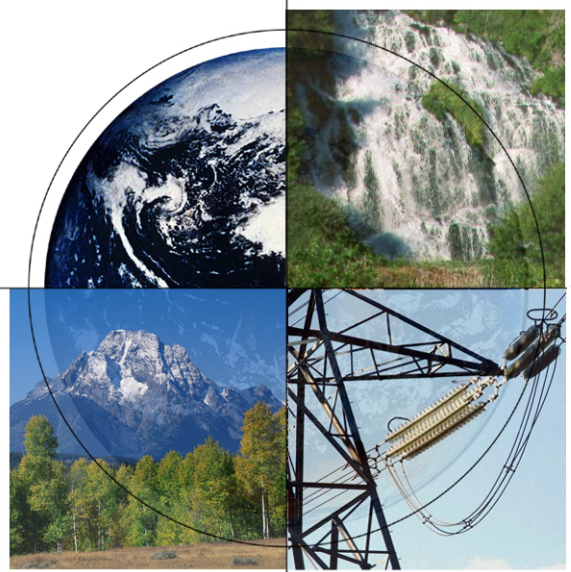
DOE-NETL's NOx Control Program



Overview of NOx Program/Solicitation

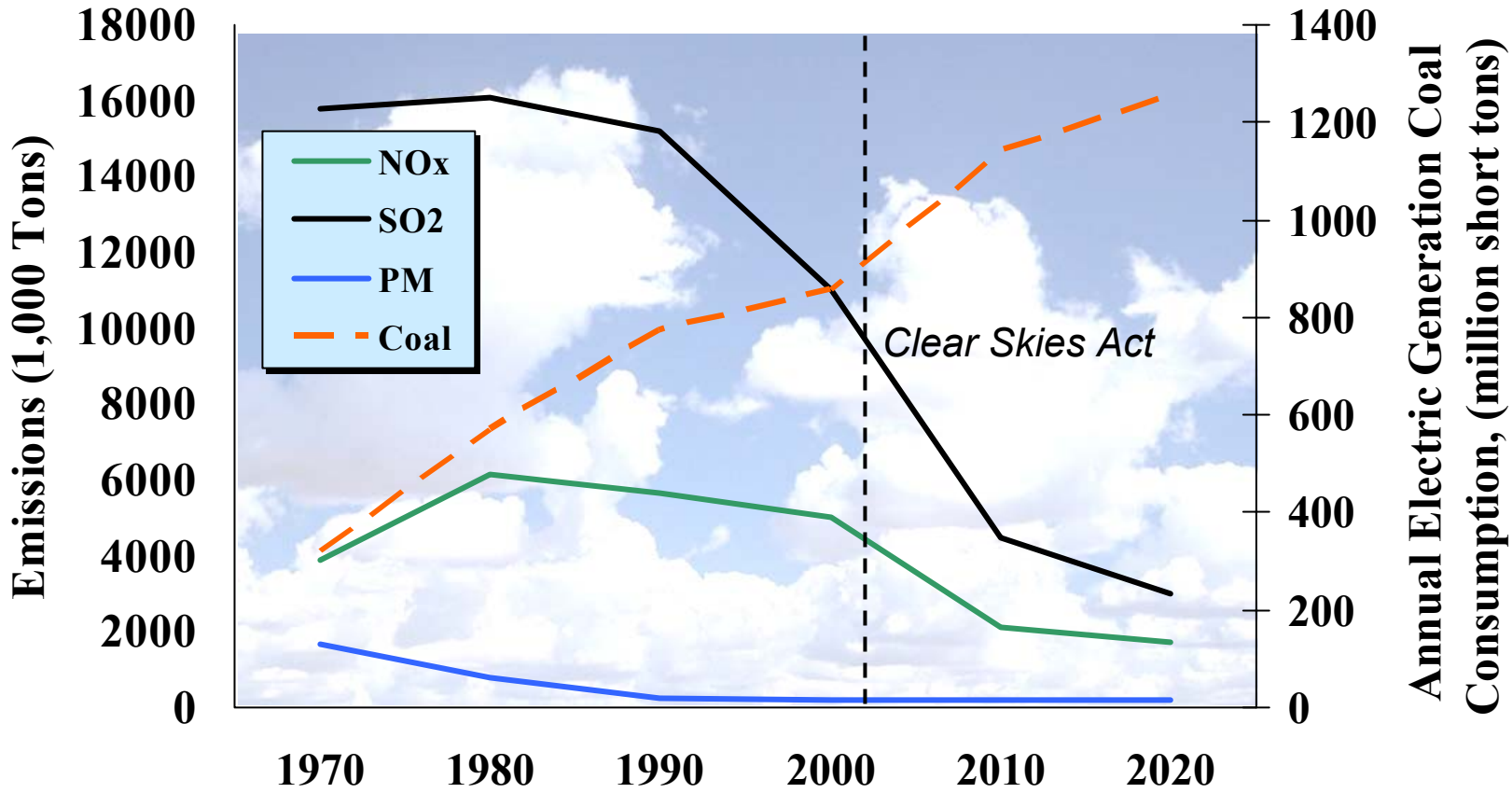
October 29, 2003
Bruce W. Lani
Project Manager

National Energy Technology Laboratory

Innovations for Existing Plants (IEP) R&D Program

- **Goal**
  - Enhance environmental performance of existing fleet of coal power plants and advanced power systems
- **R&D Approach**
  - Environmental Data and Analysis
    - Which pollutants should we control, and by how much?
  - Pollution Control Technology
    - How can we (economically) control these pollutants?

Continued Improvement in Environmental Performance of U.S. Power Plants



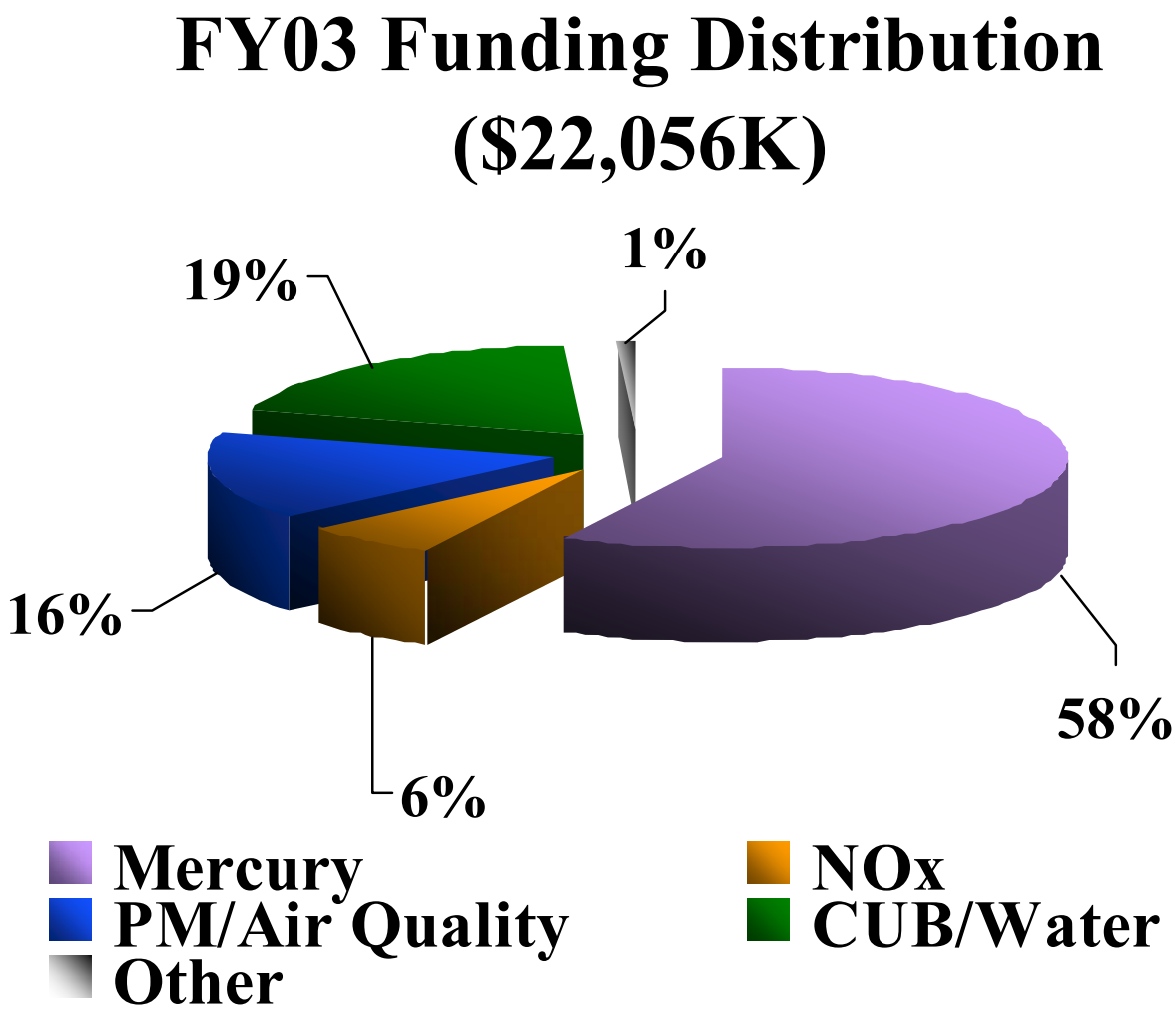
Source: U.S. EPA, "National Air Quality and Emissions Trends Report, 1999", Coal consumption projections based on EIA Reference Case from "Annual Energy Outlook 2002", and include all coal electric generation except cogenerators. Historical coal consumption from EIA "Annual Energy Review 2000" and includes only utility electric generation.

