Reinhold Environmental Ltd.

2009 NOx-Combustion Round Table & Expo Presentation

February 9 & 10, 2009, Cleveland, OH

SCR 101

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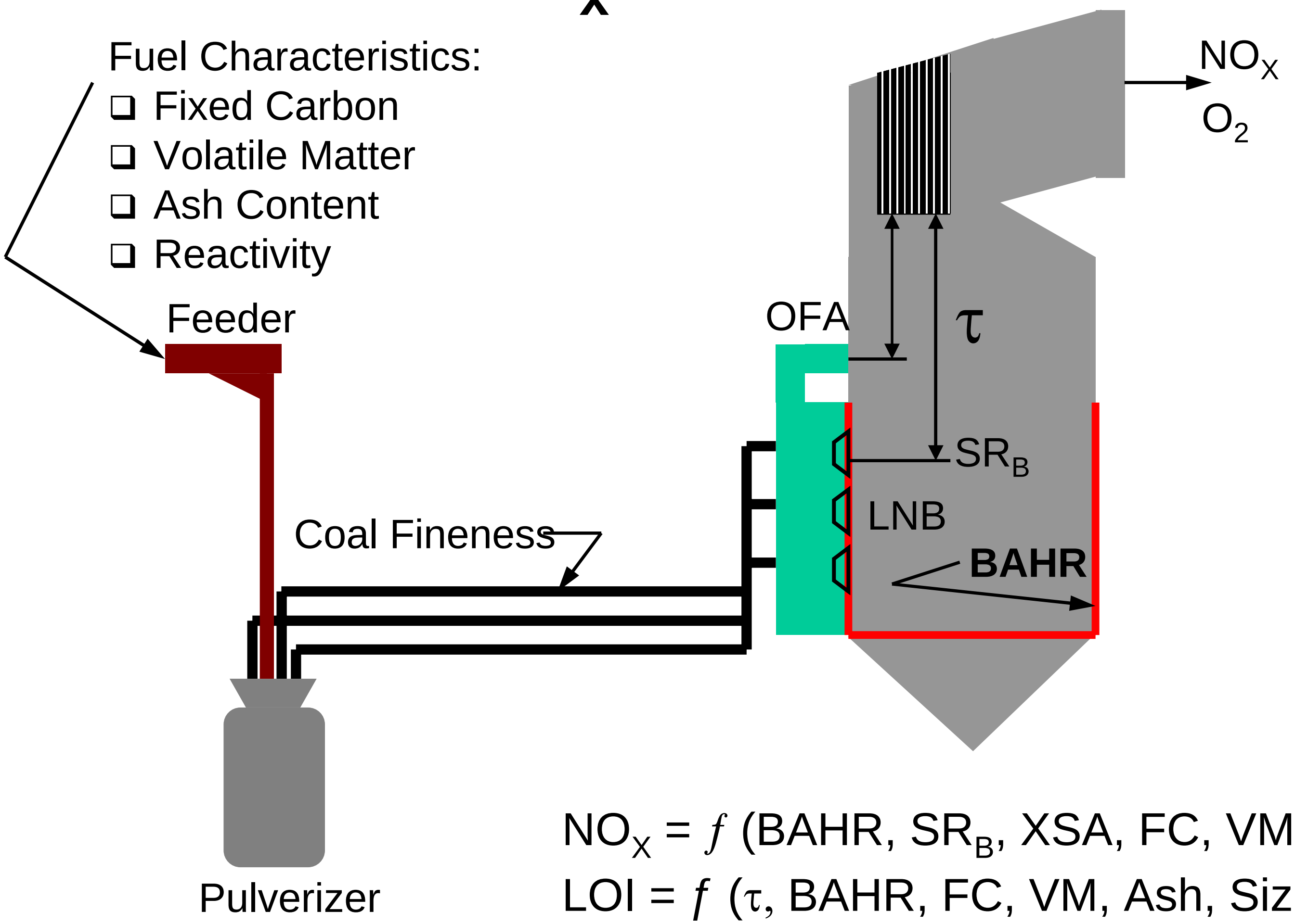
NO_x Formation

Fuel Characteristics:

- Fixed Carbon
- Volatile Matter
- Ash Content
- Reactivity



$NO_X = f$ (BAHR, SR_B, XSA, FC, VM, N, LNB)

LOI = f (τ, BAHR, FC, VM, Ash, Size, NO_X)

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SCR NO_x Outlet & Removal Efficiencies

- Reliability of firing system
- SCR system design
- Reliability of SCR system
  - Catalyst
  - Ammonia system
  - Controls
- Boiler dispatch and load characteristics
- Planned outage schedule

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SCR NO_x Outlet & Removal Efficiencies

- Current SCR system design ranges
  - Inlet NO_x 0.32 to 2.3 lbs/MMBtu
  - Outlet NO_x 0.03 to 0.15 lbs/MMBtu
  - Removal efficiencies up to 92.5%
  - Ammonia slip < 2 ppm
- Current SCR system operation (2004 Ozone Data)
  - >20 units operating at > 90% removal
  - >20 units operating at < 0.05 lbs/MMBtu

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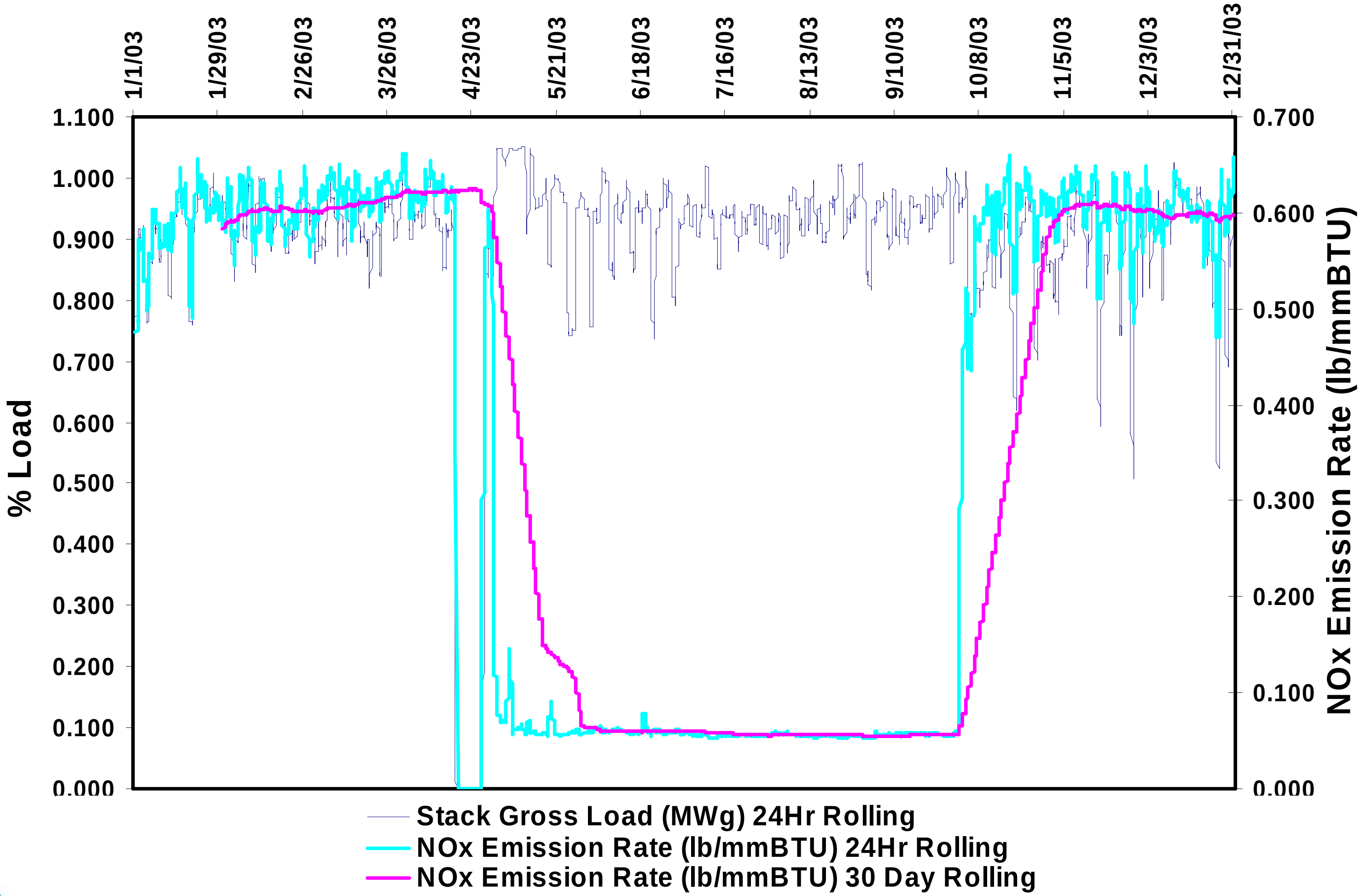
SCR NO_x Outlet & Removal Efficiencies



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Ammonia Systems

- Anhydrous Ammonia
  - Hazardous chemical governed by codes
- Aqueous Ammonia
  - Concentration based codes, maybe changed in future
- Urea Based Ammonia
  - Safe storage, more equipment and complex

