REINHOLD ENVIRONMENTAL Ltd.

2012 NOx-Combustion Round Table & Expo Presentation

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

2012 NOx-Combustion/PCUG
February 14, 2012


SCR Operation Through Regulatory Purgatory

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Presentation Agenda

- OPG and CERAM Environmental, Inc. Overview
- OPG Regulatory and Generation History
- OPG SCR Operating Summary
- Catalyst Testing Program
- Coal to Natural Gas Conversion Evaluation

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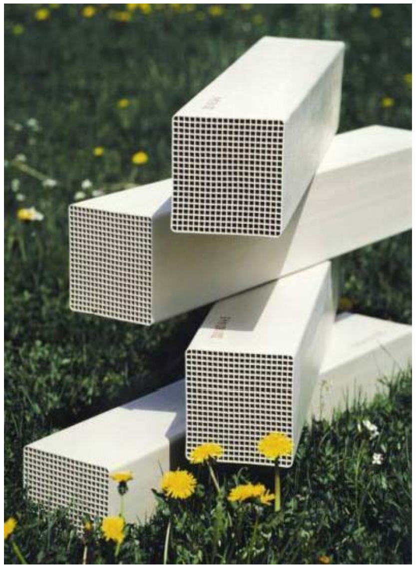
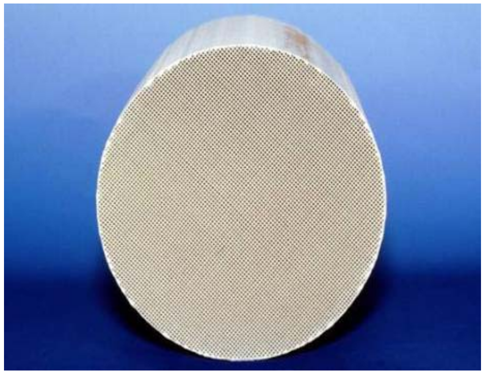
Products of Our CERAM Environmental

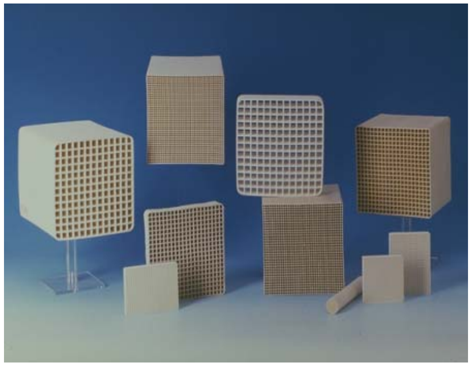
- **Catalytic Honeycombs**
  - SCR (NOx emission control)
    - Stationary Sources
    - Mobile Sources
  - Oxidation (HC, VOC)
  - Dioxin / Furan

- **Catalytic Plate**
  - SCR (NOx emission control)

- **Non-Catalytic Honeycombs**
  - Heat Storage Media
  - Casting Filters







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CERAM Environmental Inc.

- U.S. Based Subsidiary Founded by John Cochran in 2000
- Wholly Owned by Porzellanfabrik Frauenthal GmbH
- Comprehensive Direct Services
  - Catalyst Design
  - Flow Modeling Administration
  - Delivery Coordination
  - Training and Startup
  - Ammonia Injection Grid Tuning
  - Reactor Inspections
  - Catalyst Testing
  - SCR Operations (DCS) Reporting, Assessments and Troubleshooting
  - Catalyst Management and SCR Operations Planning
- Providing SCR System and Catalyst Management for >40 Coal Fired Units in North America

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Ontario Power Generation

- Total Capacity Over 19,000 MW
  - 2 Nuclear Generating Stations
  - 5 Thermal Generating Stations
  - 65 Hydroelectric Generating Stations
- Thermal Generating Stations Include
  - Nanticoke Generating Station
    - 8 x 500 MW PRB Fired
    - Largest Coal Fired Plant in North America
  - Lambton Generating Station
    - 4 x 500 MW High Sulfur Bituminous Fired
- SCR Systems Equipped on
  - Nanticoke Units 7 & 8 / Lambton Units 3 & 4

OPG Regulatory and Generation History

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Key Roles of Ontario's Electricity Sector

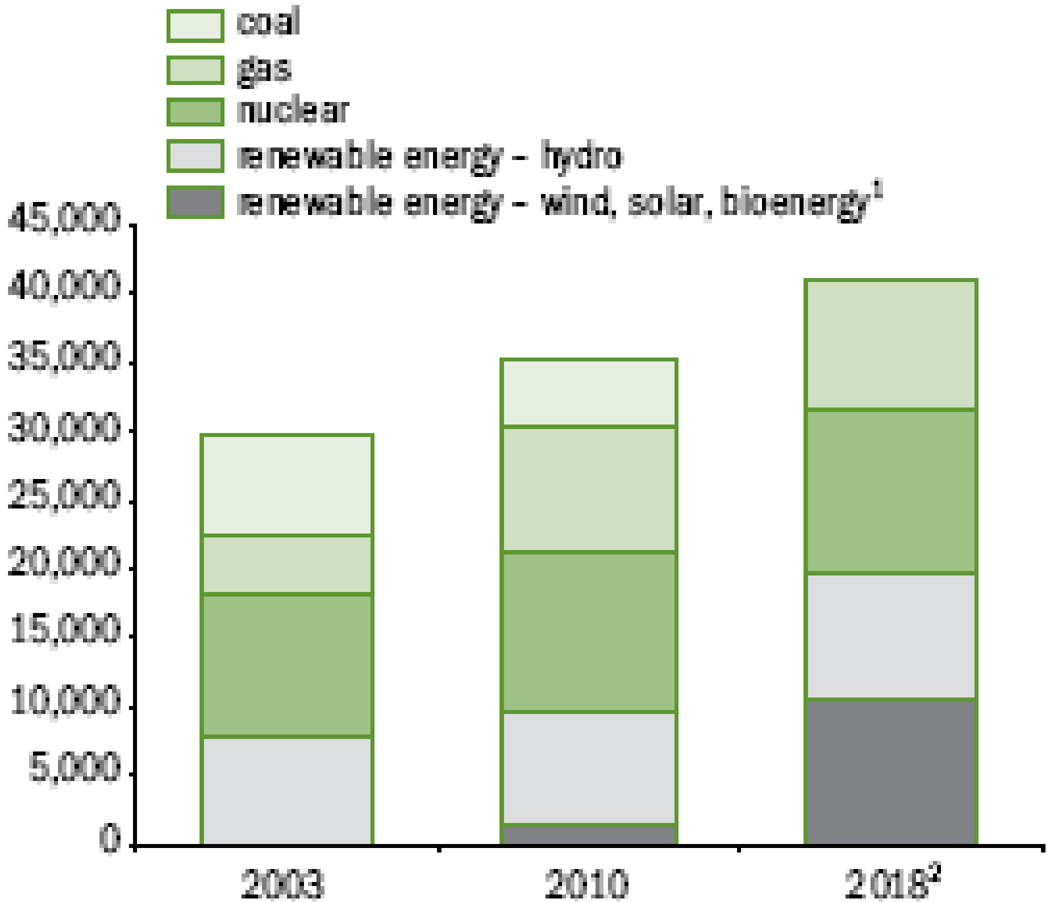
- Ministry of Energy: Sets overall policy and legislative framework
- Ontario Power Authority (OPA): Prepares overall plan and procures power supply
- Ontario Energy Board (OEB): Sets and regulates some electricity prices and performs other regulatory activities

OPG Emissions Reduction Plan History

- Provincial Government 2003 Plan to phase out coal by 2007
  - Goal not achieved due to lack of replacement power
  - Lakeview Generating Station (2400 MW) shutdown in 2005 / Demolished in 2006
- Provincial Government issued new goal to phase out coal by 2008
  - Plan abandoned in 2006 due to lack of replacement power
- In 2007 Ontario Power Authority (OPA) issued 20-year energy plan (based on directive from Minister)
  - 100% phase out of coal by 2014
  - Four units shutdown in 2010 (Lambton U1&2, Nanticoke U3&4)
  - Two additional units shutdown in 2011 (Nanticoke U1&2)
  - Double renewable supply by 2025 (15,700 MW)
- Evaluation of possible conversion from coal to natural gas in 2015
  - For SCR equipped units (Nanticoke U7 & 8 and Lambton U3 & 4)

Figure 1: Installed Capacity of Electricity Supply from Different Energy Sources (MW), 2003–2018

Source of data: Ministry of Energy



1. The expected electricity outputs from wind and solar are much lower than their installed capacity (see Figure 10).

2. Projected.

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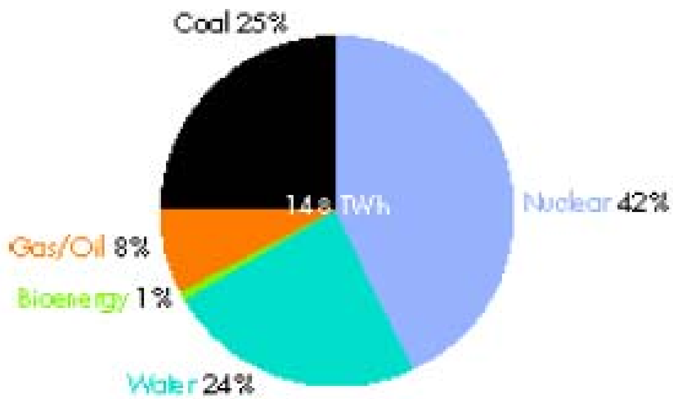
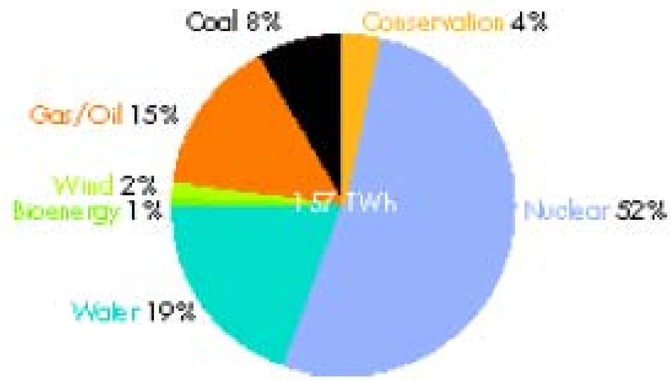
OPG Generation History and Projections: 2003 - 2030

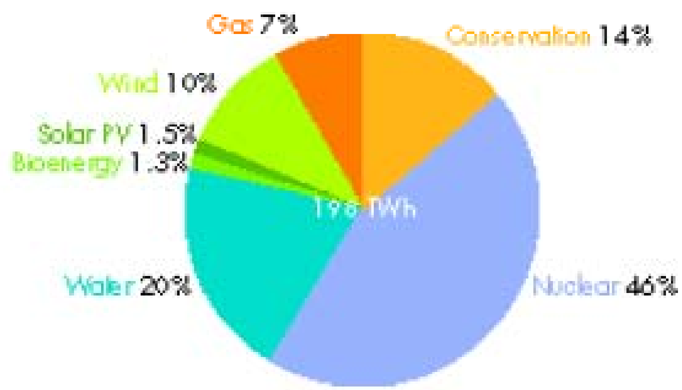
2003 Generation (TWh)



2010 Projected Generation (TWh)



2030 Projected Generation (TWh)



2010 Capacity Factor Summary

Figure 10: Capacity Factors (Expected Output) and Capacity Contributions (Output during Peak Electricity Demand), by Energy Source (%)

Source of data: OPA and IESO

	Capacity Factor	Capacity Contribution
nuclear	84	95–100
coal	66	90–100
hydroelectric	90	71
bioenergy	75–85	65–100
natural gas	85	50–100
solar	13–14	40
wind	28	11

