REINHOLD ENVIRONMENTAL Ltd.

2011 NOx-Combustion Round Table & Expo Presentation

February 7-8, 2011, in Birmingham, AL / Hosted by Southern Company

SNCR Baseline Testing - HVT

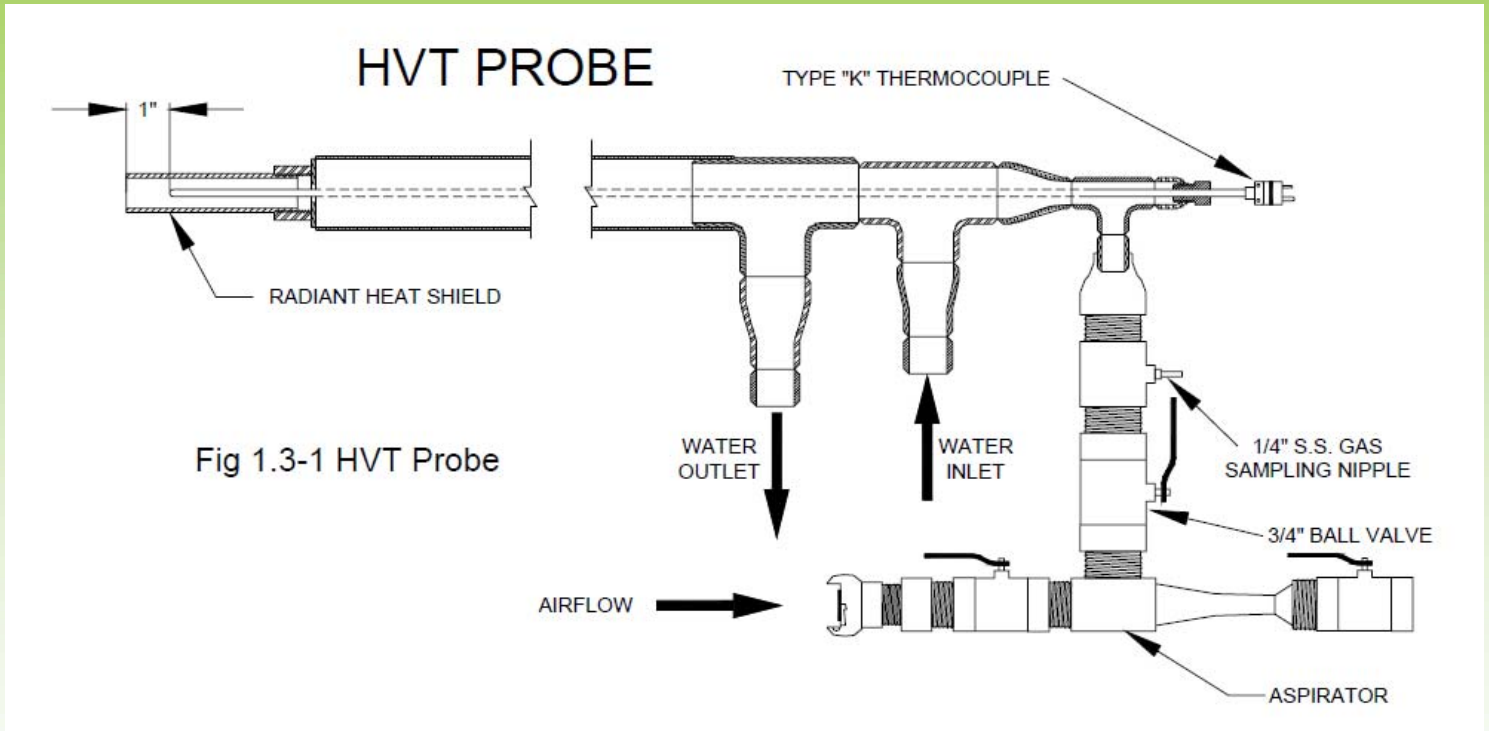
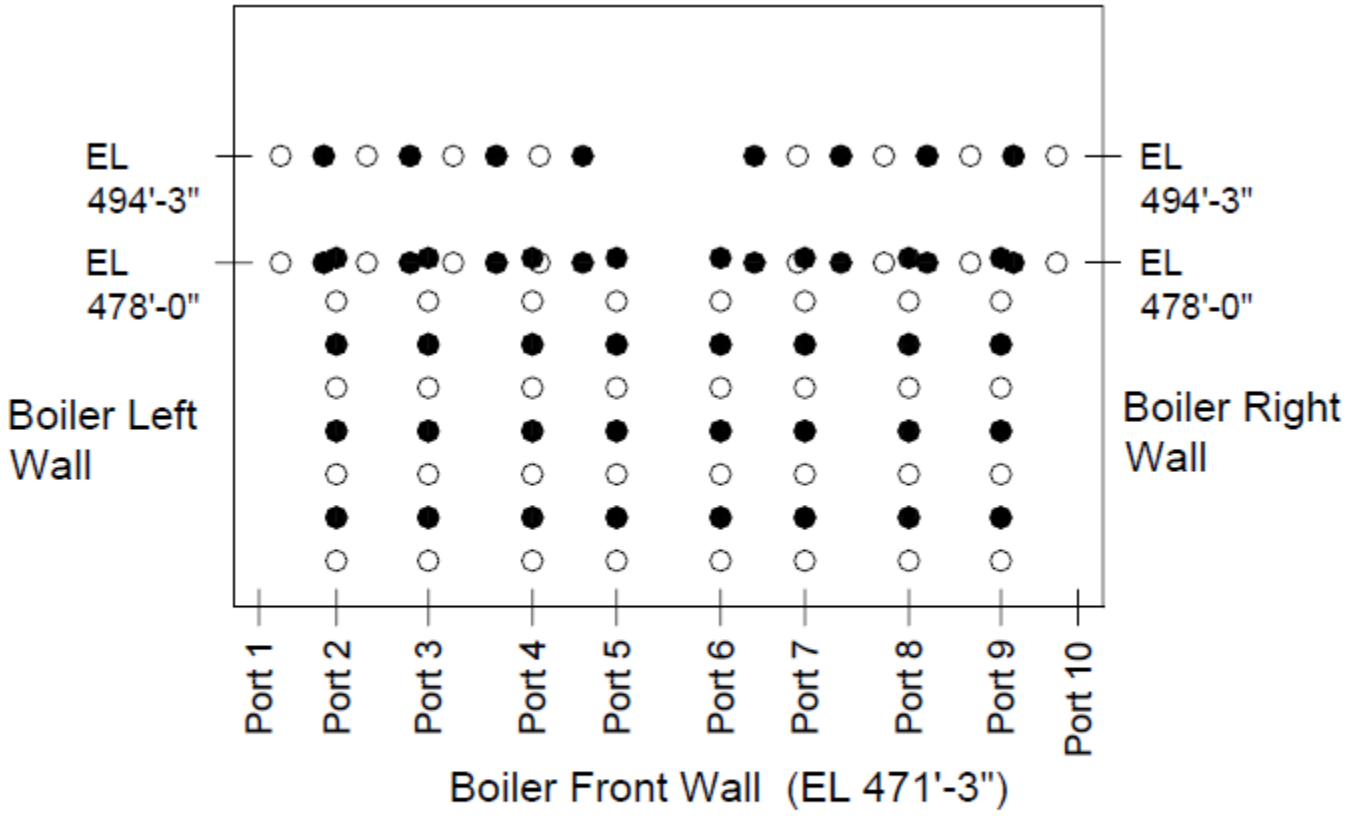


