

# Reinhold Environmental Ltd.

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2007 NOx Round Table & Expo  
Presentation

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*February 5-6, 2007 in Cincinnati, OH*

**2007 NOx Round Table Meeting  
Reinhold Environmental Ltd Conference  
February 5-8, 2007**



**SCR System Management Considerations**

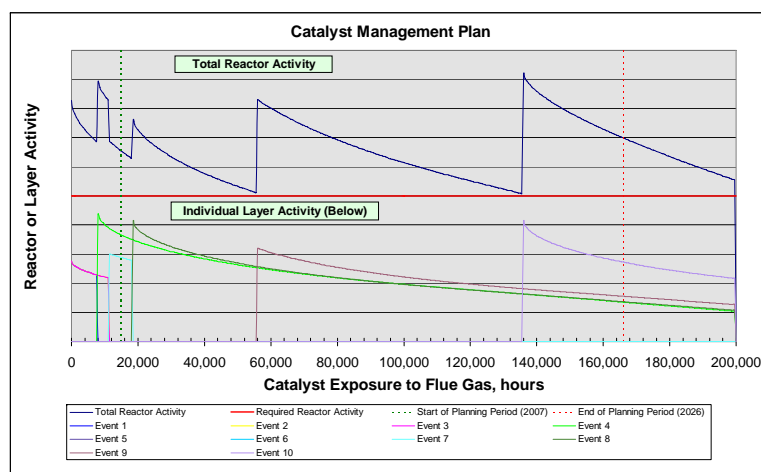
Presenters:

Dr. Greg Holscher and Noel Rosha  
CERAM Environmental, Inc.  
(913)239-9896



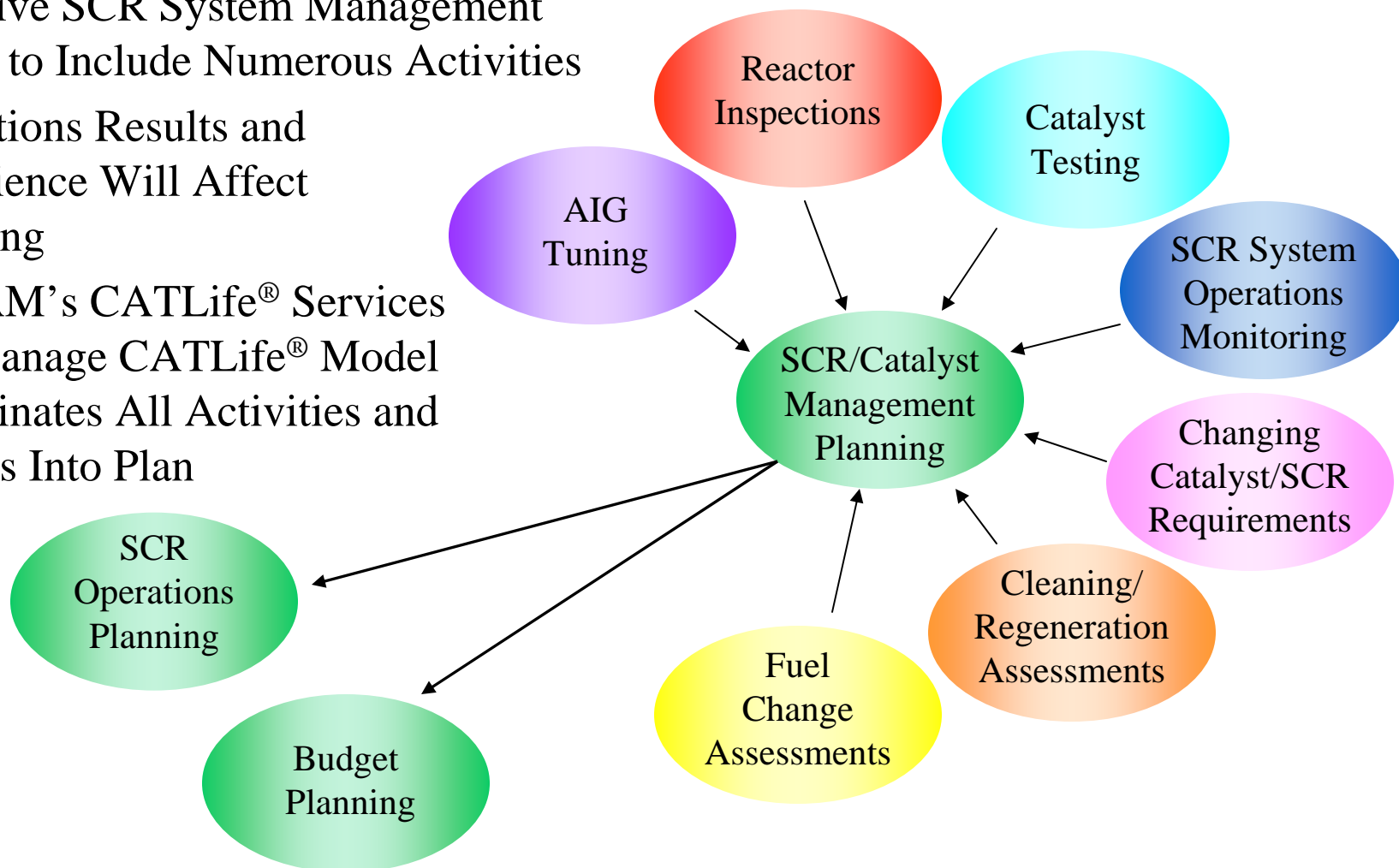
# CERAM Environmental, Inc.

- >15,000 MW of US Coal Based CERAM Catalyst References
- >300 CERAM Catalyst “Dirty Gas” References Worldwide
- >12,000 MW of North American Coal Based Catalyst Management References
  - Homogeneous Honeycomb, Plate, and Corrugated Fiber References
  - AIG Tunings
  - Reactor Inspections
  - Catalyst Testing
  - SCR Operations Assessments
  - Catalyst Management Planning



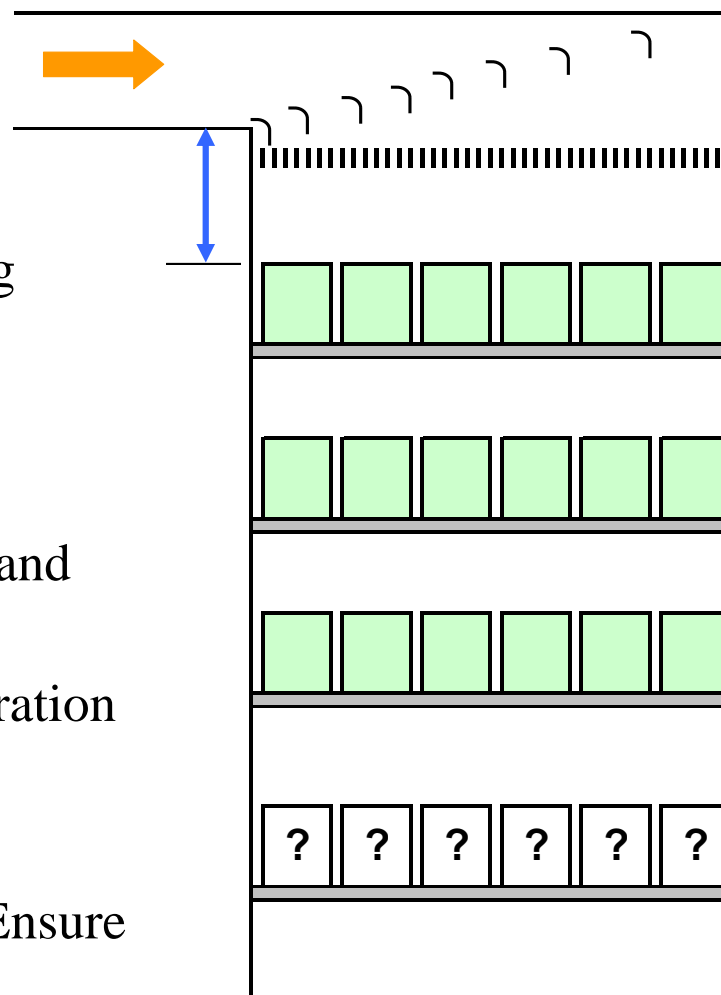
# Catalyst and SCR System Management Activities and Results

- Effective SCR System Management Needs to Include Numerous Activities
- Operations Results and Experience Will Affect Planning
- CERAM's CATLife® Services and Manage CATLife® Model Coordinates All Activities and Results Into Plan