Capacity Factor = Actual MW Output ÷ Maximum MW Output

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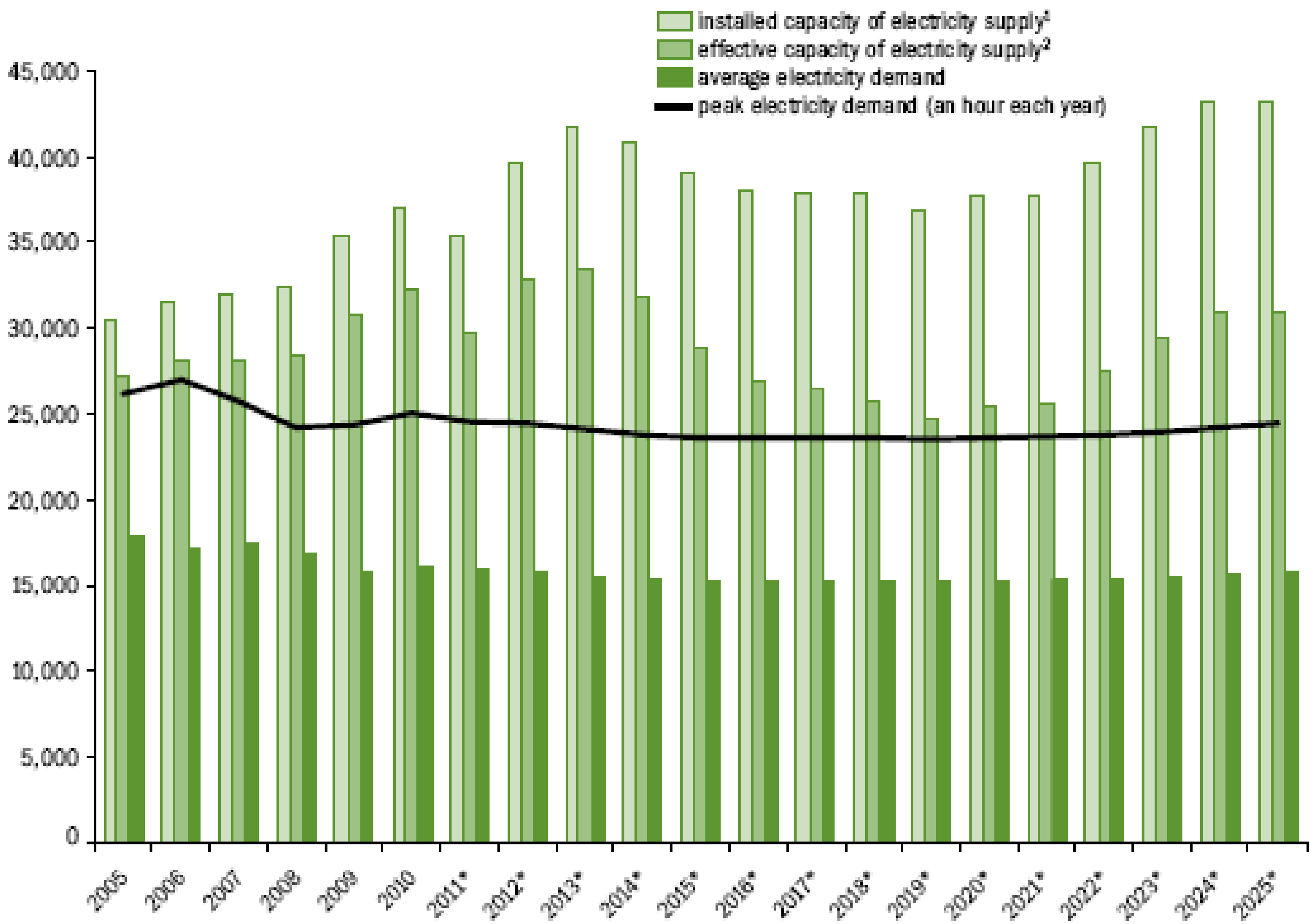
Figure 7: Ontario's Installed and Effective Capacity, and Average and Peak Electricity Demand, 2005–2025 (MW)

Source of data: OPA and IESO



* Projected. Significant uncertainty is expected beyond 2015.

1. Installed capacity is the maximum amount of electricity that can be produced by generators.
2. Effective capacity is the portion of installed capacity that can be depended on to produce electricity.

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SCR and BOP Impacts

- Capital & O&M Expenditures Difficult to Justify
  - SCR Commissioned in 2003 with Pending Shutdown Originally Scheduled for 2007
  - OPG Expenditures Required <5 Year Payback Period
  - Plant Shutdown Date Becomes a Moving Target
- Goal to Limit Expenditures While Maintaining SCR Performance
  - Lowered Boiler NOx and Increased Allowable Slip to Limit Catalyst Expenditures
  - CERAM Performed Cost Analysis Study for New vs. Regenerated Catalyst
    - Both New and Regenerated Used Depending on Station

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Comparable Regulatory Issues in Other Utility Markets (A Look to the Future???)

- United States
  - Unclear Regulatory Policy: CAIR → CATR → CSAPR
  - Decisions to justify capital and O&M projects
  - Drop in natural gas prices
  - Decisions to retire coal fired Units
  - Decisions to add AQC controls or increase performance of existing fleet
- United Kingdom
  - Large coal fired boilers are load following
    - Routine daily shutdown of coal fired units
  - Great incentives to fire renewables (biomass)

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OPG SCR Operating History
(Nanticoke and Lambton Stations)

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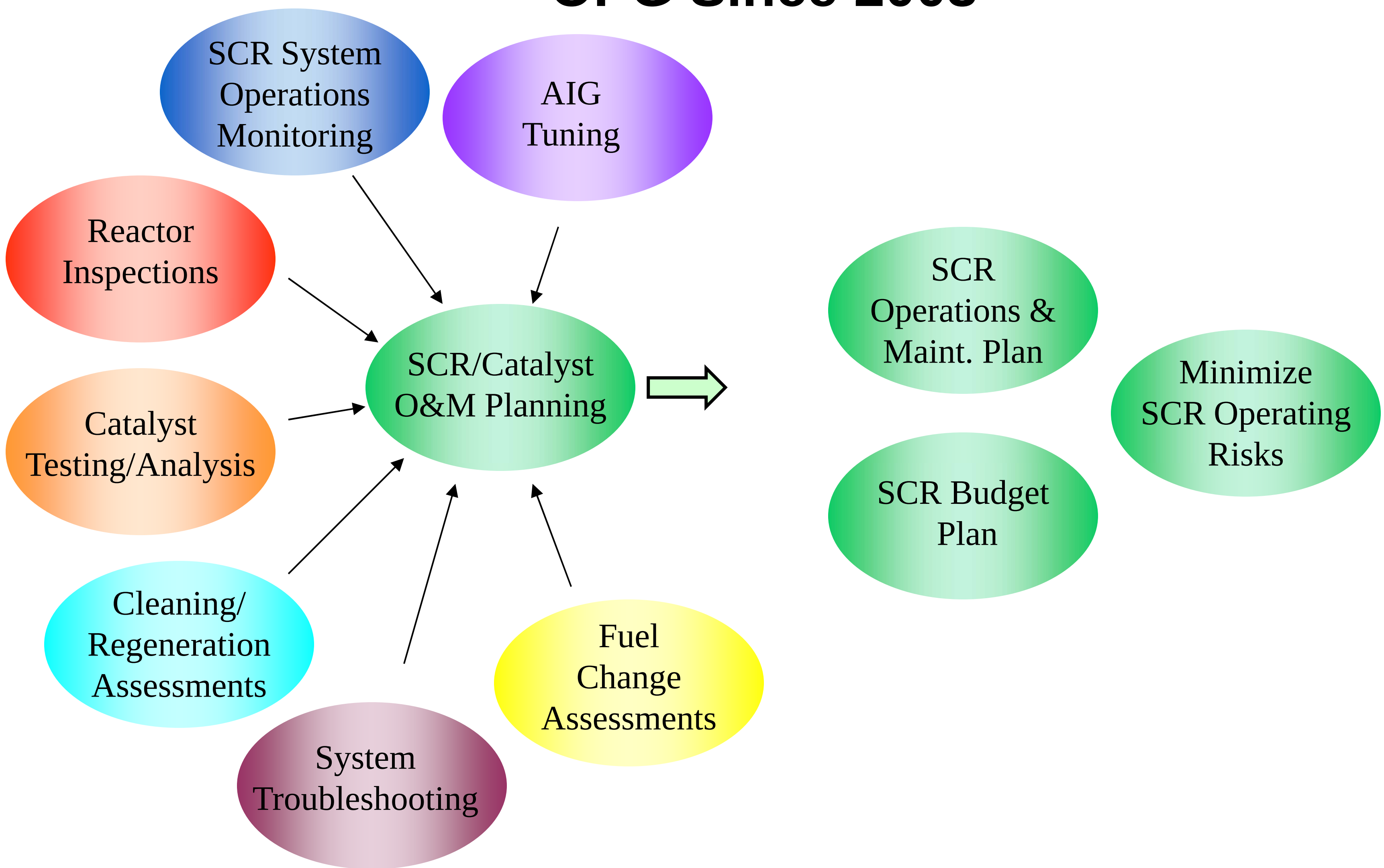
Essential Aspects of Catalyst and SCR System O&M Planning – Performed for OPG Since 2003



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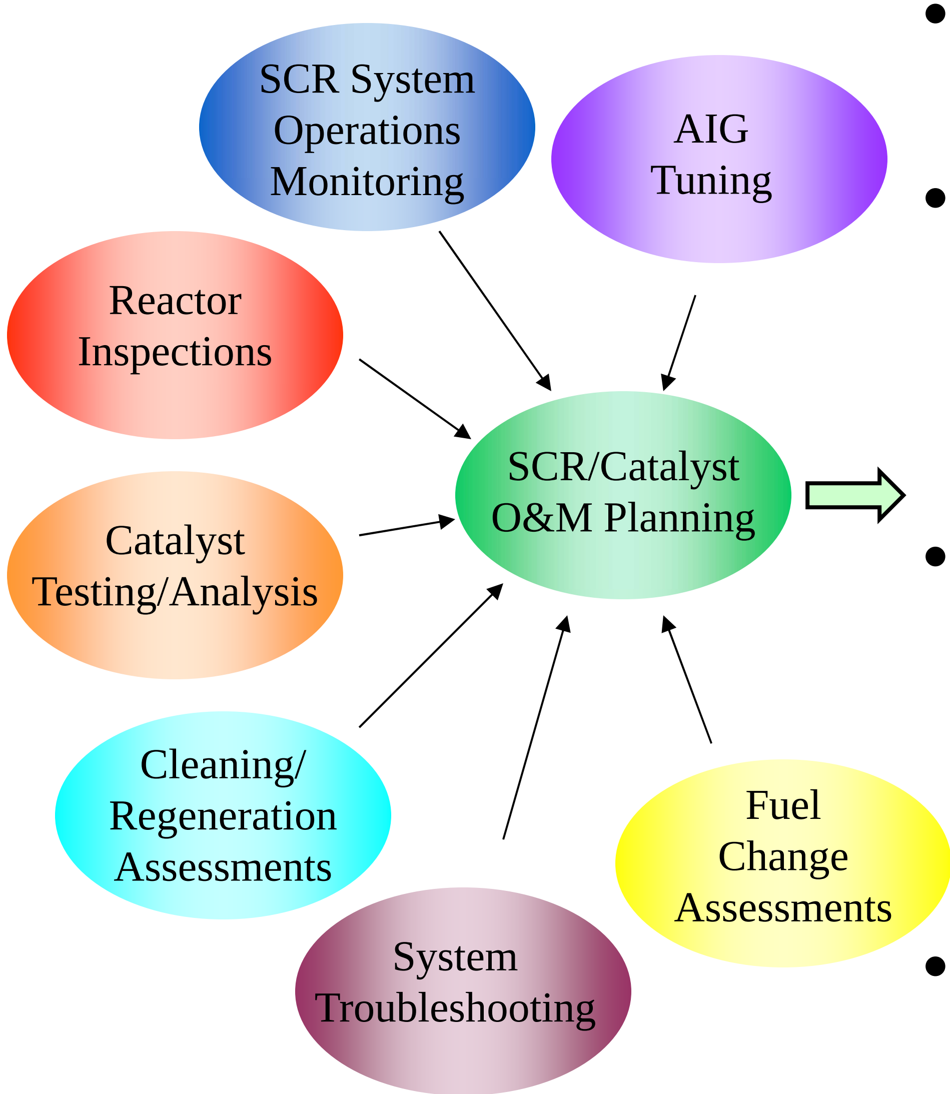
The CATLife® Program Offers All Essential Services



