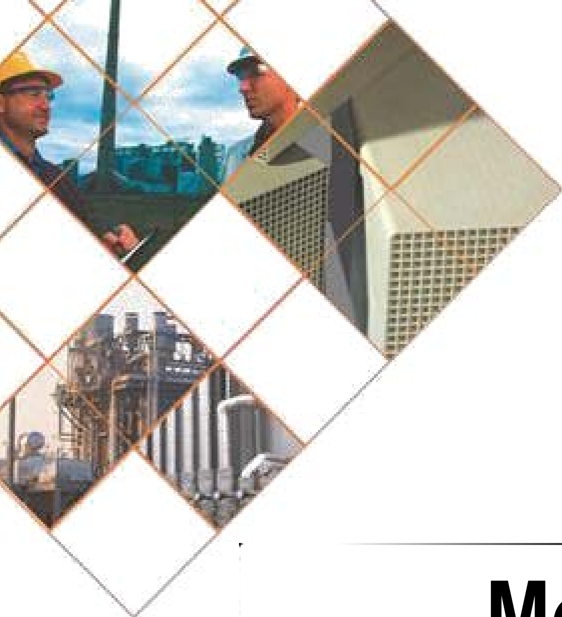
REINHOLD ENVIRONMENTAL Ltd.

2013 NOx-Combustion Round Table & Expo Presentations

February 18 & 19, 2013, in Salt Lake City, UT / Hosted by PacifiCorp



Mercury Oxidation Potential
vs.
Catalyst Condition

Scot Pritchard

Cormetech, Inc.

2013 Reinhold NOx-Combustion Round Table

Overview

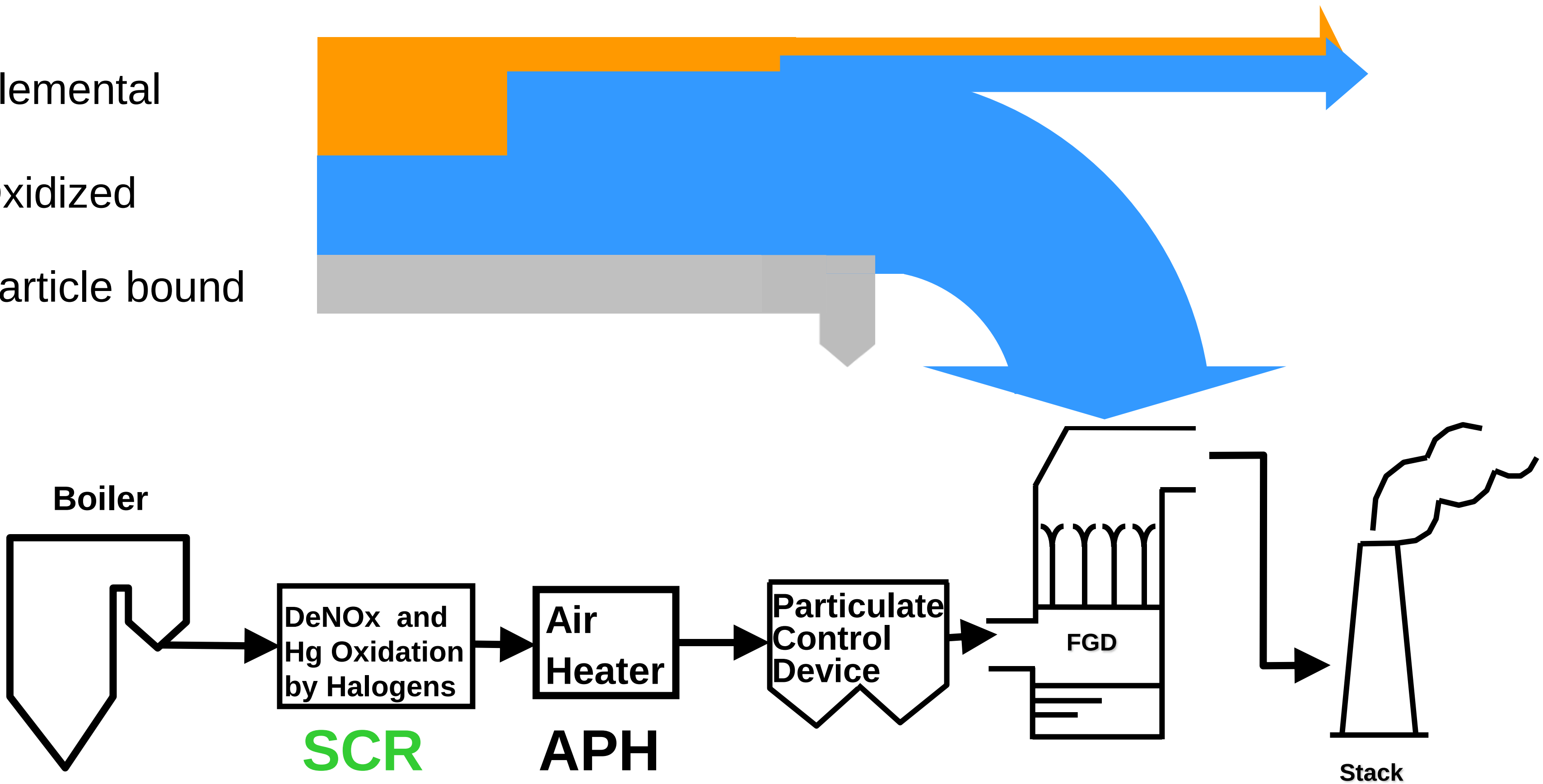
- SCR Hg Oxidation Co-benefit
- DeNOx catalyst selection and management background
- Key Differences between DeNOx & Hg Oxidation
- Catalyst Characterization Process
- Catalyst Improvements
- Evaluation Inputs
- Case Study
- Summary

