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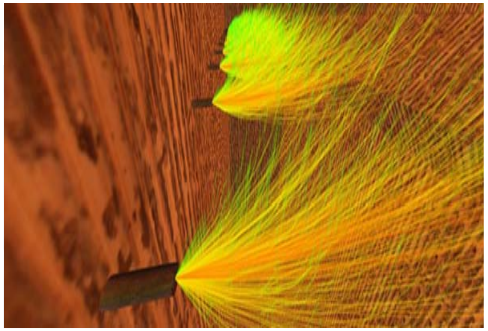

NOx Control Options for Industrial Applications

CIBO Technical Focus Group

December 8, 2009

Reducing NOx Emissions

- Combustion Controls
  - Low-NOx Burners
  - Over-Fired Air
- Post-Combustion Controls
  - Selective Non-Catalytic Reduction
  - Selective Catalytic Reduction
- Layered Technologies
  - Rich-Reagent Injection
  - OFA/SNCR
  - SNCR/SCR Systems

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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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Reducing NOx Emissions

- Combustion Controls
  - Low-NOx Burners
  - Over-Fired Air
- Post-Combustion Controls
  - Selective Non-Catalytic Reduction
  - Selective Catalytic Reduction
- How do we Capture the Strengths?
- How do we Minimize the Limitations?

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Combustion and LNB

- Ultra Low-NOx Burners
  - Coal, Oil, Natural and Refinery Gases
  - Reduce O_2 in the High-Temperature Flame
  - Provide Mixing to Complete Combustion
- OFA Systems
  - Reduce O_2 in the Combustion Zone
  - Design an Efficient CO Burnout Zone
- Combustion Tuning
  - Secondary Air Flow Testing
  - Coal Flow Testing
  - Emissions testing

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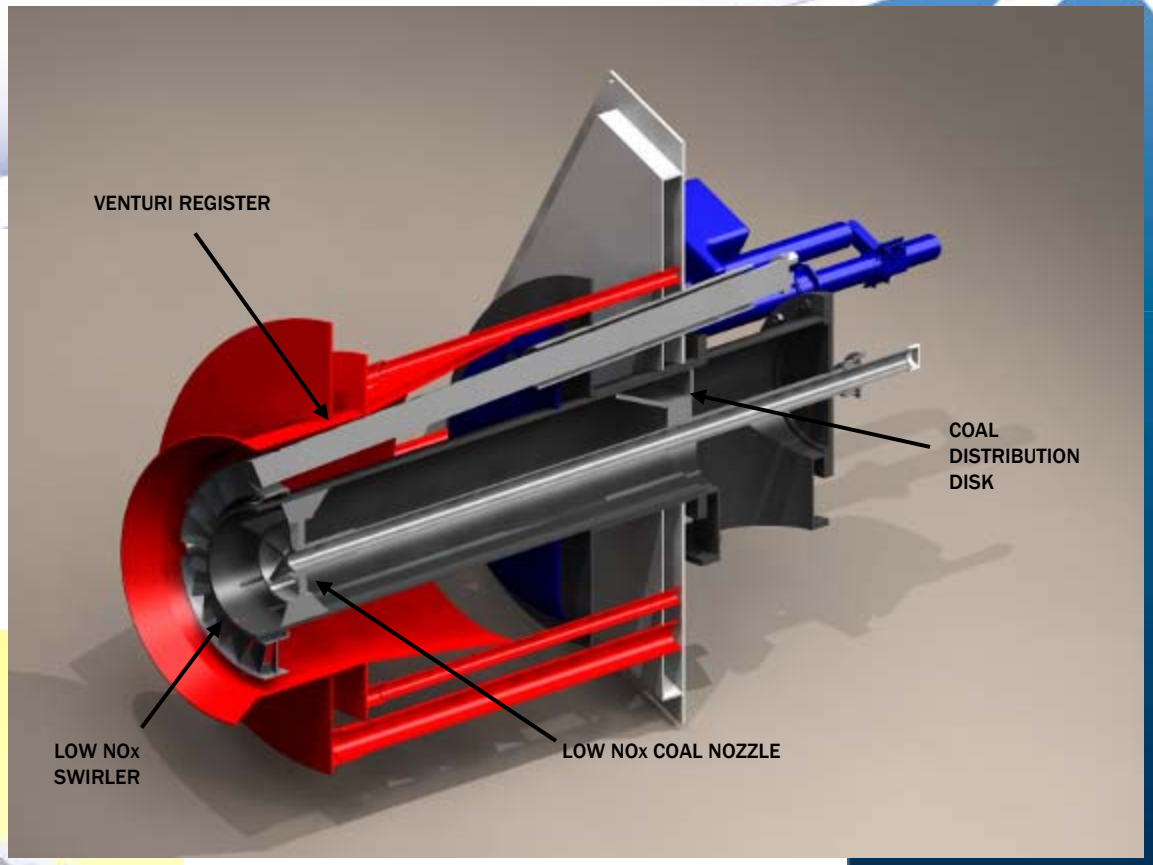
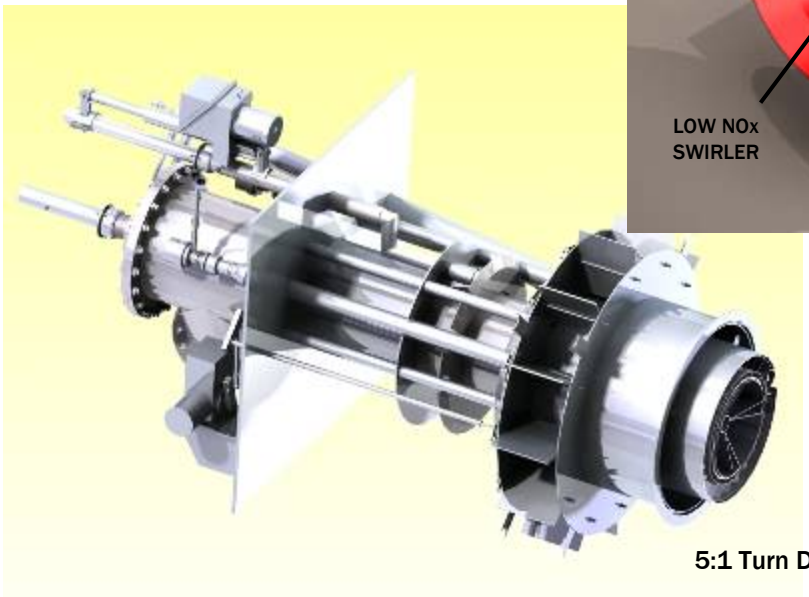
ULTRA LOW NOx BURNER





