REINHOLD ENVIRONMENTAL Ltd.

2016 NOx-Combustion-CCR Round Table Presentation

February 1 & 2, 2016, in Orlando, FL / Hosted by OUC

2016 NO_x-Combustion-CCR Round Table/PCUG Meeting
February 1 - 4, 2016 Orlando, FL

Training Class 11: SNCR Basics and O&M

William H. Sun, Ph.D.

FUEL TECH
Technologies to enable clean efficient energy

COMPANY HISTORY

1981: Fuel Tech is Incorporated

1986: Fuel Tech acquires core ***SNCR*** patents

1987: Fuel Tech N.V. Parent Holding Company Formed

2001: 73 Employees

2005: 105 Employees

2006: Fuel Tech becomes U.S. Legal Entity

2010: 173 Employees

2012: Fuel Tech SpA (***Chile***)

2009 and Earlier | **2001 -2009** | **2010 - 2014**

1990: Fuel Tech enters joint venture with Nalco Chemical

1993: Fuel Tech on NASDAQ Exchange

1996: Fuel Tech opens office in ***Italy***

1998: American Bailey Corporation buyout of Nalco interest

2007: Fuel Tech Environmental Technologies Co., LTD is created (Beijing, ***China***)

2008: Fuel Tech acquires ***Flow Tack, LLC and Tackticks, LLC Technologies***

2009: Fuel Tech acquires ***Advanced Combustion Technologies*** (ACT)

2013: 200 Employees

2014: Fuel Tech acquires ***PECO-FGC***

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GLOBAL PRESENCE

OFFICE LOCATIONS:

Warrenville, IL, USA (Corporate HQ) | Stamford, CT, USA | Durham, NC, USA | Westlake, OH, USA | Milan, Italy | Beijing, China | Santiago, Chile

COUNTRIES WHERE FUEL TECH DOES BUSINESS:

USA, Belgium, Canada, Chile, 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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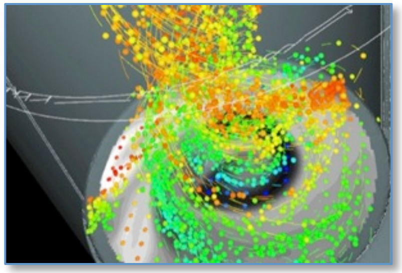
BUSINESS SEGMENTS

FUEL CHEM®

- TIFI® Targeted In-Furnace Injection™ technology
- Boiler efficiency, slag and corrosion reduction, SO_3 abatement
- Focus is on clean, efficient energy and fuel flexibility

Air Pollution Control (APC)

- NO_x and Particulate Control solutions to to meet current and upcoming regulatory mandates
- Over 900 systems installed worldwide
- Capital project sale, typically fixed price and often turn-key
- Performance-guarantee all work

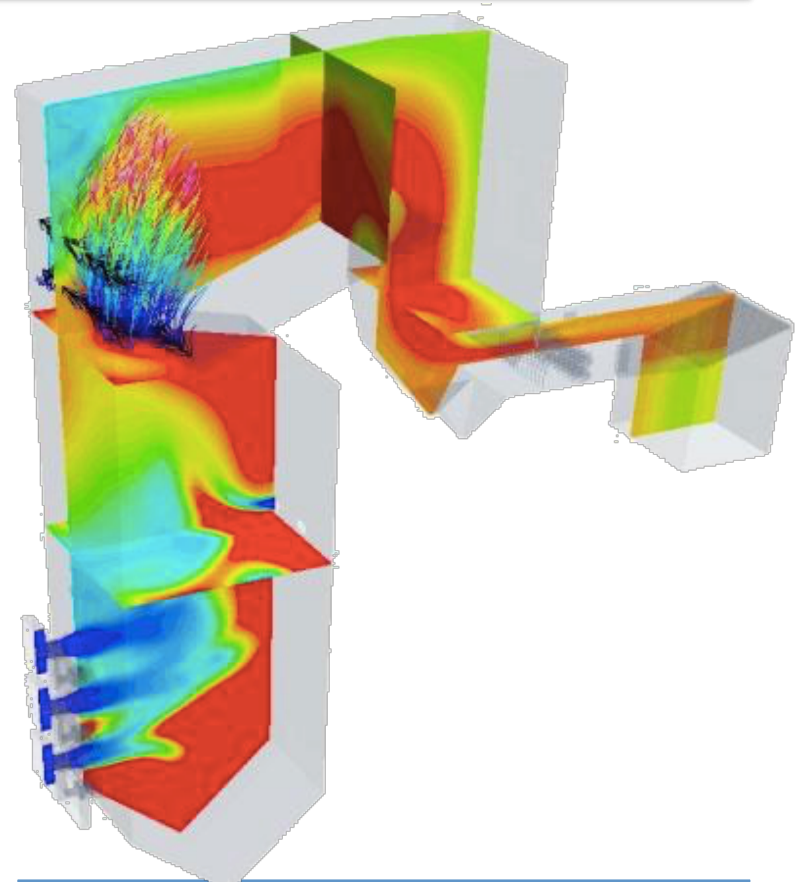




NO_X CONTROL TECHNOLOGIES

Multiple technology options which can be combined as a cost effective means for NO_X reduction. Systems are backed by performance guarantees.

Technologies Include:

- NO_xOUT® and HERT™ SNCR targets 20-50% reduction
- Low NO_x burners and Over-Fire Air systems target 40-70% reduction
- SCR systems target 80%+ reduction
- SCR Catalyst Management Services
- I-NO_X™ Integrated NO_X Reduction targets 80%+ reduction



Wide range of NO_X control technologies allow for custom system configurations specific to customer's needs

TYPICAL POWER PLANT

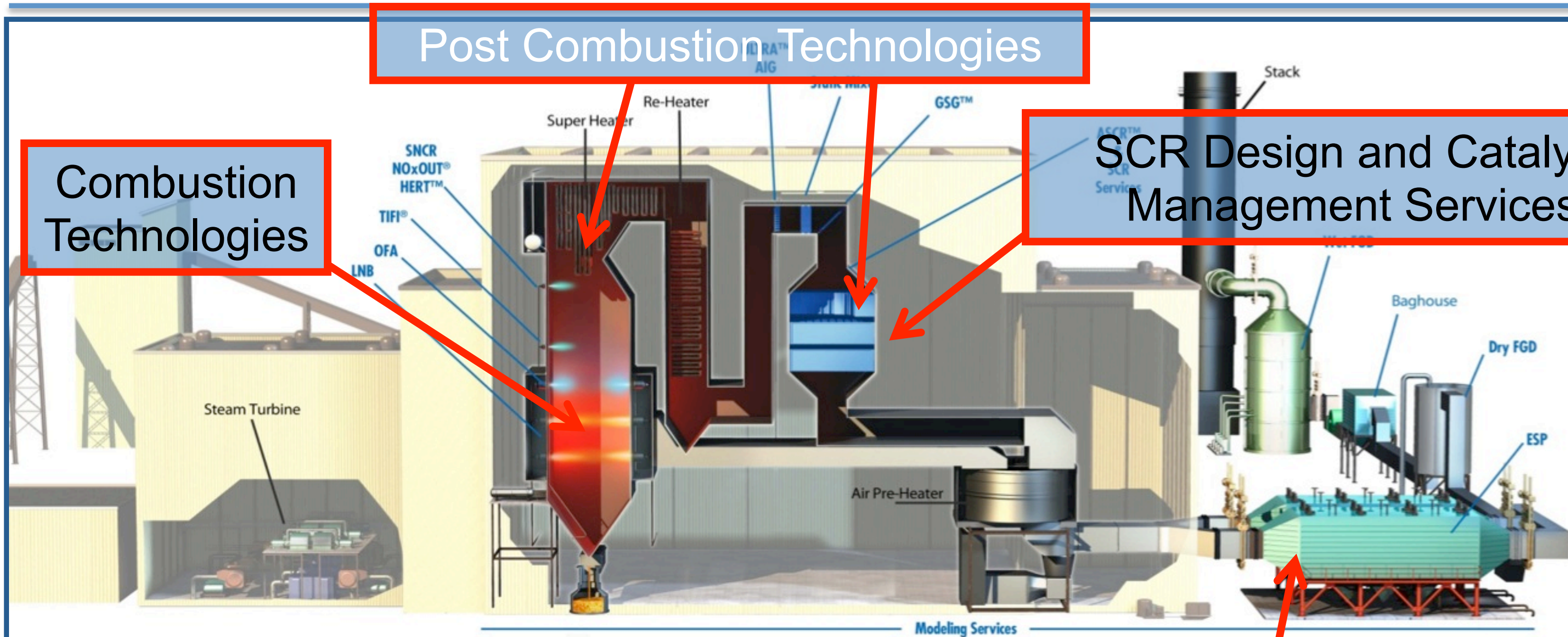
Advanced Modeling Services – All Technologies

Post Combustion Technologies

Combustion Technologies

SCR Design and Catalyst Management Services

ESP Rebuild and Flue Gas Conditioning Systems



Fuel Tech Technologies

- **ASCR™ Advanced SCR:** System which combines LNB + OFA + SNCR + AIG + GSG™ + Catalyst
- **AIG:** Ammonia Injection Grid
- **GSG™:** Graduated Straightening Grid
- **HERT™:** SNCR system using high energy injectors
- **LNB:** Low NOx Burners
- **NOxOUT®:** SNCR system using high momentum injectors
- **ULTRA™:** Urea-based ammonia generation system for SCR
- **SCR:** Selective Catalytic Reduction
- **SNCR:** Selective Non-Catalytic Reduction

- **SCR Services:** Selective Catalytic Reduction Services which include: optimizing process design, catalyst selection, and improving the overall performance of SCR
- **Static Mixer:** Equipment used to mix temperature, velocity, and NOx to optimize SCR performance ahead of the AIG
- **TIFI® Targeted In-Furnace Injection™:** Chemical Injection Programs used to target slag control SO_3 mitigation, and fuel flexibility

Non-Fuel Tech Supplied

- **Baghouse:** Controls Particulate Matter (PM) from flue gas
- **ESP:** Electrostatic Precipitator for PM Control
- **Wet FGD:** Scrubber to maximize SO_2 removal using Flue Gas De-Sulfurization (FGD)
- **Dry FGD:** Scrubber to remove SO_2 with less water than Wet FGD

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THREE DIMENSIONAL ANALYSIS SUITE

Proprietary Software with Strong IP Protection; Patented Technology

- Provides an intuitive interaction between the Models and the Design Engineers

Computational Fluid Dynamics (CFD) Model

- Customized for each boiler (more than 800 models made)

Chemical Kinetics Code

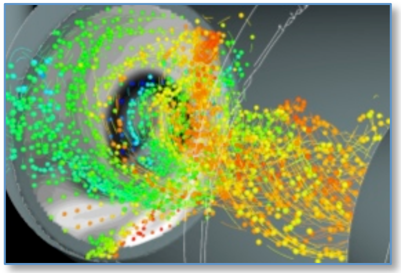
- Predicts chemical reactions along a specific particle path

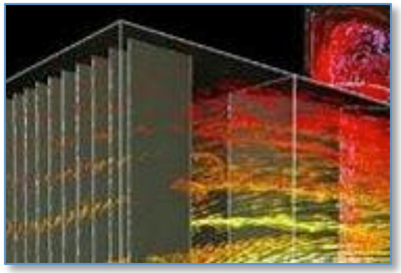
Injection Modeling

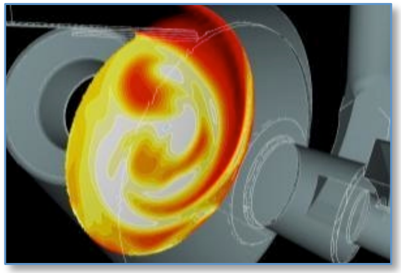
- Tuned to a variety of Fuel Tech Injector solutions.

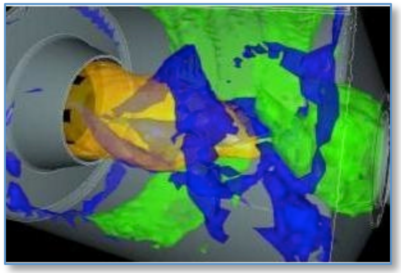
Cold Flow Modeling

- Highly accurate physical models that replicate gas flows, injection patterns, etc.









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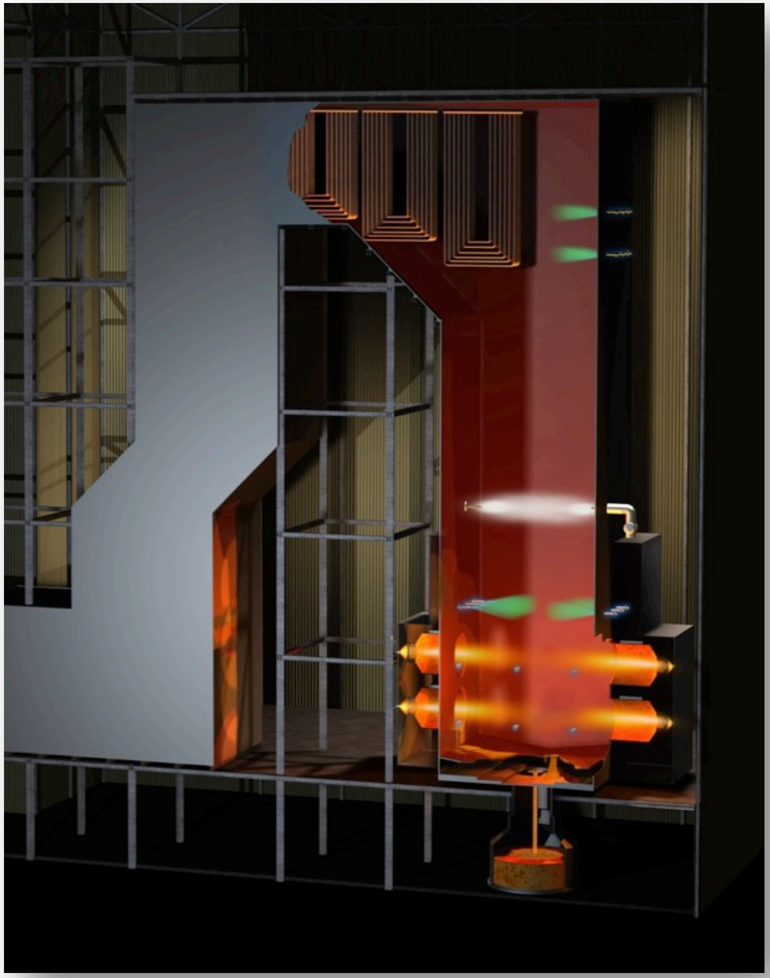
SNCR TECHNOLOGY OVERVIEW:



- In-furnace, Post-combustion NO_x Control
- Injection of Aqueous Urea Solution 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 REAGENTS

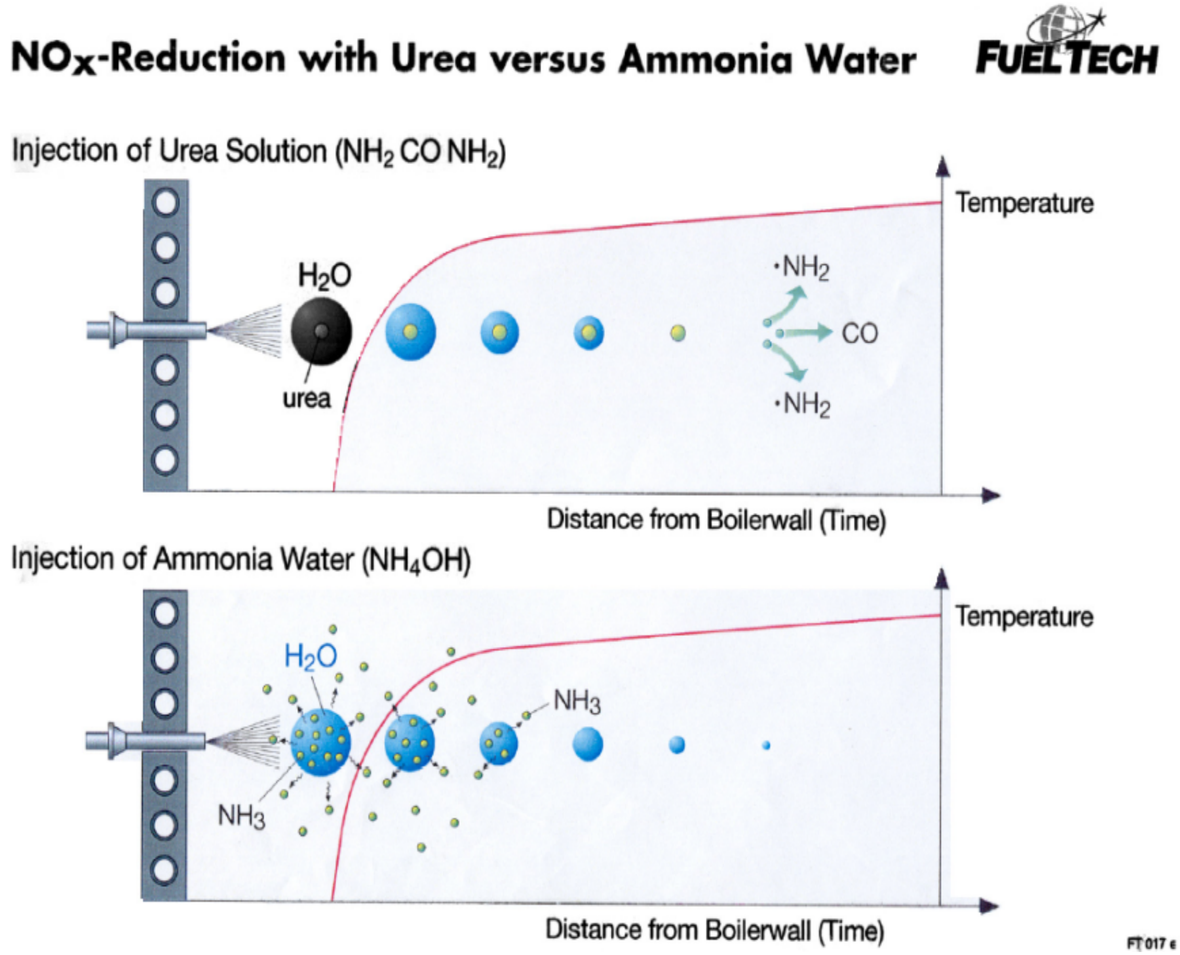
- Ammonia (NH_3)
  - $NH_3 + NO + \frac{1}{4} O_2$
    $\rightarrow N_2 + 3/2\ H_2O$
  - Thermal DeNOx
  - Exxon
  - Patent 1975

- Urea (CON_2H_4)
  - $NH_2CONH_2 + 2\ NO + \frac{1}{2} O_2$
    $\rightarrow 2N_2 + CO_2 + 2\ H_2O$
  - NOxOUT Process – Fuel Tech, Inc.
  - EPRI
  - Patent 1980

- Cyanuric Acid
  - $(HNCO)_3 + 3\ NO + \frac{3}{4} O_2$
    $\rightarrow 3\ N_2 + 3\ CO_2 + 3/2\ H_2O$
  - RAPRENOx
  - Sandia
  - Patent 1988

- Hydrazine Hydrate
  - $N_2H_4 + 2\ NO$
    $\rightarrow 2\ N_2 + 2\ H_2O$
  - Turchan
  - Patent 1988

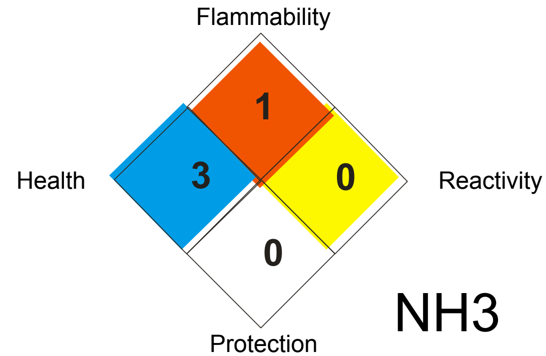
SNCR – WHY UREA



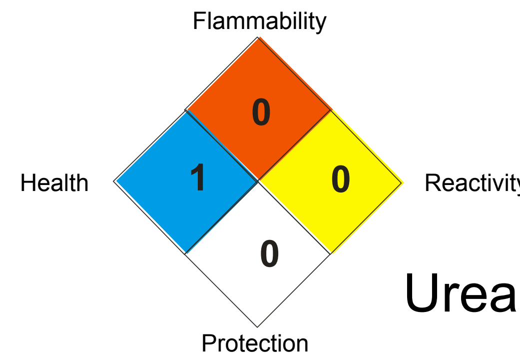
Urea droplets formed by FTI injectors are characterized in test facilities using laser Doppler techniques.

