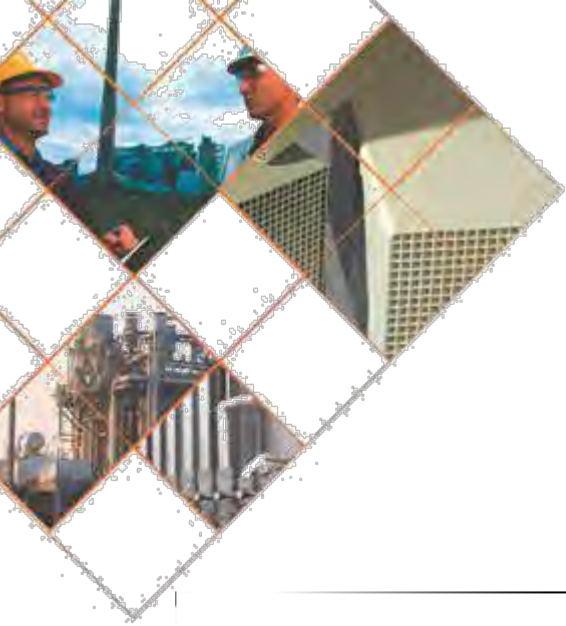
REINHOLD ENVIRONMENTAL Ltd.

2014 NOx-Combustion Round Table & Expo Presentations

February 10 & 11, 2014, in Charlotte, NC / Hosted by Duke Energy



Latest Developments in SCR Catalyst Mercury Oxidation

Christopher Bertole

Cormetech, Inc.

2014 Reinhold NOx-Combustion Round Table

Presentation Overview

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- **Background**
  - SCR Co-Benefits for Hg Removal
  - General Plant Hg Control Strategy
- **COMET™ (<u>C</u>ormetech <u>O</u>xidized <u>M</u>ercury <u>E</u>missions <u>T</u>echnology)**
  - COMET™ Introduction
  - Key Differences between Hg and NOx Control
  - Catalyst Management and Case Study 1
  - Characterization, Modeling, Advanced Hg Ox Catalyst
  - Catalyst Management and Case Study 2
- **Summary**

SCR Co-Benefits for Hg Removal

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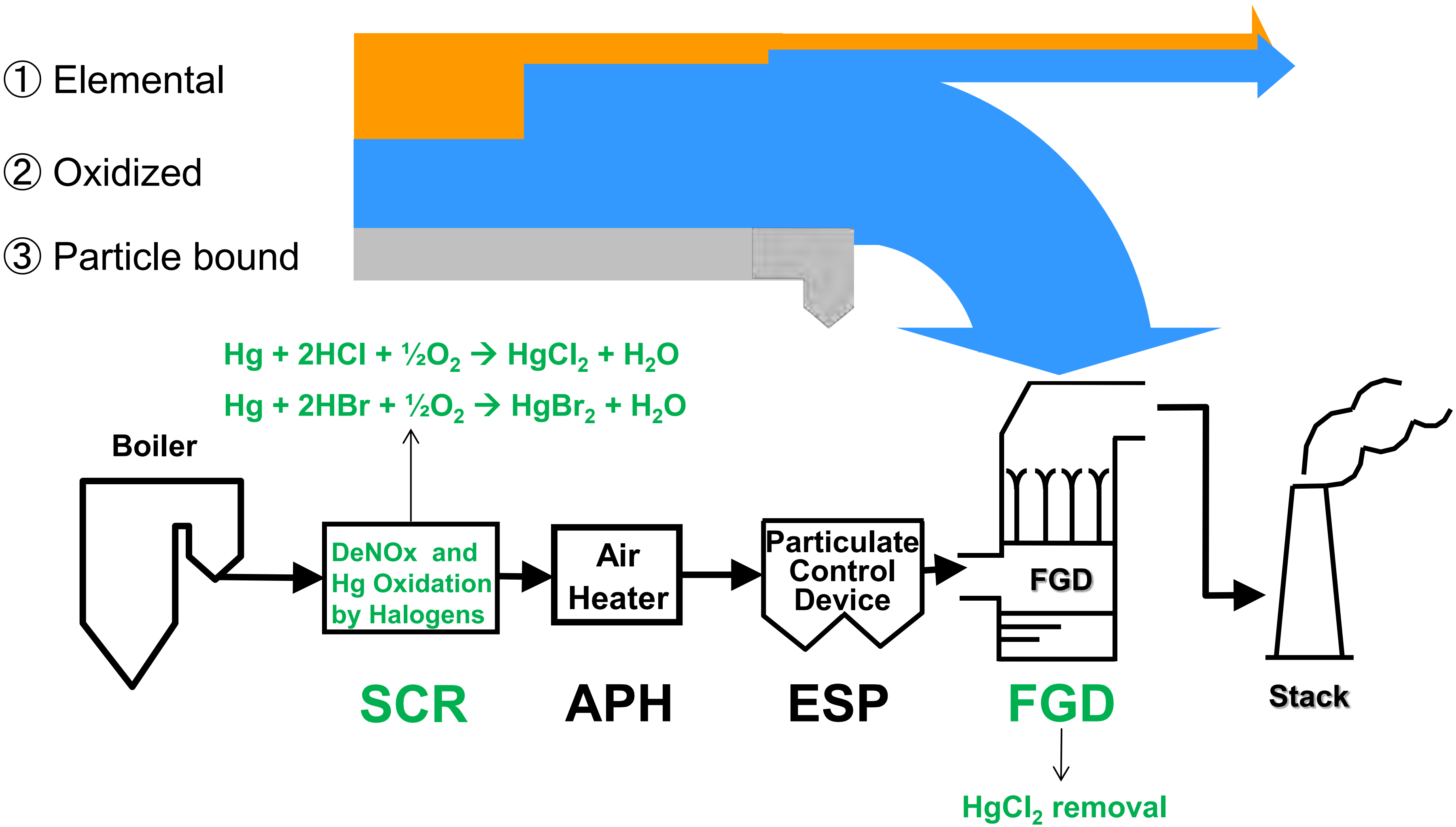


General Plant Hg Control Strategy

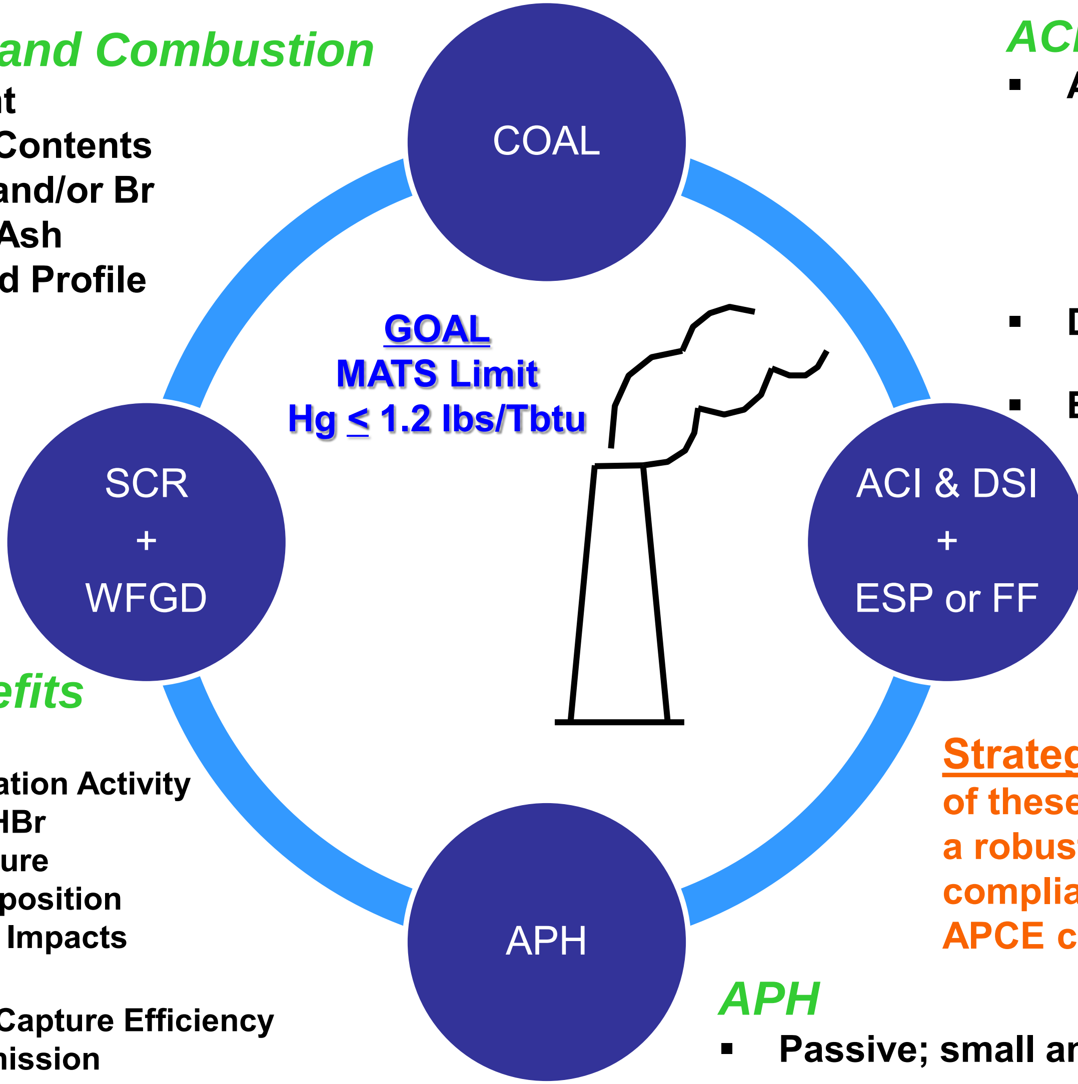
Site Specific. Includes All or Some Components.

Coal Type and Combustion

- **Hg Content**
- **Cl and Br Contents**
- **Added Cl and/or Br**
- **LOI in Fly Ash**
- **Boiler Load Profile**

ACI & DSI + ESP or FF

- **ACI:**
  - **Hg Capacity**
  - **Temperature**
  - **SO_3 Concentration**
  - **HCl and HBr**
  - **Sorbent Injection Rate**
- **DSI:**
  - **SO_3 Mitigation**
- **ESP or FF:**
  - **ACI, DSI Capture**
  - **Ash Capture (Hg on LOI)**



SCR Co-Benefits

- **SCR:**
  - **Hg^0 Oxidation Activity**
  - **HCl and HBr**
  - **Temperature**
  - **Gas Composition**
  - **Seasonal Impacts**
- **WFGD:**
  - **Hg^{2+} Net Capture Efficiency**
  - **Hg^0 Reemission**

Strategy: Utilize all or some of these components to deliver a robust control plan for MATS compliance. Currently installed APCE can influence selection.