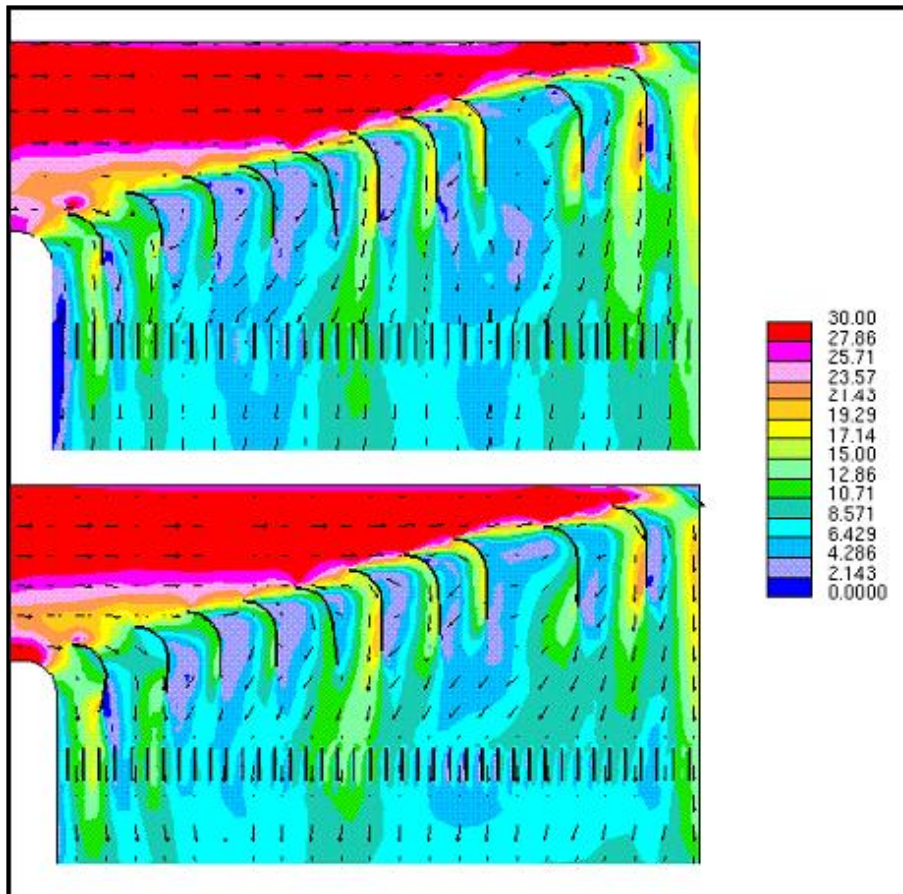


# Effective Catalyst Management Begins With SCR System Design

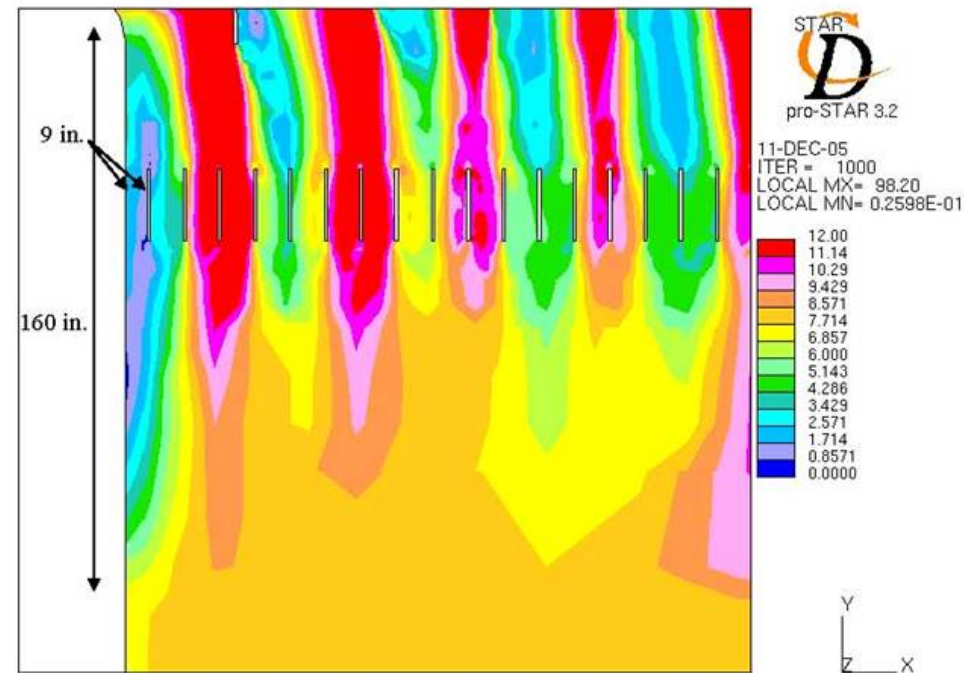
- Reactor Configuration
  - Distance From Crossover Duct Down to Top of 1<sup>st</sup> Catalyst Layer
- Perform Physical and CFD Flow Modeling
- Incorporate LPA Screen
- Consider Steady State and Full Range of Operations
- Catalyst Chemical and Mechanical (Pitch and Wall Thickness) Design
- AIG and Gas Monitoring System Configuration and Components
- Minimize LOI to Reduce Risks
- Experience Shapes Recommendations to Ensure Success



# Physical and CFD Flow Modeling



- Low Velocity Area Exists Even Though Distributions Are Achieved
- Low  $V = \text{Increased Pluggage Risk}$



# Physical and CFD Flow Modeling



Ash Buildup on Vanes

Affects of Ash Shear

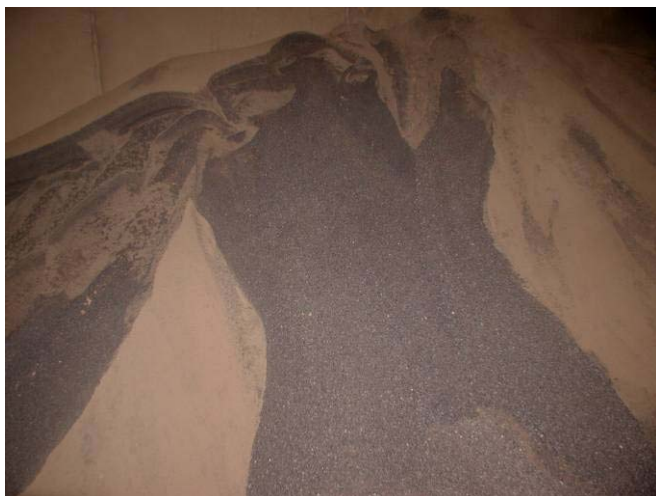


## Eliminate LPA Prior to Catalyst



- Large Particle Ash Pluggage Leads to...
  - High Pressure Drops
  - Mechanical Damage
  - Reduced Performance Potential
- Effective and Durable Screen Designs are Required
  - Located With Ash Removal
  - Located at Proper Velocity
  - Simple and Advanced Designs Have Both Succeeded and Also Had Problems
- Flow Modeling and Physical Changes are Likely Necessary

## Minimize Carbon Carryover



- All DeNOx Catalyst Has Oxidizing Properties and Will Tend to Oxidize Unburned Carbon
- Oxidized Carbon Sticks to Catalyst and Can Result in Pluggage
- Accumulation on Catalyst Increases Risk of Potential for Offline, Out of Reactor Cleaning and Fires
- Homogeneous Honeycomb Catalyst Consists of Fully Oxidized Material
- Metal Substrates Can Lead to Increased Potential for Fires

# Catalyst (Honeycomb or Plate) Can Be Susceptible to Fire Damage



## Pluggage Susceptibility – Honeycomb or Plate

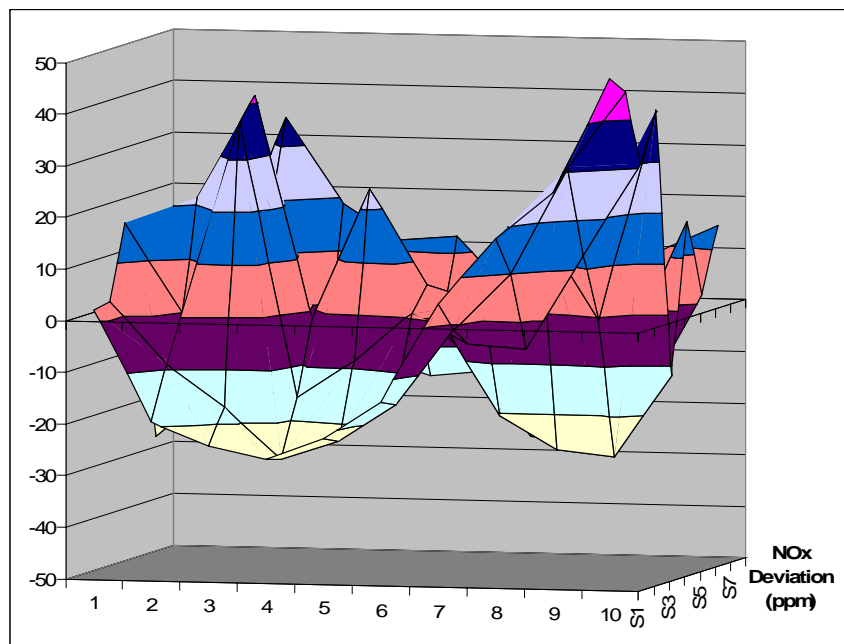


Risk Reduced by Proper Pitch  
Selection, Engineering Design, and  
Operation Practices