REAGENT ALTERNATIVES FOR SNCR SYSTEMS

- Anhydrous Ammonia
  - Highest Risk Reagent
  - Decrease in US Ammonia Production
- Aqueous Ammonia
  - 19% Concentration
  - 29% Concentration - limited availability
- Urea
  - Significant Safety Advantages
  - Worldwide Availability of Urea
  - Equivalent SCR Performance for On-site Ammonia Generation



NH3



Urea

SELECTIVE NON-CATALYTIC REDUCTION (SNCR) – UREA BASED

SNCR Process Chemical Reactions

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

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

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

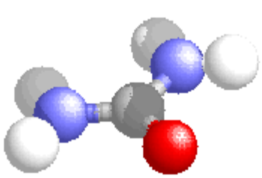
- NOx Removal Efficiency is Related to Normalized Stoichiometric Ratio (NSR)

$$\textbf{NSR} = \frac{\textbf{Actual Mole Ratio of Urea to Baseline NOx}}{\textbf{Theoretical Mole Ratio to Reduce One Mole of NOx}}$$

  - The Measure of the Rate at Which Urea is Added to the Flue Gas Relative to the Amount of Baseline NOx

AQUEOUS UREA PROPERTIES – CON_2H_4

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



Urea SNCR

- $CON_2H_4 + 2\ NO + \frac{1}{2}\ O_2 \rightarrow 2\ N_2 + 2\ H_2O + CO_2$
  - Tycally applied under Oxidizing environment
  - Sensitive to temperature, CO, and residence time
  - Byproducts: NH_3 and CO
  - Safe reagent

- Reagent Distribution
  - Flue gas velocity, temperature, droplet trajectories, and reagent dispersion modeled using CFD
  - Field measurements of temperature and flue gas species
  - Multi level injection
  - Wall injectors, High energy injection and Multinozzle lances

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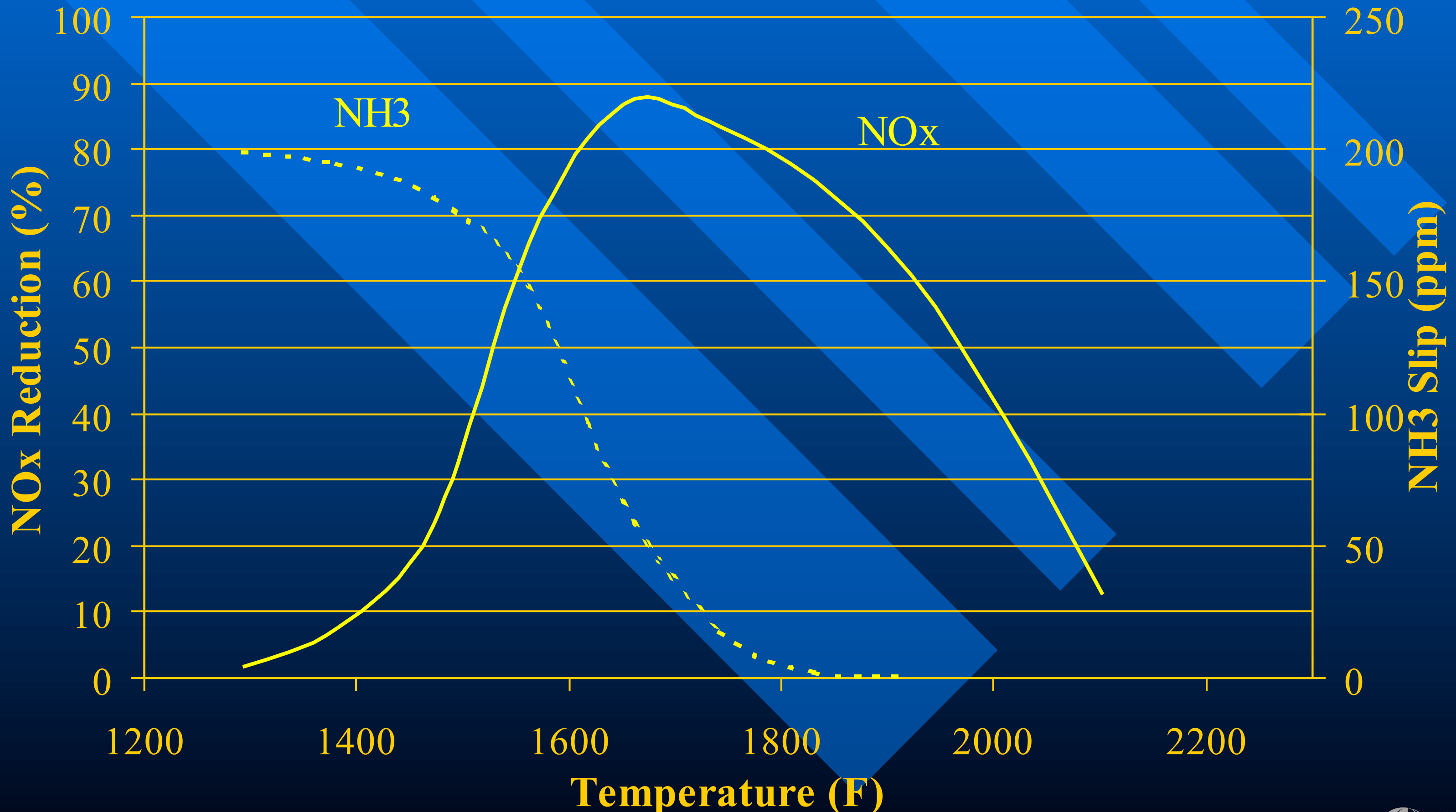
NOx reduction and NH3 Slip
chemical kinetic model



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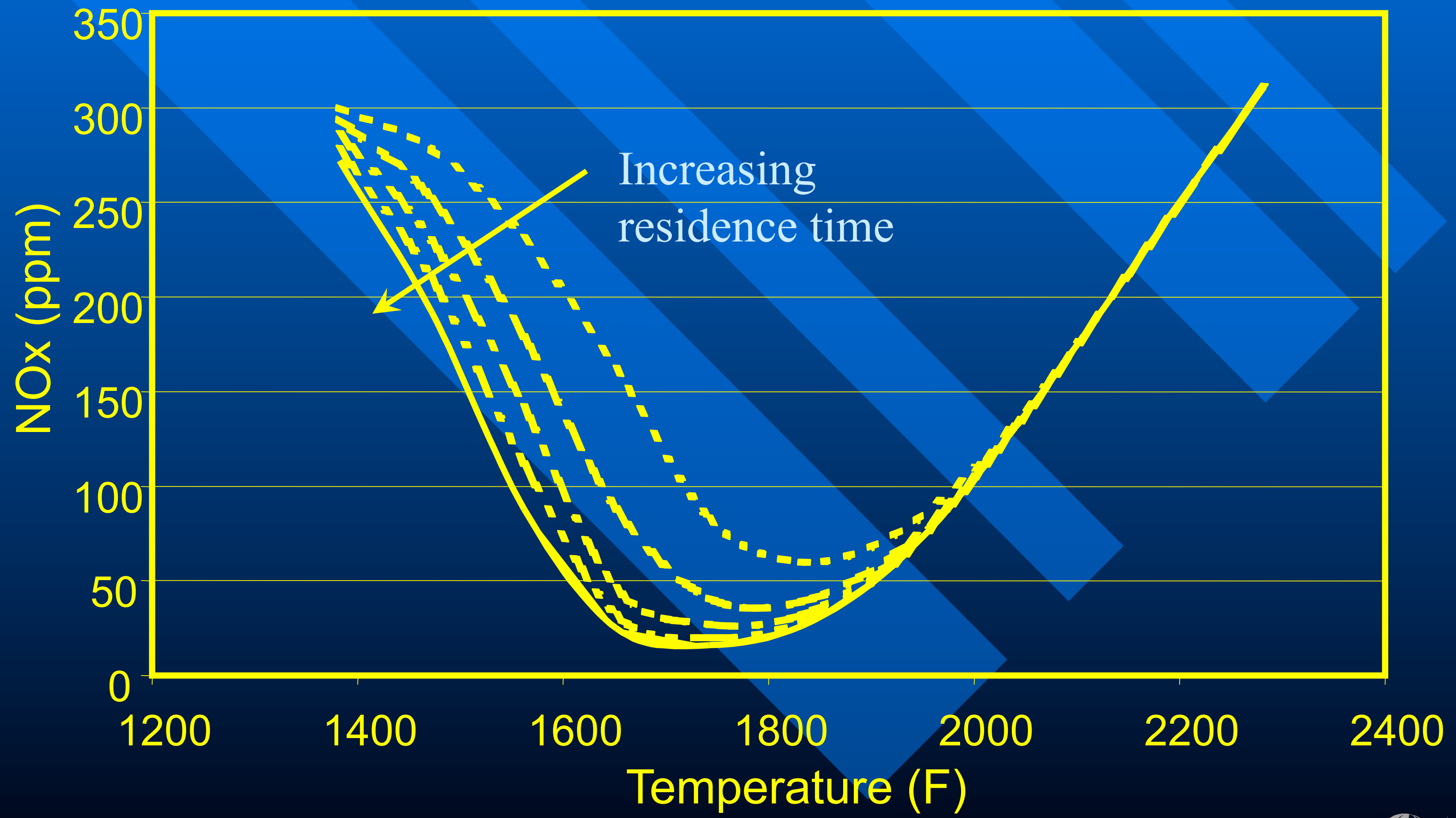
SNCR Temperature Window

chemical kinetic model



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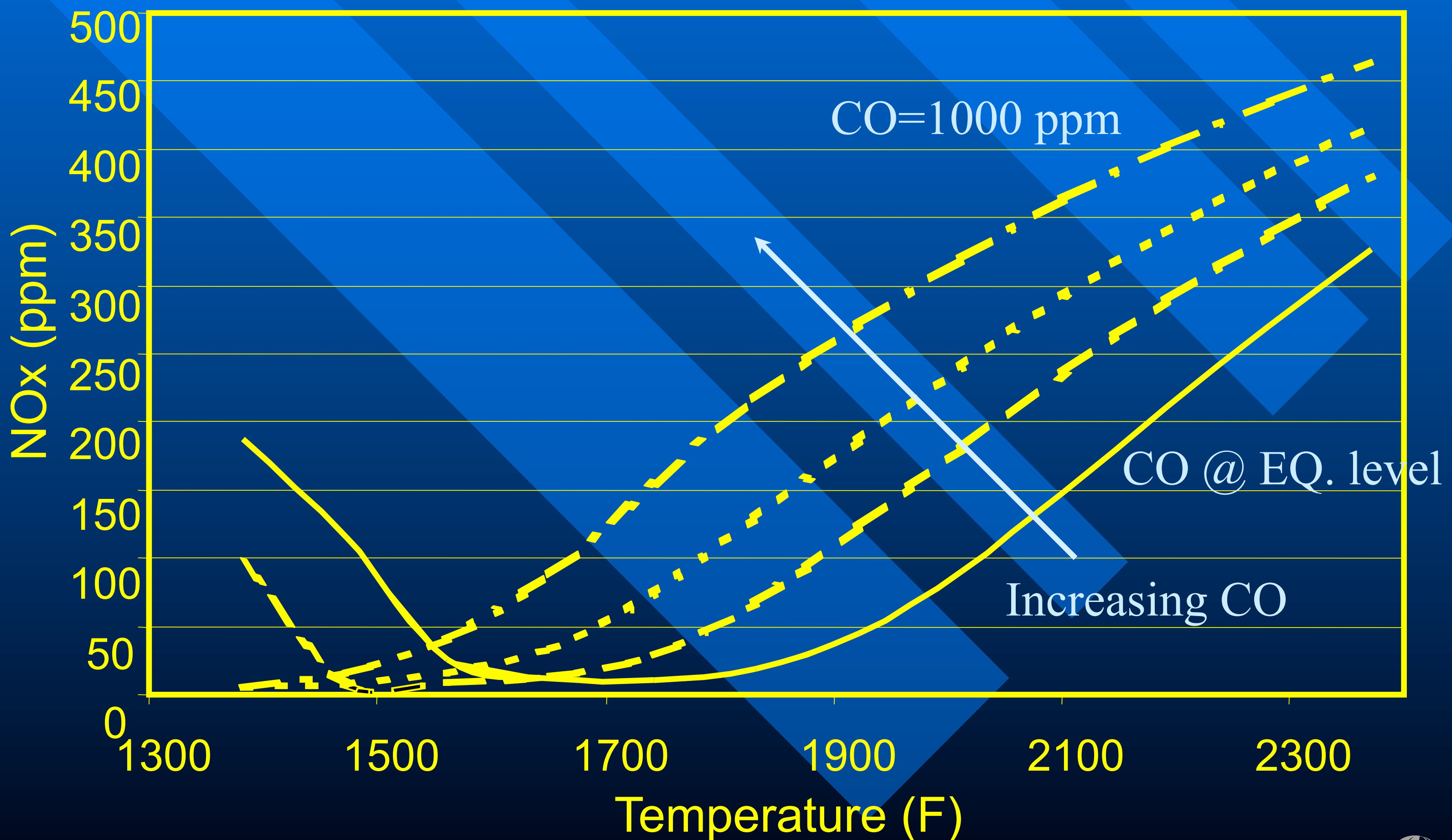
CO lowers SNCR Temperature Window
chemical kinetic model



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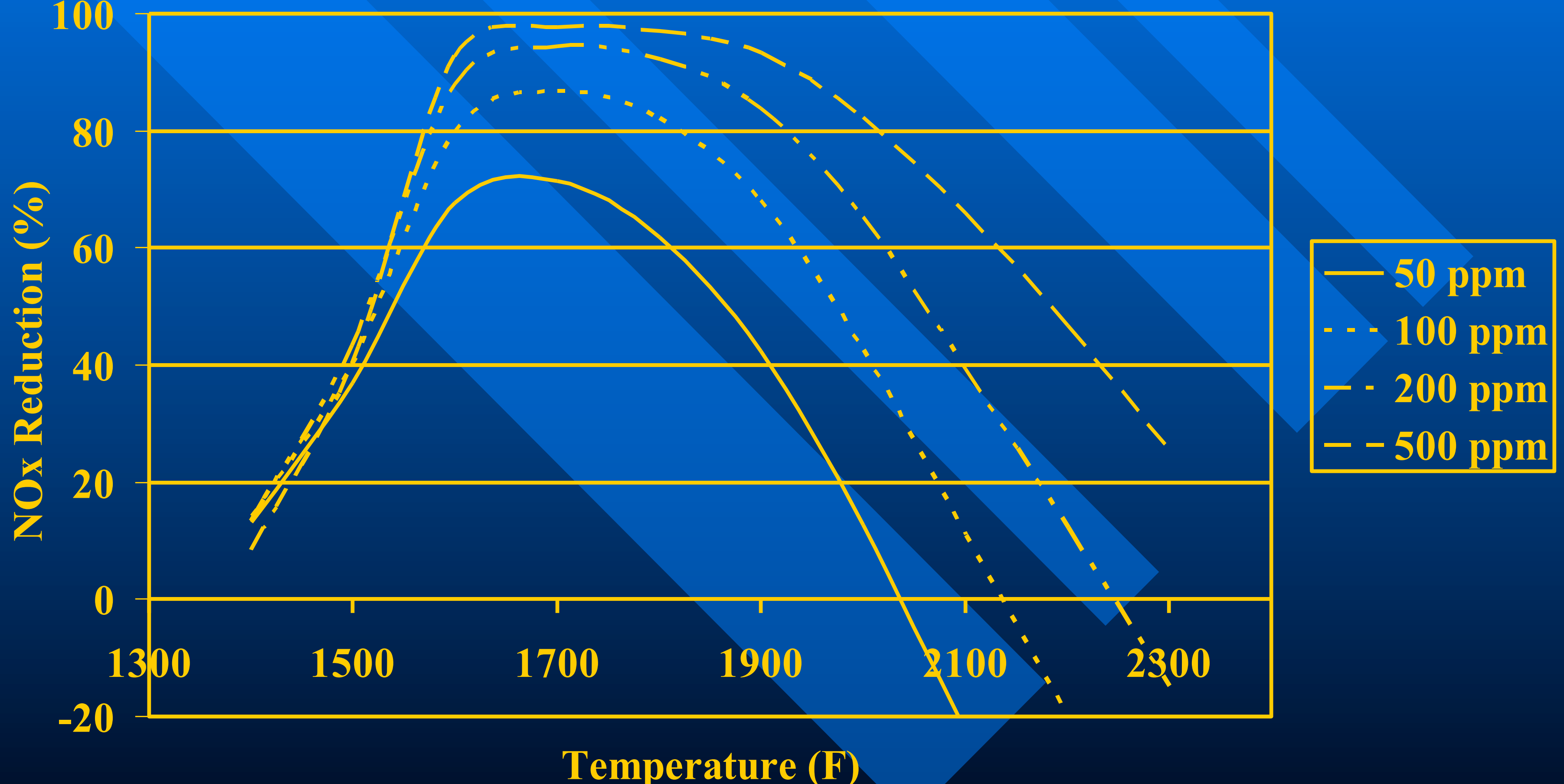
Effect of Baseline NOx on Reduction