APH

- **Passive; small amount of Hg Oxidation**

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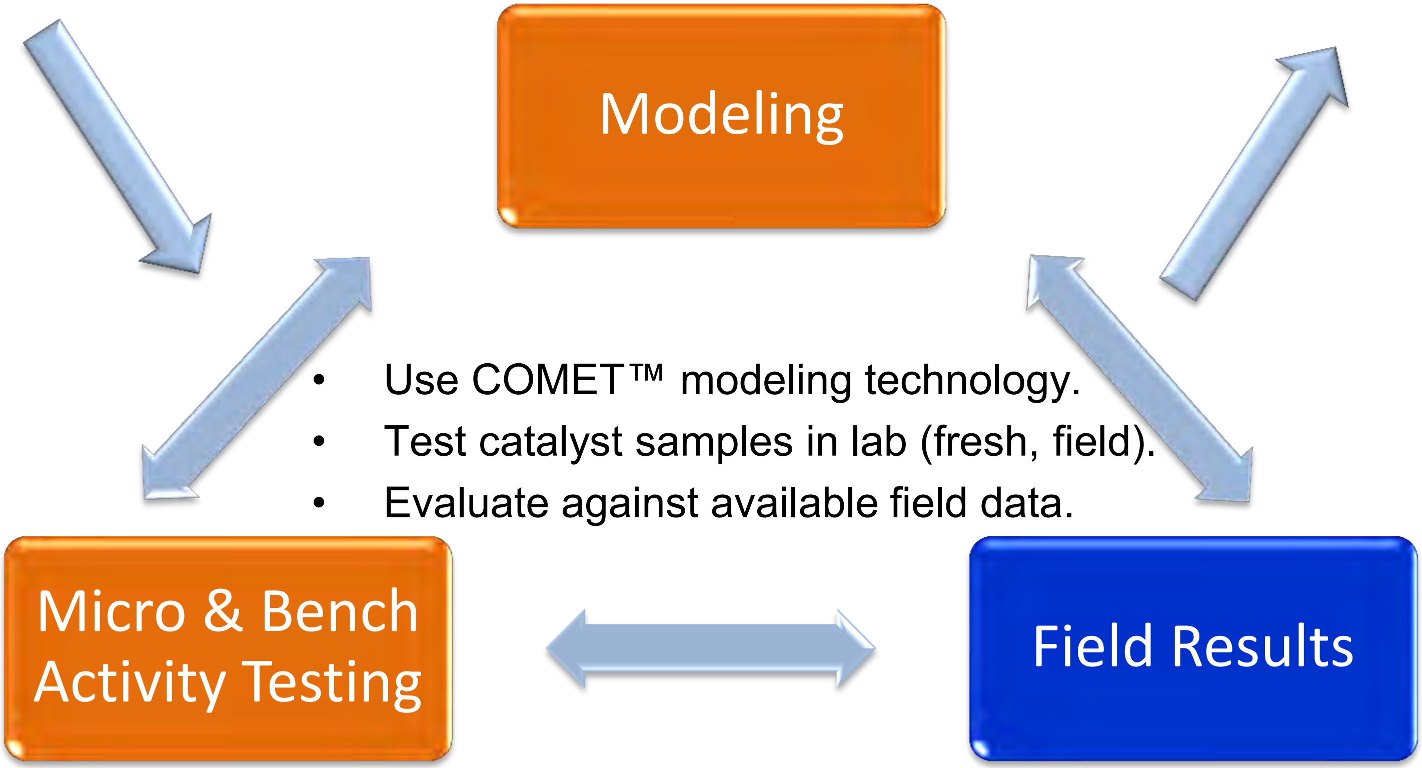
COMET™

An Integrated Approach to Solutions

CORMETECH

- Understand needs & options.
- Define SCR Hg oxidation requirement.

- Evaluate multiple scenarios.
- Develop management plans.
- Select catalyst type:
  - Standard, or
  - COMET™ Advanced Hg Ox Catalyst
- Set SCR performance guarantees.



- Use COMET™ modeling technology.
- Test catalyst samples in lab (fresh, field).
- Evaluate against available field data.

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Key Differences for Hg vs. NOx

SCR is One Component of Overall System for Hg

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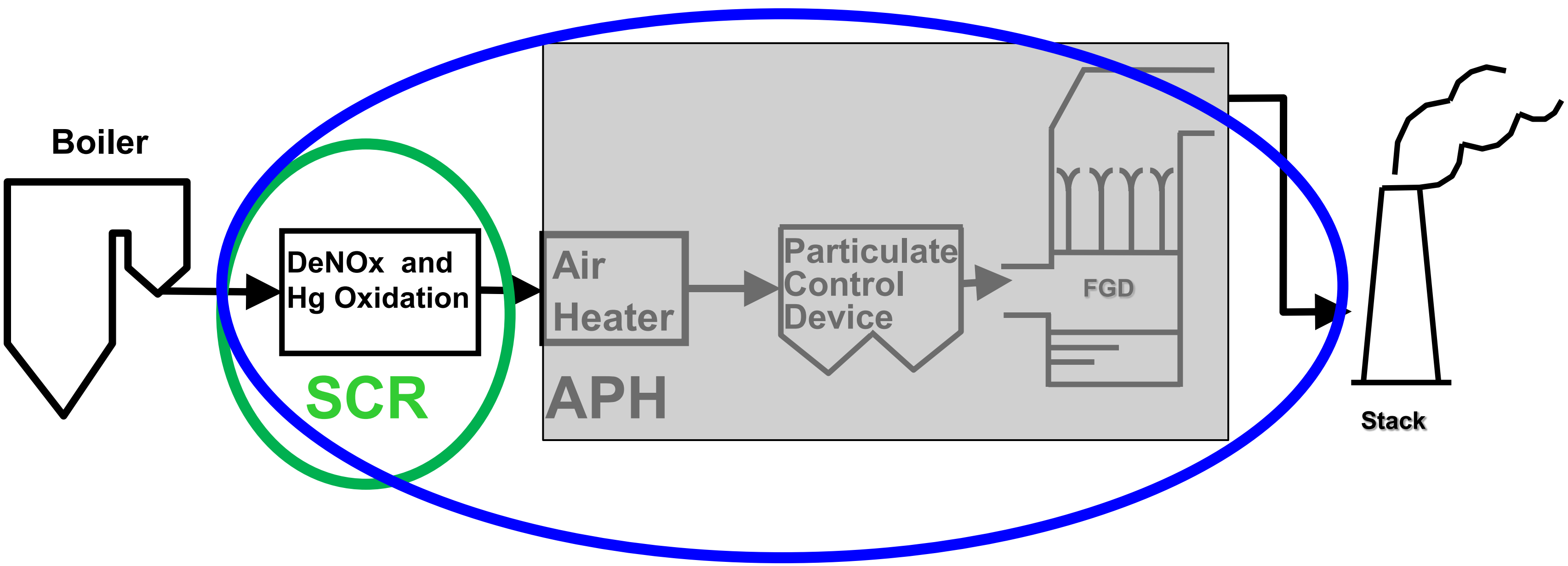
- **DeNOx**
  - Performance requirements for the SCR are typically well defined due to the sole role of the SCR for NOx reduction
- **Hg**
  - Multiple system units are involved in Hg control → SCR performance requirements are not typically as well-defined as for NOx reduction



Key Differences for Hg vs. NOx

More Factors Influence Hg Oxidation

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DeNOx

- Key Factors
  - NOx inlet
  - Efficiency
  - Slip

  Performance Threshold (NOx inlet, Efficiency, Slip)
  - Temperature
  - O_2, H_2O, SO_2 (lower impact)
  - SO_2 conversion (formulation)
  - Fuel → contaminants → K/Ko
  - Reactor condition

Hg

- Key Factors
  - Hg oxidation → **Performance Threshold**
  - NOx inlet
  - Efficiency
  - Slip

  NH_3 (negative impact) (NOx inlet, Efficiency, Slip)
  - Layer position (NH_3)
  - Halogen (Fuel or additive)
  - Temperature
  - CO, hydrocarbons
  - O_2, H_2O, SO_2 (can be larger impact)
  - SO_2 conversion (formulation)
  - Fuel → contaminants →K/Ko
  - Reactor condition

Key Differences for Hg vs. NOx

Hg Ox Catalyst Potential, K/AV

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- **Hg Oxidation K_{HgOx}/AV defines:**
  - Capacity for X% Hg oxidation
- **Activity, K_{HgOx}, depends on:**
  - Catalyst composition and age
  - Flue gas conditions (+HCl, HBr, NH_3, CO, SO_2, HC)
- AV = Area Velocity = (Gas Flow) / (Total GSA)
- First order rate equation can be applied for Hg oxidation tests, *but be careful!*

  → *This K value is strongly condition dependent!*

$$\frac{K_{HgOx}}{AV} = -\ln\left[1 - \eta_{HgOx}\right]$$

$$\eta_{HgOx} = fraction\ of\ Hg^{0}\ oxidation$$

Key Differences for Hg vs. NOx

SCR Catalyst Design Approach

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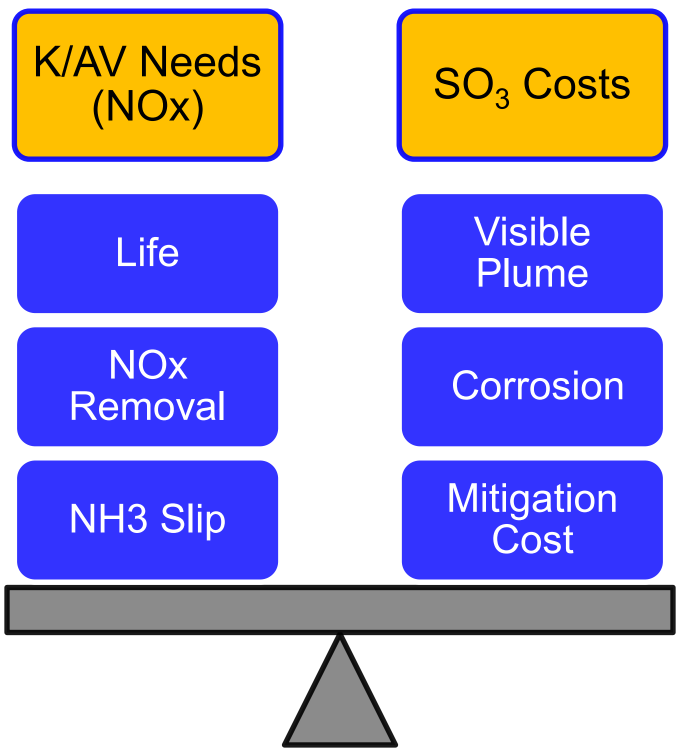
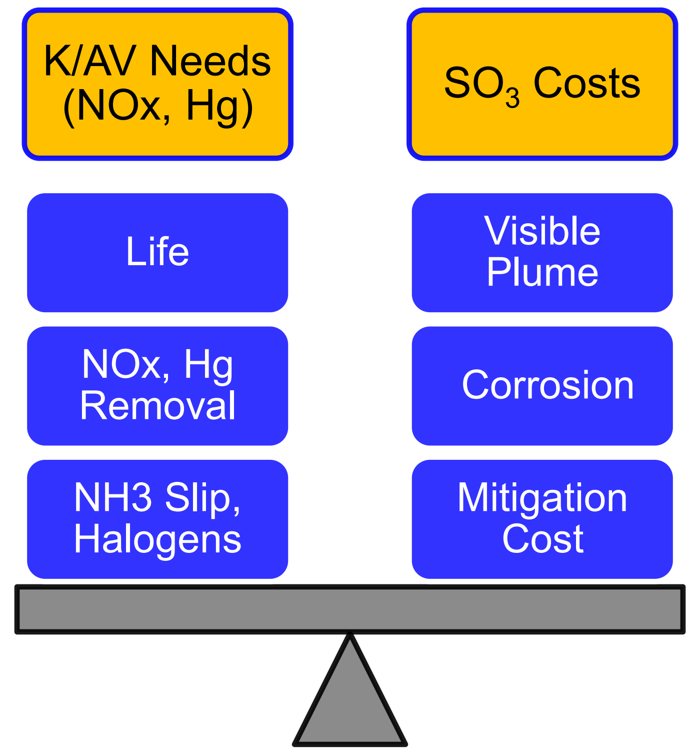
Historical:
Catalyst is formulated to achieve DeNOx requirements, while meeting SO_2 oxidation constraints.



