SNCR Operation Workshop

February 7, 2011
NO$_x$ Roundtable Conference
Birmingham, AL
Kevin Dougherty - Fuel Tech
Fuel Tech Overview

• FUEL CHEM® Technology
  – Boiler Efficiency and Availability Improvements
  – Slag and Corrosion Reduction
  – Controls SO₃ Emissions and Addresses Related Issues

• Innovative Approaches to Enable Clean Efficient Energy
  – Capital Projects for Multi-Pollutant Control
  – NOₓOUT® Products including SNCR, CASCADE, RRI, ULTRA
  – Flue Gas Conditioning Systems for Particulate Control – Outside US and Canada
  – Sorbent Injection for SO₂ Control

• Flow Modeling and SCR Catalyst Management Services
  – Computational Flow Dynamics and Physical Flow Modeling for Power Plant Systems
  – SCR System Optimization and Catalyst Management Services

• Technology solutions based on Advanced Engineering Computer Visualization and Modeling

• Strong Balance Sheet (Stock Symbol: NASDAQ – FTEK)
Recent Developments

- Full Spectrum of Multi-Pollutant Control Options to Minimize Capital Investment and Maximize Performance
- Mercury
  - TIFI through SO$_3$ Mitigation Improves Hg Capture
  - NO$_x$OUT Cascade provides 90+% Hg Oxidation with a single layer of SCR Catalyst
- Particulate
  - Flue Gas Conditioning Injection Systems for ESP Performance Enhancements
  - Markets Outside the US and Canada where Coal Ash is more difficult for ESP collection
  - Sonic Horns for Economizer and Backend Issues
- SO$_2$ - Sorbent Injection Systems Low Capital Option (30-40% Reduction)
- SO$_3$ - TIFI controls backend issues
- Large Particle Ash - TIFI reduces Popcorn Ash Cleaning
Fuel Tech’s Global Presence

Office Locations: Warrenville, IL; Stamford, CT; Durham, NC; Milan, Italy; Beijing, China
Countries where Fuel Tech does business: USA, Belgium, Canada, China, Columbia, Czech Republic,
Denmark, Dominican Republic, Ecuador, France, Germany, India, Italy, Jamaica, Mexico, Poland, Portugal, Puerto Rico,
Romania, South Korea, Spain, Taiwan, Turkey, United Kingdom, Venezuela
Our Locations

Durham, NC
Durham, NC
Stamford, CT
Milan, Italy
Warrenville, IL
Beijing, China
Typical Power Plant
FUEL CHEM®

- Multiple Solutions
- Operating Program
- Overview
FUEL CHEM® Program

• Slag – the iron, sodium and other minerals in coal that do not burn

• Above the ash fusion temperature these minerals melt and adhere to steam pipes and boiler walls

• More economical coals can have higher slagging properties

• Traditional removal methods
  - During Operations:
    • Air / water cannons
    • Thermal shocking
  - Shotguns
  - During Outages (6-10 days):
    • Dynamite
    • Mechanical Removal with Scrapers / Chisels / Etc.
FUEL CHEM® Program Benefits

• Efficiency
  - Recovery of Derated MW
  - Heat Rate Improvement for Steam Production
  - Reduced Fan Power Requirements
  - Reduced Sootblowing
  - Reduced Operating O₂ Level
  - Reduced CO in Furnace and at the Stack
  - Increased Fuel Flexibility

• Availability and Reliability
  - Reduced Forced Outage Time
  - Reduced Derates
  - Increased Capacity and Boiler Availability
  - Reduced Outage Cleaning Times
  - Reduced Exit Gas Temperatures
FUEL CHEM® Program Benefits

• **Environmental**
  - CO₂ Reduction
  - SO₃ Reduction
  - Opacity Improvement
  - Promotes Mercury Capture
  - Reduced Large Particle Ash (LPA)

• **Safety**
  - Reduced Maintenance Operations

• **Maintenance**
  - Reduced Corrosion in Economizer, Air Heater, Ductwork, and Stack
  - Reduced Clinker Grinder Maintenance
  - Tube Life Extension
    - Reduced Sootblowing
    - Reduced Slag Damage
  - Reduced Cleaning Expenses
    - Less Explosives
    - Lower Water Consumption
TIFI® Targeted In-Furnace Injection™ Technology

- Improves Fuel Flexibility
- Reduces Slagging and Fouling
  - Providing Greater Boiler Efficiency
- SO$_3$ Plume & Opacity Control
- Heat Rate Improvement

Fuel Types

<table>
<thead>
<tr>
<th>Coal</th>
<th>Alternative Fuels</th>
<th>Residual Fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRB</td>
<td>Biomass</td>
<td>No. 6 Fuel</td>
</tr>
<tr>
<td>ILB</td>
<td>Pet Coke</td>
<td>Waste Oil</td>
</tr>
<tr>
<td>Lignite</td>
<td>Hog Fuels</td>
<td>Bunker C</td>
</tr>
<tr>
<td>CAPP</td>
<td>WTE Fuels</td>
<td>Liquid Waste Fuels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Black Liquor</td>
</tr>
</tbody>
</table>
## TIFI® Technology Overview

<table>
<thead>
<tr>
<th>TIFI MG™</th>
<th>TIFI XP™</th>
<th>TIFI MP™</th>
<th>TIFI Flux™</th>
<th>TIFI BlueCat™</th>
<th>TIFI Hybrid™</th>
<th>TCI™</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Utilizes magnesium hydroxide slurry</td>
<td>• Builds upon TIFI technology</td>
<td>• Furnace chemical injection program</td>
<td>• Specifically designed for cyclone boilers</td>
<td>• Copper based product</td>
<td>• Designed for oil-fired boilers</td>
<td>• Designed principally for boilers in the waste-to-energy (WTE) industry</td>
</tr>
<tr>
<td>• Sprayed into the combustion unit at locations defined by computer modeling.</td>
<td>• Designed to provide users both slag control and fuel flexibility.</td>
<td>• Uses two reagents for the reduction of SO₂</td>
<td>• Focused on burning PRB and other low iron coals</td>
<td>• Used to lower carbon monoxide (CO) and unburned coal (LOI)</td>
<td>• Uses a combination of TIFI MG combined with in-fuel injection</td>
<td>• Inhibits corrosion and slag build-up</td>
</tr>
<tr>
<td>• TIFI MG solution reacts with slag as it is forming and penetrate existing deposits.</td>
<td>• Allows users to burn less-expensive, yet higher-slagging coals such as ILB</td>
<td>• Allows users to burn less-expensive, yet higher-slagging coals such as ILB</td>
<td>• Can be used in combination with TIFI MP to provide SO₂ trim control</td>
<td>• Can be used in combination with TIFI MP to provide SO₂ trim control</td>
<td>• Can be used in combination with TIFI MP to provide SO₂ trim control</td>
<td>• Can be used in combination with TIFI MP to provide SO₂ trim control</td>
</tr>
</tbody>
</table>