- Supports SCR Operations Planning
  - Annual Assessment of DeNOx Capability
  - Performance Monitoring and Reporting
- Controls SCR Operations Risks
  - Air Heater Pluggage (Ammonia Slip)
  - Fly Ash Contamination (Ammonia Slip)
  - Oxidation Rate Increases (T and Time Dependent)
  - Accommodate Varying Fuel Quality
- Provides Budget Planning Basis
  - Predict Timing of Next Required Catalyst Event (Outage)
  - Assess and Recommend Least Cost (NPV) Catalyst Event Alternative
  - Evaluate Fuel Changes
  - Long Range Planning
- CERAM's Manage CATLife® Model Coordinates All Activities and Results to Assess/Develop Plans

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CERAM's Manage CATLife® Model

Plant and Process Information:

- SCR System Design Information
- Site Specific Catalyst Designs
- Fuel Blend and Analysis
- Flue Gas Conditions
- NOx Removal/SCR Operations Requirements
- Economic Evaluation Parameters
- Preferred Outage Plans

CATLife® Program Services Results:

- Reactor Inspection Results
- Catalyst Test Results
- Deactivation Characterization
- Oxidation Characterization
- AIG Tuning Results
- SCR System Operations Results
- SCR System Controls Characterization

Manage CATLife® Model

Results:

- Existing Reactor Potential and Oxidation Rate Assessment
- Catalyst Addition Predictions
- Deactivation Trend Tracking
- Operations Assessments and Tracking
- Catalyst Management Strategy Evaluations
  - New, Clean, Regenerate, Move?
- SCR Operations Planning
  - NOx Reduction, SO_3 Emissions
- Short and Long Term Budgeting
- Fuel Change Assessments
- Sensitivity Analyses

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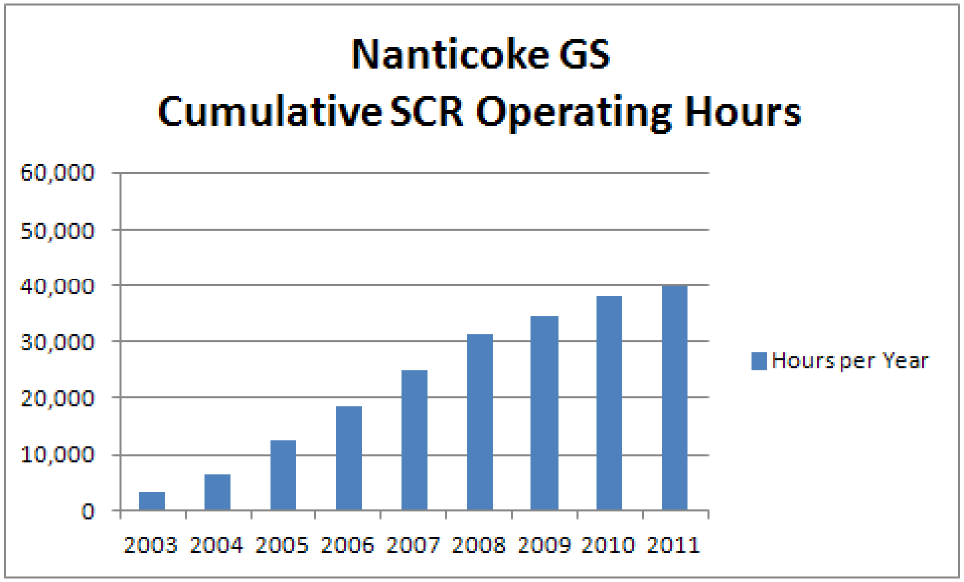
CERAM's 20+ Years of SCR System and Catalyst Know How and Experience is Incorporated Into the Model

Nanticoke Unit 7 & 8 SCR History

- Units commissioned in 1972 – 1978
- SCR Systems commissioned in 2003
  - 85% NOx Reduction
  - 0.08 lb/MBtu NOx outlet
  - 2 ppm ammonia slip
  - Initial catalyst supply – 3 layers Hitachi plate catalyst
- 6,000 to 7,000 SCR operating hours per year through 2008
- Significant reduction in hours per year by 2010



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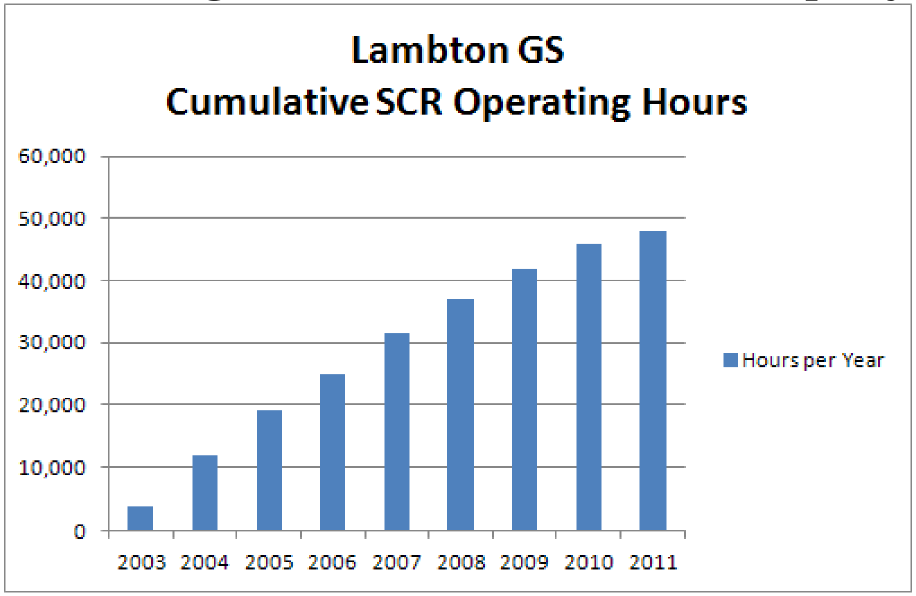
Lambton Unit 3 & 4 SCR History

- Units commissioned in 1969 – 1970
- SCR Systems commissioned in 2003
  - 82% NOx Reduction
  - 0.08 lb/MBtu NOx outlet
  - 2 ppm ammonia slip
  - Initial catalyst supply – 3 layers Hitachi plate catalyst
- 6,000 to 7,000 SCR operating hours per year through 2008
- Significant reduction in hours per year by 2010



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Critical Factors Affecting Catalyst Life

- Catalyst Pluggage Rates
  - Reduces Active Catalyst Surface Area Available
- Catalyst Deactivation Rates
  - Deactivating at Faster or Slower Rate Than Designed
- Operations Different Than Design Basis
  - Flue Gas Temperatures and Flows
  - Higher or Lower Boiler NOx
- Changes in Combustion Practices
  - Lowering Boiler NOx Through Equipment or Combustion Practices
  - Possible Changes in Catalyst Deactivation Rates

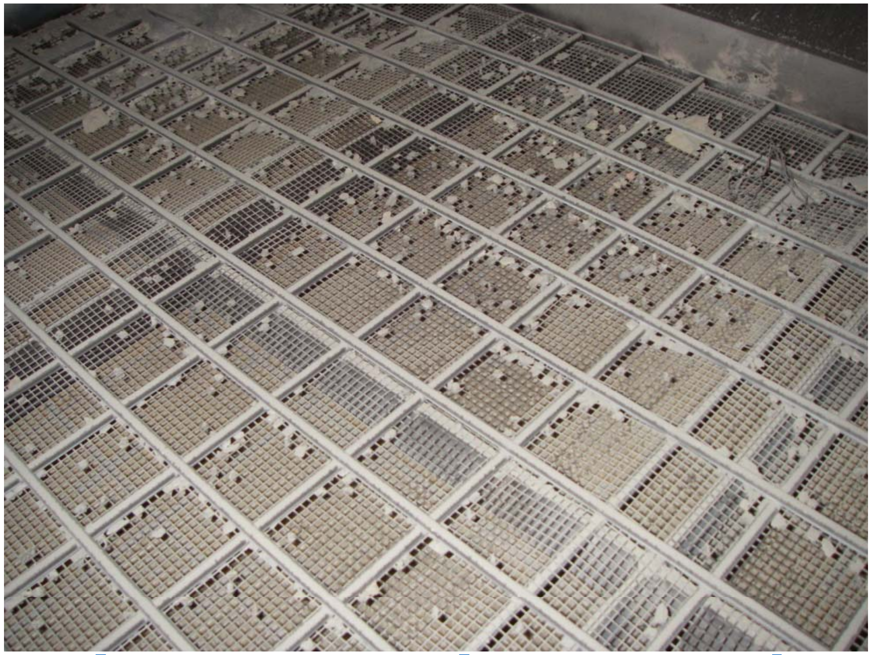
Catalyst Pluggage

- Original Plate Catalyst Design (5.7 mm Pitch) Considered 5% Max Pluggage
  - Average Pluggage Approximately Double Design after 16,000 Hours
- Spare 4th Level Installed Using Honeycomb Catalyst (7.4 – 7.1 mm Pitch)
  - Approximately 40% Pluggage After 16,000 Hours
  - Root Cause: LPA Pluggage of Cover Screen and Internal Catalyst Wall Fissures
  - Both Provide Areas For Fly Ash Accumulation

Plugged 4th Level Honeycomb (By Others)

Catalyst Pluggage

- Some Layers of Plugged Honeycomb Replaced with Regenerated Plate Catalyst / Some Continue to Operate
- Installed CERAM Honeycomb in Top Level
  - 9.2 mm Pitch and Improved Cover Screen Design
  - Pluggage <5% and No LPA Pluggage
  - 4th Level Honeycomb Continues to Plug and Erode



Clean Top Level Honeycomb (CERAM)

