Characterization of Oxy-combustion Impacts in Existing Coal-fired Boilers (DE-NT0005288)

Bradley Adams, Andrew Fry

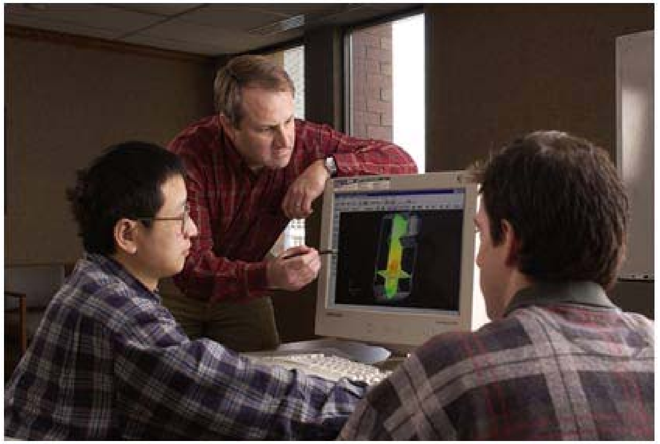
For Energy and Environmental Solutions

REACTION ENGINEERING INTERNATIONAL

77 West 200 South, Suite 210 Salt Lake City, UT 84101
TEL: +1 (801) 364-6925 FAX: +1 (801) 364-6977
http://www.reaction-eng.com

REI Profile

- **Energy And Environmental Consulting Firm**
  - Combustion System Design and Analysis
    - Combustion Performance, Emissions, Operational Impacts
  - Advanced CFD Simulations
  - Customized Process Software
  - R&D / Proof-of-Concept Testing
  - Specialized Test Equipment



- **Use Advanced Technology to Solve Industrial Challenges**

Oxy-Combustion Program Overview

- **Objective:** ***Characterize and predict performance and operational impacts of oxy-combustion retrofit designs on existing coal-fired boilers***
- **3-year program (10/1/08 – 9/30/11)**
- **Funding:**
  - **DOE Cost $2,276,327**
  - **FFRDC $100,000**
  - **Cost-Share $617,882**
  - **Total Program $2,994,209**

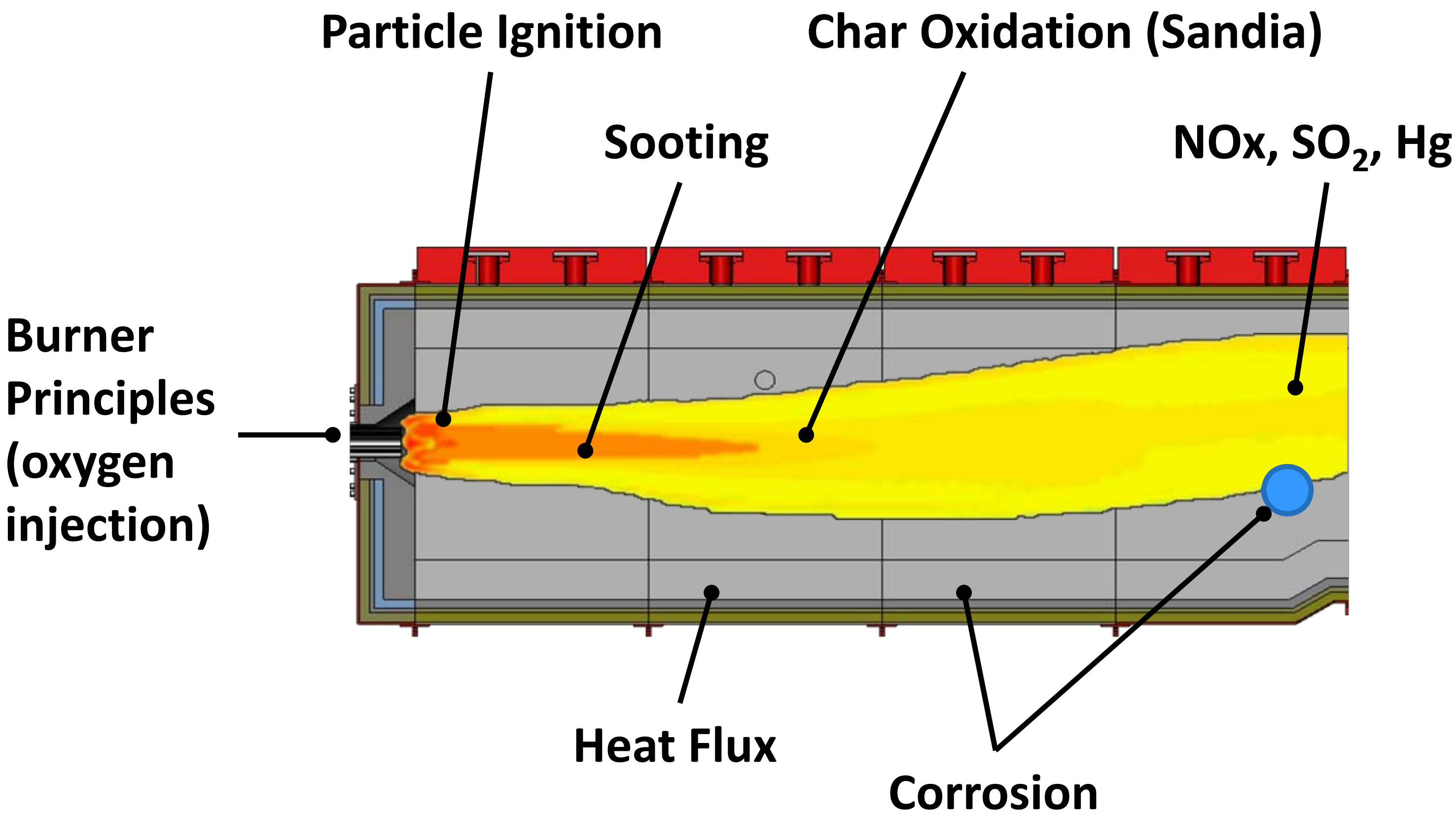
Project Approach

- **Utilize multi-scale testing and theory 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**
  - **Predict flame characteristics and surface impacts for different full-scale oxy-firing designs and FGR properties**

