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

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For Energy and Environmental Solutions

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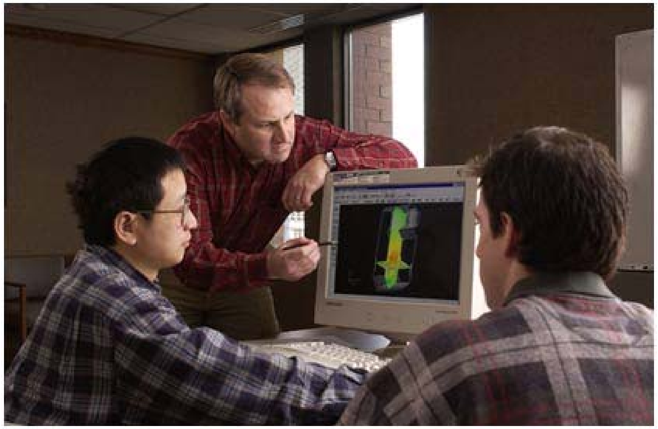
REI Profile

- Energy And Environmental Consulting Firm Specializing In:
  - Combustion System Design and Performance Analysis
  - Advanced CFD Simulations
    - Combustion Performance, Emissions, Operational Impacts
  - Customized Software
  - Specialized Test Equipment
  - Proof-of-Concept Testing



- Founded 1990, ~20 Full-Time Employees
- Develop & Apply Advanced Technology to Industry

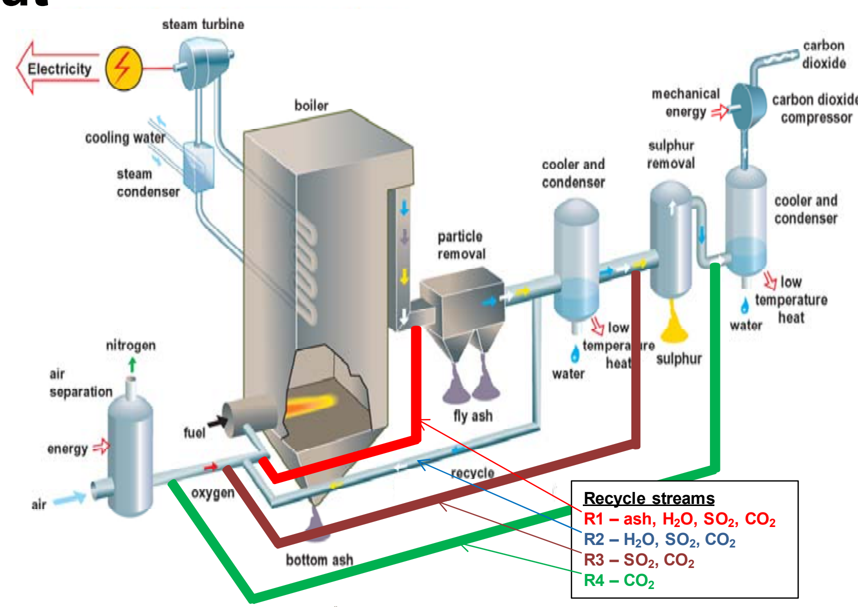
R&D Project Overview

- **Objective:** ***Characterize and predict performance and operational impacts of oxy-combustion retrofit designs on existing coal-fired boilers***
- **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 model 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