Background: SCR Co-Benefit

①Elemental

②Oxidized

③Particle bound



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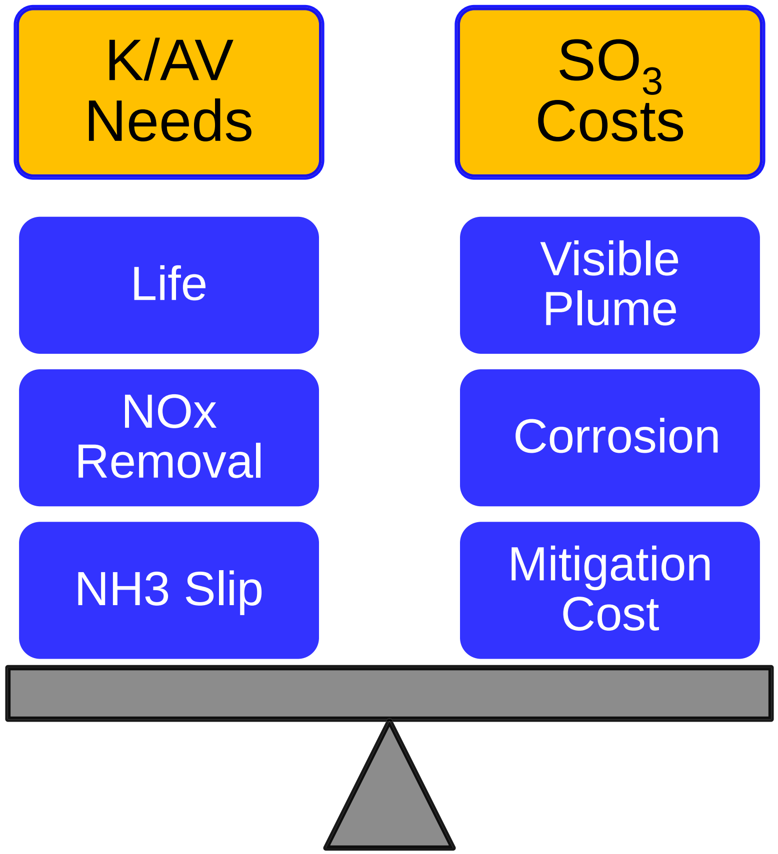
DeNOx Catalyst Potential, K/AV

- K/AV defines:
  - capacity for X% DeNOx
  - with less than Y ppm NH_3 slip
- Activity, K, depends on
  - Catalyst composition and age
  - Flue gas conditions
- AV = Area Velocity = (Gas Flow) / (Total GSA)
- Common equation for MR = 1 catalyst test:

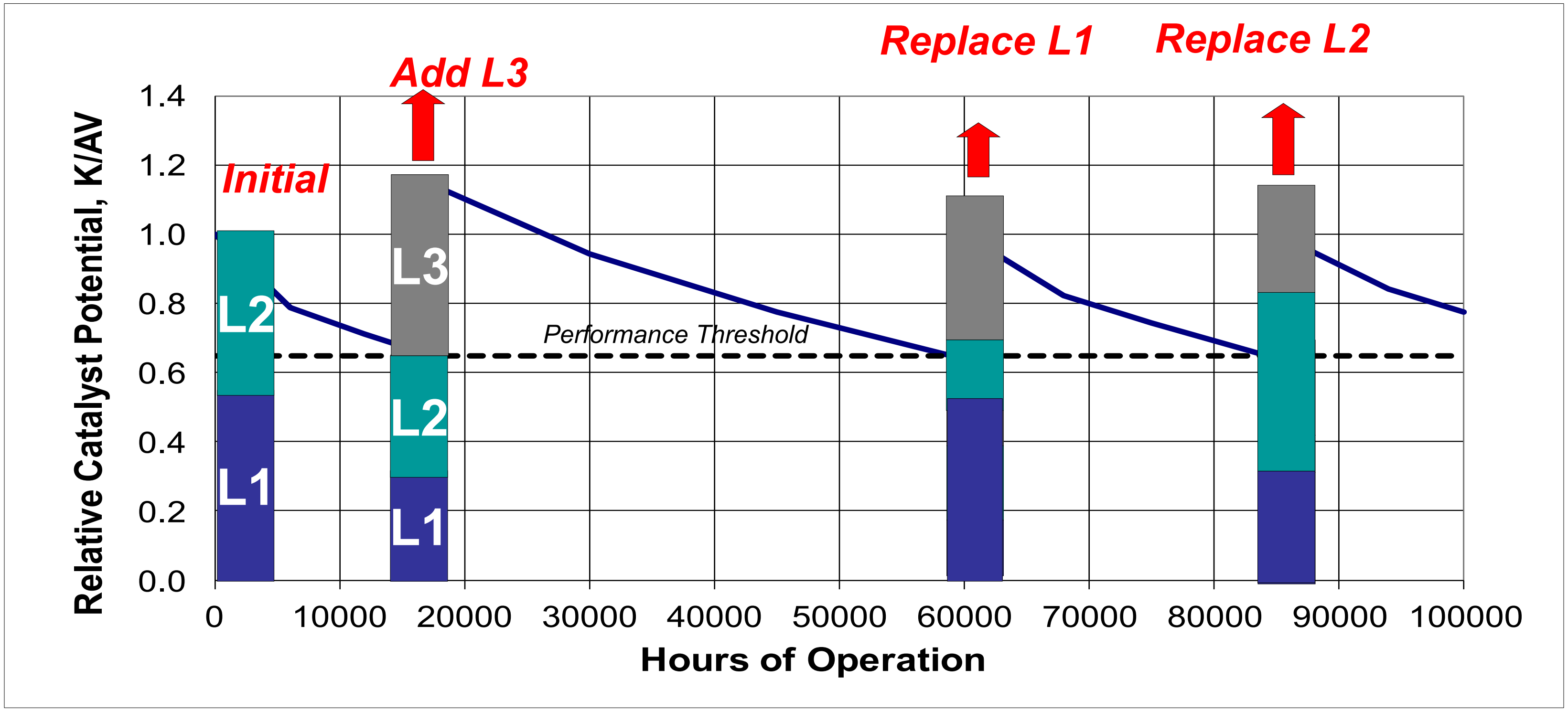
$$\frac{K}{AV} = -\ln\left[1 - \%DeNOx\right]$$

Catalyst Design Balance

Typically catalyst is formulated to achieve DeNOx requirements while meeting given SO_2 oxidation constraints



DeNOx Catalyst Management Plan



- **Catalyst Layer Potentials tracked through periodic lab tests & inspections**
- **While there is a molar ratio impact the catalytic potential of each layer for the DeNOx reaction can still be reasonably characterized by MR=1 test and are essentially additive**
- **An analogous approach can be used for Hg oxidation**

…but with some key differences which add to the complexity

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Key Differences for Hg vs. NOx