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SCR Reactor Configuration

- High Dust
  - Typical of most U.S. installations
- Low Dust
  - Used for hot ESP installations
- Tail End
  - Site constraints limit access
- In Duct
  - Limited removal efficiency for coal
  - High removal efficiency for gas and oil

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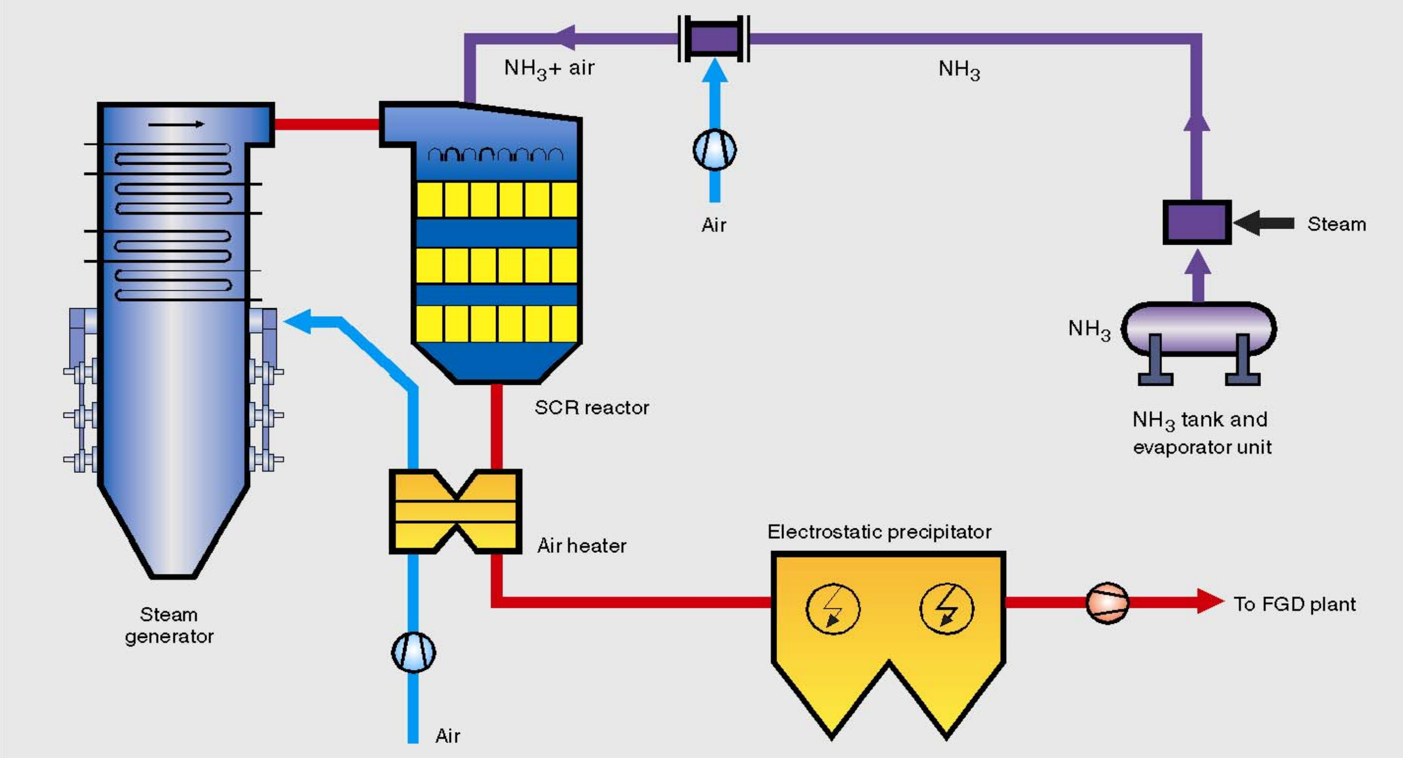
SCR Reactor Configuration
High Dust Arrangement



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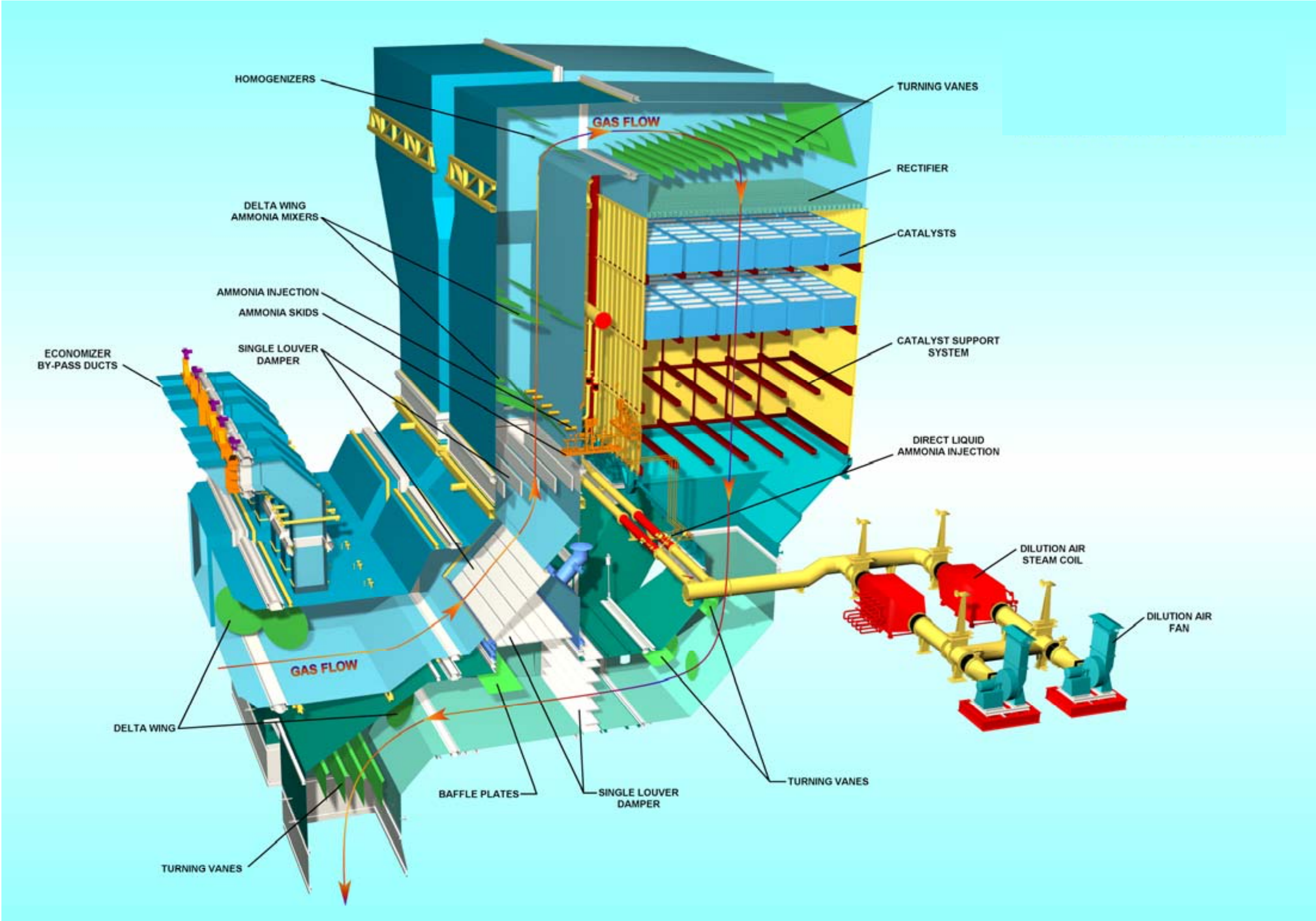
SCR Reactor Configuration – High Dust



