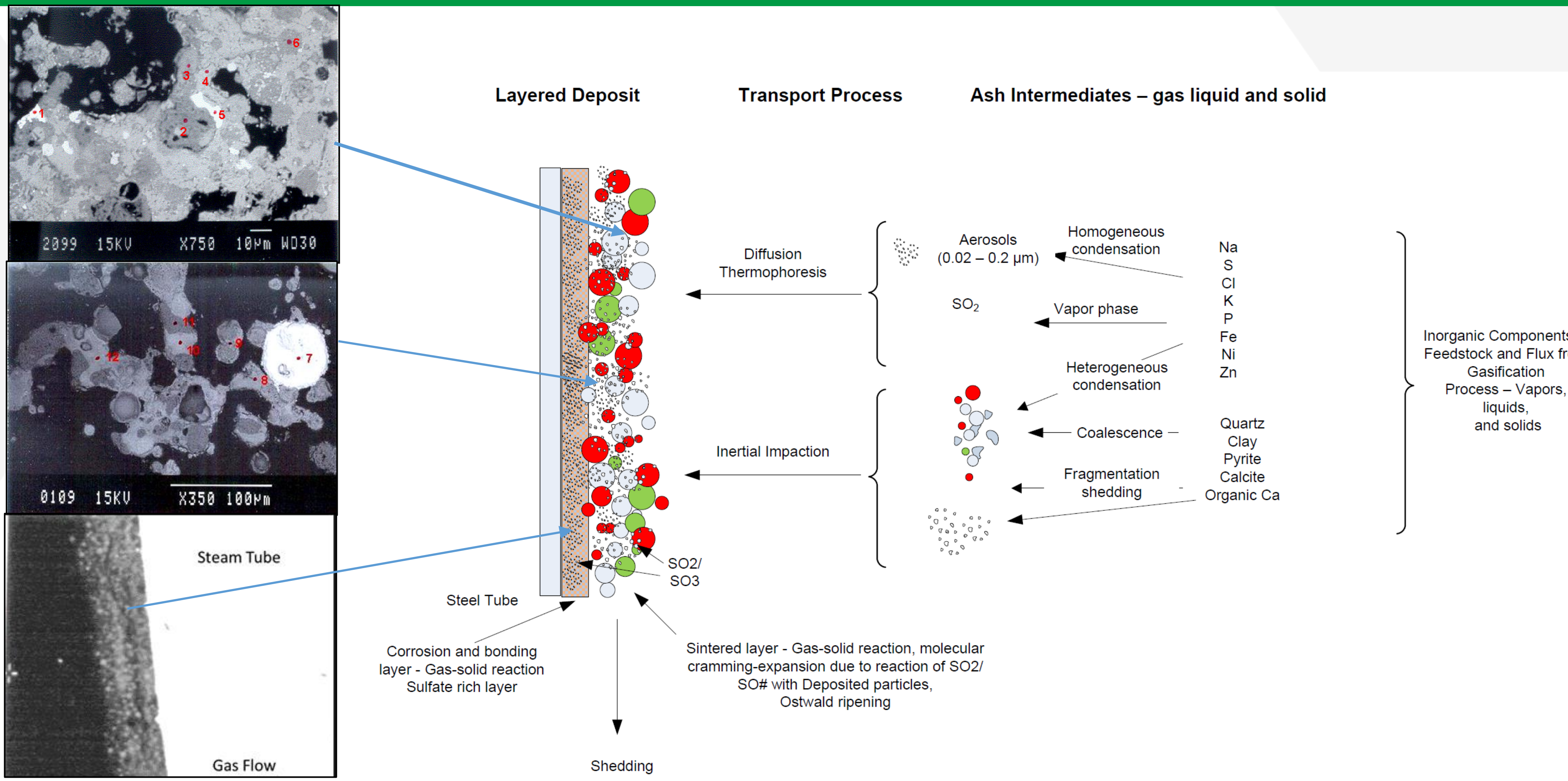
Deposit Sticking and Shedding



Walsh PM, Sayre AN, Loehden DO, Monroe LS, Beer JM, Sarofim AF. Deposition of bituminous coal ash on an isolated heat exchanger tube: effects of coal properties on deposit growth. Progress in Energy and Combustion Science 1990;16:327–34.

Layered Deposit Formation – Fouling Deposit



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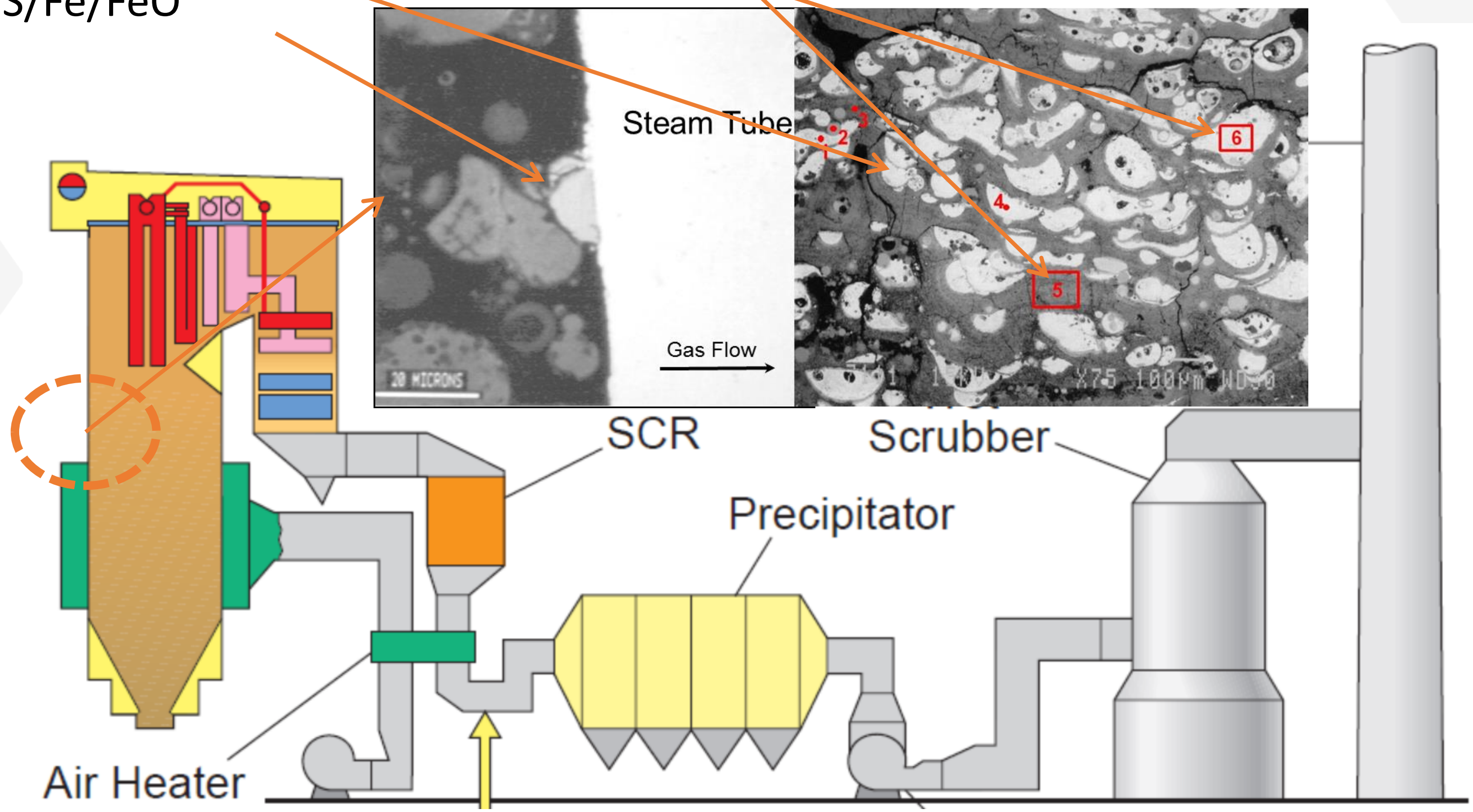
Slag formation – particle sticking growth – example – iron sulfide