Fig 1.3-1 HVT Probe

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*

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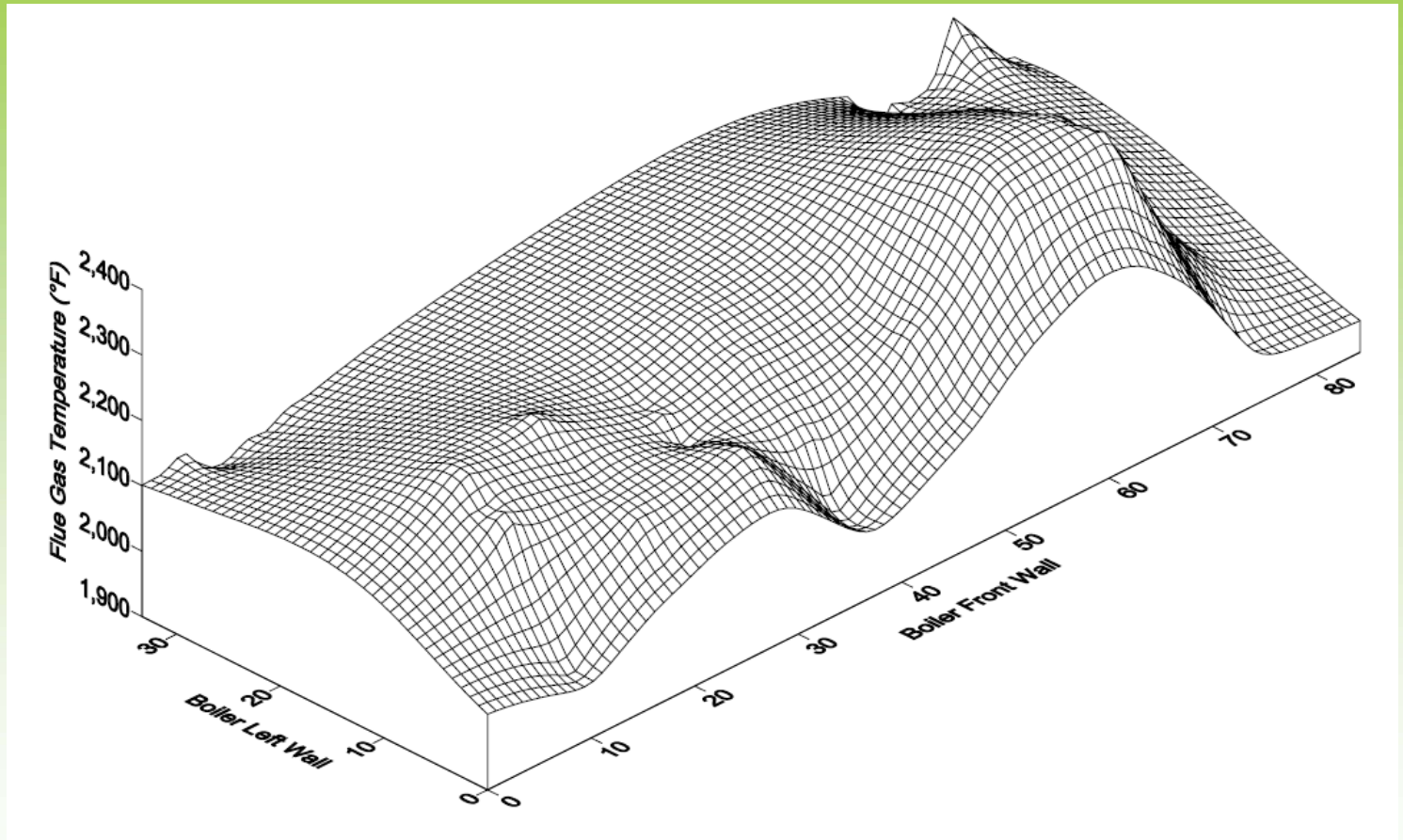
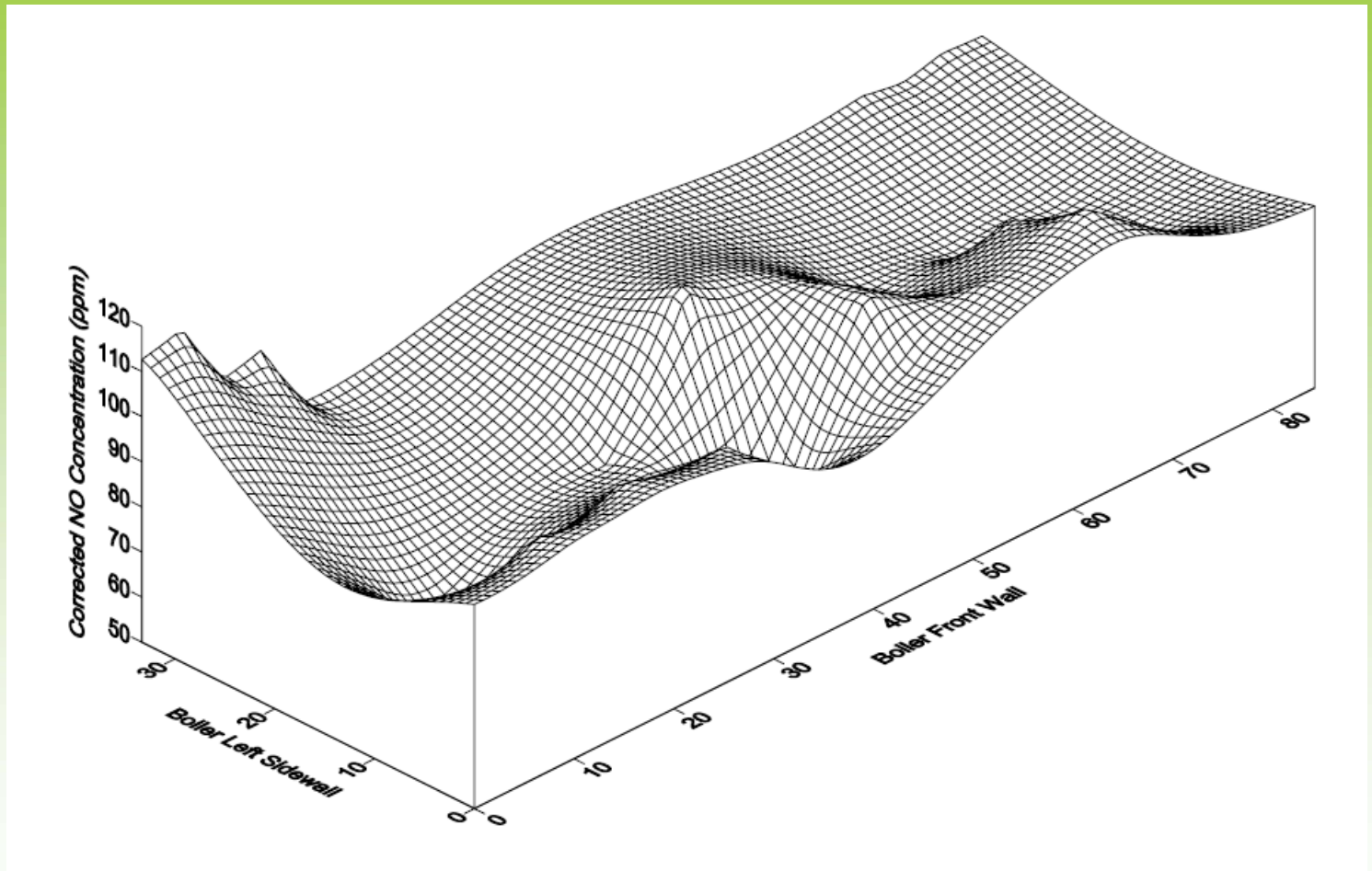
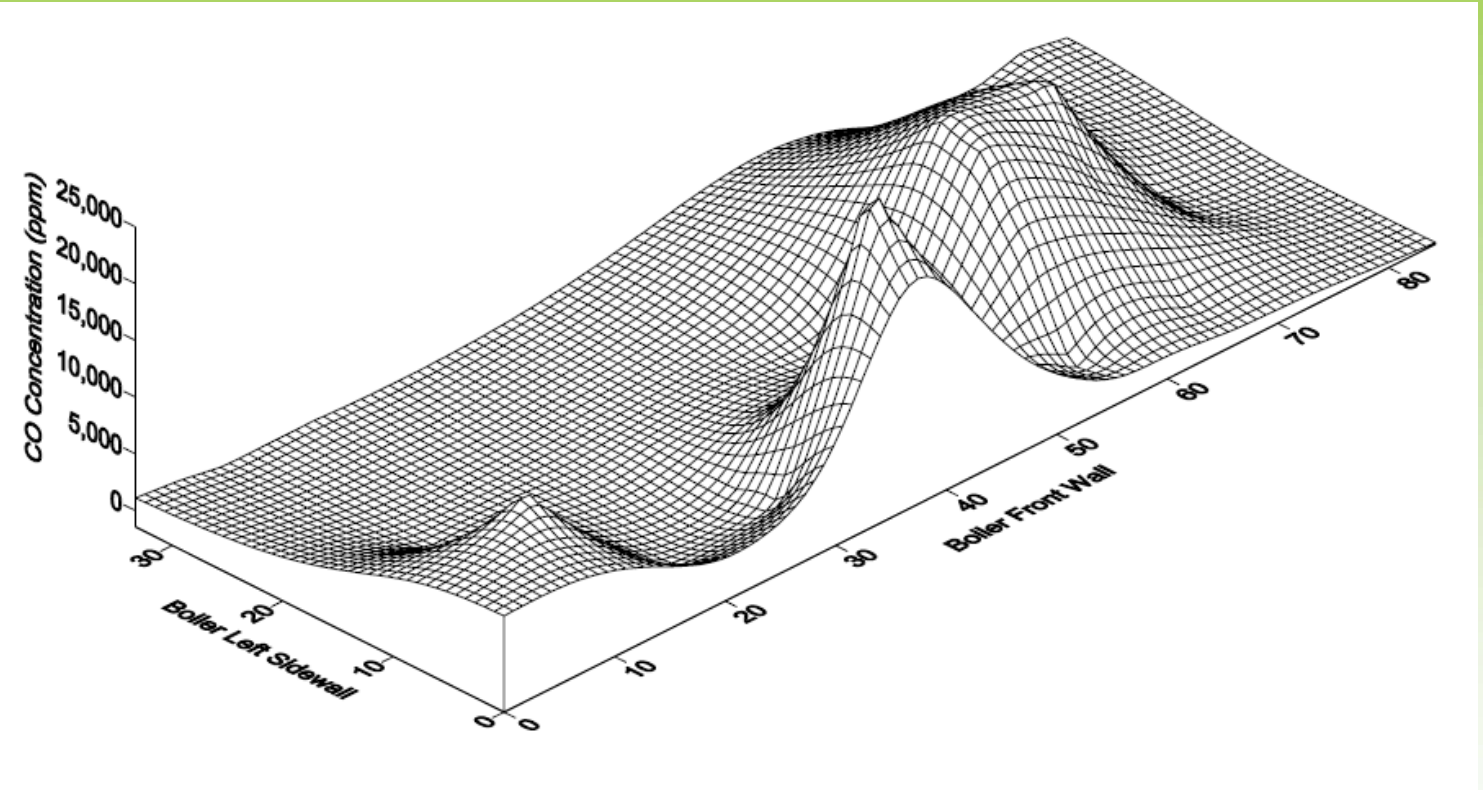
HVT Testing – Temperature (°F)



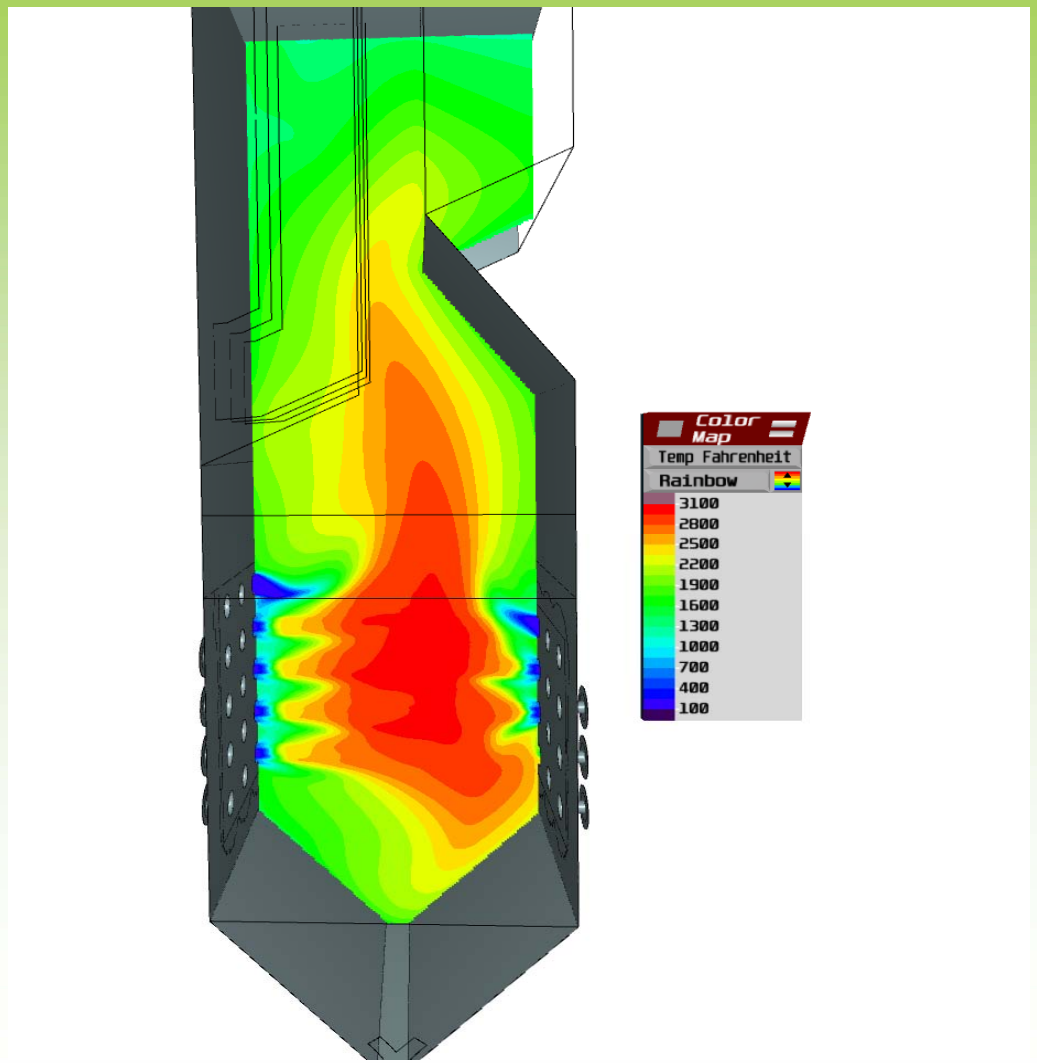
HVT Testing – NOx Concentration (ppm)



