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 SO_3 Emissions and Addresses Related Issues
- **Innovative Approaches to Enable Clean Efficient Energy**
  - Capital Projects for Multi-Pollutant Control
  - NO_XOUT® Products including SNCR, CASCADE, RRI, ULTRA
  - Flue Gas Conditioning Systems for Particulate Control – Outside US and Canada
  - Sorbent Injection for SO_2 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)**

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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_xOUT 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**

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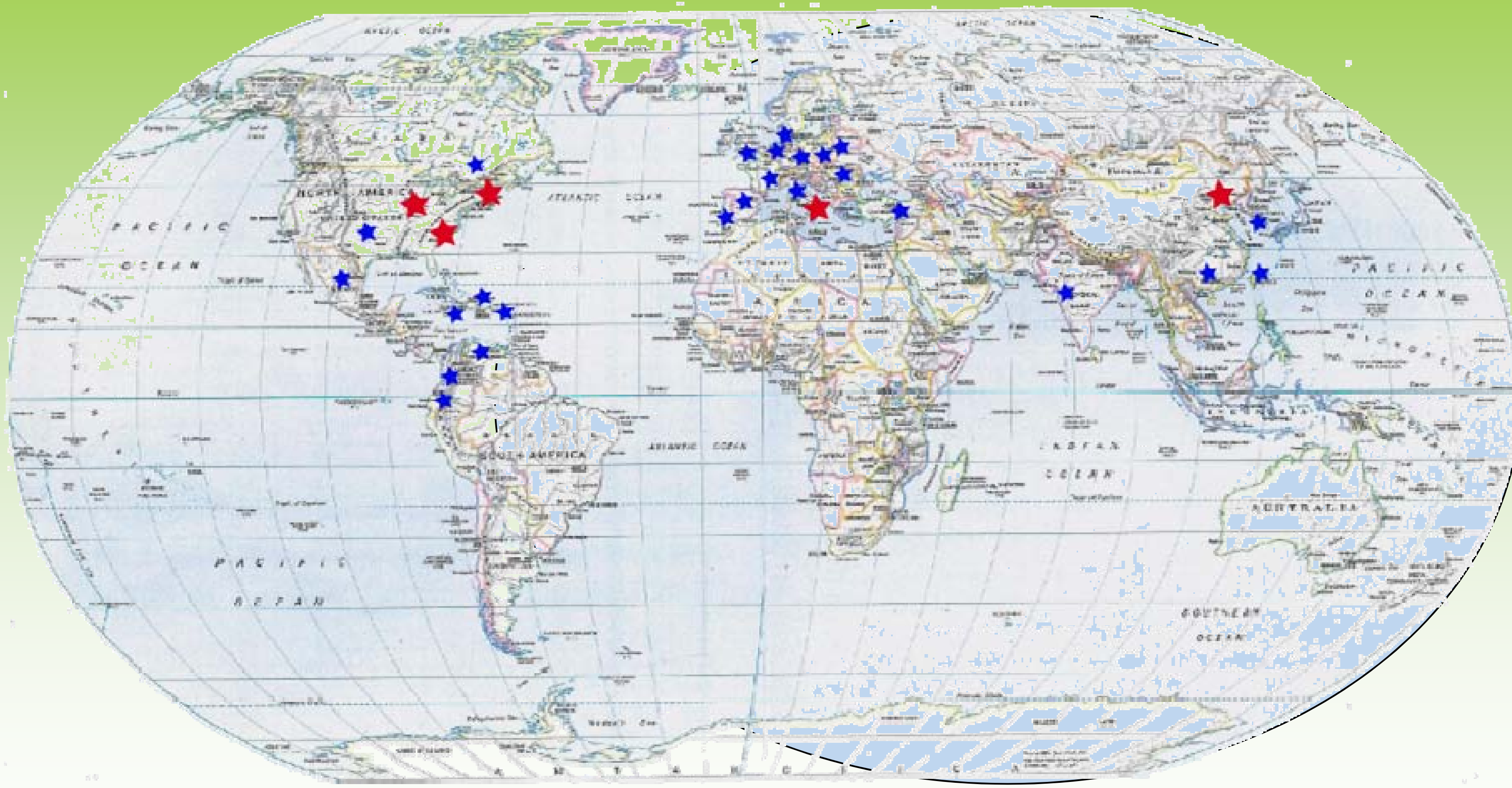
Fuel Tech's Global Presence



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

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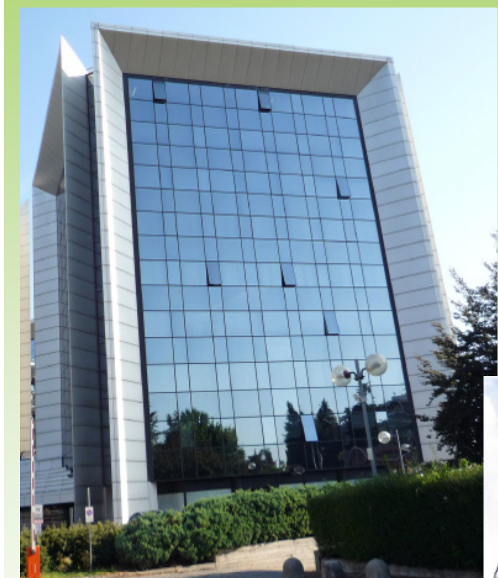
Our Locations

Stamford, CT

Durham, NC

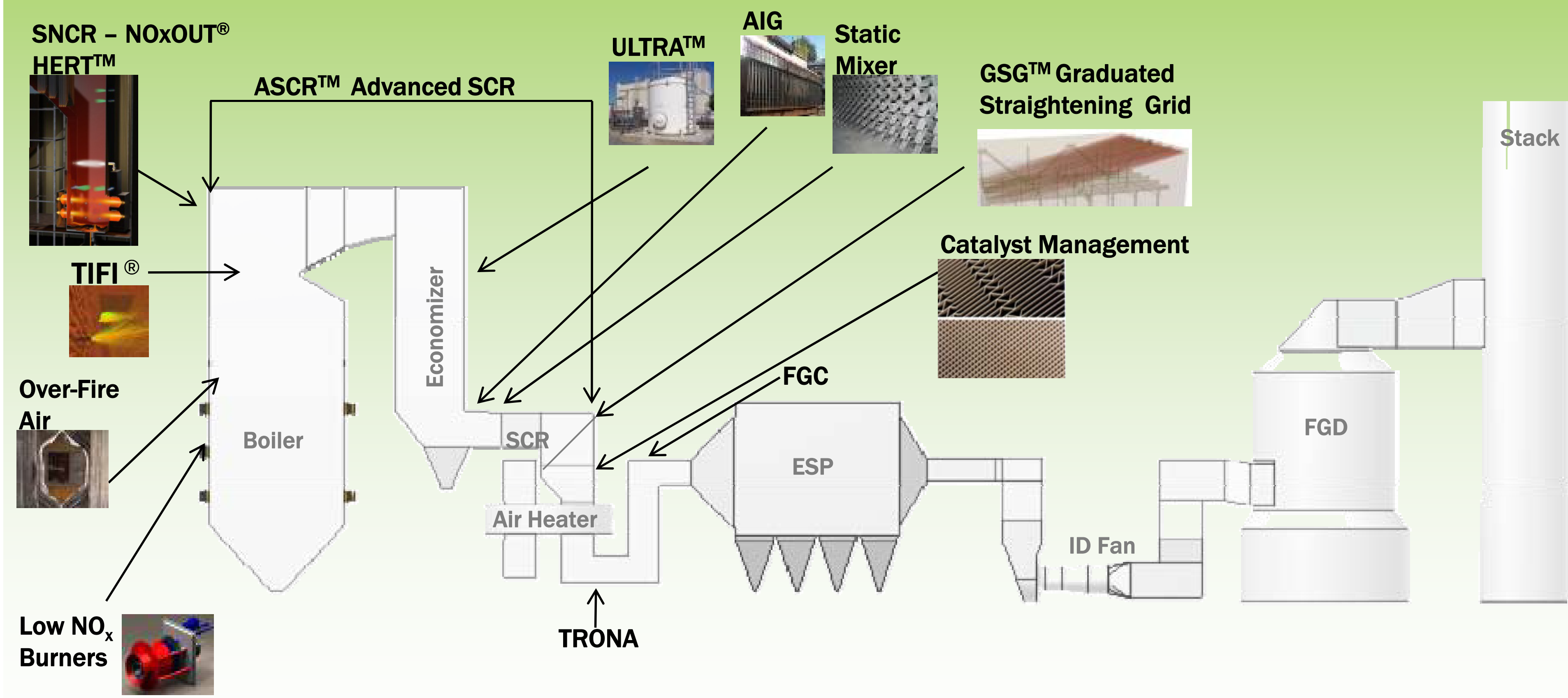


Milan, Italy

Beijing, China

Warrenville, IL

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.

Example of a clinker fall

FUEL CHEM® Program Benefits

- **Efficiency**
  - Recovery of Derated MW
  - Heat Rate Improvement for Steam Production
  - Reduced Fan Power Requirements
  - Reduced Sootblowing
  - Reduced Operating O_2 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

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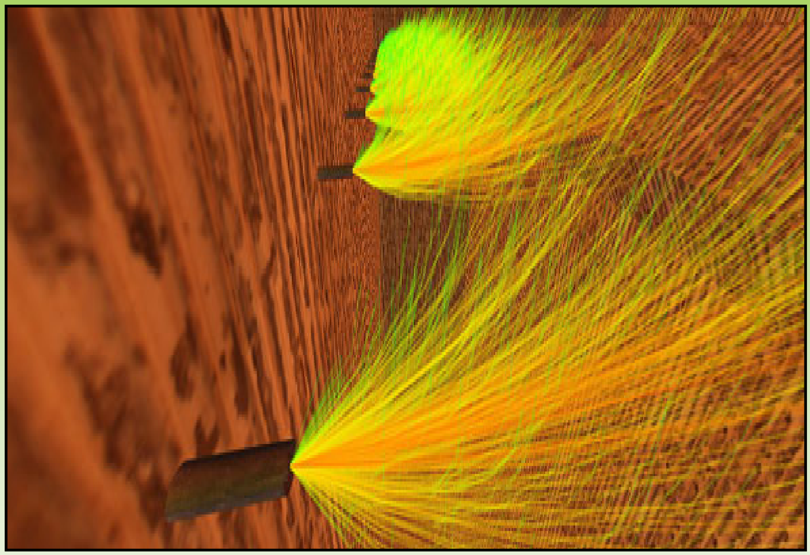
FUEL CHEM® Program Benefits

- **Environmental**
  - CO_2 Reduction
  - SO_3 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™ Program

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



TIFI® Injector on boiler wall

Fuel Types

Coal	Alternative Fuels	Residual Fuels
• PRB • ILB • Lignite • CAPP	• Biomass • Pet Coke • Hog Fuels • WTE Fuels	• No. 6 Fuel • Waste Oil • Bunker C • Liquid Waste Fuels • Black Liquor

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TIFI ® Technology Overview

TIFI MG™

- Utilizes magnesium hydroxide slurry
- Sprayed into the combustion unit at locations defined by computer modeling.
- TIFI MG solution reacts with slag as it is forming and penetrate existing deposits.

TIFI XP™

- Builds upon TIFI technology
- Designed to provide users both slag control and fuel flexibility.
- Allows users to burn less-expensive, yet higher-slagging coals such as ILB

TIFI MP™

- Furnace chemical injection program
- Uses two reagents for the reduction of SO_2

TIFI Flux™

- Specifically designed for cyclone boilers
- Focused on burning PRB and other low iron coals

TIFI BlueCat™

- Copper based product
- Used to lower carbon monoxide (CO) and unburned coal (LOI)
- Can be used in combination with TIFI MP to provide SO_2 trim control

TIFI Hybrid™

- Designed for oil-fired boilers
- Uses a combination of TIFI MG combined with in-fuel injection

TCI™

- Designed principally for boilers in the waste-to-energy (WTE) industry
- Inhibits corrosion and slag build-up

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Air Pollution Control Technologies

APC Technology Overview

Combustion		Post-Combustion		
LNB	**OFA**	**SNCR**	**ASCR**	**ULTRA**
• 40-60% NO_x Reduction • Industrial & utility applications • Upgrades to existing burners available	• 35-70% NO_x Reduction over Low NO_x burners • Unique port design enhances mixing to limit impact on combustion efficiency	• 20-50% NO_x Reduction • Urea-based maximized performance with minimal ammonia slip	• 80+% NO_x Reduction • 30-70% Less capital then traditional SCR	• Proprietary urea conversion process to generate ammonia for SCR systems • Safer than ammonia • Compatible with a wide range of urea sources

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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 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**

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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**

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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**

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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_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

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NOx Reduction Technologies

Post-Combustion Options without Full Scale SCR

- SNCR - NO_xOUT® 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)

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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**

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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.

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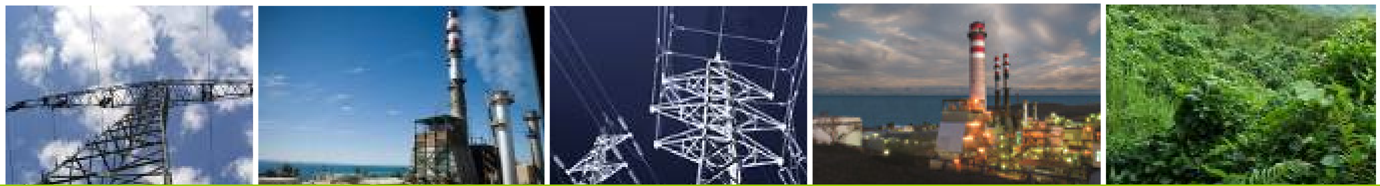
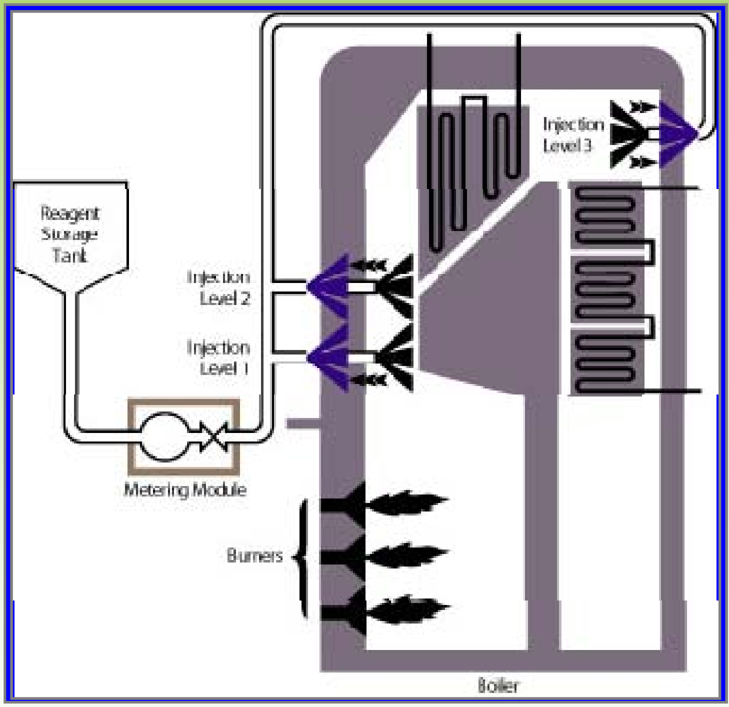


Selective Non-Catalytic Reduction (SNCR)

SNCR Technology Overview: NOxOUT® and HERT™ Systems

- **In-furnace, Post-combustion NO_x Control**
- **Injection of Urea in Upper Furnace**
- **Process Reaction Temperature Range: 1600°F to 2200°F**
- **NO_x Reduction Range**
  - **Utility Boilers: 25 to 50%**
  - **Industrial Boilers: 30 to 70%**



Selective Non-Catalytic Reduction

SNCR Process Chemical Reactions

(1) $4NO + 2CO(NH2)_2 + O_2 \Rightarrow 4N_2 + 4H_2O + 2CO_2$

(2) $2NO_2 + 2CO(NH2)_2 + O_2 \Rightarrow 3N_2 + 4H_2O + 2CO_2$

Nitrogen Oxides + Urea + Oxygen ⇨ Nitrogen + Water Vapor + Carbon Dioxide

Typically 95% of NOx is associated with Eq 1

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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

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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**

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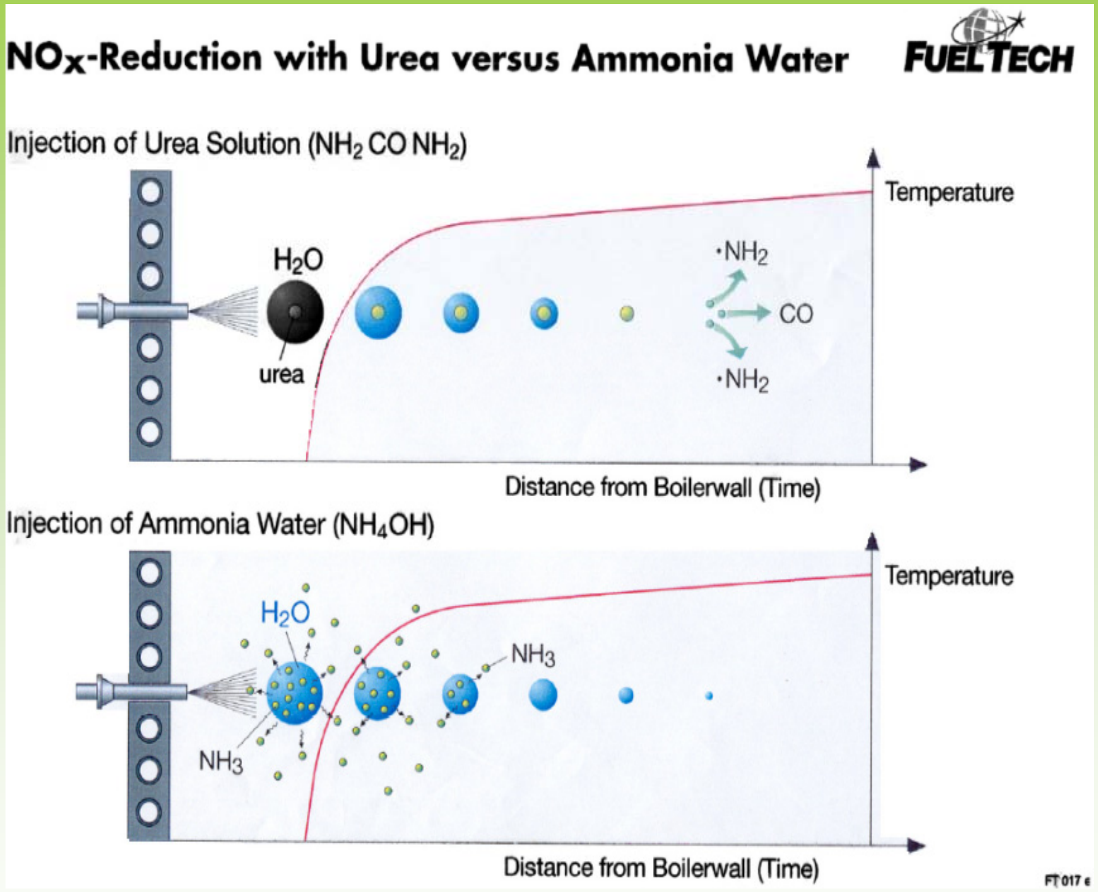
Urea vs. Ammonia for SNCR



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

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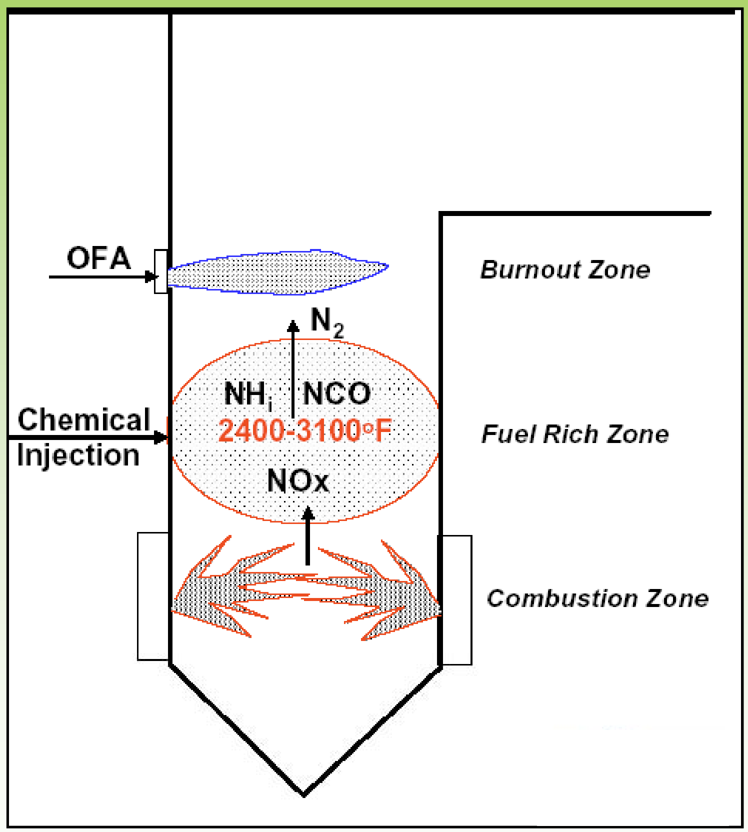
Rich Reagent Injection (RRI) Technology Overview

