Characterization of Oxy-combustion Impacts in Existing Coal-fired Boilers

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For Energy and Environmental Solutions

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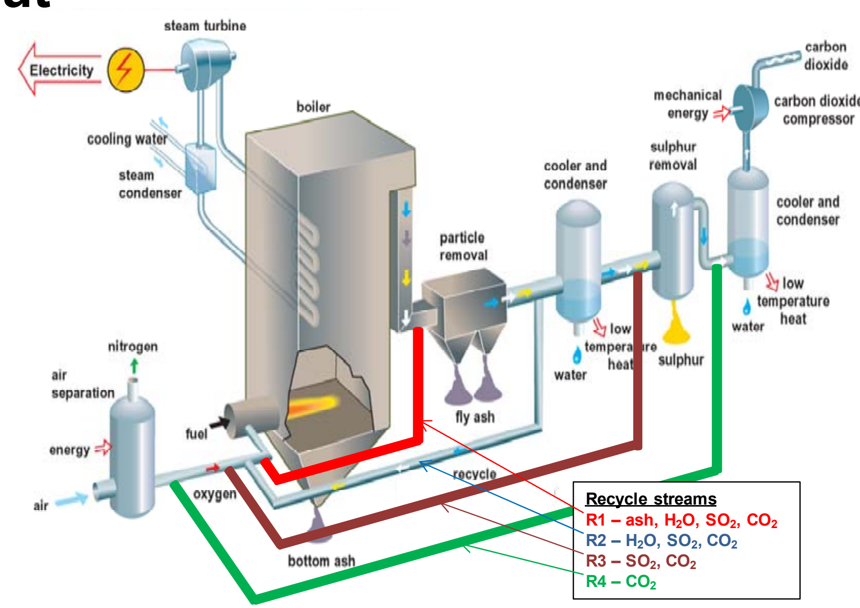
Project Overview

- **Objective:** ***Characterize and predict performance and operational impacts of oxy-combustion retrofit designs on existing coal-fired boilers***
- **Approach: Utilize multi-scale testing and theoretical investigations to develop:**
  - **Fundamental data that describe flame characteristics, corrosion rates, and ash properties 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 Capability

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



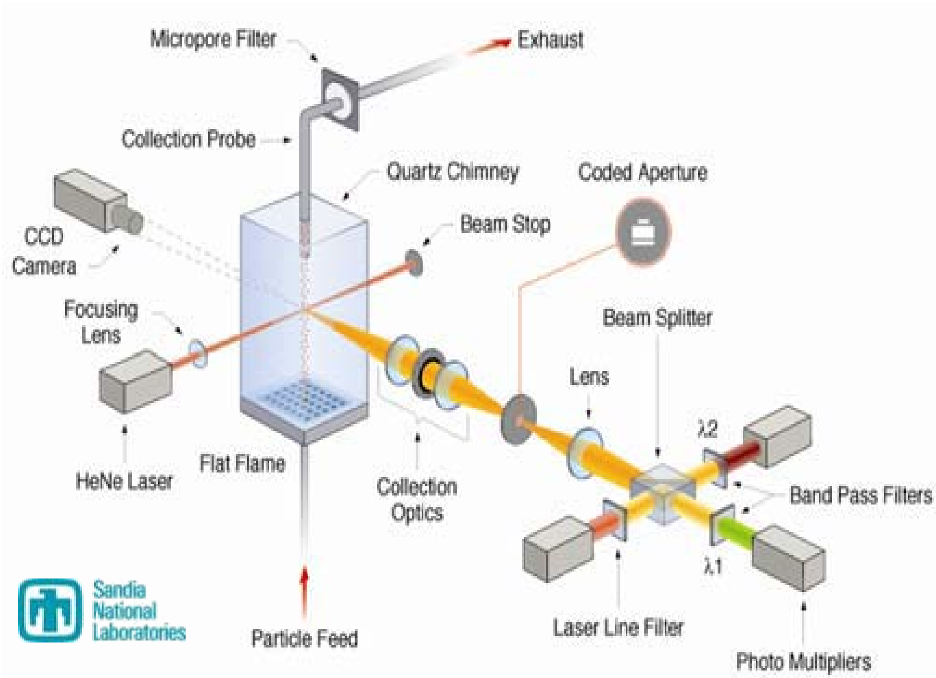
Project Team

Team Member	Project Role
REI	*program management, testing oversight, mechanism development, simulations*
University of Utah	*laboratory and pilot-scale testing, mechanism development*
Siemens Energy	*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*

