

# Reinhold Environmental Ltd.

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2008 NOx-Combustion Round  
Table & Expo Presentation

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*February 4-5, 2008 in Richmond, VA*



*Technologies to enable clean efficient energy™*

# *Fuel Tech at a Glance*

- **Innovative Approaches to Enable Clean Efficient Energy**
  - ◆ **Air Pollution Control - Capital Projects**
    - **NO<sub>x</sub>OUT® Products including SNCR, CASCADE, RRI, ULTRA**
  - ◆ **FUEL CHEM® Technology- Specialty Chemical Operating Programs**
    - **Boiler Efficiency and Availability Improvements**
    - **Slag and Corrosion Reduction**
    - **Controls SO<sub>3</sub> Emissions and Addresses Related Issues**
  - ◆ **Plant Optimization Services**
    - **Performance Improvement Solutions through Plant and Boiler Analysis**
  - ◆ **Technology solutions based on Advanced Engineering Capabilities Including State of the Art Computer Visualization and CFD/CKM Modeling**
- **Stock Symbol: NASDAQ - FTEK**
  - ◆ **Market Cap 2/04/08: >\$430M**
  - ◆ **Strong Balance Sheet**

# *Fuel Tech's Global Activities*

## Office Locations

- ★ Batavia, IL
- ★ Stamford, CT
- ★ Milan, Italy

## Countries with Fuel Tech installations

- |                  |                  |
|------------------|------------------|
| ★ USA            | ★ Mexico         |
| ★ Belgium        | ★ Poland         |
| ★ Canada         | ★ Portugal       |
| ★ China          | ★ Puerto Rico    |
| ★ Czech Republic | ★ South Korea    |
| ★ France         | ★ Spain          |
| ★ Germany        | ★ Taiwan         |
| ★ Italy          | ★ Turkey         |
| ★ Jamaica        | ★ United Kingdom |

# ***Air Pollution Control (APC) Technologies***

## **Nitrogen Oxide Reduction**

- NO<sub>x</sub>OUT<sup>®</sup> SNCR
- Rich Reagent Injection (RRI)
- NO<sub>x</sub>OUT CASCADE<sup>®</sup>
- Customer Benefits
  - ◆ Effective: 25 - 80% Reduction
  - ◆ Low Capital Cost: \$5 - 75 per kw (compare to SCR at \$250+ per kw)
  - ◆ ROI Potential: NO<sub>x</sub> Allowances
  - ◆ Flexible: Staged Implementation
  - ◆ Easy to Retrofit: Modular Designs
- Over 450 Installations So Far
  - ◆ 80 Utility Boilers

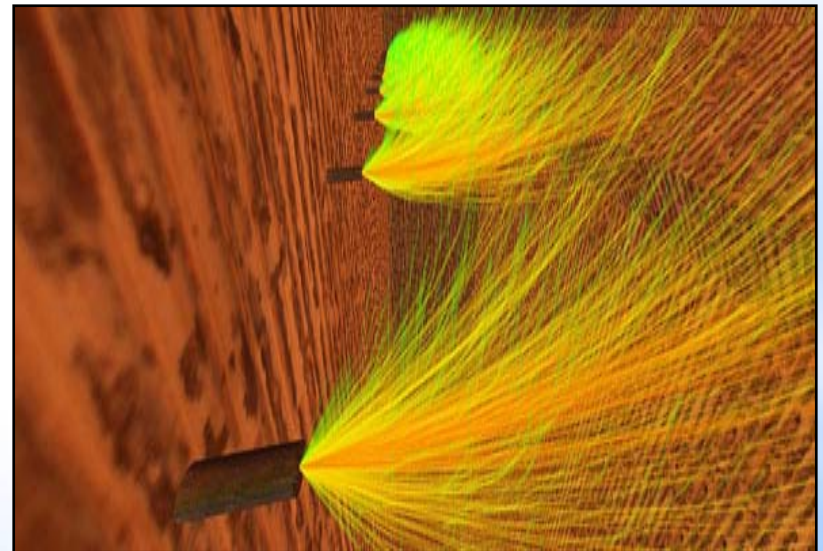
## **UREA to Ammonia Conversion**

- NO<sub>x</sub>OUT ULTRA<sup>®</sup>
- Non-Hazardous Reagent for Selective Catalytic Reduction (SCR)
- Avoids Dangers of Anhydrous & Aqueous Ammonia
- Customer Benefits
  - ◆ Low Capital and Operating Cost
  - ◆ Safe (Non-Hazardous Materials Throughout)
  - ◆ Built on Proven Fuel Tech Technologies

# ***FUEL CHEM<sup>®</sup> Technologies***

## **TIFI<sup>™</sup> Targeted In-Furnace Injection<sup>™</sup> Program**

- **Patented process for the injection of chemicals using Computational Fluid Dynamic (CFD) modeling as the primary design method**
- **TIFI Benefits:**
  - ◆ **Decreased Slag/ Fouling**
  - ◆ **Efficiency/Heat rate Improvement**
  - ◆ **Fuel Flexibility / Switching**
  - ◆ **Reduced SO<sub>3</sub> and H<sub>2</sub>SO<sub>4</sub>**



# *Upper Furnace Slag Removal*



**Initial Chemical Feed**  
7/1/2004 9:30 a.m.



**7/1/2004 5:30 p.m.**



**7/2/2004 9:30 a.m.**

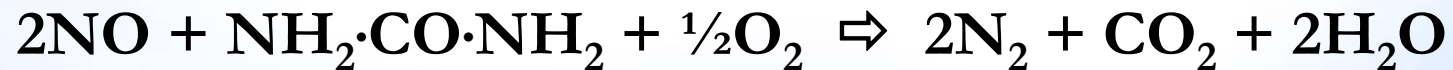
# *Fuel Tech's Air Pollution Control Technologies*

- **NO<sub>x</sub>OUT<sup>®</sup> Selective Non-Catalytic Reduction (SNCR)**
- **NO<sub>x</sub>OUT Cascade<sup>®</sup> (Hybrid SNCR and SCR)**
- **Rich Reagent Injection (RRI)**
- **Urea Based SCR (Industrial)**
- **NO<sub>x</sub>OUT ULTRA<sup>®</sup> (SCR Reagent)**

# *Urea Selective Non-Catalytic Reduction*

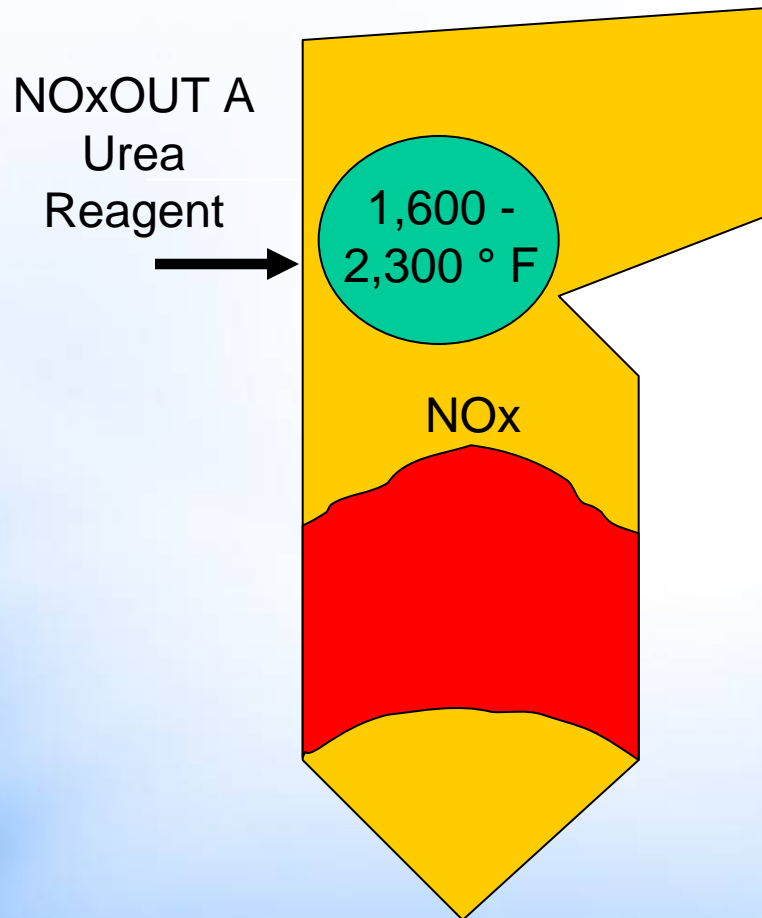
Introduction of Specific Nitrogenous Reagents at Specific Temperature Regimes to Effect a Reducing Reaction.

## *NO<sub>x</sub>OUT® Process Chemical Reaction*



NITROGEN OXIDE + UREA + OXYGEN  $\rightleftharpoons$  NITROGEN + CARBON DIOXIDE + WATER

# Urea Selective Non-Catalytic Reduction



- 20 - 35% NOx Reduction
- Post Combustion
- Gas Phase Reaction
- Furnace is the Reactor
- Typical Combustion Products
- Process Parameters
  - ◆ Time
  - ◆ Temperature and Species
  - ◆ Distribution
- Widely Applicable

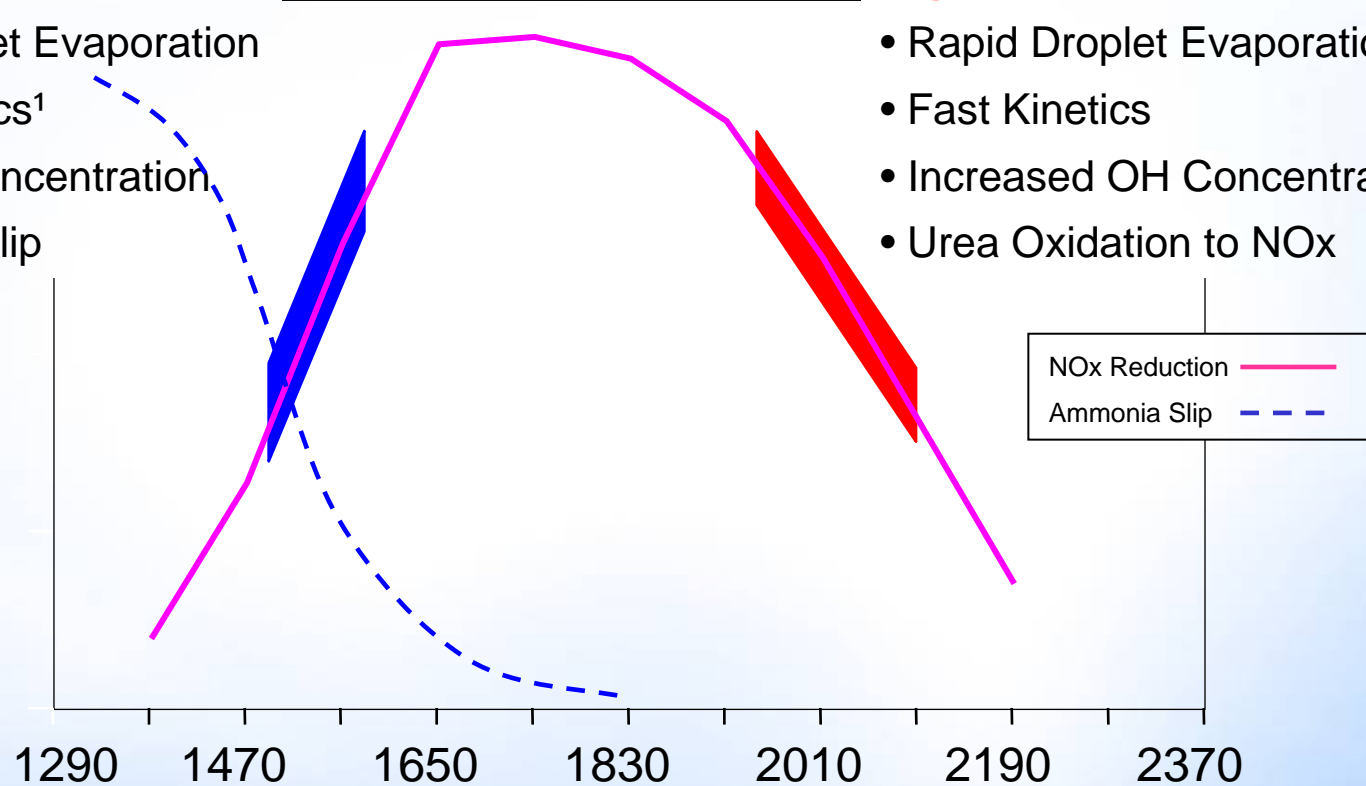
# *“Right Side of the Slope” Injection*

## Low Temperatures

- Slow Droplet Evaporation
- Slow Kinetics<sup>1</sup>
- Low OH Concentration
- Ammonia Slip

