

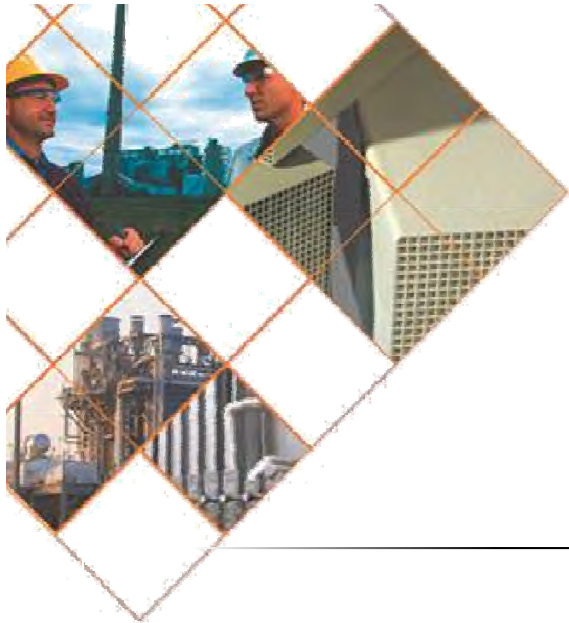
REINHOLD ENVIRONMENTAL Ltd.



**2018 NO<sub>x</sub>-Combustion Round Table  
& Expo Presentation**

February 19-20, 2018, in St. Louis, MO / Hosted by Dynegy

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**CORMETECH**

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# SCR Catalyst Application 101

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**Scott Rutherford**

Cormetech, Inc.

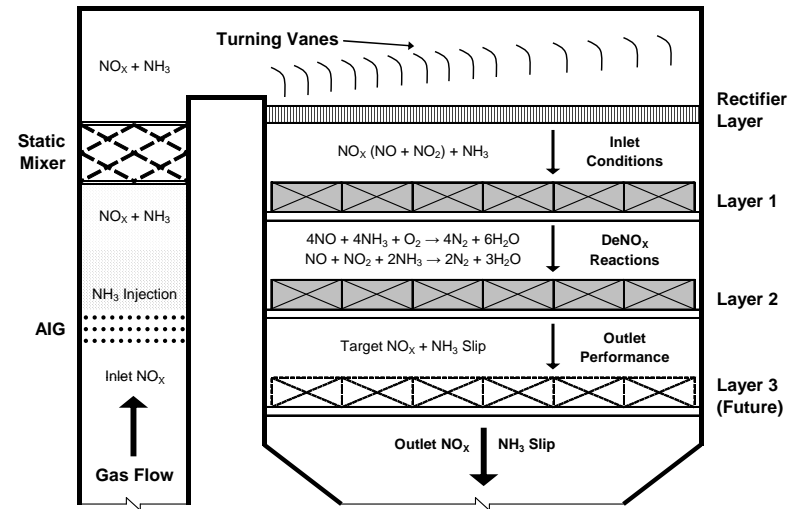
Reinhold, 2018

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# Presentation Outline



- Catalyst Functionality
- Typical SCR Applications
  - Gas
  - Coal
- Catalyst Design
  - K/AV
  - Scale Up
  - Example
- Catalyst Management
  - Overview



# SCR Catalyst Reactions



## NO<sub>x</sub> Reduction:



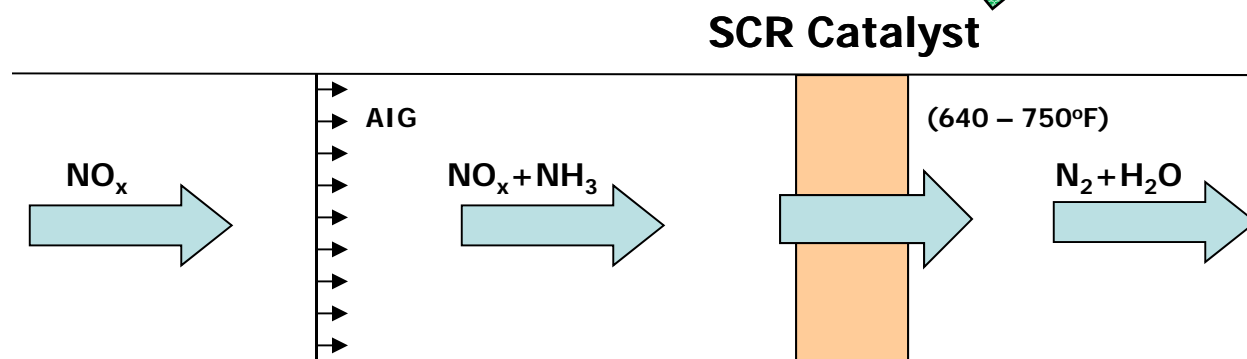
## Hg Oxidation:



## SO<sub>2</sub> Oxidation:



- V-W/Ti, or V-Mo/Ti
- Honeycomb, Plate
- Optimal: 640-750°F
- Active to 350°F

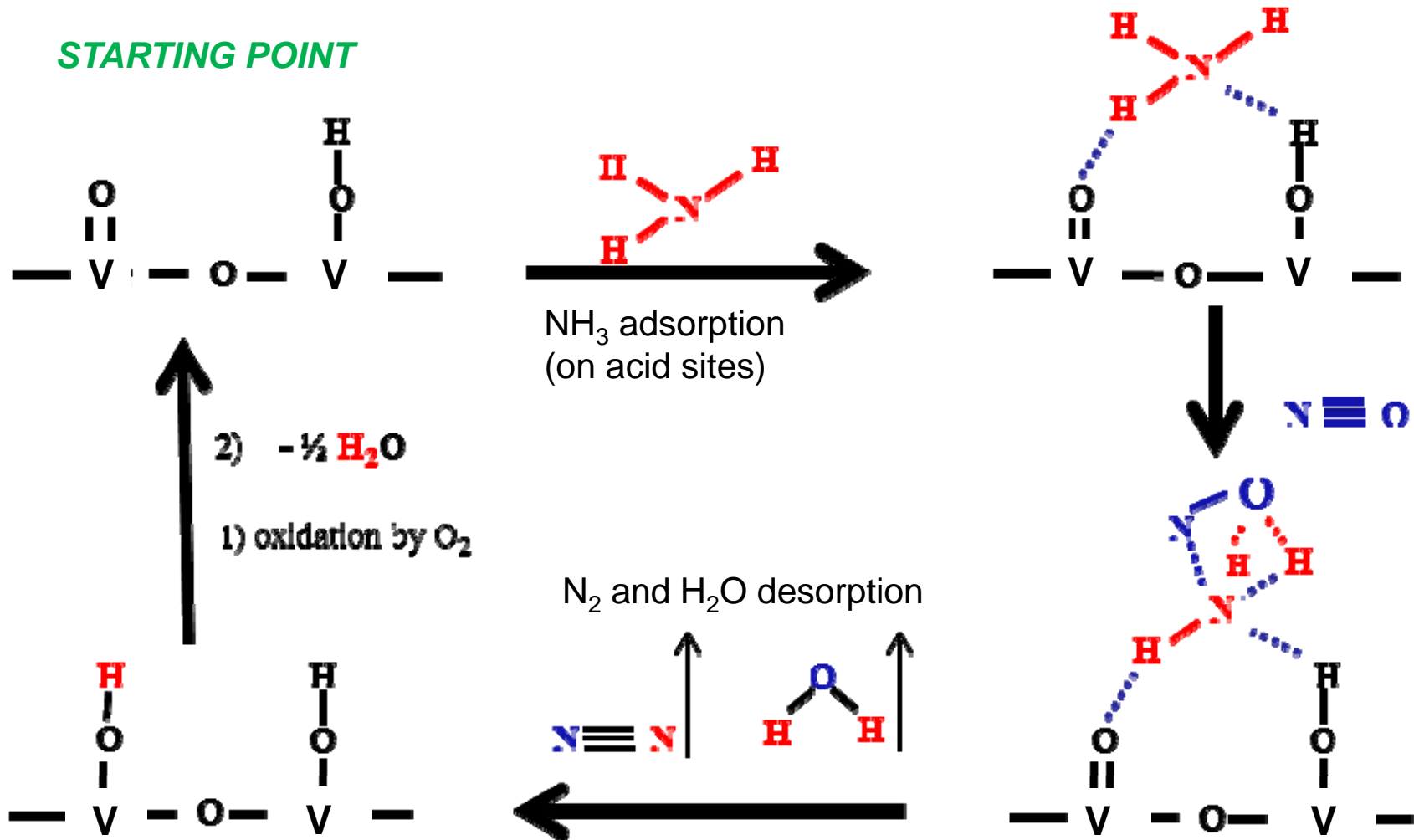


# DeNOx Catalytic Mechanism



The catalytic reactions occur on the BET-measured surface area of the V-W/Ti catalyst particles.

STARTING POINT



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# SCR Catalyst Functionality

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- **Applications**

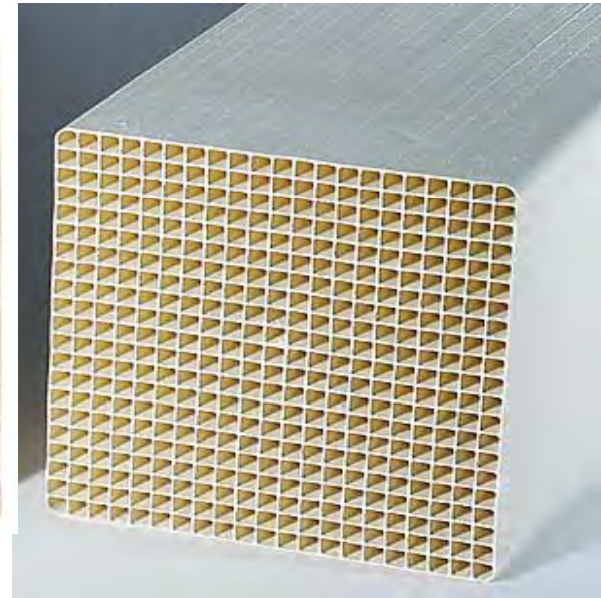
- Boilers: Coal, Oil, Gas, Biomass, and Fuel Blends
- Gas Turbines – Combined & Simple Cycle
- Refinery Applications such as FCC, Ethylene Crackers
- Cement Kilns
- Municipal Solid Waste
- Stationary Diesel Engines
- Other: Marine, Locomotive, Non-stationary Diesel

- **Typical Composition: Ti, W, V**

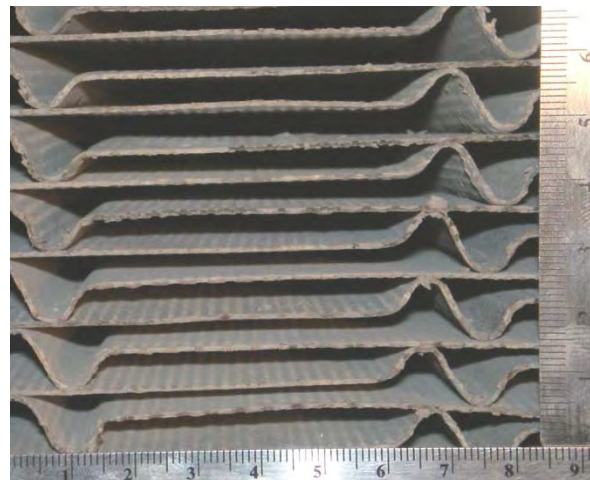
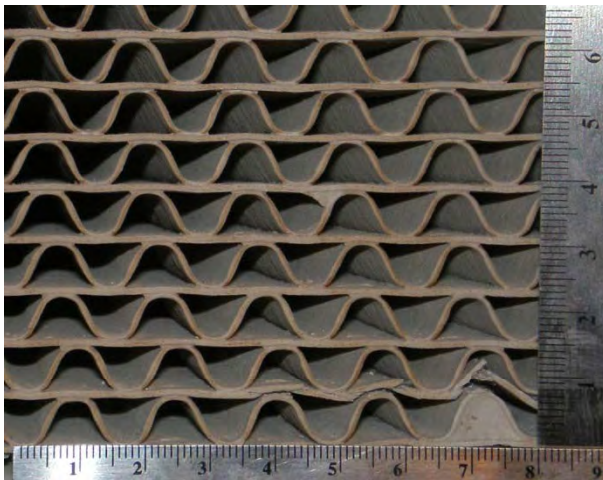
- **Temperature Range: 350° F to >1000° F**