Fig.	Pt/Area	Description	Na	Mg	Al	Si	S	K	Ca	Ti	Fe	O
1	1	Bright ptcl in deposit	1.87	0.77	0.00	1.12	1.17	0.00	0.49	0.00	79.40	14.26
	3	Deposit matrix	0.69	0.00	5.63	5.70	13.49	1.79	30.13	0.83	5.84	34.64
	4	Bright ptcl in deposit	0.00	0.00	0.82	0.96	0.00	0.00	0.81	0.00	81.16	16.25
	5	Deposit matrix	3.08	0.00	5.39	5.54	9.24	1.66	25.04	0.97	5.24	43.85
	6	Bright ptcl in deposit	0.84	0.30	0.43	0.97	0.97	0.00	1.50	0.00	74.27	20.03

Pyrite-Derived
FeS/Fe/FeO



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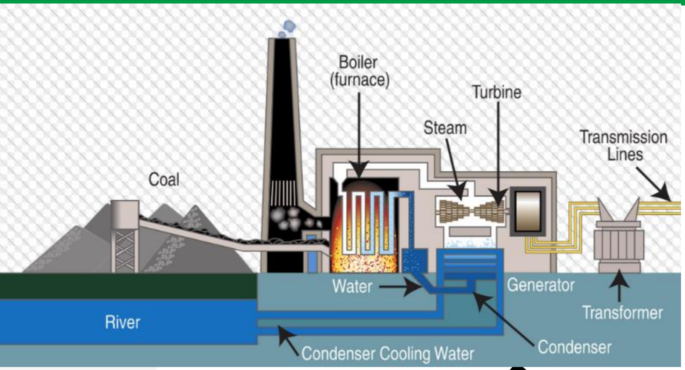
Solution: Develop Functional Relationships for Incorporation into On-line Prediction Methods



Operational parameters from power plant

Add-on modules:

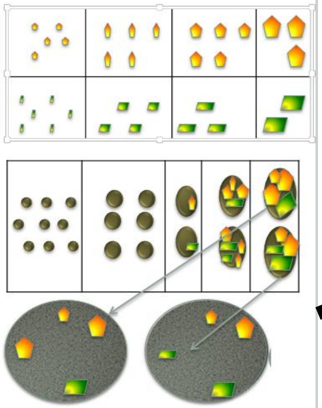
High fidelity **gas radiative property models**

Composition dependent particle radiative properties

Slag/Deposition models to predict partitioning rates, composition

Conjugate heat transfer modeling of steam tubes

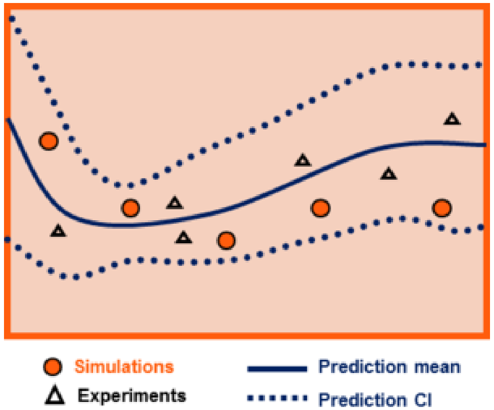
1. CCSEM and Ash Chemistry Analysis to generate mineral groupings and relative sizes
2. Mineral groups are placed in the coal particles to conform to the total ash analysis



CCSEM, PSD of parent fuels

CFD

Operational Relationships



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Scope of Work

Task 1: Project Management and Planning

Task 2: Combustion Simulations within a Full-Scale Boiler (Otter Tail Power Company (OTPC))

Task 3: Simulation validation using ash deposition data from plant

Task 4: Combustion System Performance Indices and Coal Tracker (CSPI-CT) Tool Refinement

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Task 1 Updates

- Kick-off Meeting – October 7th, 2019
- 4 Quarterly Reports submitted to DOE.
- Milestone changes

Milestone	Task/ Subtask	Milestone Title and Description	Planned Completion Date	Verification Method
3	Task 2	Combustion simulations within cyclone barrels	~~1/31/2020~~ 10/31/2020	Completion of simulations within cyclone barrels encompassing 12 representative operational scenarios
4	Task 2	Combustion simulations within a full-scale boiler employing the results from the cyclone barrel simulations	~~7/31/2020~~ 1/31/2021	Completion of simulations encompassing 12 representative operational scenarios

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Task 2. Combustion Simulations within a Full-Scale Boiler (Otter Tail Power Company (OTPC))

- Database Development
- Cyclone Burner Modification and Testing
- Boiler Geometry Modification and Particle Tracking

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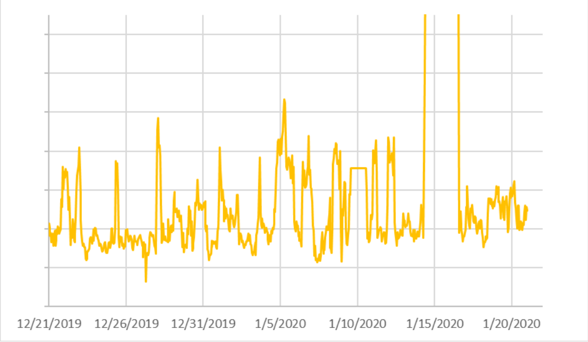
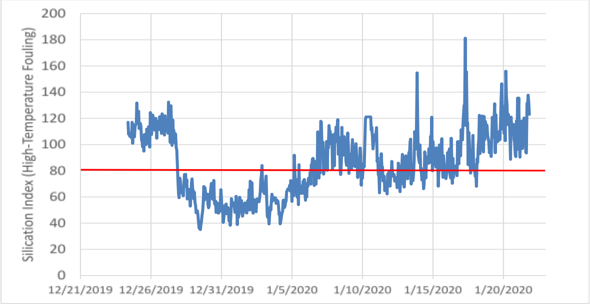
Task 2. Slagging and fouling event specific database development and data analysis