Moving Forward:
Catalyst is formulated to achieve DeNOx and Hg oxidation requirements, while meeting SO_2 oxidation constraints.



SCR Catalyst Design
Understand Needs and Options

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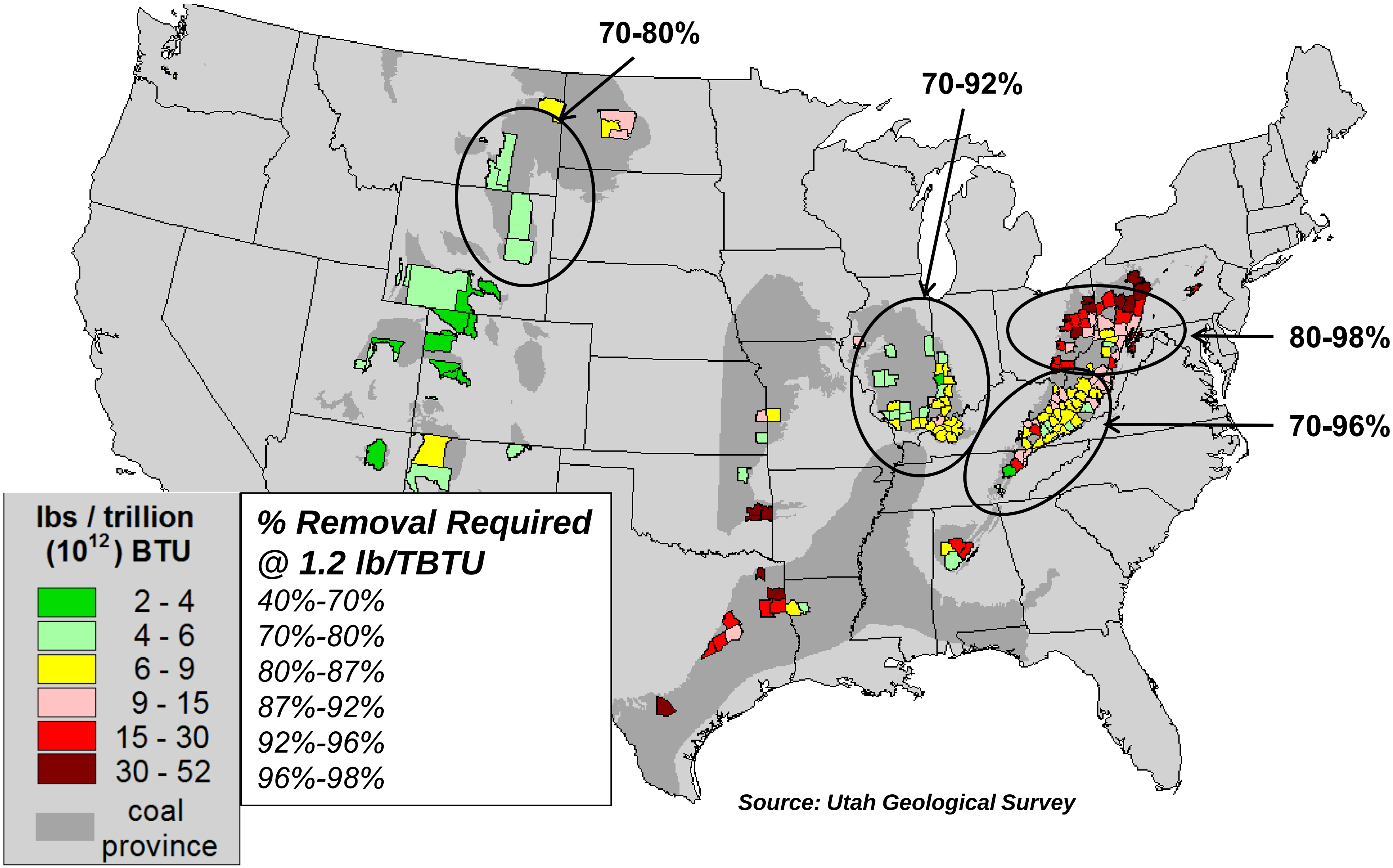
- **Hg in Coal**
- **Halogen in coal**
- **Define how much Hg oxidation is needed by the SCR, and assess vs. what can be achieved**
  - **DeNOx and SO_2 oxidation targets**
  - **Temperature and gas composition**
    - Hg, NOx, NH_3, O_2, H_2O, HCl, HBr
  - **Catalyst selection**
    - Standard Catalyst
    - COMET™ Advanced Hg Oxidation Catalyst
  - **Benefit and capability for halogen addition**
  - **Need for ACI (+ DSI) trim**

Key Factor: Hg in Coal

(Affects % Removal Needed for 1.2 lb/TBTU emission)



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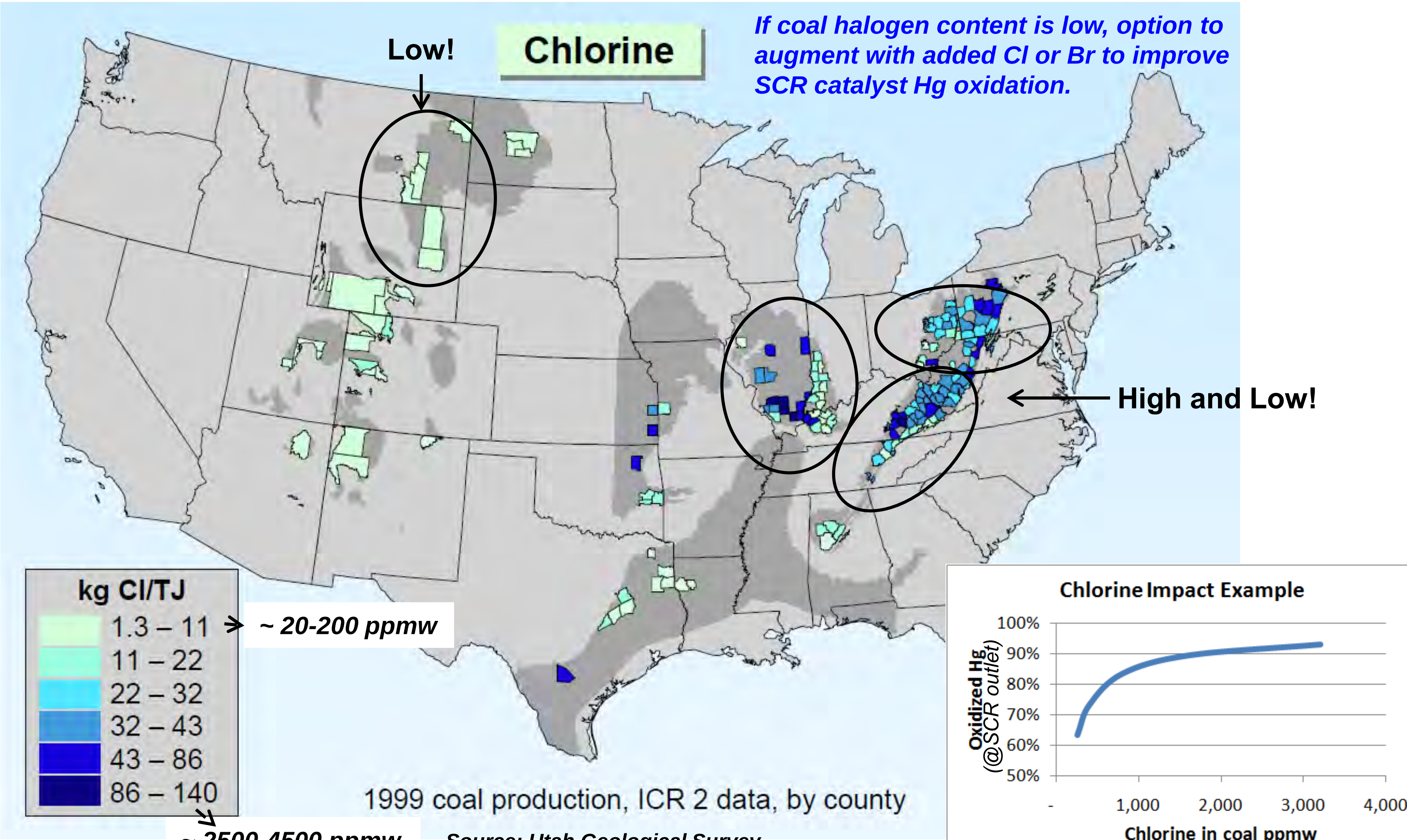
Key Factor: Chlorine in Coal

(Affects SCR Catalyst Potential for Hg Oxidation)



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Catalyst Management for Hg

- **Analogous to DeNOx…**
  - *With the caveats for K_{HgOx} previously outlined*
- **Either DeNOx or Hg oxidation establishes the design minimum volume**
  - *Depends on the relative catalyst potential and performance requirements for each reaction*
- **Case Study 1 (next slides)**
  - Situation: SCR at 70,000 hours operation requires catalyst action for DeNOx. How does consideration of Hg oxidation affect the catalyst action decision?