# Types - Catalyst Geometry

Honeycomb



Corrugated



Plate

# Catalyst "Surface Area"

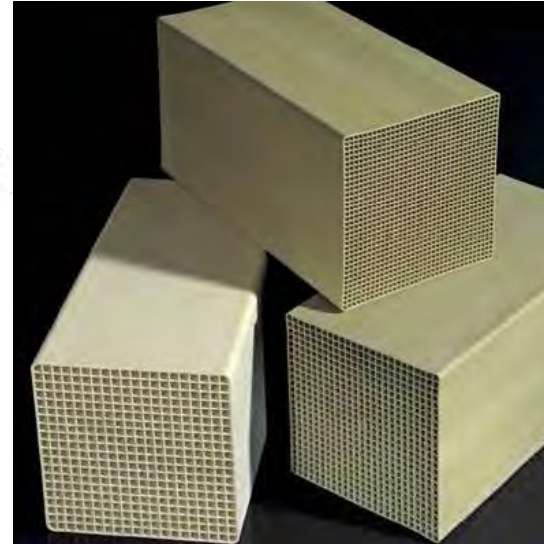


## Geometric Surface Area ( $A_p$ ):

For example, 21 cell:

$$A_p = 502 \text{ m}^2/\text{m}^3$$

$$\text{Cell opening} = \underline{6.4 \text{ mm}}$$

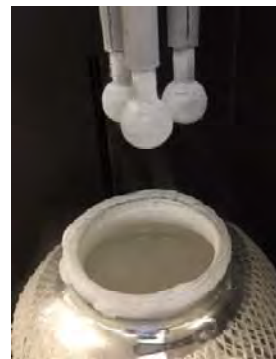


## $\text{N}_2$ BET Surface Area:

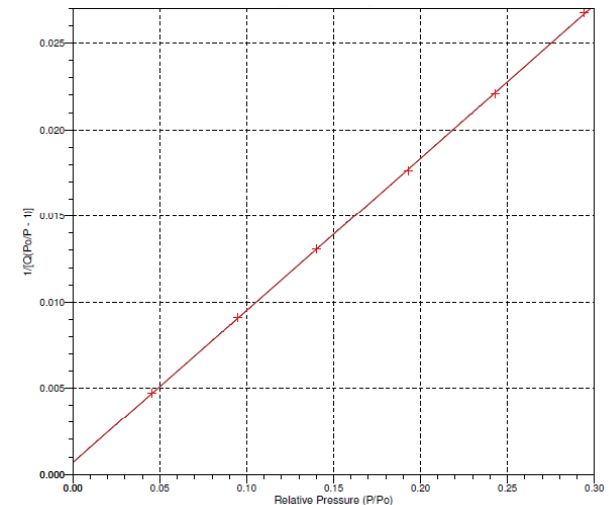
$$\text{SA} \sim 55 \text{ m}^2/\text{g}$$

$$\text{Pore diameter} = \underline{\sim 2-100 \text{ nm}}$$

Defines  $K_{\text{intrinsic}}$  (+ metal oxide loadings)



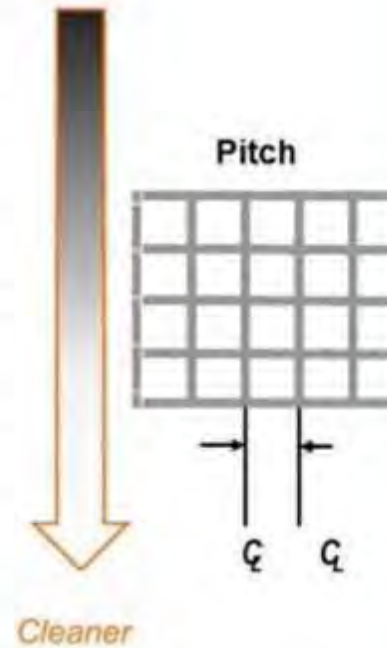
*BET Surface Area Plot*



# CORMETECH Catalyst



<u>Cells</u>	<u>Pitch</u> <u>(mm)</u>	<u>CPSI</u>	<u>Flue Gas</u> <i>Dirtier</i>
9 x 18		4.5	
16	9.2	7	
18	8.2	9	
20	7.4	11	
21	7.1	13	
22	6.9	14	
23	6.4	15	
25	5.9	18	
35	4.2	35	
40	3.7	48	
45	3.3	58	
55	2.7	86	
70	2.1	140	
108	1.4	325	



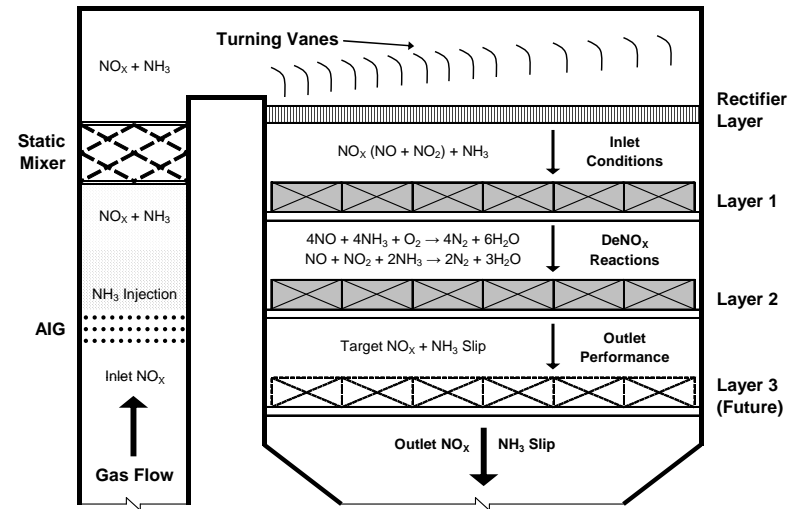
**CORMETECH**  
**Dust Buster™**



# Presentation Outline



- Catalyst Functionality
- **Typical SCR Applications**
  - Gas
  - Coal
- Catalyst Design
  - K/AV
  - Scale Up
  - Example
- Catalyst Management
  - Overview

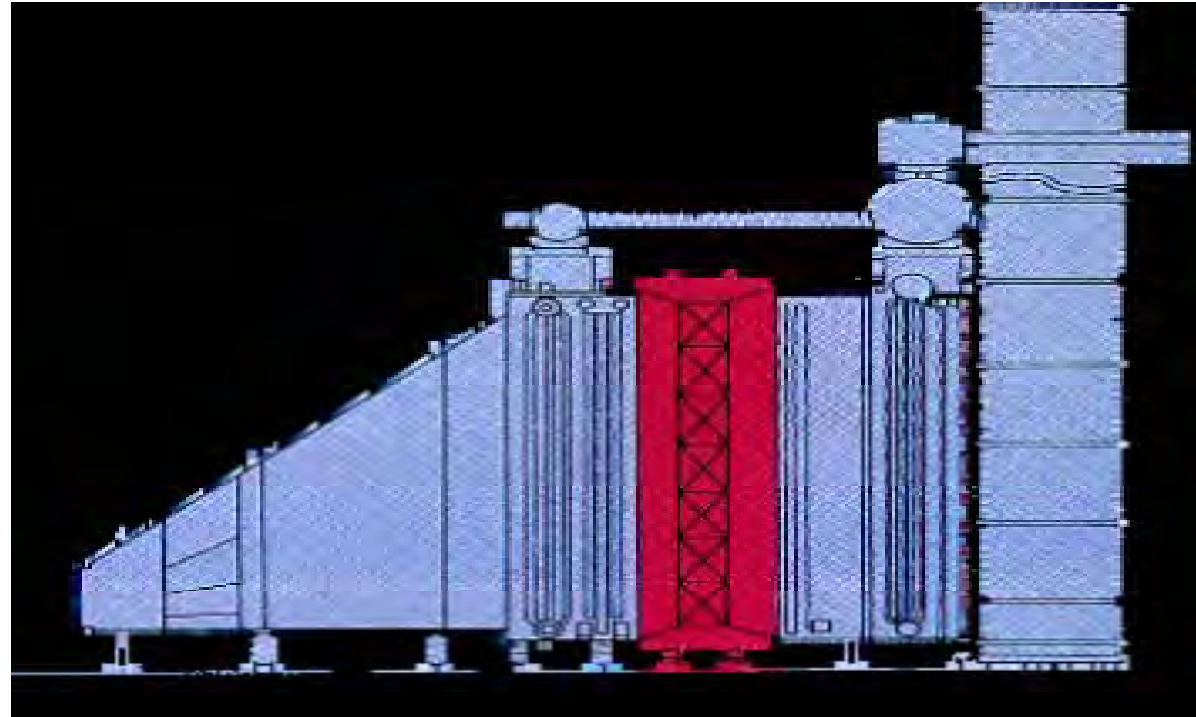


# Typical Natural Gas Fired Application



Horizontal  
Reactor

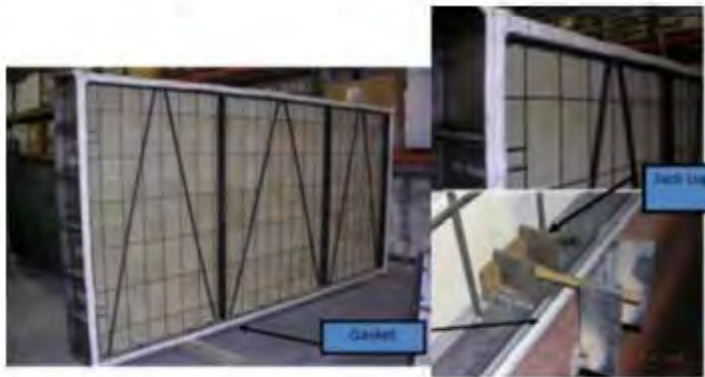
Typical for Gas  
Turbine HRSG  
and Simple Cycle  
Units



