REINHOLD ENVIRONMENTAL Ltd.

2012 NOx-Combustion Round Table & Expo Presentation

February 13-14, 2012, in Columbus, OH / Hosted by AEP

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Catalyst Management

Reinhold NOx Conference 2012

February 13, 2012

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Hitachi Power Systems America, Inc.

Agenda

- What is a Catalyst Management Plan?
- Parameters Used to Set Objectives
- General Equations Used in Catalyst Management (Catalyst Potential)
- SCR Inspections
- Catalyst Types
- Catalyst Pluggage (Hydraulic Diameter)
- Fuel Management and Impact on Catalyst Deactivation
- Catalyst Life
- Catalyst Testing and Interpretation of the Results
- Spent Catalyst
- New Regulations Impact on Your CMP
- Prioritizing Goals

What is a Catalyst Management Plan?

- A tool to help manage the SCR performance and catalyst life
- Minimize cost impact of regulatory compliance
- Considers the entire catalyst life cycle
- Plans catalyst replacements with consideration of the unit outage schedule

Optimizing Your Catalyst Management Plan Can Save Millions

Parameters Used to Set Objectives

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- Required Performance and Regulations
- NOx Removal
- NH3 Slip
- SO2 Conversion
- Pressure Loss
- Fuel Management (poisons)
- Catalyst Pluggage
- Projected Deactivation Rate of Catalyst
- Hg Oxidation
- Catalyst Life vs. Outage Schedule
- Operating Temperature
- Budget
- Etc.

Must Evaluate Case By Case

General Equations Used in Catalyst Management

Catalyst Potential

Catalyst Layer Potential…

$$P = \frac{K}{A_v}$$

Where…

K = Catalyst Activity

A_v = Area Velocity

Example:

If…

K = 43

A_v = 15.6

Then…

P = 2.76

Reactor Potential…

$$RP = \sum_{i\ layers} RP_i = \sum_{i\ layers} \frac{K_i}{A_{vi}}$$

Where…

K = Catalyst Activity

A_v = Area Velocity

Area Velocity…

$$A_v = \frac{Q}{A_{cat}}$$

$$= \frac{Q}{V_{cat} A_{sp}}$$

Example:

If…

Q = 2,900,000

A_{sp} = 351

V_{cat} = 530

Then…

A_v = 15.6

Where…

Q = flue gas flowrate, m^3/hr

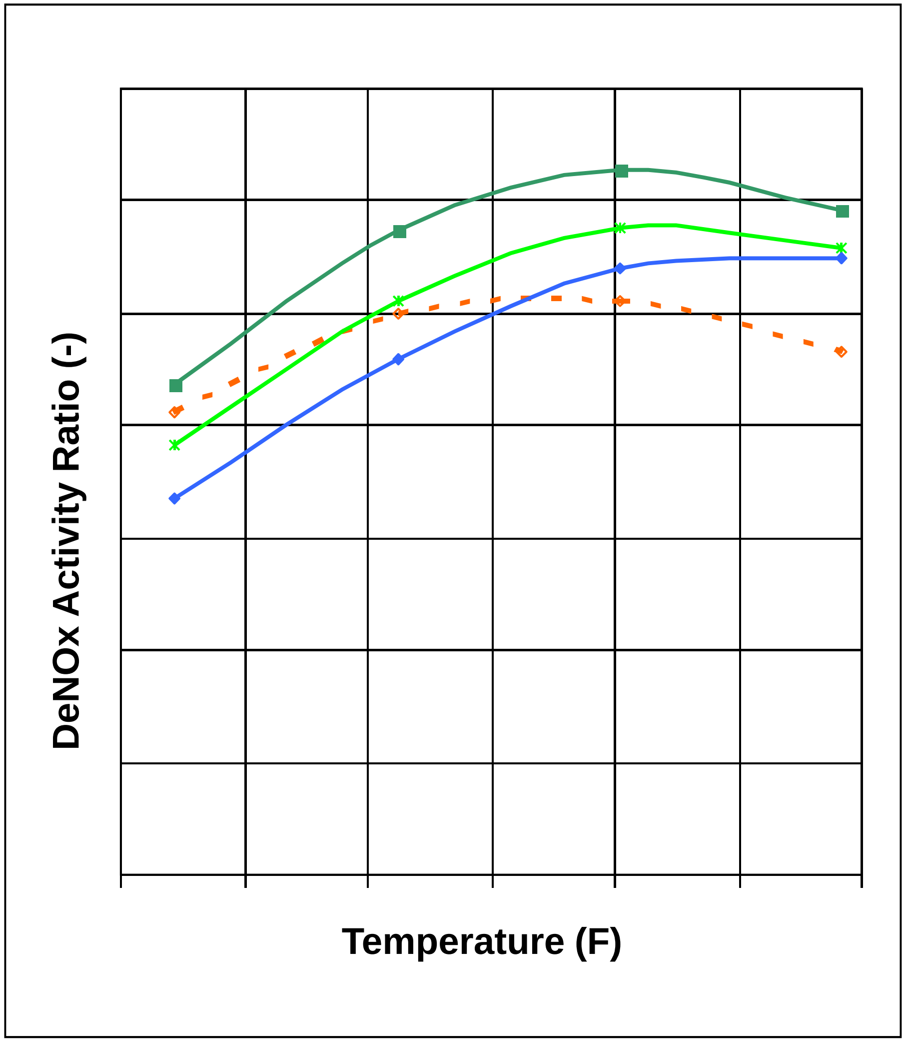
A_{cat} = catalyst surface area, m^2

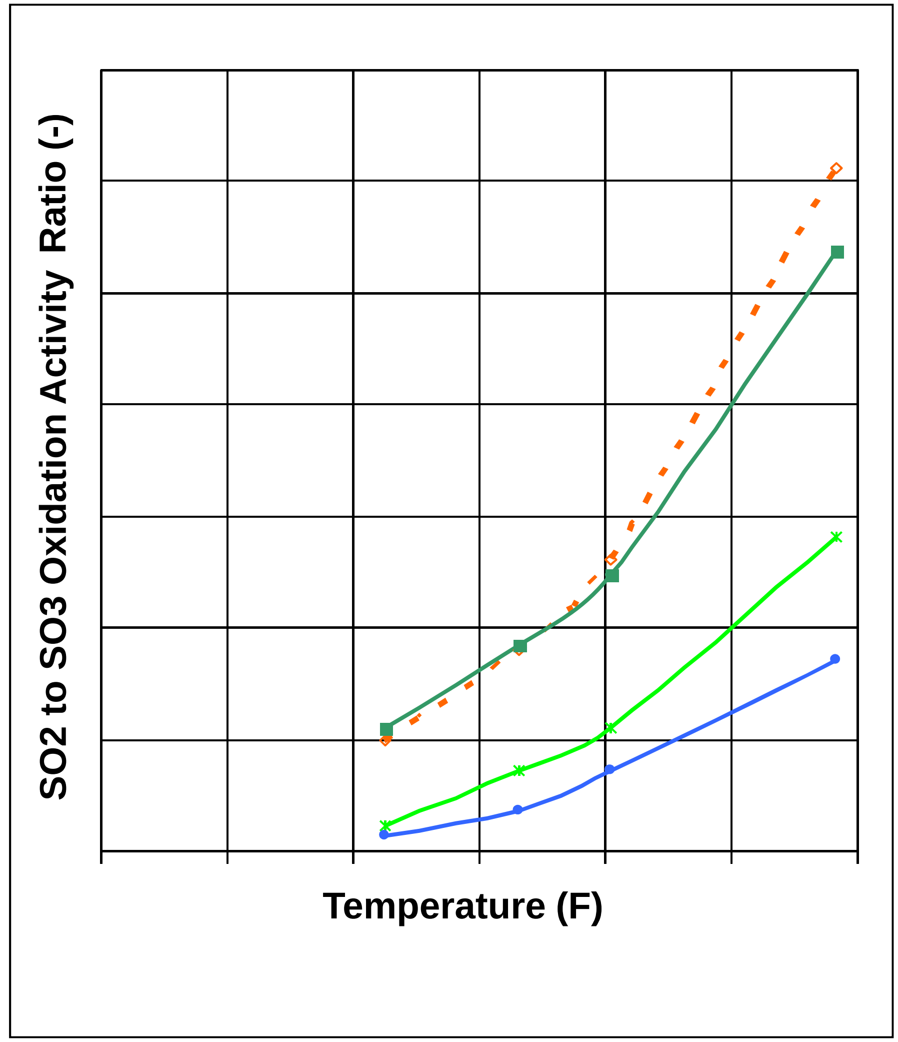
V_{cat} = catalyst volume, m^3

A_{sp} = catalyst specific surface area m^2/m^3

Impact of Temperature on Catalyst Performance

- Operating temperatures impact on catalyst activity and SO2 conversion





SCR Inspections – What To Look For

- Pluggage
  - Inspect prior to cleaning
  - Both in catalyst channels and on top of catalyst
  - Is it caused by LPA, flow distribution issues, or ash falling from beams?
- Catalyst Erosion
- Condition of Seals
- Casing Leaks
- LPA Screens
- NH3 Injection Grid/Ports
- Mixing System
- Document Findings

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Catalyst Types

And Catalyst Types Comparison

Available Catalyst Types

- Plate Catalyst
- Honeycomb Catalyst
- Corrugated Catalyst

Comparison Of Catalyst Types

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CATALYST TYPE	EROSION RESISTANCE	ASH PLUGGAGE RESISTANCE	Durability / Handling	Pressure Loss
PLATE	★★★★	★★★★	★★★★★	★★★★
HONEYCOMB	★★	★★	★★	★★★
CORREGATED	★★★	★★	★★★	★★★

★★★★★ Excellent
★★★★ Very Good
★★★ Fair
★★ Poor

Catalyst Pluggage Considerations

Pitch and Hydraulic Diameter

Hydraulic Diameter

	PLATE	HONEYCOMB	CORRUGATED
Nominal Pitch, mm	5.7 (7.0)	6.9 (9.0)	6.5 (9.0)
a, mm	5.7 (7.0)	6.9 (9.0)	6.5 (9.0)
b, mm	62 (85)	6.9 (9.0)	6.5 (9.0)
D_h, mm	9.25 (11.7)	6.2 (8.0)	5.06 (7.0)
Difference vs. Plate	--	-33% (-14%)	-45% (-24%)

