Oxy-combustion Impacts on Coal Ash Slagging and Fouling

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For Energy and Environmental Solutions

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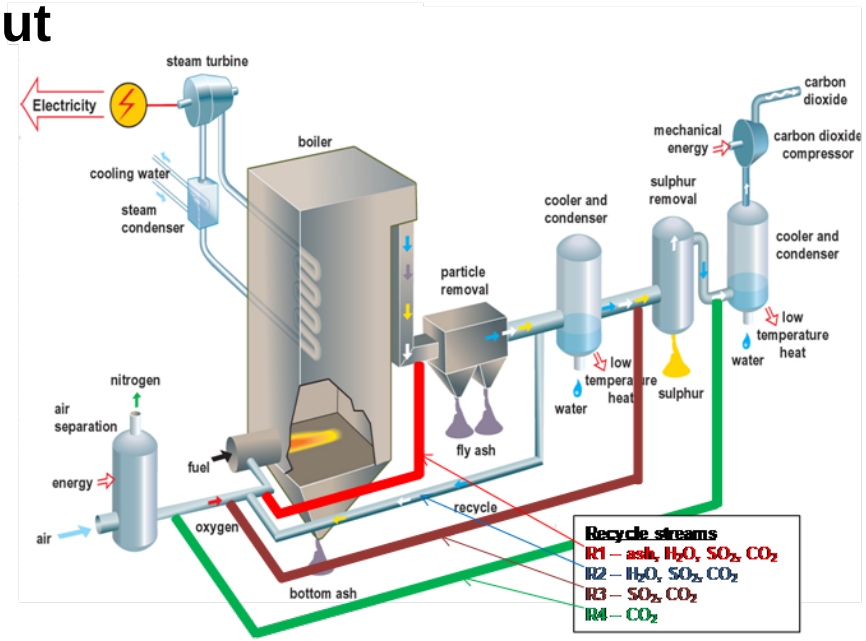
Project Overview

- **<u>Objective:</u>** ***Characterize and predict performance and operational impacts of oxy-combustion retrofit designs on existing coal-fired boilers***
- **<u>Approach:</u> Utilize multi-scale testing and theoretical investigations to develop:**
  - **Fundamental data that describe flame characteristics, ash properties and surface impacts during oxy-coal firing**
  - **Validated mechanisms that describe oxy-combustion processes**
  - **Firing system principles that guide oxy-burner design and flue-gas recycle properties**
- **Incorporate validated mechanisms into CFD software to evaluate full-scale oxy-combustion retrofit designs**

Retrofit Assessment

Evaluate impact of oxy-firing design and flue gas recycle (FGR) ratio and composition on:

- **Flame Characteristics**
  - **Heat transfer (temperature, emissivity, sooting)**
  - **Particle ignition, char burnout**
  - **NOx, SOx, fine particulates**
- **Surface Characteristics**
  - **Heat flux profiles**
  - **Slagging**
  - **Fouling**
  - **Corrosion**



Project Team

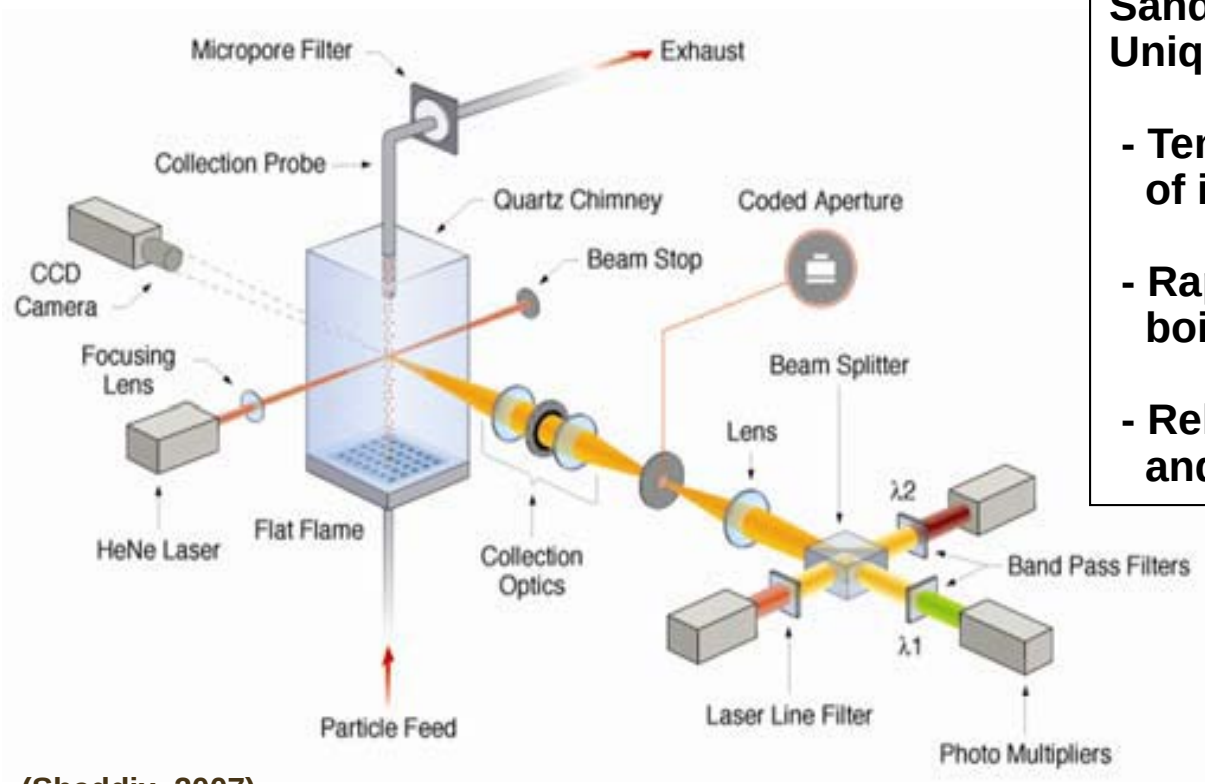
Team Member	Project Role
REI	*program management, testing oversight, mechanism development, simulations*
University of Utah	*laboratory and pilot-scale testing, mechanism development*
Siemens Energy	*oxy-burner technology*
Praxair	*oxygen and CO_2 supply*
Brigham Young Univ.	*soot measurements*
Corrosion Management	*corrosion tests, mechanism development*
Sandia National Labs	*bench-scale testing, mechanism development*
Vattenfall AB	*mechanism development, validation data*
PacifiCorp, Praxair, Southern Company, Vattenfall	*Advisory Panel provides industrial perspective on R&D needs, retrofit requirements and constraints, suggested assessment studies*