- **40 to 60% NO_x Reduction Combined with SNCR on Cyclone Boilers**
- **NO_x Reduction in 30% Range with RRI Only**
- **Non-catalytic Reduction of NO_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**



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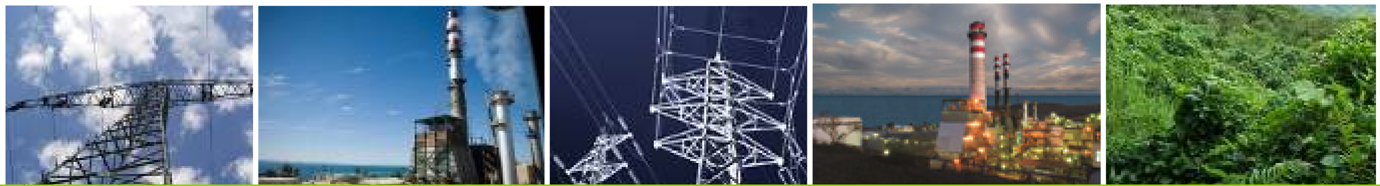

SNCR PROCESS DESIGN AND MODELING

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, O_2, and Sulfur Content of the Fuel**

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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)

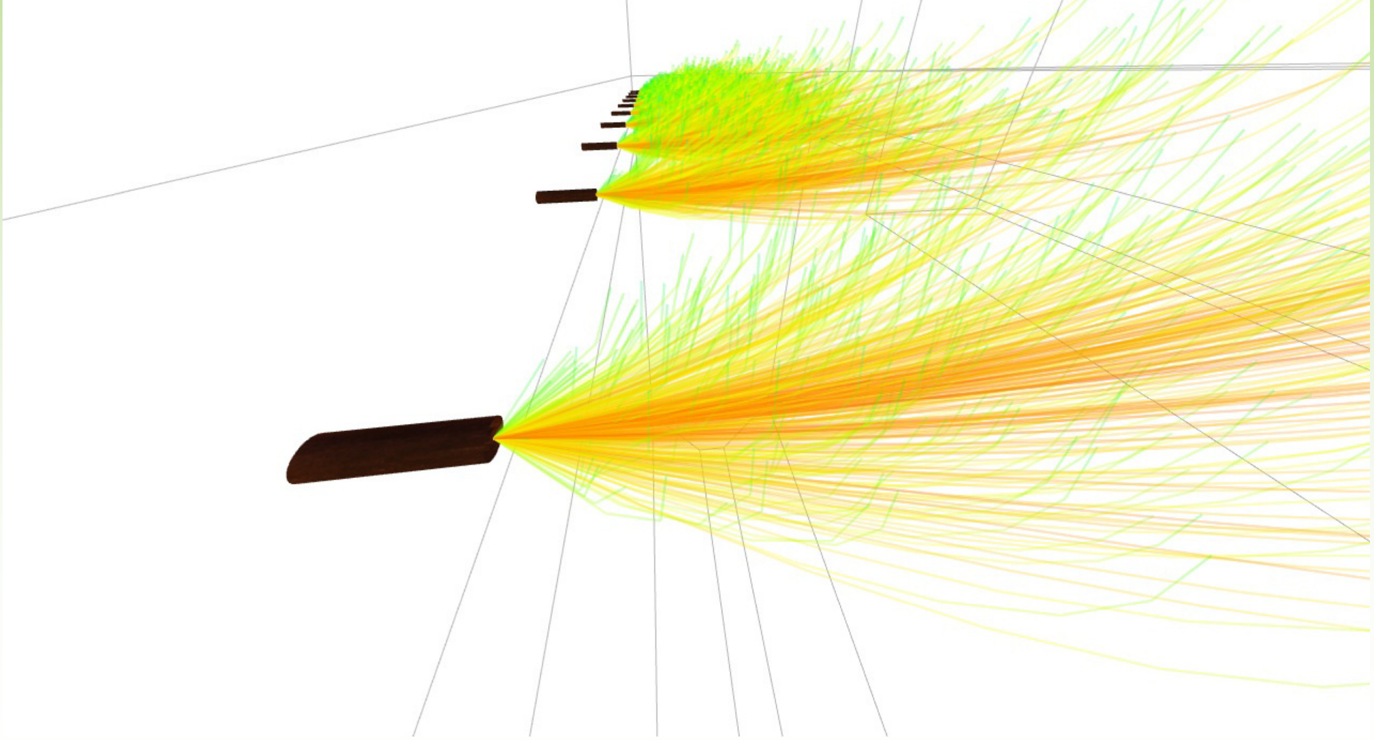
- **Used to Define Effective Boundaries of Critical Process Parameters, Test Effectiveness of Distribution Strategies, Identify/Locate/Define Gas Species Concentrations – Physical Unit Data (Drawings, etc.) and Field Testing as Input**

Chemical Kinetic Model (CKM)

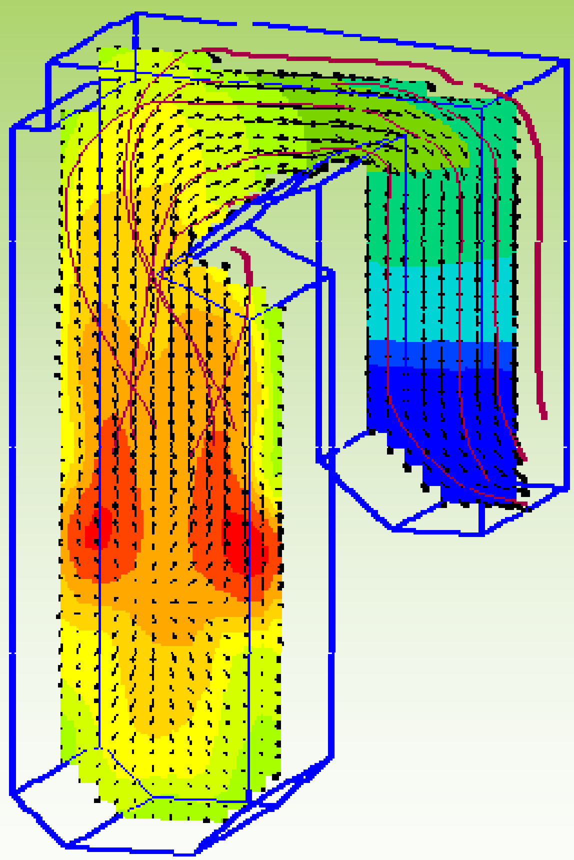
- **Used to Calculate Each Specific Time/Temperature Reduction Reaction – Overlay the SNCR Process on the CFD**

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

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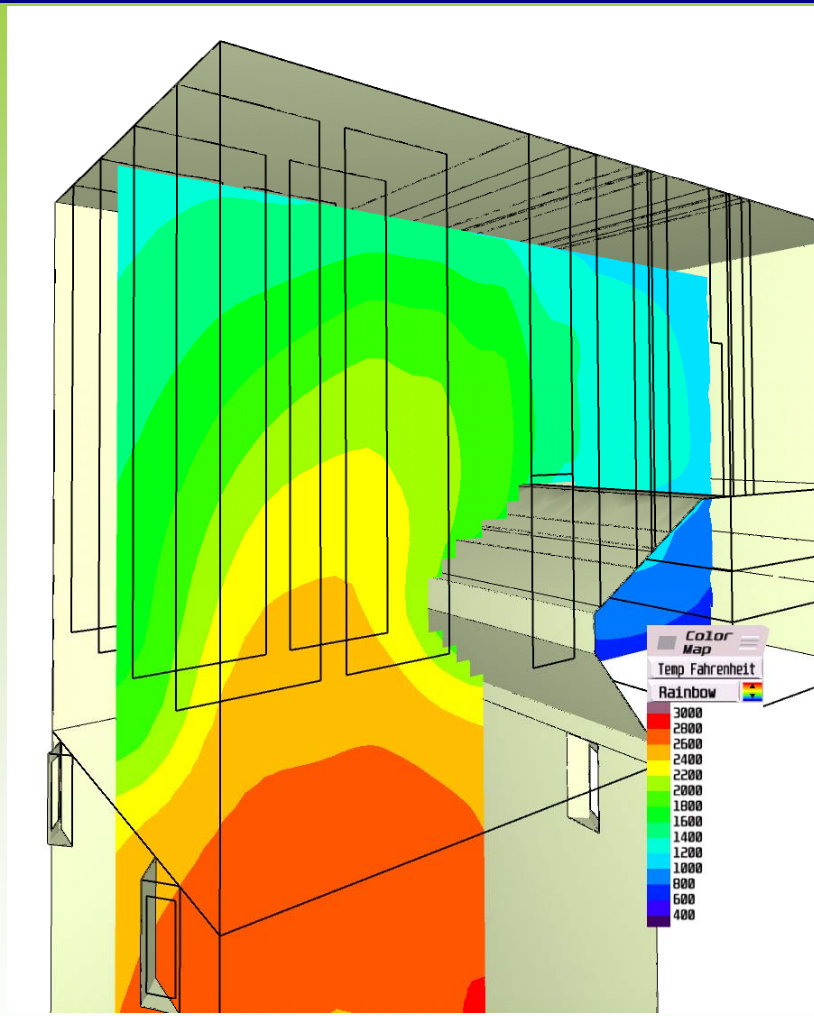
Baseline Testing (HVT) for CFD/CKM



- 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

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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**

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SNCR Baseline Testing - HVT

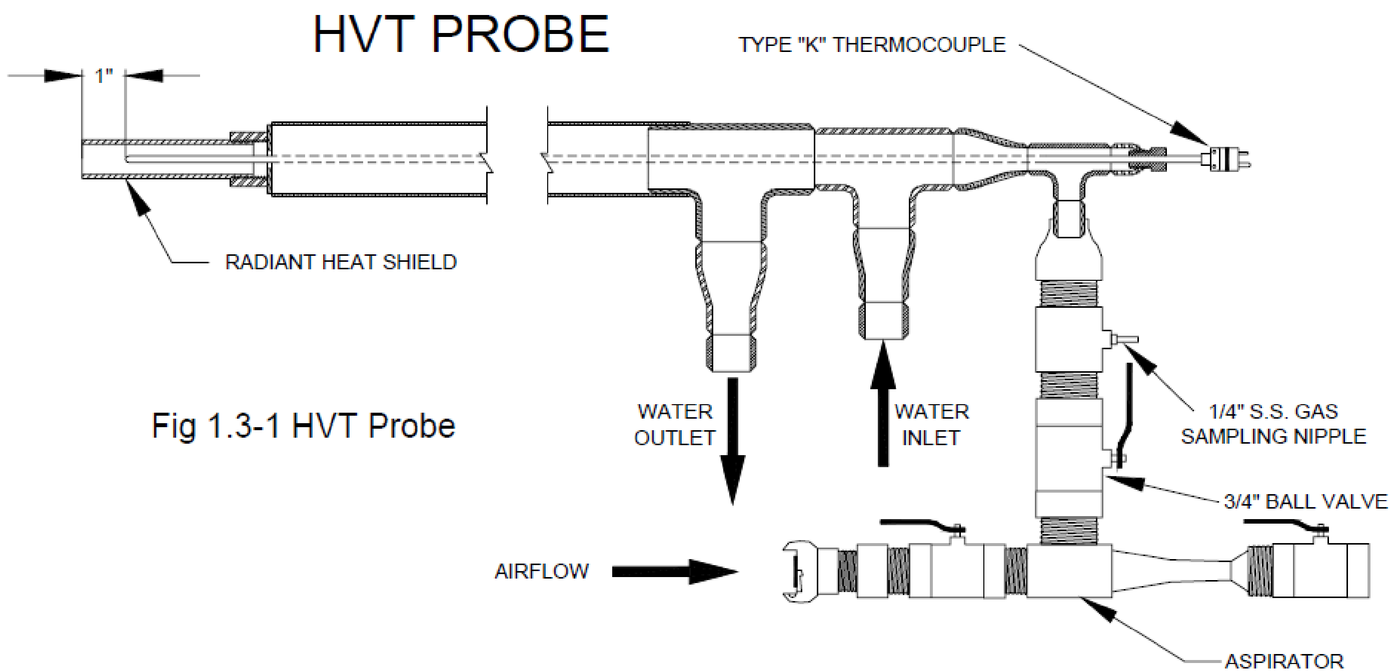
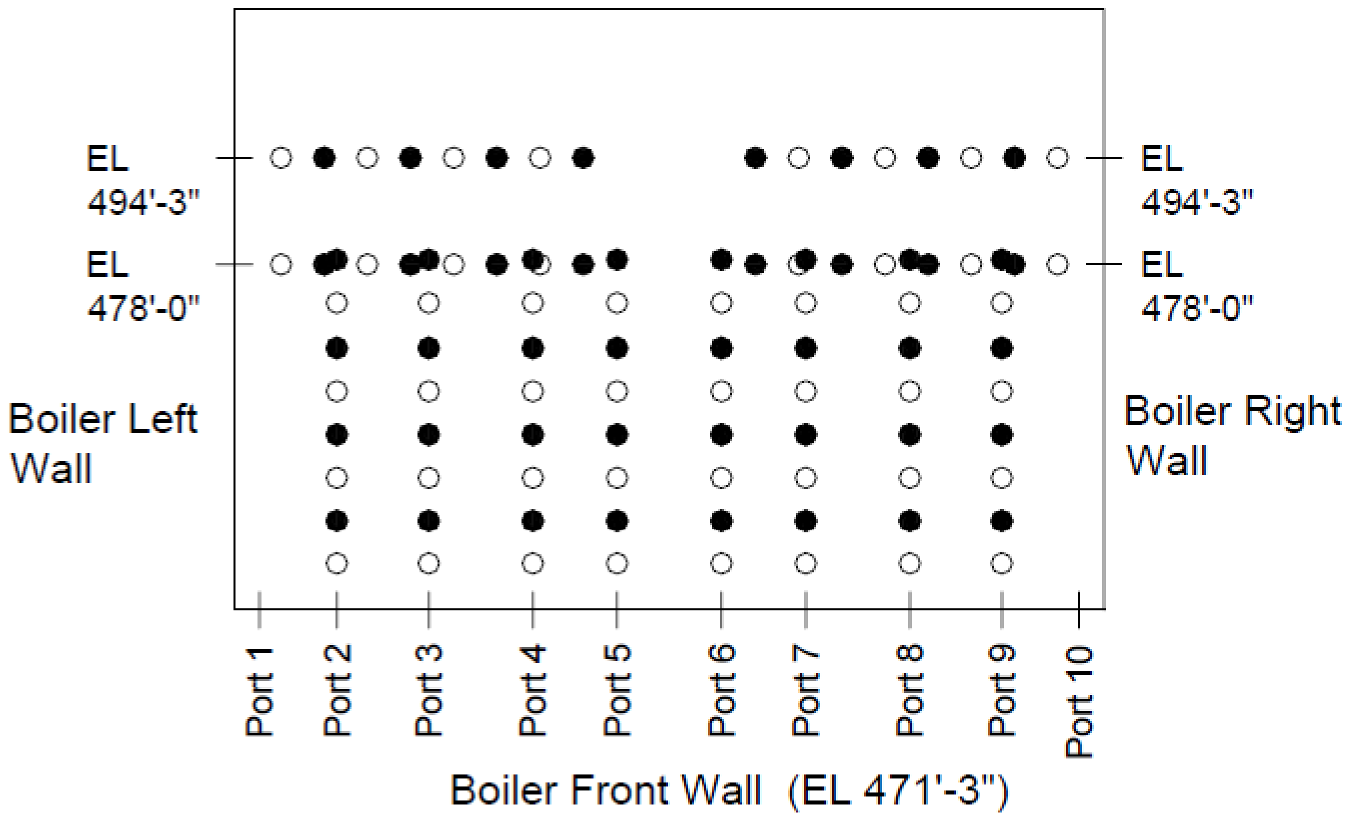


Fig 1.3-1 HVT Probe

SNCR Baseline Testing - HVT



- ● Temperature Measurement and Gas Species
- ○ Temperature Measurement Only

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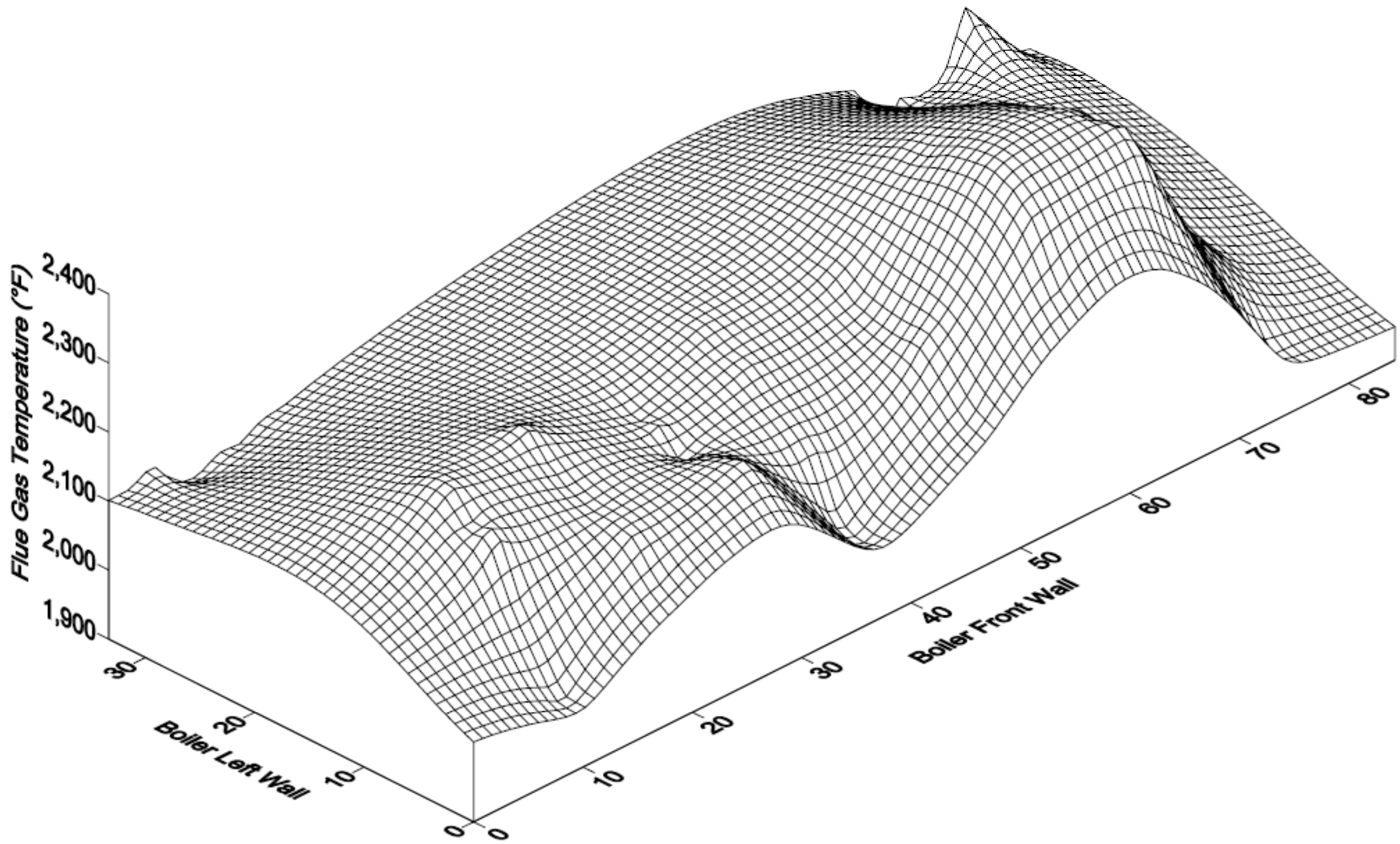
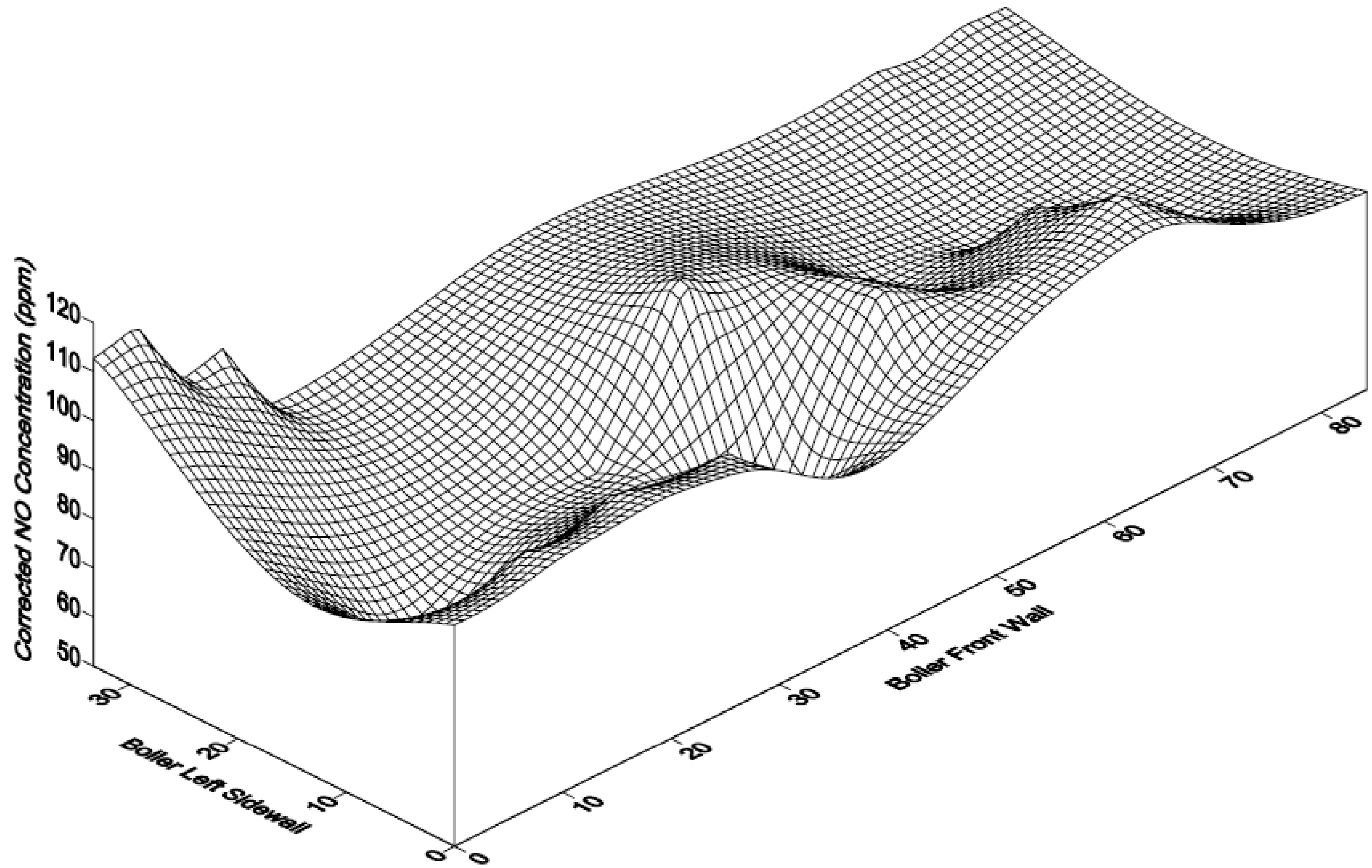
SNCR Baseline Testing - HVT

