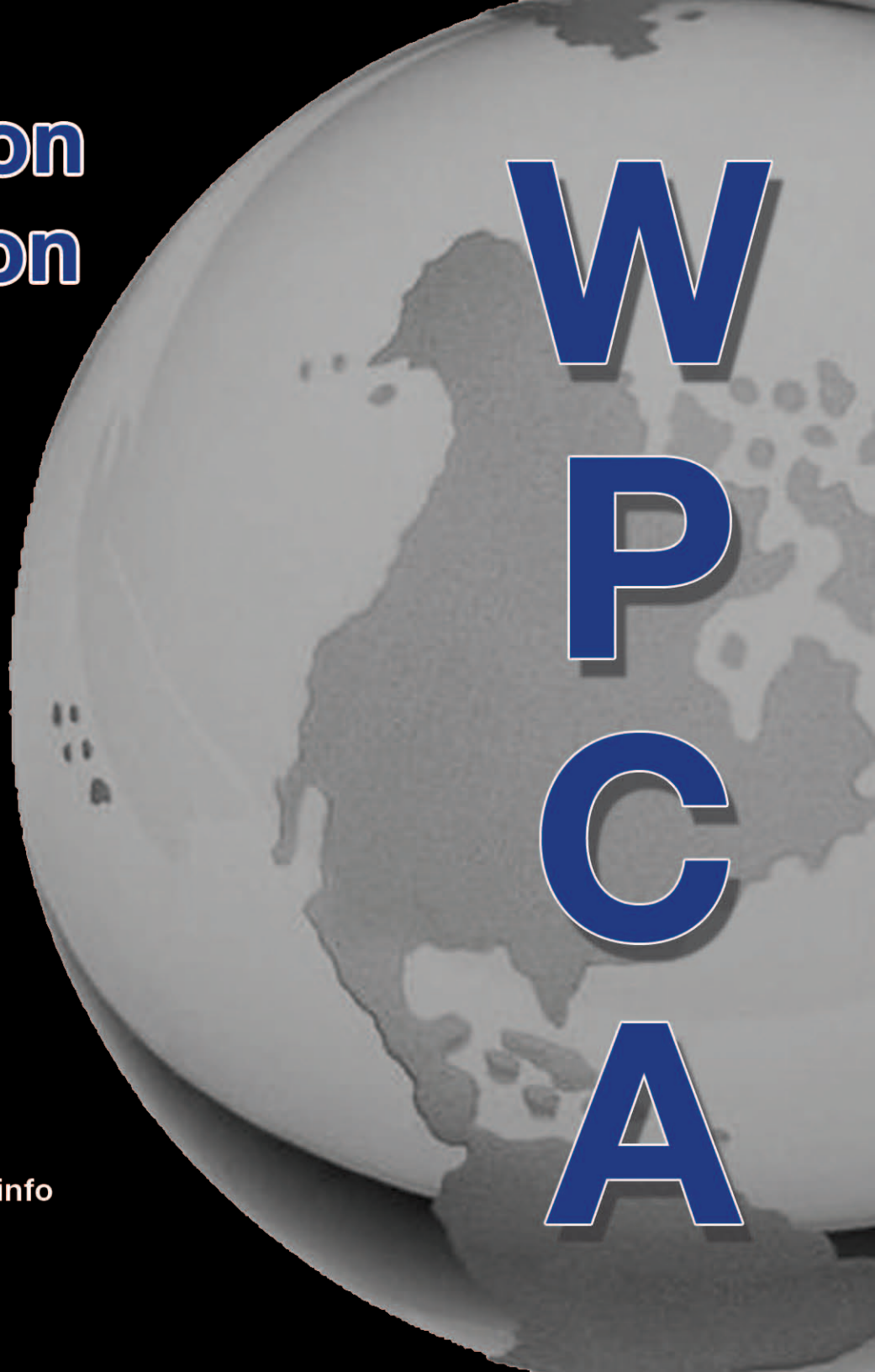
Worldwide Pollution Control Association



Duke Energy Seminar

September 3 – 5, 2008

Concord, NC

WPCA

Vist our website at www.wpca.info

One Source…Many Solutions…One Purpose

Overview of SCR's

Terence Ake
Process Engineering
Babcock Power, Inc.

Agenda
Overview of SCR Systems

- Definitions
- NO_x Formation
- Chemistry & Catalyst
- SCR Reactor and Ductwork
- Ammonia Storage and Supply
- Ammonia Injection and Flue Gas Mixing
- Controls and Instrumentation
- Testing and Commissioning

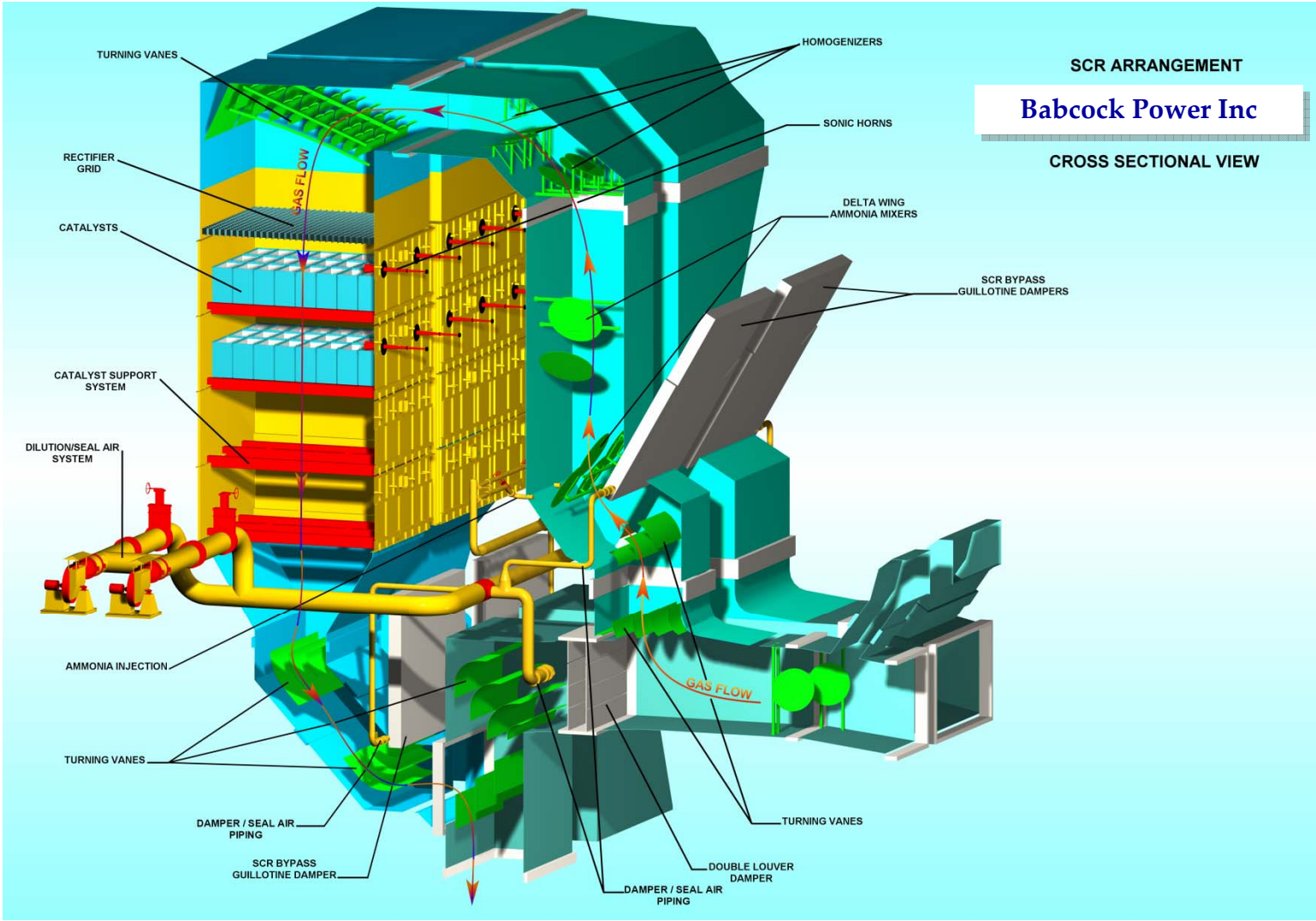
DEFINITIONS

- SCR = Selective Catalytic Reduction
- NO_x = Nitrogen Oxides, (NO or NO_2)
- NH_3 = Ammonia
- Catalyst = Increases reaction without being consumed

Atmospheric NO_x forms Nitric Acid (HNO_3), a component of acid rain.

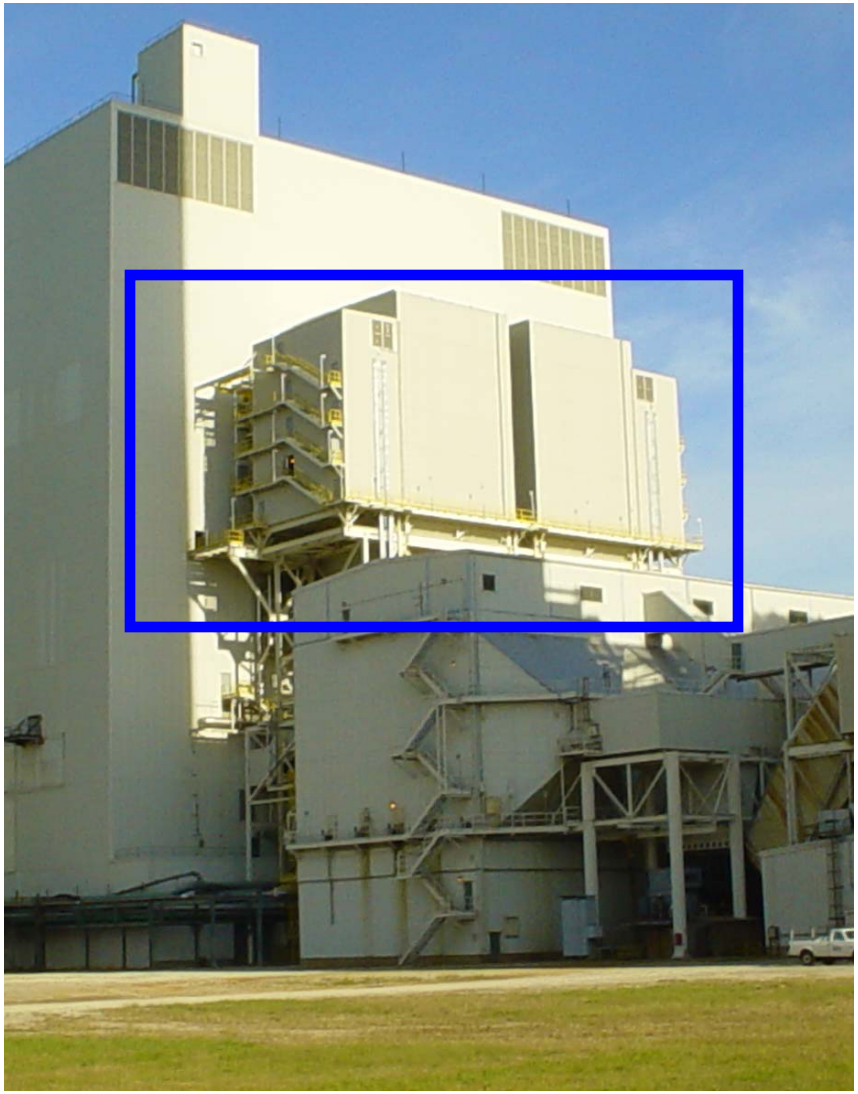
Ground Level Ozone (O_3) forms from sunlight and NO_x.

SCRs remove NO_x from boiler flue gas before it is emitted to the atmosphere by reacting it with NH_3 over a catalyst.