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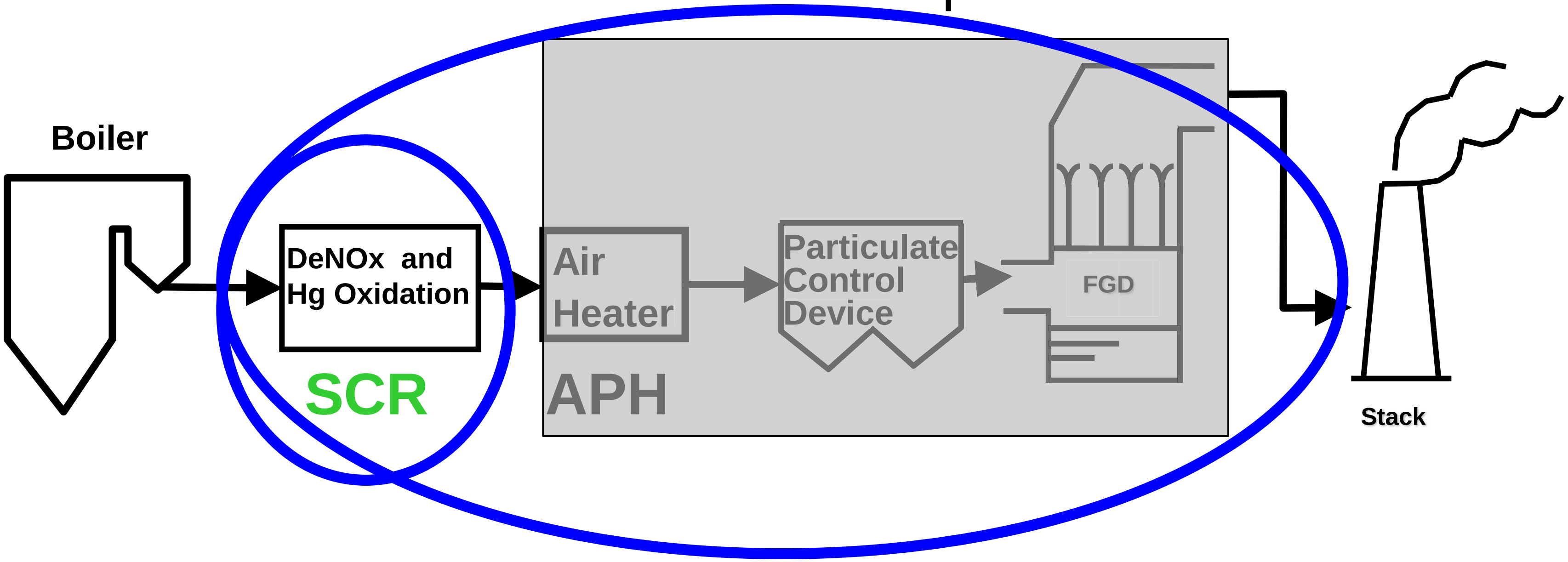
- DeNOx
  - Performance requirements typically well defined due to sole role of the SCR
- Hg
  - Performance requirements for the SCR typically not as well defined due to roles of downstream equipment in total compliance



Key Differences for Hg vs. NOx

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DeNOx

- Key Parameters
  - NOx inlet
  - Efficiency
  - Slip

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

Hg

- Key Parameters
  - NOx inlet
  - Efficiency
  - Slip

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

Catalyst Deactivation

- The deactivation trend for DeNox and Hg Oxidation from a catalytic potential under a defined test condition is similar however;

- Due to the additional parameters which influence the Hg oxidation reaction and the interdependency on the DeNox reaction, in terms of ammonia concentration throughout the catalyst layer(s), the trend alone does not provide enough information to form a management plan decision

- Therefore parametric tests and accurate modeling are necessary to assist with the management decision

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Test Reactor Capabilities

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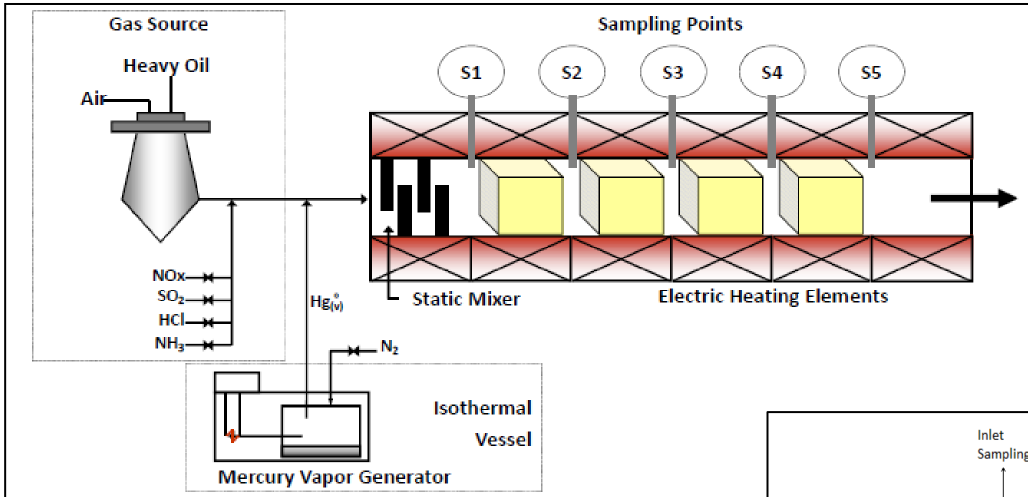
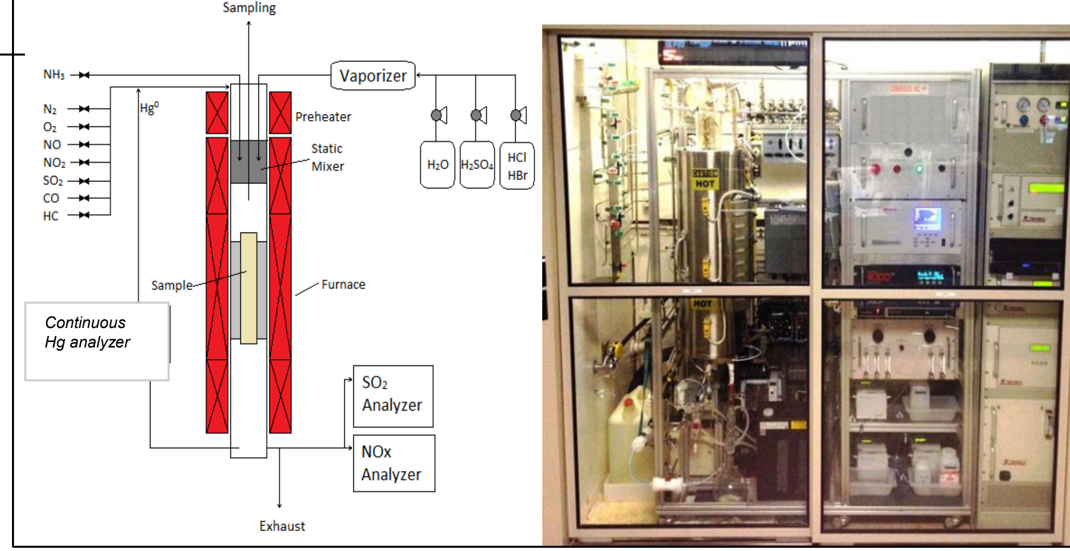