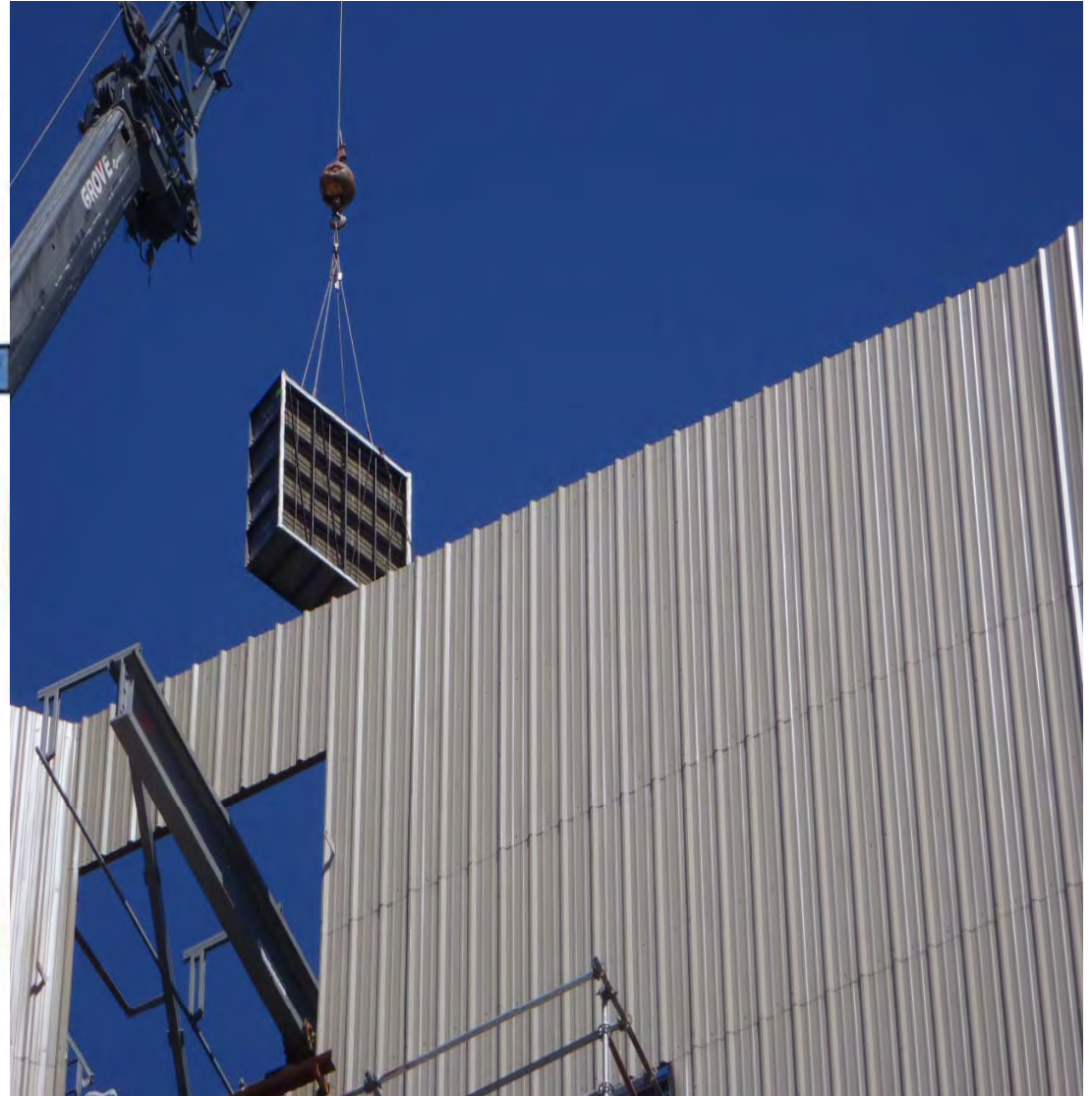
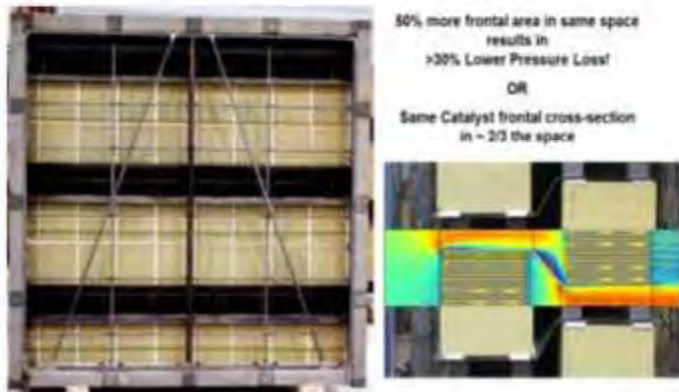
# Gas Catalyst Modules



Traditional Horizontal Flow "Standard Module"



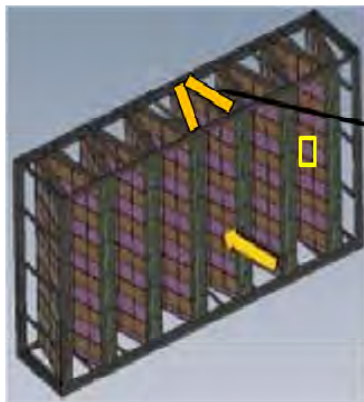
Patented "Advanced Module"  
for Gas-Fired SCR Units



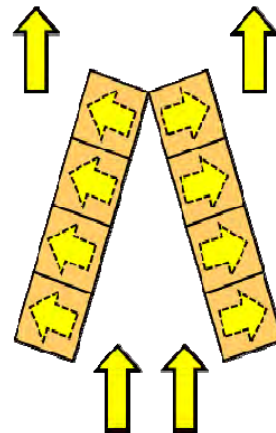
# Gas Pleated Module



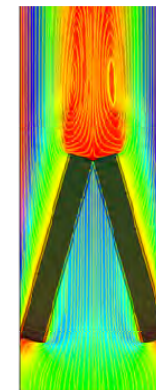
Single  
150 x 150 mm  
Element  
Inlet face



Top View  
One Pleat



CFD Model



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# Gas Turbine Operation

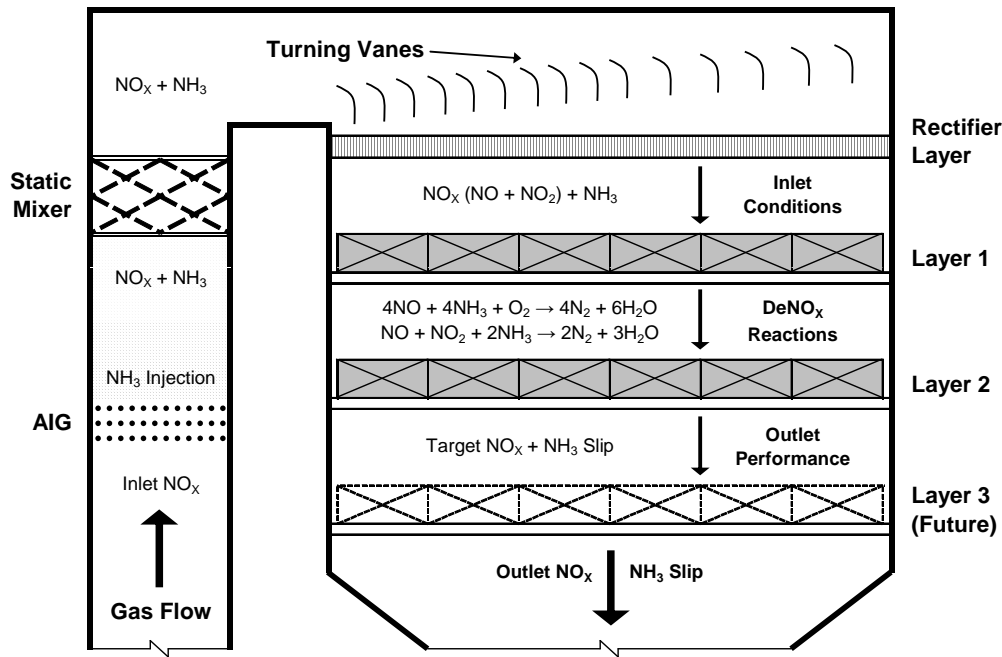
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- **Gas Unit Challenges**

- Pressure Drop - Duct Size
- High Performance
  - Example: 2 ppm NO<sub>x</sub> Outlet & 2 ppm Ammonia Slip
- Temperature
  - Formulations
- Ammonia/NO<sub>x</sub> Mixing
  - Short mixing distance
- Fast Starts & Cycling
- Some Machines have high NO<sub>2</sub>
- CO, VOC Control

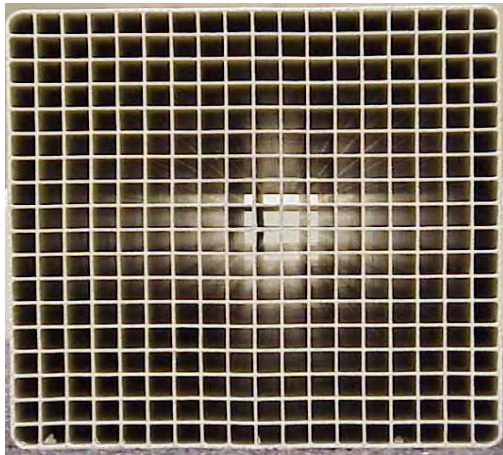
# Typical Coal Application



# Coal Catalyst



*Catalyst Element*



*Module*



*~6' wide x ~3' deep x ~5' tall*

*Element: 150 mm x 150 mm square*

*up to 1350 mm long*

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# Coal Boiler Operation

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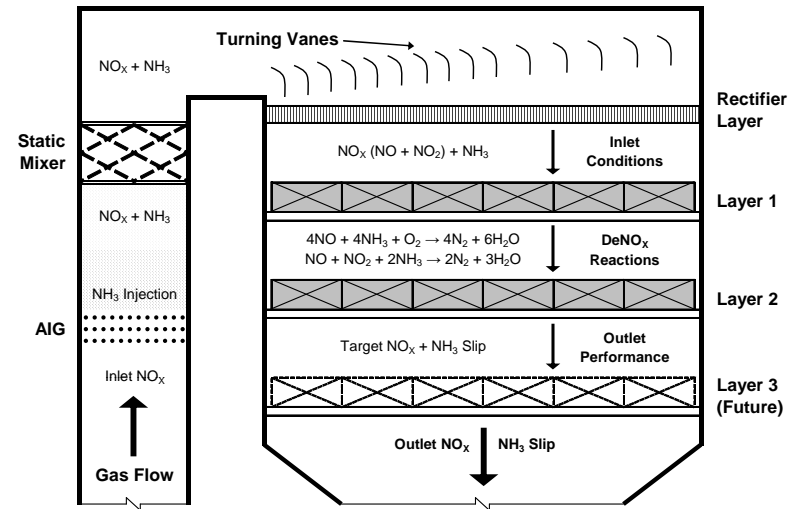
- **Coal Unit Challenges**

- Ash Control
  - LPA, Distribution, Cycling Influence
- Catalyst Deactivation
  - Bituminous Coal – Arsenic
  - PRB Coal – CaO & P
- High Performance
  - Control Ammonia Slip
- Hg Control
- Increased Turndown, Frequent Cycling
  - Minimum Operating Temp for ABS Formation
- Economic Pressures

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# Catalyst Potential



## ***Design Background – Catalyst Potential K/AV***

- *Function of: Inlet NO<sub>x</sub>, Removal Efficiency, Ammonia Slip*
- *Capacity to reduce XX% NO<sub>x</sub> with less than Y ppm slip*
- *Activity, K, depends upon test/operating conditions*
- *AV = (Gas Flow) / (Catalyst Surface Area)*
- *Potential or K/AV is commonly calculated as:  
-ln [1-Efficiency] @ MR=1; K=DeNO<sub>x</sub> Activity*

$$\frac{K}{AV} = \frac{\text{Activity} \cdot \text{Volume} \cdot \text{AP}}{\text{Volume Flow Rate}}$$

Surface Area

A diagrammatic element consisting of a horizontal bracket above the word "Volume" in the numerator of the equation. A vertical line extends upwards from the center of this bracket to a rectangular box containing the text "Surface Area".