Case Study 1
w/ DeNOx Potential & Hg Oxidation

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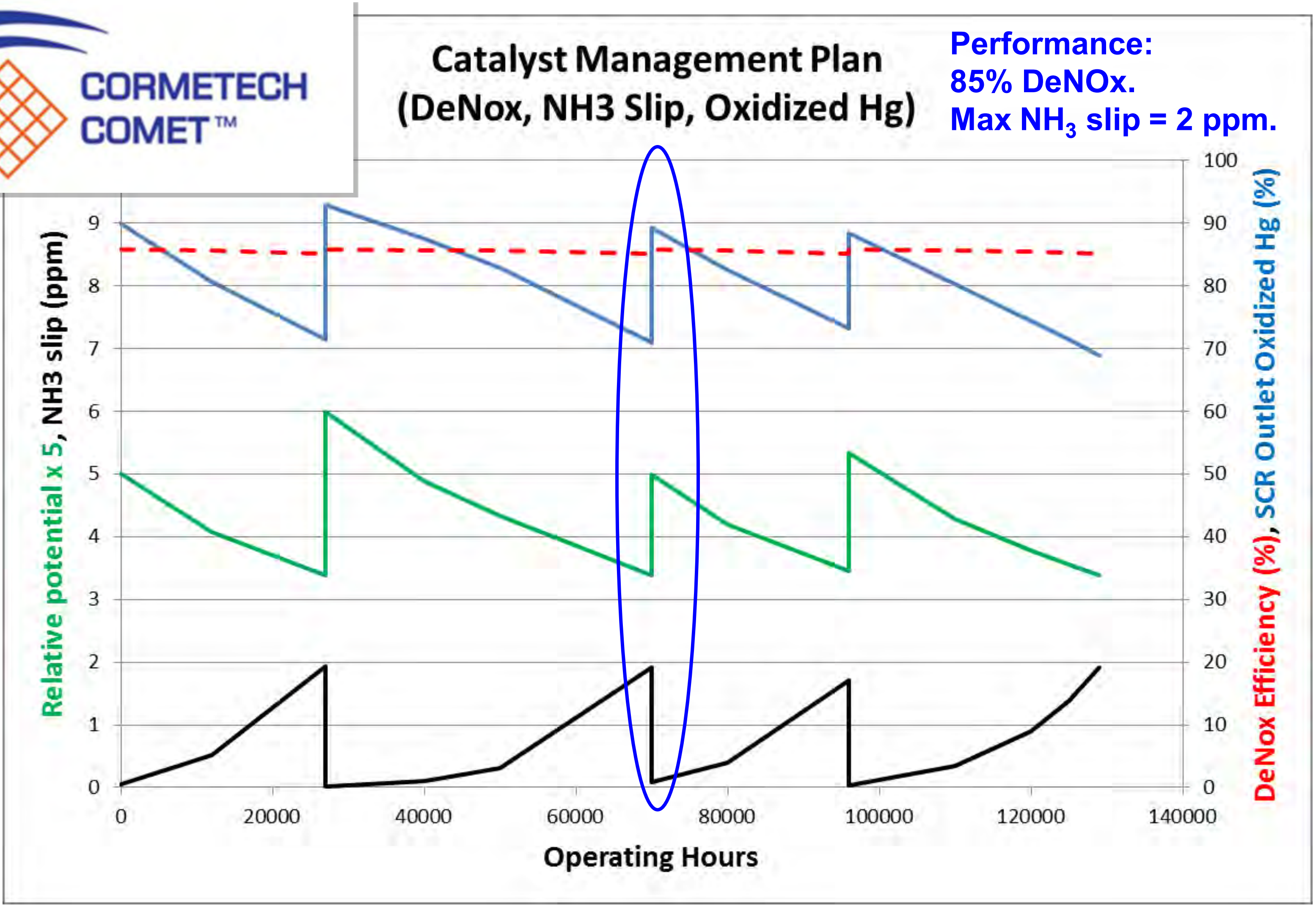

Case Study 1
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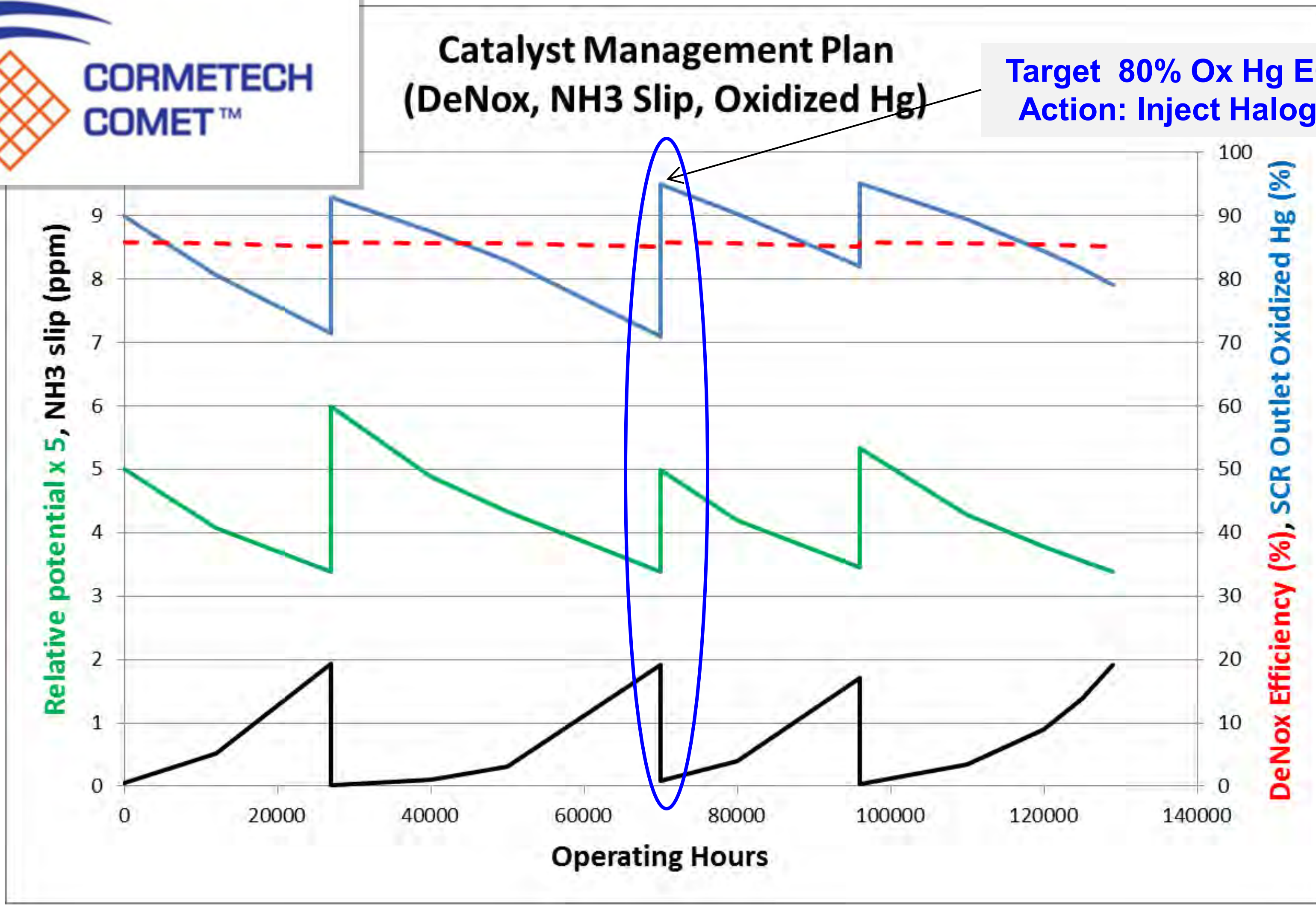

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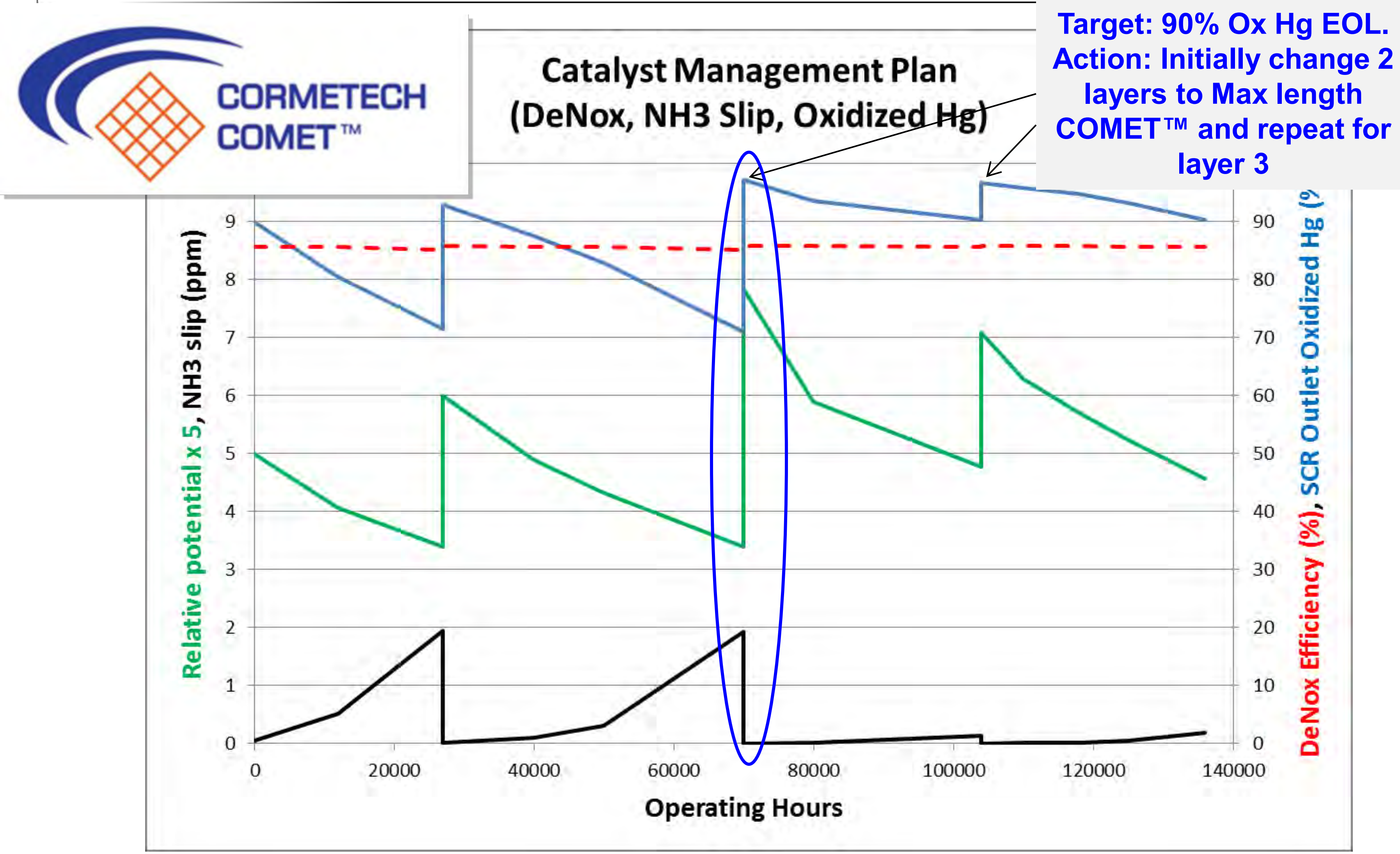