Courtesy of: MITSUBISHI HEAVY INDUSTRIES, LTD. TECHNICAL HEADQUARTERS

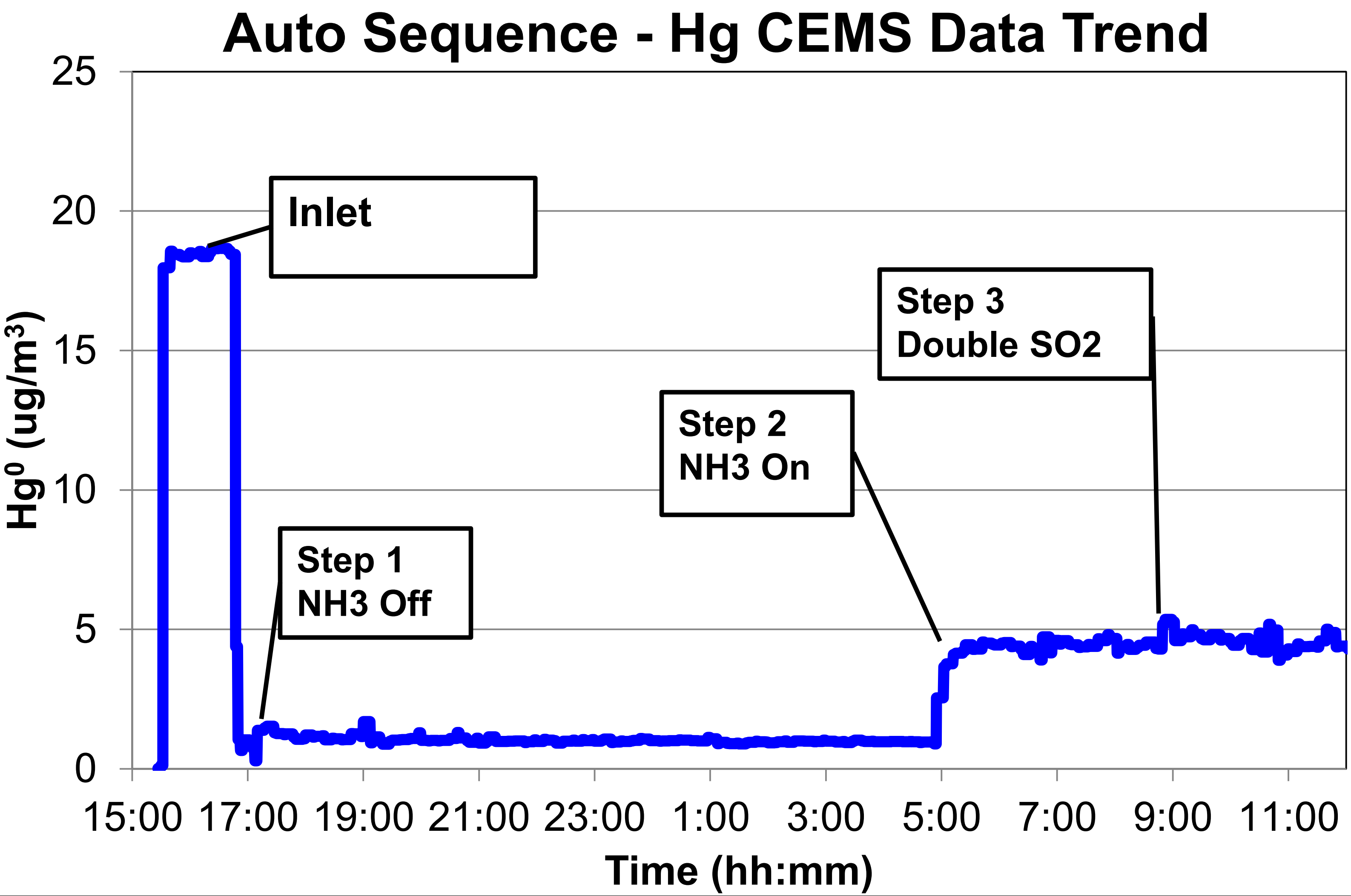
- Collecting Hg oxidation data for development, designs, deactivation studies,
- and quality assurance since 2002.
- Allows necessary characterization of catalyst of any type/vintage



Cormetech Mercury Activity Test Reactor System

Mercury Assurance Testing Reactor System

Automation allows us to understand the impact of many factors and interactions



Understanding Parameter Impacts
(Temperature, Flow, Halogens)