---

# Design Process

---



- **Input information:**

- **Requirements**

- Inlet/Outlet NO<sub>x</sub>
    - NH<sub>3</sub> slip
    - Hg oxidation (coal)
    - CO/VOC oxidation (gas)
    - SO<sub>2</sub> conversion (coal)
    - Life
    - Pressure Drop

- **Conditions**

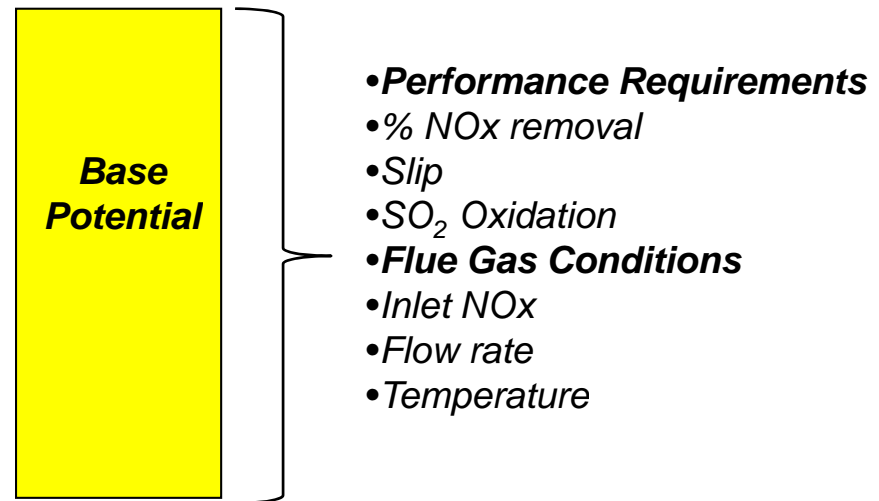
- Flows
    - Temperatures
    - Gas Composition
    - Unit Information
      - Fuel Type
      - Particulate Loading
      - Maldistribution (Flow, Temp, NH<sub>3</sub>/NO<sub>x</sub>)

- Catalyst is designed to meet the most challenging condition(s)

# Base Potential



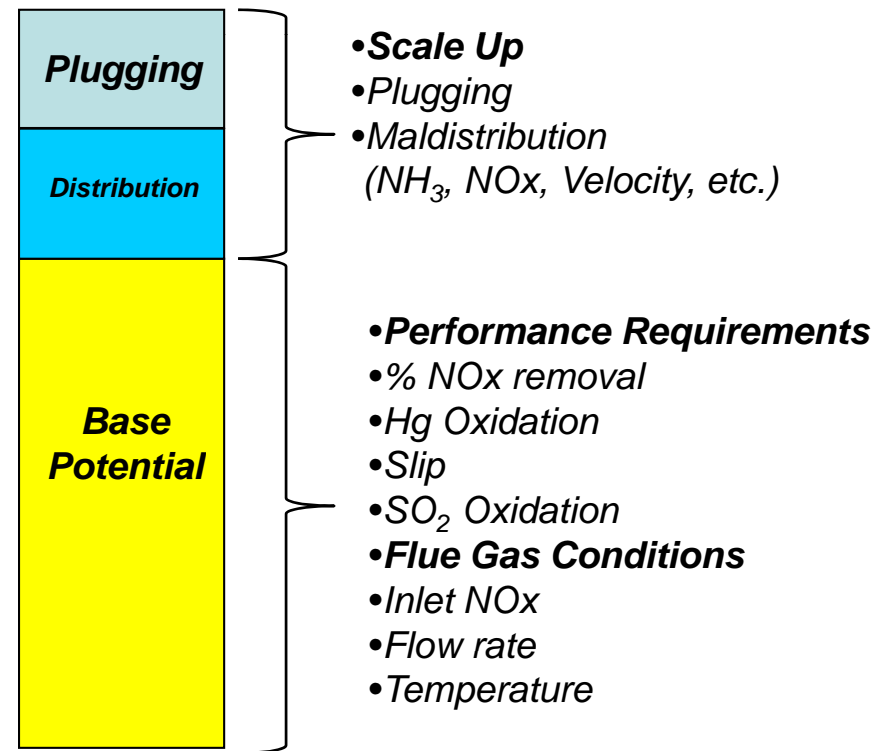
- Base potential is the amount of catalyst required to meet the requirement in a theoretically ideal reactor.



# Scale-Up



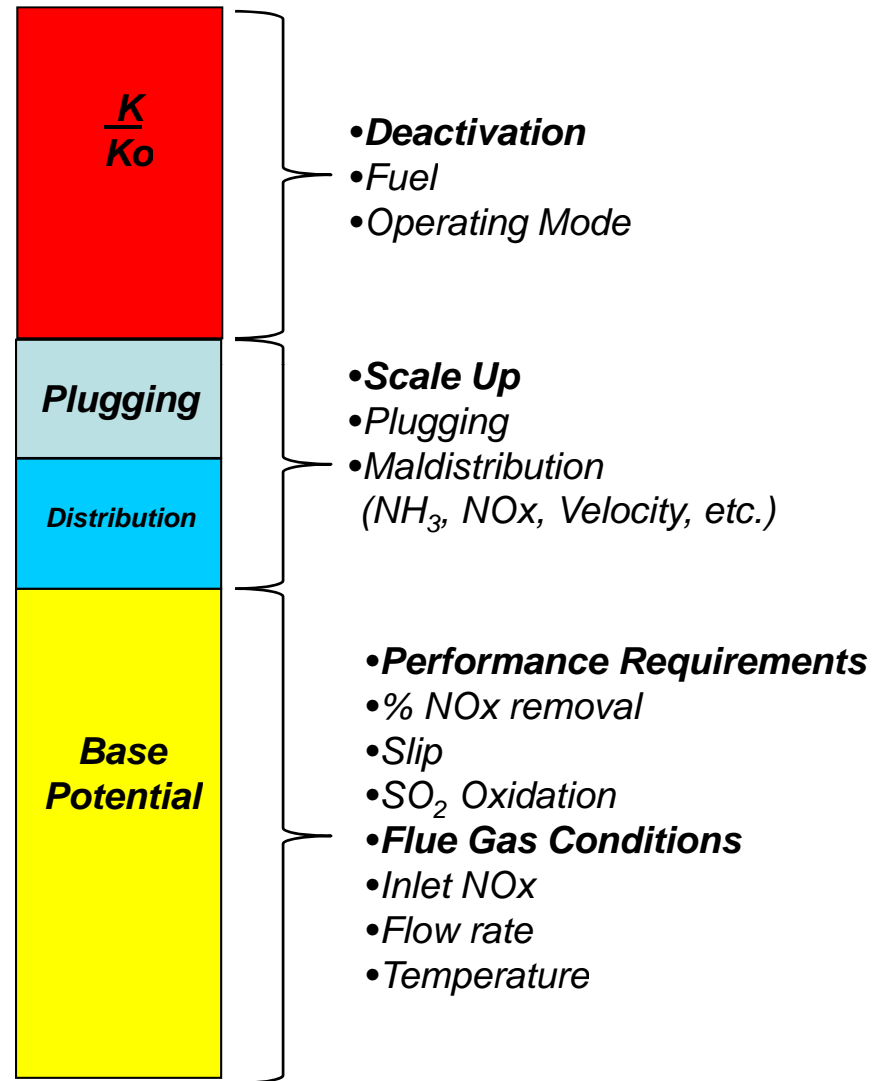
- Additional scale-up margin is needed for a real reactor.
- Plugging from ash and blocked catalyst from structural elements.
- Maldistribution means that in some locations, excess NO<sub>x</sub> gets through, more catalyst required.



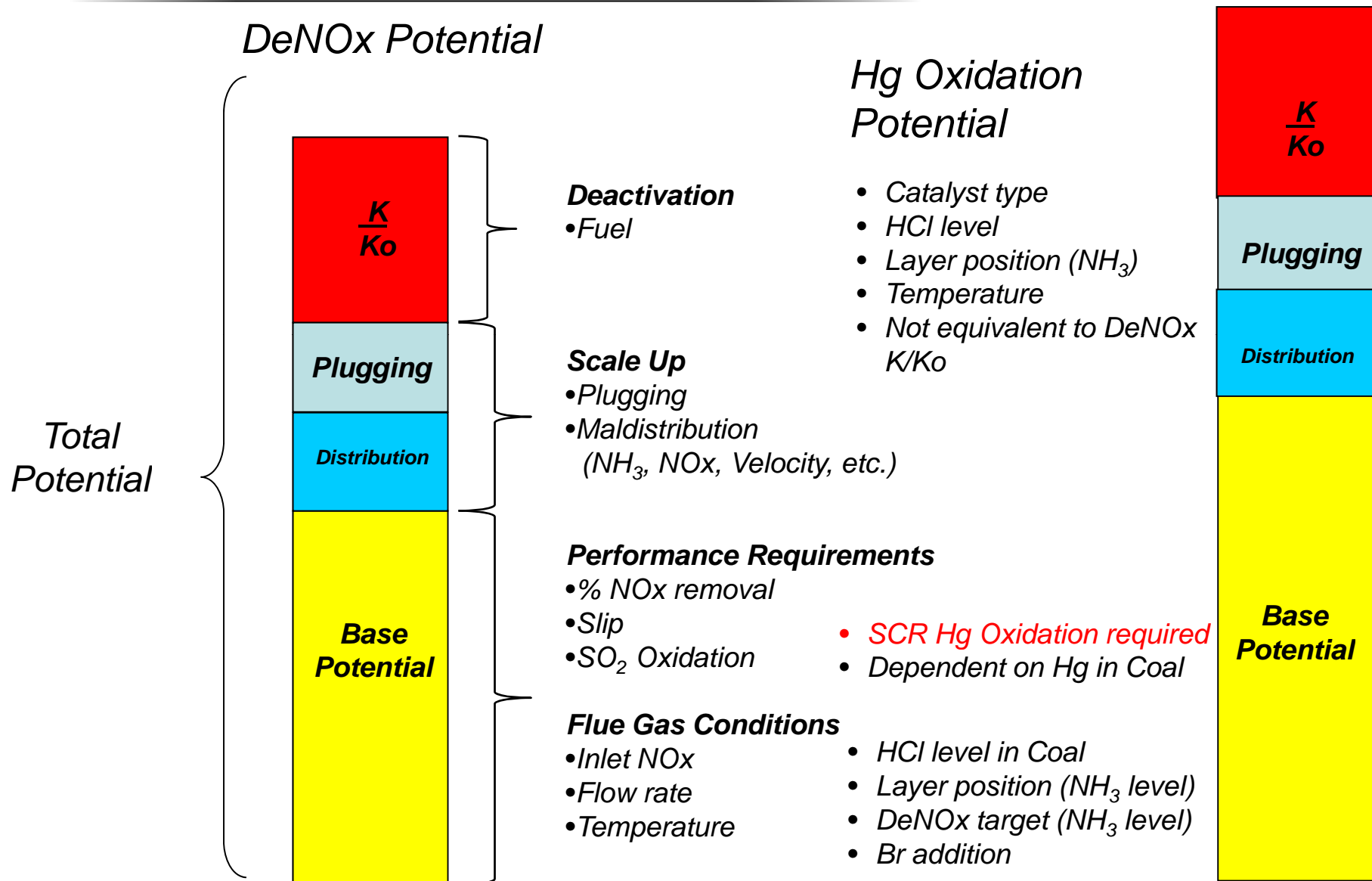
# Scale-Up



- Deactivation occurs over time, and the catalyst must meet the requirements at the end of life.
- Varies according to the type and composition of fuel used and the operating conditions.