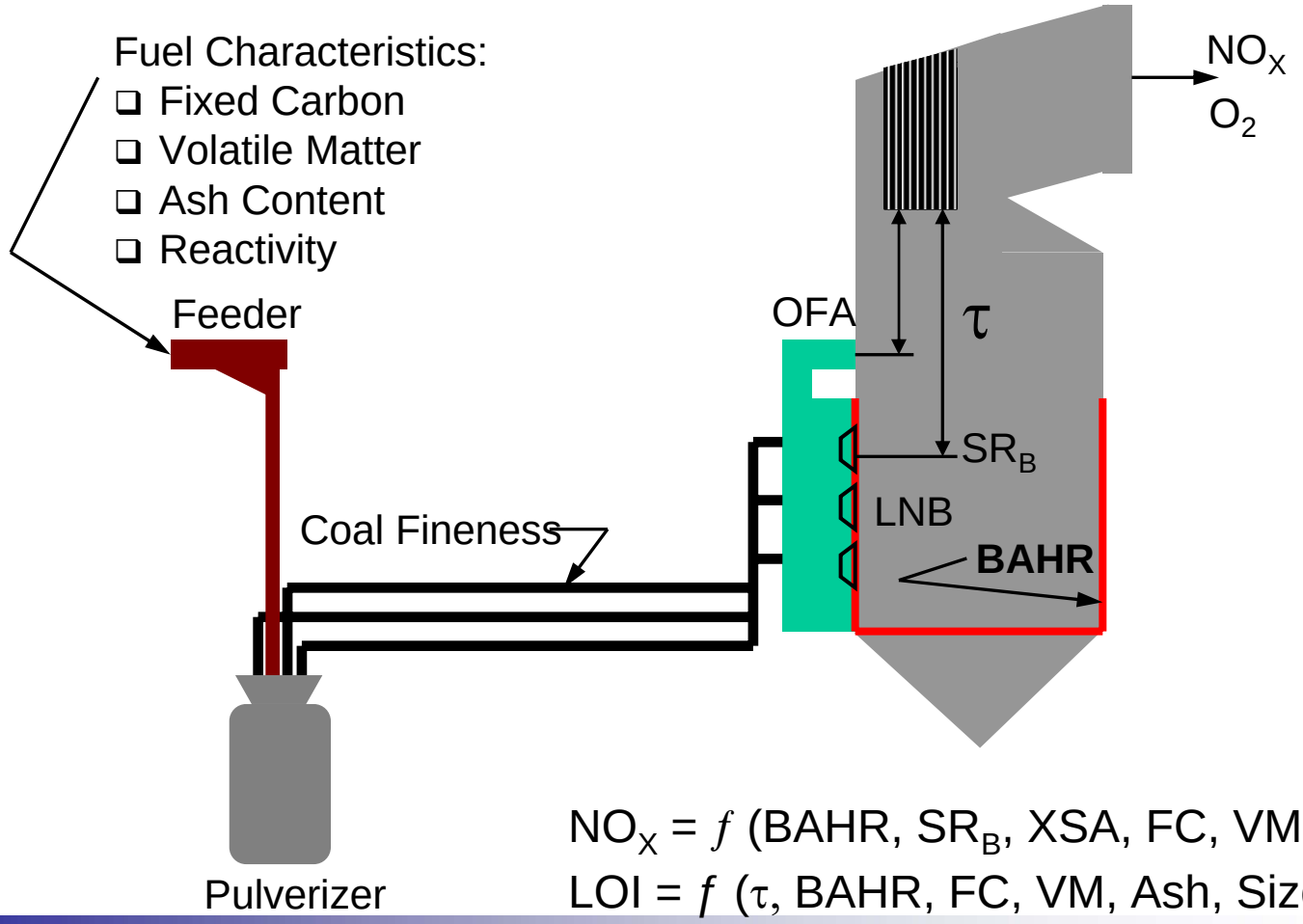


Typical SCR Installation

- LG&E Trimble County Power Plant
  - 90% reduction SCR system
  - Low NOx Burners (0.32 lb/MBtu)
  - WFGD System
  - High Sulfur Coal Design (~4%)



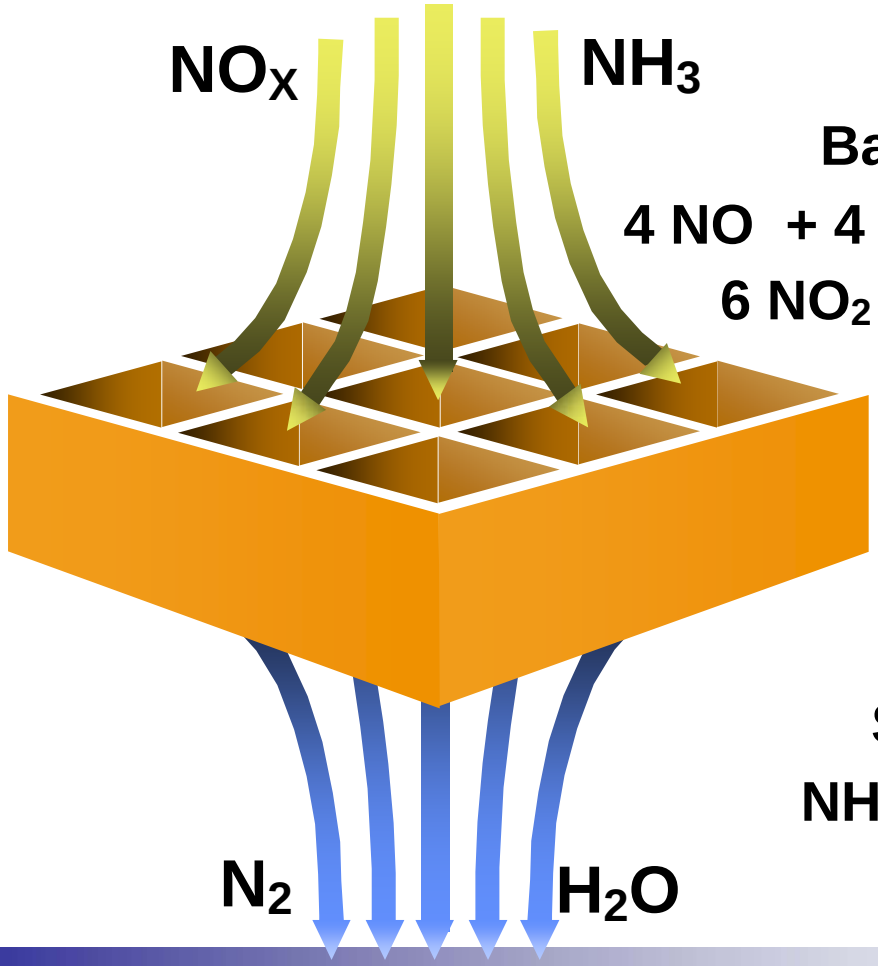
NO_X Formation in a Coal Fired Boiler



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

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

NOx Reduction in SCR



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

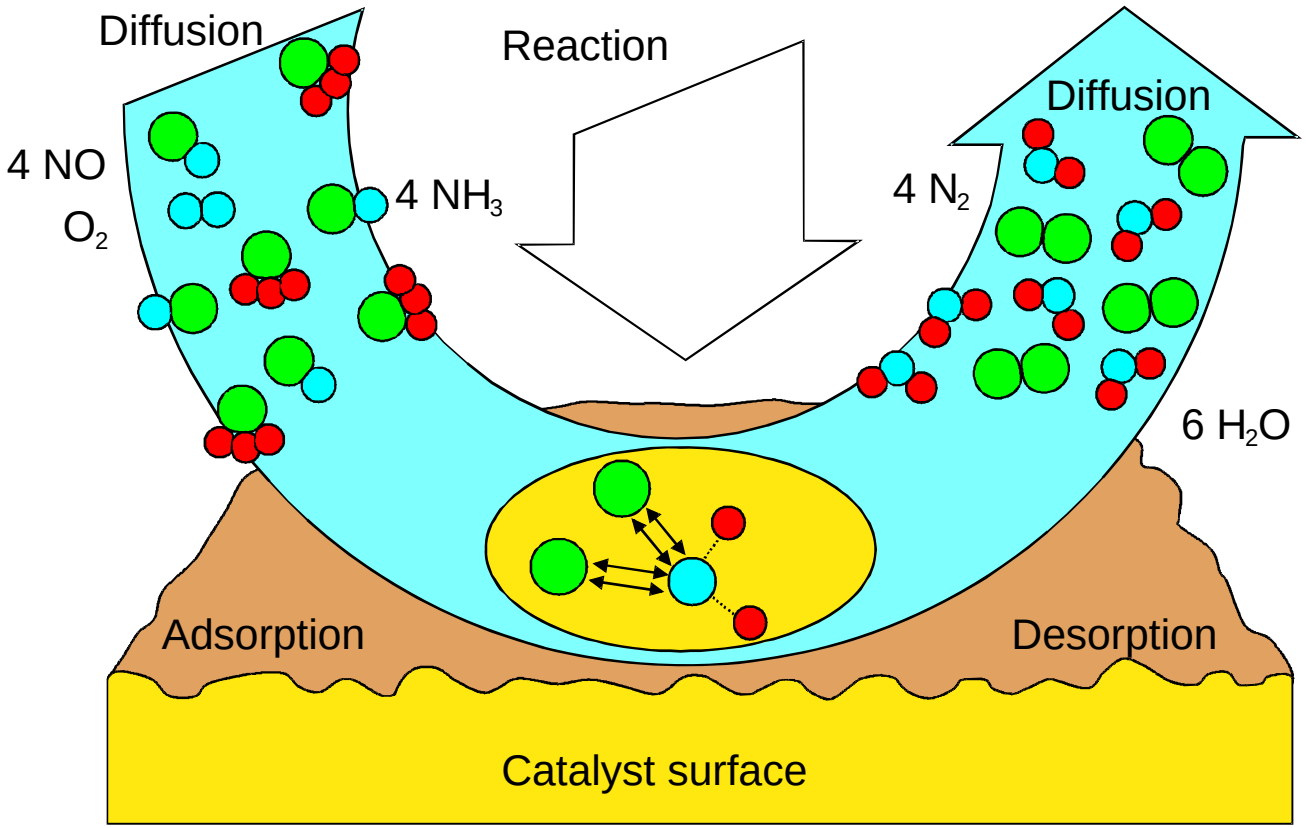
95% NO & 5% NO_2

Undesirable side reactions

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

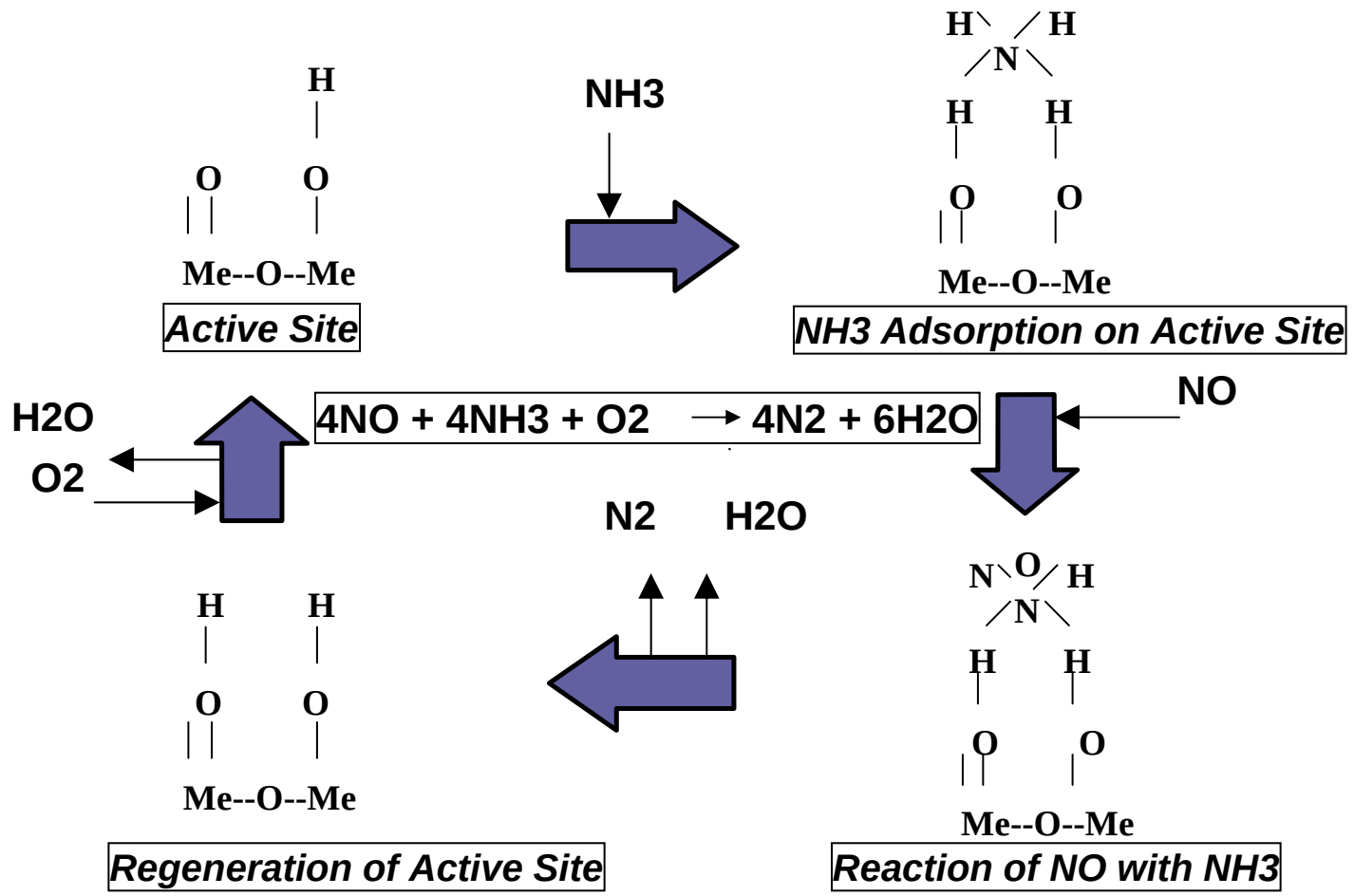
$$NH_3 + SO_3 + H_2O \rightarrow NH_4\ HSO_4$$