5:1 Turn Down

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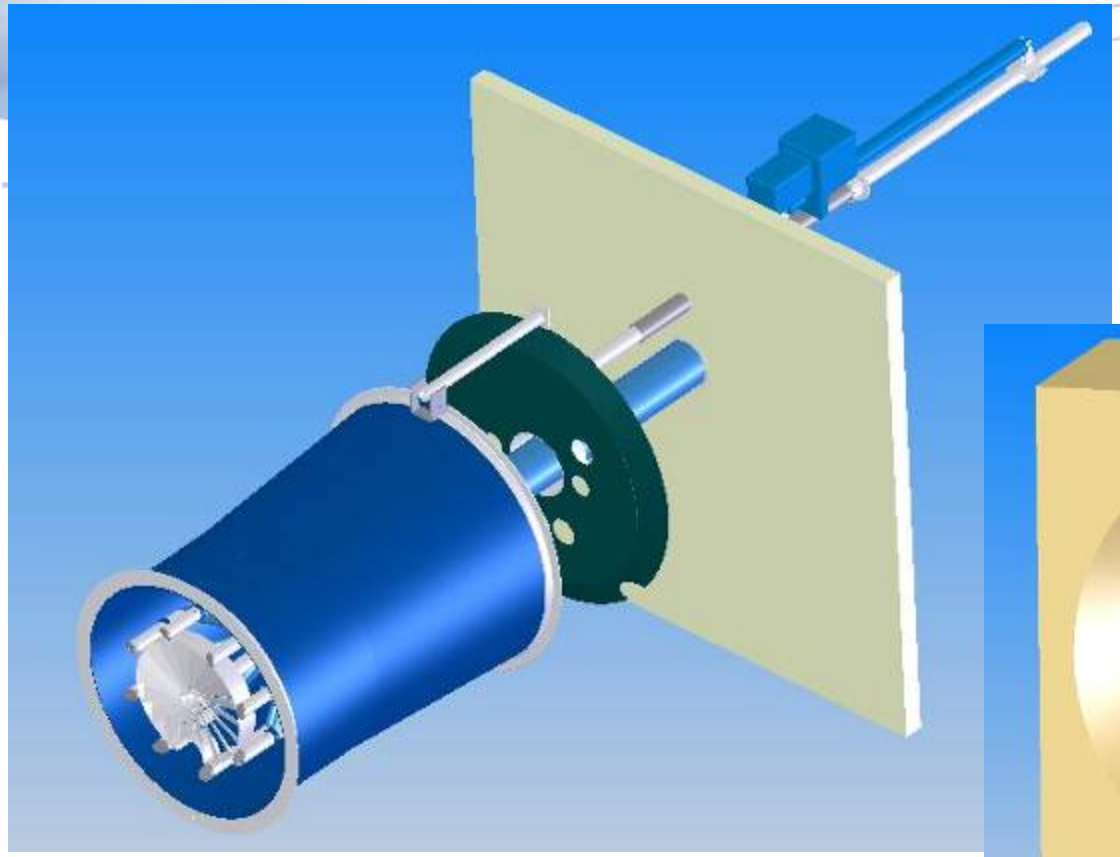
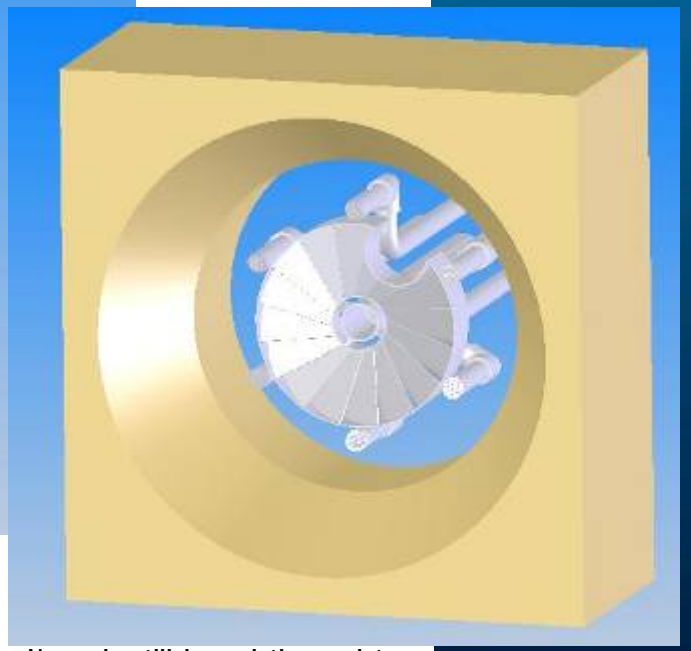
LOW NOx GAS BURNER