"NETL Product Line"
Environmental & Water Resources

- **Technology Manager: Tom Feeley**

- **5 Technical Focus Areas & Managers:**
  - Mercury Emissions Control (Scott Renninger)
  - Advanced NOx Emissions Control (Bruce Lani)
  - PM/SO_3 Emissions Control / Air Quality Research (Bill Aljoe)
  - Coal Utilization Byproducts (Lynn Brickett)
  - Power Plant Water Issues (Tom Feeley & Barb Carney)

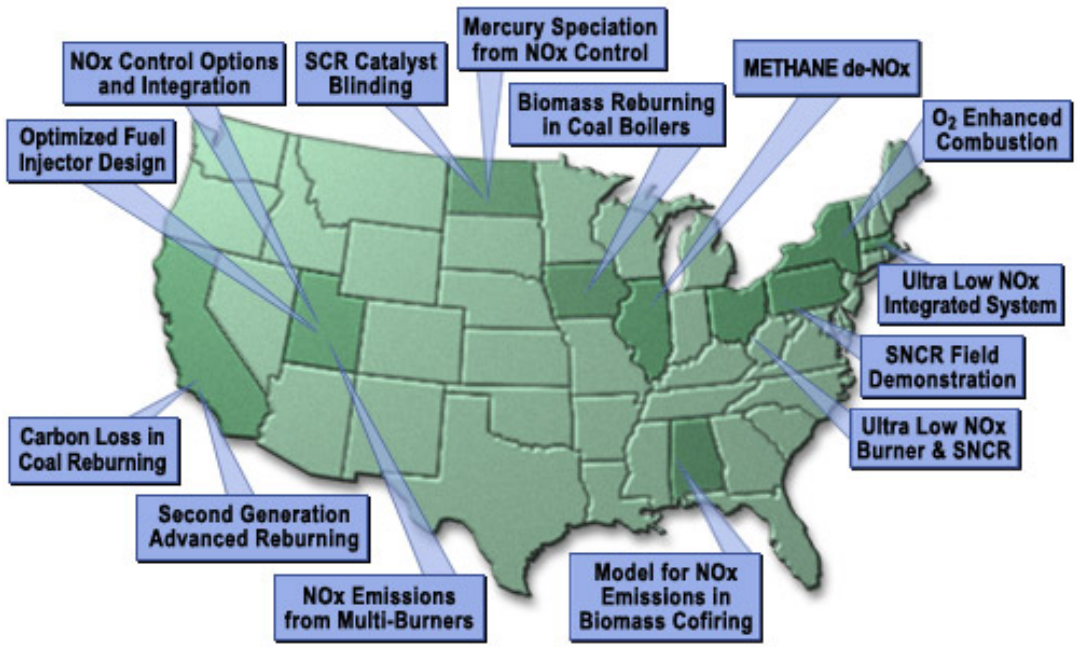
Program Funding by R&D Activity



NETL's Advanced NOx Control Technology for Coal-Fired Power Plants Goals

Program Goals

- Develop technologies capable of achieving NOx emissions of 0.15 lb/MMBtu or less
- Realize a cost savings at least 25% lower than SCR
- Improve understanding of the impact of these technologies on balance of plant issues



Environmental & Regulatory Drivers

- **Environmental Drivers**
  - Acid Rain
  - Ground Level Ozone
  - Ambient Fine Particulate
  - Regional Haze
  - Eutrophication
  - Climate Change
- **Regulatory Drivers**
  - 1990 CAAA—Criteria Pollutant
  - 1990 CAAA—Title IV Acid Rain
  - Clean Water Act
  - Proposed Multi-Pollutant Legislation

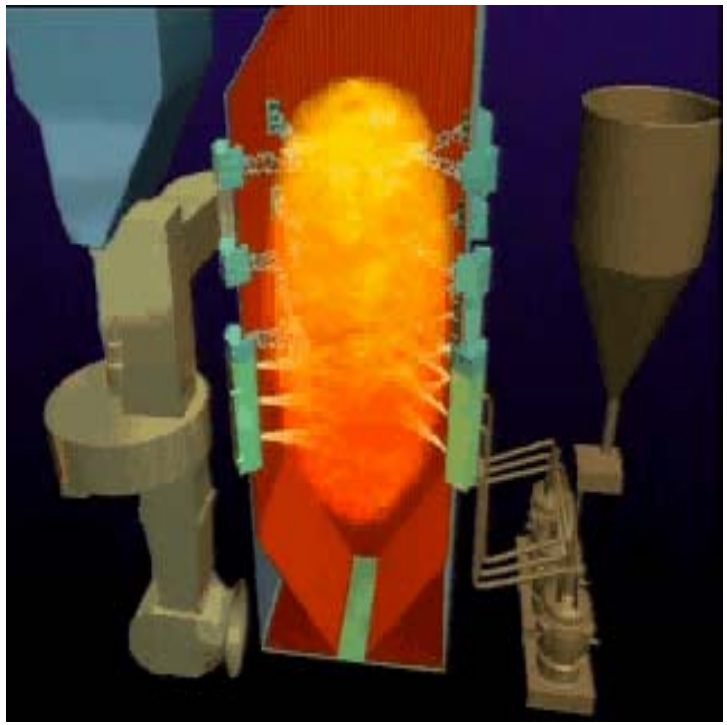
Seven NOx Control Projects

Participant / Technology	Completion Dates
Alstom—ULNB for Tangential-fired Boilers	December 2002
MTI/B&W—ULNB/SNCR for Wall-fired Boilers	December 2002
Praxair—Oxygen Enhanced Combustion	December 2003
PCI—Catalytic Burner for IGCC	June 2004
GTI—LNB with Coal Preheating	September 2004
REI—Modeling of NOx Control Technologies and Balance of Plant Issues	December 2004
Wiley—Micronized Coal Combustion	January 2005

Alstom

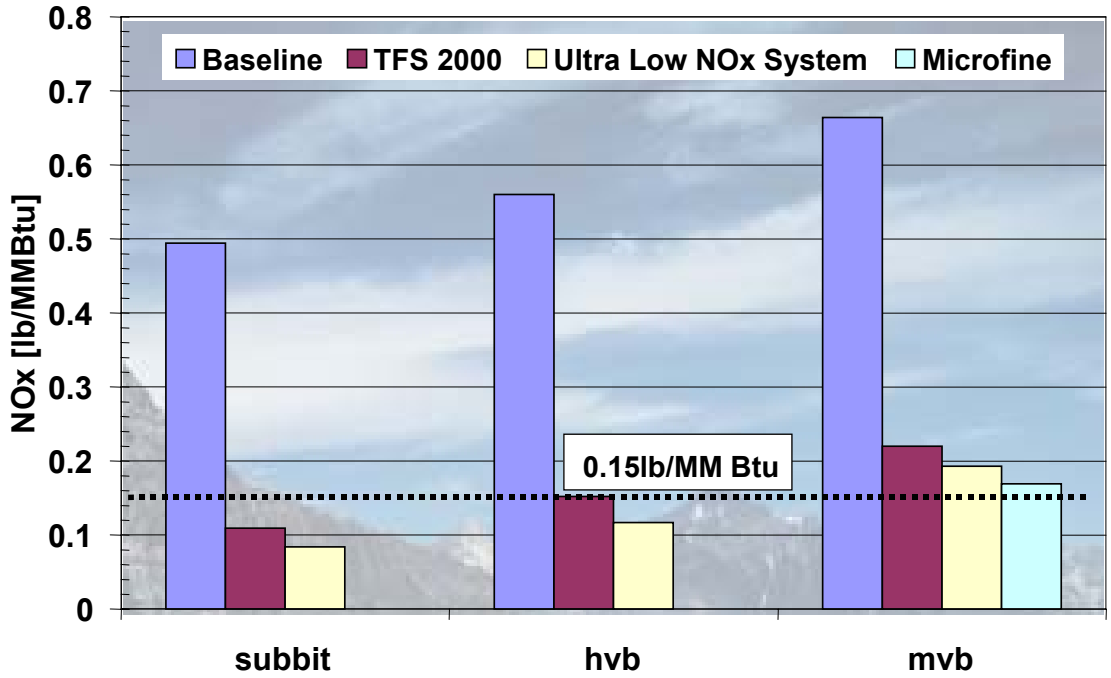
Development of an Ultra-Low NOx Integrated System for Pulverized Coal Fired Power Plants

- **Build upon commercially proven TFS 2000™ technology**
- **Integrate systems solution to further reduce boiler emissions by:**
  - Enhancing current system components
  - Optimizing fuel and air distributions
  - Adding post-combustion measures (as needed)
  - Incorporating advanced sensors and control technology to assist in achieving and maintaining desired boiler performance



