Layered NOx Reduction Technologies for Effective NOx Control

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NOx Regulations

- Clean Air Interstate Rule
  - 0.15 lb/MMBtu for 2009
  - 0.12 lb/MMBtu by 2015
- Transport Rule (final by mid-2011)
- Carper/Alexander Legislation (2011?)
- Boiler MACT Rule
  - Sources < 250MMBtu
  - Final Rule by April 2012
- Other State Options and Rules
Reducing NOx Emissions

- Fuel Switching
- Combustion Tuning
- Combustion Controls
  - Low-NOx Burners
  - Over-Fired Air
- Post-Combustion Controls
  - Selective Non-Catalytic Reduction
    - Fuel-Rich Reducing Environment
    - Fuel-Lean Oxidizing Environment
  - Selective Catalytic Reduction

NOx Reduction Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Strengths</th>
<th>Limitations</th>
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<tbody>
<tr>
<td>Low-NOx Burners</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
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Reducing NOx Emissions

- How to Capture the Strengths?
- How do we expand the Limits?
- Are there Synergies?
- Customized Solutions:
  - Emission Requirements
  - Existing NOx Controls
  - Total Site Emissions: GHG, CO, etc.
- A Complete Site Perspective

A Complete Site Perspective

- Coal Specifications
- Combustion Systems: Burners & OFA
- Furnace Slag / Fouling
- Heat Rate and Furnace Efficiency
- Unit Capacity Factor
- Excess O2 / LOI
- Post-Combustion NOx Control
- SO2 and SO3
**Advanced SCR - ASCR™**

- A customized solution
- Advanced SCR reactor
  - Retrofit in existing footprint
  - Rapid Mixing and Flow Conditioning
- Provides Quality SCR NOx Control
  - LNBs and OFA
  - Advanced SNCR Application
  - 75%-85% NOx Reduction
  - Lower Capital Cost
  - Variable Operating Cost

**Layered NOx Reduction**

- Combustion NOx Control
  - Combustion Tuning
  - Low-NOx Burners
  - OFA
- Post-Combustion NOx Control
  - Rich Reagent Injection
  - Selective Non-Catalytic Reduction
  - Selective Catalytic Reduction
Combustion and LNB

- Combustion Tuning
  - Secondary Air Flow Testing
  - Coal Flow Testing
- Low-NOx Burners
  - Coal, Oil, Natural and Refinery Gases
  - Reduce O2 in the High-Temperature Flame
  - Rapid Heating to release volatiles
  - Provide Mixing to Complete Combustion
- OFA Systems
  - Reduce O2 in the Combustion Zone
  - Design an Efficient CO Burnout Zone

ULTRA LOW NOx BURNER

- 5:1 Turn Down
- Coal, Oil, Natural and Refinery Gases
- Reduce O2 in the High-Temperature Flame
- Rapid Heating to release volatiles
- Provide Mixing to Complete Combustion
- Design an Efficient CO Burnout Zone
Baseline Furnace Model

CO Profiles in Baseline Furnace
Flow Traces from New OFA
CO Profiles in Low-NOx Furnace

Controlling Risks LNB/OFA:

- Custom Fit to the Application
  - CFD Modeling
  - Physical Modeling
- Minimize Impact on Operations
  - Limited CO
  - Fuel Flexibility
  - More Balanced Furnace Conditions
- Guaranteed Performance
**Low-Nox Burner OFA System**

Effective Combustion!
Effective NOx Reduction
Effective CO Control
Room for SNCR

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**Post Combustion Controls**  
**Selective Non-Catalytic Reduction**

Urea SNCR Chemical Reaction

\[2\text{NO} + \text{NH}_2\text{-CO-NH}_2 + \frac{1}{2}\text{O}_2 \rightarrow 2\text{N}_2 + \text{CO}_2 + 2\text{H}_2\text{O}\]