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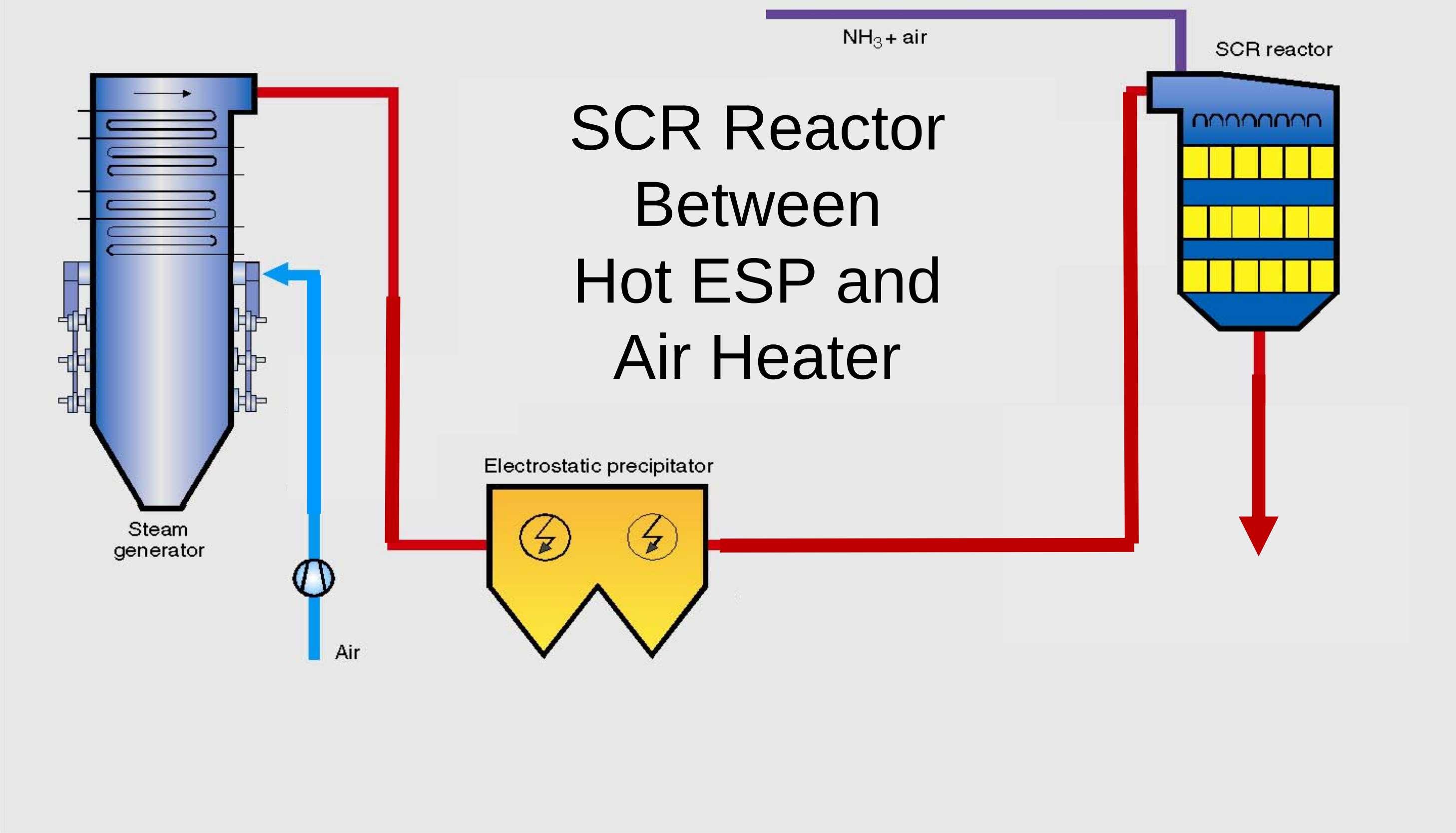
SCR Reactor Configuration
Low Dust Arrangement



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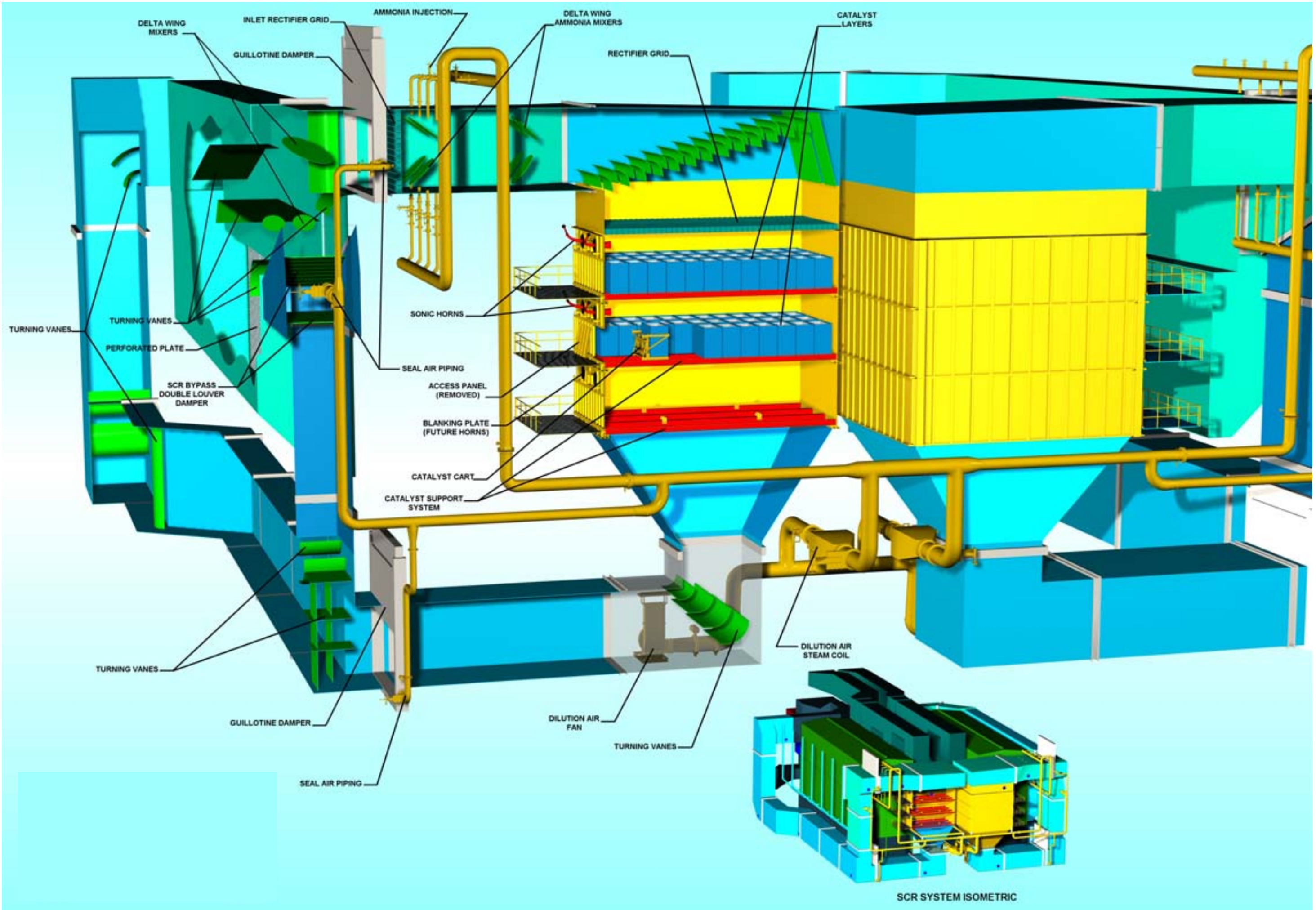
SCR Reactor Configuration – Low Dust



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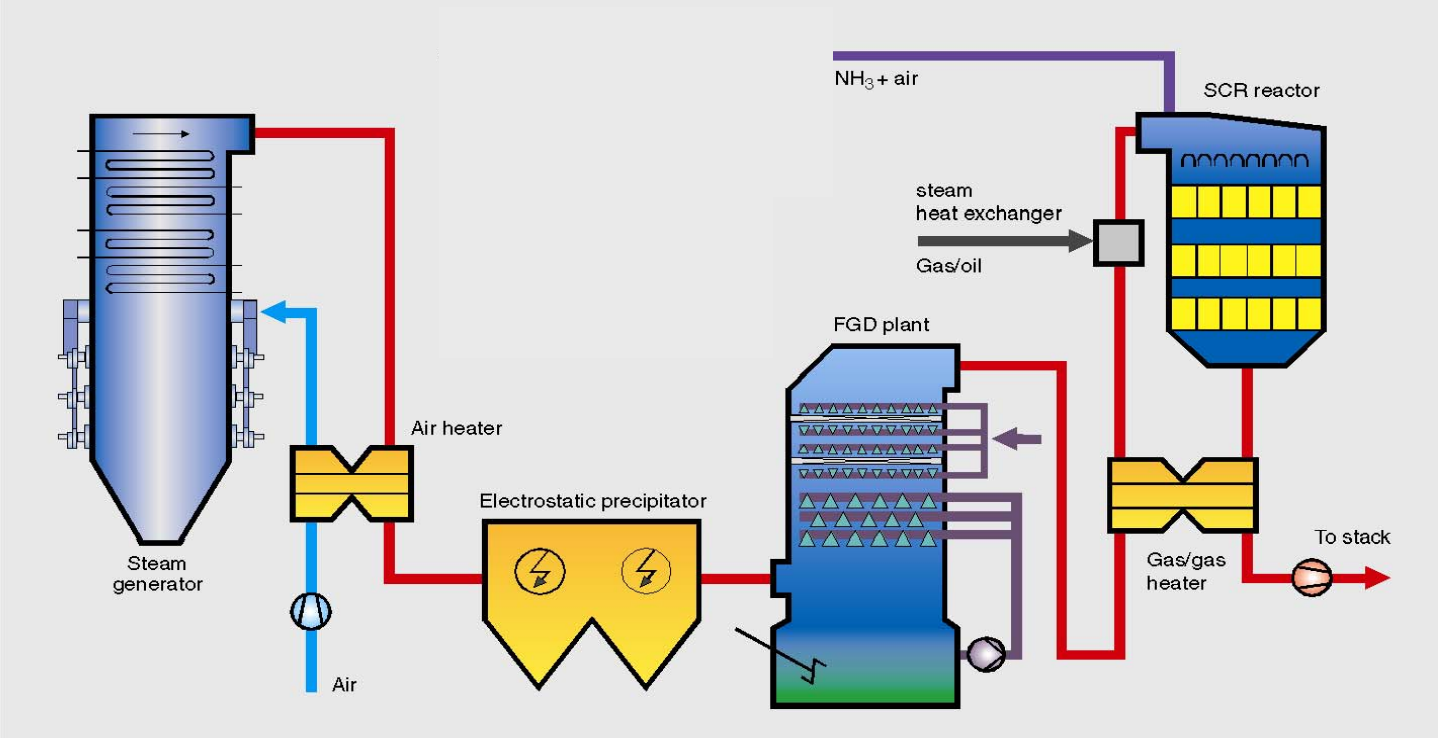
SCR Reactor Configuration
Tail End Arrangement