TCI TCI™
Air Pollution Control Technologies
# APC Technology Overview

## Combustion

- **LNB**
  - 40-60% NO\textsubscript{x} Reduction
  - Industrial & utility applications
  - Upgrades to existing burners available

- **OFA**
  - 35-70% NO\textsubscript{x} Reduction over Low NO\textsubscript{x} burners
  - Unique port design enhances mixing to limit impact on combustion efficiency

## Post-Combustion

- **SNCR**
  - 20-50% NO\textsubscript{x} Reduction
  - Urea-based maximized performance with minimal ammonia slip

- **ASCR**
  - 80+% NO\textsubscript{x} Reduction
  - 30-70% Less capital than traditional SCR

- **ULTRA**
  - Proprietary urea conversion process to generate ammonia for SCR systems
  - Safer than ammonia
  - Compatible with a wide range of urea sources
NOx Regulations

- Clean Air Interstate Rule
  - 0.15 lb/MMBtu for 2009
  - 0.12 lb/MMBtu by 2015
- Transport Rule (final by mid-2011 for 2012 compliance)
- Transport Rule 2 (final by 2012 for 2014 compliance)
- Carper/Alexander Legislation (2011?)
- Boiler MACT and CISWI Rule
  - MACT Sources < 250MMBtu
  - Final Rule by February 2012 – 3 years to implement
- 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
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
NOx Reduction Strategies

• Cost Effective Total NOx Reduction
  - Starts with Combustion
  - Capitalize on Synergies of Combining Technologies
  - Get Guaranteed Performance on each Technology

• Fuel Tech Advanced SCR (ASCR)
  - LNB/OFA
  - SNCR
  - Reduced SO\textsubscript{3} Levels
  - ASCR catalyst will provide Hg Oxidation
  - Reduced On-going Catalyst Replacement Costs
  - NOx Reduction at Low Boiler Load and Low SCR Temperature
  - 80-85% Combined NOx Reduction
NOx Reduction Technologies

Post-Combustion Options without Full Scale SCR

- **SNCR - NO\textsubscript{x}OUT\textsuperscript{®} and HERT Systems**
  - $5-20/kW Capital Cost including Installation
  - 25-50% Reduction
- **SNCR/RRI**
  - $7-22/kW and 40-60% Reduction
- **ASCR™ Advanced SCR Systems**
  - $30-75/kW and 65-85% Reduction

Full Scale SCR Technology

- Up to $300+/kW with 85-90% Reduction
- Fuel Tech Option for Safe Urea Reagent Supply – ULTRA™ ($2-3M Capital)
NOx Reduction Technologies – Summary

- Low Capital Cost NOx Reduction Solutions
- Guaranteed NOx Reduction Process Performance and Compliance Assurance
- Complete Plant/Process Integration & Seamless Control
- Minimal Maintenance Requirements & Proven System Reliability
- Full Line of NOx Control Solutions
- More Than 25 Years Serving Owners of Power and Steam Generating Facilities
APC Installed Experience

• Advanced Combustion Systems
  – Over 100 Units to Date for Low NOx Burners, OFA, and Combustion Optimization from 20 MW to 1200 MW

• NOxOUT® and HERT™ SNCR Systems
  – Over 600 Units to Date, With > 100 Utility Units
  – All Combustion and Fuel Types

• NOxOUT ULTRA® Systems
  – Over 24 Units to Date, 5 to 1,250 PPH of SCR Reagent Feed Systems

• SCR Design and Modeling Services
  – Over 55,000 MW’s of SCR Design, 20,000 MW’s of AIG Tuning
  – Modeling Solutions for Scrubbers, ESPs, FF, Dry Sorbent, HXs, Etc.
Selective Non-Catalytic Reduction (SNCR)
SNCR Technology Overview: NOxOUT® and HERT™ Systems

- In-furnace, Post-combustion NO\textsubscript{x} Control
- Injection of Urea in Upper Furnace
- Process Reaction
  Temperature Range: 1600°F to 2200°F
- NO\textsubscript{x} Reduction Range
  - Utility Boilers: 25 to 50%
  - Industrial Boilers: 30 to 70%
Selective Non-Catalytic Reduction

**SNCR Process Chemical Reactions**

(1) \[ 4\text{NO} + 2\text{CO(NH}_2\text{)}_2 + \text{O}_2 \Rightarrow 4\text{N}_2 + 4\text{H}_2\text{O} + 2\text{CO}_2 \]

(2) \[ 2\text{NO}_2 + 2\text{CO(NH}_2\text{)}_2 + \text{O}_2 \Rightarrow 3\text{N}_2 + 4\text{H}_2\text{O} + 2\text{CO}_2 \]

Nitrogen Oxides + Urea + Oxygen \(\Rightarrow\) Nitrogen + Water Vapor + Carbon Dioxide

*Typically 95% of NOx is associated with Eq 1*
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
  – Option for Aqueous or Anhydrous Ammonia
Advantages of Fuel Tech’s SNCR System

- Guaranteed Proven NOx Reduction
  - 15 – 35% Utility
  - 20 – 70% Industrial/Incineration
  - Repeatable
  - Controlled NH3 Slip
- Low Capital Cost
- Fast Implementation
- Turn On/Off As Needed
- Compatible with Other APC Technologies
  - LNB/OFA
  - ASCR or SCR
  - ESP’s and Fabric Filters
Urea vs. Ammonia for SNCR

Urea droplets formed by FTI injectors are characterized in test facilities using laser Doppler techniques.
SNCR Boiler and Fuel Experience

Utility Boilers
- T-fired
- Wet Bottom
- Wall Fired
- Cyclone
- Tower

Industrial
- Circulating Fluidized Bed
- Bubbling Fluidized Bed
- Stoker, Grate Fired
- Incinerators
- Industrial