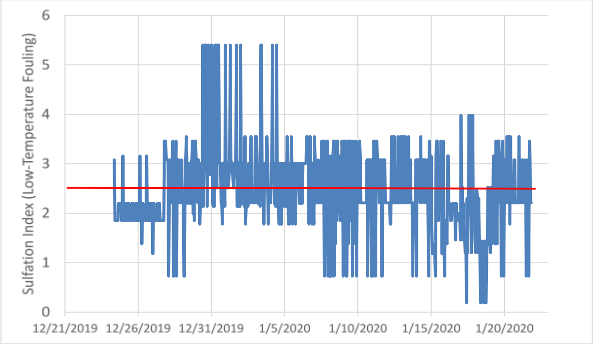
- Database of Plant Operating Parameters/coal properties
- Performance data – CSPI-CT
  - Heat Rate
  - Fireside performance indices
- 12 Cases for simulations
  - Load
  - Boiler Cleanliness
  - Coal Properties
    - Ash Content
    - Base/Acid Ratio (sodium Level)



Heat Rate



High Temperature Fouling - Index



Low Temperature Fouling - Index

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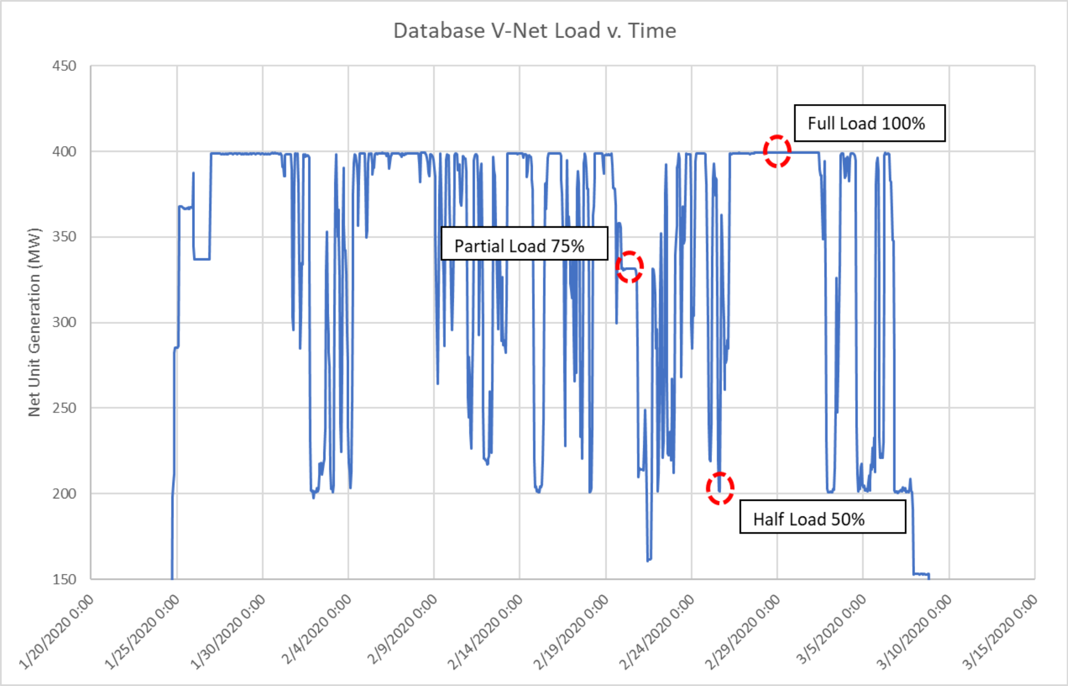
Load Definition Selection



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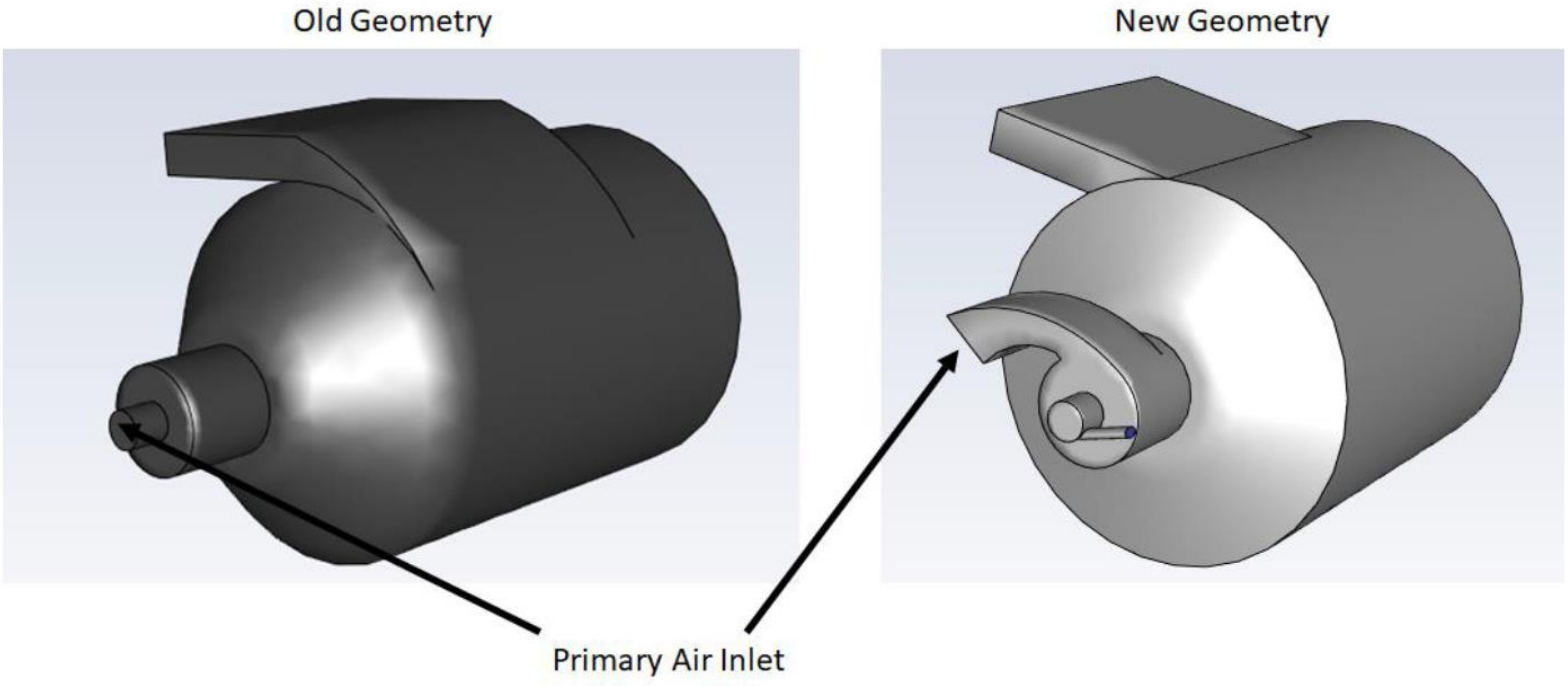
Task 2. Modifications to Cyclone Geometry