HVT Testing – CO Concentration (ppm)



Baseline Furnace Model



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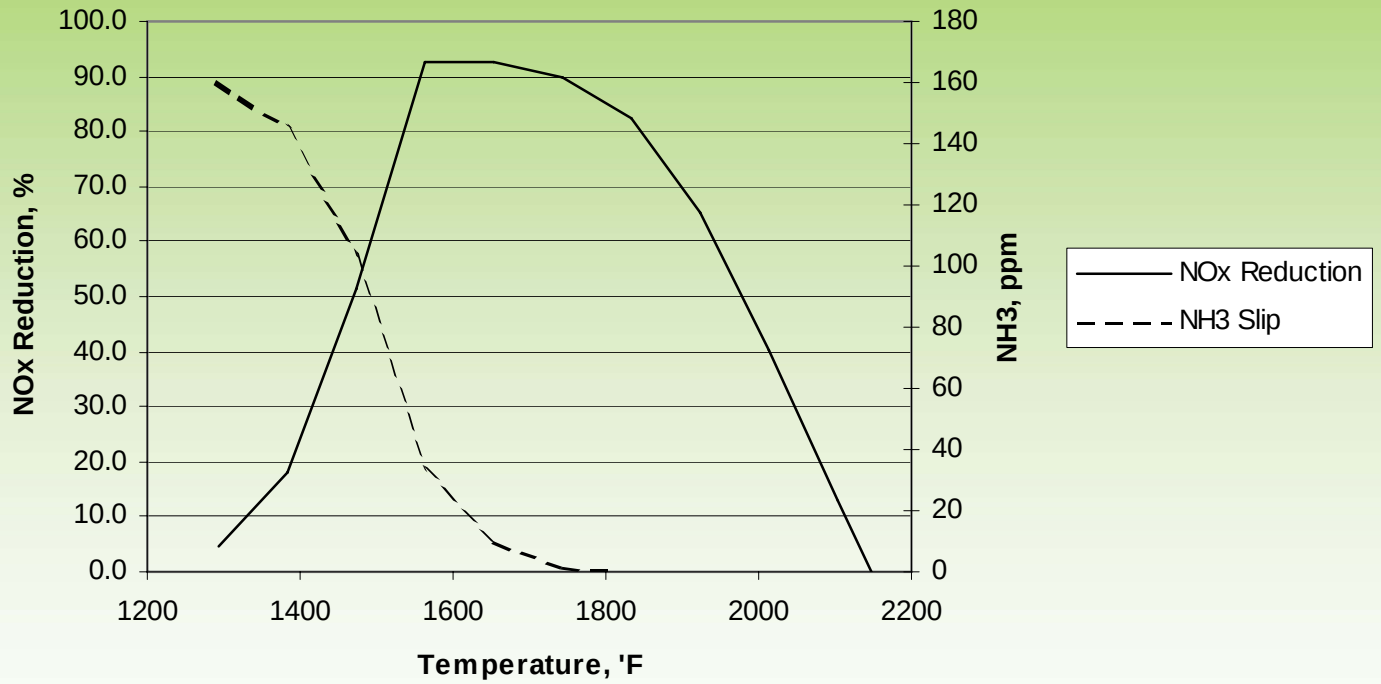
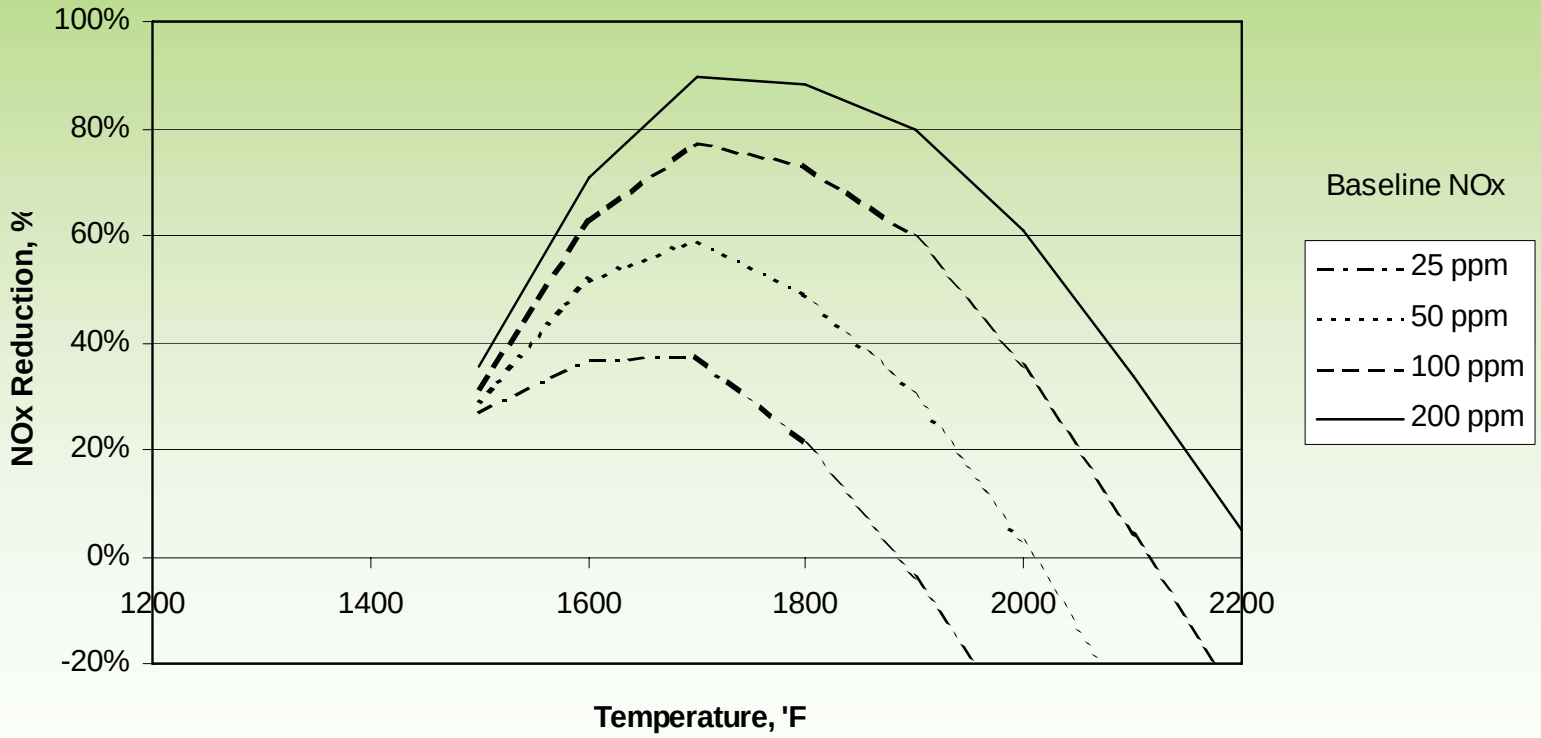
SNCR Design – Temperature Window