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***

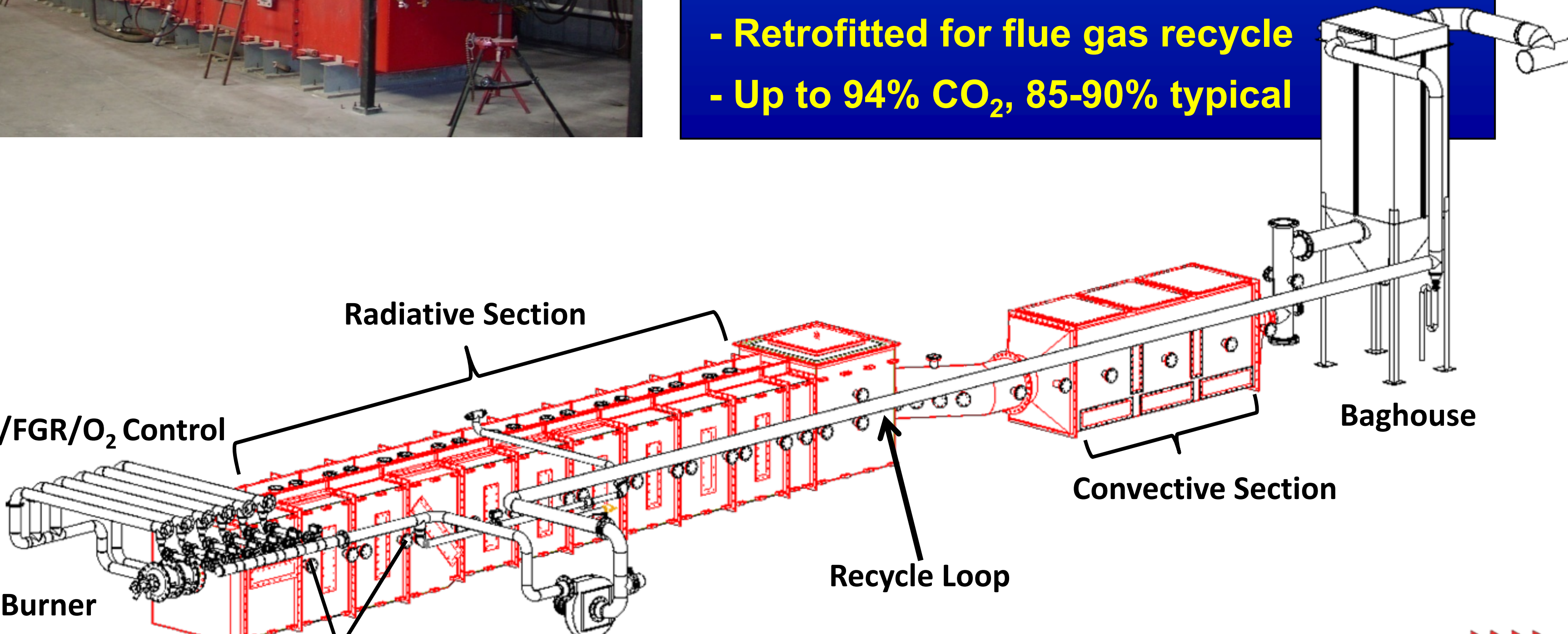
Year 2 Testing Focus



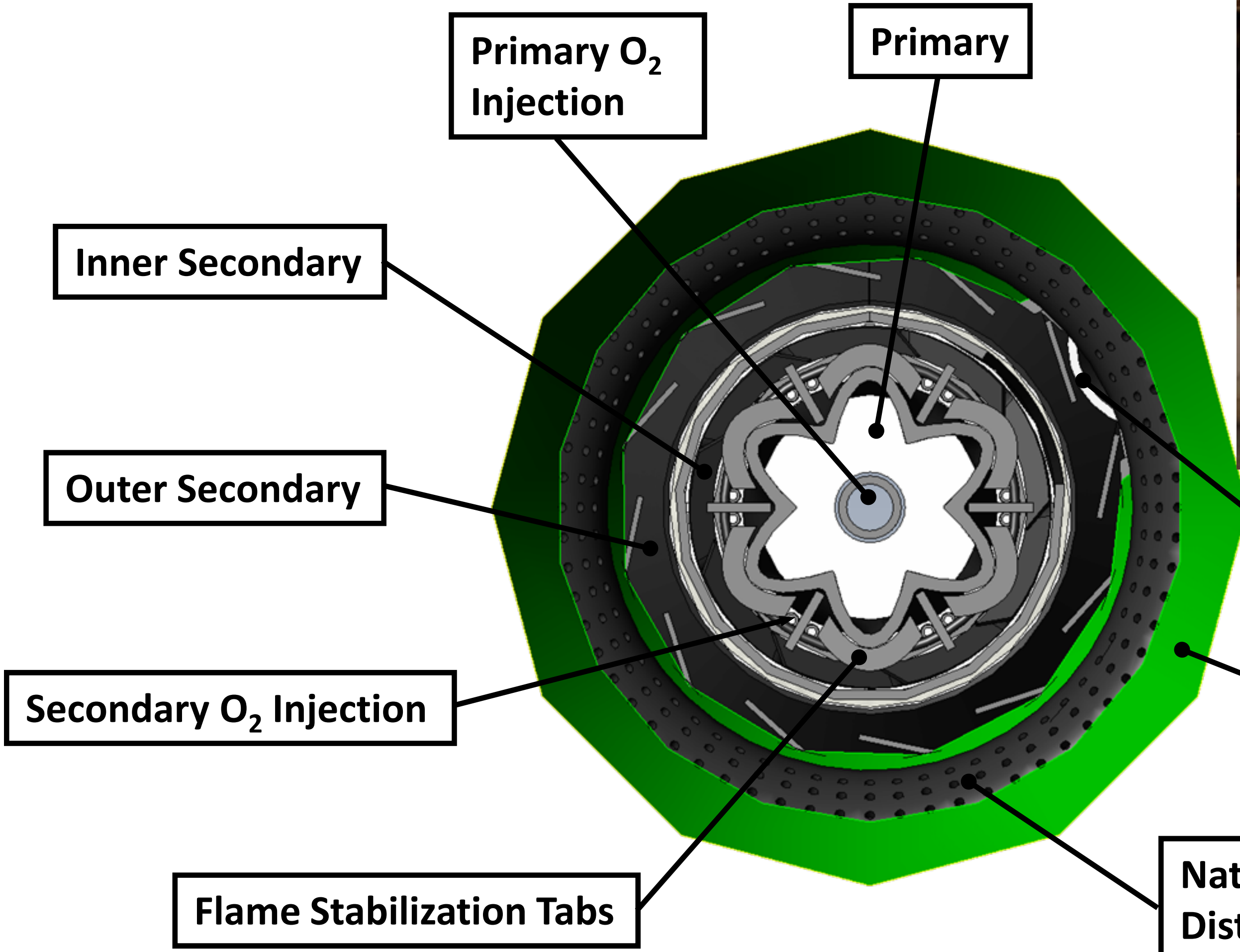
3.5 MBtu/hr Pilot-Scale Furnace (L1500)

L1500 Capabilities:

- Realistic Burner Turbulent Mixing Scale
- Realistic Radiative Heat Flux Conditions
- Realistic Time - Temperature Profiles
- Retrofitted for flue gas recycle
- Up to 94% CO_2, 85-90% typical



Oxy-Coal Research Burner Configuration



Burner Primary Questions

What primary retrofit conditions provide a stable flame?

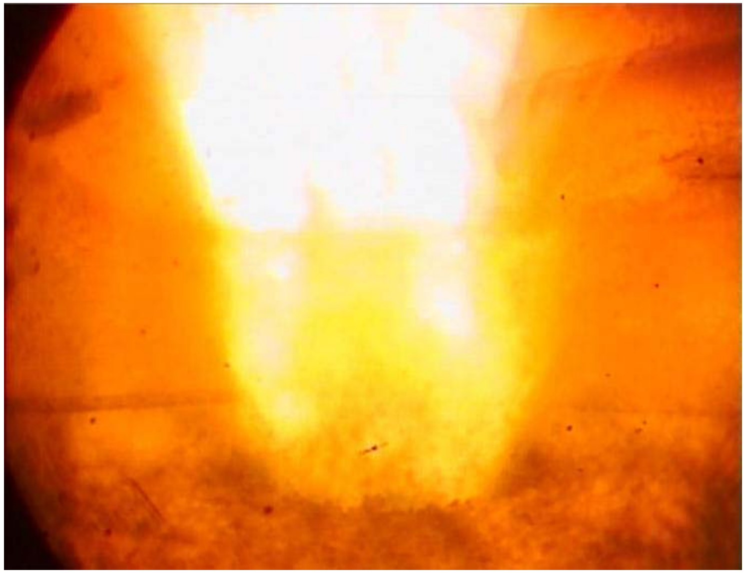
Match primary:
- Gas/fuel mass ratio?
- Momentum?
- Velocity?

Can we operate without O_2 enrichment of the primary?

Comparison of Air and Oxy Flames

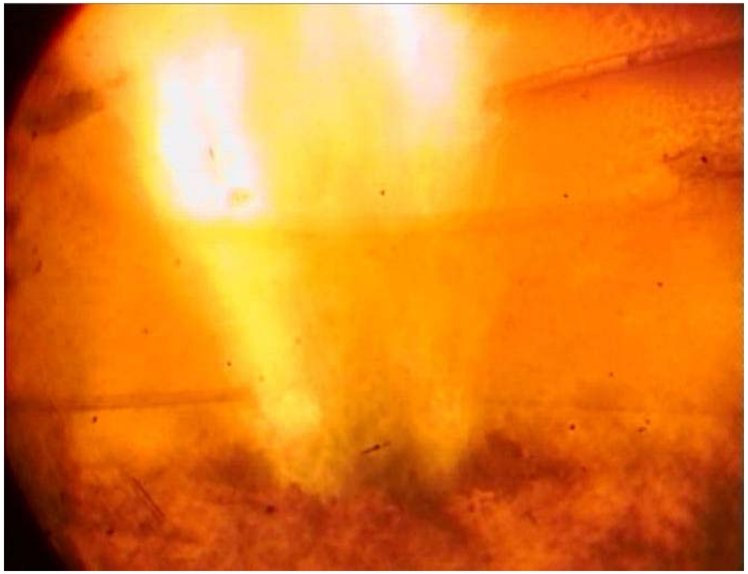
Air-Fired

BSR = 0.9
Air/Fuel = 1.8
IS/OS = 20/80



Oxy-Fired

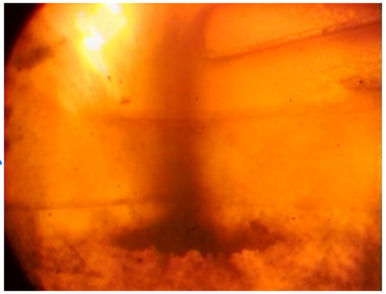
BSR = 0.9
Primary Gas/Fuel = 1.8
IS/OS = 20/80
Primary O_2 Conc. = 21%
Inner Secondary O_2 Conc. = 28.8%
Outer Secondary O_2 Conc. = 28.8%
Overall O_2 in O_2/FGR mixture = 27%



Burner Primary Retrofit Results

- Matching burner primary gas/fuel ratio or momentum ratio with air-fired operation produced a stable attached flame (good retrofit strategies)

- Matching primary velocity with air-fired operation did not provide a stable attached flame (may depend on burner flexibility)



- There is a fundamental difference in devolatilization rates and ignition between air and oxygen/FGR firing
- A stable flame can be achieved with no oxygen enrichment in the primary