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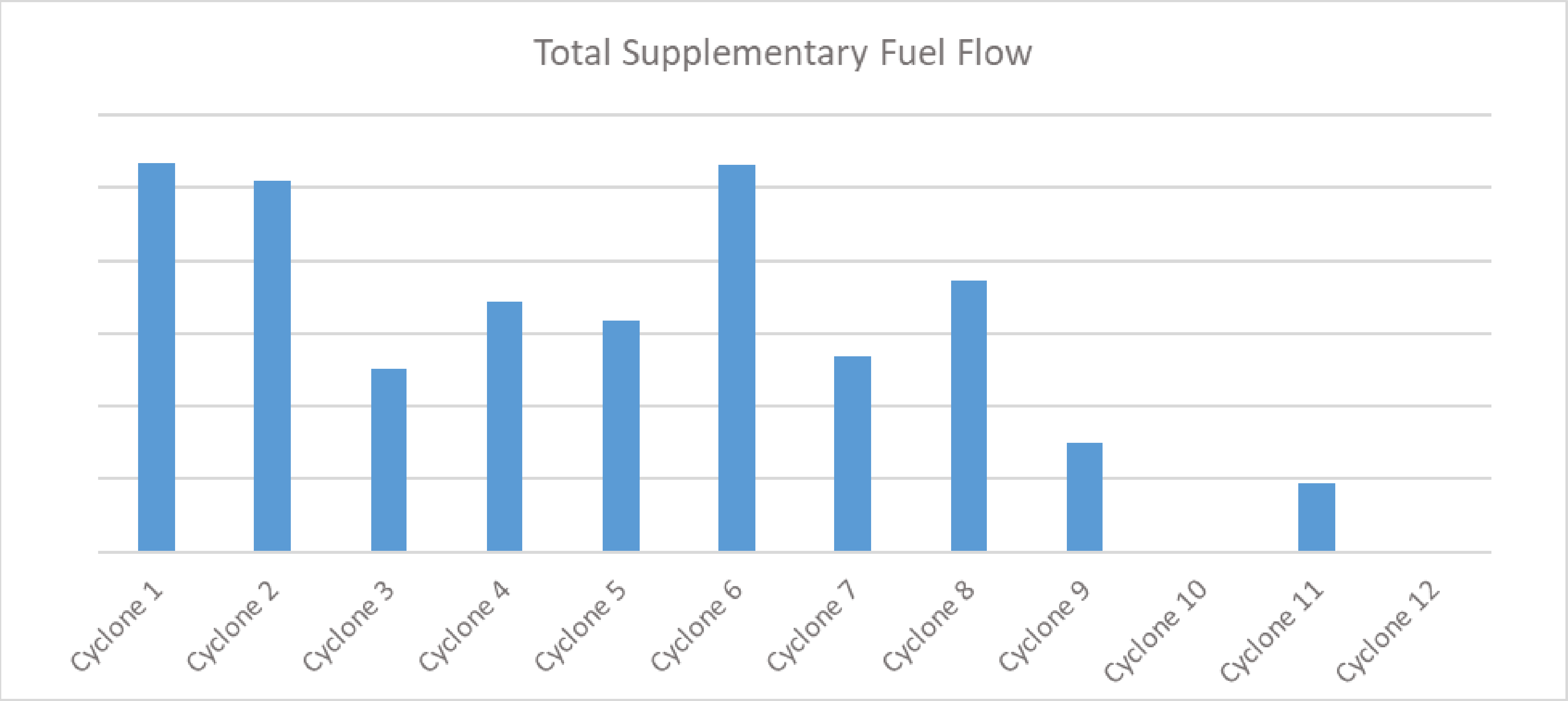
Cyclone Performance Comparison



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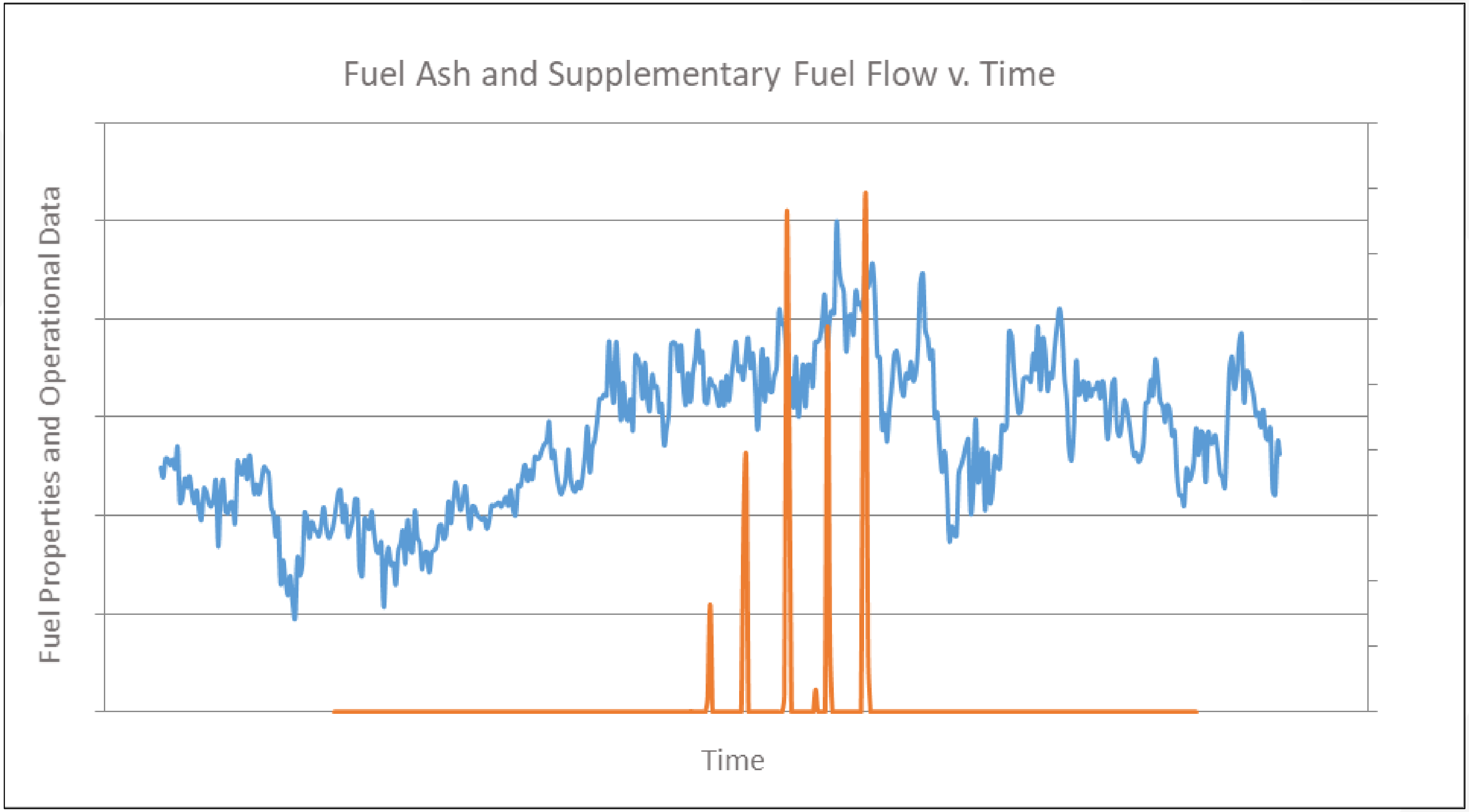
Fuel Ash and Supplementary Fuel Flow



