Fuel Effects on NOx Control

2006 NOx Round Table

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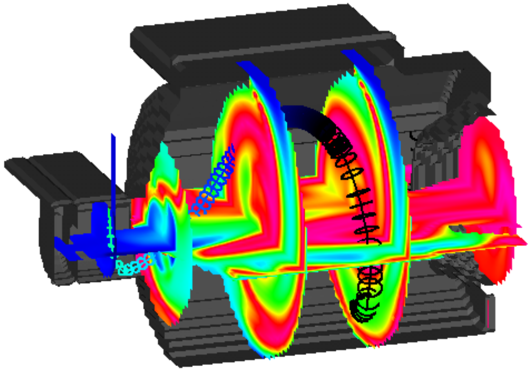
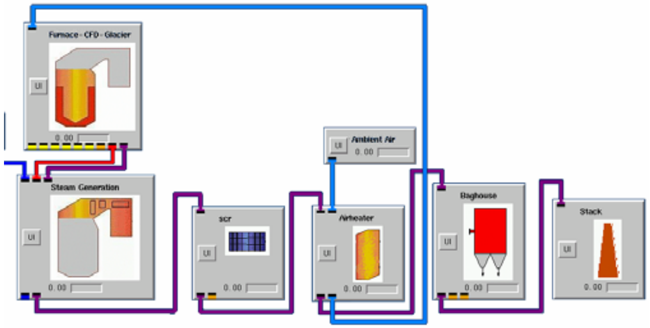
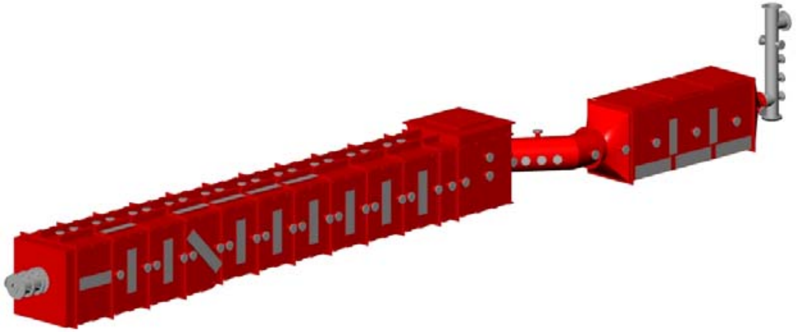
Introduction to REI



- Simulations for Utility/Industrial Applications
  - Performance, emissions, operational impacts
- Customized Software
  - Simplified unit-specific CFD tools, advanced process simulation software, chemical kinetic software
- Specialized Equipment
  - Development and evaluation of equipment and instrumentation concepts
- Proof-of-Concept Testing
  - Access to a unique collection of lab and pilot-scale facilities at the University of Utah





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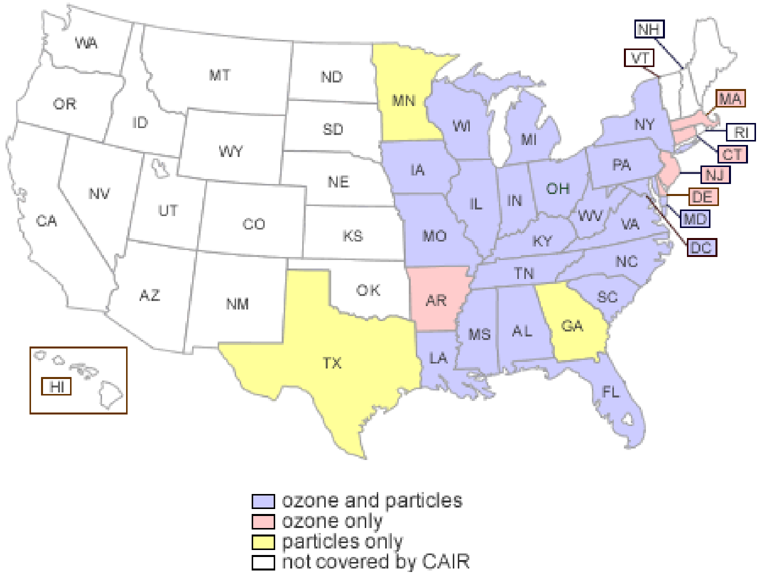
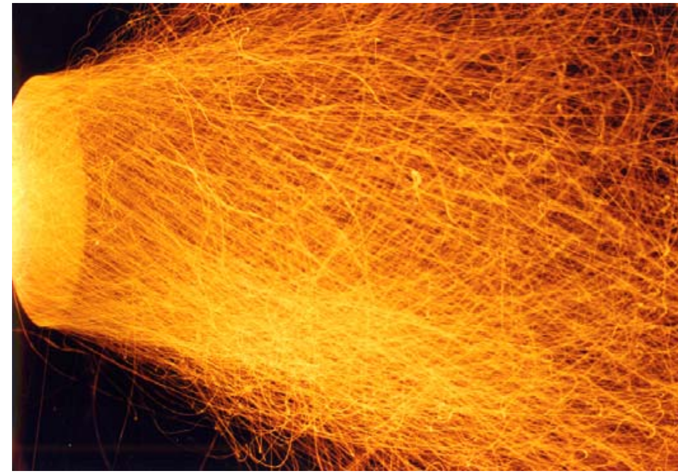
Recent Utility NOx Regulations

- **CAIR**
  - permanent, year-round cap in 28 states and DC
  - implemented through SIPs
  - 0.15 lbs/MMBtu by 2010 and 0.125 lbs/MMBtu by 2015
- **Regional Haze**
  - new driver for non-CAIR (western) plants in regions near 156 national parks/wilderness areas
  - implemented through SIPs, due on or before end of 2008
  - BART compliance within five years of SIP



Fuel Selection Issues

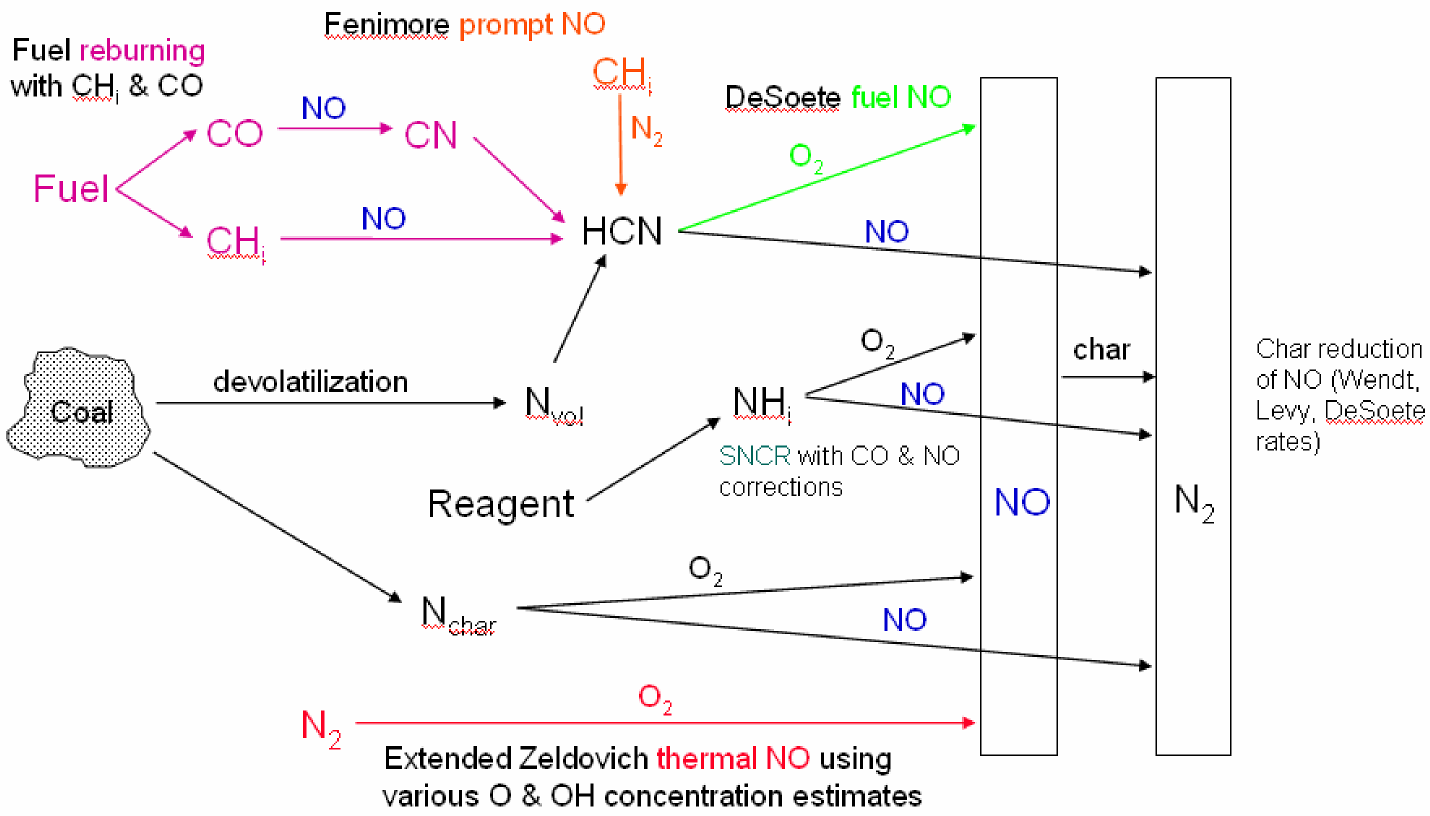
- Regulatory pressures
- Equipment compatibility
- Asian demand for low sulfur compliance coals
- Mine/seam or transportation availability
- Emphasis on renewable fuels



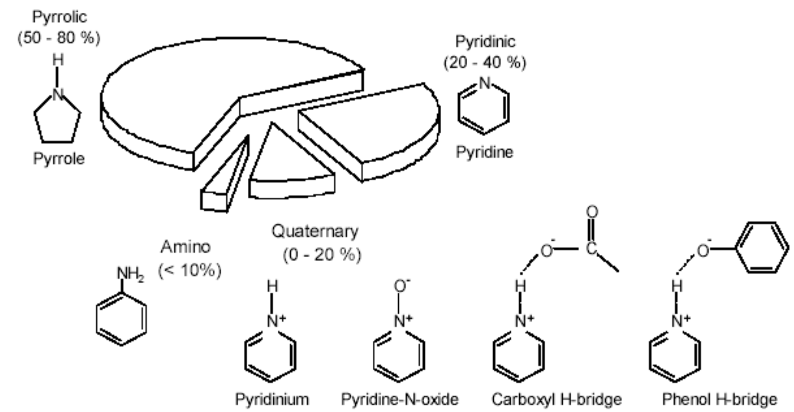
- Coal – anthracite, bituminous coal, subbituminous coal, lignite, blends
- Opportunity fuels – petcoke, woodwaste, agricultural residues, TDF, RDF
- Specialty fuels – synfuel, micronized coal

NOx Fundamentals

- *Fuel NOx*
- *Thermal NOx*
- *Prompt NOx*

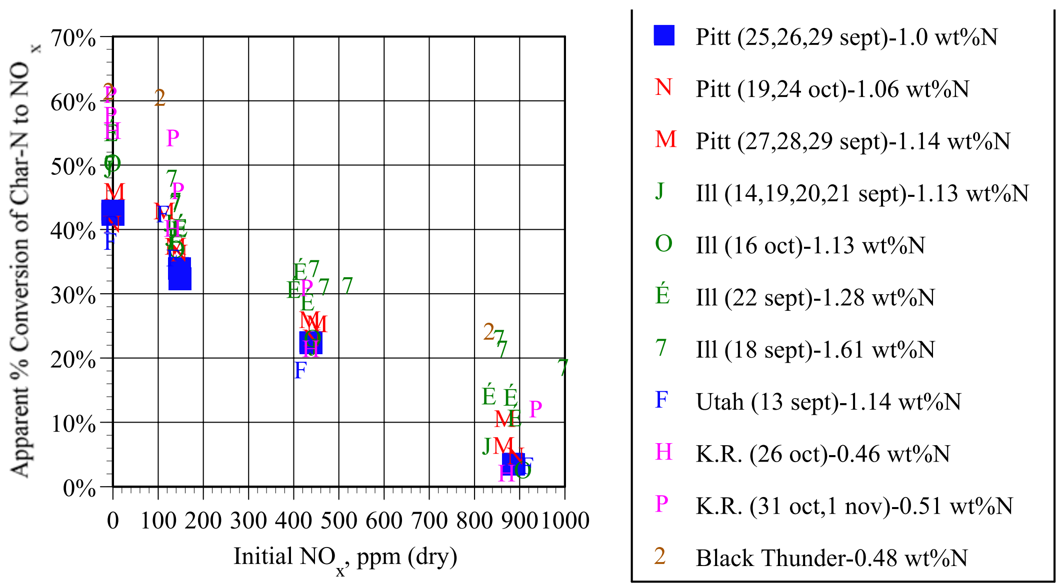


Fuel NOx



Molina, PhD Thesis (2002)

- **Fuel NOx from pyrolysis**
  - **Fuel nitrogen content**
  - **Pyrolysis yield (coal rank)**
  - **Preferential nitrogen release**



- **Fuel NOx from char oxidation**
  - **Char yield**
  - **NOx in gas-phase**

In-furnace NOx Control Technologies

- **Air Staging (low NOx burners, over-fire air, biasing)**
- **Fuel Switching and additives (nitrogen content, volatility, preferential nitrogen release)**
- **Fuel Staging (reburn, lower fire incremental respacing)**
- **Amine Injection (SNCR, Rich Reagent Injection)**
- **Tempering (flue gas recirculation, water/steam injection, air preheat reduction)**
- **Combustion Control/Optimization**
  - **monitoring of coal flow, air flow, emissions, flame stability, carbon-in-flyash, corrosion**
  - **simple or advanced control schemes**
- **Oxygen (targeted injection, nitrogen elimination & CO_2 recycle)**
- **Technology Hybrids and Layering**
- **Multi-pollutant Developments**

