

NOx PCUG Round Table SCR Fundamentals Workshop

Charlotte, NC

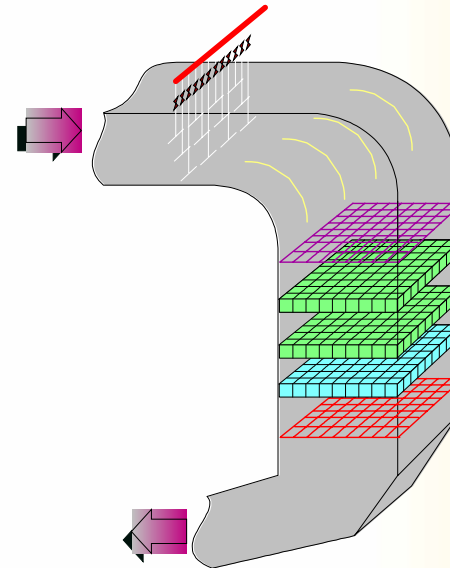
January 23, 2006

Keith Harrison
Research & Environmental Affairs



Outline

- SCR System Overview
 - Process chemistry/equipment
 - Catalyst properties and mgmt
 - Ammonia system
 - Operations & maintenance
- SCR Installed Capacity and Cost
- Industry SCR Issues: past, current, and emerging
 - Control Issues
 - LPA: “popcorn ash”
 - Catalyst management
 - Unit turn-down
 - Acid aerosol emissions



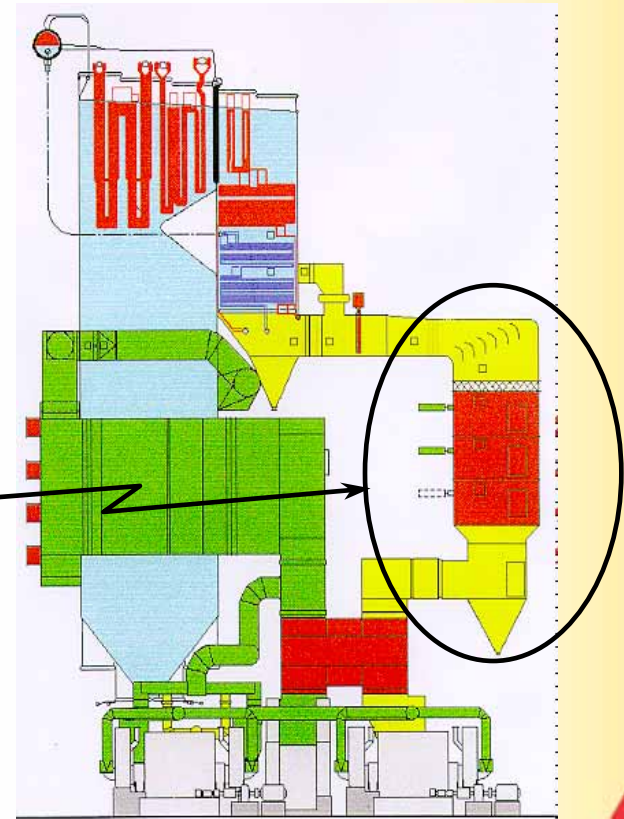
Year-round Operation

SCR Overview (SCR 101)

SCR System Overview

Selective Catalytic Reduction

- 550 – 750°F
- 50 – 90% reduction
- <2ppm NH₃ slip
- \$55–125/kW capital cost
- \$1500-5300/ton levelized cost

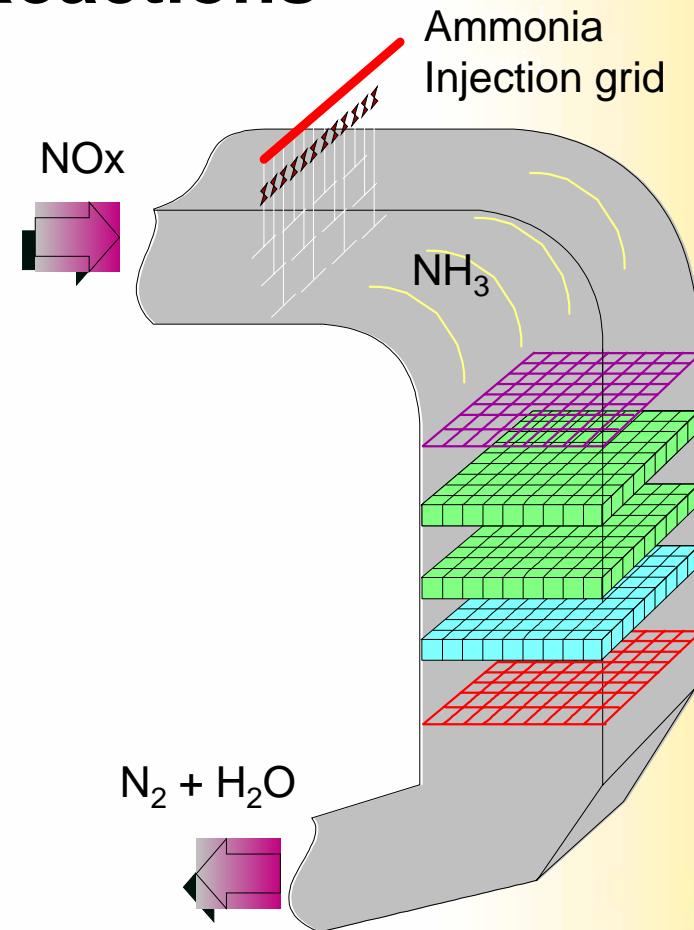
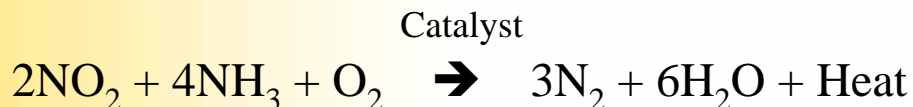
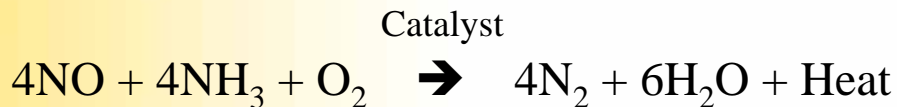


SCR Overview (SCR 101)

SCR Process Reactions

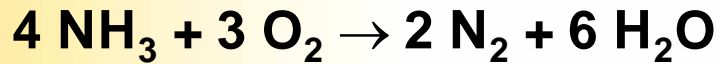
- The SCR process works by injecting ammonia into flue gas as a reagent for reducing nitrogen oxides of NO
- Flue gas passes over a fixed bed catalyst installed in a reactor
- Ammonia reacts with nitrogen oxides on the catalyst surface to form molecular nitrogen and water

Desired Reactions:

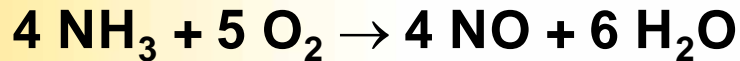


SCR Overview (SCR 101)

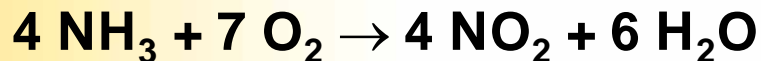
Possible Side Reactions



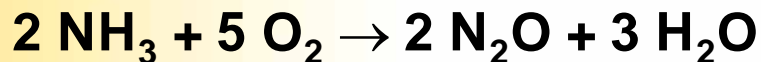
Not observed



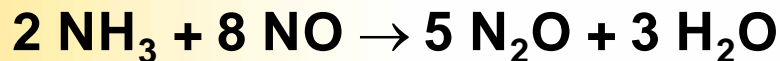
1050°C - 1200°C



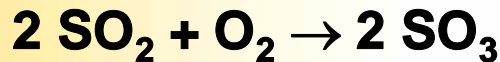
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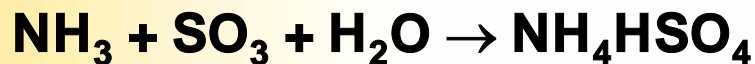
Not observed



Not observed



Limited by catalyst
composition and design



Limited by catalyst design
and proper operating
temperature

Undesired reactions are controlled by appropriate system design and operation to minimize ammonia slip (primarily) and SO₂ oxidation

SCR Overview (SCR 101)

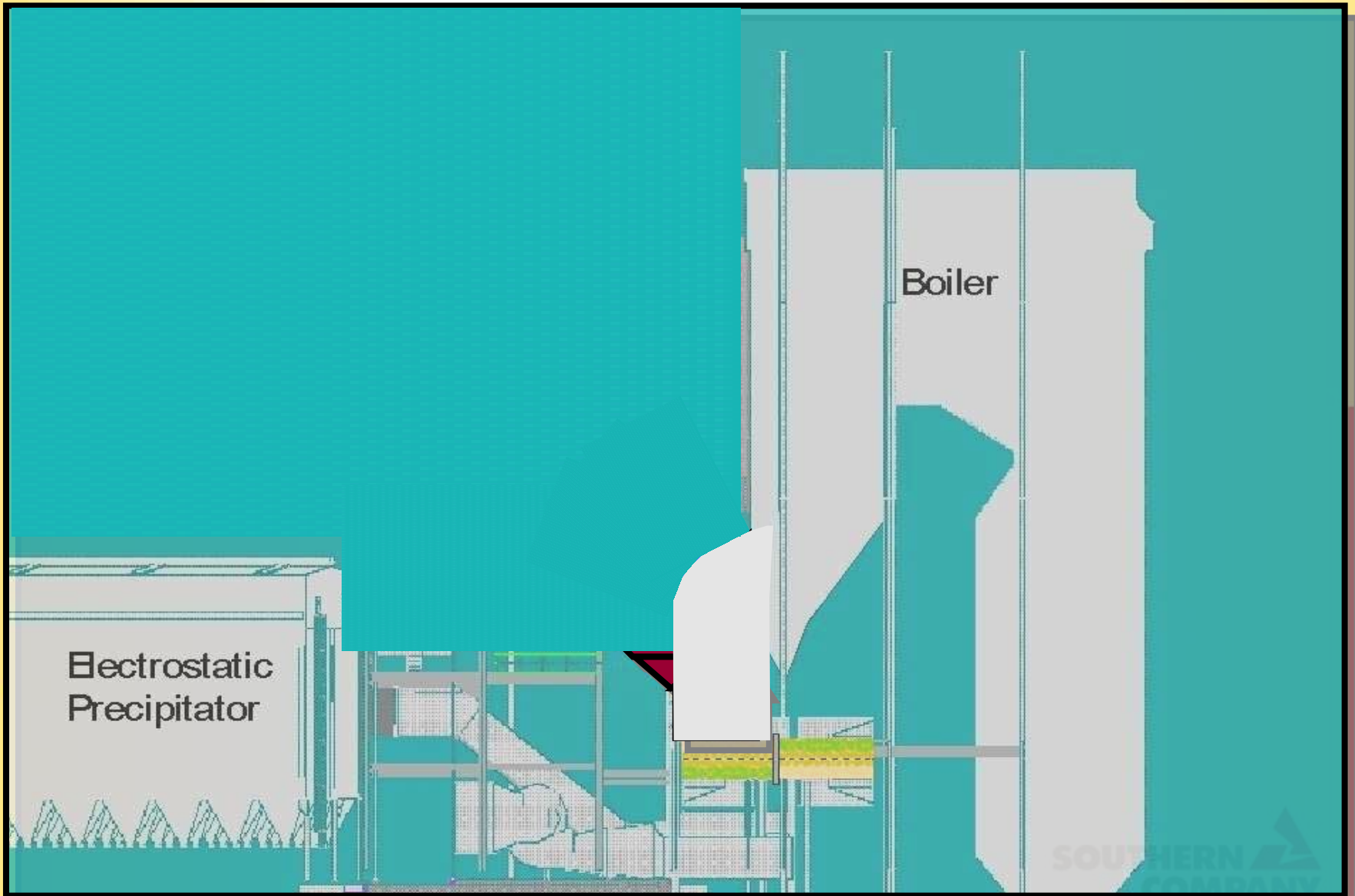
SCR Process Equipment - Scope of Supply

- Reactor & Related Equipment
 - Reactor Vessel
 - Catalyst
 - Ammonia Supply
 - Process Controls
 - Structural Support / Foundations
- Balance of Plant
 - Connecting Ductwork
 - Economizer Bypass (Temperature Control)
 - Fan and Air Preheater Modifications
 - Auxiliary Power Supply
 - Relocation or Removal of Existing Equipment