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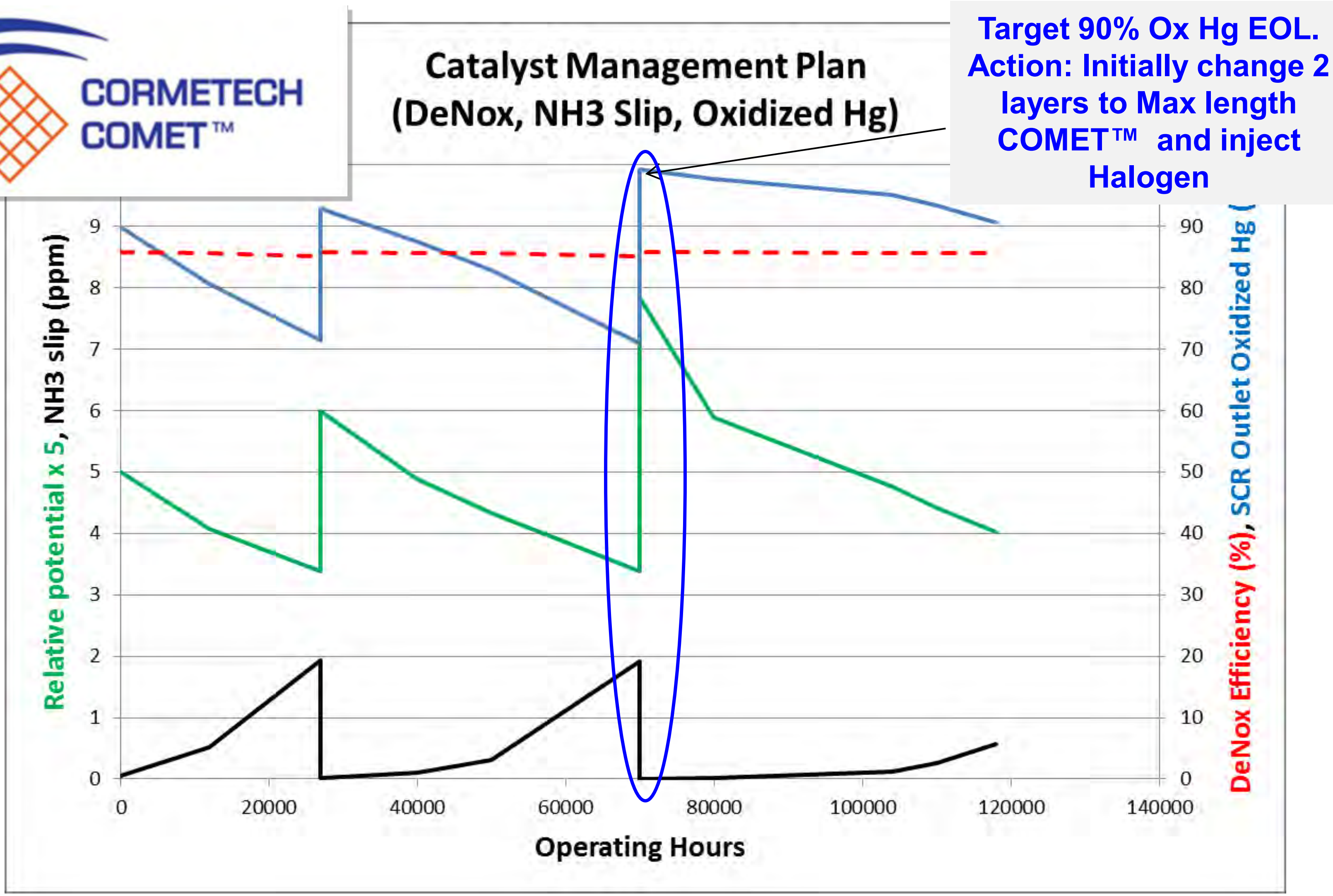

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Lab Reactor Activity Testing

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- Fresh catalyst characterization
- Model development
- Catalyst management and field catalyst audits
- Case study validations

MHI Semi-Bench Reactor

Reflects Years of Experience for Hg Ox Testing

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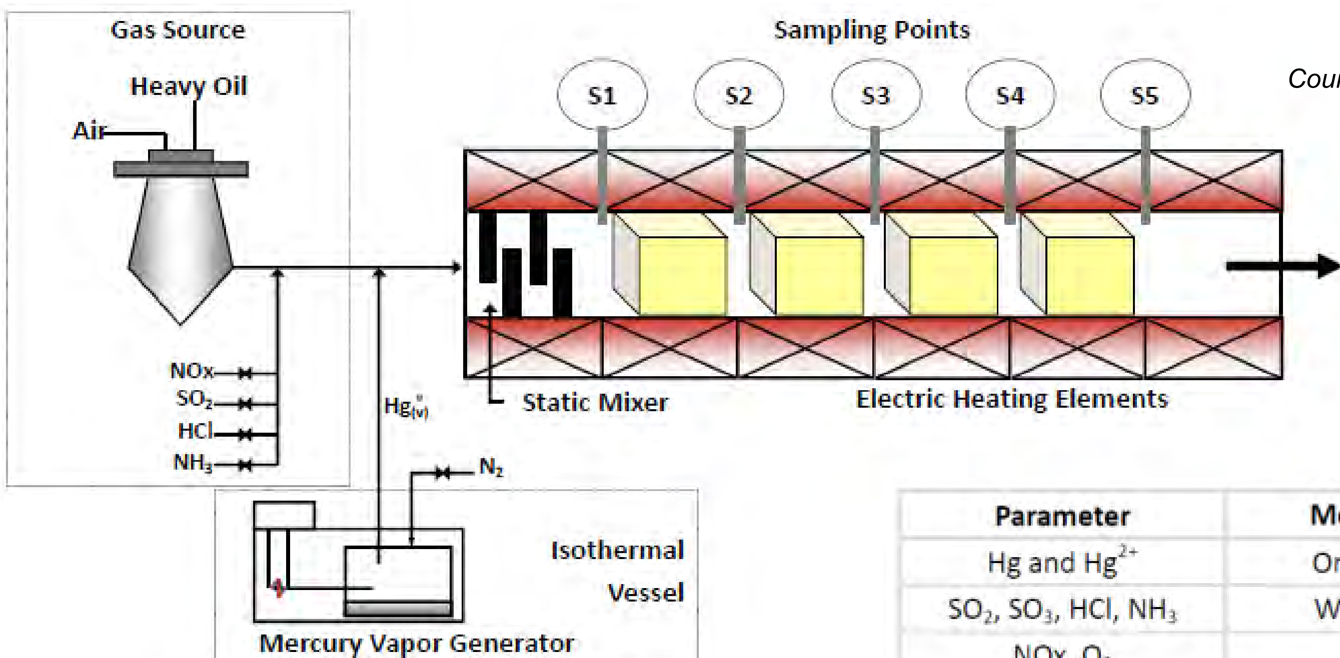
- Collected Hg oxidation data for development, designs, deactivation studies, and quality assurance since 2002.
- Total system testing (fresh and deactivated) up to 4 layers

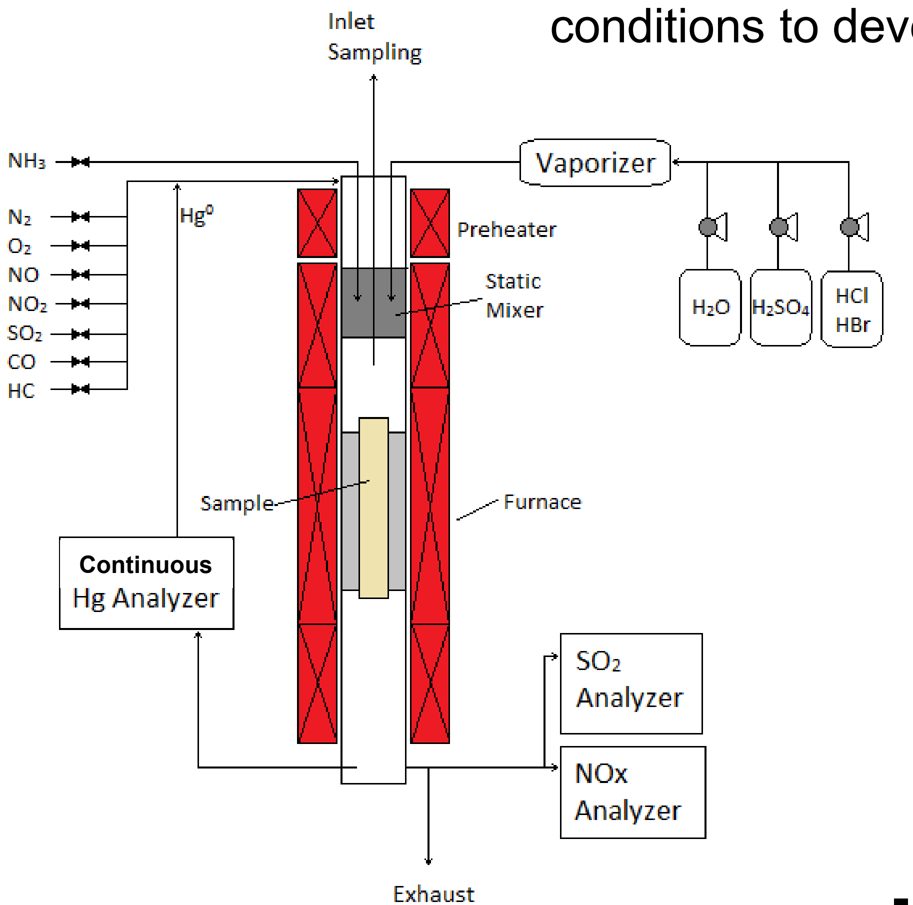


Courtesy of: MITSUBISHI HEAVY INDUSTRIES, LTD. TECHNICAL HEADQUARTERS

Parameter	Measurement Method
Hg and Hg^{2+}	Ontario Hydro Method
SO_2, SO_3, HCl, NH_3	Wet Chemical Analysis
NOx, O_2	CEMs

Cormetech Micro-Reactor

- Versatile and fully-automated for efficient data collection. CEMS for Hg, NO_x, SO_2.
  - Allows us to measure Hg oxidation under a full range of conditions to develop catalysts and management strategies.
    - Capable of characterizing any catalyst type/vintage.



- Cormetech participated in the first VGB Round Robin test series for Hg oxidation.

Cormetech Bench Reactor

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- **Added Bench scale Hg oxidation test capability.**
  - Construction is complete
  - Validation testing is underway

- Full size element testing.
- Individual element and multi-layer testing.
- Any catalyst type or combination.
- Fresh or deactivated.
- HCl/HBr, O_2, H_2O, SO_2, SO_3, NO_x, CO, HC.