Alstom
Pilot Plant Test Results

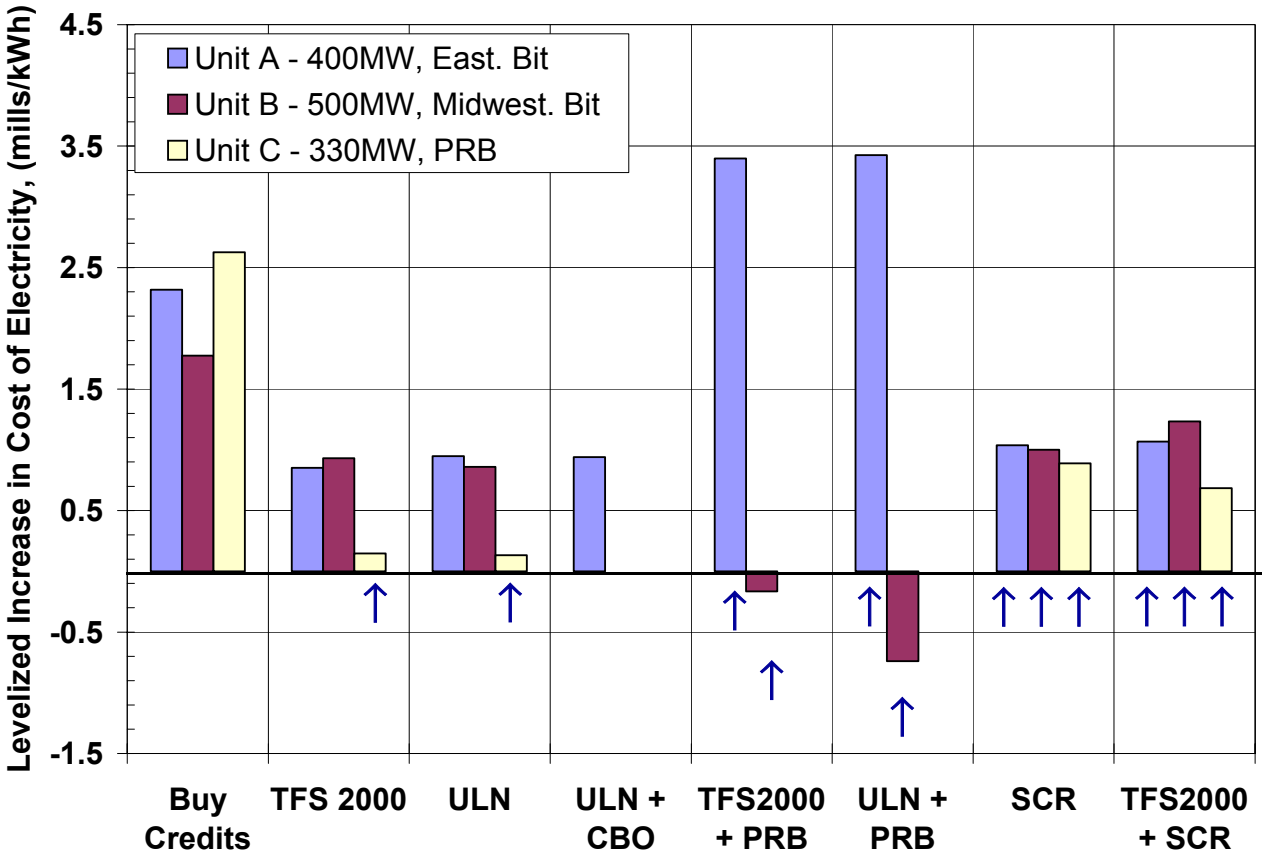
- **TFS 2000™ achieves good balance of NOx reduction and unburned carbon**
- **Ultra Low NOx Integrated System achieves up to 0.03 lb/MMBtu additional NOx reduction over TFS 2000™**
- **0.10 lb/MMBtu can be achieved with subbit coals and 0.15 lb/MMBtu can be achieved with hvb**



Alstom

Economic Analysis

Note: All cases meet NOx compliance by performance or purchased credits

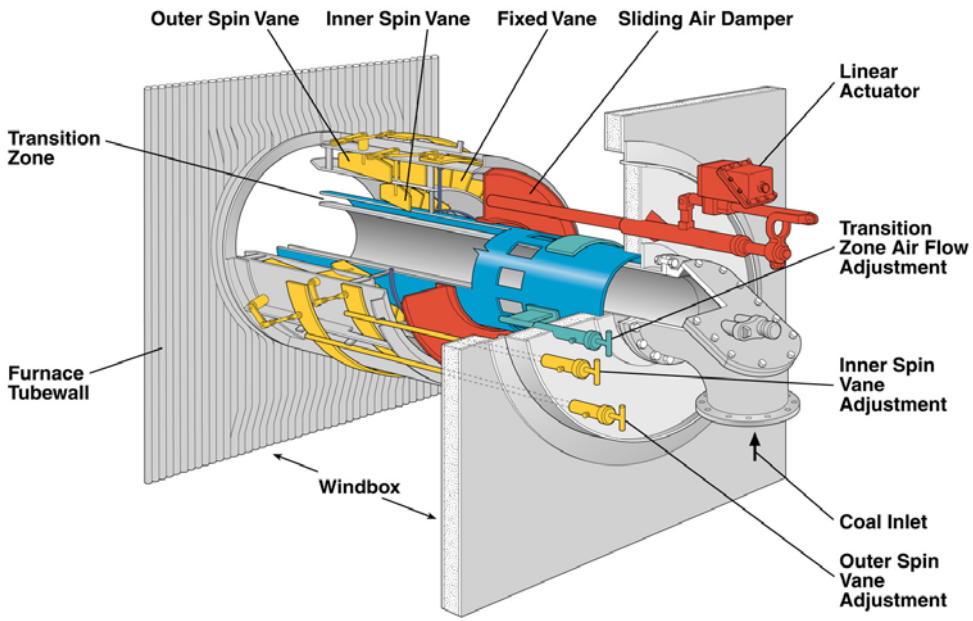


↑ = NOx compliant by performance

McDermott Technology and B&W

Cost-Effective Control of NOx with Integrated Ultra-Low-NOx Burners and SNCR

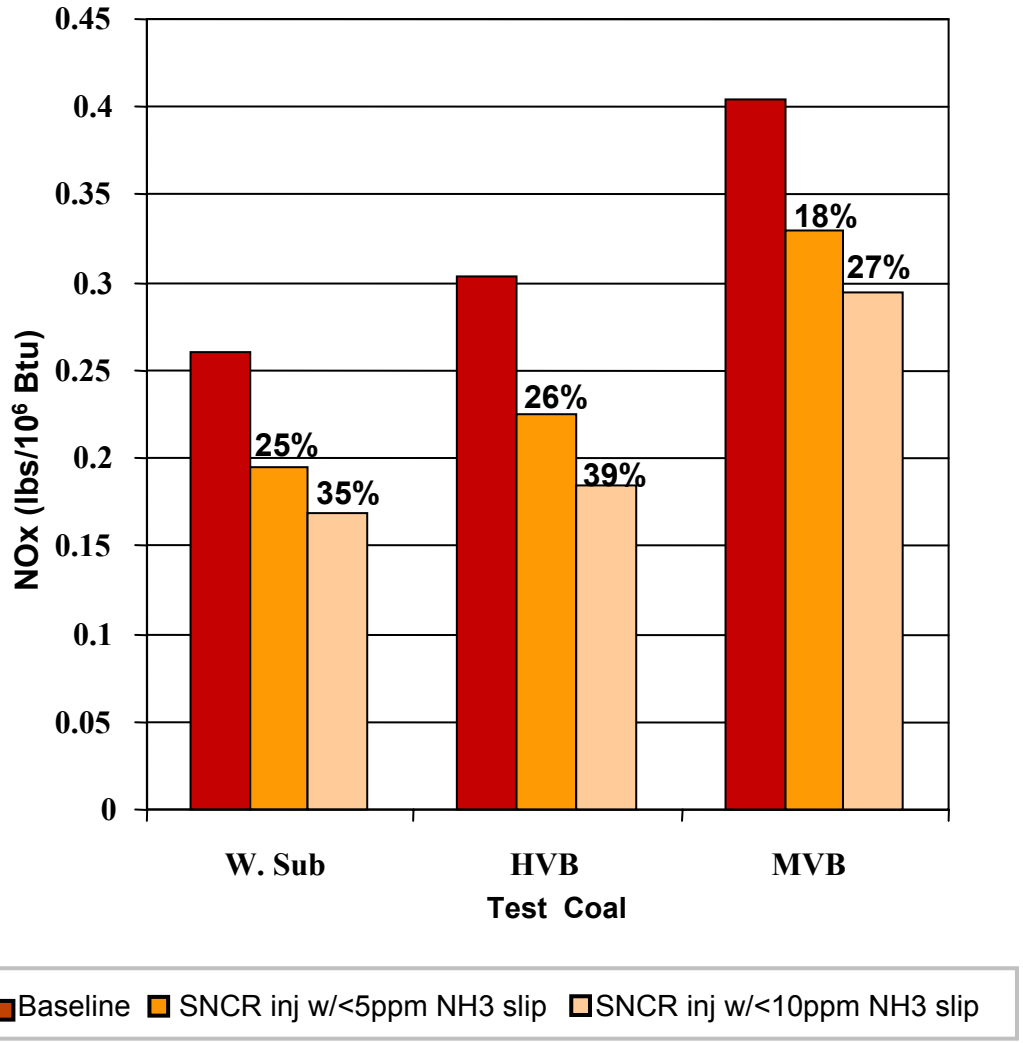
- **Optimize B&W's commercial DRB-4Z plug-in ULNB without OFA in 100 MMBtu/hr facility to achieve low in-furnace NOx levels**
- **Utilize standard grind for coal (75% through 200 mesh)**
- **Evaluate SNCR to determine its effectiveness at low combustion NOx levels**