SCR Installation

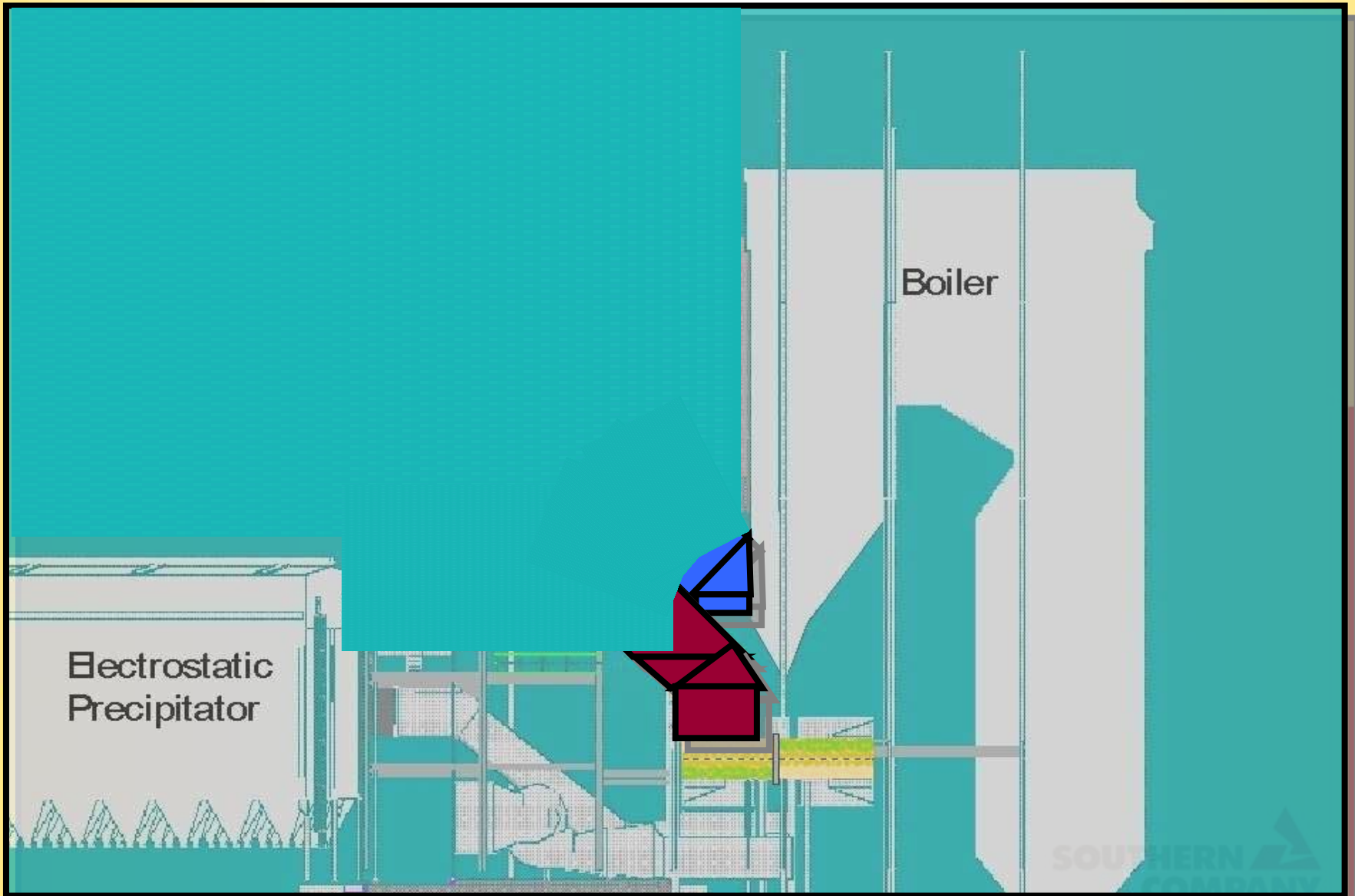
Southern Company Generation



Energy to Serve Your World®

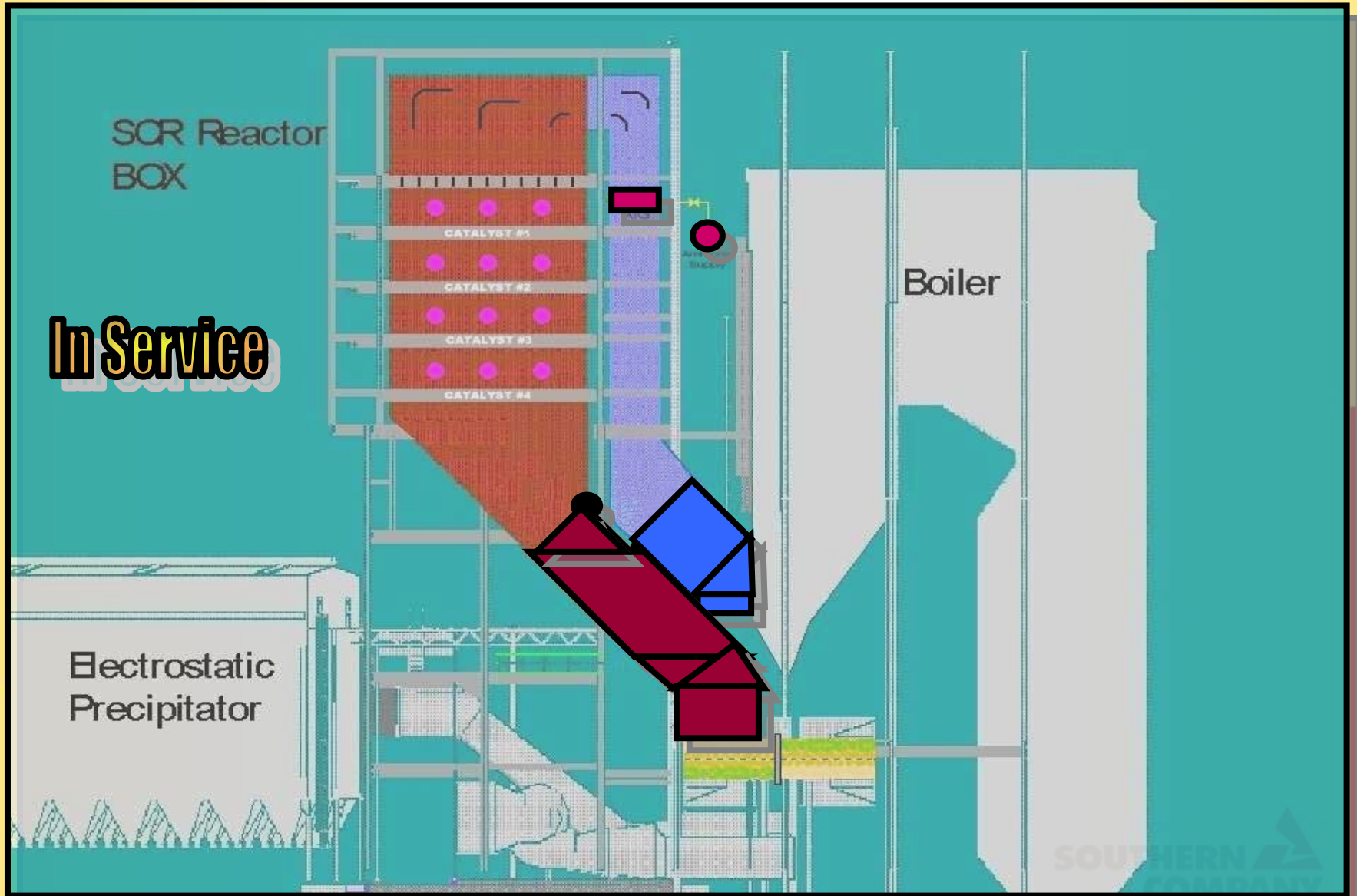
SCR Installation

Southern Company Generation



SCR Installation

Southern Company Generation



SCR Overview (SCR 101)

Selective Catalytic Reduction Overview

- Introduction
- SCR Process Overview
- **Catalyst Overview**
- Ammonia System Overview
- Operations & Maintenance Overview
- Questions

SCR Overview (SCR 101)

Catalyst Performance Requirements

- High activity over a wide temperature range
- High selectivity (low SO₂/SO₃ conversion rate)
- Thermal stability
- Mechanical stability
- Low pressure loss
- Recyclable / disposable
- Resistant to deactivation mechanisms

SCR Overview (SCR 101)

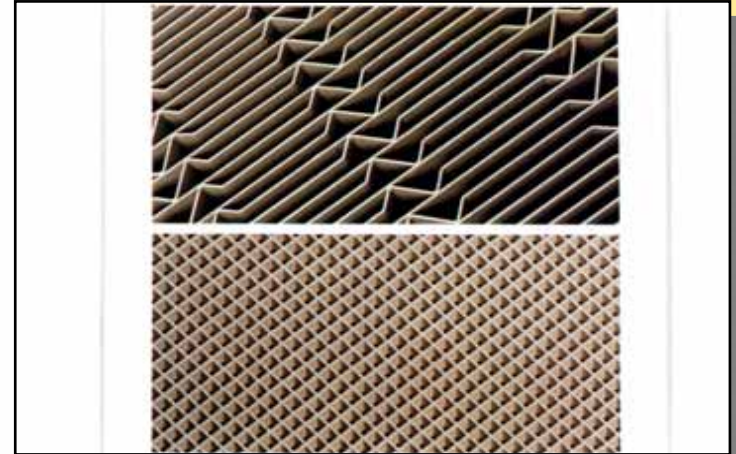
SCR Catalyst Types

- Plate and Honeycomb catalysts
- Vanadium-pentoxide (V_2O_5) is the active catalyst
- Catalyst additions / replacements represent the largest SCR O&M expense
- Approximately 1 to 1.2 m³/MW



Catalyst elements being loaded into a frame

Plate



Honeycomb



SCR Overview (SCR 101)

SCR Catalyst Modules

- **Standard Module Size (Nominal Dimensions)**
 - 2 meters long x 1 meter wide x 1.5 meter high
- **Honeycomb Catalyst**
 - Standard commercial catalyst module made up of 6 x 12 catalyst monoliths, or “elements”
 - Each catalyst monolith has dimensions of 150 mm x 150 mm
 - Separated by fibrous seals
 - For special applications, other module arrangements such as 6 x 6 or 12 x 12 can be manufactured
 - Test coupons can be placed in module
- **Plate Catalyst**
 - Standard modules have two layers of 2 x 4 catalyst cartridges
 - Each cartridge is equal to 3 x 3 honeycomb monoliths
 - Easy to add catalyst in 1/2 layer increments

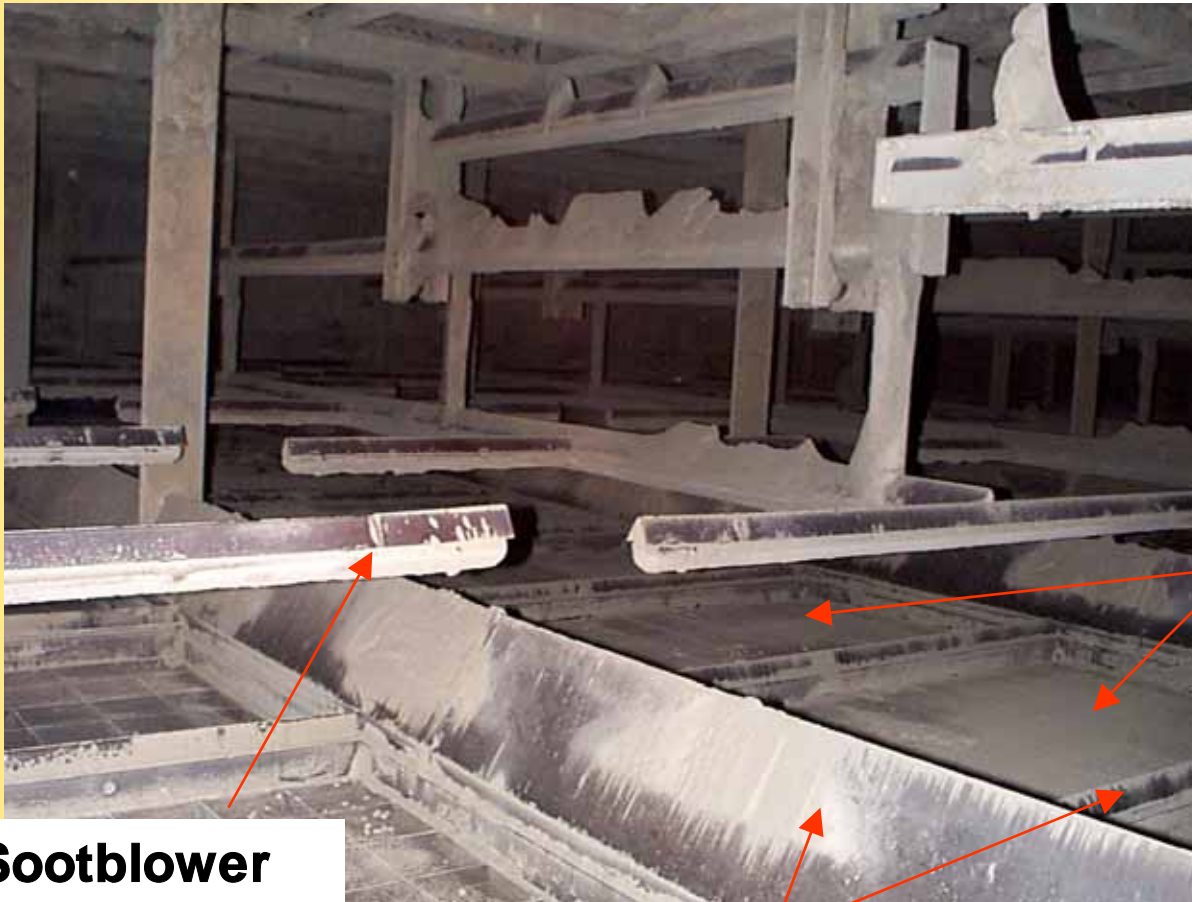
SCR Overview (SCR 101)

SCR Catalyst Modules (Catalyst Loading at Plant Bowen Unit 1)



SCR Overview (SCR 101)

SCR Catalyst Modules



Sootblower

**Catalyst
modules**

Seals between modules

SCR Overview (SCR 101)

SCR Catalyst Definitions

- Pitch – catalyst wall centerline to centerline spacing

	<u>High Dust</u>	<u>Low Dust</u>
Plate	5.2 – 6.0 mm	5.2 mm
Honeycomb	6.4 – 9.2 mm	4.2 mm

- Specific surface area – catalyst surface area divided by gas volume

	<u>High Dust</u>	<u>Low Dust</u>
Plate	330 – 380 m ² /m ³	500 m ² /m ³
Honeycomb	550 – 620 m ² /m ³	620-750 m ² /m ³

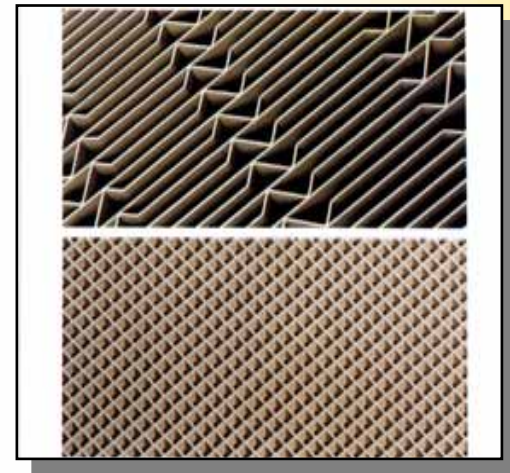
- Wall Thickness

	<u>High Dust</u>	<u>Low Dust</u>
Plate	1.0 mm	1.0 mm
Honeycomb	0.8-1.2 mm	0.7-1.0 mm

SCR Overview (SCR 101)

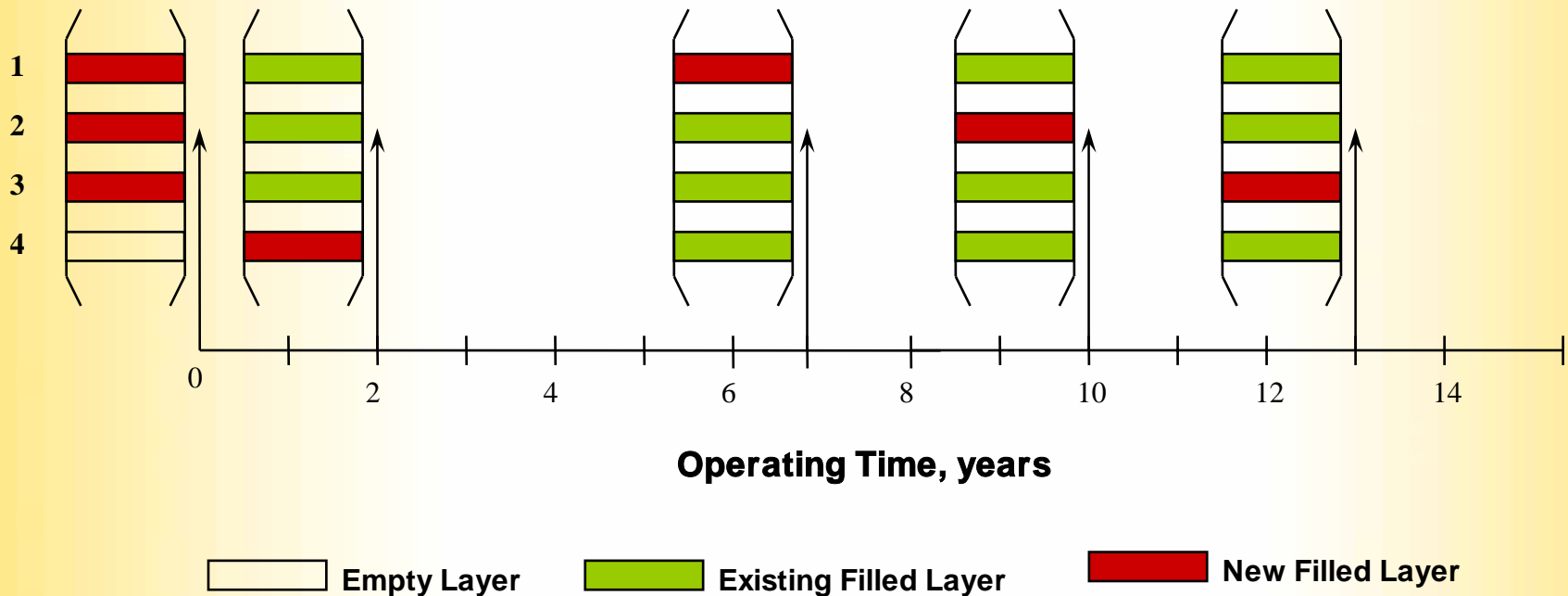
SCR Catalyst Design

- Factors for Determining Cross Sectional Area
 - Flue Gas Flow Rate
 - Maximum Allowable Pressure Drop
- Factors for Determining Allowable SCR Operating Temperature Range
 - SO_3 and Required Ammonia in Flue Gas
- Factors for Determining Catalyst Volume
 - Trace Elements in Flue Gas (Arsenic, Calcium, etc.)
 - NO_x Reduction Required
 - Flue Gas Temperature at Catalyst
 - Maximum Allowable Ammonia Slip
 - Allowable SO_2 to SO_3 Oxidation Rate
 - Required Catalyst Life