Upgrade utilizing existing register

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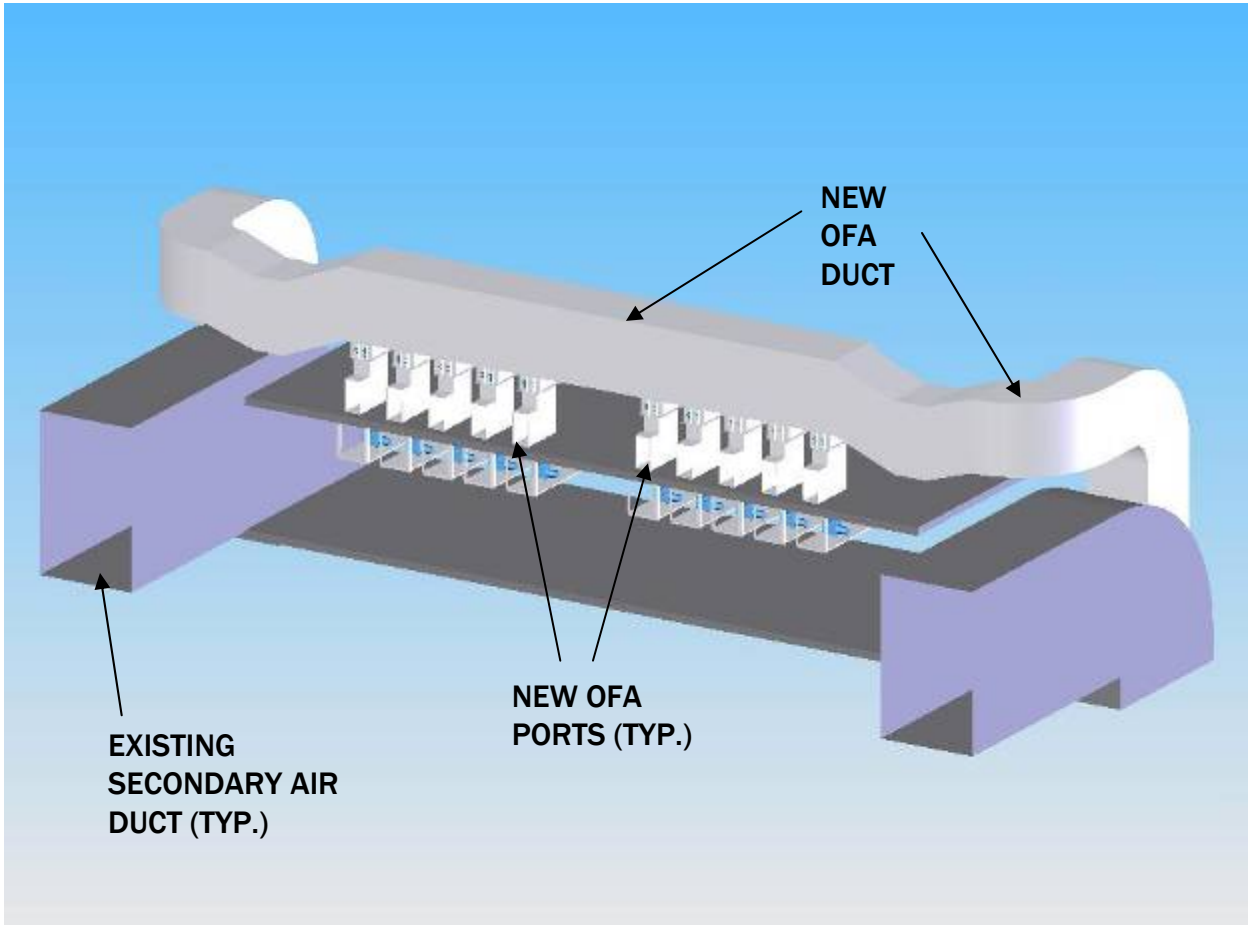
New OFA Duct Layout (OFA) SYSTEM



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Post Combustion Controls
Selective Non-Catalytic Reduction

Urea Process Chemical Reaction

$$2NO + NH_2\text{-}CO\text{-}NH_2 + \tfrac{1}{2}O_2 \Rightarrow 2N_2 + CO_2 + 2H_2O$$

NITROGEN OXIDE + UREA + OXYGEN ⇨
NITROGEN + CARBON DIOXIDE + WATER

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SNCR Technology Overview:

- In-furnace, Post-combustion Control
  - Injection of Aqueous Urea Droplets
  - Aqueous Urea vs. Ammonia:
    - Safety Concerns/Costs
    - Better Ammonia Slip Control
    - Advantageous Temperature Window
    - Significantly Better Distribution
  - Package Boilers to Utility Boilers
  - Target Temperature: 1500F – 2200F