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



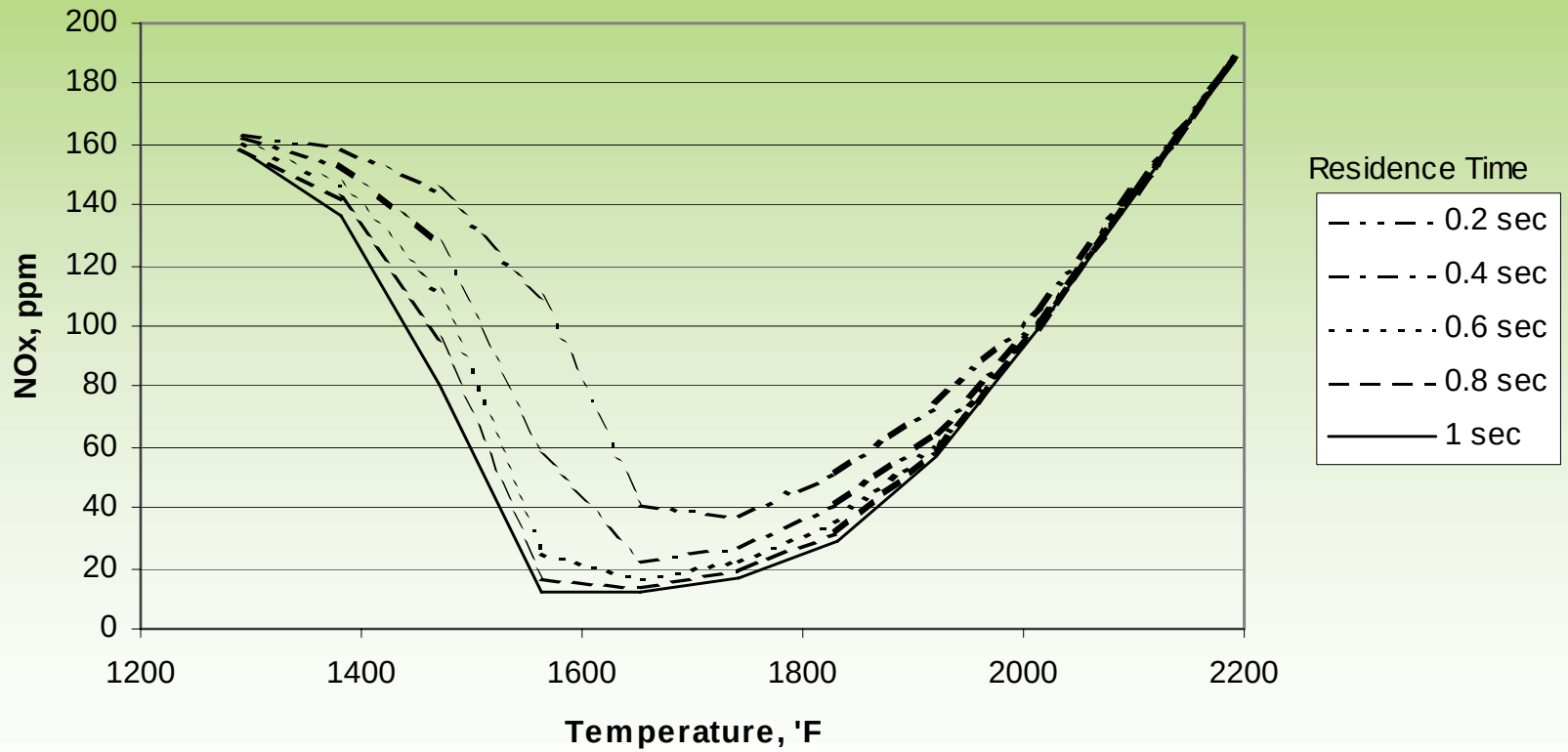
SNCR Design – Baseline NOx

Figure 3. Effect of Baseline NOx
Chemical Kinetic Model, NSR=2, COi=100, 1 sec



SNCR Design – Residence Time

Figure 2. Effect of Residence Time
Chemical Kinetic Model, NSR=2, COi=100 ppm, NOxi=200 ppm



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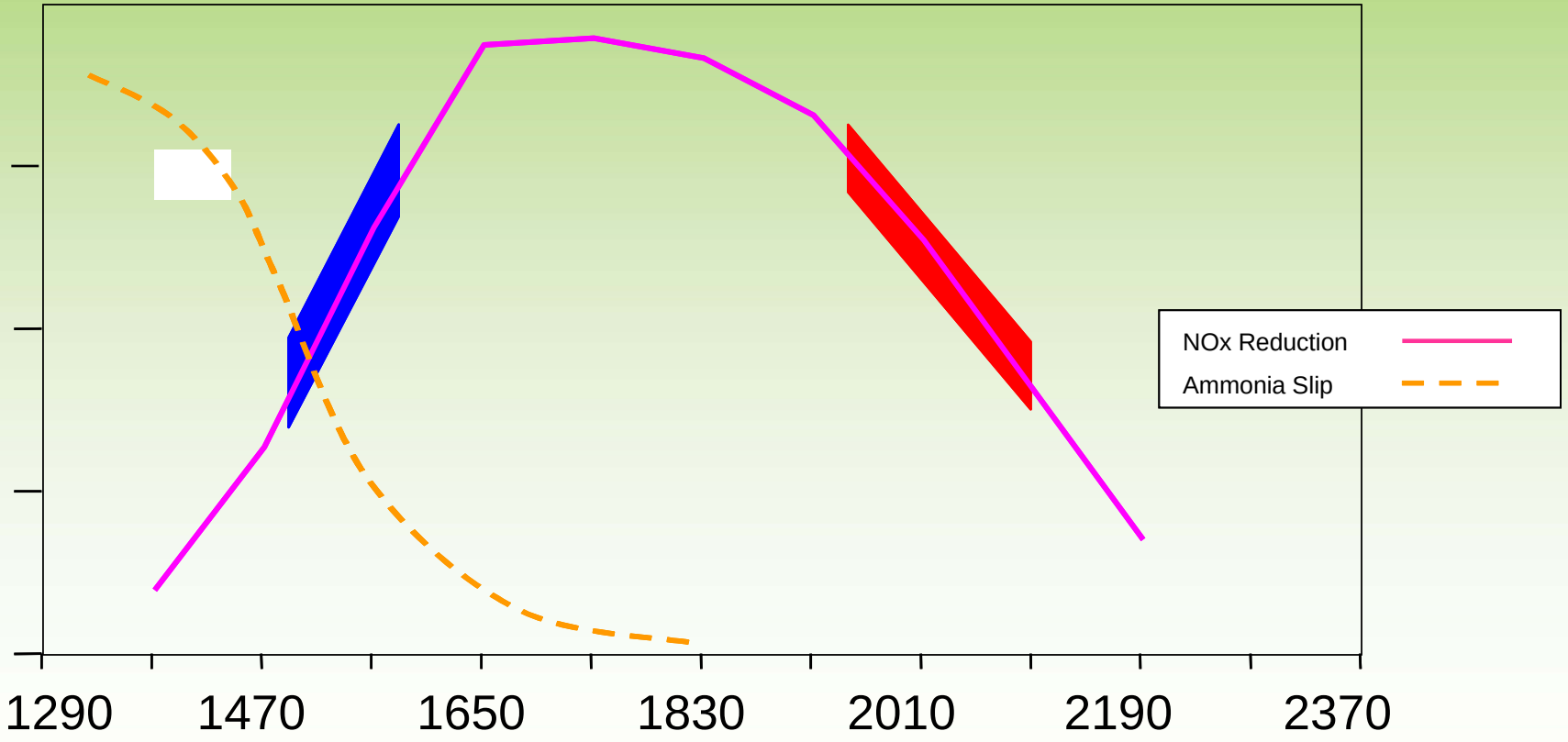
“Right Side of Slope” Injection

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



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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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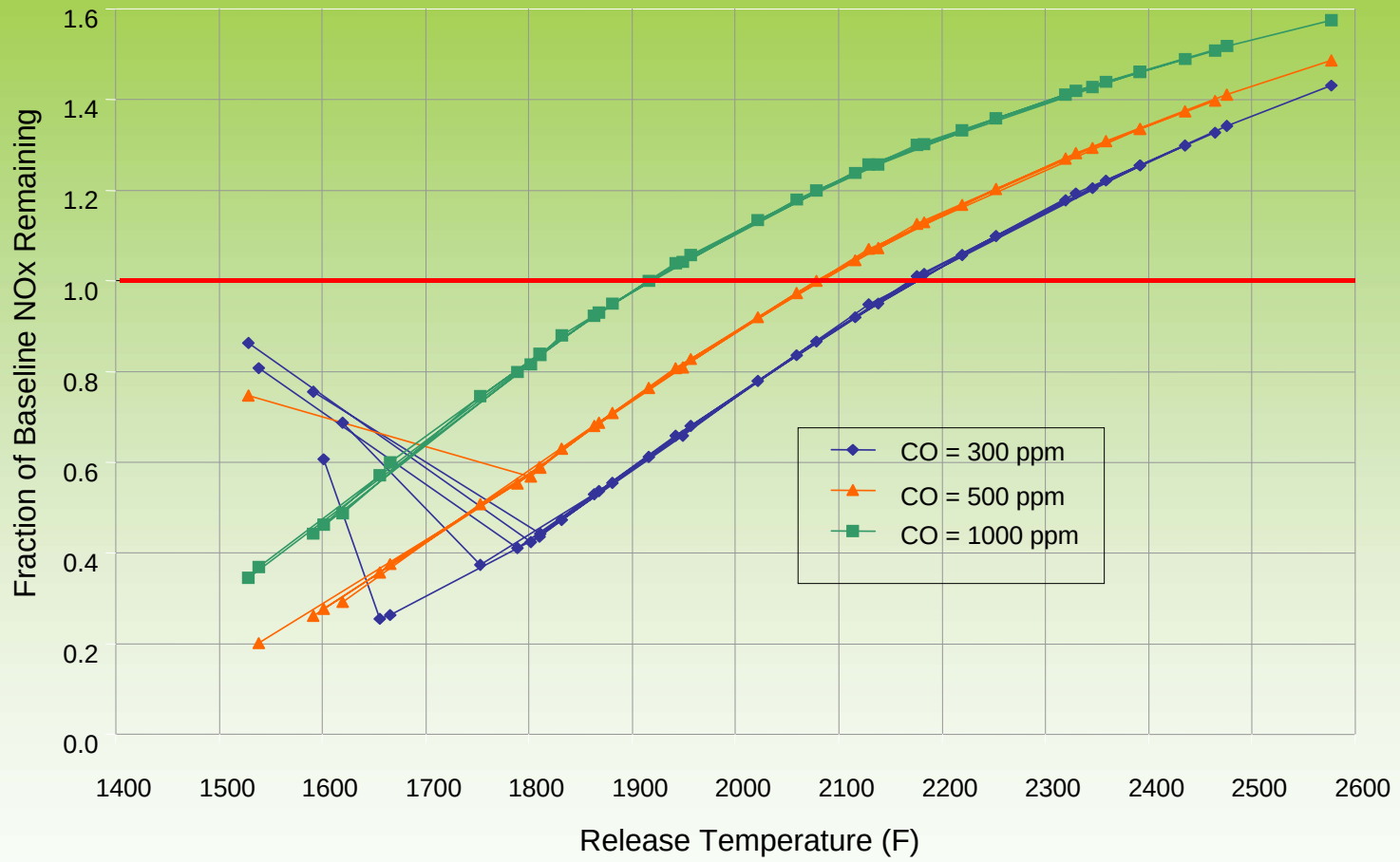
Influence of CO on SNCR Process



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.