 Coal
- Bituminous
- Sub-bituminous
- Lignite

Other Fuels
- Oil – #2 and #6
- Natural Gas
- Refinery Gases (High CO)
- Municipal Solid Waste
- Tire Derived Fuel
- Wood
- Sludge
SNCR Systems – Industry Experience

- Electric Utilities
- Wood-fired IPPs / CoGen
- TDF Plants
- Pulp & Paper
  - Grate-fired
  - Sludge Combustors
  - Recovery Boilers
  - Wellons Boilers
  - Cyclones
- Refinery Process Furnaces
- CO Boilers
- Petrochemical Industry
- CoGeneration Boilers
- Municipal Solid Waste
- Process Units
- Cement Kilns
Rich Reagent Injection (RRI) Technology Overview

- 40 to 60% NO\textsubscript{x} Reduction Combined with SNCR on Cyclone Boilers
- NO\textsubscript{x} Reduction in 30% Range with RRI Only
- Non-catalytic Reduction of NO\textsubscript{x} via Urea Injection in Sub-stoichiometric Conditions (SR: 0.85 to 0.95)
- No Reagent Slip Due to High Residence Time and Reagent Oxidation in the Burnout Zone
- Process Reaction Temperature Range: 2600°F to 3100°F
- Technology Licensed from REI
SNCR PROCESS
DESIGN AND
MODELING
SNCR Critical Process Parameters

- Effective Temperature Window for Chemical Release and Reaction – 1600°F to 2200°F, Depending on Application
- Temperature too High ⇒ NH2 Oxidation to NOx, Temperature too Low ⇒ Ammonia Slip
- Flue Gas Velocity and Residence Time Considerations
- Background Gas Composition – NOx, CO, O₂, and Sulfur Content of the Fuel
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
SNCR Process Design

Computational Fluid Dynamics (CFD)
Used to Define Effective Boundaries of Critical Process Parameters, Test Effectiveness of Distribution Strategies, Identify/Locate/Define Gas Species Concentrations – Physical Unit Data (Drawings, etc.) and Field Testing as Input

Chemical Kinetic Model (CKM)
Used to Calculate Each Specific Time/Temperature Reduction Reaction – Overlay the SNCR Process on the CFD
SNCR Process Application

- Computational Fluid Dynamics
- Chemical Kinetics Model
- Injection Model
SNCR Process Modeling Steps

Step 1: Define the Unit Geometry
Step 2: Block Out Obstructed Cells and Faces
Step 3: Define Mass and Heat Sources
Step 4: Solve for Flue Gas Temperatures and Velocities
Step 5: Generate Temperature Versus Residence Time Data for CKM
Step 6: Identify Temperature Limits for Effective NOxOUT Performance
Step 7: Select Injector Locations and Spray Characteristics
Baseline Testing (HVT) for CFD/CKM

- High Velocity Thermocouple Suction Pyrometer and Portable Gas Analyzer Used to Gather Temperature and Flue Gas Composition
- Develop Grid of Measurements Based on Actual Operating Conditions
- Build CFD Model Using Data Gathered from Field
- Overlay SNCR Process on CFD to Determine Reagent Distribution and Performance
Temperature and Species Mapping

• Three (3) Boiler Loads
  – Full, Mid, and Low Load Depending on NOx Removal Requirements

• Typical One (1) Week Service
  – One (1) Field Engineer, Two (2) Technicians

• Fuel Tech to Provide All Equipment Including High Velocity Thermocouple (HVT), Cooling Water Pumps, Hoses, and Analyzers

• Scope By Others
  – Maintain Steady State Boiler Conditions for 4 – 6 Hours per Load
  – DCS Data during Testing
  – Water and Electrical Hook-ups
  – Observation Doors or Ports for HVT Testing
  – Fuel and Operational Data, Boiler Drawings
SNCR Baseline Testing - HVT

Fig 1.3-1 HVT Probe

HVT PROBE

RADIANT HEAT SHIELD

WATER INLET

WATER OUTLET

1/4" S.S. GAS SAMPLING NIPPLE

3/4" BALL VALVE

ASPIRATOR

AIRFLOW
SNCR Baseline Testing - HVT

- Temperature Measurement and Gas Species
- Temperature Measurement Only

Diagram showing temperature measurement locations on the boiler's left and right walls, as well as the front wall.
SNCR Baseline Testing - HVT

<table>
<thead>
<tr>
<th>Depth</th>
<th>Temp.</th>
<th>%Oxygen</th>
<th>CO (ppm)</th>
<th>NO (ppm)</th>
<th>NO (corr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2'</td>
<td>2,003°F</td>
<td>0.0</td>
<td>49,910</td>
<td>114</td>
<td>98</td>
</tr>
<tr>
<td>4'</td>
<td>2,105°F</td>
<td>0.0</td>
<td>49,910</td>
<td>114</td>
<td>98</td>
</tr>
<tr>
<td>6'</td>
<td>2,136°F</td>
<td>0.0</td>
<td>49,910</td>
<td>114</td>
<td>98</td>
</tr>
<tr>
<td>8'</td>
<td>2,173°F</td>
<td>0.3</td>
<td>22,095</td>
<td>122</td>
<td>107</td>
</tr>
<tr>
<td>10'</td>
<td>2,181°F</td>
<td>0.7</td>
<td>22,095</td>
<td>122</td>
<td>107</td>
</tr>
<tr>
<td>12'</td>
<td>2,181°F</td>
<td>2.1</td>
<td>5,648</td>
<td>94</td>
<td>91</td>
</tr>
<tr>
<td>14'</td>
<td>2,154°F</td>
<td>2.6</td>
<td>5,648</td>
<td>94</td>
<td>91</td>
</tr>
<tr>
<td>16'</td>
<td>2,184°F</td>
<td>6.8</td>
<td>239</td>
<td>72</td>
<td>93</td>
</tr>
<tr>
<td>18'</td>
<td>2,222°F</td>
<td>6.9</td>
<td>72</td>
<td>72</td>
<td>91</td>
</tr>
<tr>
<td>Average</td>
<td>2,149°F</td>
<td>3.29</td>
<td>15,593</td>
<td>95</td>
<td>96</td>
</tr>
</tbody>
</table>

Start Time: 12:42
Finish: 12:58

Eastern Port (forward of RH Pend Platen) Elevation 506'-3'
HVT Testing – Temperature (°F)
HVT Testing – NOx Concentration (ppm)
HVT Testing – CO Concentration (ppm)
Baseline Furnace Model
Figure 1. SNCR Temperature Window
Chemical Kinetic Model, NOxi=200 ppm, COi=100 ppm, NSR=2, 1 sec.
Figure 3. Effect of Baseline NOx
Chemical Kinetic Model, NSR=2, COi=100, 1 sec