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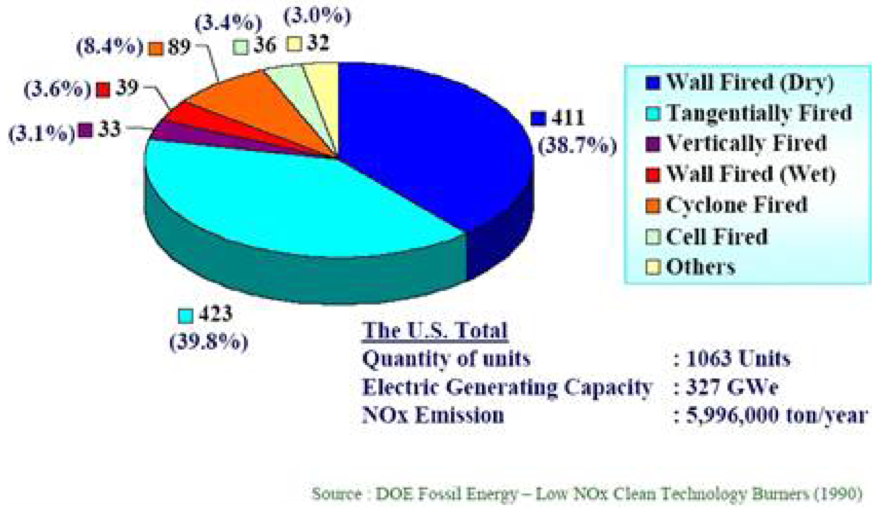
Low-NOx Burners and Over-fire Air

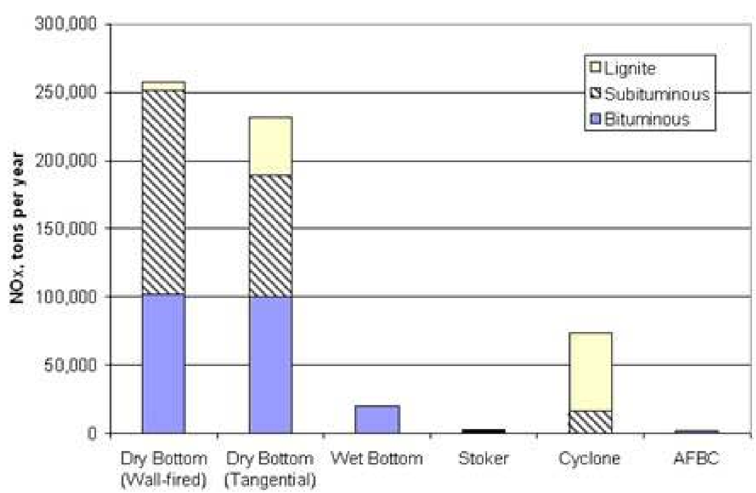
Boiler Type[a]	Coal Type	Primary Control Technology	1995 Average Baseline NO_x Emission ($lb/10^6$ Btu)	2003 Average Controlled NO_x Emission ($lb/10^6$ Btu)	Average NO_x Reduction Efficiency (%)	Range of NO_x Reduction Efficiencies (%)	No. of Boilers
Wall-fired	Bituminous	LNB	0.71	0.41	39.2	8.6–70.1	62
Wall-fired	Bituminous	LNBO	0.81	0.35	53.3	32.7–71.9	16
Wall-fired	Subbituminous	LNB	0.59	0.28	45.5	19.4–80.3	16
Wall-fired	Subbituminous	LNBO	0.41	0.14	63.4	40.0–80.9	4
Tangential-fired	Bituminous	LNC1	0.62	0.39	35.0	17.2–65.4	26
Tangential-fired	Bituminous	LNC2	0.48	0.31	36.6	23.3–70.8	15
Tangential-fired	Bituminous	LNC3	0.56	0.25	54.9	38.1–72.2	19
Tangential-fired	Subbituminous	LNC1	0.38	0.21	45.4	11.3–74.4	18
Tangential-fired	Subbituminous	LNC2	0.43	0.23	45.6	33.9–65.4	3
Tangential-fired	Subbituminous	LNC3	0.35	0.14	60.5	48.2–77.2	23

Notes: LNB = low-NO_x burner; LNBO = LNB with OFA; LNC1 = LNB with close-coupled OFA; LNC2 = LNB with separated OFA; and LNC3 = LNB with both close-coupled and separated OFA. [a]All boilers are dry-bottom type.

Srivastava et al., JAWMA (2005)

Firing Configurations and NOx Emissions





WRAP, 1996

- ➔ Wall- and corner-fired units dominate US coal-fired generation
- ➔ Cyclone-fired units are also important due to their relatively high NOx production
- ➔ Control technology selection can be firing system dependent

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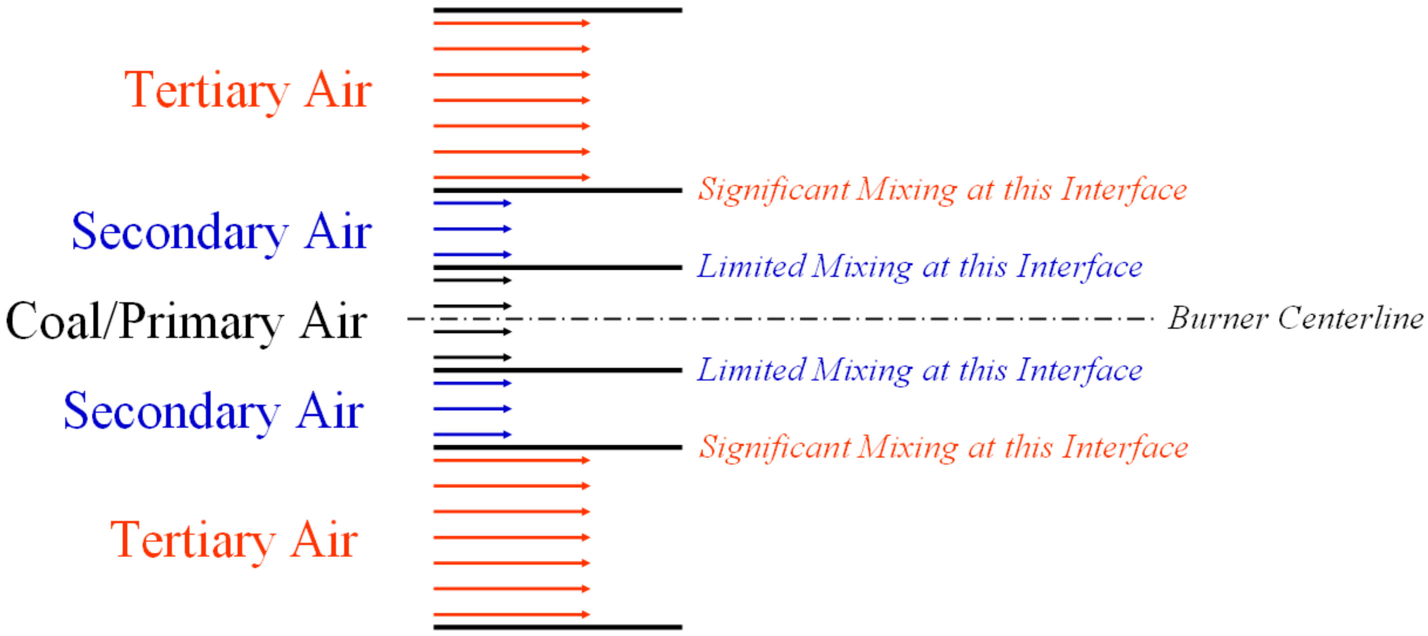
Early Low NOx Burner Approach



- **Minimize fuel transport air**
- **Secondary air stream delays mixing of air with fuel**
- **Peak flame temperatures and available oxygen in the flame can be reduced**
- **Practice and theory often at odds due to equipment limitations and simplistic view**

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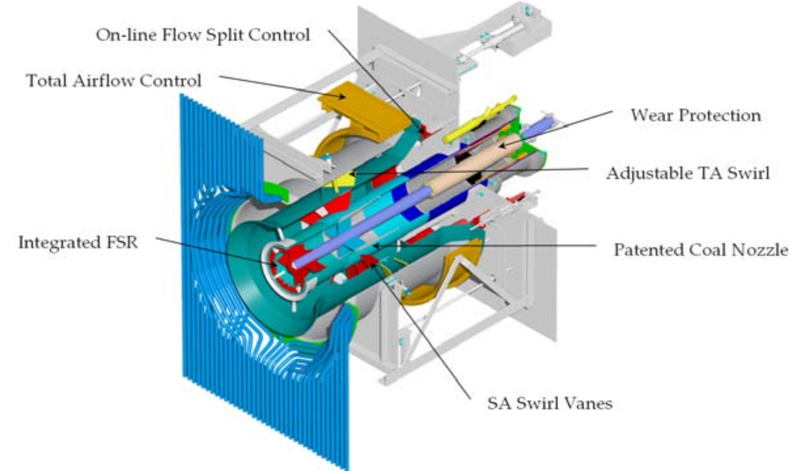
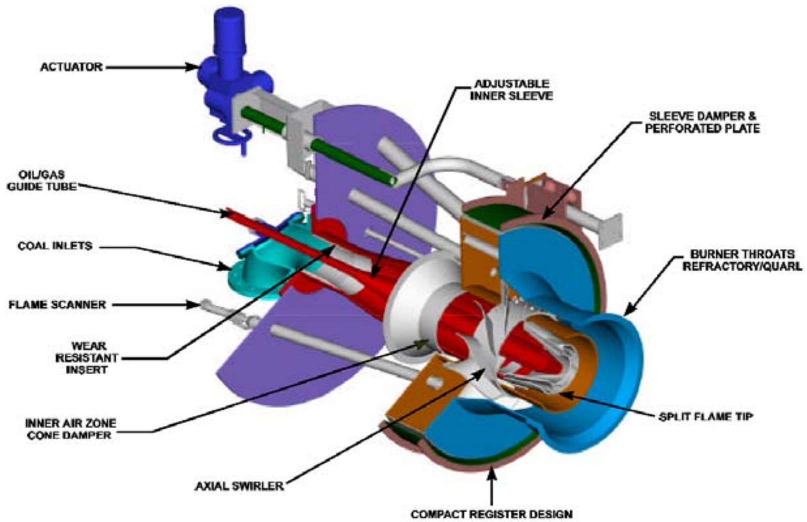
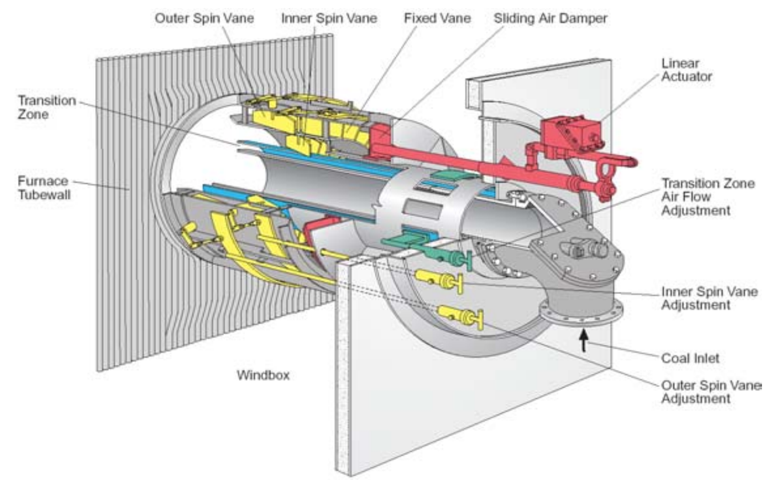
Advanced Low NOx Swirl Burners



Babcock & Wilcox DRB-4Z



Foster Wheeler Vortex



Riley Power CCV-DAZ

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LNB Performance and Developments

Low-NO_x Burner Retrofit Performance and Costs

Boiler Type	Wall-Fired	T-Fired	Cell Burner
Technology	LNB	LNCFS I	LNCB
Size, MWe	500	200	600
NO_x Reduction, %	48	37	55
Capital Cost, $/kW	6	7	9

DOE Clean Coal Technology Topical Report (1996)

Takahashi (2001)

- **Fuel concentration in primary air stream to create NOx reducing regions and improve flame stability**
  - Reductions in primary air to fuel ratio using improved mills and ducting
  - Creation of local enrichment in particle loading (coal spreaders, Foster Wheeler Split Flame, Riley Venturi, B&W diffuser
- **Physical and aerodynamic creation of recirculation zones in/near fuel rich regions**
  - Burner core bluff bodies or low velocity flows
  - Hitachi coal pipe ring
  - Riley Power secondary air diverter
- **Independent control of secondary and tertiary swirl and flow**

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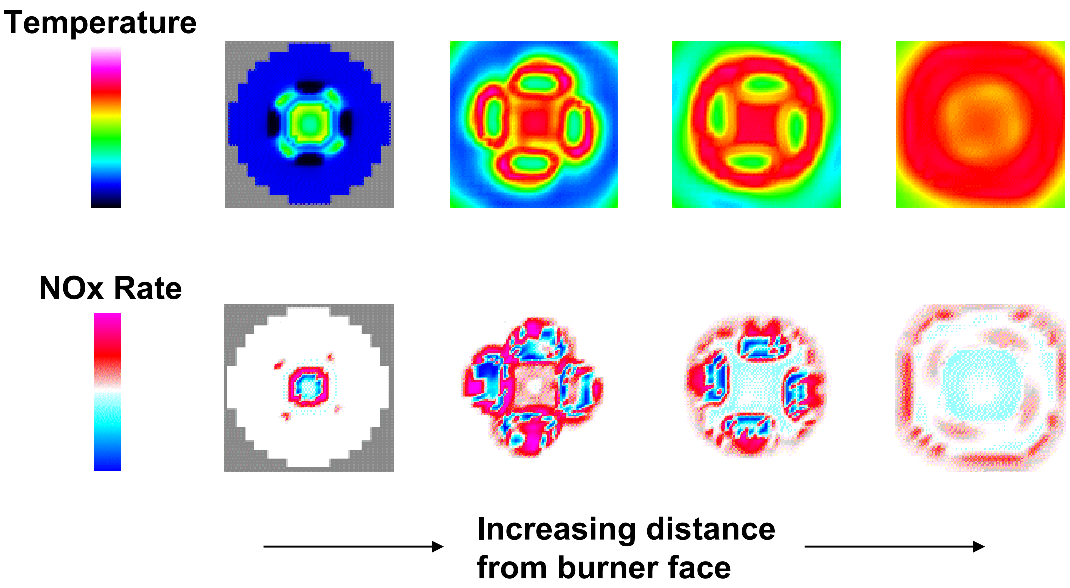
NOx Formation and Reduction in LNBs