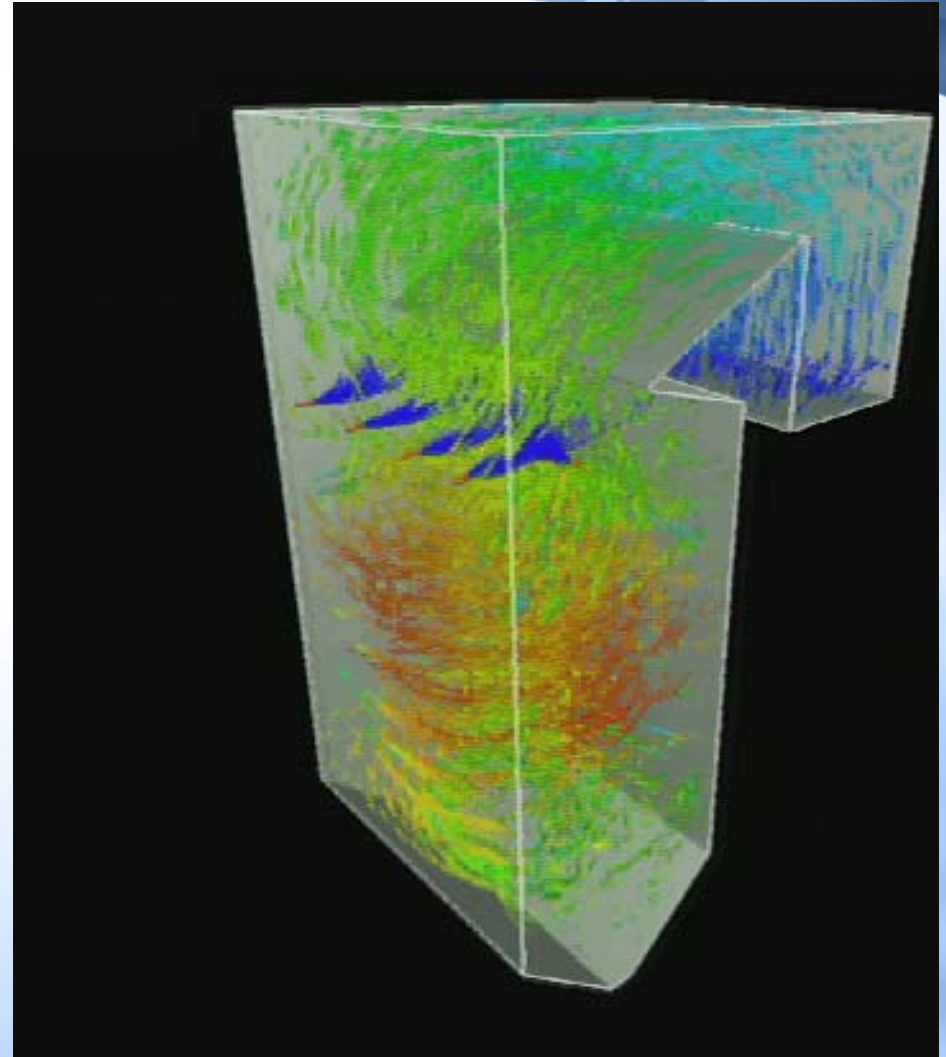
## High Temperatures

- Rapid Droplet Evaporation
- Fast Kinetics
- Increased OH Concentration
- Urea Oxidation to NOx

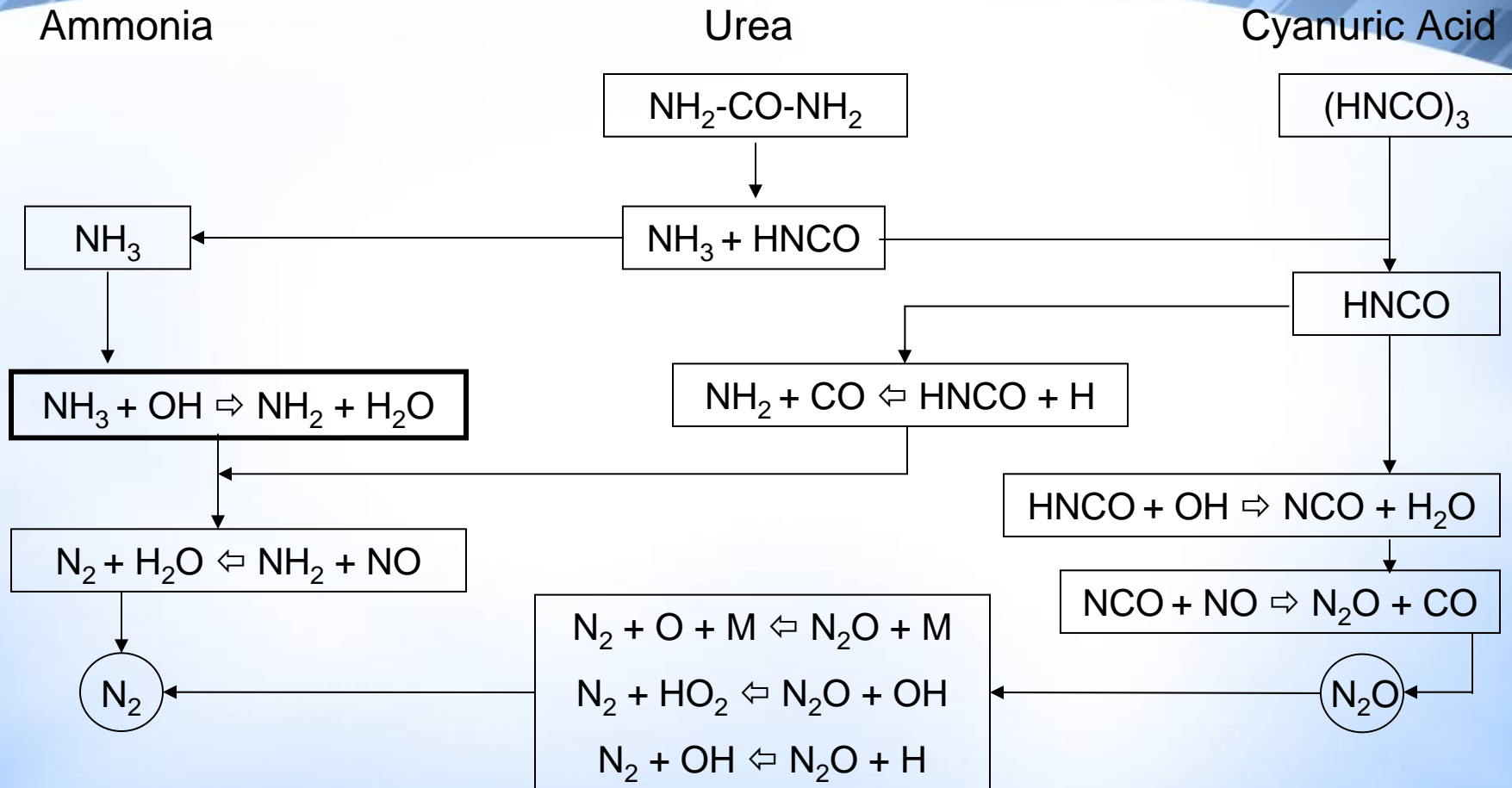


# ***SNCR Process Application***

- **Computational Fluid Dynamics**
  - ◆ Define the Reactor
  - ◆ Temp and Flow Field
  - ◆ Field Testing
- **Chemical Kinetic Model**
  - ◆ Identify the Window
  - ◆ Potential for Reduction
- **Injection Model**
  - ◆ Identify effective Zone
  - ◆ Injection Strategy

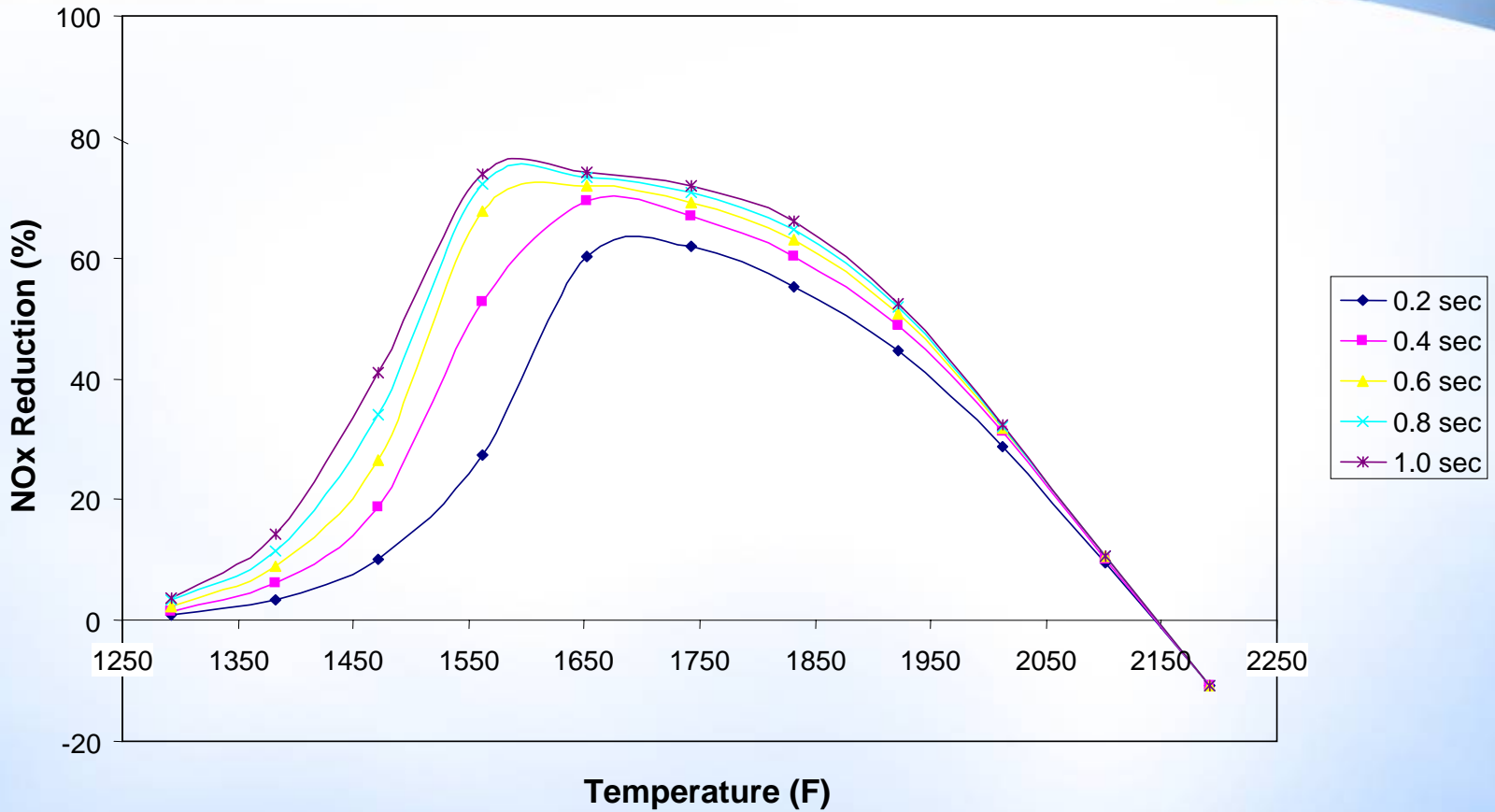


# SINCR Reaction Paths



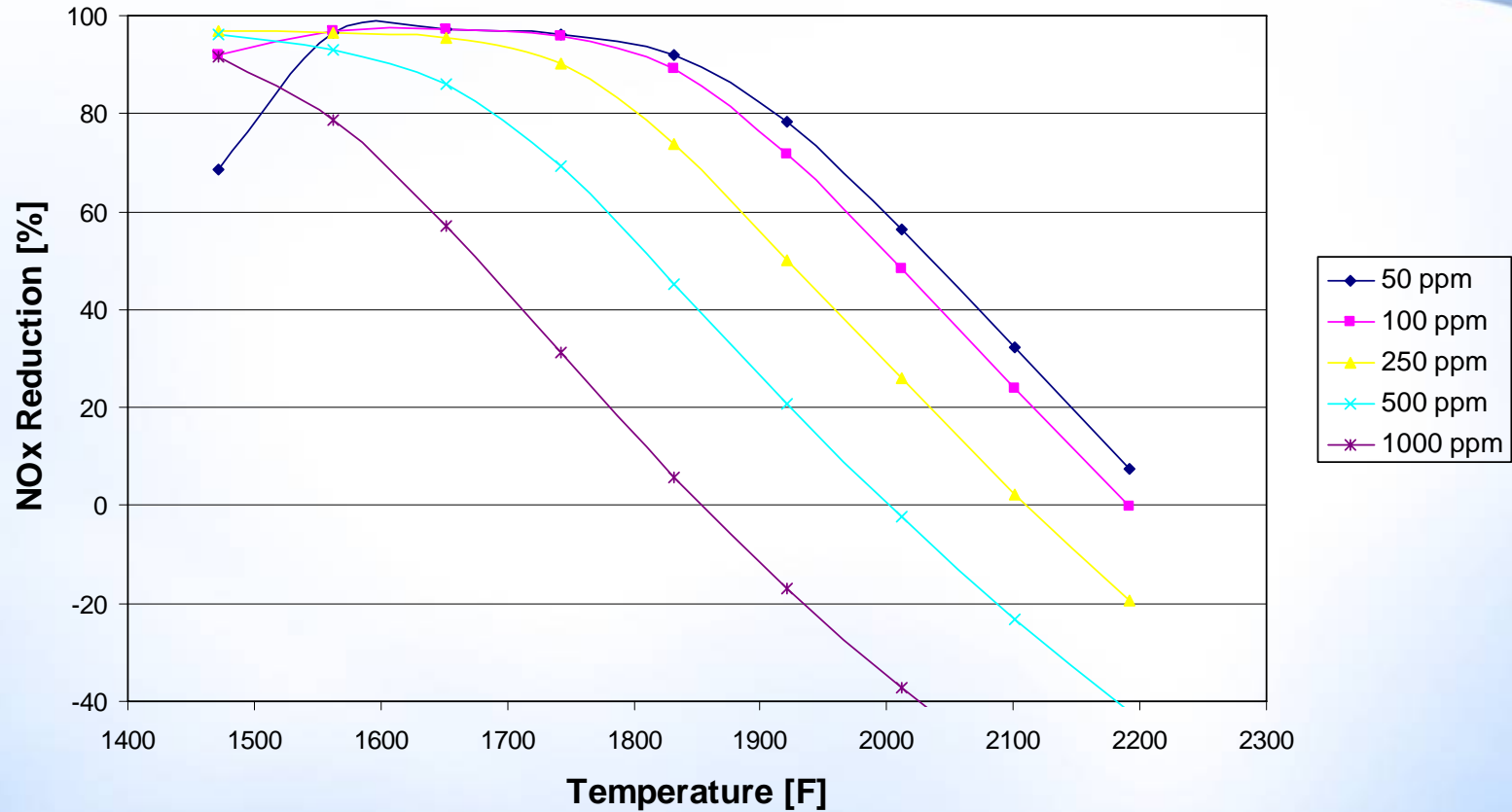
# NOx Reduction as a Function of Temperature and Residence Time