# Breakdown of Design Potential



---

# Calculate Volume

---



- **Scenario**

- 400 MW Unit
- Gas Flow Rate: 1,400,000 Nm<sup>3</sup>/hr [~4MM lb/hr]
- Gas Temperature 680° F
- Bituminous Unit 1%-1.5% S
- Reduce NO<sub>x</sub> by 80% - 90%
- 2 ppm Ammonia Slip
- 1% SO<sub>2</sub> Conversion
- 24,000 Operating Hours
- Reactor Size: 9 x 12 Module Array x 2 Layers
  - X-Section sized to target ~5 m/s at catalyst face

---

# Calculate Volume

---



- **K/AV**

- K/AV is Calculated as Function of Inlet NO<sub>x</sub>, NO<sub>x</sub> Removal Efficiency and Ammonia Slip
- In this example, let's say  $K/AV = 3.5 \text{ Nm/hr}$

- **Scale It Up**

- Catalyst Blockage and Plugging Allowance → 10%
- Flow, Temperature and NH<sub>3</sub>/NO<sub>x</sub> Imbalance → 10%
- Scale up:  $0.9 \times 0.9 = 0.81$
- Scaled Up  $K/AV = 3.5/0.81 = 4.3 \text{ Nm/hr}$

---

# Calculate Volume

---



- **Determine Deactivation Rate**
  - Coal Ultimate Analysis
  - Coal Trace Element Analysis
  - Ash Mineral Analysis
  - For This Example, let's say we calculate that the catalyst will deactivate 30% in 24,000 hours

Apply Deactivation to the Scale Up

$$4.3/0.70 = 6.2 \text{ Nm/hr}$$

---

# Calculate Volume

---



- **Calculate Ko**

- Function of Product Type, Formulation, Gas Conditions, Temperature
- For this example use  $K = 40 \text{ Nm/hr}$

- **Math**

- $K/AV = 6.2, K=40 \rightarrow AV = 6.45 \text{ Nm/hr}$
- $AV = \text{Gas Flow Rate/Catalyst Surface Area}$
- $6.45 \text{ Nm/hr} = 1,400,000 \text{ Nm}^3/\text{hr} / \text{Surface Area}$ 
  - $\rightarrow SA = 217,000 \text{ m}^2$

- **Choose Appropriate Pitch**

- In this case assume 6.9 mm Pitch [ $538 \text{ m}^2/\text{m}^3$ ]

---

# Calculate Volume

---



- **More Math to Calculate Volume**

- Total Surface Area = 217,000 m<sup>2</sup>
- Catalyst Geometric Surface Area = 538 m<sup>2</sup>/m<sup>3</sup>
- 217,000 m<sup>2</sup> / 538 m<sup>2</sup>/m<sup>3</sup> = 403 m<sup>3</sup>

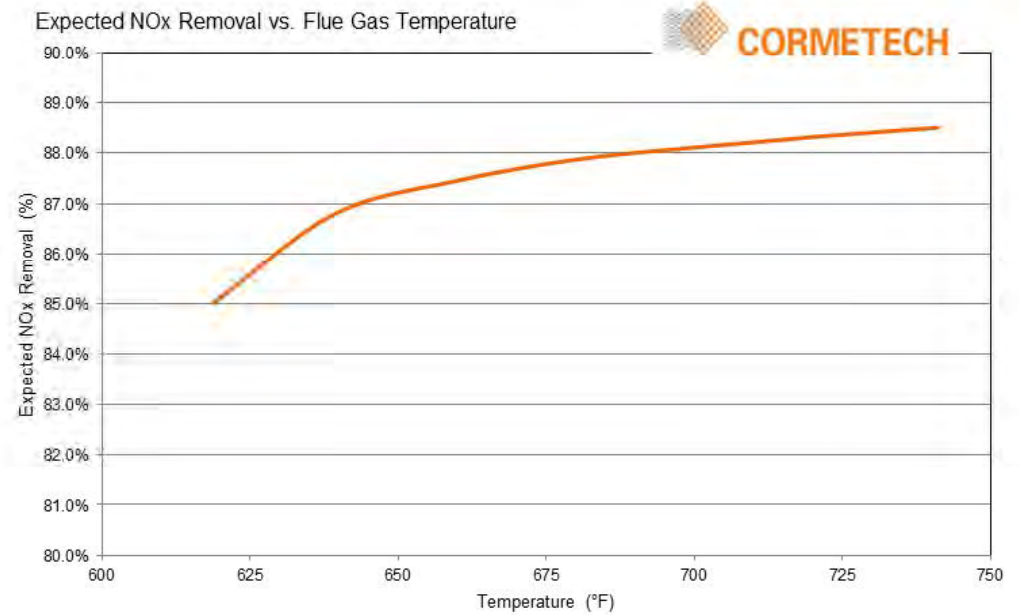
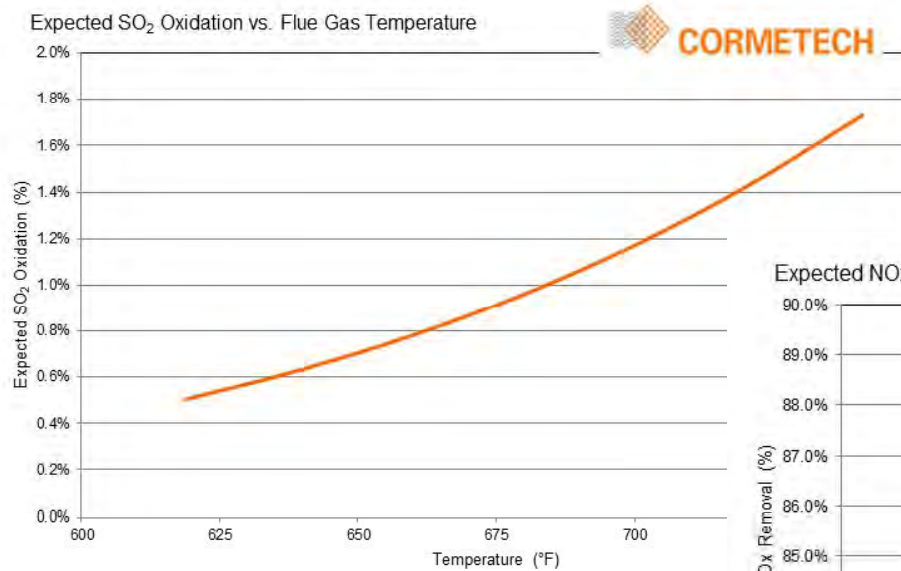
- **Geometry**

- Volume is divided into 216 modules
- 1.86 m<sup>3</sup>/module
- Element Length = 1150 mm
- Catalyst Module: 1910mm x 970mm x 1430mm; 2700 lb.

## **Iterative Process to Balance DeNO<sub>x</sub> & SO<sub>2</sub> Conversion & Geometry**

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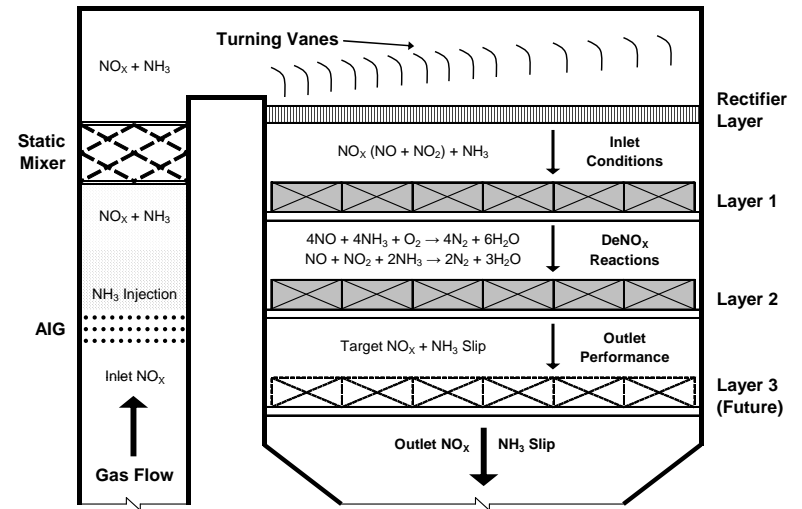
# Assess Operating Range



# Presentation Outline



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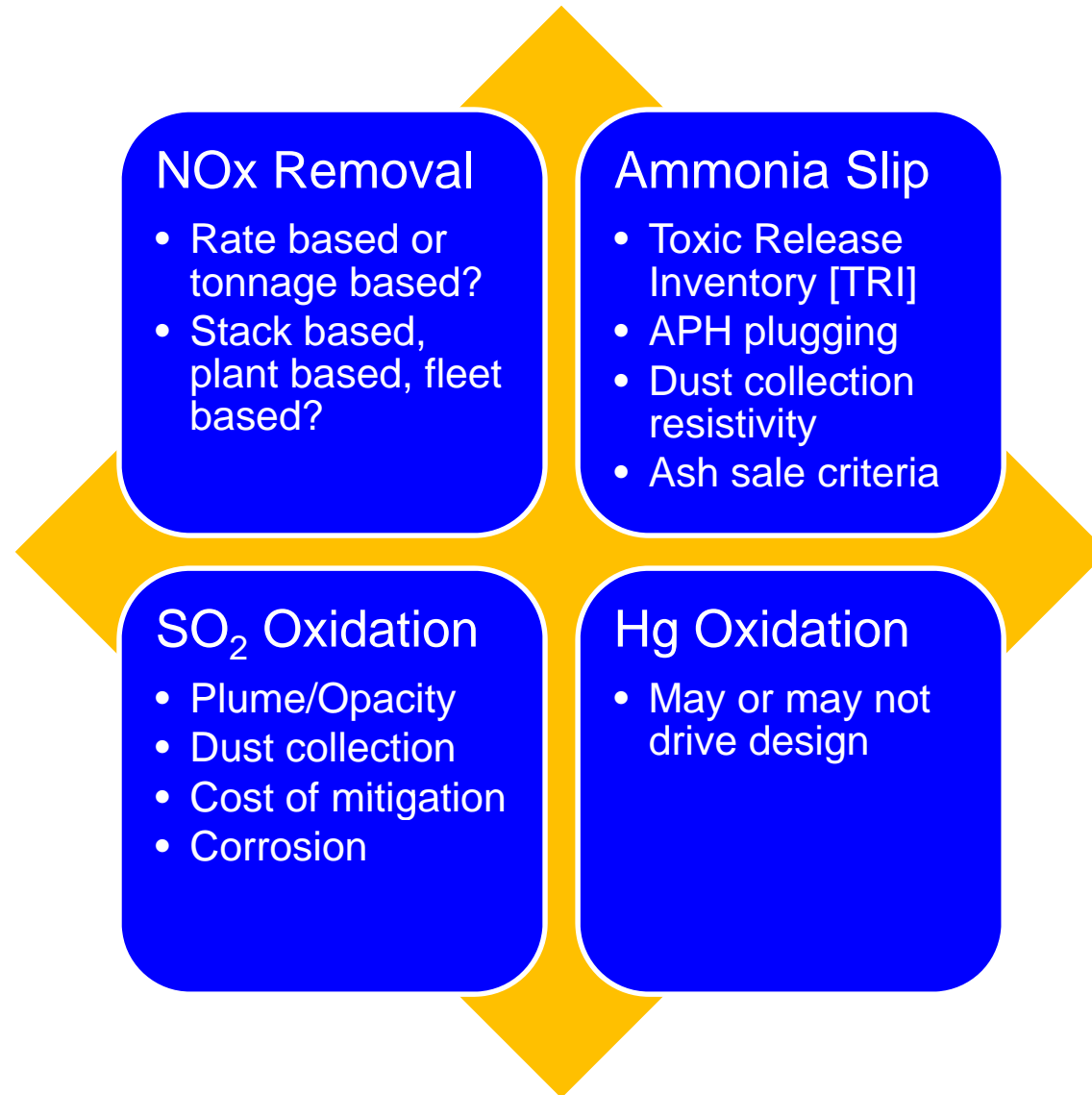
# Catalyst Management Strategies