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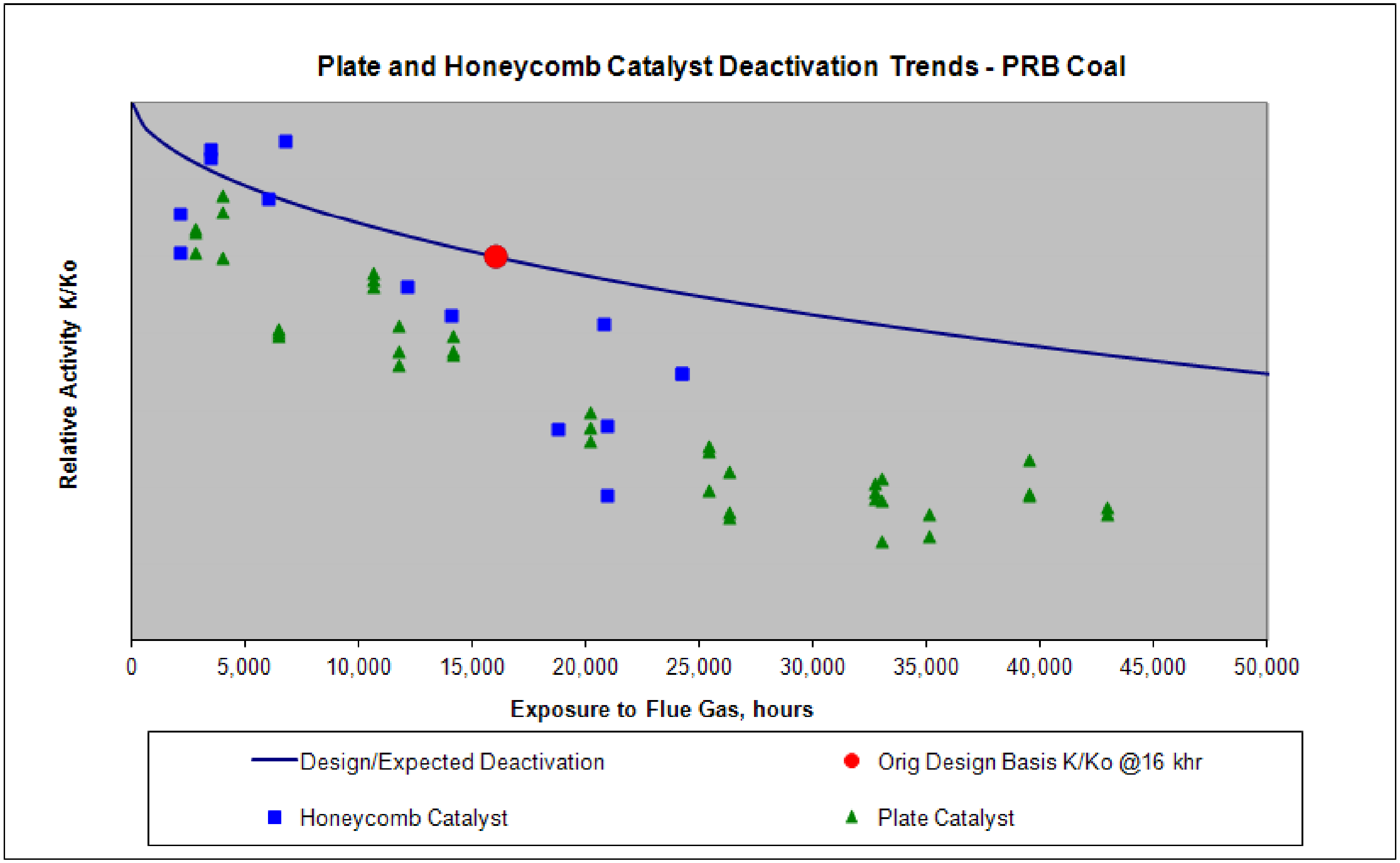
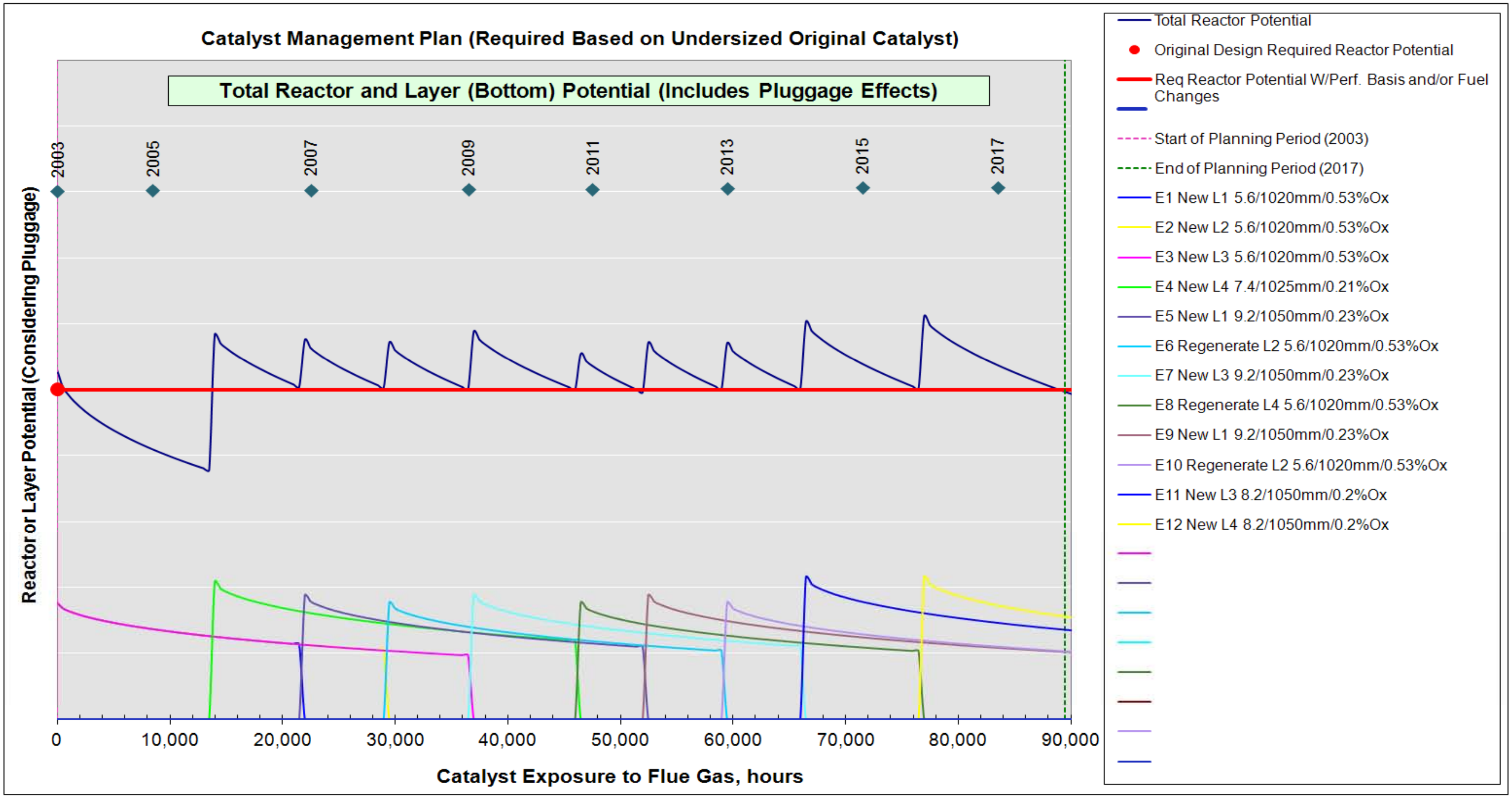
Catalyst Deactivation Trends with PRB Coal



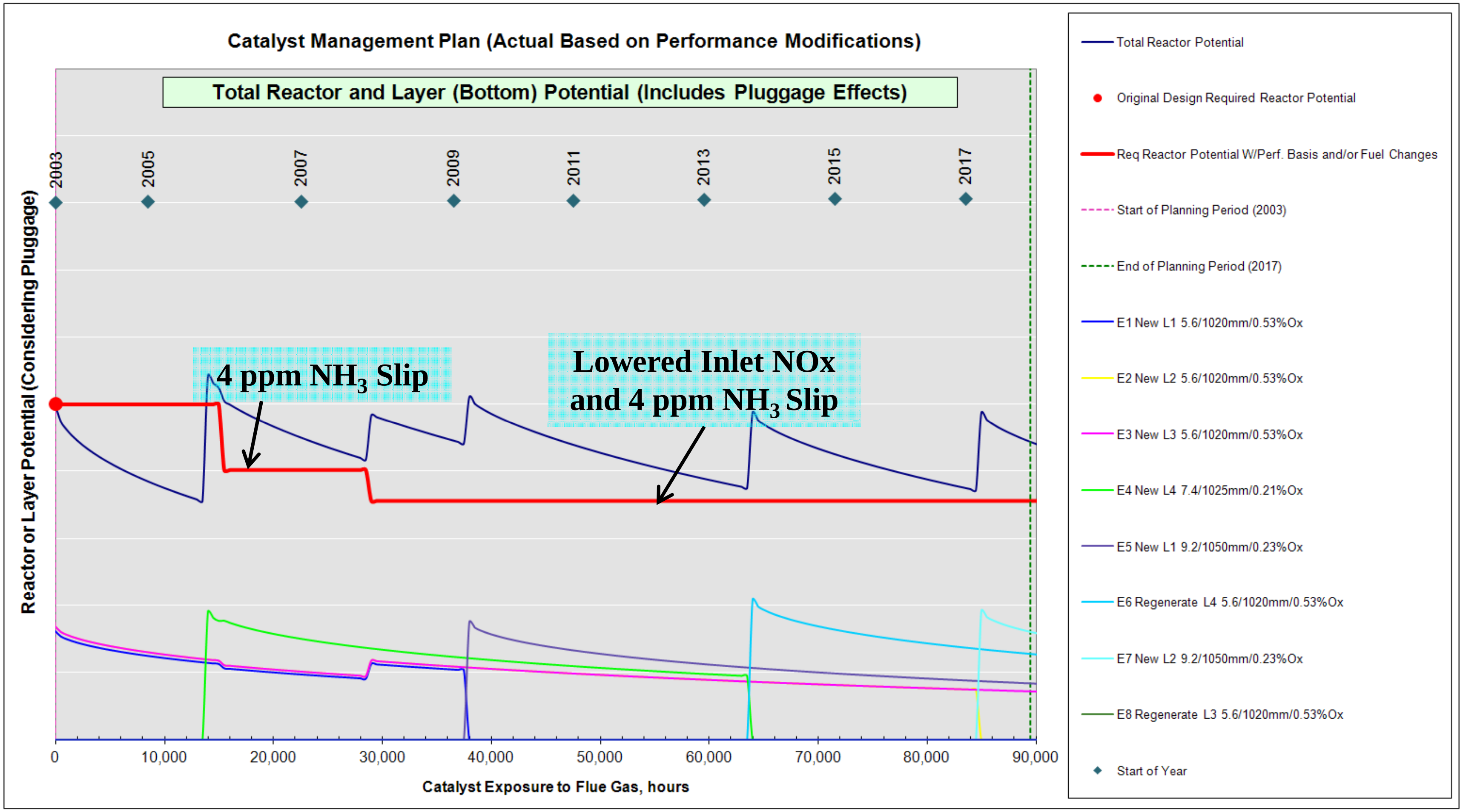
- **Initial Plate Catalyst Design Incorrectly Predicted Deactivation Rate**
- Honeycomb Catalyst Replacements Exhibit Similar Deactivation Rate

Required Catalyst Management Plan for Original Under Sized PRB Catalyst Design



- Under Sized Catalyst Results in 9 Catalyst Events in 15 Years
- New and Regenerated Catalyst Used

Optimized Catalyst Management Plan for PRB Unit



- SCR Operations Compromises (Increased Slip and Reduced Inlet NOx) Required to Achieve Reasonable Catalyst Management Plan
- Four Catalyst Events in 15 Years

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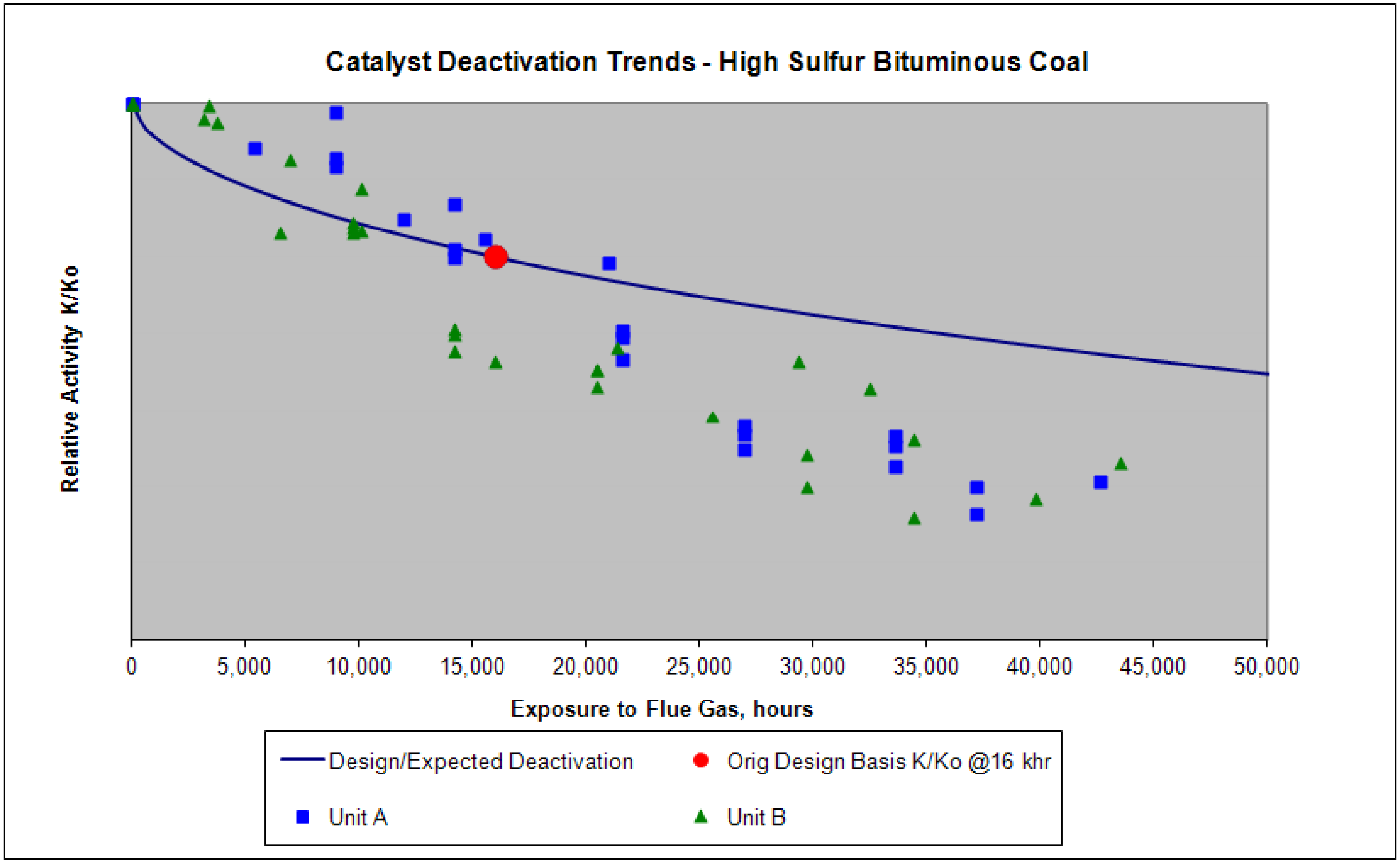
Catalyst Deactivation Trends with Bituminous Coal