NOxOUT Kinetic Model  
NO<sub>x</sub>i = 200 ppm, CO = 100 ppm, NSR = 2



# NOx Reduction as a Function of CO Concentration

NOxOUT Kinetic Model  
NOxi = 200 ppm, Time = 1.0 s, NSR = 2

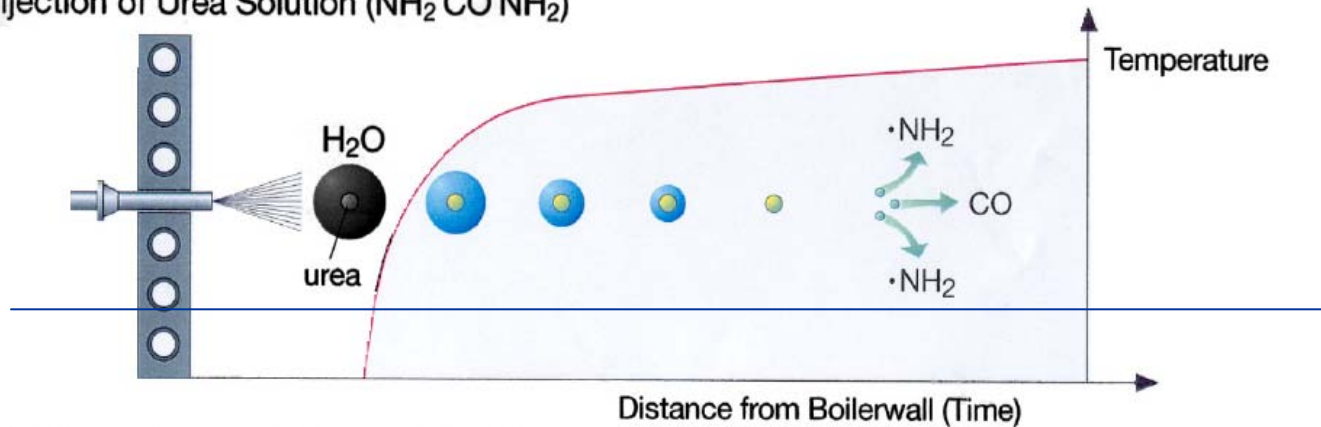


# *Droplet Injection, Evaporation, and Chemical Release*

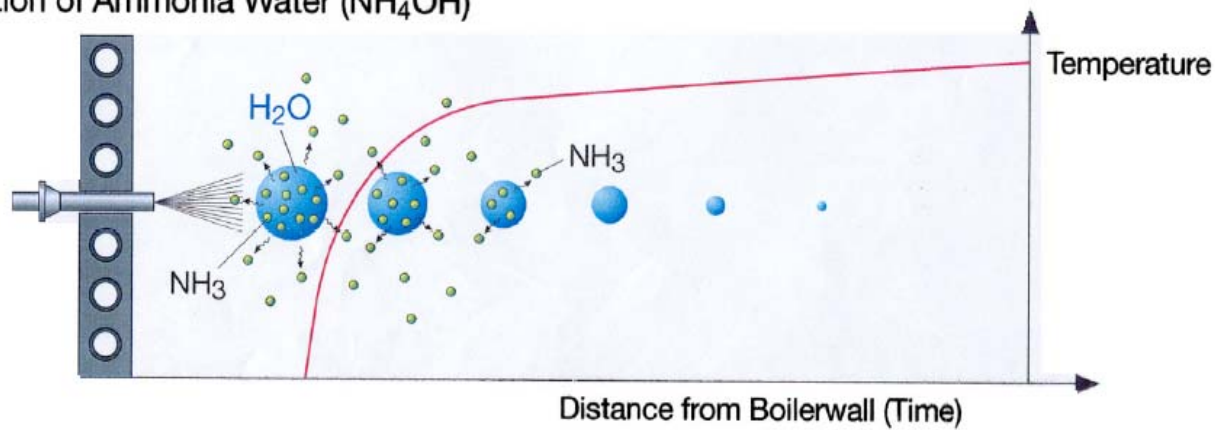
## **NO<sub>x</sub>-Reduction with Urea versus Ammonia Water**



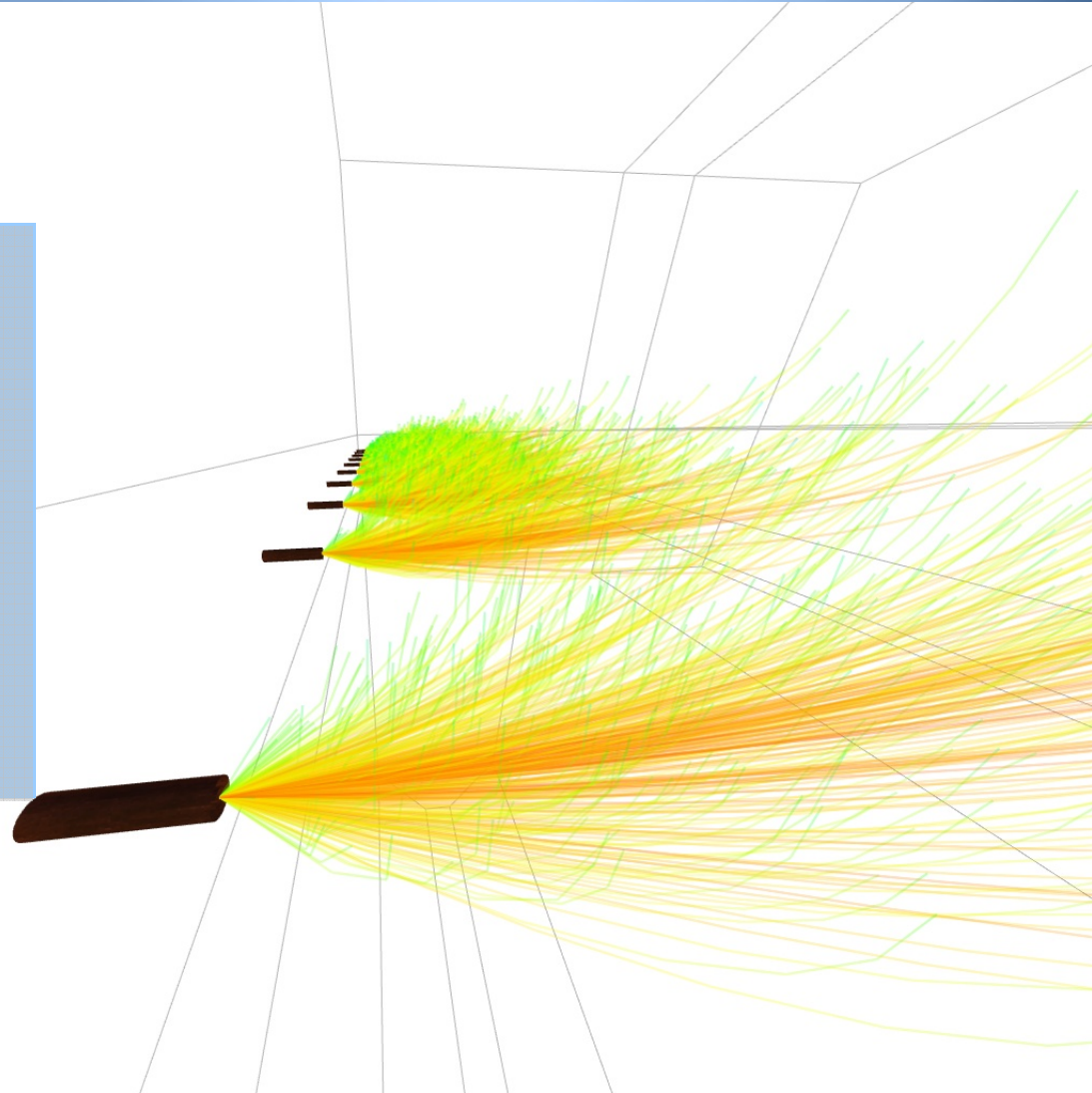
Injection of Urea Solution ( $\text{NH}_2 \text{CO NH}_2$ )



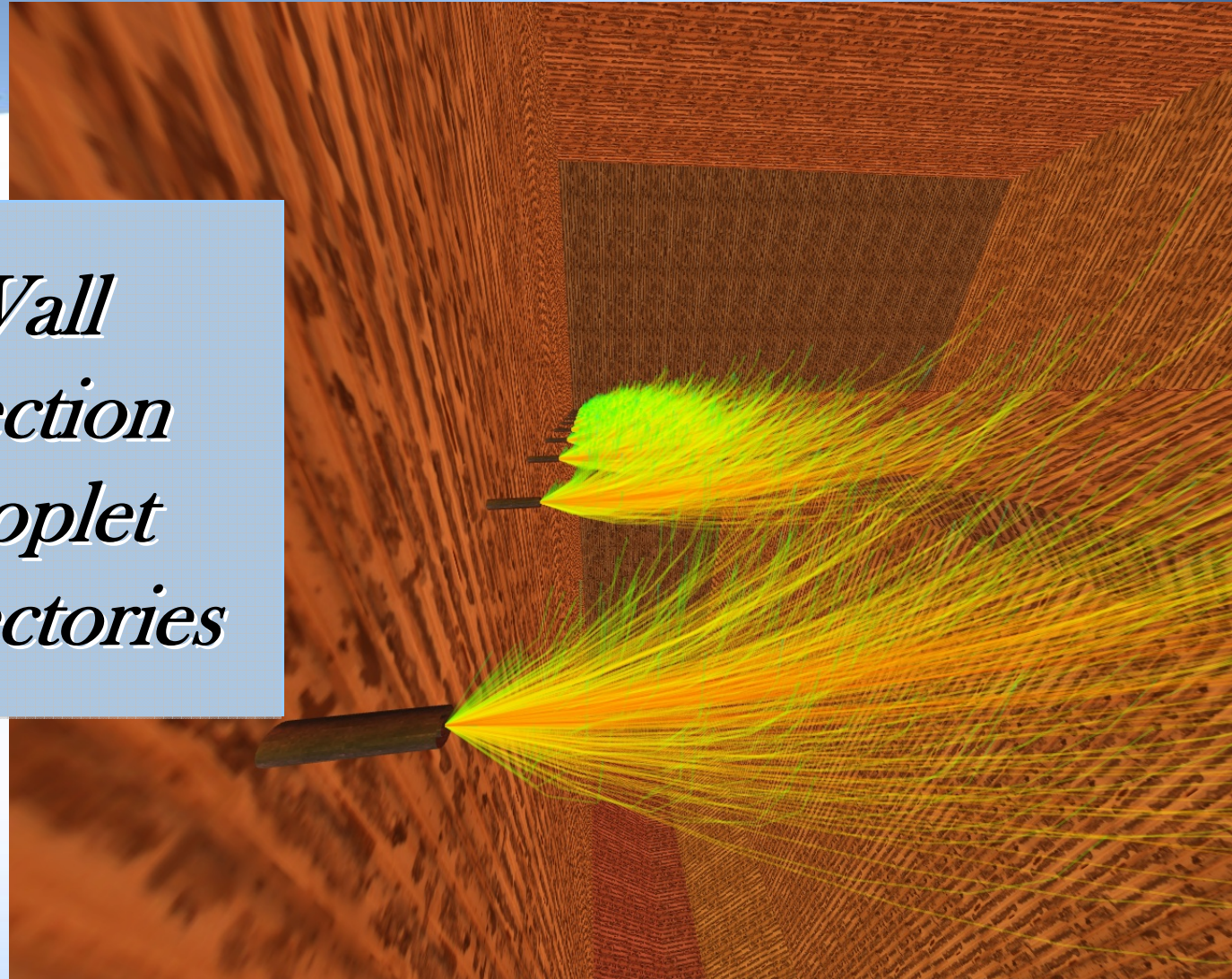
Injection of Ammonia Water ( $\text{NH}_4\text{OH}$ )