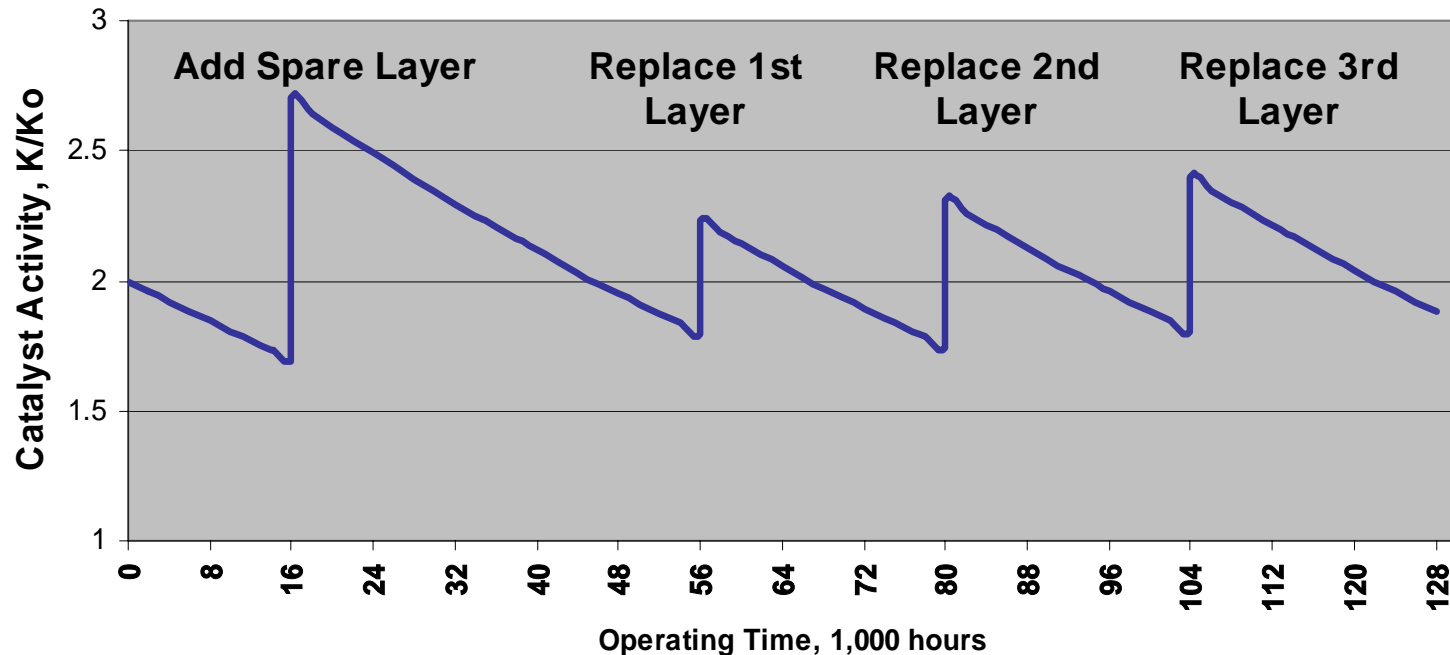
SCR Overview (SCR 101)

SCR Catalyst Management



SCR Overview (SCR 101)

SCR Catalyst Management



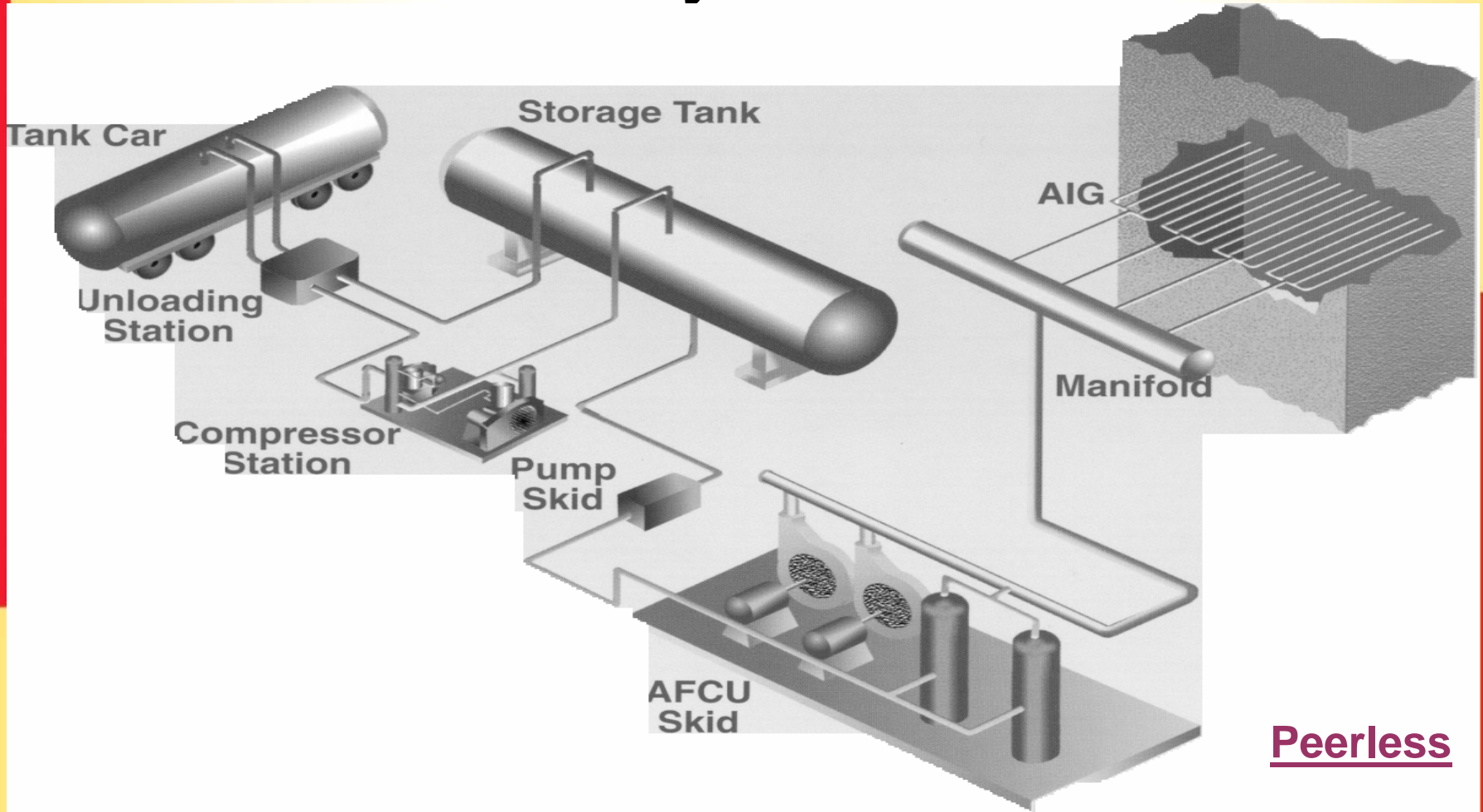
SCR Overview (SCR 101)

Selective Catalytic Reduction Overview (SCR 101)

- Introduction
- SCR Process Overview
- Catalyst Overview
- **Ammonia System Overview**
- Operations & Maintenance Overview
- Questions

SCR Overview (SCR 101)

Ammonia System Overview



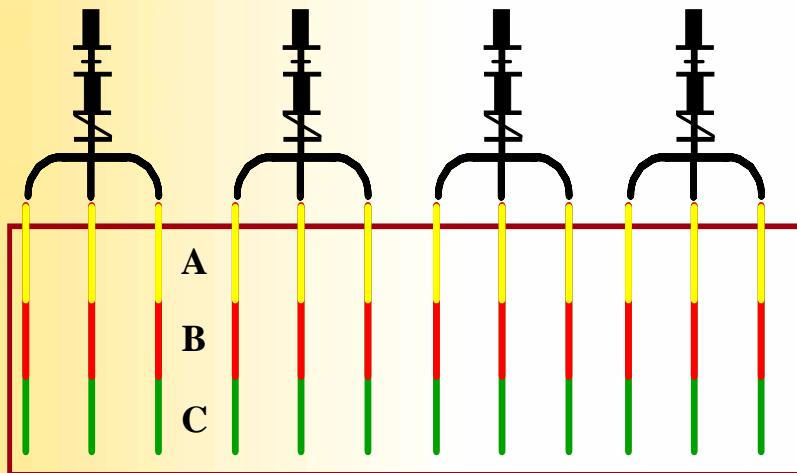
Peerless

SCR Overview (SCR 101)

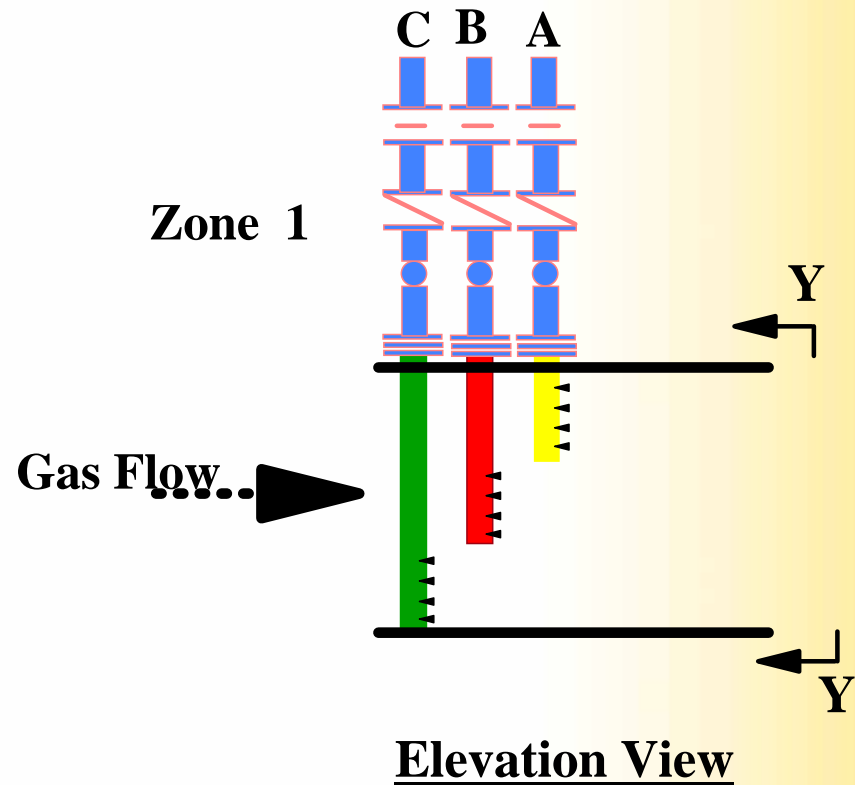
Ammonia Injection Grid Design



Zone 1 A,B,C Zone 2 A,B,C Zone 3 A,B,C Zone 4 A,B,C

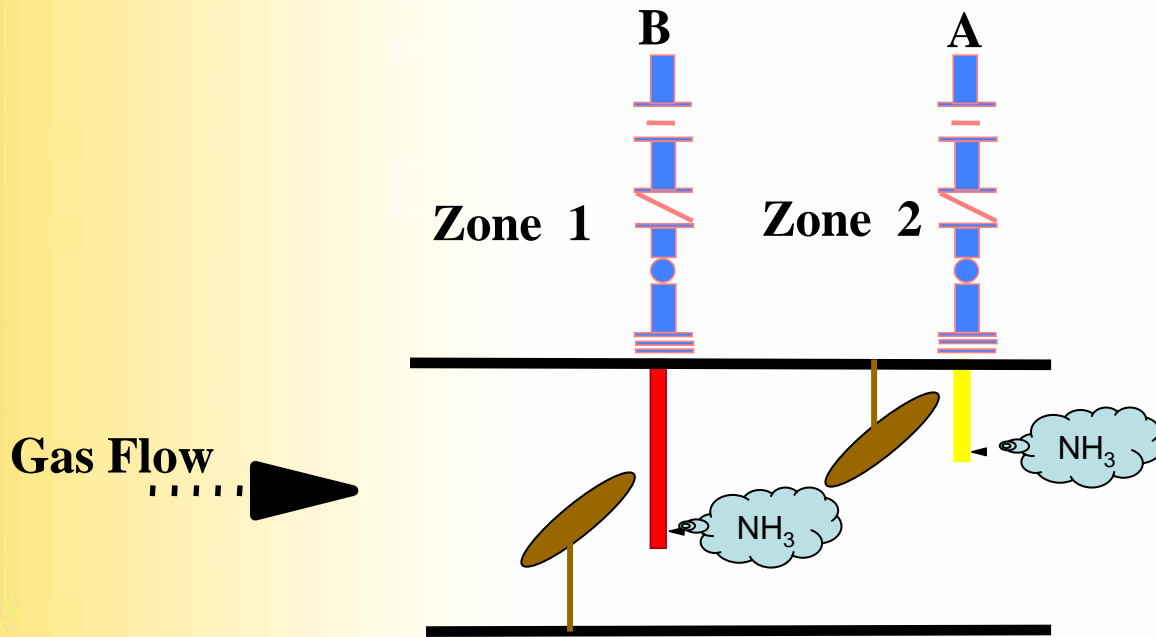


Section Y-Y



SCR Overview (SCR 101)

Delta wing design



Elevation View

NH_3 mixed in turbulent zones downstream of delta wing

SCR Overview (SCR 101)

Selective Catalytic Reduction Overview (SCR 101)

- Introduction
- SCR Process Overview
- Catalyst Overview
- Ammonia System Overview
- **Operations & Maintenance Overview**
- Questions

SCR Overview (SCR 101)

SCR O&M Considerations

Achieving NO_x Removal Efficiency is Never the Problem

1st Priority - Minimize Ammonia Slip!!

- Ensure Uniform Gas Velocity
- Ensure Uniform Ammonia/NO_x Distribution (Diagnostic Testing /Tuning)
- Carefully Track Ammonia Slip/Catalyst Deactivation Trends
- Control System

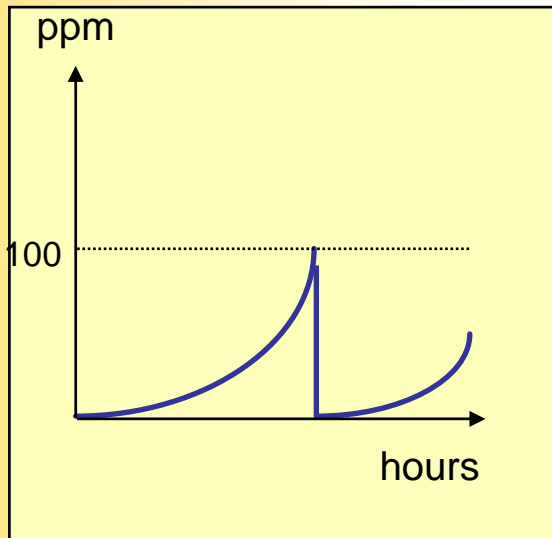
2nd Priority - Minimize SO₂ to SO₃ Oxidation

- Proper Catalyst Selection
- Minimize Amount of Catalyst Volume
- SO₃ Will Always be Present in the Gas Stream

SCR Overview (SCR 101)

Monitoring Ammonia Slip

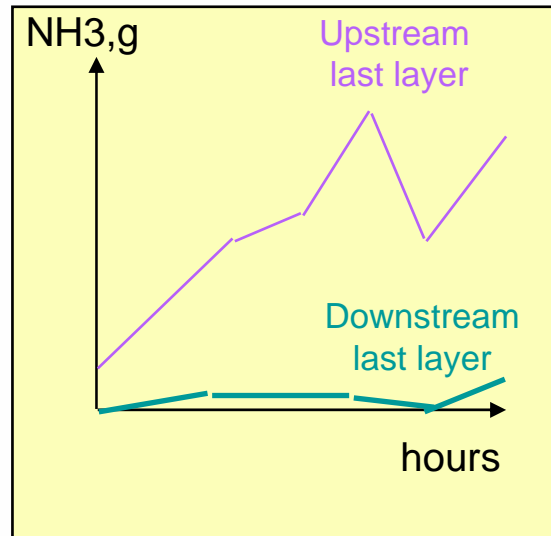
NH₃ concentration
on fly ash



Operator

Measurements:
daily / weekly

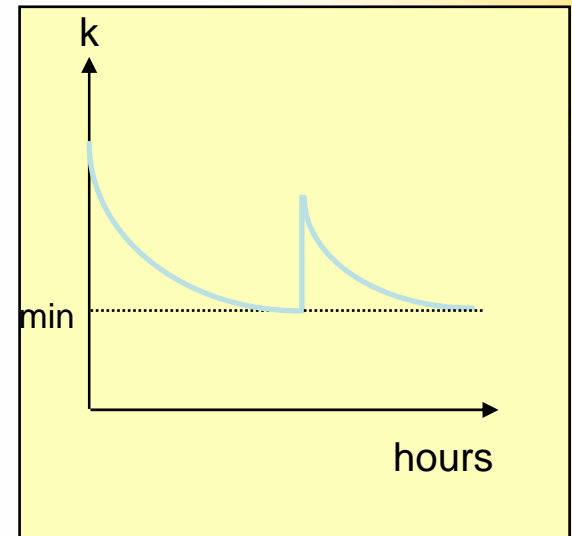
NO_x distribution and
NH₃ measurements



Third Party

Measurements:
once or twice a year

catalyst activity
measurements



Catalyst Supplier

Measurements:
once a year

SCR Overview (SCR 101)

Prediction of Ammonia in Flyash (ppm by mass)

% Ash in Fuel

		6	8	10	12	14	16	18
NH ₃ Slip (ppm)	1	84	62	48	39	33	28	24
	2	169	124	97	79	66	56	49
	3	253	185	145	118	99	84	73
	4	337	247	193	157	131	112	97
	5	421	309	241	197	164	140	122
	10	843	618	483	393	329	281	243
	15	1264	927	724	590	493	421	365
	20	1686	1236	966	786	657	561	486
	25	2107	1545	1207	983	822	701	608