Burner Oxygen Injection Questions

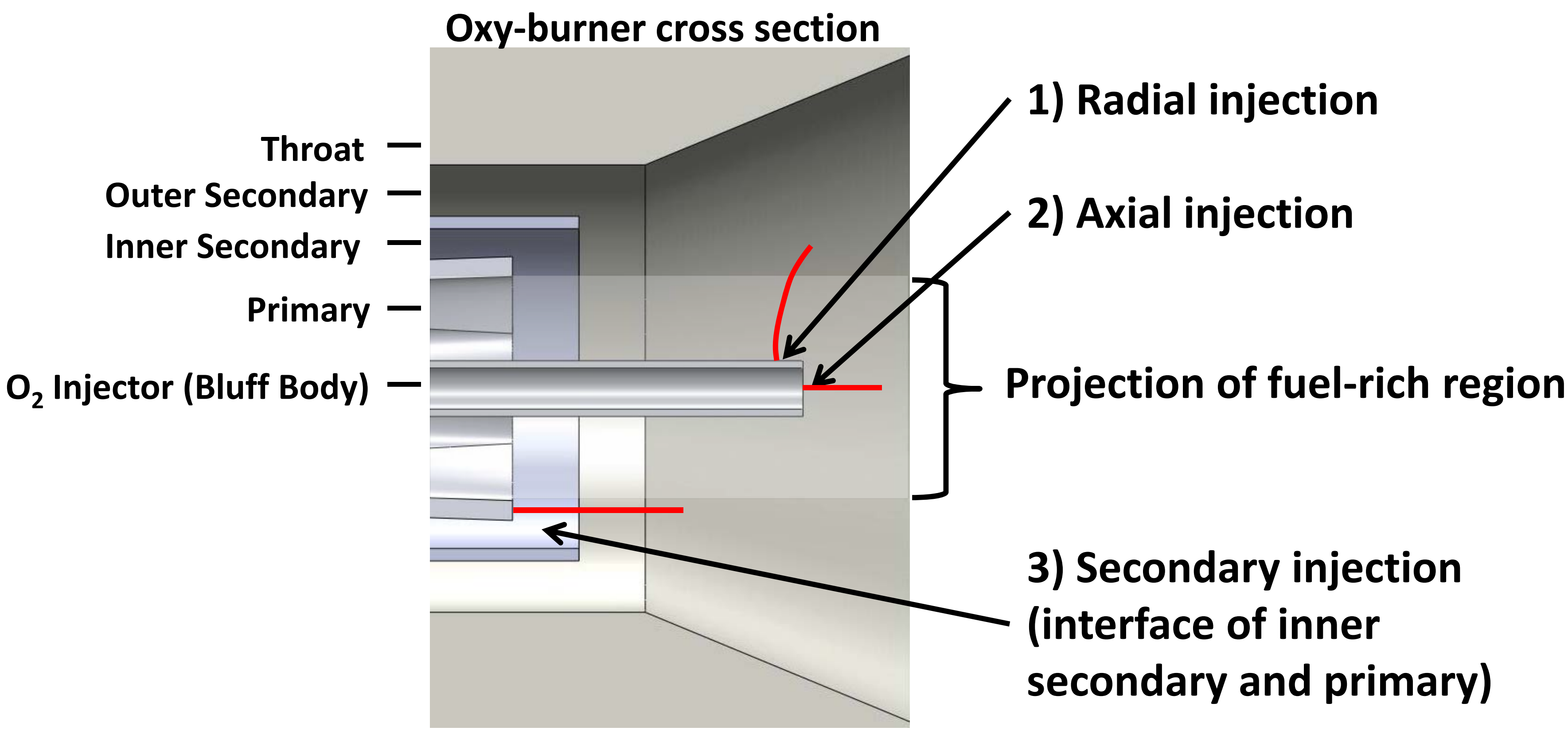
How can we use O_2 injection to simplify retrofit and improve flame stability?

Primary oxygen replacement?

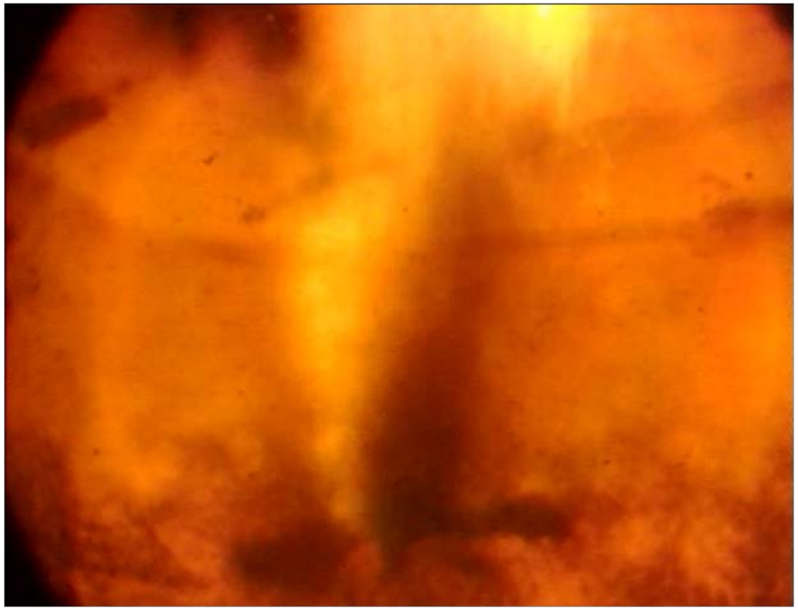
Injection in the burner primary or secondary?

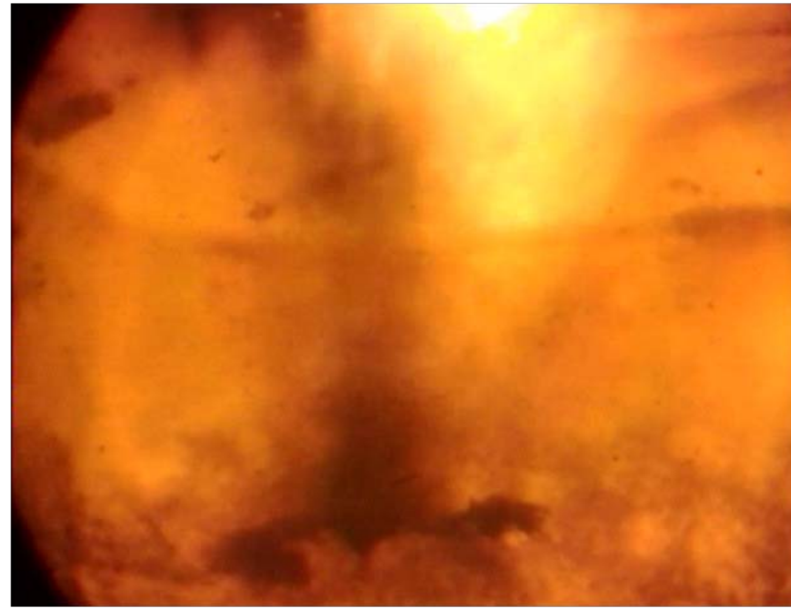
Oxygen Injection Configurations

- O_2 removed from the premixed primary and replaced by FGR to maintain gas/fuel ratio

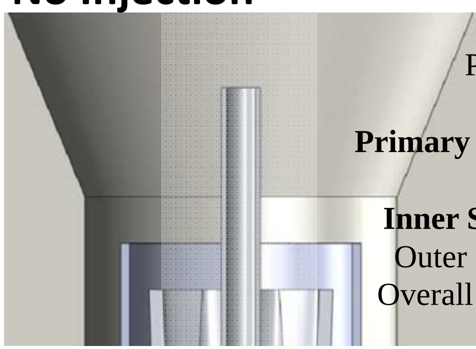


Primary O_2 Replacement (Axial Injection)