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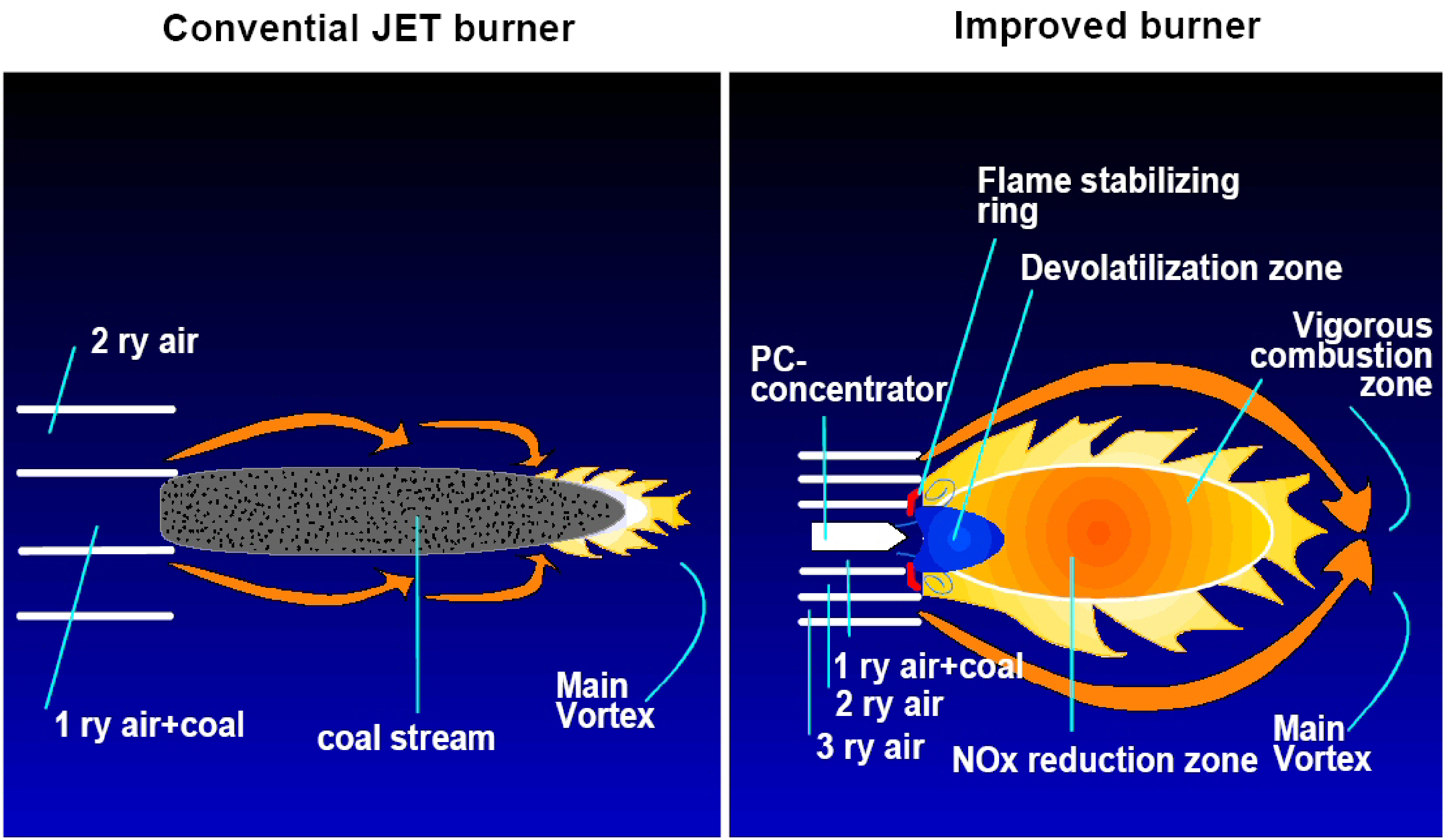
Hitachi High Swirl Approach



Takahashi (2001)

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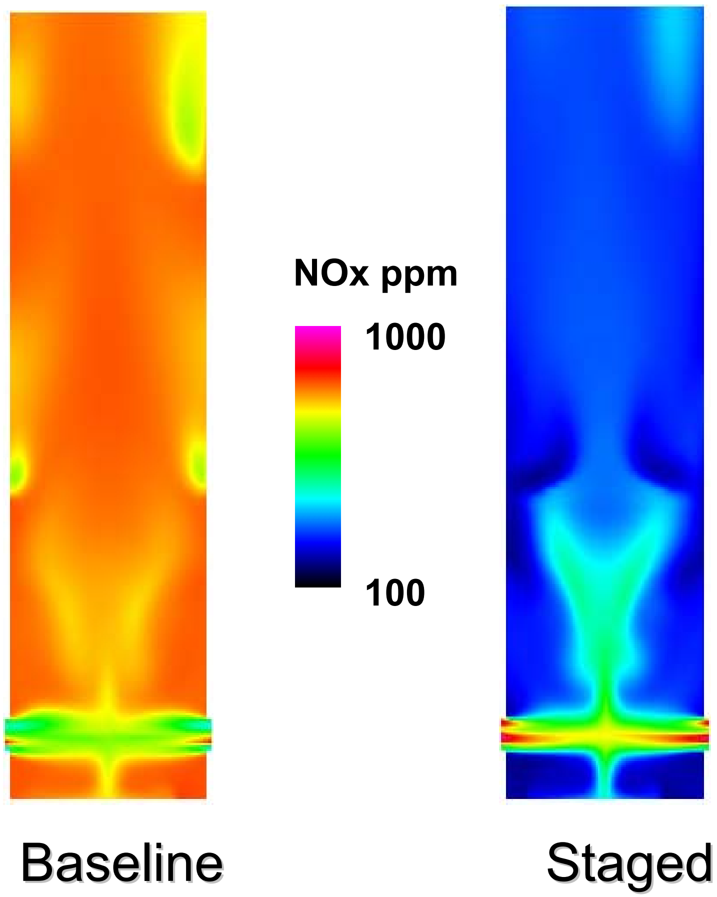
Overfire Air

- Fuel rich chemistry reduces formation of NOx and, given adequate reaction time, can destroy a portion of the NOx formed initially
- Final addition of air is staged significantly, allowing heat to be removed prior to completion of oxidation



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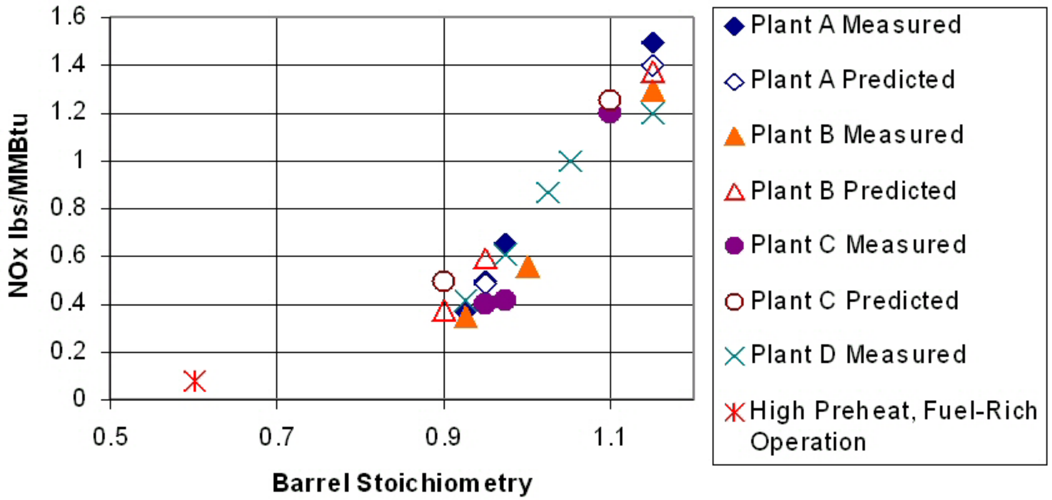
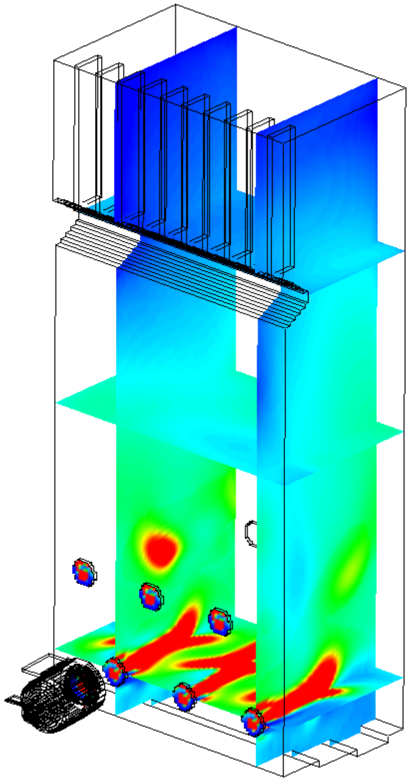
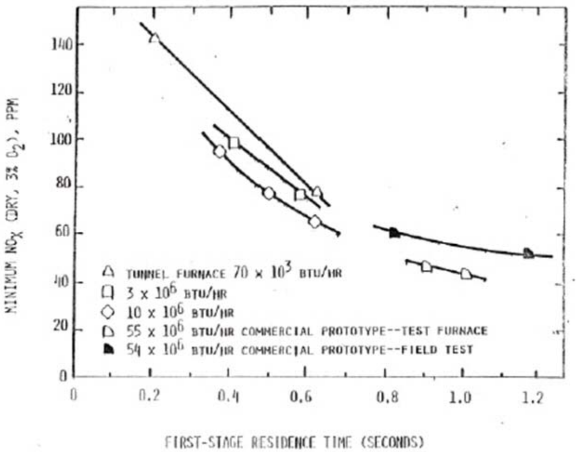
Air Staging Stoichiometry





- Staging reaches an optimum between SRs of 0.6 and 0.8
- Residence time required under fuel-rich conditions is ~1 sec
- Fuel effects are minimal for cyclone firing



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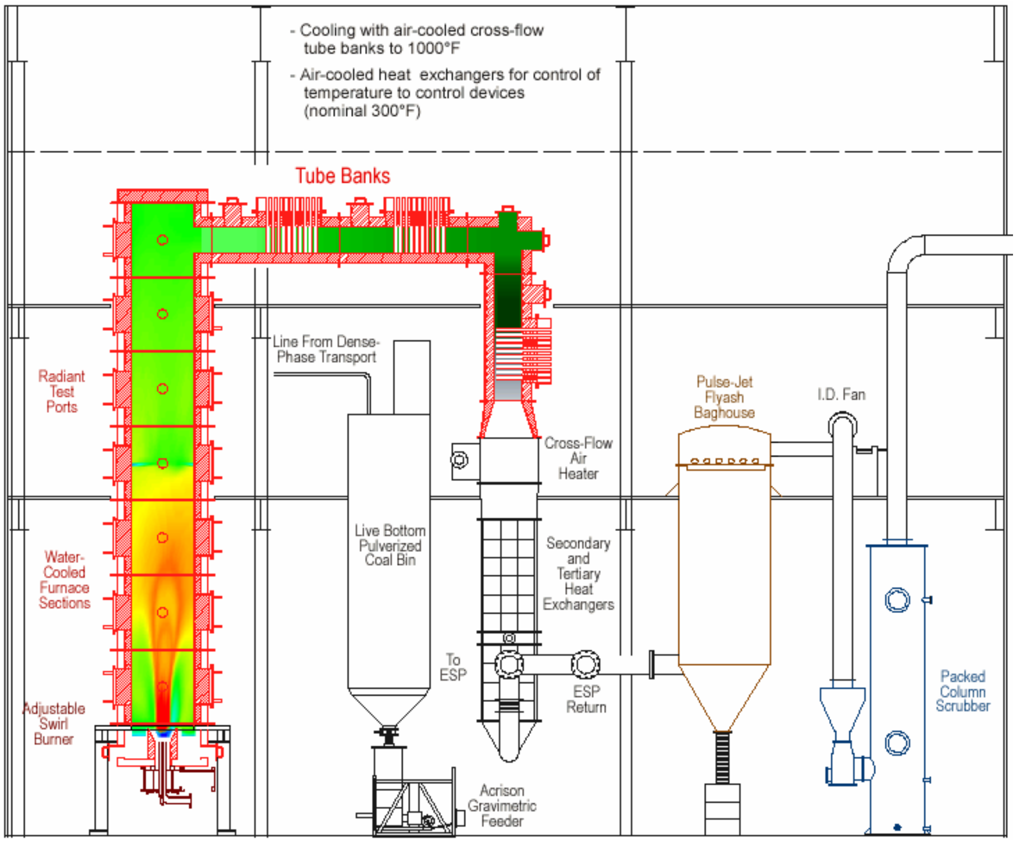
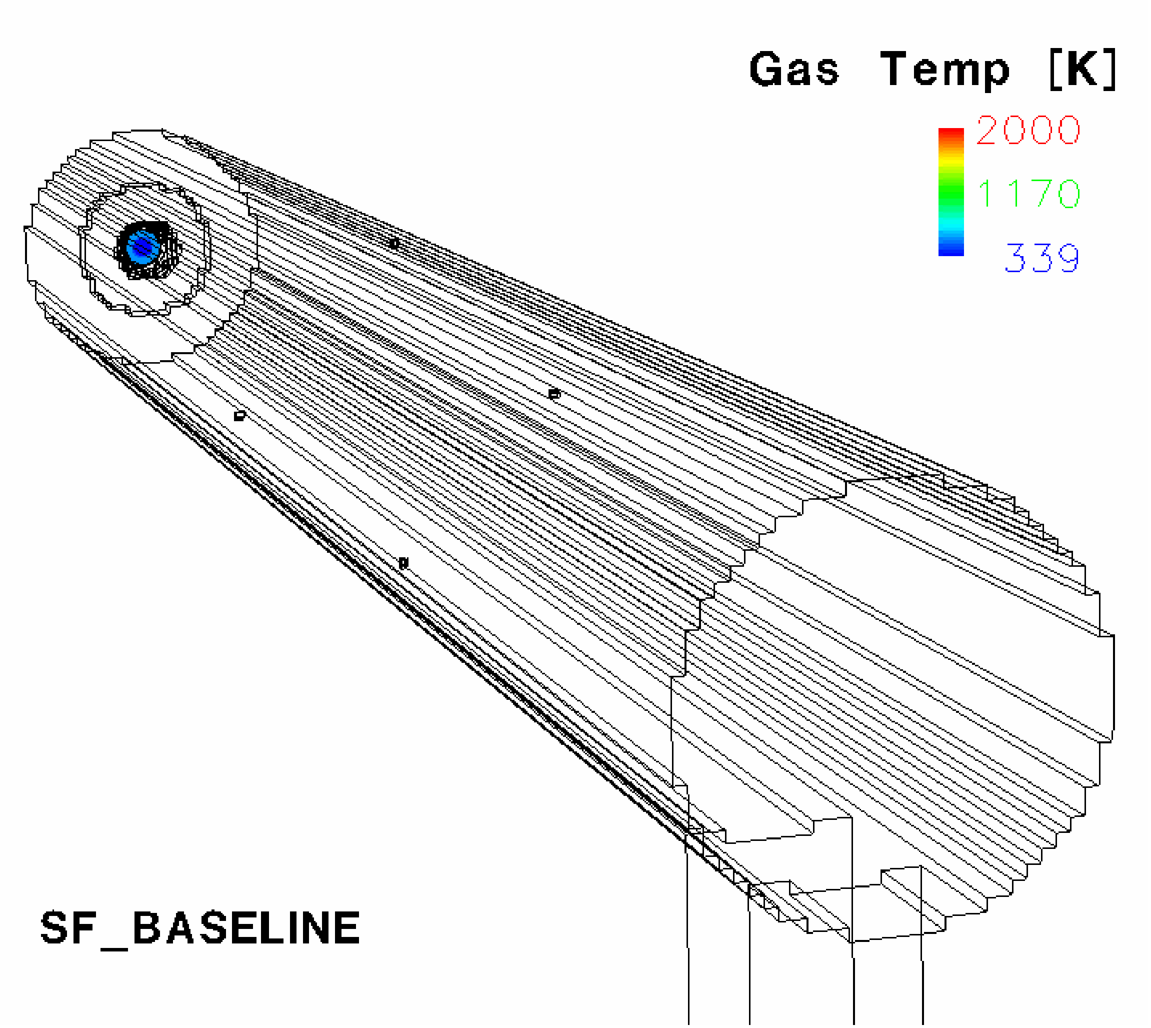
Wood Co-firing