	Start Time:	12:42		Finish:	12:58	
Eastern Port (forward of RH Pend Platen) Elevation 506'-3"						
Depth	Temp.	%Oxygen		CO (ppm)	NO (ppm)	NO (corr)
2'	2,003°F					
4'	2,105°F	0.0	0.0	49,910	114	98
6'	2,136°F					
8'	2,173°F	0.3	0.7	22,095	122	107
10'	2,181°F					
12'	2,187°F	2.1	2.6	5,648	94	91
14'	2,154°F					
16'	2,184°F	6.8	7.4	239	72	93
18'	2,222°F	6.1	6.9	72	73	91
Average	*2,149°F*	*3.29*		*15,593*	*95*	*96*
Low	*2,003°F*	*0.00*		*72*	*72*	*91*
High	*2,222°F*	*7.40*		*49,910*	*122*	*107*

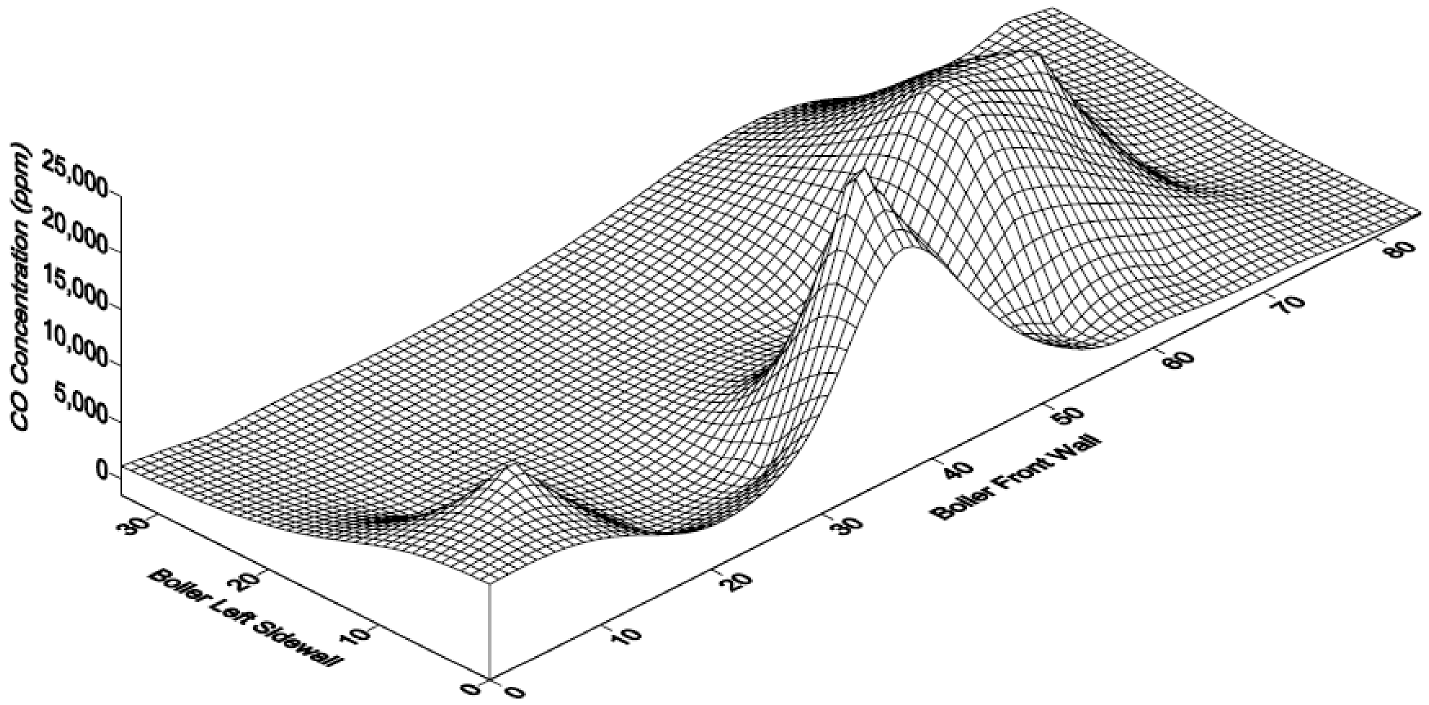
HVT Testing – Temperature (°F)



HVT Testing – NOx Concentration (ppm)



HVT Testing – CO Concentration (ppm)



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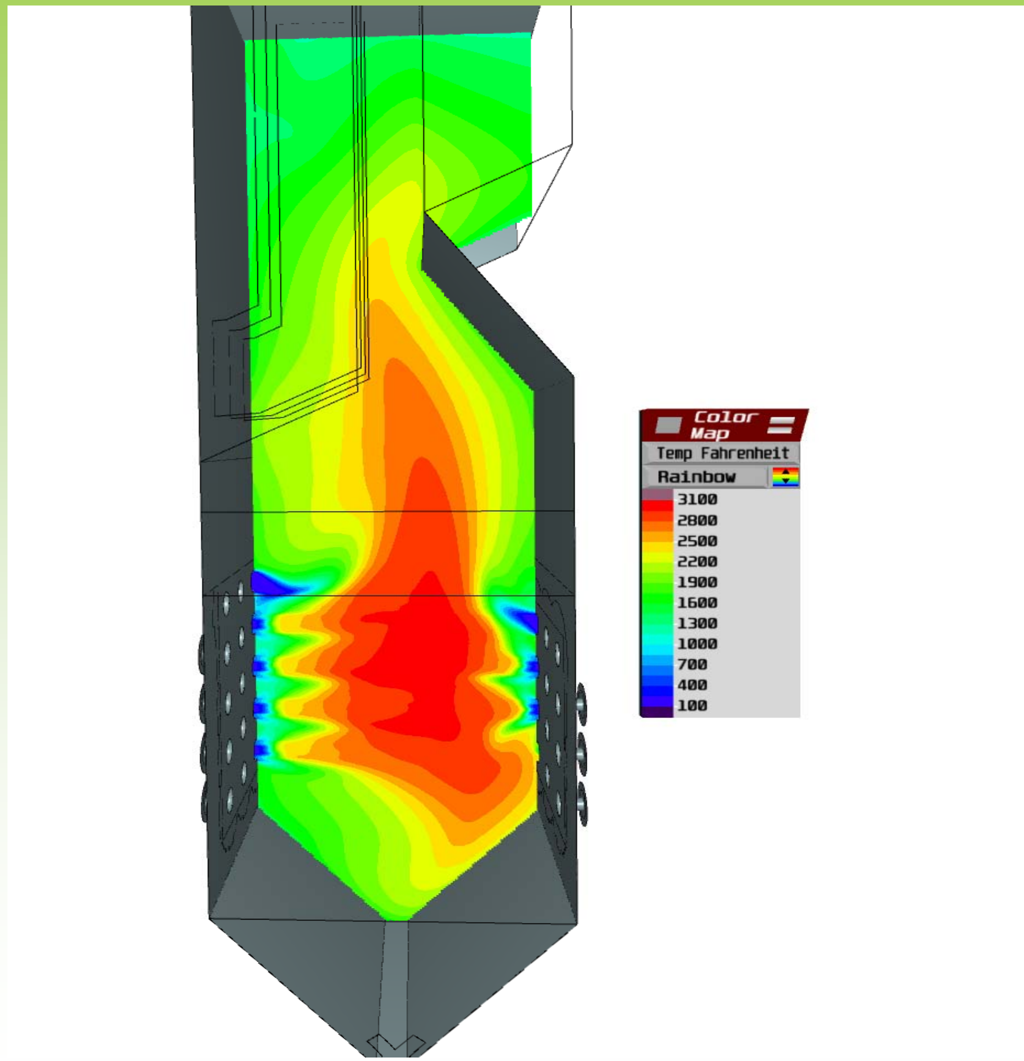
Baseline Furnace Model



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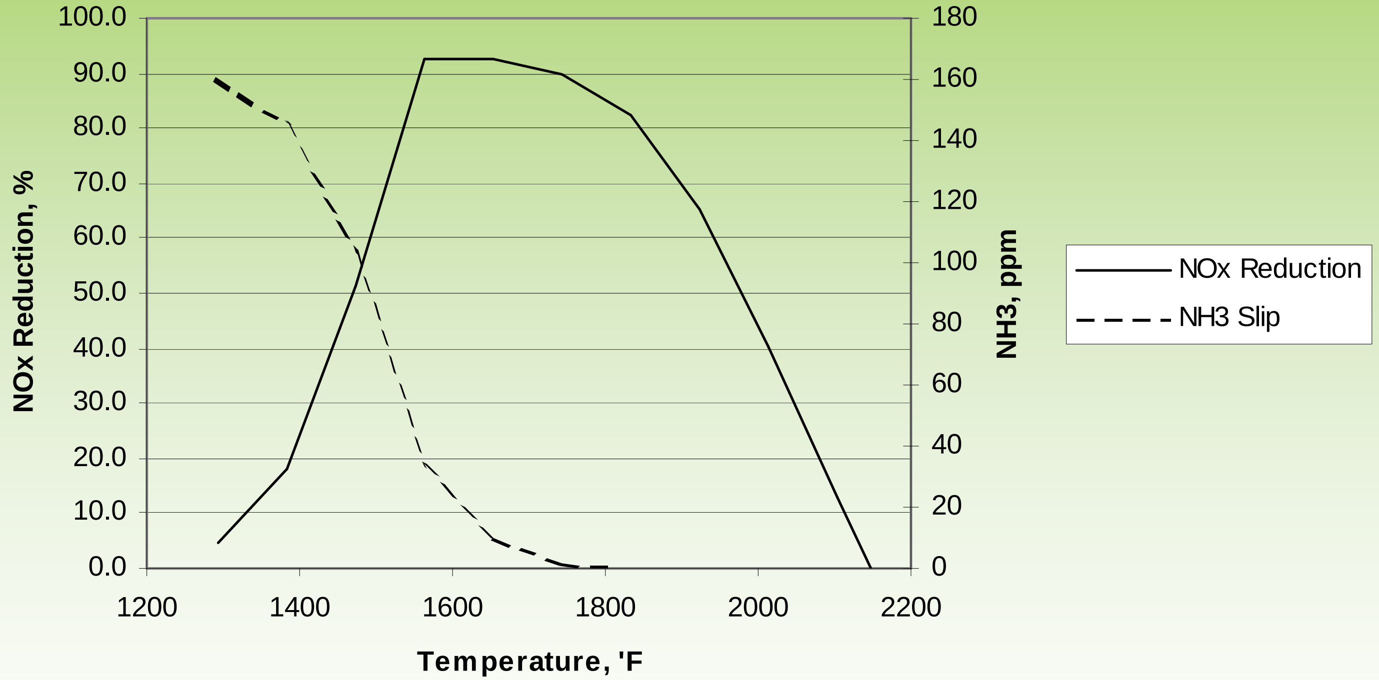
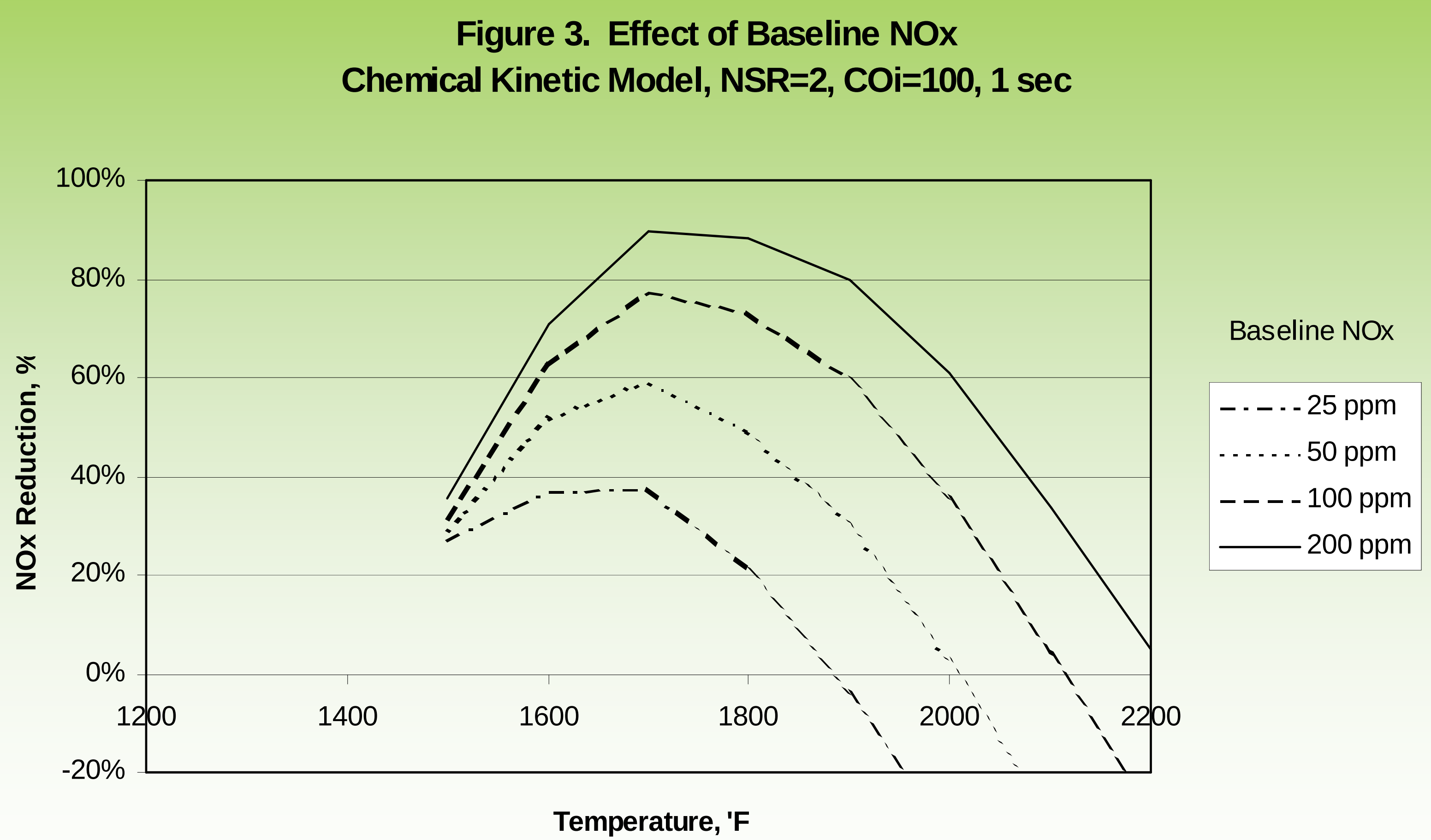
SNCR Design – Temperature Window

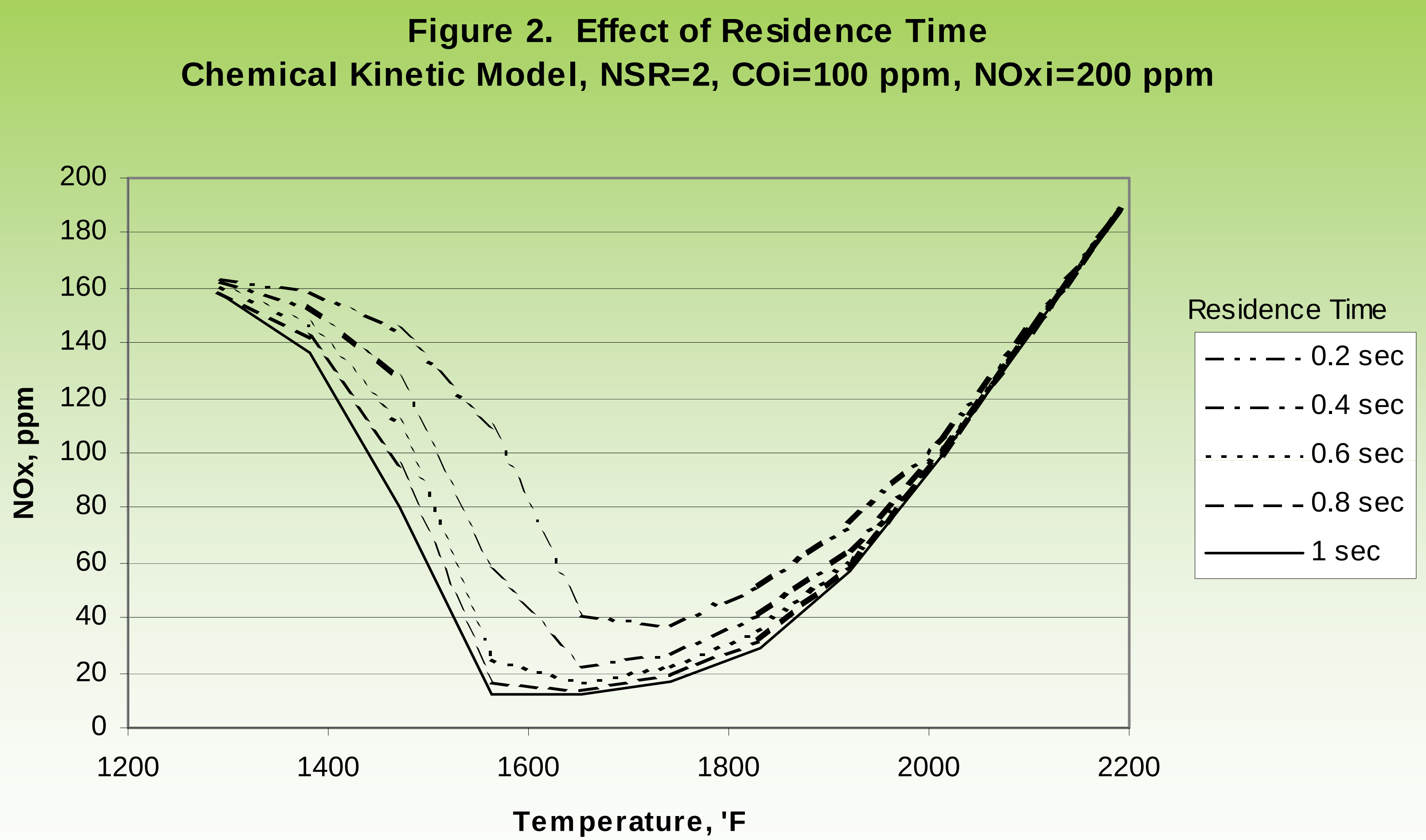
Figure 1. SNCR Temperature Window
Chemical Kinetic Model, NOxi=200 ppm, COi=100 ppm, NSR=2, 1 sec.