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SCR SYSTEMS

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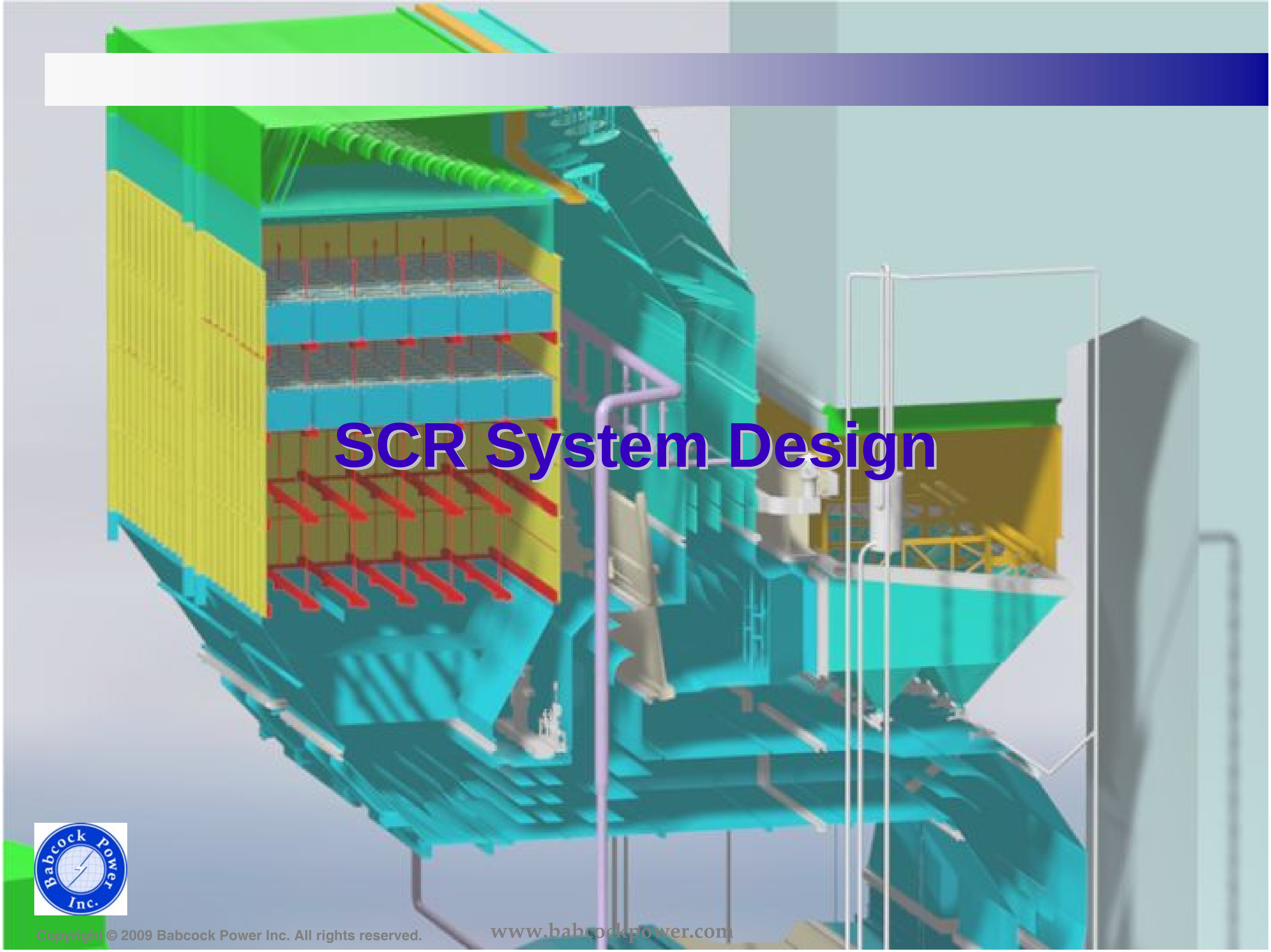
SCR System Design



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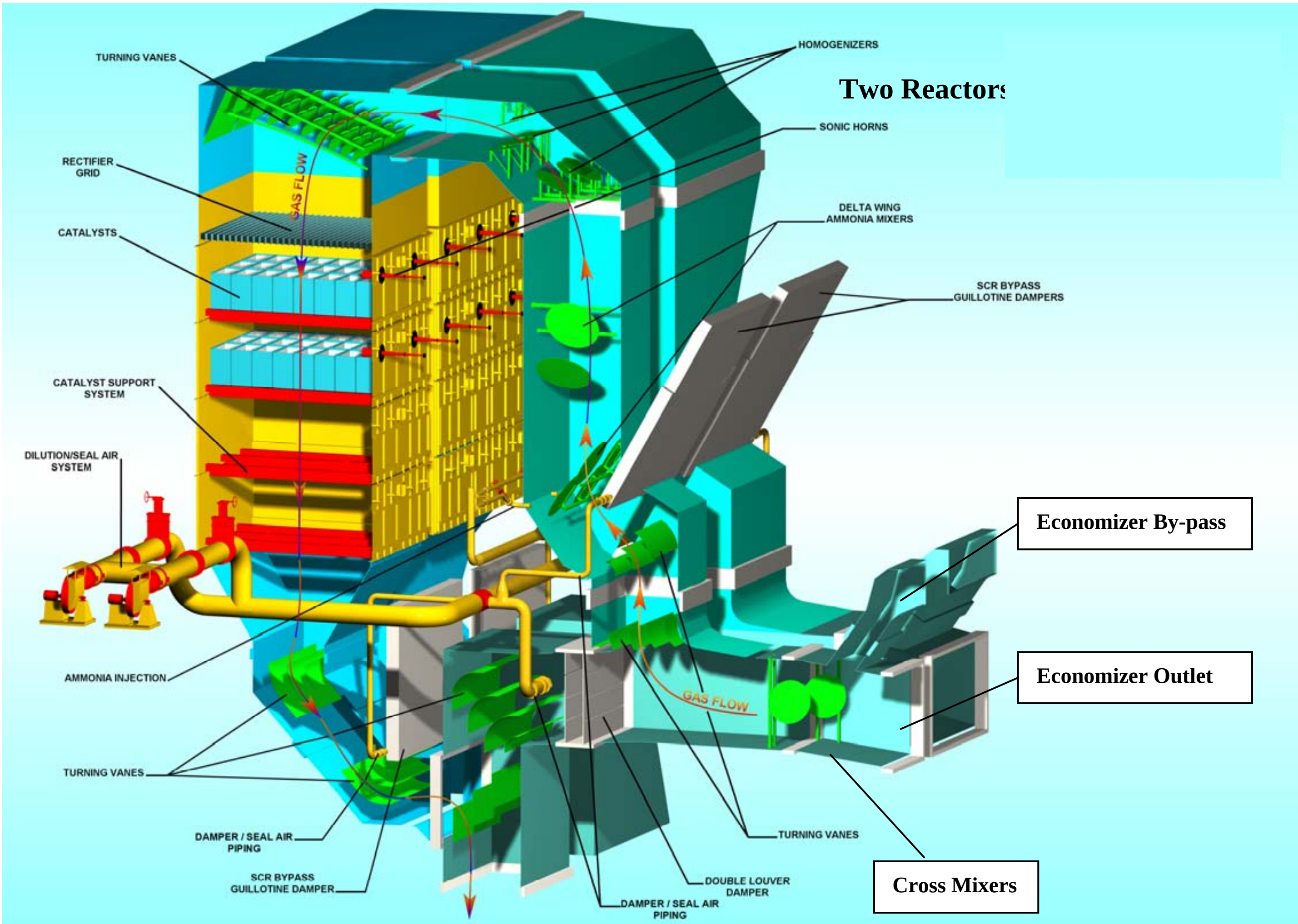
SCR System Design