Multi-Scale Experiments

- **Designed to provide fundamental data on:**
  - **Char oxidation kinetics**
  - **Soot evolution**
  - **Flame temperature and chemistry**
  - **Heat flux profiles**
  - **Ash deposition and characterization (slagging, fouling)**
  - **Corrosion**
  - **Burner configuration impacts**
- **Bench-Scale Optical Entrained Flow Reactor**
- **Lab-Scale 100 kW Oxy-Fuel Combustor (OFC)**
- **Pilot-Scale 1.2 MW Furnace (L1500)**

Bench-Scale Optical Entrained Flow Reactor

(char oxidation)



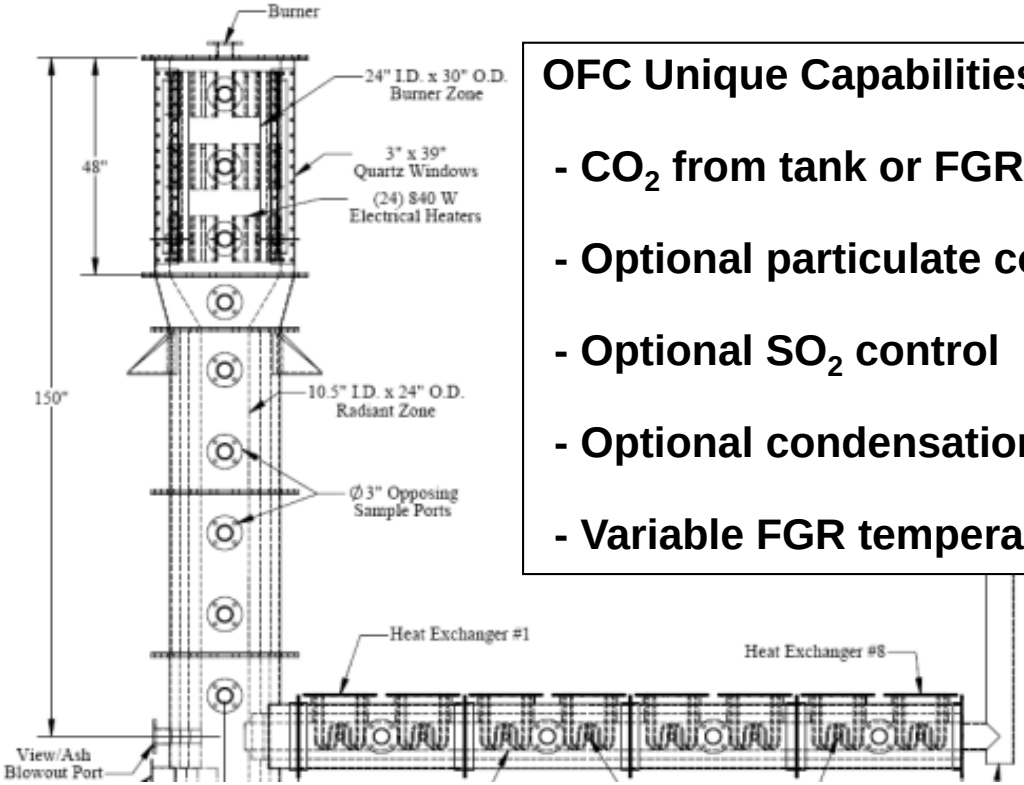
(Shaddix, 2007)

Sandia Entrained Flow Reactor Unique Capabilities:

- **Temperature measurements of individual particles**
- **Rapid devolatilization under boiler relevant conditions**
- **Relevant gas temperatures and compositions**

100 kW Oxy-Fuel Combustor (OFC)

(ash deposition & characterization, sooting)



OFC Unique Capabilities:

- **CO_2 from tank or FGR**
- **Optional particulate control**
- **Optional SO_2 control**
- **Optional condensation**
- **Variable FGR temperature**

Data for air-firing and oxy-firing

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1.2 MW Pilot-Scale Furnace (L1500)