McDermott Technology and B&W

Pilot Plant Test Results

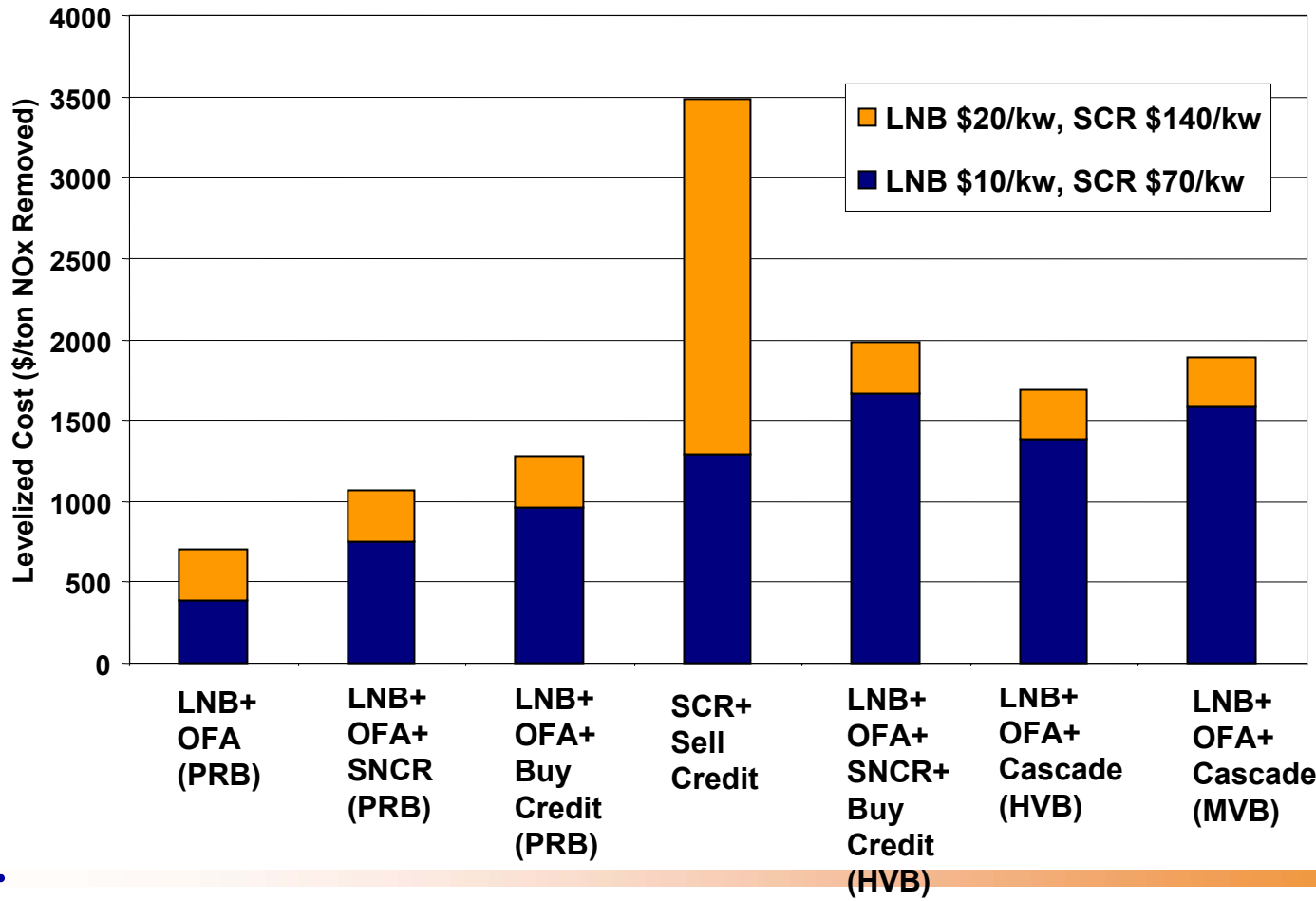
- Substantial NOx reductions were achieved without OFA
- Reactivity of coal was critical
- Side effects of ammonia slip were manageable
- Higher than expected furnace temperatures suggest utilization of SNCR water-cooled lance in front of superheater tubes
- NOx testing with OFA and lance to be conducted January 2004



McDermott Technology and B&W

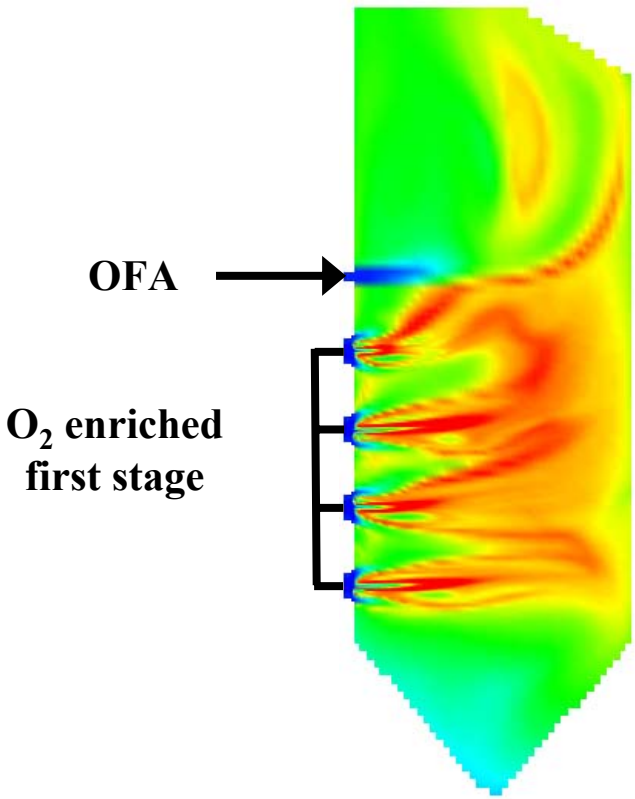
Economic Analysis

Note: All cases meet NOx compliance by performance or purchased credits



Praxair

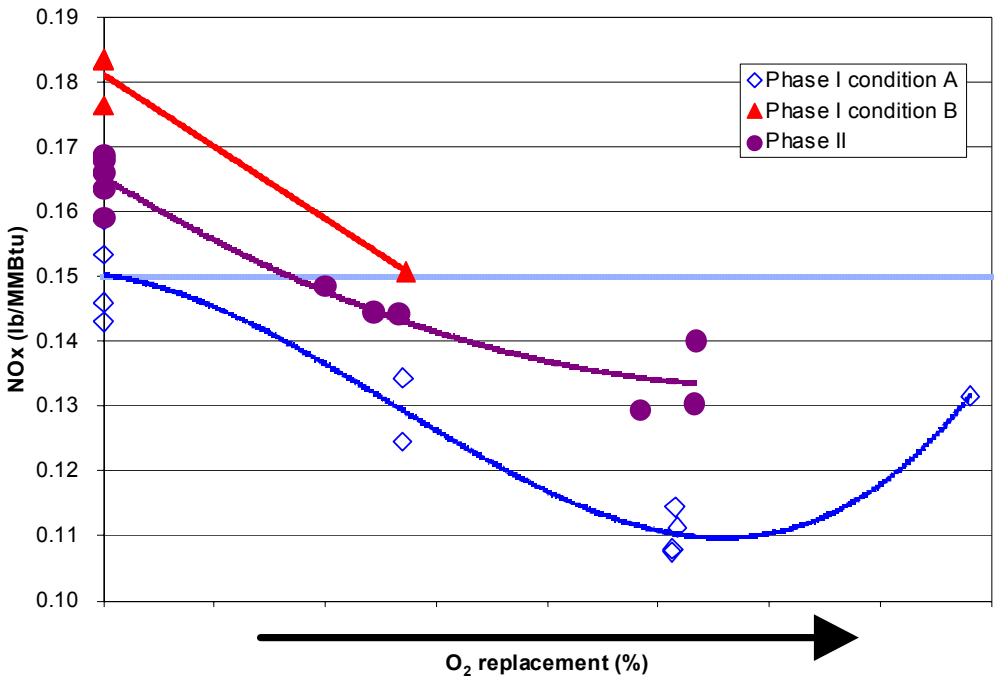
Oxygen Enhanced Combustion for NOx Control



- **Oxygen use can reduce NOx formation in the primary combustion zone**
  - O_2 anchors coal flame
  - O_2makes gas phase more fuel rich
  - O_2 increases temperature which enhances pyrolysis and accelerates NOx reduction kinetics
  - O_2 allows more fuel rich operation
- **Oxygen reduces LOI/Unburned Carbon**

Praxair
Pilot Plant Test Results

- CFD model used to evaluate concept and indicates O_2 addition reduces NOx
- Parametric studies suggested NOx emissions below 0.11 lb/MMBtu
- Even when initial NOx concentrations are low, O_2 addition reduces NOx even further