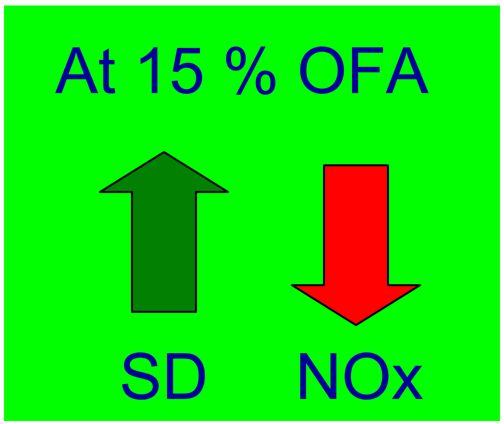
- Pilot scale
- Two injection strategies
  - co-milled
  - separate center injection
- Simulations exhibit excellent agreement with detailed temperature measurements
- Post-processor for simulation of NOx chemistry

Temperature Predictions

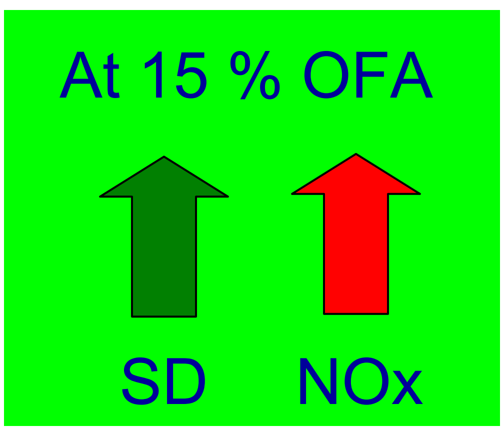


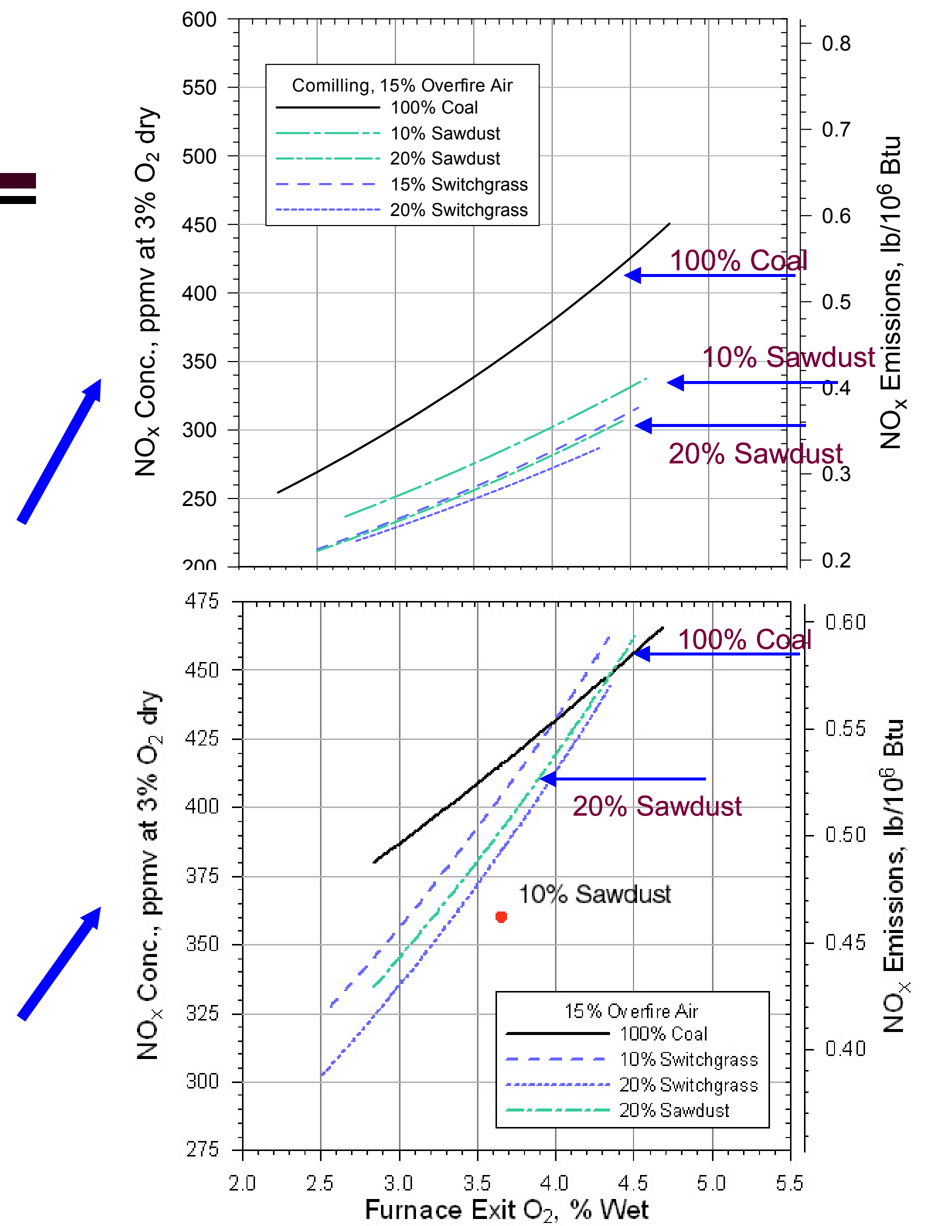
NOx Measurements during Testing

Co-milled

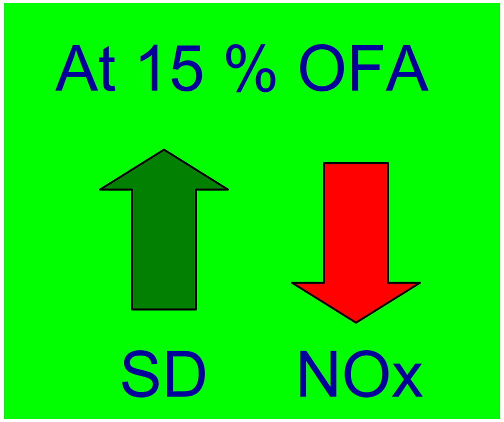


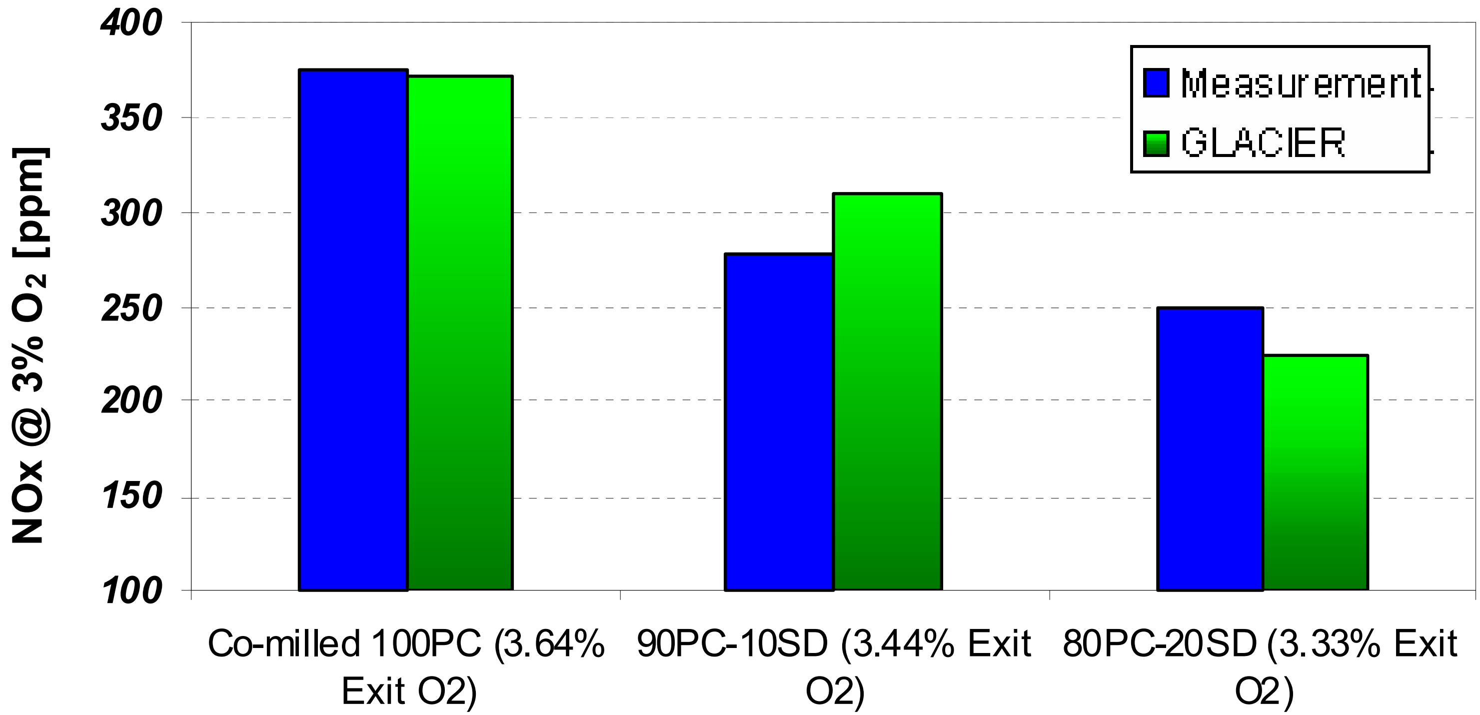
Center Injection



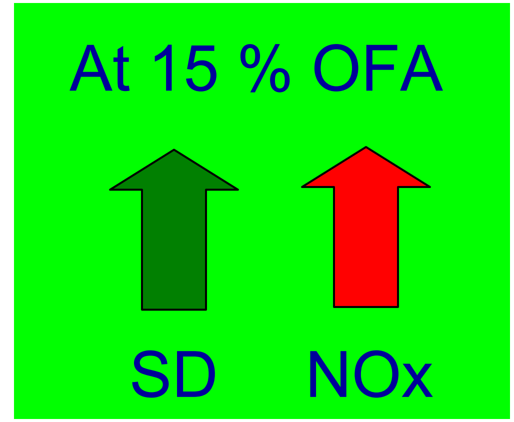


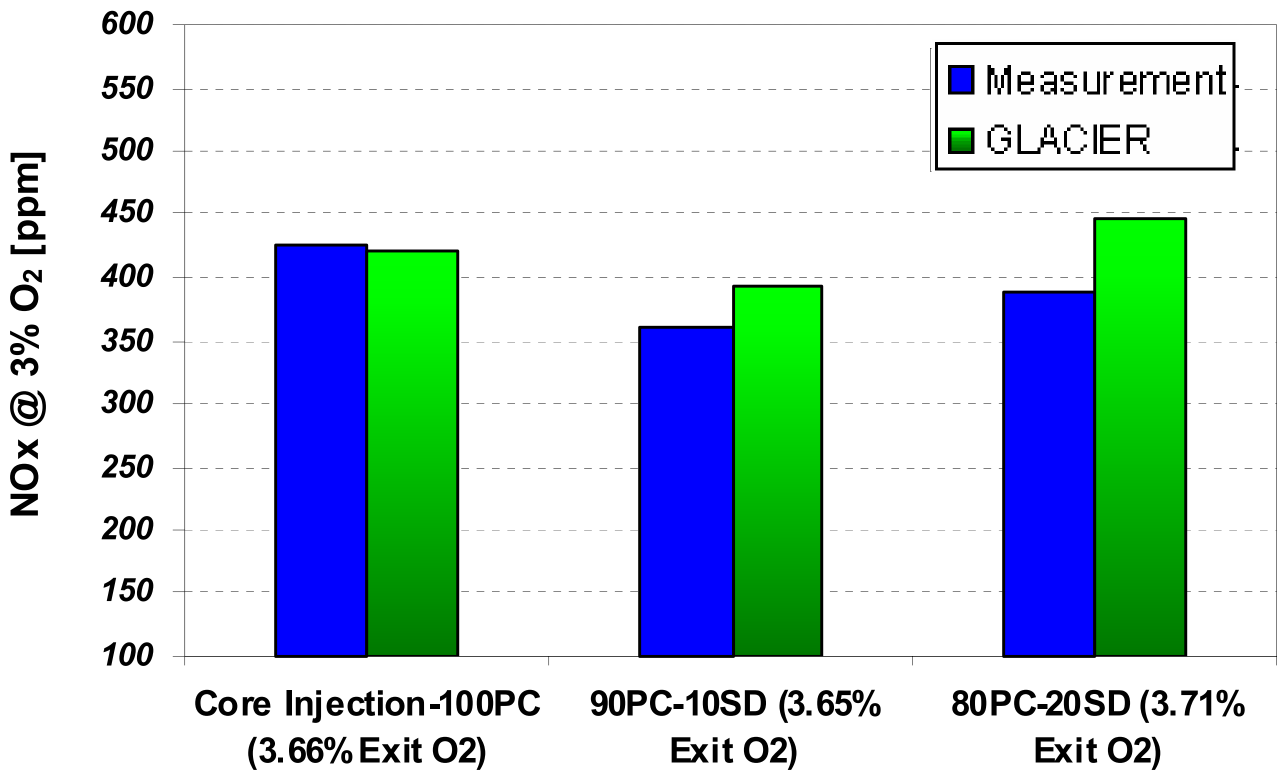
Exit NOx Concentration: Co-milled



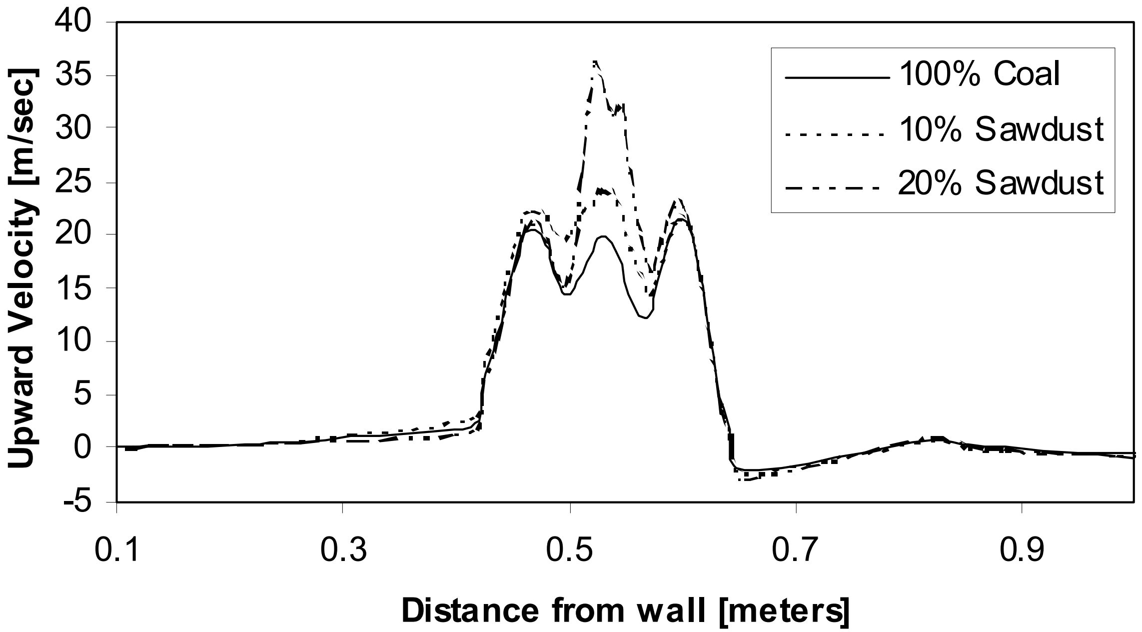


Exit NOx Concentration: Center Injection



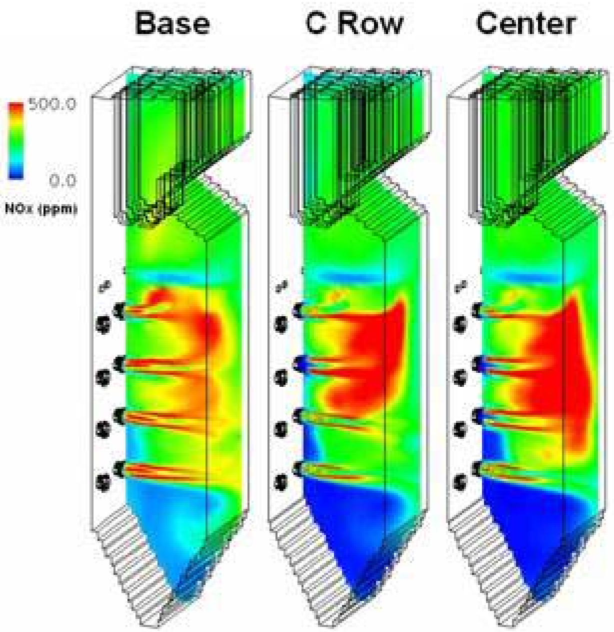


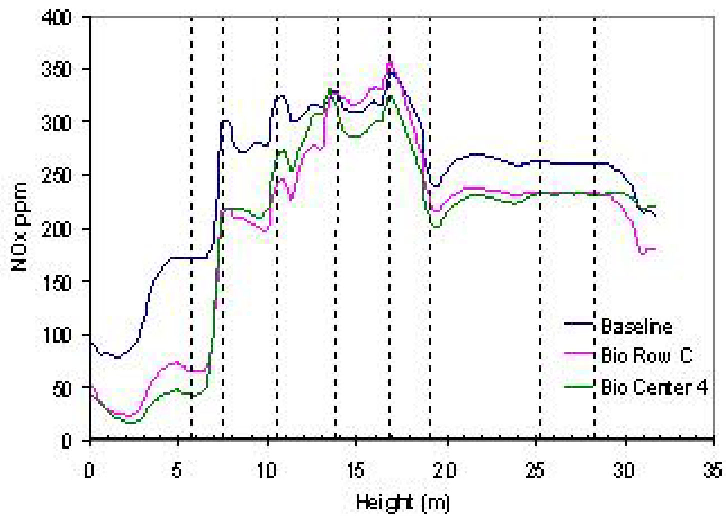
Near Burner Velocity Profile



Complex Nature of Fuel Effects on NOx

- **Two biomass injection scenarios**
  - **Configuration 1: Four "C Row"**
  - **Configuration 2: Center four burners**
  - **10% NOx reduction for both configurations**
  - **Fuel nitrogen reduction accounts about half of total reduction**
- **Volatility effect**
  - **Greater for center injection**
  - **Wet biomass releases volatiles in lower furnace more effectively**
- **Heating value effects**
  - **Thermal NOx decrease greater for "C Row"**
  - **Delayed mixing of volatiles leads to lower peak flame temperatures and extended NO reduction**