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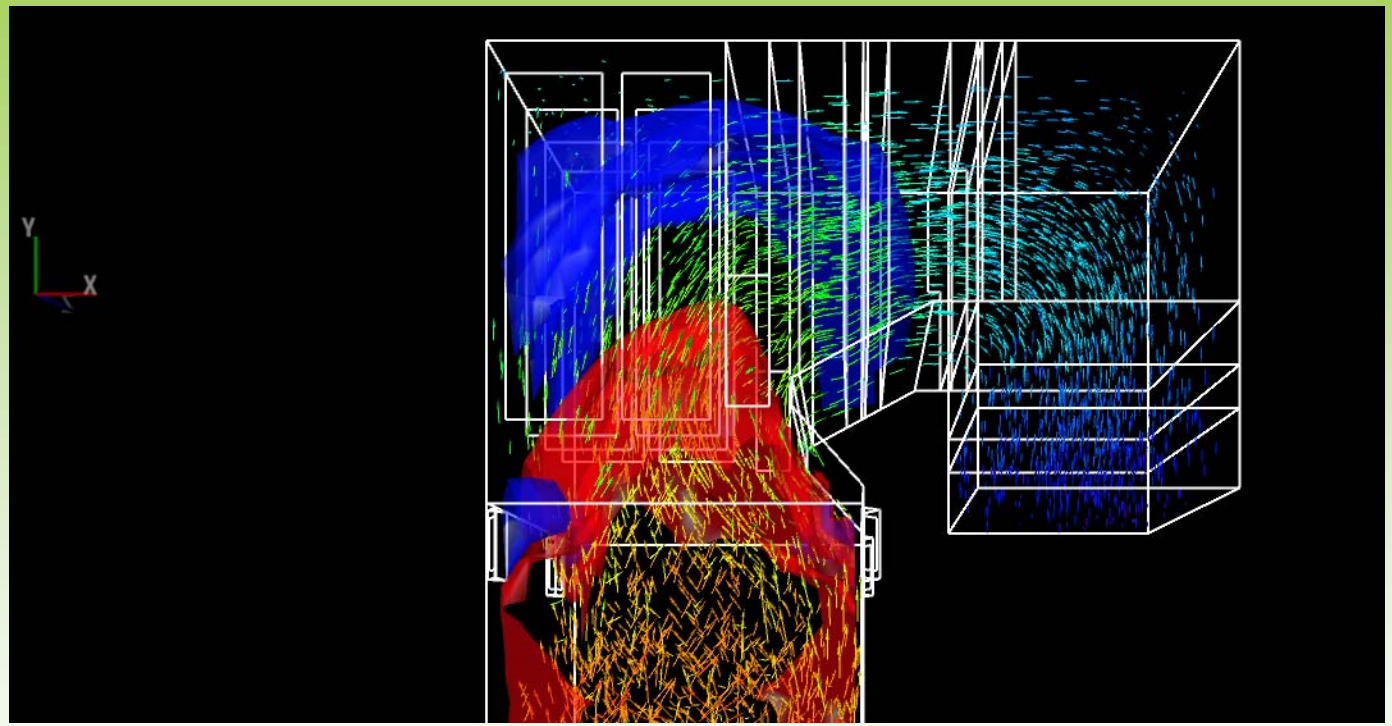
SNCR Effective Temperature Window



2200°F 1600°F

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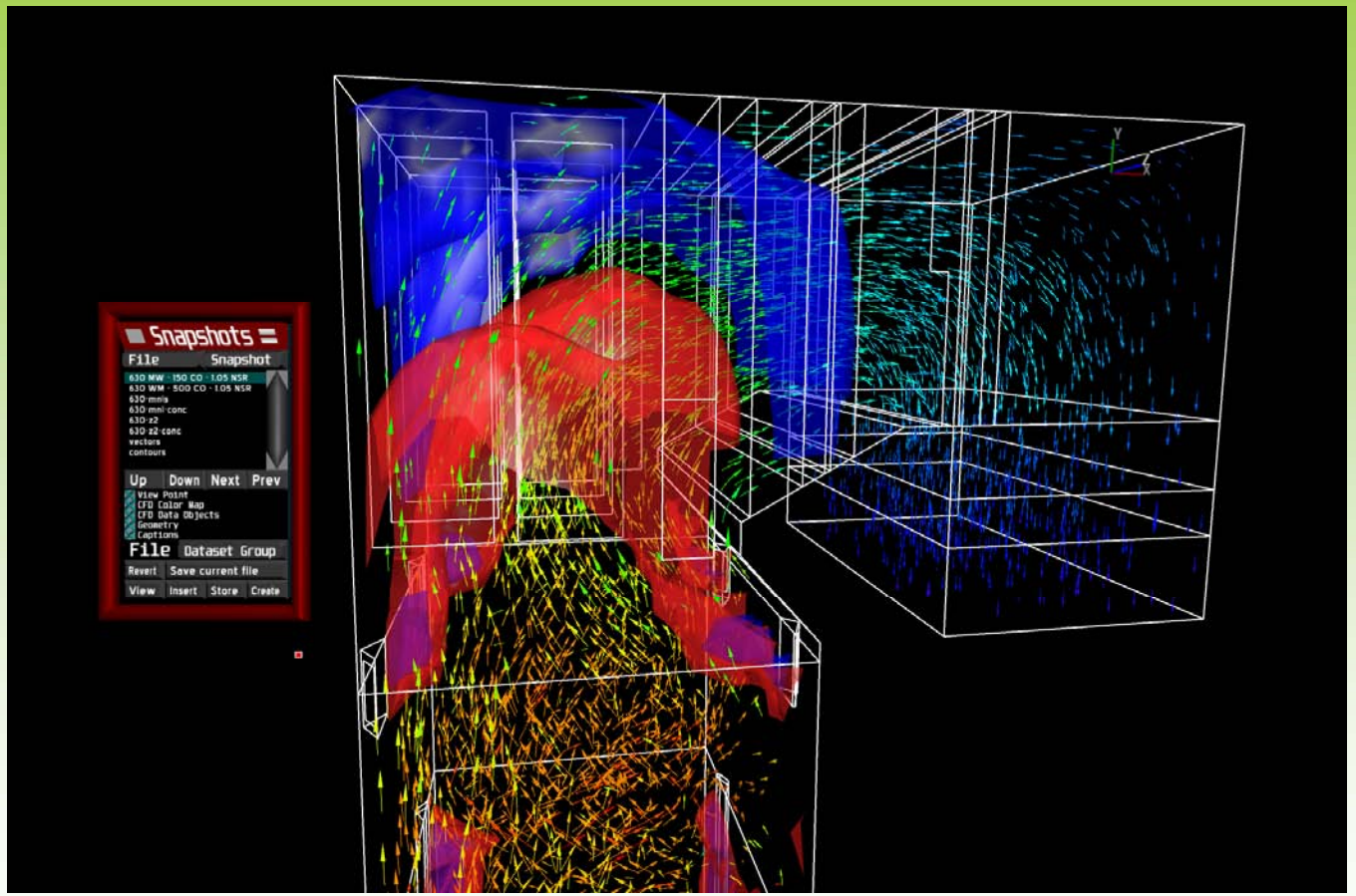
Temperature Window – 150 ppm CO



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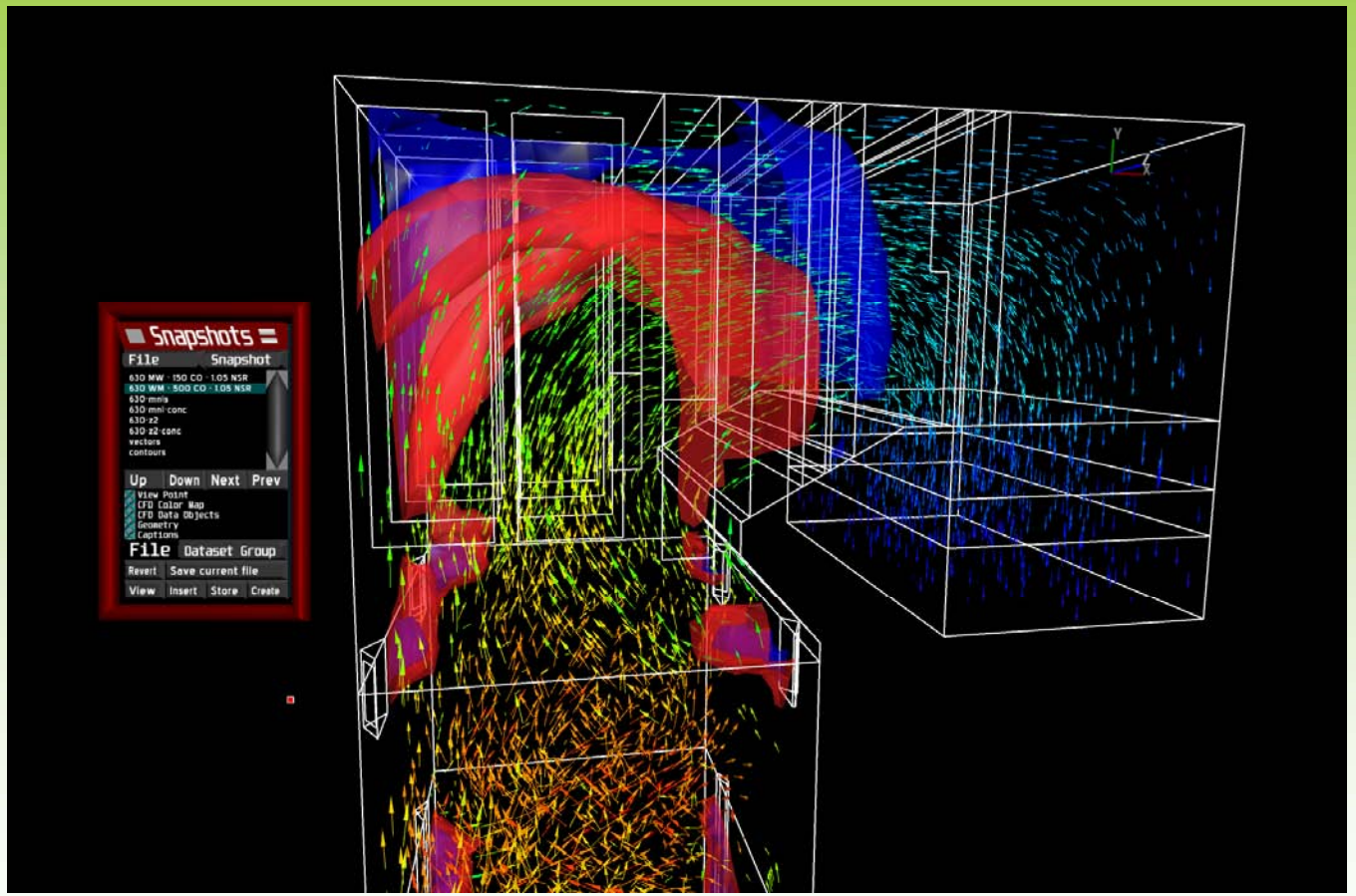
Temperature Window – 500 ppm CO