- **Initial Plate Catalyst Design Incorrectly Predicted Deactivation Rate**
- Honeycomb and Regenerated Catalyst Replacements Exhibit Similar Deactivation Rate

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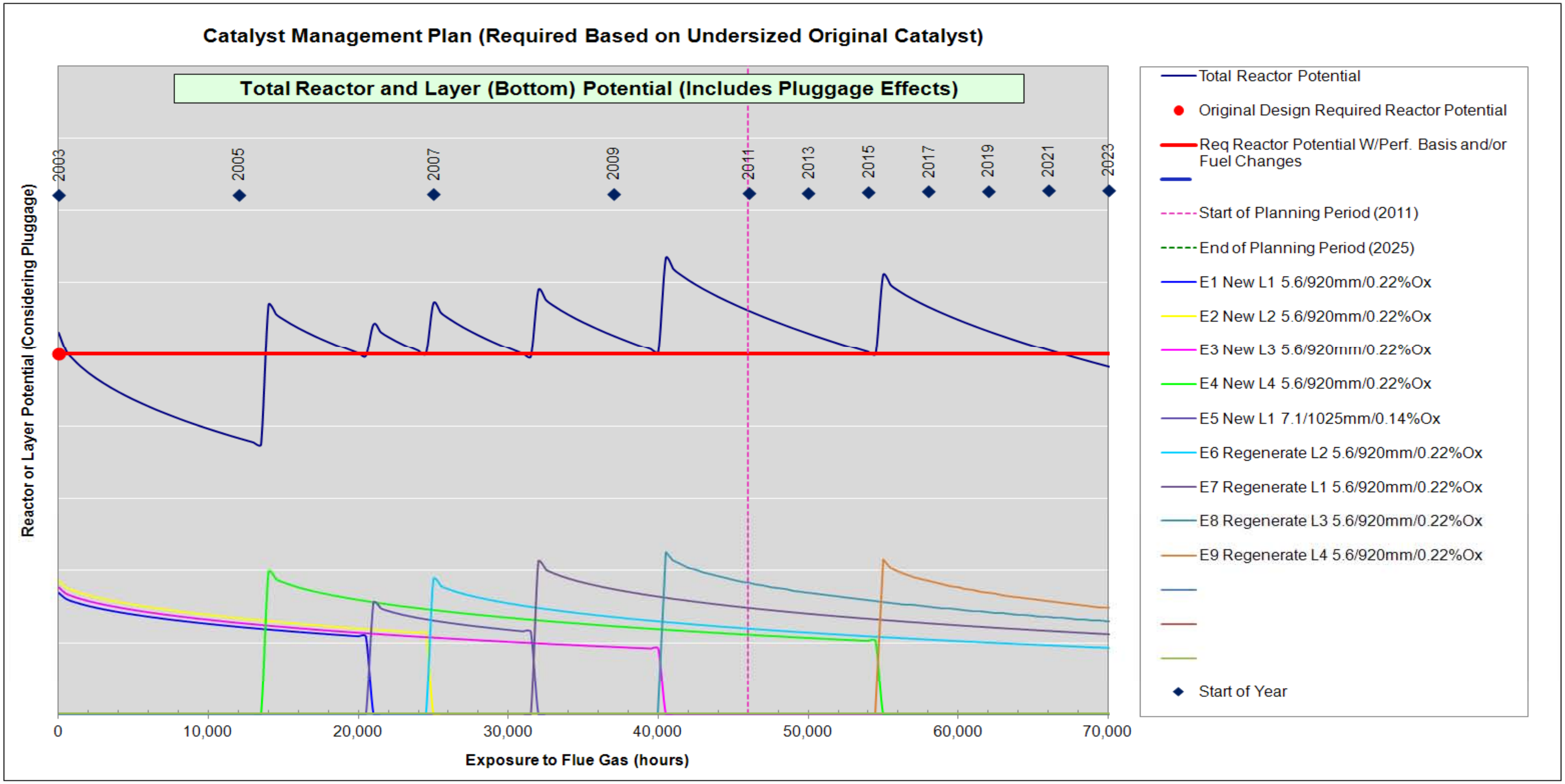
Required Catalyst Management Plan for Original Under Sized Bituminous Catalyst Design



- Under Sized Catalyst Results in 6 Catalyst Events in 15 Years
- New and Regenerated Catalyst Used

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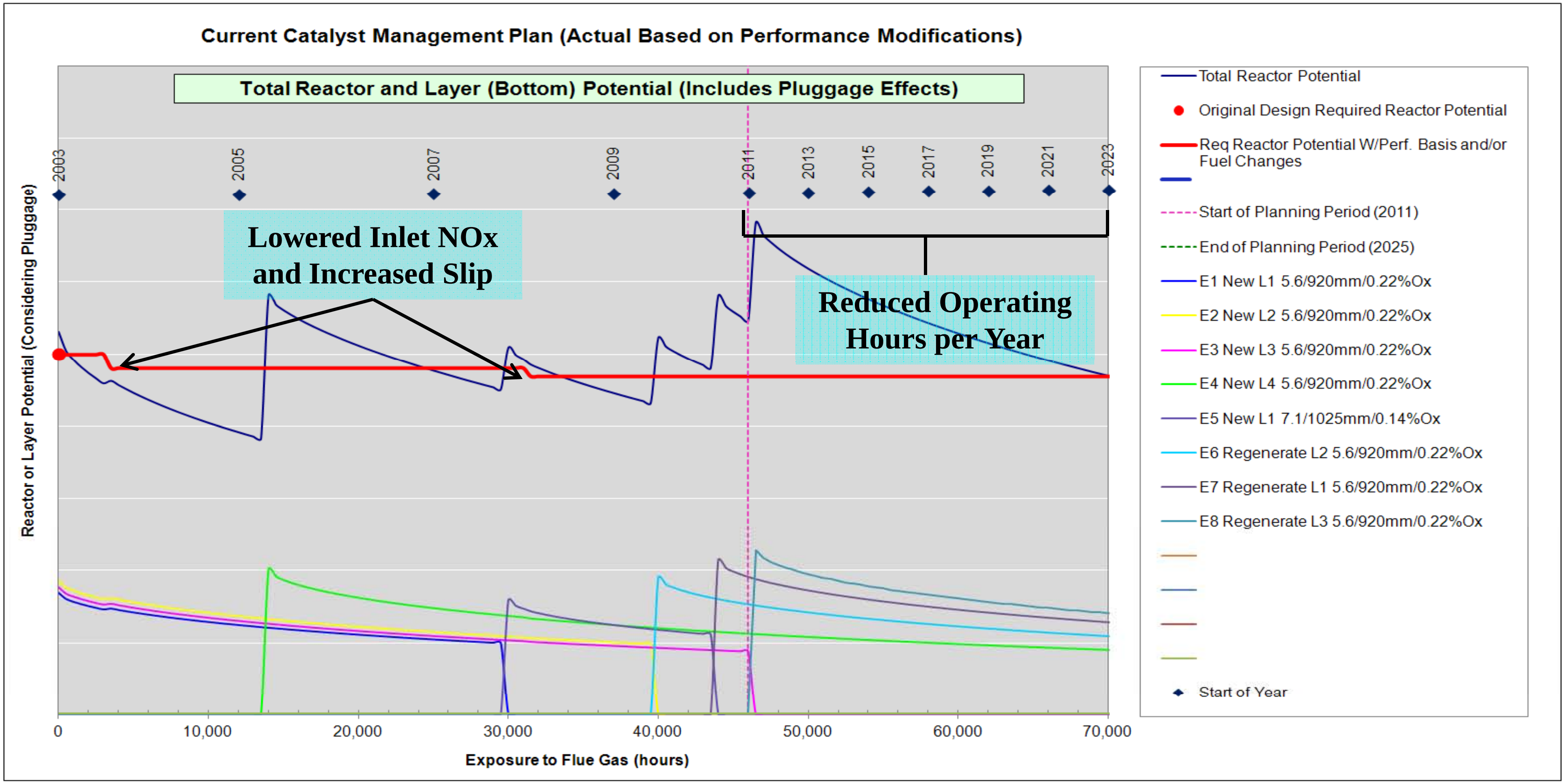
Optimized Catalyst Management Plan for Bituminous Coal Unit



- Optimized Plan Considered Reduced Inlet NOx and Slightly Higher Slip Allowance
- Use of Regenerated Catalyst Replacements
- Five Catalyst Events in 15 Years

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Coal to Natural Gas Conversion

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Coal to Natural Gas Conversion

- Investigation of Coal to Natural Gas Conversion
  - Will Affect SCR Equipped Units at Nanticoke and Lambton
- CERAM Contracted by OPG to Perform Technical and Economic Analysis of Existing SCR Systems
- Analysis Considered:
  - Effects on Catalyst Activity and Deactivation Rate
  - Changes in the SCR DeNOx Demand
  - Unit Capacity Factors and Operating Hours per Year
  - Viability of Using Only Existing Catalyst
  - Viability of Using Regenerated Catalyst or New Natural Gas Formulated Catalyst
  - Economic NPV Analysis

Natural Gas Conversion: Effects on Existing Catalyst

- Catalyst designed for coal relies on SO_2 in the flue gas to promote the DeNOx reaction
- In natural gas flue gas stream without SO_2, the catalyst activity will be reduced (Reduced Reactor Potential)
- This is why natural gas type catalyst generally used more active metals (vanadium)
- Catalyst Tests Performed in CERAM's ISO9001 and VGB certified laboratory in the Bench Scale Reactor

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Catalyst Test Program

- Laboratory testing of both plate and honeycomb catalyst from Nanticoke and Lambton Stations
- Baseline activity testing performed in "as received" condition with SO_2 in flue gas
- Catalyst exposed to SO_2 free flue gas for multiple days to drive off residual SO_2
- Catalyst activity tests performed daily until activity levels out
- Final catalyst activity test performed without SO_2 to determine catalyst activity in natural gas flue gas regime