D_h = 4 x Cross Sectional Area (mm^2) / Perimeter (mm)

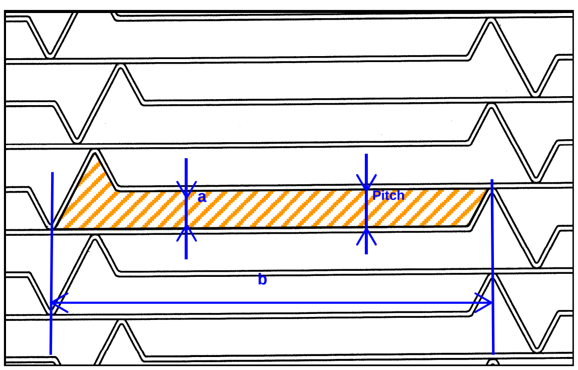
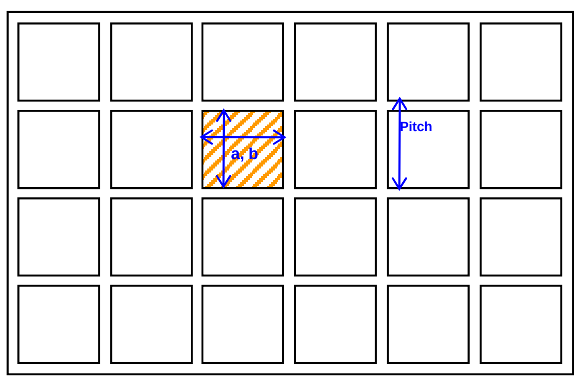
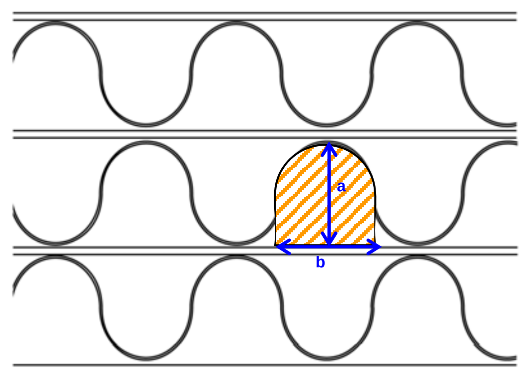


Plate type



Honeycomb type



Corrugated type

Possibility Of Dust Plugging

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Effect of catalyst shape on dust plugging

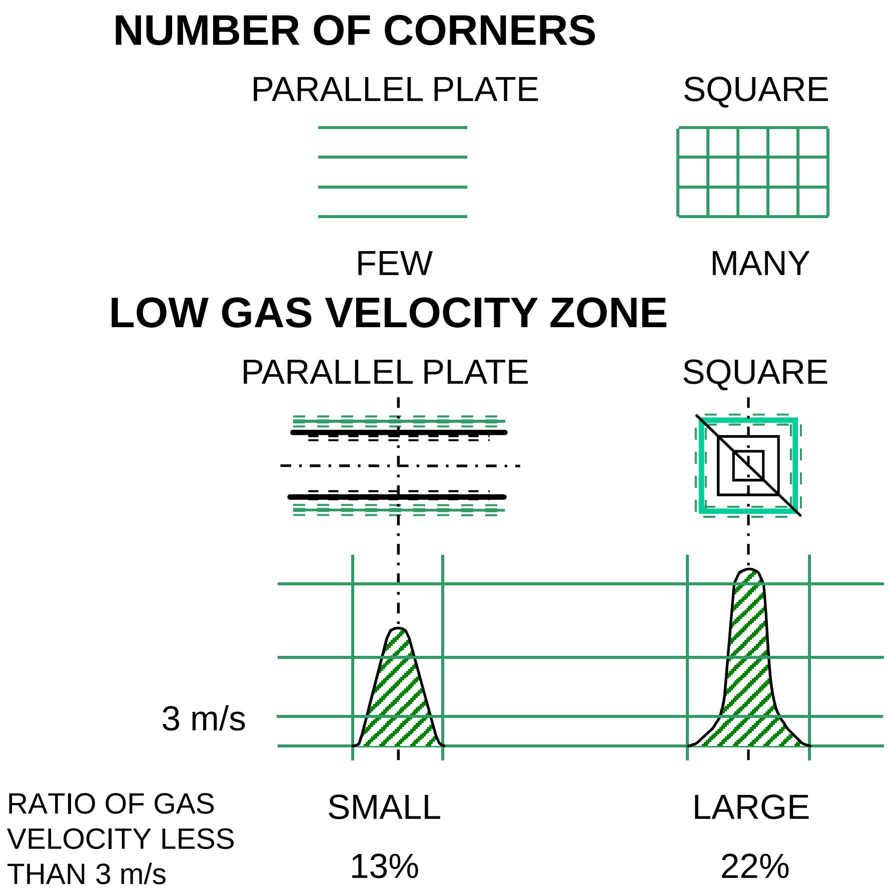

PLATE TYPE has fewer corners.

+

PLATE TYPE has fewer low velocity zones.

⇩

ANTI - PLUGGING

Variation of Catalyst Pitch

	Catalyst Pitch (mm)	
	Larger	Smaller
Catalyst Volume	Maximum ⟷	Minimum
Pressure Loss	Minimum ⟷	Maximum
Dust Plugging	Minimum ⟷	Maximum

5.7mm vs. 7mm Pitch Hitachi Catalyst

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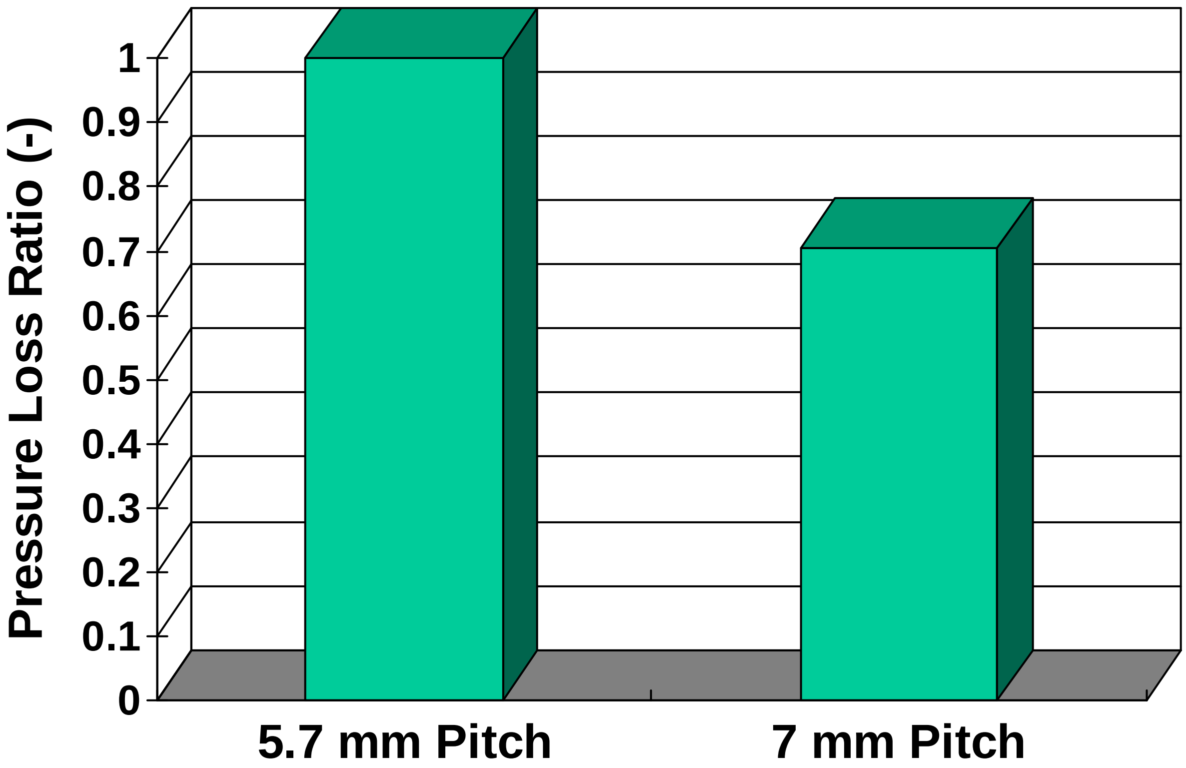
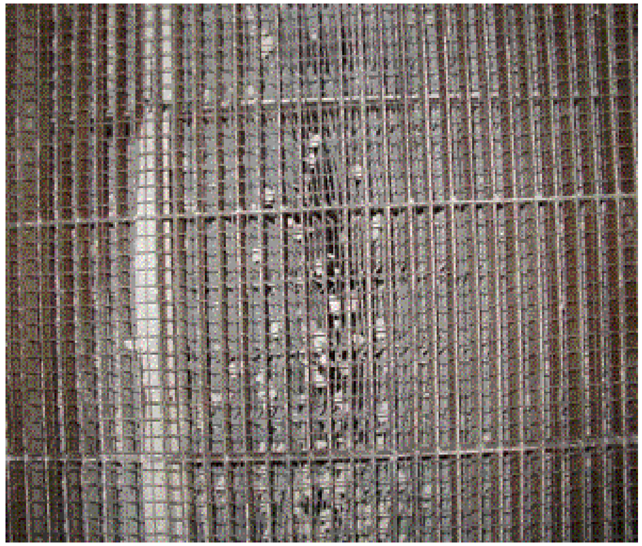
Comparison of Pressure Loss

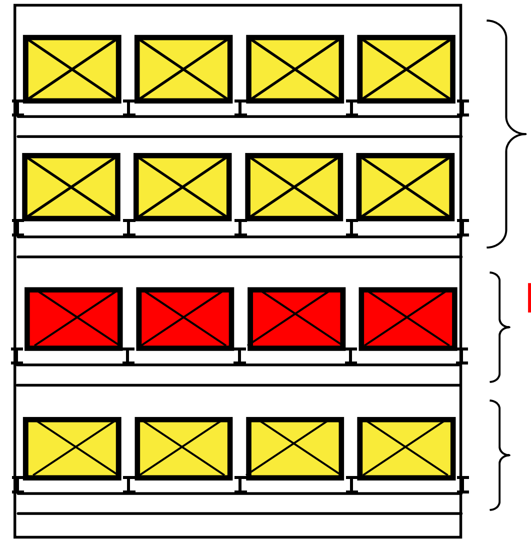


Catalyst Plugging Factor

Plate Catalyst In 1st Layer (5.7 mm Pitch)