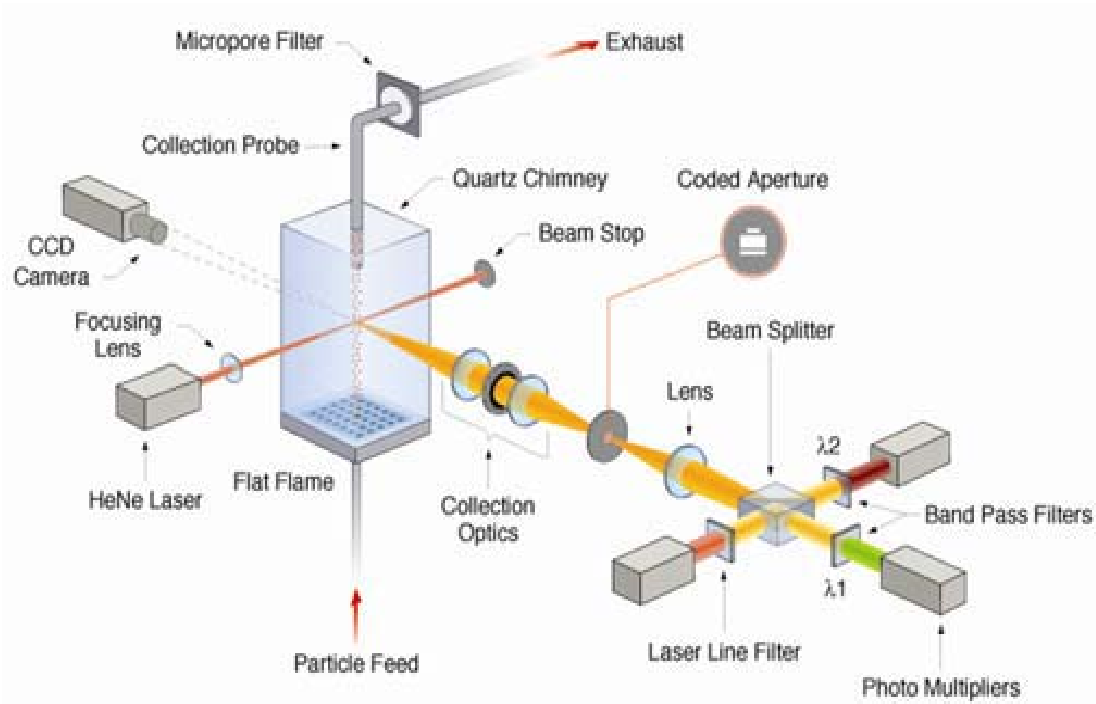
Team Member	Project Role
REI	*program management, testing oversight, mechanism development, simulations*
University of Utah	*laboratory and pilot-scale testing, mechanism development*
Siemens Energy	*burner technology*
Praxair	*oxygen and CO_2 supply*
Brigham Young Univ.	*soot measurements*
Corrosion 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*

- **Development of Fundamental Data**
- Development and Validation of Mechanisms
- Firing System Principles
- Assessment of Oxy-combustion Retrofit
- Program Funding and Schedule

Multi-scale Experiments

- **Bench-Scale Optical Entrained Flow Reactor**
  - Char Oxidation Kinetics
- **100 kW Oxy-Fuel Combustor (OFC) Tests**
  - Ash Deposition and Characterization
  - Soot Evolution
- **1.2 MW Pilot-Scale Furnace (L1500) Tests**
  - Impacts of Burner Configuration
  - Heat Flux, Corrosion and Particle Deposition
  - Flue Gas Chemistry

Bench-Scale Optical Entrained Flow Reactor Experiments



(Shaddix, 2007)

Sandia Entrained Flow Reactor Unique Capabilities:

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

Bench-Scale Optical Entrained Flow Reactor

Experiments

Char Oxidation

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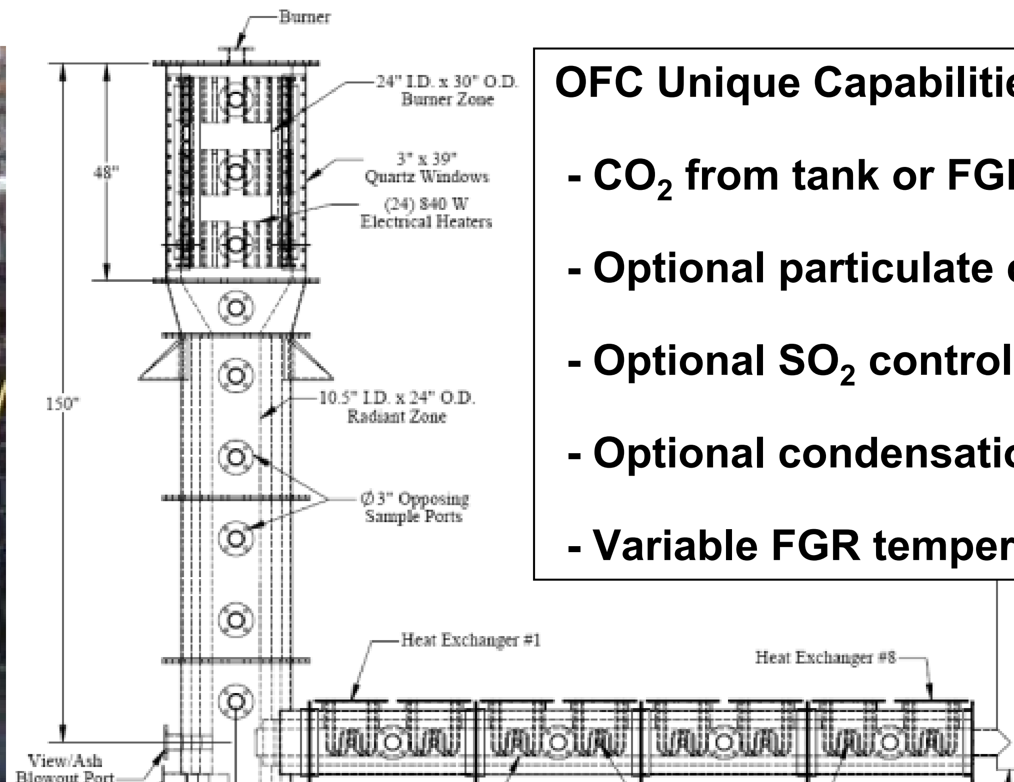
Measurements