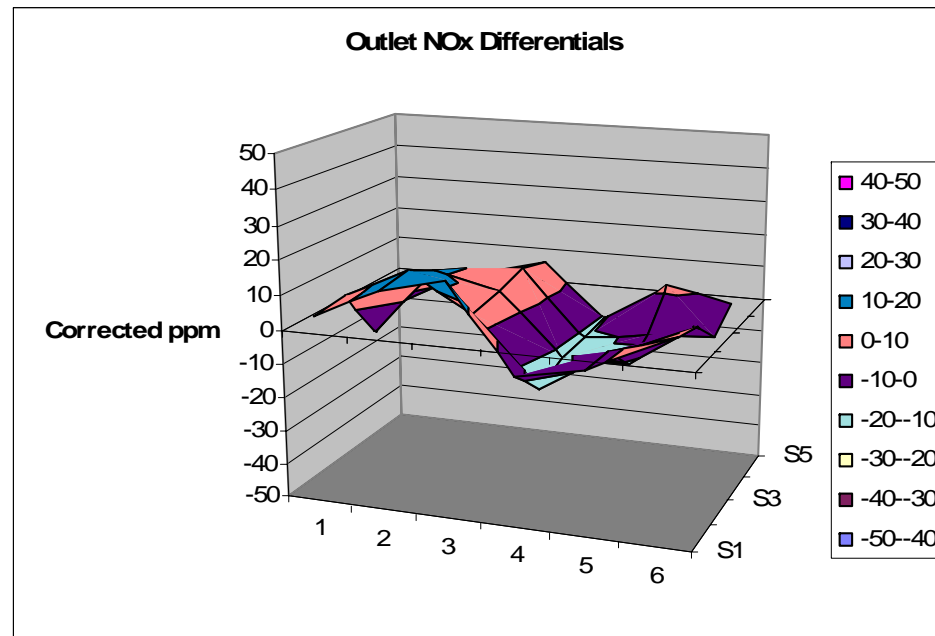
# Operations Begin: The Cornerstones of Effective SCR System Management

- Reactor Inspections – Assess Pluggage and Mechanical Condition
- Catalyst Testing – Assess Activity Levels and Deactivation Trends
- AIG Tuning – Optimize  $\text{NH}_3/\text{NO}_x$  Distribution
- Monitor Ammonia in Ash Levels
- Operations Data Assessment
- Monitor Fuels Data
- Determine SCR Performance Requirements (Near Term and Long Term)
- Assess SCR System (It's Not Just the Catalyst) Performance Capabilities (e.g.,  $\text{NH}_3$  control upgrades...)
- Accurately Predict Catalyst Needs

# The Value of AIG Tuning (Areas of Low NOx = Increased Slip)



**Actual Plant "Tuned" By Others  
(~ +/-9 to 10% NH<sub>3</sub>/NOx Distribution)**



**CATLife® Program Tuning Result (~ +/-3 to 4% NH<sub>3</sub>/NOx Distribution)**

**Lower Outlet NOx and Year Round Operations will Require  
Due Diligence on AIG Tuning and AIG Tuning Checks**

# CERAM's Manage CATLife<sup>®</sup> Model

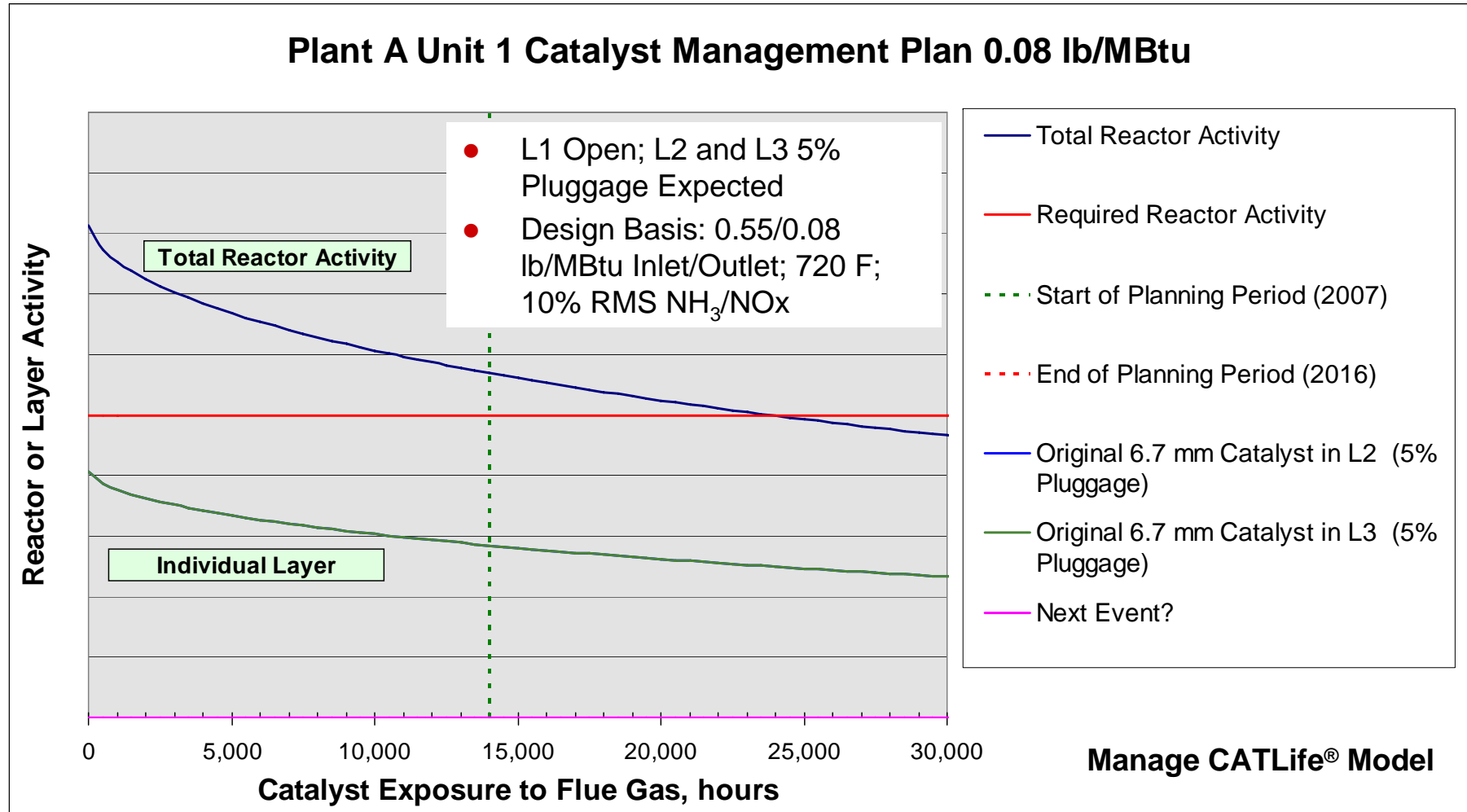
- Fully Integrated Analysis Considers
  - Various SCR System Performance Requirements
  - Current Mechanical Condition
  - Catalyst Activity Monitoring and Aging Models
  - Considers All Catalyst Management Choices (New, Cleaned, Regenerated, Moved)
  - Various Catalyst Types (Honeycomb and Plate), Geometry, and Chemical Compositions/Performance
  - Actual Gas Condition Based Determination of Activity, Oxidation Rates, and Pressure Drops
  - Full NPV Economic Analysis
- Developed With Utility User Feedback

# Unit 1 Original Design Basis

| at 24000 hr (2009) | Layer Age     | Pitch, mm       | Pluggage Rate | Delta P, in wg | Oxidation Rate |
|--------------------|---------------|-----------------|---------------|----------------|----------------|
| Layer 1            | Empty         | Empty           | Empty         | Empty          | Empty          |
| Layer 2            | 24,000        | 6.74            | 5%            | 1.2            | 0.23%          |
| Layer 3            | 24,000        | 6.74            | 5%            | 1.2            | 0.23%          |
|                    |               |                 |               |                |                |
| Design/Expected 0% | 0.68 K/Ko 16k | No Fuel Changes | 5%            | 2.3            | 0.47%          |