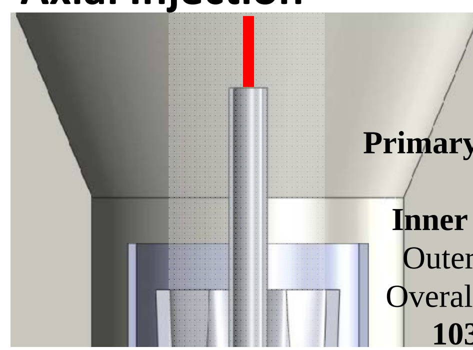


No Injection



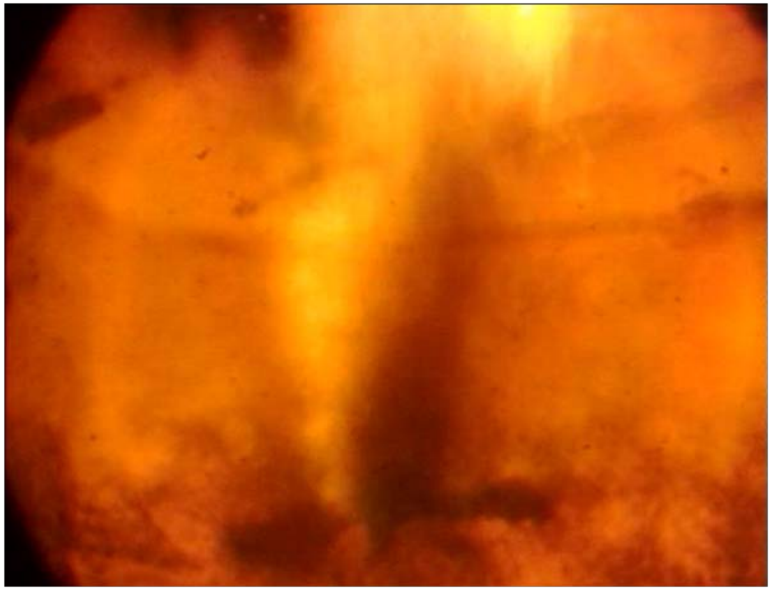
BSR = 0.9
Primary Gas/Fuel = 2.08
IS/OS = 20/80
Primary O_2 Conc. = 21.4% (Premixed)
Primary SR = 0.188
Inner Secondary O_2 Conc. = 29.8%
Outer Secondary O_2 Conc. = 29.2%
Overall O_2 in O_2/FGR mixture = 27%

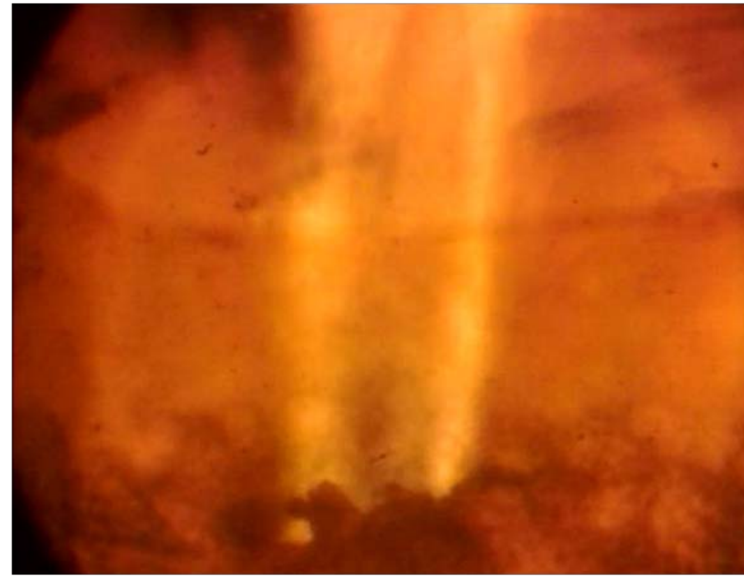
Axial Injection



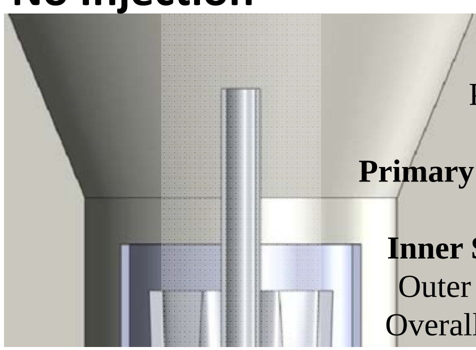
BSR = 0.9
Primary Gas/Fuel = 2.05
IS/OS = 20/80
Primary O_2 Conc. = 2.46% (Premixed)
Primary SR = 0.018
Inner Secondary O_2 Conc. = 38.1%
Outer Secondary O_2 Conc. = 29.5%
Overall O_2 in O_2/FGR mixture = 27%
103 lb/hr O_2 (Axial Injection)

Primary O_2 Replacement (Sec. Injection)



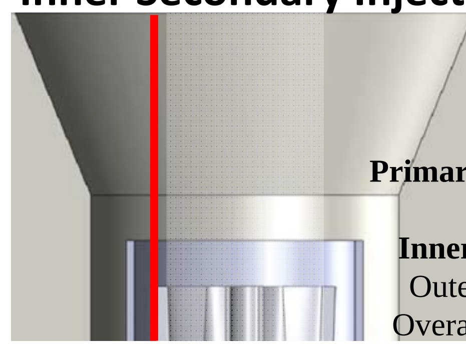


No Injection



BSR = 0.9
Primary Gas/Fuel = 2.04
IS/OS = 20/80
Primary O_2 Conc. = 20.9% (Premixed)
Primary SR = 0.180
Inner Secondary O_2 Conc. = 29.5%
Outer Secondary O_2 Conc. = 29.1%
Overall O_2 in O_2/FGR mixture = 27%

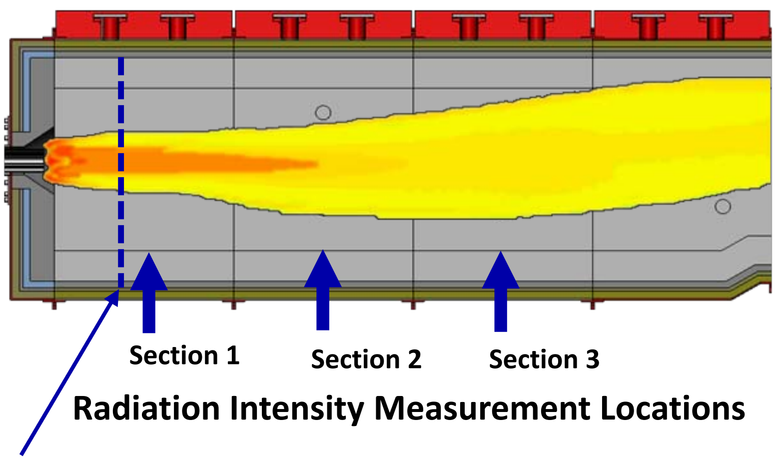
Inner Secondary Injection



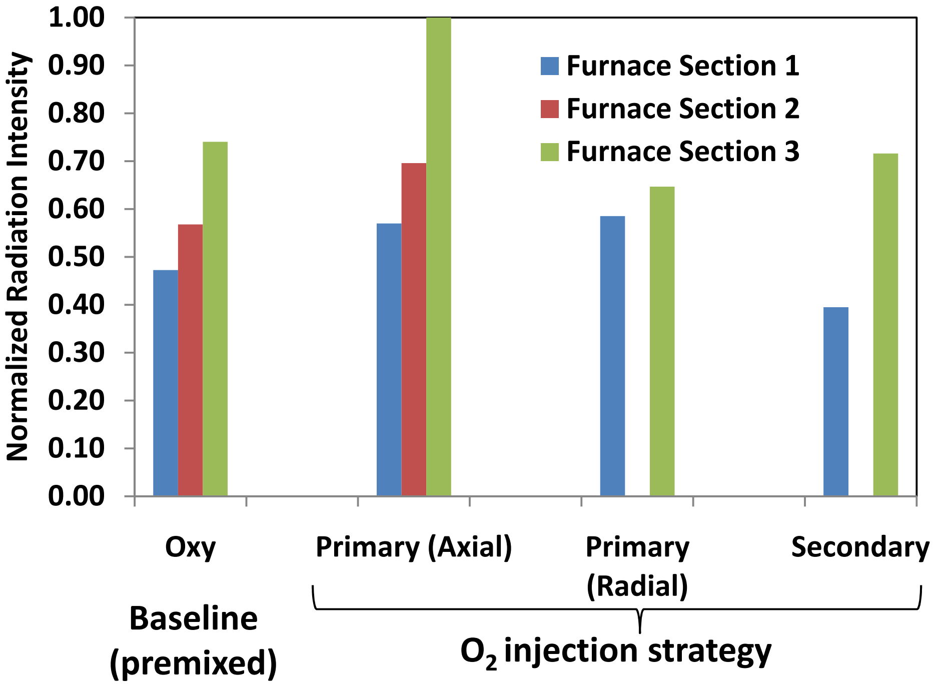
BSR = 0.9
Primary Gas/Fuel = 2.06
IS/OS = 20/80
Primary O_2 Conc. = 2.62% (Premixed)
Primary SR = 0.022
Inner Secondary O_2 Conc. = 40.6%
Outer Secondary O_2 Conc. = 29.4%
Overall O_2 in O_2/FGR mixture = 27%
100 lb/hr O_2 (Secondary Injection)