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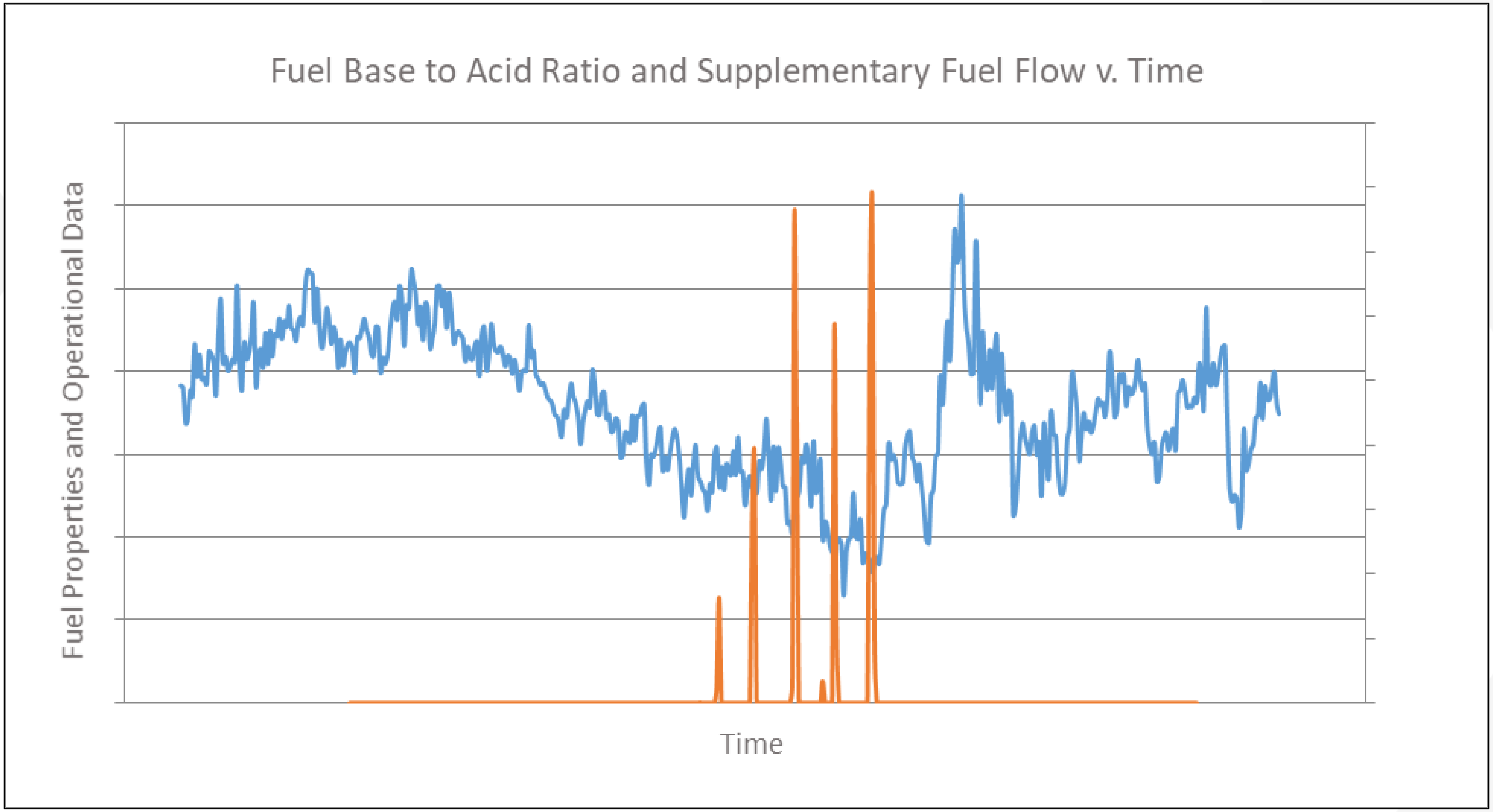
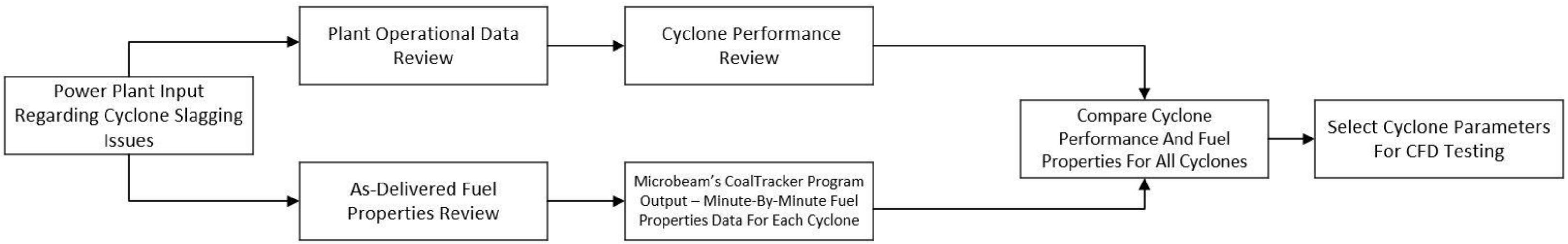
Fuel Base to Acid Ratio and Supplementary Fuel Flow



Cyclone Operational Parameter Selection



- Worked with OtterTail Power's Coyote Station to identify the plant operational data and as-delivered fuel properties associated with the time period during which Coyote faced slagging issues.
- As-delivered fuel properties data was used as input and predictions of as-fired fuel quality were made with the help of Microbeam's CoalTracker program.
- Fuel properties hourly averages were calculated and compared for each cyclone.
- A cyclone with high amount of supplemental oil flow was selected for further testing.