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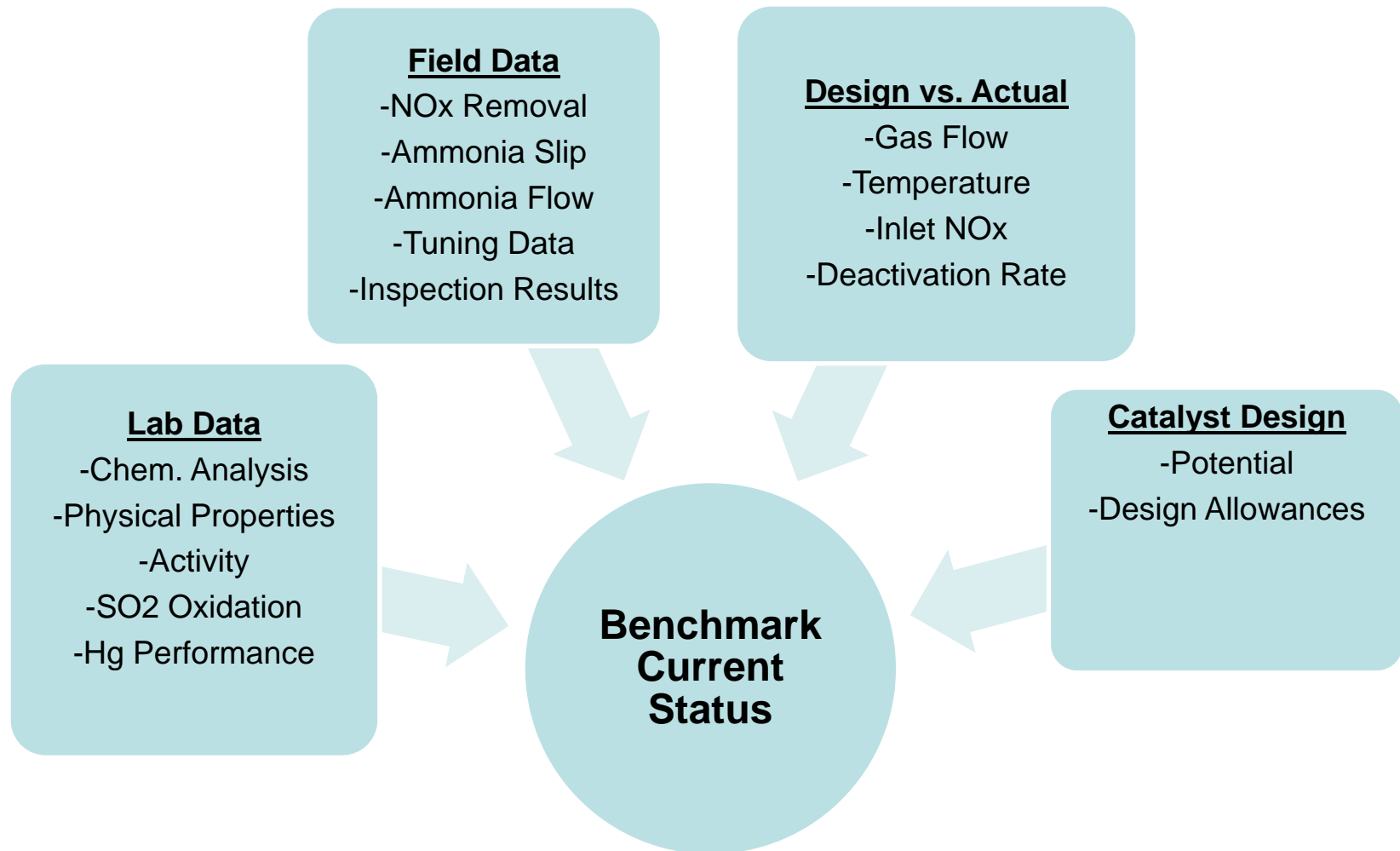


- Use Best Practices
- Understand Your Requirements
- Know Where You Are
  - Models, Lab, Field Inspection & Testing
- Know Your Destination
- Anticipate Your ETA
- Take Action