Equilibrium CO, NSR = 2, t =1 sec



Byproduct: NH_3 Slip

$H_2O + SO_3$	→	H_2SO_4
$NH_3 + SO_3 + H_2O$	→	NH_4HSO_4 (l)
$NH_3 + NH_4HSO_4$	→	$(NH_4)_2SO_4$ (s)

- Formation temperature exists within the air heater
- Formation temperature increases with SO_3 and NH_3 concentration
- Higher formation temperature moves the deposition from cold to intermediate to hot baskets of the air heater.
- Ammonium salt deposition increases pressure drop across the air heater
- High fuel sulfur generates high SO_3 → must maintain low NH_3 slip

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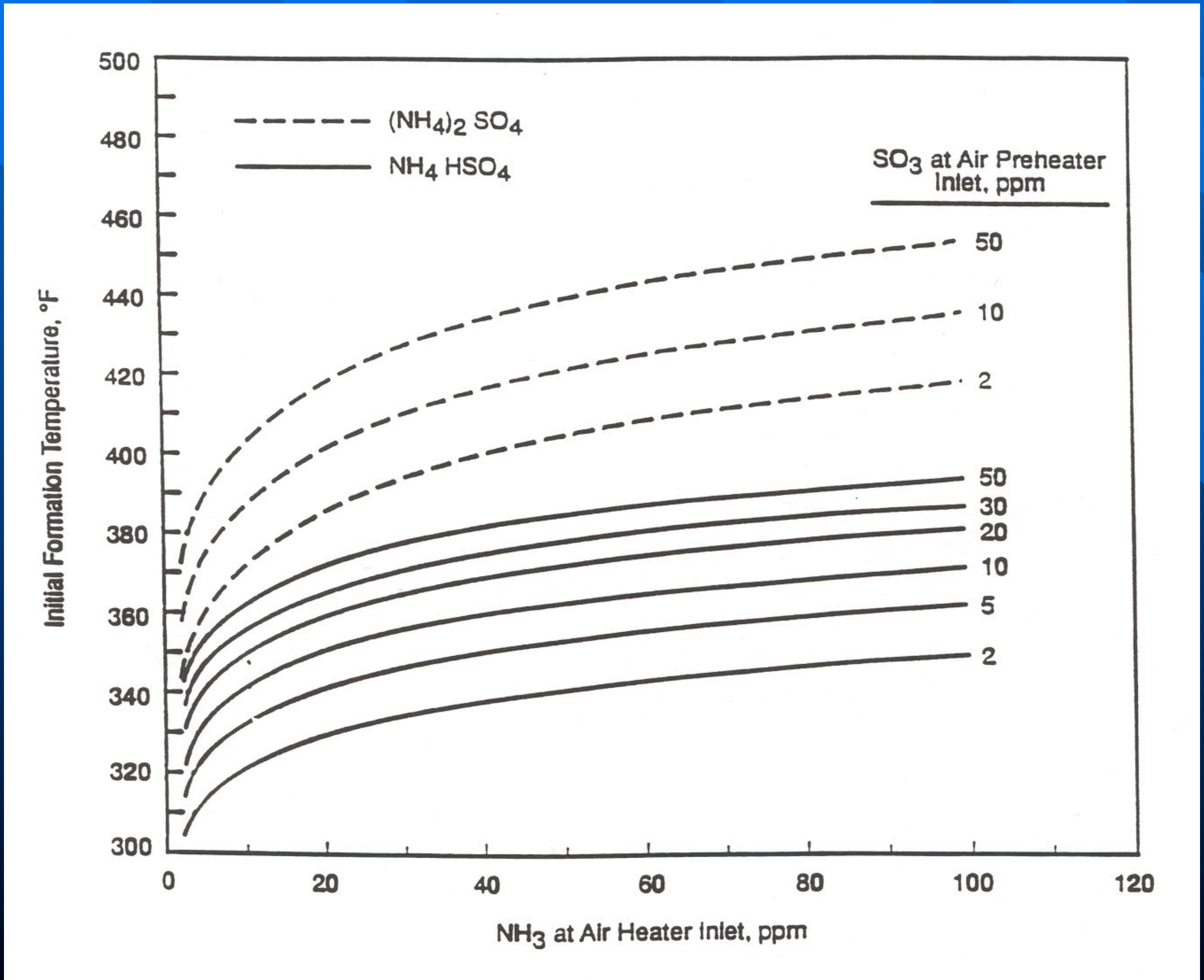
Formation Temperatures for Ammonium Sulfates



SNCR Critical Process Parameters

- Residence Time
- Temperature
- Baseline NOx
- CO concentration in the injection region
- Fuel Sulfur
- Reagent distribution

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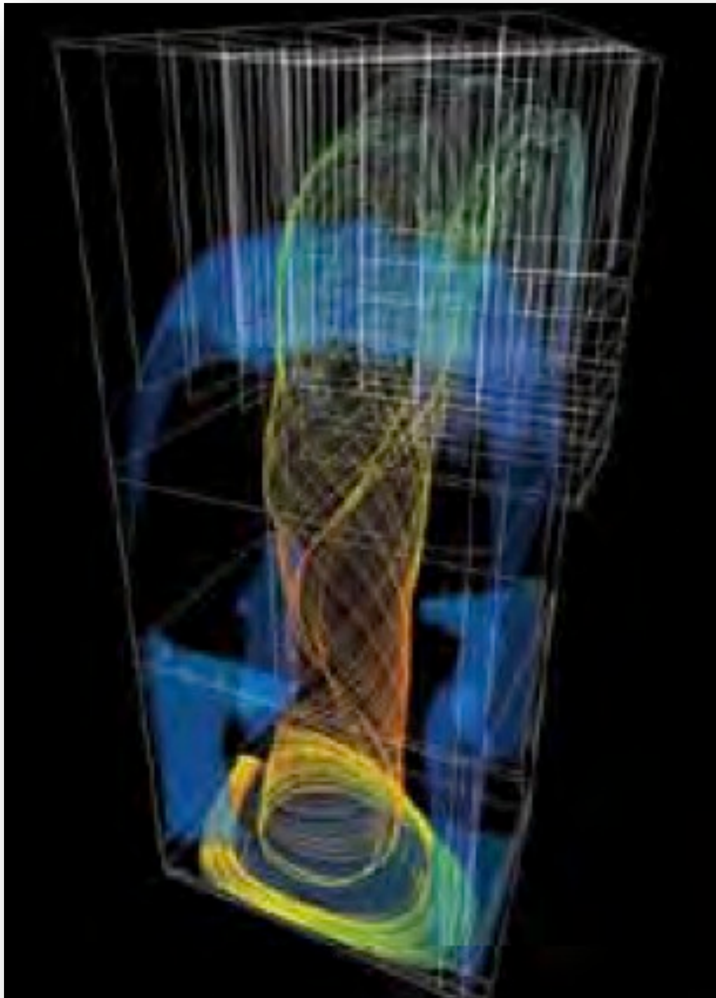
SNCR PROCESS DESIGN (CUSTOMIZATION)



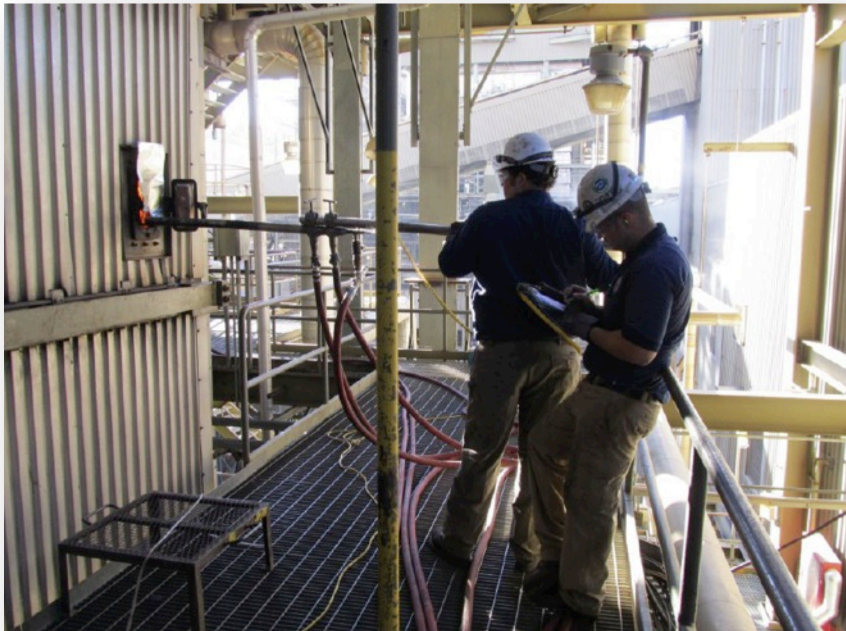
Computational Fluid Dynamics (CFD)
Used to Define Effective Boundaries of Critical Process Parameters, Test Effectiveness of Distribution Strategies, Identify/Locate/Define Gas Species Concentrations – Physical Unit Data (Drawings, etc.) and Field Testing as Input

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

A COMPLETE SITE PERSPECTIVE

- Coal Specifications
- Combustion Systems: Burners & OFA
- Furnace Slag / Fouling
- Heat Rate and Furnace Efficiency
- Unit Capacity Factor (Load range)
- Excess O2 / LOI
- Post-Combustion NOx Control
- SO_2 and SO_3

UPPER FURNACE MEASUREMENT GOALS



- High Velocity Thermocouple and Probe to Extract Flue Gas
- Measurement of Upper Furnace Temperatures and Species
  - Concentrations of O_2, CO, and NOx
- Data taken typically at three (3) loads; full, mid, and low load
- Testing on front and side walls to obtain realistic view of temperature and species differences at each plane.

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

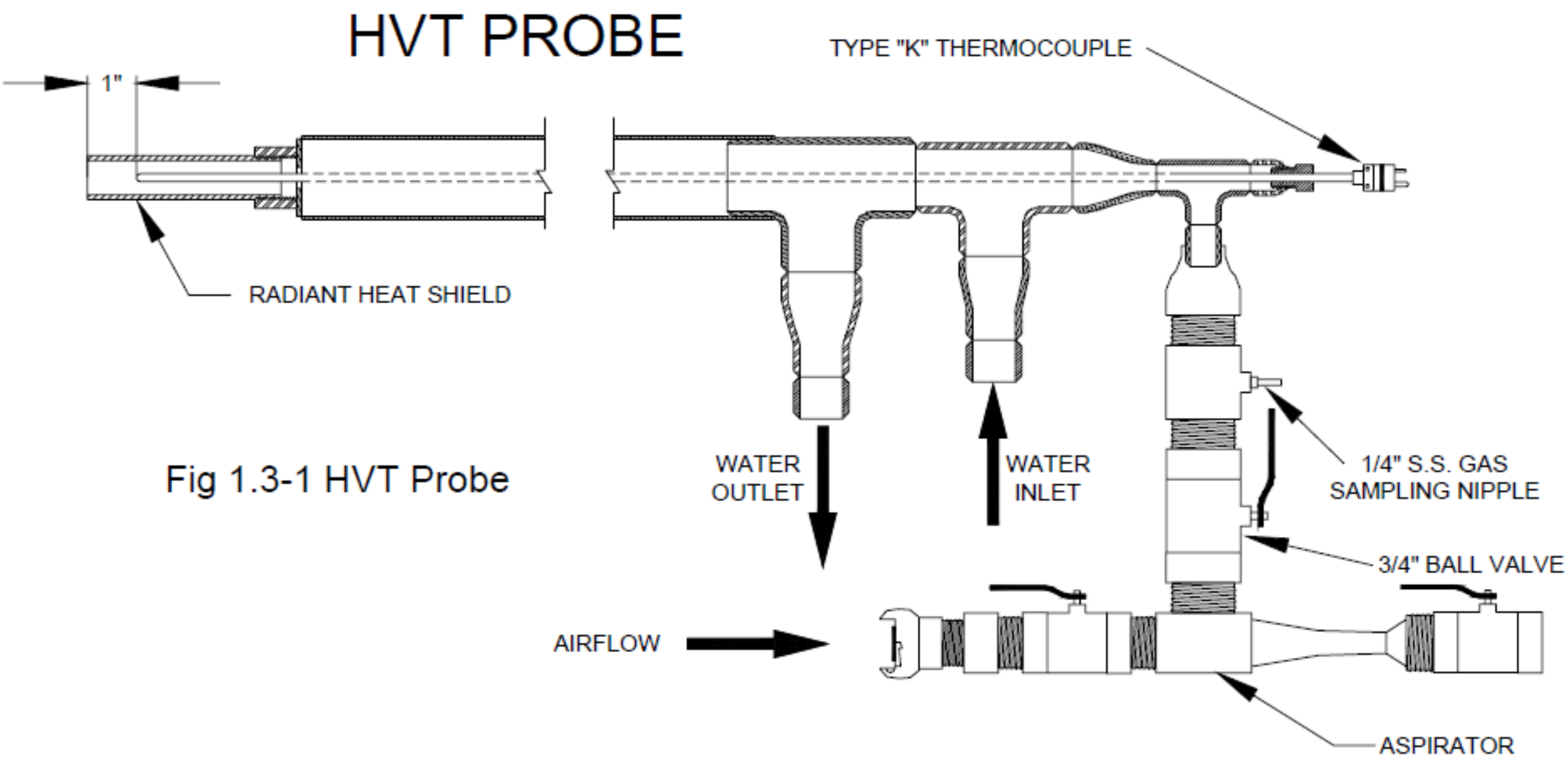
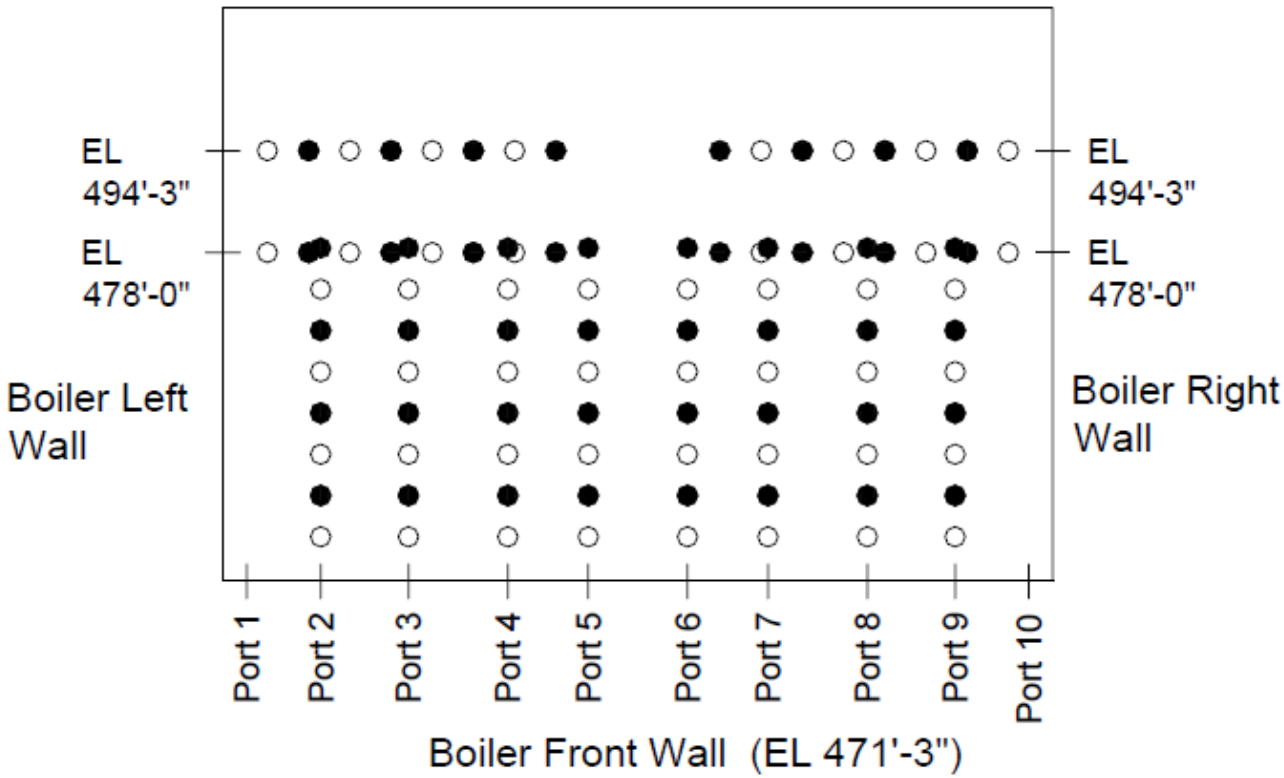