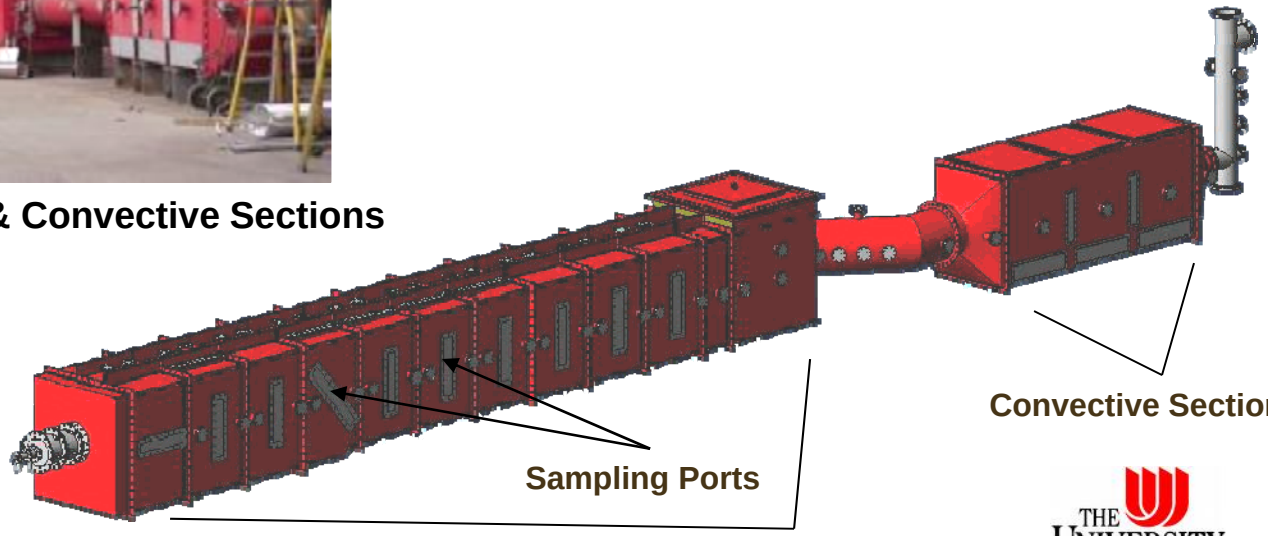
(deposit characterization, heat flux, corrosion, flame properties, oxy-burner characterization)

Air & FGR Train

Radiant & Convective Sections

L1500 Unique Capabilities:

- Realistic Burner Turbulent Mixing Scale
- Realistic Radiative Heat Flux Conditions
- Realistic Time - Temperature Profiles
- Retrofitted for flue gas recycle



Data for air-firing and oxy-firing

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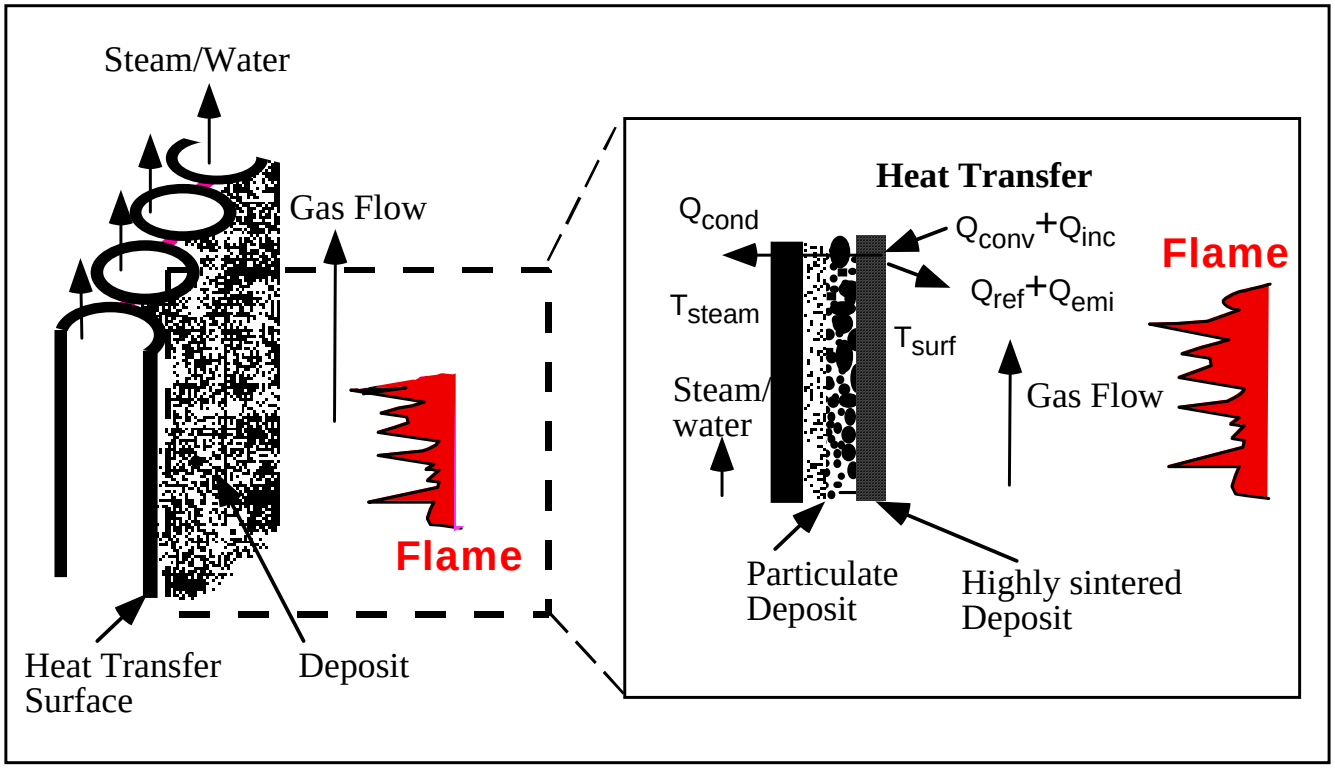
Mechanism Development