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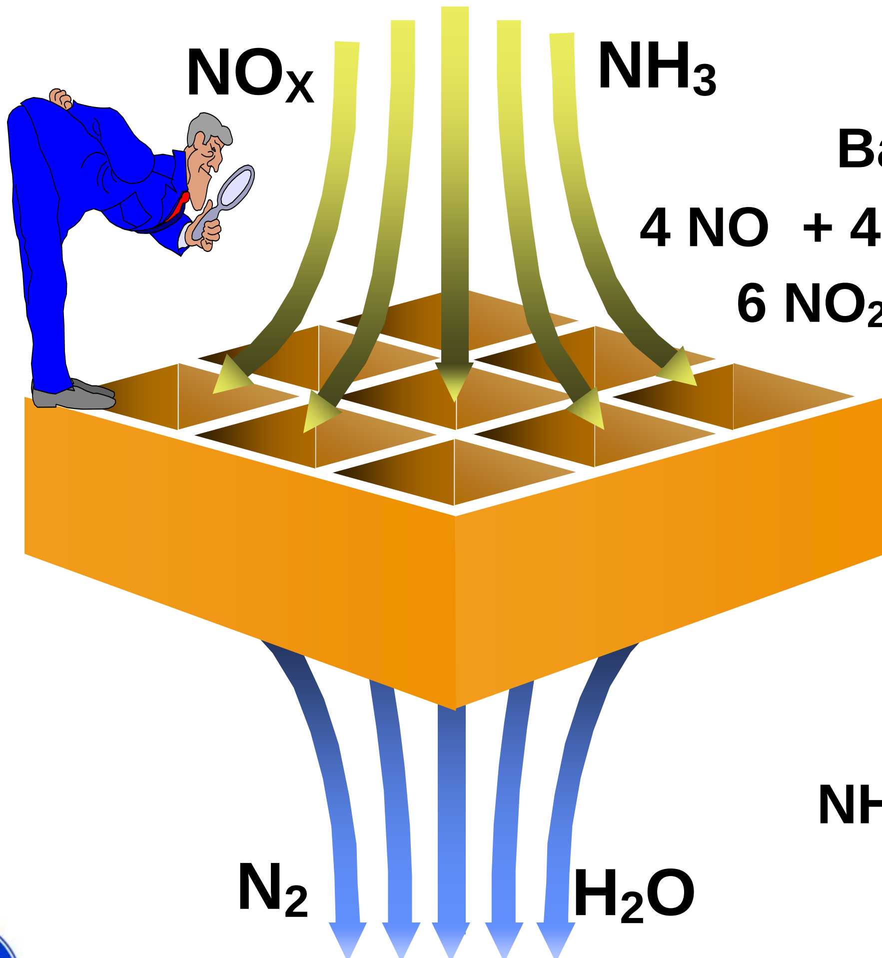
Basic SCR Chemistry



Basic reaction equations

$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$

$6\ NO_2 + 8\ NH_3 \rightarrow 7\ N_2 + 12\ H_2O$

Typical coal flue gas
95% NO & 5% NO_2

Undesirable side reactions

$SO_2 + 1/2\ O_2 \rightarrow SO_3$

$NH_3 + SO_3 + H_2O \rightarrow NH_4\ HSO_4$

Mercury Oxidation

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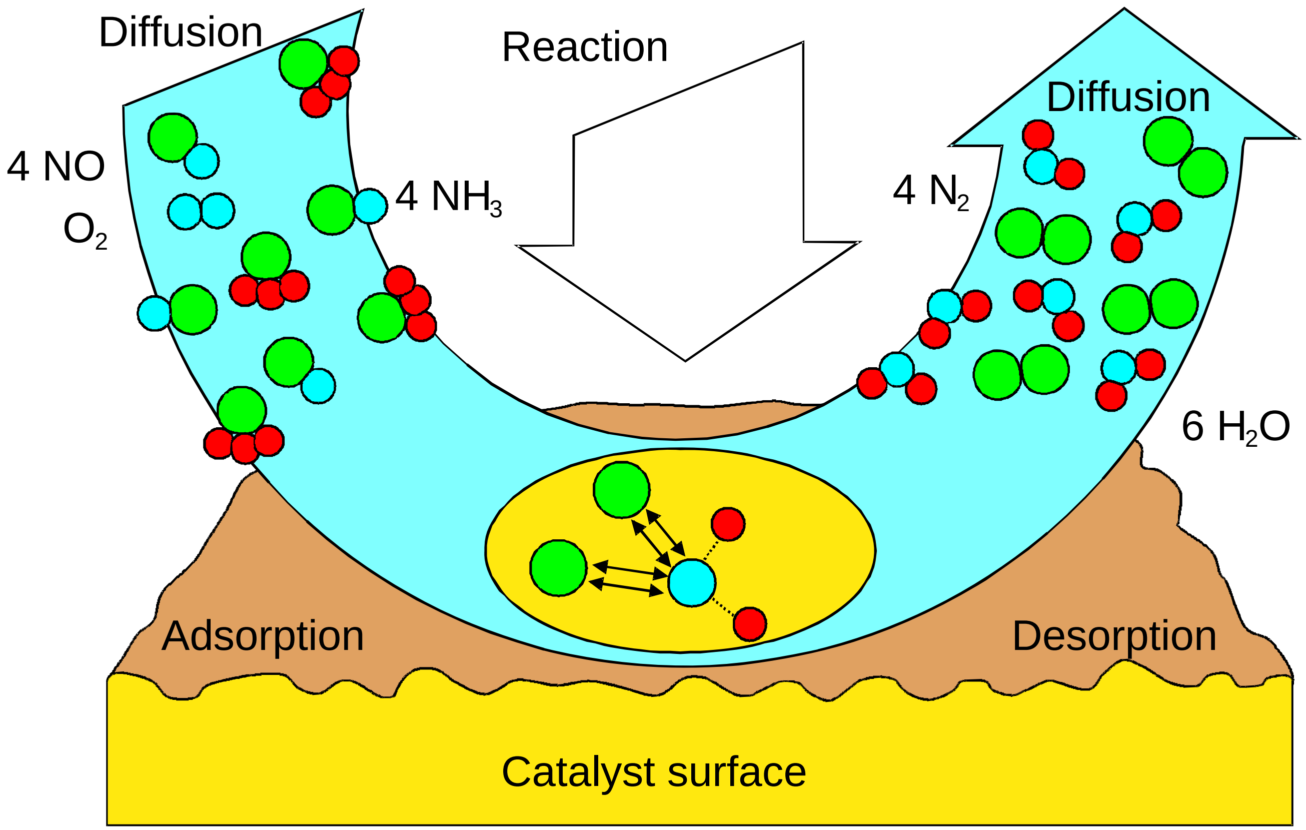
Basic SCR Chemistry



NO_x reactor occurs on catalyst pore surface

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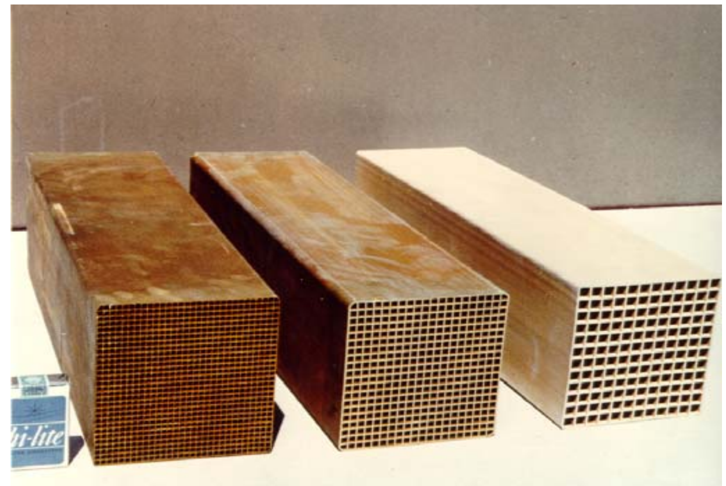
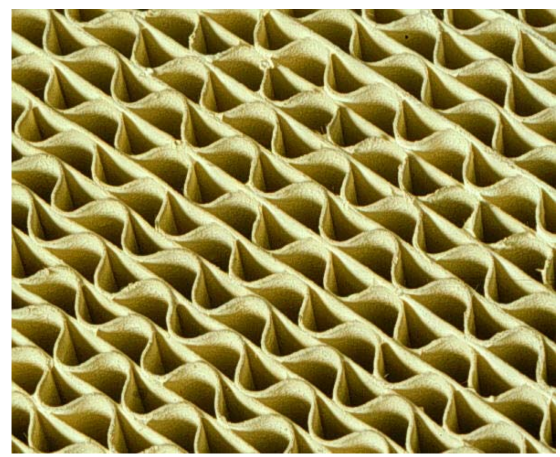
Catalyst - Types

- Honeycomb



- Plate

- Corrugated



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Catalyst Design

- Fuel Considerations
  - Sulfur content
    - Ammonium salts
    - Minimum continuous operating temperature
  - Ash loading
  - Arsenic in coal
  - CaO in flyash
- Ammonia Slip
- Catalyst Life
- SO_2 to SO_3 Conversion