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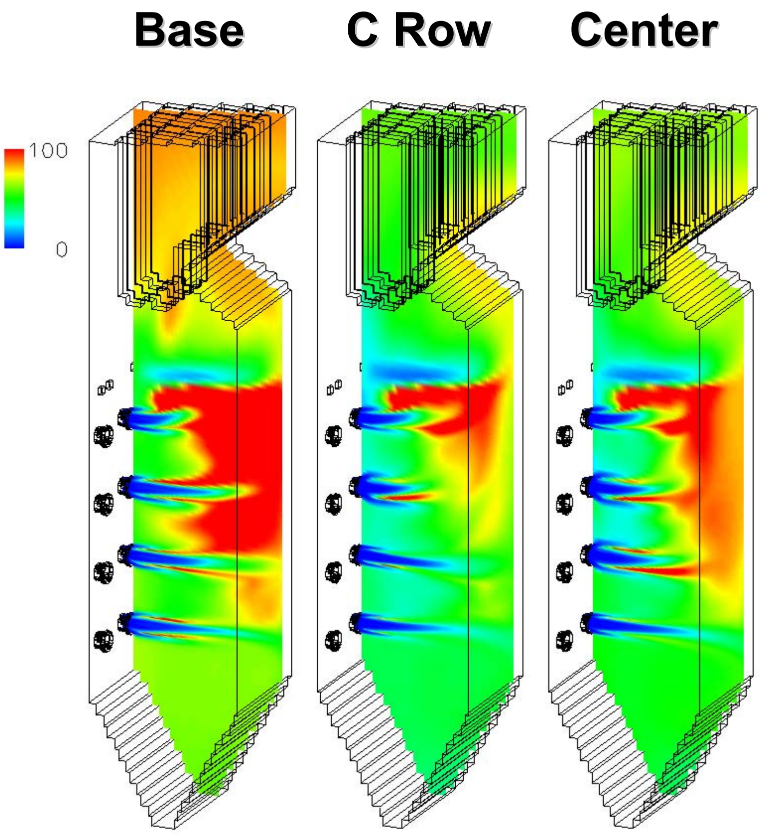
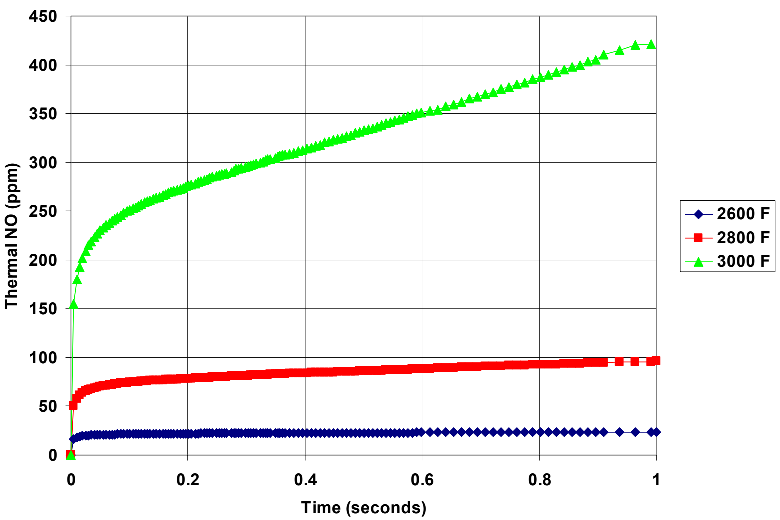
Thermal NOx



Thermal NOx (ppm)



Coal Combustion Additives for NOx Control

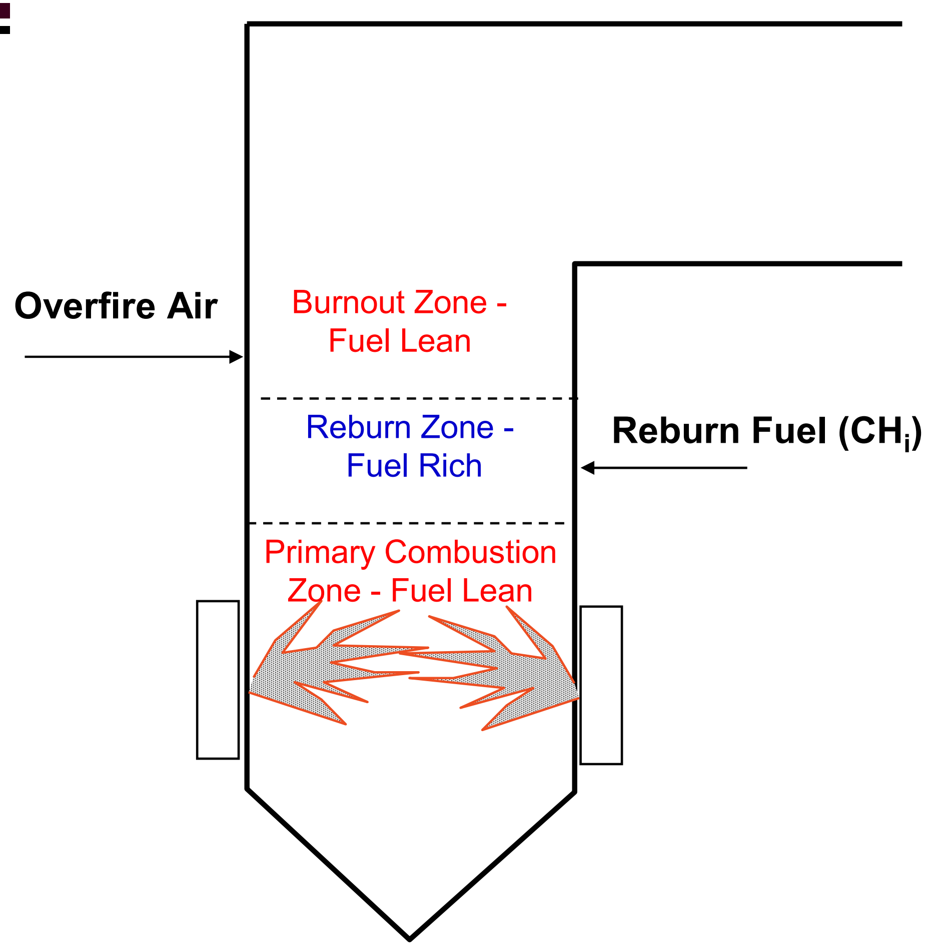
Ohtsuka et al., Energy&Fuels (1998)

		Conversion of coal-N (%)						
coal	Catalyst Loading (wt%)	N_2	NH_3	HCN	Oil-N	Tar-N	Char-N	Total
LY	0.0	3.9	16.0	5.8	22.0	7.6	52.0	107
LY	0.7	49.0	10.0	2.1	10.0	5.4	25.0	102
LY	2.8	53.0	13.0	1.3	14.0	3.6	17.0	102
BA	0.0	7.8	17.2	4.7	12.5	3.1	62.5	108
BA	1.9	28.1	12.5	1.6	10.9	3.4	46.9	103

- **Typically metallic, often nanoscale**
- **Application/dispersion challenges**
- **Related objectives in modifying fuel properties:**
  - **Enhance volatile yield**
  - **Enhance nitrogen yield during pyrolysis**
- **Potential co-benefits for combustion performance, slagging, corrosion, other emissions**

Reburning

- **Conventional Reburn**
  - >10% of thermal input
  - OFA required
  - Gas, coal, biomass
- **Fuel Lean Gas Reburn**
  - 5-7% of thermal input
  - OFA not required
  - Limited by CO emissions
- **Amine enhanced fuel lean gas reburn**
  - Urea co-injected with gas
  - Usually combined with FLGR and SNCR



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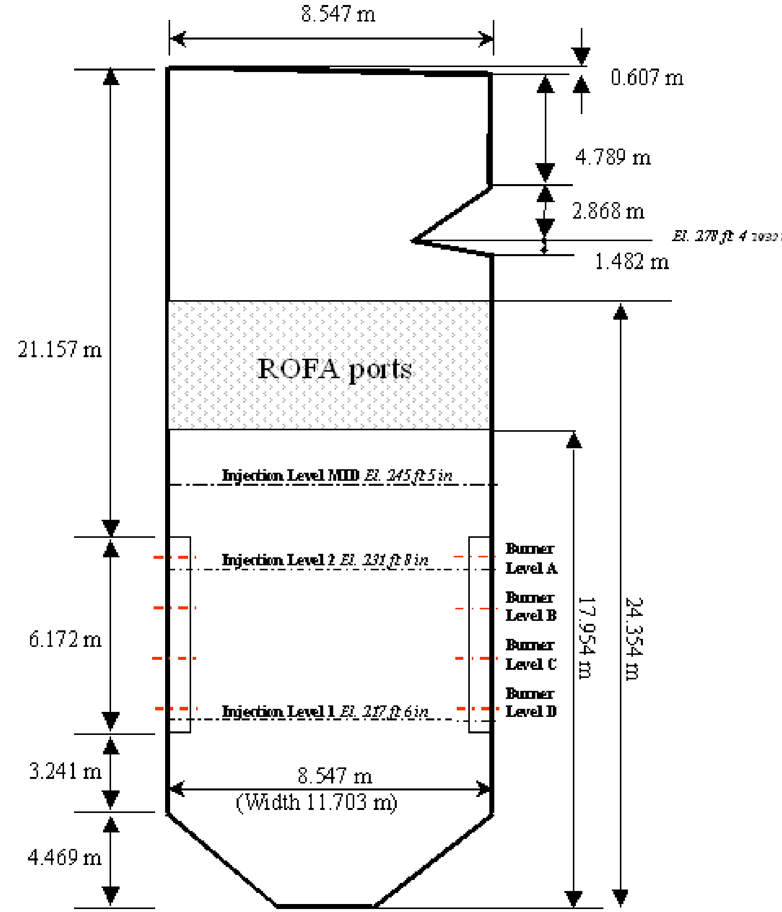
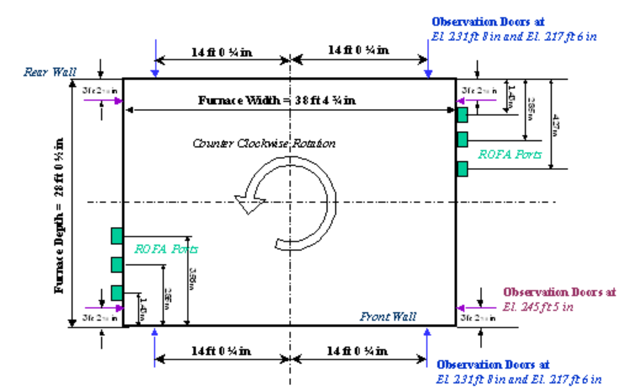
Micronized Coal Reburn/Co-firing