NOx Reduction, %

Temperature, 'F

Baseline NOx
- - - - 25 ppm
- - - - 50 ppm
- - - - 100 ppm
- - - - 200 ppm
SNCR Design – Residence Time

Figure 2. Effect of Residence Time
Chemical Kinetic Model, NSR=2, COi=100 ppm, NOxi=200 ppm
“Right Side of Slope” Injection

**Low Temperature Issues**
- Slow Droplet Evaporation
- Slow Kinetics
- Low OH Concentration
- Ammonia Slip Increase

**High Temperature Issues**
- Rapid Droplet Evaporation
- Fast Kinetics
- Increased OH Concentration
- Urea Oxidation to NOx
Influence of CO on SNCR Process

1) $\text{NH}_3 + \text{OH} \rightleftharpoons \text{NH}_2 + \text{H}_2\text{O}$ and $\text{HNCO} + \text{OH} \rightleftharpoons \text{NCO} + \text{H}_2\text{O}$
   Note: Reaction rates increase with temperature, which explains low ammonia slip for high temperature applications. Clearly, OH is needed for this step.

2) $\text{NH}_2 + \text{NO} \rightleftharpoons \text{NNH} + \text{OH} \rightleftharpoons \text{N}_2 + \text{H}_2\text{O}$
   $\text{NCO} + \text{NO} \rightleftharpoons \text{N}_2\text{O} + \text{CO} \rightleftharpoons \text{N}_2 + \text{CO}_2$
   Note: NH2 and NCO are NOx reducing species – these reactions take place if working within the appropriate temperature window.
Influence of CO on SNCR Process

3) \[ \text{NH}_2 + \text{OH} \rightleftharpoons \text{NH} + \text{H}_2\text{O} \]
\[ \text{NH} + \text{OH} \rightleftharpoons \text{HNO} + \text{H} \]
\[ \text{HNO} + \text{OH} \rightleftharpoons \text{NO} + \text{H}_2\text{O} \text{(NOx Formation)} \]
\[ \text{NCO} + \text{OH} \rightleftharpoons \text{NO} + \text{CO} + \text{H} \text{(NOx Formation)} \]

Note: If the operating temperature is high, these reactions will occur rather than the desirable NOx reducing reactions. In this case, the OH works against us… CO Enters into the picture –

4) \[ \text{CO} + \text{O}_2 + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + 2\text{OH} \]

Note: The higher the CO concentration, the higher the OH generated. The elevated OH concentration generates increased levels of NH2 and NCO (Equation 1), even at low temperatures.
Influence of CO on SNCR Process

Note: Higher CO Levels Increase the Rates of NH2 Formation and NH3 Oxidation to NO; Effective NOx Reduction Window for Process is Shifted to a Lower Temperature.
SNCR Effective Temperature Window

2200°F
1600°F
Temperature Window – 150 ppm CO

1950°F  1750°F
Temperature Window – 500 ppm CO

1750°F
1450°F
SNCR INJECTION SYSTEMS
SNCR Injection Strategies

- **NOxOUT® Technology**
  - Air Atomized Urea Injection
  - Larger Droplet Size for Hot and/or Large Boilers and Furnaces

- **High Energy Reagent Technology (HERT)**
  - Mechanically Atomized Urea Injection through OFA Ports (High Momentum Injectors) and Additional Levels of Injectors in Upper Furnace (Low Momentum Injectors)
  - Recent Applications with Low Baseline Applications and Control Levels at or Below 0.100 lb/MMBtu

- **Multiple Nozzle Lances (MNLs)**
  - Air Atomized, Fine Mist
  - Convection Pass Injection

- **Combined Injection Strategy for Significant NOx Reduction with NH3 Low Slip Control**
In Injection Strategy for SNCR Process

In this figure, the CKM results are overlaid on the ammonia slip limit surface from the previous slide. The colored bands illustrate that NOx reduction is very limited near the plane formed by the bullnose while NOx reduction approaching 60% can be achieved near the low temperature limit.
SNCR Injection Options

• HERT
  – Lower ammonia slip
  – Higher allowable injection rates
  – Higher NOx reduction performance and higher chemical usage

• NOxOUT
  – More flexibility to control reaction zone
  – Lower chemical usage
  – Ammonia slip can be used with ASCR
HERT™ Injection Dynamics

- Air Jet penetrates the flue gas flow
- Small urea droplets
- Air and flue gas (NOx) mix
- Droplets heat up and evaporate
- Urea and NO_x Mix
- Urea decomposes to N_2 and H_2O
- Urea reacts with NO
SNCR PERFORMANCE
SNCR NOx Reduction Performance

- Gathering of Data and Information
  - Operational Data
  - Drawings
- Temperature and Species Mapping
  - Upper Furnace Temperatures, NOx, CO, and O2
- Computational Fluid Dynamics (CFD) and Chemical Kinetics Modeling (CKM)
  - Boiler Model for Performance and Injector Placement
- Demonstration System Option
  - 2 to 3 Week Test System
  - Fuel Tech Personnel for Setup, Operation, and Teardown
HERT Performance

- High reductions from low NOx baseline conditions
- Outlet NOx below 0.1 lb/MMBtu
- Low ammonia slip
- Experience on Range of boiler sizes and types
- Over 40 Combined Commercial and Demonstration Systems
# HERT Performance Summary

## Partial List of Commercial and Demo (D) Systems

<table>
<thead>
<tr>
<th>MW</th>
<th>BASELINE NOx</th>
<th>% REDUCTION</th>
<th>OUTLET NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>0.18</td>
<td>39%</td>
<td>0.11</td>
</tr>
<tr>
<td>60</td>
<td>0.19</td>
<td>42%</td>
<td>0.11</td>
</tr>
<tr>
<td>100</td>
<td>0.21</td>
<td>38%</td>
<td>0.13</td>
</tr>
<tr>
<td>120</td>
<td>0.22</td>
<td>32%</td>
<td>0.15</td>
</tr>
<tr>
<td>180</td>
<td>0.40</td>
<td>40%</td>
<td>0.24</td>
</tr>
<tr>
<td>200</td>
<td>0.15</td>
<td>25%</td>
<td>0.11</td>
</tr>
<tr>
<td>200</td>
<td>0.15</td>
<td>50%</td>
<td>0.08</td>
</tr>
<tr>
<td>275 D</td>
<td>0.11</td>
<td>27%</td>
<td>0.08</td>
</tr>
<tr>
<td>275 D</td>
<td>0.10</td>
<td>35%</td>
<td>0.07</td>
</tr>
<tr>
<td>350 D</td>
<td>0.36</td>
<td>55%</td>
<td>0.16</td>
</tr>
<tr>
<td>425 D</td>
<td>0.26</td>
<td>73%</td>
<td>0.07</td>
</tr>
<tr>
<td>600 D</td>
<td>0.41</td>
<td>30%</td>
<td>0.29</td>
</tr>
</tbody>
</table>
Biomass-fired Applications – Boiler Options