Some LPA





Hitachi Catalyst

Honeycomb Catalyst

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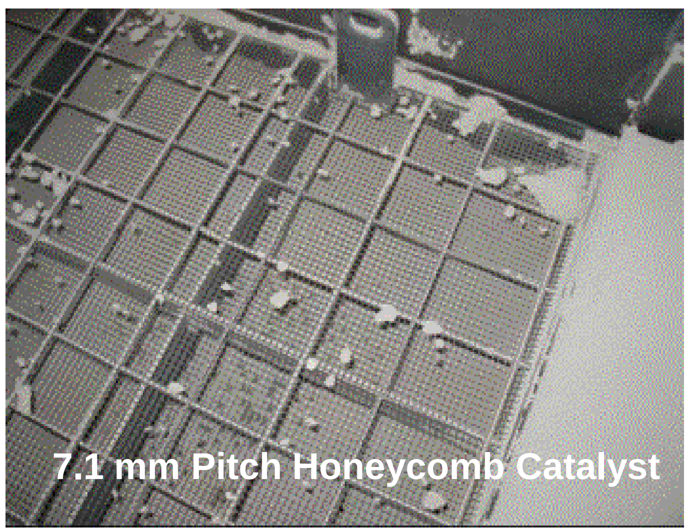
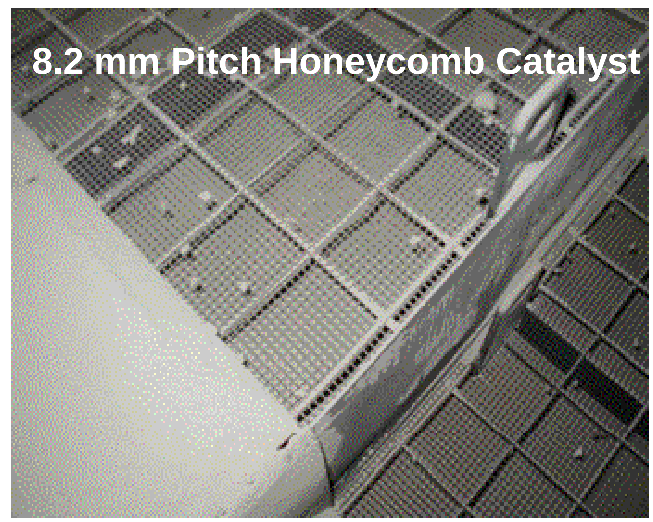
Honeycomb Catalyst in 3rd Layer

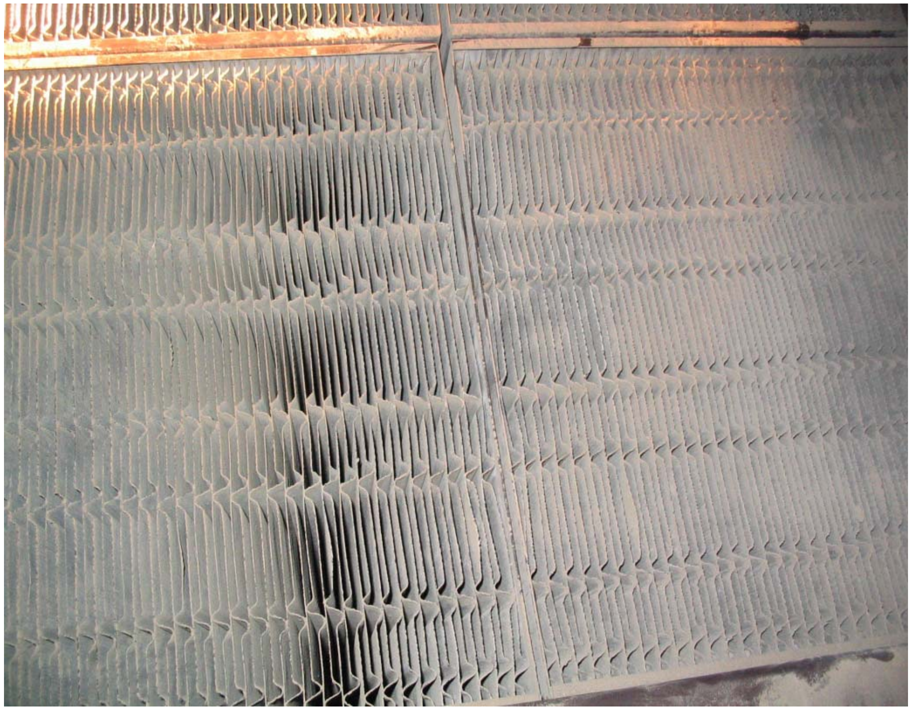
Severe Pluggage



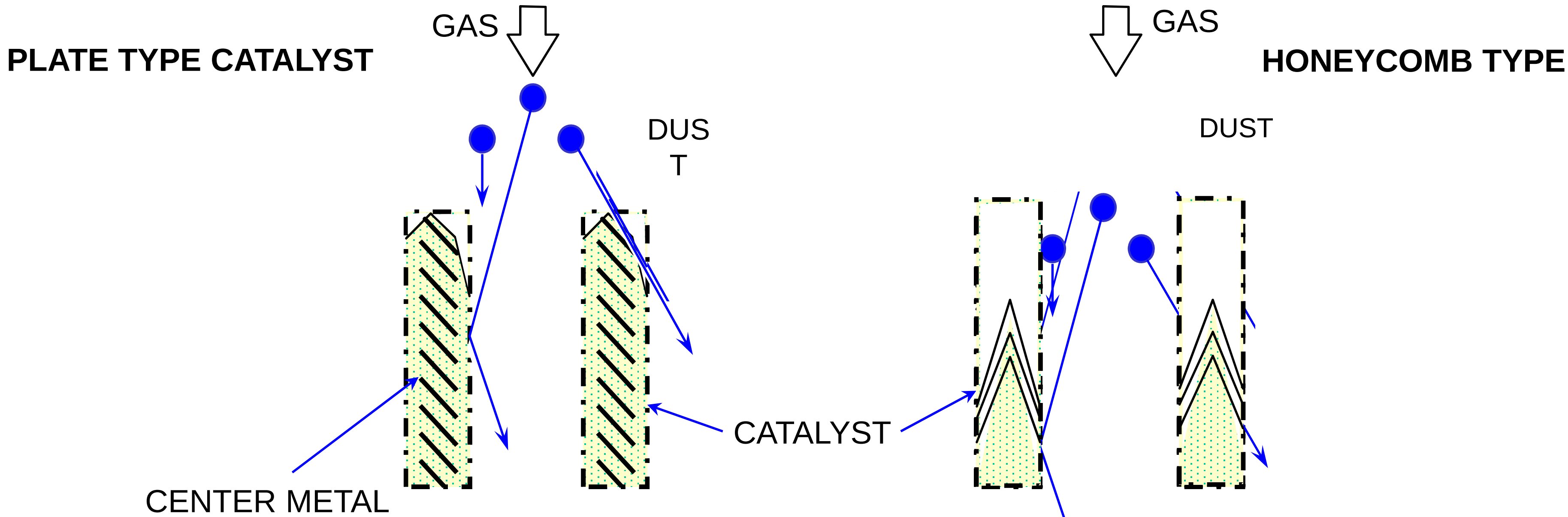


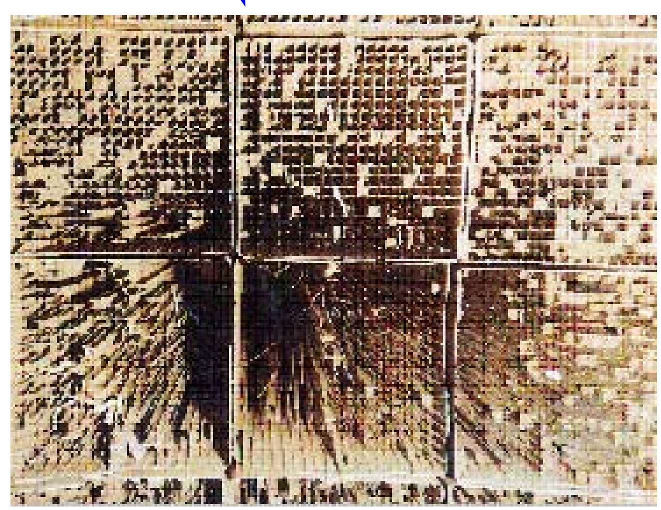
Non-Plugged Plate Catalyst

First Layer of Hitachi catalyst after 20,000 hours of operation
100% PRB Burning Plant