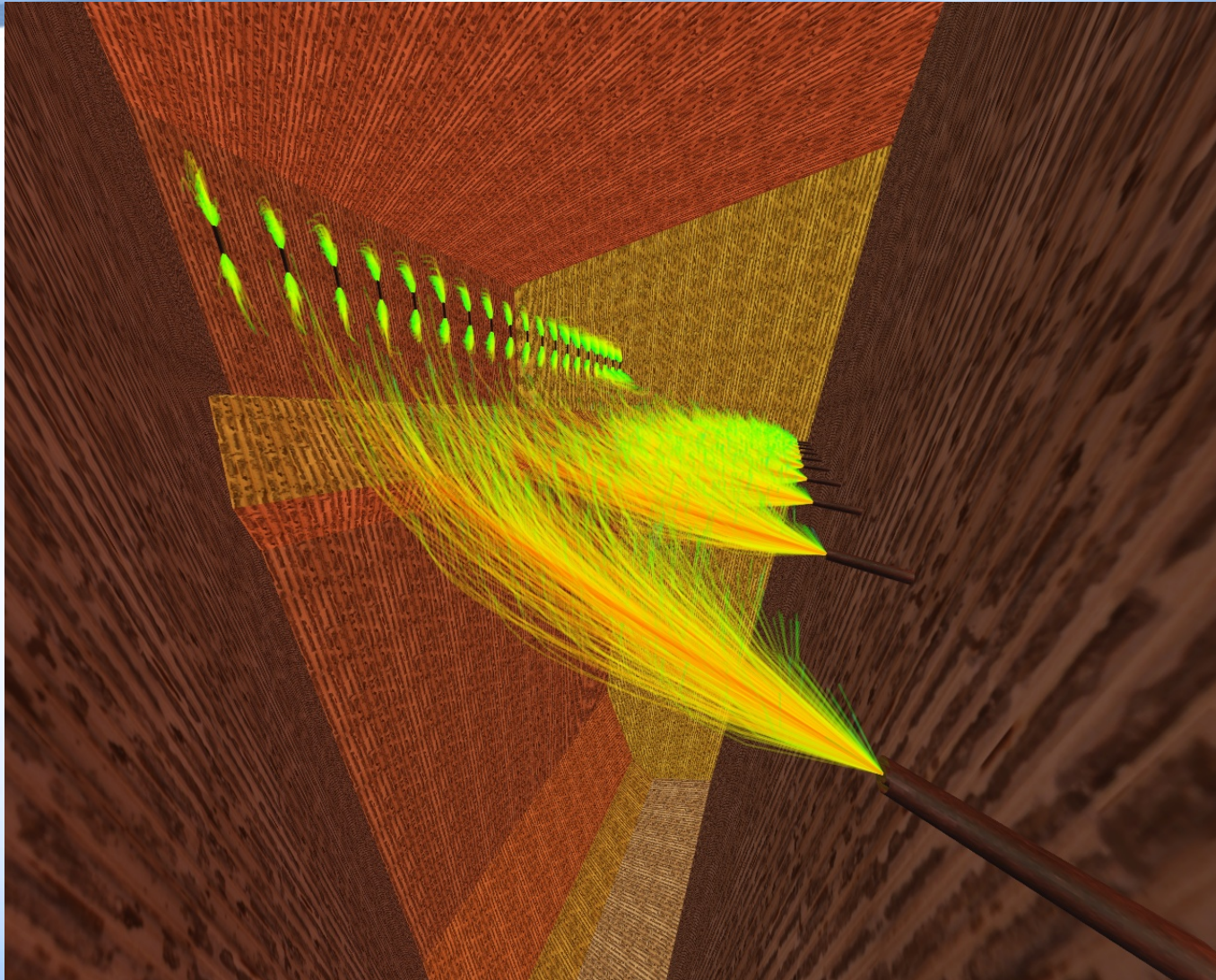
*Wall  
Injection  
Droplet  
Trajectories*



*Wall  
Injection  
Droplet  
Trajectories*



# *Front Wall and MNL Trajectories*



# ***FUEL SULFUR***

## Ammonium Bisulfate/Sulfate Formation

Fuel Sulfur Content ( $\text{SO}_2$  to  $\text{SO}_3$ ), Ammonia Slip ( $\text{NH}_3$ ), and Flue Gas Temperature can lead to formation of ammonium Bisulfate/Sulfate which can lead to air heater fouling



# *Performance Guarantees*

- **NO<sub>x</sub> Reduction**
- **NH<sub>3</sub> Slip: 2ppm, 5ppm, 10ppm, 20ppm+**
- **Chemical, Water, and Air Consumption**

**Based on:**

- **CFD and CKM Models**
  - **State of the Art Visualization**
  - **Detailed Injector Design and Analysis**
- **Extensive Database of Completed Projects (450+)**

# *SINCR Process Summary*

- 20 – 35% NO<sub>x</sub> Reduction @ NSR's ~ 1.0
- 35 – 65% NO<sub>x</sub> Reduction – some Industrial
- Commercial Guarantees
  - ◆ NO<sub>x</sub> Reduction or Target Setpoint
  - ◆ NH<sub>3</sub> Slip of 5 ppm, 10 ppm, 20 ppm+
  - ◆ Reagent Consumption
- Effective on Different Fuels
- Many Different Boiler Types
- Many Utility Units in Service

# *APC 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

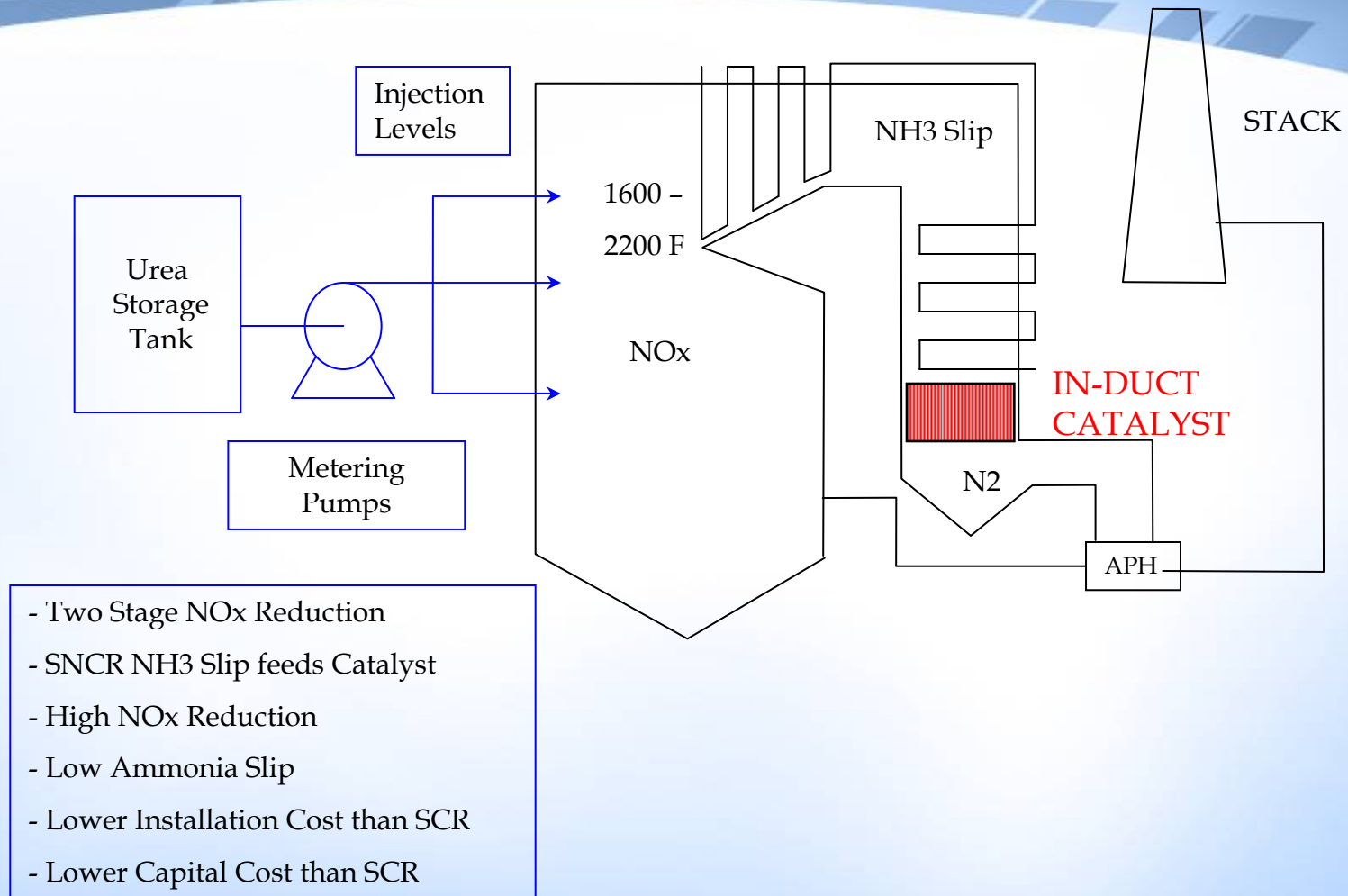
- Bituminous
- Sub-bituminous
- Lignite

## Other Fuels

- Oil - #2 and #6
- Natural Gas
- Refinery Gases (High CO)
- Municipal Solid Waste
- Tire Derived Fuel
- Wood
- Sludge

# *NO<sub>x</sub>OUT CASCADE<sup>®</sup> Process*

## *SNCR/SCR Hybrid*



# *Combining NO<sub>x</sub> Reduction Technologies*

Technology	Strength	Limitations
Combustion: LNB, OFA, etc	Low Capital and Operating	Tube wastage, LOI, CO
Rich Reagent Injection	Low Capital No NH <sub>3</sub> Slip	Fuel Rich High NSR
SNCR	Low Capital Mid NSR	NH <sub>3</sub> Slip ABS
SCR	NO <sub>x</sub> Red % Low NH <sub>3</sub> Slip	High Capital SO <sub>3</sub> Oxidation

# *Moderate Combustion Modifications*

Technology	Strength	Limitations
Combustion: LNB, OFA, etc	<u>Low Capital</u> <u>and Operating</u>	Tube wastage, LOI, CO
Rich Reagent Injection	Low Capital No NH <sub>3</sub> Slip	Fuel Rich High NSR
SNCR	Low Capital Mid NSR	NH <sub>3</sub> Slip ABS
SCR	NO <sub>x</sub> Red % Low NH <sub>3</sub> Slip	High Capital SO <sub>3</sub> Oxidation

## *Well-defined Fuel Rich Zone?*

Technology	Strength	Limitations
Combustion: LNB, OFA, etc	<u>Low Capital</u> <u>and Operating</u>	Tube wastage, LOI, CO
Rich Reagent Injection	<u>Low Capital</u> <u>No NH3 Slip</u>	<u>Fuel Rich</u> High NSR
SNCR	Low Capital Mid NSR	NH3 Slip ABS
SCR	NO <sub>x</sub> Red % Low NH3 Slip	High Capital SO <sub>3</sub> Oxidation

# *Post Combustion Zone*

Technology	Strength	Limitations
Combustion: LNB, OFA, etc	<u>Low Capital</u> <u>and Operating</u>	Tube wastage, LOI, CO
Rich Reagent Injection	<u>Low Capital</u> <u>No NH3 Slip</u>	<u>Fuel Rich</u> High NSR
SNCR	<u>Low Capital</u> <u>Mid NSR</u>	NH3 Slip ?? ABS: SO <sub>3</sub> ?
SCR	NO <sub>x</sub> Red % Low NH3 Slip	High Capital SO <sub>3</sub> Oxidation