Circulating Fluidized Bed (CFB) Boilers

Grate-fired Stoker Boilers

Bubbling Fluidized Bed (BFB) Boilers

Drawing courtesy of McBurney

Drawing courtesy of Foster Wheeler

Drawing courtesy of B&W
SNCR for Grate-fired Stoker

Stoker Boiler Example
- 50 MW Design
- Uncontrolled NOx: 0.25 lb/MMBtu
- Flue Gas Temp @ SH Entrance: 1850°F to 1950°F
- Upper Furnace CO: 400 ppm
- SNCR Performance: 40-50%
- NH3 Slip: 20 ppm
- Comments
  - Working with boiler OEMs to modify designs to provide more favorable upper furnace conditions for SNCR – reducing temperature and increasing residence time
SNCR for Circulating Fluidized Bed (Utility)

CFB Boiler Example
- 2 × 325 MW Boilers
- Uncontrolled NOx: 0.150 lb/MMBtu
- Flue Gas Temp @ Cyclone Entrance: 1575°F to 1650°F
- Upper Furnace CO: < 100 ppm
- SNCR Performance: 40-60%
- NH3 Slip: 20 ppm
- Comments
  - Eight (8) SNCR Injectors per Cyclone, Three Cyclones
  - NOx Controlled to 0.085 lb/MMBtu
  - Aqueous NH3 Used
SNCR for Circulating Fluidized Bed (Industrial)

CFB Boiler Example
- 50 MW Design
- Uncontrolled NOx: 0.18 lb/MMBtu to 0.20 lb/MMBtu
- Flue Gas Temp @ Cyclone Entrance: 1600°F to 1650°F
- Upper Furnace CO: < 200 ppm
- SNCR Performance: 50% to 70%
- NH3 Slip: 20 ppm
- Comments
  - NOx Controlled to 0.075 lb/MMBtu
  - Urea and Aqueous NH3 Options, Low Temperature and Long Residence Time Favors Both
SNCR for Bubbling Fluidized Bed

BFB Boiler Example

- 50 MW Design
- Uncontrolled NOx: 0.18 lb/MMBtu to 0.20 lb/MMBtu
- Flue Gas Temp @ Cyclone Entrance: 1600°F to 1650°F
- Upper Furnace CO: < 200 ppm
- SNCR Performance: 50% to 75%
- NH3 Slip: 20 ppm
- Comments
  - Controlled NOx = 0.075 lb/MMBtu
  - Urea and Aqueous NH3 Options, Low Temperature and Long Residence Time Favors Both
SNCR EQUIPMENT LAYOUT AND COMPONENTS
Note: A key difference between HERT and NOxOUT SNCR is the use of small, mechanically atomized droplets that are guided to the high NOx regions using high momentum injectors installed in OFA ports and low momentum injectors in upper level ports where blower air guides the diluted urea.
SNCR Distribution Modules & NOxOUT Injectors

Notes
1) Number of levels is determined by the furnace geometry and the desired load range for SNCR operation.
2) The location of injectors is generally dictated by access and physical obstructions – CFD/CKM model determines preferred locations.
3) Compressed air and diluted urea is sent from the Metering Module to the Distribution Modules, where the air pressure and urea flow rate to each injector are controlled.
Urea Tanks
NOxOUT Reagent Storage
Circulation Modules
HERT Circulation Skid
Metering Module
HERT System Solenoid Rack
NOxOUT Injection
Multiple Nozzle Lances
HERT INJECTOR

Blower Air Isolation Valve

Dilution Water & UREA Isolation Valve

Injector
Blower Skid

- Motorized Butterfly Valves MBV
- Redundant Blowers
- Discharge Piping
- Suction Piping
Blower Skid Screen

- Select Blower A K1
- Select Blower B K2

- Blower Permissive OK
- Blowers Enabled K3

- Reheat Purge Complete
- No Alarms
- Superheat Purge Complete

Blower A Selected

Blower B Selected
NOxOUT® SNCR Control Loop

Feed Forward Control

Load

Temp

Feed Forward Chemical Flow Generator

Chemical Flow

Chemical Flow

Feedback Control

Stack NOx

PV

-1.0 ~ 1.0

NOx Setpoint

SP

PID

0.2

Adjustability Factor

NOx Setpoint

PID

0.2

Adjustability Factor

PID

0.2

Adjustability Factor

PID

0.2

Adjustability Factor

PID

0.2

Adjustability Factor
UREA REAGENT OPTIONS
# Liquid Urea Properties – NH₂CONH₂

<table>
<thead>
<tr>
<th></th>
<th>NOxOUT LT</th>
<th>NOxOUT A</th>
<th>Urea Liquor</th>
</tr>
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<tbody>
<tr>
<td><strong>at 60°F</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea Concentration</td>
<td>32.5%</td>
<td>40.0%</td>
<td>50.0%</td>
</tr>
<tr>
<td></td>
<td>60.0%</td>
<td>70.0%</td>
<td>85.0%</td>
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<tr>
<td>Specific Gravity</td>
<td>1.0897</td>
<td>1.1113</td>
<td>1.1400</td>
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<tr>
<td></td>
<td>1.1688</td>
<td>1.1976</td>
<td>1.2407</td>
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<tr>
<td>Pounds per Gallon</td>
<td>9.085</td>
<td>9.265</td>
<td>9.505</td>
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<tr>
<td></td>
<td>9.643</td>
<td>9.767</td>
<td>9.970</td>
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<td>Crystallization Temperature (°F)</td>
<td>11.3</td>
<td>33</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>96</td>
<td>135</td>
<td>195</td>
</tr>
<tr>
<td>Boiling Point (°F)</td>
<td>220</td>
<td>225</td>
<td>231</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biuret</td>
<td>0.14</td>
<td>0.17</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>0.3 to 0.4</td>
<td>0.3 to 0.4</td>
<td>0.36</td>
</tr>
<tr>
<td>pH</td>
<td>7.0 to 10.0</td>
<td>7.0 to 10.0</td>
<td>7.0 to 10.0</td>
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<tr>
<td>lb-NH₃/gallon</td>
<td>1.67</td>
<td>2.10</td>
<td>2.70</td>
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<tr>
<td></td>
<td>3.28</td>
<td>3.88</td>
<td>4.81</td>
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</table>
## Urea and Dilution Water Quality