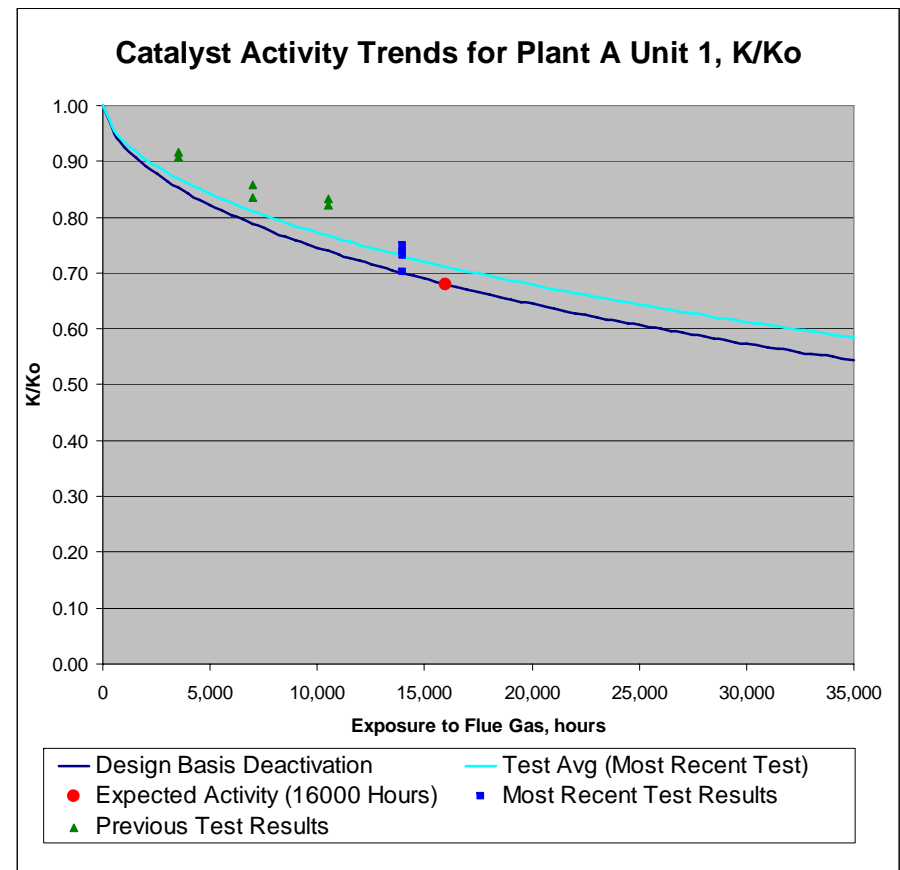
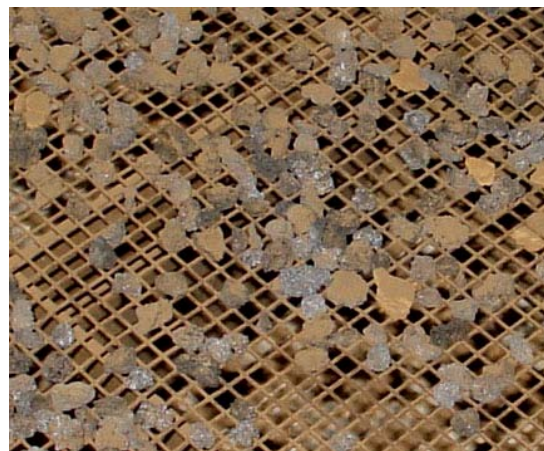
- Flue Gas Temperature = 720 F
- Inlet NOx = 0.55 lb/MBtu
- Outlet NOx = 0.08 lb/MBtu
- Ammonia Slip = 2 ppm
- SO<sub>2</sub> to SO<sub>3</sub> Conversion Rate < 0.75% (3 Layers)
- 5% or Less Pluggage Expected
- Maximum 4.0 in wg Pressure Drop Expected (3 Layers)
- 24,000 Hour Catalyst Life Expected

# The Original Plan – 24,000 Hour Design Unit 1 (600 MW) Basis

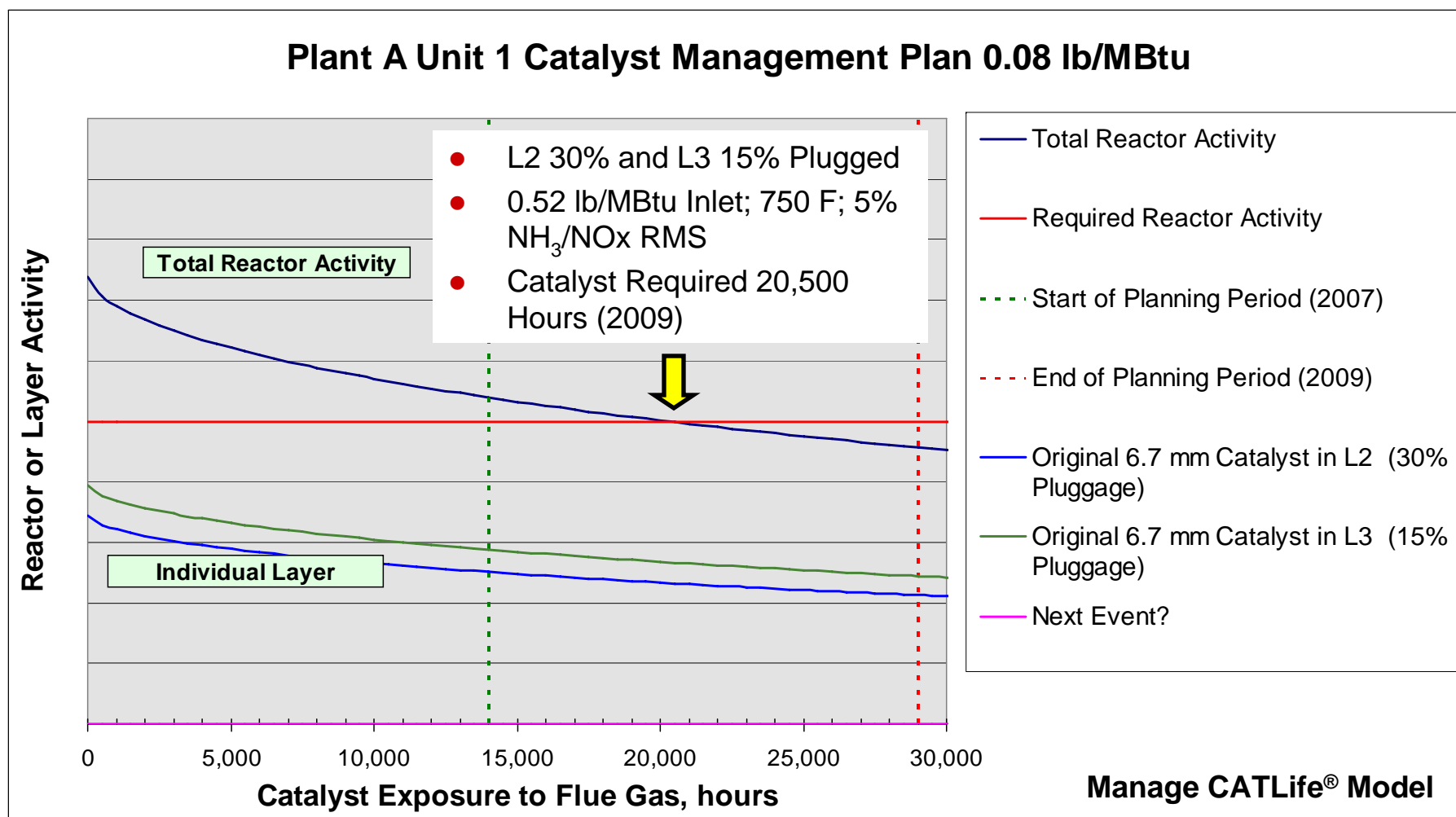


# Operations Experience Enters the Picture

- Reactor Inspection Finds LPA and Increased Pluggage (15% to 30% vs. 5% Expected)
- Catalyst Deactivation Less Than Expected (K/Ko of 0.71 vs. 0.68 Expected)
- AIG Performs Better Than Design (5% NH<sub>3</sub>/NO<sub>x</sub> vs. 10% Expected)
- Inlet T Higher Than Design (750 F vs. 720 F Expected)
- Inlet NO<sub>x</sub> Lower Than Design (0.52 vs. 0.55 lb/MBtu Expected)
- Desire to Increase Design NO<sub>x</sub> Removal and Increase Fuels Flexibility