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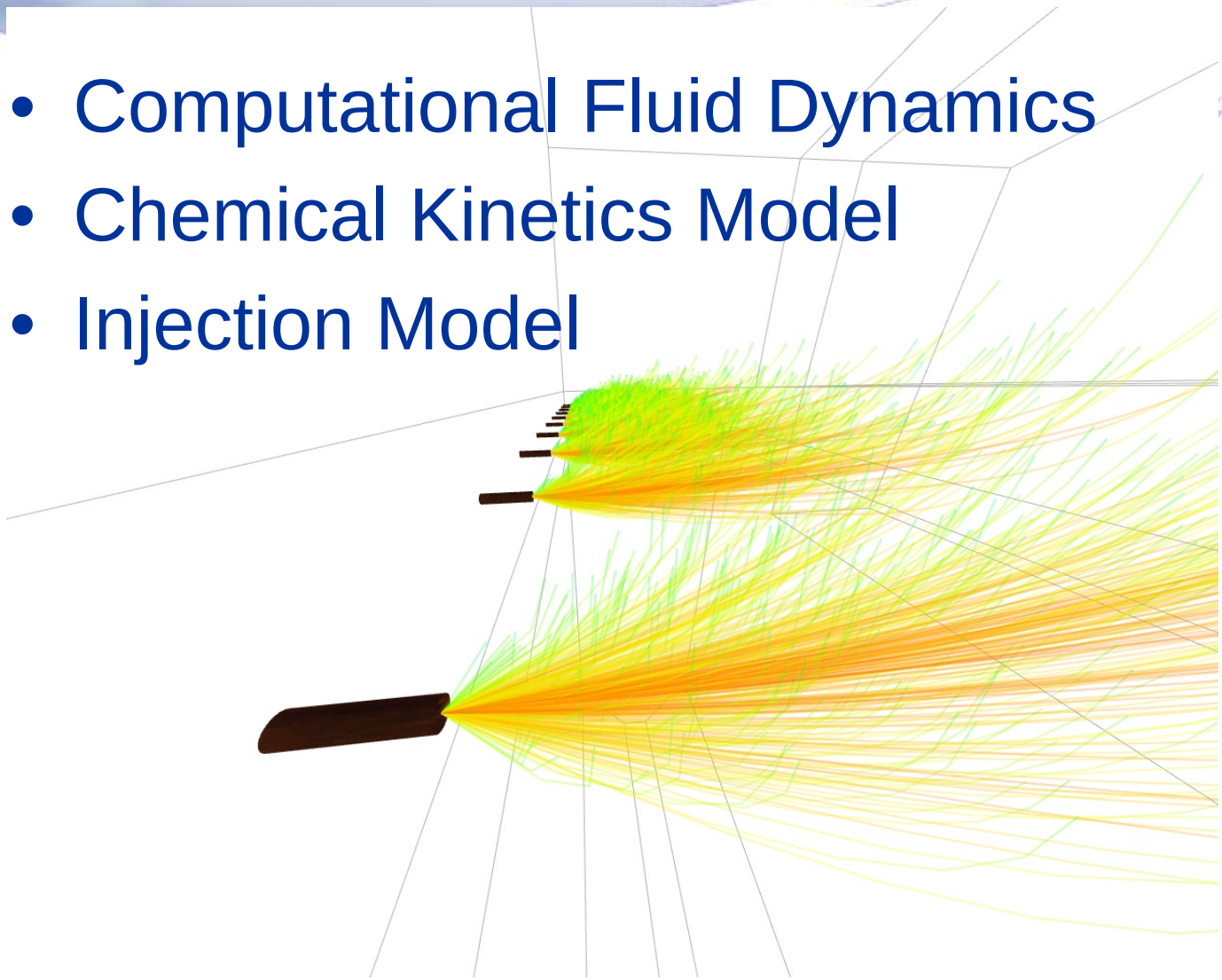
SNCR Process Application

- Computational Fluid Dynamics
- Chemical Kinetics Model
- Injection Model



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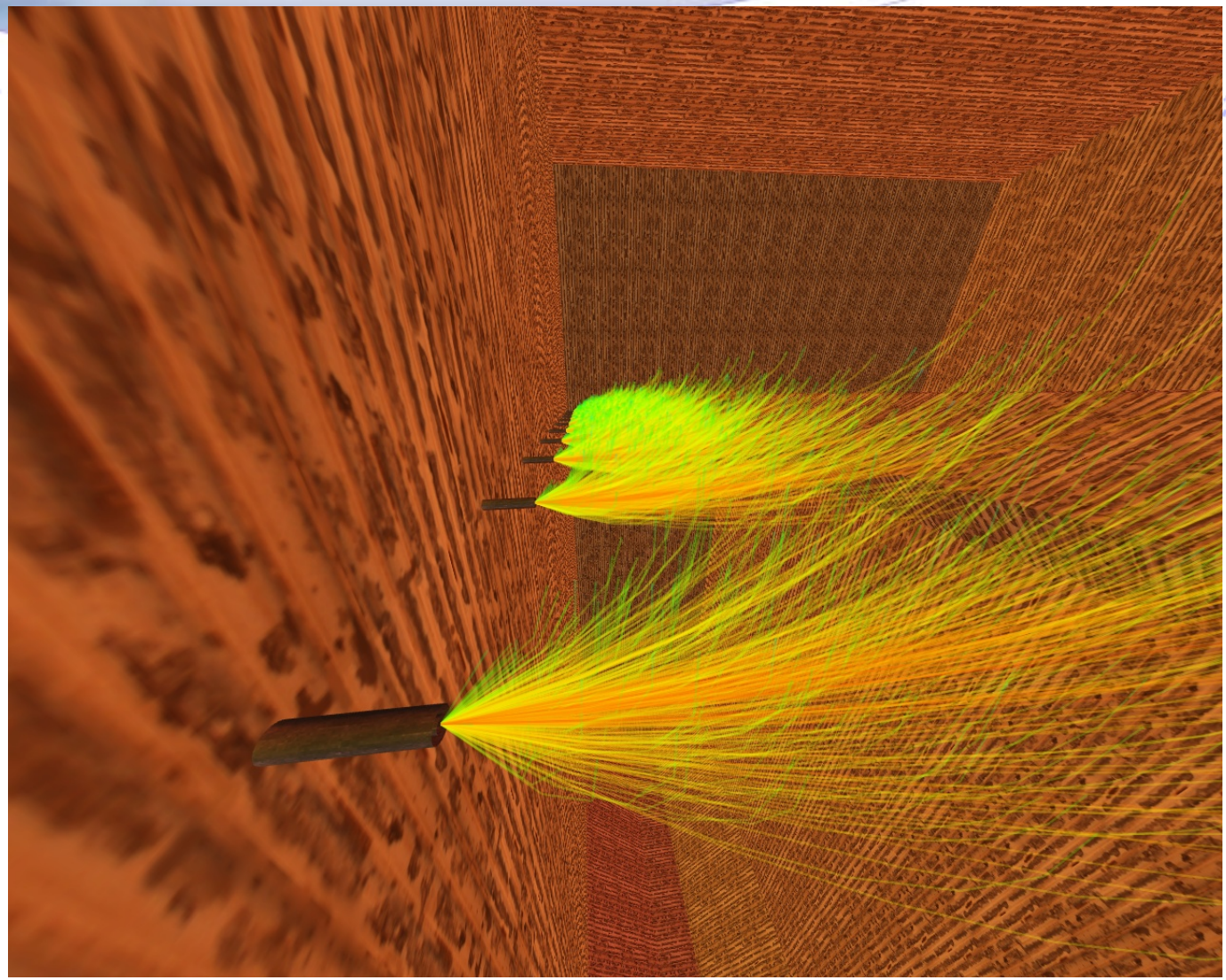
SNCR Process Application