1750°F 1450°F

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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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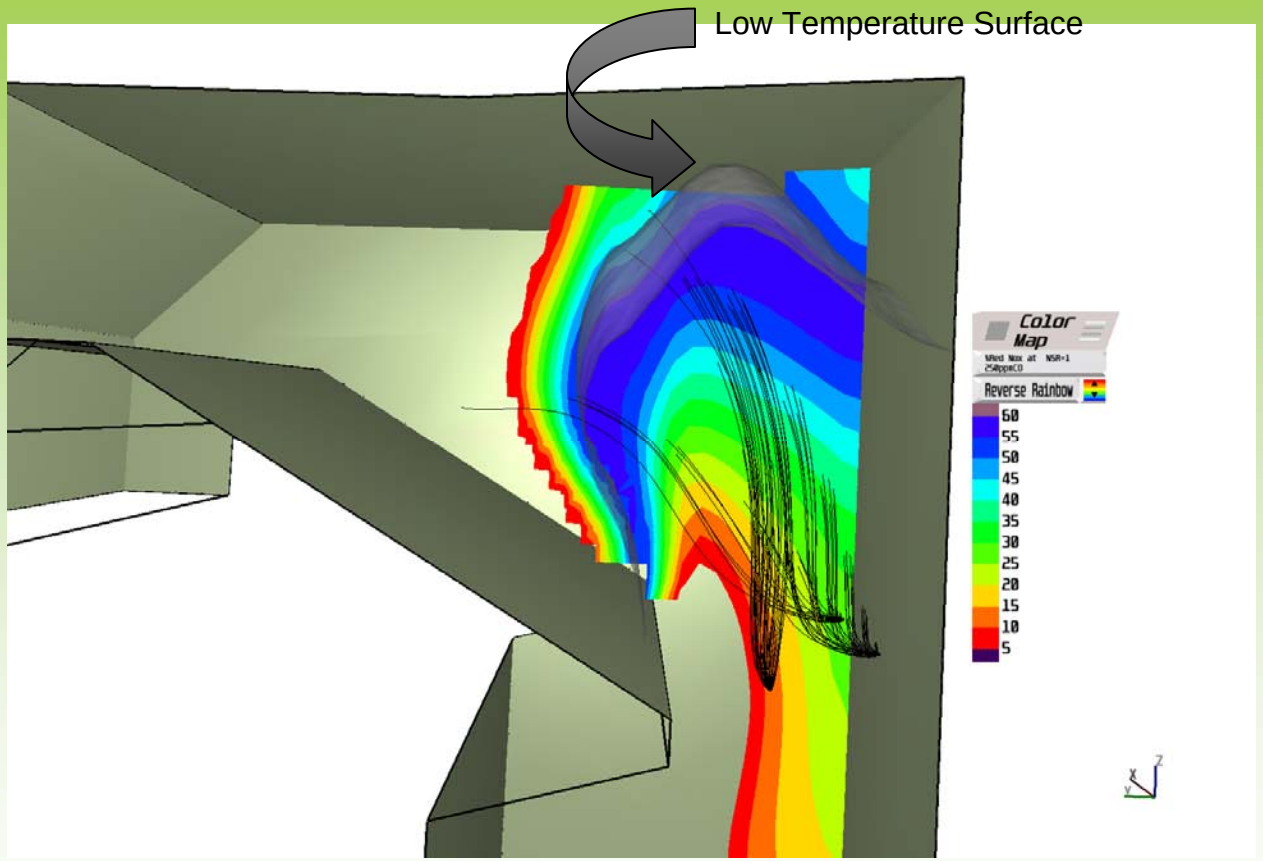
Injection Strategy for SNCR Process



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**

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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**

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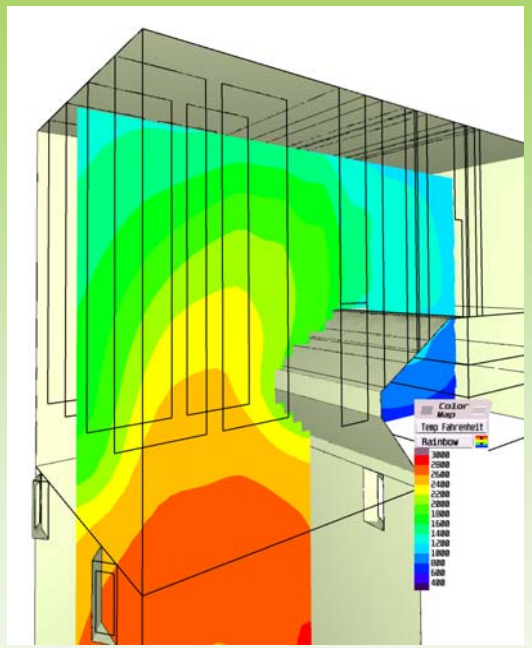
SNCR PERFORMANCE

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**

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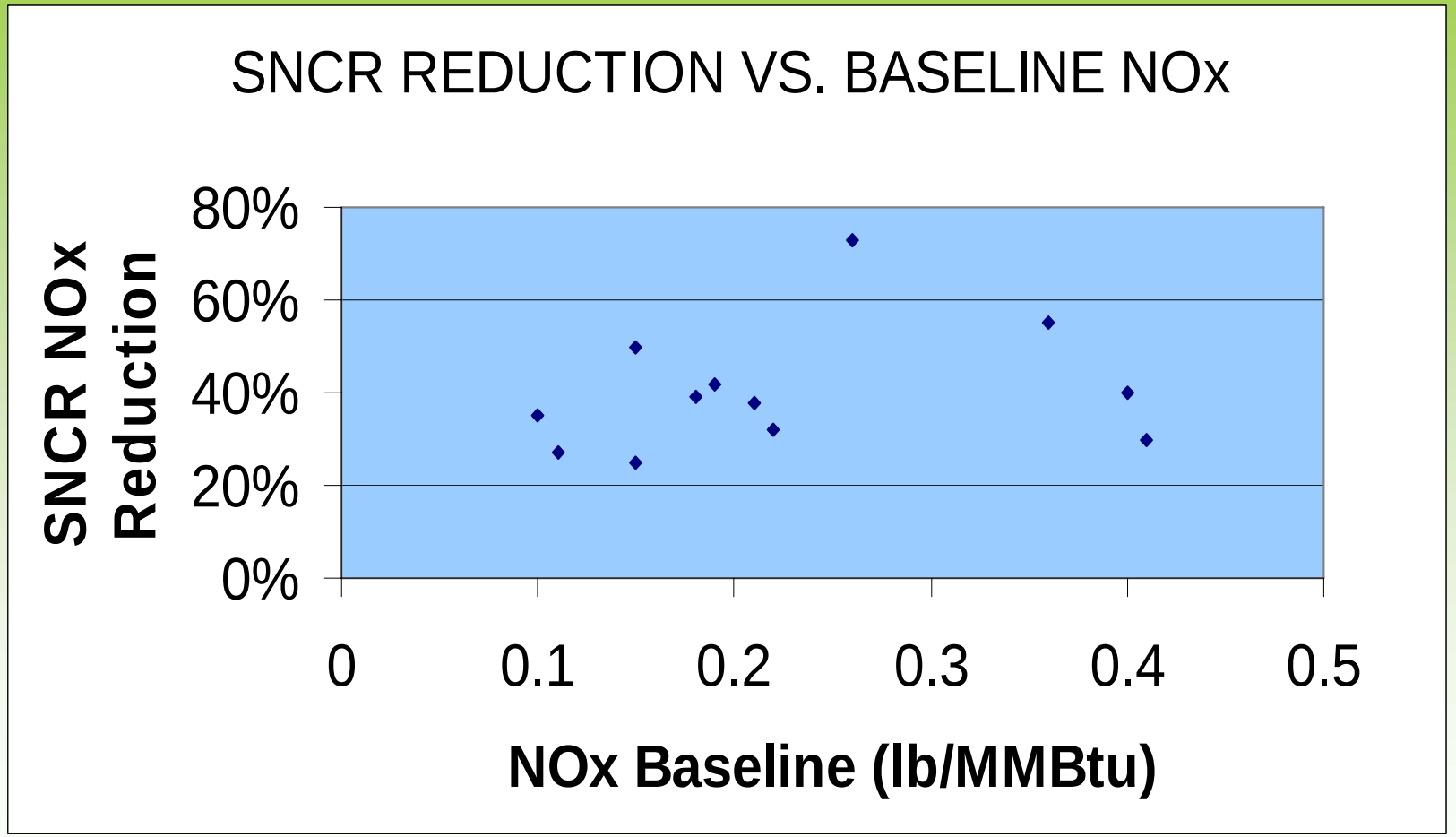
HERT Performance



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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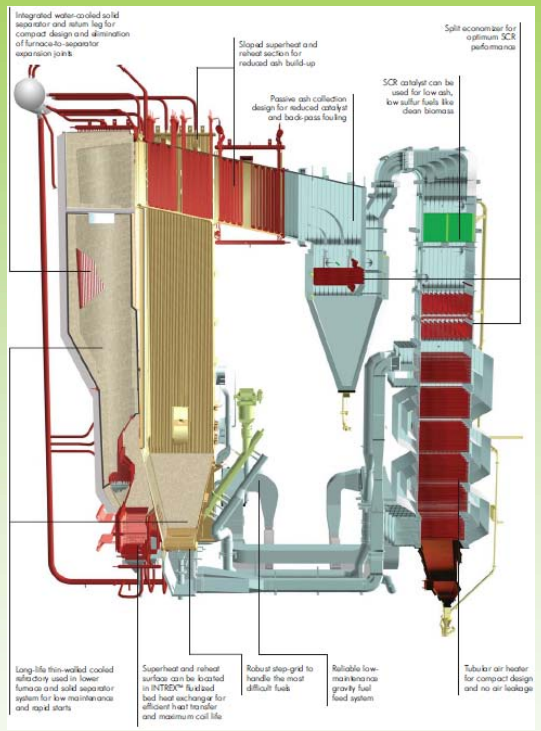
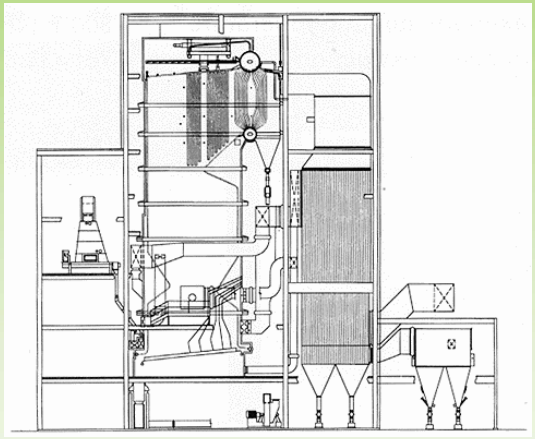
Biomass-fired Applications – Boiler Options