Chemistry & Catalyst



NO_x reduction occurs on catalyst surface

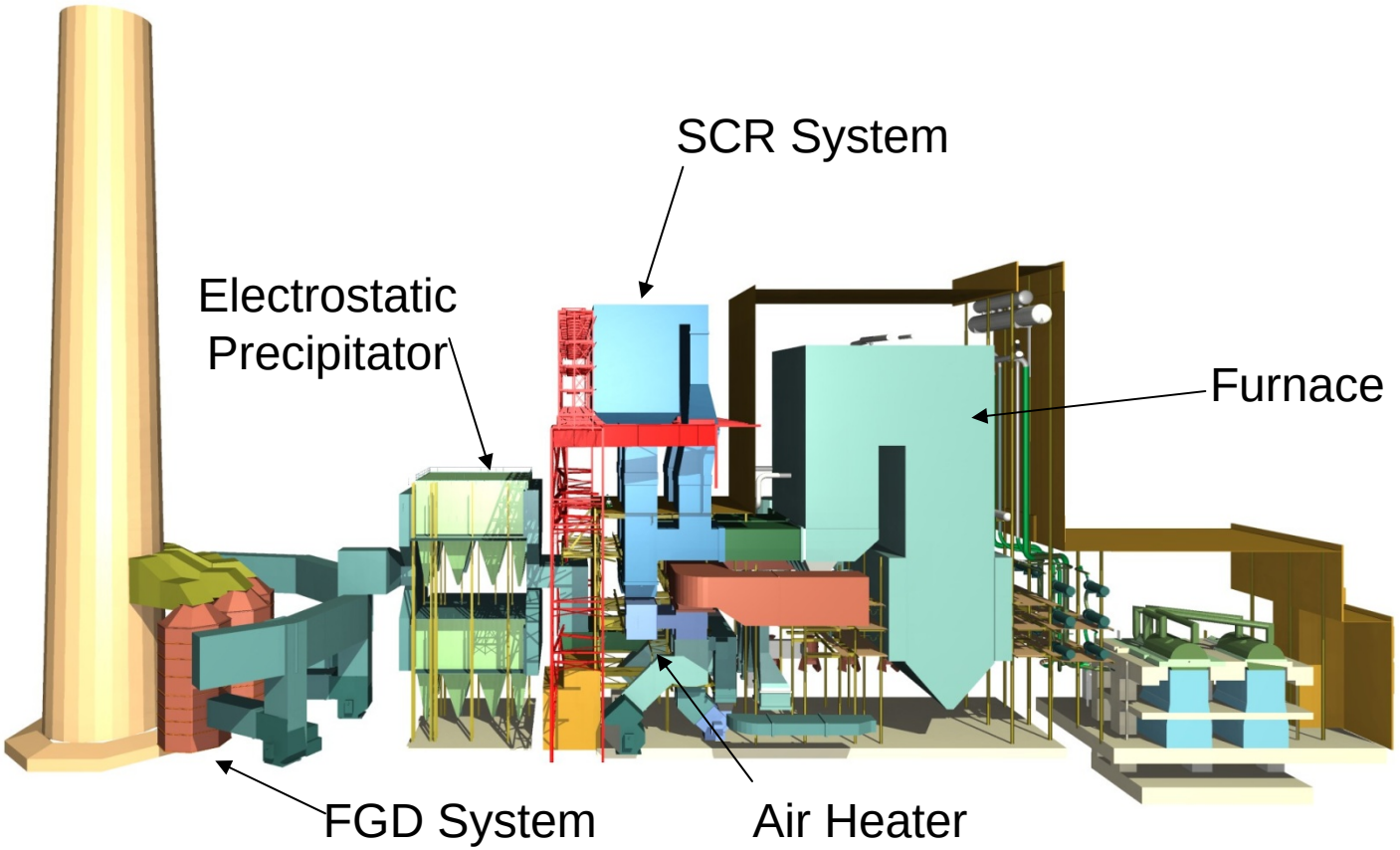
SCR Catalyst Surface Reactions



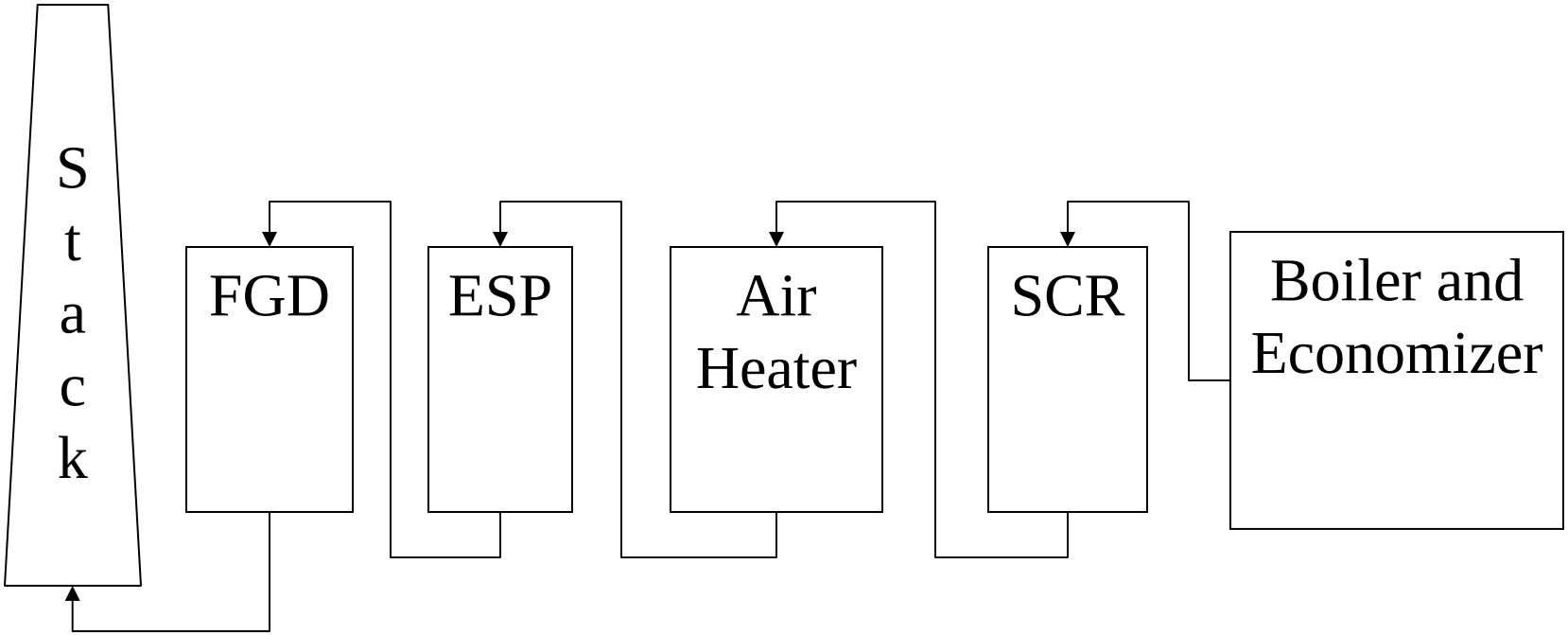
SO_2 to SO_3 Conversion

- Furnace conversion rates 0.1 to 1.5%
- SCR conversion occurs inside catalyst wall
- System component removal varies
- Stack rule of thumb
  - 10 ppm H_2SO_4 Dry stack
  - 5 ppm H_2SO_4 Wet Stack

SO_3 Balance – Flue Gas System



SO_3 Balance – Diagram



Parameters Affecting SO_3 Production and Capture in Furnace

- Slagging and fouling characteristics of coal
- Sulfur content of fuel
- Furnace type, wet bottom, cyclone or dry bottom
- Alkali content of fuel
- Furnace exit gas temperatures, equilibrium concentration and reaction kinetics
- Furnace gas retention times, kinetic formation rate
- Typical furnace conversion 0.1 to 1.8%

Parameters Affecting SO_2 to SO_3 Conversion In SCR System Catalyst

- SCR reactor operating temperature, strong function - increased inlet temperatures increases SO_3 conversion
- SO_2 inlet concentration, increased inlet SO_2 decreases SO_2 to SO_3 percent conversion rate
- NH_3 inlet concentrations and NH_3/NO_x ratios, increased NH_3 decreases SO_3 conversion
- O_2, H_2O and NO_x inlet concentrations, weak functions in coal fired operating ranges
- Typical catalyst conversion 0.8 to 3.0% (Full reactor)

Parameters Affecting SO_3 Capture in Air Heaters and Electrostatic Precipitator (ESP)

- Type of air heater, regenerative or tubular
- Operating flue gas and air temperatures
- Fly ash alkali content with respect to inlet SO_3 concentration
- Air leakage rates affecting gas temperatures
- Type of ESP, cold or hot
- Typical capture 25 to 70%

Parameters Affecting SO_3 Capture in FGD Systems

- Type of FGD system, wet, semi-dry, or dry
- Absorber configuration, counter or concurrent flow
- Absorber gas velocities and pressure loss
- Absorber inlet temperature
- Absorber operating parameters - L/G
- Typical capture 25 to 60%
  - Gaseous vs Aerosol Removal

Case Study Low Sulfur Bituminous Coal (< 1.5%) Plant Operating Parameters

- Furnace SO_2 to SO_3 conversion 0.33 to 1.8% (furnace type and ash alkali dependent)
- Regenerative air heater SO_3 capture rate 25 to 70% (temperature and ash alkali dependent)
- Tubular air heater SO_3 capture rate ~10%
- ESP SO_3 capture rate 0 to 20%

SO_3 Balance – Potential Mitigations

- Furnace alkali addition, MgO injection or limestone addition to fuel.
- SCR catalyst temperature control, design or operating
- SCR catalyst selection
  - High vs low conversion
- Ammonia injection after air heater
- Alkali injection after air heater

Case Study High Sulfur Coal (> 2.5%)
Plant Operating Parameters

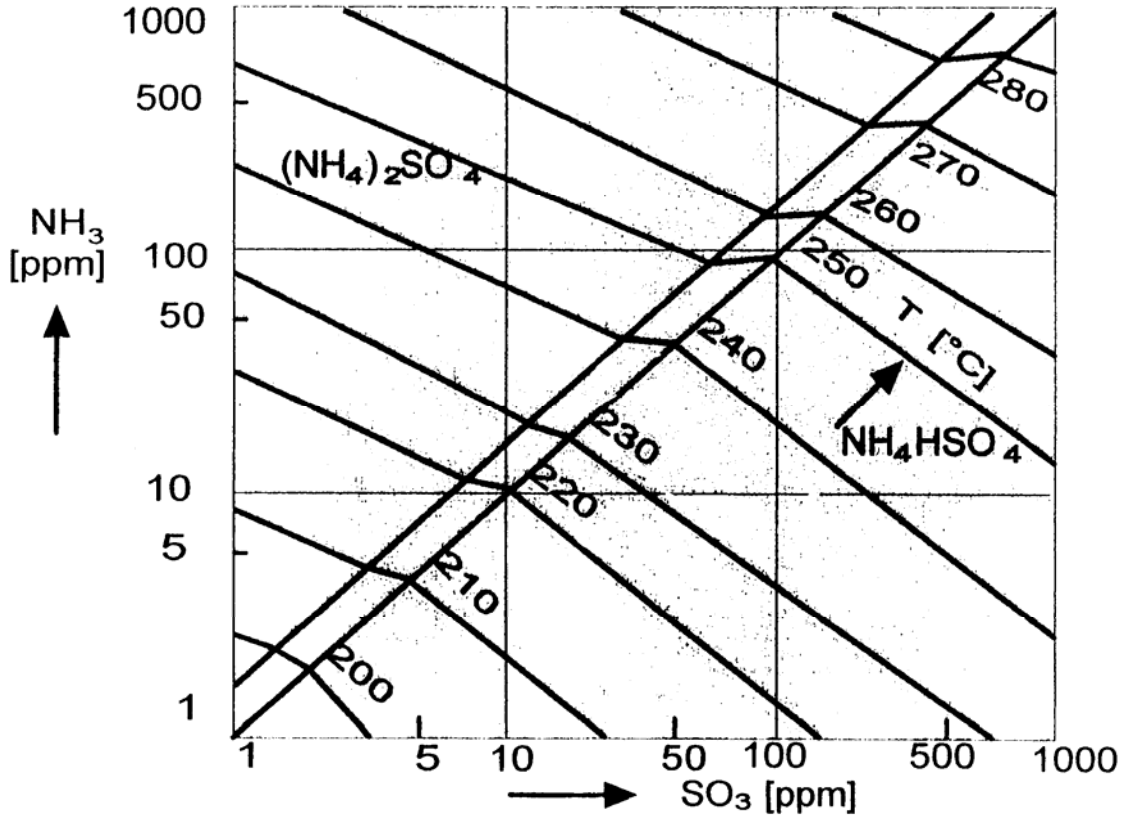
- Furnace SO_2 to SO_3 conversion 0.8 to 1.25%
- Air heater SO_3 capture rate 15 to 35% (temperature dependent)
- ESP SO_3 capture rate 0 to 5%
- WFGD SO_3 capture rate 40 to 50%

Case Study PRB Coal
Plant Operating Parameters

- Furnace SO_2 to SO_3 conversion 0.1%
- Air heater SO_3 capture rate ~0%
- ESP SO_3 capture rate ~0%
- SO_3 concentrations are within the resolution of the test measurement equipment