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Two Aqueous Urea Injection Techniques

- NOxOUT
  - Air atomized injector
  - High momentum droplets
  - 200 to 500 microns, 20-30 m/s
- HERT™
  - Mechanically atomized
  - High velocity carrier air, 45 m/s
  - Narrow Droplet Size Distribution

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Controlling Risks SNCR:

- Carefully Target the Injection Zone
  - CFD Modeling
  - Field Assessments / Demonstrations
- Understanding the Chemistry
  - Ammonium Bisulfate Formation
- Referring to Experience Database
  - More Than 450 Application
  - Vast Majority Industrial Applications

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SNCR Systems - Industry Experience

- Electric Utilities
- Wood-fired IPPs / CoGen Plants
- TDF Plants
- Pulp & Paper
  - Grate-fired
  - Sludge Combustors
  - Recovery Boilers
  - Wellons Boilers
  - Cyclones
- Refinery Process Furnaces
- CO Boilers
- Petrochemical Industry
- CoGeneration Package Boilers
- Municipal Solid Waste
- Process Units
- Cement Kilns

NOx Reductions from 30% to 70%

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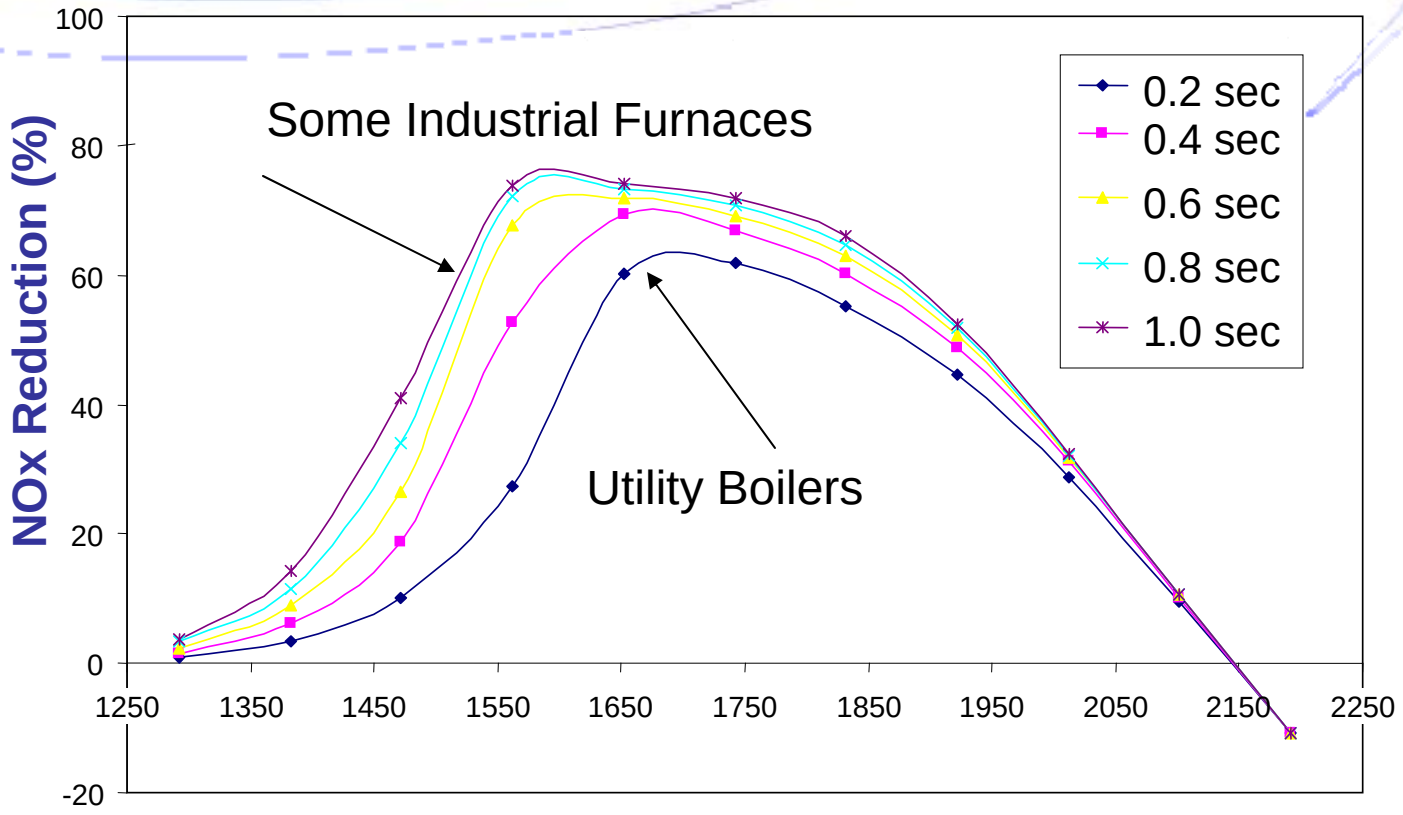
NOx Reduction is a Function of Temperature and Residence Time



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Post Combustion Controls
Selective Catalytic Reduction