# Understand Performance Requirements

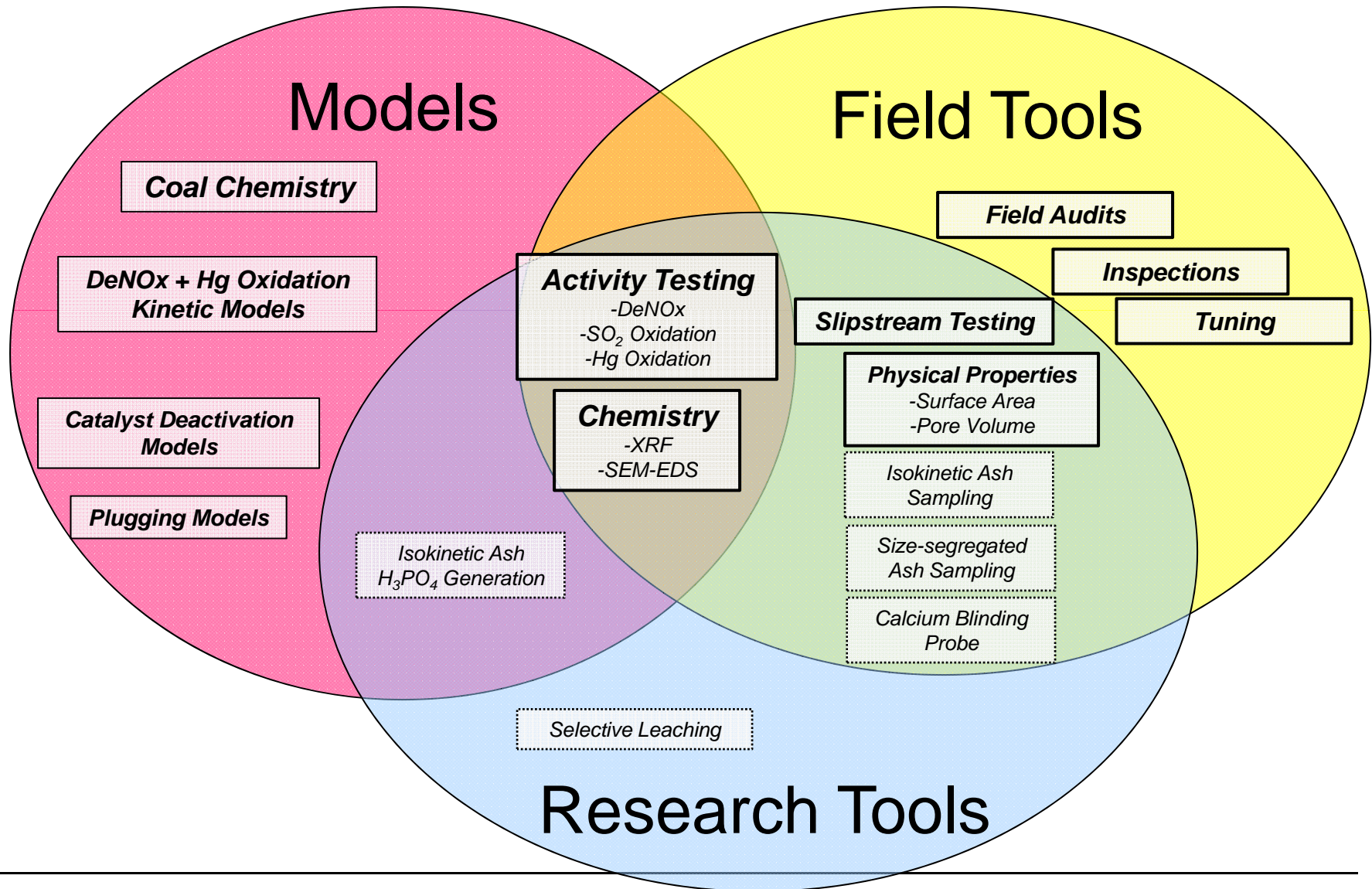


# Benchmark Current Status

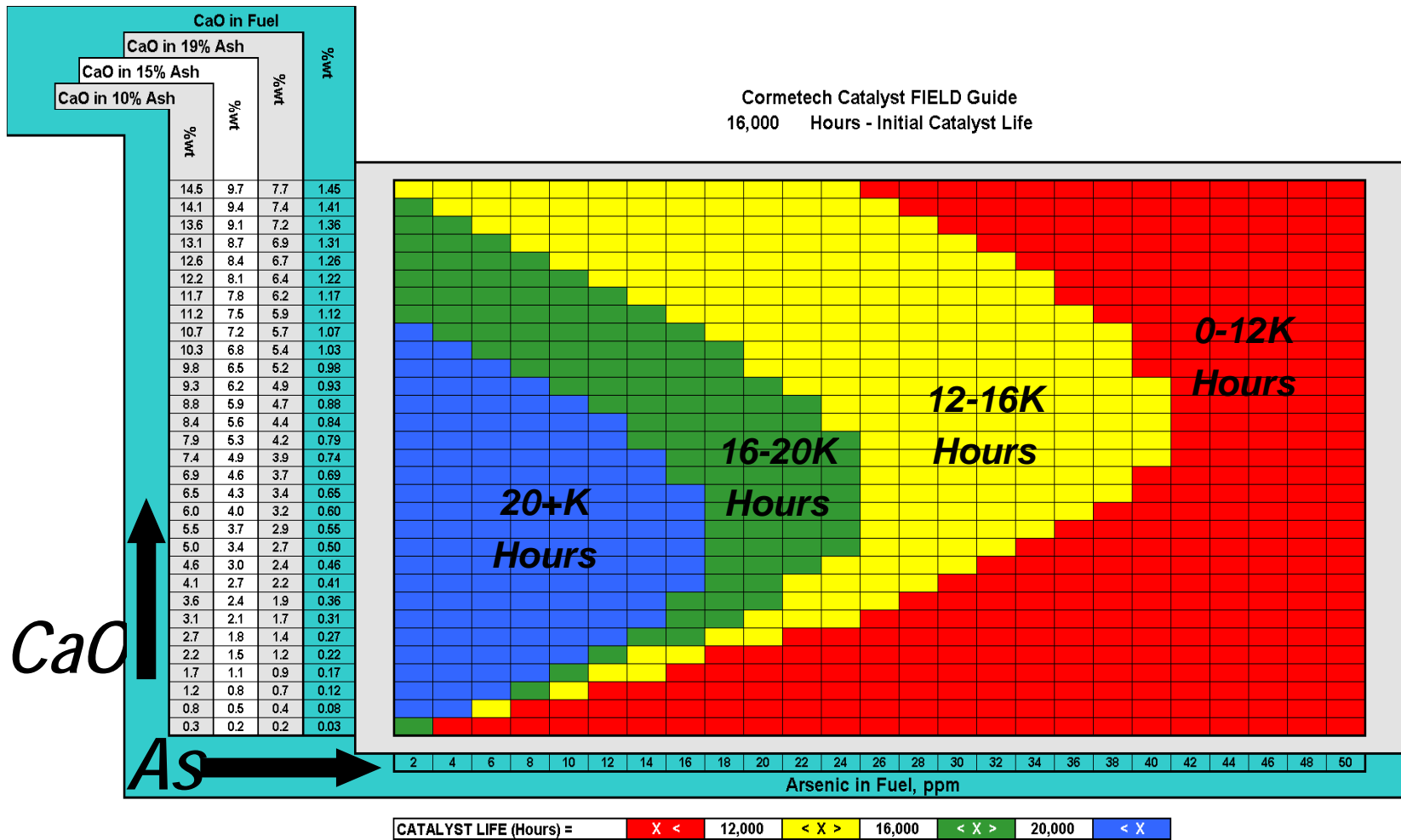


We use all of the tools available to us

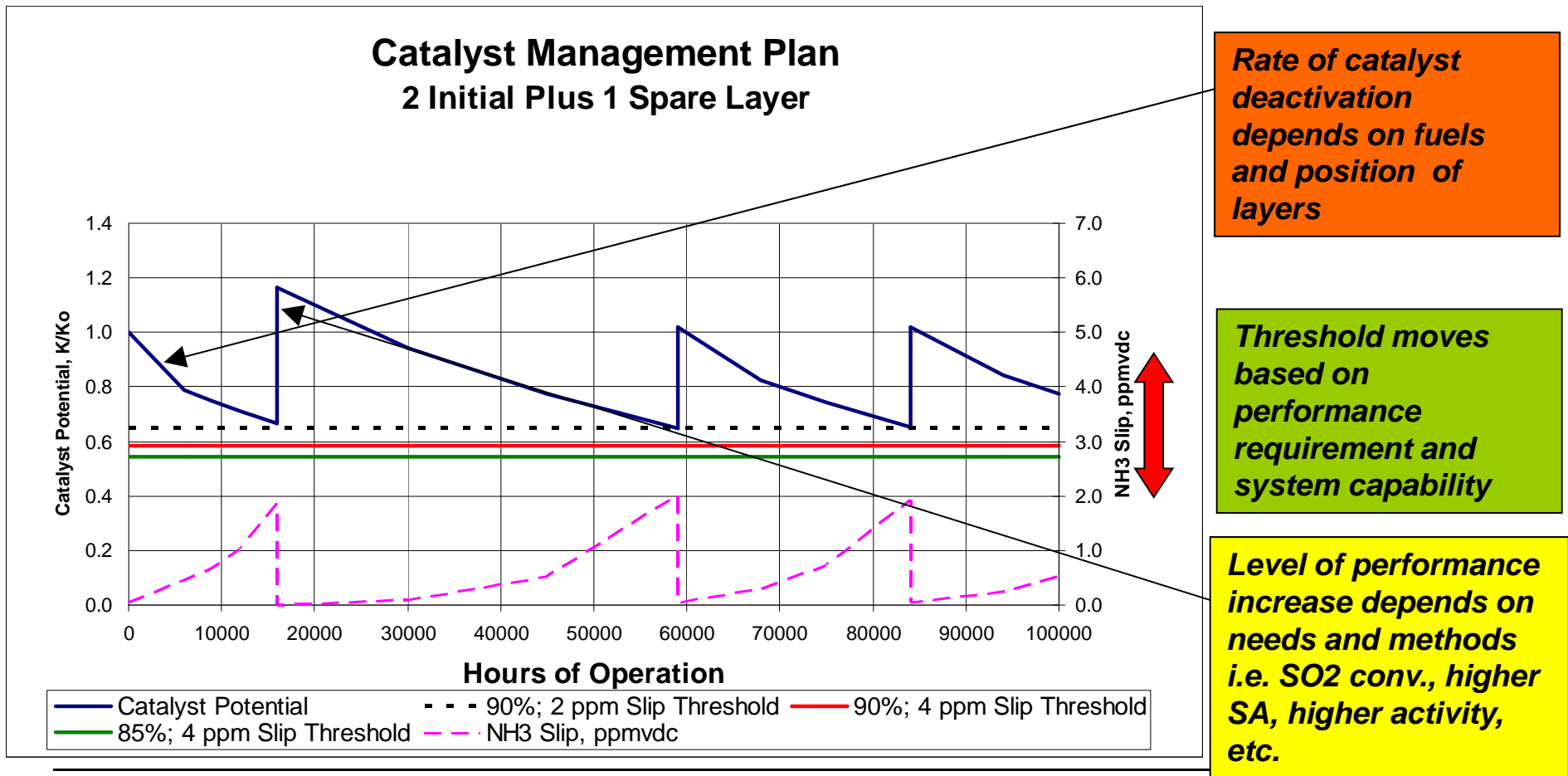
# Catalyst Management Tools



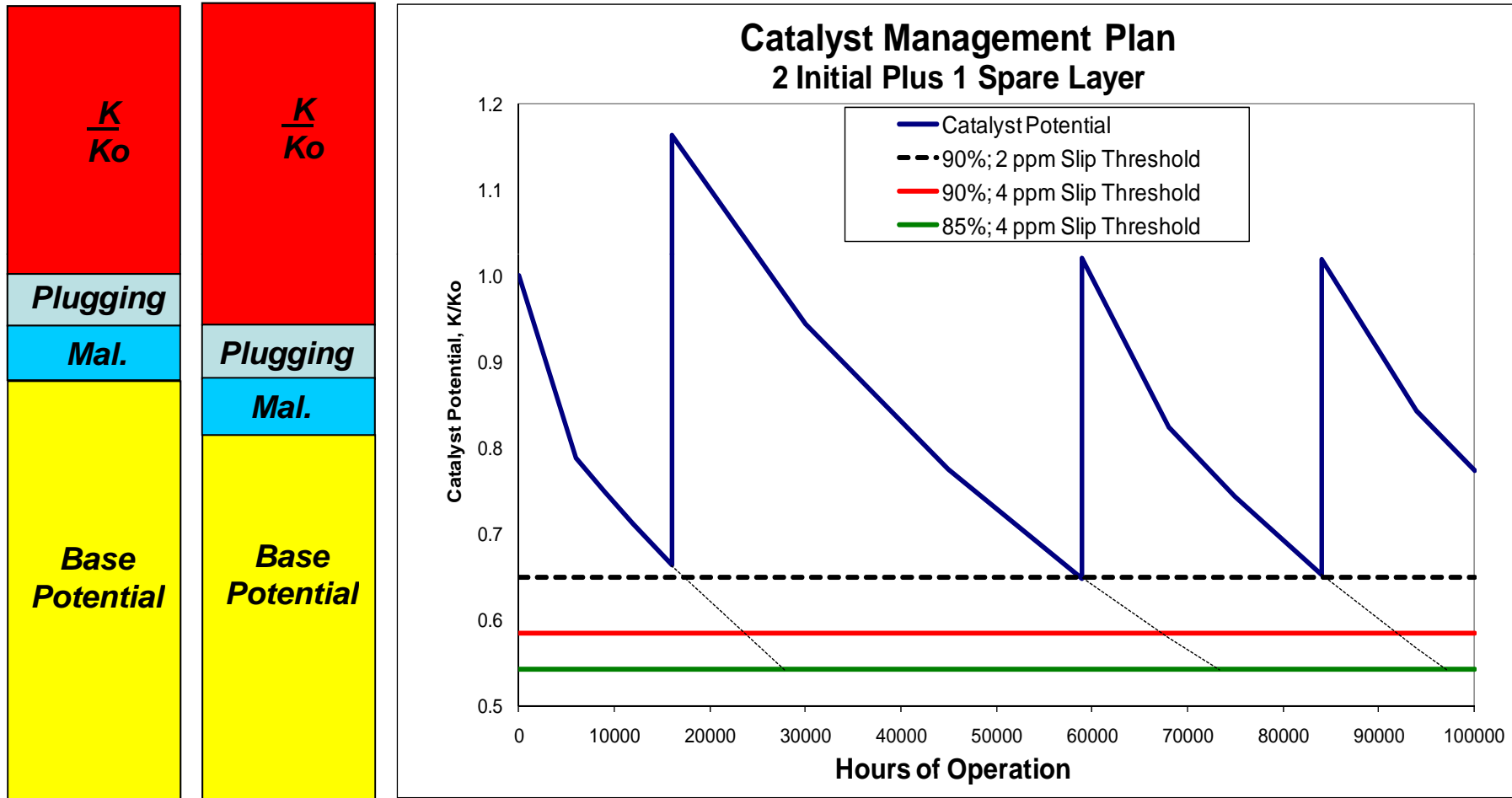
# Assess Fuel Impact



# Catalyst Management Plan



# Know Your Destination



# Catalyst Management - Field



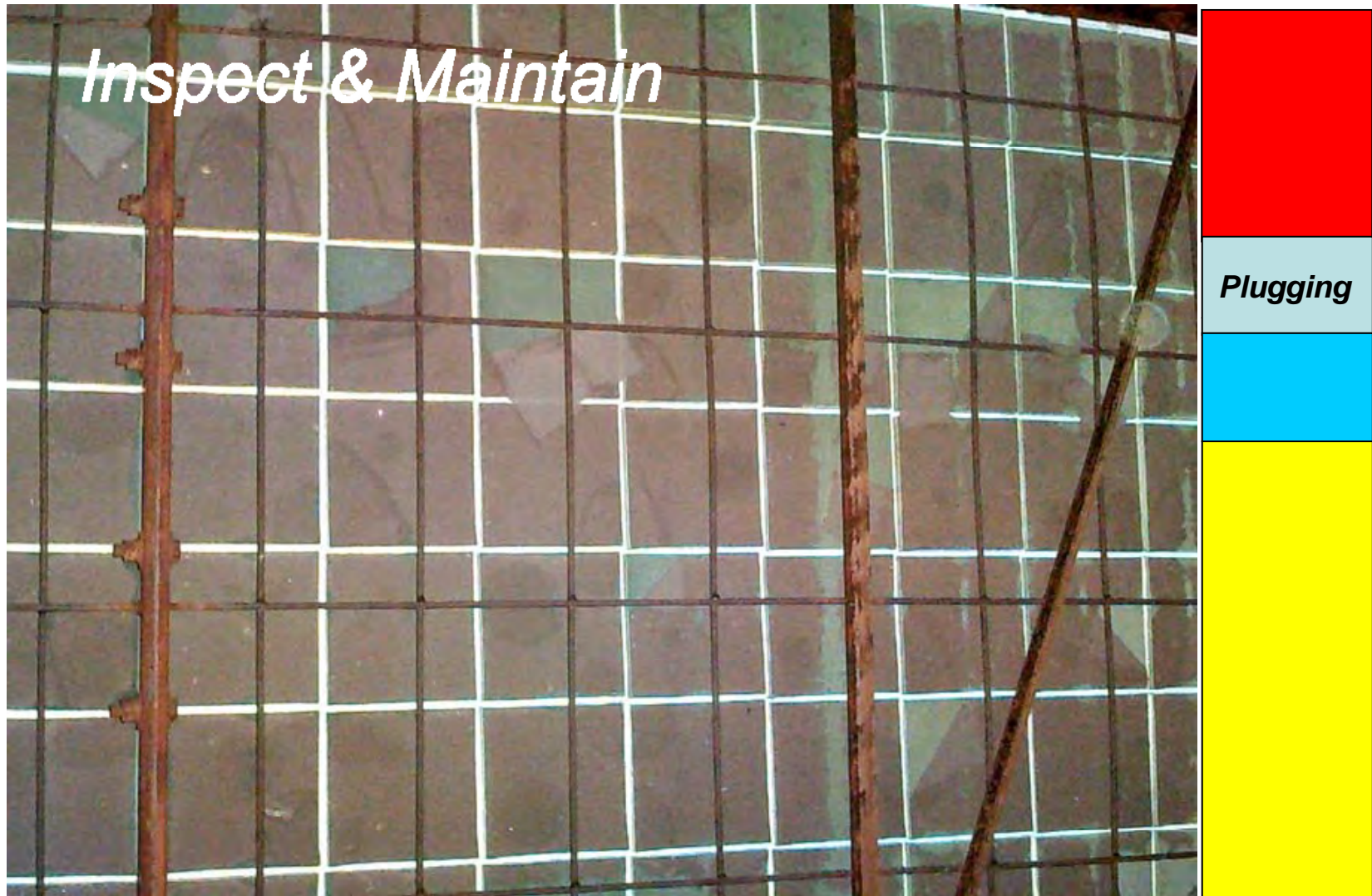
- **Inspection/Maintenance**
  - Catalyst
  - Ash Layout/Plugging
  - Ammonia Injection System
  - Ductwork
  - Expansion Joints
  - Cleaning Equipment
- **Performance**
  - Testing-NOx, Slip, SO<sub>3</sub>, Hg
  - NH<sub>3</sub> Balancing
- **Manage Potential**
  - DeNOx & Hg Oxidation