- **Develop or enhance mechanisms for:**
  - **Char Oxidation**
  - **Sooting**
  - **Flue Gas Chemistry**
  - **Slagging**
  - **Fouling**
  - **Waterwall and Steam Tube Corrosion**
- **Validate from data and literature**
- **Implement validated mechanism descriptions into existing CFD code**

Slagging Mechanism



Key Processes: Particle capture; Deposit sintering; Deposit growth; Deposit heat transfer

Slagging Dependencies

Process	Properties
Particle capture	Particle impaction rate Particle viscosity (temperature, ash composition, LOI) Deposit surface viscosity (temperature, composition, local flue gas oxygen concentration)
Deposit sintering	Deposited particle size distribution and deposit viscosity, surface tension
Deposit growth	Particle capture rate, sintering (porosity)
Deposit heat transfer	Thermal resistance (thickness, conductivity), emissivity, absorptivity, deposit temperature Incident radiative and convective heat flux

Oxy-combustion Impacts

Process	Properties
Particle capture	Particle impaction rate Particle viscosity (temperature, ash composition, LOI) Deposit surface viscosity (temperature, composition, local flue gas oxygen concentration)
Deposit sintering	Deposited particle size distribution and deposit viscosity, surface tension
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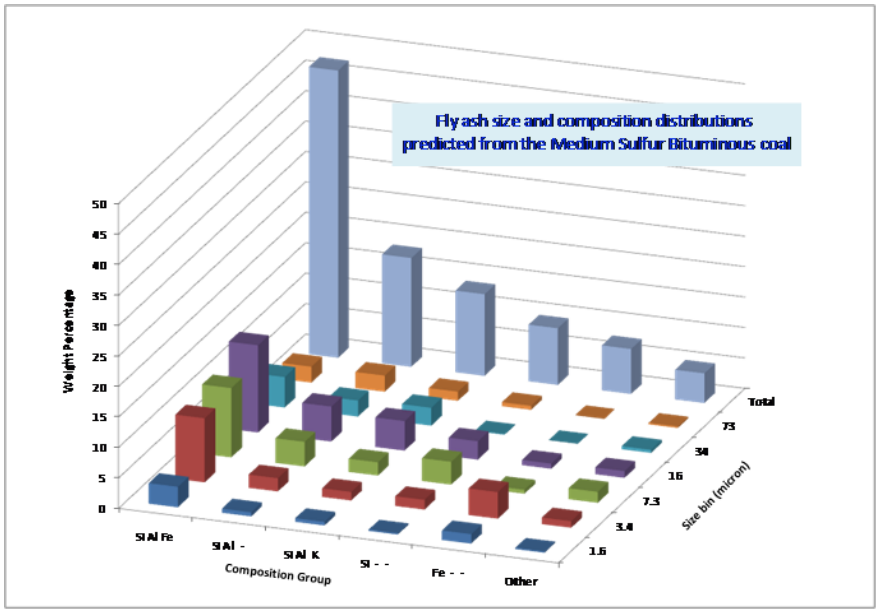
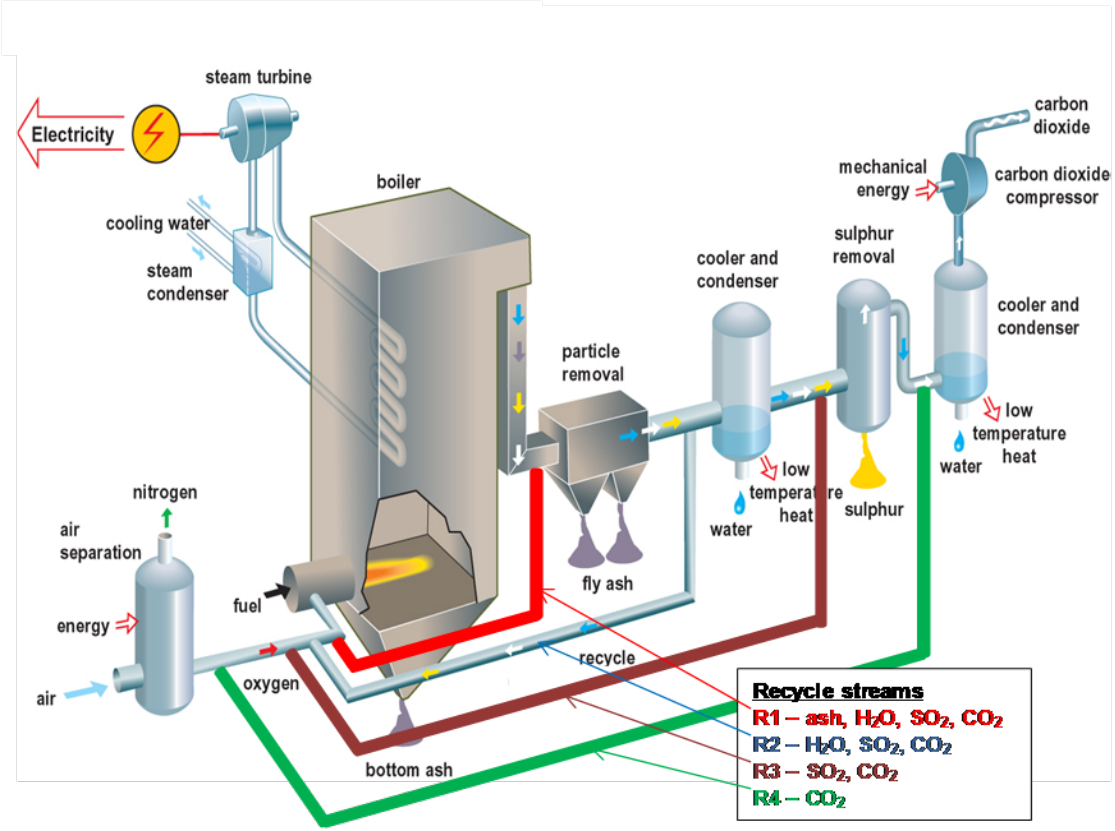
Key Slagging Model Features