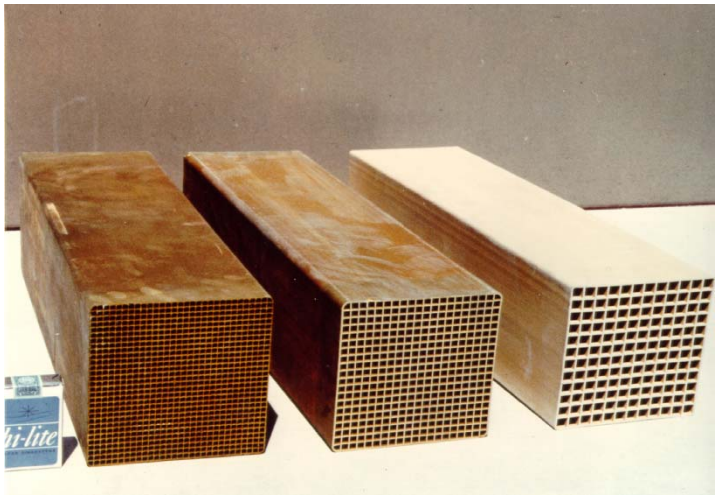
Minimum Catalyst Operating Temperature

- SCR inlet SO_3, NH_3 and H_2O
- Varies with fuel
- Catalyst pore size effects



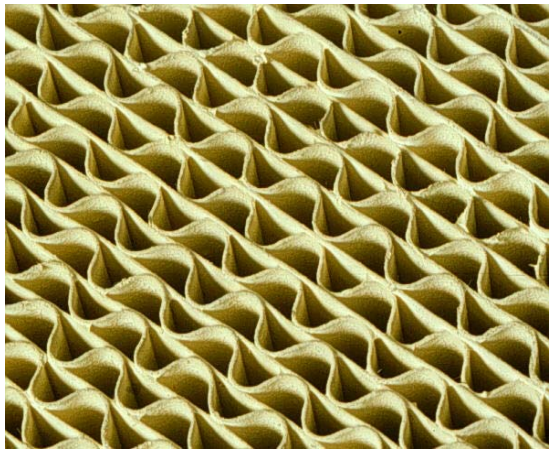
SCR Catalyst Types

- **Honeycomb**



- **Plate**

- **Corrugated**



Chemistry & Catalyst

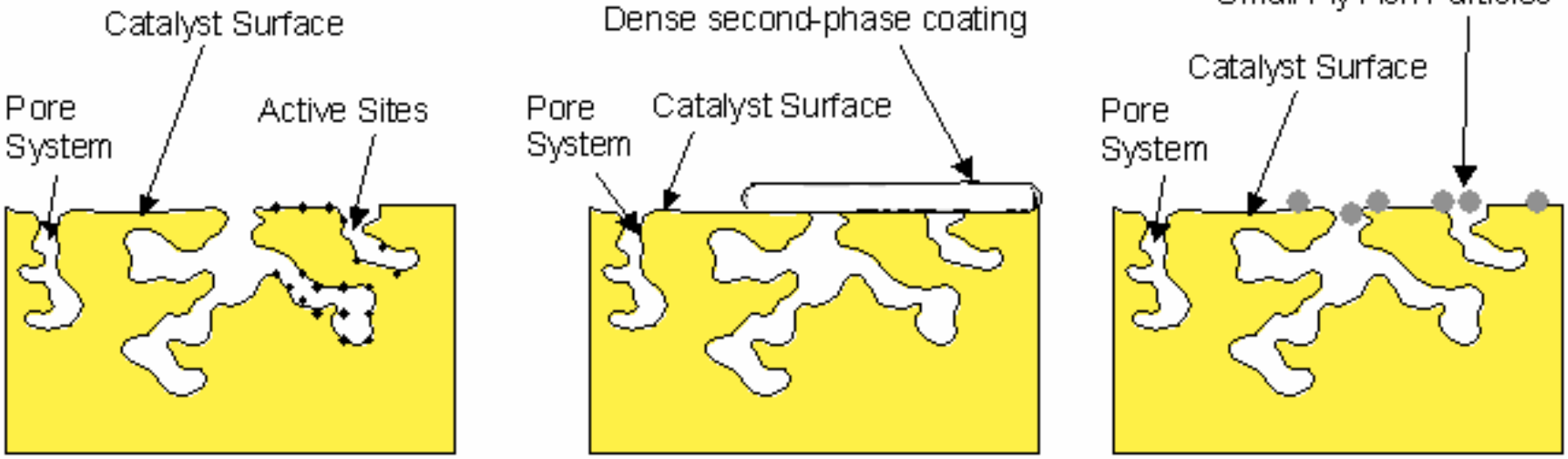
- Major Catalyst Deactivation Issues
  - Arsenic
  - CaO
  - Ash Content
  - Ammonia Bisulfate

Chemistry & Catalyst

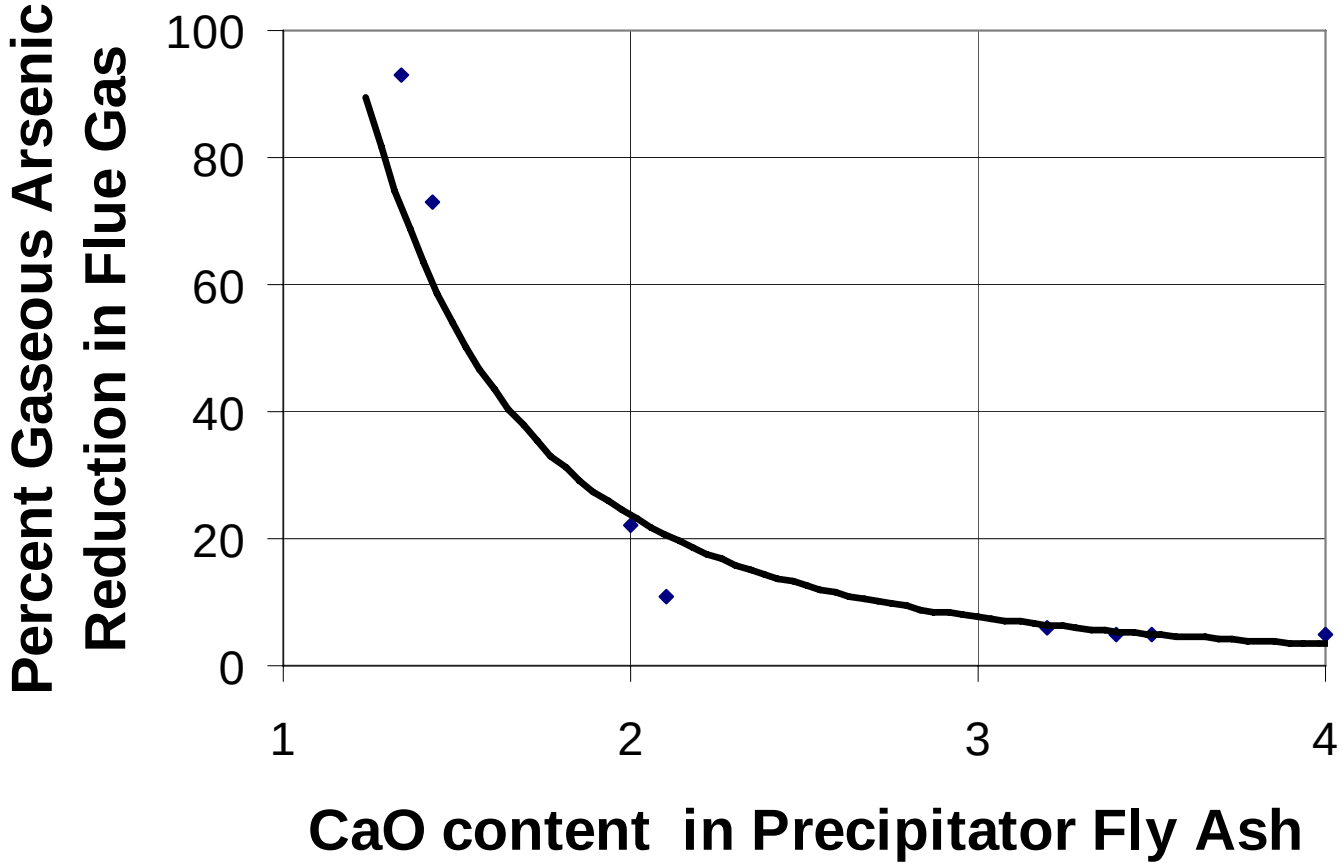
Poisoning:
Deactivation of active catalyst sites by chemical attack