O_2 Injection Radiation Intensity

Side Cross-Section of Furnace



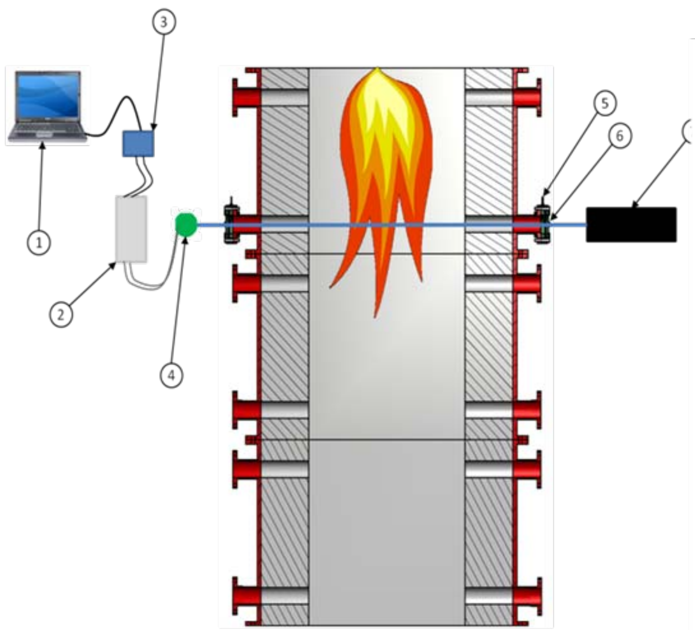
Radiation Intensity Measurement Locations

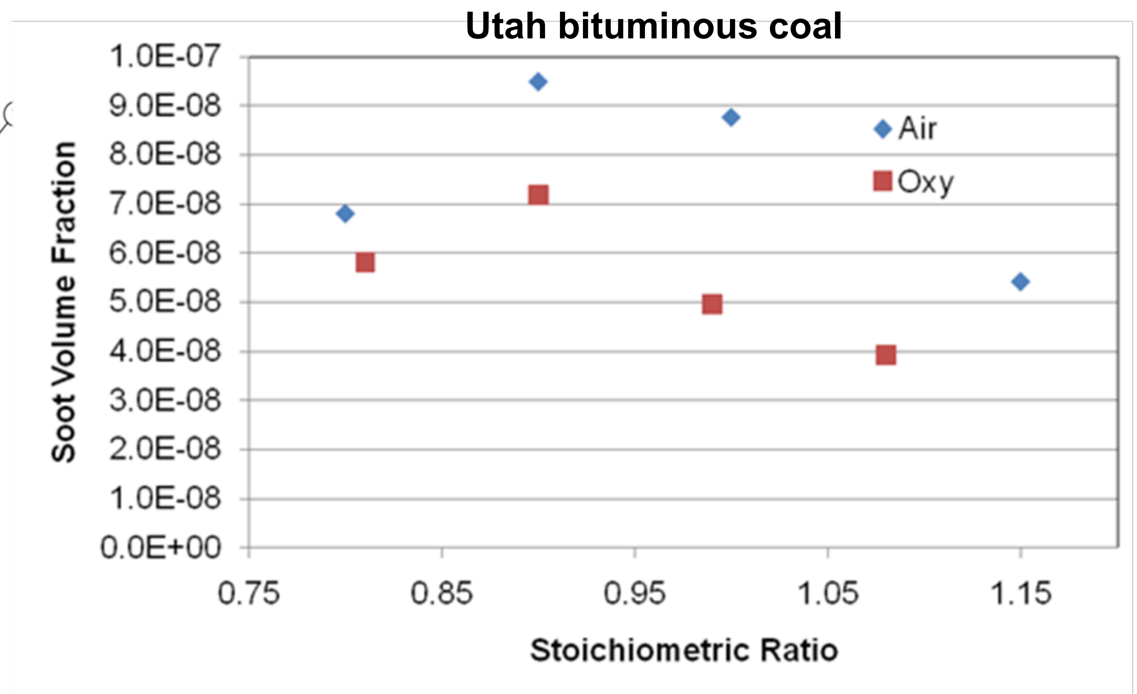


Oxygen Injection Conclusions

- Targeted oxygen injection at the burner primary-inner secondary boundary produced the most effective flame stabilization and ignition
  - Axial injection produced a permanently detached flame
  - Radial injection produced a wider flame, but did not improve flame attachment
- Axial injection in the primary produced a more intensely radiating flame downstream of burner
- For maximum pre-mixed primary O_2, adding small amounts of oxygen enrichment radially through the bluff body did not improve flame attachment