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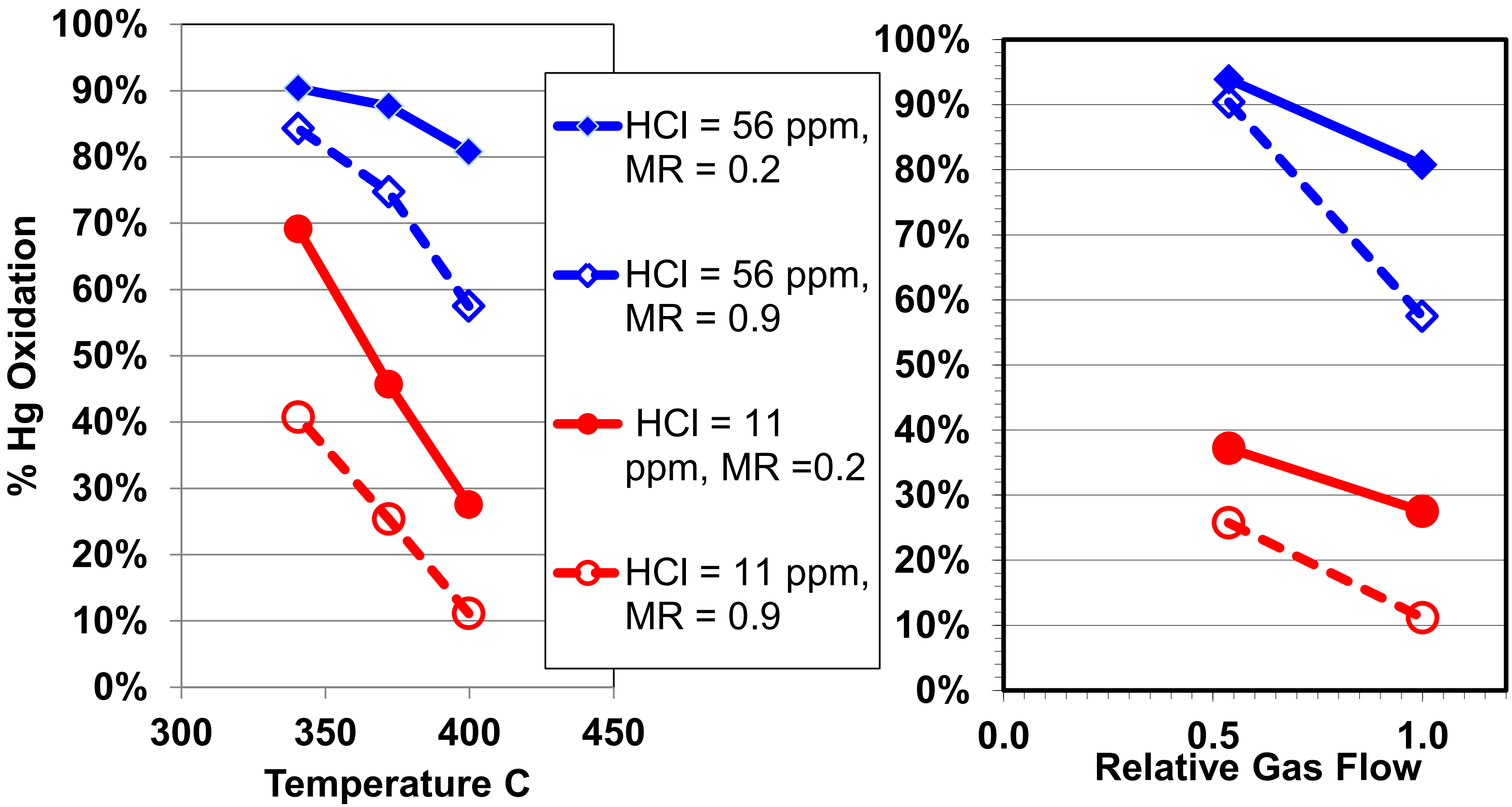
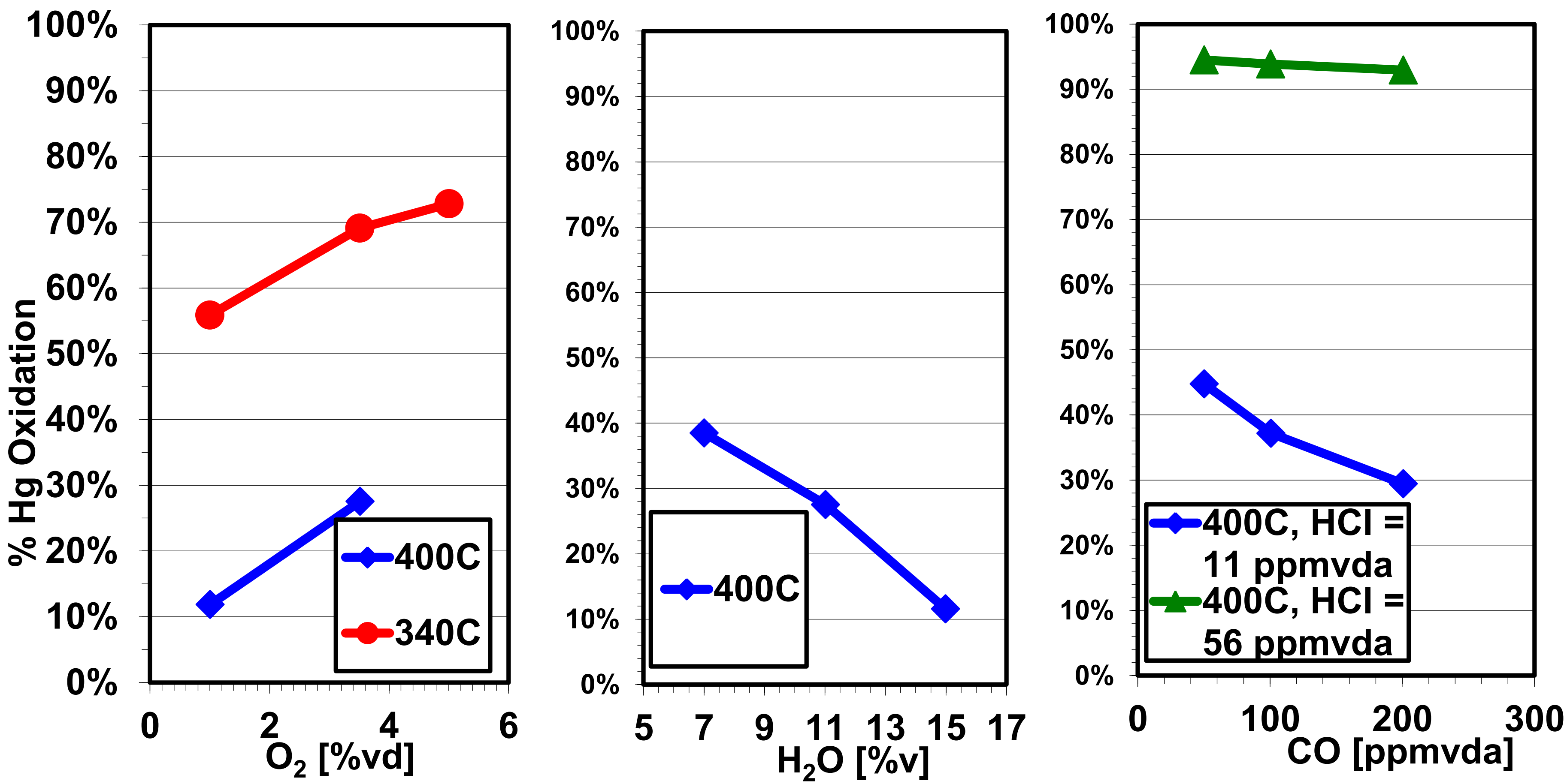


- Highest temperature with highest flow (i.e. Full load) typically design condition.
- Temperature impact more significant than for DeNOx and condition dependent
- Distribution of HCl content must be considered (May result in more than one design condition).