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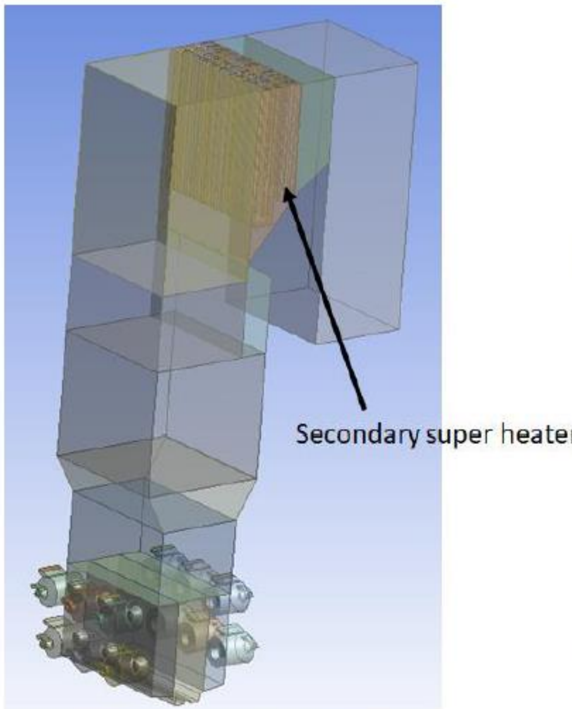
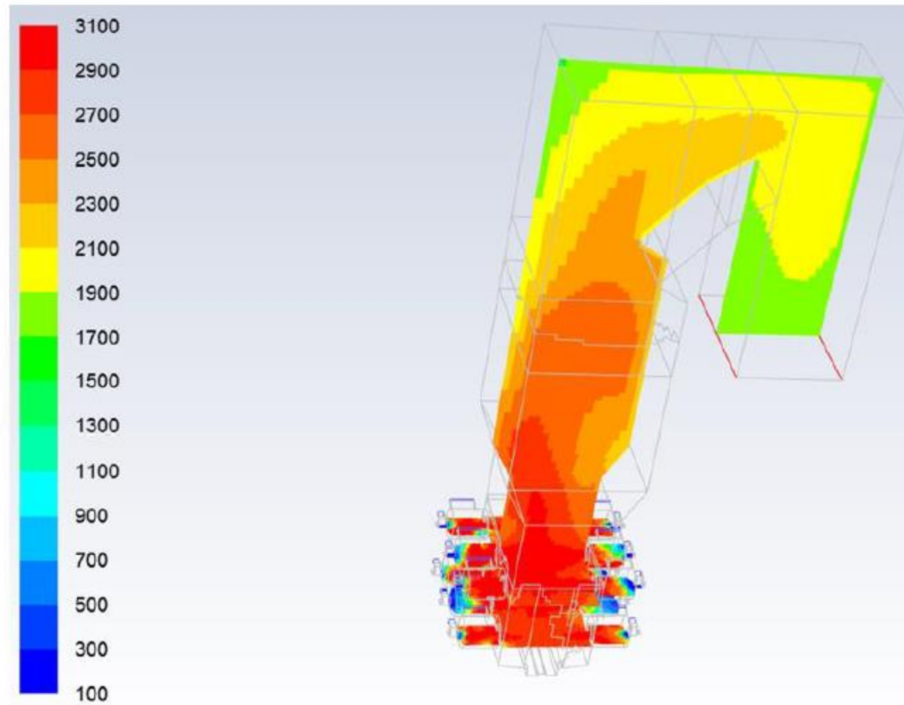
Task 2. Modified Boiler Geometry



Modified Boiler Geometry



End-to-End boiler simulation of fuel combustion (i.e., combustion within the cyclone barrel fully integrated with that within the boiler)

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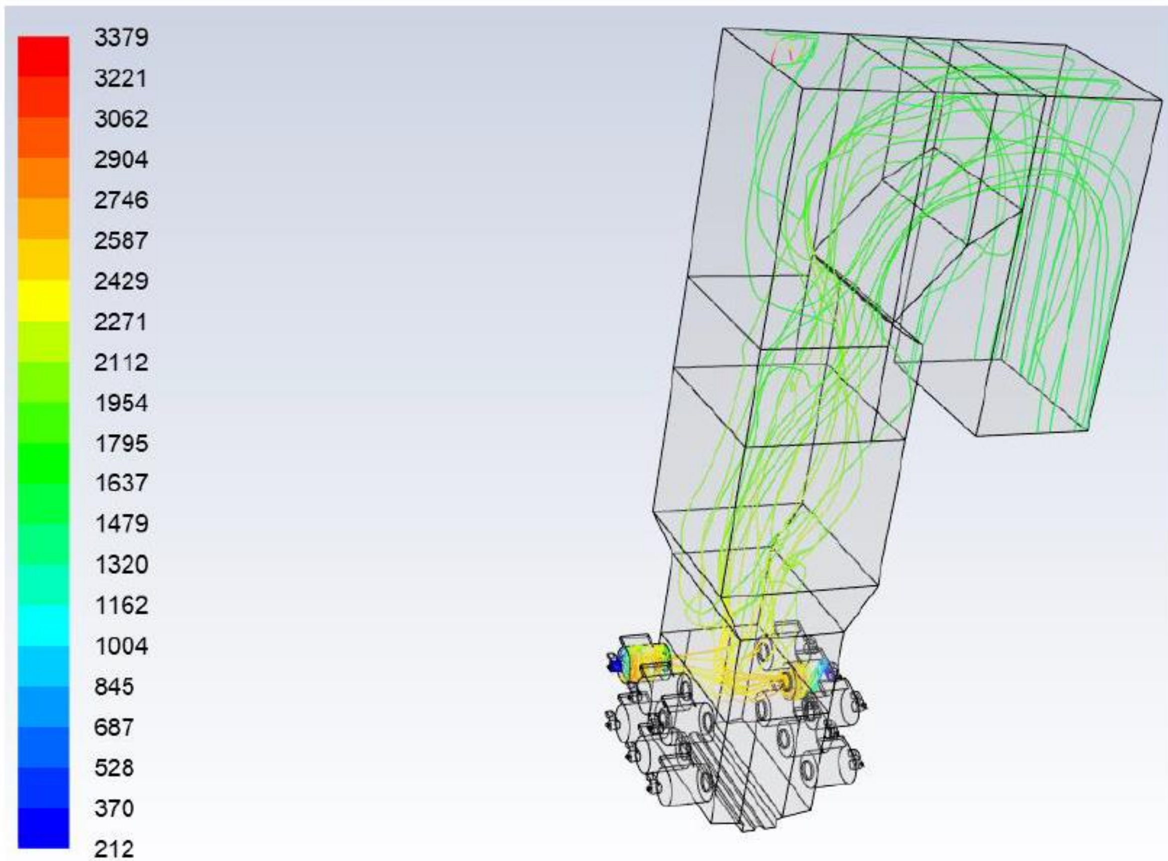
Fuel Particle Trajectories