Marginal Contamination
 150 ppm to 200 ppm

Unacceptable Contamination
 Above 200 ppm

Based on German cement industry practice with 60% adsorption

SCR Overview (SCR 101)

Ammonia Slip Distribution

10	10	1	1	1
10	10	1	1	1
1	1	0.5	0	0
0.5	0.5	0.5	0	0
0	0	0	0	0

Ammonia Concentration

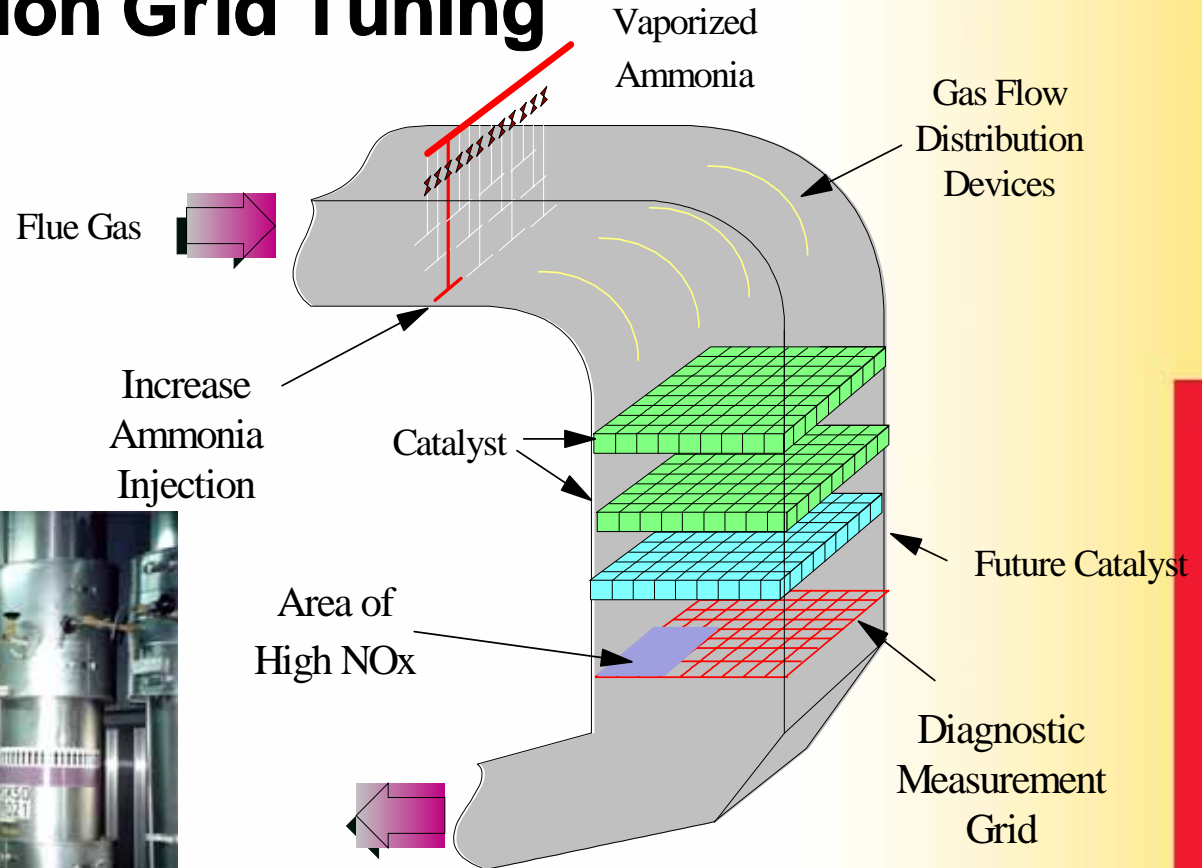
Average = 2 ppm

Ammonia slip peak concentration is critical parameter during operation



SCR Overview (SCR 101)

Ammonia Injection Grid Tuning



SCR Overview (SCR 101)

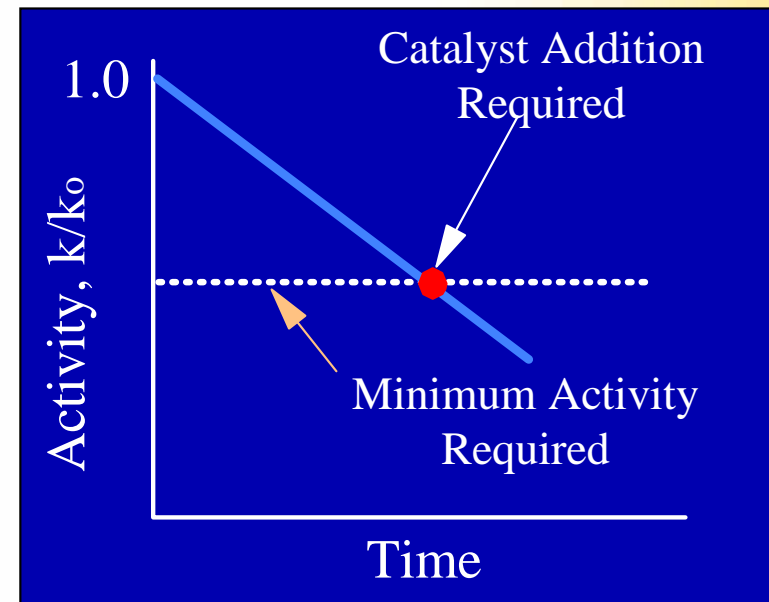
SCR O&M Cost & Risk

- O&M Costs (Descending Magnitude)
 - Catalyst Replacements
 - Ammonia/Reagent
 - Power (Differential ID Fan Power)
 - Steam/Vaporization Medium
 - General Maintenance (Sootblowers, Ammonia System, Dampers, Monitors)
 - Ammonia Injection Tuning
 - Diagnostic Testing
- O&M Risks - Impacts
 - Air Heater Fouling - Forced Outage for Washing
 - Lost Fly Ash Sales/Landfill Disposal Problems

SCR Overview (SCR 101)

SCR Catalyst is a Consumable

- Periodic replacements or supplements will be necessary
- Catalyst replacements are the largest O&M expense
- Catalyst deactivation is caused by
 - Chemical degradation by trace elements (As, Ca, K, Na)
 - Masking of catalyst micro pores by ammonium bisulfate
 - Thermal degradation / sintering
 - Plugging and mechanical failures
- An effective catalyst management and O&M plan can greatly reduce catalyst replacement costs



Outline

- SCR Systems Overview
 - Process and Chemistry
 - Catalyst
 - Ammonia System
 - Operations & Maintenance

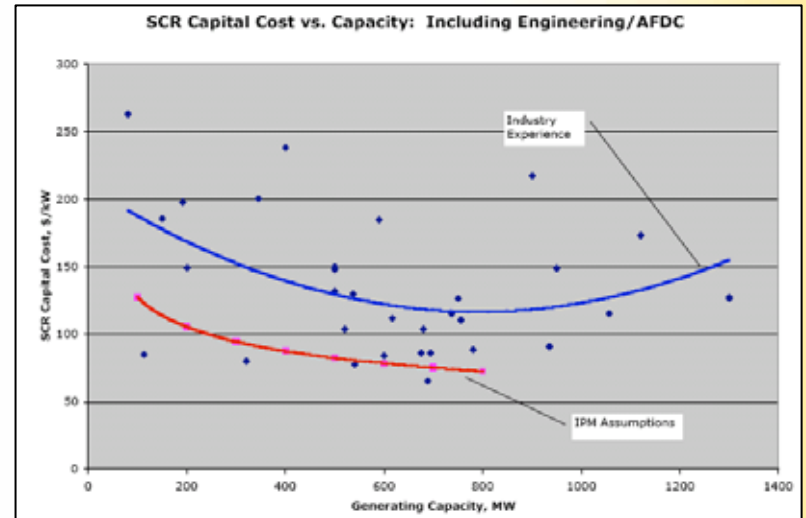
- SCR Installed Capacity and Cost

- Industry SCR Issues: past, current, and emerging

- Control Issues
- LPA: “popcorn ash”
- Catalyst management
- Unit turn-down
- Acid aerosol emissions



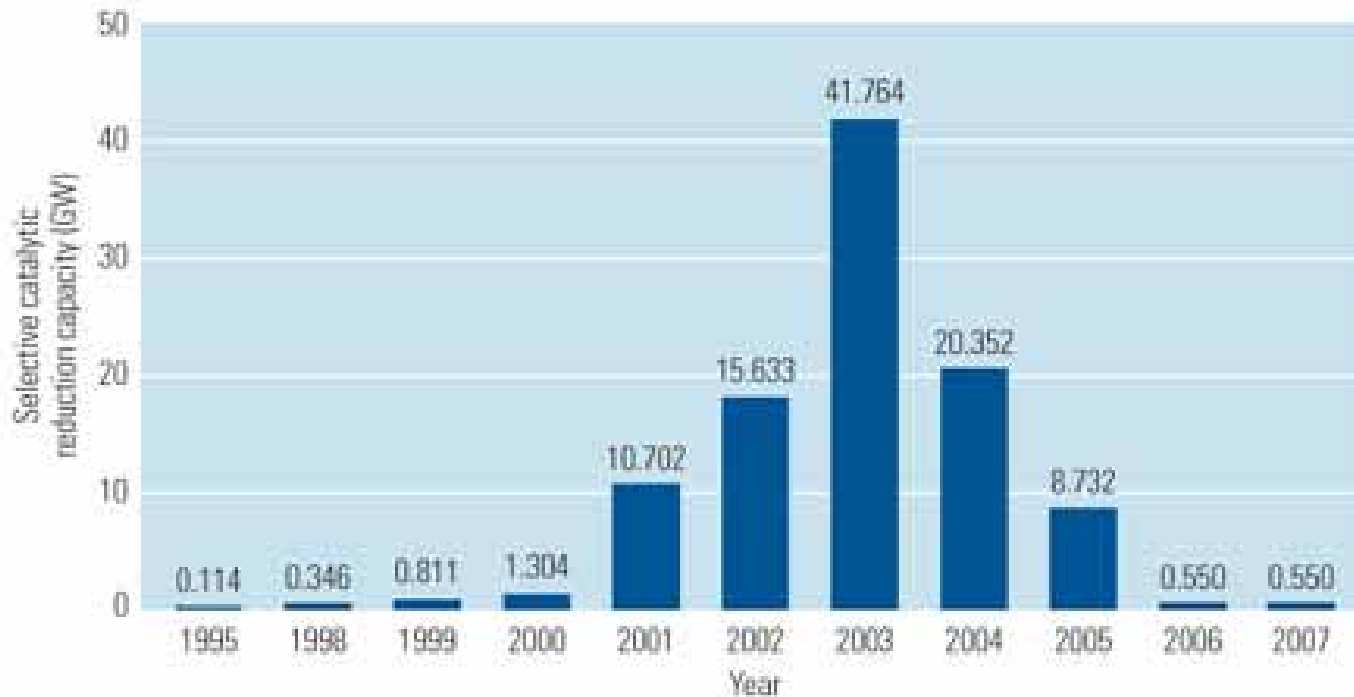
Year-round Operation



Source: Marchetti, J., et. al, *Comparison of FGD and SCR Capital Cost Assumptions*; Sep 2005

SCR Installed Capacity

1. Existing and planned SCR system installations



Source: J.E. Cichanowicz

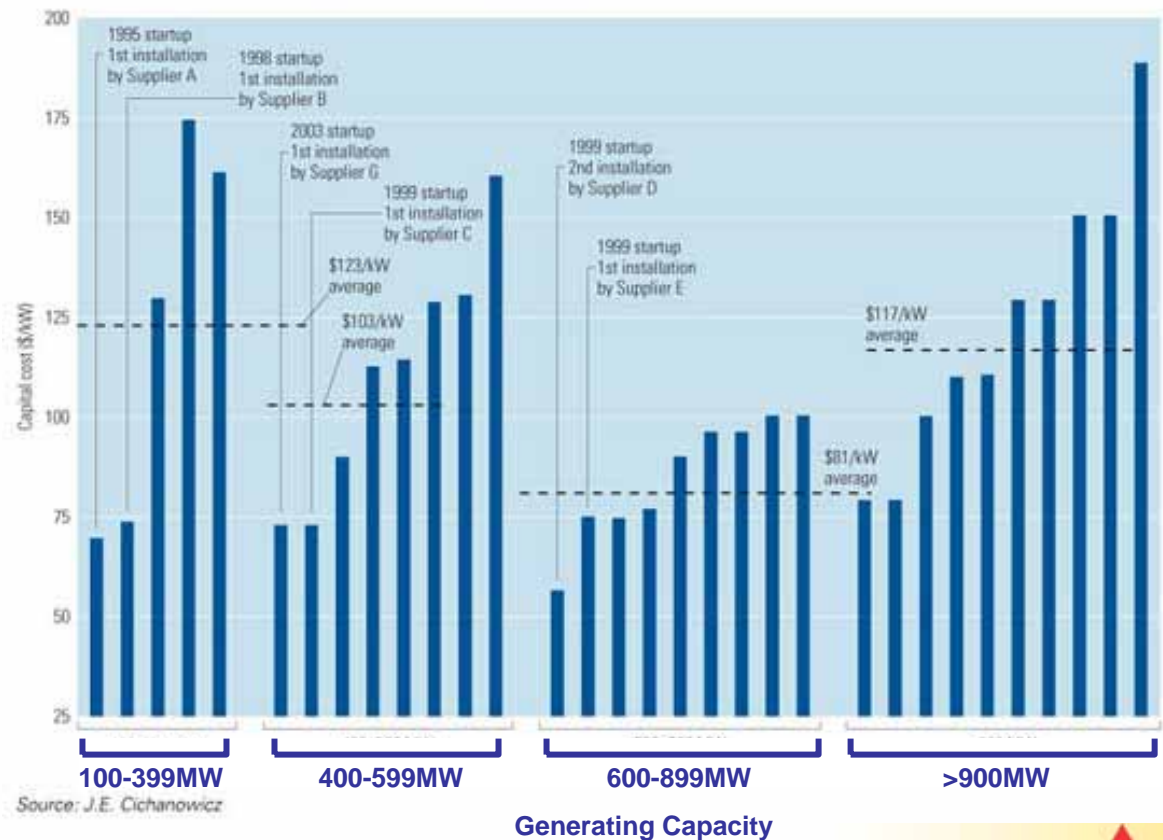


CAIR

SCR Cost Comparison

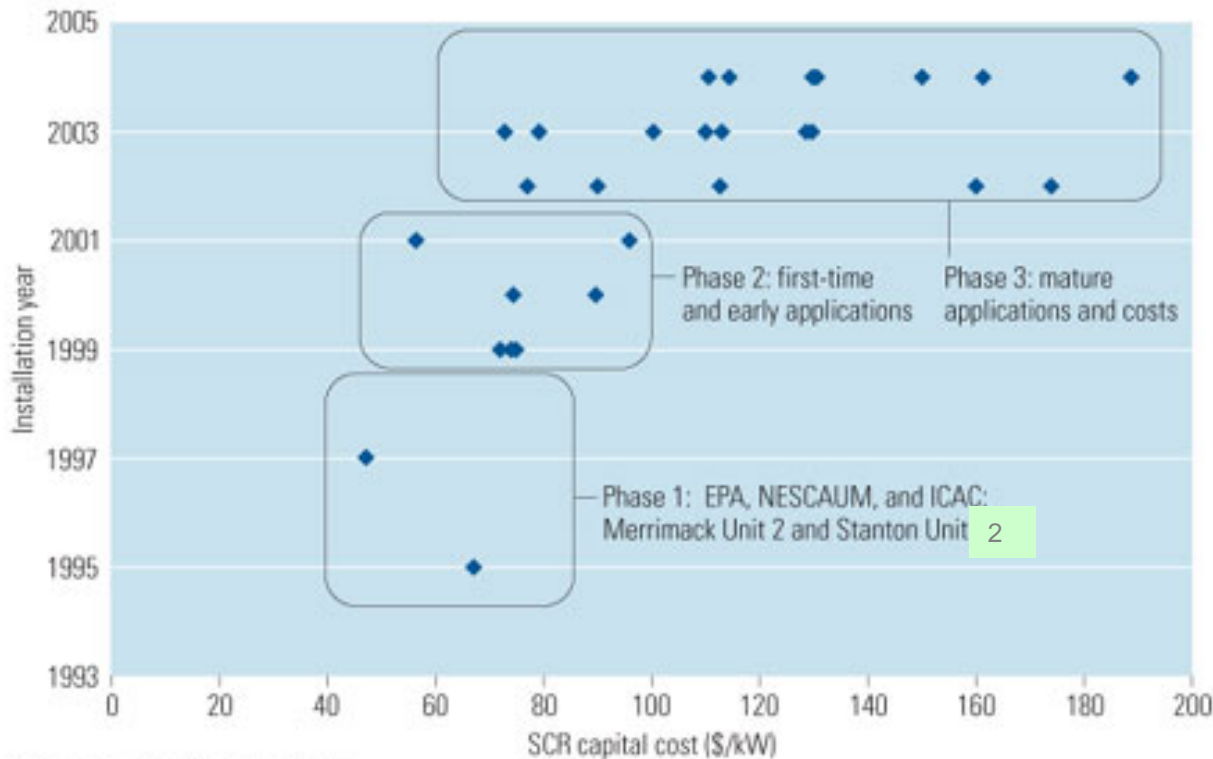
- Cost data from 24 stations and 6 suppliers
- Average cost decreases with increasing generating capacity, except for >900MW
- Does not include owners' engineering and AFDC (could add up to 20%)