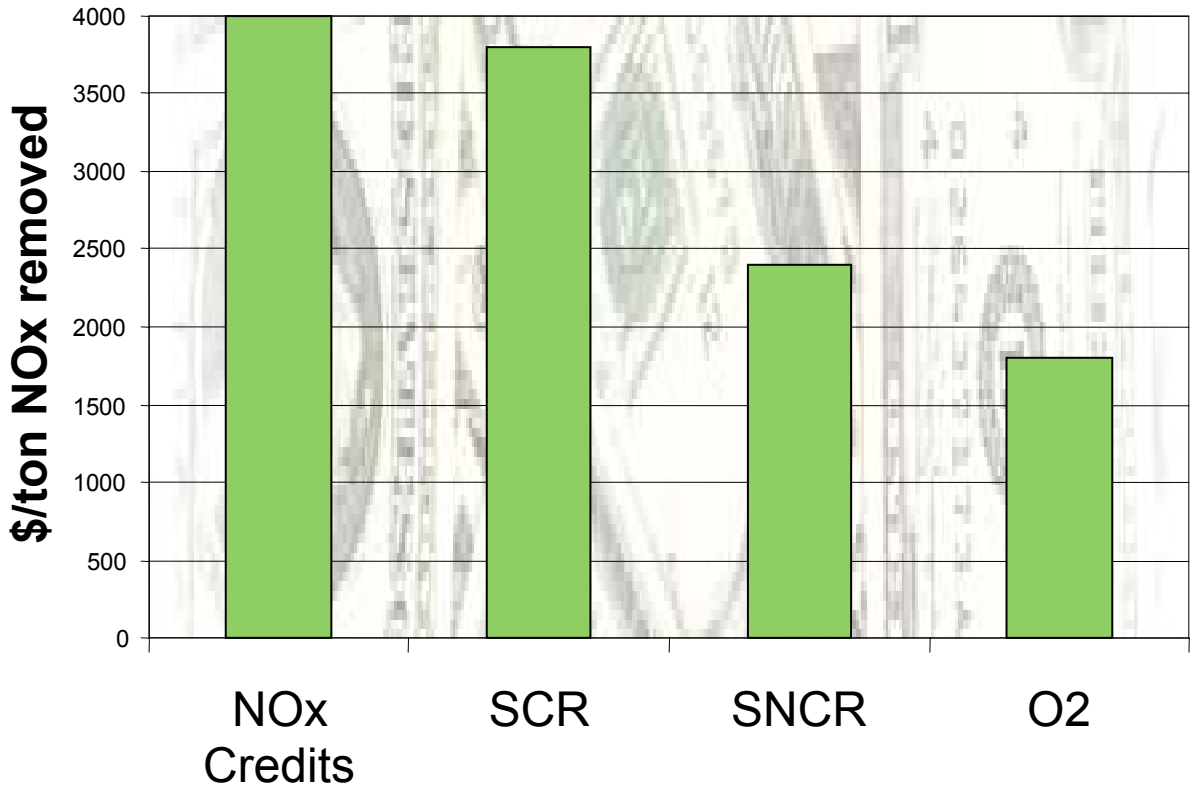


Praxair
Field Test Results

- **Oxygen enhancement demonstrated at 44 MW boiler**
  - NOx reduction 10-40% from staged air baseline
  - LOI reduction ~30% from staged air baseline
  - Opacity decreased, flame stability enhanced
  - Relatively small oxygen requirement
- **CFD modeling suggests negligible impact on waterwall wastage**
- **First commercial installation starting up Summer 2003**

Praxair

Economic Analysis

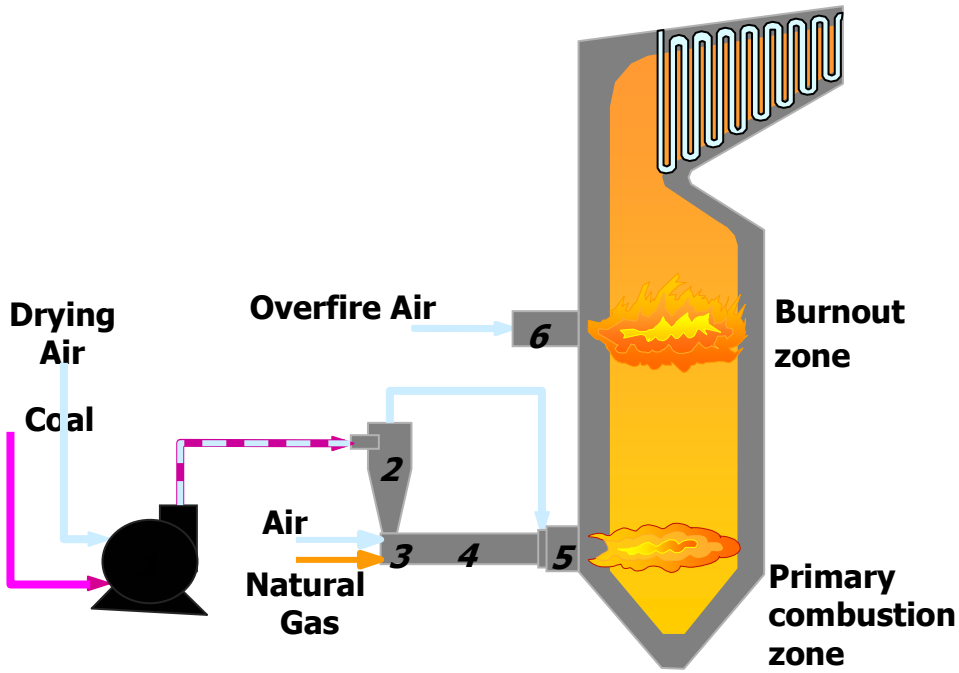


***Based on 5 month operation**

Gas Technology Institute

Pulverized Coal Preheating/METHANE De-NOX for Utility PC Boilers

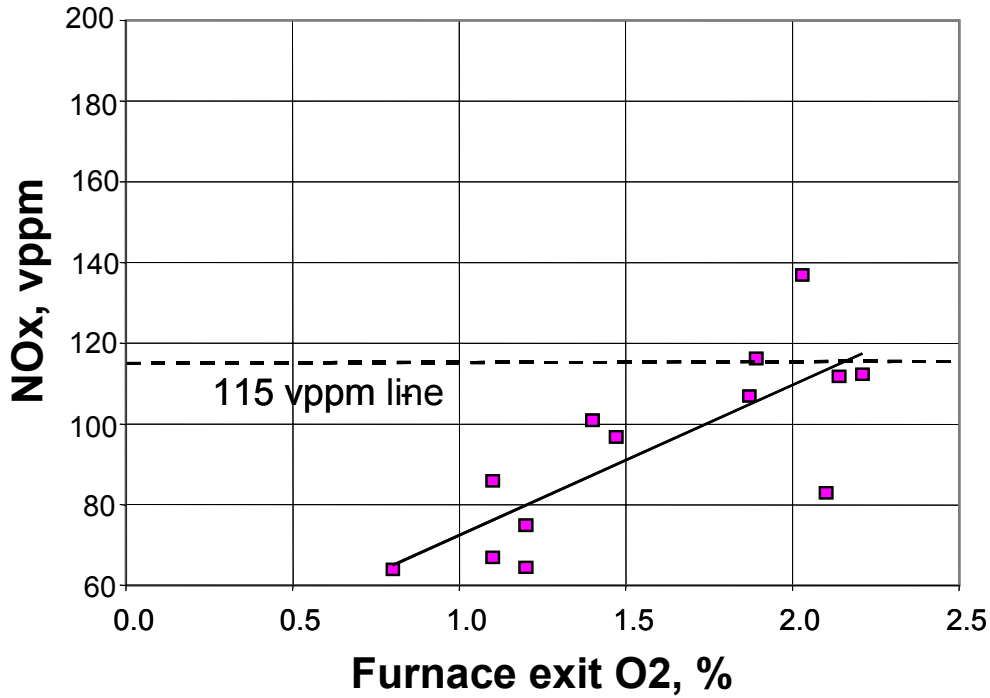
- Novel PC burner design using gas-fired coal preheating ahead of the primary combustion zone
- Natural gas replaces 3 – 8% of coal
- Internal combustion staging in burner (LNB)
- Additional natural gas injection in primary zone, integrated with overfire air in upper combustion chamber



1 Dryer/Pulverizer
2 Separator
3 NG burner
4 NG-fired PC preheater
5 PC burner
6 OFA injector

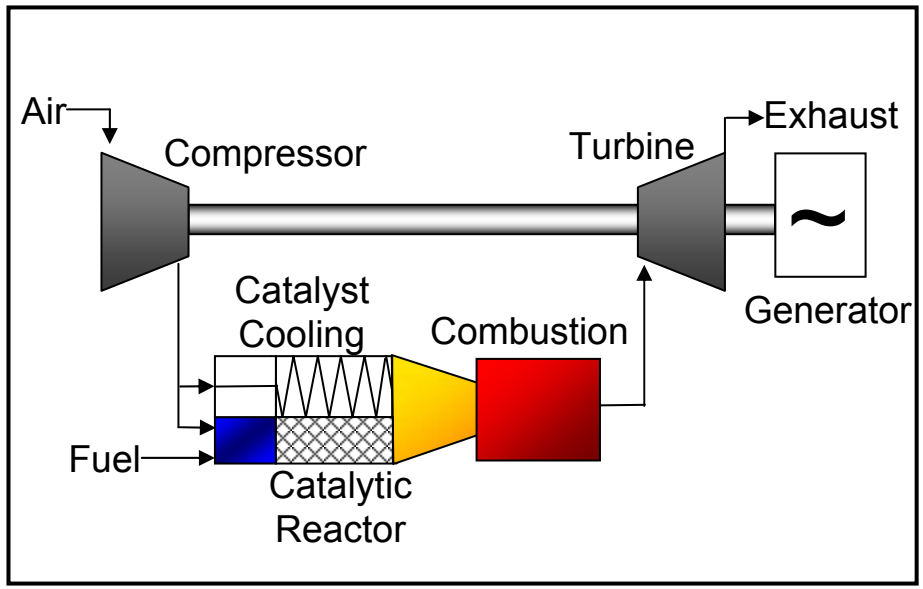
Gas Technology Institute
Pilot Plant Test Results