Catalyst Erosion





Fuel Management

Impact on Catalyst Deactivation

Fuel Management

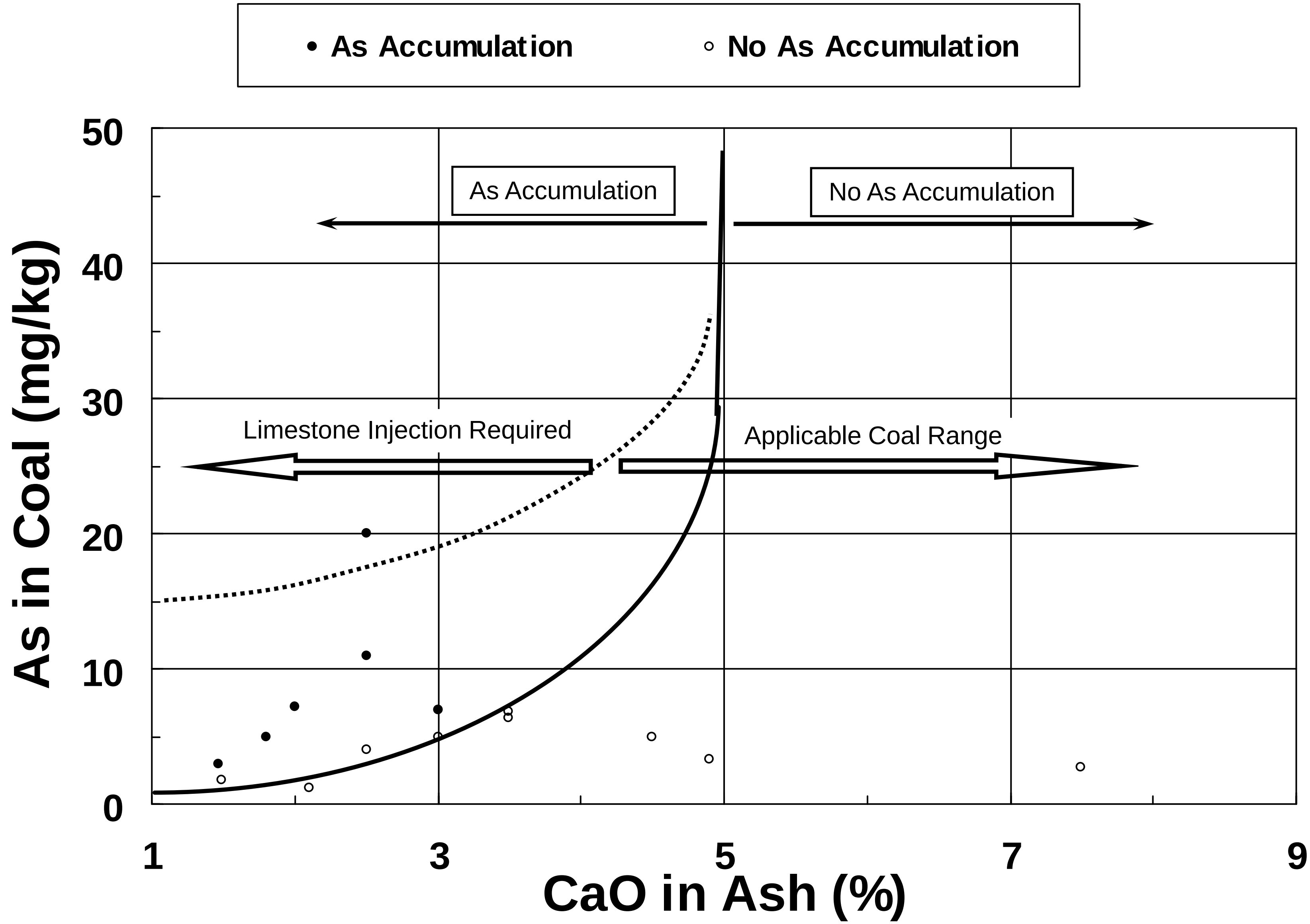
- Fuel Specification
  - Do you consider the impact on catalyst life?
  - Very important when considering Biomass
  - Do you received washed coal?
- Fuel Composition Testing
  - How Often?
  - How Consistent are Results?
- Impact of Fuel on Catalyst
  - Case by Case
  - Know Your Boundaries

It is typical for the fuel to control your CMP… not your CMP controlling the fuel

Typical Catalyst Deactivation Factors

Deactivation Factor	Effect on Catalyst	Types of Fuel
Arsenic (As)	Deactivates Sites	Bituminous
Alkaline metals (K_2O, Na_2O)	Deactivates Sites	Biomass SO3 Mitigation
Phosphorus (P_2O_5)	Deactivates Sites	PRB Biomass
Iron (Fe_2O_3) Produced by catalyst wetting due to tube leakage etc.	Increase SO_2 conversion rate	Bituminous
Calcium (CaO)	Covers Active Sites	PRB
Ash Content / Silica	Erosion	Lignite
Vanadium	Increase SO_2 conversion rate	Pet Coke

Coal Properties on As Accumulation



Comparison of Catalyst Management Plan

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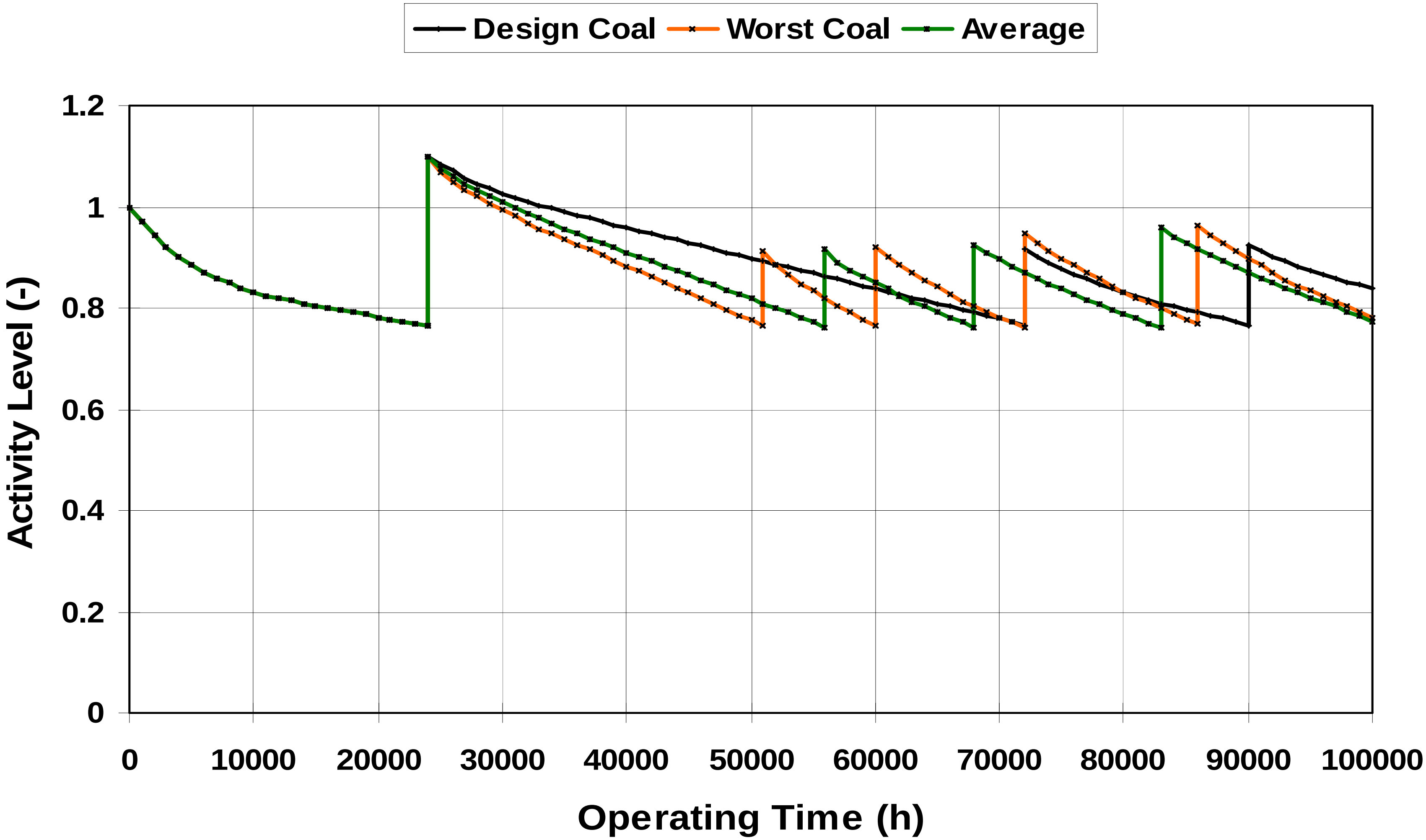

Catalyst Life

Impact on Your CMP Economics

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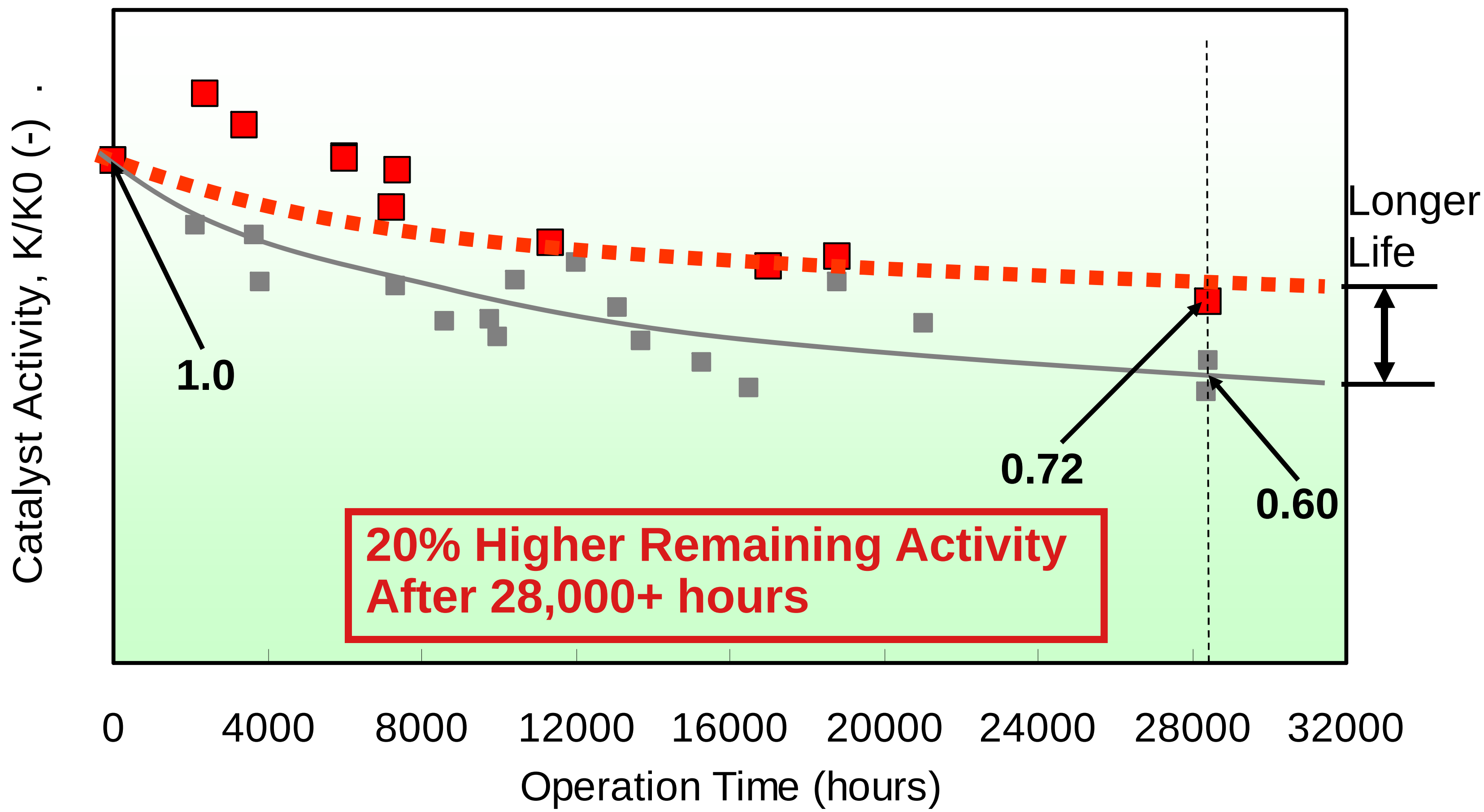
- Do you Evaluate Catalyst Life based on Initial Performance or End of Life Performance?
  - Initial Performance: Assume all catalyst deactivates at the same rate. Is this Correct?
  - When catalyst is initially installed there is lots of margin on meeting required performance.
  - End of Life: there is little or no margin remaining to meet required performance