Fig 1.3-1 HVT Probe

SNCR BASELINE TESTING - HVT



● Temperature Measurement and Gas Species

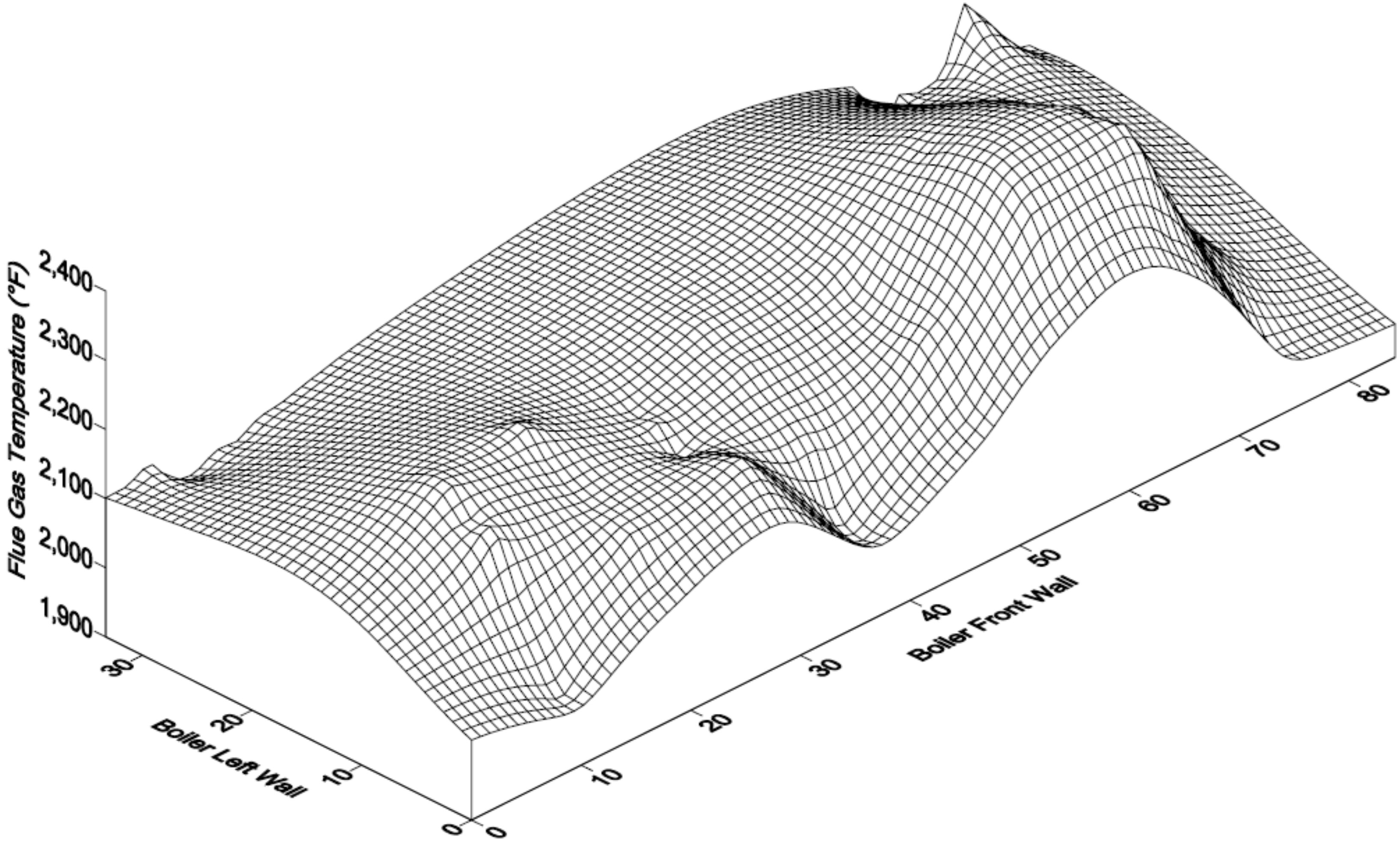
○ Temperature Measurement Only

SNCR BASELINE TESTING - HVT

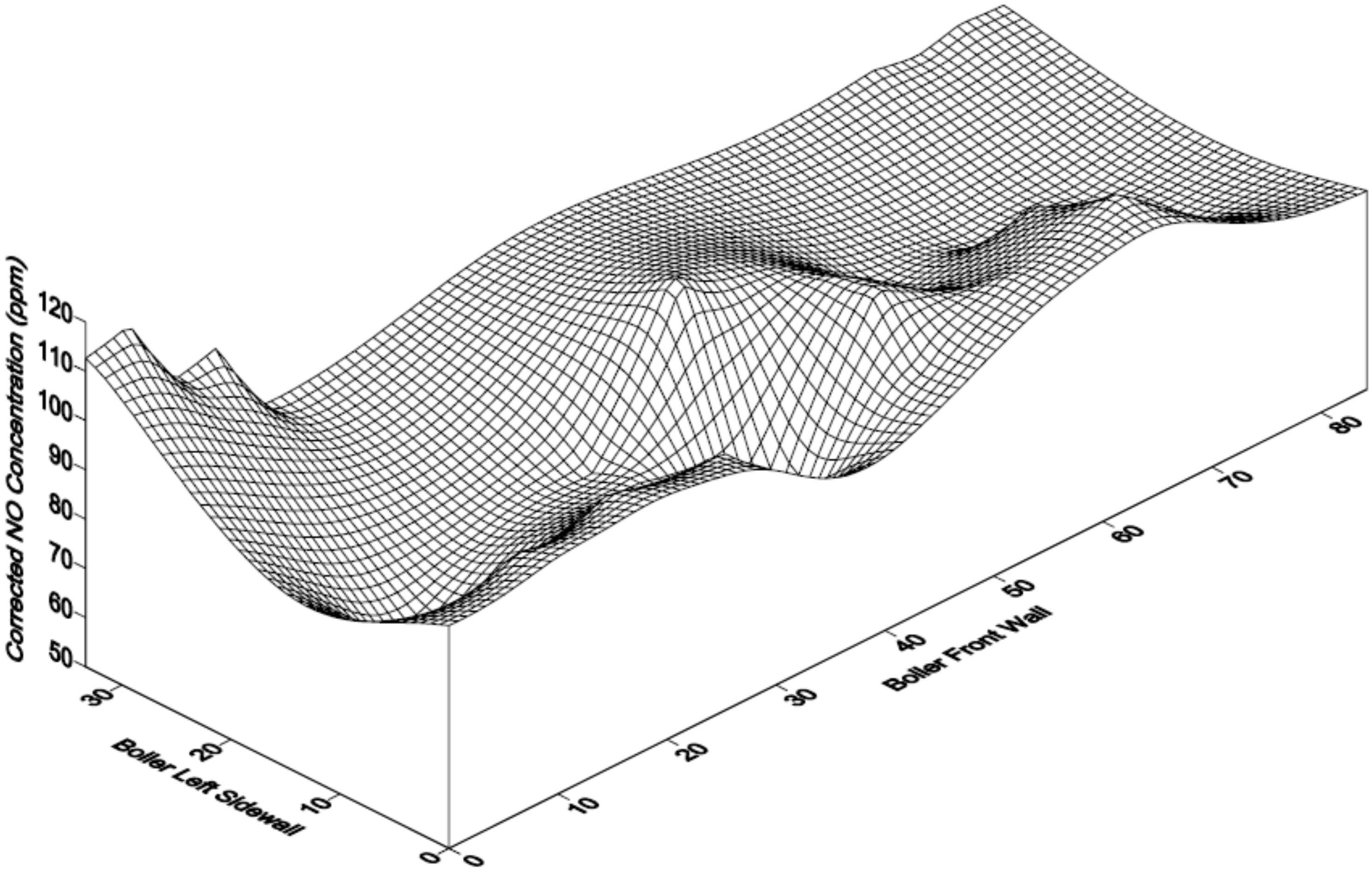
Start Time: 12:42 Finish: 12:58

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 (ºF)



HVT TESTING – NO_X CONCENTRATION (PPM)



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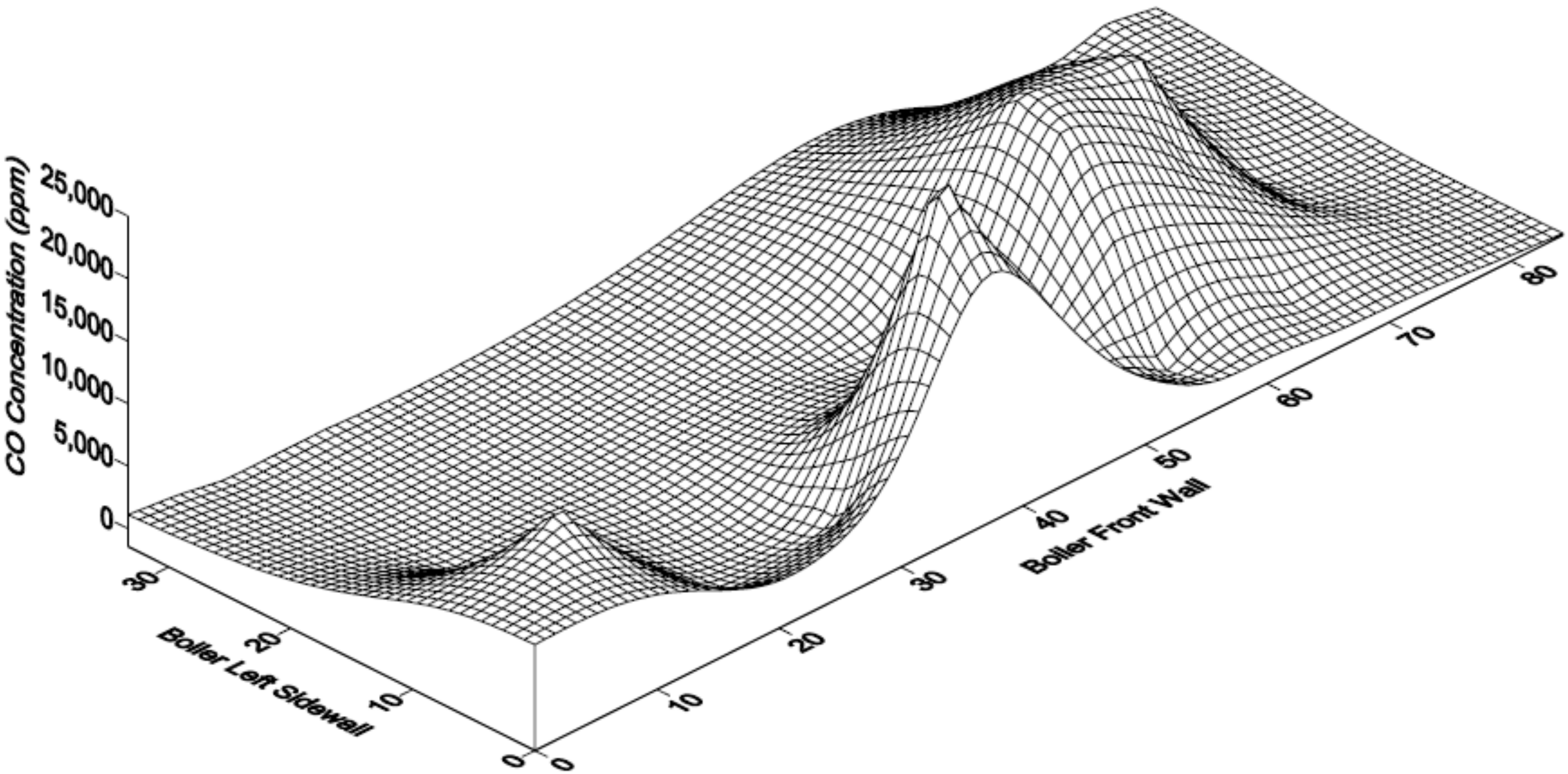
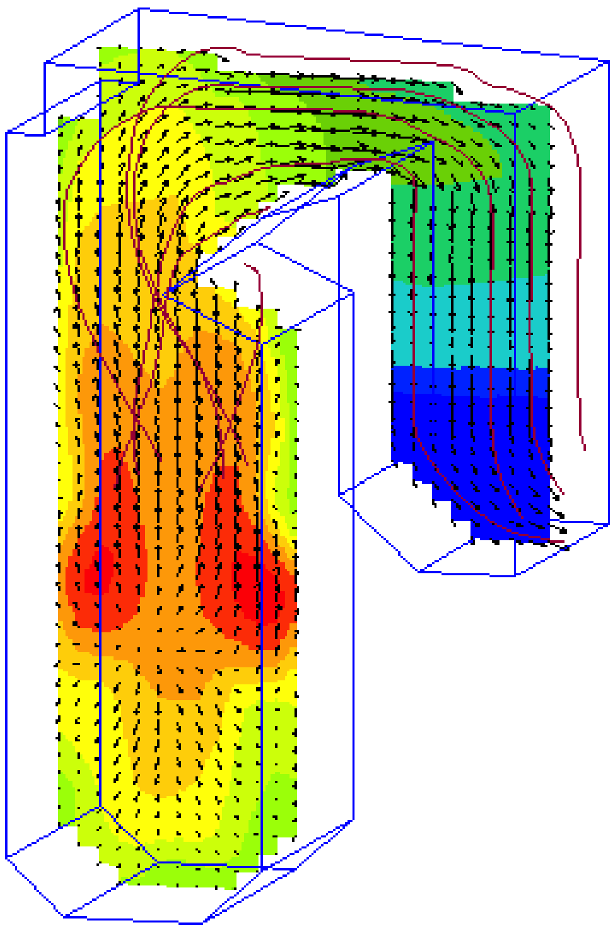
HVT TESTING – CO CONCENTRATION (PPM)



SNCR CFD MODELING STEPS



Step 1: Define the Unit Geometry

Step 2: Block Out Obstructed Cells and Faces

Step 3: Define Mass and Heat Sources

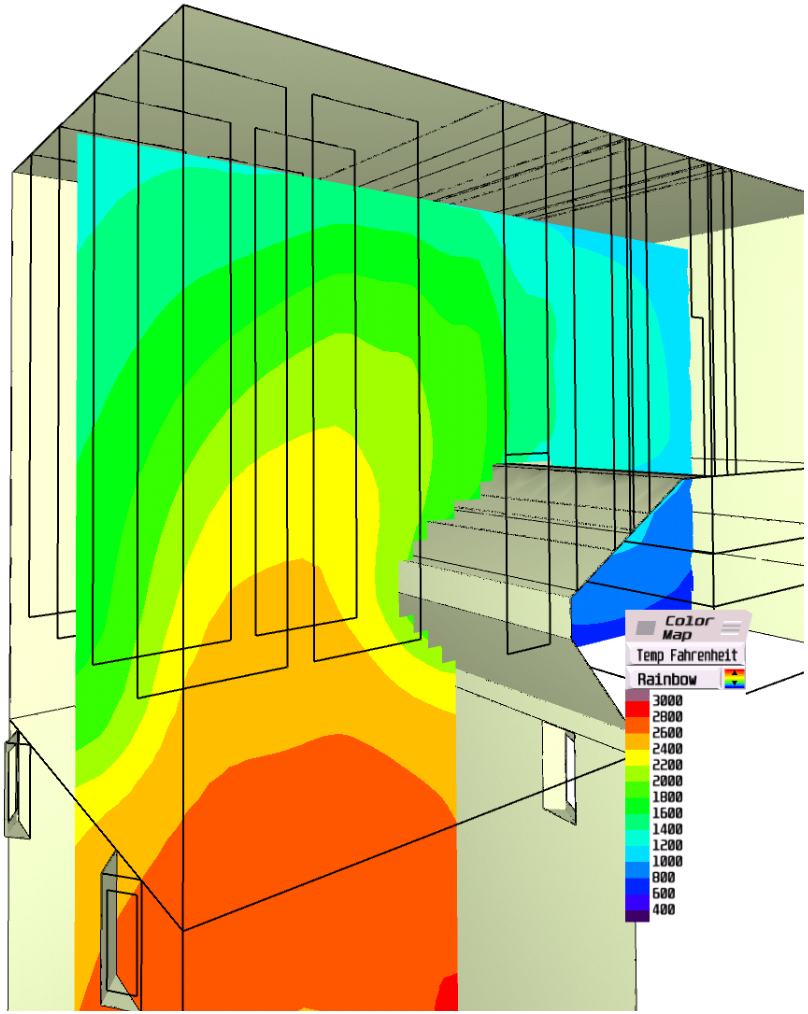
Step 4: Solve for Flue Gas Temperatures and Velocities

<u>Step 5</u>: Generate Temperature Versus Residence Time Data for CKM

Step 6: Identify Temperature Limits for Effective NOxOUT Performance

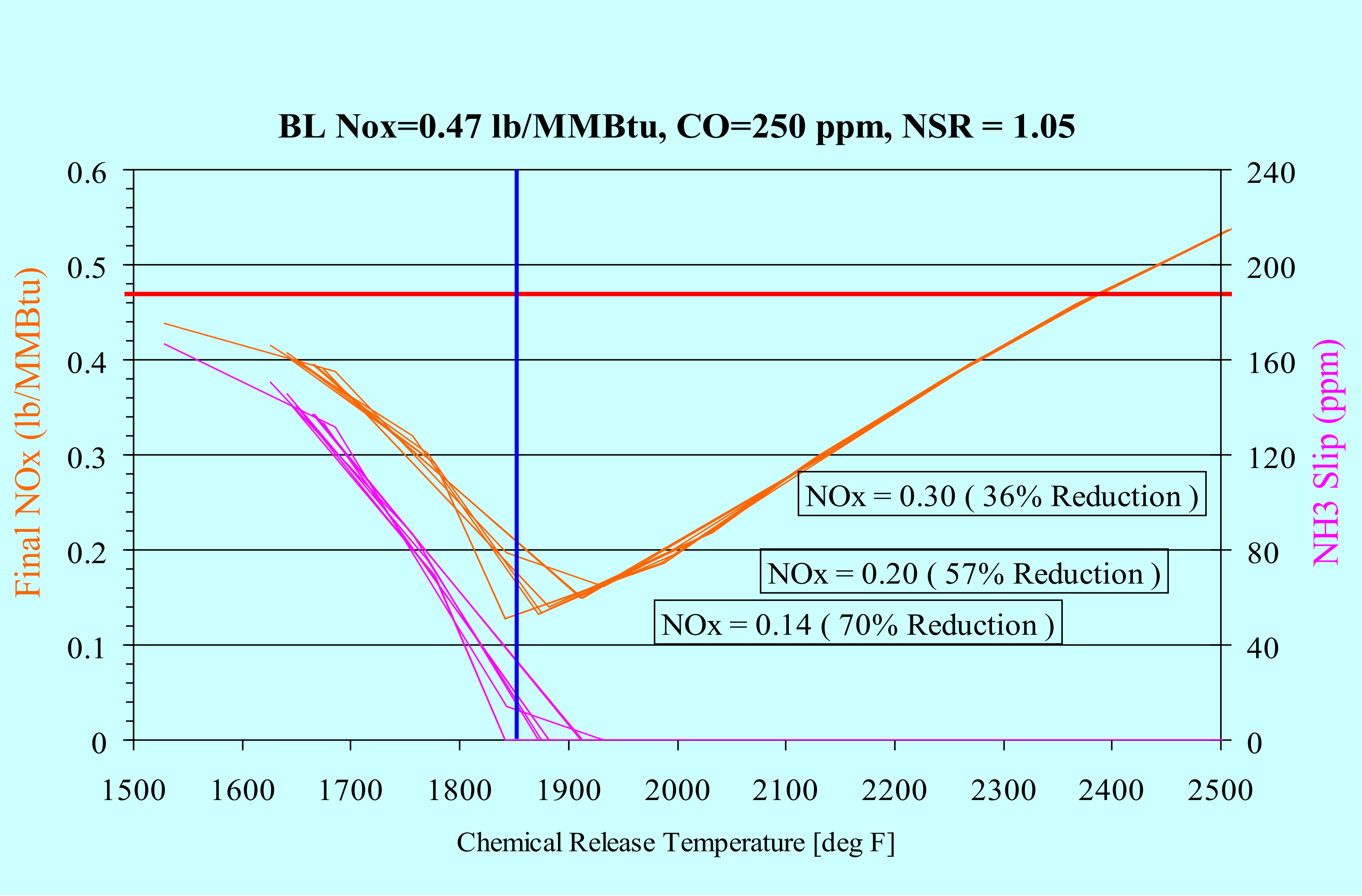
Step 7: Select Injector Locations and Spray Characteristics

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 Chemistry on CFD to Determine Reagent Distribution and Performance