- NOx reduced to below 100 vppm with 35-112 vppm CO and 2% O_2 at boiler exit
- 115 vppm NO_x (0.15 lb/MMBtu) achieved with gas input as low as 8 % of total thermal input
- Resuts achieved without OFA
- Identified potential methods to minimize caking of coal
- Commercial prototype testing to be initiated in Fall 2003



Precision Combustion, Inc.
Catalytic Combustors for IGCC

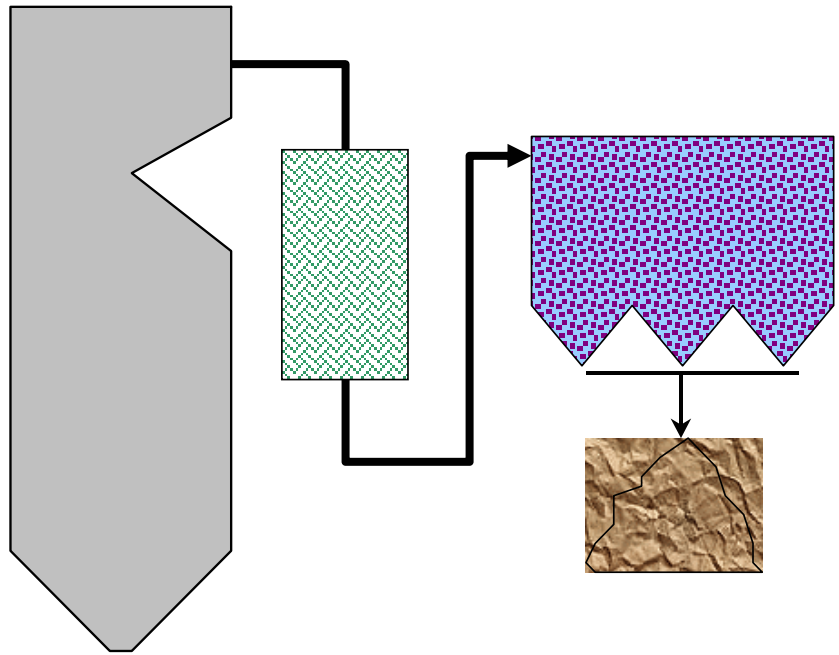
- **Development of catalytic burner for IGCC**
  - Fuel-rich partial oxidation on catalyst
  - Fuel-lean premixed combustion in gas phase
- **Benefits for Syngas combustion**
  - Improves flame stability with low Btu uels
  - Reduces flame temperature and corresponding NOx emissions (0.01 lb/MMBtu)
- **Pilot scale testing to be initiated in Fall 2003**



Reaction Engineering International

NOx Control Options and Integration for Coal-Fired Boilers

- **Evaluate problems associated with NOx control**
  - In Furnace
    - Waterwall Wastage
    - Soot Formation
  - Post-combustion
    - Analysis of SCR Poisoning
    - Fly Ash Ammonia Adsorption
- **Develop cost effective technologies**
  - Equipment/Testing
    - Corrosion Probe
  - In Furnace NOx Control
    - RRI for Cyclone Furnaces
    - RRI + OFA + SNCR + FLGR for PC Furnaces



Reaction Engineering International
Analysis of SCR Poisoning

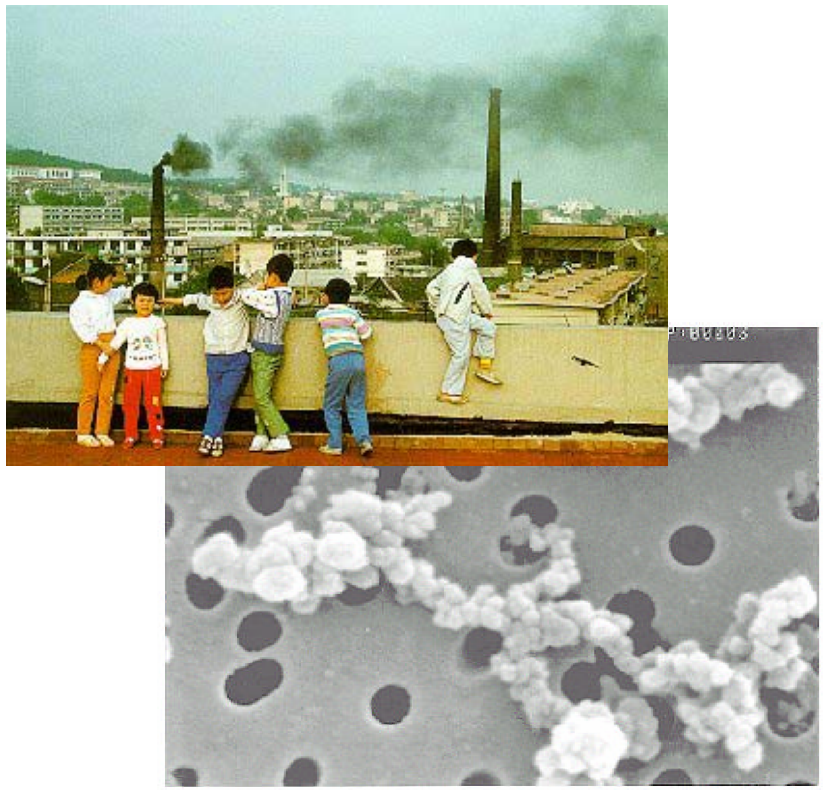
- **Impact of fuel selection for blending or switching can adversely affect SCR catalyst performance**
- **Develop predictive model for catalyst deactivation**
  - Fundamental laboratory analysis of SCR catalyst poisoning and regeneration
  - Multi-catalyst slipstream reactor to be tested at two utility boilers for six months
  - Formulate deactivation model based on laboratory and field testing
- **Both laboratory and slipstream studies are progressing at BYU and AEP's Rockport Station, respectively**

Reaction Engineering International
Monitoring Techniques for Corrosion

- **Low NOx combustion systems increase the rate of waterwall wastage due to:**
  - Thermal conditions – heat flux and tube temperatures
  - Gaseous species concentration – H2S, CO, O2
  - Solids deposition – unburned carbon and iron sulfide
- **Development of Corrosion Management System**
  - CFD model predicts boiler conditions leading to corrosion and the corresponding rate
  - Probe monitors the radiate section of boiler
  - Combination of probe and model provides operators with real-time data for avoidance of high corrosion rate conditions
- **Field test of Corrosion Management System will be initiated at AEP's Gavin Station in Fall 2003**

Reaction Engineering International
Development of Soot Formation Model

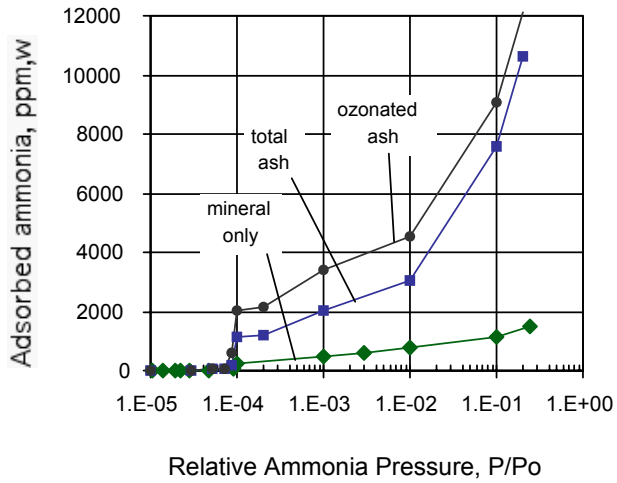
- **Low NOx combustion modifications can result in formation of sub-micron soot particles**
- **Impact of soot particles:**
  - Increases PM2.5 and opacity
  - Causes boiler heat imbalance
  - Decreases effectiveness of air staging
  - Reduces fly ash salability
- **Model is useful as a design tool to limit soot formation through burner stoichiometry, OFA placement, and improved mixing**