SNCR Design – Baseline NOx



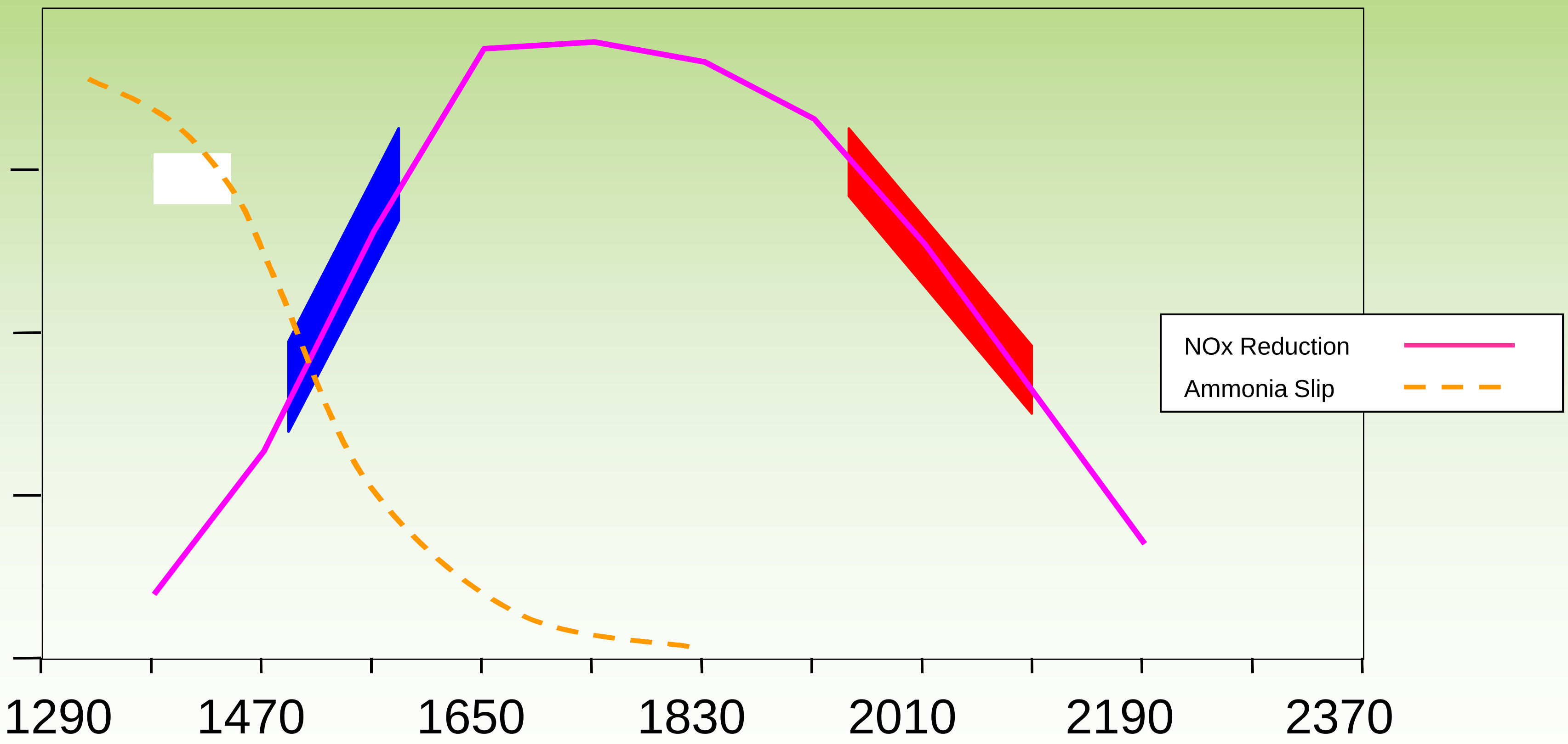
SNCR Design – Residence Time



“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) $NH_3 + OH \Rightarrow NH_2 + H_2O$ and $HNCO + OH \Rightarrow NCO + H_2O$

Note: Reaction rates increase with temperature, which explains low ammonia slip for high temperature applications. Clearly, OH is needed for this step.

2) $NH_2 + NO \Rightarrow NNH + OH \Rightarrow N_2 + H_2O$

$NCO + NO \Rightarrow N_2O + CO \Rightarrow N_2 + CO_2$

Note: NH2 and NCO are NOx reducing species – these reactions take place if working within the appropriate temperature window.

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Influence of CO on SNCR Process

3) $NH_2 + OH \Rightarrow NH + H_2O$

$NH + OH \Rightarrow HNO + H$

$HNO + OH \Rightarrow NO + H_2O$ (***NOx Formation***)

$NCO + OH \Rightarrow NO + CO + H$ (***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) $CO + O_2 + H_2O \Rightarrow CO_2 + 2OH$

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.

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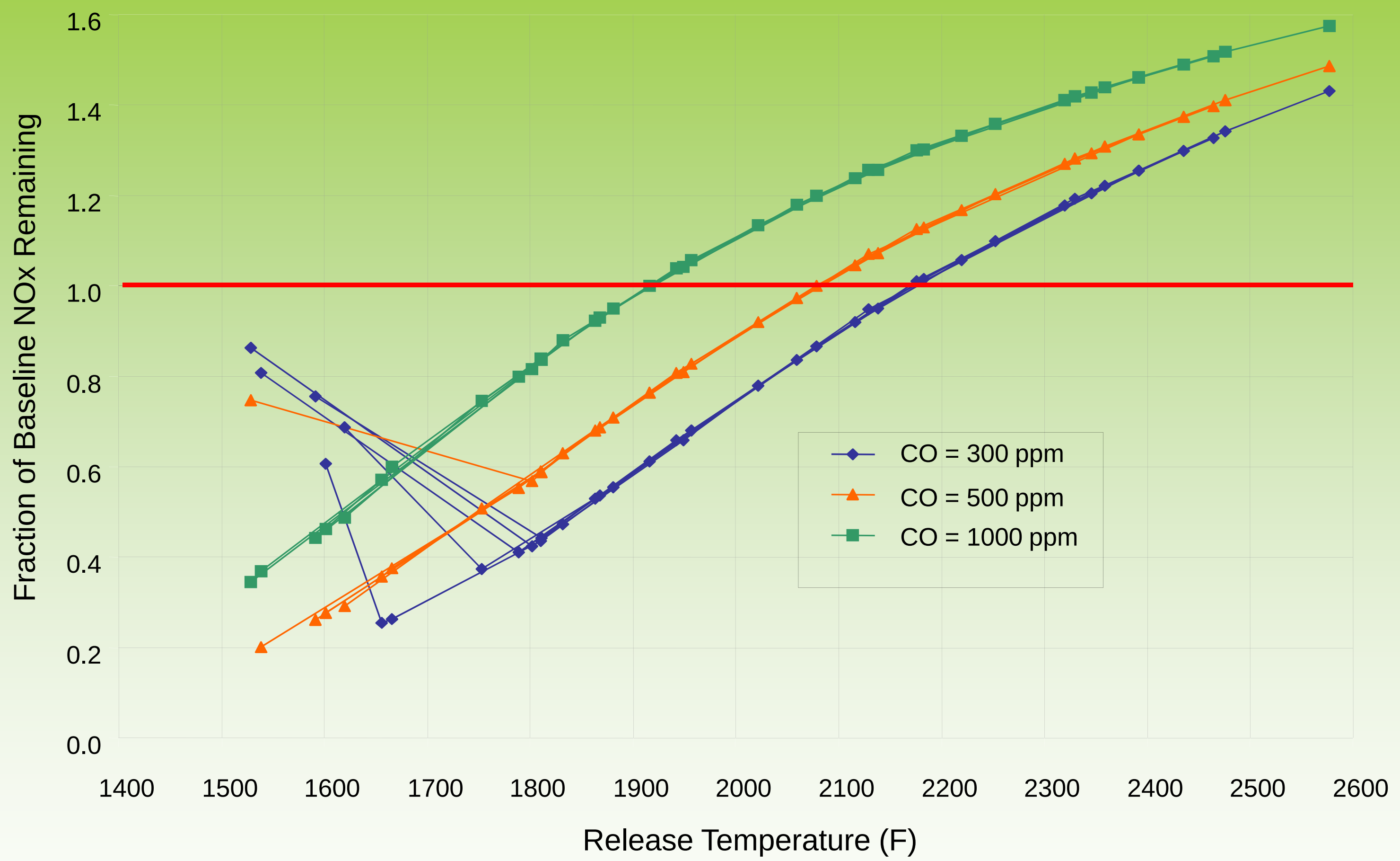
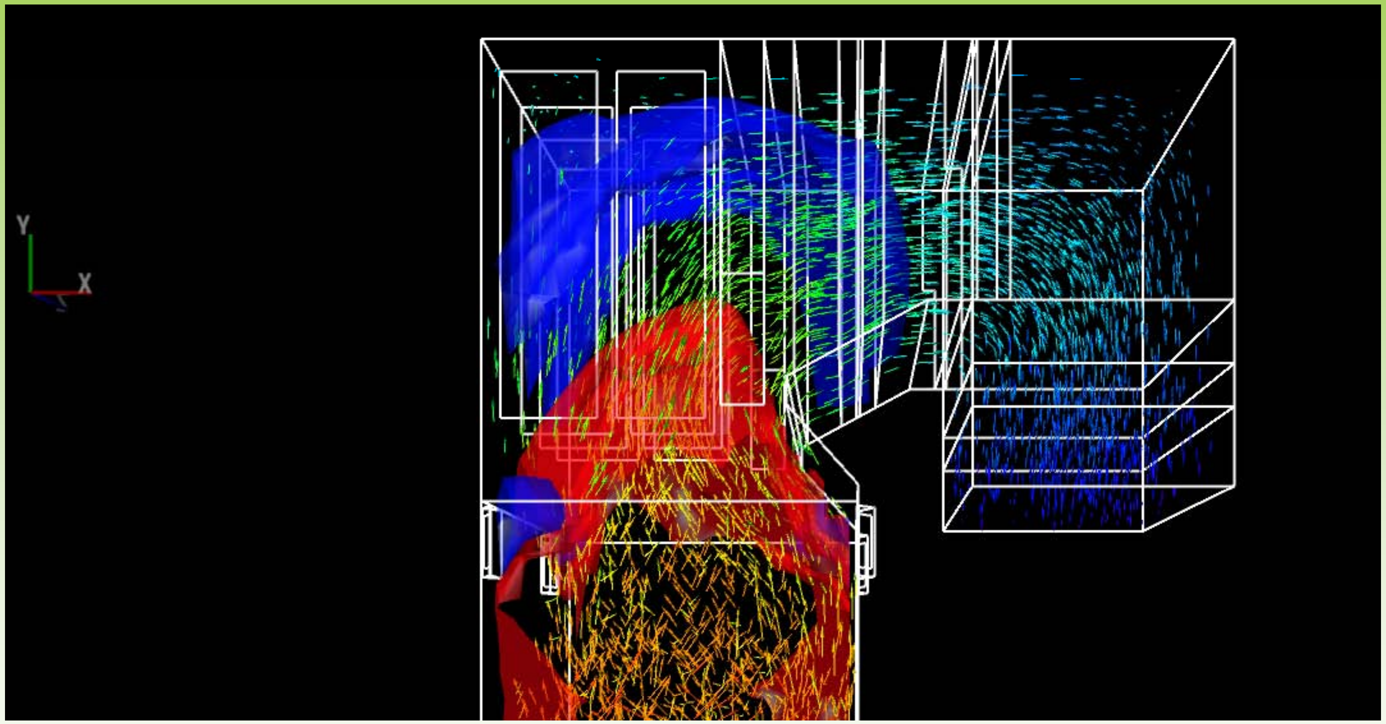
Influence of CO on SNCR Process



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

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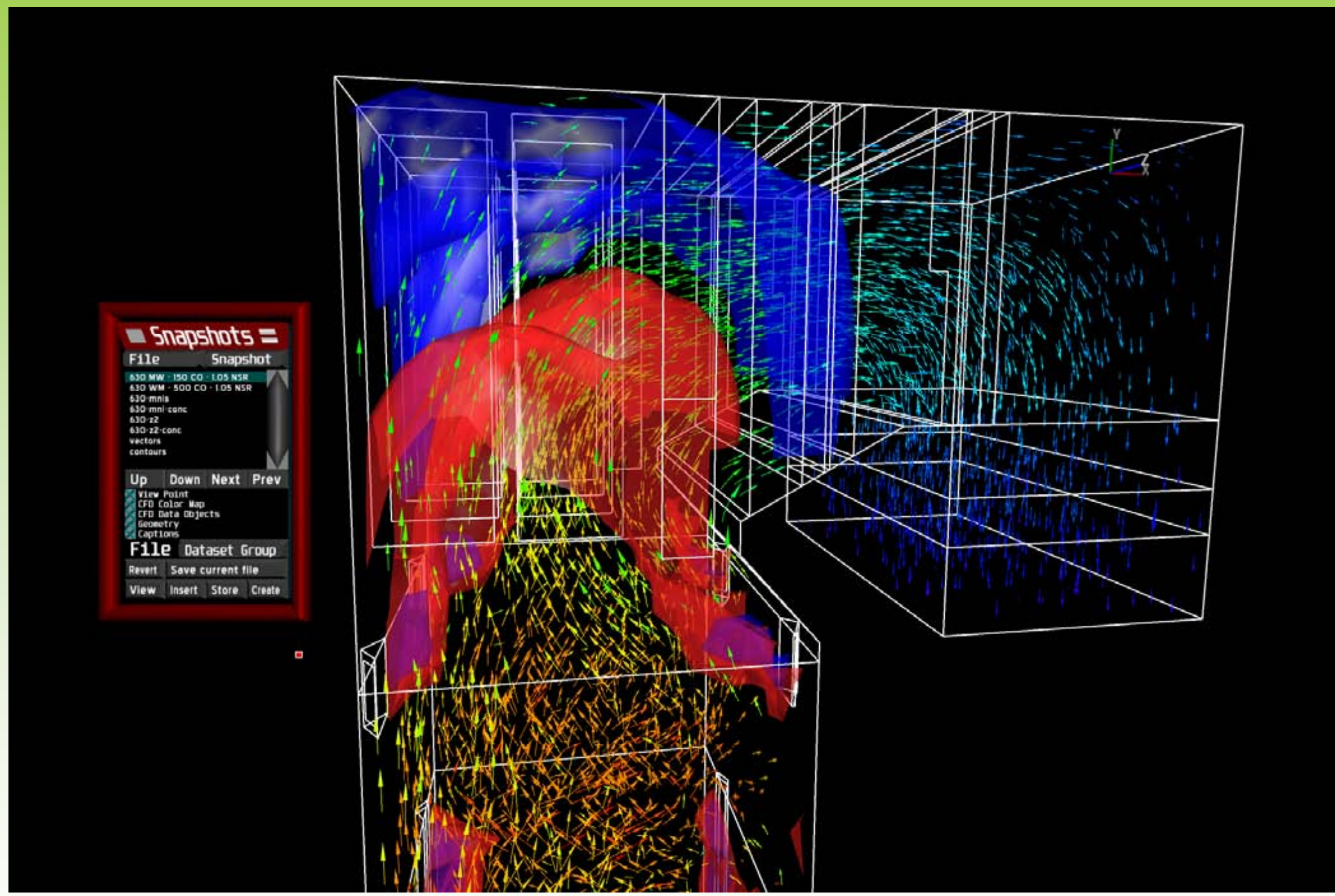
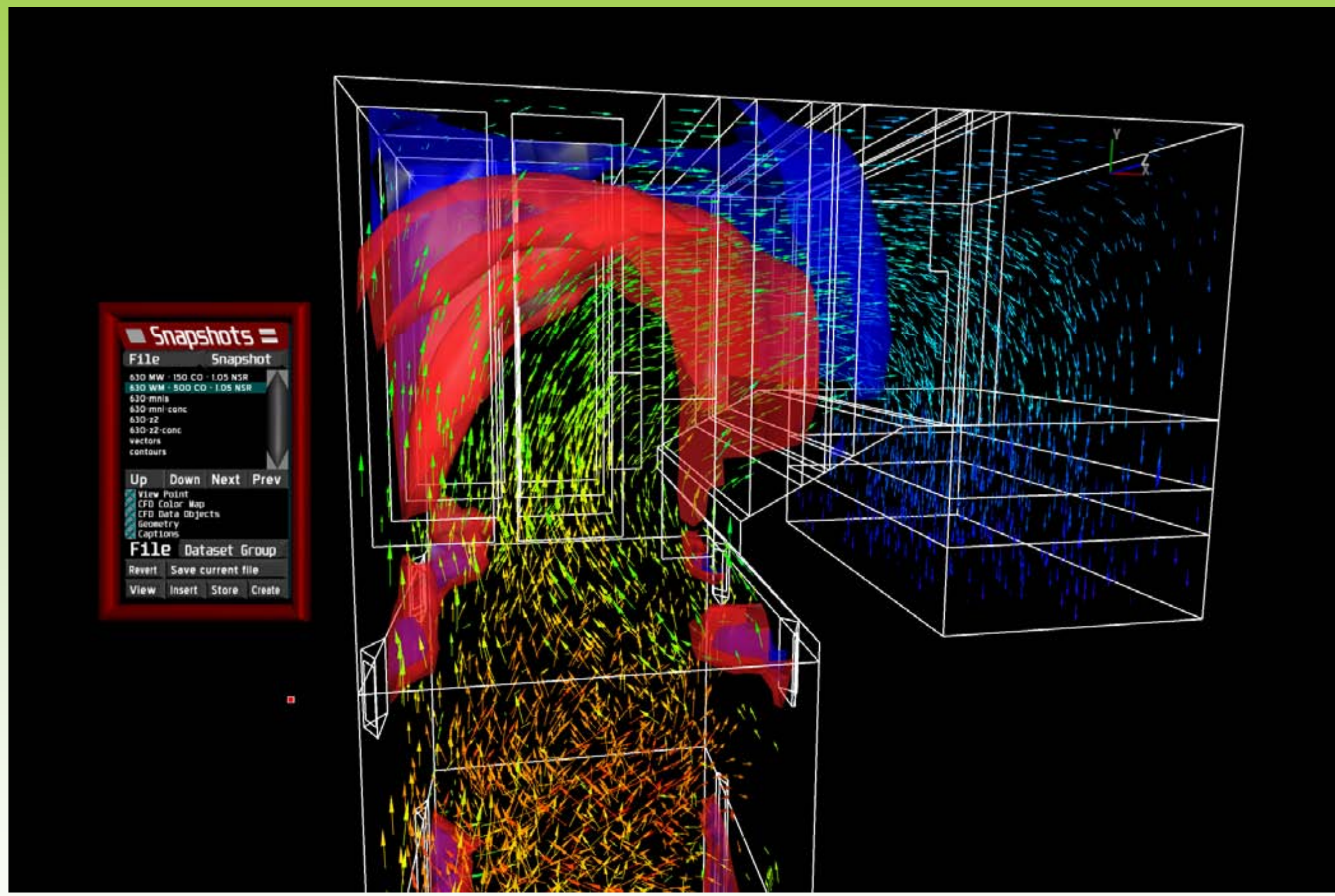
Temperature Window – 150 ppm CO

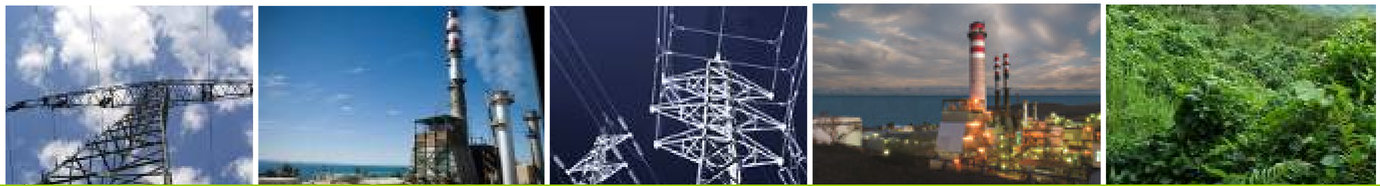


1950°F 1750°F

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**

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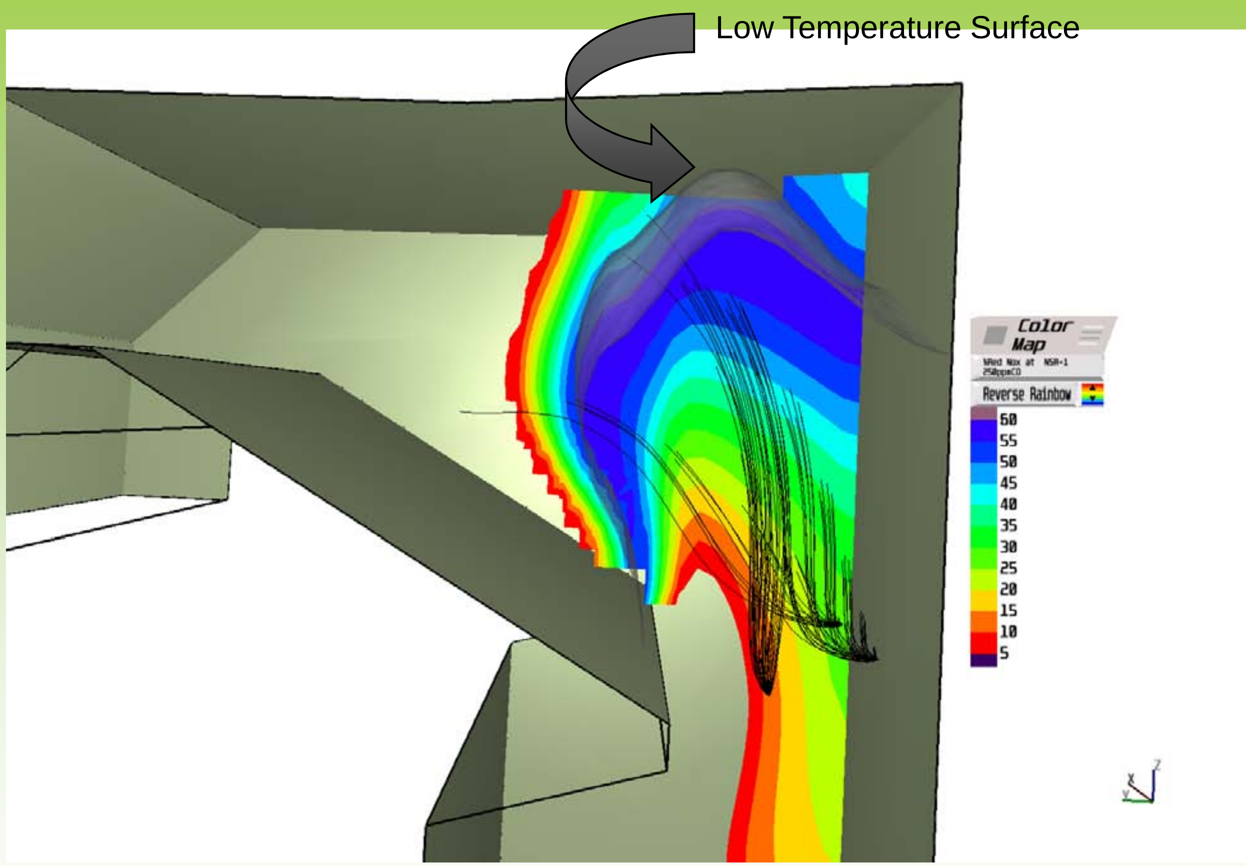
Injection Strategy for SNCR Process



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.