CHEMICAL KINETICS MODEL



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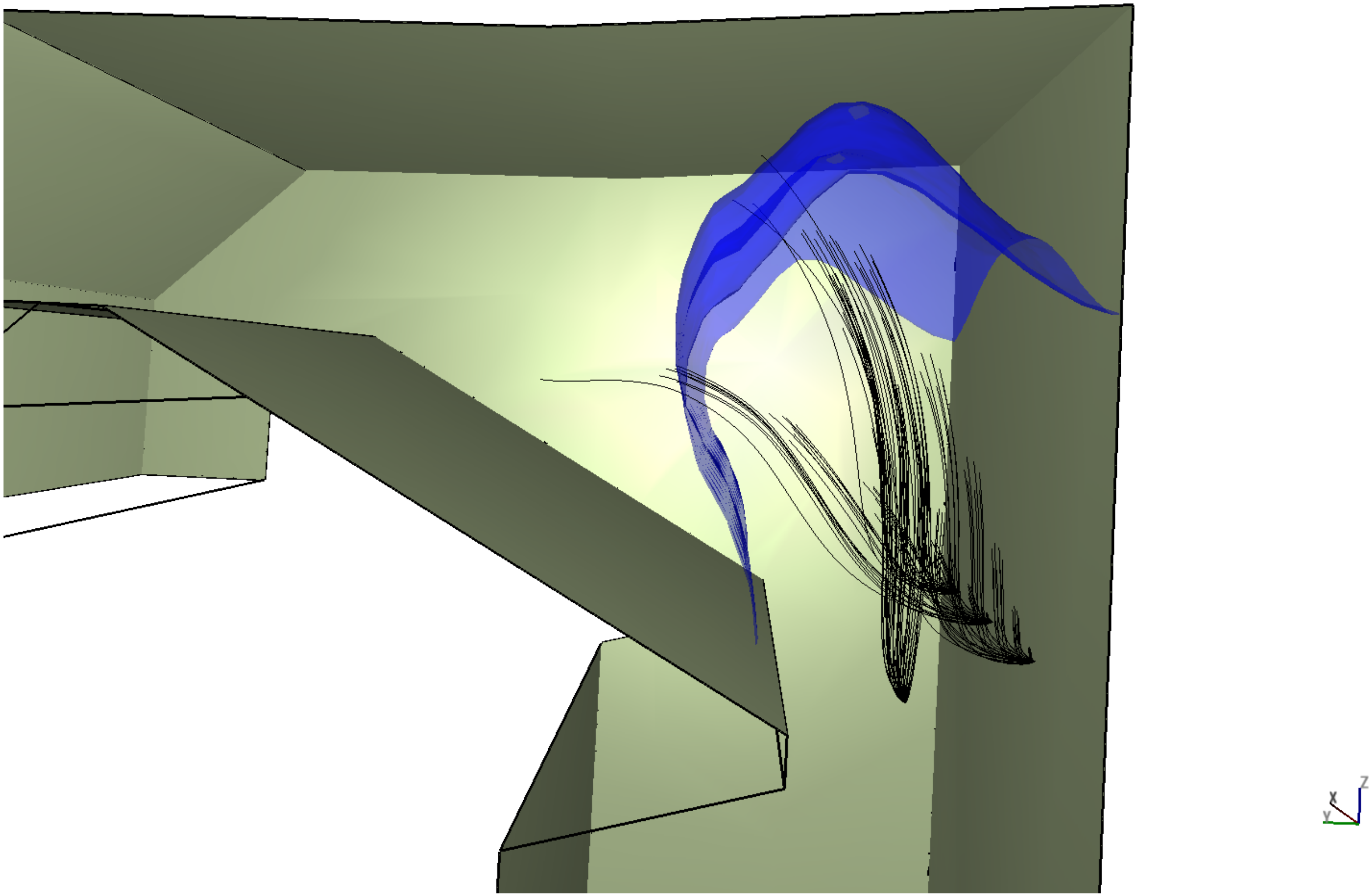
LOW-TEMPERATURE LIMIT SURFACE



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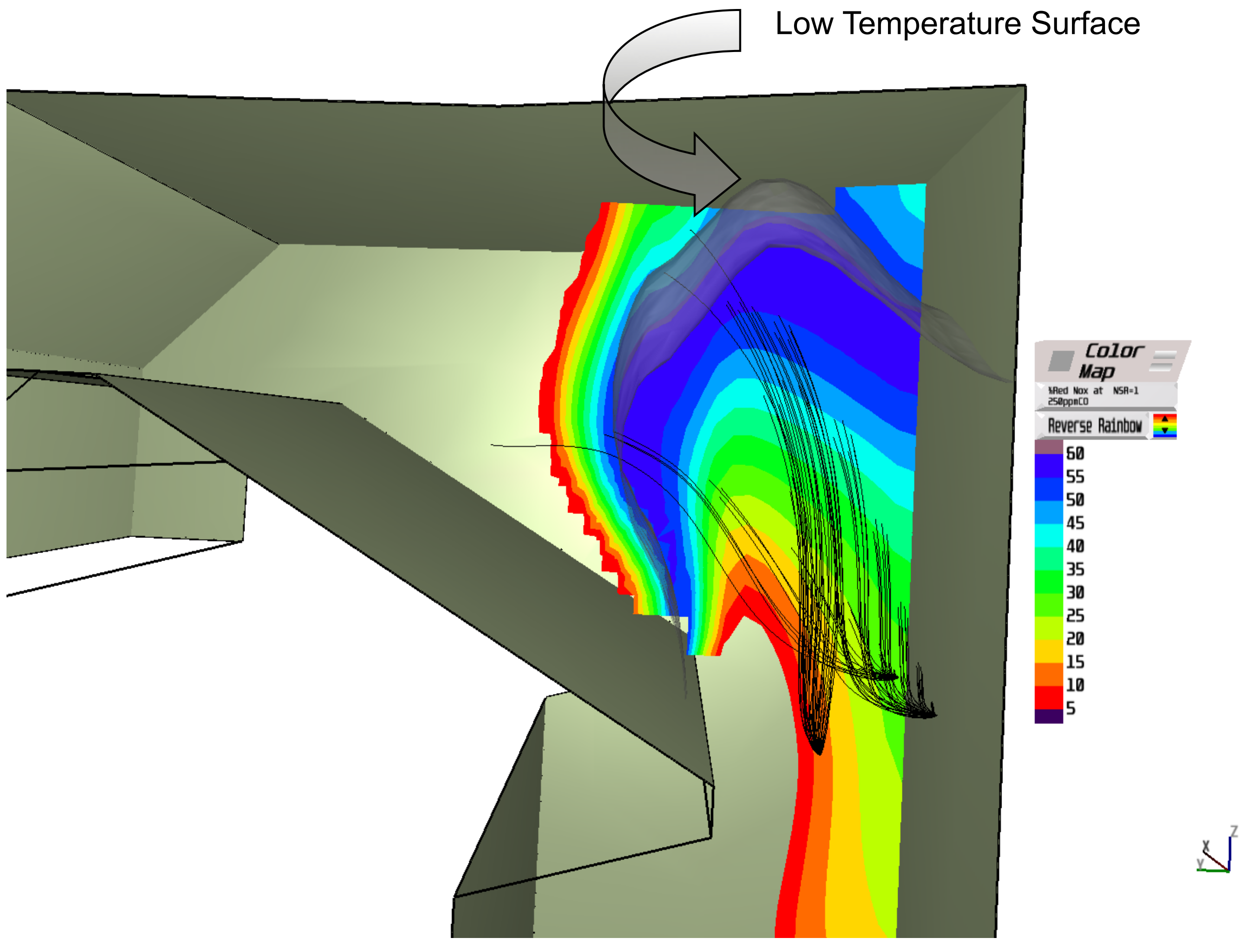
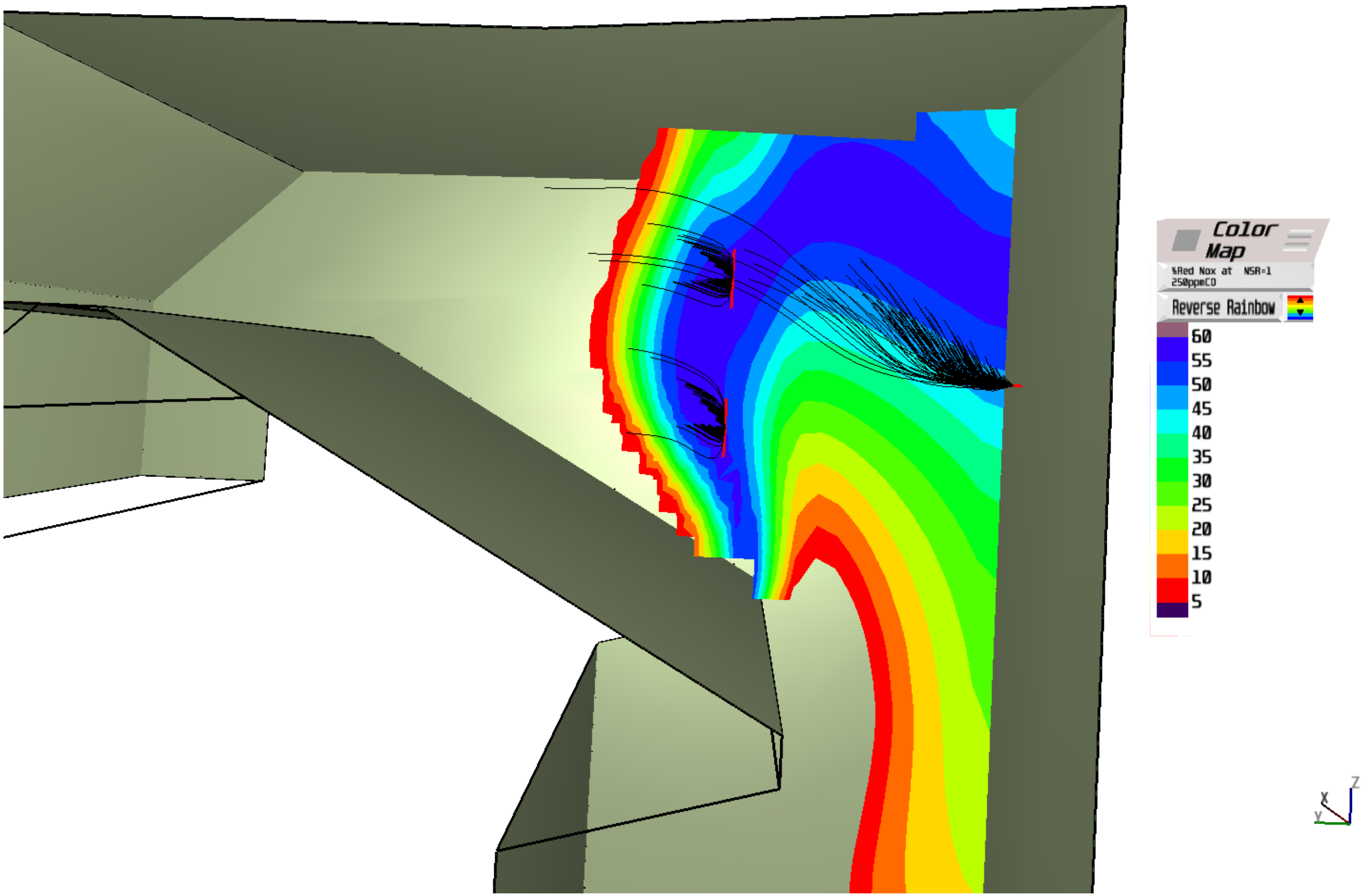
INJECTION STRATEGY FOR SNCR PROCESS
WALL INJECTORS

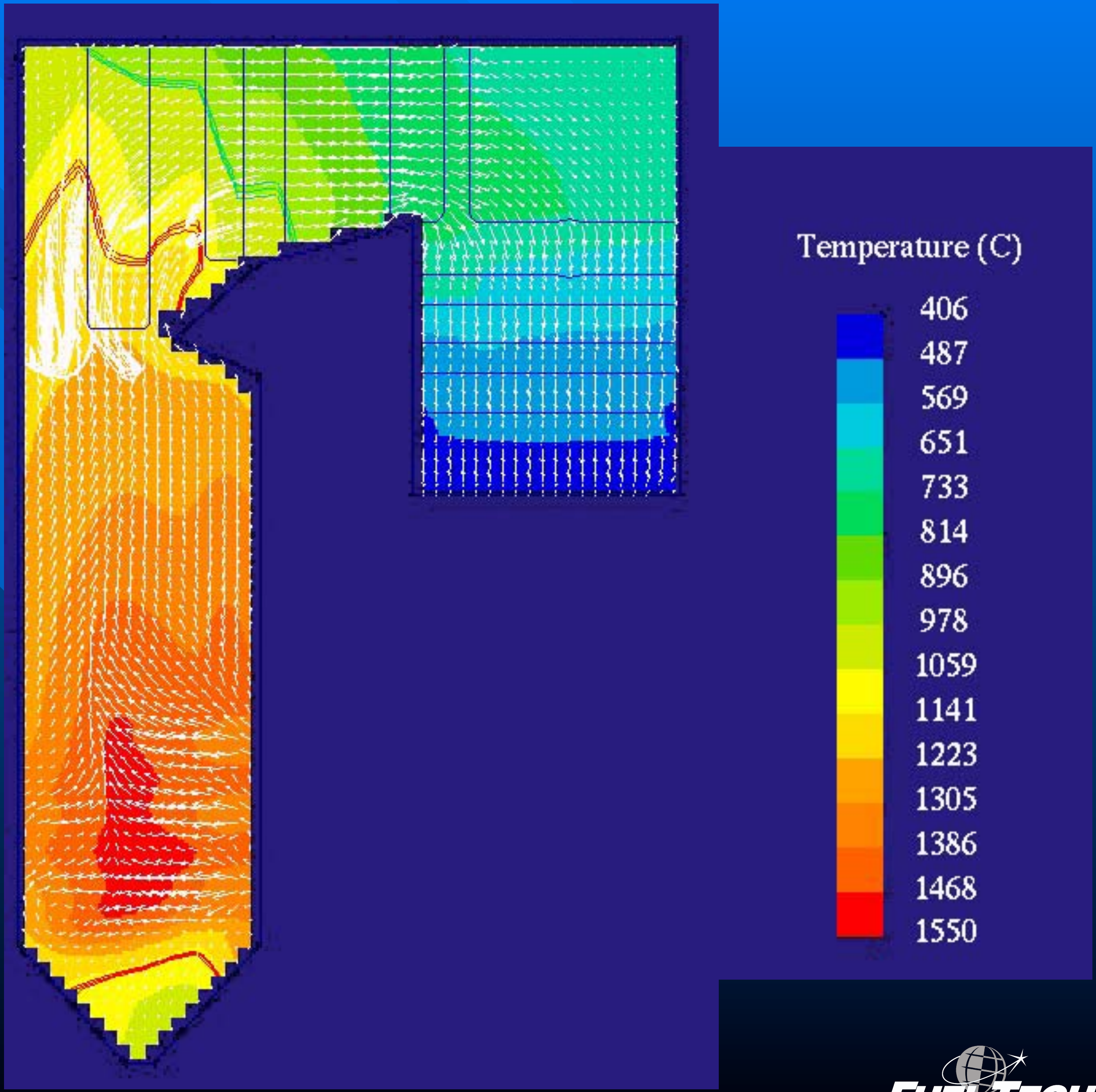
In this figure, the CKM results are overlaid on the ammonia slip limit surface from the previous slide. The colored bands illustrate that NOx reduction is very limited near the plane formed by the bullnose while NOx reduction approaching 60% can be achieved near the low temperature limit.



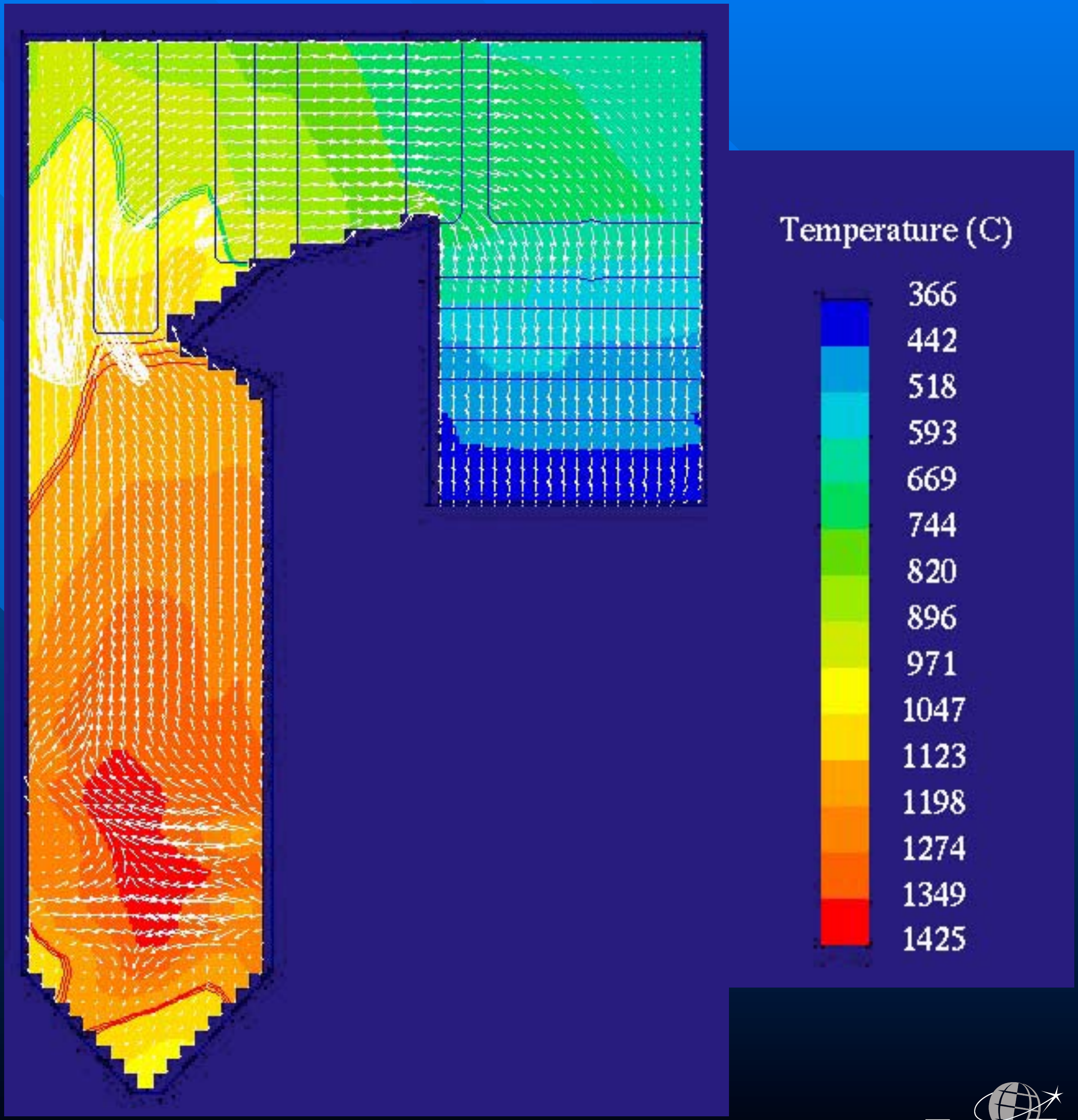
NO_x REDUCTION CONTOUR: WALL INJECTORS AND MNLS