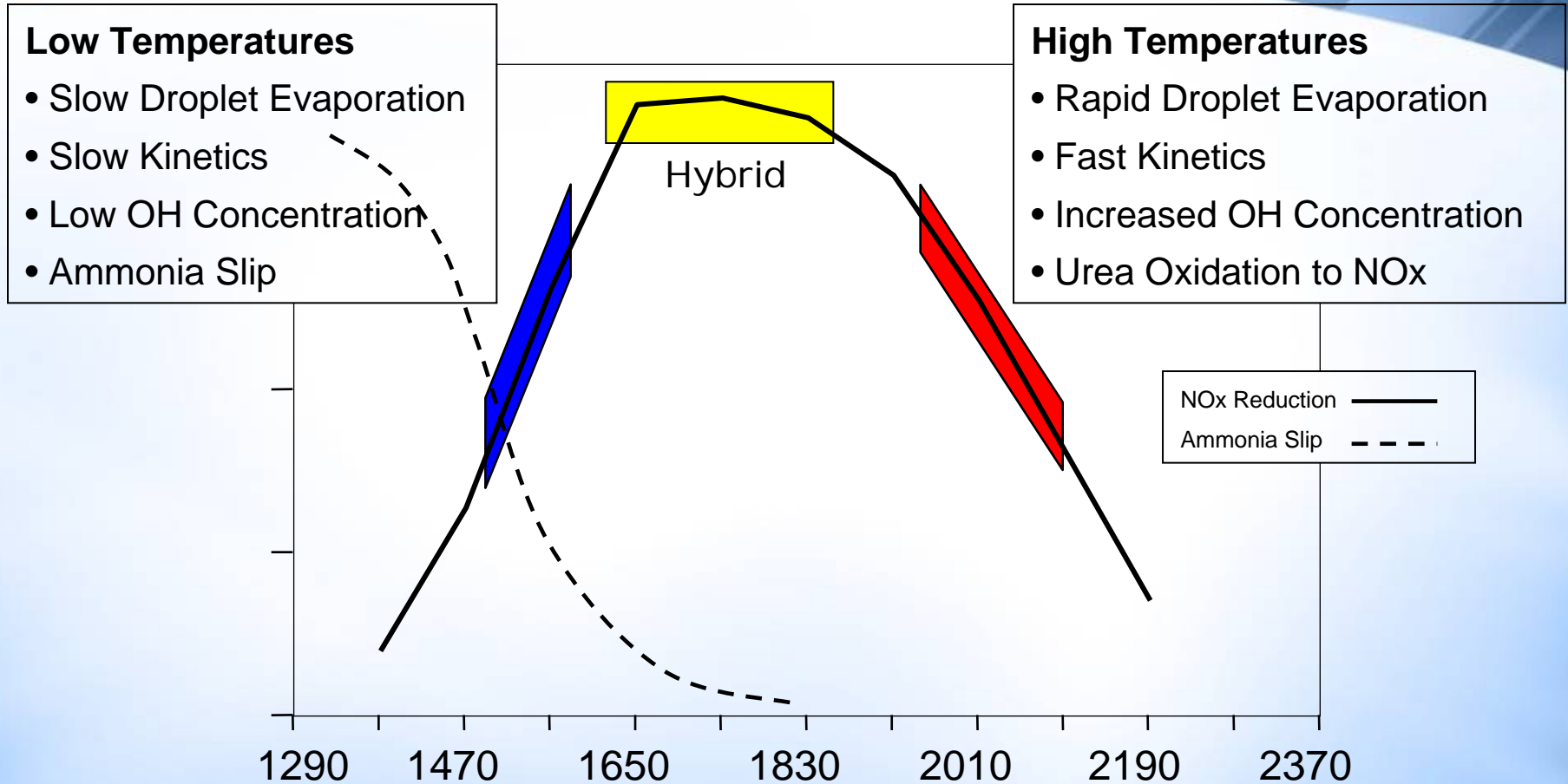
## *In-Duct or Small SCR Space*

Technology	Strength	Limitations
Combustion: LNB, OFA, etc	<u>Low Capital</u> <u>and Operating</u>	Tube wastage, LOI, CO
Rich Reagent Injection	<u>Low Capital</u> <u>No NH3 Slip</u>	<u>Fuel Rich</u> High NSR
SNCR	<u>Low Capital</u> <u>Mid NSR</u>	<u>NH3 Slip !!</u> SO <sub>3</sub>
SCR	<u>NOx Red %</u> <u>Low NH3 Slip</u>	High Capital SO <sub>3</sub> Oxidation

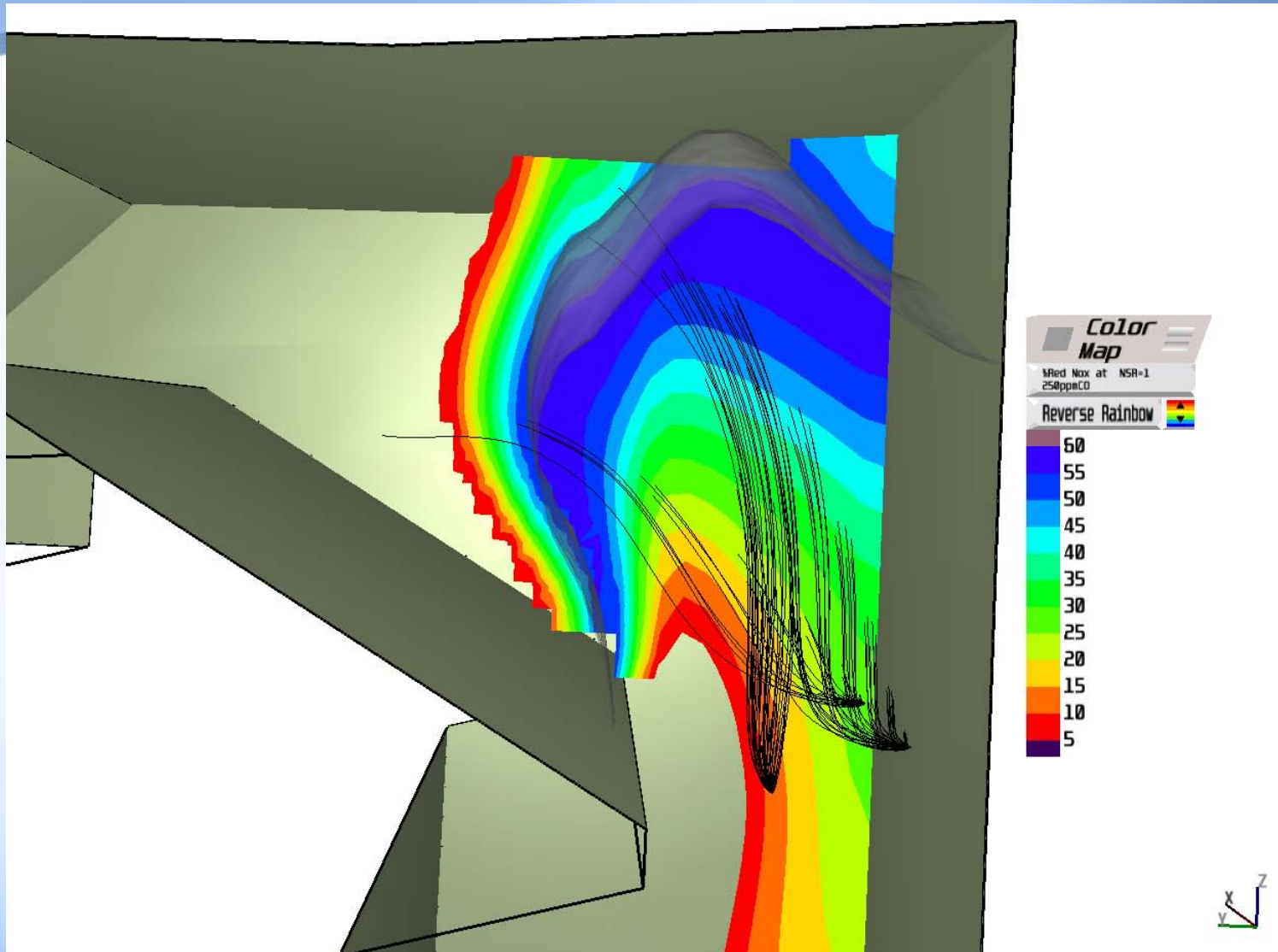
# *Combining NO<sub>x</sub> Reduction Technologies*

Technology	Strength	Limitations
Combustion: LNB, OFA, etc	Multiple Technologies  Combine Strengths  Reduce Limitations  Enhance System Flexibility	
Rich Reagent Injection		
SNCR		
SCR		

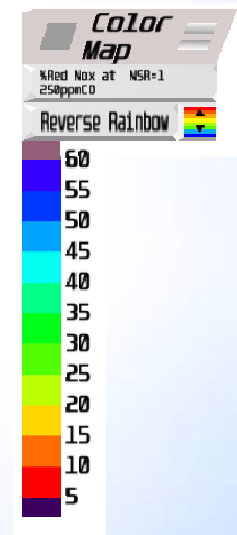
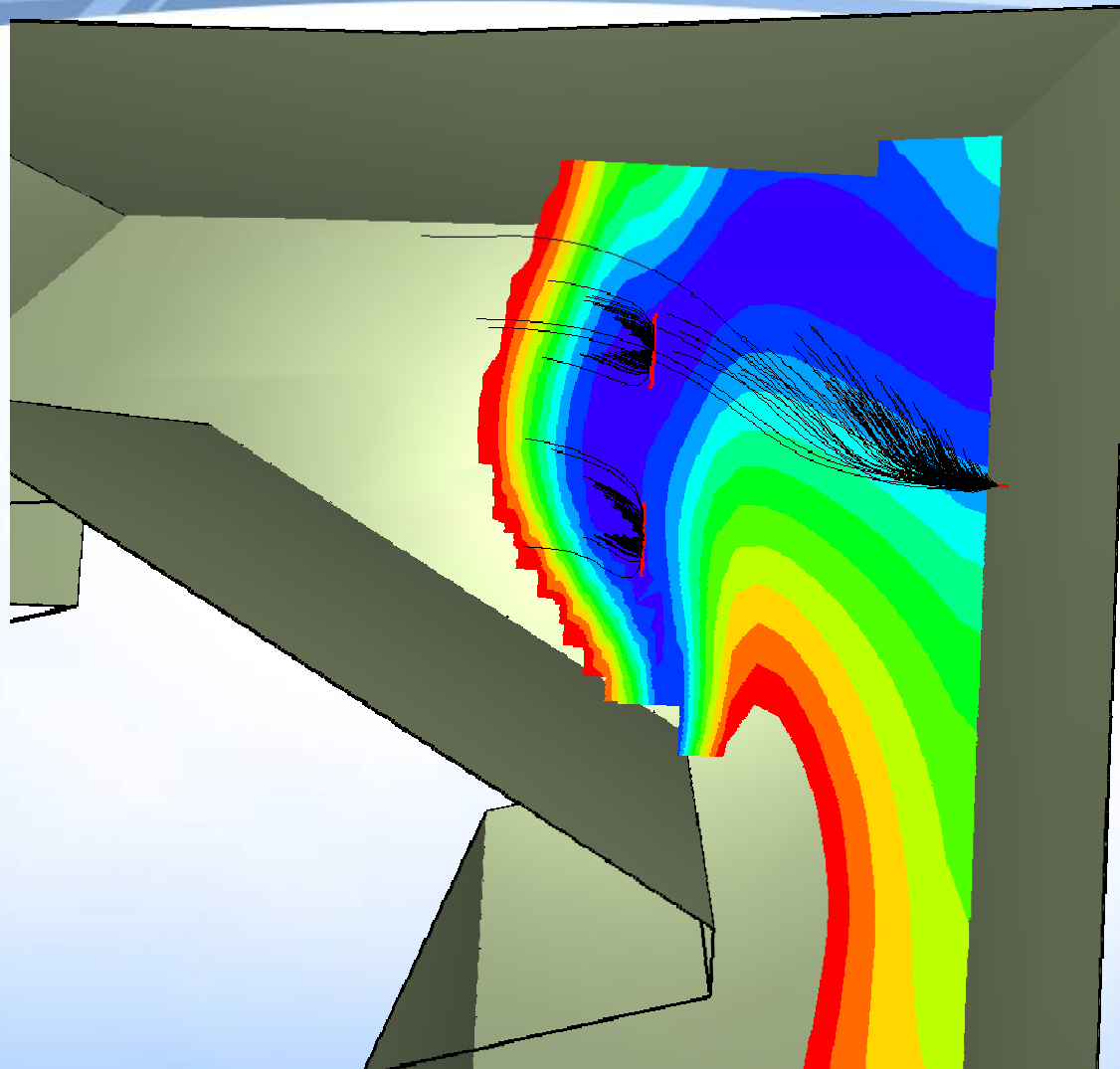
# *“Top of the Curve” Injection*