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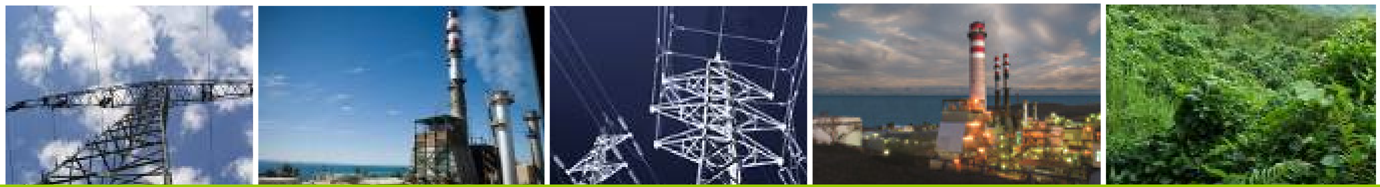
SNCR Injection Options

- 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

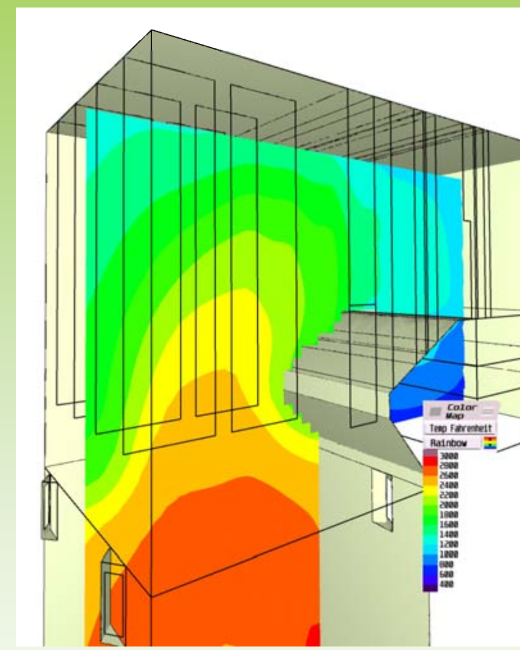
- **Air Jet penetrates the flue gas flow**
- **Small urea droplets**
- **Air and flue gas (NOx) mix**
- **Droplets heat up and evaporate**
- **Urea and NO_x Mix**
- **Urea decomposes to N_2 and H_2O**
- **Urea reacts with NO**



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**



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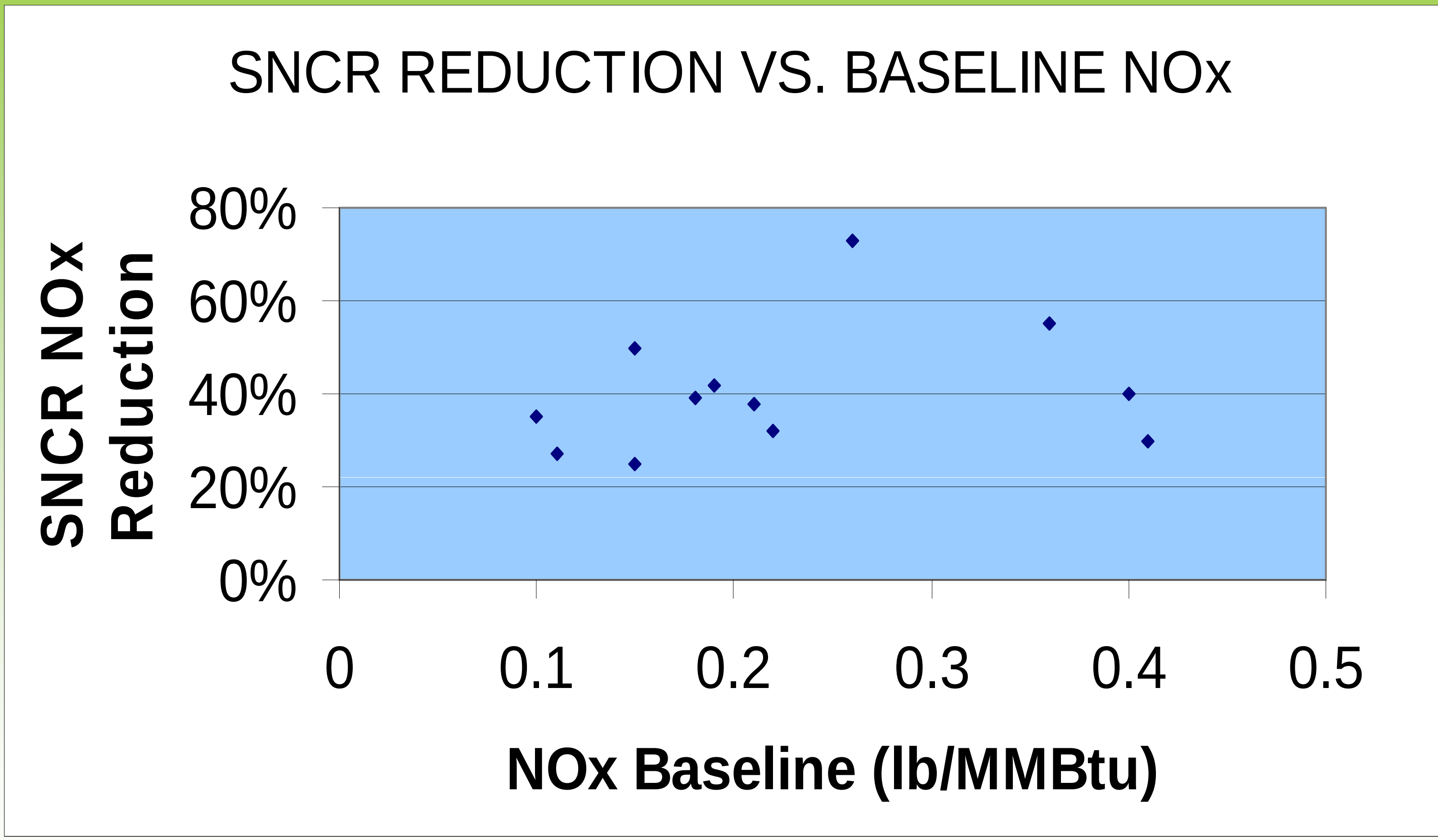
HERT Performance

- **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



HERT Performance Summary

Partial List of Commercial and Demo (D) Systems

MW	BASELINE NOx	% REDUCTION	OUTLET NOx
45	0.18	39%	0.11
60	0.19	42%	0.11
100	0.21	38%	0.13
120	0.22	32%	0.15
180	0.40	40%	0.24
200	0.15	25%	0.11
200	0.15	50%	0.08
275 D	0.11	27%	0.08
275 D	0.10	35%	0.07
350 D	0.36	55%	0.16
425 D	0.26	73%	0.07
600 D	0.41	30%	0.29

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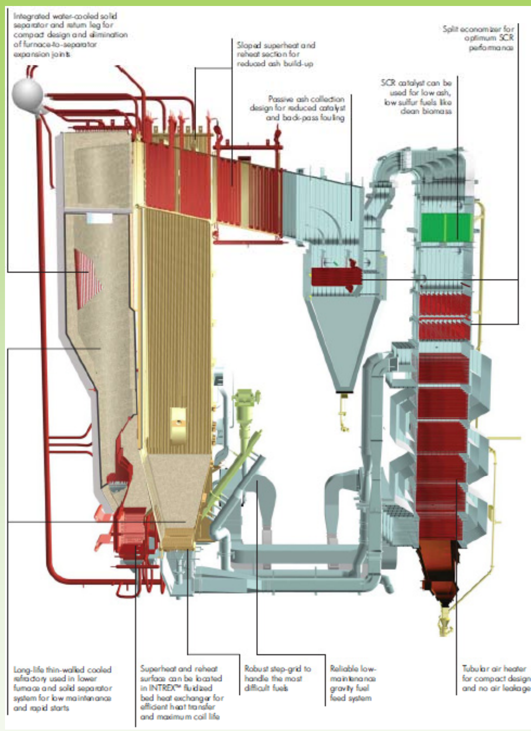
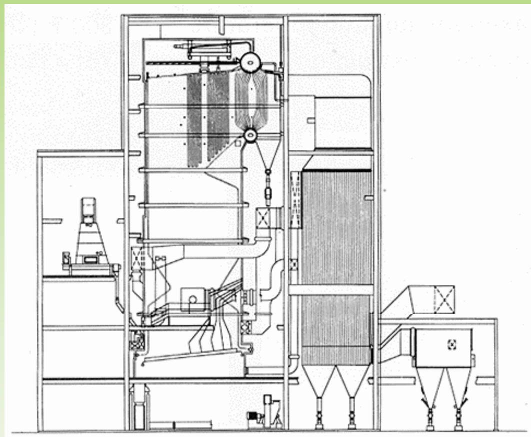
Biomass-fired Applications – Boiler Options

Circulating Fluidized Bed (CFB) Boilers



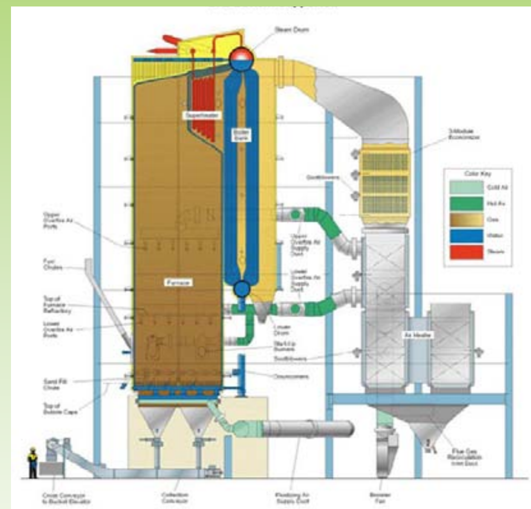
Drawing courtesy of Foster Wheeler

Grate-fired Stoker Boilers



Drawing courtesy of McBurney

Bubbling Fluidized Bed (BFB) Boilers



Drawing courtesy of B&W

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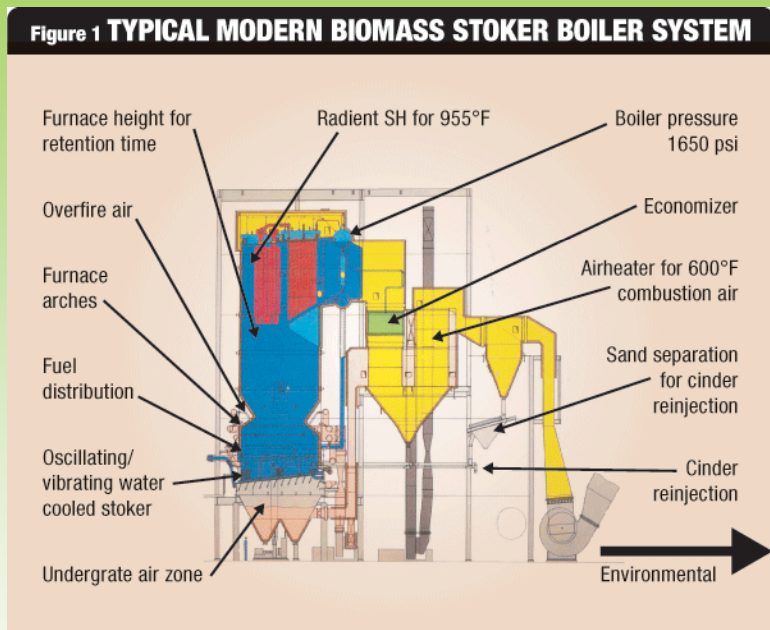
SNCR for Grate-fired Stoker

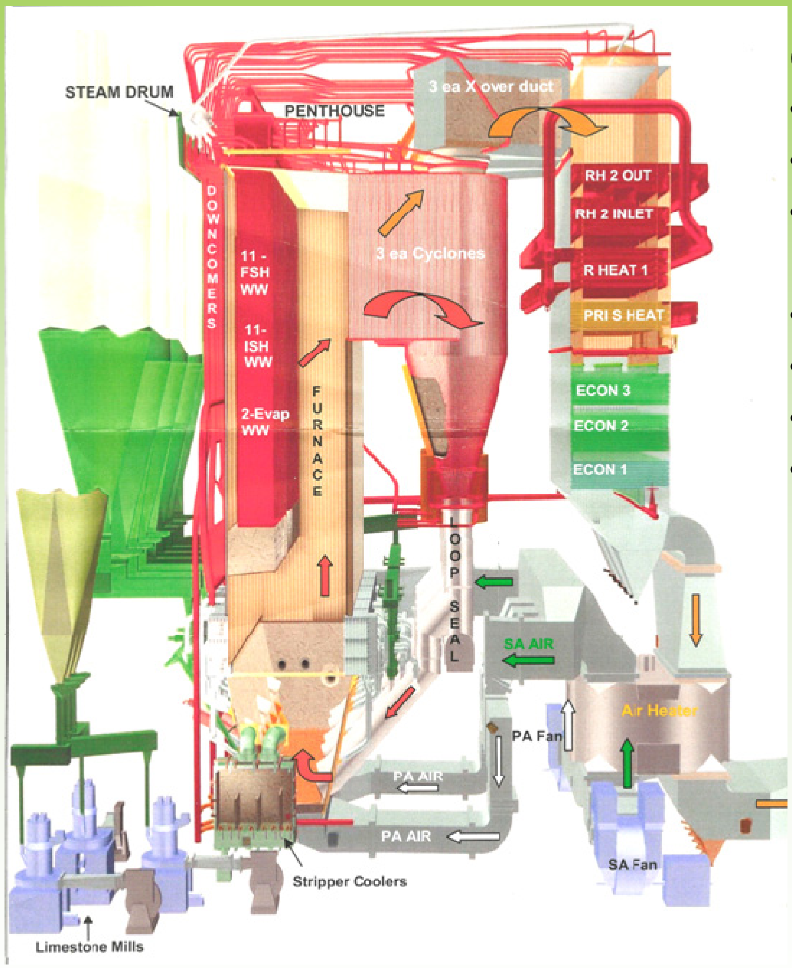


Drawing Courtesy of Babcock & Wilcox

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
  - o Working with boiler OEMs to modify designs to provide more favorable upper furnace conditions for SNCR – reducing temperature and increasing residence time

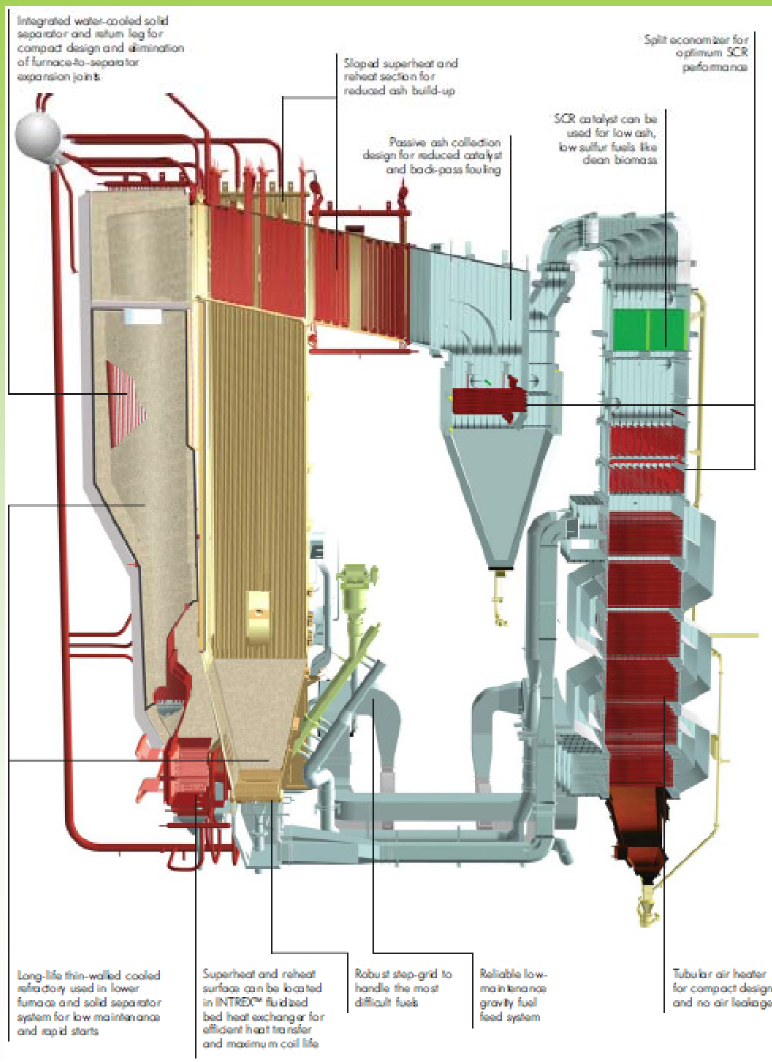
SNCR for Circulating Fluidized Bed (Utility)



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%
- NH_3 Slip: 20 ppm
- Comments
  - o Eight (8) SNCR Injectors per Cyclone, Three Cyclones
  - o NOx Controlled to 0.085 lb/MMBtu
  - o Aqueous NH_3 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
  - o NOx Controlled to 0.075 lb/MMBtu
  - o Urea and Aqueous NH3 Options, Low Temperature and Long Residence Time Favors Both