2. SCR capital cost by category of generating capacity



SCR Cost Comparison

3. SCR capital cost by installation date



Source: J.E. Cichanowicz

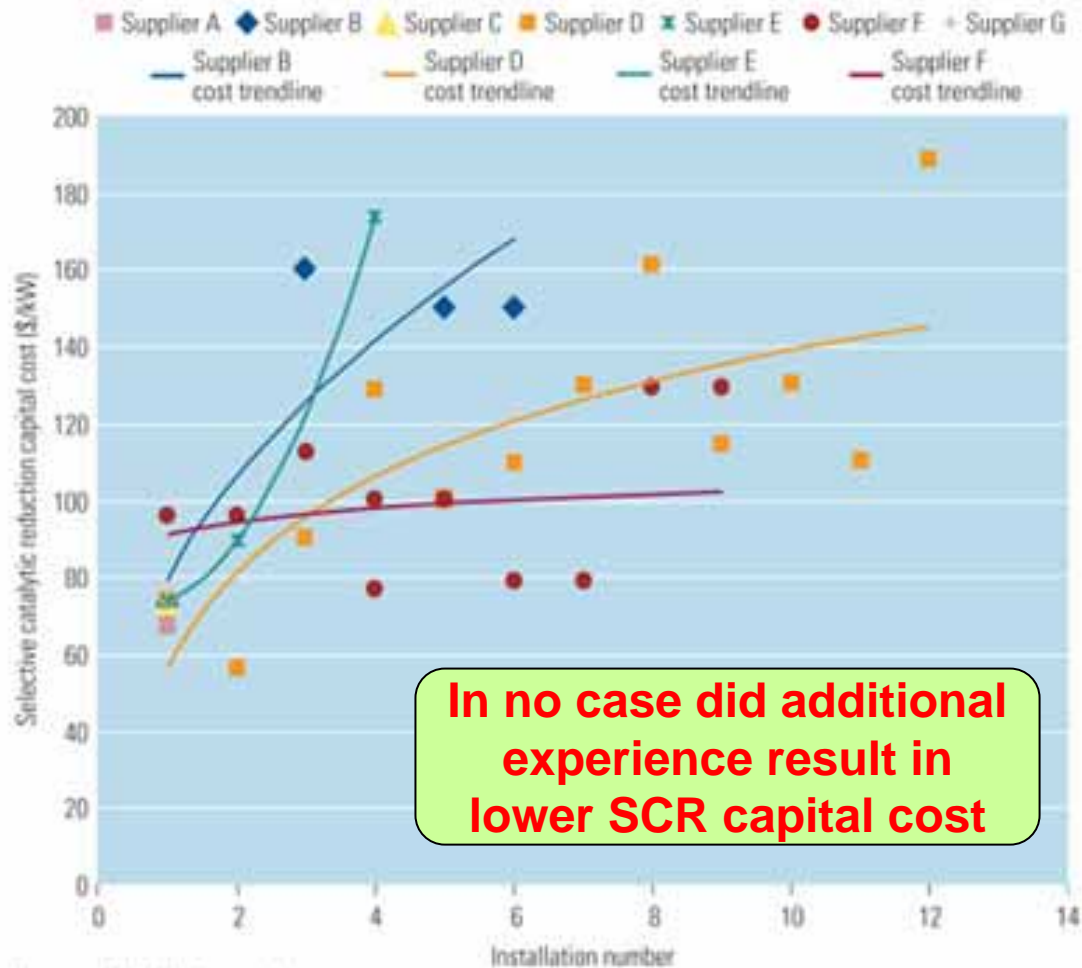
All but 4 exceed \$100/kW
1 in 4 exceed \$150/kW

Costs exceeded that proposed by the regulatory community – still below \$100/kW

Initial U.S. SCR installations

SCR Cost Comparison

4. Selective catalytic reduction capital cost by number of supplier installations



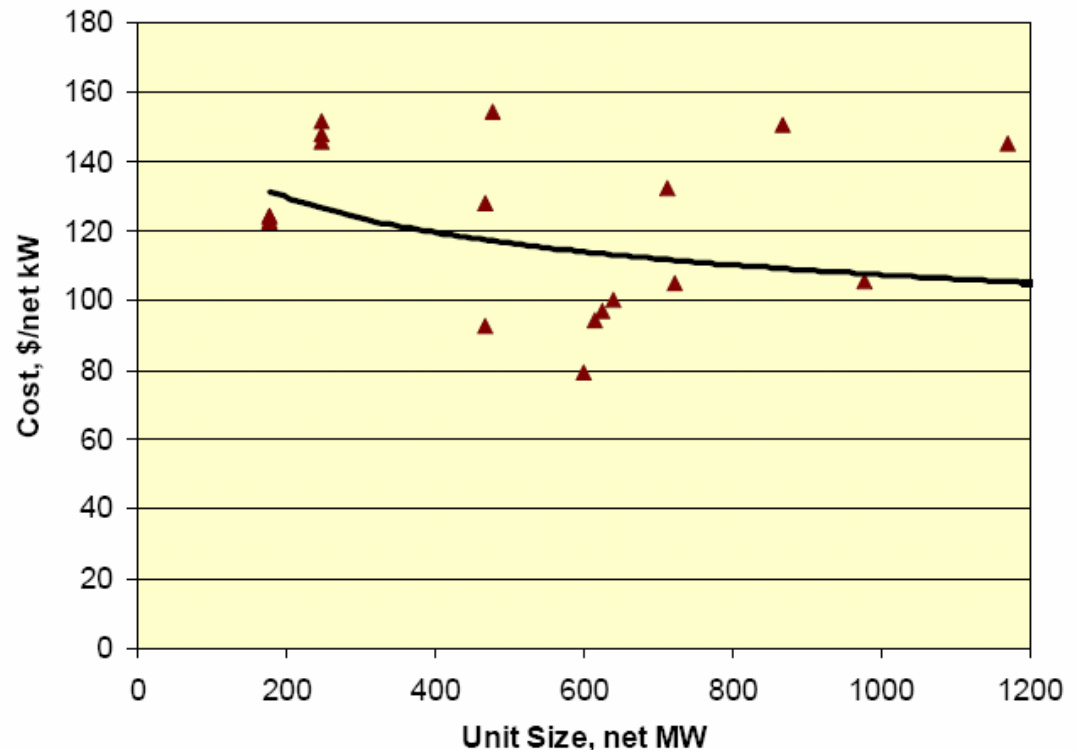
In no case did additional experience result in lower SCR capital cost

Source: J.E. Cichanowicz

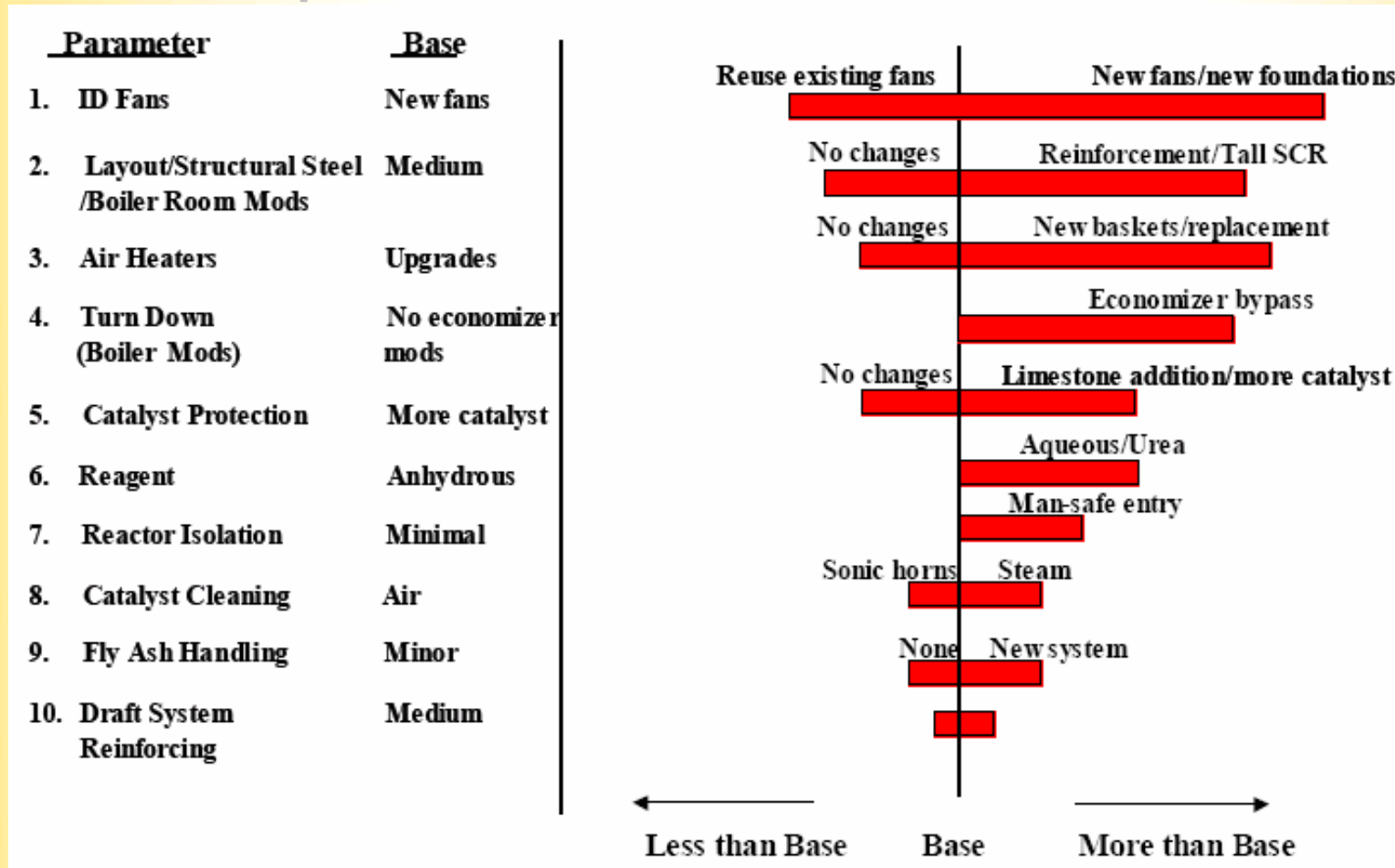
SCR Cost Comparison

- Capital costs from several units ranged from \$80 - 160/kW
- 70% of units over \$100/kW
- Wide cost range reflects site-specific conditions

Total SCR Retrofit Project Cost for Coal-Fired Units

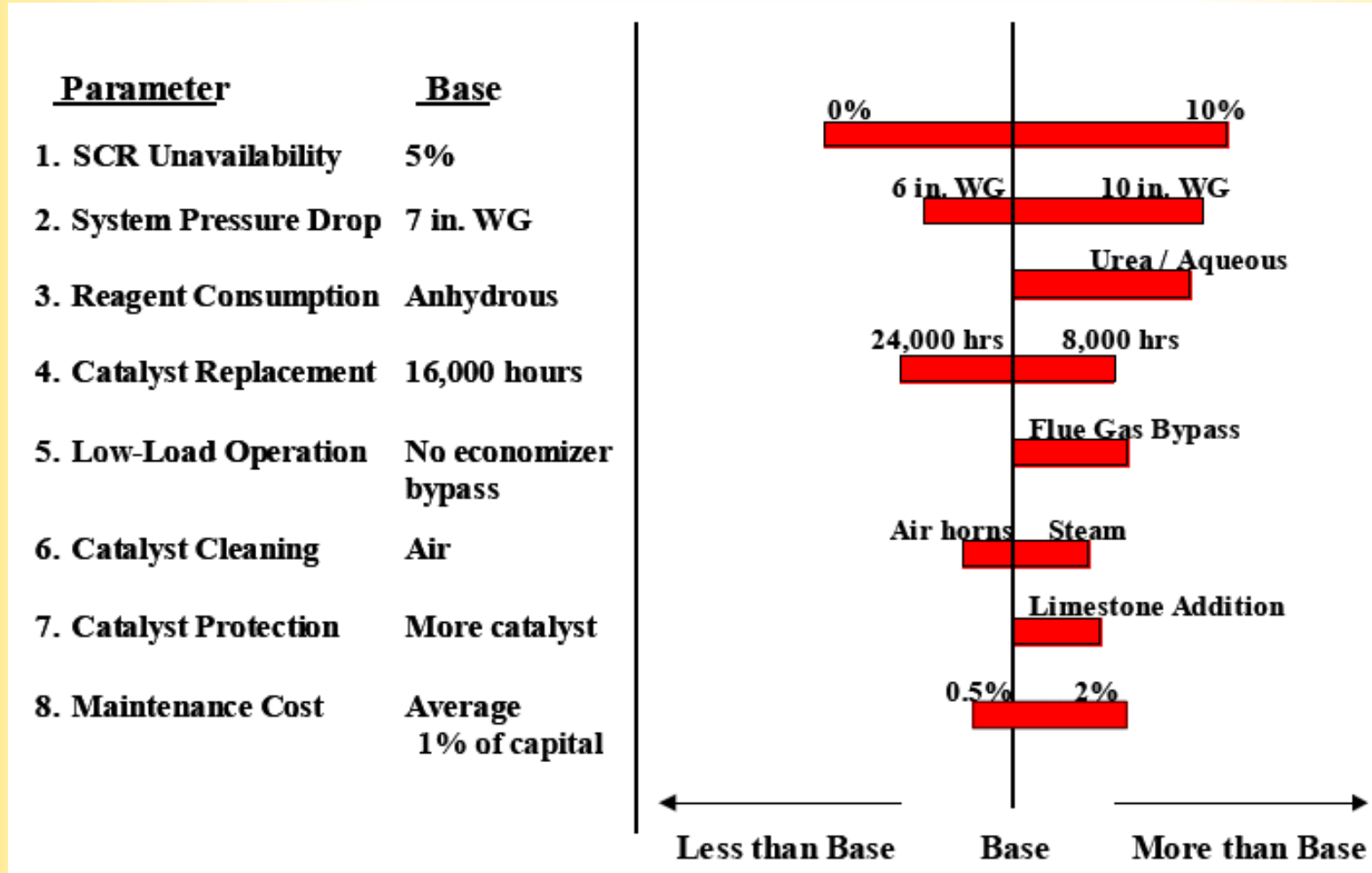


SCR Capital Cost Drivers

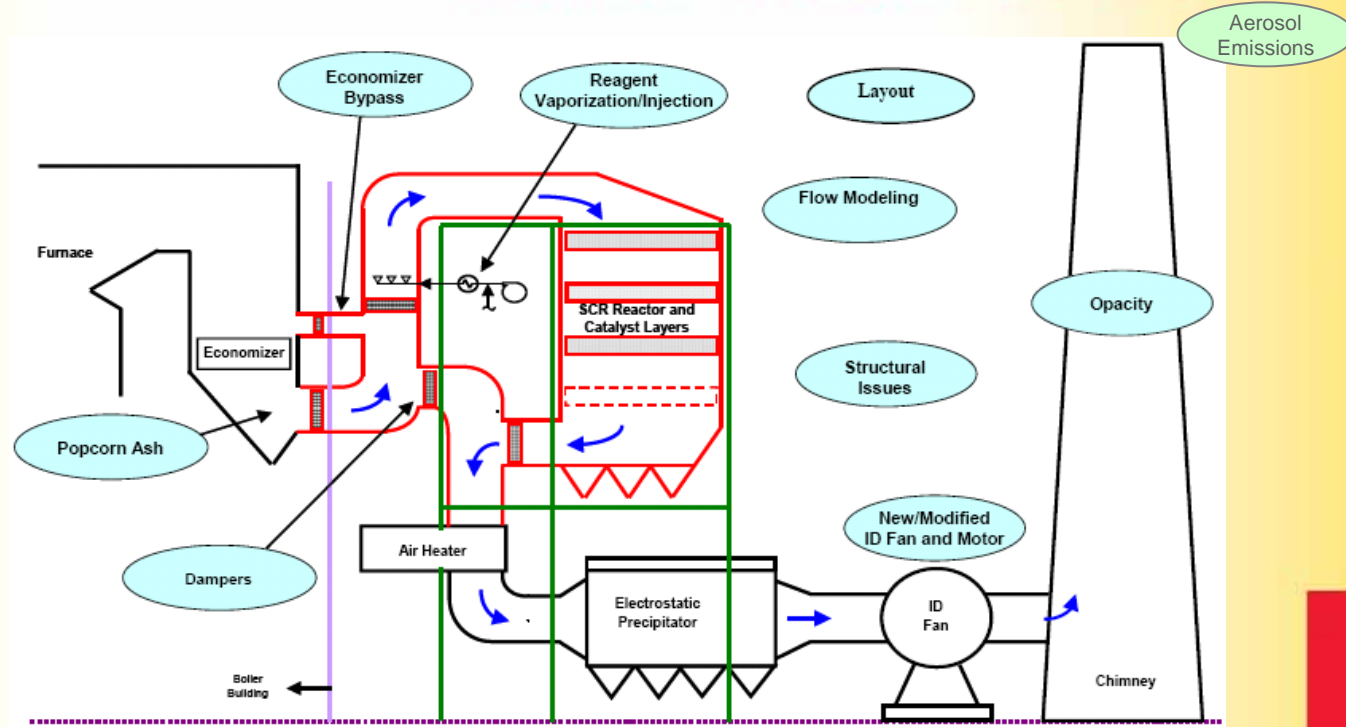


Consideration for some of these drivers can increase the capital cost by 100% or more!