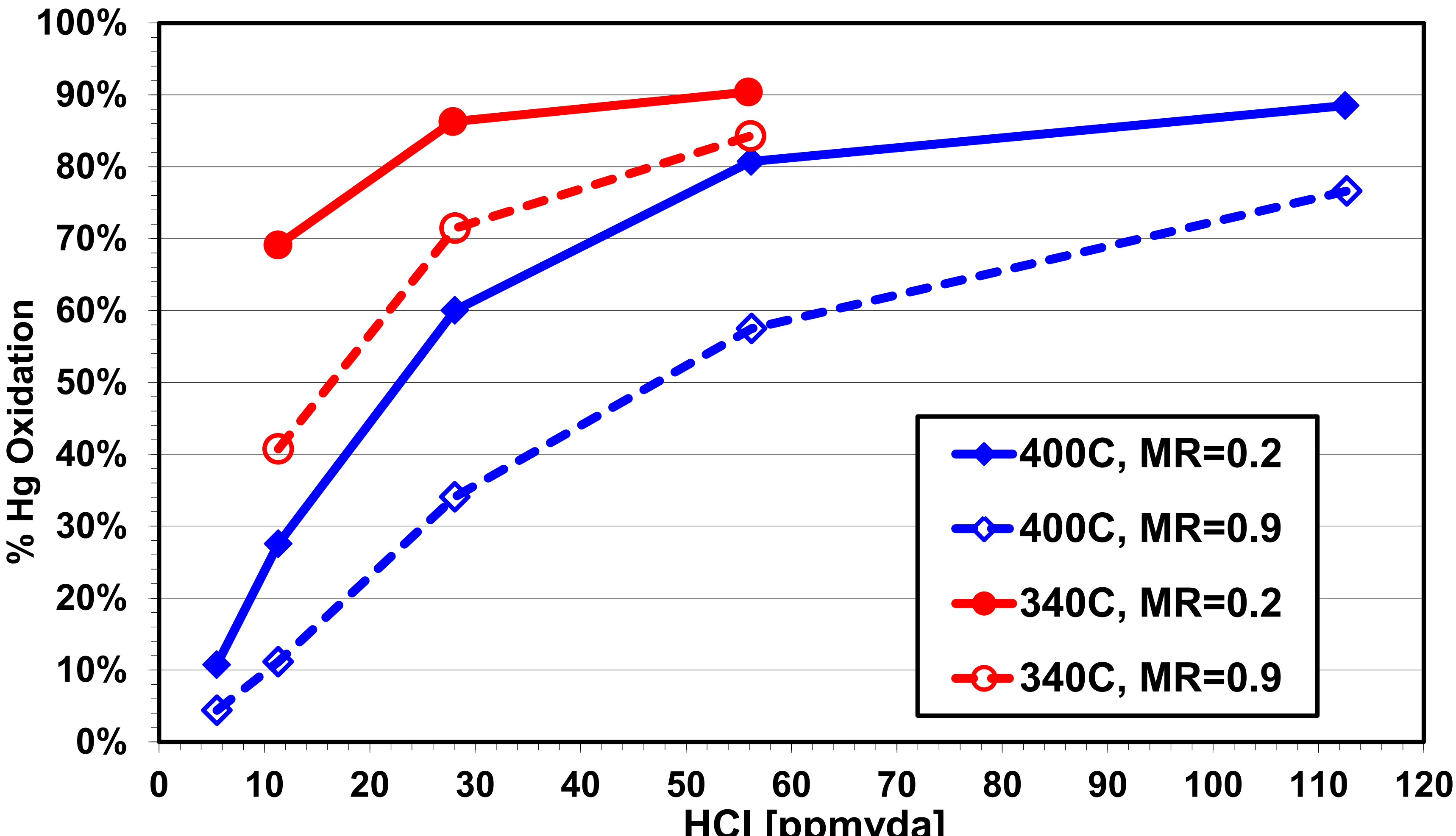
Understanding Parameter Impacts
(O2, H2O, CO)



- O2, H_2O and CO have significant impact (minimal impact on DeNOx);
- Impact is condition dependent (CO for example)
- Distribution of these parameters should be considered in setting design conditions.