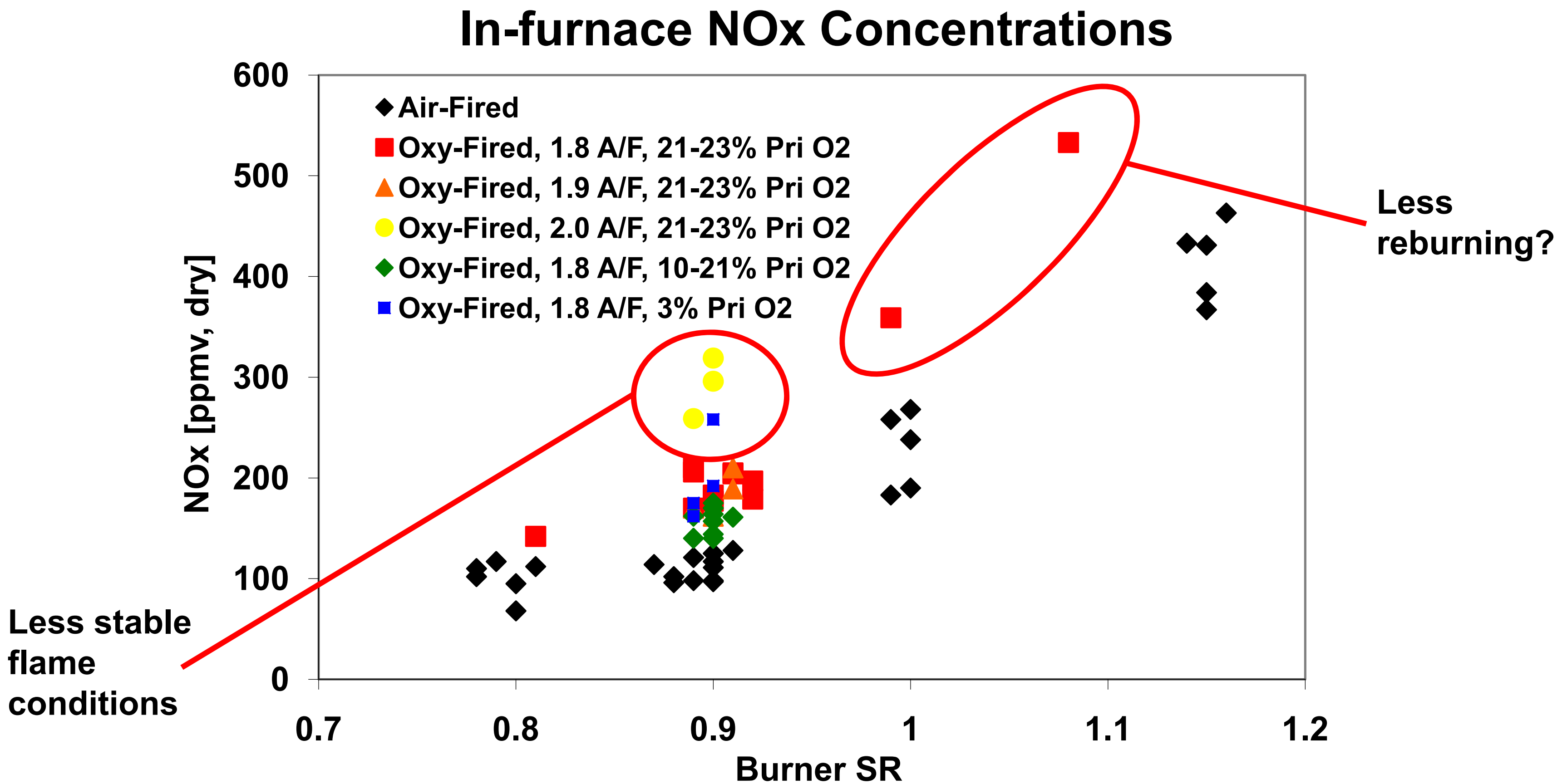
Soot Measurements



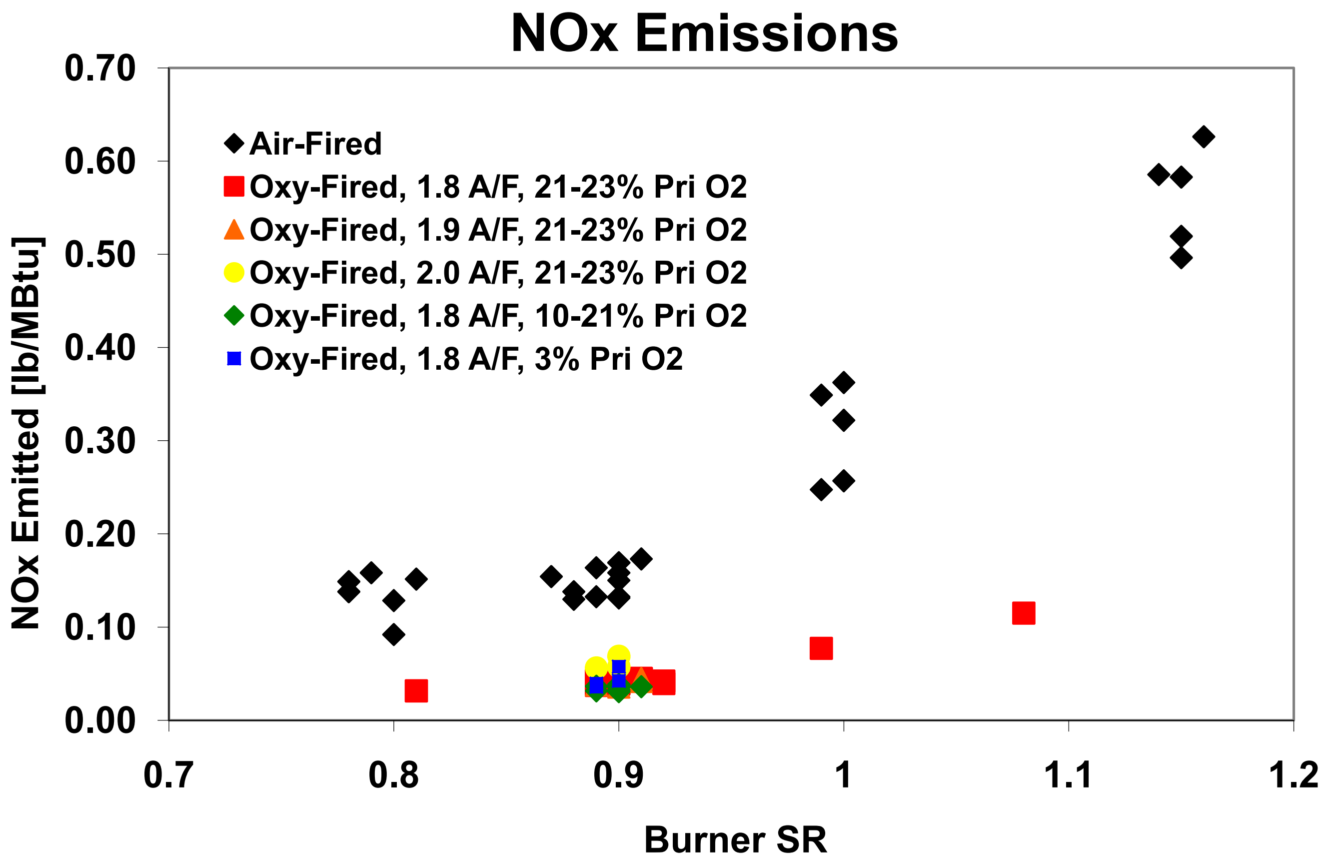


- **Soot volume fraction ~40% lower for oxy-fired cases than air-fired cases for the Utah coal, and 10-20% lower for PRB coal**
- **Only one flame measurement location**

Impact of Staging on NO_x Concentration



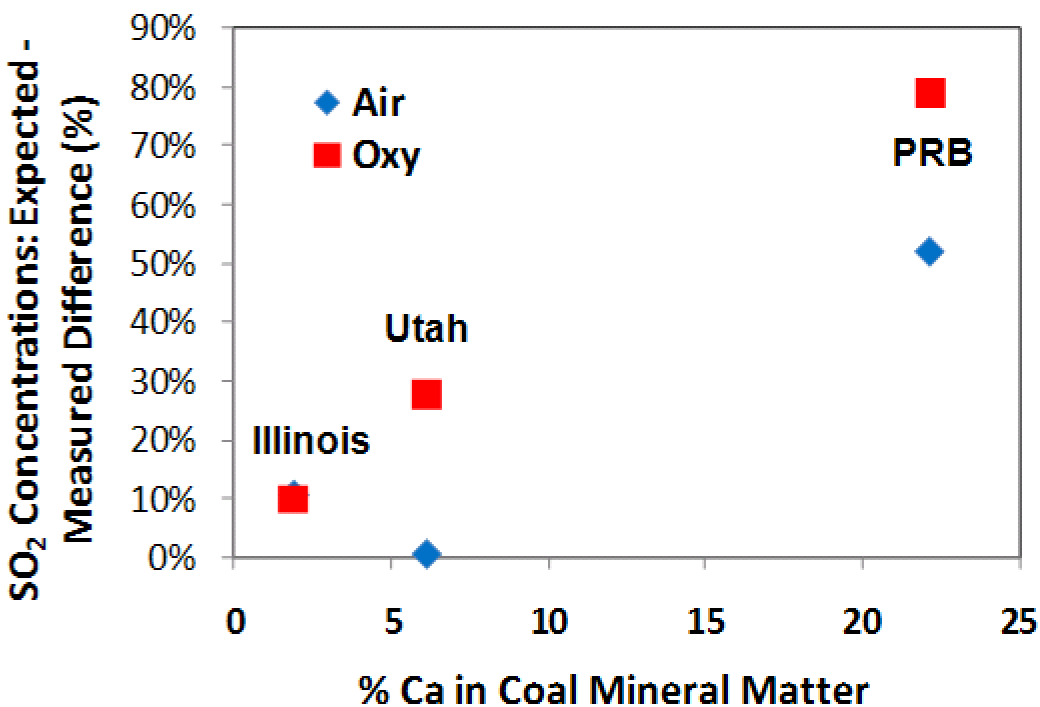
Impact of Staging on NO_x Emissions



- NOx *emissions* up to 75% lower with oxy-firing; *concentrations* similar with staging, higher without

Impact of Calcium on SO_2 Capture

Coal	Firing Condition	Measured Ave SO_2 Conc, ppmv
PRB	Air	128
PRB	Oxy	289
Skyline	Air	445
Skyline	Oxy	1,737
Illinois	Air	3,219
Illinois	Oxy	17,642



Capture correlates with calcium content

Where does capture occur?

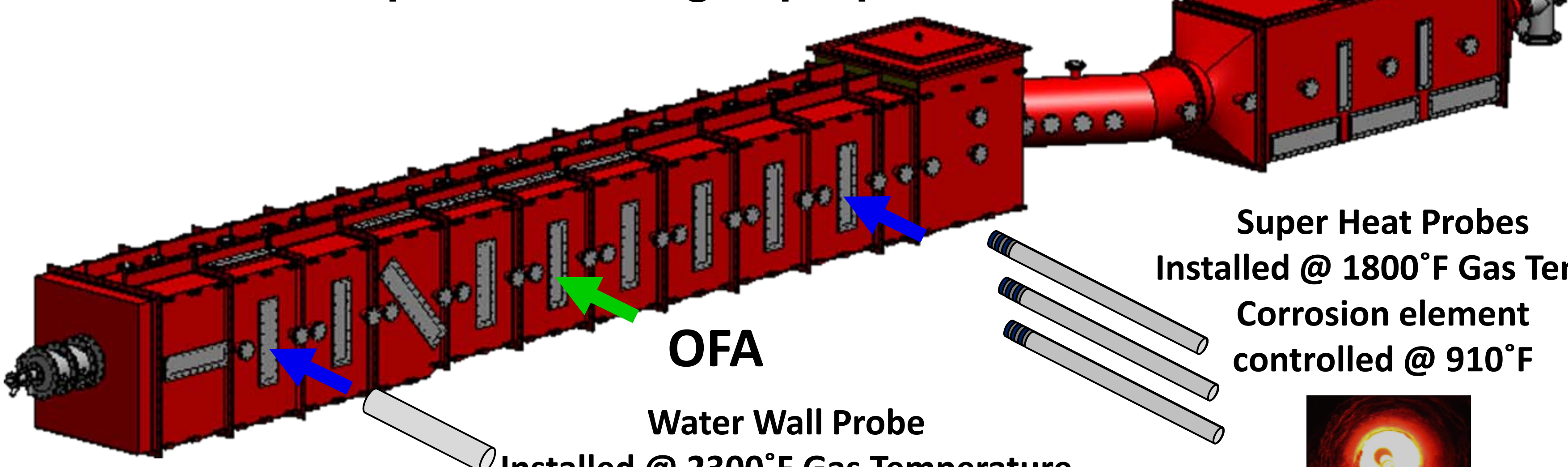
- **Fly-ash in flight?**
- **Baghouse filter cake?**
- **Condensation?**

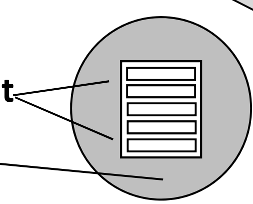
Mercury Measurements

- Short-term Hg measurements made on OFC and L1500 firing Utah bituminous coal
- OFC
  - Hg mass balance closed well (no recycle)
  - Hg removal (~70%) and oxidation (~55%) similar for air and oxy-firing
- L1500
  - Hg mass balance did not close well (with recycle)
  - Possibly due to surface-based Hg sink in recycle loop