SCR Operating Cost Drivers



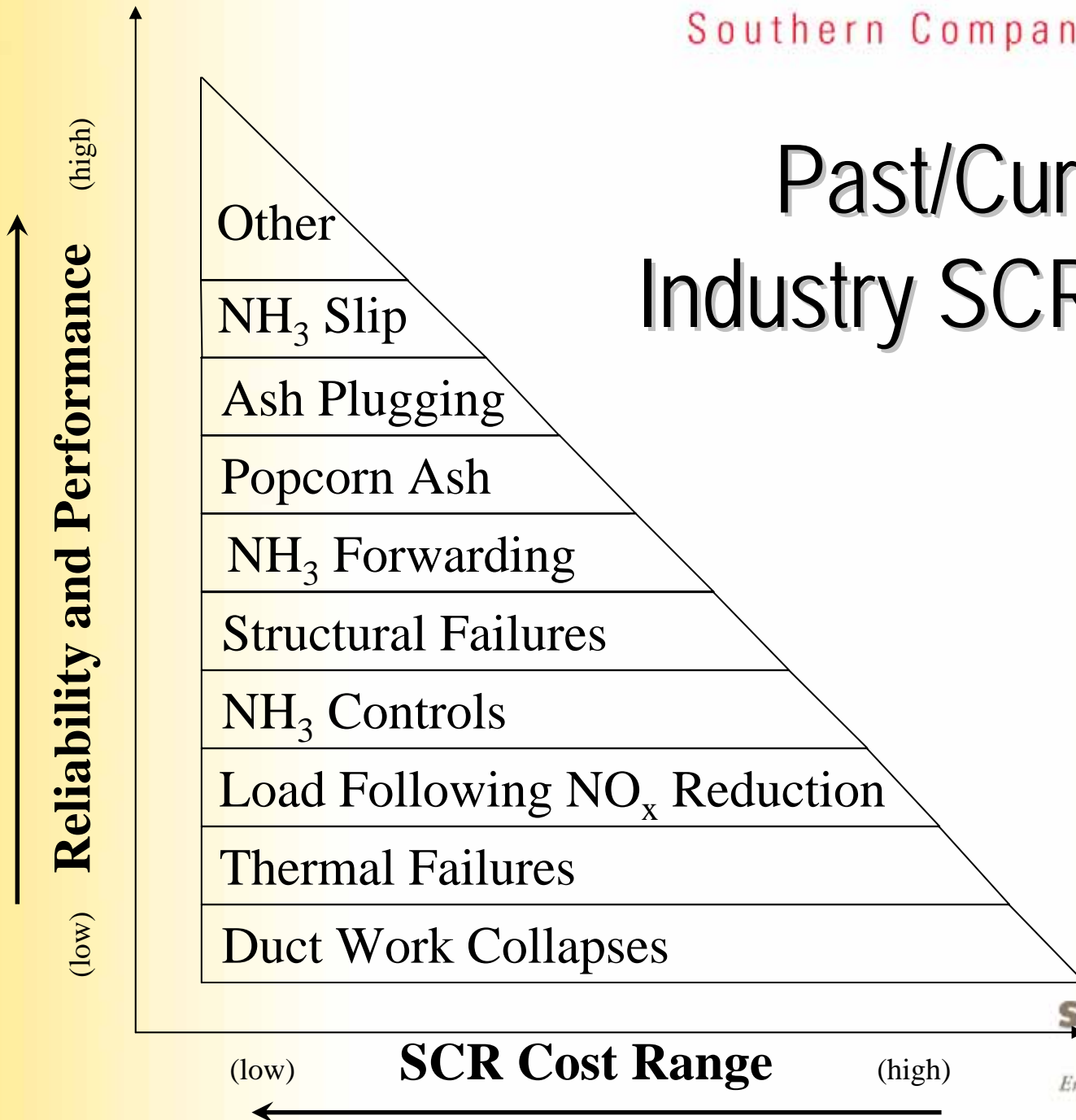
Outline



Source: McLaughlin, B., et. al, *SCR Retrofits for Coal Fired Plants: Lessons Learned*; Mega Symposium 2004

- Industry SCR Issues: past, current, and emerging
 - Control Issues
 - LPA: “popcorn ash”
 - Catalyst management
 - Unit turn-down
 - Acid aerosol emissions
- } Year-round Operation

Past/Current Industry SCR Issues



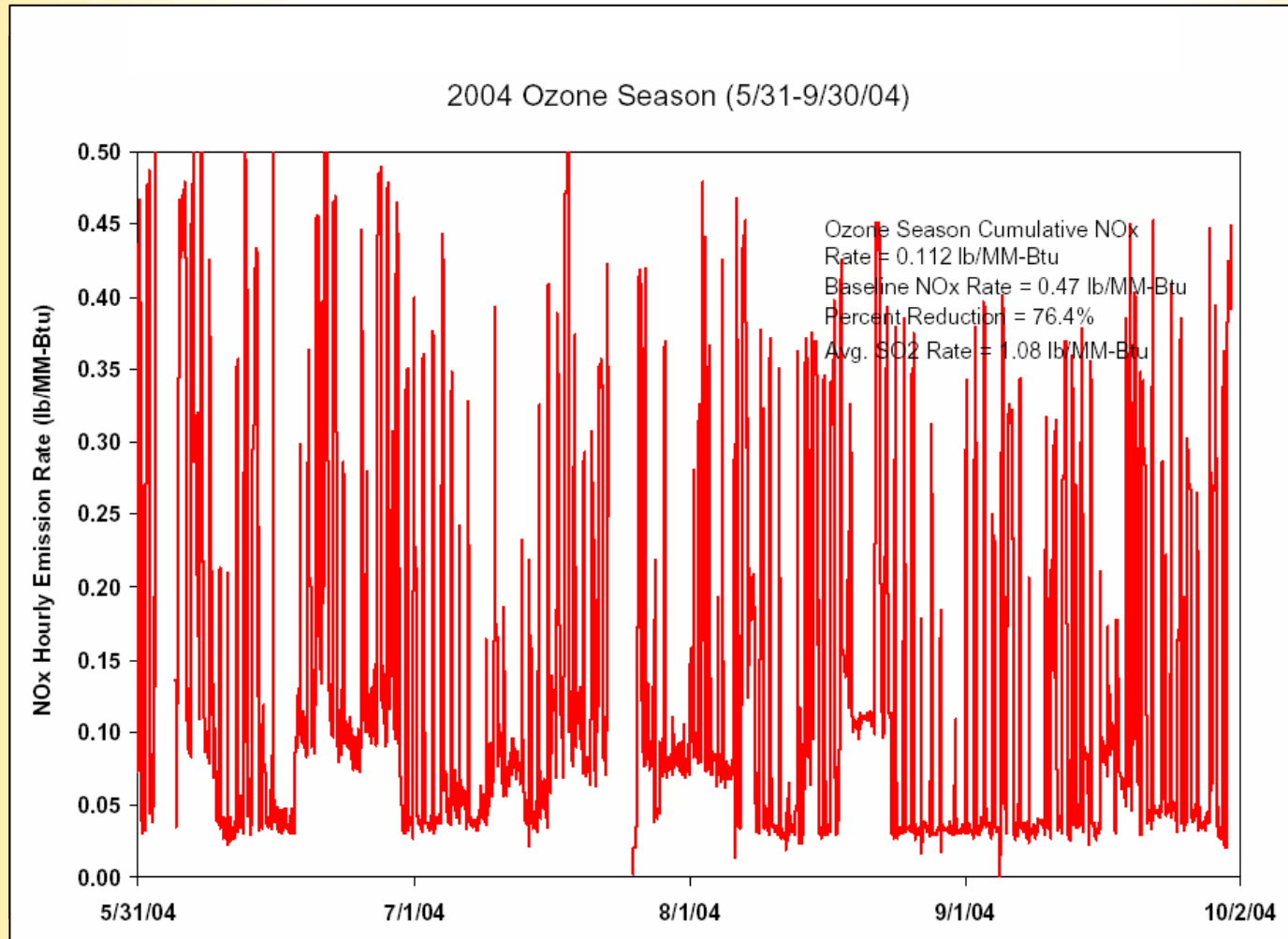
SCR Industry Issues

• Control Issues

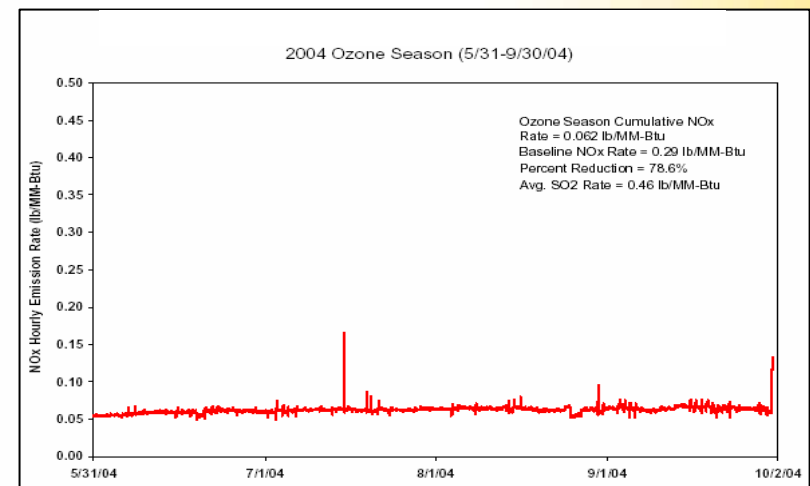
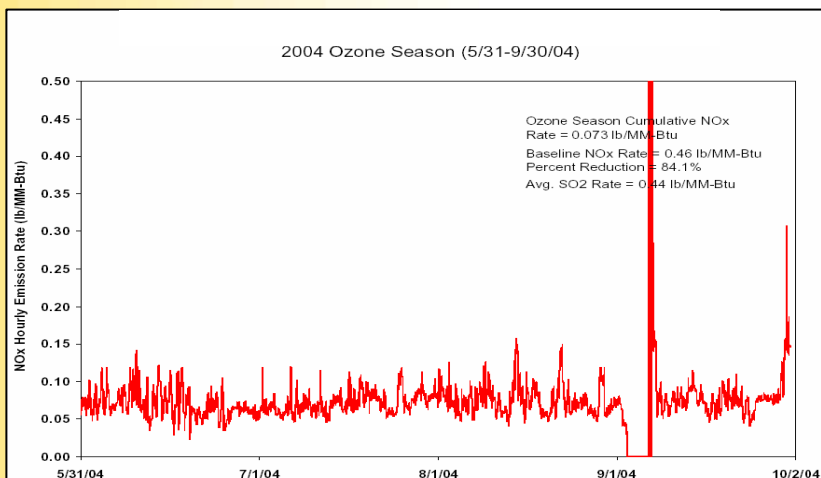
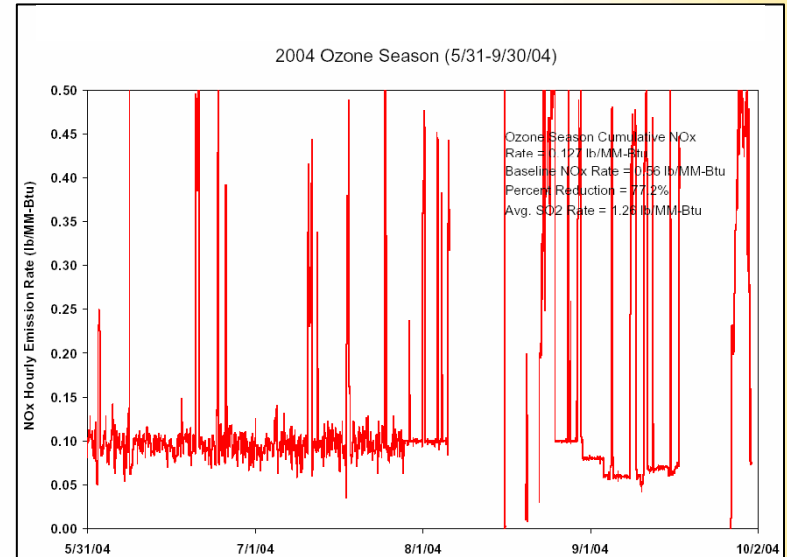
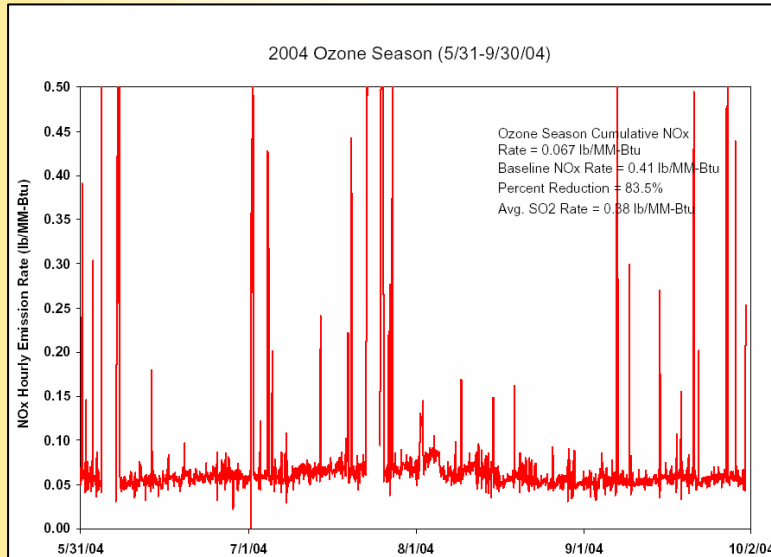
- “You can’t control what you can’t measure!”
- Unreliable NO_x analyzer/
sampling system
 - single point vs. sample grid
 - in situ vs. extractive
 - equipment failures
- Ammonia injection
 - AIG plugging
 - Forwarding pumps
 - Vaporizers