Circulating Fluidized Bed (CFB) Boilers



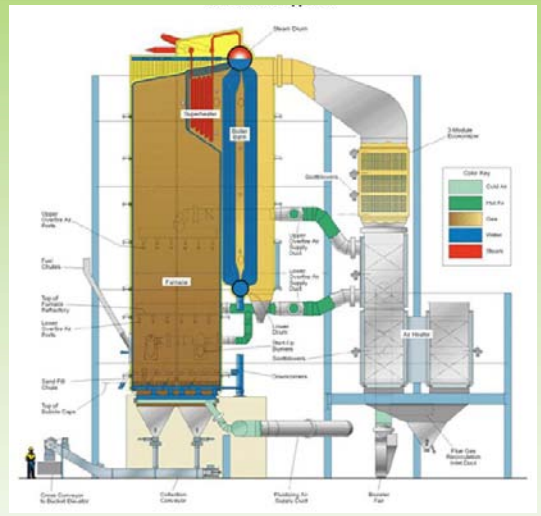
Drawing courtesy of Foster Wheeler

Grate-fired Stoker Boilers



Drawing courtesy of McBurney

Bubbling Fluidized Bed (BFB) Boilers



Drawing courtesy of B&W

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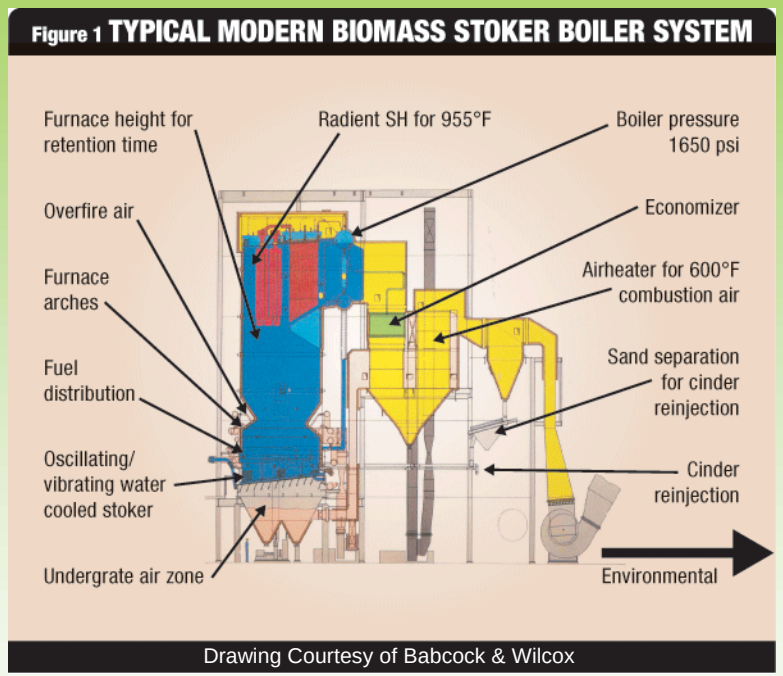
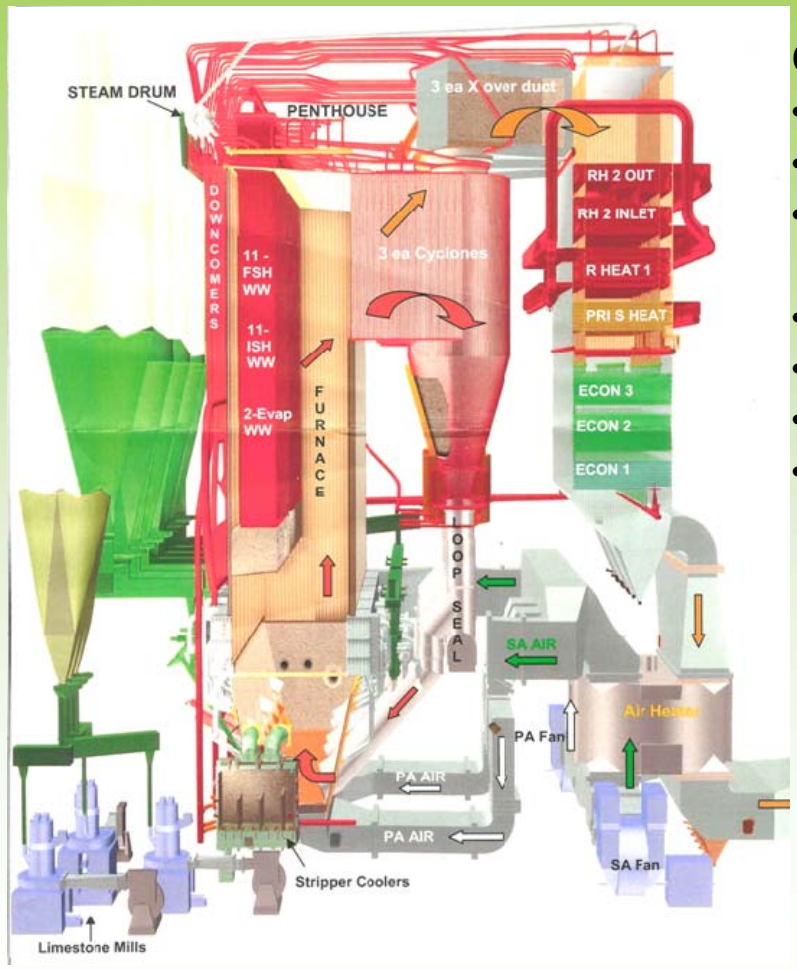
SNCR for Grate-fired Stoker



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

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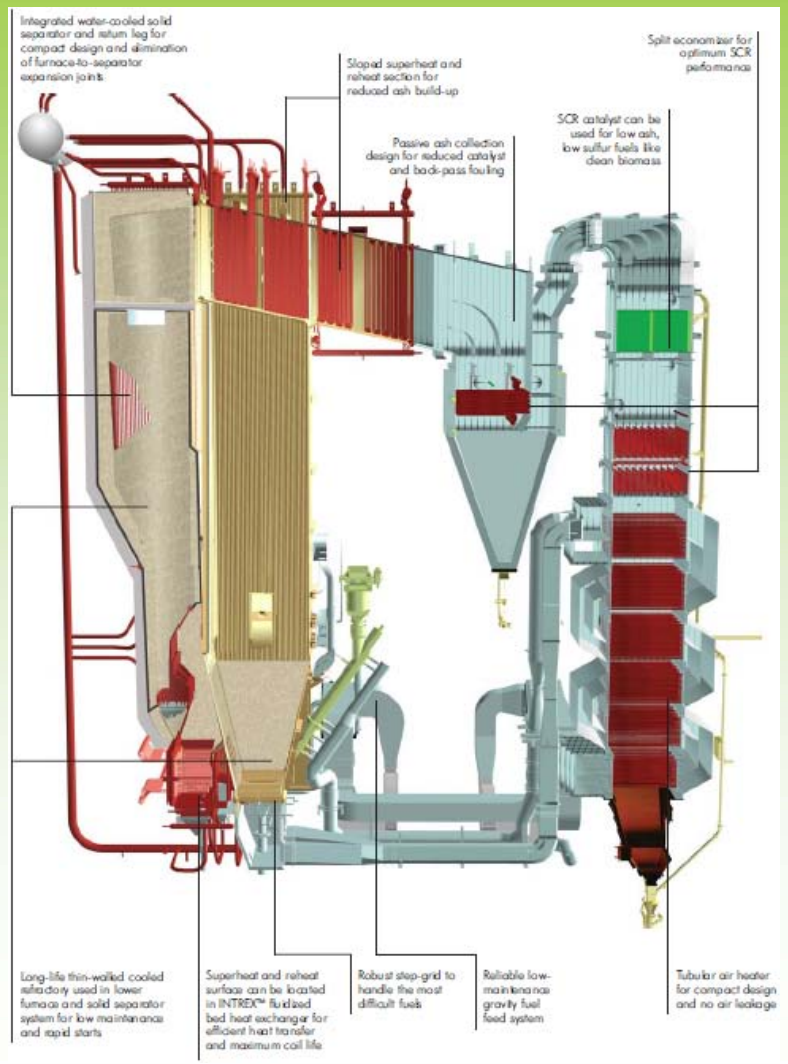
SNCR for Circulating Fluidized Bed (Industrial)



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

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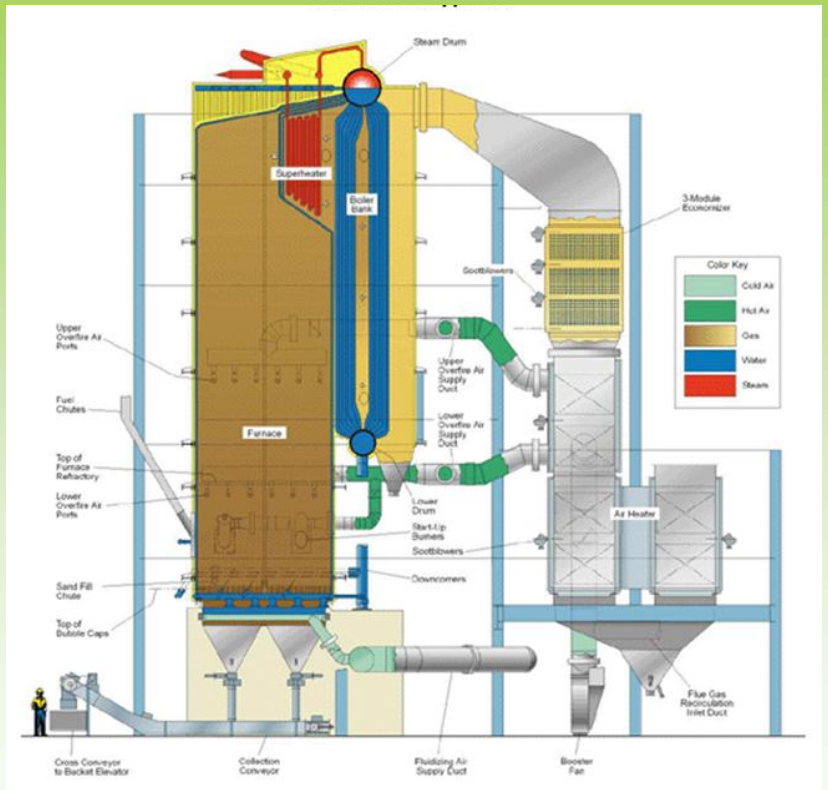
SNCR for Bubbling Fluidized Bed