# Unit 1 Current Projection for 0.08 lb/MBtu



## Unit 1 Current Operations Situation (Catalyst Activity Needed @ 20,500 Hours)

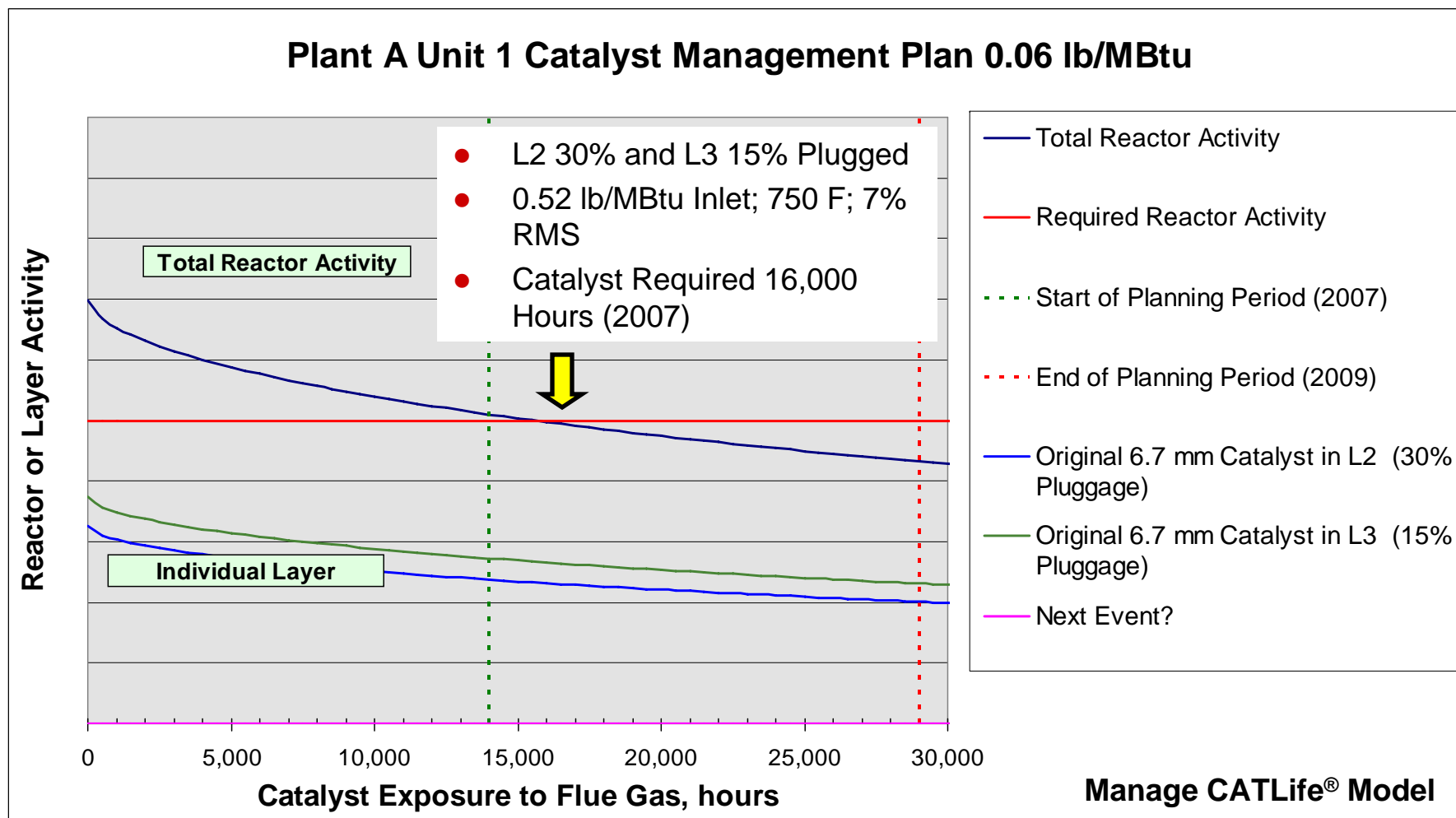
| at 20500 hr (2008) | Layer Age     | Pitch, mm       | Pluggage Rate | Delta P, in wg | Oxidation Rate |
|--------------------|---------------|-----------------|---------------|----------------|----------------|
| Layer 1            | Empty         | Empty           | Empty         | Empty          | Empty          |
| Layer 2            | 20,500        | 6.74            | 30%           | 1.9            | 0.33%          |
| Layer 3            | 20,500        | 6.74            | 15%           | 1.5            | 0.33%          |
|                    |               |                 |               |                |                |
| Avg Measured 0%    | 0.71 K/Ko 16k | No Fuel Changes | 23%           | 3.3            | 0.67%          |

- LPA Pluggage Leads to 23% Reactor Pluggage
- 750 F Gas T vs. 720 F Design
- Less Than Expected Deactivation

## Unit 1 Original Design Basis

| at 24000 hr (2009) | Layer Age     | Pitch, mm       | Pluggage Rate | Delta P, in wg | Oxidation Rate |
|--------------------|---------------|-----------------|---------------|----------------|----------------|
| Layer 1            | Empty         | Empty           | Empty         | Empty          | Empty          |
| Layer 2            | 24,000        | 6.74            | 5%            | 1.2            | 0.23%          |
| Layer 3            | 24,000        | 6.74            | 5%            | 1.2            | 0.23%          |
|                    |               |                 |               |                |                |
| Design/Expected 0% | 0.68 K/Ko 16k | No Fuel Changes | 5%            | 2.3            | 0.47%          |

## Unit 1 Current Projection for 0.06 lb/MBtu



# The Complicating Factors

- Desire to Achieve 0.06 lb/MBtu (Designed for 0.08 lb/MBtu)
- Year Round Operation Starting 2009
- Oxidation Rates:
  - Original Design (720 F) – 0.50%
  - Current Operations (750 F) – 0.67%
- Desire to Maintain 0.06 lb/MBtu Performance
- Planned Outage Fall 2008
  - Installing LPA Device
  - Catalyst Addition
- What Should be Done???

# Catalyst Management Options

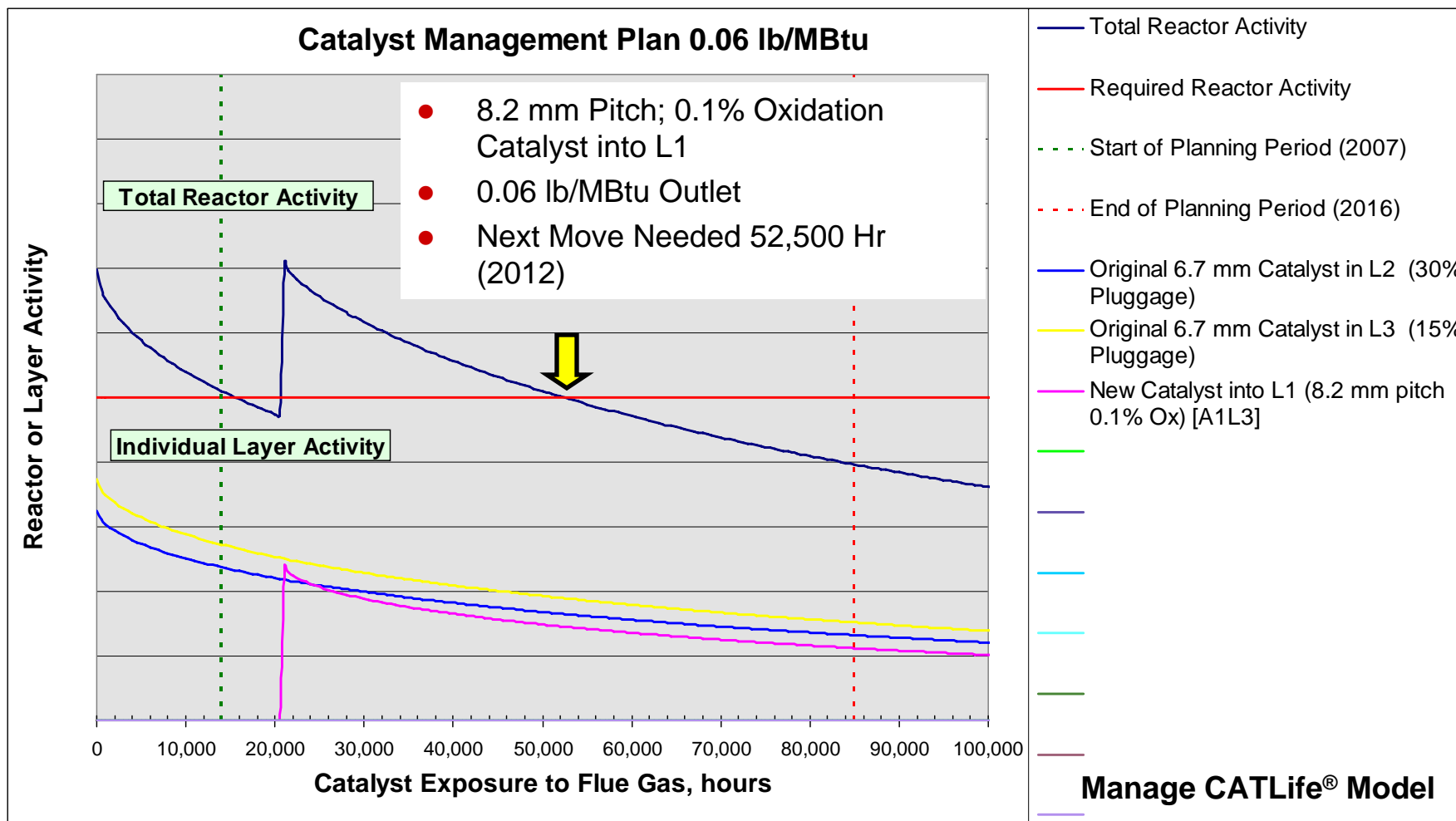
1. Add New Catalyst
  - New L1 or Replace L2
  - Pitch and Length
  - Oxidation Rate
2. Move Catalyst From Existing Plant
3. Rejuvenate/Clean Existing Catalyst
4. Regenerate Existing Catalyst
  - Activity, Cleanliness, and Oxidation Rate Critical for 2-4



## **Selection of the Best Option Complicated by Many Considerations**

- Desired Performance
  - Increase NO<sub>x</sub> Removal
  - Reduce or Maintain Oxidation Rate
  - Reduce Pressure Drop/Pluggage
  - Increase Fuel Flexibility
- Catalytic Activity and Oxidation Rate of Various Catalyst Types, Geometries, and Chemistries
- Required Timing/Outage Availability
- Direct and Indirect Costs of Options
  - NPV's Presented Include Catalyst Related Costs as Well as Labor, Disposal, and ID Fan Power Costs