Catalyst Performance Example

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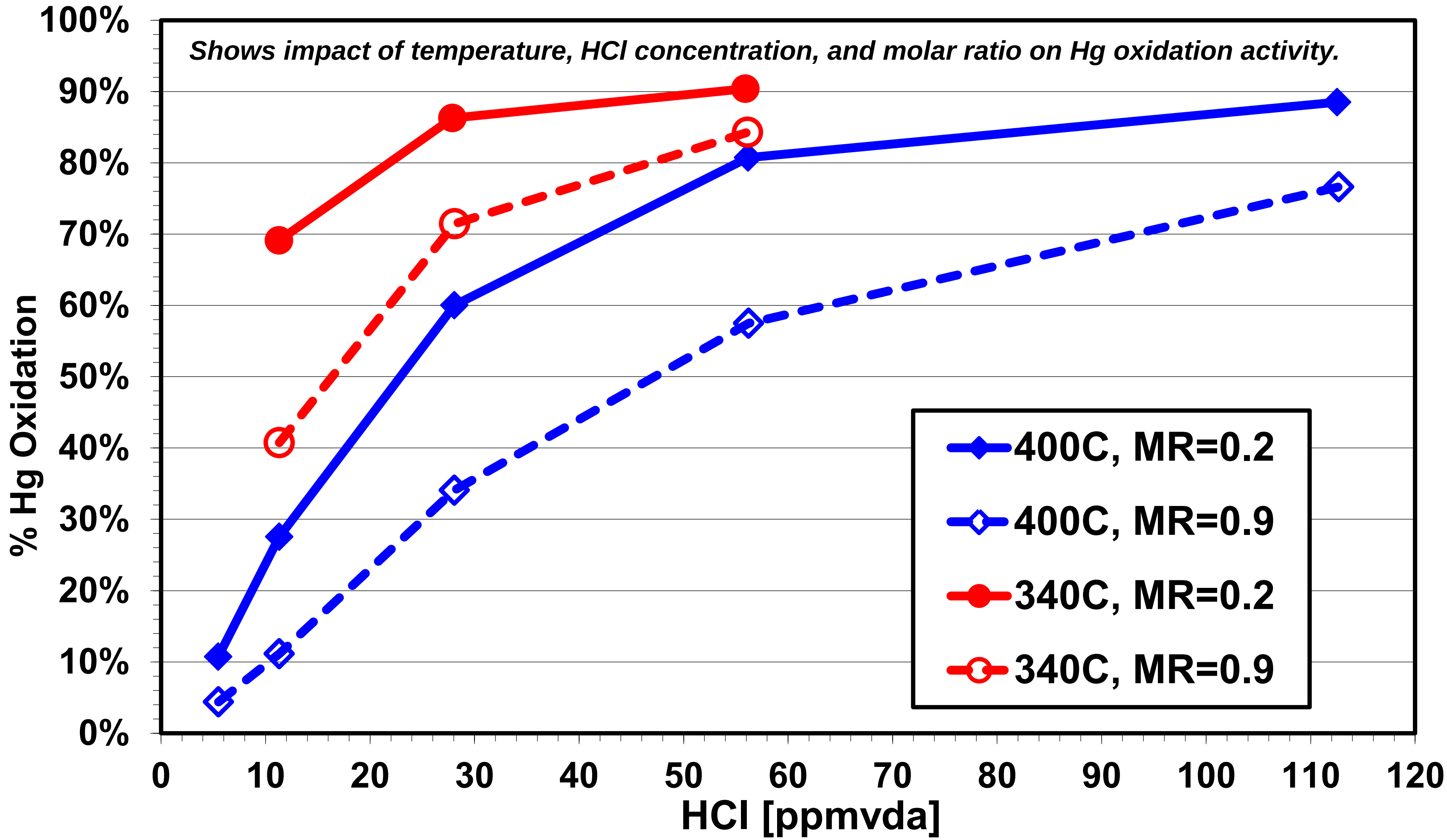
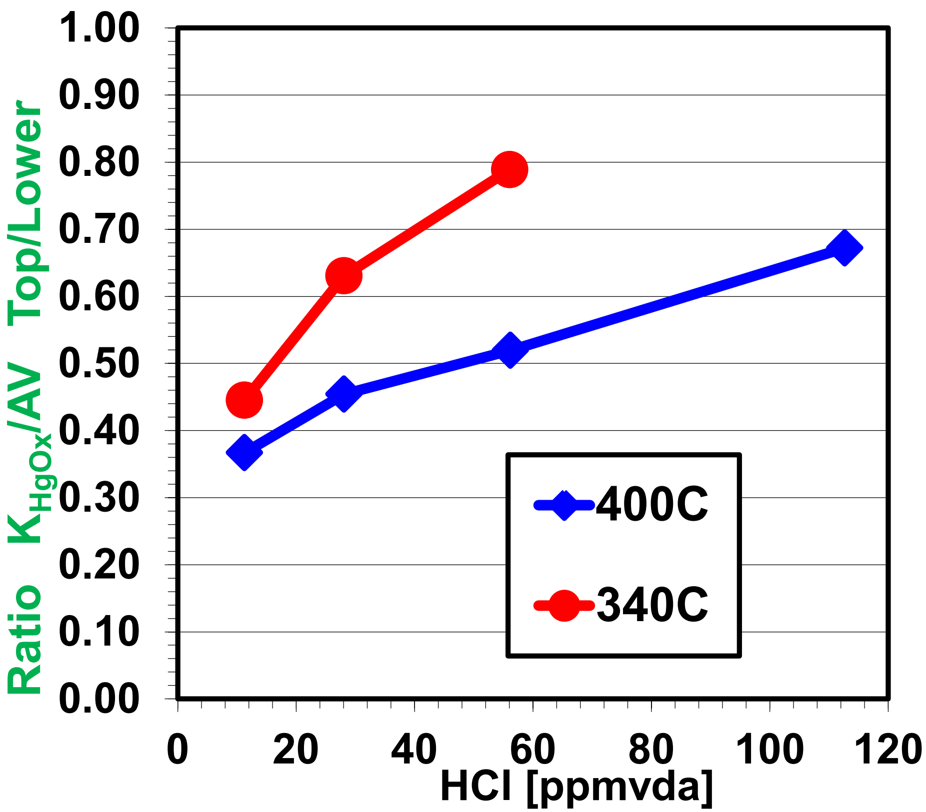
Lab Data Shown (Models were Developed from Lab Data).

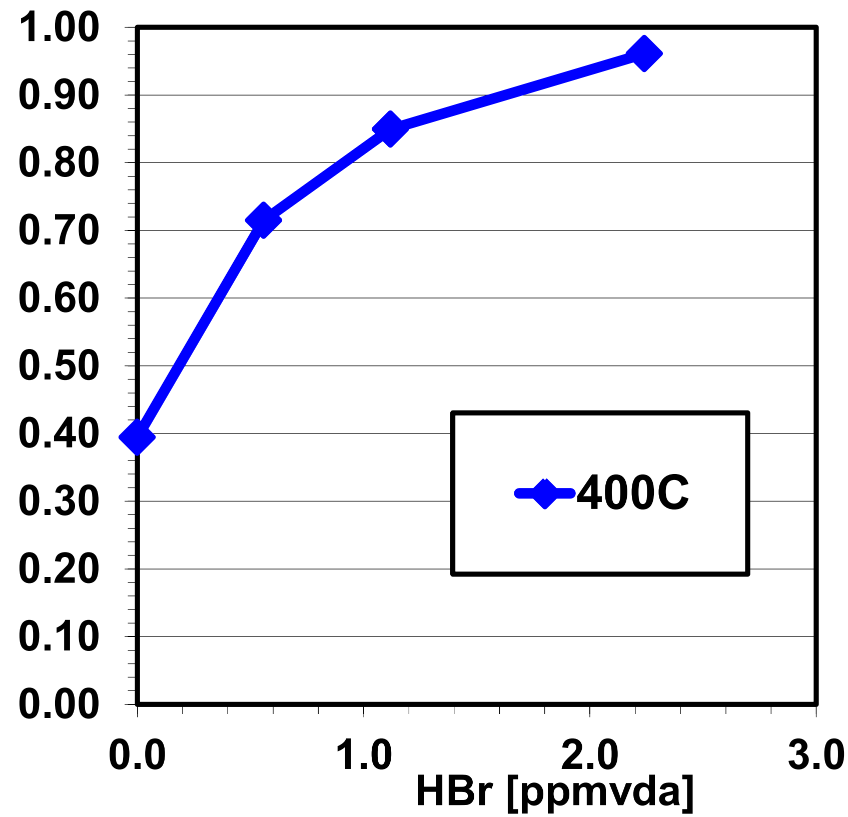


Layer Dependency: MR = 0.9 represents top layer
MR = 0.2 represents a lower layer

Layer Dependency

Influenced by Temperature and Halogen Level. Lab Data Shown.





- Hg oxidation catalyst potential is a function of layer position, due to NH_3 inhibition
  - *All catalyst layers still contribute to the overall Hg oxidation performance*
- High halogen levels significantly reduce the NH_3 impact: more Hg ox from layer 1!

Parameter Impacts

(Temperature, Flow, Halogens)