Particle Burnout
(through collection and analysis)

Optical Sizing Pyrometry
(particle size and
temperature profile)

Sandia National Laboratories

100 kW Oxy-Fuel Combustor (OFC)



OFC Unique Capabilities:

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

100 kW Oxy-Fuel Combustor (OFC) Experiments

Experiments

Ash Deposition and Characterization

Soot Evolution

Measurements

Ash Deposition and Characterization:

- Low-Pressure Impactor Collection
- Computer Controlled Scanning Electron Microscope (CCSEM) particle composition analysis
- Scanning Mobility Particle Sizer (SMPS)

Soot Evolution:

- Two-Color Extinction Pyrometry

Data will be tailored for mechanism development and validation

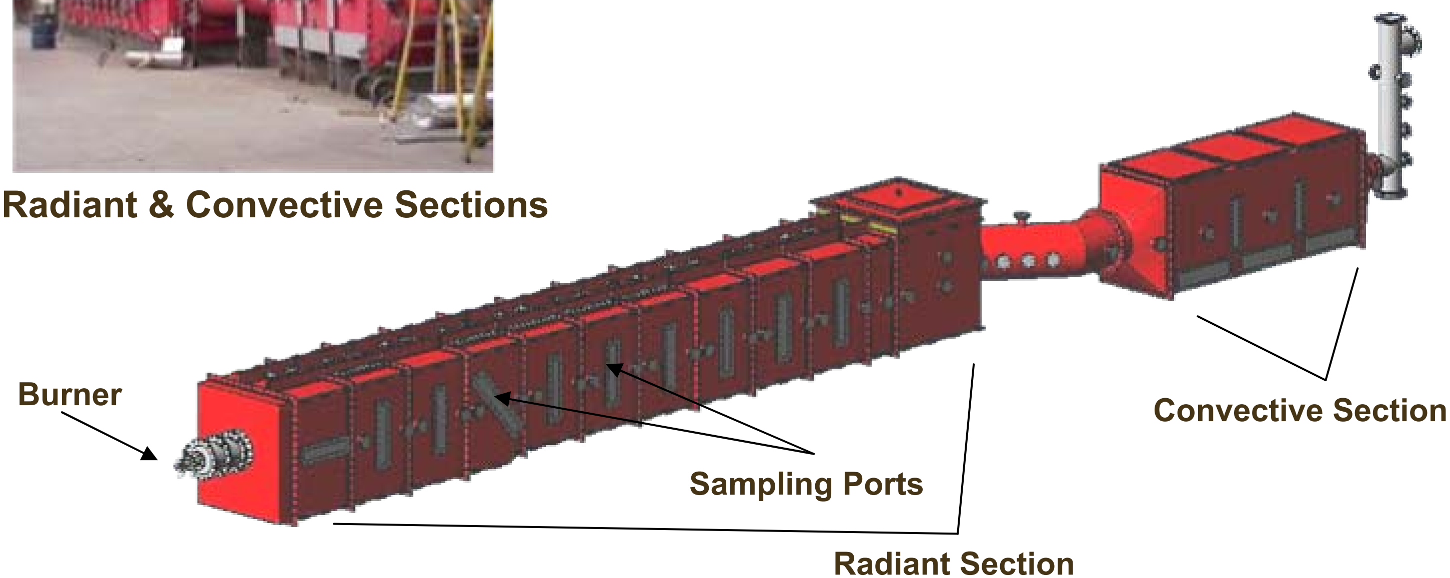
1.2 MW Pilot-Scale Furnace (L1500)