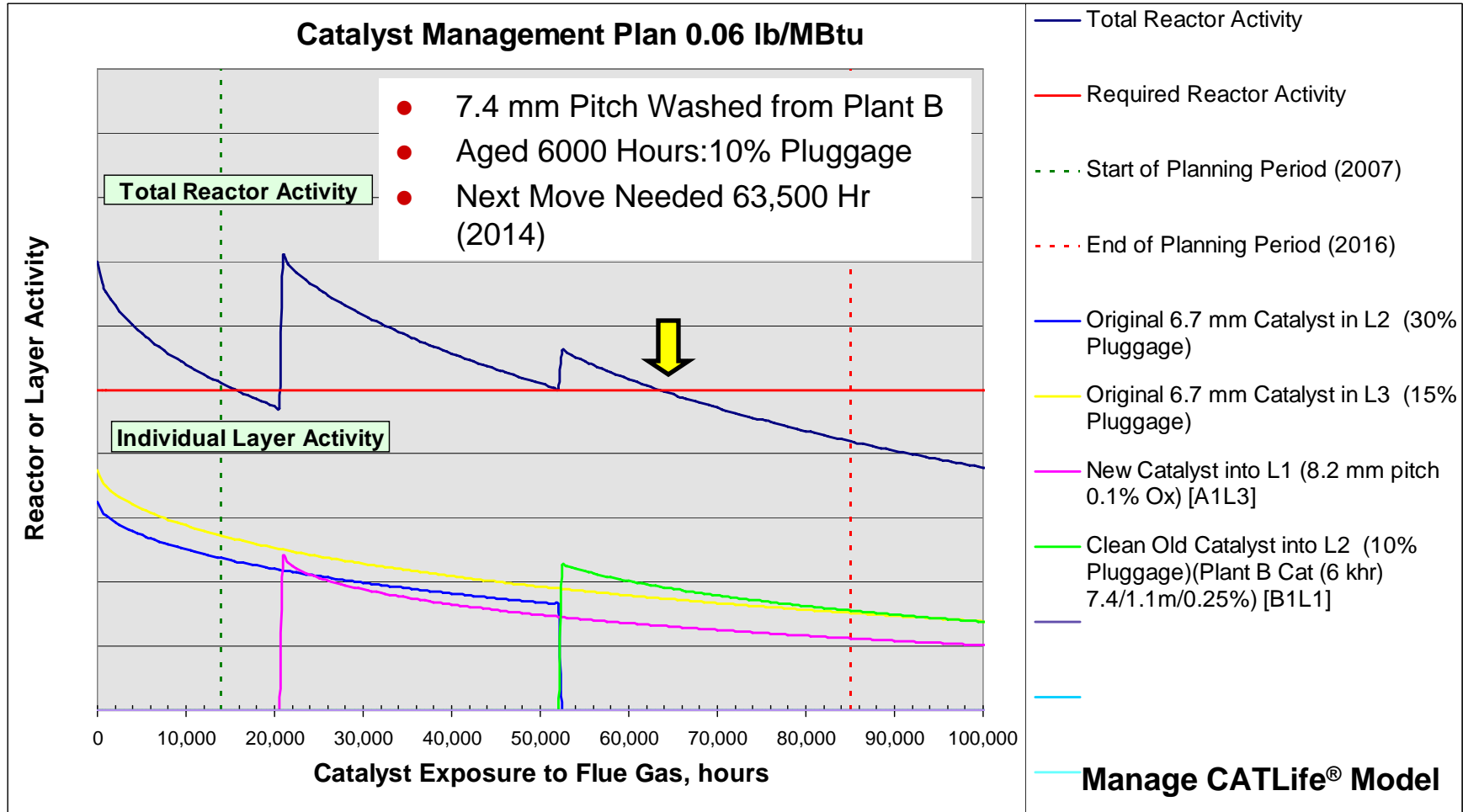
# Unit 1's First Move; Increase Pitch and Lower Oxidation Basis



# Unit 1 Reactor Status After First Move

| at 52500 hr (2012) | Layer Age     | Pitch, mm       | Pluggage Rate | Delta P, in wg | Oxidation Rate |
|--------------------|---------------|-----------------|---------------|----------------|----------------|
| Layer 1            | 31,500        | 8.19            | 5%            | 0.9            | 0.09%          |
| Layer 2            | 52,500        | 6.74            | 30%           | 1.9            | 0.33%          |
| Layer 3            | 52,500        | 6.74            | 15%           | 1.5            | 0.33%          |
|                    |               |                 |               |                |                |
| Avg Measured 0%    | 0.71 K/Ko 16k | No Fuel Changes | 17%           | 4.2            | 0.76%          |

# Unit 1's Next Move; Reuse 7.4 mm Pitch Catalyst From Plant B



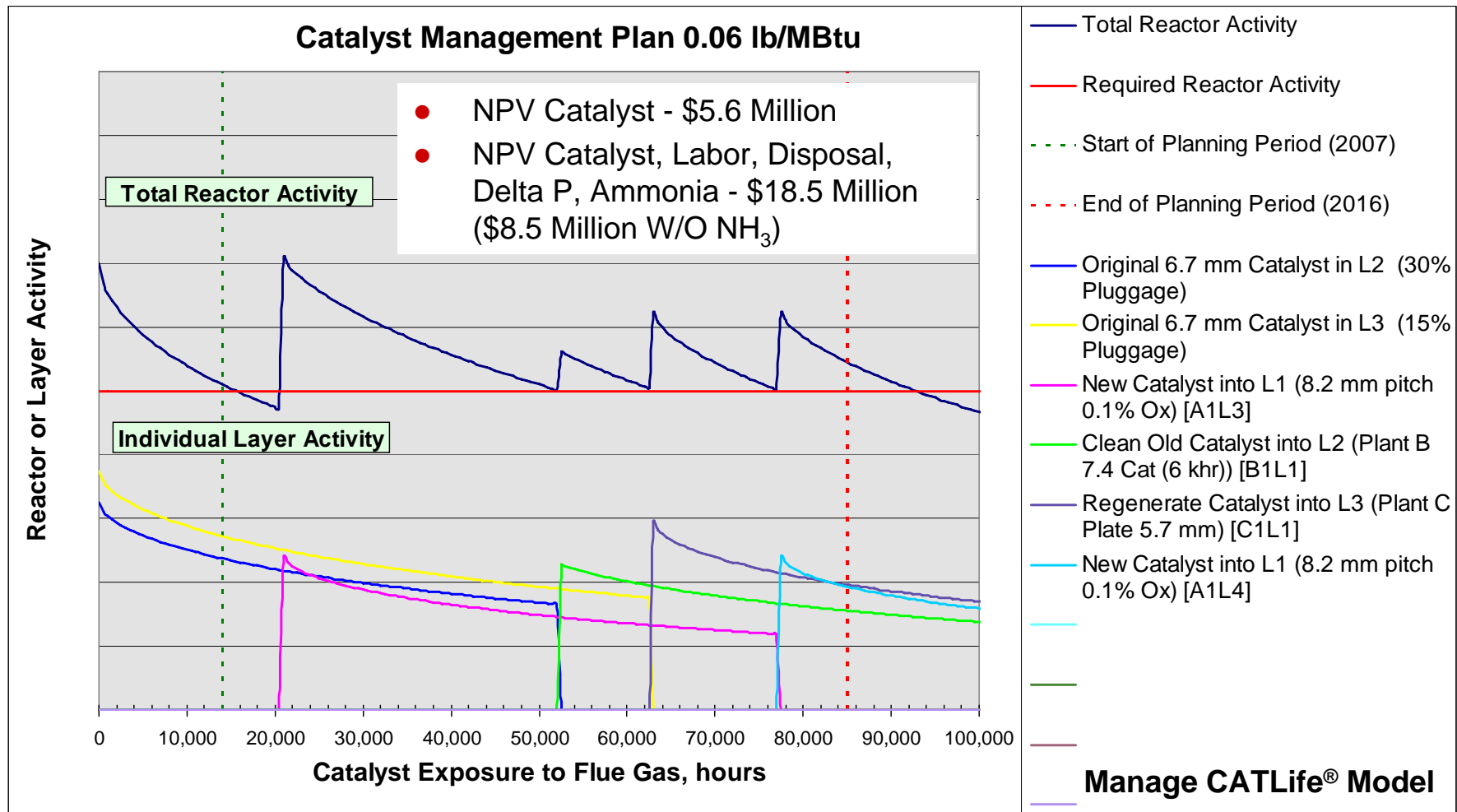
# Reactor Status After Installing Used 7.4 mm Pitch Catalyst

| at 63500 hr (2014)     | Layer Age     | Pitch, mm       | Pluggage Rate | Delta P, in wg | Oxidation Rate |
|------------------------|---------------|-----------------|---------------|----------------|----------------|
| Layer 1                | 42,500        | 8.19            | 5%            | 0.9            | 0.09%          |
| Layer 2                | 17,000        | 7.39            | 10%           | 1.1            | 0.28%          |
| Layer 3                | 63,500        | 6.74            | 15%           | 1.5            | 0.33%          |
|                        |               |                 |               |                |                |
| <b>Avg Measured 0%</b> | 0.71 K/Ko 16k | No Fuel Changes | 10%           | 3.4            | 0.71%          |