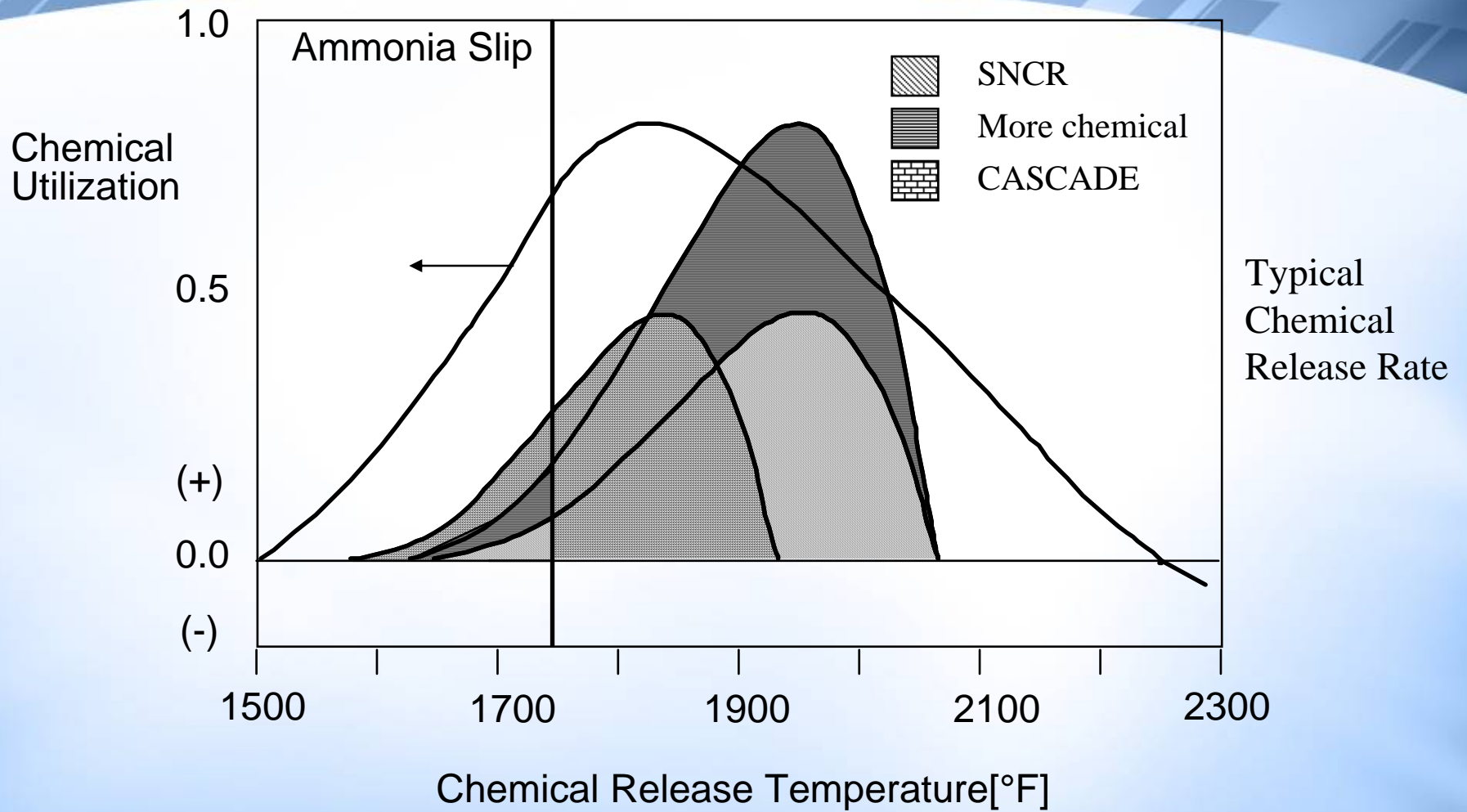
# *SNCR Injection Strategy*



# *Modified Hybrid Injection*



# *NH<sub>3</sub> Slip from Effective Low-Temp Injection*



## *Mercer Station (320MWe) Hybrid (1994)*

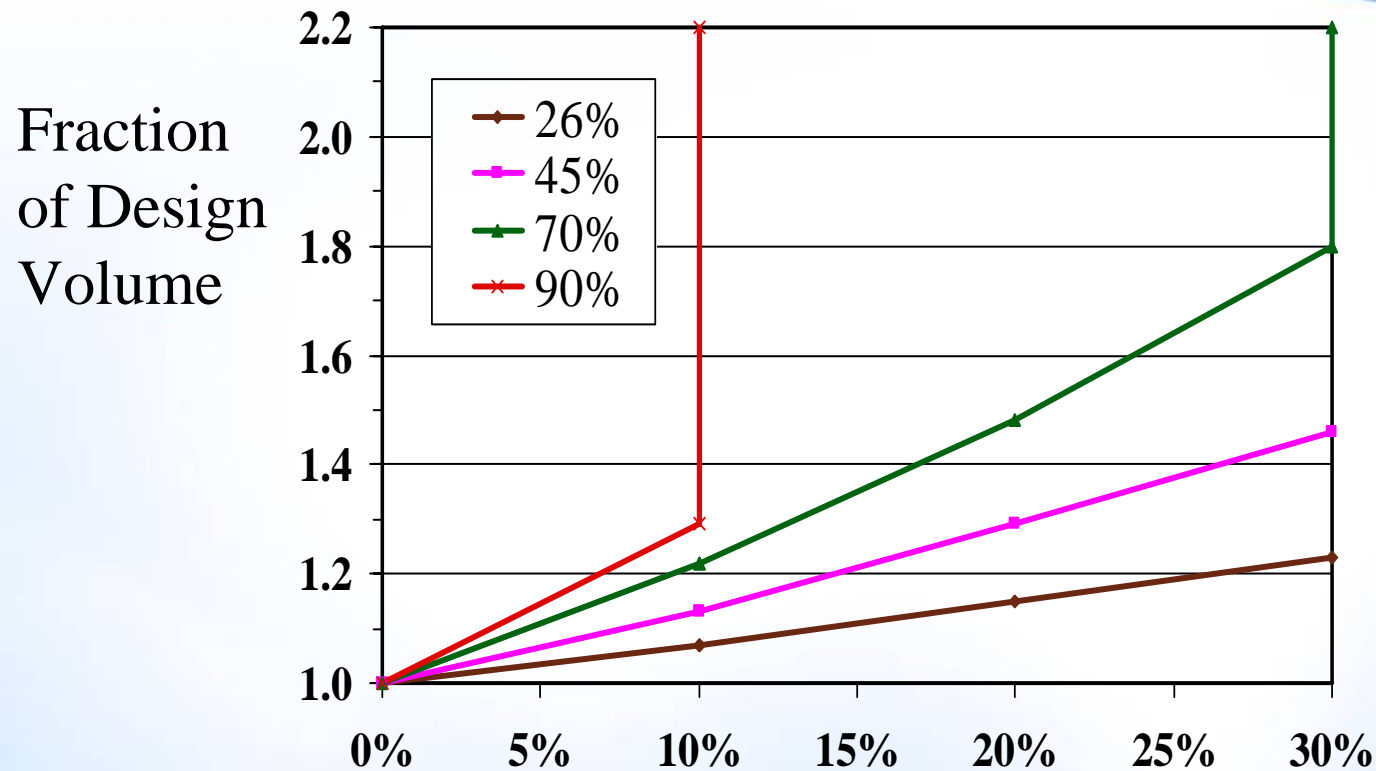
Fuel	NOx Control System	NSR	SNCR Reduction	SNCR Utilization	SCR Reduction	Total Reduction	Overall Utilization
Coal	Standard SNCR	1.19	37.0%	31.1%	-	37.0%	31.1%
Coal	Hybrid	0.79	41.1%	59.2%	16.3%	50.7%	64.2%
Coal	Hybrid	1.15	36.9%	45.7%	54.2%	71.1%	61.8%
Gas	Hybrid	1.44	36.1%	38.6%	78.9%	86.5%	60.1%
Gas	Hybrid	1.56	39.0%	37.1%	83.6%	90.0%	57.7%

- Ammonia Slip at 10 ppm or less

# *In-Duct Catalyst Reactor Design*

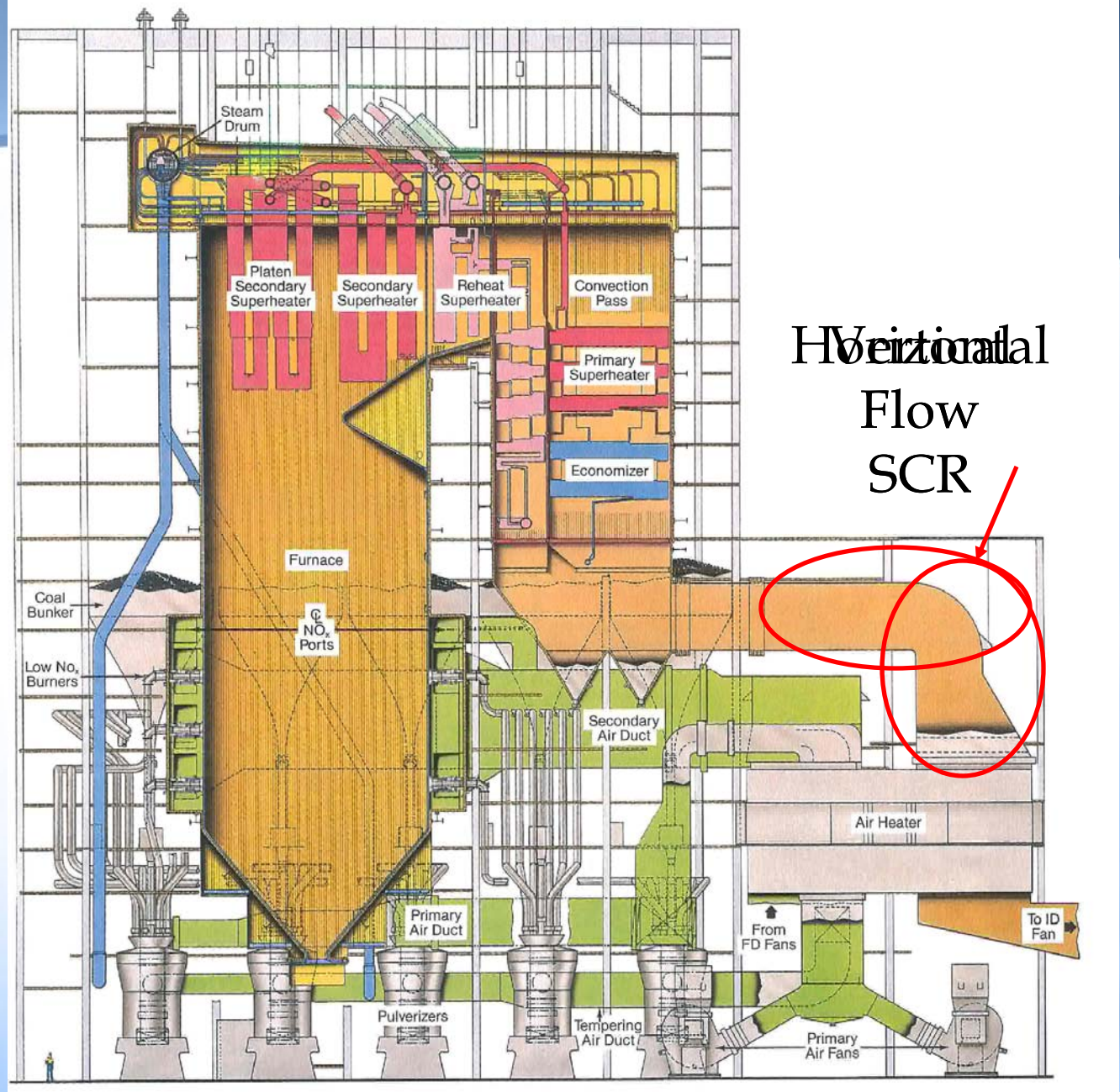
- **Design for Removal of NH<sub>3</sub> Slip**
  - ◆ 1 catalyst layer required: 3-4 feet
  - ◆ Ideal between Economizer and APH
    - Temperature: 570 – 720 deg F
    - NO<sub>x</sub> > NH<sub>3</sub> at each SCR position
- **Design for additional NO<sub>x</sub> Reduction**
  - ◆ 2 catalyst layers
    - NH<sub>3</sub>:NO<sub>x</sub> ratio more important
    - Additional back-end injection possible