- Micronized coal (~85%<325 mesh) vs. pulverized coal (~75%<200 mesh)
- DOE Demonstration on a staged 143 MW T-fired unit
- 16% pulverized coal replacement
- MC injection evaluated at multiple locations/elevations including:
  - conventional reburn location between burner stack and OFA
  - with OFA
  - upper and lower burner stack elevations





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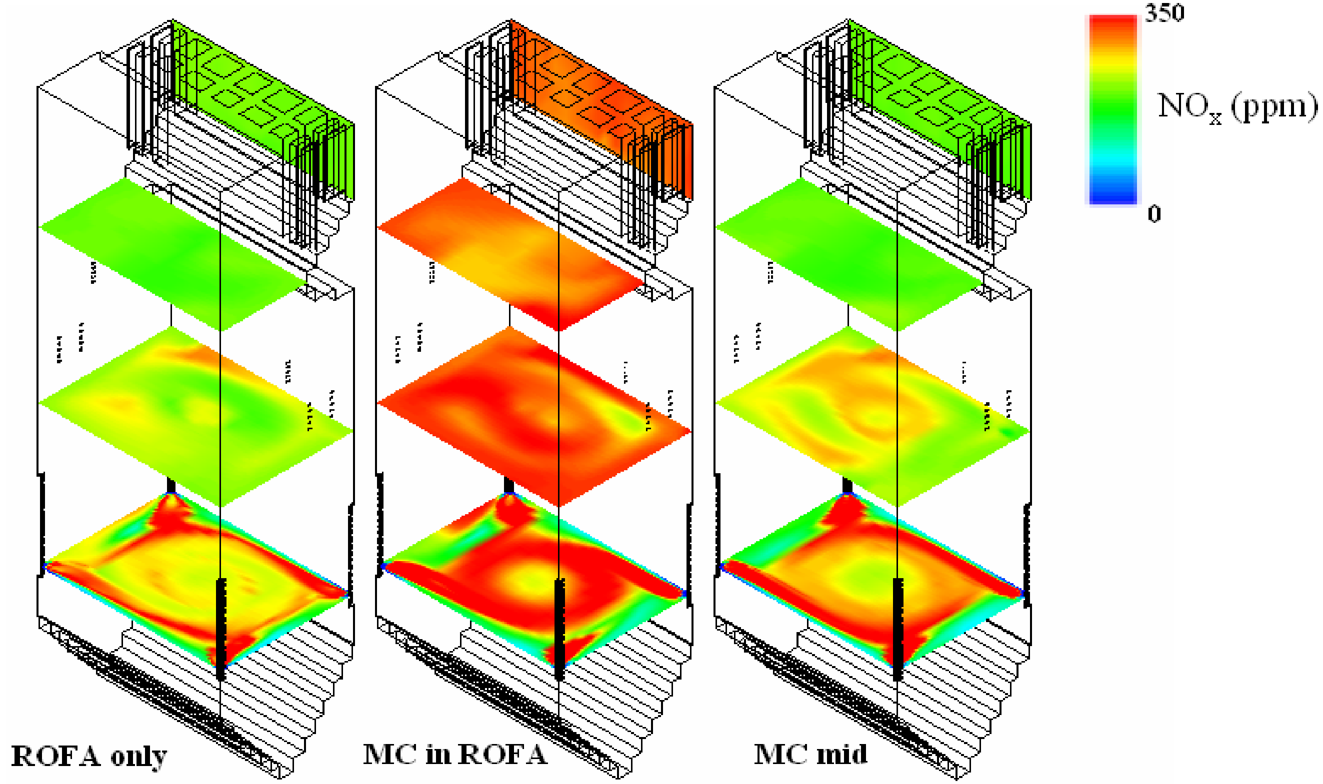
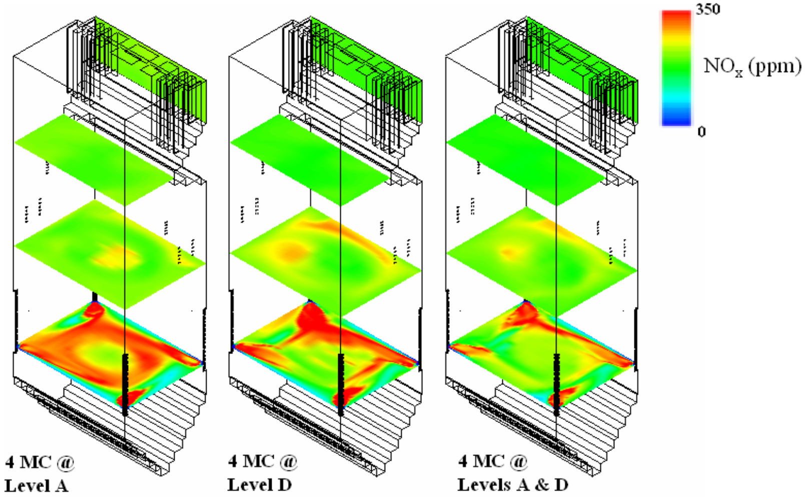
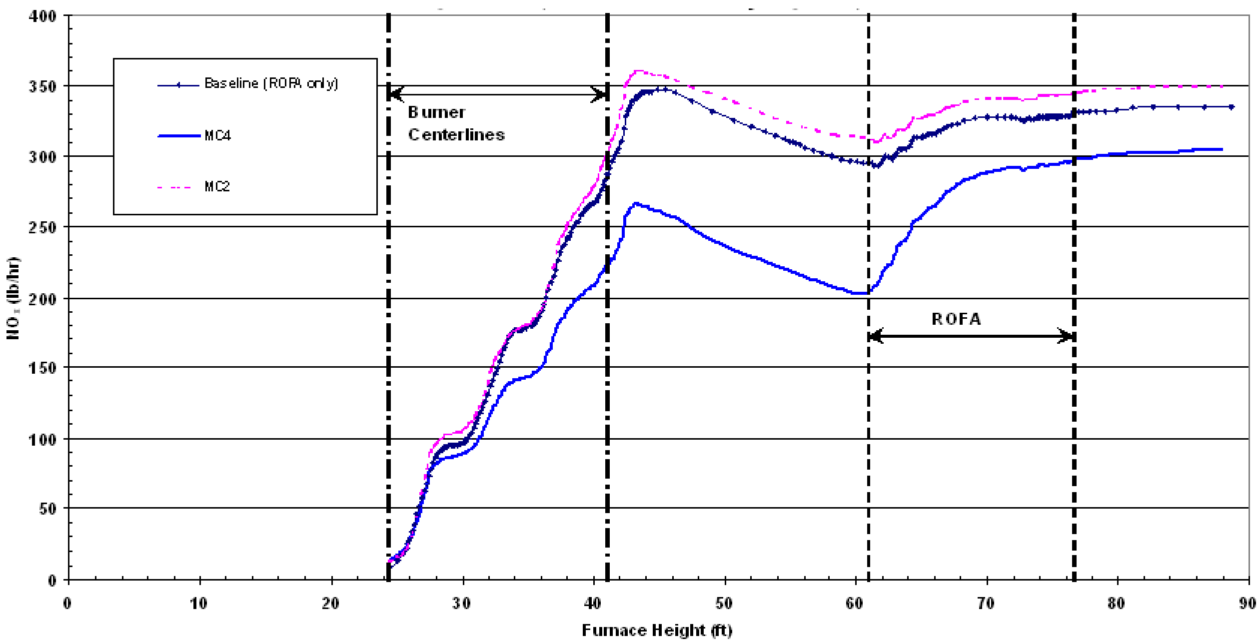
Micronized Coal "Reburn" Results



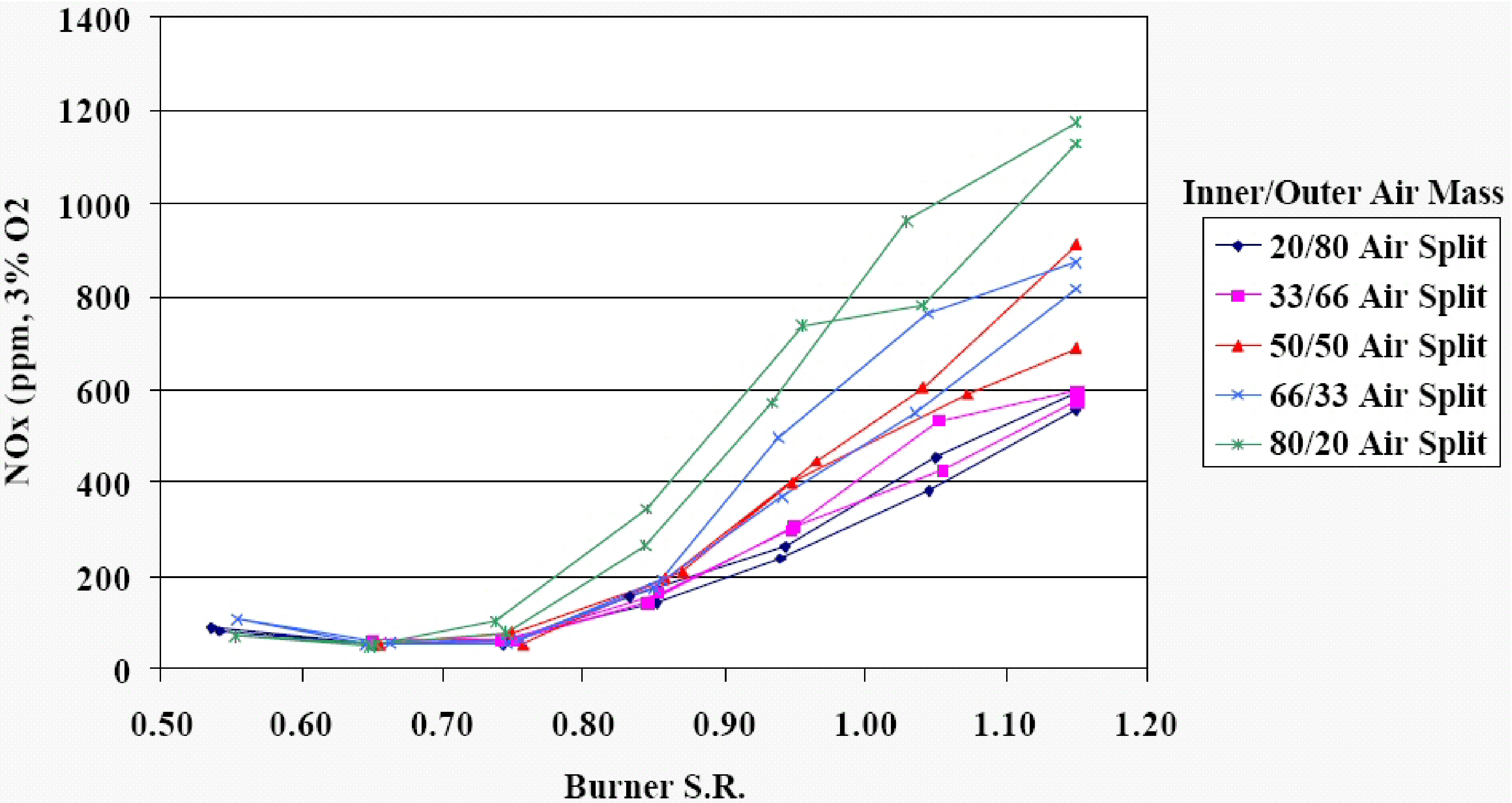
Micronized Coal "Co-firing" Results

- Micronized coal enhances lower furnace volatile yield
- Co-firing more effective than reburn
- Creating uniformly rich conditions across furnace cross section most effective