– Conclusion –
End of Life Catalyst Guarantees are More Important than Initial Guarantees

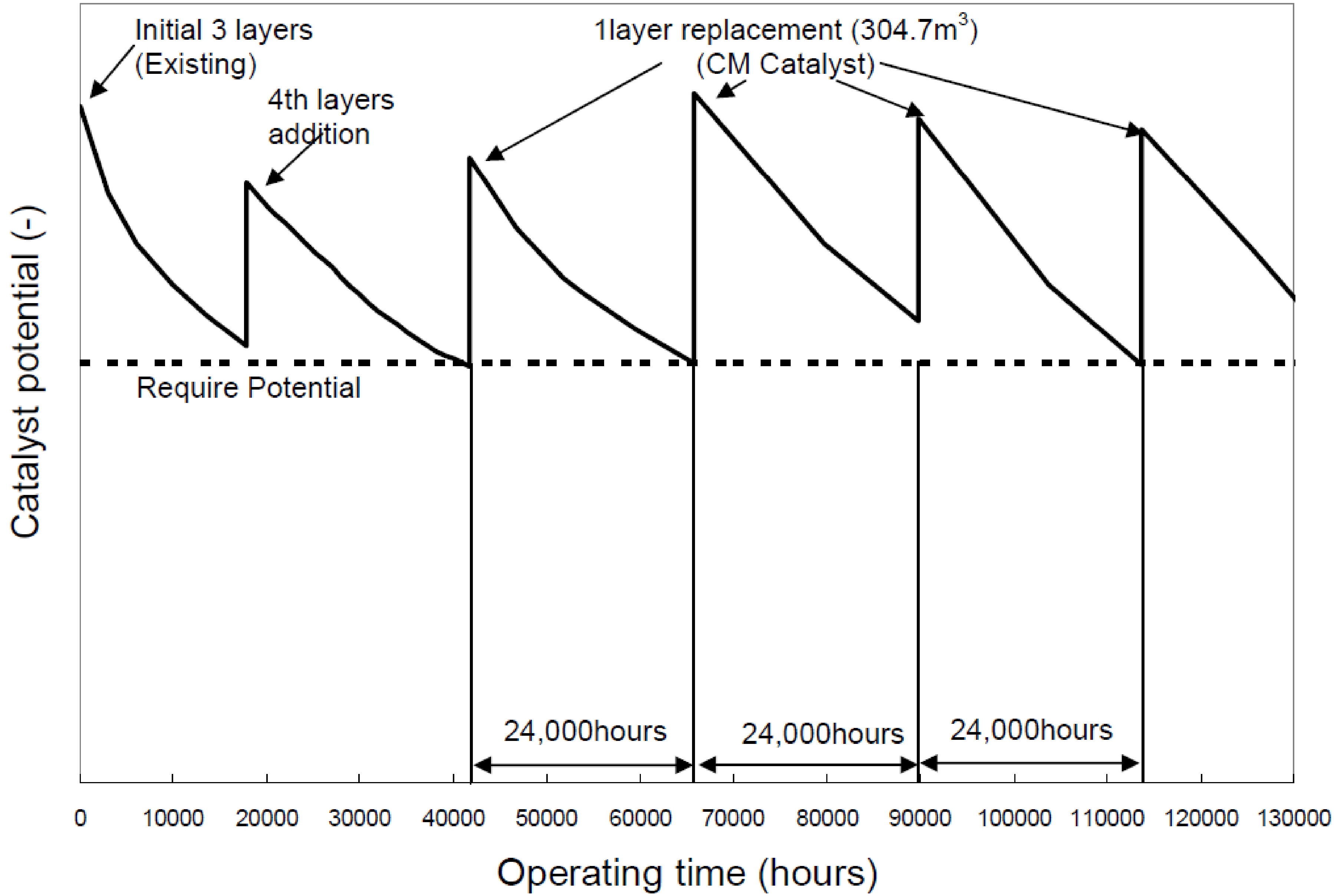
CM Catalyst Deactivation Rate

Life of TRAC®/CM catalyst is extremely improved



TRAC®/CM catalyst has longer life compared with conventional. It is possible to save money for long term operation or reduce catalyst volume to be applied to actual plants.

Hitachi CM Catalyst – Case Study



Hitachi CM Catalyst vs. Conventional/Traditional Catalyst

Catalyst Replacement Cycle	Required number layers in next 11 years	Estimated Catalyst Material Cost (per Layer)	Total Material Cost in next 11yrs (today's $)	Estimated Catalyst Loading Costs (today's $)	Year Total Cost for Catalyst Plan
18 months	**8**	**$1,000,000**	**$8,000,000**	**$2,000,000** Assumes $250K per layer	**$10,000,000**
3 years with Hitachi CM	**4**	**$1,200,000**	**$4,800,000**	**$1,000,000** Assumes $250K per layer	**$5,800,000**

Based on the deactivation tendencies of CM catalyst vs. traditional catalyst, the extended life allows for fewer future catalyst layer replacements.

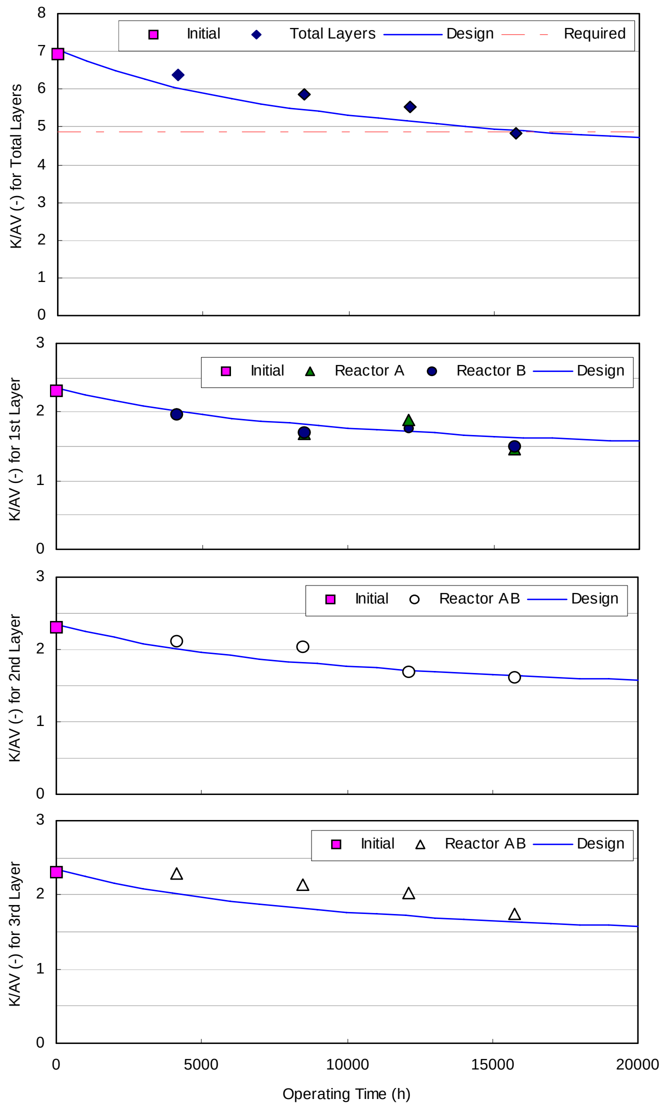
Estimated Savings of $4,200,000 Over next 11 years

Catalyst Testing and Interpretation of the Results

Sample Catalyst Testing – Key Components

- **Bench Scale Activity Testing**
  - Should be conducted once per year
  - Used to establish a deactivation trend line to extrapolate when catalyst replacement will need to take place.
  - Can be used to determine which catalyst layer should be replaced
- **SO_2 to SO_3 Oxidation Rate**
  - Determined during the bench scale test
  - Used to determine if or how much SO3 mitigation sorbent is needed
- **Chemical Composition Analysis**
  - To determine the elements / compounds accumulated on the catalyst
  - Semi-quantitative analysis is performed via x-ray fluorescence analysis (XRF)
  - Typically catalyst surface and bulk are tested
- **Specific Surface Area and Porosity**
  - Performed to determine if any unexpected operating conditions aversely affected the catalyst such as sintering

Bench Scale Testing Example



Sample of Activity Results from a Typical Test Report

Bench Scale Reactor

Sample of SO_2 to SO_3 Conversion Rate Results from a Typical Test Report

Sample			Inlet SO_2 (ppm)	Inlet SO_3 (ppm)	Outlet SO_3 (ppm)	Measured SO_2 to SO_3 Conversion Rate (%)	Estimated SO_2 to SO_3 Conversion Rate/Layer (%)
1st Sampling	1st Layer	A Reactor	1723	3.2	6.0	0.16	0.29
		B Reactor	1790	4.4	6.8	0.13	
	2nd Layer	A+B Reactor	1732	3.1	5.7	0.15	0.30
	3rd Layer	A+B Reactor	1787	3.6	4.5	0.05	0.10
	Total Layers						0.69