SCR Control Issues

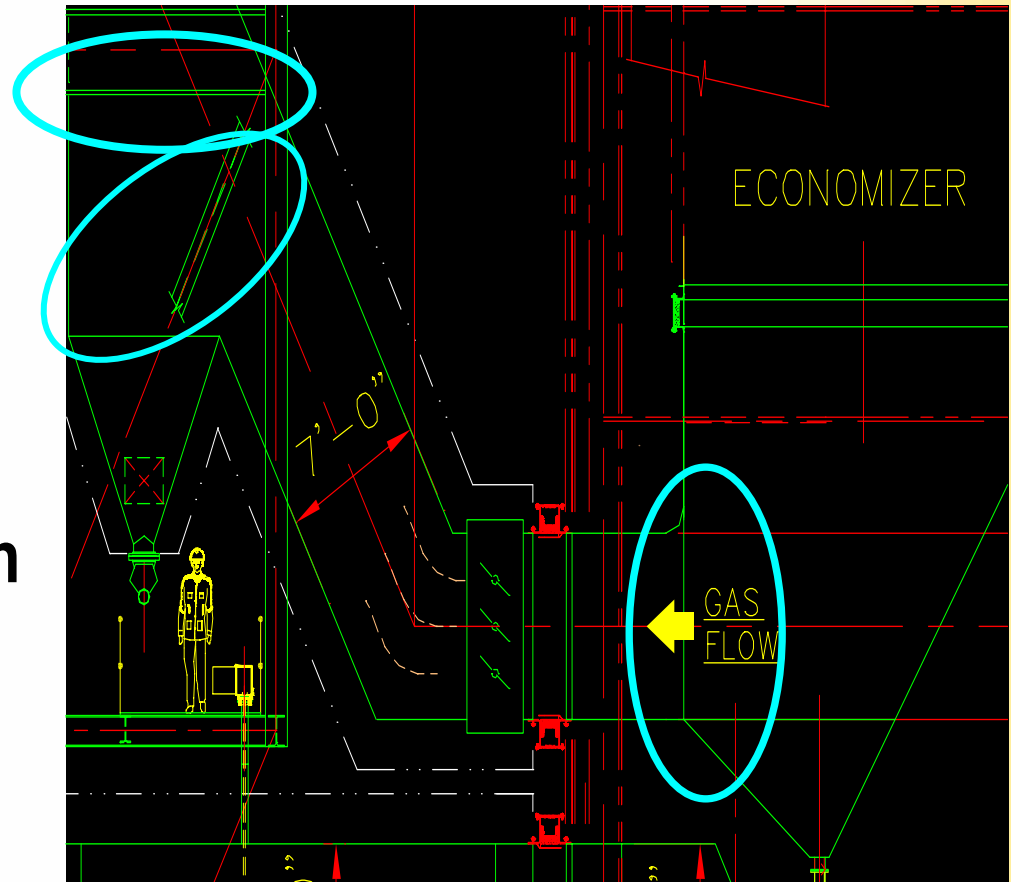


Selected Industry SCR Performance



LPA – “popcorn ash”

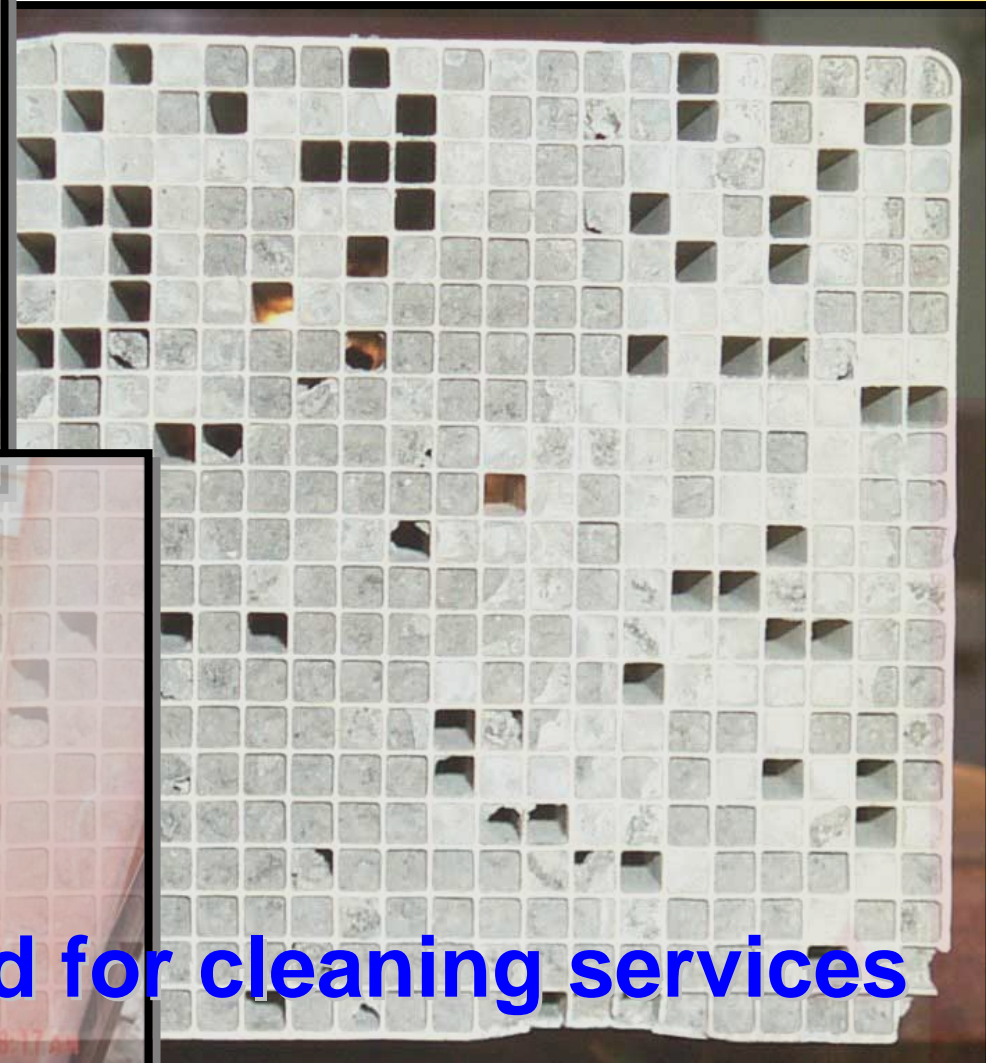
- STILL one of the most significant challenges to the industry
- **Industry responses:**
 - Screens/baffles
 - kicker plates
 - larger pitch catalyst
 - slower velocities
 - prevent formation!
- **Generally successful for seasonal operation**
- **Broad implications:**
 - Screen life = SCR availability
 - NO_x compliance
 - Hg compliance



Catalyst Management Issues

- **Consistent testing protocol**
 - Activity, K
 - SO₂ oxidation
- **Impacts of catalyst regeneration**
 - Mechanical strength/module integrity?
 - Deactivation rate?
 - SO₂ oxidation?
 - Hg oxidation?

How did we stumble upon this issue?

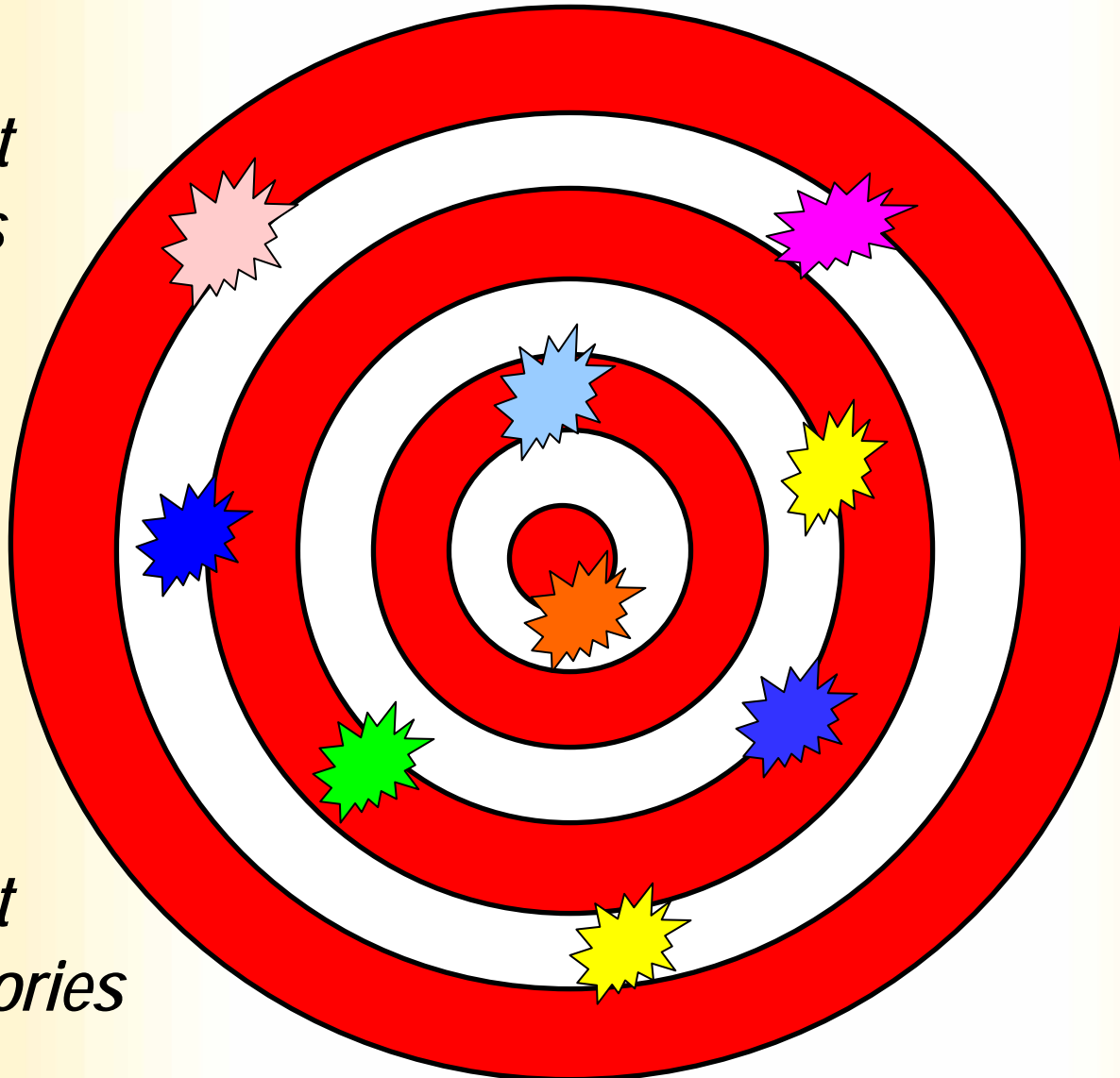


Guarantees required for cleaning services

Why is there an issue with catalyst testing?

Different Vendors

Different catalyst conditions



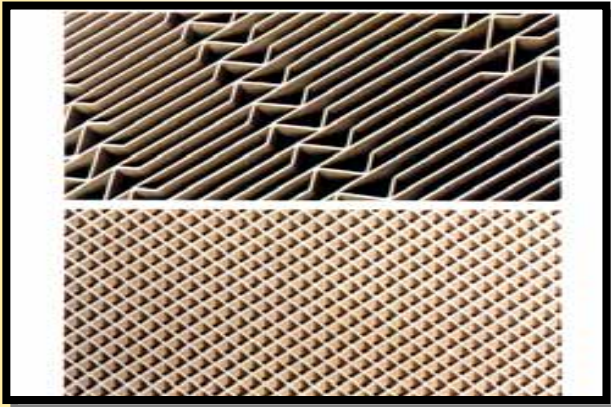
Different Laboratories

Different Testing Protocols

Why is catalyst testing important?

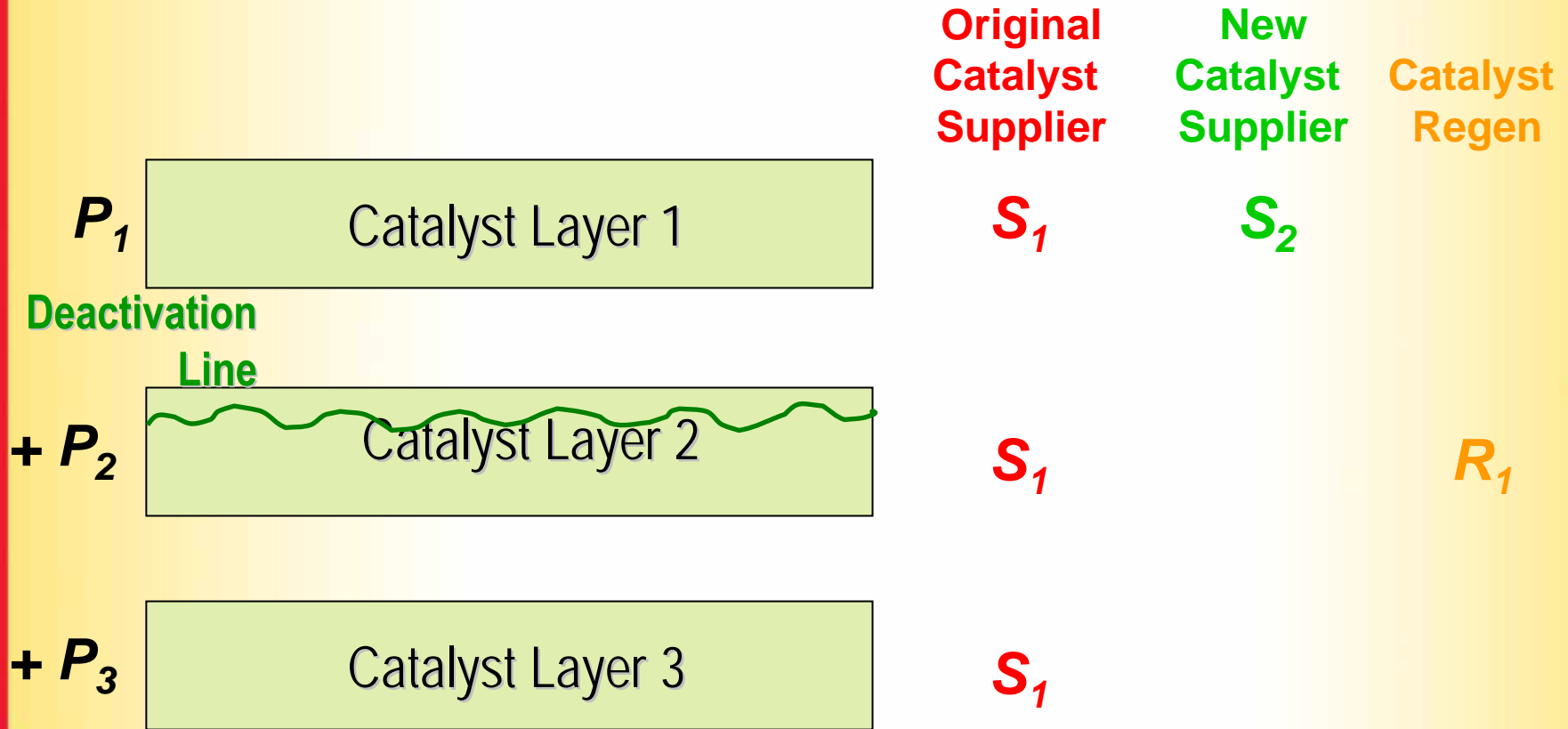
- Southern Company 2005 Ozone Season:
 - 25 SCR Reactors
 - 2 catalyst types
(3rd type in '06)
 - 13,099 m³ of catalyst
 - Over 50 samples/year

Plant Bowen



~\$70 million of asset management!

Efficient Catalyst Management



$$P_{TOT} = \frac{K}{AV}$$

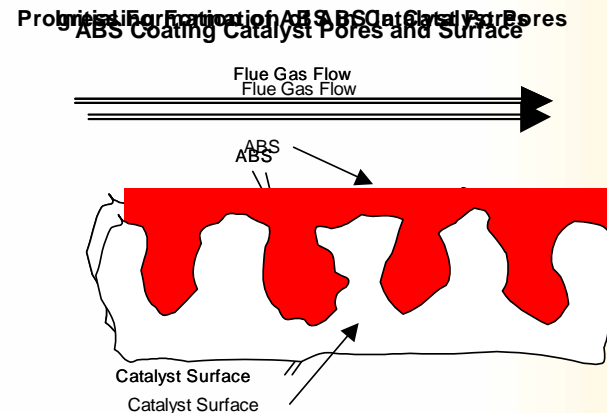
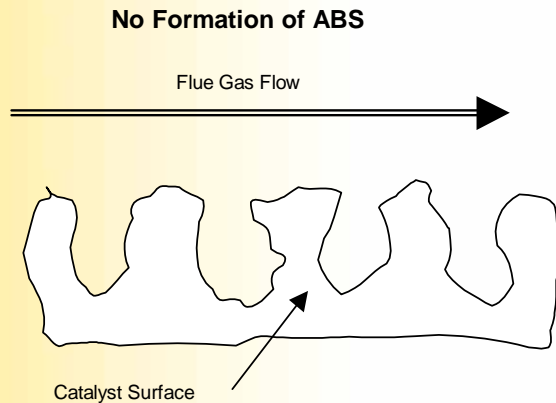
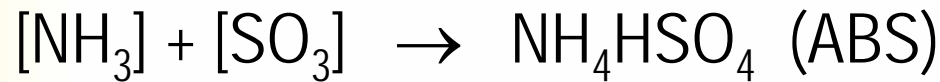
KNOW YOUR REACTOR!

Catalyst Regeneration Issues

- Mechanical strength - OK
- Deactivation rate - OK
- Recovering or even increasing activity – OK
- Reduction of SO₂ oxidation – to be continued...
- Hg oxidation? Who knows?
 - active surface area?
 - affected by SO₂ oxidation potential?
 - other flue gas constituents: Cl, SO₃?