Approach

- **Development of Fundamental Data (Multi-Scale Experiments)**
- Development and Validation of Mechanisms
- Firing System Principles
- Assessment of Oxy-combustion Retrofit

Bench-Scale Optical Entrained Flow Reactor



(Shaddix, 2007)

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

Experiments

Char Oxidation

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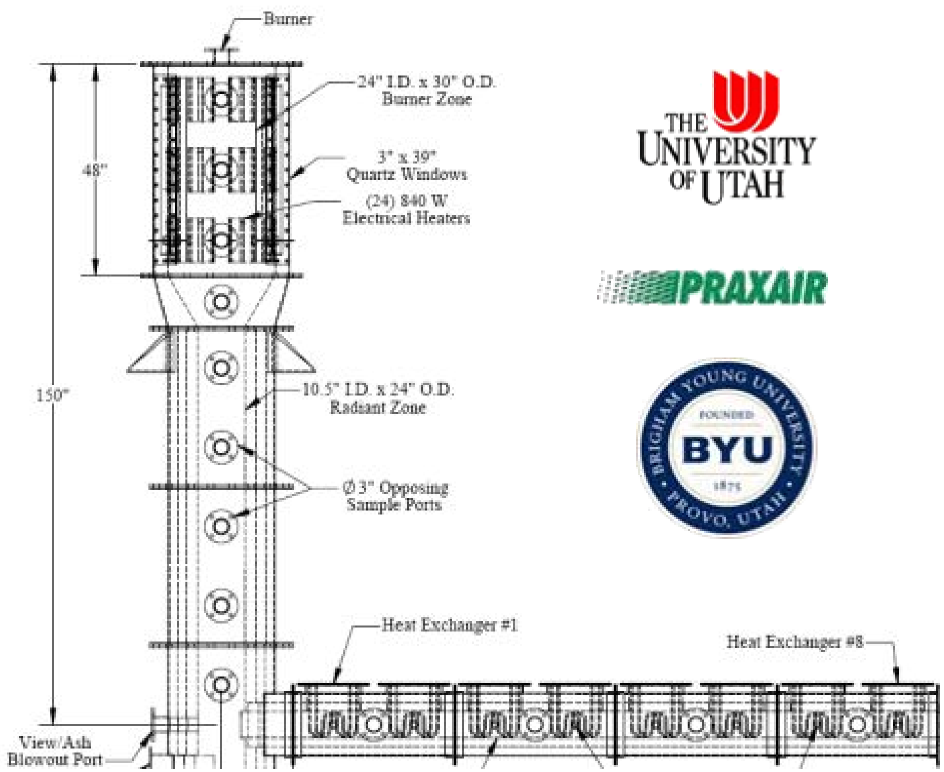
Measurements

Particle Burnout
(through collection and analysis)

Optical Sizing Pyrometry
(particle size and temperature profile)

100 kW Oxy-Fuel Combustor (OFC)



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

Experiments

Ash Deposition and Characterization

Soot Evolution

↓

Measurements

Low-Pressure Impactor Collection

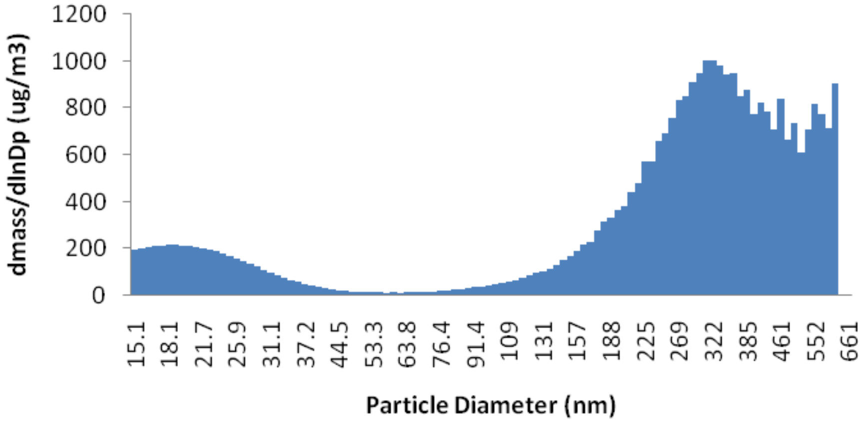
Computer Controlled Scanning Electron Microscope (CCSEM) particle composition analysis