Furnace & Injection Modeling @ 100% MCR



Furnace & Injection Modeling @ 75% MCR



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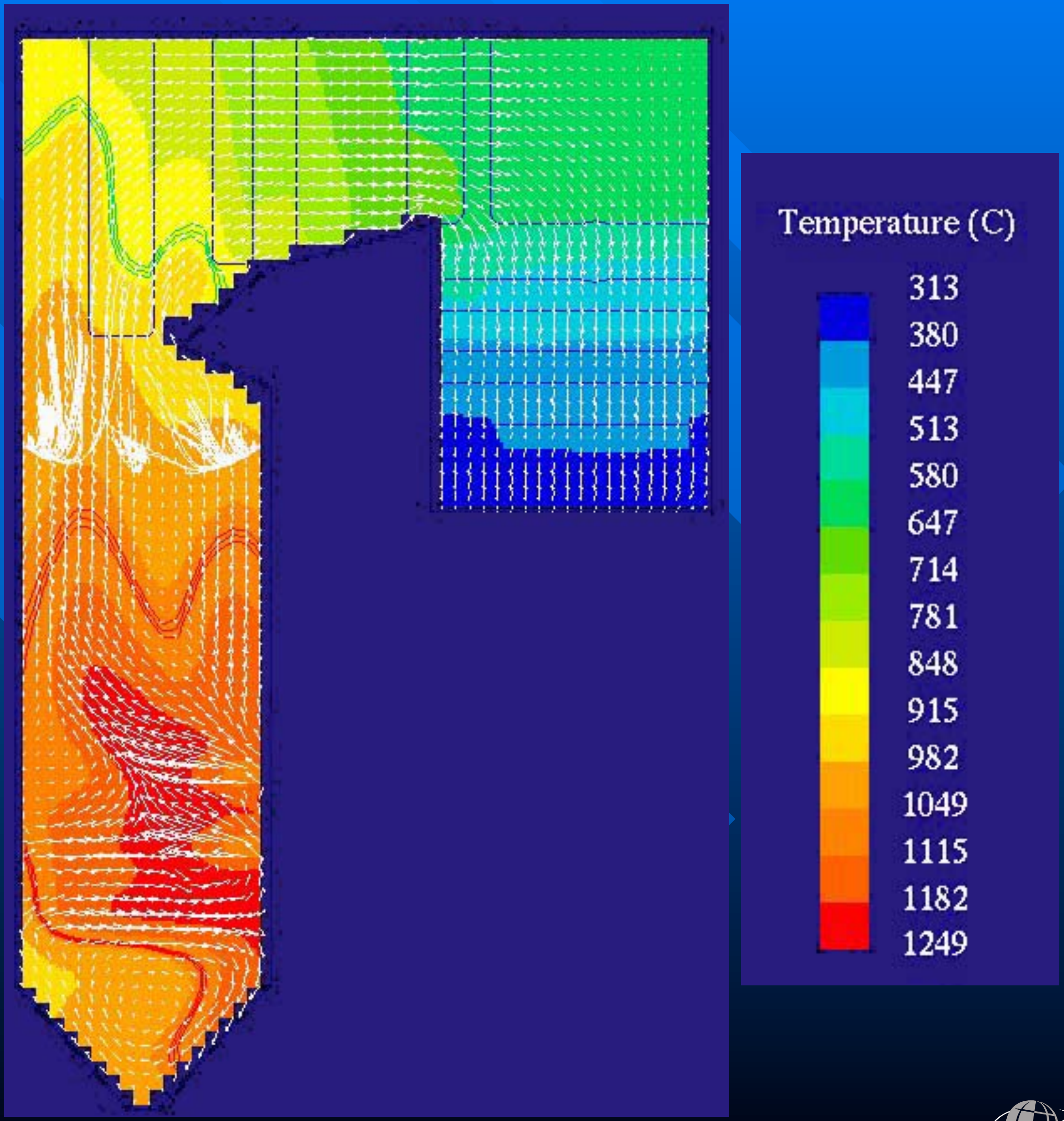
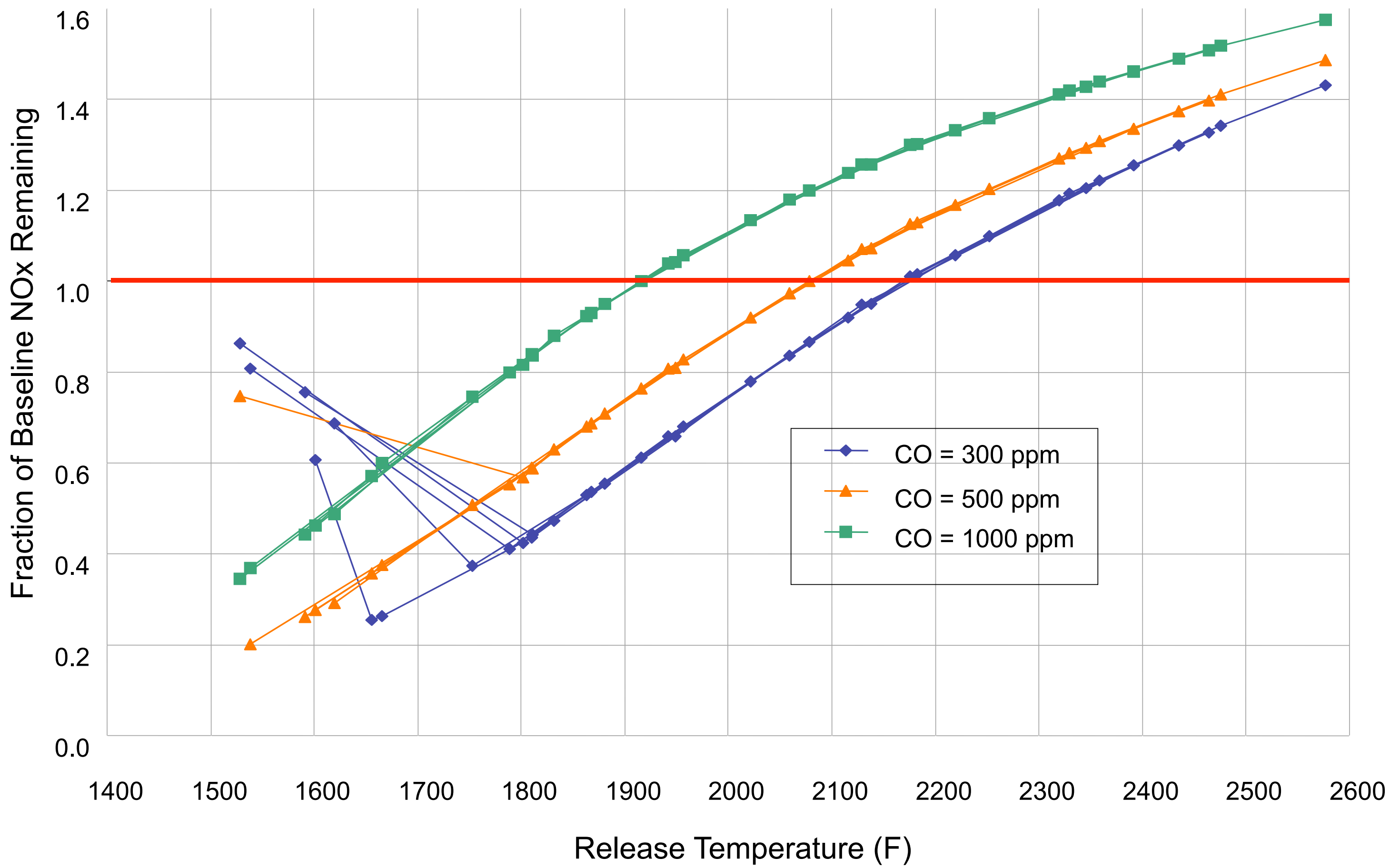
Furnace & Injection Modeling @ 50% MCR

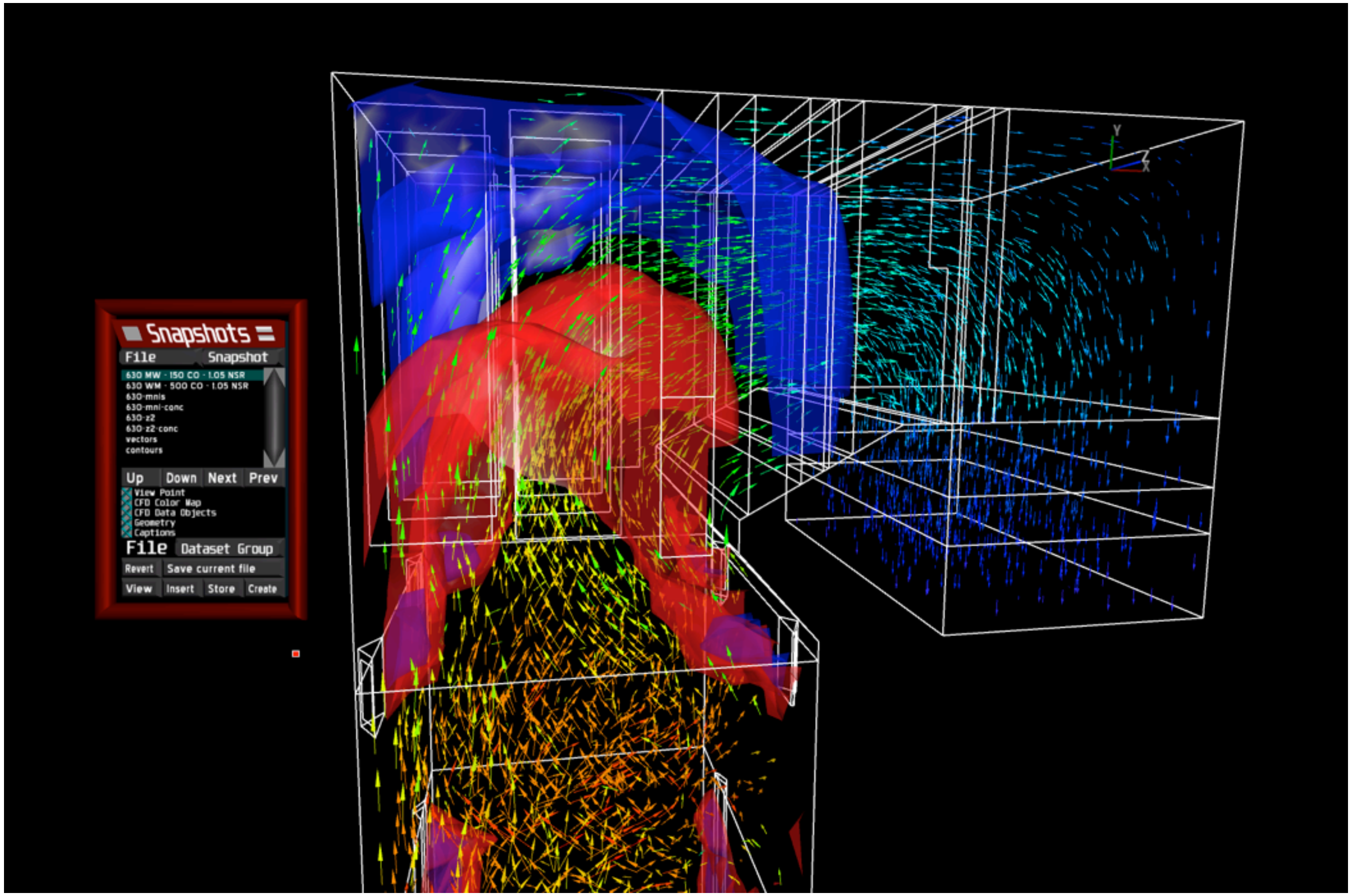


CO EFFECT ON SNCR



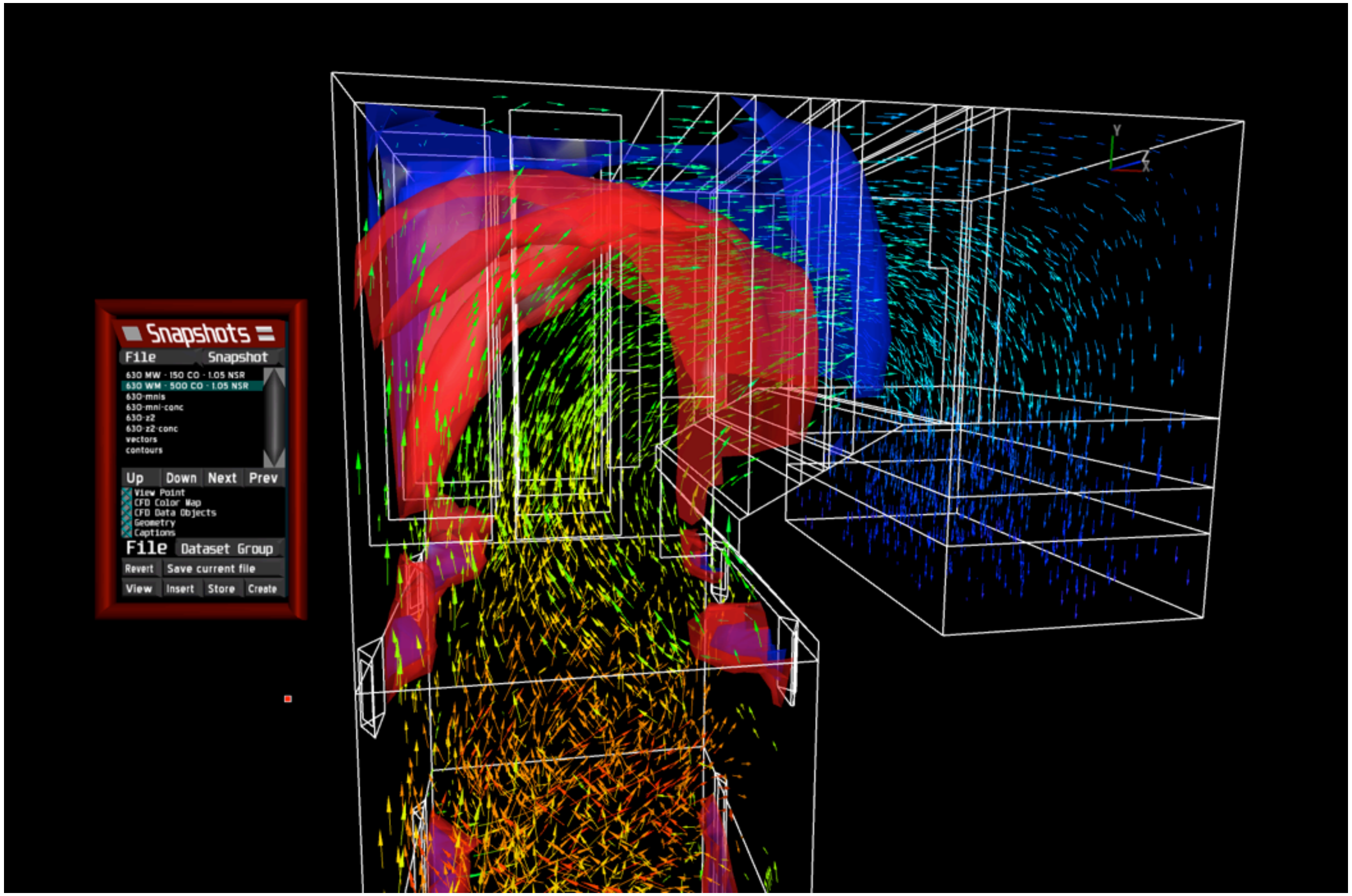
Note: Higher CO Levels Increase the Rates of NH_3 and HNCO Oxidation to NO; Effective NOx Reduction Window for Process is Shifted to a Lower Temperature.

TEMPERATURE WINDOW: 150ppm CO



1950°F 1750°F

TEMPERATURE WINDOW
500ppm CO



1750°F 1450°F

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SNCR INJECTION STRATEGIES

NO_XOUT® Process Injection ←	SNCR Technology	→ HERT™ High Energy Reagent Technology Injection
• High momentum injectors • Maximize performance • Adjustable for NO_X reduction downstream of injection point	• CFD/CKM Modeling • Reliable equipment • On-site optimization	• High energy, low momentum injectors • Maximize performance with minimal ammonia slip • Localized NO_X reduction

Wall Injectors

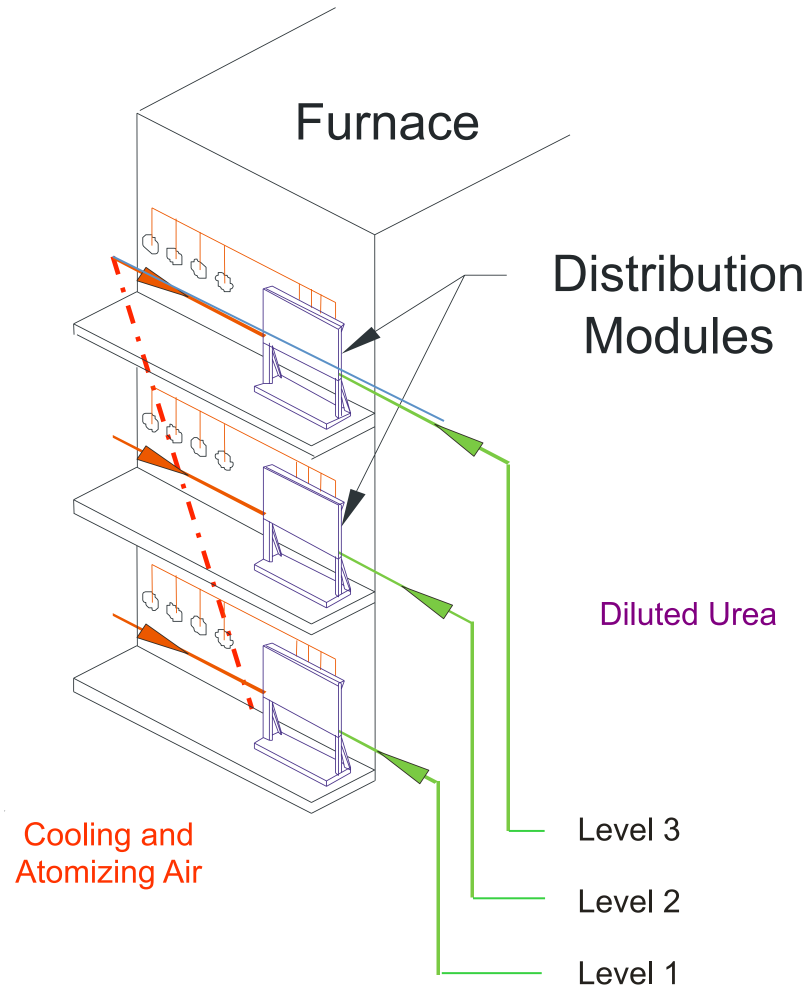
- Air Atomized Urea Injection
- Larger Droplet Size for Hot and/or Large Boilers and Furnaces
- Mechanically Atomized Urea Injection

Multiple Nozzle Lances (MNLs)