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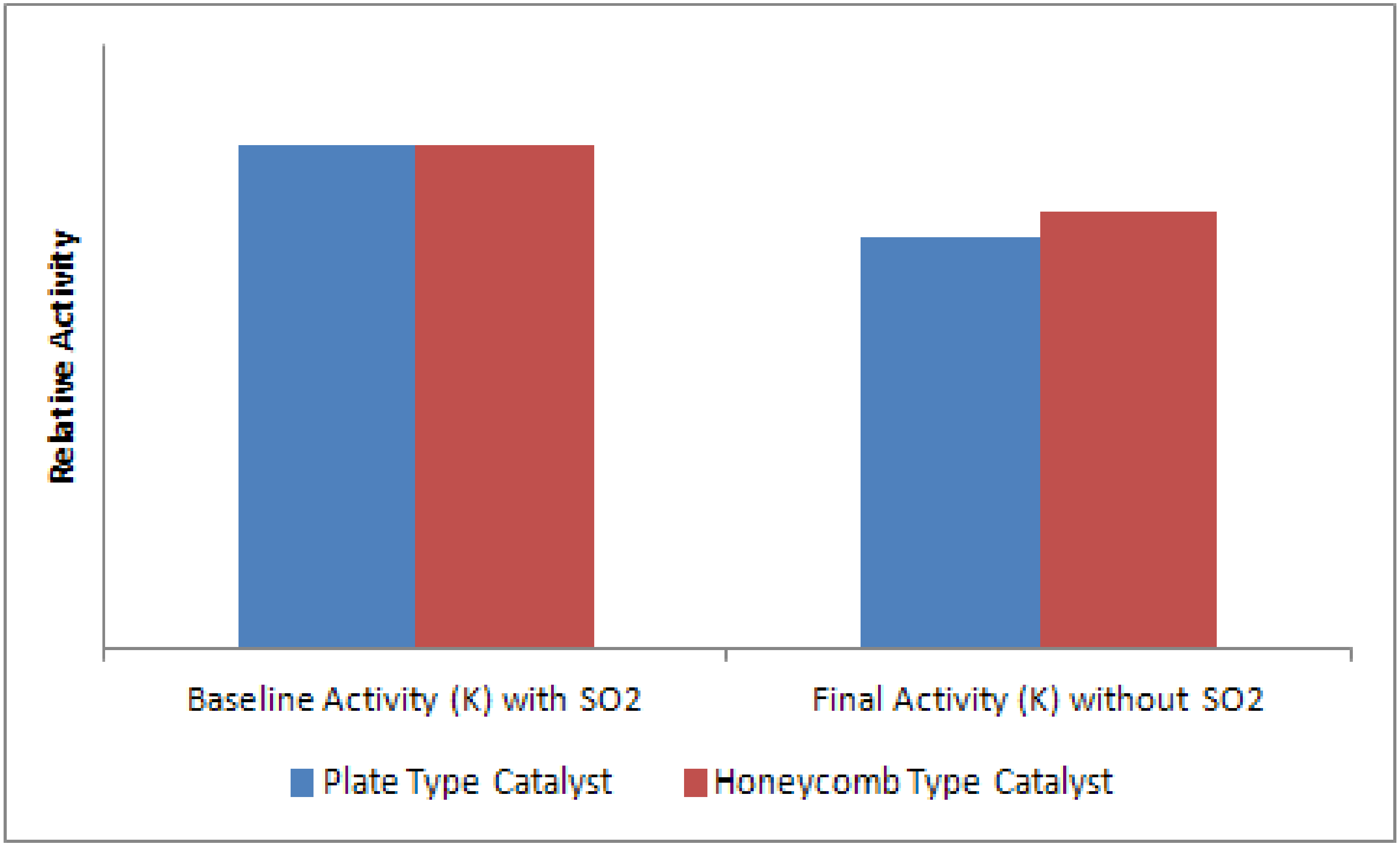
Catalyst Test Results



- DeNOx reactor slows without SO_2 present (Occurs deeper in catalyst pores)
- Plate catalyst had slightly higher activity drop due to less catalytic material thickness

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Reactor Potential

$$P = K/A\nu$$

P = Reactor Potential

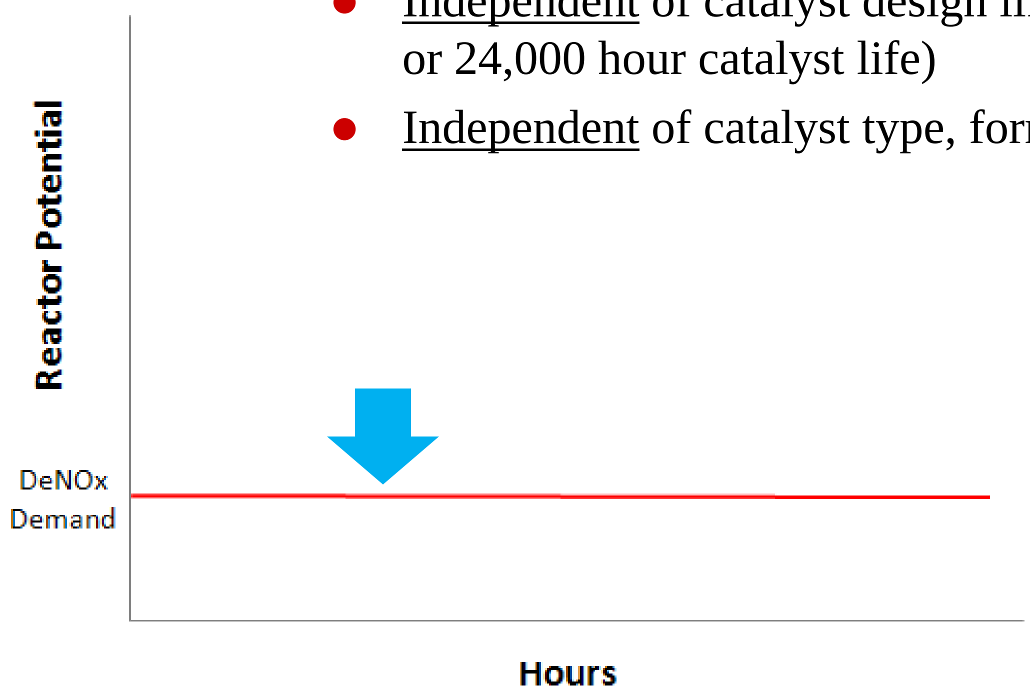
K = Catalyst Activity, Nm^3/m^2h or Nm/h

$A\nu$ = Area Velocity, Nm/h
(normal gas flow, Nm^3/h divided by total installed catalyst surface area, m^2)

The Magnitude of Reactor Potential Determines the Amount of SCR System Performance Possible (DeNOx & Ammonia Slip Control)

DeNOx Demand

- DeNOx Demand (P_{req}) = The reactor potential required to meet NOx removal and ammonia slip requirements
- Calculated based on NO_X removal requirements, NH_3 slip, and SCR reactor pluggage and distributions (velocity, NH_3/NOx, temperature)
- <u>Independent</u> of catalyst design life (i.e. same value for 16,000 or 24,000 hour catalyst life)
- <u>Independent</u> of catalyst type, formulation or manufacturer



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SCR DeNOx Demand Evaluation
Coal vs. Natural Gas

- SCR DeNOx Demand a Function of:
  - Flue Gas Flow and Composition
  - SCR Inlet and Outlet NOx
  - Ammonia Slip Target
- SCR DeNOx Demand is Reduced Significantly When Firing Natural Gas
  - Estimated 60% to 70% Reduction in SCR Inlet NOx
  - Higher Ammonia Slip Allowances (2 – 4 ppm for Coal & 5 ppm or more for Natural Gas)
- Overall 50% to 60% Drop in DeNOx Demand with Natural Gas Compared to Coal

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Economic Factors and Operating Scenarios

Economic Analysis Assumptions	
Parameter	
Base Year for Economic Analysis	2011
New Catalyst Cost (Natural Gas Type)	$(Dependent on plan)/m^3
Catalyst Cleaning Cost	$/m^3
Catalyst Regeneration Cost	$/m^3
Catalyst Removal Cost	$ per Layer
Catalyst Installation Cost	$ per Layer
Catalyst Salvage Value	$ per Catalyst Layer
Catalyst Disposal Cost	$ per Catalyst Layer
Ammonia Cost	$/ton
Fan Energy Cost	$/kWh
Escalation Rate	X%
Present Worth Discount Rate	Y%
Annual Operating Hours / Capacity Factor Options	Hours Per Year = Flue Gas Exposure Capacity Factor = Aux Power & Consumables

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Technical Evaluation Factors

- Tentative plan to operate on natural gas beginning after coal eliminated in 2014
- Goal is to avoid catalyst events for 10 years after conversion
- Primary ammonia slip limit of 5 ppm / Secondary limit of 15 ppm with natural gas
- Looked at Multiple Alternatives:
  - Plan A: "Do Nothing" – Is the existing catalyst acceptable
  - Plan B: Regenerate one or more existing plate catalyst layers
  - Plan C: Replace one layer with new natural gas type catalyst
  - Plan D: Replace all catalyst with one new natural gas type catalyst layer

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Technical Evaluation Factors

- Evaluated Various Plant Operating Scenarios
  - 2,000 – 8,600 Hours per Year
  - Capacity Factor 5 – 30% after Natural Gas Conversion
    - Units will be on Spinning Reserve → Many hours at minimum unit load
- Operating Hours Per Year Primarily Impacts Catalyst Deactivation
  - Example: 20,000 Hrs vs. 86,000 Hrs of Flue Gas Exposure to Catalyst Over 10 Years.
- Capacity Factor Impacts Auxiliary Power and Ammonia Consumption Costs

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2010 Capacity Factor Summary

Figure 10: Capacity Factors (Expected Output) and Capacity Contributions (Output during Peak Electricity Demand), by Energy Source (%)

Source of data: OPA and IESO

	Capacity Factor	Capacity Contribution
nuclear	84	95–100
coal	66	90–100
hydroelectric	90	71
bioenergy	75–85	65–100
natural gas	85	50–100
solar	13–14	40
wind	28	11

Capacity Factor = Actual MW Output ÷ Maximum MW Output

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Evaluation Results

- Low cost option always “Do Nothing” – Use existing catalyst
- “Do Nothing” only possible if ammonia slip allowed to exceed 15 ppm over 10 year operating period
- Low cost option to assure 5 ppm slip for a 10 year operating period
  - Station A: Replace existing plugged 4th level with new natural gas formulated catalyst (Plan C)
  - Station B: Replace existing 4th level with regenerated plate catalyst (Plan B)
  - Results in no additional catalyst events required in 10 years

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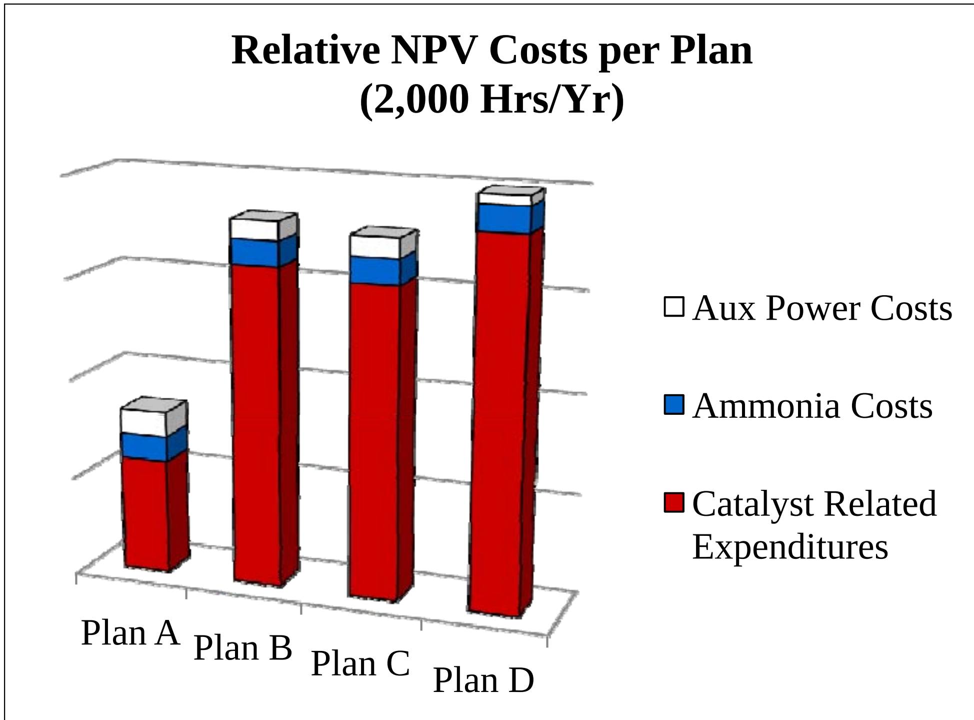