- NH_3 and NO React over a Catalyst
  - 600F to 700F
  - Nearly 100% Chemical Utilization
  - Capable of Very High Reductions
- Limitations
  - Capital Cost Modifications
  - Industrial Poisons
  - Unsteady Operations
  - SO_3 formation
  - Additional pressure drop

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Controlling Risks SCR:

- Lower the NOx Baseline
  - Decrease Ammonia Slip
  - Increase Performance of the SCR
- Utilize a Simple Single-layer SCR
  - Reduced Capital
  - Reduced Catalyst Replacement Cost
  - Reduced SO_3 and Pressure Drop
- Layered Technologies
  - Reduced Reliance on the SCR
  - Improved Flexibility for Operations

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ASCR - Advanced

- A State of the Art small SCR
  - Optimal Use of Available Space
  - In-duct Ammonia Injection Grid (AIG)
  - Fully Engineered Flow Devices
  - Supported by Catalyst Manufactures
  - Guaranteed Performance

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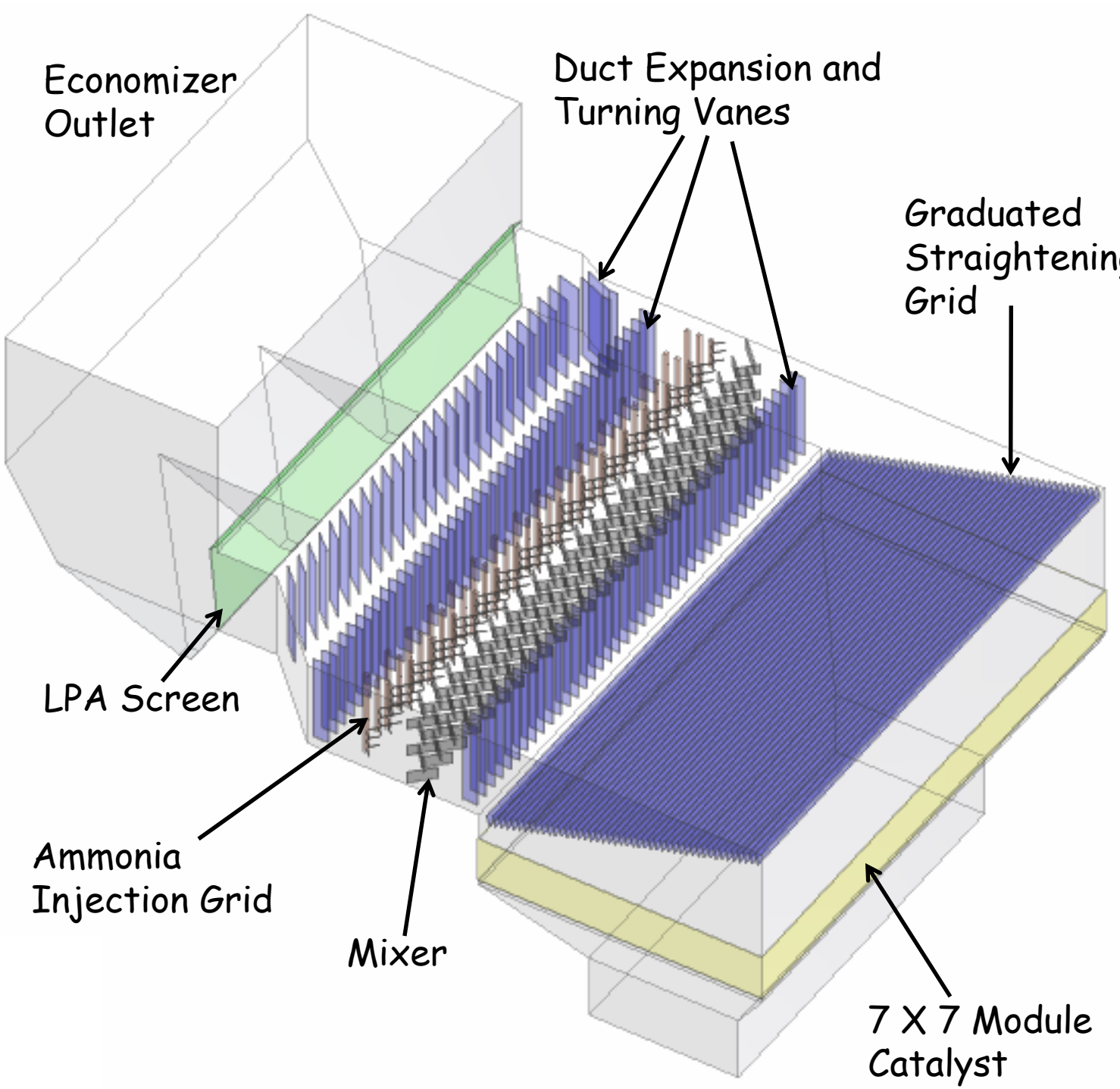
Economizer Outlet
Duct Expansion and Turning Vanes
Graduated Straightening Grid
LPA Screen
Ammonia Injection Grid
Mixer
7 X 7 Module Catalyst

Physical Flow Modeling Facility

- Over 16,000 ft^2 of Laboratory, Office and Storage Space
- Capacity to Handle Several Large Models Simultaneously
- Full Welding, Machining and Fabrication Capabilities
- Durham, NC Facility