### QUALITY SPECIFICATIONS – UREA

<table>
<thead>
<tr>
<th>Description</th>
<th>NOxOUT® A</th>
<th>NOxOUT® HP</th>
<th>UNSTABILIZED UREA</th>
<th>NOxOUT® LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified 50% Aqueous Solution of Urea</td>
<td>Modified 50% Aqueous Solution of Urea</td>
<td>50% Aqueous Solution of Urea</td>
<td>Modified 32.5% Aqueous Solution of Urea</td>
<td></td>
</tr>
<tr>
<td>Density (g/ml @ 25° C)</td>
<td>1.13 - 1.15</td>
<td>1.13 - 1.15</td>
<td>1.13 - 1.15</td>
<td>1.085 - 1.105</td>
</tr>
<tr>
<td>pH</td>
<td>7.0 - 10.8</td>
<td>7.0 - 10.8</td>
<td>7.0 - 10.8</td>
<td>5.0 - 10.8</td>
</tr>
<tr>
<td>Appearance</td>
<td>Light Yellow, Clear to Slightly Hazy</td>
<td>Light Yellow, Clear to Slightly Hazy</td>
<td>Light Yellow, Clear to Slightly Hazy</td>
<td>Light Yellow, Clear to Slightly Hazy</td>
</tr>
<tr>
<td>Salt Out Freeze Point</td>
<td>64°F (18°C)</td>
<td>64°F (18°C)</td>
<td>64°F (18°C)</td>
<td>40°F (4°C)</td>
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<tr>
<td>Foam (after bottle is shaken)</td>
<td>Foam Lasts &gt; 15 seconds</td>
<td>Foam Lasts &gt; 15 seconds</td>
<td>Not Applicable</td>
<td>Foam Lasts &gt; 15 seconds</td>
</tr>
<tr>
<td>Free NH3</td>
<td>&lt; 5000 ppm</td>
<td>&lt; 5000 ppm</td>
<td>&lt; 5000 ppm</td>
<td>&lt; 3000 ppm</td>
</tr>
<tr>
<td>Biuret Content</td>
<td>&lt; 5000 ppm</td>
<td>&lt; 5000 ppm</td>
<td>&lt; 5000 ppm</td>
<td>&lt; 3000 ppm</td>
</tr>
<tr>
<td>Organic Phosphate</td>
<td>55 - 85 ppm as PO4</td>
<td>22 - 40 ppm as PO4</td>
<td>Not Applicable</td>
<td>55 - 85 ppm as PO4</td>
</tr>
<tr>
<td>Orthophosphate</td>
<td>&lt; 6 ppm as PO4</td>
<td>&lt; 6 ppm as PO4</td>
<td>&lt; 2 ppm as PO4</td>
<td>&lt; 6 ppm as PO4</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>&lt; 10 ppm</td>
<td>&lt; 10 ppm</td>
<td>&lt; 10 ppm</td>
<td>&lt; 10 ppm</td>
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<tr>
<td>Urea Makeup Water</td>
<td>Total Hardness as CaCO3 ≤ 300 ppm</td>
<td>Total Hardness as CaCO3 ≤ 150 ppm</td>
<td>Total Hardness as CaCO3 ≤ 20 ppm</td>
<td>Total Hardness as CaCO3 ≤ 300 ppm</td>
</tr>
</tbody>
</table>

### QUALITY SPECIFICATIONS – DILUTION WATER

<table>
<thead>
<tr>
<th>Description</th>
<th>NOxOUT® A</th>
<th>NOxOUT® HP</th>
<th>UNSTABILIZED UREA</th>
<th>NOxOUT® LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilution Water Analysis</td>
<td>Total Hardness as CaCO3 (ppm)</td>
<td>&lt;450</td>
<td>&lt;150</td>
<td>&lt;20</td>
</tr>
<tr>
<td><em>M</em> Alkalinity as CaCO3 (ppm)</td>
<td>&lt;300</td>
<td>&lt;100</td>
<td>&lt;100</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Conductivity (µmho)</td>
<td>&lt;2500</td>
<td>&lt;1000</td>
<td>&lt;1000</td>
<td>&lt;2500</td>
</tr>
<tr>
<td>Silica as SiO2 (ppm)</td>
<td>&lt;60</td>
<td>&lt;60</td>
<td>&lt;60</td>
<td>&lt;60</td>
</tr>
<tr>
<td>Iron as Fe (ppm)</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Manganese as Mn (ppm)</td>
<td>&lt;0.3</td>
<td>&lt;0.3</td>
<td>&lt;0.3</td>
<td>&lt;0.3</td>
</tr>
<tr>
<td>Phosphate as P (ppm)</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Sulfate as SO4 (ppm)</td>
<td>&lt;200</td>
<td>&lt;200</td>
<td>&lt;200</td>
<td>&lt;200</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>pH</td>
<td>&lt; 8.3</td>
<td>&lt; 8.3</td>
<td>&lt; 8.3</td>
<td>&lt; 8.3</td>
</tr>
</tbody>
</table>
Urea vs. Ammonia

• Safety Considerations
  – Safety can be Engineered into the Design, but Considerations may Drive the Decision

• Natural Gas Pricing
  – Elevated Price of NG in North America is Forcing the Shutdown of NH3 Productions and an Increase in Dry Urea Imports
  – LNG is an Alternative but Supply Insufficient to Cover Demand

• On-site Ammonia Storage
  – DHS has Promulgated Final Rule for On-site Storage of Chemicals – Unsure How this Will Impact Anhydrous NH3 Storage for SCR’s

• Transportation
  – “Chain of Custody” Regulations for TIH* Rail Shipments Driving Transportation Costs Considerably Higher, Some Carriers May Opt and are Currently Being Forced to Reroute Shipments to Avoid HTUA’s