Chemical Composition Analysis

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Sample of Semi-Quantitative (Surface) Results from a Typical Test Report

Sample	Unused	1st Sampling					
Location	-	1st Layer		2nd layer		3rd Layer	
	-	3A-1-C	3B-1-C	3A-2-C	3B-2-C	3A-3-C	3B-3-C
Na_2O	-	0.13	0.12	0.051	0.12	0.052	0.1
MgO	-	-	-	-	-	-	0.19
Al_2O_3	3.9	6.5	7.7	4.2	7.3	4.6	7.1
SiO_2	13.0	16.0	18.0	12	17	16	15
P_2O_5	0.12	0.34	0.55	0.33	0.49	0.26	0.48
SO_3	-	3.0	2.4	3.4	2.5	3.5	3.5
Cl	0.049	0.018	0.017	0.032	0.019	0.029	0.018
K_2O	Trace	0.12	0.12	0.035	0.092	0.079	0.12
CaO	0.019	0.27	0.31	0.087	0.37	0.09	0.36
Cr_2O_3	0.76	0.35	0.65	0.84	0.12	0.22	0.29
Fe_2O_3	2.0	1.4	1.9	1.6	0.71	0.76	1.2
As_2O_3	**Trace**	**2.9**	**3.1**	**0.91**	**2.6**	**0.13**	**1.9**
SrO	-	-	-	-	-	-	Trace
ZrO_2	0.043	0.036	0.021	0.025	0.04	0.027	0.035
Nb_2O_5	0.11	0.11	0.12	0.15	0.01	0.13	0.091

Chemical Composition Analysis

Sample of Quantitative (Bulk) Results from a Typical Test Report

Sample	Unused	1st Sampling						
Location	-	1st Layer		2nd layer		3rd Layer		Average
	-	3A-1-C	3B-1-C	3A-2-C	3B-2-C	3A-3-C	3B-3-C	-
Na	0.022	0.036	0.032	0.027	0.029	0.027	0.031	0.030
K	0.002	0.026	0.027	0.014	0.016	0.014	0.023	0.020
Ca	0.017	0.028	0.028	0.017	0.023	0.02	0.025	0.024
Mg	0.020	0.002	0.002	0.002	0.008	0.003	0.004	0.003
Si	5.92	5.91	6.08	5.81	5.99	5.78	5.81	5.90
Al	3.79	3.91	4.18	3.94	4.04	3.88	3.84	3.97
P	0.023	0.010	0.014	0.01	0.007	0.012	0.008	0.010
SO_4	0.20	1.75	1.49	2.94	1.89	3.18	3.16	2.40
As	**0.02**	**1.37**	**1.42**	**0.33**	**0.62**	**0.22**	**0.53**	**0.75**

Specific Surface Area and Porosity Test

Sample of Results of a Typical Test Report

Sample		Item	Unused	1st Sampling	2nd Sampling
Sample Coupon	Inlet	S.A.	1.00	0.834/0.858	0.787/0.826
		P.V.	1.00	0.912/0.944	0.926/0.951
	Outlet	S.A.	1.00	0.851/0.851	0.766/0.781
		P.V.	1.00	0.895/0.930	0.898/0.930
Catalyst Elements	No.1	S.A.	-	-	0.821/0.873/0.883
		P.V.	-	-	0.947/0.989/0.965
	No.2	S.A.	-	-	0.831/0.897/0.894
		P.V.	-	-	0.923/0.954/0.972
	No.3	S.A.	-	-	0.802/0.848/0.844
		P.V.	-	-	0.989/0.982/1.014
	No.4	S.A.	-	-	0.815/0.831/0.850
		P.V.	-	-	0.968/0.972/0.993

Spent Catalyst

Optimizing Its Use

Options for Spent Catalyst

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- Regenerate
  - Used catalyst can be regenerated and reinstalled in an SCR
  - Saves on initial cost of catalyst
  - Catalyst Quality and Performance is not the same as new catalyst
- Recycle
  - Plate type catalyst only can be recycled.
  - Recycling is done by a scrap metal processing company
  - You recover the salvage value and save on landfill and transportation costs
- Landfill - Try to Avoid
  - Cost to landfill and for transportation
  - Least environmentally friendly option

New and Future Regulations

How They Impact Your SCR

CSAPR – Map of Impacted States

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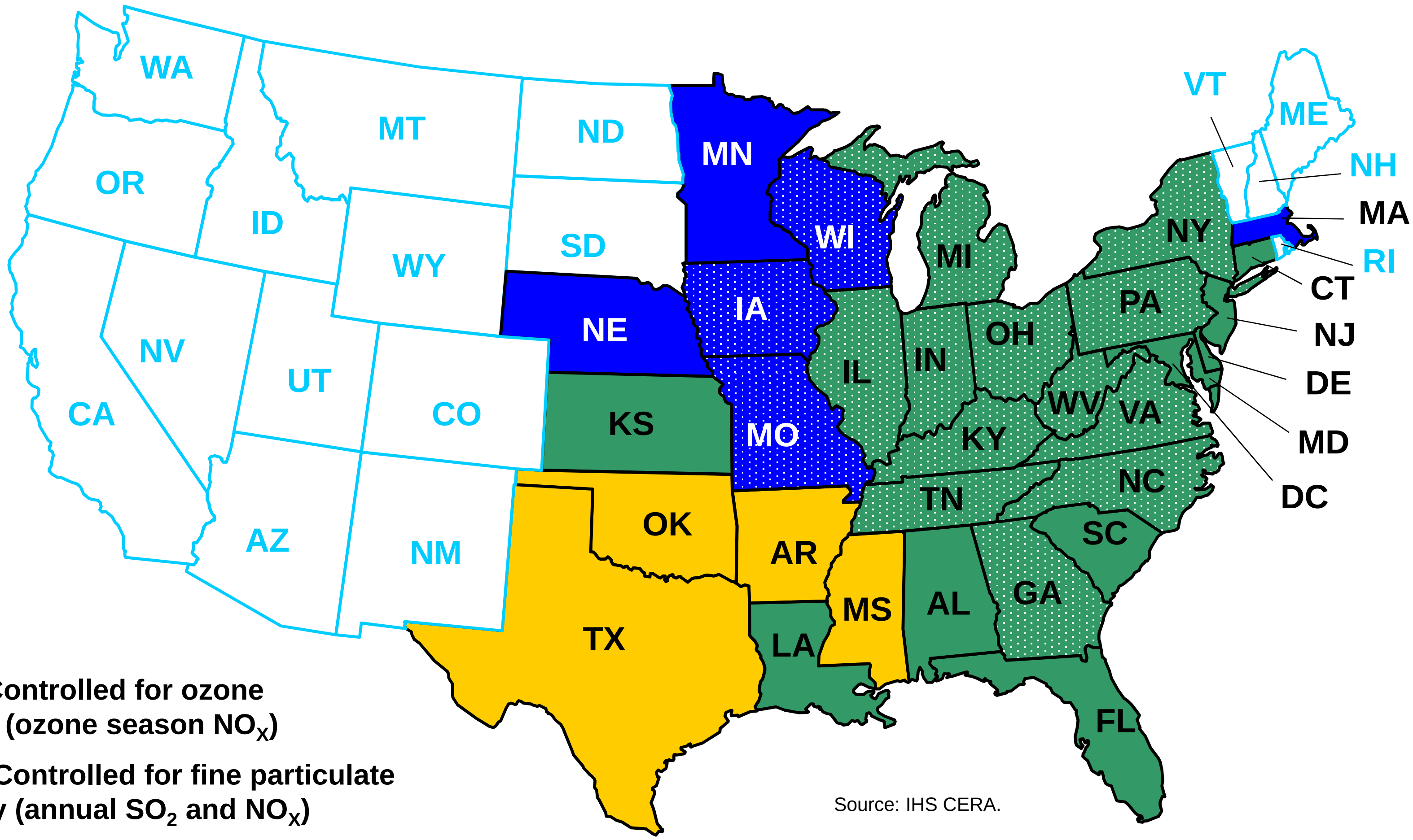

Source: IHS CERA.

4—Controlled for ozone only (ozone season NO_X)

6—Controlled for fine particulate only (annual SO_2 and NO_X)

22—Controlled for fine particulate (annual SO_2 and NO_X) and ozone (ozone season NO_X)