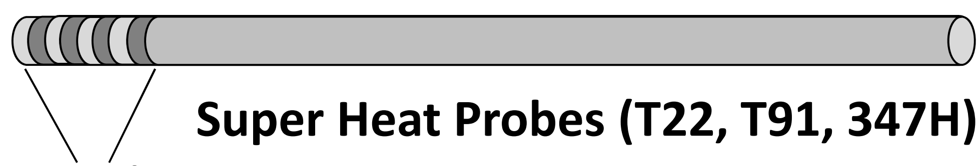
Corrosion Testing

- "Typical" boiler tube corrosion materials
- Tested 3 coals, staged & unstaged, air and oxy-firing
- Real-time corrosion rates with simultaneous measurement of heat flux, deposition and gas properties





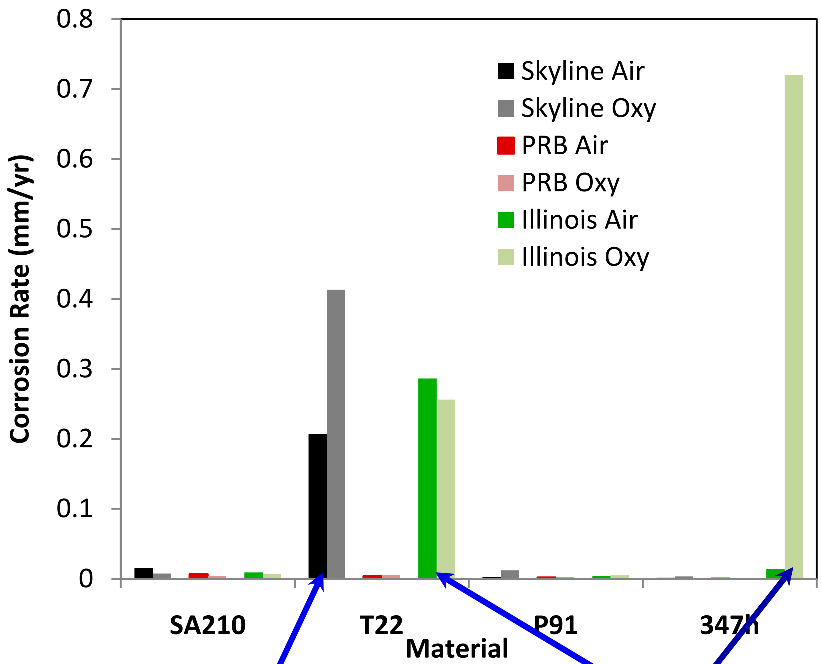
Water Wall Probe (SA210)

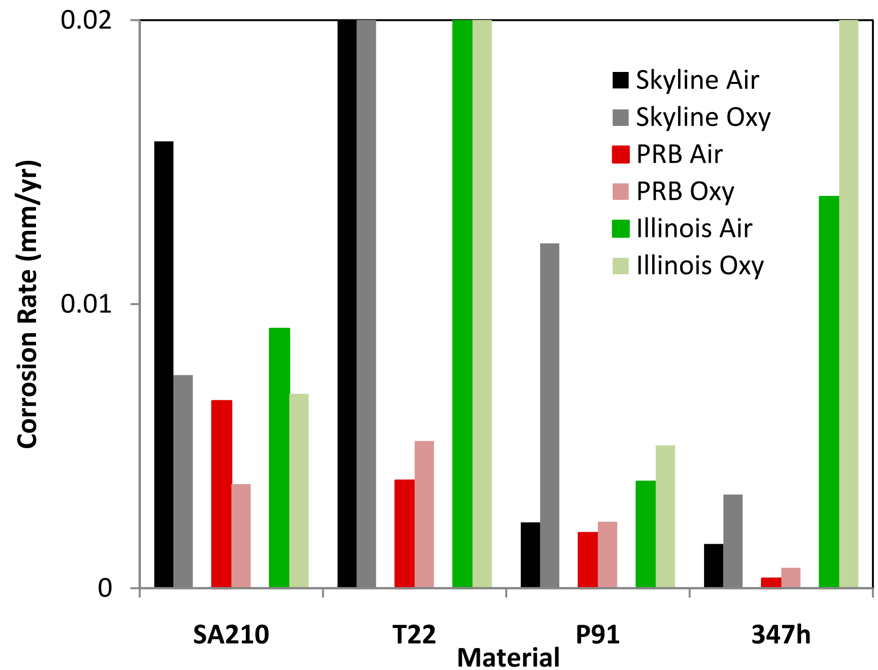


Super Heat Probes (T22, T91, 347H)

Reaction Engineering International

Average Corrosion Rates



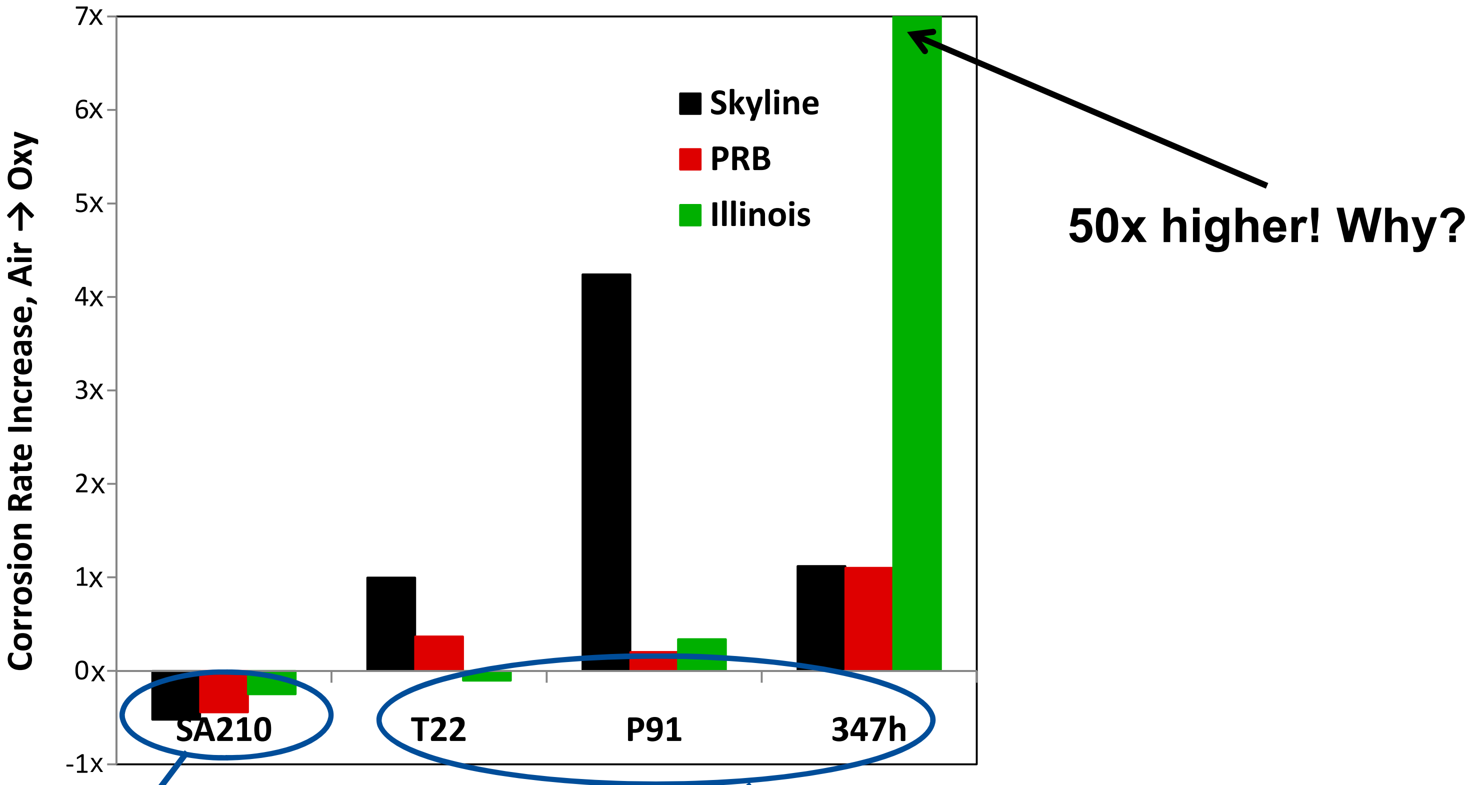


High corrosion rates for high SO_2 conditions (3,000 – 17,000 ppmv)