# *Sensitivity to $NH_3$ / $NO_x$ Deviations*

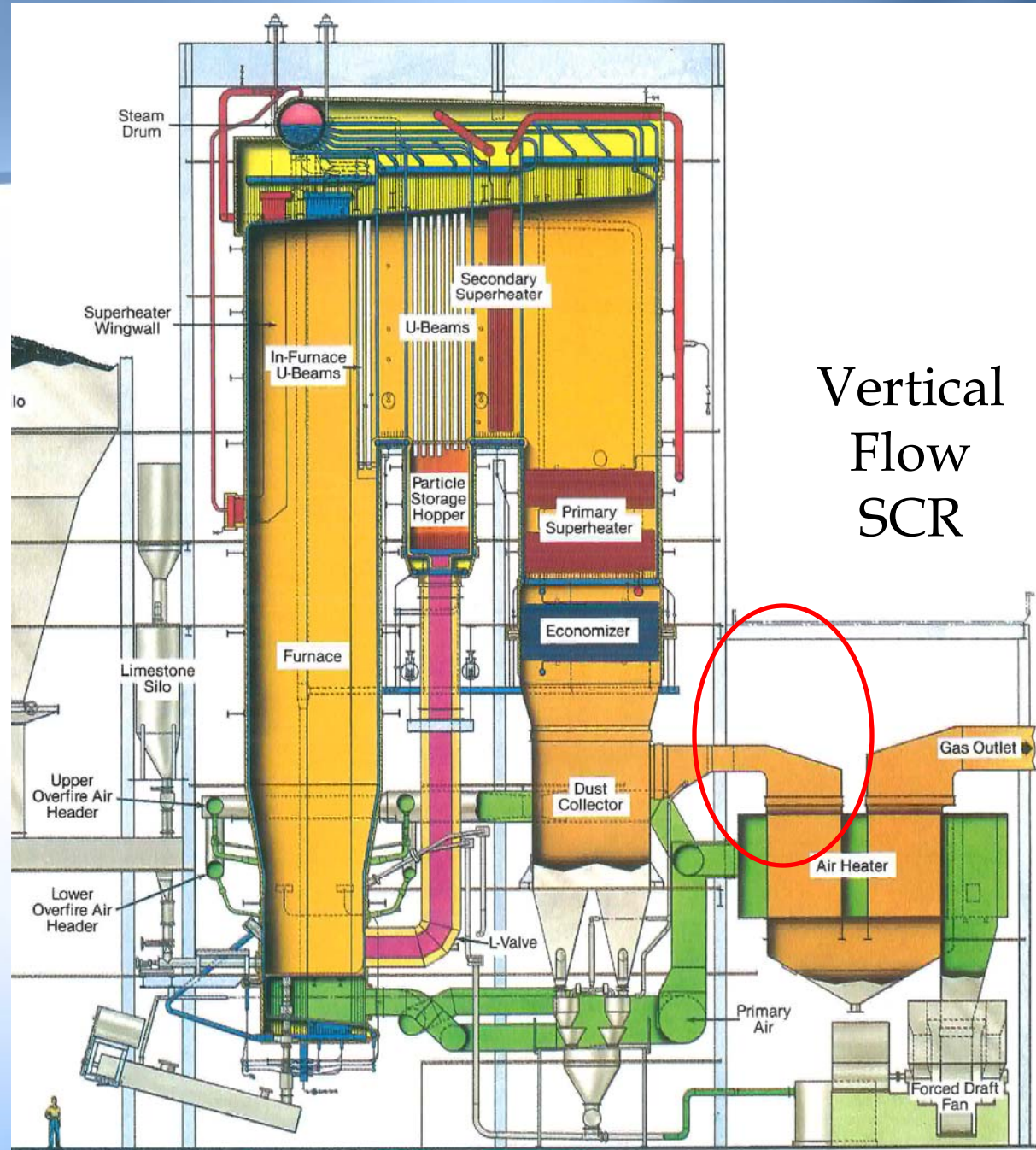


- Based on control of local ammonia slip to 5 ppm

# *In-Duct SCR Design*

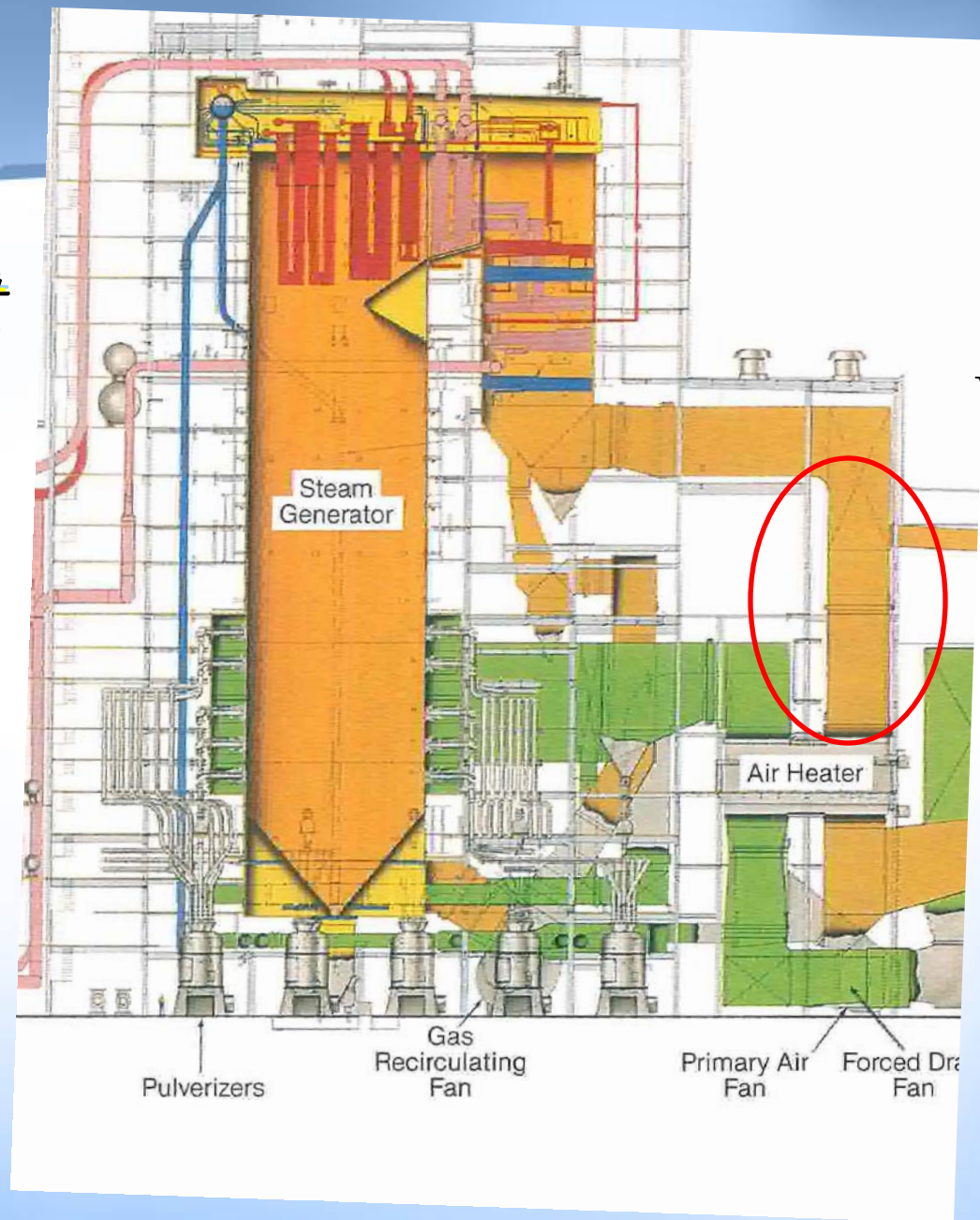


# *In-Duct SCR Design*



Vertical  
Flow  
SCR

# *In-Duct SCR Design*



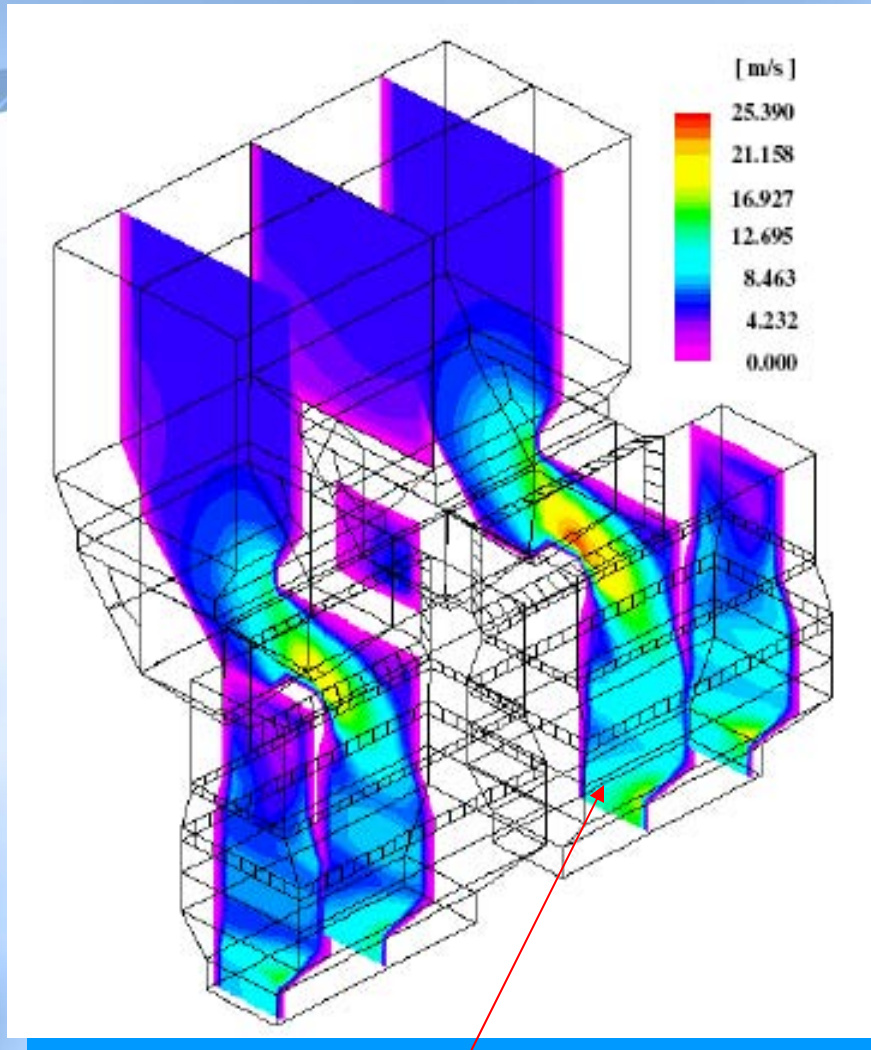
Vertical  
Flow  
SCR

# *CASCADE Example - Seward Station (1997)*

## *NO<sub>x</sub>OUT<sup>®</sup> Performance - 147 MWg*

- Furnace and convective pass injection
  - 42% reduction, 0.45 #/MMBtu, <5 ppm NH<sub>3</sub> slip
  - 35% reduction, 0.5 #/MMBtu, <2 ppm NH<sub>3</sub> slip
    - Less than 10 % in convective pass
  - 54% reduction, 0.36 #/MMBtu, <10 ppm NH<sub>3</sub> slip
    - Short-term testing

# *In Duct Catalyst Design*



- CFD Modeling
- Cold Flow Modeling



Expanded Duct Section

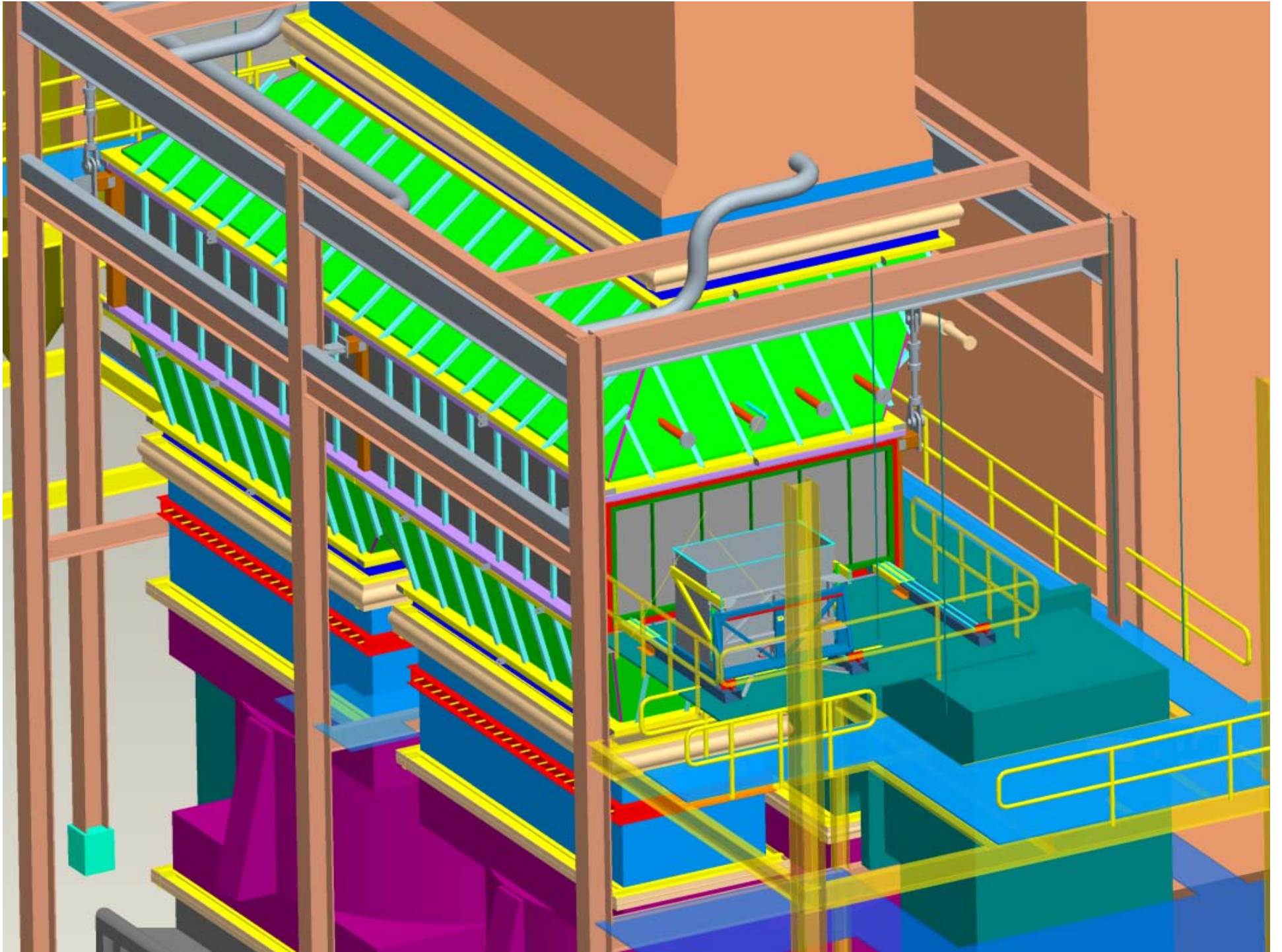


## *Seward SNCR/SCR Performance*

- **Maximum Reduction Achieved (>50%)**
  - **System Tuned to 2, 10, or 20 ppm slip**
- **Increased Chemical Utilization**
- **Less than 2 ppm ammonia slip at SCR Outlet**
- **Less than 4 inches water column additional pressure drop**
  - **< 2 inches in duct, < 2 inches in catalyst**
- **Less than 1% SO<sub>2</sub> oxidation to SO<sub>3</sub>**