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SCR Scale Model

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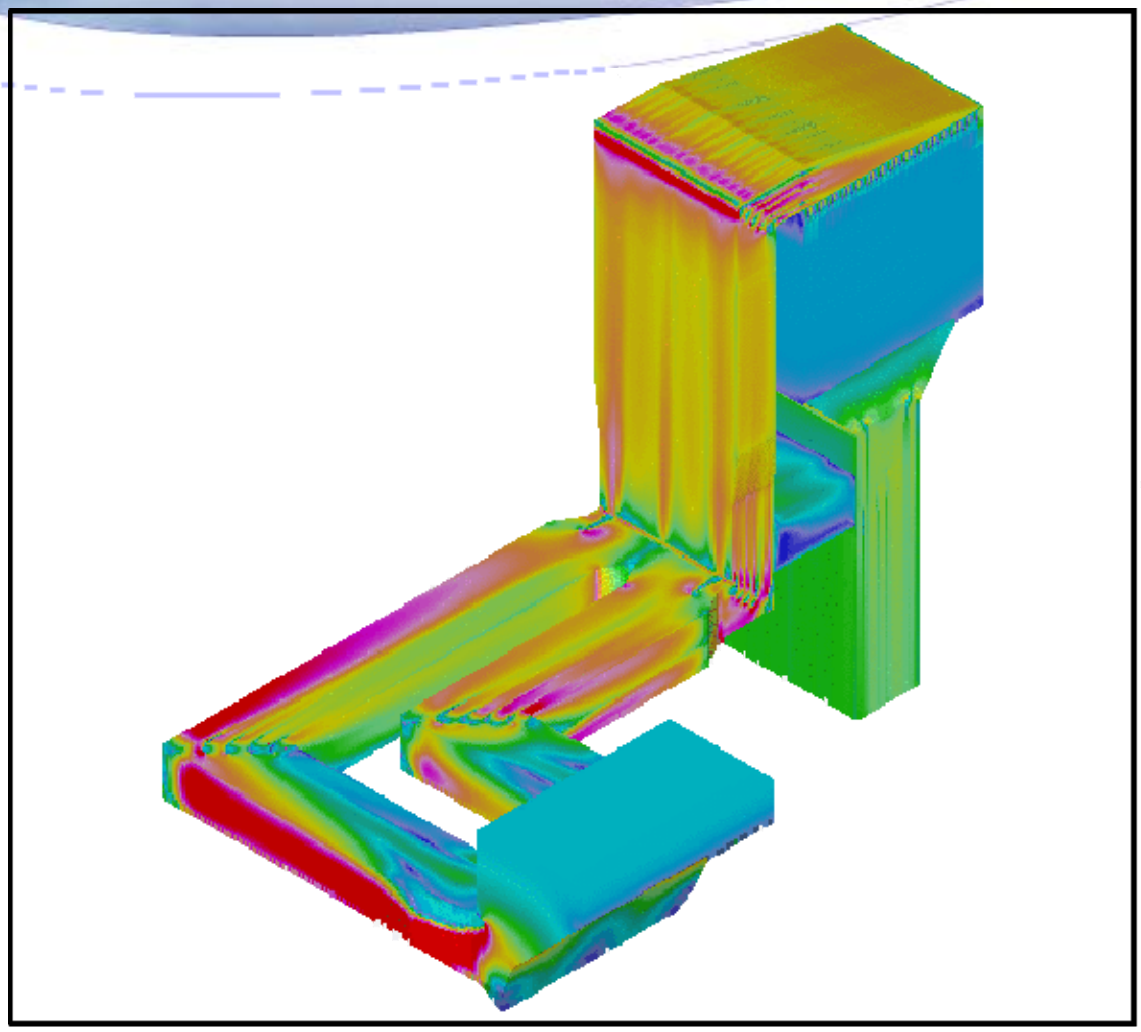
SCR Scale Model



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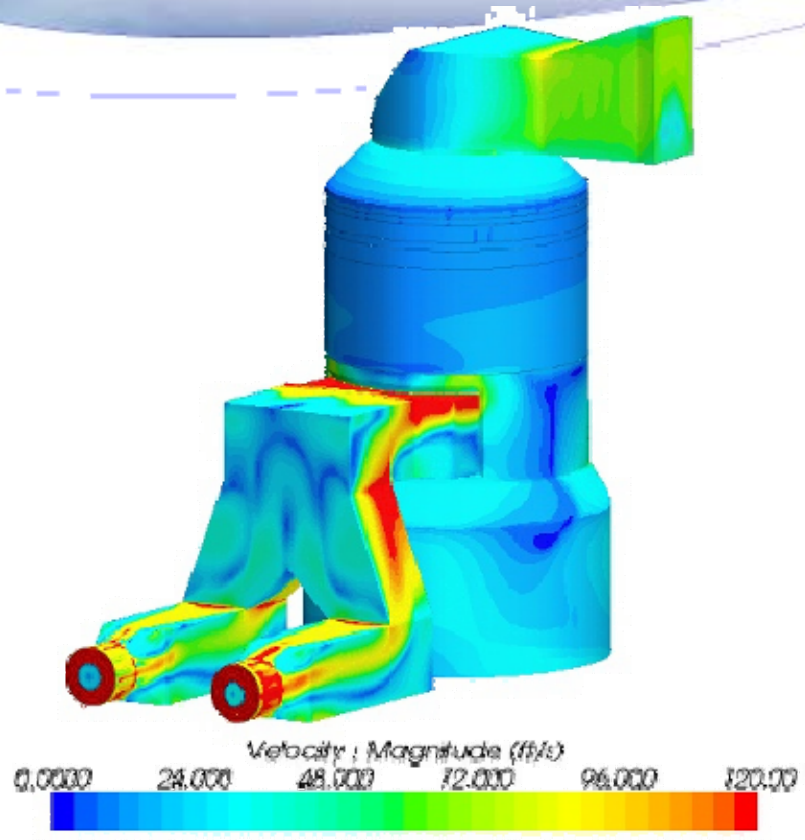
WFGD Scale and CFD Modeling