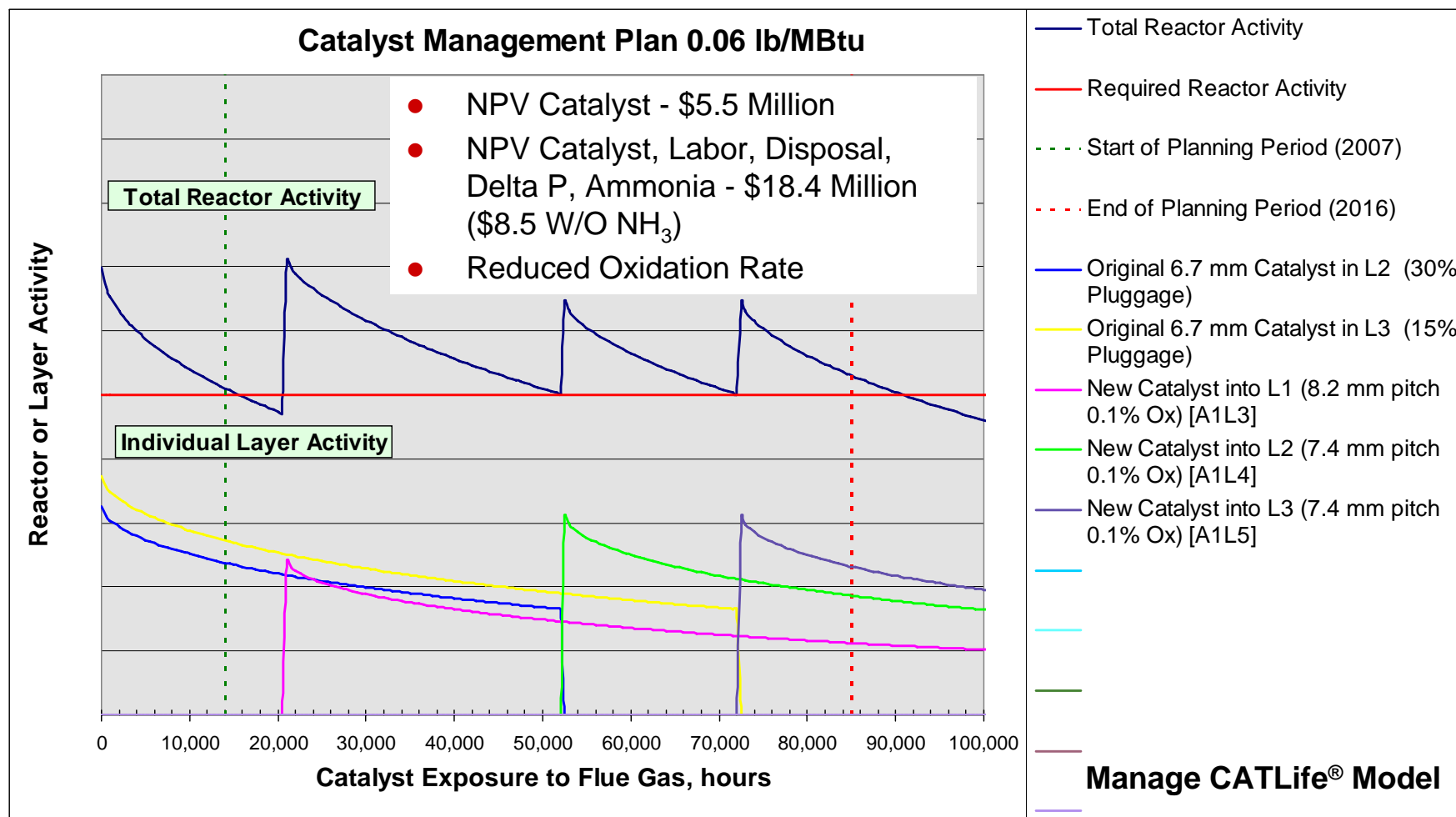
# Economic Analysis Basis

- Plant Size 550 MW
- 2007 Cost Basis
- New Catalyst Cost \$6,000/m<sup>3</sup>
- Existing Catalyst at No Charge (Inter Utility)
- Catalyst Washing (All In) \$2,500/m<sup>3</sup>
- Catalyst Regeneration (All In) \$3,200/m<sup>3</sup>
- Removal \$600/m<sup>3</sup>
- Installation \$700/m<sup>3</sup>
- Disposal \$600/m<sup>3</sup>
- Ammonia \$400/ton
- Fan Energy \$0.05/kwh
- Capacity Factor:
  - Ozone Season – 85%
  - Year Round – 75%
- Available Outages Match Needs
- 4% Escalation
- 8.6% Present Worth Discount Rate

# The 10 Year Plan – Maximum Reuse of Owned Catalyst



# The Alternate 10 Year Plan – New Catalyst Based



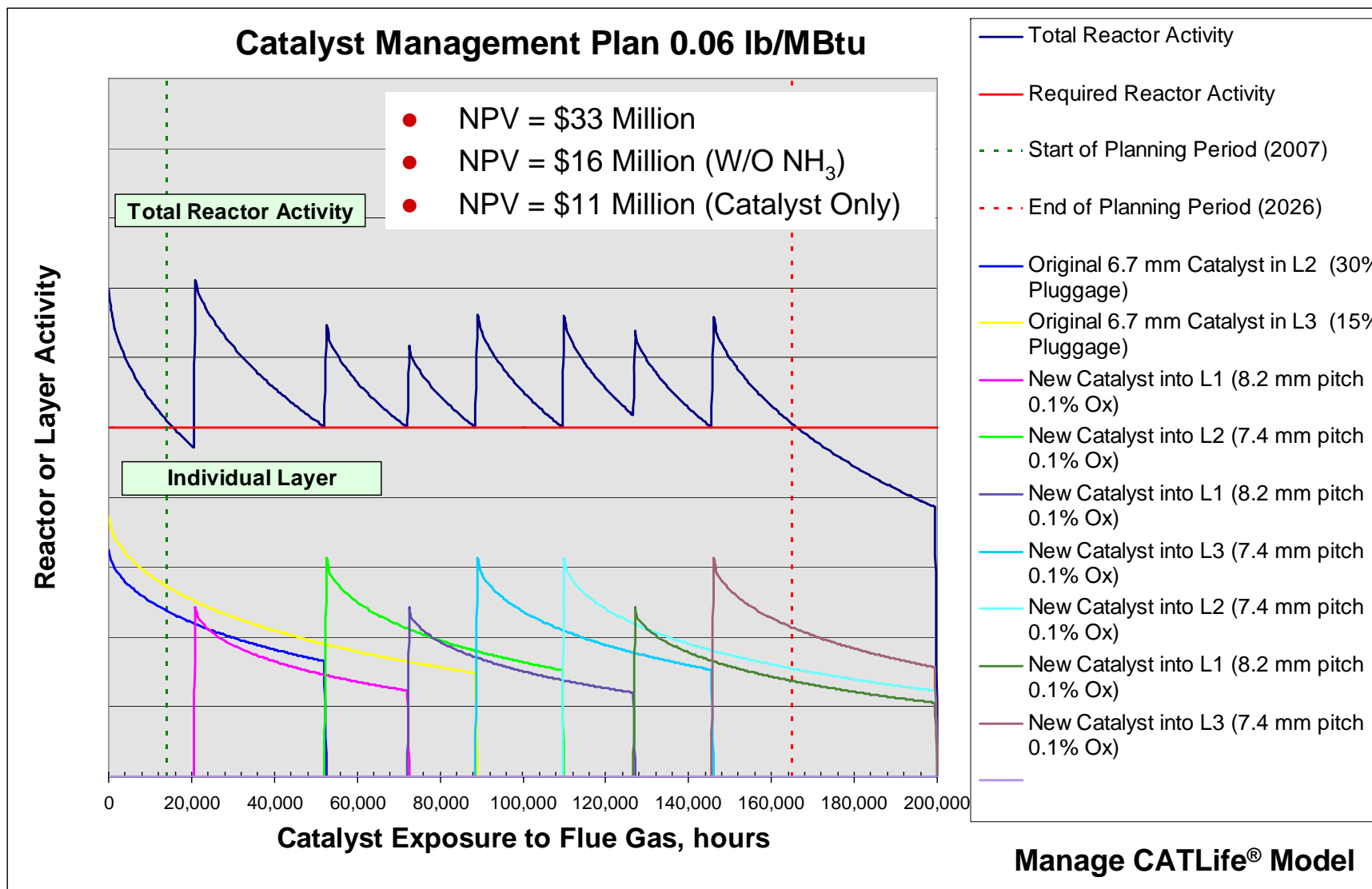
## End of Plan Reactor Status and Event Summary