Group–1 SO_2 States

CSAPR placed on "Stay"
Compliance Likely Pushed to 2014

CSAPR – Emissions Reductions

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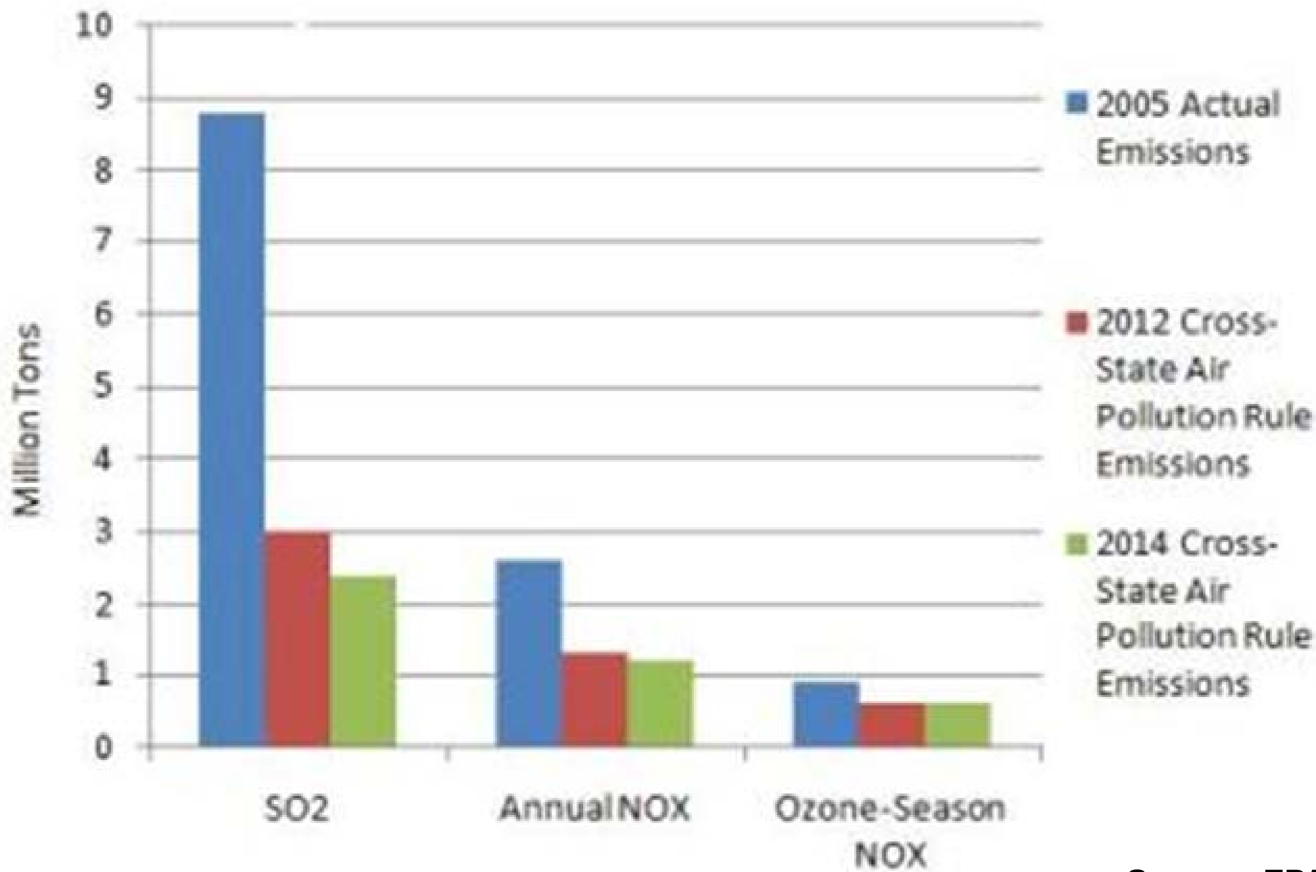


Source: EPA

CSAPR Will Establish the Basis for NOx and SO2 Credit Trading

MATS Hg Emission Limit (Existing Units)

- Mercury
  1.2 lb/TBtu

SCR can contribute to Hg Removal

- Other Emissions Requirements that are unrelated to SCR Performance
  (PM and HCl)

NOx

- Units with an SCR should be able to meet future NOx regulations
- Units without an SCR will likely have to retrofit with NOx reduction technology or purchase NOx Credits under CSAPR
- NOx Credit Trading puts a value on removing as much NOx as possible
  - Reduce Costs of Buying Credits
  - Revenue from Sales of Credits

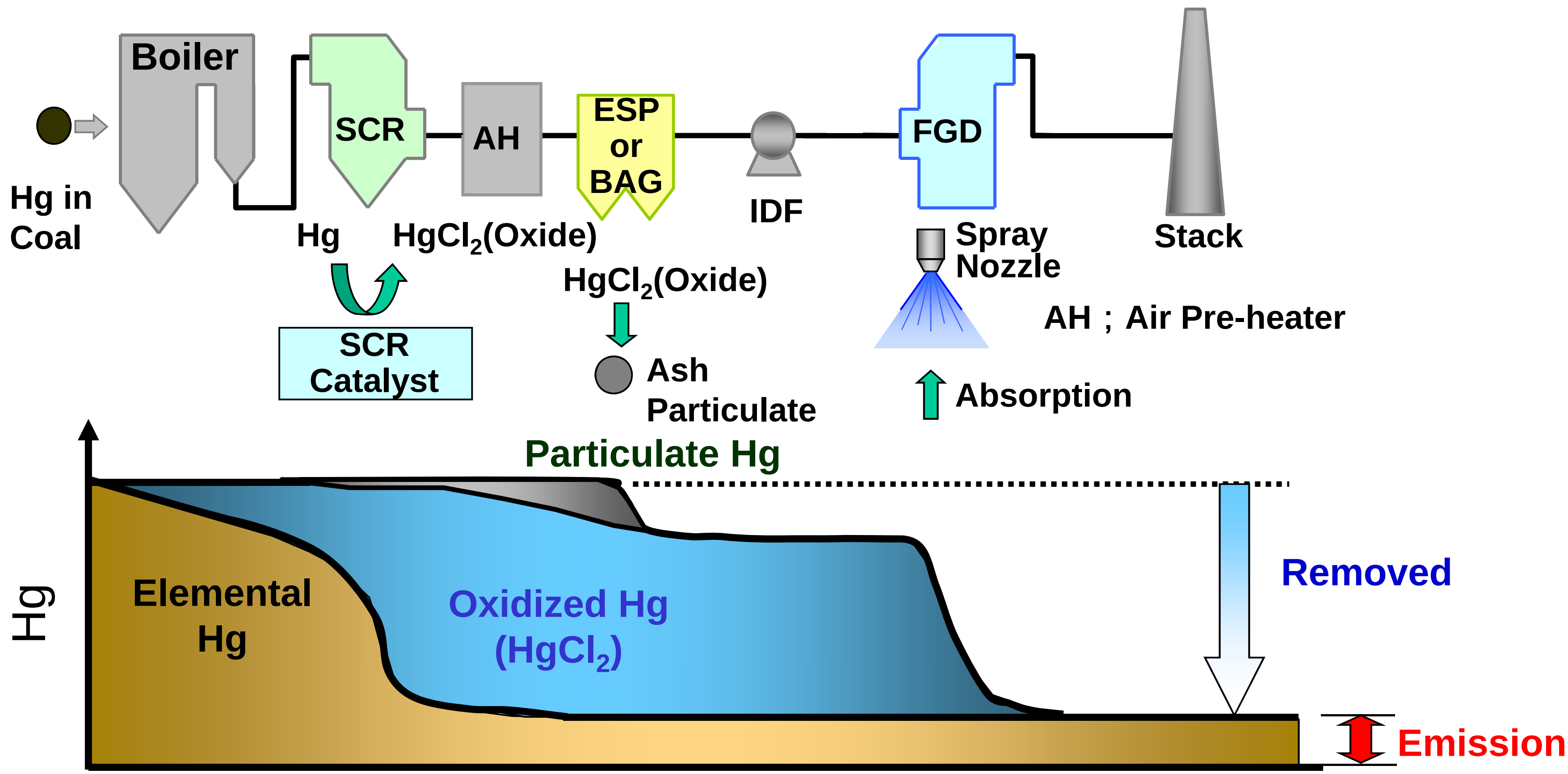
Hg

- Hg emissions of 1.2 lb/TBtu represent a 91% reduction from baseline emissions (on average)
- SCR Catalyst can be utilized for Hg oxidation in addition to controlling NOx
- Catalyst is most effective on Hg Oxidation when there is less NH3 flow (importance of last catalyst layer)
- Hg Oxidation Bench Scale Test?
- CMP will need to consider Hg oxidation of the catalyst and its deactivation rate

Comparison of Hg Removal Key Technologies

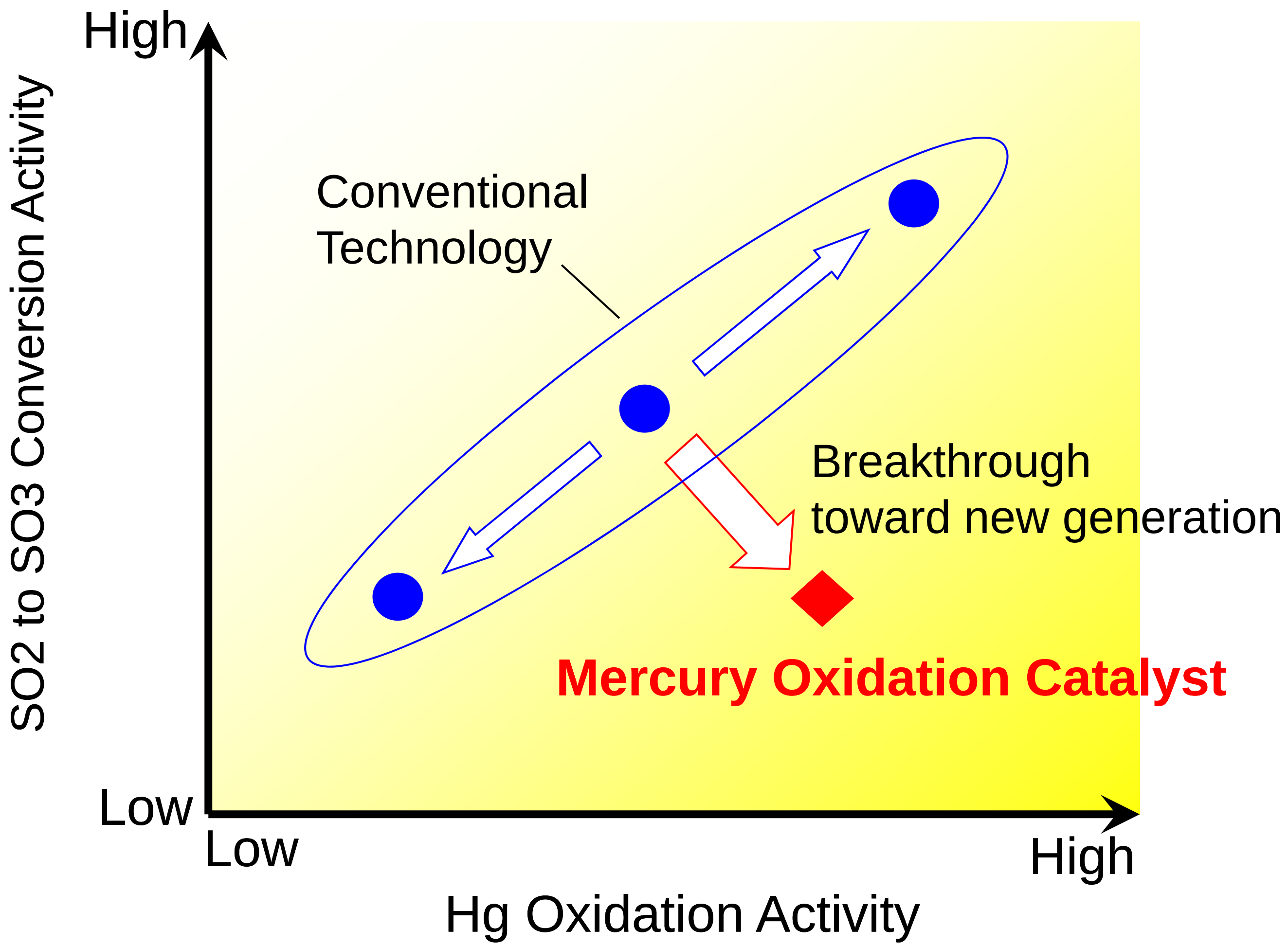
Function	Key Technology	Advantage	Disadvantage/Challenge
Adsorption	Activated Carbon Injection (ACI)	**- Commercialized** **- w/o SCR** **- High Hg removal**	- High Operating Cost **- ACI facility** **- Operation and maintenance** **- High carbon content in ash** **- SO3 impact on removal efficiency**
Oxidation	Halogen Injection	**- Commercialized** **- Simple system** **- High Hg removal** **- Relatively low cost**	- Balance of plant impacts **- Less effective on bituminous coal**
	SCR Catalyst	- Low operating cost - No additional facility - High operation reliability	- To improve Hg oxidation