Scanning Mobility Particle Sizer (SMPS)

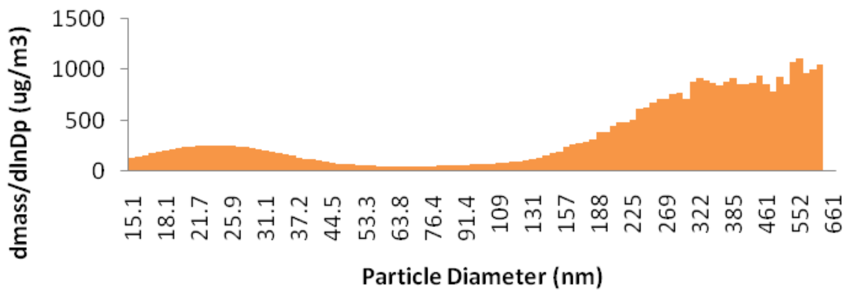
Two-Color Extinction Pyrometry

OFC Preliminary SMPS Data

AIR SMPS Mass Distribution



SMPS distribution for matched flame temp O2/CO2



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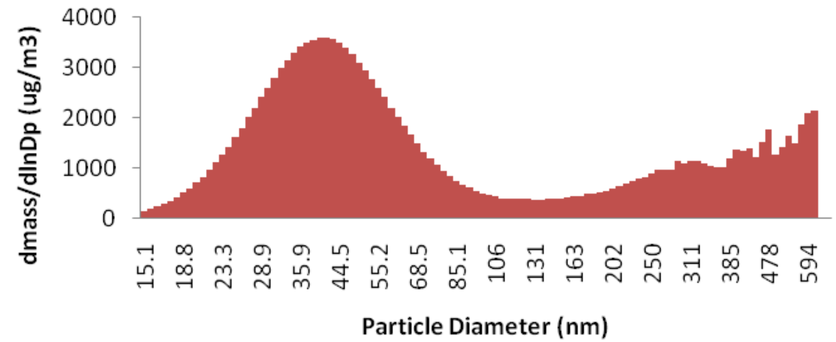
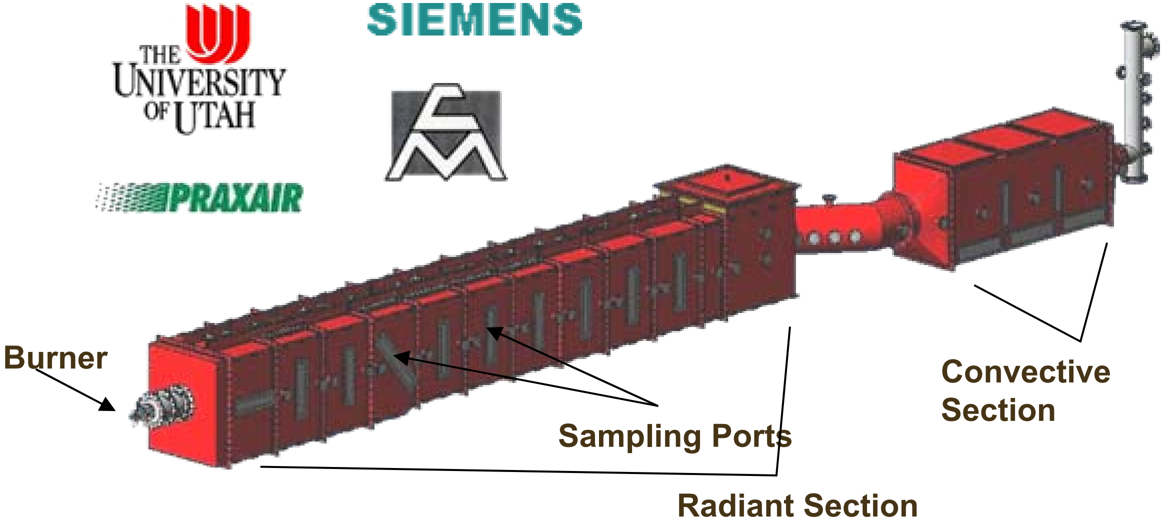
SMPS Mass distribution of O2/CO2 high temp attached flame