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



1.2 MW Pilot-Scale Furnace (L1500) Experiments

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

Data for air-firing and oxy-firing

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PRAXAIR

- Development of Fundamental Data
- **Development and Validation of Mechanisms**
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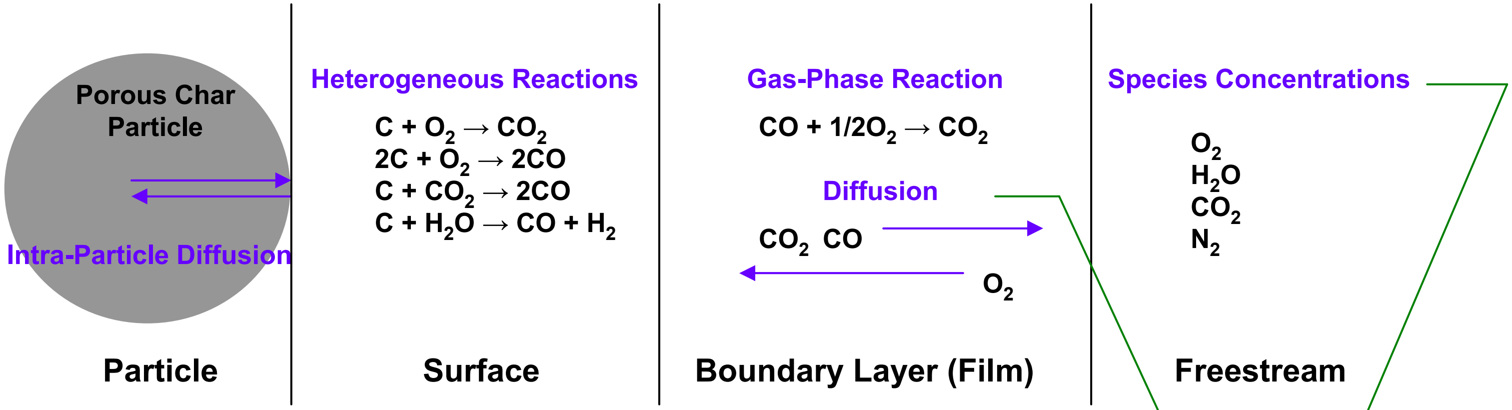
Mechanism Development Overview

- **Mechanism Review and Development for:**
  - Char Oxidation
  - Sooting
  - Slagging
  - Fouling
  - Waterwall and Steam Tube Corrosion
- **Mechanism Validation**

Char Oxidation Mechanism Development

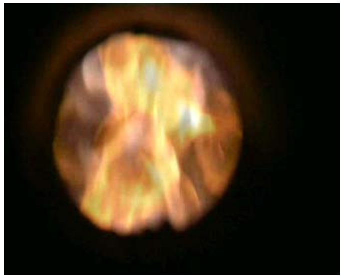


Current char oxidation model assumes reactions occur only at the surface (reaction limited). Data indicate that O_2 film diffusion may be limiting for oxy-combustion conditions (O_2 thru CO_2 slower than O_2 thru N_2), necessitating an improved model.

Impacted by oxy-combustion conditions

Surface Kinetics in Porous Particles (SKIPPY) modeling will be combined with measured data to suggest the form of the 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) has been shown to be dependent on oxygen concentration in oxy-fuel flames.

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

A mechanism for soot formation and radiation under oxy-combustion conditions will be developed based on REI's existing soot model.