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

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

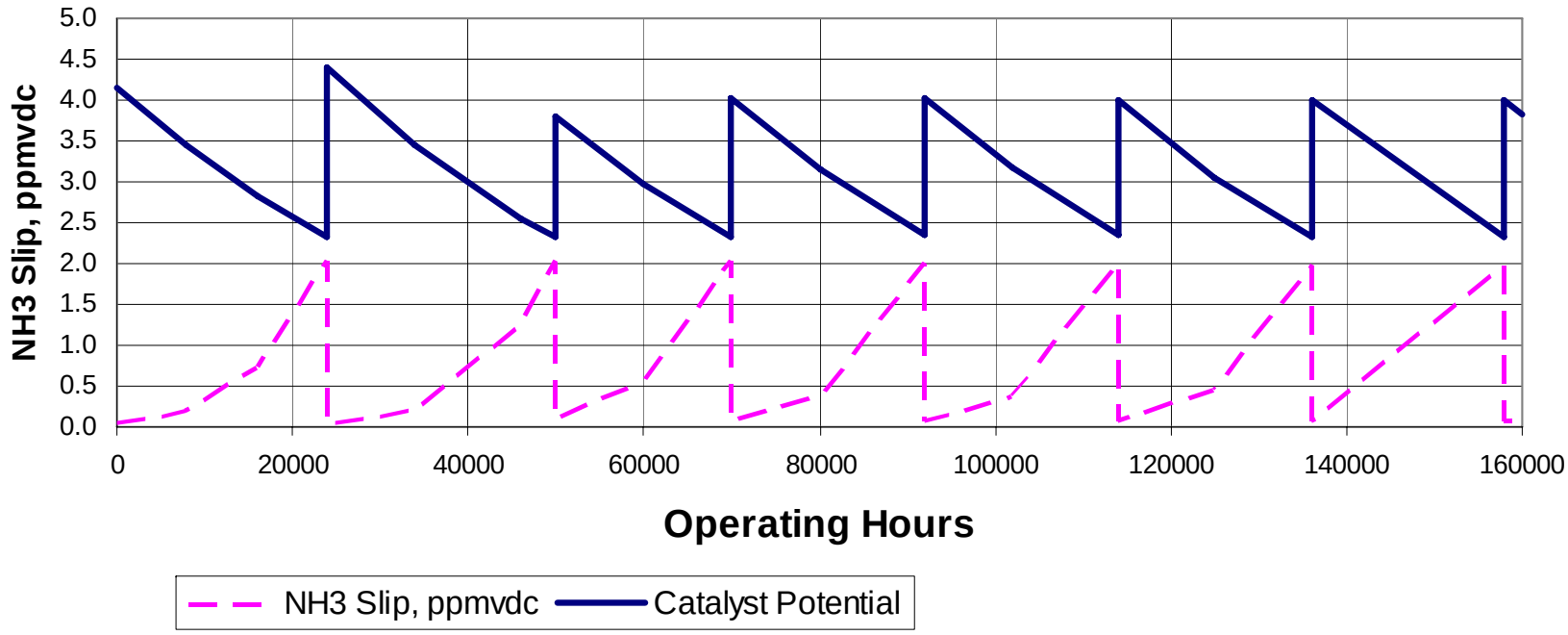


Control of Flue Gas Gaseous Arsenic



Catalyst Management Plan

2 Initial Layers + 1 Spare Layer

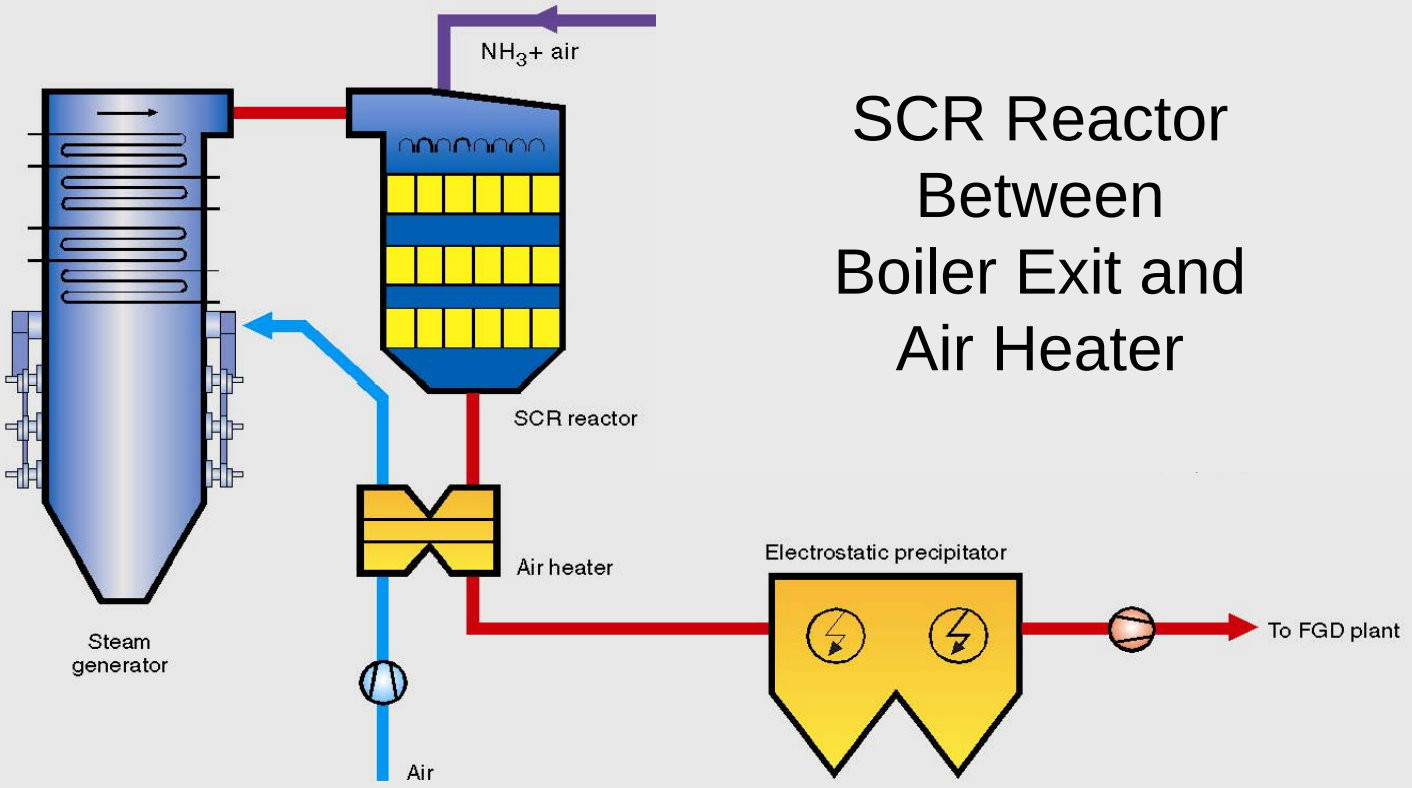


Catalyst Loading and Unloading

SCR Reactor and Ductwork

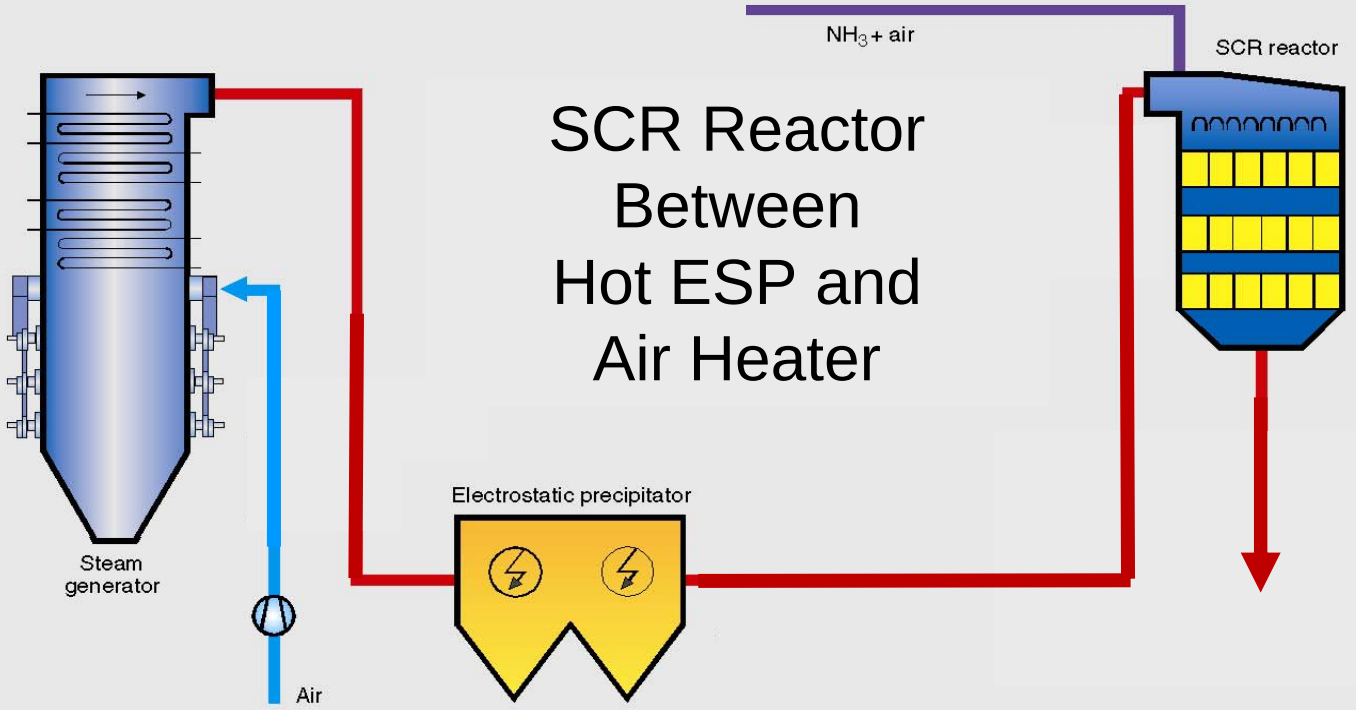
- SCR System Configurations
- Damper and SCR Bypass Configurations
- Low Load Temperature Control
- Catalyst Cleaning
- Large Particle Ash (Popcorn ash)

High Dust Arrangement

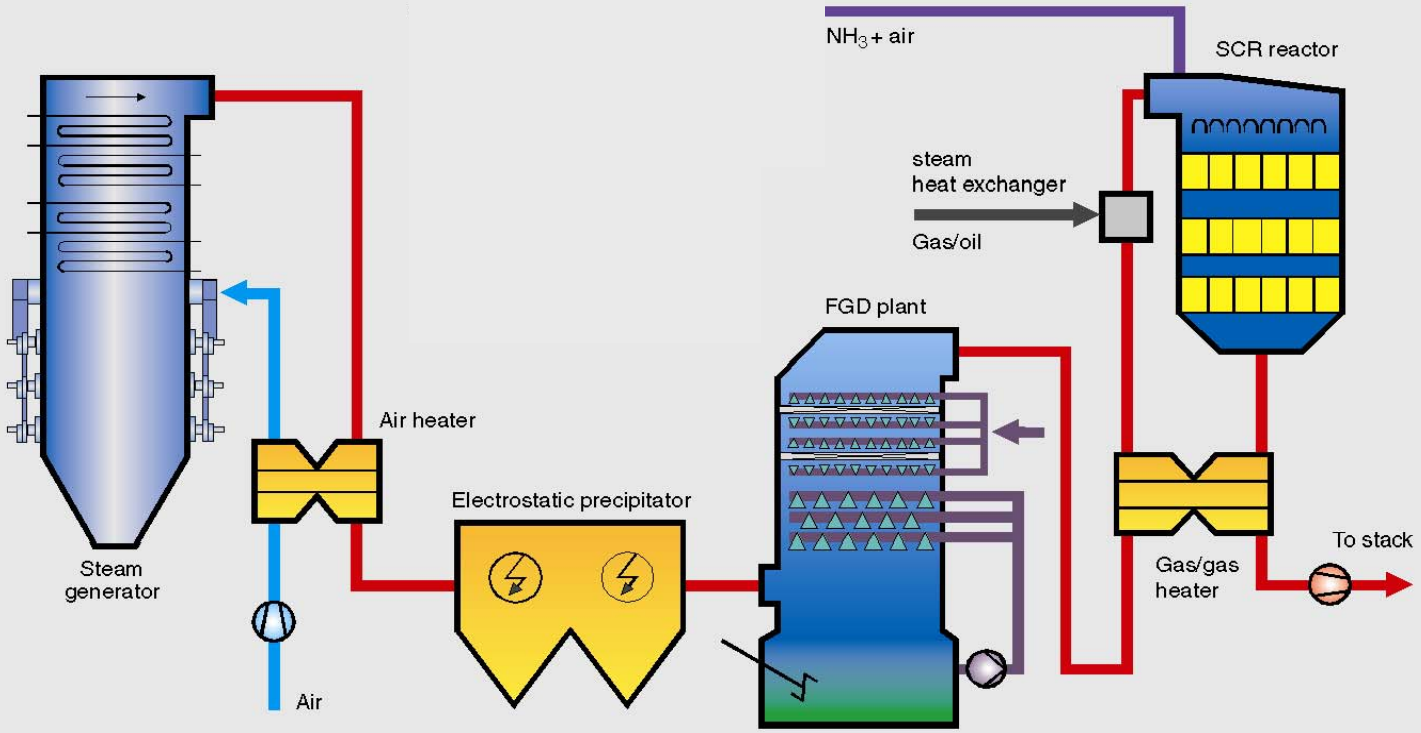


SCR Reactor Between Boiler Exit and Air Heater

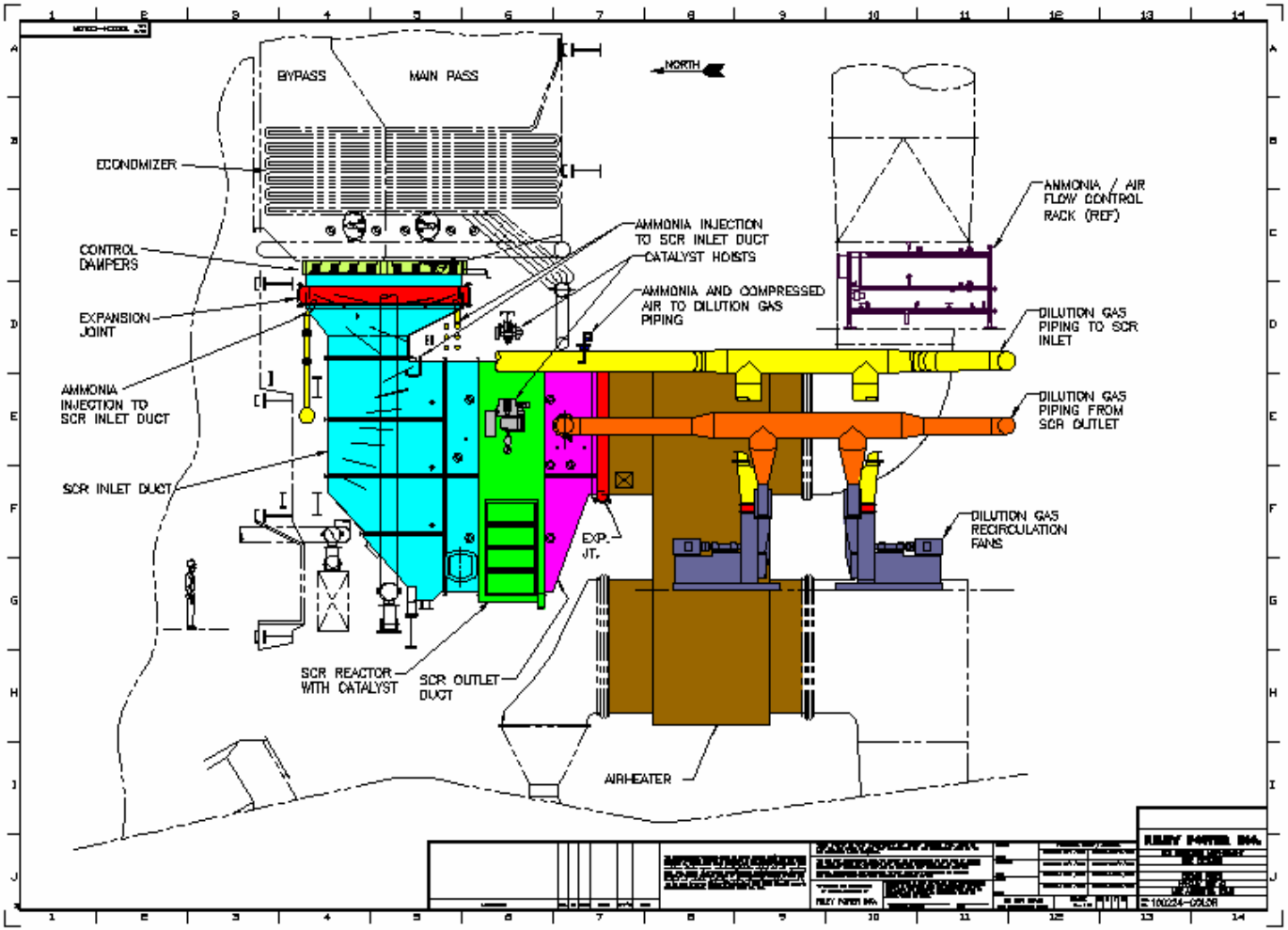
Low Dust Arrangement



Tail End Arrangement



In Duct SCR



SCR Reactor and Ductwork

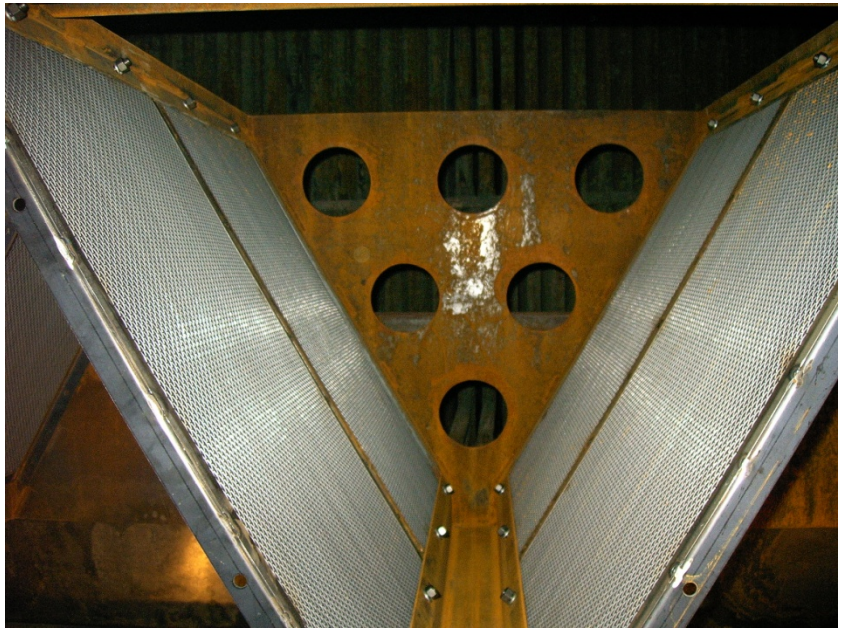
- Full SCR bypass
  - Able to isolate reactor during operation and startup
  - No catalyst deactivation during non-ozone season
- Partial SCR bypass for startup
  - Able to isolate during startup only
- No SCR bypass or dampers

SCR Reactor and Ductwork

- Low Load Temperature Control
  - Flue gas economizer bypass
  - Economizer water side bypass
  - Split economizer
  - Feed water heater pegging
- Catalyst Cleaning
  - Steam rake type soot blowers
  - Sonic horns