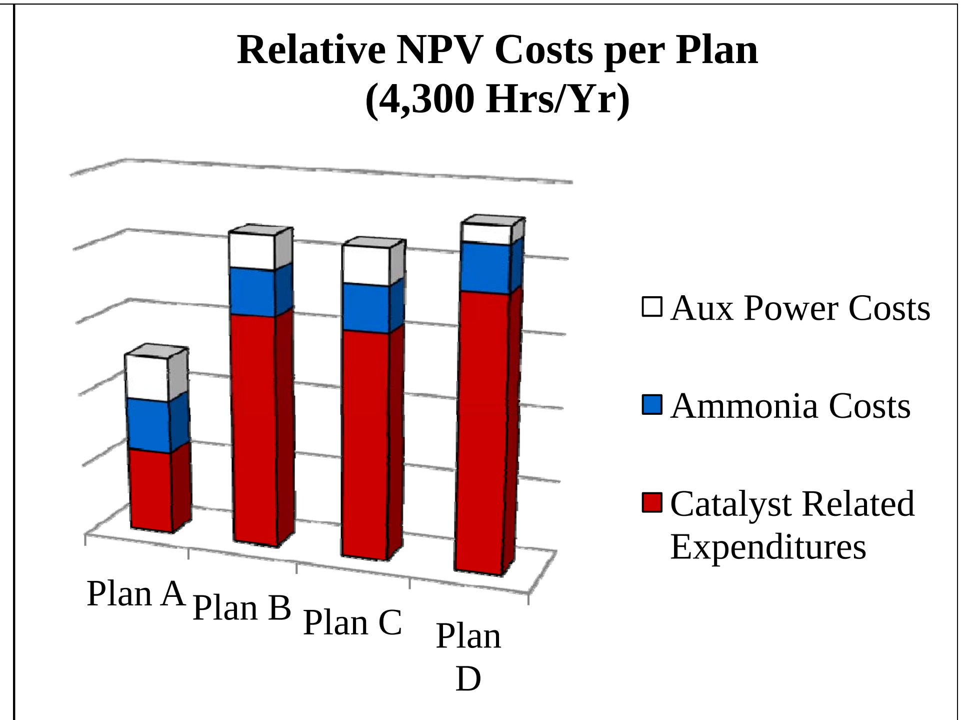

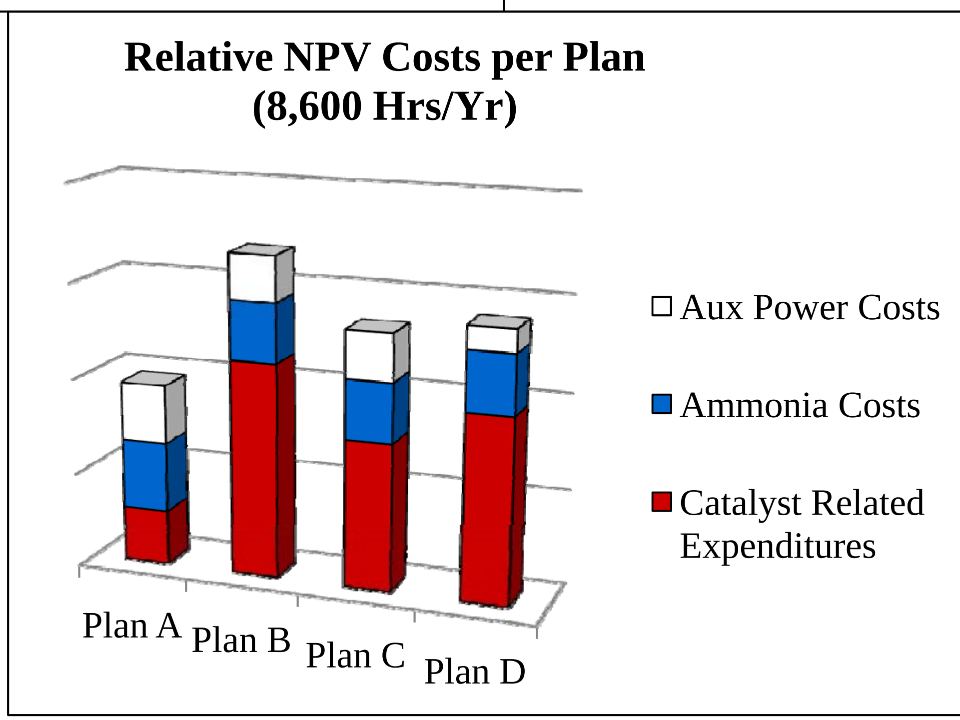

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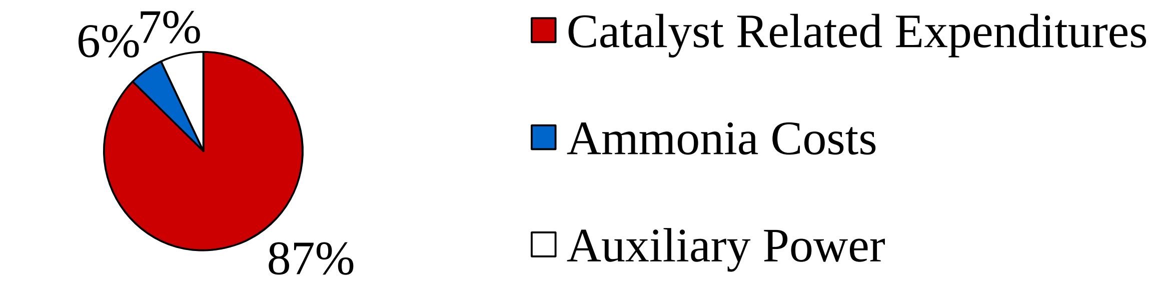
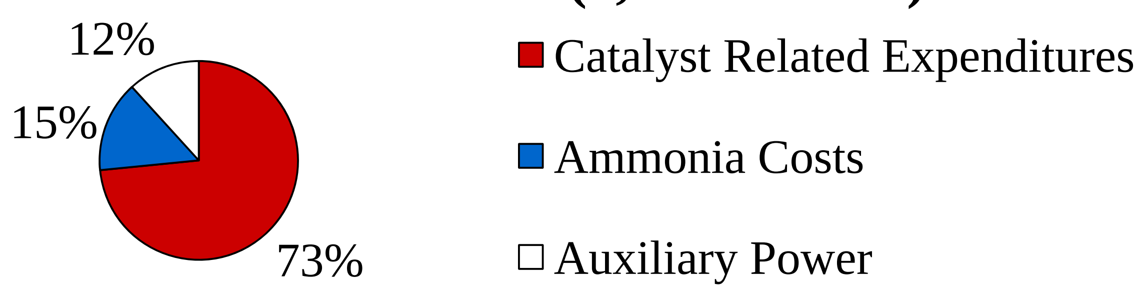
Station A NPV Economic Evaluation Cost Breakdown

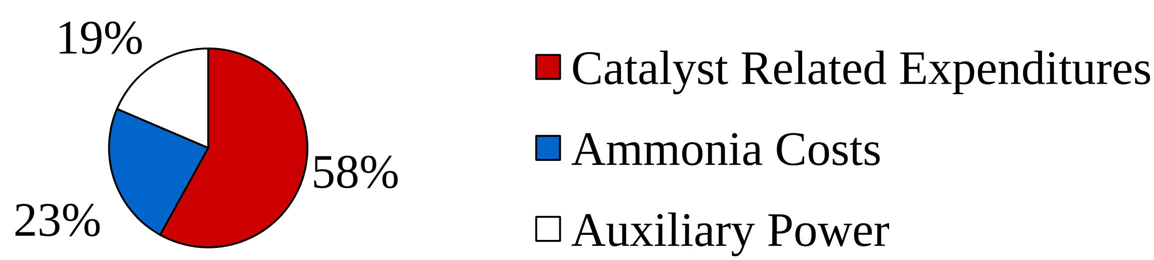
"Plan C" NPV Cost Factors (2,000 Hrs/Yr)



"Plan C" NPV Cost Factors (4,300 Hrs/Yr)



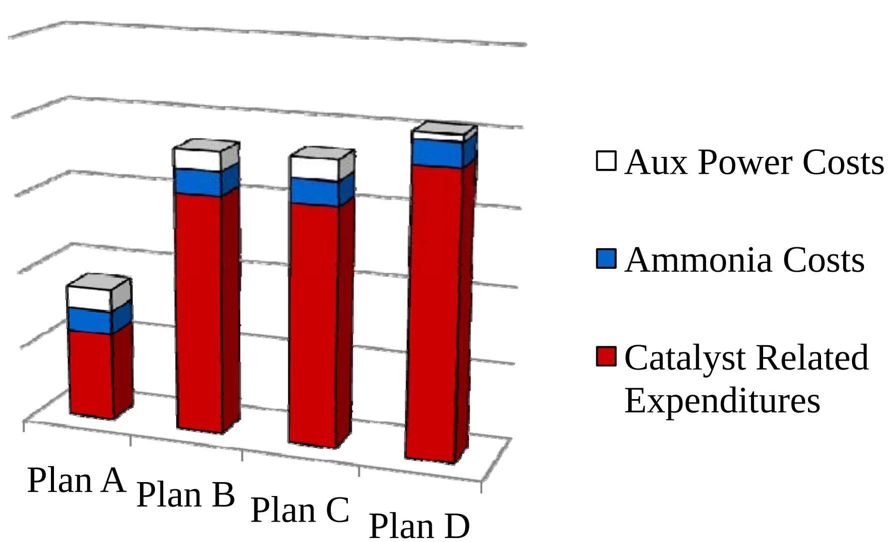
"Plan C" NPV Cost Factors (8,600 Hrs/Yr)



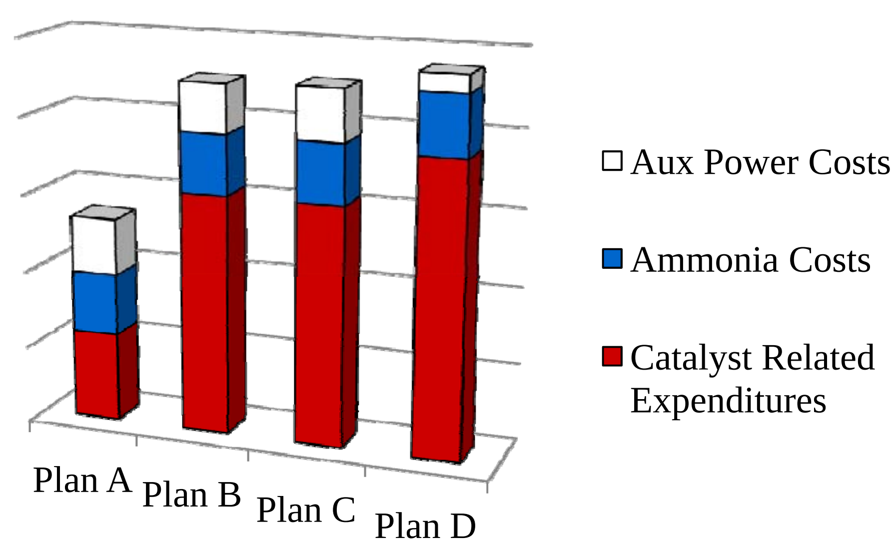
***Catalyst Related Expenditures Include In/Out Costs, Salvage, and Disposal**