SMPS = Scanning Mobility Particle Sizer

1.2 MW Pilot-Scale Furnace (L1500)



Experiments

Fuel, Oxygen and
FGR Mixing in Burner

Corrosion, Radiation,
Particle Deposition

Measurements

Flame Stabilization Location,
Temperature Profile, Flue Gas
Composition, Unburned Carbon in Ash

Real-Time Corrosion Rates of different
materials using EN Technology

Heat Flux

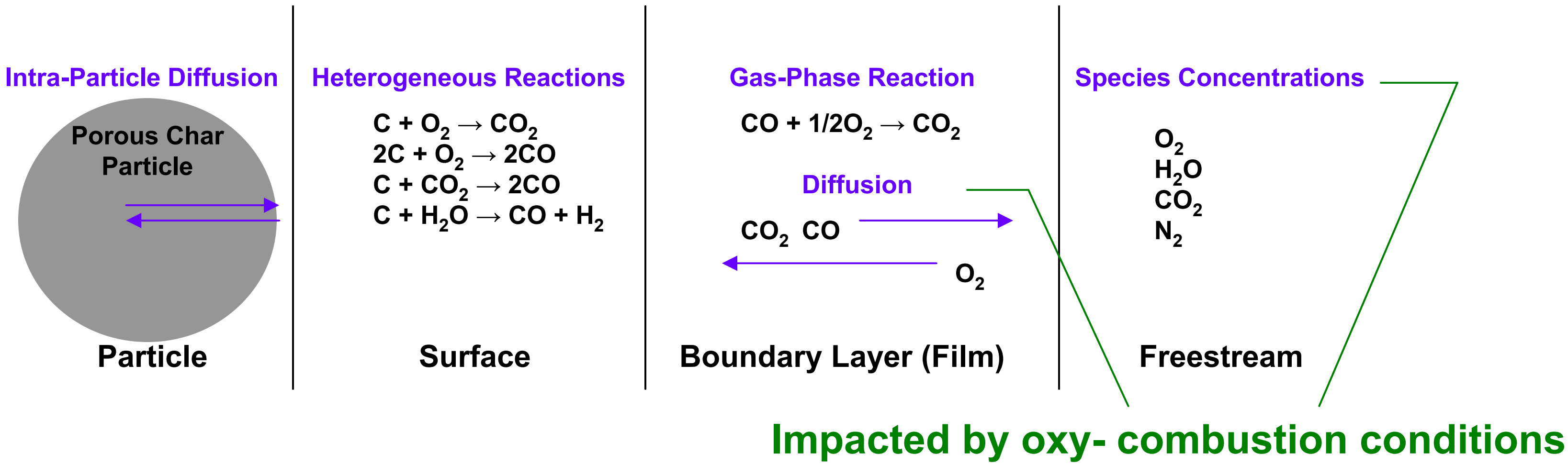
Deposition Rate and Characterization

- Realistic burner turbulent mixing scale
- Realistic radiative heat flux conditions
- Realistic time–temperature profiles
- Retrofitted for flue gas recycle