# Know Where You Are



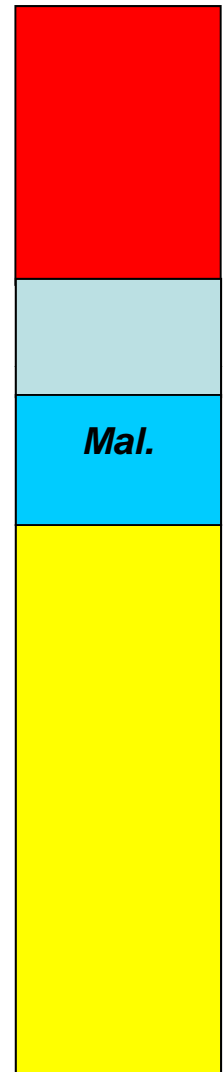
# Know Where You Are



# Know Where You Are



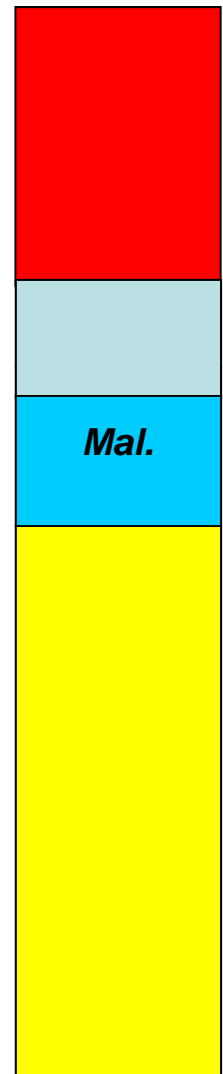
## *Inspect & Maintain*



# Know Where You Are



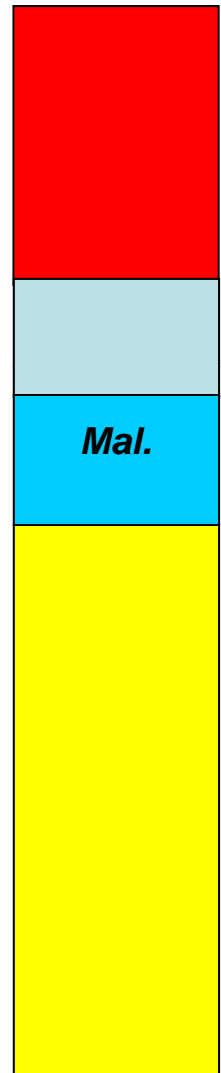
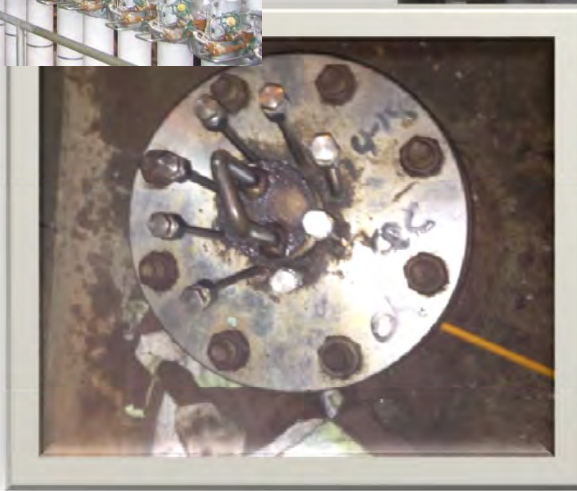
## *Inspect & Maintain*



# Know Where You Are



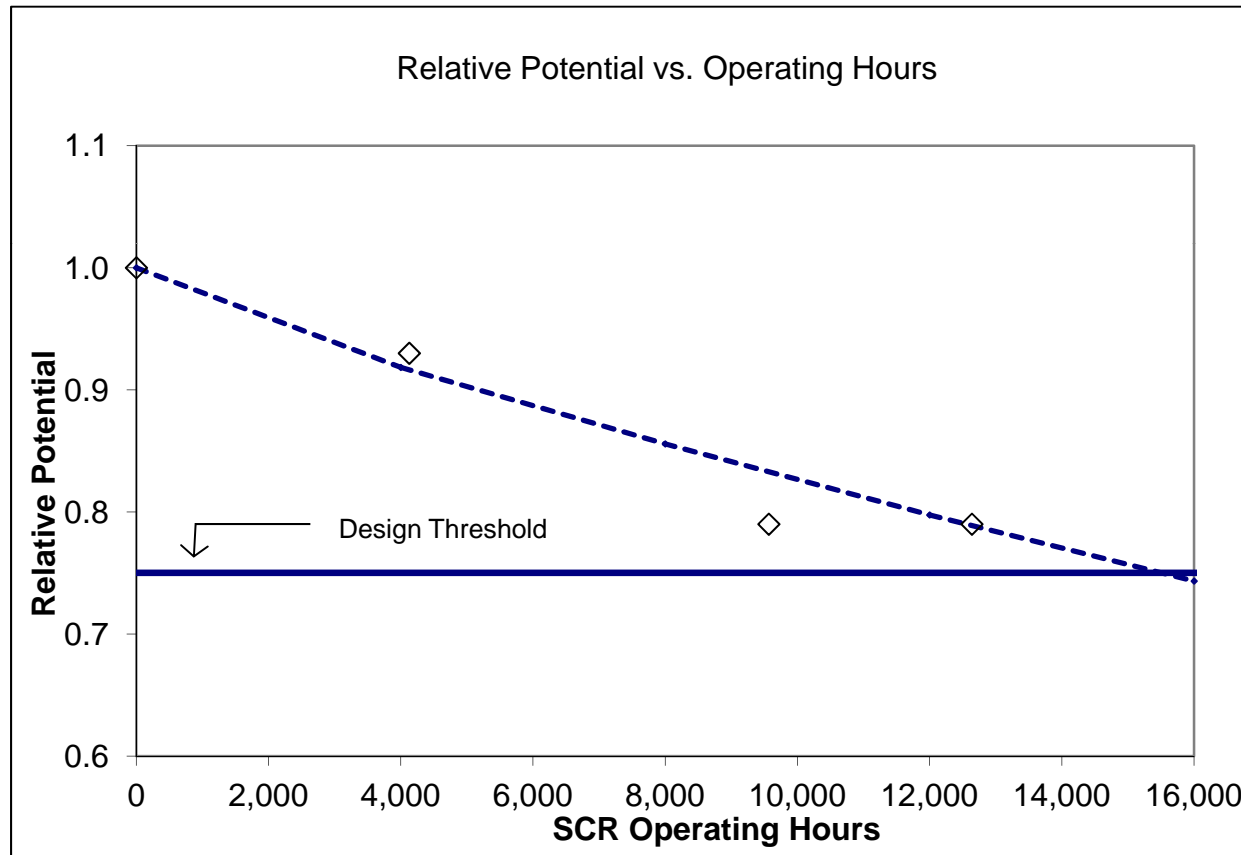
*Tune*



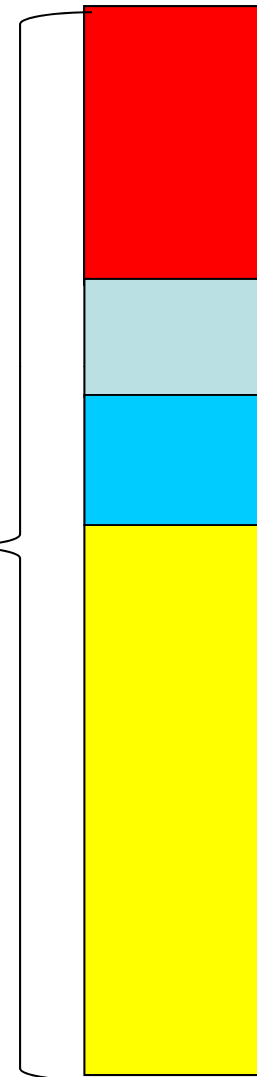
# Know Where You Are



## *Basic Lab Report for Coal*



**Total Potential**

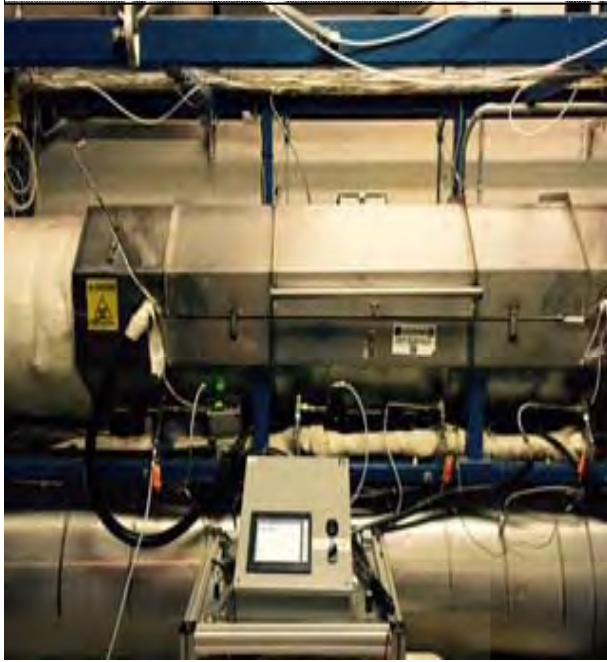


# Reactor Test Types



## **Semi-Bench**

DeNox Activity(gas)  
High NO<sub>2</sub>  
DP  
CO Oxidation



## **Full Bench**

DeNox Activity (gas/coal)  
SO<sub>2</sub> Oxidation  
DP  
Mercury Oxidation



## **Micro**

DeNox Activity (gas/coal)  
SO<sub>2</sub> Oxidation  
Mercury Oxidation  
CO Oxidation  
High NO<sub>2</sub>



# Take Action - Coal



## Layer Addition

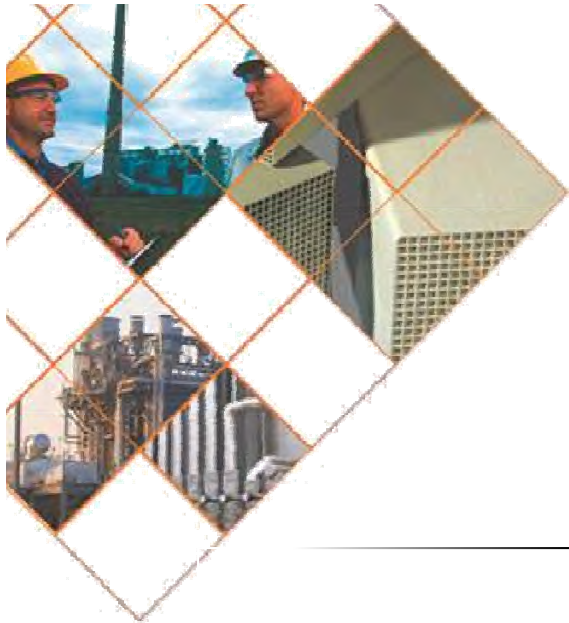
- Greater net increase in potential and life
- Greater pressure drop and SO<sub>2</sub> Oxidation

## Layer Replacement

- Less net increase in potential and life
- Variable pressure drop, variable SO<sub>2</sub> oxidation change

## Regeneration

- Applicable to addition or replacement
- Or regenerate your own, existing layer(s)



**CORMETECH**

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**Thank You!**

**Questions?**

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