Large Particle Ash Removal

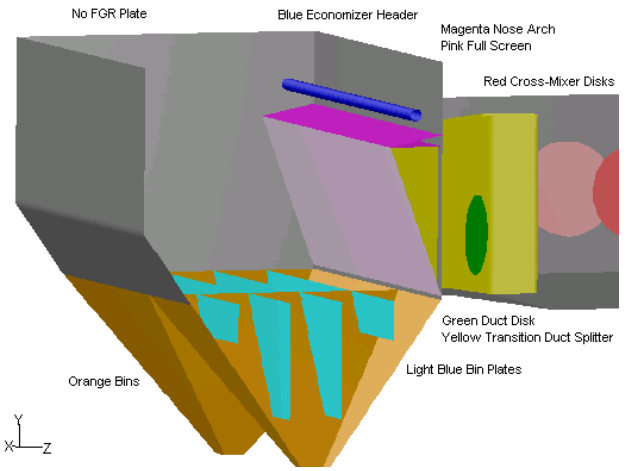
- LPA Properties
  - Size >4.0 mm
  - Density 0.7 to 1.25 g/cc
  - Sphericity 0.7 to 0.99
  - Coefficient of Restitution 0.15 to 0.2

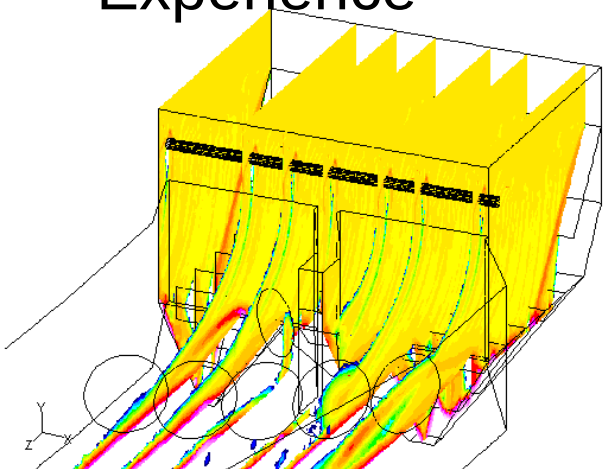


- Screen Design Important
- Pluggage
- Erosion

Large Particle Ash Removal

- Design and Modeling
  - CFD Modeling
  - Industry Coated Screens
  - Experience





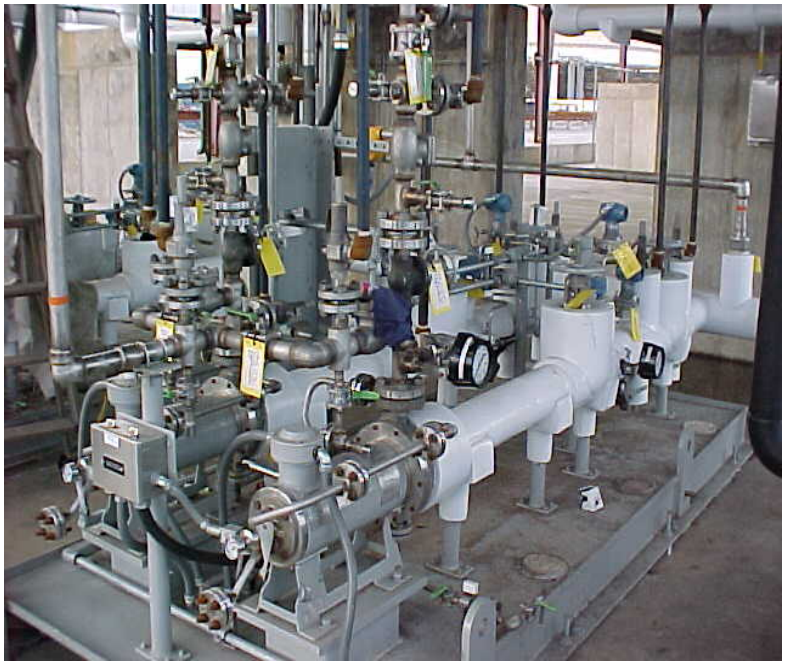
- Soot Blowers
- Low Velocity
- Low Pressure Loss

Ammonia Systems

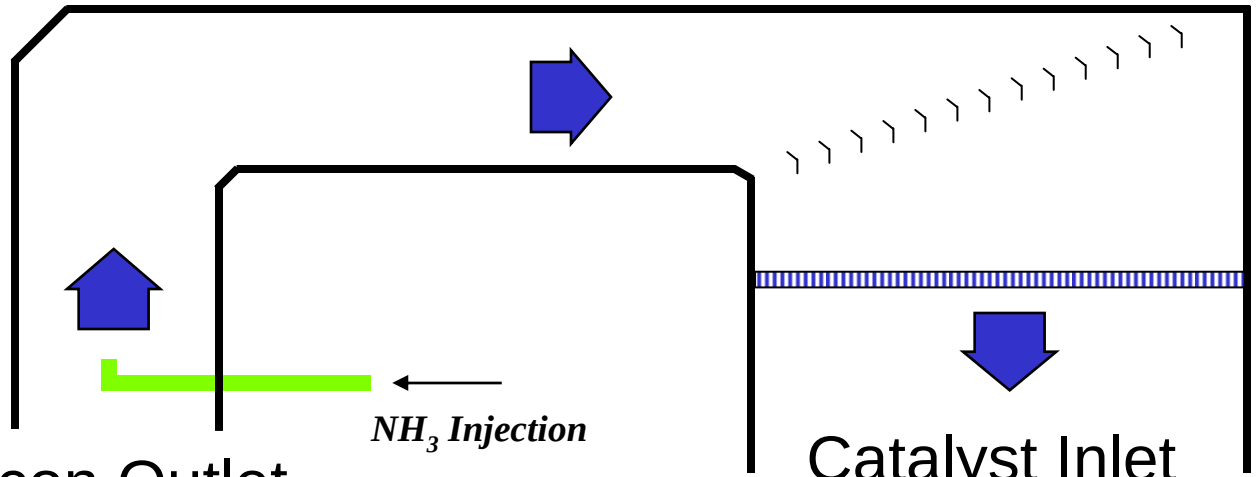
- Anhydrous Ammonia
  - Hazardous chemical governed by codes
- Aqueous Ammonia
  - Concentration based codes, maybe changed in future
- Urea Based Ammonia
  - Safe storage, more equipment and complex

Ammonia Injection

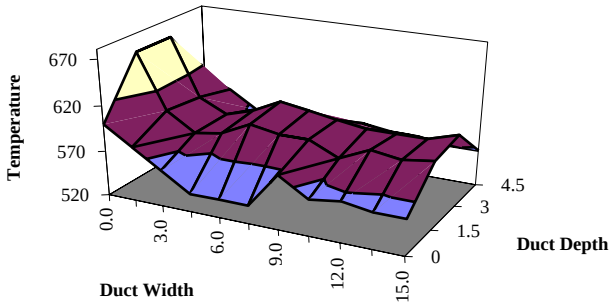
- Anhydrous
  - Dilution Air, 5% by volume
- Aqueous
  - Vaporizer
  - Atomizing Air
  - Protection Air
- Urea
  - Converted to NH3 vapor
  - Direct Injection