Approach

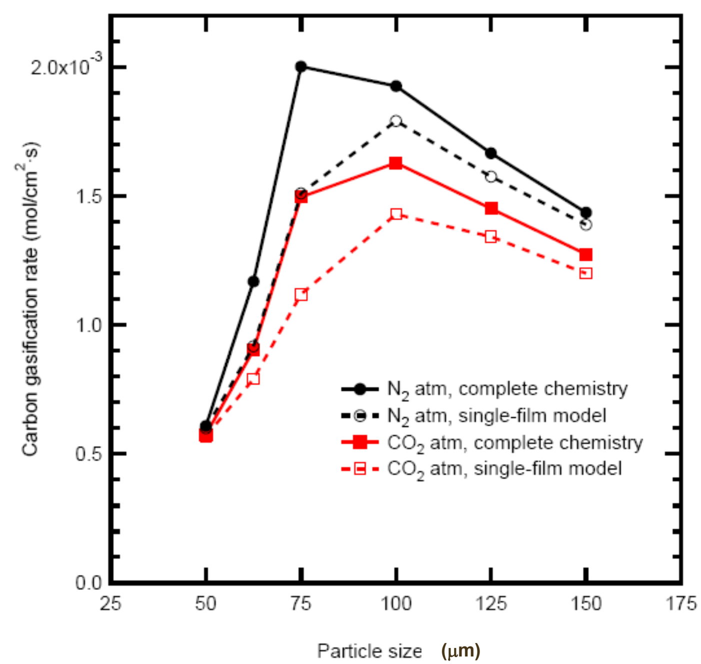
- Development of Fundamental Data (Multi-Scale Experiments)
- **Development and Validation of Mechanisms**
- Firing System Principles
- Assessment of Oxy-combustion Retrofit

Char Oxidation Mechanism Development

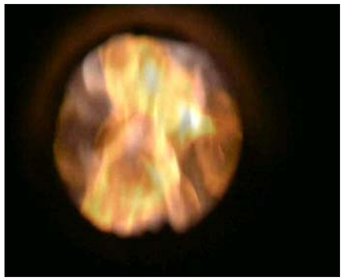


Existing char oxidation model assumes reactions occur only at the surface (reaction limited). Data indicate O_2 film diffusion may be limiting for oxy-combustion (O_2 thru CO_2 slower than O_2 thru N_2)

Measured data combined with Surface Kinetics in Porous Particles (SKIPPY) modeling to guide development of new mechanism



Soot Mechanism Development



a. Air flame

b. 21% oxygen flame

c. 27% oxygen flame

(propane flame, K. Anderson, 2008)

Soot formation (through cracking of tars in coal volatiles) shown to be dependent on oxygen concentration in oxy-fuel flames

Contribution of soot to flame emissivity, relative to CO_2 and H_2O, will be evaluated using the narrow band model Radcal.

REI's existing soot model combined with Radcal data and soot measurements to develop improved mechanism for soot formation and radiation

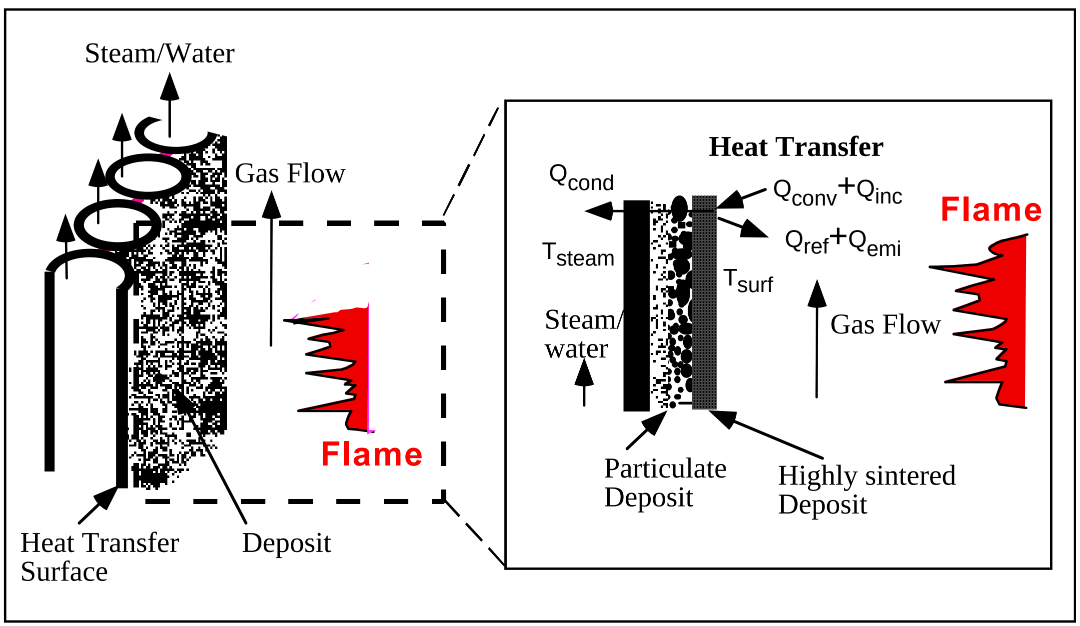
Slagging Mechanism Development

Slagging (deposition in radiant section)