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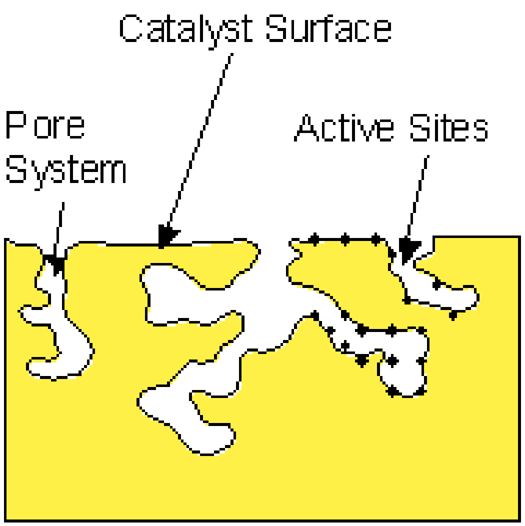
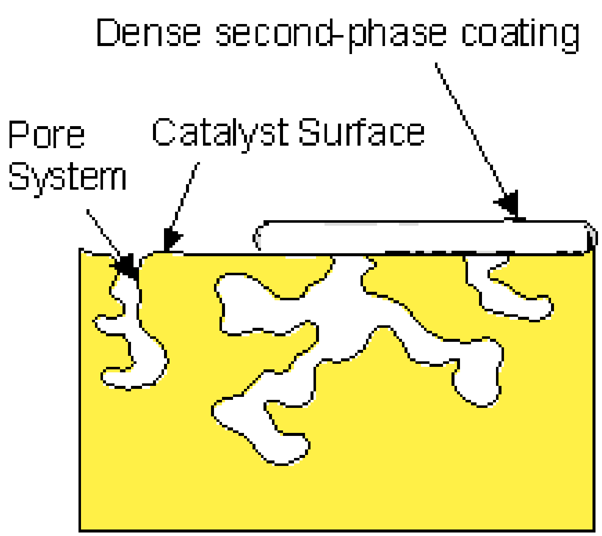
Catalyst – Deactivation

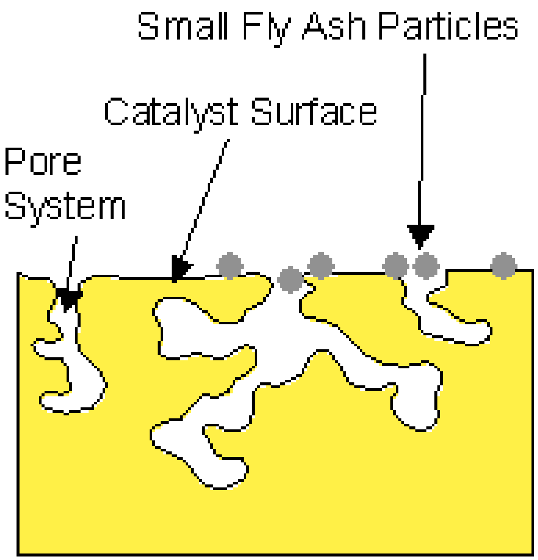
Poisoning:
Deactivation of active catalyst sites by chemical attack



Masking:
Macroscopic blockage of catalyst surface by dense second-phase coating



Plugging:
Microscopic blockage of catalyst pore system by small fly ash particles



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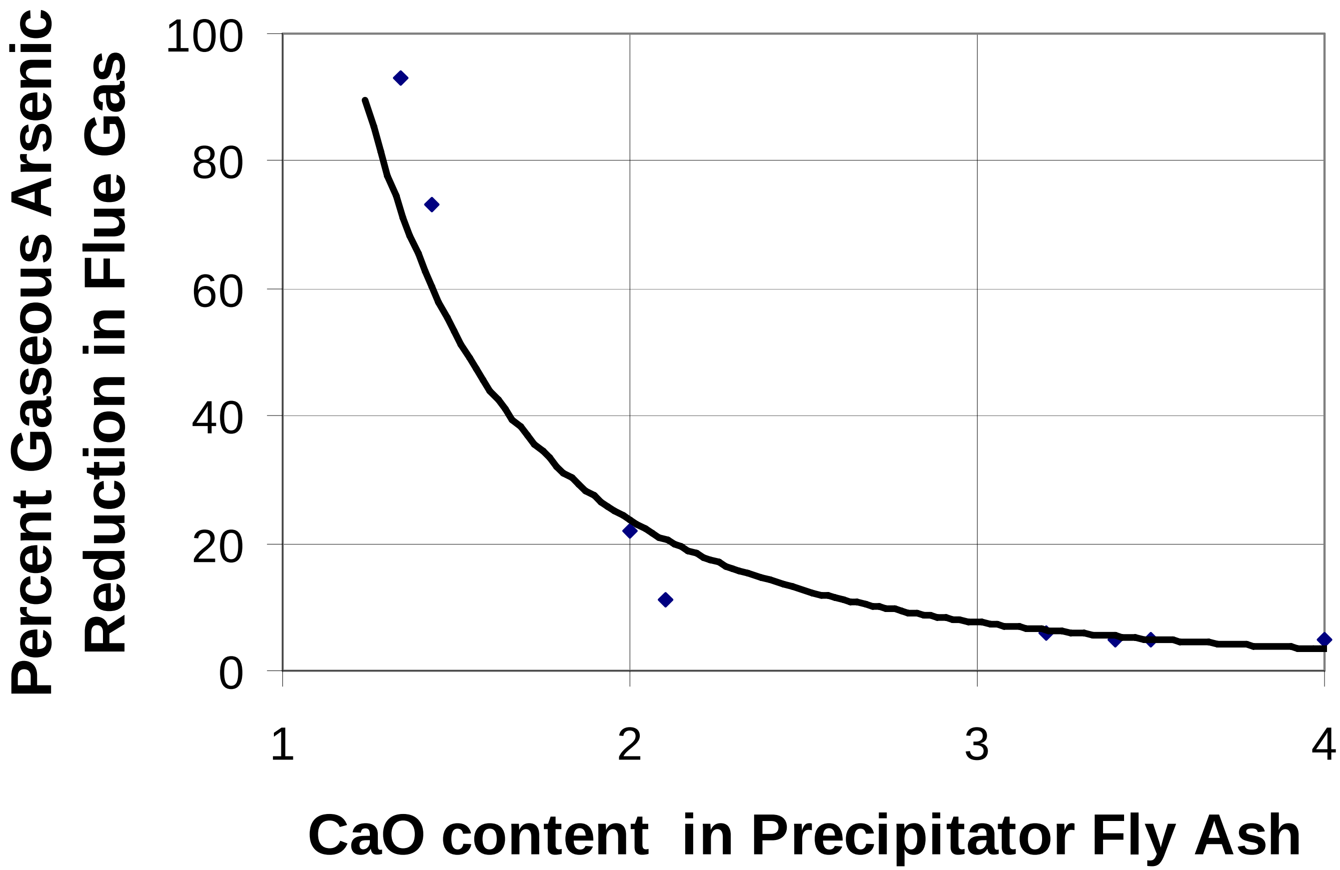
Catalyst – Arsenic Control



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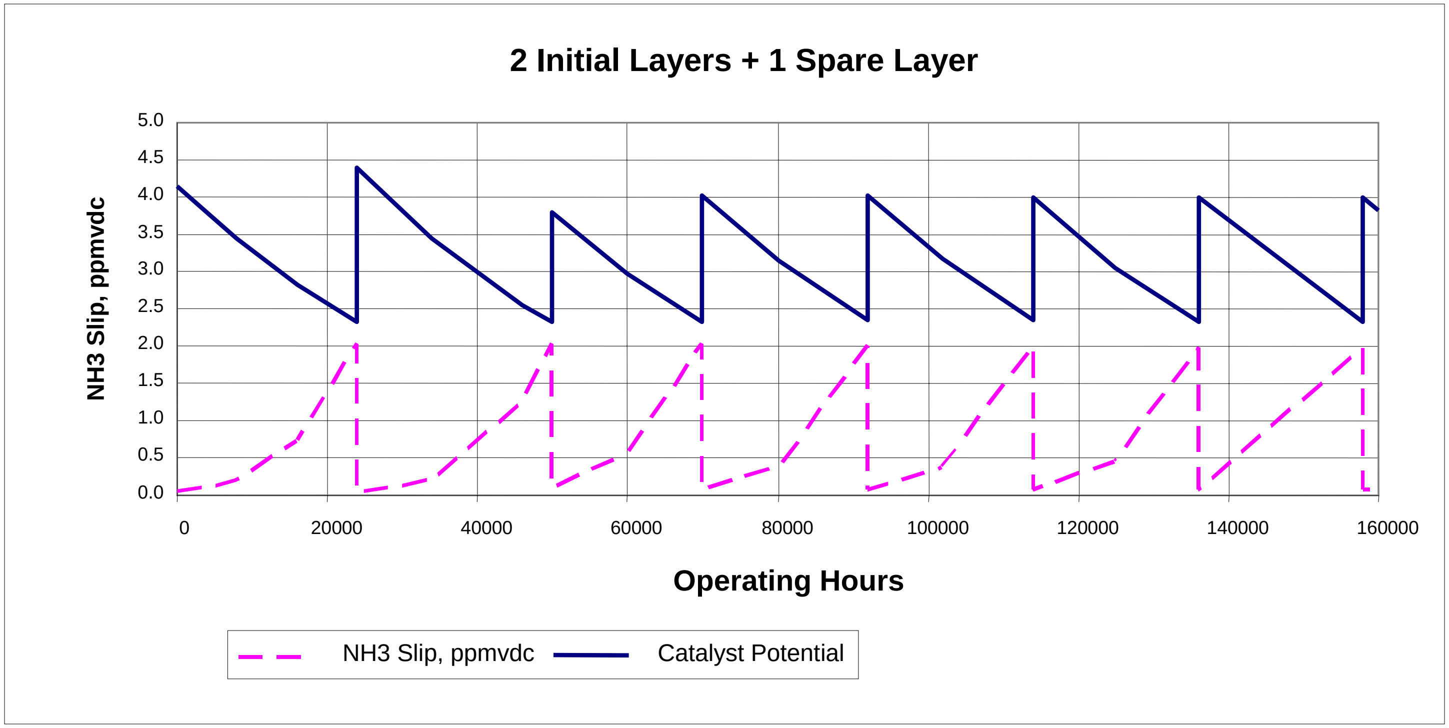
Catalyst – End of Life