***Aux Power & NH3 Costs More Relevant with Increased Operating Hrs**

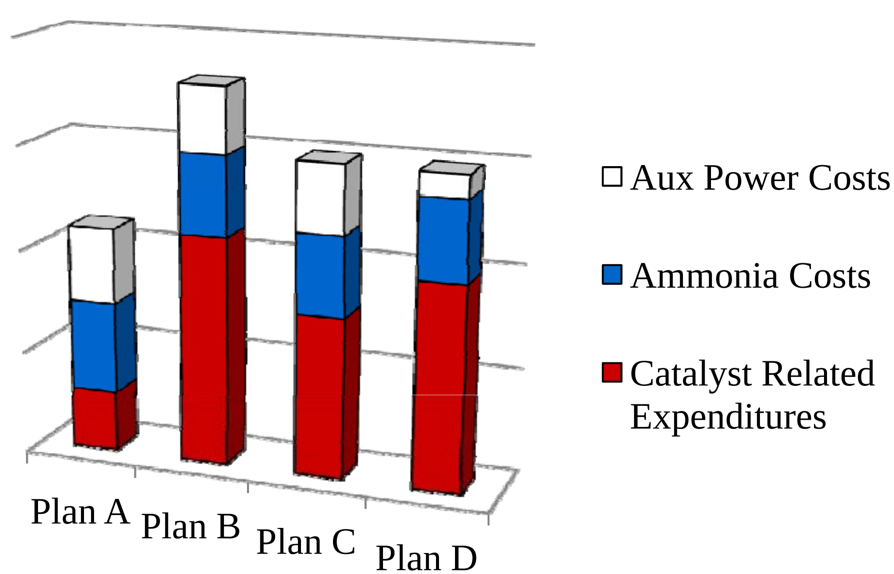
Relative NPV Costs per Plan
(2,000 Hrs/Yr)



Relative NPV Costs per Plan
(4,300 Hrs/Yr)



Relative NPV Costs per Plan
(8,600 Hrs/Yr)



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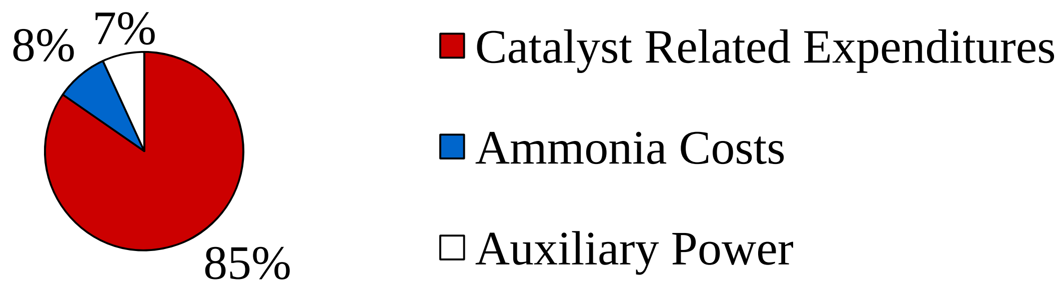
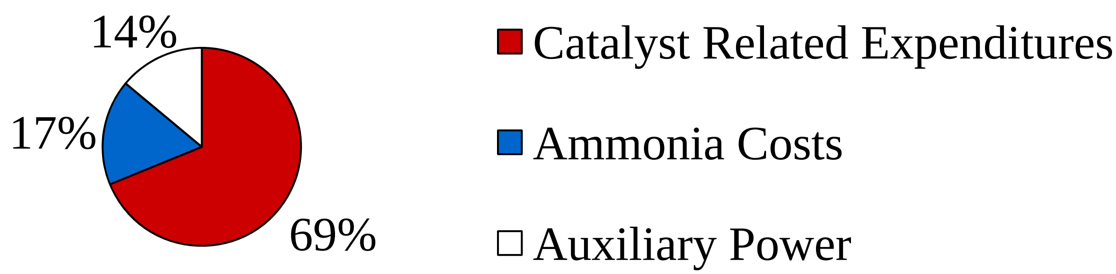
Station B NPV Economic Evaluation Cost Breakdown

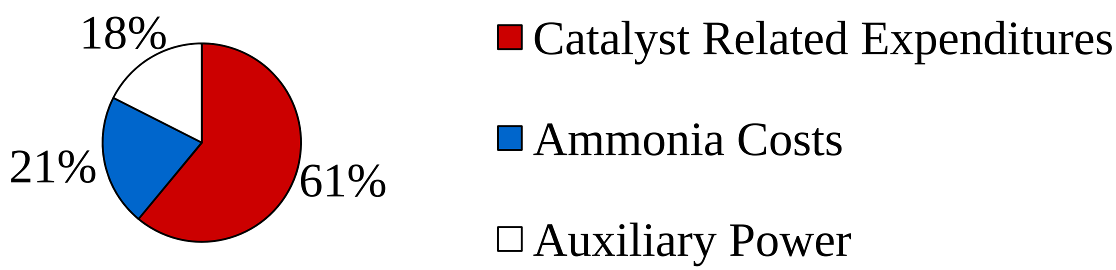
"Plan B" NPV Cost Factors (2,000 Hrs/Yr)



"Plan B" NPV Cost Factors (4,300 Hrs/Yr)



"Plan B" NPV Cost Factors (8,600 Hrs/Yr)



***Catalyst Related Expenditures Include In/Out Costs, Salvage, and Disposal**

***Aux Power & NH3 Costs More Relevant with Increased Operating Hrs**

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Risk Factors

- Lowest Cost Option (Plan A "Do Nothing") is Also the Highest Risk Option
  - SCR Operating Experience with Coal to Natural Gas Conversion Non-Existent
  - Accuracy of Catalyst Test Program at Heart of Analysis
  - No Experience Regenerating Existing Plate Catalyst for Natural Gas Application
  - Sensitivity Analysis Must be Performed
- Mechanical Condition of the Severely Plugged Catalyst
  - High Pluggage Rates and Catalyst Erosion
  - Can This Layer Be Counted on Long Term?

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Risk Factors

- Relying on Regeneration is Moderate Risk (Plan B)
  - OPG Has Plate Catalyst Available for Regeneration
  - Limited Regeneration Experience with Plate Catalyst for Natural Gas Application
  - Availability of "Used" Vertical Flow Natural Gas Type Catalyst
- Lowest Risk Option: Add Natural Gas Specific Formulated Catalyst (Plans C or D)
  - Large Experience Base with Natural Gas Applications
  - Lower Risk, but Higher Costs

Conclusions

- Reducing Long Term SCR Operating Costs Requires Comprehensive Catalyst Management Plan
- Drivers for OPG Coal to Natural Gas Conversion
  - Politics & Reduction in Greenhouse Gases
  - Reduced Demand with Economic Downturn
  - Lower Natural Gas Prices Currently
  - Increased Hydro & Alternative Generation
- Catalyst Test Program Required to Determine Effect on Existing Catalyst
  - Even with 4 Installed Layers, Existing SCR Catalyst May Not be Suitable Due to Lack of SO_2 in Natural Gas Flue
- Economic Analysis Must Consider NH_3, Aux Power, and Catalyst In/Out and Salvage/Disposal Costs
- Must Balance Cost with Risk Factors for Each Alternative

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http://www.auditor.on.ca/en/reports_energy_en.htm

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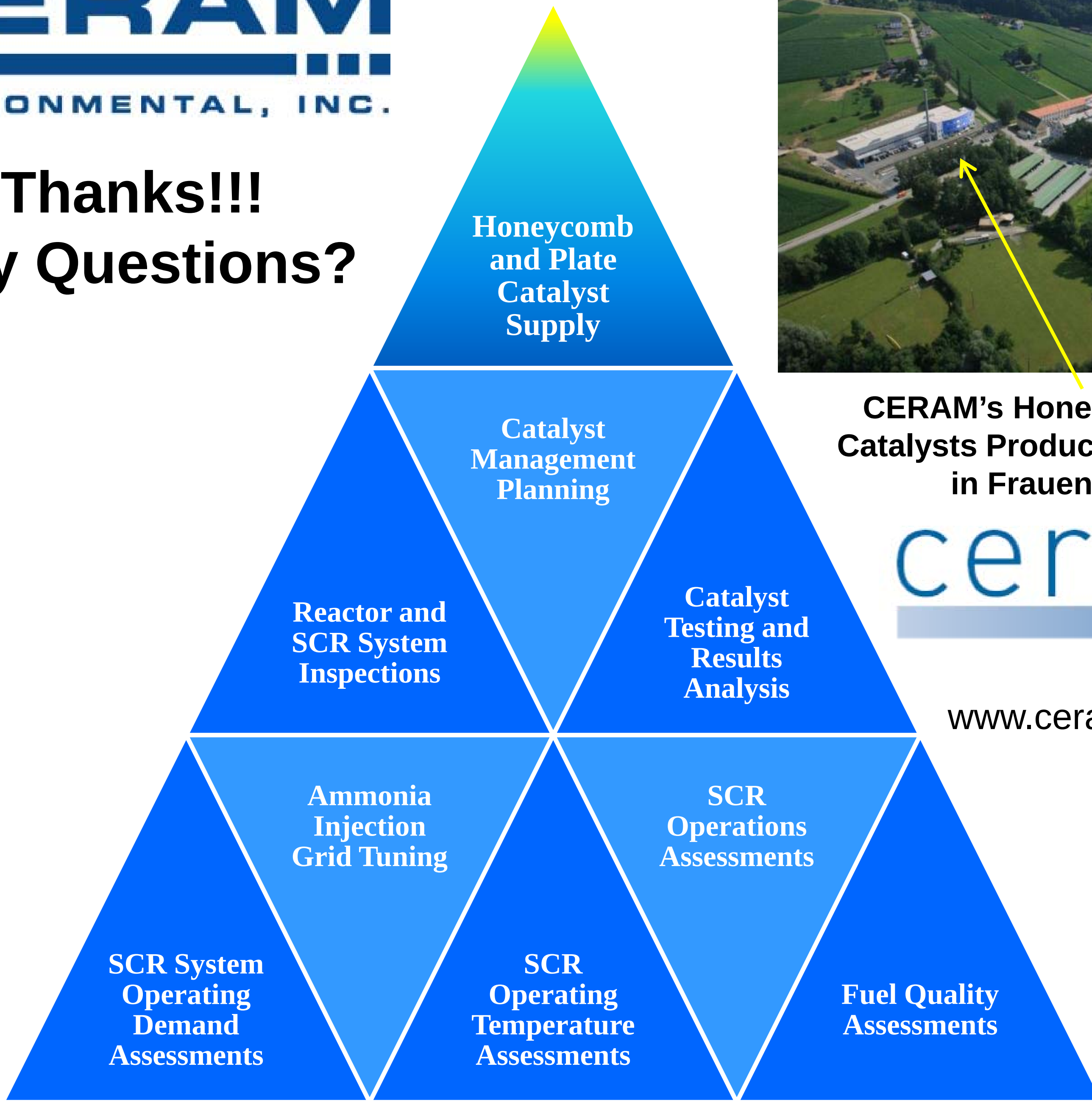
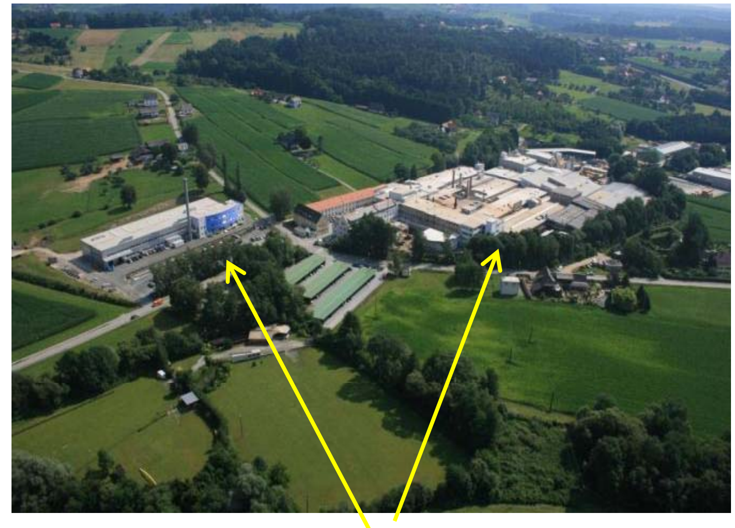
Thanks!!!
Any Questions?





CERAM's Honeycomb and Plate Catalysts Production Plant Located in Frauental, Austria

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