* The TSA component of the DHS is about to implement a series of federal regulations affecting the transportation of Toxic Inhalation Hazard (TIH) materials such as Chlorine and Anhydrous Ammonia – will require “documented chain of command handoffs” along distribution zone.
Reagent Alternatives for SNCR Systems

- **Anhydrous Ammonia**
  - Highest Risk Reagent
  - Decrease in US Ammonia Production

- **Aqueous Ammonia**
  - 19% Concentration
  - 29% Concentration - limited availability

- **Urea for On-Site Ammonia Generation**
  - Significant Safety Advantages
  - Worldwide Availability of Urea
  - Equivalent SCR Performance
Anhydrous Ammonia – Safety Considerations

• Ammonia Storage
  - Department of Homeland Security (DHS) has identified ammonia as a chemical of interest for anti-terrorism standards

• Transportation
  - Rail carrier risks and freight rate increases to handle anhydrous ammonia
  - Department of Transportation Restrictions
  - State and local restrictions on shipping and routing

• Safety Risks
  - *EPA Worst Case Release Analysis* – Toxic Endpoint for 60,000 Gallon Release Covers a Radius of 7 to 10 Miles

Aqueous Ammonia – Safety Considerations

• Ammonia Storage
  - Containment for possible liquid leaks/spills

• Transportation
  - 29% Aqueous ammonia is restricted by Department of Transportation in many areas
  - State and local restrictions on shipping and routing

• Safety Risks
  - Increased transportation risk due to more shipments of dilute chemical
  - 1.2 mile toxic radius for 60,000 gallon spill
  - Much higher unloading frequency at plant site raises potential incident probability
# Licensed NOxOUT Reagent Suppliers

<table>
<thead>
<tr>
<th>Licensee Corporate Office</th>
<th>Address</th>
<th>Contact Person</th>
<th>Telephone/Fax</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDI, Inc.</td>
<td>P.O. Box 9083 Brea, CA 92821 -or- 471 W. Lambert Rd Suite 100 Brea, CA 92821</td>
<td>Luis Cervantes</td>
<td>714.990.3940 714.329.2281 (cell) 714.990.4073 (fax)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rick Gross</td>
<td>(901) 867-8186 office (901) 233-2336 mobile</td>
</tr>
<tr>
<td>Mosaic Company (formerly Cargill, Inc)</td>
<td>12800 Whitewater Dr MS 190 Minnetonka, MN 55343</td>
<td>Bob Ness</td>
<td>800.918.8270 763.577.2781 952.742.7313 (fax)</td>
</tr>
<tr>
<td>PCS Nitrogen, Inc</td>
<td>1101 Skokie Blvd Northbrook, IL 60062</td>
<td>Jennifer A. Zagorski</td>
<td>847.849.4377 (office) 847.612.5301 (cell) 847.849.4489 (fax)</td>
</tr>
<tr>
<td>Distribution Points</td>
<td>– Augusta, GA - Lima, OH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Licensed NOxOUT Reagent Suppliers

<table>
<thead>
<tr>
<th>Company</th>
<th>Address</th>
<th>Contact Person</th>
<th>Phone Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monson Companies, Inc.</td>
<td>One Runway Rd P.O. Box 2405 South Portland, ME 04116-2406</td>
<td>Jeff Pellerin</td>
<td>207.885.5072 x 423 207.885.0569 (fax)</td>
</tr>
<tr>
<td><strong>Distribution Points</strong></td>
<td>South Portland, ME</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agrium USA</td>
<td>13132 Lake Fraser Dr SE Calgary, AB T2J7E8 CANADA</td>
<td>Gerry Kroon</td>
<td>403.335.7597 403.471.6473 (cell)</td>
</tr>
<tr>
<td><strong>Distribution Points</strong></td>
<td>Stockton, CA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Andersons, Inc.</td>
<td>480 W. Dussel Drive P.O. Box 119 Maumee, OH 43537</td>
<td>Bill Wolf</td>
<td>419.897.3689</td>
</tr>
<tr>
<td><strong>Distribution Points</strong></td>
<td>Logansport, IN – Maumee, OH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colonial Chemical Co.</td>
<td>78 Carranza Rd Tabernacle, NJ 08088</td>
<td>Eric Wegelius</td>
<td>609.268.1200 x 112 609.268.2117 (fax)</td>
</tr>
<tr>
<td><strong>Distribution Points</strong></td>
<td>Frederick, MD – Tabernacle, NJ</td>
<td></td>
<td></td>
</tr>
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</table>

### Information Needed by Licensees:
- Company Name
- Location
- Scheduled Start-Up Date
- If rail delivery- specify railroad
- NOxOUT® Reagent Type Required (A, HP, LT)
- NOxOUT® Reagent Usage Rate
- NOxOUT® Reagent Storage Tank Size
SNCR Combined with other NO\textsubscript{x} Control Technologies
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
## Combining NOx Reduction Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Strength</th>
<th>Limitations</th>
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</thead>
<tbody>
<tr>
<td>Low-NOx Burners</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
</tr>
<tr>
<td>Combustion Mods / OFA</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
</tr>
<tr>
<td>SNCR</td>
<td>Low Capital NOx Red%</td>
<td>NH3 Slip ABS</td>
</tr>
<tr>
<td>SCR</td>
<td>NOx Red% Low NH3 Slip</td>
<td>High Capital SO₃ Oxidation</td>
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## Retrofit Low-NOx Burner Installation

<table>
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<th>Strength</th>
<th>Limitations</th>
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<td>Low-NOx Burners</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
</tr>
<tr>
<td>Combustion Mods / OFA</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
</tr>
<tr>
<td>SNCR</td>
<td>Low Capital NOx Red%</td>
<td>NH3 Slip ABS</td>
</tr>
<tr>
<td>SCR</td>
<td>NOx Red% Low NH3 Slip</td>
<td>High Capital SO₃ Oxidation</td>
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# Moderate Combustion Modifications

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<td>Low-NOx Burners</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
</tr>
<tr>
<td>Combustion Mods / OFA</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
</tr>
<tr>
<td>SNCR</td>
<td>Low Capital NOx Red%</td>
<td>NH3 Slip ABS</td>
</tr>
<tr>
<td>SCR</td>
<td>NOx Red%, Low NH3 Slip</td>
<td>High Capital SO₃ Oxidation</td>
</tr>
</tbody>
</table>
# Conservative SNCR application