- **Pseudo-transient coupling between deposit build up and furnace combustion (CFD)**
- ***Ash transformation sub-model*** **uses detailed analysis of the coal minerals (CCSEM) to predict distribution of fly ash size and composition (gives different viscosity than bulk properties)**
- **Viscosity predicted as a function of temperature and composition**
- **Sticking dependent on both impacting ash properties and surface deposit properties**
- **Deposit properties calculated from deposit composition and thermal history**



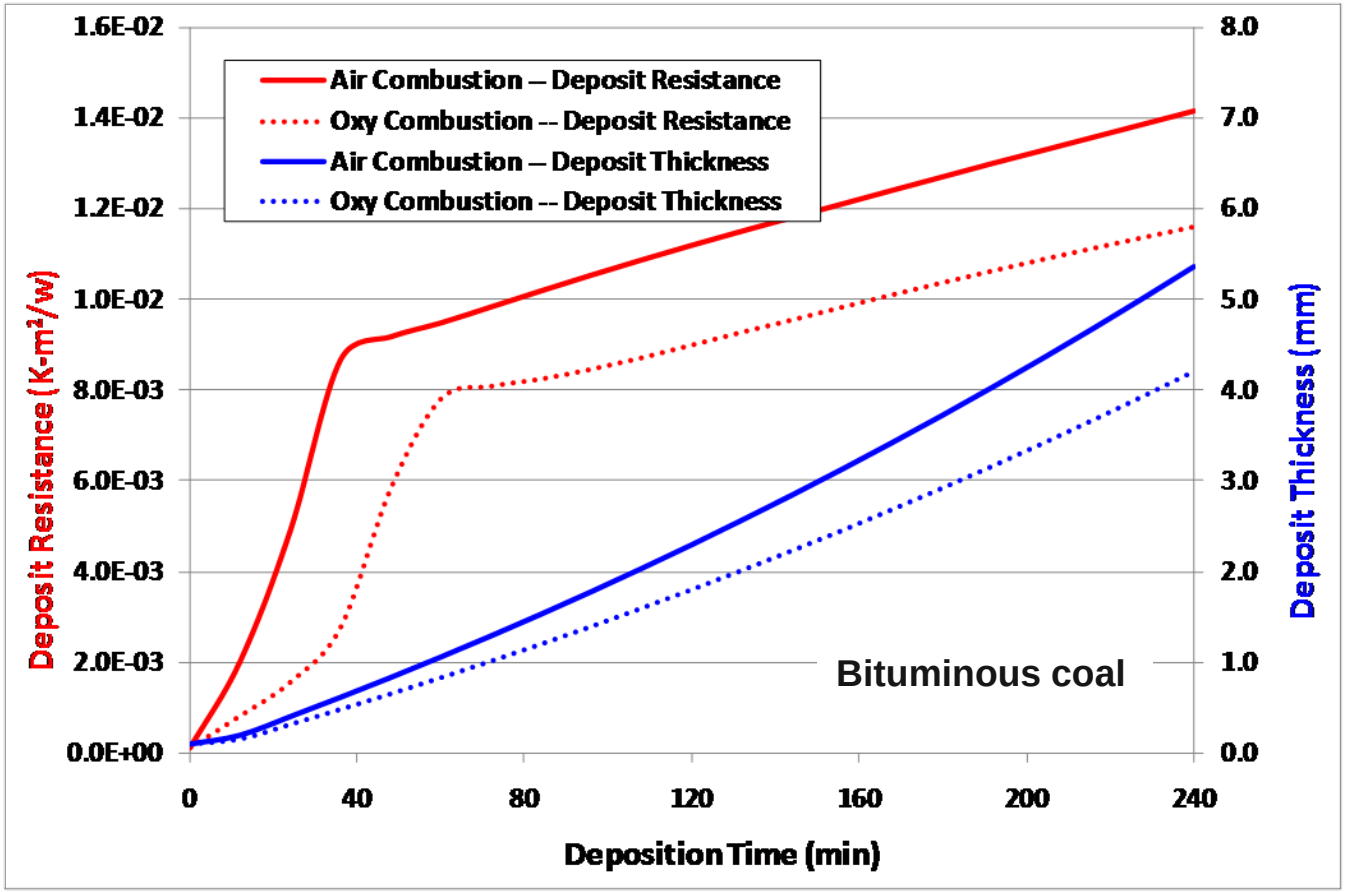
Example Flue Gas Changes with Oxy-combustion Recycle