Understanding Parameter Impacts

Layer Dependency



MR = 0.9 represents top layer

MR = 0.2 represents a lower layer

Understanding Parameter Impacts

Layer Dependency

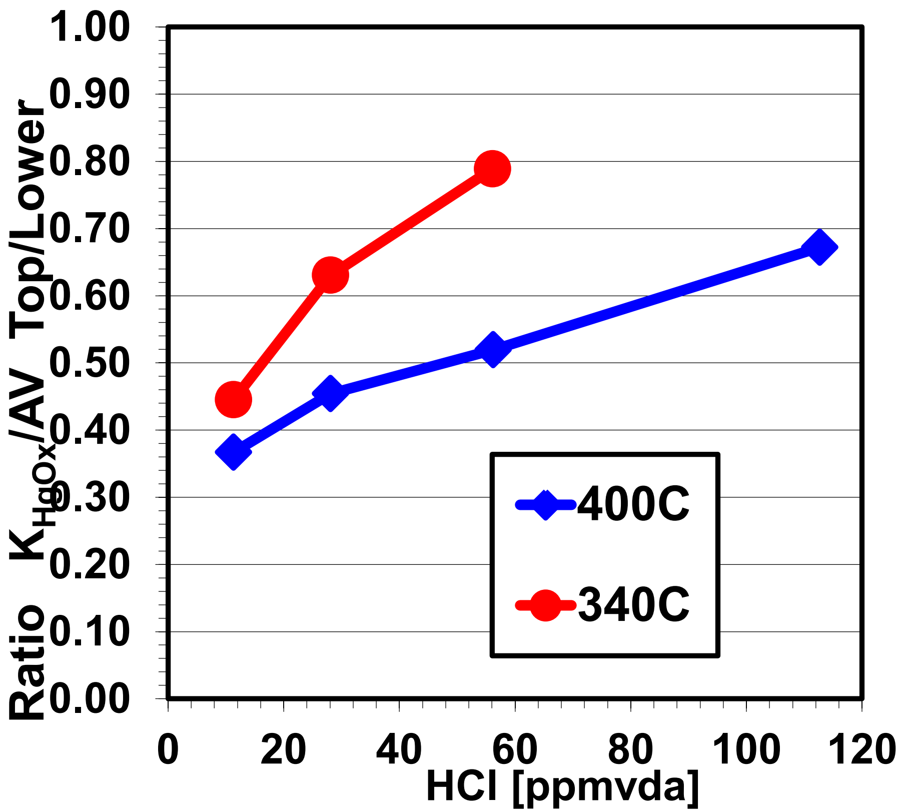
$$\frac{K}{AV} = -\ln[1 - \%DeNOx]$$

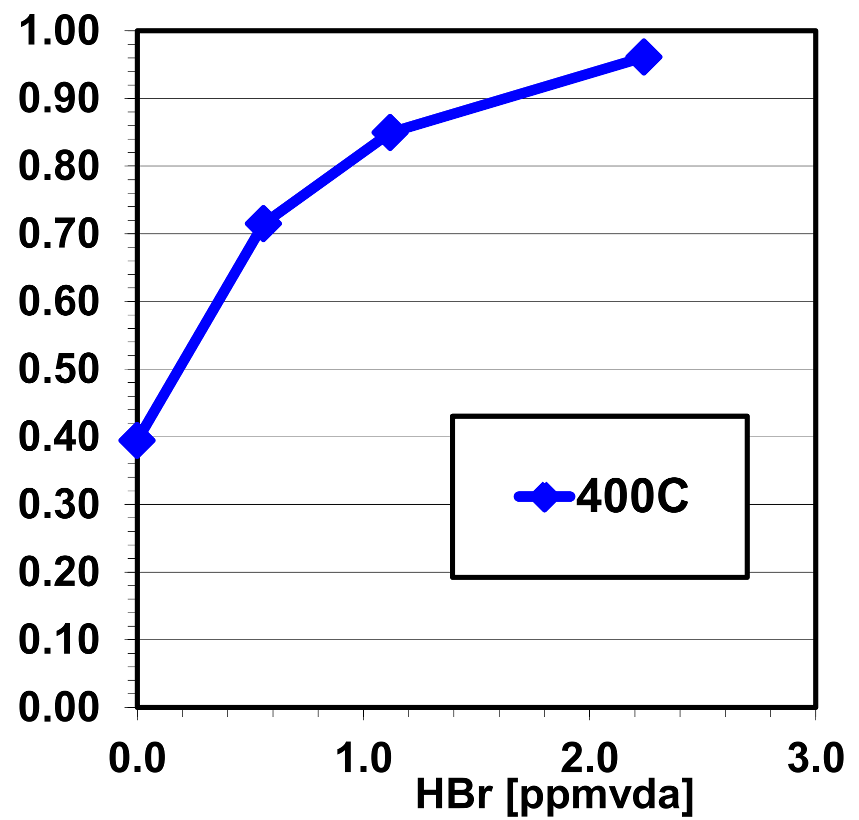
@ MR=1

For Illustration →

$$\frac{K_{HgOx}}{AV} = -\ln[1 - \%HgOx]$$

f(variable MR)





- Due NH3 inhibition, Hg oxidation potential depends on layer position.
- The degree of dependency is dependent on temperature and halogen content

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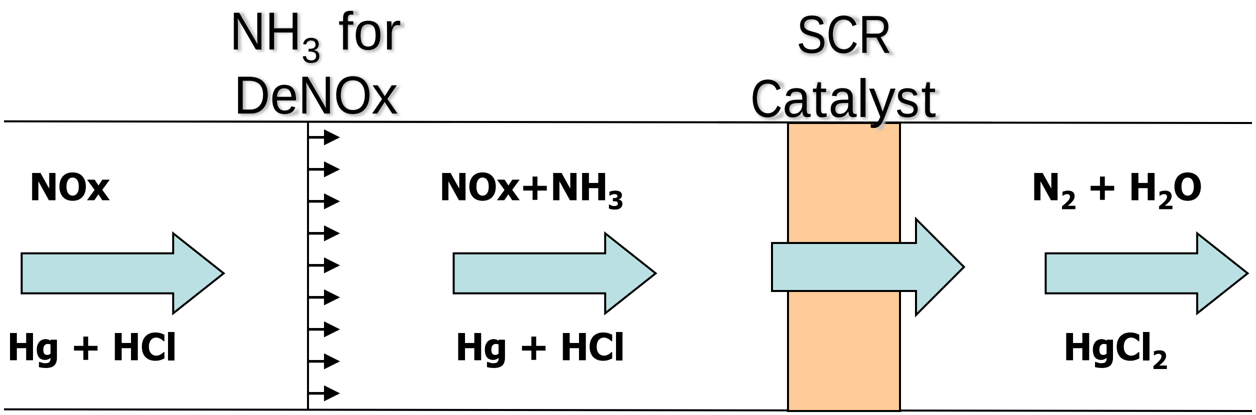
Catalyst Improvements

Desired Reactions:

$NO + NH_3 + 1/4\ O_2 \rightarrow N_2 + 3/2\ H_2O$ (NO$_x$ Reduction)

$Hg + 2\ HCl + ½\ O_2 \rightarrow HgCl_2 + H_2O$ (Hg Oxidation)



Undesired Reactions:

$HgCl_2 + NH_3 + ¼\ O_2 \rightarrow Hg + 2\ HCl + ½\ N_2 + ½\ H_2O$ (HgCl$_2$ Reduction by NH$_3$)

$HgCl_2 + SO_2 + H_2O \rightarrow Hg + 2\ HCl + SO_3$ (HgCl$_2$ Reduction by SO$_2$)

$SO_2 + ½\ O_2 \rightarrow SO_3$ (SO$_2$ Oxidation)

Enhance Desired Reactions while reducing Undesired Reactions

Catalyst Improvements

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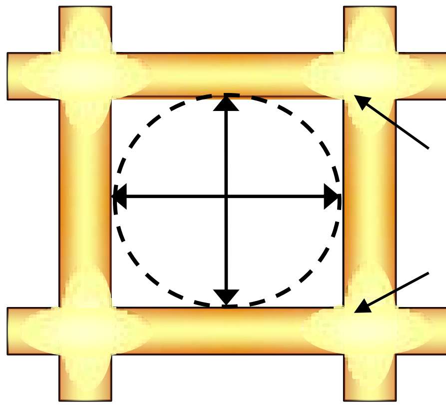
- Catalyst Properties & Reaction Mechanisms