<table>
<thead>
<tr>
<th>Technology</th>
<th>Strength</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>
</tr>
<tr>
<td>Combustion Mods / OFA</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
</tr>
<tr>
<td>SNCR</td>
<td>Low Capital NOx Red%</td>
<td>No NH3 Slip</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No ABS</td>
</tr>
<tr>
<td>SCR</td>
<td>NOx Red%</td>
<td>High Capital SO₃ Oxidation</td>
</tr>
<tr>
<td></td>
<td>Low NH3 Slip</td>
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## Aggressive SNCR application

<table>
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<tr>
<td>Low-NOx Burners</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
</tr>
<tr>
<td>Combustion Mods / OFA</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
</tr>
<tr>
<td>SNCR</td>
<td>Low Capital &gt; Red%</td>
<td>NH3 Slip ABS</td>
</tr>
<tr>
<td>SCR</td>
<td>NOx Red%</td>
<td>High Capital SO\textsubscript{3} Oxidation</td>
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## In-Duct or Small SCR Space

<table>
<thead>
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<th>Limitations</th>
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<tr>
<td>Low-NOx Burners</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
</tr>
<tr>
<td>Combustion Mods / OFA</td>
<td>Low Capital and Operating</td>
<td>Combustion, Corrosion, CO</td>
</tr>
<tr>
<td>SNCR</td>
<td>Low Capital &gt; Red%</td>
<td>NH3 is OK</td>
</tr>
<tr>
<td></td>
<td>More Red% Low NH3 Slip</td>
<td>Mod Capital, SO$_3$ and Cost</td>
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<tr>
<td>Single Layer SCR</td>
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## Advanced SCR Application

<table>
<thead>
<tr>
<th>Technology</th>
<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>
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<tr>
<td>SNCR</td>
<td>30%</td>
<td>66%</td>
</tr>
<tr>
<td>Single Layer SCR</td>
<td>45%</td>
<td>81%</td>
</tr>
</tbody>
</table>
Chemical Release Point Comparison

SNCR

CASCADe

Releasing chemical at or near the top of the curve versus “right side of the slope” favors increased NOx reduction efficiency and better utilization of reagent – NH3 slip is absorbed by catalyst.
Benefits of Hybrid SNCR + SCR System

- SNCR Not Restricted to “Right Side of Slope” Injection Strategy
- Impact of “High” CO can, in many cases, be Minimized
- Controlled Increase in Ammonia Slip (versus SNCR) is Desirable, Significant Improvement in SNCR Efficiency and Chemical Utilization
- Relax Inlet Conditions to SCR, Design for Incremental SCR Reduction and NH3 Absorption
- Pressure Drop is Minimized as a Result of Reduced Volume and Treatment Length, Allowable Gas Velocity Now Higher with State-of-the-Art Flue Gas Mixing and Straightening Devices
- Reduced Conversion of SO2 to SO3
- Lower Catalyst Replacement Cost, Single Layer
NOxOUT CASCADE® Technology Overview

- Combined SNCR/SCR Process
- Single Layer SCR Catalyst – Reduced Volume
- Improved SNCR Chemical Utilization and Reduction Efficiency with Higher, Controlled Level of Ammonia Slip
- Ammonia Slip from SNCR Provides Reagent for Catalytic Reactions
- \( \text{NO}_x \) Reduction Performance - 65-85%
- Lower Capital Cost ($30 to $75 per kW) compared to Full Scale SCR (Up to >$300/kW)
- Demonstrated Mercury Oxidation of >90% with Single Layer Catalyst for Capture with FGD System
Penelec Seward Duct Modifications
AES Greenidge - Multi-P w/ CASCADE

AES Greenidge Unit 4 (Boiler 6)

- Dresden, NY
- Commissioned in 1953
- 107 MWₑ (net) reheat unit
- Boiler:
  - Combustion Engineering tangentially-fired, balanced draft
  - 780,000 lb/h steam flow at 1465 psig and 1005 °F
- Fuel:
  - Eastern bituminous coal
  - Biomass (waste wood) – up to 10% heat input
- Existing emission controls:
  - Overfire air (natural gas reburn not in use)
  - FSP
  - No FGD - mid-sulfur coal to meet permit limit of 3.8 lb SO₂/MMBtu
AES Greenidge – Multi-P w/ CASCADE

- DOE Cooperative Agreement signed May 2006
- Goal: Demonstrate a Multi-pollutant Control System to Cost-effectively Reduce Emissions of NOx, SO2, Hg, Acid Gases (SO3, HCl, HF), and PM Smaller Coal-fired Power Plants
- 115 MW Coal-fired Boiler, 2.9% Sulfur Bituminous Coal, 10% Biomass
- SNCR: Two Levels of Wall Injectors, plus Multiple Nozzle Lances
- BPI Designed SCR Reactor and Delta Wing Flue Gas Mixing
- In-duct SCR Reactor, Single Layer of Catalyst
- SNCR NOx Reduction = 42%, SCR NOx Reduction = 30%
- Overall Post-combustion NOx Reduction ≈ 60%
- SNCR Chemical Utilization ≈ 40%
ASCR™ Advanced SCR

- 80+% NO\textsubscript{x} Reduction
- 40-60% less than conventional SCR
Advantages of ASCR Technology

• Capital Cost
  – Limited Structural Steel – Modify Existing, No New Steel to Grade
  – Less Catalyst
  – Less Ductwork

• Better Reagent Utilization
  – SNCR Process
  – Separate AIG

• Low Pressure Drop

• Low SO\textsubscript{2} to SO\textsubscript{3} Conversion Rate

• Broader Range of Operation
  – Lower Electrical Demand
ASCR™ Advanced SCR

- Maximize In-furnace NOx Reduction through Combustion Modifications and Post-combustion Controls
- Apply SNCR for Maximum Performance, NH3 Slip Control
- On-site Urea Conversion with AIG for 90+% Chemical Utilization
- Employ FTI Mixing and Flow Correction Devices to Provide Uniform Flow and Distribution Across Catalyst Face
- Utilize Catalyst That Maximizes Use of Available Space
- NOx Reduction Efficiency Across Single Layer is Increased As the NOx Entering the SCR is Reduced
Optimized SCR System

- Turning Vanes
- Mixer
- Large Particle Ash Screen
- Ammonia Injection Grid
- GSG
- Catalyst
Summary

• Flexible, Cost Effective NOx Reduction
• SNCR complementary to other NOx control technologies

Questions?