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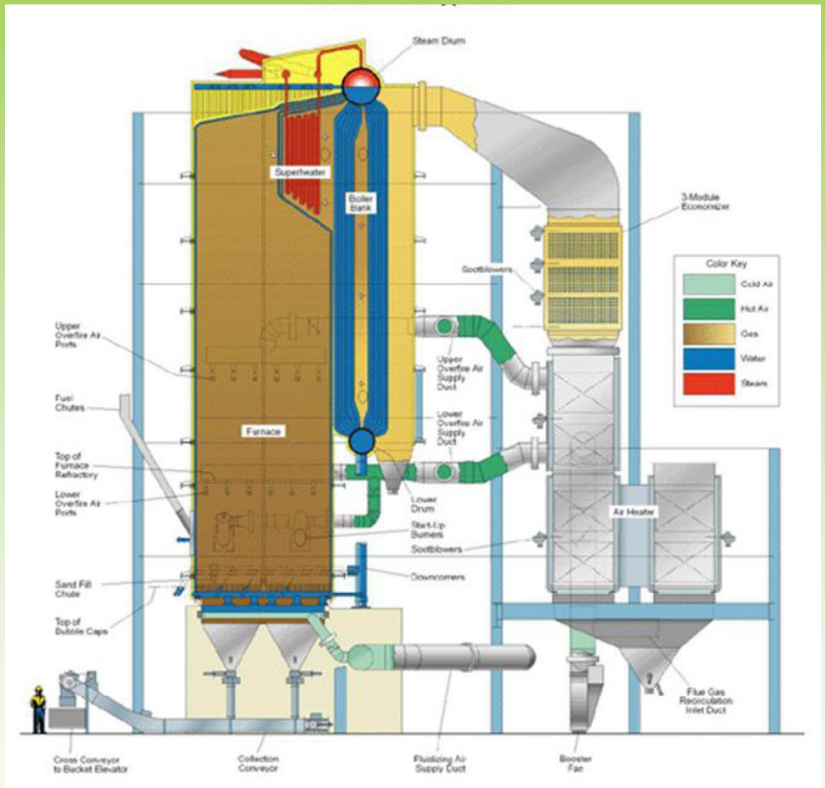
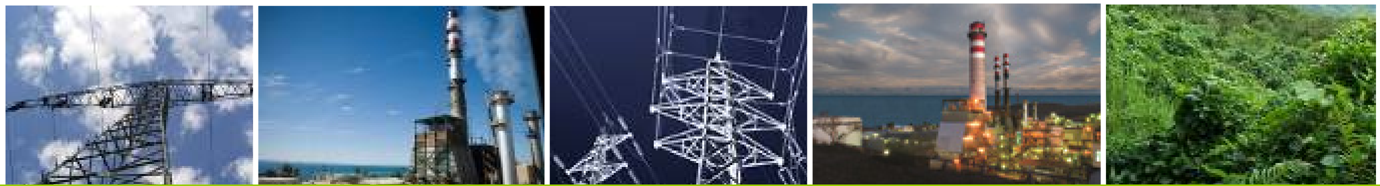
SNCR for Bubbling Fluidized Bed



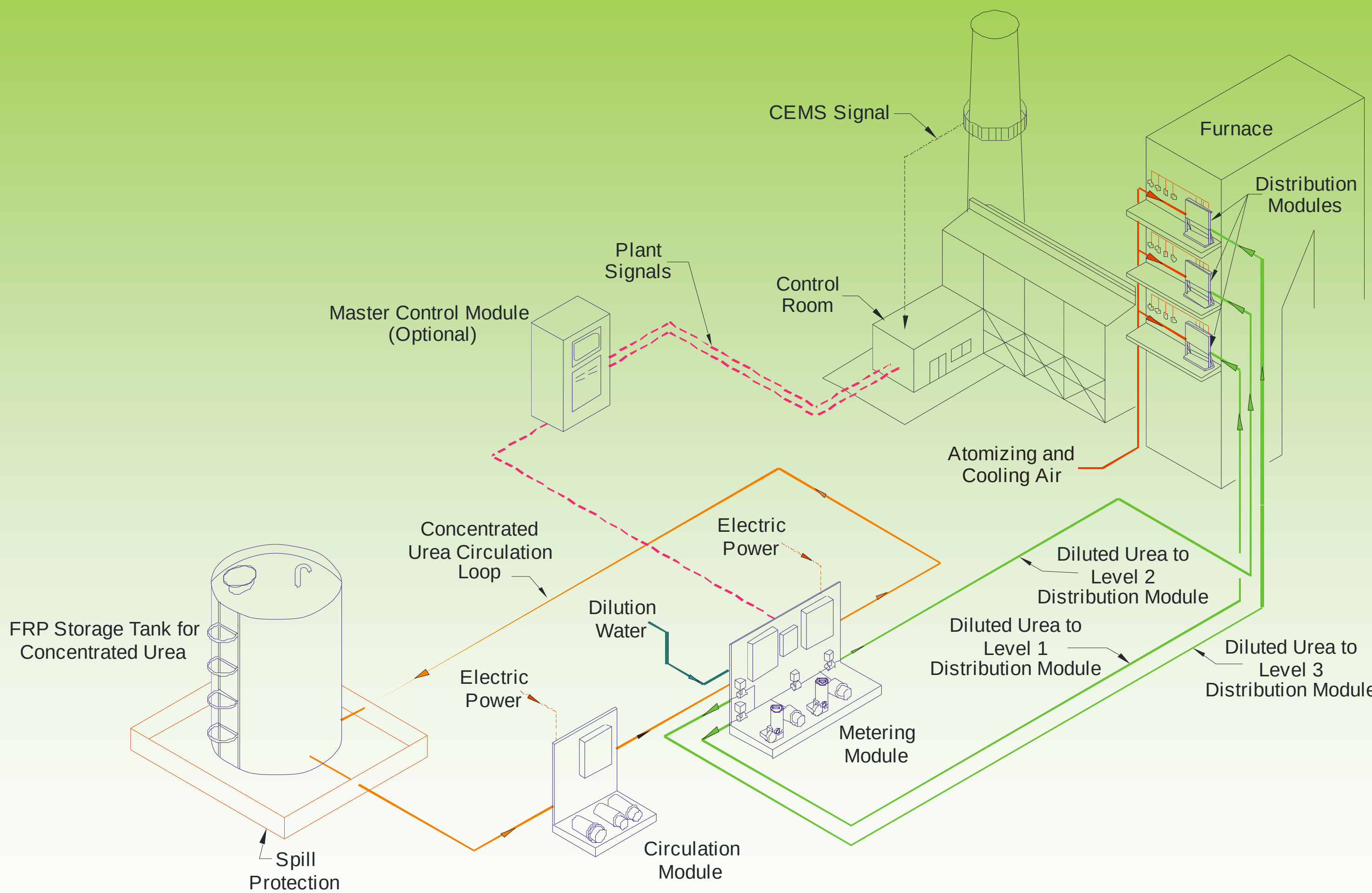
BFB Boiler Example

- 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

NOxOUT® SNCR Process Schematic



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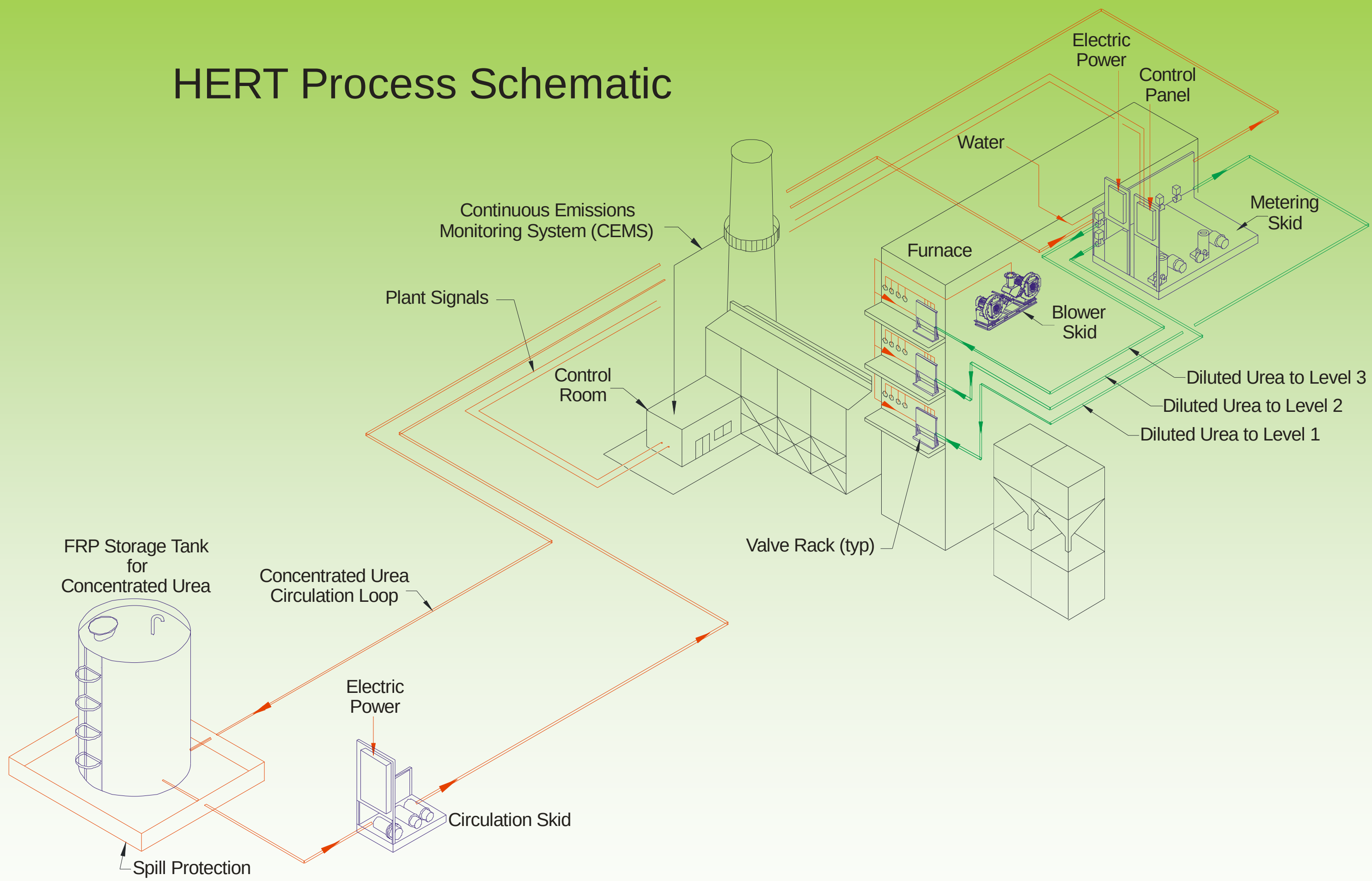
HERT™ SNCR Process Schematic



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.

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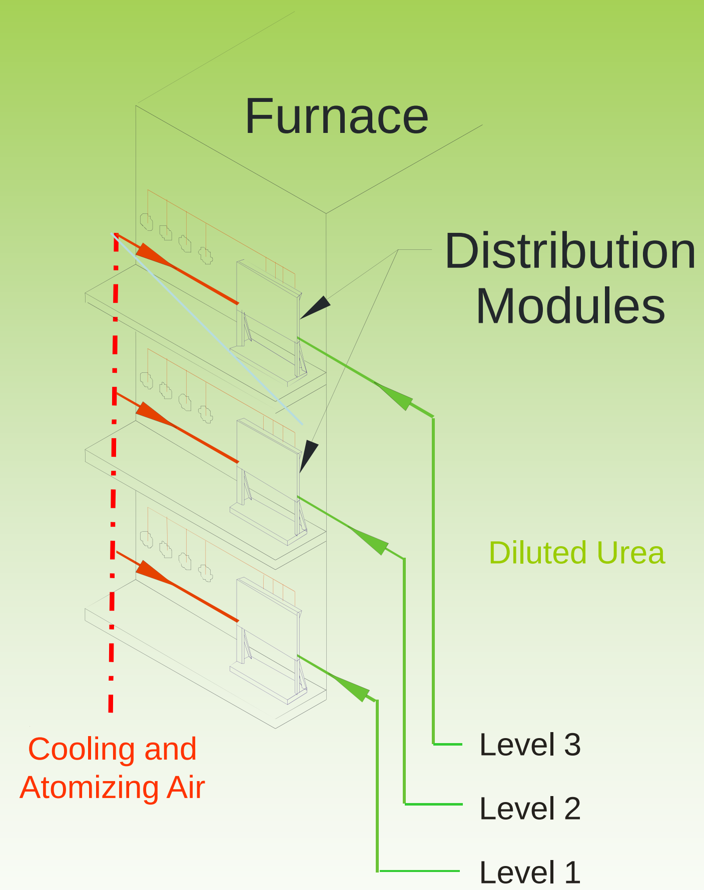
SNCR Distribution Modules & NOxOUT Injectors



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.

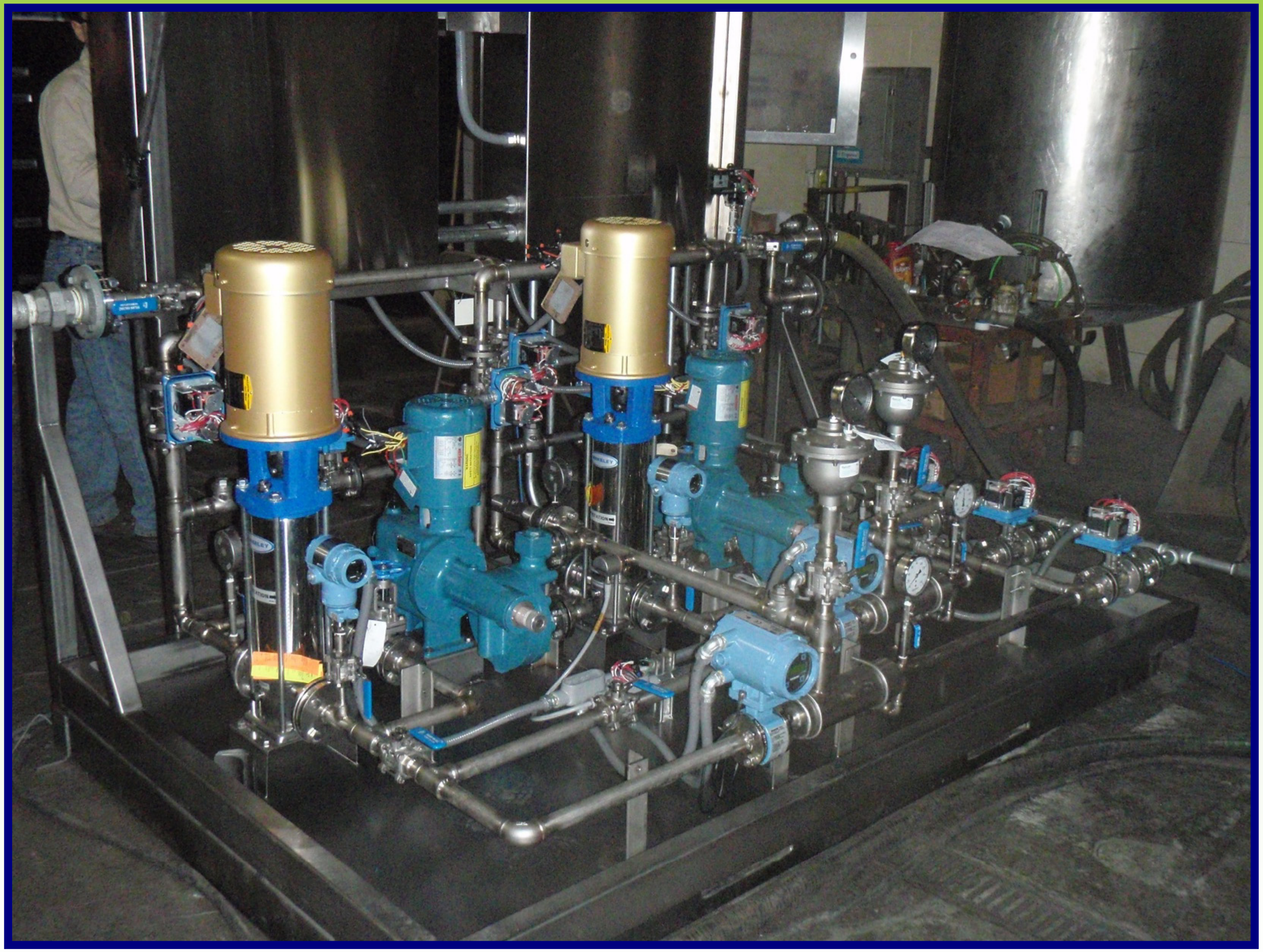
Urea Tanks

Urea Tank

NOxOUT Reagent Storage

Circulation Modules

HERT Circulation Skid



Metering Module

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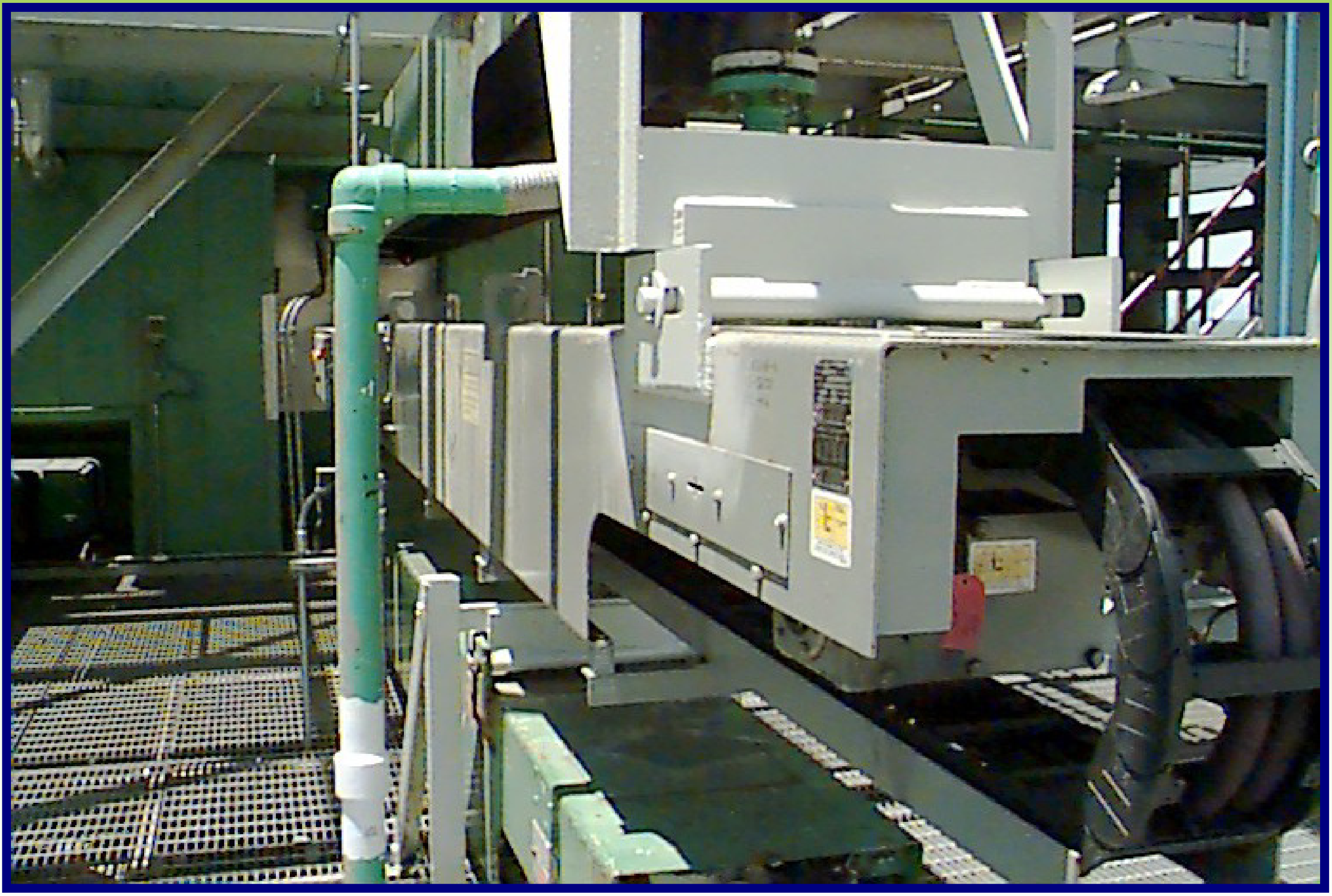
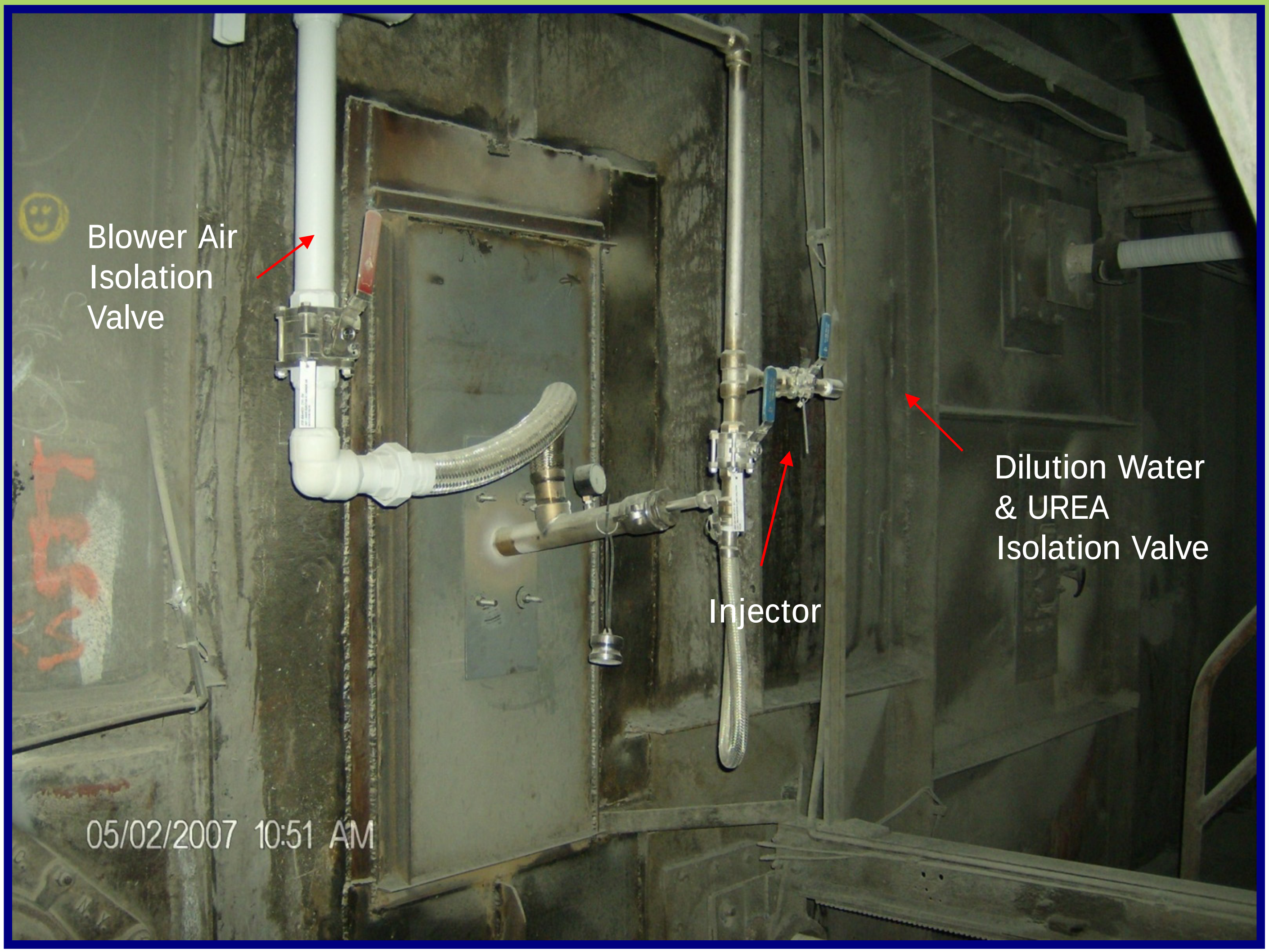
HERT System Solenoid Rack