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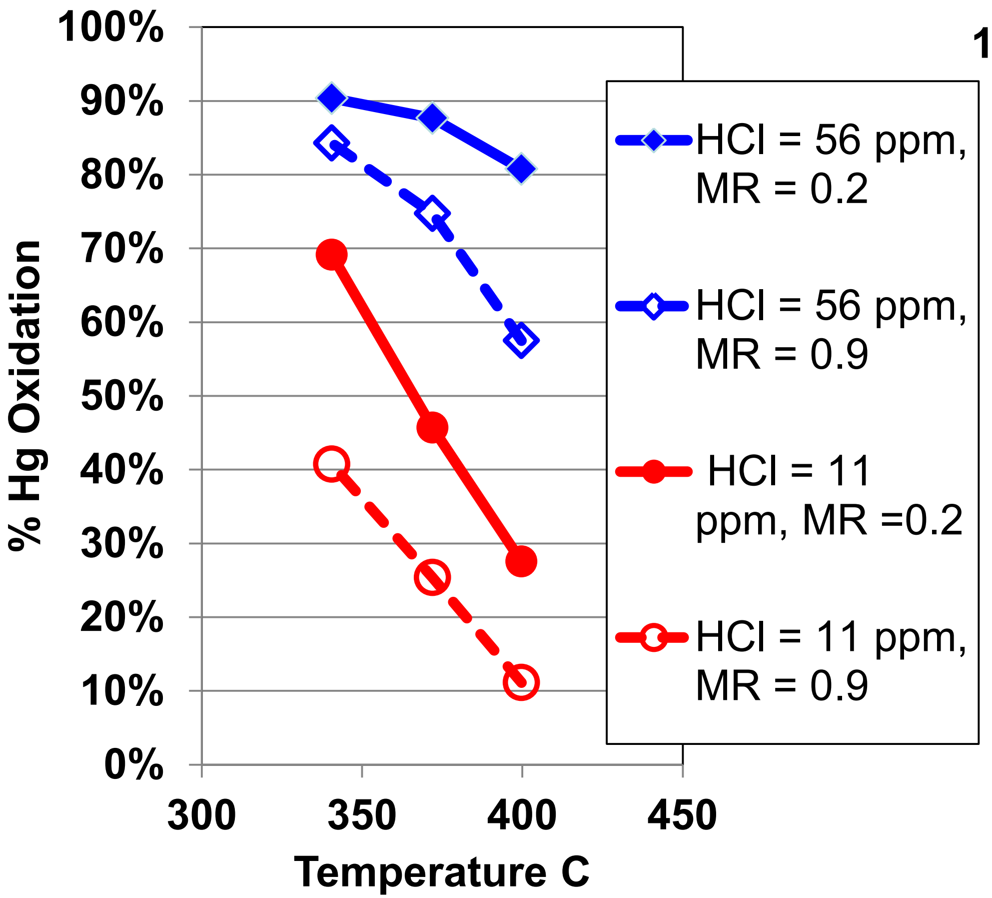
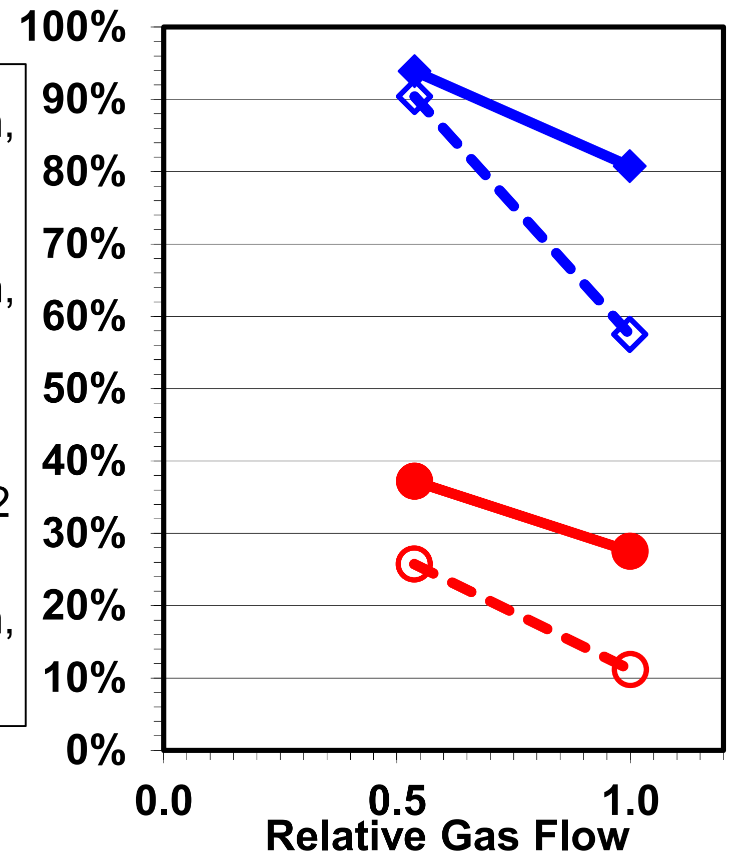
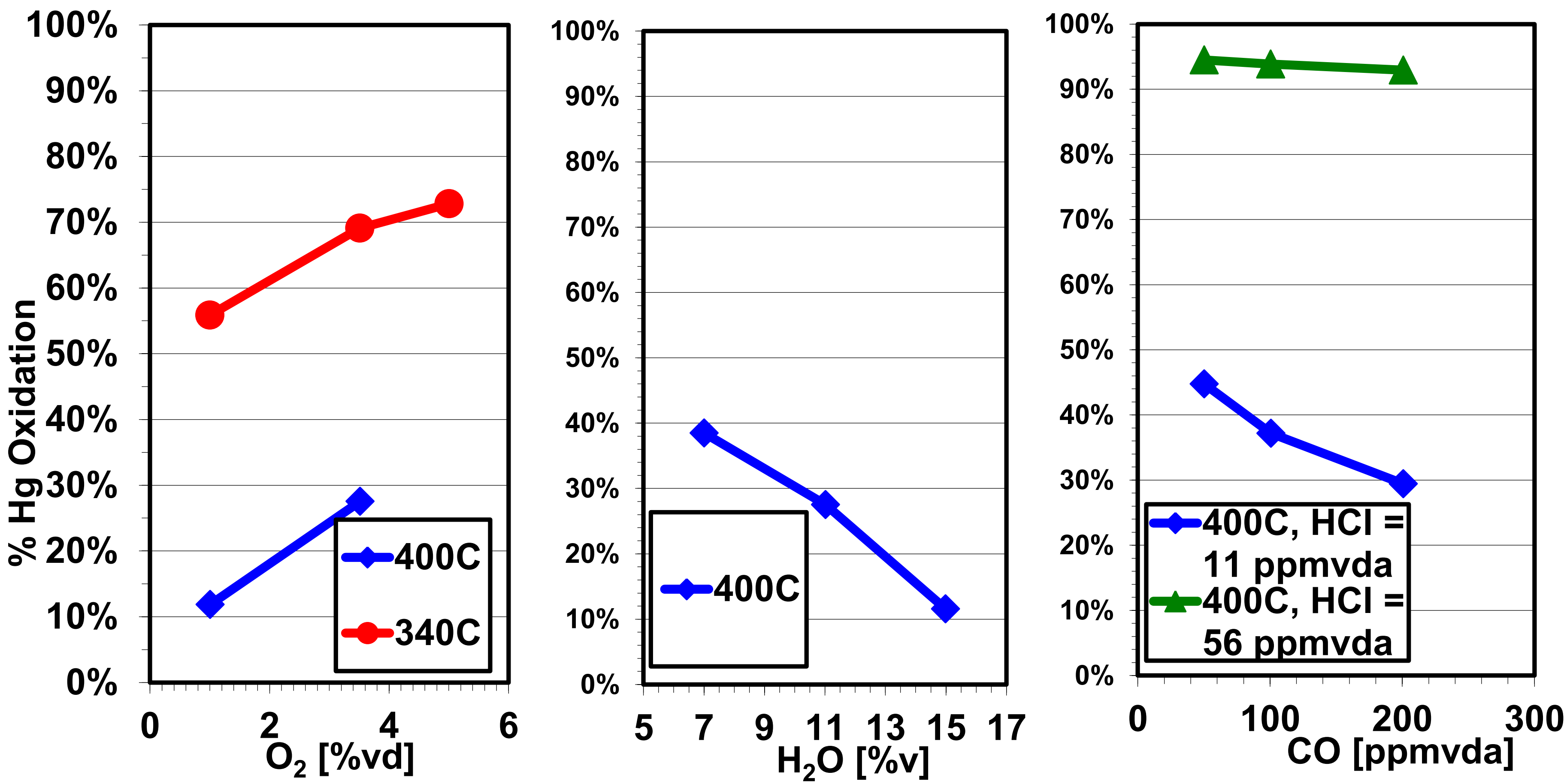




- Highest temperature with highest flow (i.e. Full load) typically design condition
- Temperature impact more significant than for DeNOx and condition dependent
- Distribution of HCl content must be considered (may result in more than one design condition)

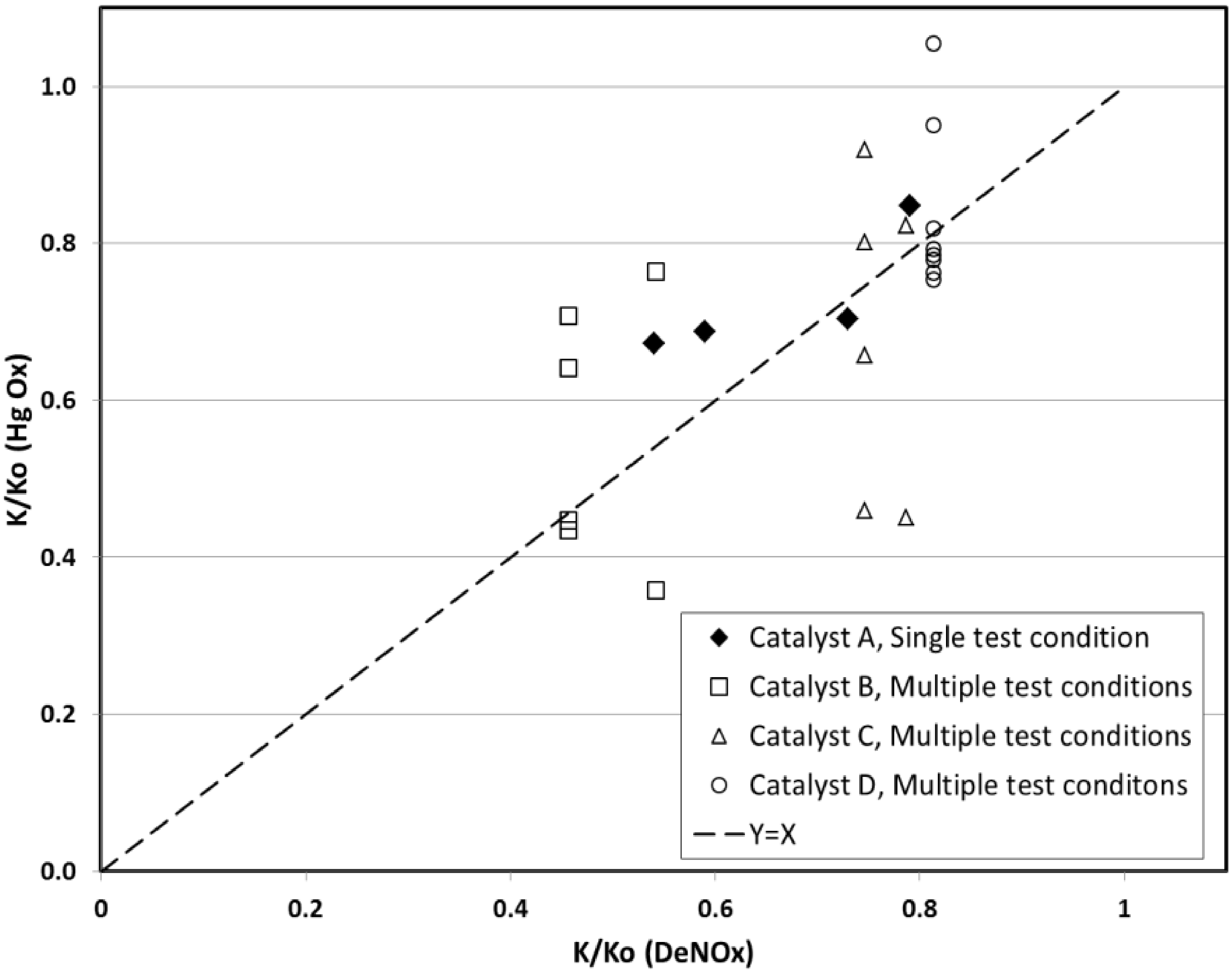
Parameter Impacts

(O_2, H_2O, CO)



- O_2, H_2O and CO have significant impact (much lower impact on DeNOx)
- Impact is condition dependent (CO for example)
- Distribution of these parameters should be considered in setting design conditions

Deactivation Studies



Hg oxidation deactivation generally correlates with DeNOx deactivation.

However, the extent of deactivation for the two reactions are not equivalent (Hg oxidation deactivation is influenced by test condition).