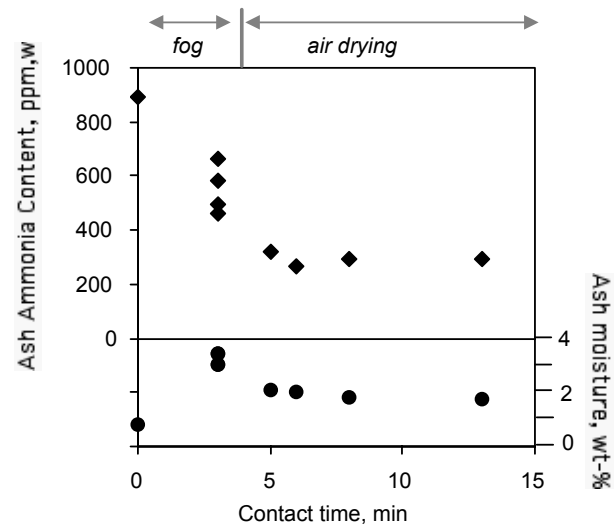


Reaction Engineering International

Evaluation of Fly Ash Ammonia Adsorption and Post Processing

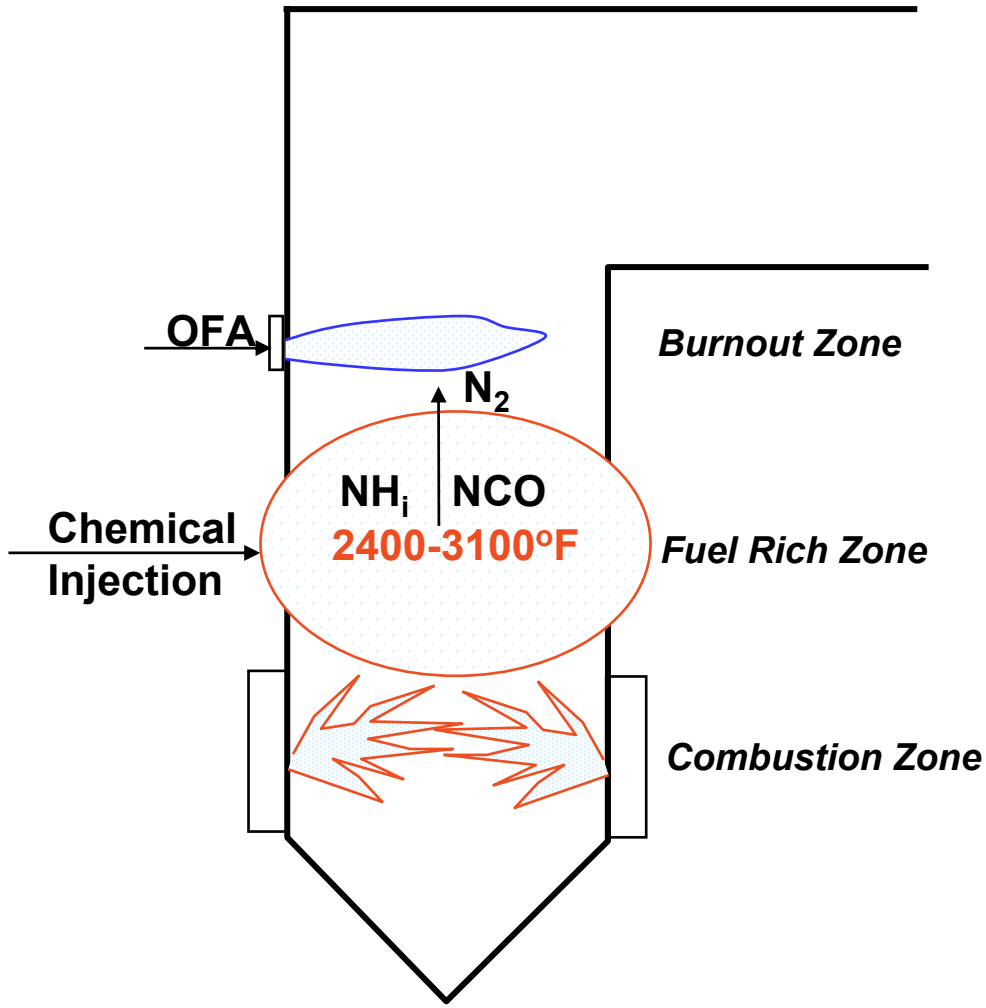
- **Use of SCR and SNCR can reduce the salability of the ash due to ammonia contamination**
- **Determine factors related to adsorption:**
  - Coal rank and sulfur content
  - Slip concentration
  - Duct temperatures
  - Ash carbon content
- **Evaluate individual and combinations of dry, wet and thermal removal processes**
- **Studies have shown that carbon content increases ammonia uptake and processing by water mist followed by air drying is effective for removal**





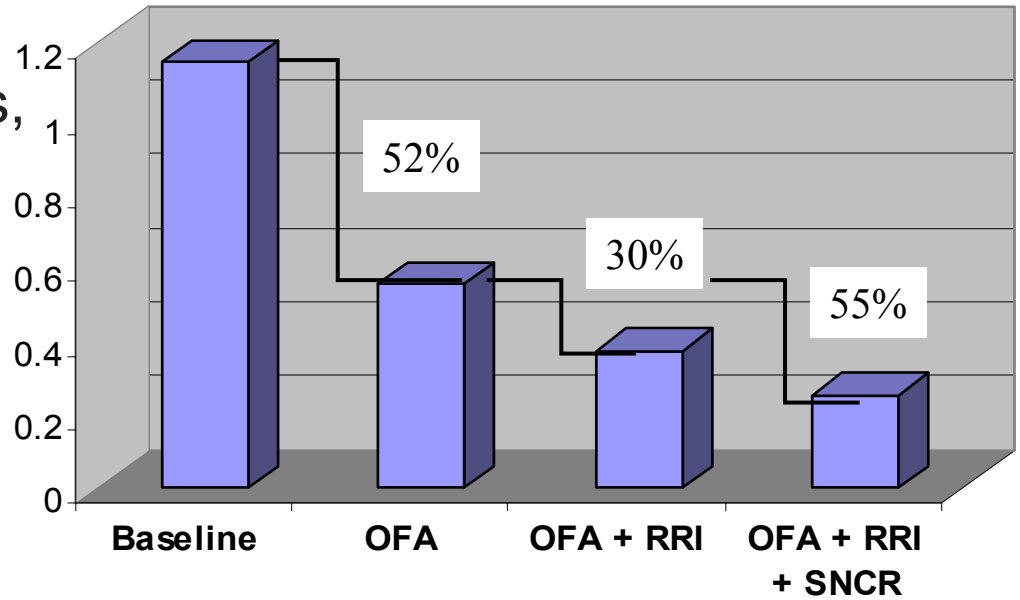
Reaction Engineering International
Rich Reagent Injection

- **Significant NOx reductions achievable with air staging for cyclone boilers**
- **Staging creates a hot, fuel rich lower furnace**
  - In-situ reburning
  - Increased NOx reduction with reduced SR and increased residence time
- **Amine reagents accelerate the rate of NOx reduction**
  - NOx reduction in rich zones
  - NOx formation in lean zones



Reaction Engineering International
Field Test Results

- **Conectiv's B.L. England Unit 1**
  - 130 MW, 3 cyclone barrels, front wall fired, OFA
  - Existing 3-zone SNCR hardware
  - 8 RRI ports/injectors installed for testing



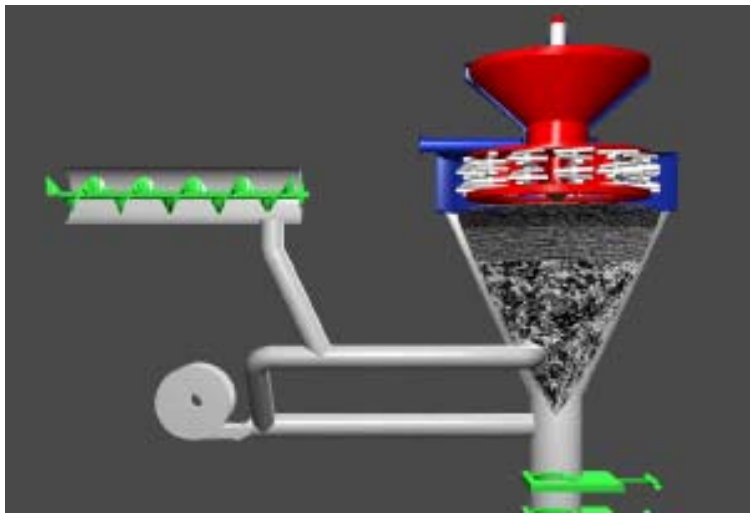
Reaction Engineering International

Economic Analysis

- **Capital Costs – Similar to SNCR**
  - RRI Alone: $8-$18/kW
  - RRI+SNCR: $12-$25/kW
- **Operating Costs**
  - RRI Alone: ~ $1500/ton
  - RRI+SNCR: ~ $1000/ton
- **RRI commercially available from two licensed implementers**