Flue Gas Type	O_2 %	N_2 %	CO_2 %	H_2O %
Air	3.35	75.7	14.2	6.4
R1	13.7	0.4	58.4	26.3
R2	13.7	0.4	58.4	26.3
R3	18.6	0.59	79.2	-
R4	18.9	0.6	80.05	-

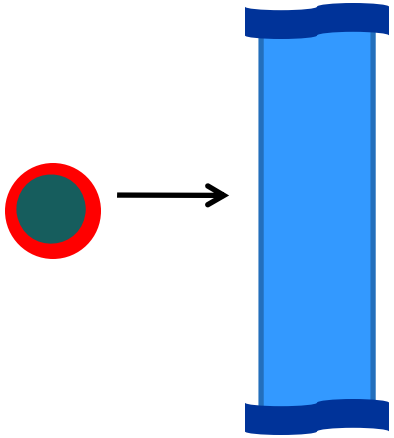
Local surface may go from reducing to oxidizing with recycle

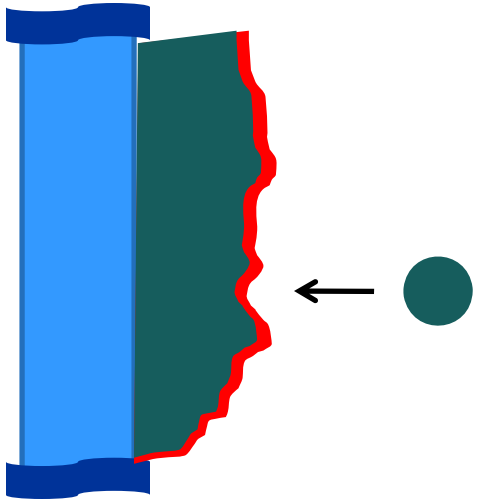
Predicted Slagging Under Air (reducing) and Oxygen (oxidizing) Firing Conditions



Mechanisms for Na_2SO_4 Fouling

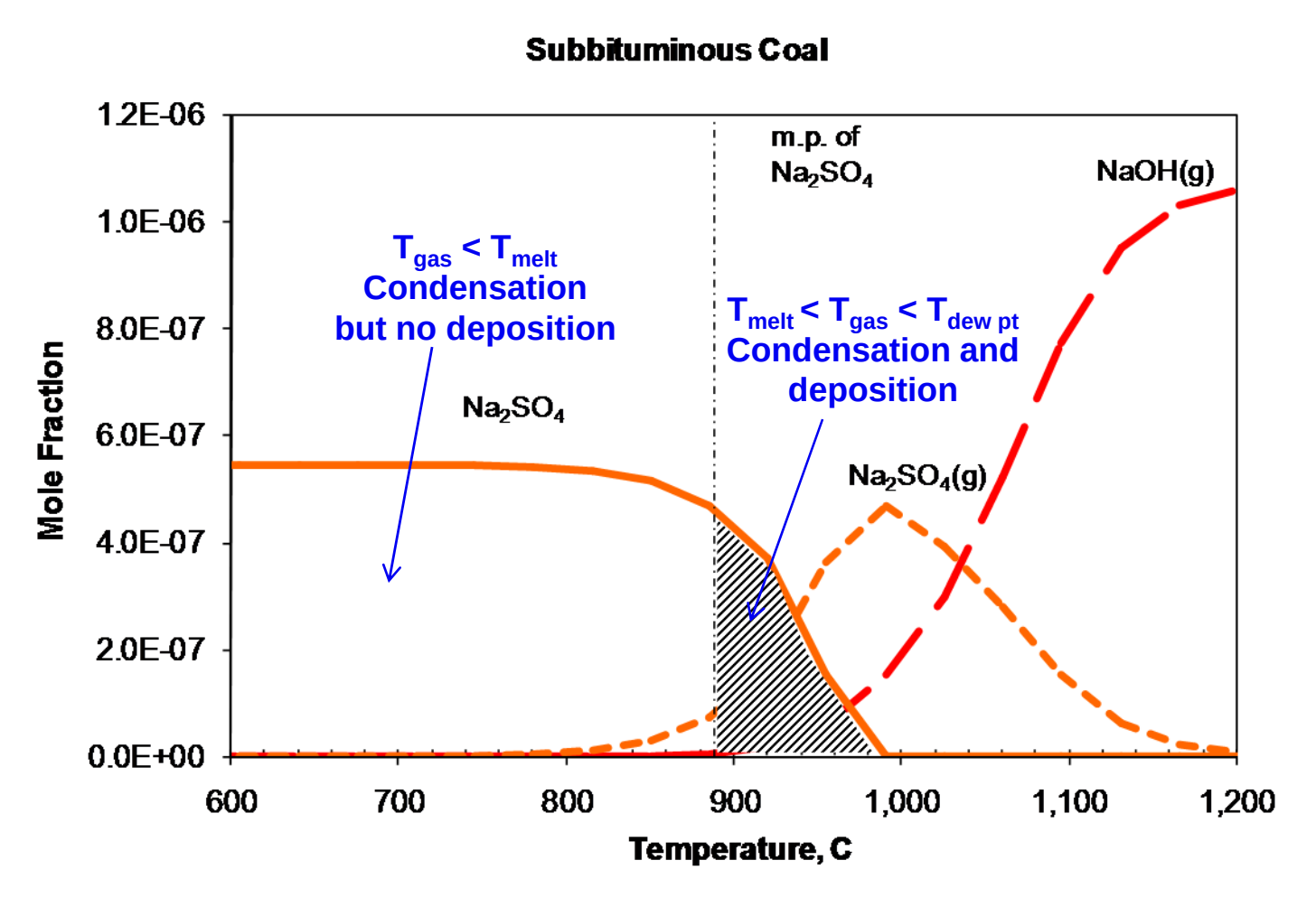
- **Dry deposition**
  - $T_{melt} < T_{gas} < T_{dew\ point}$
  - Na_2SO_4 condenses on entrained ash
  - Sticky ash deposits on tube surfaces