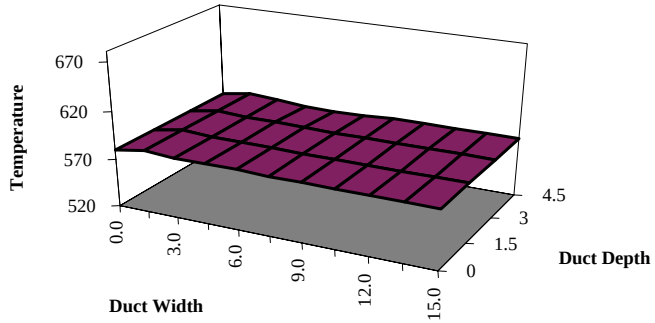
Ammonia & Flue Gas Mixing



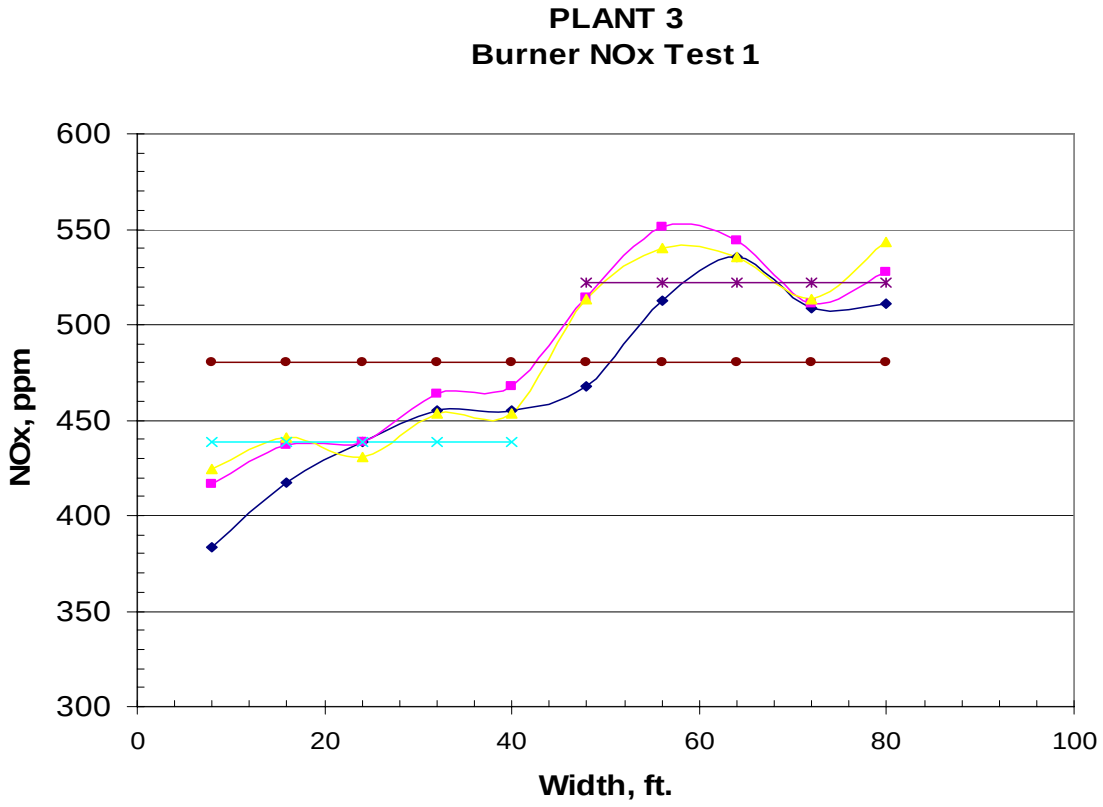
Econ Outlet



Catalyst Inlet

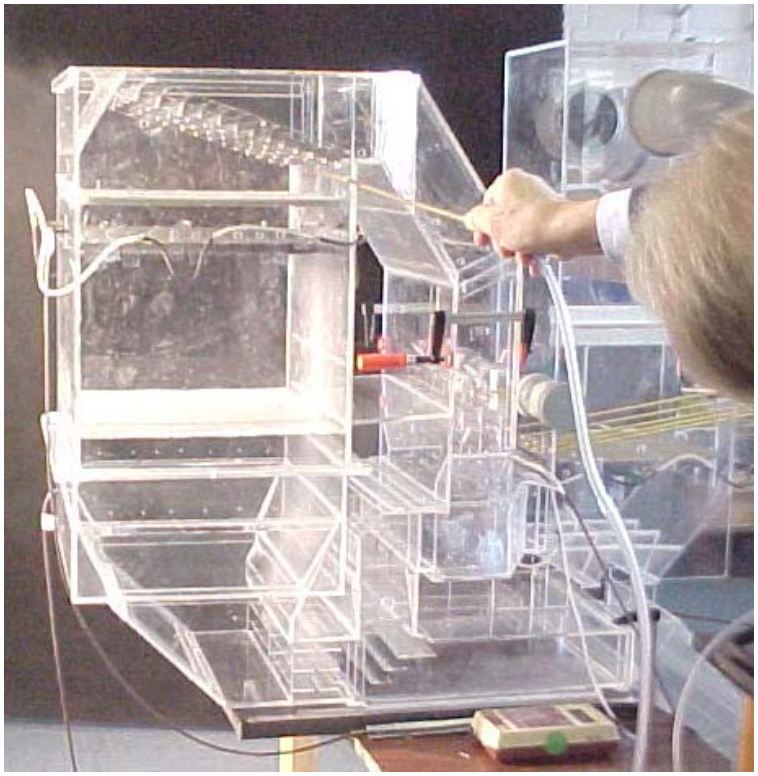


Ammonia & Flue Gas Mixing



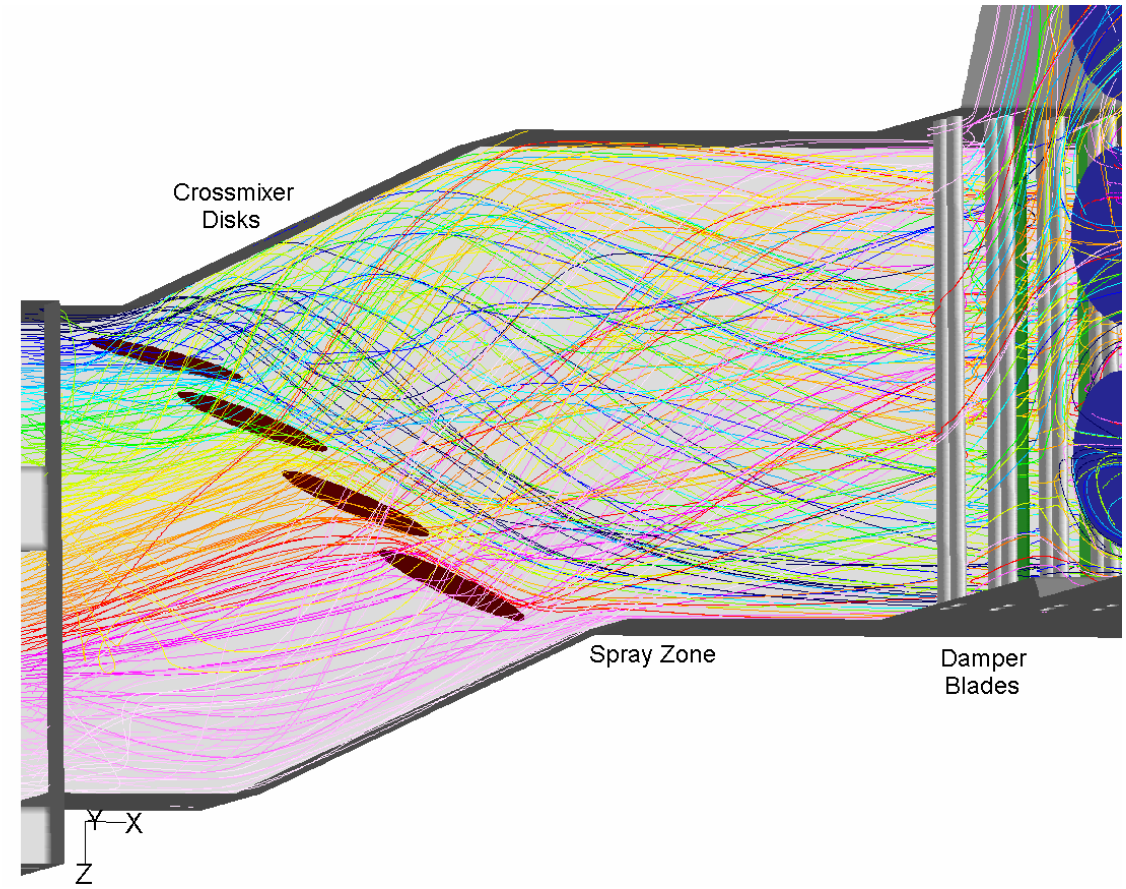
- Inlet variations of flue gas composition
- Load and burner group dependent
- Mix prior to ammonia injection

SCR Flow Models

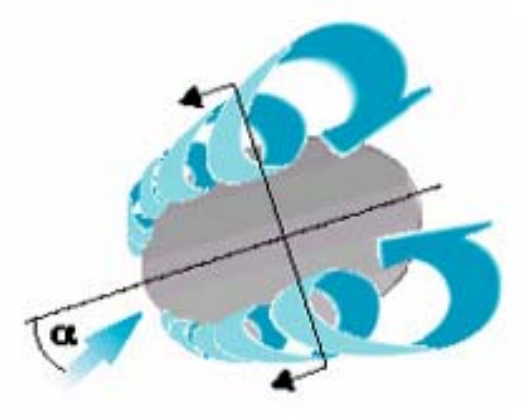


Mixing Upstream of Ammonia Injection

Gas Flow from Boiler



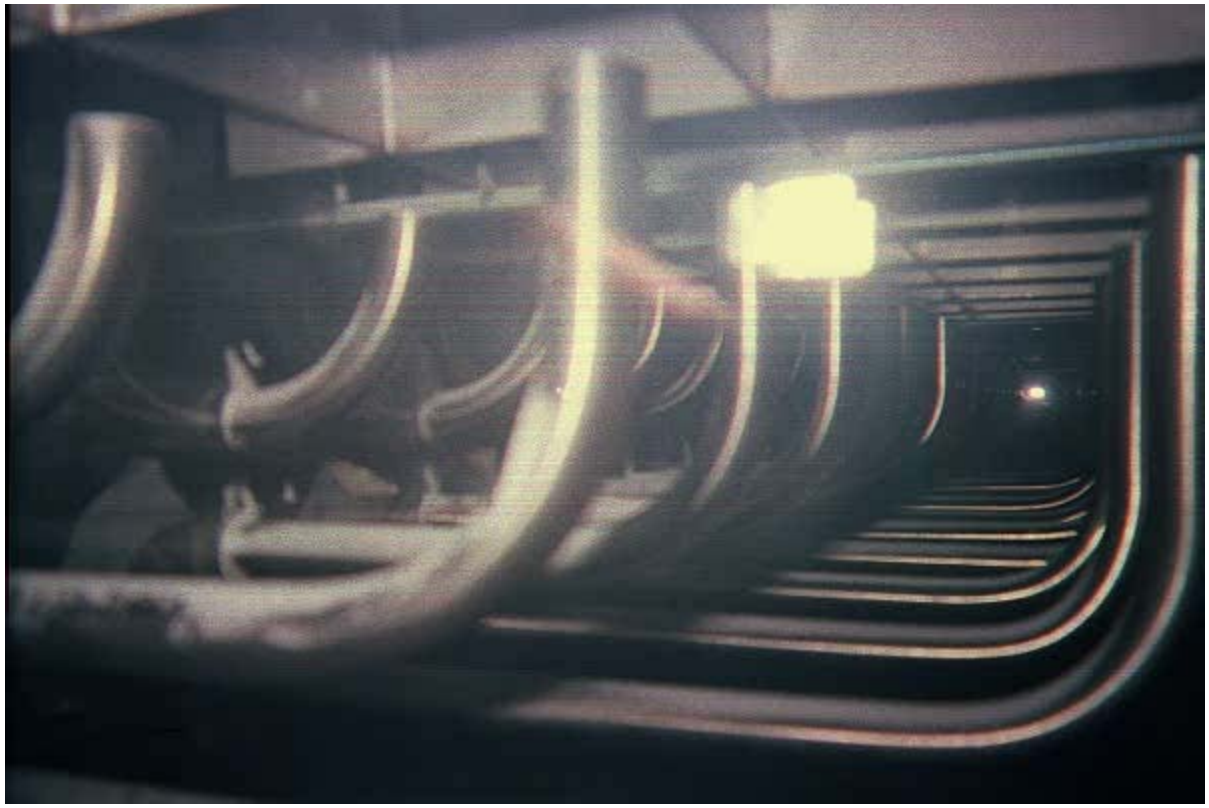
Static Mixers – Delta Wings



Delta Wing Ammonia Injection

Static Mixer

Static Mixer – Injection Grid



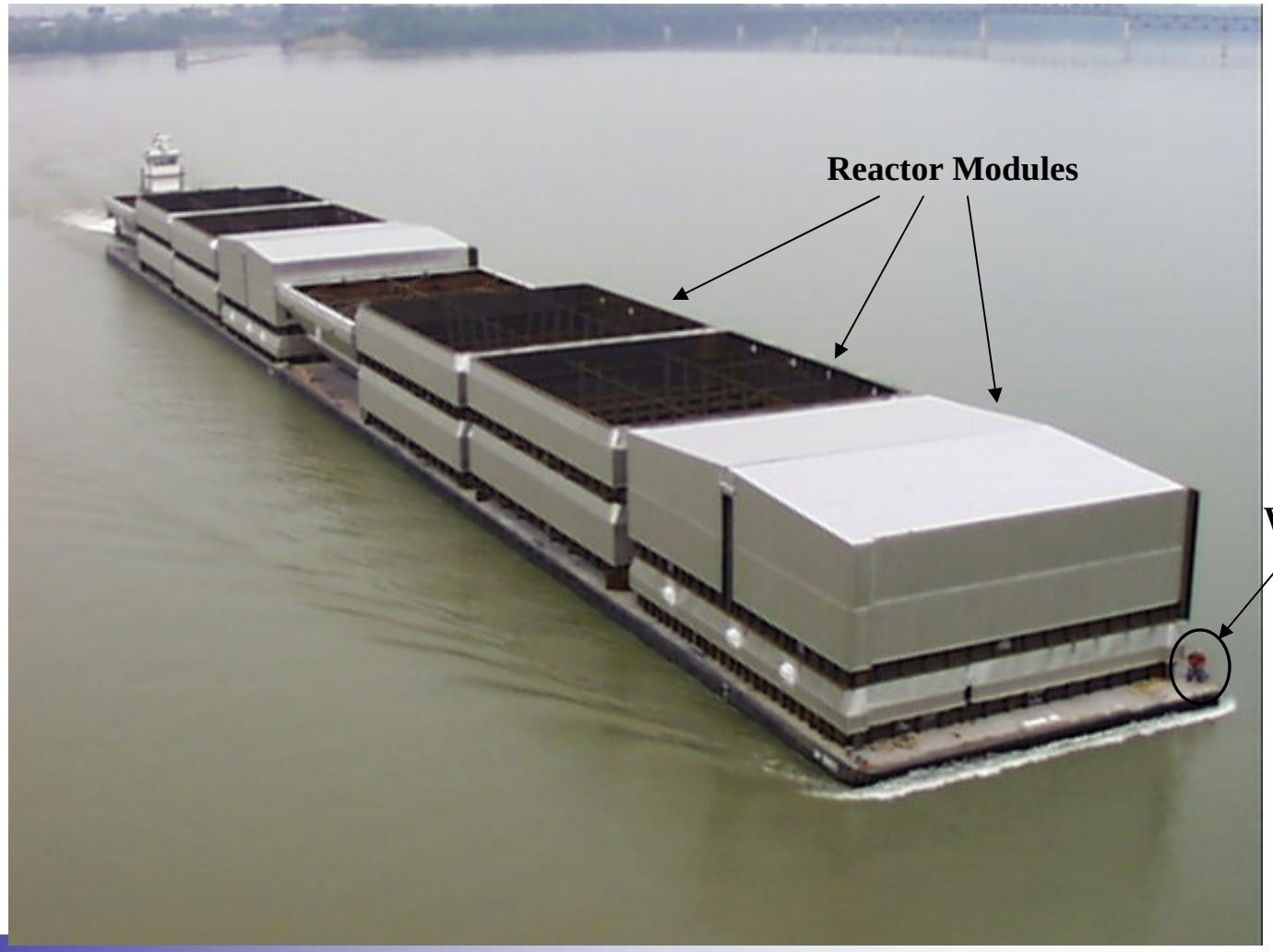
Ammonia Injection Control

- **Adjusted based on testing**

Construction

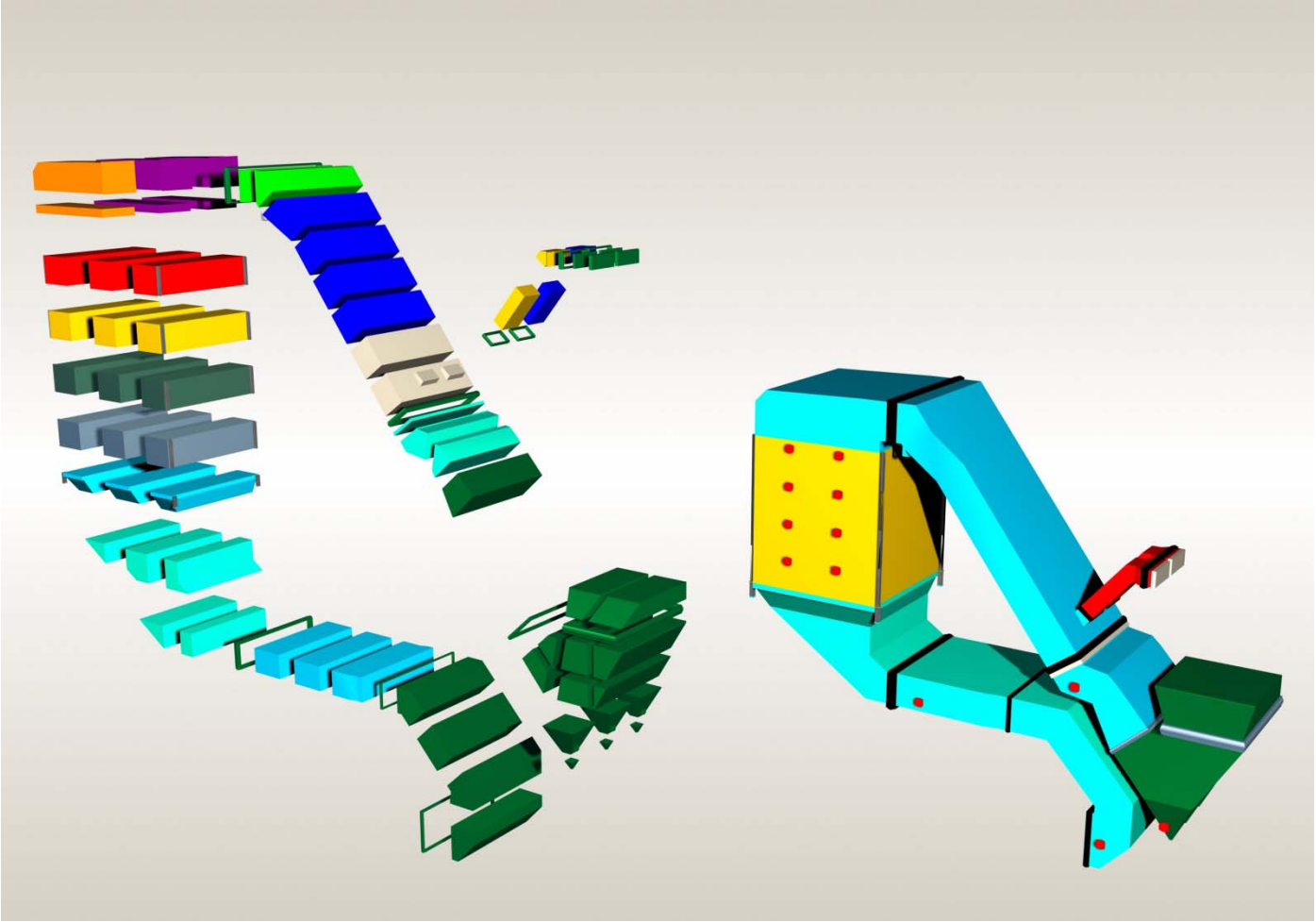
- Method of Shipping
  - Truck
  - Barge
- Crane Selection and Placement
  - Maximum Lift Ranges
- Site Laydown and Storage