- Air Atomized, Fine Mist
- Convection Pass Injection

Combined Injection Strategy for Significant NO_X Reduction with Low NH_3 Slip

SNCR DISTRIBUTION MODULES & NO_XOUT INJECTORS



Notes

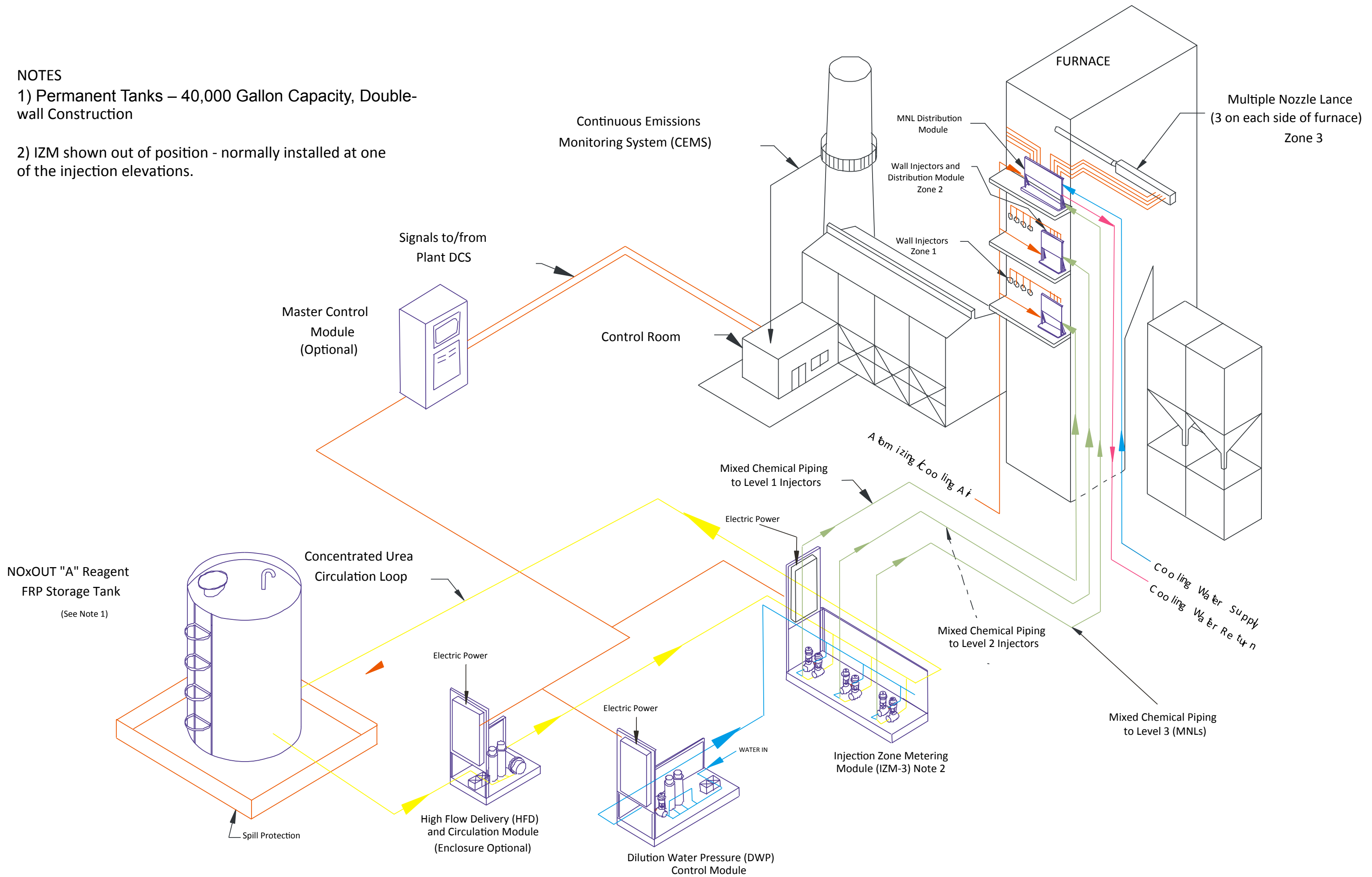
1) Number of levels is determined by the furnace geometry and the desired load range for SNCR operation.
2) The location of injectors is generally dictated by access and physical obstructions – CFD/CKM model determines preferred locations.
3) Compressed air and diluted urea is sent from the Metering Module to the Distribution Modules, where the air pressure and urea flow rate to each injector are controlled.

SNCR SYSTEM LAYOUT

NOTES

1) Permanent Tanks – 40,000 Gallon Capacity, Double-wall Construction

2) IZM shown out of position - normally installed at one of the injection elevations.



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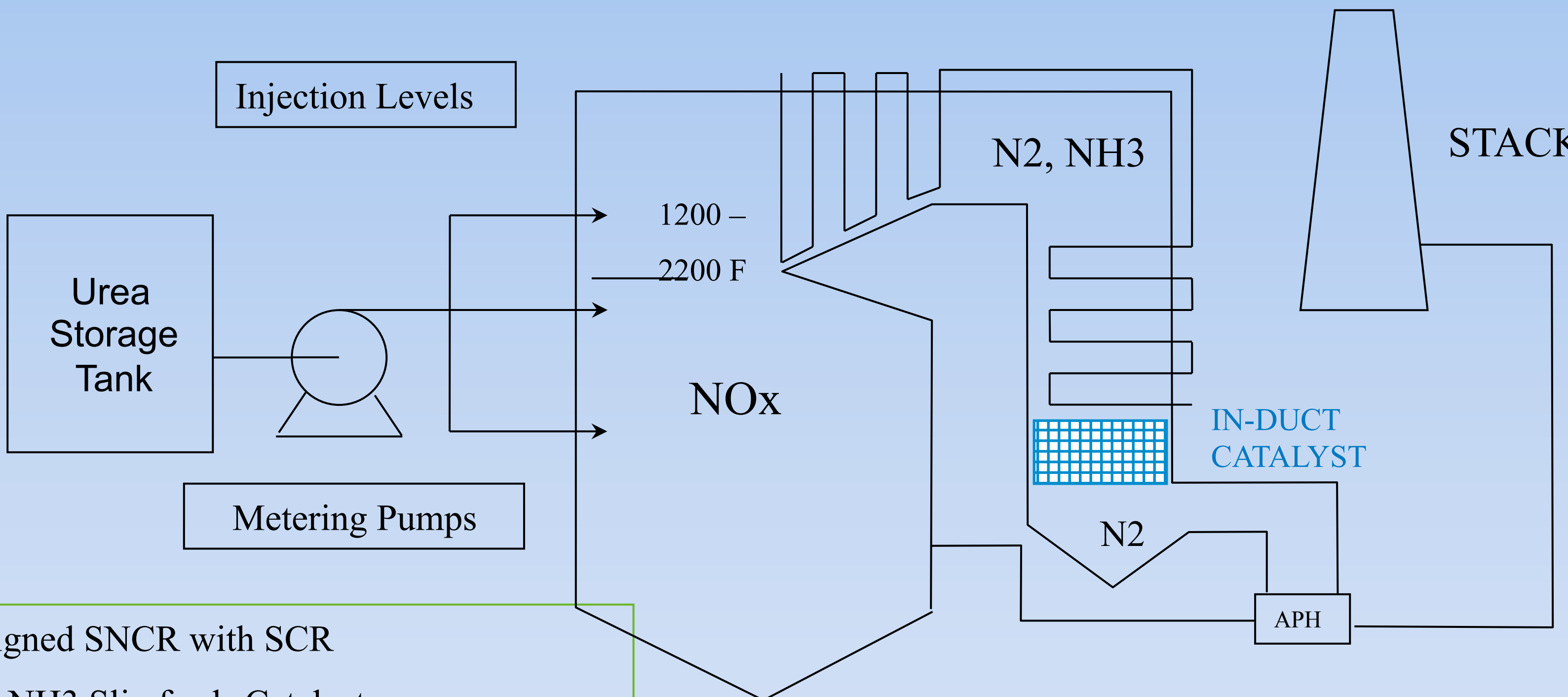
NO_xOUT PROCESS CONTROL

A. Feedforward Control (Look-up Tables)
   - Input Signals: Boiler load and flue gas temperature
   - Controlling Parameters:
     - injection zone
     - chemical flowrate
     - atomizing air & dilution water pressures

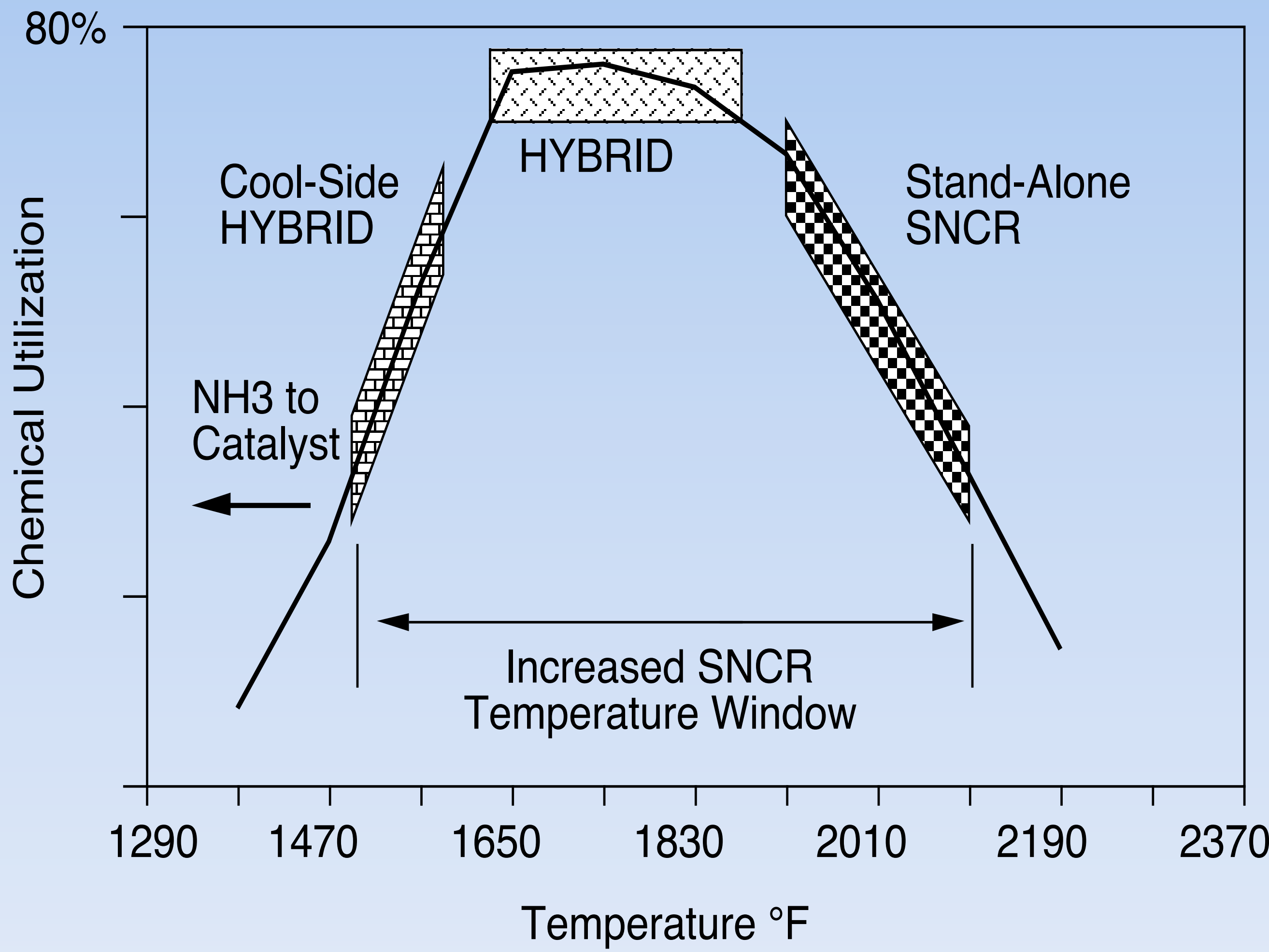
B. Feedback Control (PID Controller)
   - Input Signal: NOx CEM
   - Controlling Parameter: Chemical flow rate to each zone

NOxOUT SNCR/SCR Hybrid Process - ASCR



- Redesigned SNCR with SCR
- SNCR NH3 Slip feeds Catalyst
- High NOx Reduction & Utilization than SNCR
- Low Ammonia Slip
- Lower Installation Cost than SCR
- Lower Capital Cost than SCR
- Greater Operational Flexibility

HYBRID IMPROVES CHEMICAL UTILIZATION



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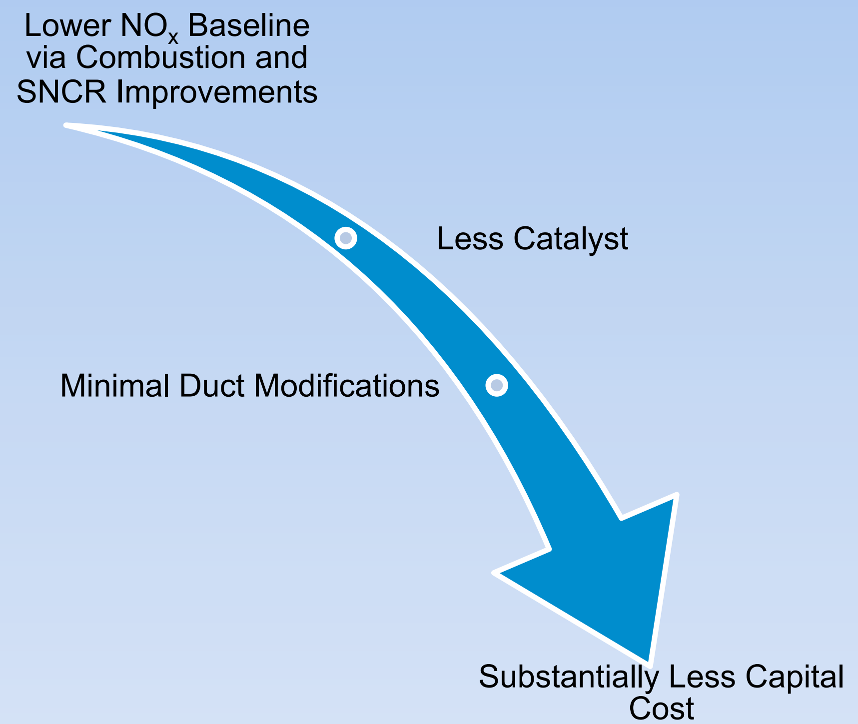
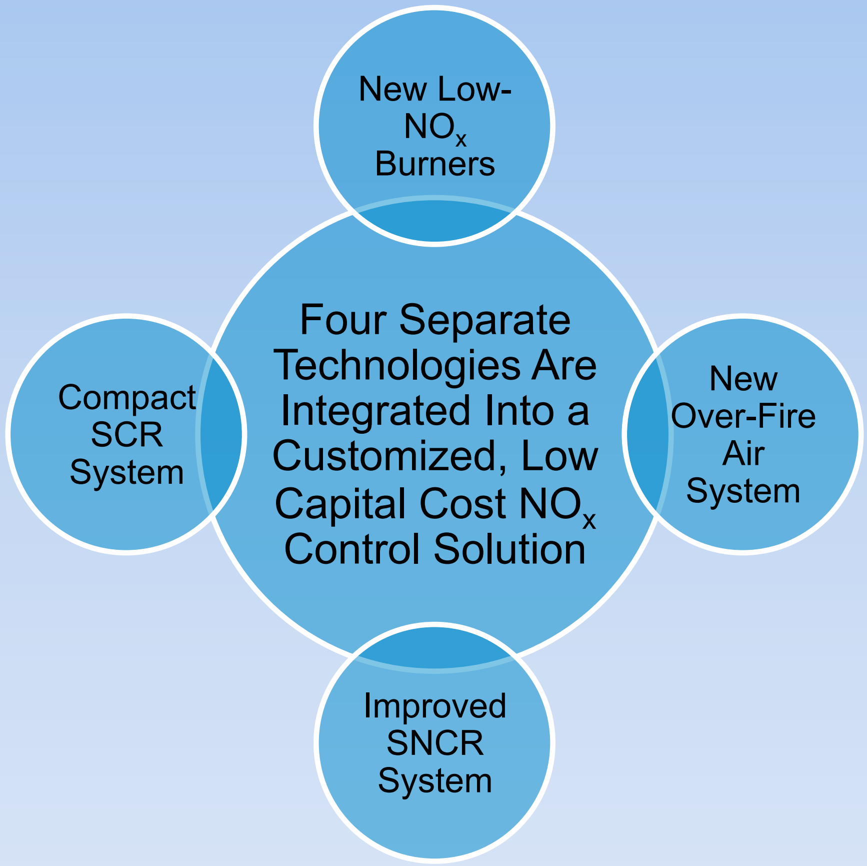
HYBRID or ADVANCED SCR Design Principles

- Selective Catalytic Reduction (SCR) is the Best Available Control Technology for NO_x reduction. High capital cost requirements and retrofit difficulty.
- The ASCR approach can achieve similar overall NO_x reduction as a SCR but with a greatly reduced capital cost.
- An ASCR combines multiple low capital cost technologies including Low-NO_x burners, OFA, and/or SNCR in combination with a compact SCR reactor.
- The ASCR reactor requires less catalyst, a smaller footprint and less duct modifications - all resulting in a greatly reduced capital cost when compared with a traditional SCR.



ASCR Case: Project Background

- The plant needed to reduce NO_x emissions by >78% from a baseline of 230 ppm to below 50 ppm (dry basis @6% O_2).
- The unit had existing low-NO_x burners and an existing SNCR system.
- The project added:
  - New Low-NO_x burners.
  - New Over-Fire Air (OFA) System.
  - Improved SNCR System
  - Small SCR reactor between the economizer and air heater.
    - Single layer reactor with 12 modules of plate catalyst.



Capital Cost Savings – Compared to SCR Only

ASCR

- The ASCR approach minimizes the NO_x reduction burden of the catalyst to approximately 29% (70 to 50 ppm).
- Requires only a single layer of 12 catalyst modules.
- Installation of all systems (OFA, burners, SNCR, and SCR) combine for an approximate cost of $5 million USD.

SCR

- A standalone SCR would need to accomplish the entire >78% NO_x reduction (230 to 50 ppm).
- The standalone SCR would require >3x the catalyst volume and about 4x the construction footprint.
- Approximate cost is $10 million USD.

The ASCR achieves substantial capital cost savings. The reactor size necessary for a SCR only approach would require substantial duct modifications, civil engineering, and catalyst. For this example project, there was a 50% capital cost savings = approximately $5,000,000 USD.

Design Challenges

- All of the systems had to work together simultaneously. A problem or error in one system would cause problems in all systems downstream of it.

Combustion

- Strongly Influenced by fuels.
- Different fuel combinations required different settings.
- Wet coal would produce greater CO.
- Mistuned and poor combustion settings would produce greater NO_x and CO.