Dependent on:

- **Particle size and composition**
- **Surface and particle temperatures**
- **Radiation heat flux conditions**
- **Local oxygen concentration**

Impacted by oxy-combustion conditions



New mechanism extended from REI's current deposition mechanism, which tracks ash composition and size distribution

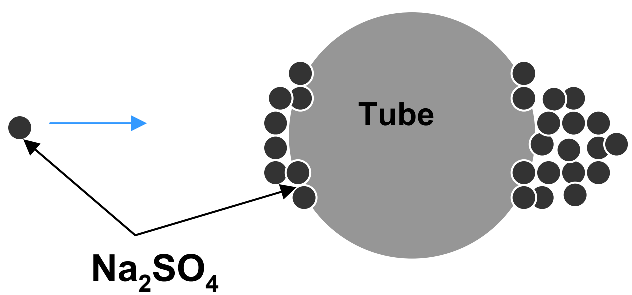
Fouling Mechanism Development

Fouling (deposition in convective section)

Dependent on:

- **Gas-phase alkali sulfates concentration**
- **Particle and tube temperatures**
- **Particle size distribution**
- **Tube geometry and velocity field**

Impacted by oxy-combustion conditions (applies to the first three items)



Dew Point $< T_{gas} <$ Melting Point (1157 K)
Becomes sticky and condenses

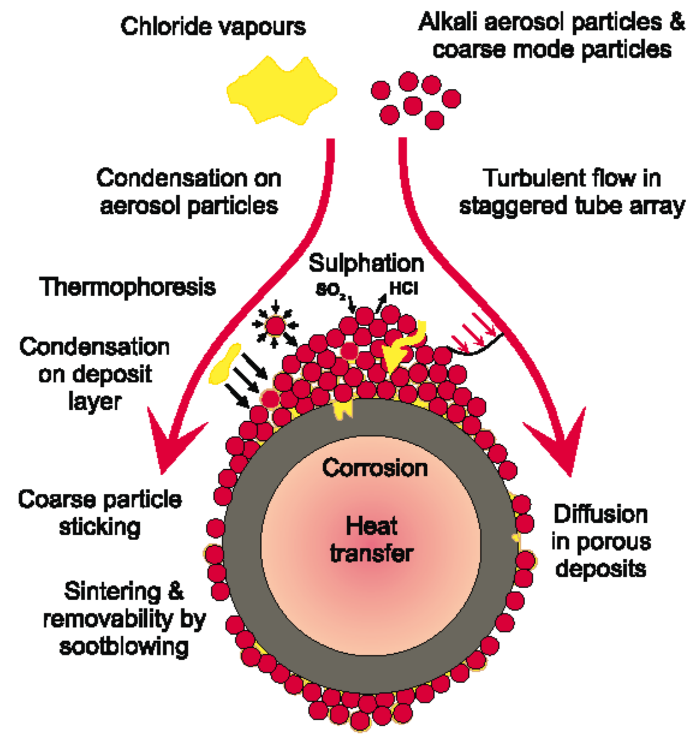
New mechanism extended from REI's current deposition mechanism, which tracks ash composition and size distribution

Corrosion Mechanism Development

Factors Important For Corrosion

- Temperature
  - Metal and gas temperature
  - Heat flux
  - Temperature gradient
  - Temperature fluctuations
- Fuel/Deposit Characteristics
  - Sulfur, chlorine, alkali metals
- Local Gas-Phase Stoichiometry
- Tube Metallurgy
  - Cr, Ni, Al, etc.
- Boiler Design & Operation
  - Tube spacing, tube location, etc.
  - Flue gas velocity

Impacted by oxy-combustion conditions



"Biomass Co-firing", European Bioenergy Networks, VTT Processes, March 2003

Extend current REI corrosion mechanisms for:

- Oxidation, Chloridation, Sulfidation (gaseous H_2S, deposited FeS, molten sulfate)