- Period of time in which the catalyst will reach its designed slip



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Catalyst – Ammonia Slip

- Unreacted ammonia exiting SCR reactor
- Increases throughout life to design
- Need to control for ammonia salt pluggage
  - European experience 5 ppm slip
  - U.S. experience 2 ppm slip
- Function of NH_3/NO_x distribution
- Typical guarantee

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Catalyst – Cleaning

- Steam Sootblowers
  - Requires controlled steam quality, dry steam
  - Rake type sootblower
  - Required for high ash concentration (> 20 g/Nm^3)
- Sonic Horns
  - Compressed air requirements typical of service air
  - Low air quantities required
  - Continuous operation
  - U.S. application and popularity increasing

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Catalyst – Typical Mixing / Flue Gas Conditions

- Temperature ± 15 °C (27 ° F)
- Velocity ± 20%
- Flow Direction ± 10 °
- Inlet NO_x 5% rms from the mean
- NH_3/NO_x 5% rms from the mean

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Catalyst and Reactor Sizing

- Catalyst inlet velocity 12 to 14 ft/s
- Reactor size and structure to accept any catalyst type
- Spare catalyst layers as required per catalyst management
- Total reactor catalyst volume capacity for current and future fuels

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Catalyst Design Process

1) Design Input
2) Performance Requirements
3) Pitch Selection & Deactivation
4) Formulation
5) Final Design

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Catalyst Design Input

- Flue gas flowrate
- Inlet NO_x
- Flue gas composition
- Current and future fuel constituents
- Reactor cross section and number of layers
- SCR configuration
- Ash Loading
  - Properties
  - Large Particle Ash

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Catalyst Performance Requirements

- NO_x removal efficiency
- Ammonia slip at end of life
- Pressure drop
- Required SO_2 to SO_3 oxidation
- Catalyst life for initial volume
- Mixing performance

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Catalyst “Co-benefit” – Mercury Oxidation

- Mercury Speciation in Flue Gas
  - Elemental Mercury (Hg^0)
  - Oxidized Mercury (Hg^{2+})
  - Particulate Mercury (Hg_p)
- Mercury Removal in Flue Gas Desulfurization (FGD) Processes
  - Wet FGD removal
    - High removal of Hg^{2+} and Hg_p
    - No removal of Hg^0
  - Dry FGD removal
    - High removal of Hg^{2+} and Hg_p
    - High removal of Hg^0 for bituminous and no removal for sub-bituminous coals
- Catalyst Typically Oxidizes Hg^0 to Hg^{2+}

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Catalyst "Co-benefit" – Mercury Oxidation

- Mercury Oxidation Dependent on Multiple Factors
  - Fuel Composition (Primarily Cl)
  - Residence time or Space velocity
  - Flue Gas Temperature (Secondary)
- No Apparent Affect on Oxidation with Catalyst Variables
  - Formulation
  - Type
  - Age

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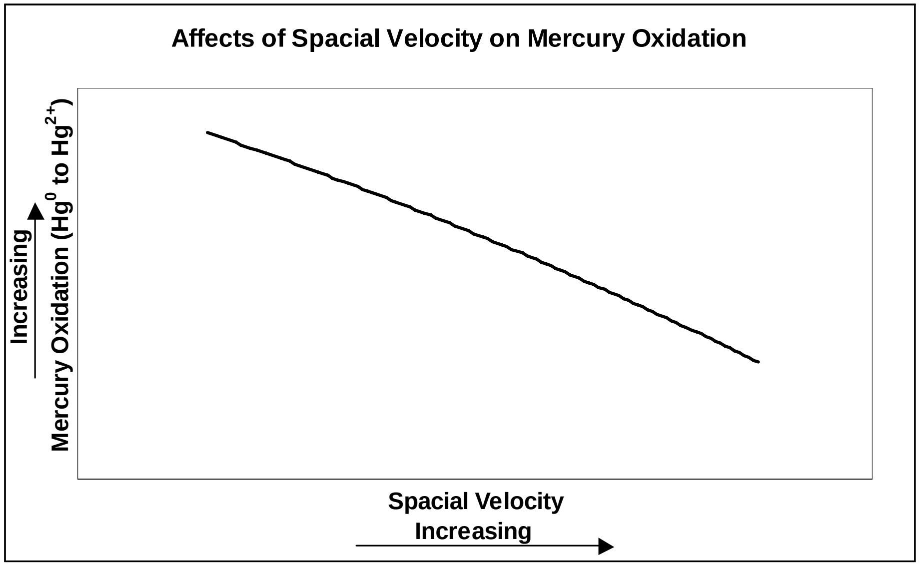
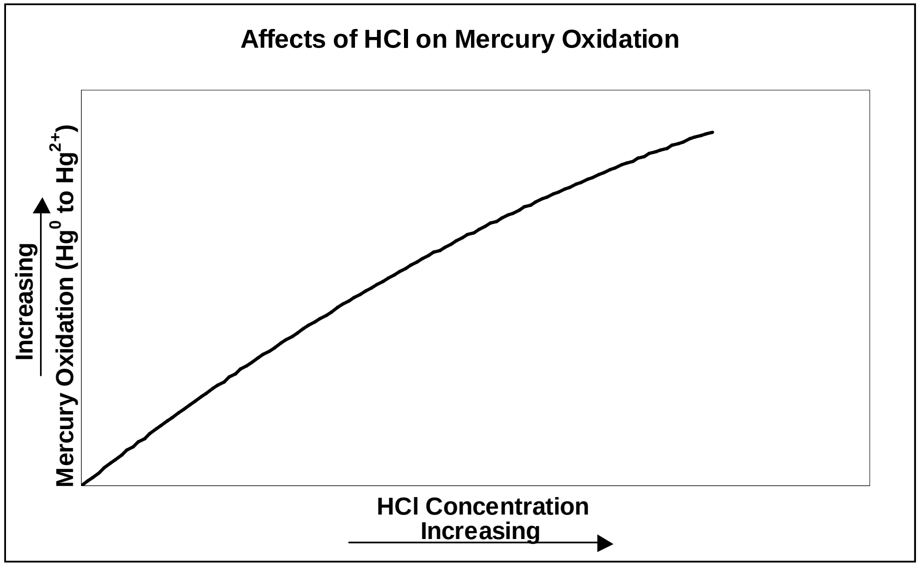
Catalyst "Co-benefit" – Mercury Oxidation

- Temperature Affects – Curve Shift





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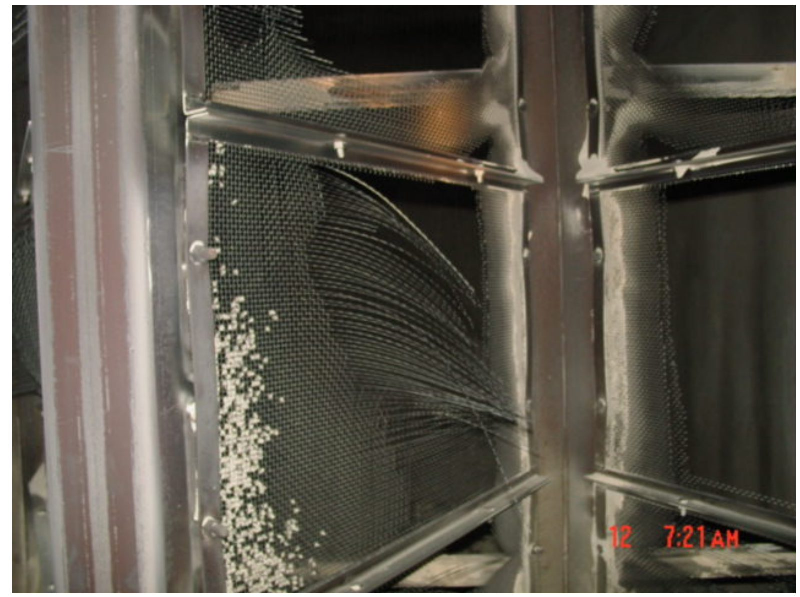
Large Particle Ash (LPA)

- LPA Properties
  - Size >4.0 mm
  - Density 0.7 to 1.25 g/cc
  - Sphericity 0.7 to 0.99
  - Coefficient of Restitution 0.15 to 0.2