Deep Staging



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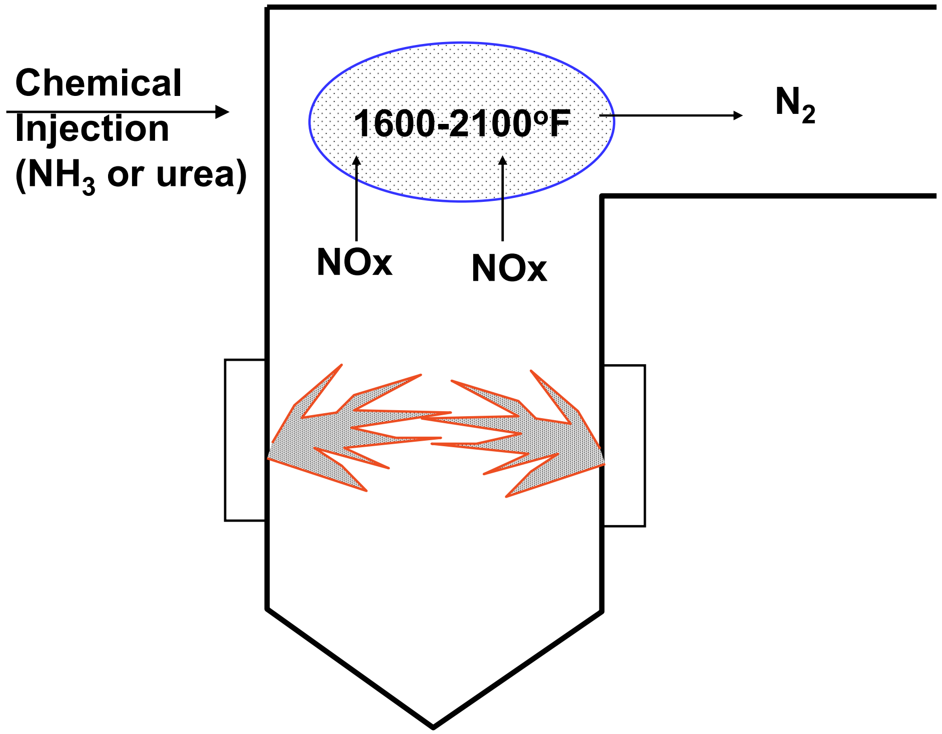
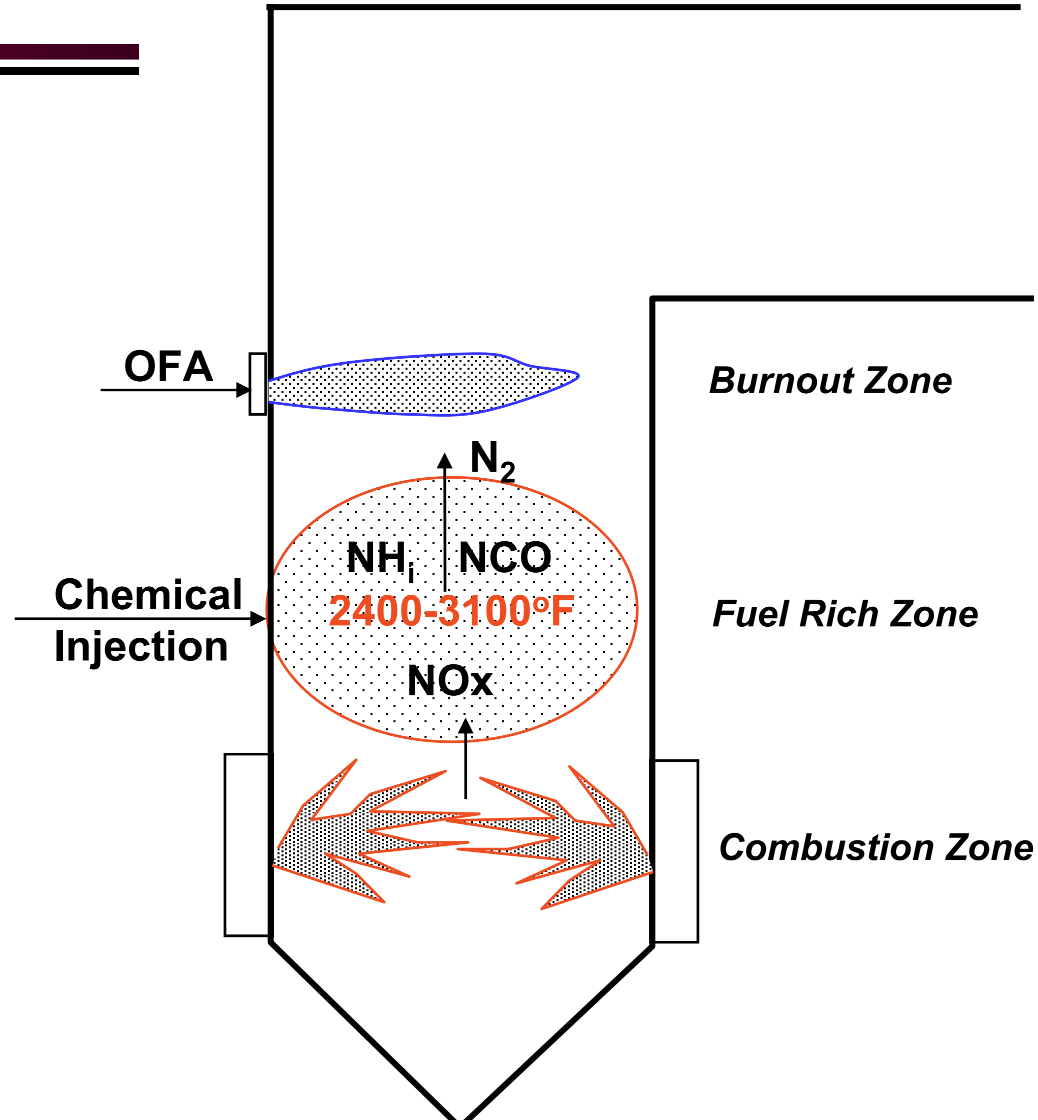
Selective Noncatalytic Reduction (SNCR)

- **Benefits:**
  - Low cost compared to SCR
  - Significant NOx reductions (>50%) in small units
  - 25-30% reduction with <5 ppm NH3 slip recently demonstrated in 600 MW unit
- **Difficulties:**
  - Mixing limitations
  - Temperature window may not be accessible
  - Other emissions may increase (NH3 and N2O)



Rich Reagent Injection

- Significant NOx reductions achievable by air staging
- Staging creates a hot, fuel rich lower furnace
  - In-situ reburning
  - NOx reduction improves with reduced SR and increased res. time
- Amine reagents accelerate the rate of NOx reduction
  - NOx reduction in rich zones
  - NOx formation in lean zones



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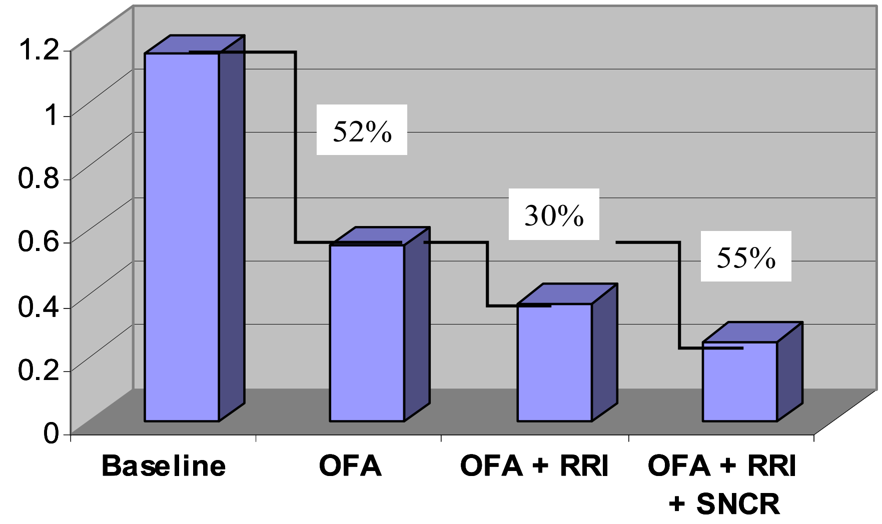
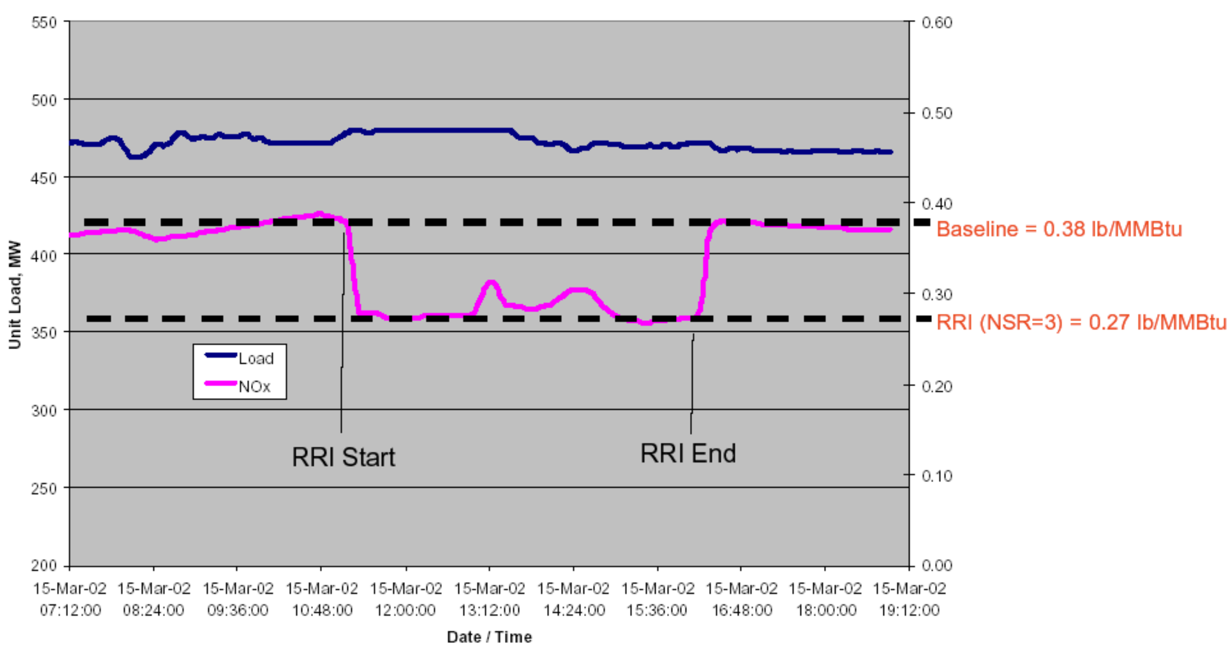
RRI Field Results



Conective BL England Station

Ameren Sioux Station



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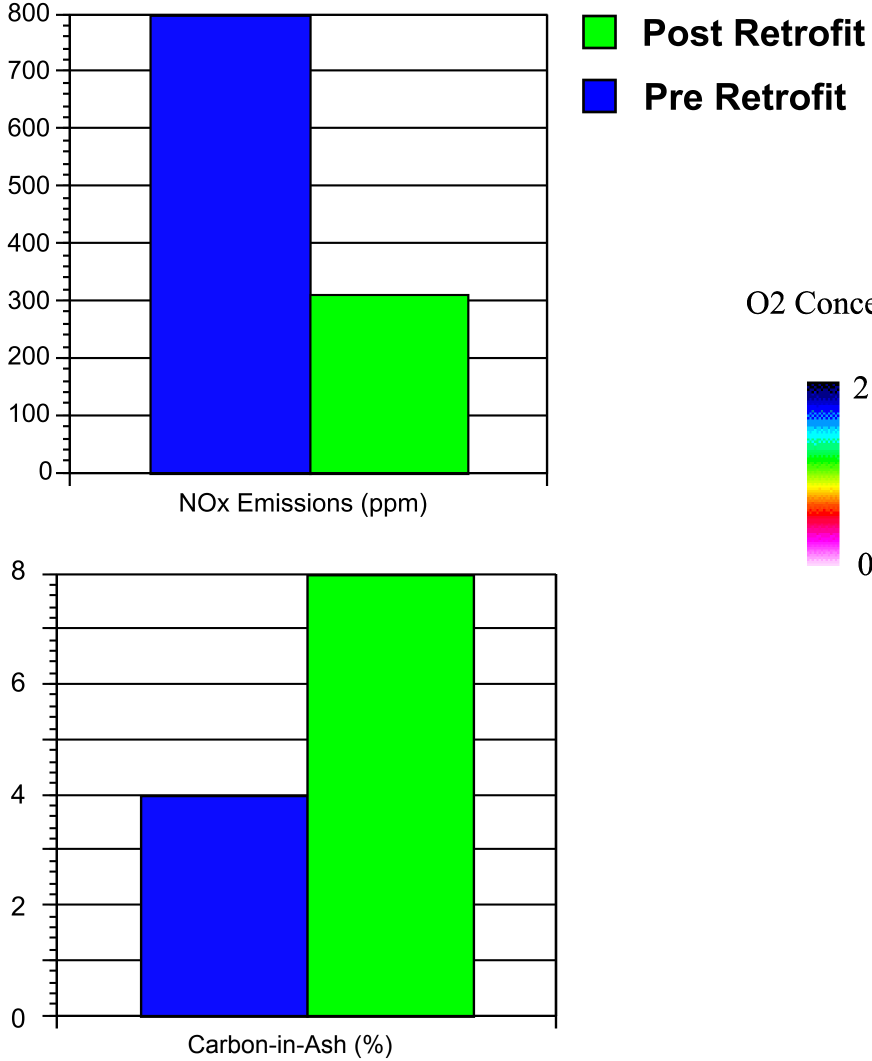
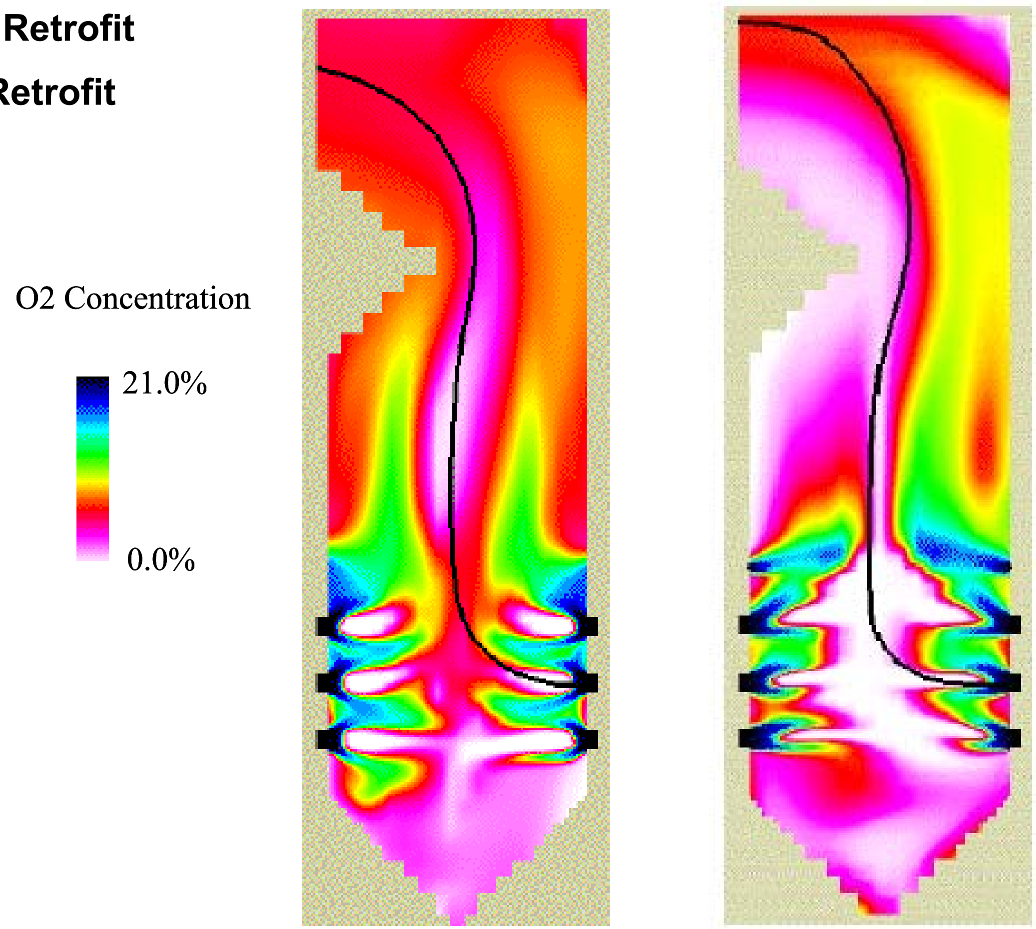
Balance of Plant