Review Carburization mechanism

Mechanism Validation

- **All mechanisms will be validated against data taken in the experimental program and against other available data**
- **Mechanisms will be implemented into CFD coal combustion code *Glacier***
- **Overall CFD model will be validated against available pilot-scale and full-scale furnace data**

Approach

- Development of Fundamental Data (Multi-Scale Experiments)
- Development and Validation of Mechanisms
- **Firing System Principles**
- Assessment of Oxy-combustion Retrofit

Firing System Principles

- Determine firing system dependencies based on:
  - Theoretical calculations extending air-firing experience and oxy-firing properties
  - Pilot-scale testing
  - CFD modeling
- Sensitivities to be investigated include:
  - Composition and amount of flue gas recycle
  - Oxy-burner design
- Develop firing system principles and use them to guide full-scale firing system design

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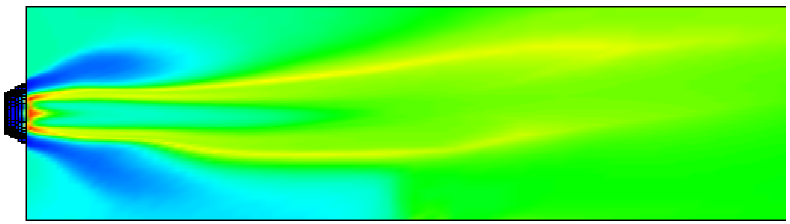
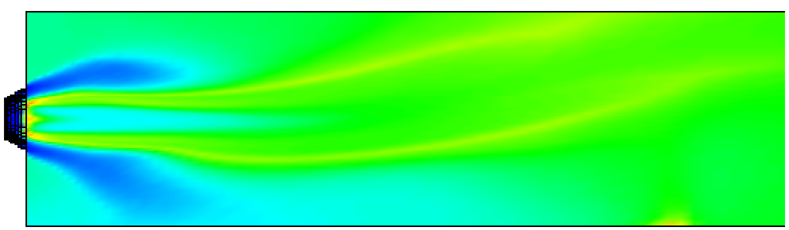
Preliminary Pilot-scale Burner Modeling

Gas Temperature Profiles

Existing Air Burner

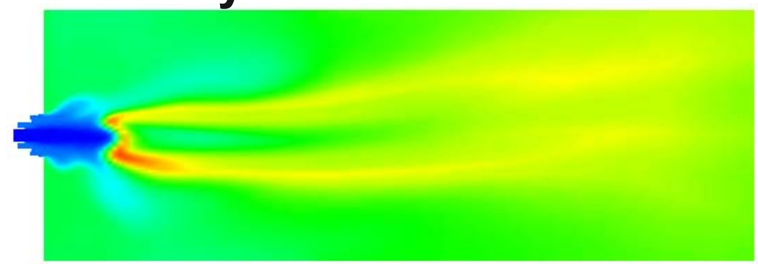


Air fired



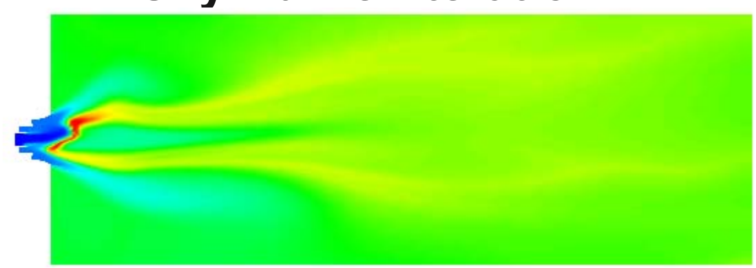
O_2-CO_2 fired (27% O_2)

Oxy Burner Iteration 1



O_2-CO_2 fired (27% O_2)