Construction



Construction

Construction



Construction – Catalyst Loading

Commissioning – Training

- SCR theory
- SCR process description
- Ammonia system
  - Unloading & Storage
  - Injection
- Lay-up/Dilution Air System
- Start-up and shutdown
- Catalyst handling, cleaning and management

Commissioning – C.O.P.s

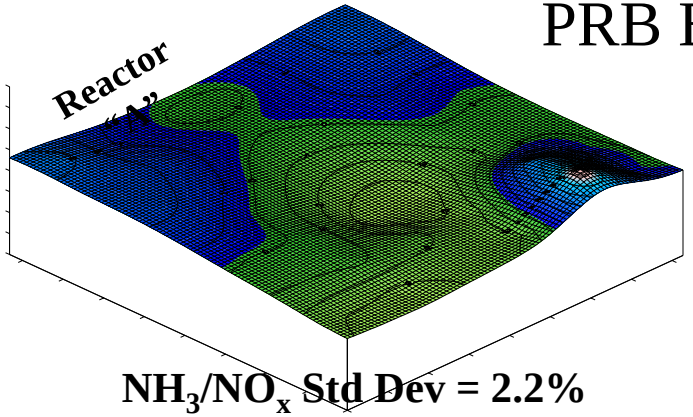
- Commissioning and Optimization Procedures for all subsystems (Ammonia Unloading & Storage, Ammonia Injection, etc…)
- Detailed "checklist" format with descriptions and tag numbers for thorough commissioning

System Optimization - Goals

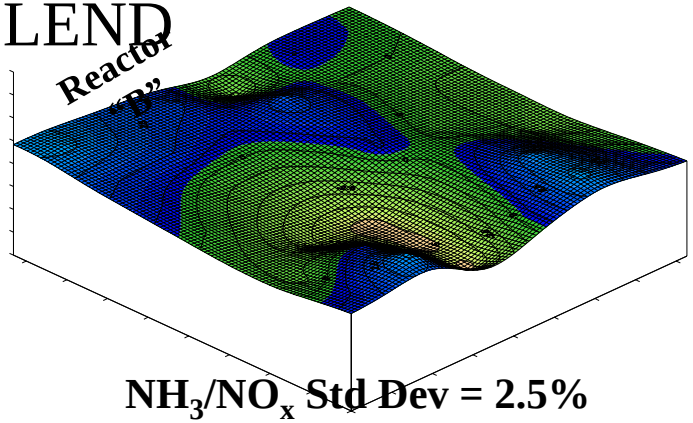
- Verify System / Reactor Inlet Conditions
- Outlet NO_x Distribution Near Uniform
- NH_3/NO_x Profile < 5.0% Std Dev
  - < 3.0% Std Dev Optimal

Commissioning Results

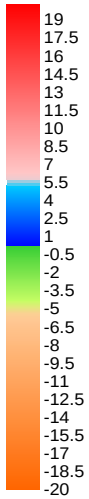
PRB BLEND



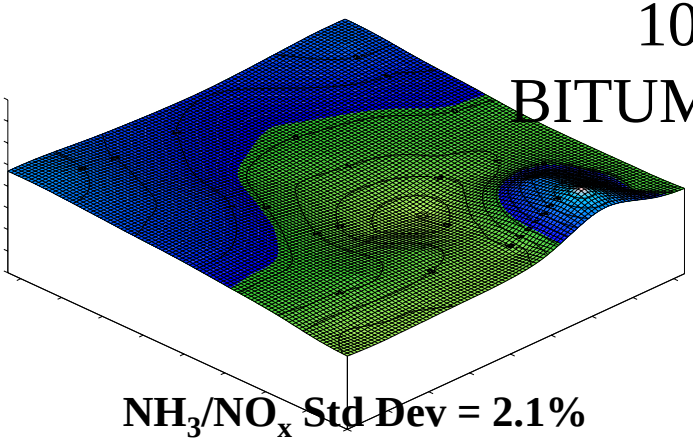
NH_3/NO_x Std Dev = 2.2%



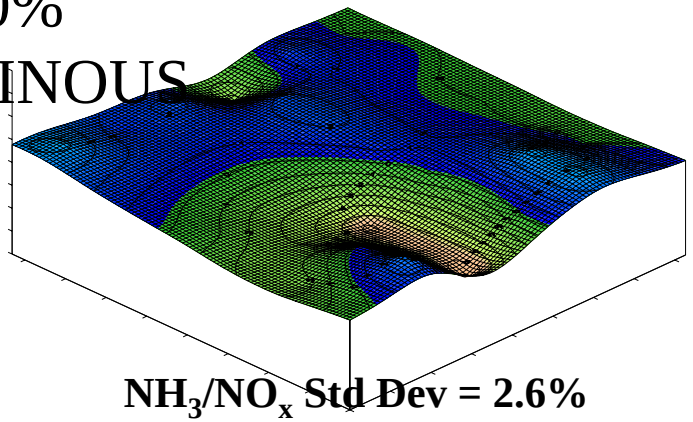
NH_3/NO_x Std Dev = 2.5%



100% BITUMINOUS

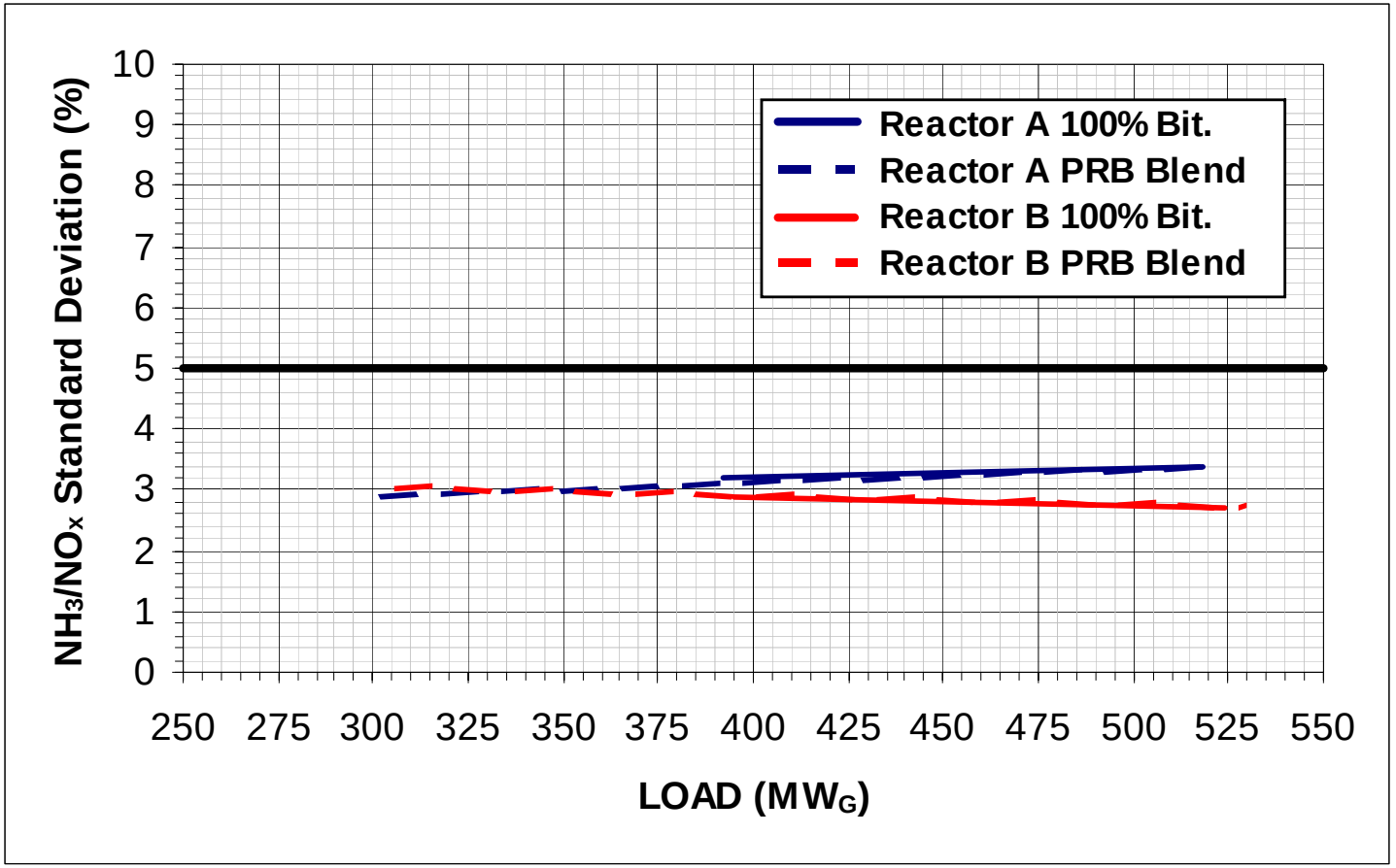


NH_3/NO_x Std Dev = 2.1%

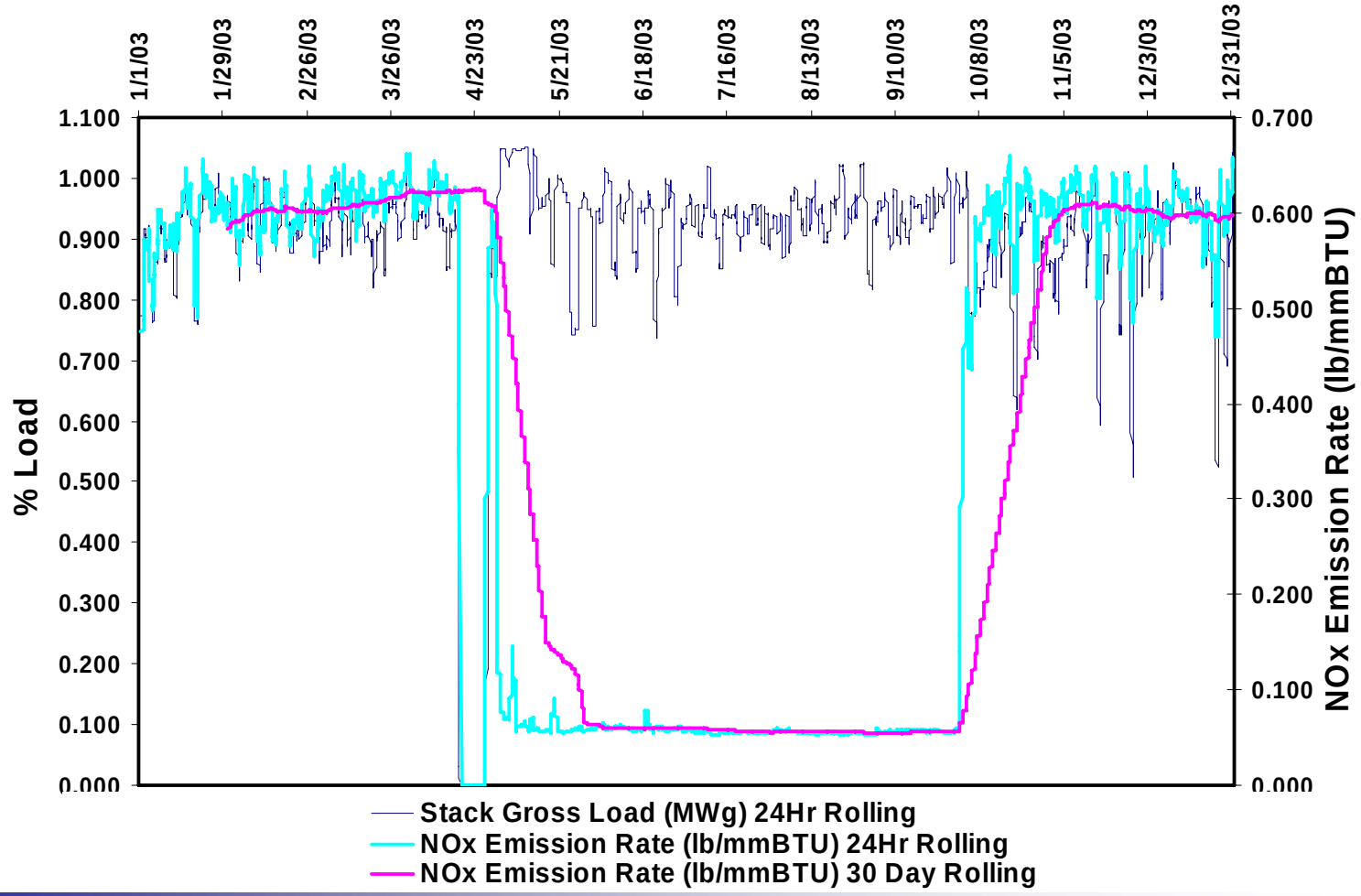


NH_3/NO_x Std Dev = 2.6%

Commissioning Results



SCR System Performance



Questions?

Thank You