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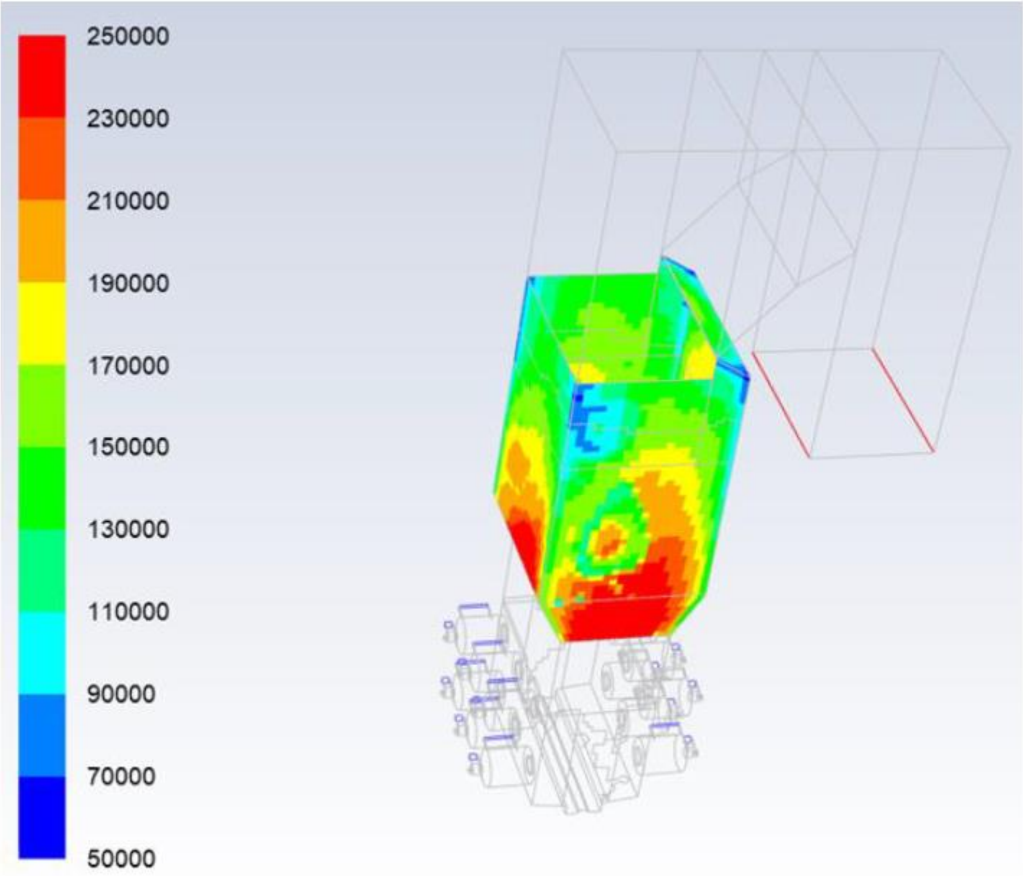
Net Radiative Flux



Task 2 Accomplishments

- Construction of geometries of full-scale utility boilers
- Slagging and fouling event specific database development and data analysis
- Simulations of coal combustion the boiler units

Next Steps – Boiler CFD Model Test Matrix

No.	Na content/ Na flowrate	Load	Time since last shutdown/cleaning outage
1	High	Full	30 Days after cleaning outage
2	Medium	Full	30 Days after cleaning outage
3	Low	Full	30 Days after cleaning outage
4	High	Medium	30 Days after cleaning outage
5	Medium	Medium	30 Days after cleaning outage
6	Low	Medium	30 Days after cleaning outage
7	High	Low	30 Days after cleaning outage
8	Medium	Low	30 Days after cleaning outage
9	Low	Low	30 Days after cleaning outage
10	Medium	Full	15 Days after cleaning outage
11	Medium	Full	30 Days after cleaning outage
12	Medium	Full	45 Days after cleaning outage

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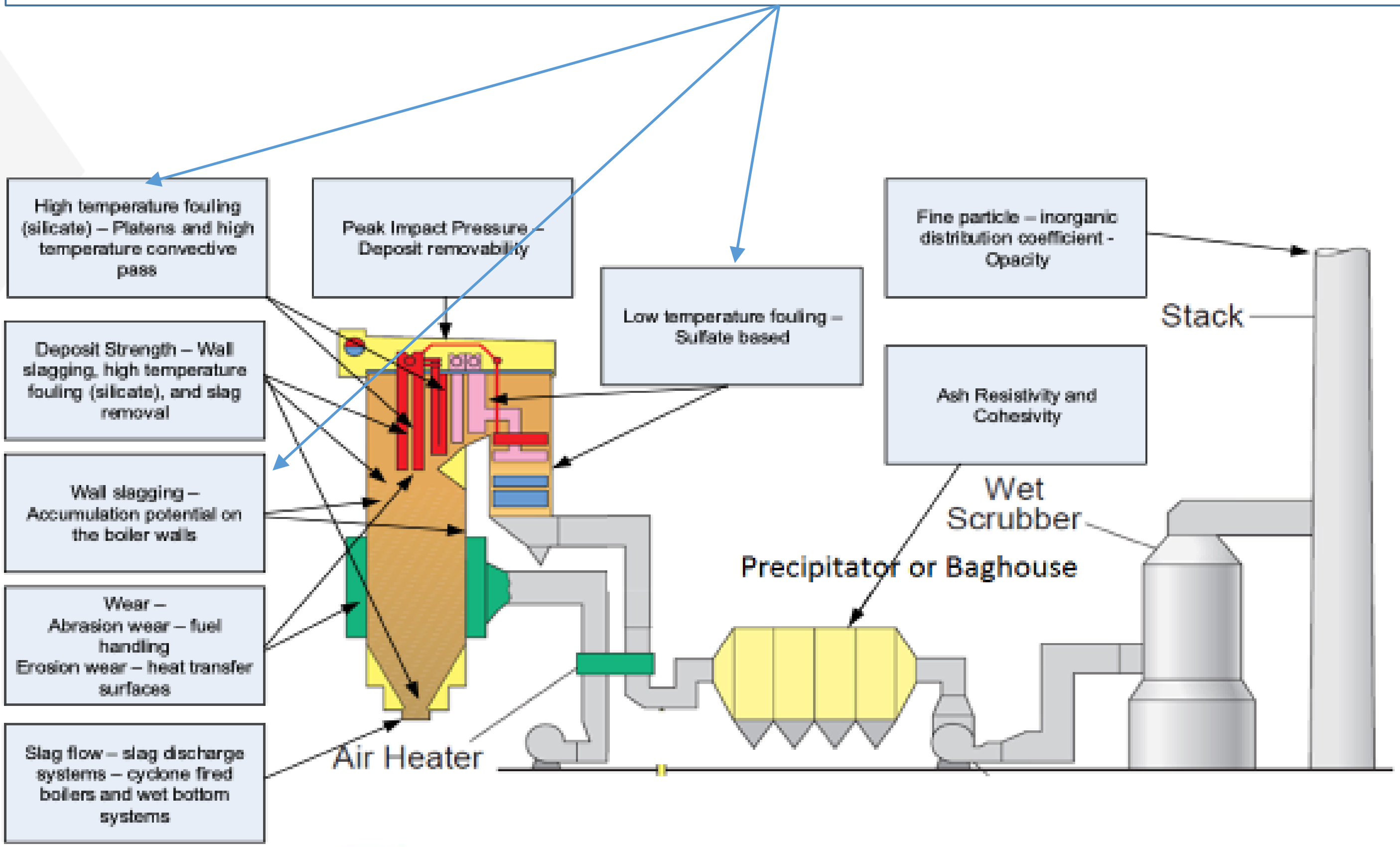
Task 4. Combustion System Performance Indices and Coal Tracker (CSPI-CT) Tool Refinement