Deactivation Studies

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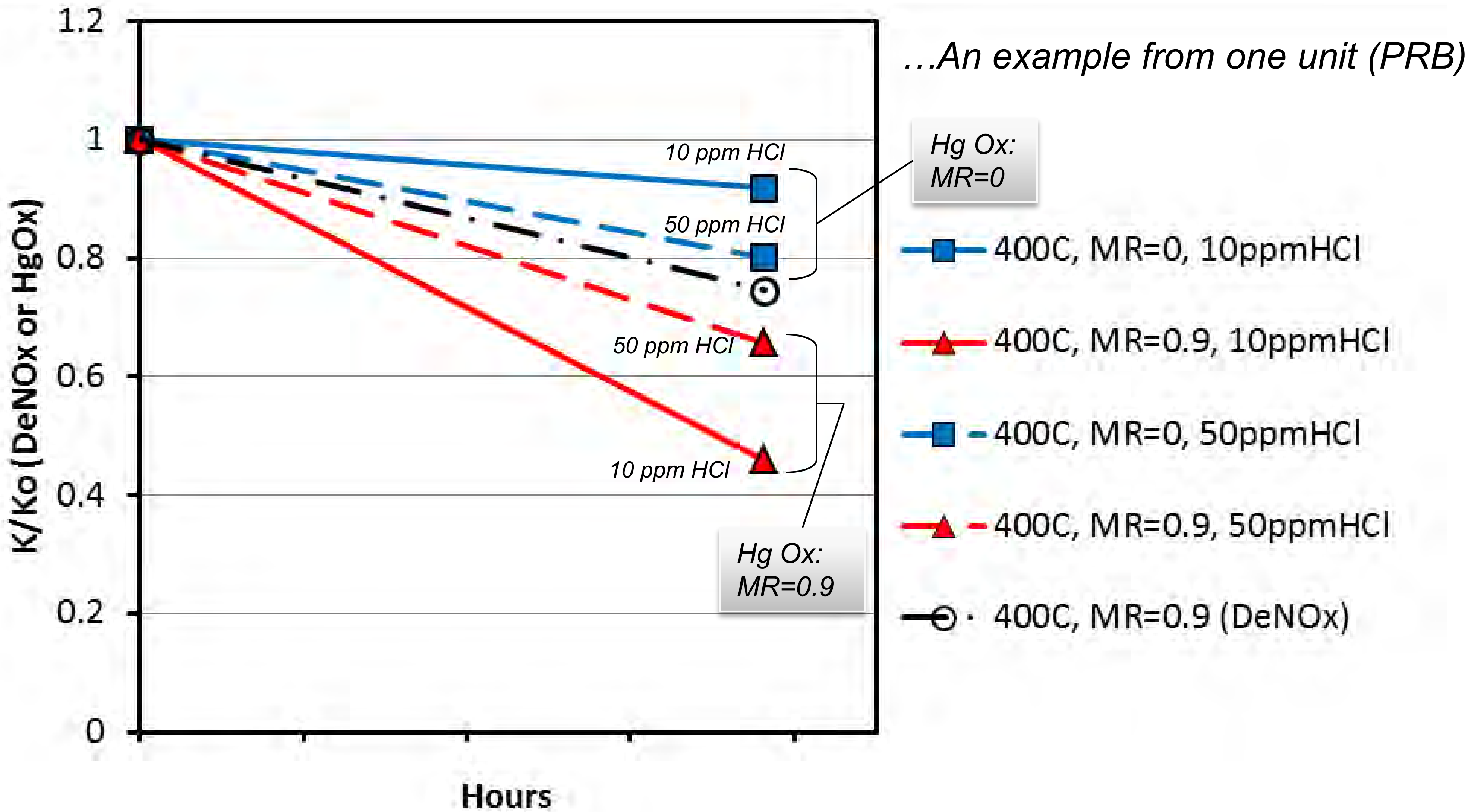

- Measured K/Ko for Hg oxidation is sensitive to operating conditions (NH_3, HCl, Temperature)

Advanced Hg Oxidation Catalyst

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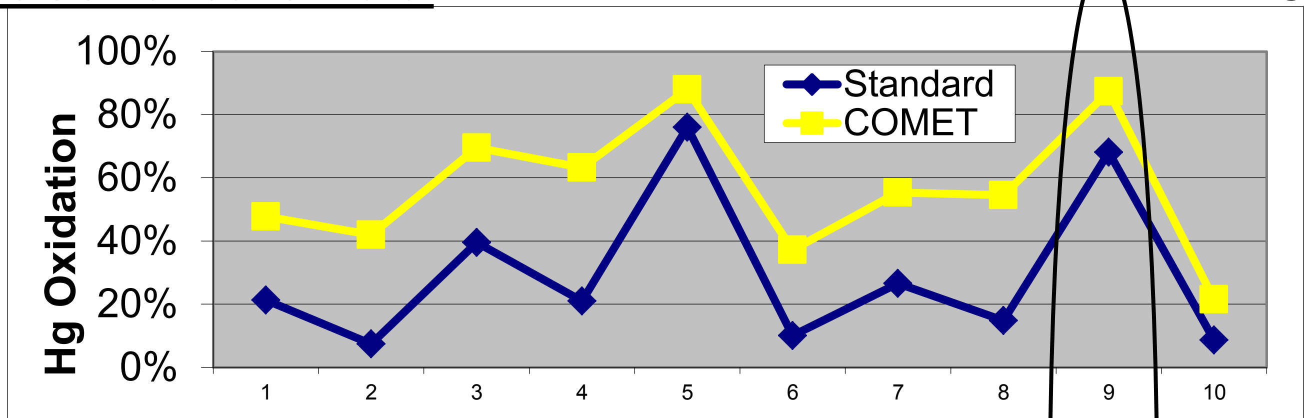
PRB Unit - Lab Testing Case Study: COMET[TM] –vs.- Standard

At same SO2 oxidation rate.

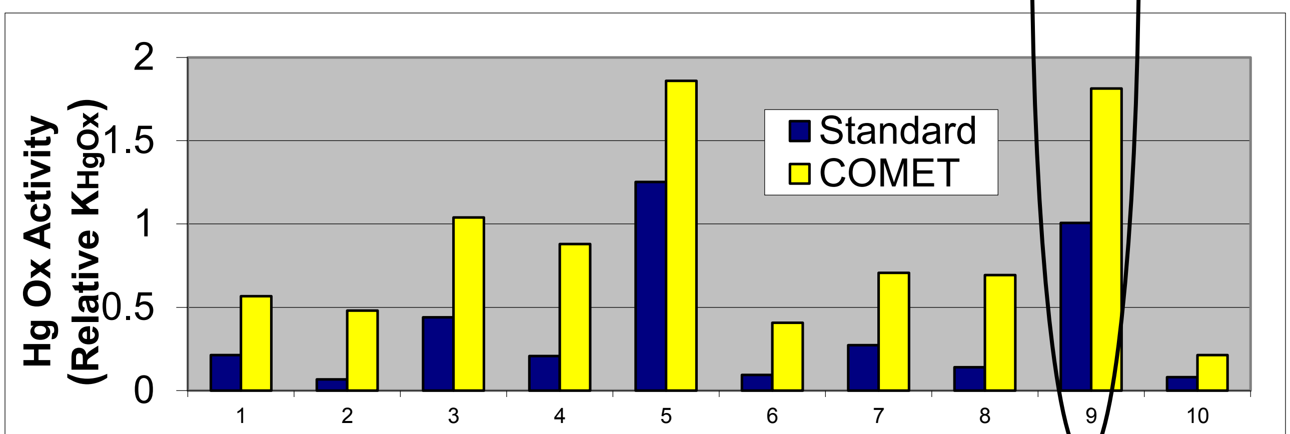
Design Case

Constants	
Temp C	403
NOx ppm	107
O2 %	3.5
H2O %	14
SO2 ppm	345
HCl ppm	**8**



NH3	**ppm**	**0**	**0**	**0**	**0**	**0**	**21**	**21**	**21**	**21**	**86**
CO	**ppm**	**0**	**100**	**0**	**100**	**0**	**0**	**0**	**100**	**0**	**0**
HBr	**ppm**	**0**	**0**	**0.1**	**0.1**	**1**	**0**	**0.1**	**0.1**	**1**	**0**

80% higher Hg ox Activity at design case! (Range: 50% - 400%)



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  - *Modeling, Advanced Hg Ox Catalyst, Characterization*
  - Catalyst Management and Case Study 2
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An Integrated Approach to Solutions

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- Understand needs & options.
- Define SCR Hg oxidation requirement.

Modeling

- Evaluate multiple scenarios.
- Develop management plans.
- Select catalyst type:
  - Standard, or
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- Set SCR performance guarantees.

- Use COMET™ modeling technology.
- Test catalyst samples in lab (fresh, field).
- Evaluate against available field data.

Micro & Bench Activity Testing ⟷ **Field Results**

Case Study 2

System Characterization and Options Analysis

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- **Evaluation of impacts to Hg oxidation and DeNOx performance for catalyst replacement options**
- **4 layer system – replacement of first and last layer**
  - Layer 1: Honeycomb A
  - Layer 2: Honeycomb B
  - Layer 3: Honeycomb B
  - Layer 4: Plate
- **Layer 1 – replace with fresh catalyst**
  - Layer was already purchased
- **Options for Layer 4 replacement:**
  - Regenerated honeycomb (from layer 1)
  - Fresh COMET™ catalyst

Case Study 2
System Characterization and Options Analysis

- **Lab tested 7 samples of field and fresh catalyst**
  - MR = 0, 0.2, 0.3
  - Over 60 tests completed.
- **Validated lab data against model**
  - Average absolute deviation within 3% across range of MR
- **Field data in good agreement**
- **Options analyzed and management plan developed.**

	Baseline	Option 1	Option 2
Layer 4	Existing	Fresh Regen	Fresh COMET™
Hg Oxidation (System)	40%	55%	70%

  - Higher oxidation can be achieved with additional COMET™ layers.

Summary

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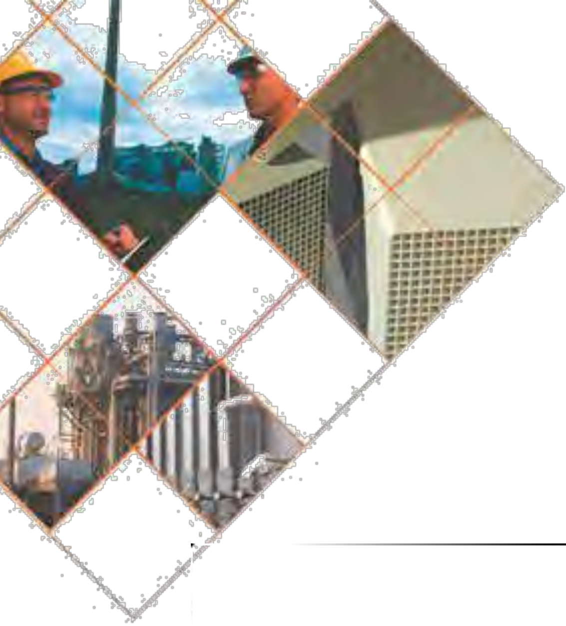
- **Hg oxidation is influenced by multiple factors**
  - Layer dependency
  - More factors in setting design conditions
  - Impacts of catalyst type & formulation
- **Cormetech has developed testing capabilities to characterize performance under all operating conditions**
- **COMET™**
  - Testing and Modeling Technology allows us to predict system performance and evaluate options for catalyst actions.
  - Advanced Hg Oxidation Catalyst can significantly improve SCR co-benefit for Hg oxidation.
  - Used in combination to provide optimal solutions.

CORMETECH COMET™ ***can help you evaluate and meet Hg Emissions Goals***



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Thank You!

Questions?

Christopher Bertole

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