- **Wet deposition**
  - Deposit on tube increases surface temperature
  - Surface temperature is above melting temperature of Na_2SO_4 ($T_{melt} < T_{surface}$)
  - Fly ash sticks to surface

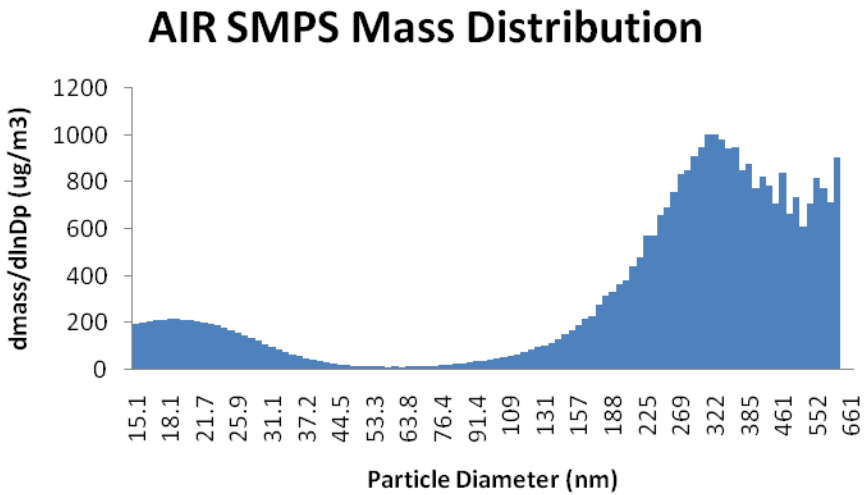
Na_2SO_4 Fouling Illustration

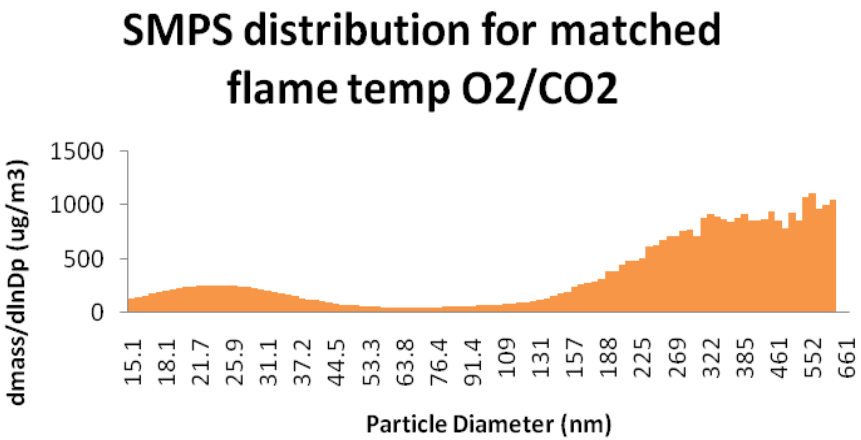


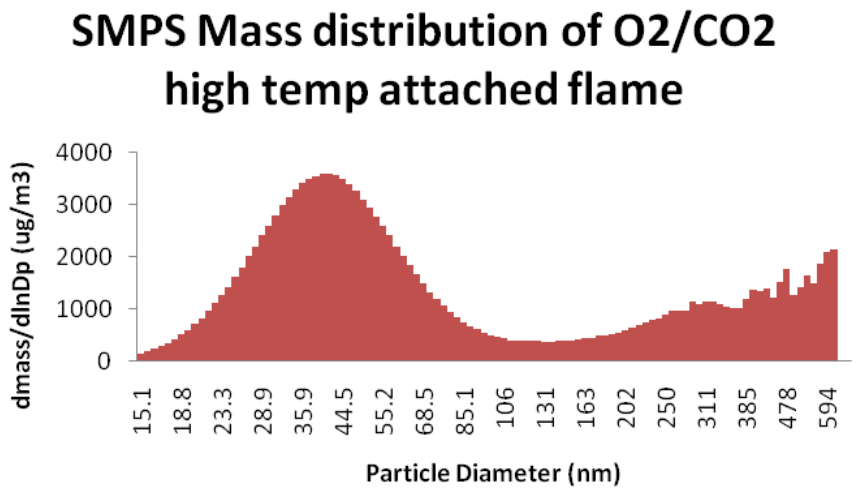
Fouling Dependencies

Characteristic	Dependencies	Oxy-combustion Impacts
Particle stickiness (dry deposition)	Dew point	Temperature, alkali concentration
	Alkali concentration	Sodium vaporization rate (size distribution)
Surface stickiness (wet deposition)	Tube/deposit surface temperature	Particle temperature, heat flux
Tube impaction rate	Particle size distribution, aerodynamics	Size distribution, flue gas velocities (velocity also impacted by tube geometry)