Oxy Burner Iteration 2



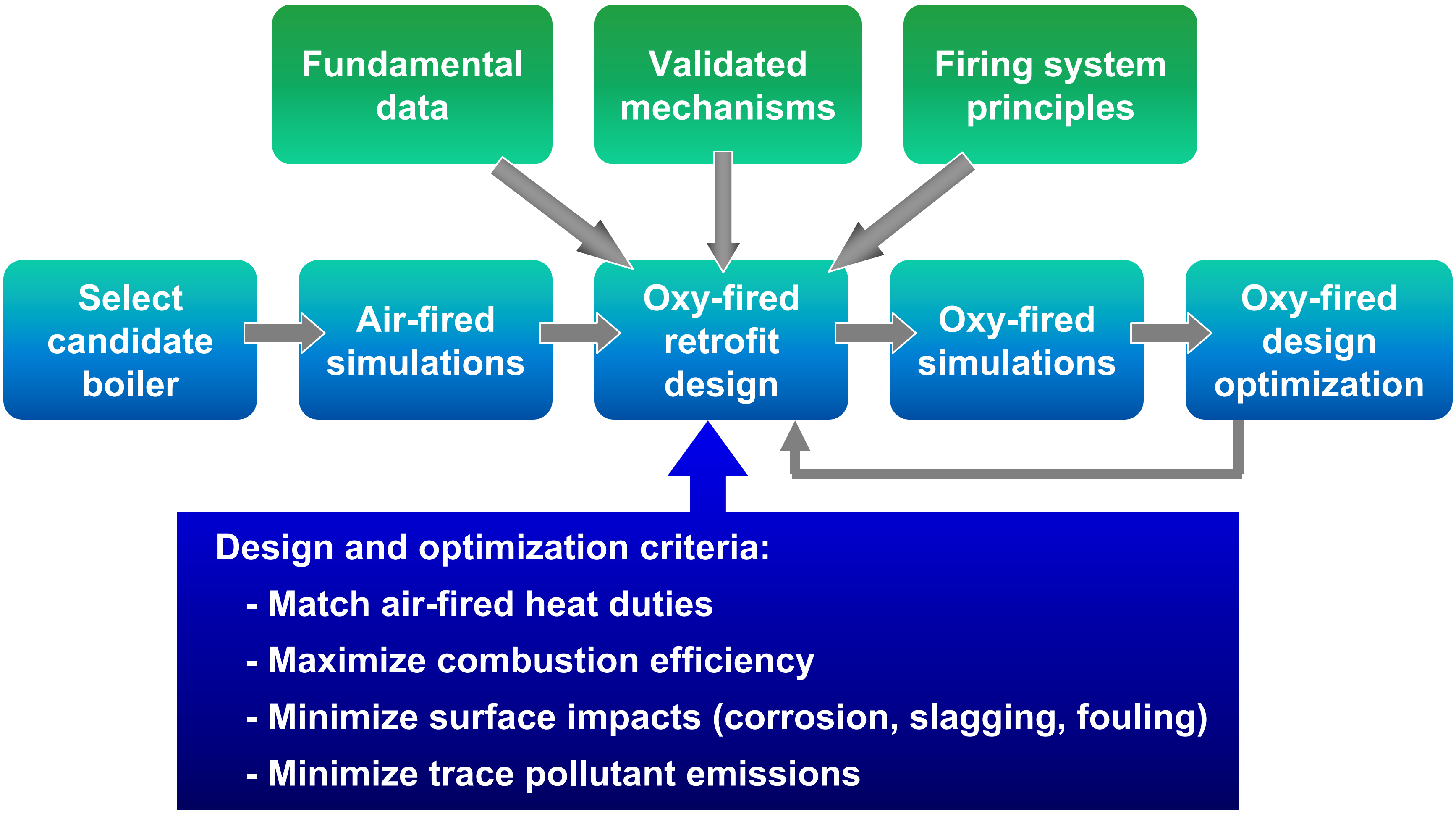
O_2-CO_2 fired (27% O_2)

(CFD graphics created with Fieldview software from Intelligent Light)

Approach

- Development of Fundamental Data (Multi-Scale Experiments)
- Development and Validation of Mechanisms
- Firing System Principles
- **Assessment of Oxy-combustion Retrofit**

Assessment Approach



Program Status

- OFC measurement equipment assembled and initial air-firing and oxy-firing testing started
- Char oxidation testing and SKIPPY modeling started
- Initial pilot-scale oxy-burner design completed and being evaluated
- Development of slagging, fouling and corrosion mechanisms on-going
- L1500 testing to begin in Program Year 2 (Oct 2009)

Questions?

This material is based upon work supported by the Department of Energy under Award Number DE-NT0005288; Timothy Fout, Project Manager.