SCR Minimum Operating Temperature?

- Minimum Operating Temperature Set To Prevent Formation of Ammonium Bisulfite (ABS) in Pores of Catalyst



What Determines SCR Minimum Operating Temperature?

$$\text{Minimum Operating Temp} = K \times [\text{SO}_3] \times [\text{NH}_3]$$

[SO₃]

Sulfur Trioxide Concentration

- Depends on Fuel Sulfur Content
- Depends on SO₂ to SO₃ Conversion in boiler

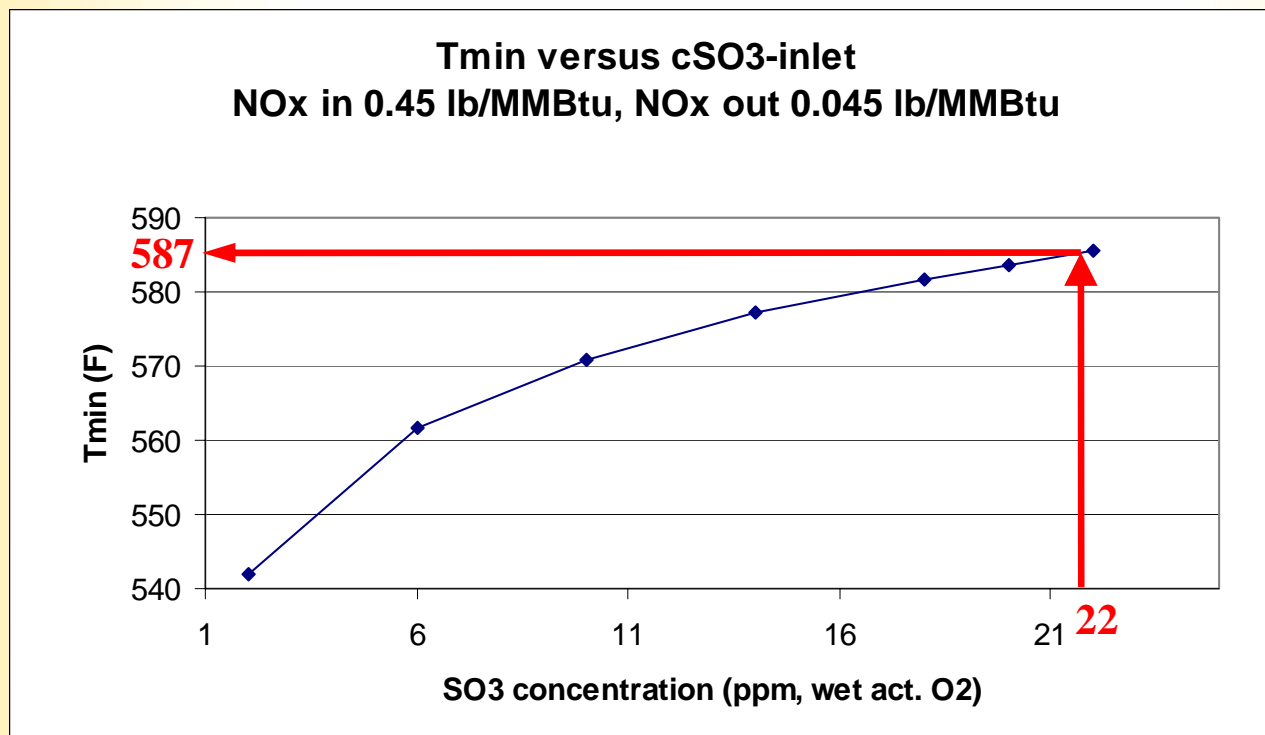
[NH₃]

Ammonia Concentration

- Depends on Inlet NOx and Required NOx Removal

SCR MOT Affects Unit Turn-Down

- Some units use economizer bypass to make up for low load temperatures – more load flexibility
- Lower oxidation catalyst allows lower MOT, more load flexibility



Acid Aerosol Emissions

“Sulfuric Acid Plume”

7 10:39 AM

“SO₃ Plume”

“Blue Plume”

APR 26 3303

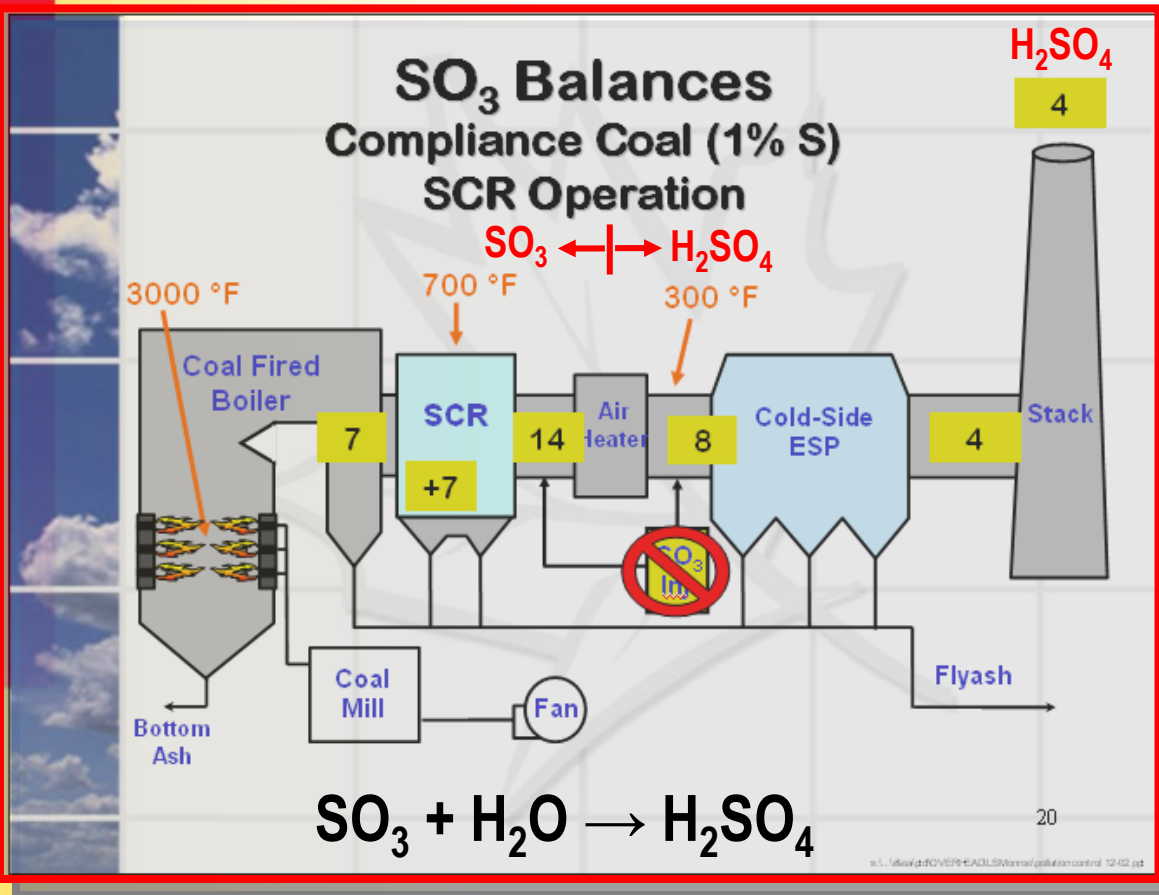
Where does it come from?

Adds H₂SO₄ Emissions

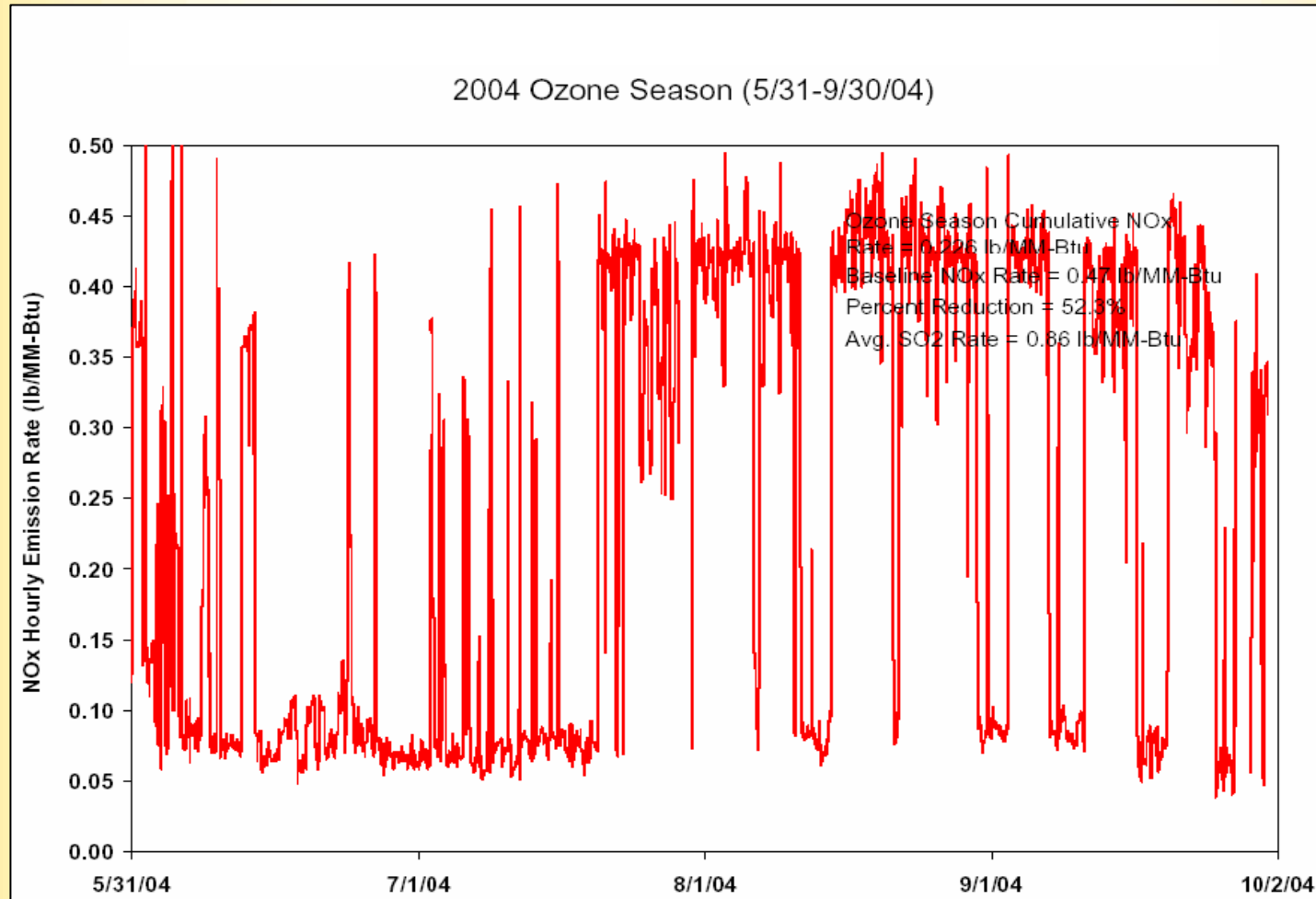
- coal S
- SCR (SO₂ oxid)
- sulfur burners

Reduces H₂SO₄ Emissions

- air preheater
- ESP
- scrubber
- add-on technology



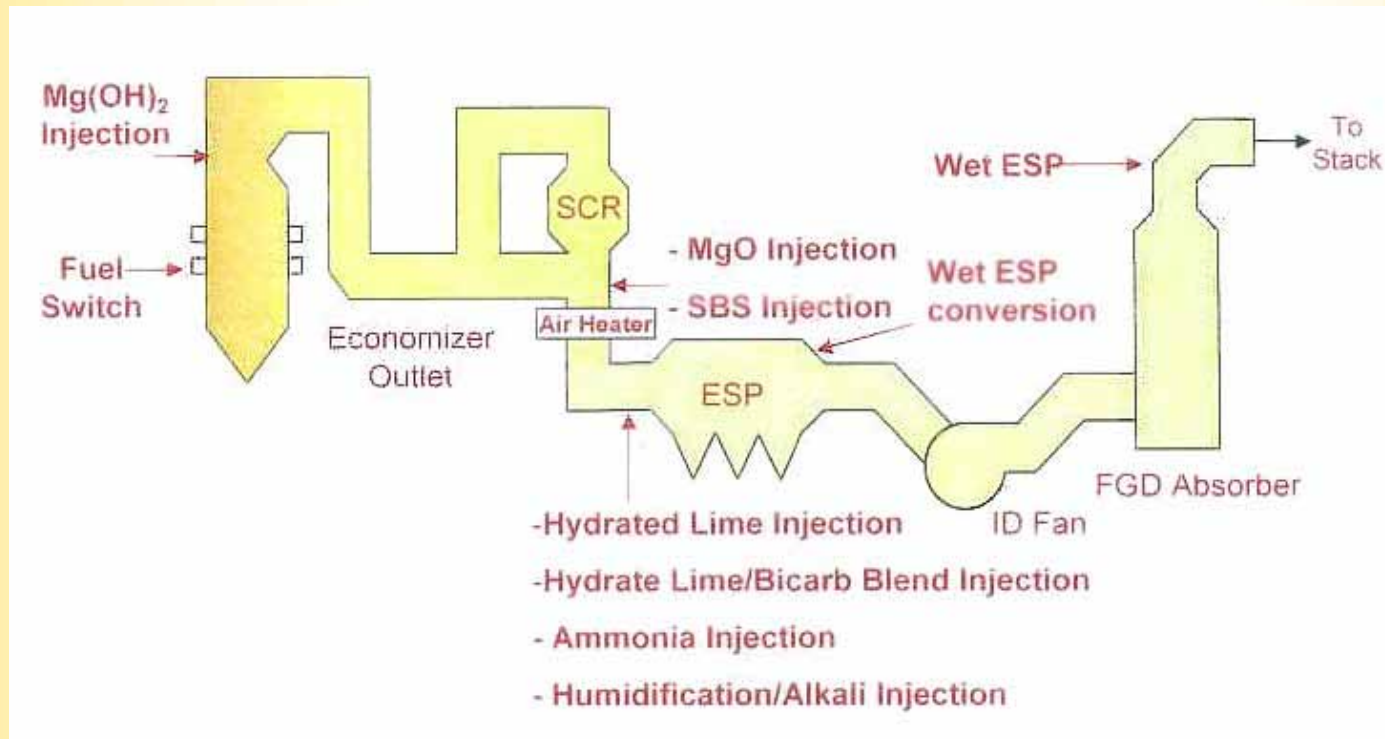
Acid Aerosol Plume Implications



Can Affect NOx Compliance!

Industry Responses

- Rush to install $\text{SO}_3/\text{H}_2\text{SO}_4$ control technologies
 - Lessons being learned “in the thick of it”
 - Some severe operational impacts: APH, duct, turning vane pluggage
- EPRI AECIG - sharing industry experience



Other Industry Responses

- Replacing existing catalyst with new lower SO₂ oxidation catalyst
- Specifying lower SO₂ oxidation standards for new SCR applications

Comparison of SCR Catalyst Design Variables and Their Effect on Operating Performance							
Major Process Variable:	NOx Removal	Ammonia Slip	SO ₂ Oxidation	Hg Oxidation	Pressure Drop	Plugging Potential	Erosion Potential
SCR Operating Temperature							
High Temp	Positive	Positive	Negative	Positive	Neutral	Positive	Negative
Low Temp	Negative	Positive	Positive	Negative	Neutral	Positive	Positive
Catalyst Pitch							
Large Pitch	Positive	Positive	Negative	Positive	Neutral	Positive	Negative
Small Pitch	Negative	Positive	Positive	Negative	Neutral	Positive	Positive
Catalyst Wall Thickness							
Thick Wall	Positive	Positive	Negative	Positive	Neutral	Positive	Negative
Thin Wall	Negative	Positive	Positive	Negative	Neutral	Positive	Positive
Catalyst Vanadium Content							
High V ₂ O ₅ Content	Positive	Positive	Negative	Positive	Neutral	Positive	Negative
Low V ₂ O ₅ Content	Negative	Positive	Positive	Negative	Neutral	Positive	Positive

Multi-Pollutant Control -
A Balancing Act

Rating Scale

Positive	Neutral	Negative
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Questions?

- SCR System Overview
- SCR Installed Capacity and Cost
- Industry SCR Issues: past, current, and emerging

- Control Issues

- LPA: low-pollution area

- Catalyst management

- Unit turn-down

- Acid aerosol emissions

Year-round Operation!

Alabama Power Company's Plant Miller