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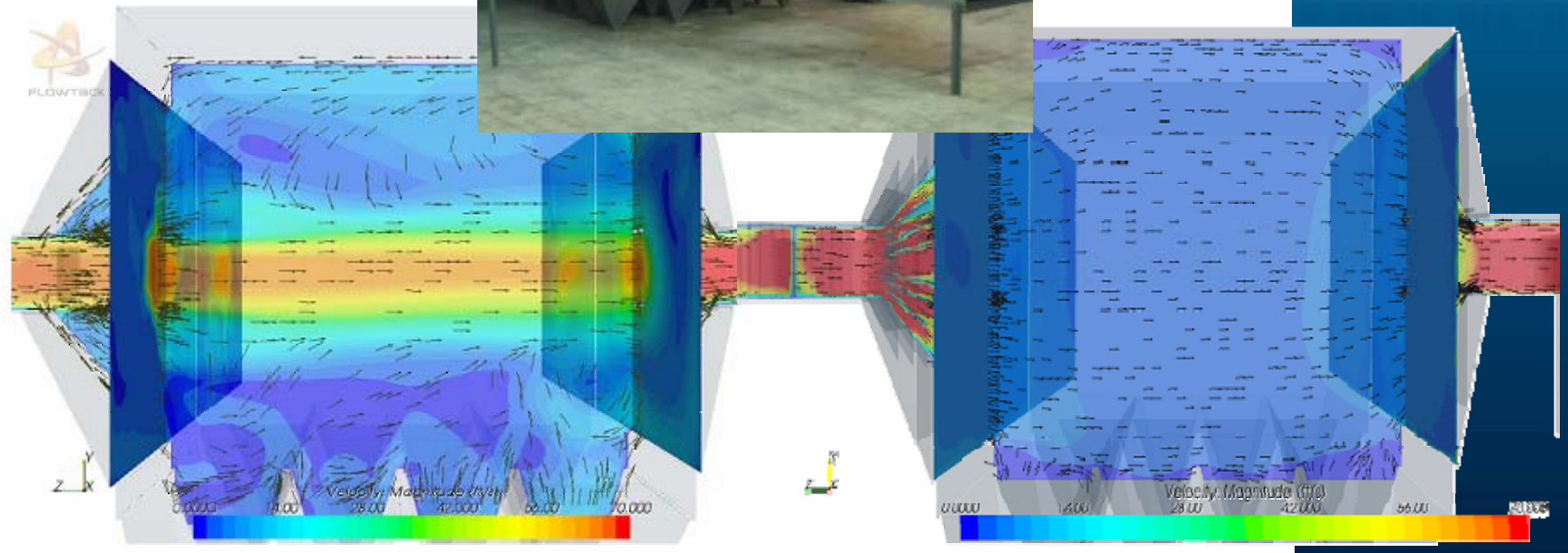
ESP Modeling



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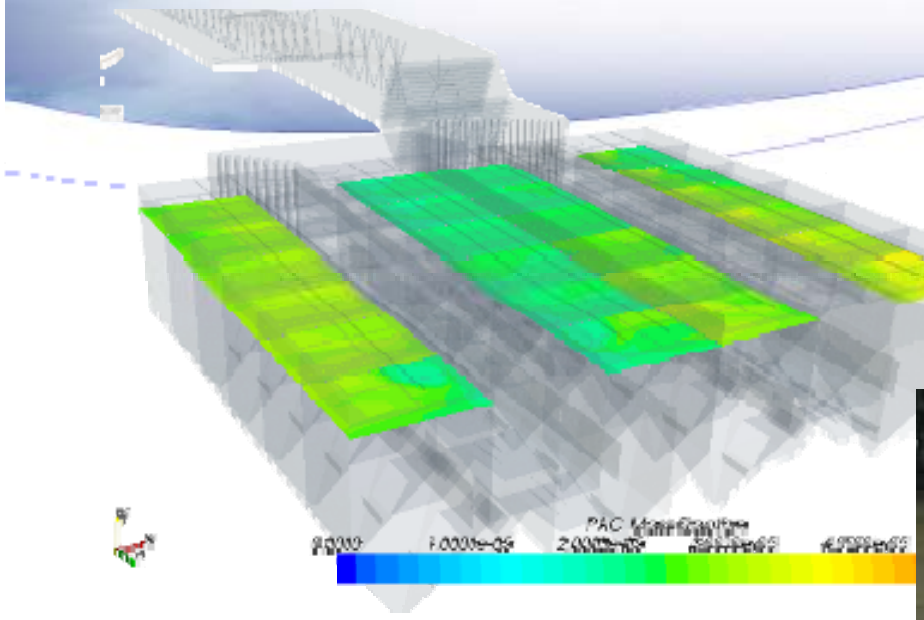
Fabric Filter Modeling



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Combining NOx Reduction Technologies

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

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Retrofit Low-NOx Burner Installation

Technology	Strength	Limitations
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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 Improve 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 Improve Red%	NH3 is OK Feed to SCR
Small SCR	More Red% Low NH3 Slip	Mod Capital, SO_3 and Cost

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Layered NOx Solutions

- Utilize Optimal Technology Suite
- Custimized to Reduce Risks
- Balanced to Reduce Costs
  - Capital vs. Operation Costs
  - Variations in Fuel and Capacity
- Best Possible Performance
  - NOx Reduction
  - Secondary Impacts (BOP)

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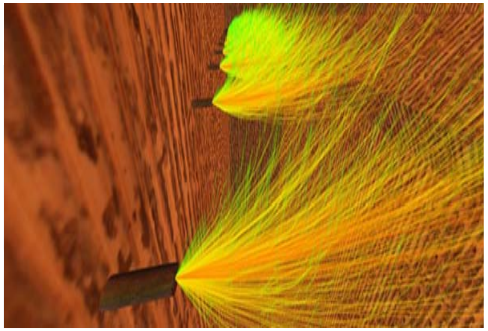

NOx Control Options for Industrial Applications

QUESTIONS?