# ***AES Greenidge (2007) Hybrid System***

- **115 MW Coal Fired Unit, 2.9% S Bituminous coal**
- **Two wall-injection levels and MNLs**
- **BPI designed reactor and mixing ( $\Delta$ -wing)**
- **In-duct reactor; single layer of catalyst**
- **SNCR provides 42% reduction**
- **Overall system provides ~ 60% reduction**
- **Currently: 60% reduction, 40% SNCR Utilization**





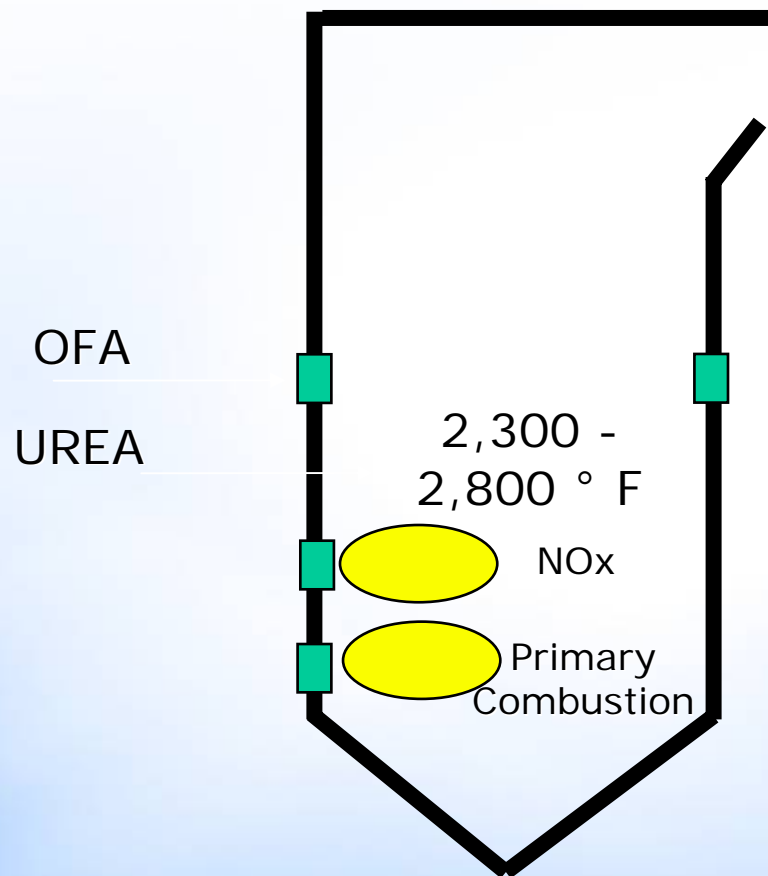
# ***AES Greenidge - Status***

- **Combustion modifications:**
  - Achieve 0.25 lb/MMBtu baseline – CO issues
- **SNCR/SCR Hybrid:**
  - 60% Reduction to 0.10 lb/MMBtu
  - NH<sub>3</sub> Slip < 2 ppm on average
- **Operating at 0.15 lb/MMBtu (40%)**
- **LPA plugging the SCR**

## *Hybrid SNCR/SCR - CASCADE*

- A Redesigned SNCR System with SCR
- Higher NO<sub>x</sub> Reduction and Utilization than SNCR
- Lower Capital Costs than Full-scale SCR
- Greater Operational Flexibility
  - Seasonal NO<sub>x</sub> Emission Limits
  - Seasonal and Daily Load Variations
- Dependent on locating an SCR

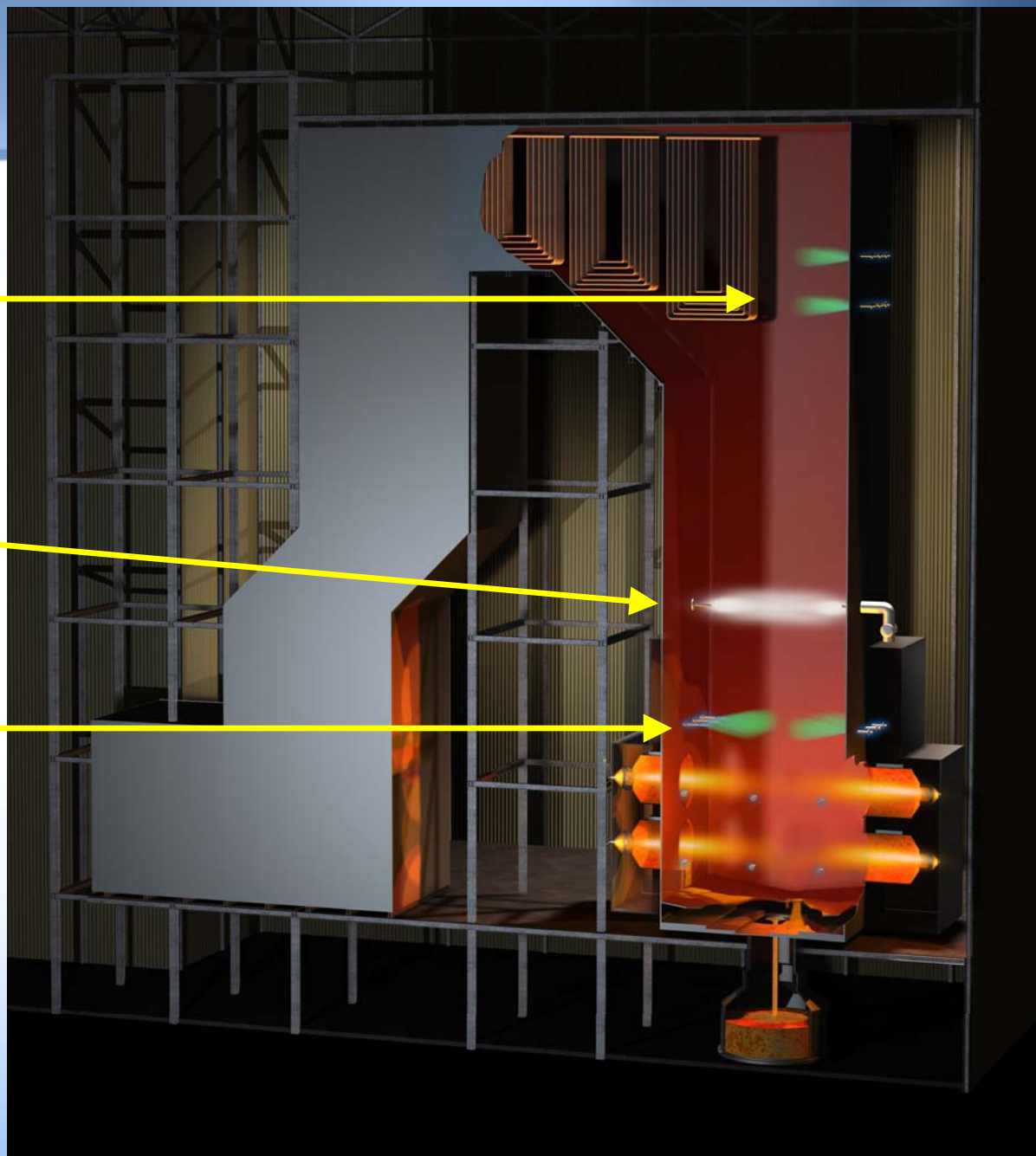
# *Rich Reagent Injection (RRI)*



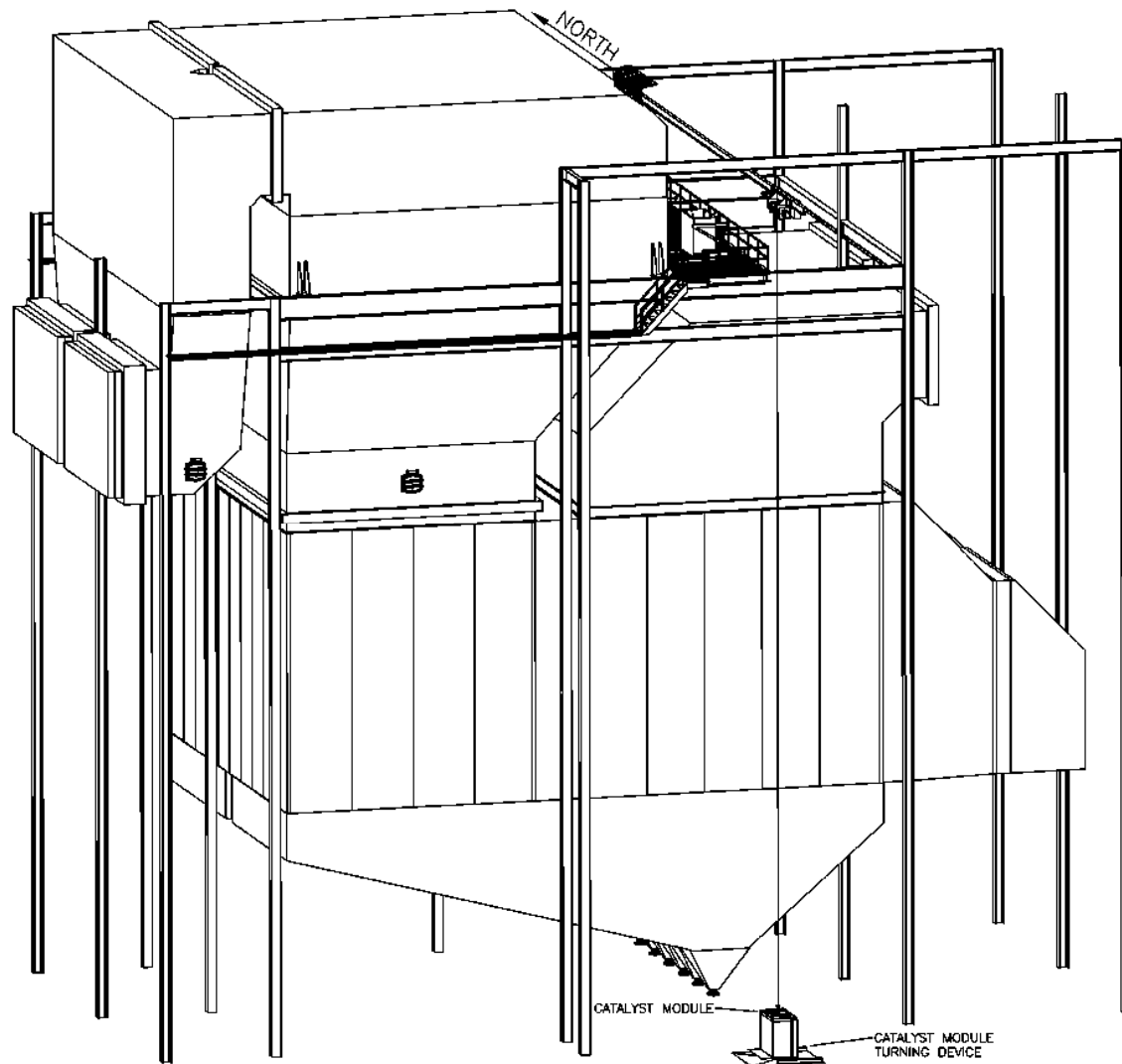
- ◆ Urea Injection into Fuel Rich Zone
- ◆ 20 - 30% NO<sub>x</sub> Reduction
- ◆ Applicable to Cyclones
- ◆ High Temperature: Fast Reaction Rates
- ◆ No Ammonia Slip
- ◆ Easily Installed
- ◆ Low Capital Cost
- ◆ Easily Combined with SNCR

# Ameren Sioux Station

- SNCR
- Over-fired Air
- RRI



# *SCR Reactor at Tubular AH Inlet*



# *Combination of Technologies*

- Low NO<sub>x</sub> Burners and/or Burner Mods
- Over-Fire Air
- SNCR
  - ◆ 20 - 35% Additional NO<sub>x</sub> Reduction
- SNCR + RRI
  - ◆ 45 - 55% Additional NO<sub>x</sub> Reduction
- SNCR + Compact SCR = Cascade
  - ◆ 50 - 80% Additional Reduction @ 2 ppm Slip



*Technologies to enable clean efficient energy™*