- Screen Design Important
- Pluggage
- Erosion

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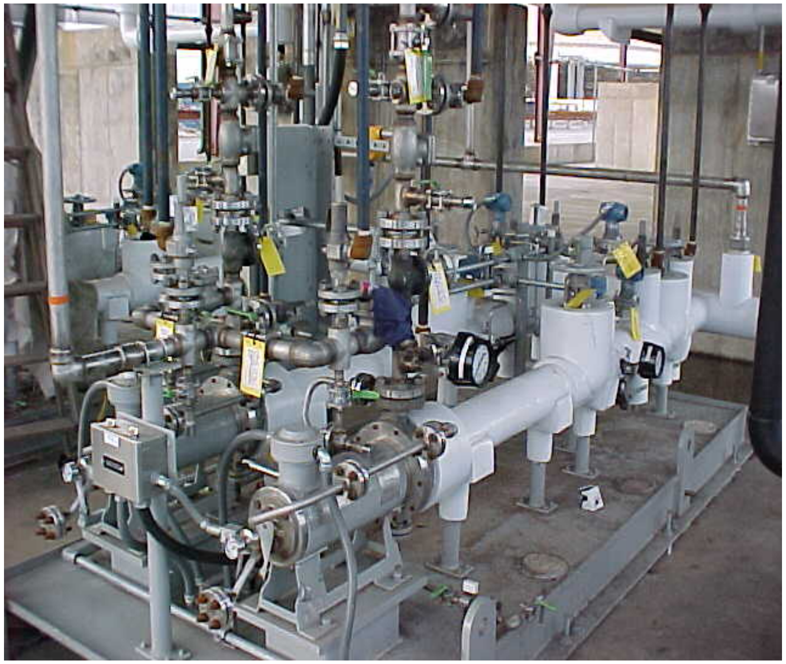
Ammonia Injection Systems

- **Anhydrous**
  - Vaporizers
  - Direct Injection
  - Dilution air, 5% by Volume
- **Aqueous**
  - Vaporizers
  - Direct Injection
  - Dilution air, 5% by Volume
- **Urea**
  - Direct Injection
  - Dilution air, 5% by Volume



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Ammonia System – Anhydrous Codes

- OSHA 29 CFR 1910.111, Storage and Handling of Anhydrous Ammonia
- ANSI/CGA K61.1, Safety Requirements for the Storage and Handling of Anhydrous Ammonia
- ASME B31.3, Process Piping

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Ammonia System – Anhydrous Equipment Selection

- Piping / Valves
  - No copper, brass, or galvanized steel
  - Conforming to ASME B31.3, Process Piping
  - Minimum number of threaded connections
  - Hydrostatic relief required on all isolatable sections
  - Leak / Pressure tests of system prior to service
  - All instrumentation suitable for anhydrous ammonia

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Ammonia System – Aqueous

- 3 Common concentrations
  - 9% Ammonia
  - 19% Ammonia
  - 29% Ammonia
- No definitive codes or standards
- Sound engineering practices need to be applied

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Ammonia System – Aqueous Equipment Selection

- Storage Tanks
  - ASME Section VIII
  - API 610
- Pumps same as anhydrous
- Pipes and valves
  - No definitive codes or standards
  - Typical ASME B31.1 acceptable
- Unloading by truck only

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Ammonia System – Urea

- Multiple conversion technologies available
- Typically delivered in dry or liquid form
- Best stored on site as liquid
- No definitive codes or standards
- Good engineering practice need to be applied
- Heat tracing critical
- Urea Quality Issues

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Static Mixers – Large Vortices

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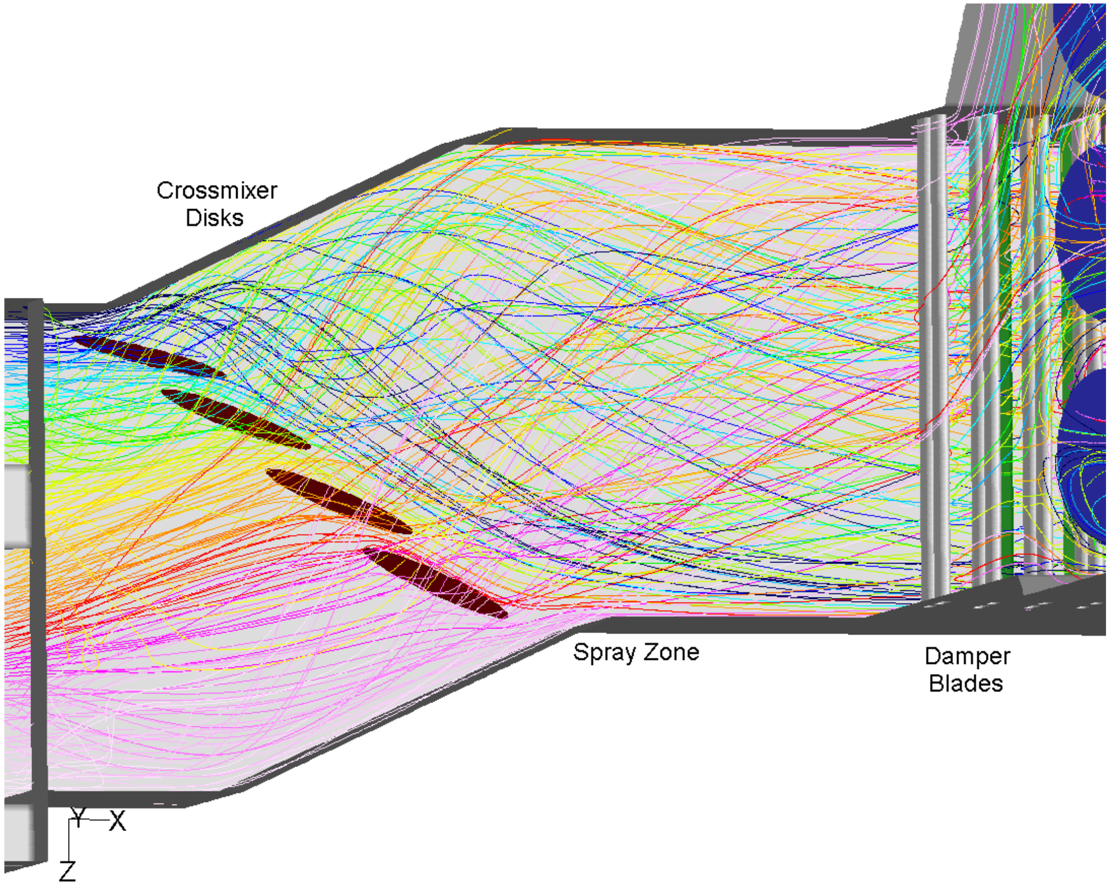
Mixing Prior to Ammonia Injection

Gas Flow from Boiler



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Flow Modeling - Goals

- Minimize Ductwork Pressure Drop
- Assure Mixing and Flow Distribution
- Study and Minimize Potential Ash Layout Areas
- Optimize SCR as Complete System
- Required on all Projects due to Changing Configurations
- Special Cases – Single Model for Two Units

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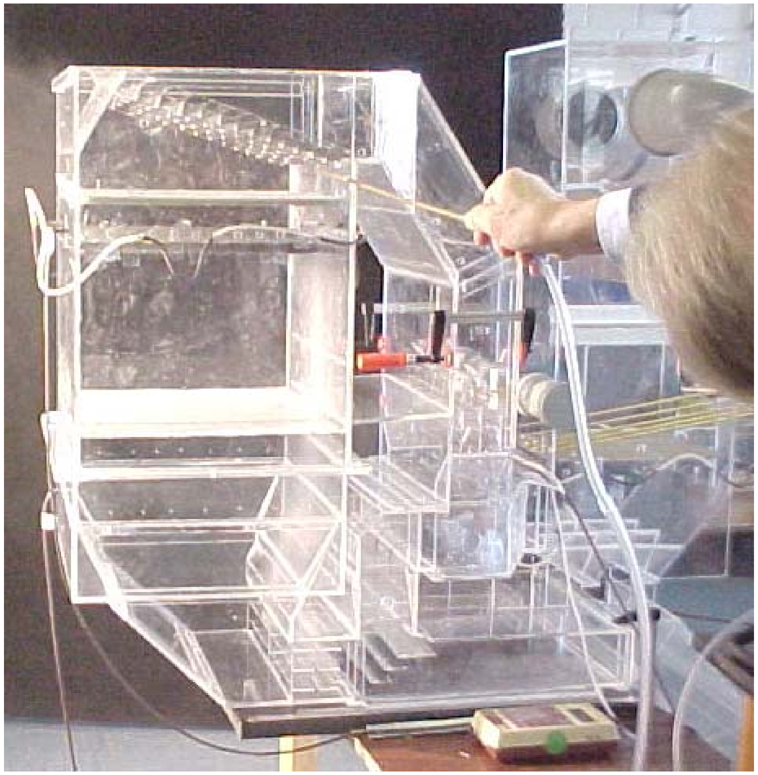
SCR Flow Models



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Thank You

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