Efforts focused on Wall Slagging and Convective Pass Indices – CFD Enhanced



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Project Schedule

		2019				2020				2021				2022			
Task ID	Task Name	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
1	Project Management Planning																
1	Project kick-off meeting																
2	Combustion Simulations of the cyclone barrel																
2	Combustion simulations of the full-scale boiler																
3	Thermal modeling refinement with validation against data from plant																
3	Deposition modeling refinement with validation against data from plant																
4	CSPI-CT Tool Refinement																
4	Installation, testing, and performance assessment of the CSPI-CT Tool																

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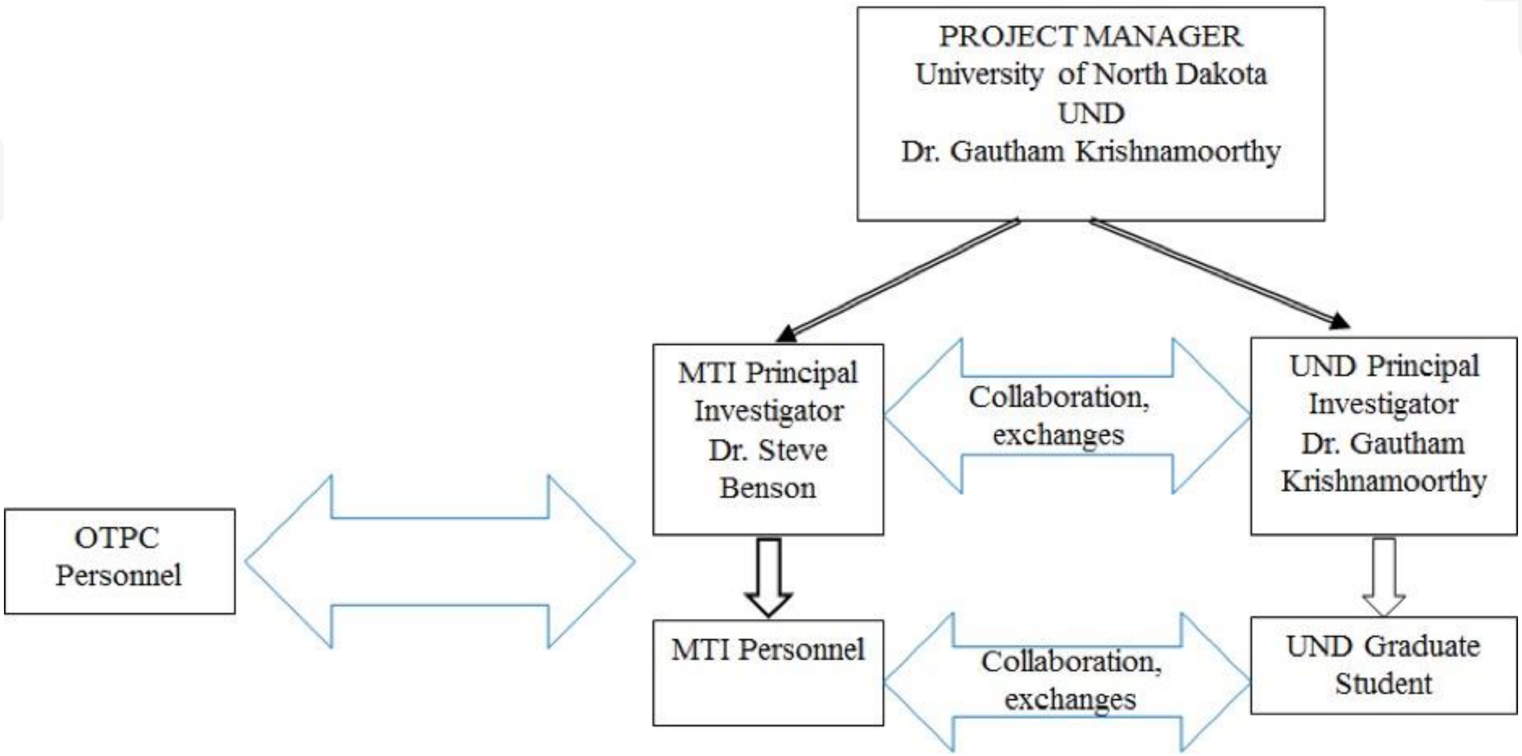
Project Organization



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Take-Home Message(s)

<u>Predicting ash deposition</u>: This is almost as complicated as it gets…

- Its important to have high-fidelities in:
  - coal PSD
  - particle radiative properties
  - gas radiative properties
  - ash composition
- However, complexity in predicting ash deposition (capture criteria) depends on: fuel, boiler configuration, temperature zone (where the deposition occurs)
- Multiphase turbulent combustion + fuel properties and flow rates
- But our understanding of physical and chemical transformations associated with ash deposition is improving
- <u>Close interactions between</u>: boiler personnel, coal quality experts and CFD practitioners are necessary

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Acknowledgements

- This research is being funded by the University Coal Research Program which is administered by DOE-NETL (Award #: DE-FE0031741)
- Otter Tail Power Company – Providing data on fuel properties and plant operations.

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Questions?

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