Ammonia SNCR Chemical Reaction

\[2\text{NO} + 2\text{NH}_3 + \frac{1}{2}\text{O}_2 \rightarrow 2\text{N}_2 + 3\text{H}_2\text{O}\]
**SNCR Technology Overview:**

- In-furnace, Post-combustion Control
  - Injection of Aqueous Urea Droplets
  - 25 – 70% NOx Reduction
  - Many Injection Options:
    - Compressed Air
    - Mechanical
    - Multiple Nozzle Lances – Water Cooled
  - Package Boilers to Utility Boilers
  - Effective on All Fuels and Blends

**SNCR Process Application**

- Computational Fluid Dynamics
- Chemical Kinetics Model
- Injection Model
$SNCR \, Temperature \, Window$

BL Nox = 0.47 lb/MBtu, CO = 250 ppm, NSR = 1.05

Chemical Release Temperature [deg F]

Final NOx (lb/MBtu)

NH3 Slip (ppm)

NOx = 0.30 (36% Reduction)

NOx = 0.20 (57% Reduction)

NOx = 0.14 (70% Reduction)

$SNCR \, Low-Temperature \, Surface$
NOx Reduction Contour

Optimized SNCR Performance
**Controlling Risks SNCR:**

- Carefully Target the Injection Zone
  - CFD Modeling
  - Field Assessments / Demonstrations
- Understand the Chemistry
  - Urea and ammonia Mechanisms
  - Ammonium Bisulfate Formation
- Refer to Experience Database
  - More Than 500 Applications
  - More Than 100 Utility Furnaces

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**Post Combustion Controls**  
**Selective Catalytic Reduction**

- NH3 and NO React over a Catalyst
  - 600F to 700F
  - Very High Reductions / Utilization
- Limitations
  - Capital Cost Modifications
  - Poisons and High Dust Issues
  - Temperature Limits: SO3 formation
  - Pressure Drop
**Controlling Risks SCR:**

- Lower the NOx Baseline
  - Decrease Ammonia Slip
  - Increase Performance of the SCR
- Utilize a Simple Single-layer SCR
  - Reduced Capital and Risk
  - Reduced SO3 and Pressure Drop
- Advanced Design
  - Best Available Flow Mixing
  - Uniformity of Gases at Catalyst Face

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**Lower the Baseline to Improve SCR Performance**

![Graph showing NOx removal efficiency vs. NOx Inlet PPM](image)

Single Layer of Catalyst
ASCR - Advanced

- A Synergistic Layering of NOx Control
  ♦ SCR Levels of NOx Control
  ♦ Flexibility vs. Uncertainty
  ♦ Improved Operation of all Components
  ♦ Guaranteed Performance

♦ Does this introduce Risk?
### Combining NOx Reduction Technologies

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### Retrofit Low-NOx Burner Installation

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### Conservative SNCR application

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<td>Low Capital NOx Red%</td>
<td>No NH3 Slip, No ABS</td>
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## Aggressive SNCR application

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## In-Duct or Small SCR Space

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<td>SNCR</td>
<td>Low Capital &gt; Red%</td>
<td>NH3 is OK, Feed to SCR</td>
</tr>
<tr>
<td>Small SCR</td>
<td>More Red%, Low NH3 Slip</td>
<td>Mod Capital, SO₃ and Cost</td>
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### Advanced SCR Application

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<th>Reduction</th>
<th>Total %</th>
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<tbody>
<tr>
<td>Low-NOx Burners</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Combustion Mods / OFA</td>
<td>30%</td>
<td>51%</td>
</tr>
<tr>
<td>SNCR</td>
<td>30%</td>
<td>66%</td>
</tr>
<tr>
<td>Small SCR</td>
<td>45%</td>
<td>81%</td>
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### Layered NOx Solutions

- Utilize Optimal Technology Suite
- Customized to Reduce Risks
- Balanced to Reduce Costs
  - Capital vs. Operation Costs
  - Variations in Fuel and Capacity
- Best Possible Performance
  - NOx Reduction
  - Secondary Impacts (BOP)
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