Wiley & Associates

Dense Phase Reburn Combustion System



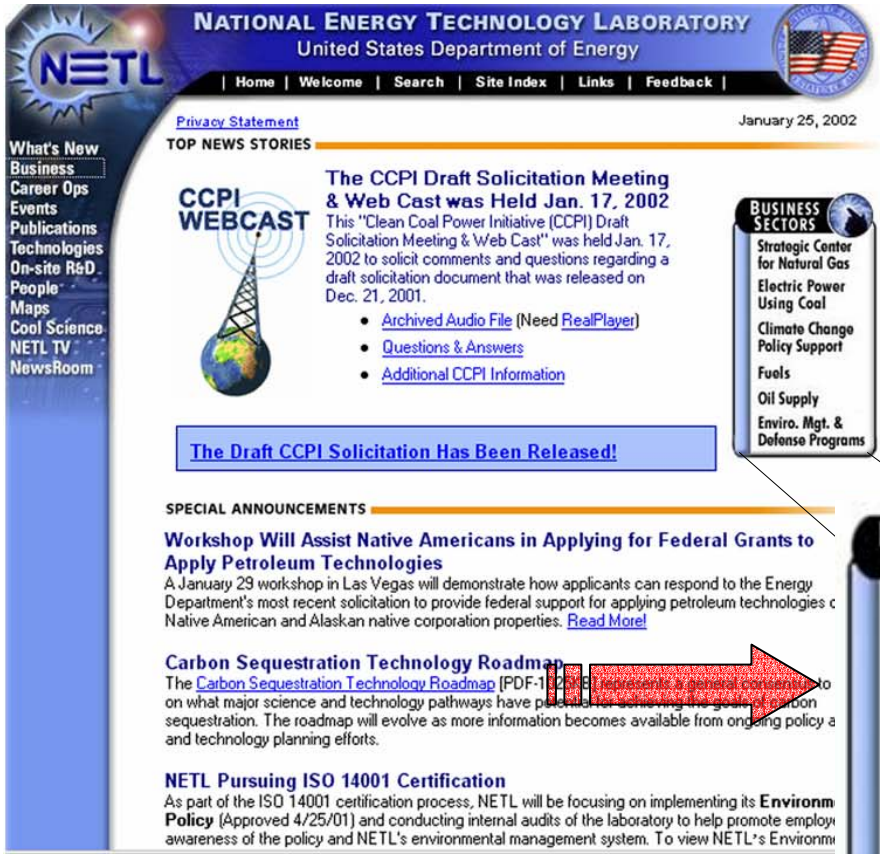
- **Demonstrate the advantages of micronized coal for NOx control (25-65%) in the boiler**
  - Staged Reburning
    - Gas performance at lower cost
    - Reduced LOI
  - Main Burner Co-firing
    - Improved flame stabilization
    - Tuning boiler stoichiometry
- **Develop the CentroFloat Mill**
  - High Speed Micronizing Mill
  - Rotating Assembly Rotates on Air Cushion
    - Accommodates milling upsets and variable feedstocks
- **Testing of combustion concepts conducted at CP&L's Cape Fear 5 Station**

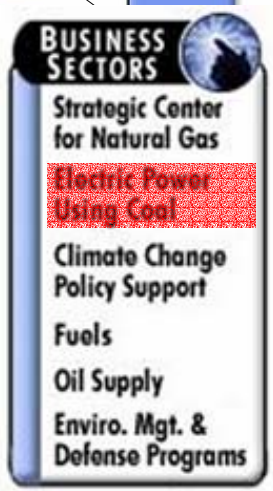
Visit Our NETL Website

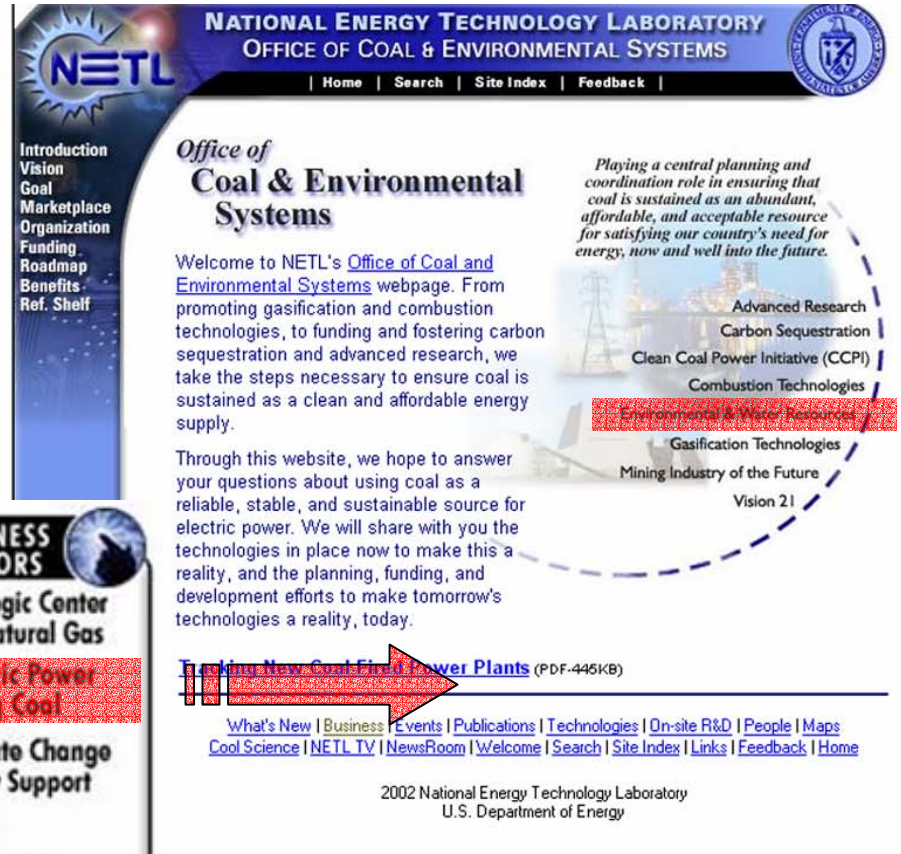
www.netl.doe.gov

Visit Our IEP Website

www.netl.doe.gov/coalpower/environment







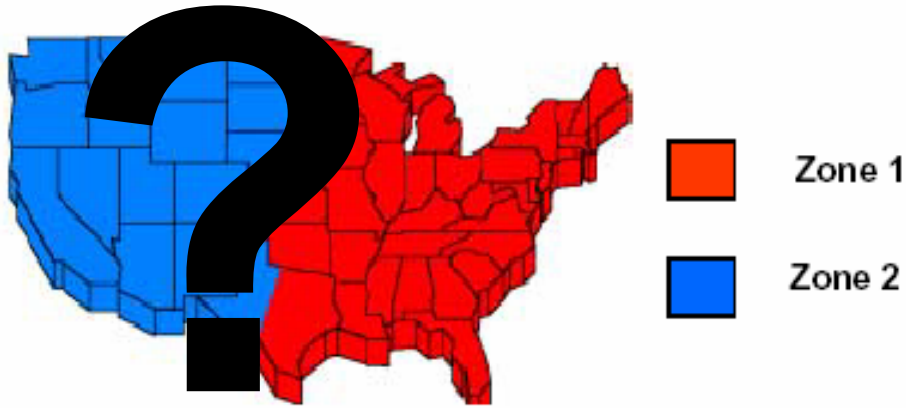
NETL's Proposed NOx Control Solicitation

Current Thoughts and Discussion

NETL's Proposed NOx Control Solicitation

Clear Skies NOx Program

- The Clear Skies Initiative has two trading zones for NOx.



NOx Caps Under The Clear Skies Initiative									
	2000 Emissions			2008 Caps			2018 Caps		
	Total	Zone 1	Zone 2	Total	Zone 1	Zone 2	Total	Zone 1	Zone 2
Caps *	**5.1 million tons**	4.35 million tons	750,000 tons	**2.1 million tons**	1.582 million tons	538,000 tons	**1.7 million tons**	1.162 million tons	538,000 tons
(effective emissions rate)	**(0.40 lb/mmBtu)**	(0.41 lb/mmbtu)	(0.33 lb/mmBtu)	**(0.16 lb/mmBtu)**	(0.15 lb/mmBtu)	(0.24 lb/mmBtu)	**(0.13 lb/mmBtu)**	(0.11 lb/mmBtu)	(0.24 lb/mmBtu)

* Numbers for 2000 represent actual emission levels, not caps.

NETL's Proposed NOx Control Solicitation

Objectives

- Develop combustion-based technologies capable of achieving NOx emissions of 0.15 lb/MMBtu or less for high volatile bituminous coal. These technologies should be available for commercial demonstration by 2005 – 2006.
- Develop combustion-based technologies capable of achieving NOx emissions of 0.10 lb/MMBtu or less for high volatile bituminous coal. These technologies should be available for commercial demonstration by 2010.
- Develop low temperature/dust, high efficiency SCR catalysts capable of achieving NOx reductions of 90%. These technologies should be available for commercial demonstration by 2015.
- Realize a cost savings at least 25% lower than SCR
- Improve understanding of the impact of these and existing technologies on balance of plant issues

NETL's Proposed NOx Control Solicitation

Advanced Combustion Concepts

- Advanced burner concepts for internal staged combustion.
- Burners that utilize pre-combustor, oxygen or other means to enhance coal pyrolysis and improve the reduction of NOx in staged combustion.
- Layered NOx reduction strategies and enhancements based on deep air staging with amine-based injection, reburn, etc.

NETL's Proposed NOx Control Solicitation

SCR Catalyst Development

- Catalysts that utilize reducing agents other than NH3 or NH3 derivatives.
- Catalysts that are more reactive and less prone to erosion.
- Catalysts that operate at temperatures typical to "cold-side" particulate collection devices.
- SCR monitoring instrumentation and software to provide real time information on catalyst operation and deactivation predictions for catalyst management.

NETL's Proposed NOx Control Solicitation

Enhanced Mercury Oxidation in the Combustor

- **Utilization of chemical injection/radical production with ultra-LNB, reburn, and/or SNCR technologies that would enhance Hg oxidation, thereby eliminating reliance on the SCR catalyst for oxidation.**

NETL's Proposed NOx Control Solicitation

Funding

- ~$1.0 million per year for FY-04, FY-05, & FY-06
- Minimum of 25% cost share

Schedule

- Solicitation Issued – December 15
- Proposals Received – February 15
- Awards – May 15

Scale*

- Pilot-scale
- Field test

* All technologies should have successfully completed prior bench-scale or pilot-scale testing to demonstrate capabilities and cost

NETL's Proposed NOx Control Solicitation

Discussion