Process of Hg Removal by SCR + FGD



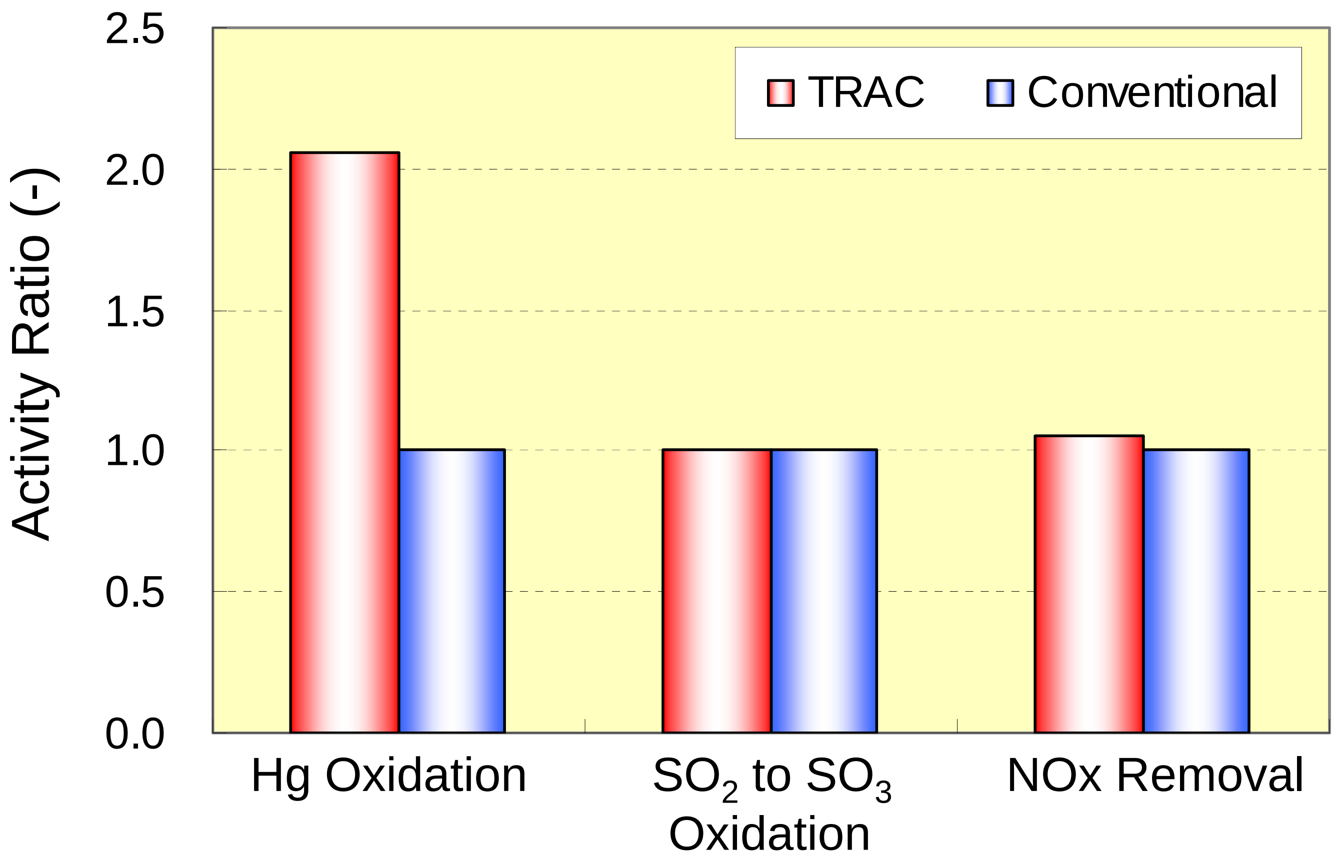
SCR Catalyst is a key component for mercury oxidation

Lower SO_2 conversion is required while keeping higher Hg oxidation.



TRAC® – TRiple Action Catalyst

1st High Mercury Oxidation
2nd High DeNOx Performance
3rd Low SO_2 to SO_3 Oxidation



Is This A Future CMP Under MATS ???

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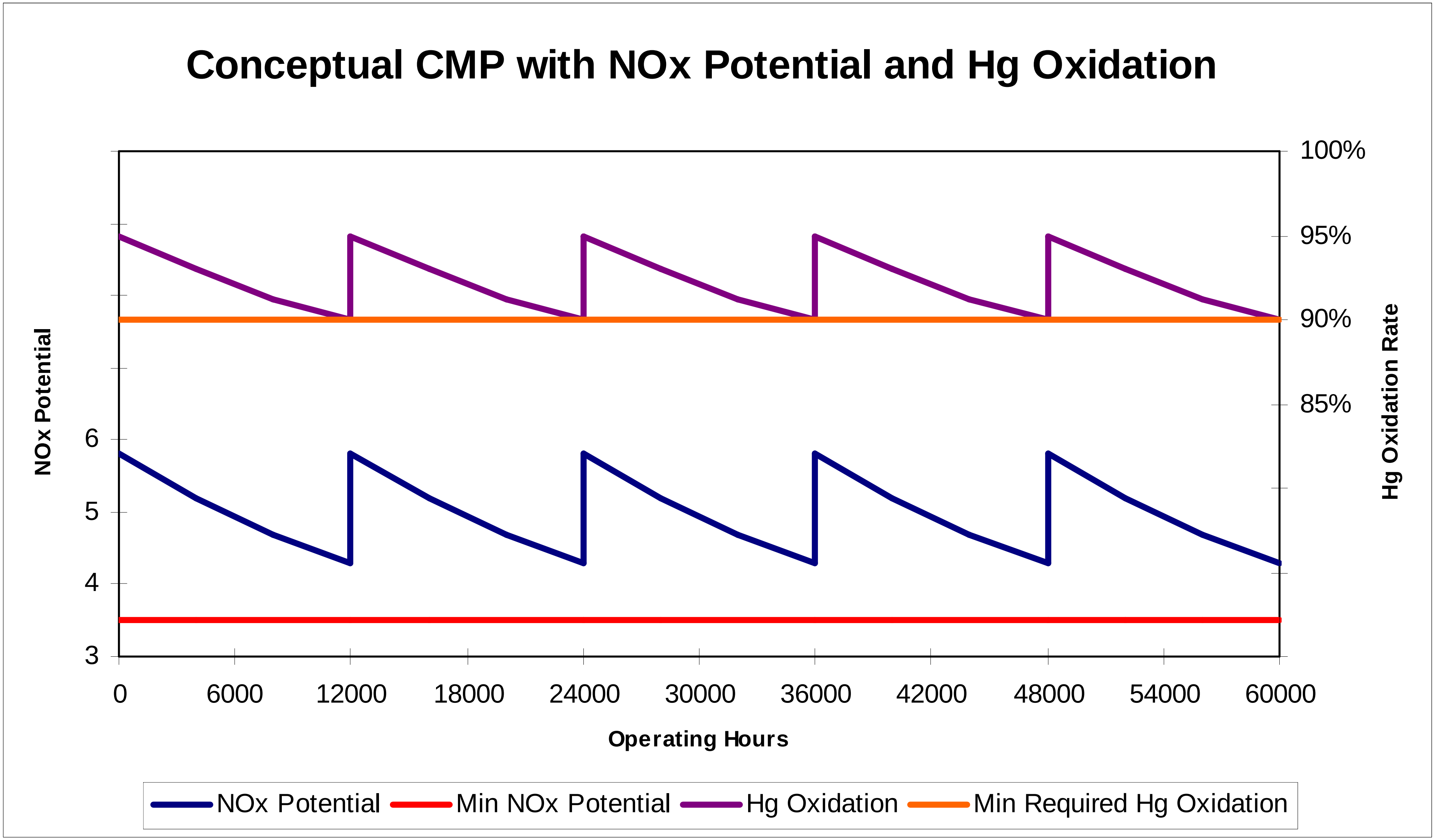

NOTE – Above Hg Graphs for Concept Only

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How will you use your SCR to help Comply with New Regulations?

- Increasing NOx removal for Credit Trading?
- Use TRAC – Last layer only or other plan?
- Bromine Injection to help promote Hg Oxidation in the SCR
- Other Ideas?

Prioritize Your Goals

- Not all goals can always be achieved simultaneously
- It is best to prioritize by what has the most significant impact to unit operation
  - NOx Emissions
  - Pluggage Mitigation
  - SO2 to SO3 Conversion
  - Catalyst Life Required to get to a Planned Outage
  - Hg Oxidation
  - Other
- Do your best to meet all remaining goals after top priorities are achieved

Hitachi Aftermarket Services

- SCR System Inspections
- Fuel Consultation – Determining Impact to SCR Operations
- Catalyst Sampling
- Catalyst Testing and Analysis
  - Bench Scale
  - XRF (Composition Analysis)
  - Surface Area and Porosity
  - Strength Test
- Engineering Studies for Specific SCR Evaluations