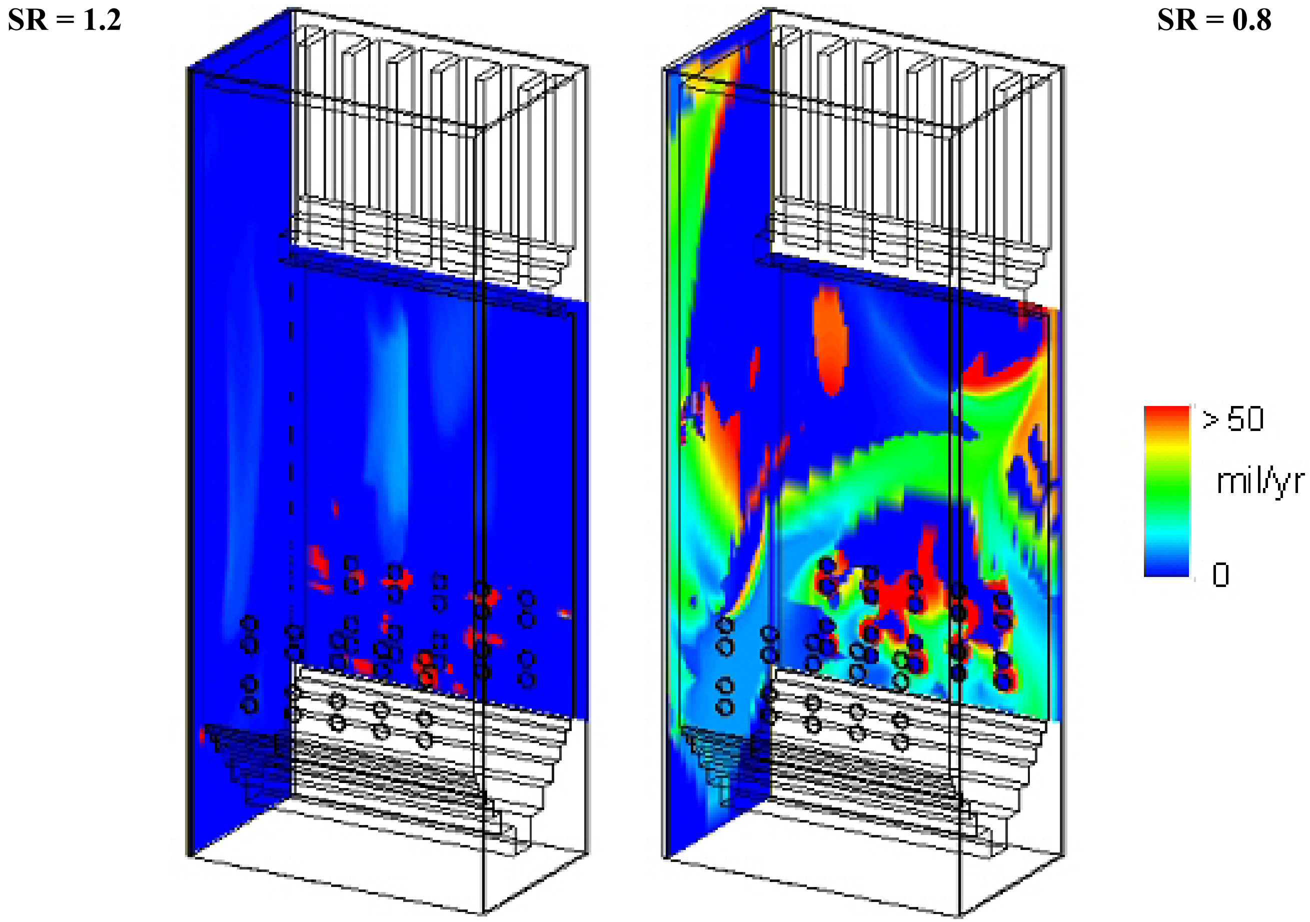
- Carbon Monoxide Emissions
- Carbon-in-Flyash (LOI)
- Waterwall Corrosion
- Heat balance and Efficiency
- Combustion Equipment Complexity and Performance
  - Coal pipe fires
  - Burner/air port maintenance
  - FD fan requirements
  - Fine particle emissions (ash & soot)

Carbon in Flyash



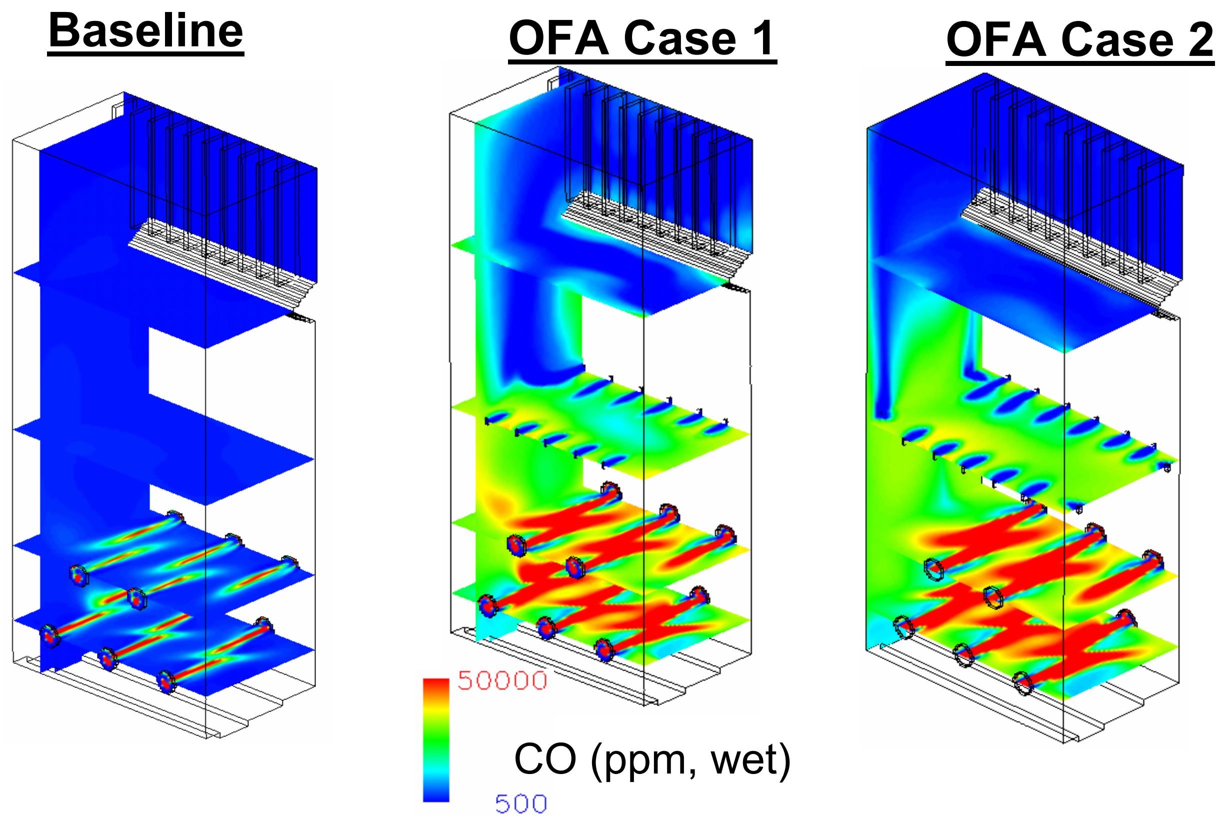


Corrosion and Staging



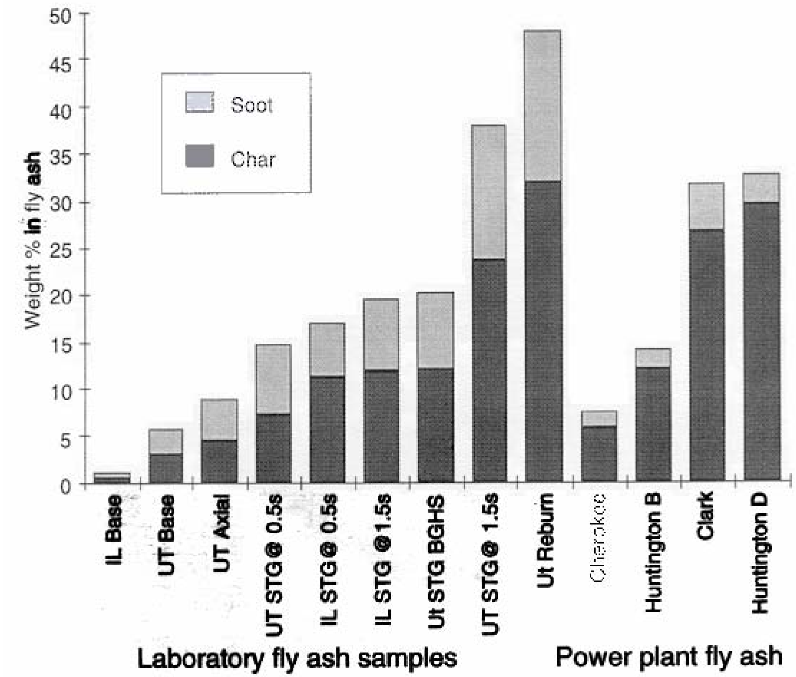
Carbon Monoxide Levels

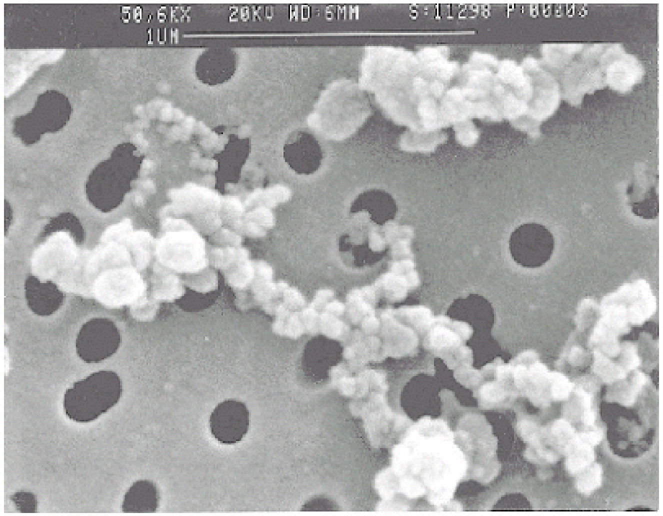
- Emissions
- Efficiency
- Safety
- Black Bottom (soot)



Soot in Low NOx Flames

- ➔ **Low-NOx combustion can result in significant concentrations of submicron soot particles**
- ➔ **Potential Impacts:**
  - **Increase in fine particulate emissions and opacity**
  - **Boiler heat imbalances due to enhanced lower furnace radiation**
  - **Potential decrease in effectiveness of air staging for NOx control**
  - **Potential impact on high temperature reagent injection effectiveness**
  - **Ash salability**





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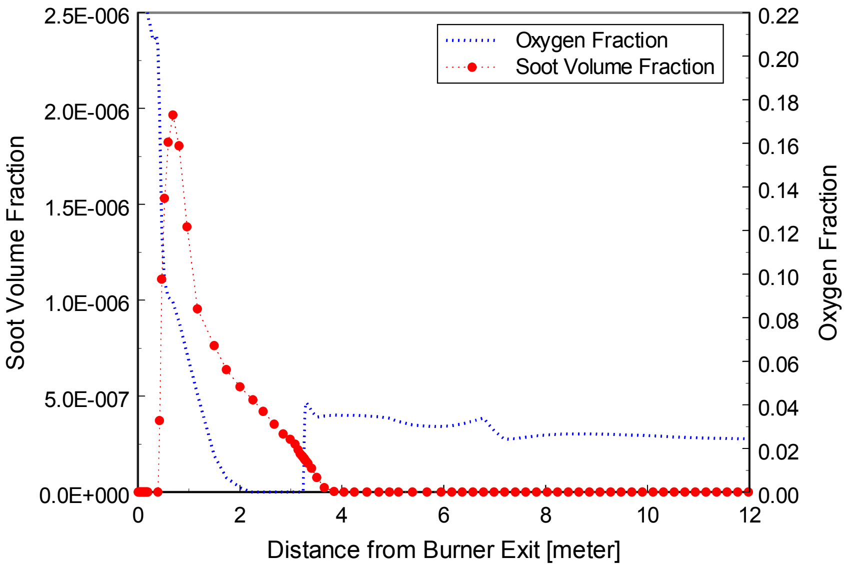
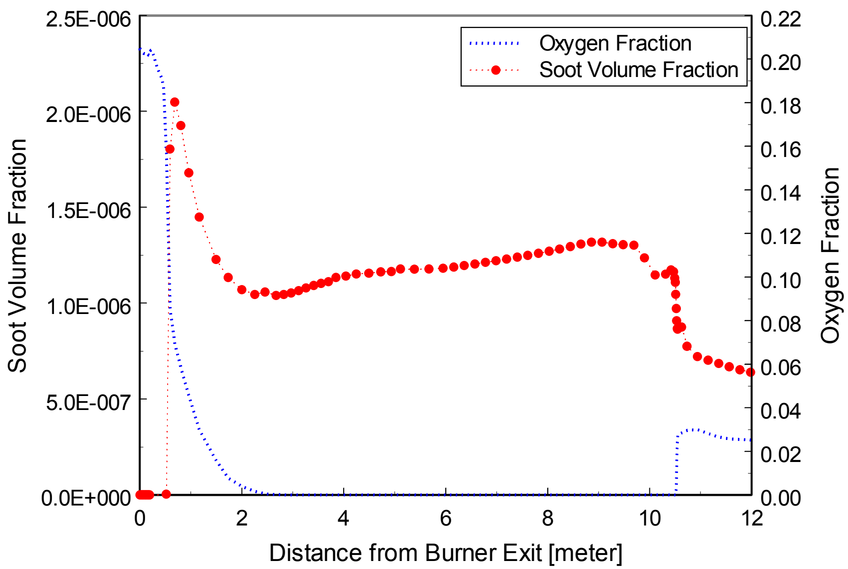
Pilot-scale Modeling Insight

- ➔ **Reasonable soot concentrations are predicted**
- ➔ **A residence time threshold exists for soot breakthrough under typical low-NOx conditions**





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Summary

- **Target fuel and the importance of fuel flexibility play a key role in NOx control technology selection**
- **Appropriate fuel selection can enable attainment of substantially lower NOx emissions**
- **Balance of plant impacts must be considered when NOx control technology & fuel selection decisions are made**