| Complete 2016          | Layer Age            | Pitch, mm              | Pluggage Rate | Delta P, in wg | Oxidation Rate |
|------------------------|----------------------|------------------------|---------------|----------------|----------------|
| Layer 1                | 70,000               | 8.19                   | 5%            | 0.9            | 0.09%          |
| Layer 2                | 38,500               | 7.40                   | 5%            | 1.0            | 0.09%          |
| Layer 3                | 18,500               | 7.40                   | 5%            | 1.0            | 0.09%          |
|                        |                      |                        |               |                |                |
| <b>Avg Measured 0%</b> | <b>0.71 K/Ko 16k</b> | <b>No Fuel Changes</b> | <b>5%</b>     | <b>2.9</b>     | <b>0.27%</b>   |

| Event | Description*                                       | Year of Event | SCR Operating Hour | Pitch/Wall Thickness/ Length, mm | Catalyst Installed/ Removed, m3 |
|-------|--|---------------|--------------------|----------------------------------|---------------------------------|
| 1     | Original 6.7 mm Catalyst in L2 (30% Pluggage)      | 2003          | 0                  | 6.74/0.8/1270                    | 309/0                           |
| 2     | Original 6.7 mm Catalyst in L3 (15% Pluggage)      | 2003          | 0                  | 6.74/0.8/1270                    | 309/0                           |
| 3     | New Catalyst into L1 (8.2 mm pitch 0.1% Ox) [A1L3] | 2009          | 21,000             | 8.19/0.9/1300                    | 316/0                           |
| 4     | New Catalyst into L2 (7.4 mm pitch 0.1% Ox) [A1L4] | 2012          | 52,500             | 7.4/0.8/1300                     | 316/309                         |
| 5     | New Catalyst into L3 (7.4 mm pitch 0.1% Ox) [A1L5] | 2015          | 72,500             | 7.4/0.8/1300                     | 316/309                         |



# 20 Year Plan; 0.3% Max Oxidation



## Representative Catalyst Washing Process



Mechanical Motion, Bubbles, and Ultrasonics

# Catalyst Washing Videos



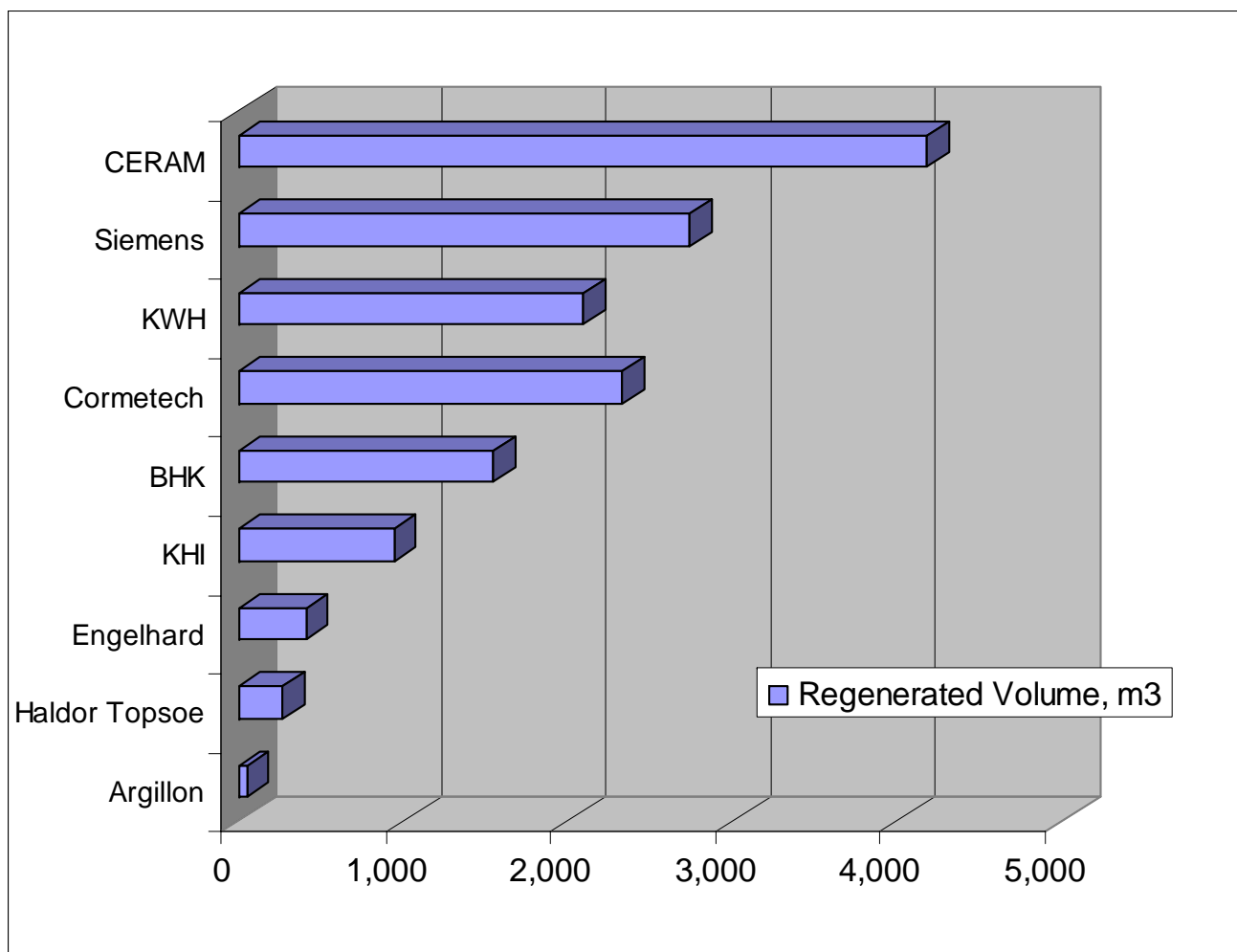
Washing and Regeneration Reliant on  
Mechanical Energy to Process Catalyst

## Wall Thickness vs. Mechanical Strength

- Critical Mechanical Strength Parameters
  - Transverse – Critical to Support Module Packing and Washing
  - Longitudinal – Critical to Support Ash Loads and Erosion
- Strength Affected by Inner and Outer Wall Thickness
- Strength Decreases As Number of Cells (# of Walls) and Wall Thickness Decrease
- CERAM Catalyst Has Demonstrated Superior Ability for Washing and Long Life – >120,000 Hours



## Envica/SCR Tech Regenerated Catalyst Volume Experience (Worldwide May 2006)



## The Influence of Wall Thickness on Required Volume, Pressure Drop and Oxidation Rate

|                                 |  |                                  |                |
|---------------------------------|--|----------------------------------|----------------|
| Pitch                           | 7.4 mm                                 | 7.4 mm                           | 7.4 mm         |
| <b>Wall Thickness</b>           | <b>0.9 mm</b>                          | <b>0.8 mm</b>                    | <b>0.7 mm*</b> |
| Outer Wall Thickness            | 1.5                                    | 1.4                              | 1.1            |
| Cumulative Wall Thickness       | 20.1 (100%)                            | 18.0 (90%)                       | 15.5 (77%)     |
| Open Area (Material Area Ratio) | 75% (100%)                             | 77% (90%)                        | 80%* (78%)     |
| Volume                          | 100%                                   | 97%                              | 94%            |
| Pressure Drop                   | 100%                                   | 91%                              | 82%            |
| Oxidation Rate                  | 0.3%                                   | 0.3%                             | 0.3%           |
| Expected Mechanical Life        | >90,000 hours<br>and Multiple Washings | >60,000 hours<br>and One Washing | ???            |

\*CERAM Will Not Offer <0.8 mm Wall Thickness and Greater Than 77% Open Area Catalyst for High Dust Units

CERAM Custom Formulates Catalyst to Meet Oxidation Rate Requirements

## Washing Durability a Function of Wall Thickness

- In 2005 270 Modules of CERAM Catalyst (1.0 mm) Washed With Integral Developed Process to Remove LPA and Carbon Deposits (20 to 100% Pluggage)
  - **ZERO** Elements Lost During Washing
  - **ZERO** Required Repacking
  - 90 to 95% Cleanliness Achieved
- Washing of >150 Modules of Competitor's Thin Wall Catalyst (0.7 mm) Lost 14% of Catalyst to Cleaning Process Damage
  - Required Repacking of Numerous Modules

# Conclusions

- The Cornerstones of Effective Catalyst Management
  - Annual Reactor Inspections, Catalyst Testing and AIG Tuning
  - Frequently Assess Operations Needs and Capabilities
  - Comprehensive Evaluation of All Options Available
- Design and Procurement Efforts Need to Consider and Value Mechanical Life
- CERAM's Manage CATLife Model Can Assist to...
  - Coordinate Wide Range of SCR System and Catalyst Data
  - Accurately Predict Timing for Next Catalyst Management Event
  - Allows Analysis of Full Variety of Catalyst and Performance Possibilities
  - Utilized to Analyze Full Range of Catalyst Types
  - Commercially Available and Developed in Conjunction With Utility Based Experience

**Thank you for your attention.**

**Questions?**