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

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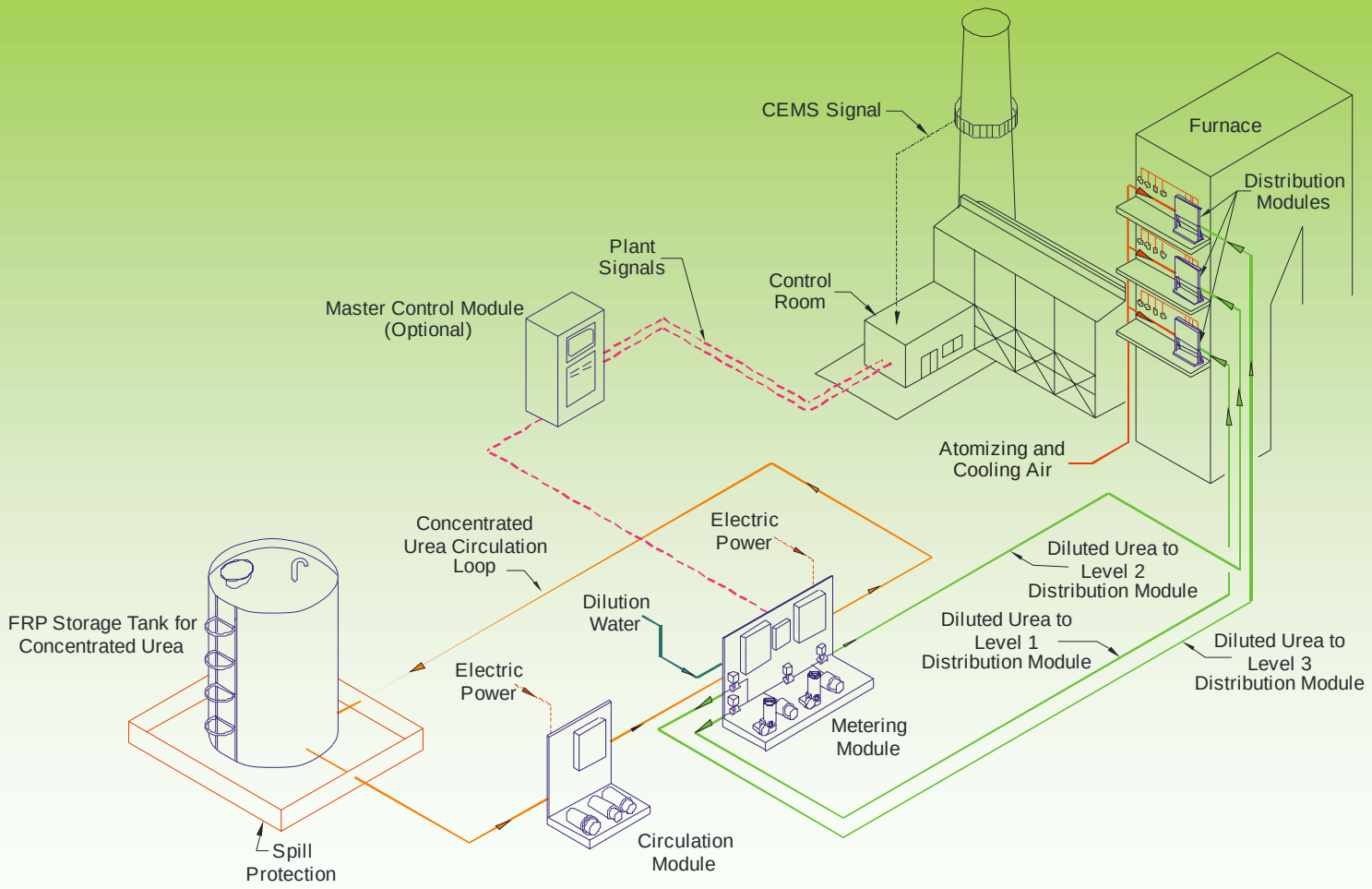
SNCR EQUIPMENT LAYOUT AND COMPONENTS

NOxOUT® SNCR Process Schematic



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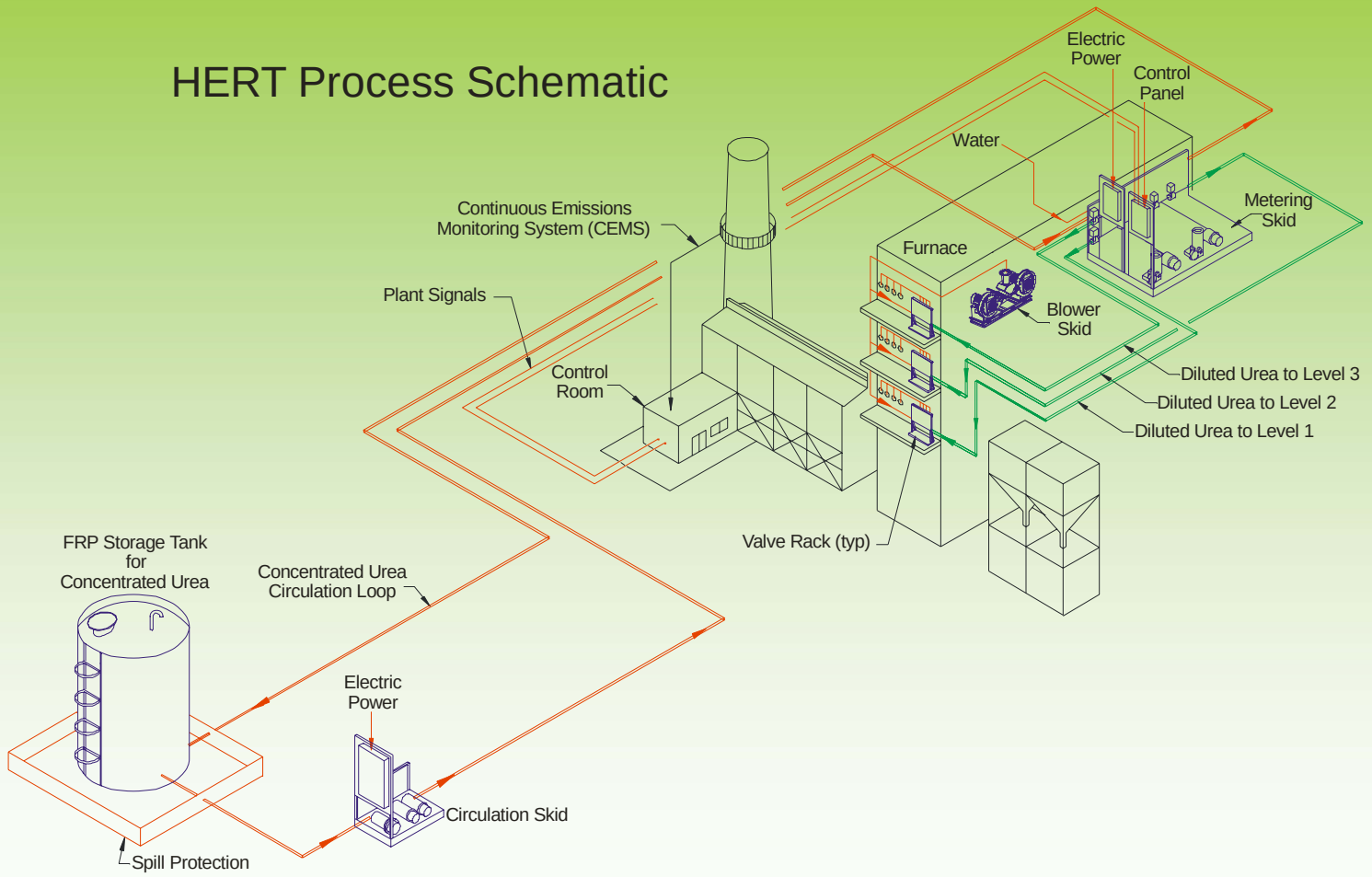
HERT™ SNCR Process Schematic



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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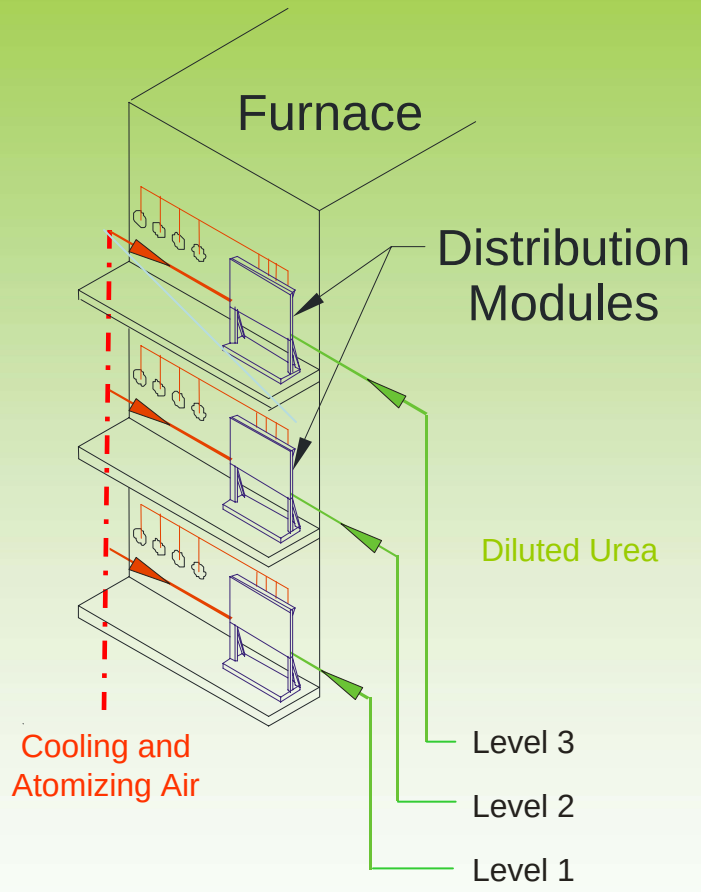
SNCR Distribution Modules & NOxOUT Injectors



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.

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Urea Tanks

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Urea Tank

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NOxOUT Reagent Storage

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