NOxOUT Injection

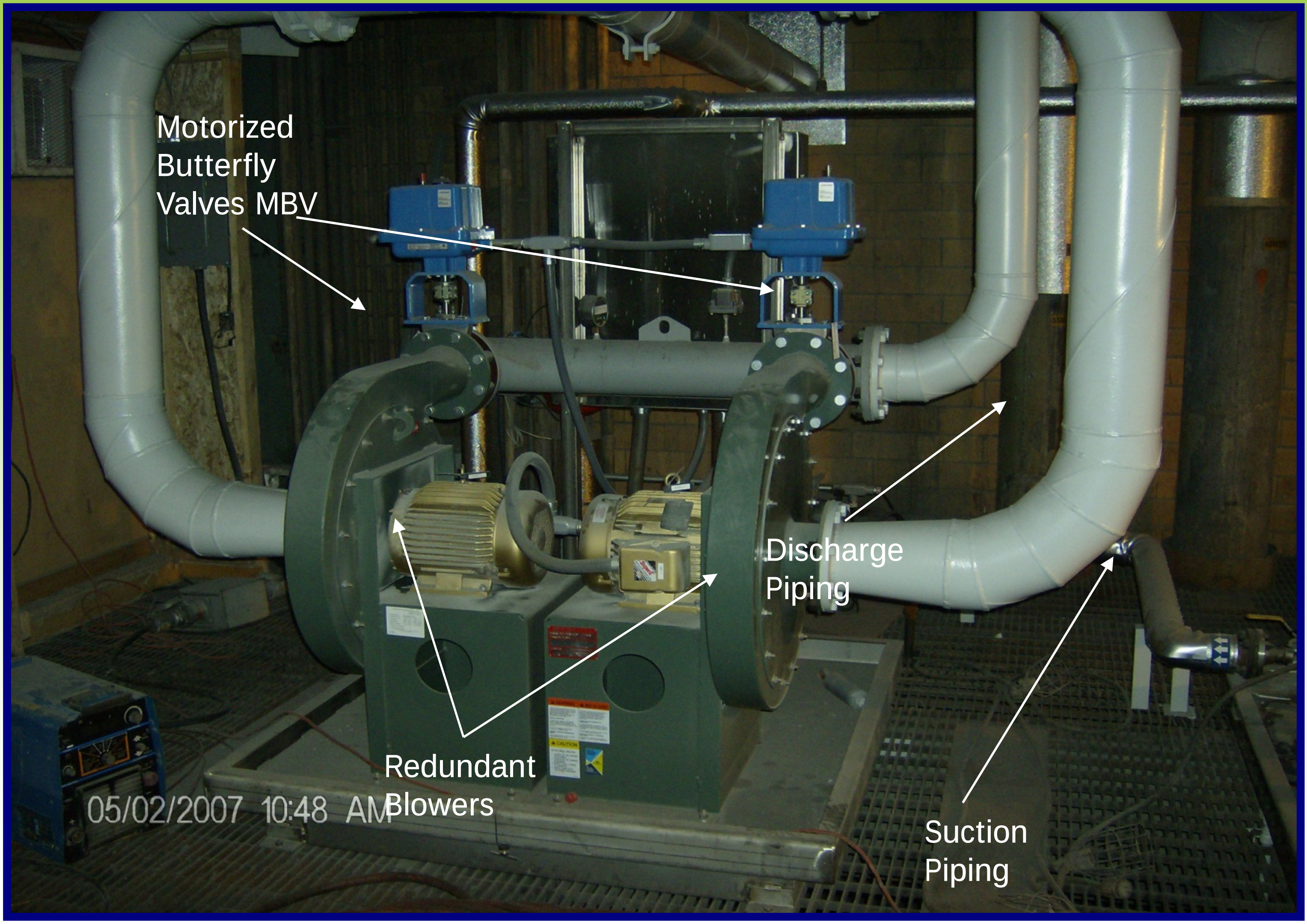
Multiple Nozzle Lances



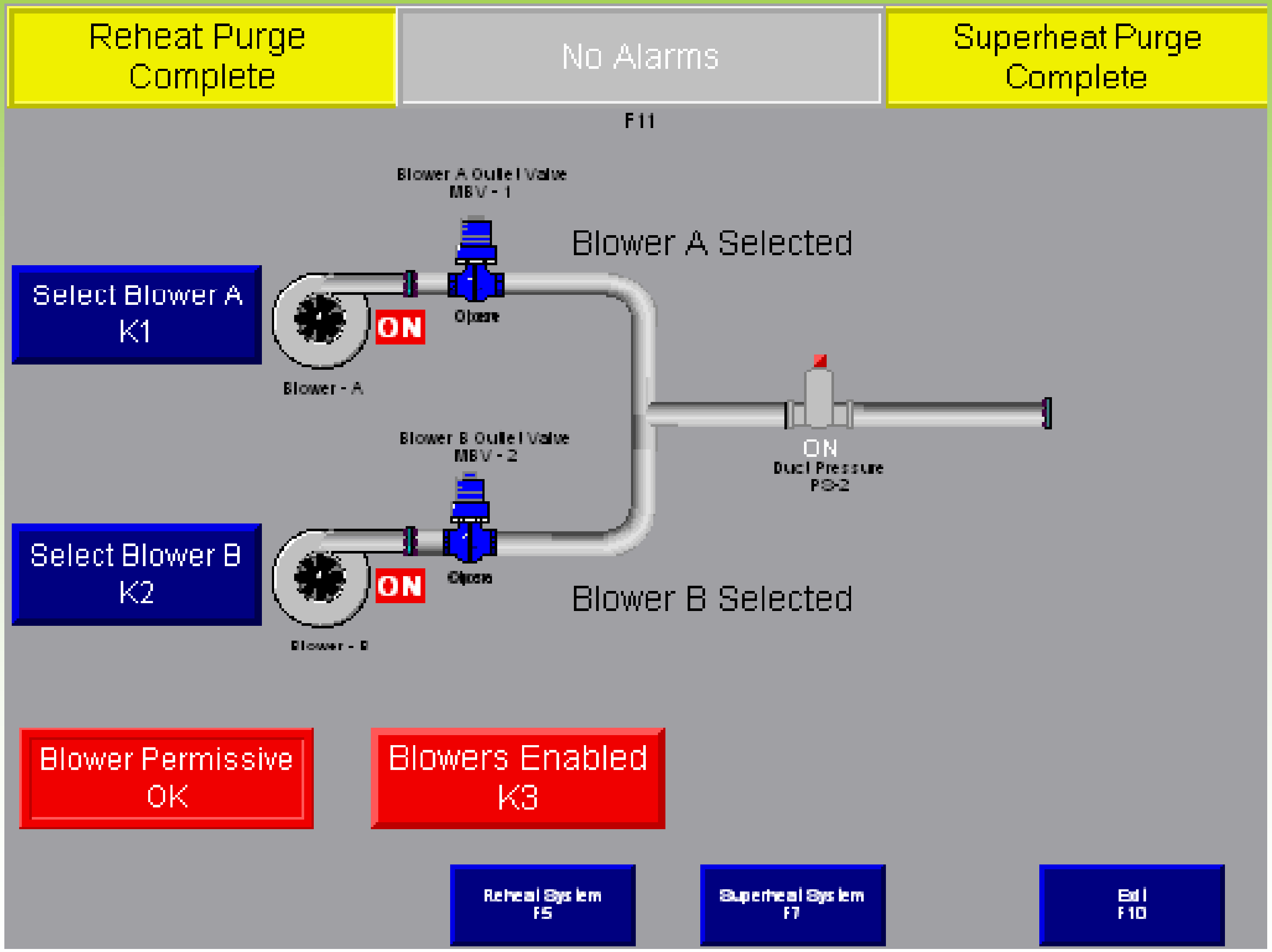
HERT INJECTOR



Blower Skid


Motorized
Butterfly
Valves MBV
Discharge
Piping
Redundant
Blowers
05/02/2007 10:48 AM
Suction
Piping

Blower Skid Screen



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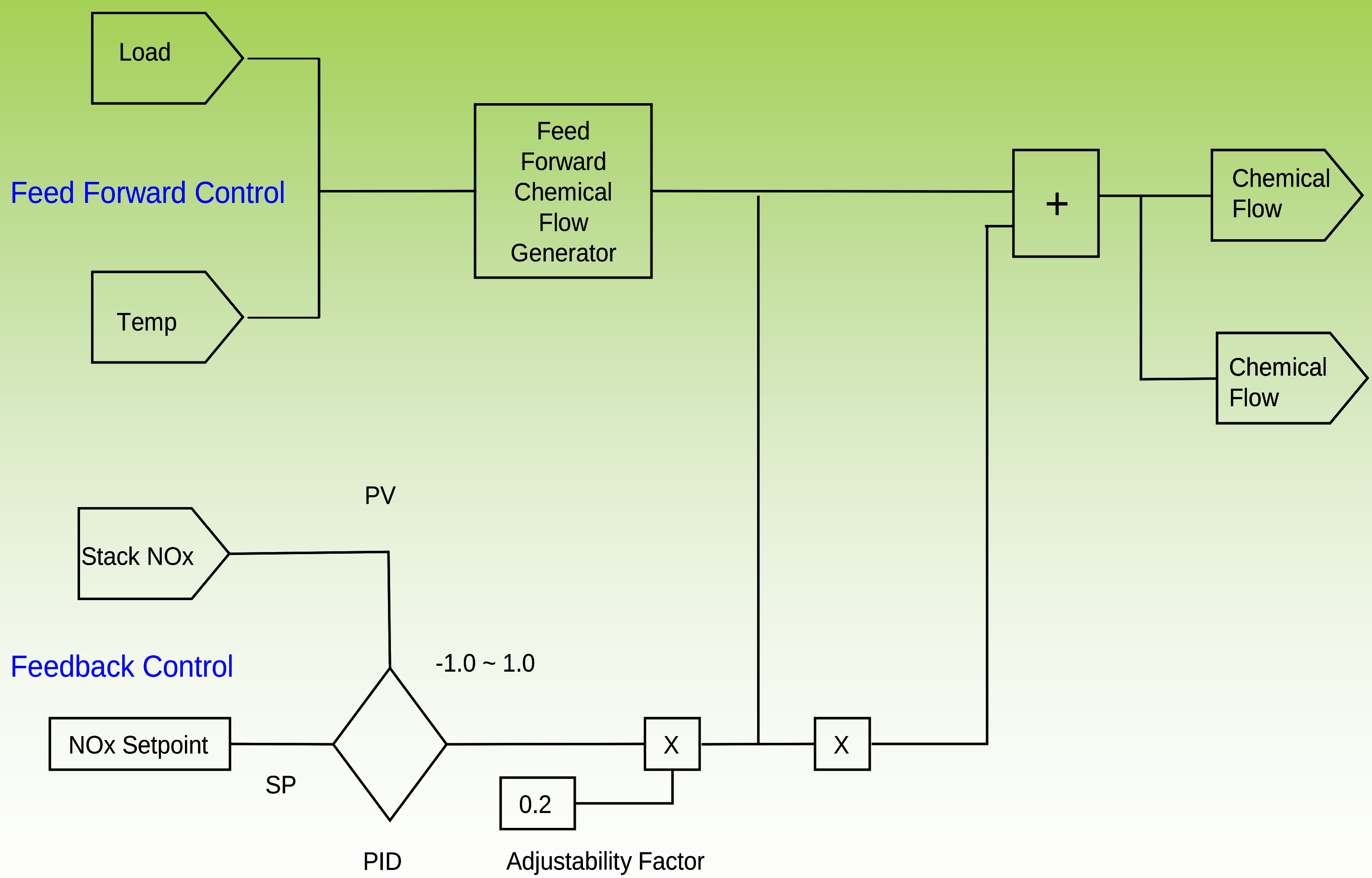
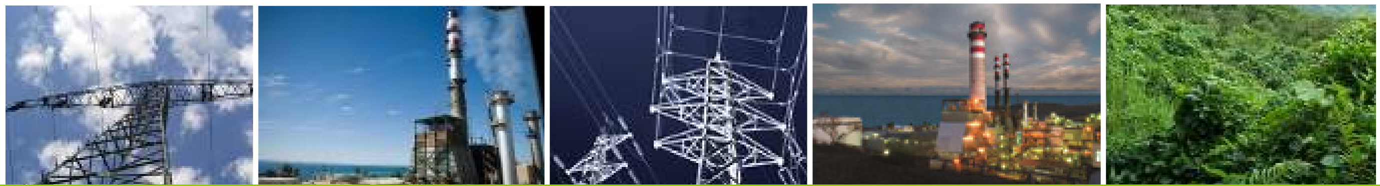
NOxOUT® SNCR Control Loop

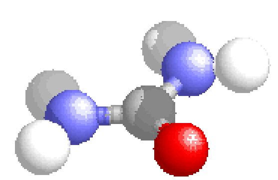




UREA REAGENT OPTIONS

Liquid Urea Properties – NH_2CONH_2

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



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Urea and Dilution Water Quality

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

QUALITY SPECIFICATIONS – DILUTION WATER				
	NOxOUT® A	NOxOUT® HP	UNSTABILIZED UREA	NOxOUT® LT
	Dilution Water Analysis	Dilution Water Analysis	Dilution Water Analysis	Dilution Water Analysis
Total Hardness as CaCO3 (ppm)	<450	<150	<20	<450
"M" Alkalinity as CaCO3 (ppm)	<300	<100	<100	<300
Conductivity (µmho)	<2500	<1000	<1000	<2500
Silica as SiO2 (ppm)	<60	<60	<60	<60
Iron as Fe (ppm)	<1.0	<1.0	<1.0	<1.0
Manganese as Mn (ppm)	<0.3	<0.3	<0.3	<0.3
Phosphate as P (ppm)	<1.0	<1.0	<1.0	<1.0
Sulfate as SO4 (ppm)	<200	<200	<200	<200
Turbidity (NTU)	< 10	< 10	< 10	< 10
pH	<8.3	<8.3	<8.3	<8.3

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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.

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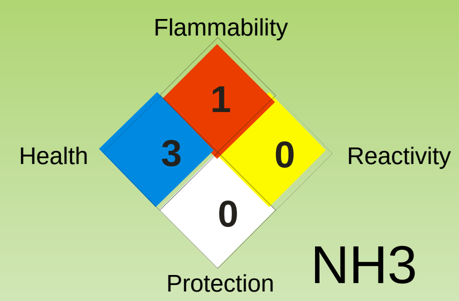
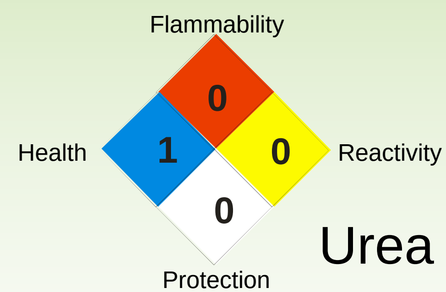
Reagent Alternatives for SNCR Systems

- **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 indentified 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[1]**

1 http://yosemite.epa.gov/oswer/ceppoweb.nsf/vwResourcesByFilename/backup.pdf/$File/backup.pdf

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

Licensee Corporate Office	Address	Contact Person	Telephone/Fax
CDI, Inc.	P.O. Box 9083 Brea, CA 92821 -or- 471 W. Lambert Rd Suite 100 Brea, CA 92821	Luis Cervantes Rick Gross	714.990.3940 714.329.2281 (cell) 714.990.4073 (fax) (901) 867-8186 office (901) 233-2336 mobile
Distribution Points	– Crossett, AR – Casa Grande, AZ - City of Industry, CA – Imperial, CA – San Jose, CA – Stockton, CA – Greeley, CO – Jacksonville, FL – Augusta, GA – Kimberly, ID – Baltimore, MD – St. Paul, MN – Albany, NY – Elizabeth, NY – Cincinnati, OH – Lima, OH – Deer Island, OR – Russellville, SC – Memphis, TN – Houston, TX – Lufkin, TX – Pasco, WA		
Mosaic Company (formerly Cargill, Inc)	12800 Whitewater Dr MS 190 Minnetonka, MN 55343	Bob Ness	800.918.8270 763.577.2781 952.742.7313 (fax)
Distribution Points	– Brandon, FL – Baltimore, MD – St. Paul, MN – Albany, NY – Cincinnati, OH – Wellsville, OH – Philadelphia, PA – Menomonie, WI		
PCS Nitrogen, Inc	1101 Skokie Blvd Northbrook, IL 60062	Jennifer A. Zagorski	847.849.4377 (office) 847.612.5301 (cell) 847.849.4489 (fax)
Distribution Points	– Augusta, GA - Lima, OH		

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Licensed NOxOUT Reagent Suppliers

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

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

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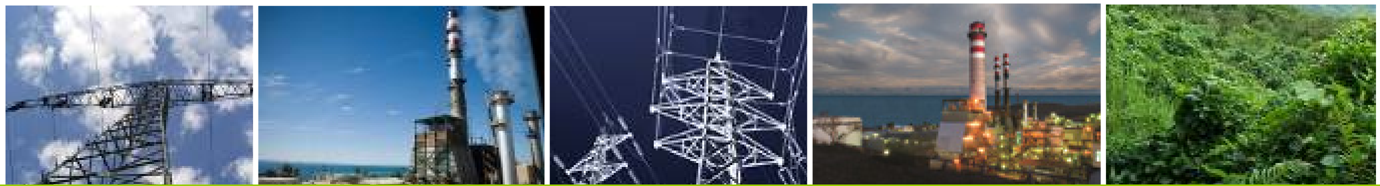

SNCR Combined with other NO_x Control Technologies

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

Technology	Strength	Limitations
Low-NOx Burners	Low Capital and Operating	Combustion, Corrosion, CO
Combustion Mods / OFA	Low Capital and Operating	Combustion, Corrosion, CO
SNCR	Low Capital NOx Red%	NH3 Slip ABS
SCR	NOx Red% Low NH3 Slip	High Capital SO_3 Oxidation

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Retrofit Low-NOx Burner Installation

Technology	Strength	Limitations
Low-NOx Burners	Low Capital and Operating	Combustion, Corrosion, CO
Combustion Mods / OFA	Low Capital and Operating	Combustion, Corrosion, CO
SNCR	Low Capital NOx Red%	NH3 Slip ABS
SCR	NOx Red% Low NH3 Slip	High Capital SO_3 Oxidation

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Moderate Combustion Modifications

Technology	Strength	Limitations
Low-NOx Burners	Low Capital and Operating	Combustion, Corrosion, CO
Combustion Mods / OFA	Low Capital and Operating	Combustion, Corrosion, CO
SNCR	Low Capital NOx Red%	NH3 Slip ABS
SCR	NOx Red% Low NH3 Slip	High Capital SO_3 Oxidation

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Conservative SNCR application

Technology	Strength	Limitations
Low-NOx Burners	Low Capital and Operating	Combustion, Corrosion, CO
Combustion Mods / OFA	Low Capital and Operating	Combustion, Corrosion, CO
SNCR	Low Capital NOx Red%	No NH3 Slip No ABS
SCR	NOx Red% Low NH3 Slip	High Capital SO_3 Oxidation