SNCR

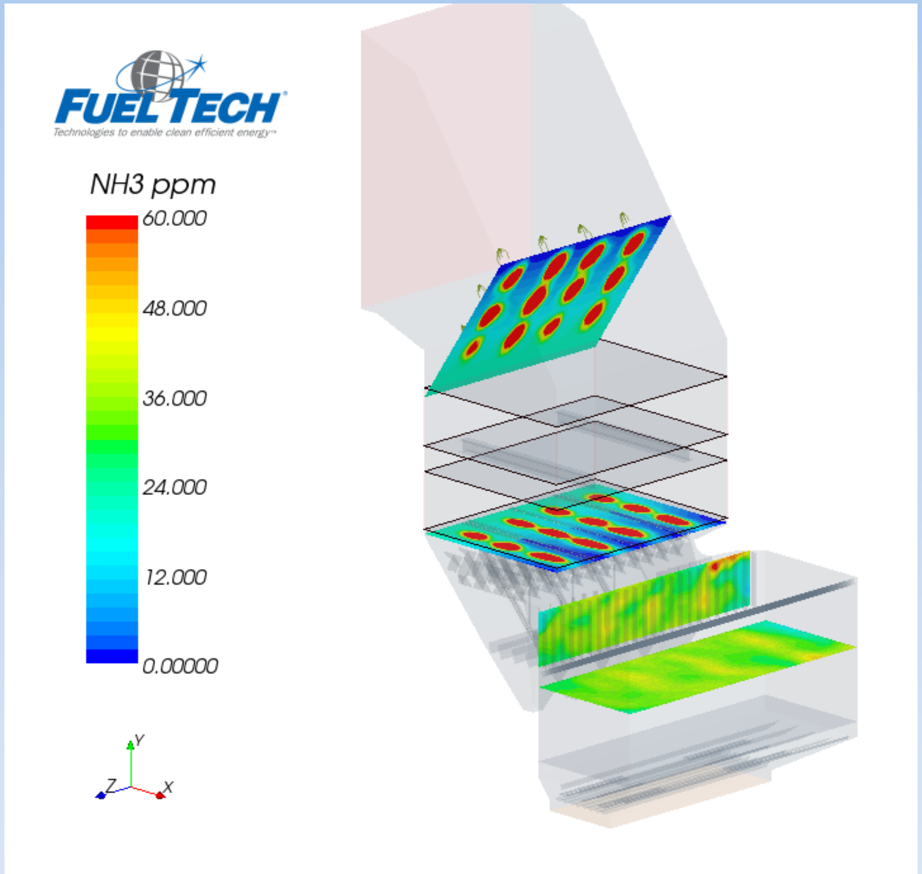
- High CO would decrease SNCR performance (less NO_x removal and greater NH_3 slip). This happens at local zones with high CO and/or if the boiler has high overall CO levels.
- Care had to be taken to achieve an even distribution of NH_3 and NO_x at the economizer.
- Final combustion NO_x affects final SNCR NO_x.

SCR

- NO_x/NH_3 maldistributions after the SNCR greatly affect SCR performance. Regions with elevated NO_x or NH_3 concentrations would reduce SCR performance.
- Final SNCR NO_x affects the final SCR NO_x.

Design Challenges

- This site required a complex control system capable of handling any fuel combination of coal, COG, and BFG. Depending on the fuel combination the NO_x and temperature in the boiler varied significantly. This affected the OFA and SNCR systems.
- Designing duct modifications for the catalyst can be challenging:
  - Maintaining even NO_x/NH_3 distribution at the catalyst face.
  - Avoiding angled flow into the catalyst.
  - Avoiding excessive velocity into the catalyst.
  - Significant CFD is required to find a suitable design.

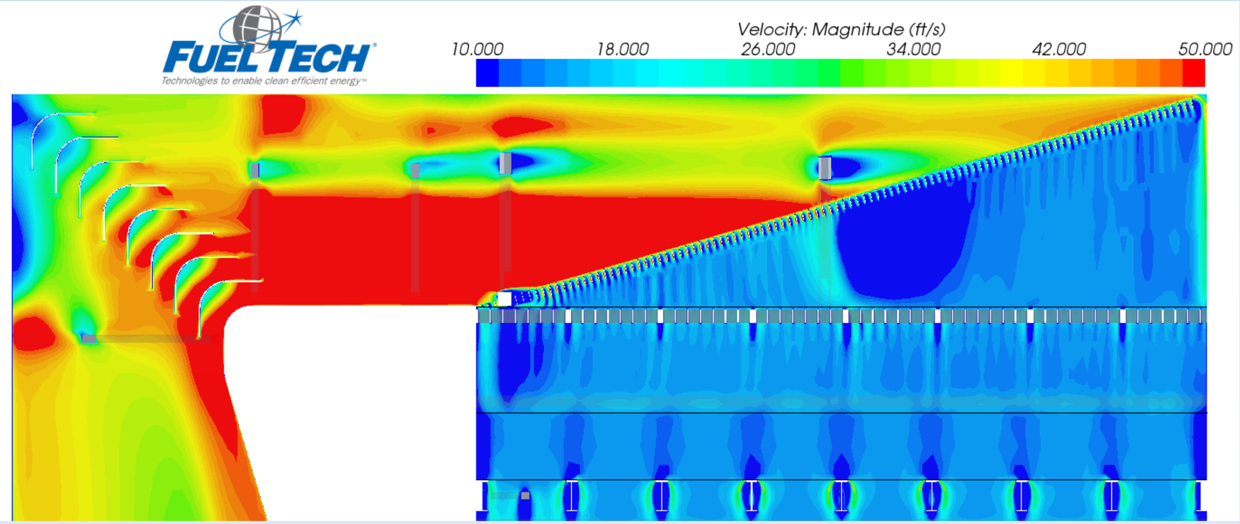


Design Challenges - SCR

Fitting the SCR reactor into narrow section of ductwork can be challenging for numerous reasons.

- The gas must be turned and straightened with minimal space.
- Flow recirculation must be avoided.
- Care must be taken to avoid angled flow.

The solution to these challenges was the use of a patented graduated straightening grid (GSG).



Project Results – Full Load Coal

CEMS NO_x

- 48 ppmd @6% O_2

NH_3 Slip at SCR Outlet

- 4.3 ppmd @6% O_2

Factory Acceptance Tests

- First 4 Hour FAT Passed
- Second 4 Hour FAT Passed

Project Results – Low Load Coal

CEMS NO_x

- 45 ppmd @6% O_2

NH_3 Slip at SCR Outlet

- 3.1 ppmd @6% O_2

Factory Acceptance Tests

- First 4 Hour FAT Passed
- Second 4 Hour FAT Passed

Second ASCR Project: Two More Units

- Upon successful completion of the first project the client requested additional ASCR for its two other identical units.
  - The new project required greater NO_x reduction down to 30ppm compared to 50ppm in the original project.
  - Fuel Tech increased the size of its SCR to 2 layers of catalyst to accommodate additional NO_x reduction.
  - Fuel Tech devised a new control philosophy designed to reduce operational costs at times when the outlet NO_x can be greater than 30ppm.

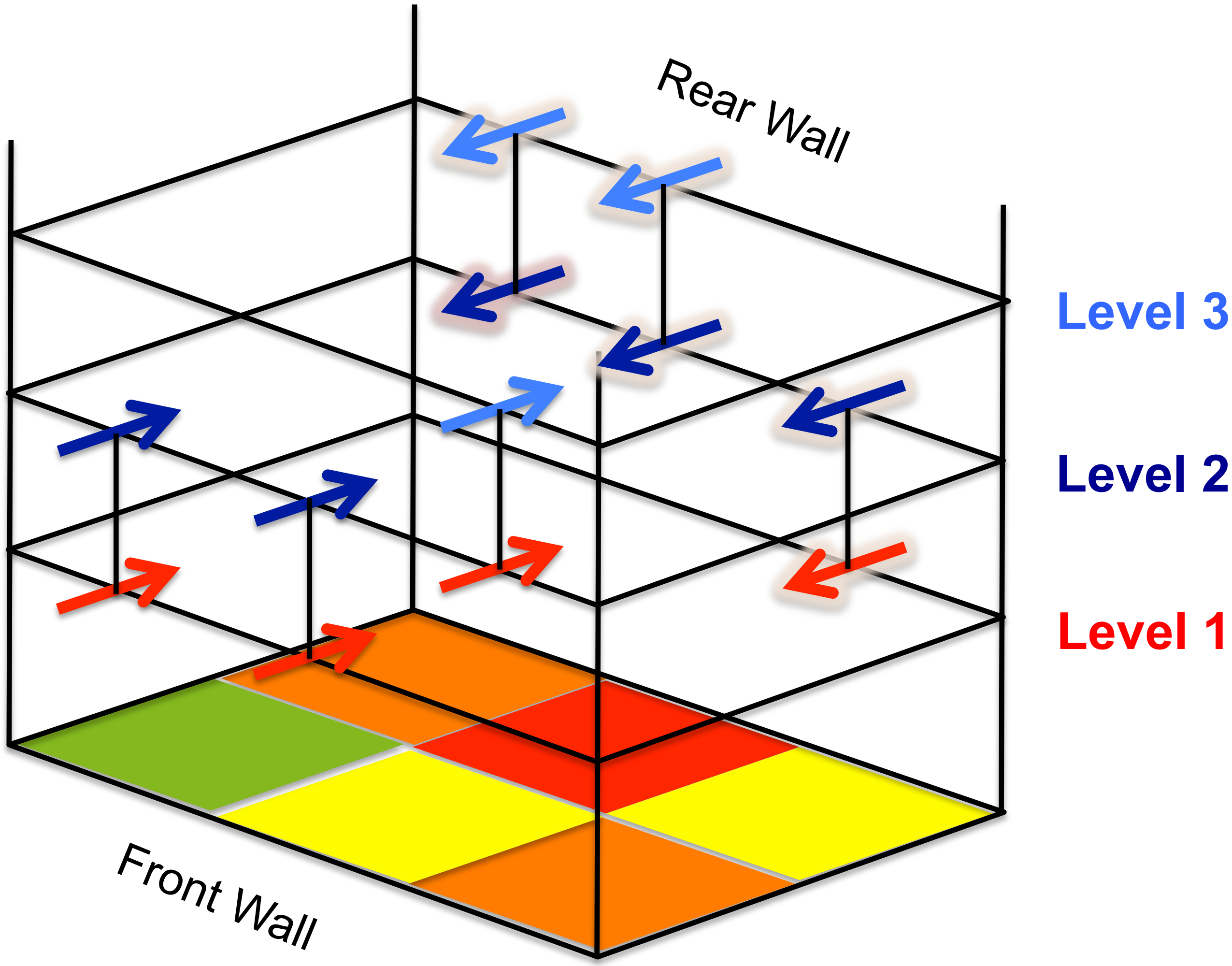
Original Project	Second Project
☐ 1 Layer of Catalyst	☐ 2 Layers of Catalyst
☐ 1 Unit	☐ 2 Units
☐ Standard Control System	☐ Advanced Control System

ADVANCED SNCR

- Utilizes Advanced Diagnostics and Controls
  - Acoustic/Laser Temperature/CO Profiles
  - Individual Injector Control
  - Continuous Ammonia Measurements
- Detailed Injector Control
- Range of Injector Types
- Maximize NOx Reduction
- Improve Chemical Utilization

Goal: Automatically maintain peak performance throughout load, fuel and operational variations

INDIVIDUAL INJECTOR CONTROL



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SCALE-UP TO LARGE FURNACES

- Extensive Models predict effective zone
  - Dependent on Temperature, NOx, CO
  - Validated with field measurements
- Chemical distribution in effective zone
  - Requires a suite of injector options
- Large furnaces offer unique challenges
  - Low NOx baseline
  - High gas temperatures (and often high CO)
  - Very large sectional area

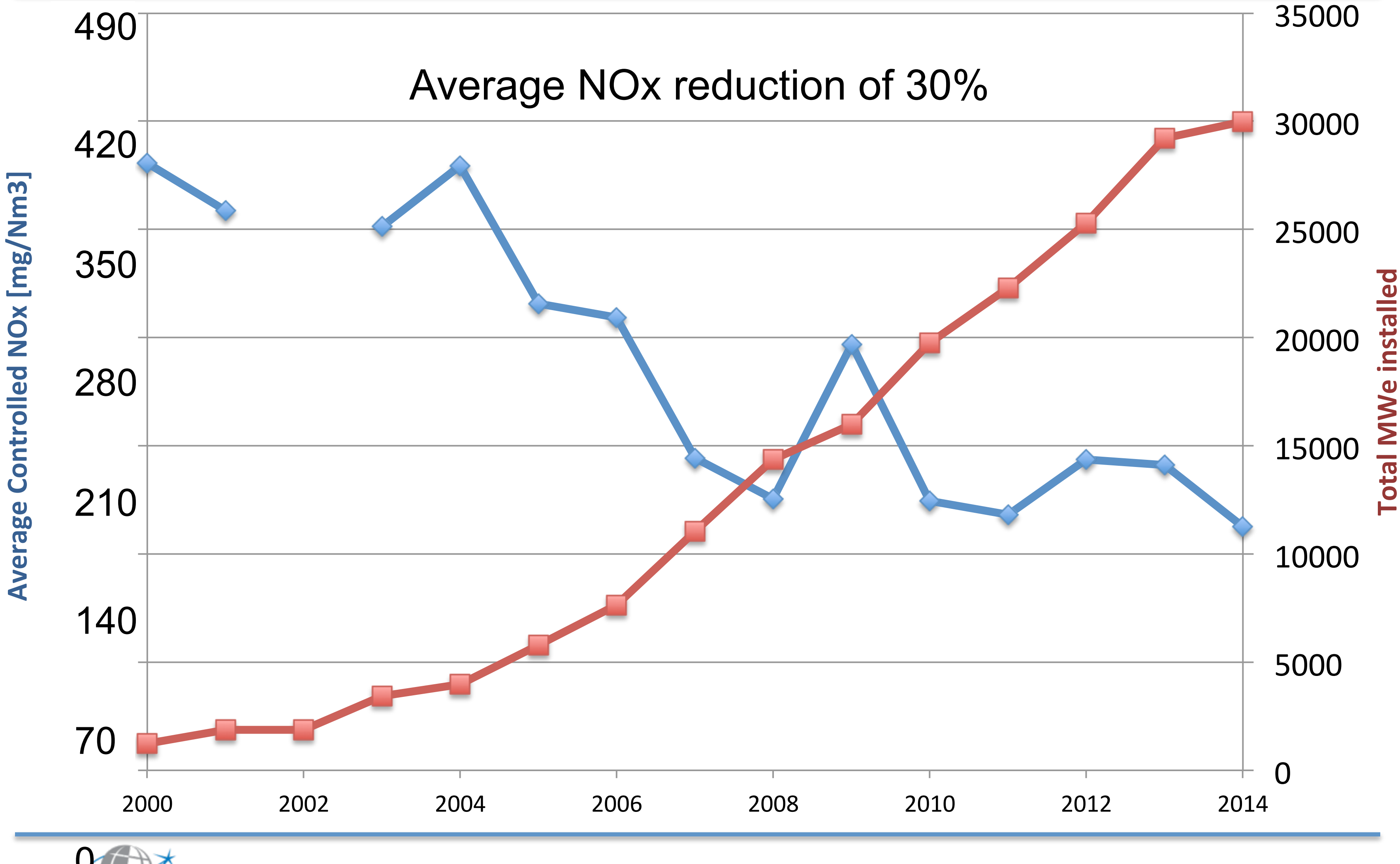
LARGE UTILITY BOILERS

- Approximately 50 large coal-fired units
  - 10% of Fuel Tech's installed base
  - As large as 850MWe, majority > 600MWe
  - Bituminous
  - Lignite
  - Subbituminous, including PRB
  - Other: High-S and Fe, Chinese, blends
- Oil-fired
- Biomass

FUEL TECH SNCR ON UNITS > 400MW

- Continuously improving applications on large utility furnaces since 1993
- NOx baselines have decreased
- LNBs have generally caused higher CO
- NOx emissions limits have decreased
- NOx reductions still average 30%
- Wide variation in required reduction
  - Client needs determine system design

SNCR ON UNITS > 400MWe



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LARGE UTILITY SNCR APPLICATIONS

- SNCR is very effective on large furnaces
  - Fuel Tech, Inc. has 30GW of SNCR experience on units > 400MWe
  - Average NOx reduction of 30%
- Sophisticated design and control:
  - Simple systems to operate
  - Guaranteed performance over the load range
  - Low capital cost solution

LARGE UTILITY SNCR APPLICATIONS

- SNCR integrates well with other APC:
  - Low-NOx Burners require further reduction
  - SCR reactors can be made smaller
  - SCR catalyst life can be extended
- SNCR supports fuel diversity
  - Biomass fuels or blends
  - Co-firing Tires or waste gases

RECENT SNCR APPLICATIONS

- Westar Jeffrey Energy Center
  - Units 2 & 3 ⇨ 775 MW CE T-Fired Units
- Nipsco Schahfer
  - Unit 15 ⇨ 500 MW FW Wall Fired
- Alcoa – Warrick Station
  - Three (3) ⇨ 170 MW B&W Wall Fired Units
- Tri-State Generation and Transmission (On-going)
  - Craig Unit 3 ⇨ 448MWn B&W Opposed Wall Fired
- CLECO Power
  - Rodemacher ⇨ 535 MW Opposed Wall Fired
  - Dolet Hills ⇨ 700 MW Opposed Wall Fired
- MidAmerican Energy George Neal Units 3 & 4
  - Unit 3 ⇨ 530 MW FW Opposed Wall Fired Unit
  - Unit 4 ⇨ 695 MW FW Opposed Wall Fired Unit

Ex #1 LARGE UTILITY BOILERS – 2013

- Two 620MWe PRB-fired, Riley-turbo units
  - Baselines of 155 ppm, @ 3% O2
- Single zone of wall-injection
  - 25% reduction on one unit
  - 13% reduction on the other, identical unit
- Performance highly dependent on slag
  - Higher upper furnace gas temperatures
  - Higher CO concentration

Ex #1 LARGE UTILITY BOILERS – 2013

- Second zone of air-atomized wall-injectors
- Third zone: multiple nozzle lances (MNLs)
  - 36% reduction on both units to 100 ppm
  - Operation of injection elevations is dependent on furnace conditions
  - Ammonia slip below permit limits
- Additional wall-injectors
  - Installed to provide control to 50% MCR

Ex #2 LARGE UTILITY BOILERS – 2013

- B&W 620MWe PRB, Opposed-wall-fired
  - Baseline is 120 ppm, @ 3% O2
- Single zone of mechanical wall-injectors
  - 25% reduction target achieved
  - < 90 ppm controlled NOx
- Additional zone of air-atomized injectors
  - Reduction target maintained
  - Chemical use decreased by 35%

SNCR EXPERIENCE: BOILER AND FUEL

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 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**

2016 NO_x-Combustion-CCR Round Table/PCUG Meeting
February 1 - 4, 2016 Orlando, FL

Thank You!

William H. Sun, Ph.D.

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