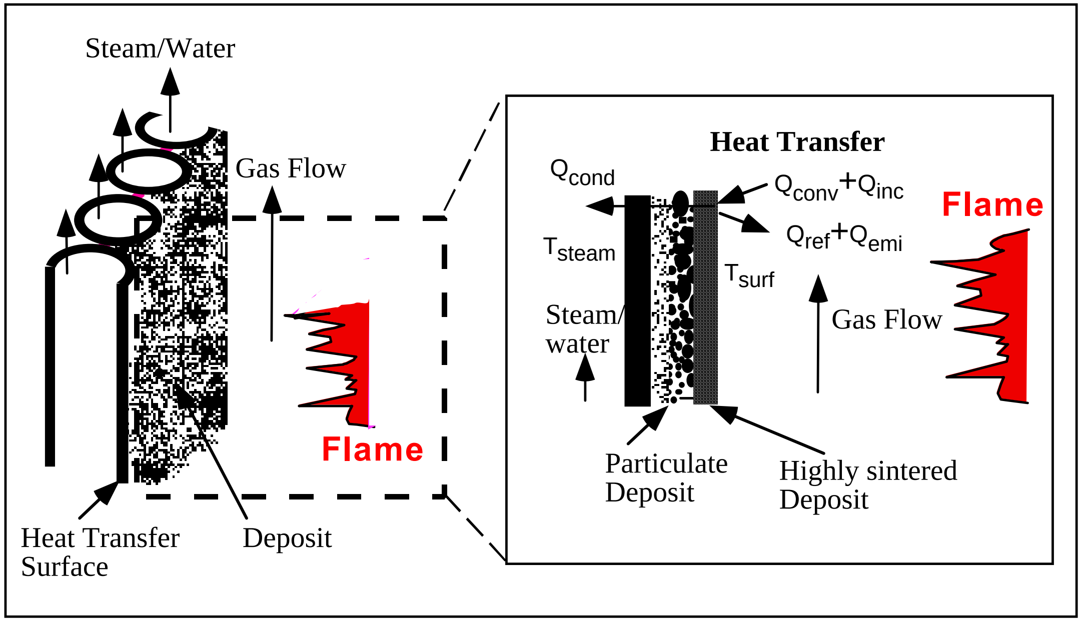
Slagging Mechanism Development

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 particle composition and size distribution

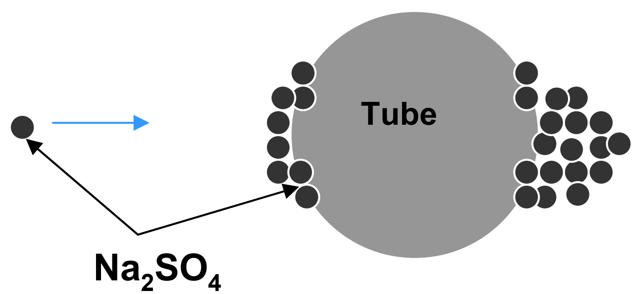
Fouling Mechanism Development

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



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

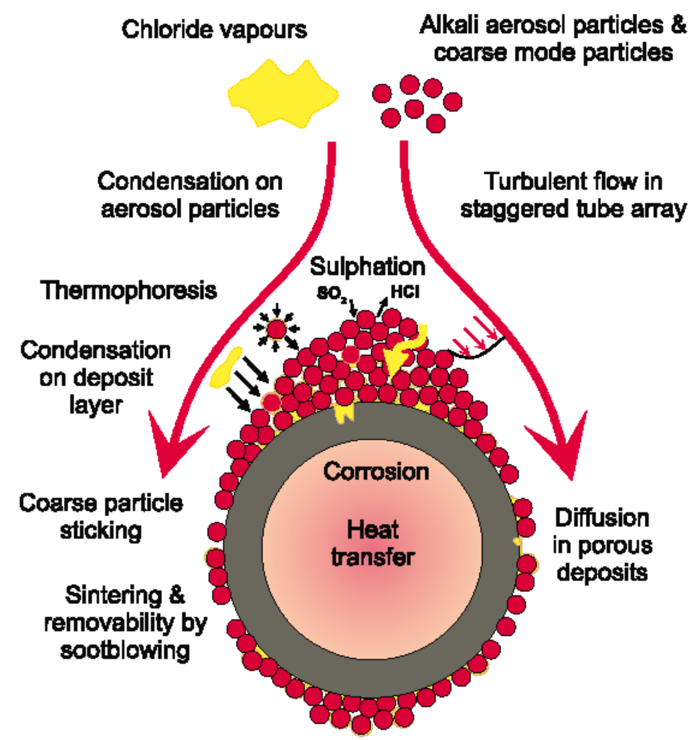
New mechanism extended from REI's current deposition mechanism, which tracks ash particle composition and size distribution

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:

- Chlorine attack
- H_2S gaseous attack
- FeS corrosion

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

- Development of Fundamental Data
- Development and Validation of Mechanisms
- **Firing System Principles**
- Assessment of Oxy-combustion Retrofit
- Program Funding and Schedule