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Aggressive SNCR application

Technology	Strength	Limitations
Low-NOx Burners	Low Capital and Operating	Combustion, Corrosion, CO
Combustion Mods / OFA	Low Capital and Operating	Combustion, Corrosion, CO
SNCR	Low Capital > Red%	NH3 Slip ABS
SCR	NOx Red% Low NH3 Slip	High Capital SO_3 Oxidation

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In-Duct or Small SCR Space

Technology	Strength	Limitations
Low-NOx Burners	Low Capital and Operating	Combustion, Corrosion, CO
Combustion Mods / OFA	Low Capital and Operating	Combustion, Corrosion, CO
SNCR	Low Capital > Red%	NH3 is OK Feed to SCR
Single Layer SCR	More Red% Low NH3 Slip	Mod Capital, SO_3 and Cost

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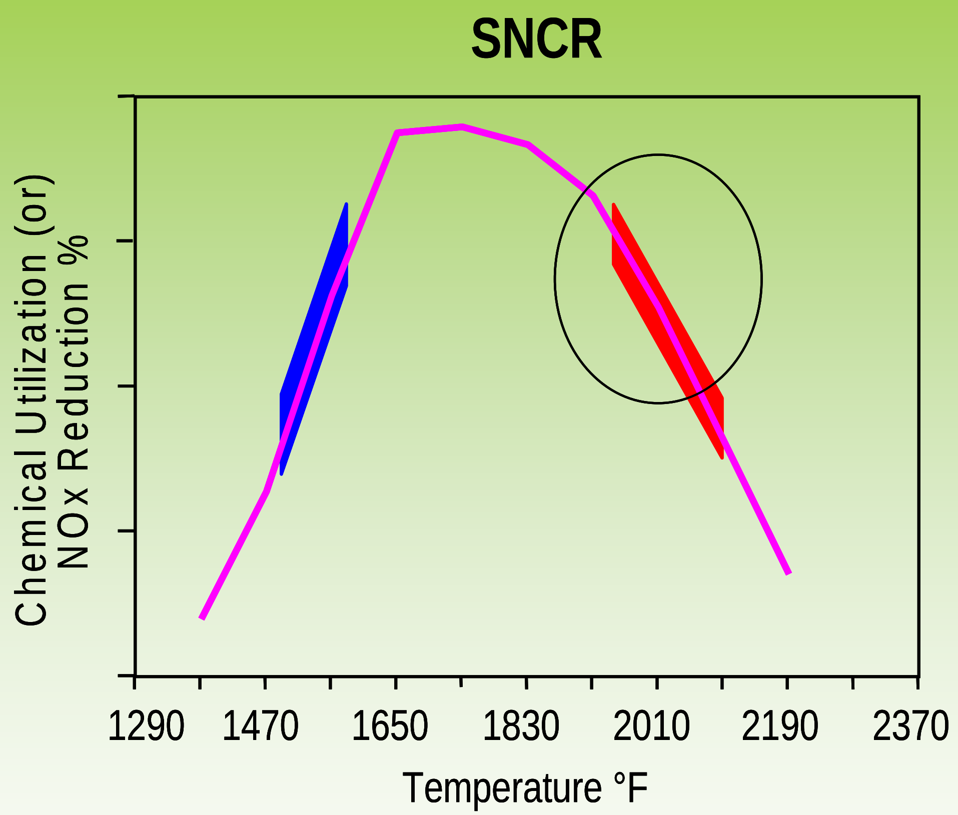
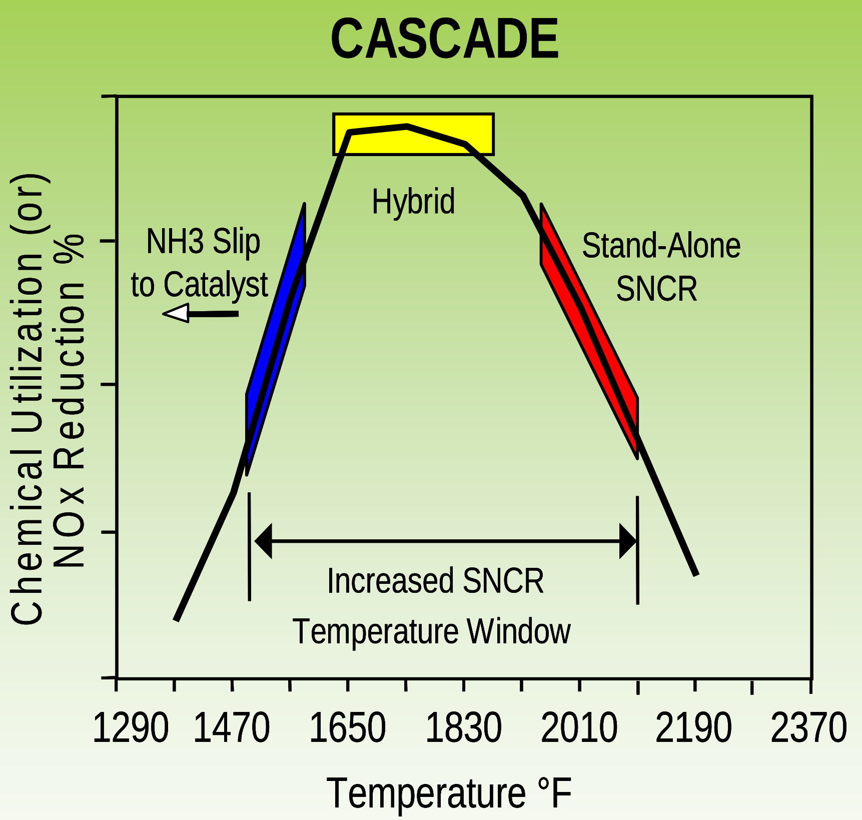
Advanced SCR Application

Technology	Reduction	Total %
Low-NOx Burners	30%	30%
Combustion Mods / OFA	30%	51%
SNCR	30%	66%
Single Layer SCR	45%	81%

Chemical Release Point Comparison





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 SO_2 to SO_3**
- **Lower Catalyst Replacement Cost, Single Layer**

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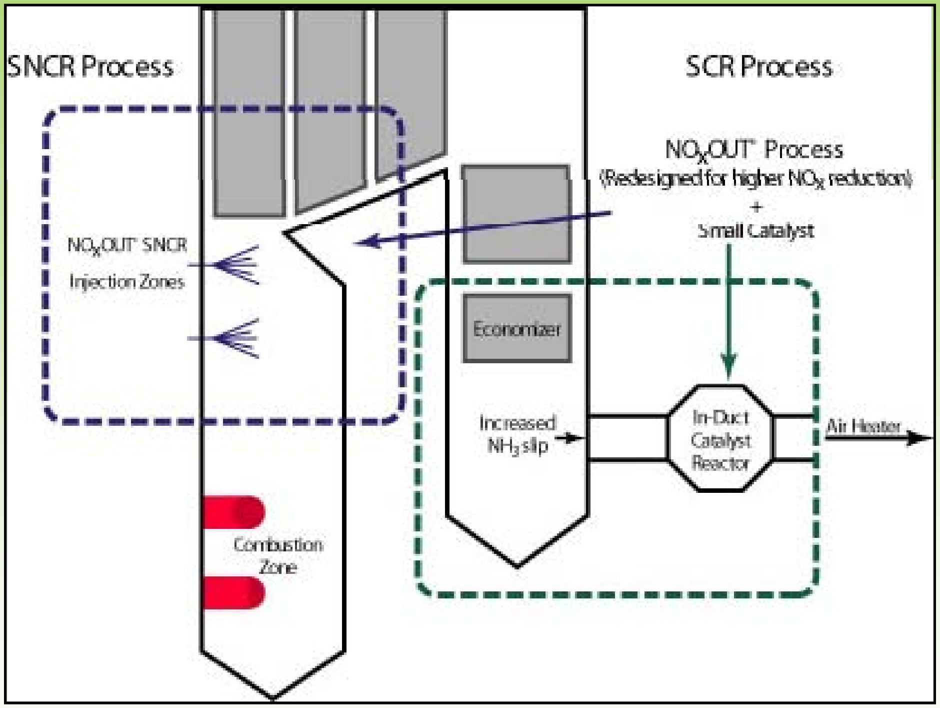
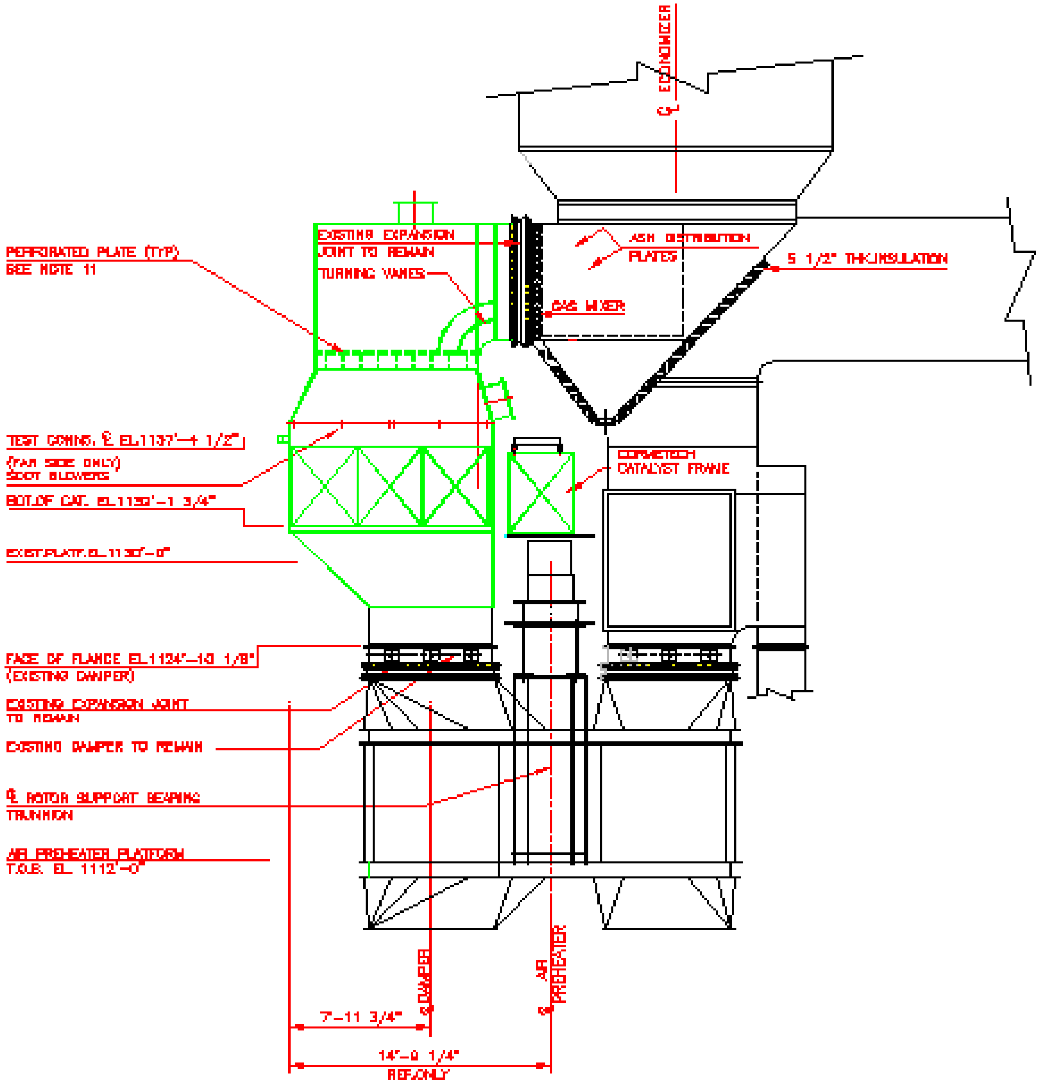
NOxOUT CASCADE® Technology Overview

- 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
- 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



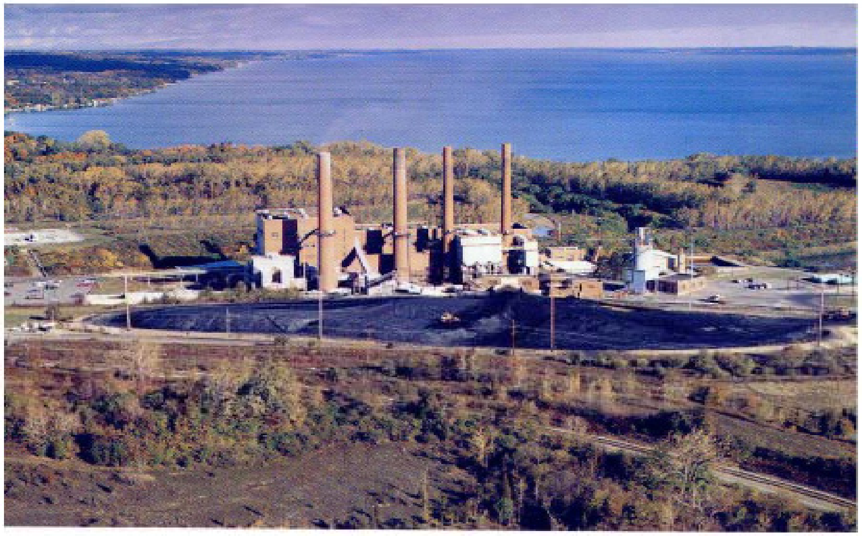
Penelec Seward Duct Modifications



AES Greenidge – Multi-P w/ CASCADE

AES Greenidge Unit 4
(Boiler 6)

ELECTRIC POWER CONFERENCE & EXHIBITION



- Dresden, NY
- Commissioned in 1953
- 107 MW_e (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)
  - ESP
  - No FGD - mid-sulfur coal to meet permit limit of 3.8 lb SO_2/MMBtu

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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%**

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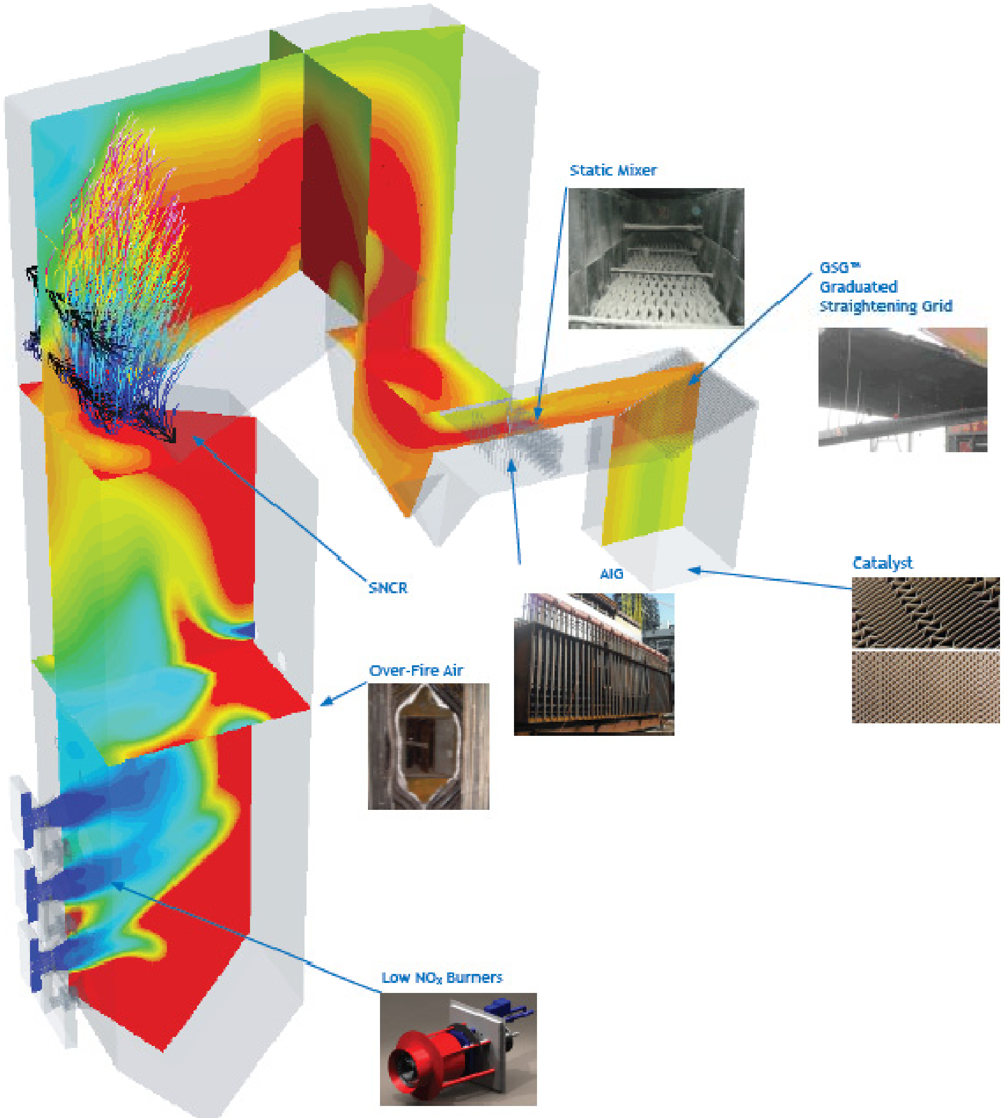
ASCR™ Advanced SCR



- 80+% NO_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_2 to SO_3 Conversion Rate
- Broader Range of Operation
  - Lower Electrical Demand

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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**

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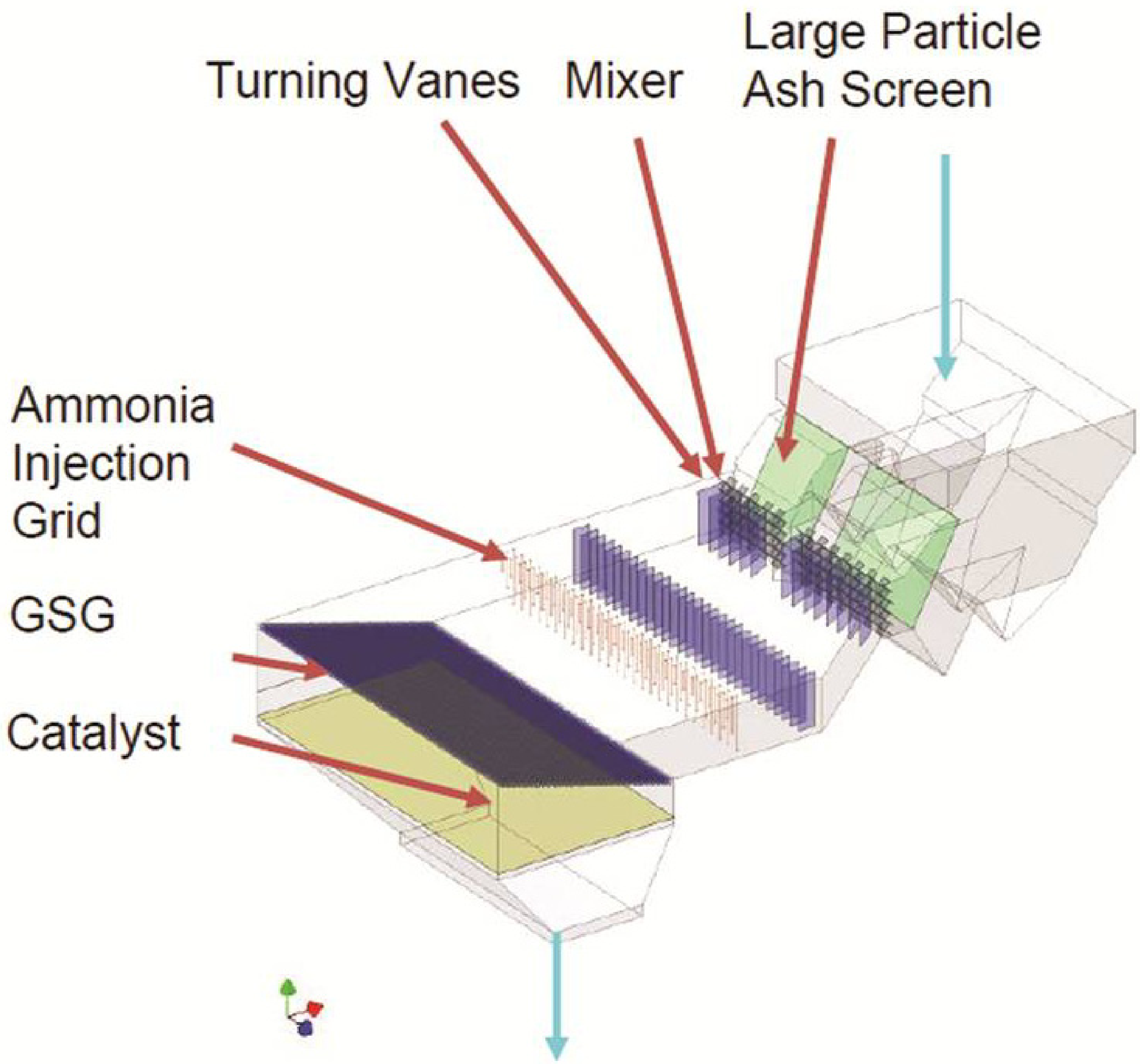
Optimized SCR System



Summary

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

Questions?