All other corrosion rates very low

High corrosion rates for low- alloy T22 with Utah and Illinois coals

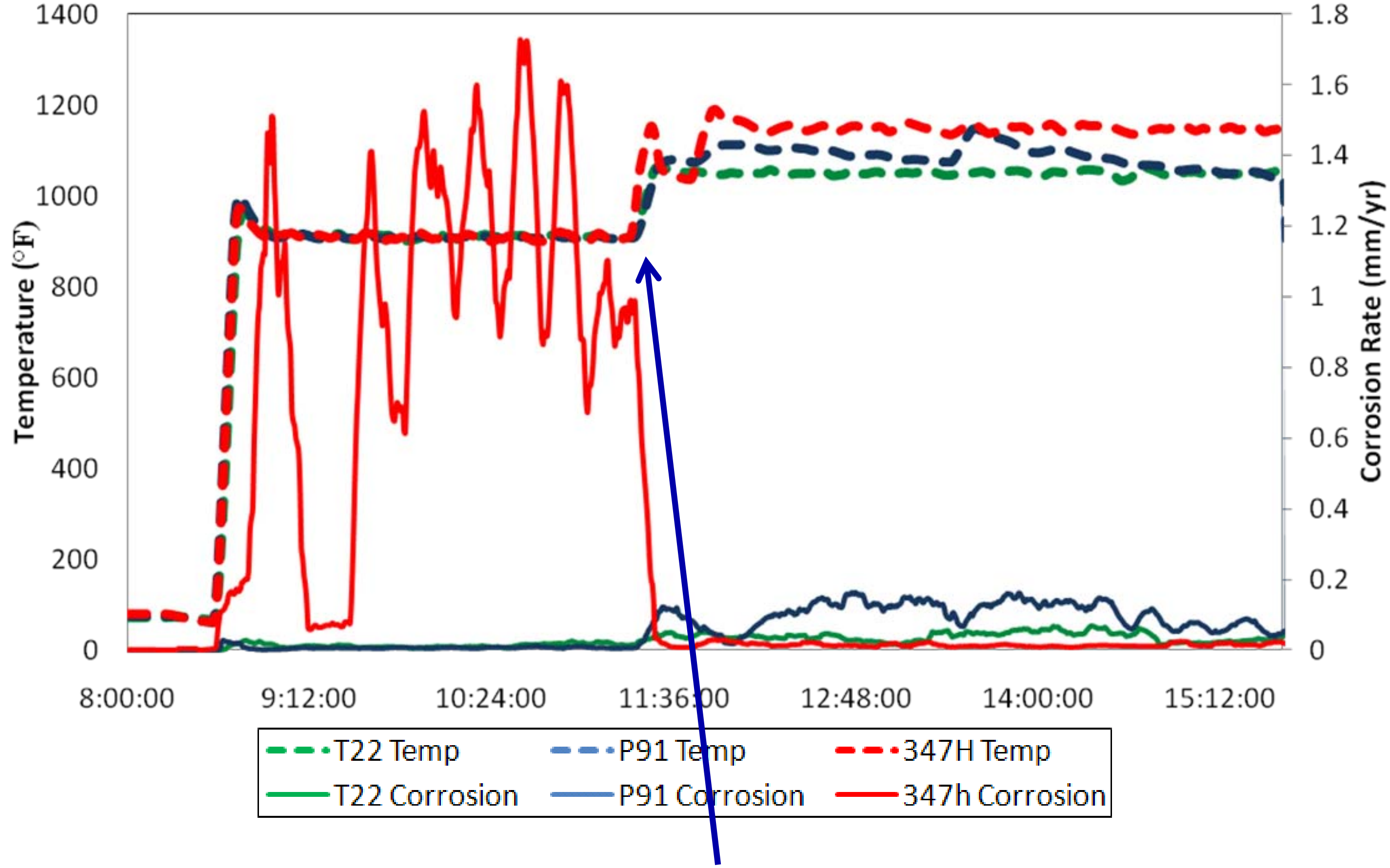
Increase in Corrosion Rate Air → Oxy



Waterwall Probe - corrosion decreases moving from air to oxy combustion

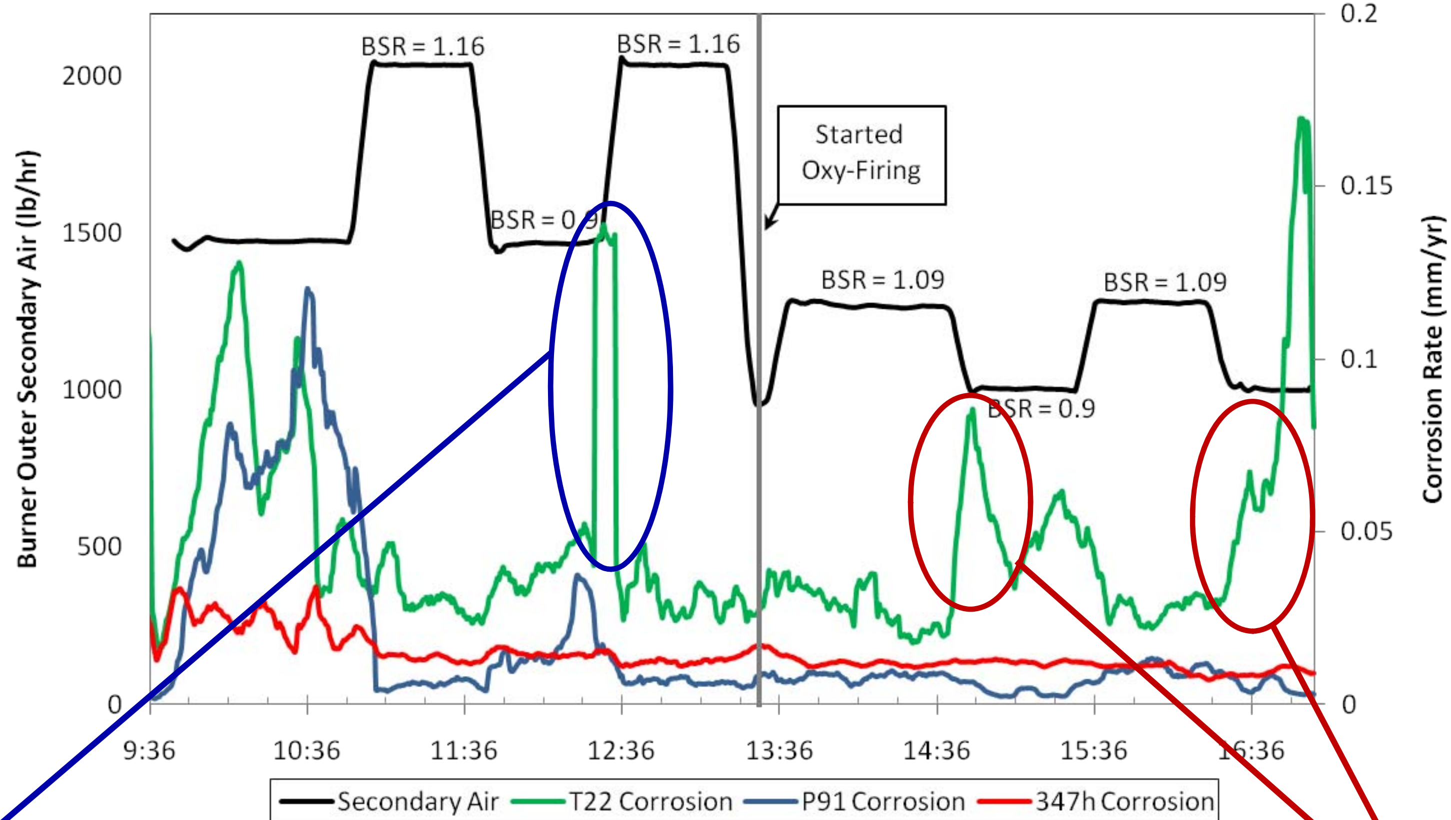
Superheat Probes – corrosion increases going from air to oxy combustion

Temperature Effects on Corrosion



Likely due to trisulphate formation at lower temperatures and high SO_2 concentration (Illinois coal)

Effect of Stoichiometric Ratio



(Air) T22 corrosion rate spikes when going from reducing to oxidizing

T22 rate spikes when going from oxidizing to reducing (Oxy)

Corrosion Testing Conclusions

- Waterwall (SA210) corrosion rates decreased when converting from air to oxy-firing for all coals
- Superheater (T22, P91 and 347H) rates generally increased when converting from air- to oxy-firing
- 347H corrosion rates increased dramatically for SO_2 > ~3,000 ppm and T_{probe} < ~1150 °F
- Corrosion for lower alloyed materials (T22, SA210) increased when changing between oxidizing-reducing
  - Likely to contribute to in-plant corrosion in near-burner and near-OFA port regions
  - Transient effects cannot be resolved using coupon tests

Future Work

- **Year 3 Key Tasks**
  - Continue ash characterization and soot tests
  - Reduce and report data from Year 2 and Year 3 tests
  - Validate and refine mechanisms (char oxidation, soot, slagging, fouling, corrosion); implement in CFD code
  - Design conceptual commercial-scale retrofit firing system
  - Assess oxy-combustion retrofit impacts on existing boiler

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