Oxy-combustion Impacts - OFC Preliminary SMPS Data





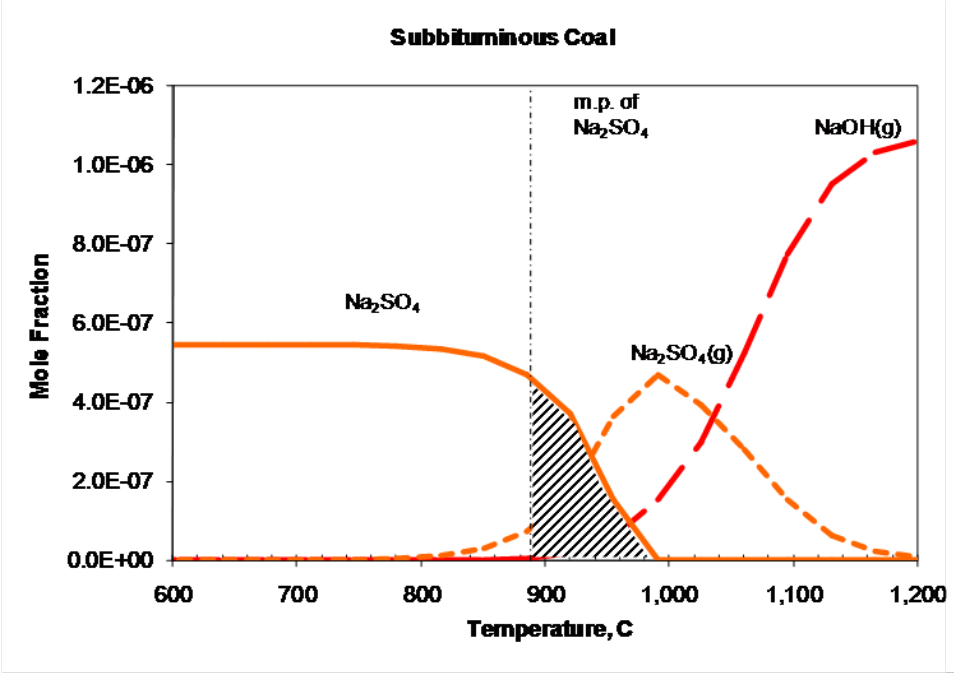


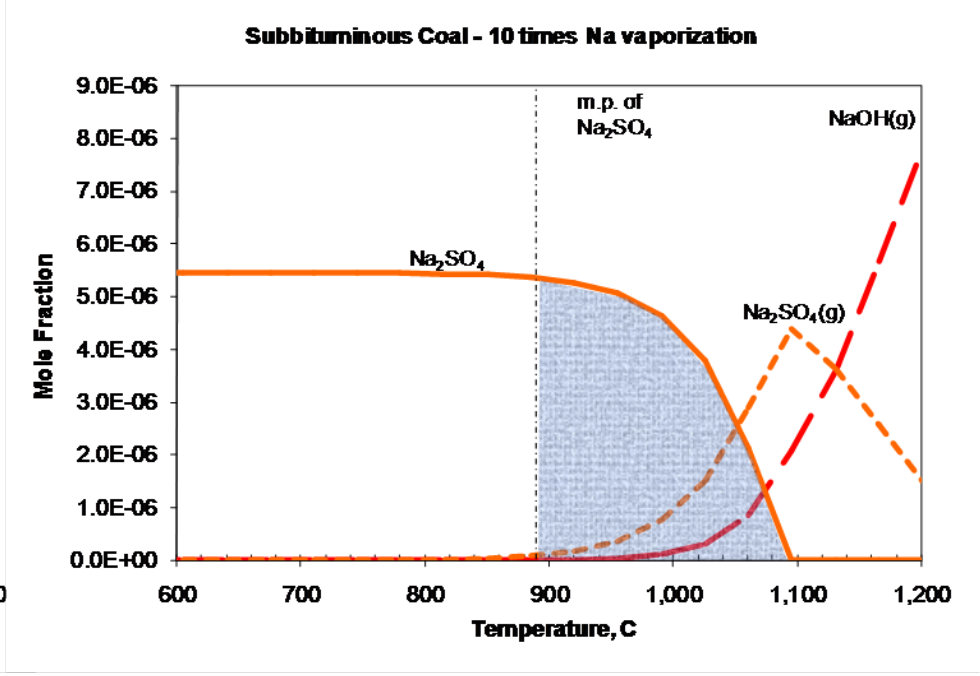
Size shift with higher oxygen suggests potential higher sodium vaporization rate

SMPS (Scanning Mobility Particle Sizer) data from University of Utah

Example Fouling Impact

- Increasing Na vaporization by a factor of 10
- Dew point of Na_2SO_4 increases from ~1000°C to ~1100°C
- Increased dew point and concentration of Na in gas phase will increase area and extent of fouling in convective pass





Program Status – Slagging and Fouling

- **Finishing Year 1 of three-year program**
  - **Developed mechanisms and calculation approaches for slagging and fouling**
  - **Completing initial ash characterization testing in OFC**
- **Year 2 slagging and fouling tasks**
  - **Conduct additional OFC ash characterization tests**
  - **Begin pilot-scale air and oxygen firing tests**
  - **Use data from tests to validate slagging and fouling mechanisms**
  - **Implement/update descriptions of mechanisms in existing CFD code**
- **Hear more: Wendt (1C), Shaddix (3C), Eddings (4A), Fry (6A)**

Acknowledgment

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