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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- Development and Validation of Mechanisms
- Firing System Principles
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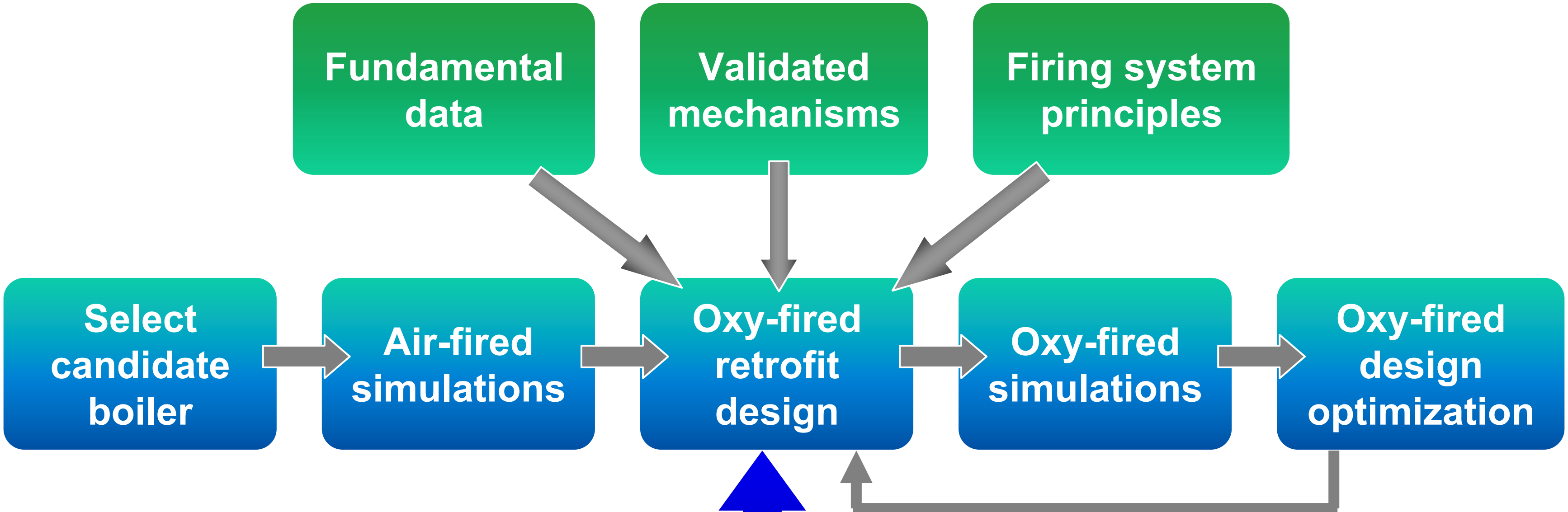
Assessment Approach



Design and optimization criteria:

- Match air-fired heat duties
- Maximize combustion efficiency
- Minimize surface impacts (corrosion, slagging, fouling)
- Minimize trace pollutant emissions

- Development of Fundamental Data
- Development and Validation of Mechanisms
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- **Program Funding and Schedule**

Program Funding

- **3-year program started 10/1/08 (10/1/08 – 9/30/11)**

Year	DOE Cost	FFRDC	Cost-Share	Total
1	$ 663,414	$ 50,000	$ 256,426	$ 969,840
2	$ 1,063,505	$ 50,000	$ 230,706	$ 1,344,211
3	$ 549,408	$ -	$ 130,750	$ 680,158
Total	$ 2,276,327	$ 100,000	$ 617,882	$ 2,994,209

Overall Program Cost-Share: 20.6%

Program Schedule

- Year 1 Key Tasks
  - Complete OFC ash characterization measurements without FGR
  - Complete baseline char oxidation experiments
  - Design and fabricate pilot-scale oxy-burner
  - Complete initial slagging and fouling mechanism development
- Year 2 Key Tasks
  - Complete OFC ash characterization measurements with FGR
  - Complete pilot-scale burner, slagging, fouling, corrosion testing
  - Finish char oxidation experiments and validate mechanism
  - Validate slagging, fouling, corrosion mechanisms
- Year 3 Key Tasks
  - Implement validated mechanisms into CFD code
  - Complete boiler retrofit assessment

Program Status

- OFC measurement equipment assembled and initial air-firing and oxy-firing testing started
- Pilot-scale oxy-burner preliminary design completed
- Char oxidation SKIPPY modeling started
- Data and mechanism review meeting with Vattenfall completed
- Development of slagging, fouling and corrosion mechanisms on-going

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