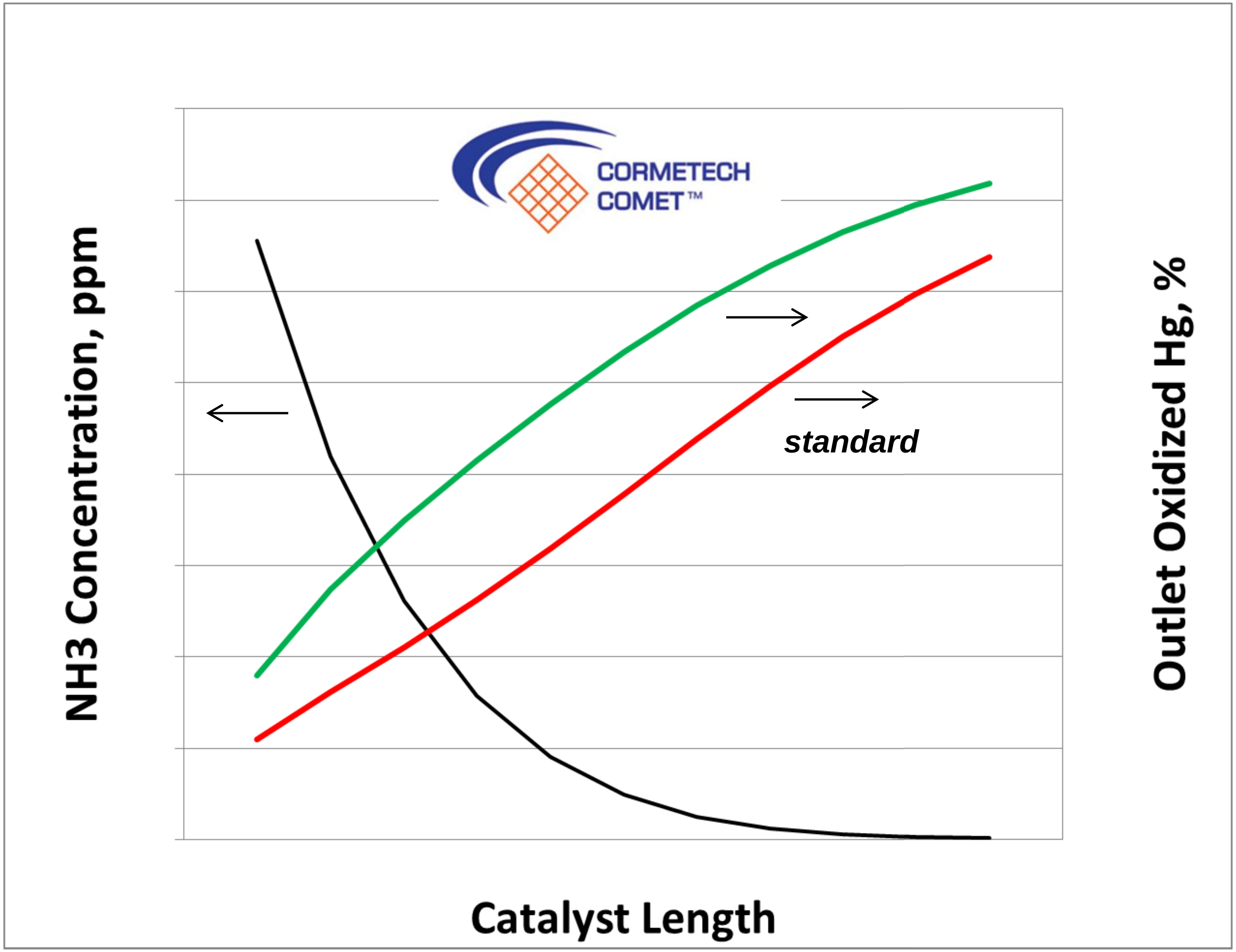


Fast DeNOx and Hg ox reactions limited by mass transport to wall (esp. corners). Slow SO2 oxidation reaction is not.

Patented Gradient Technology allows optimized utilization of active components

- Catalyst Formulations
  - Enhanced formulations which allow greater utilization and/or enhanced capability to apply higher levels of active components through suppression of negative reactions

Ammonia & Hg Ox. vs. Length



Catalyst Improvements

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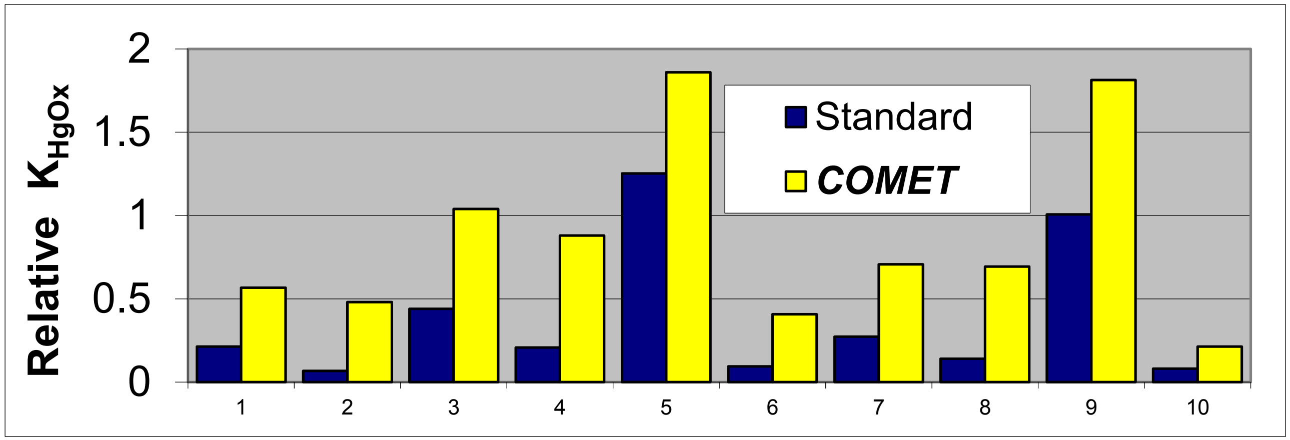
Constants	
Temp C	**403**
NOx ppm	107
O2 %	3.5
H2O %	14
SO2 ppm	345
HCl ppm	**8**

PRB Unit - Case Study: COMET™ –vs-Traditional

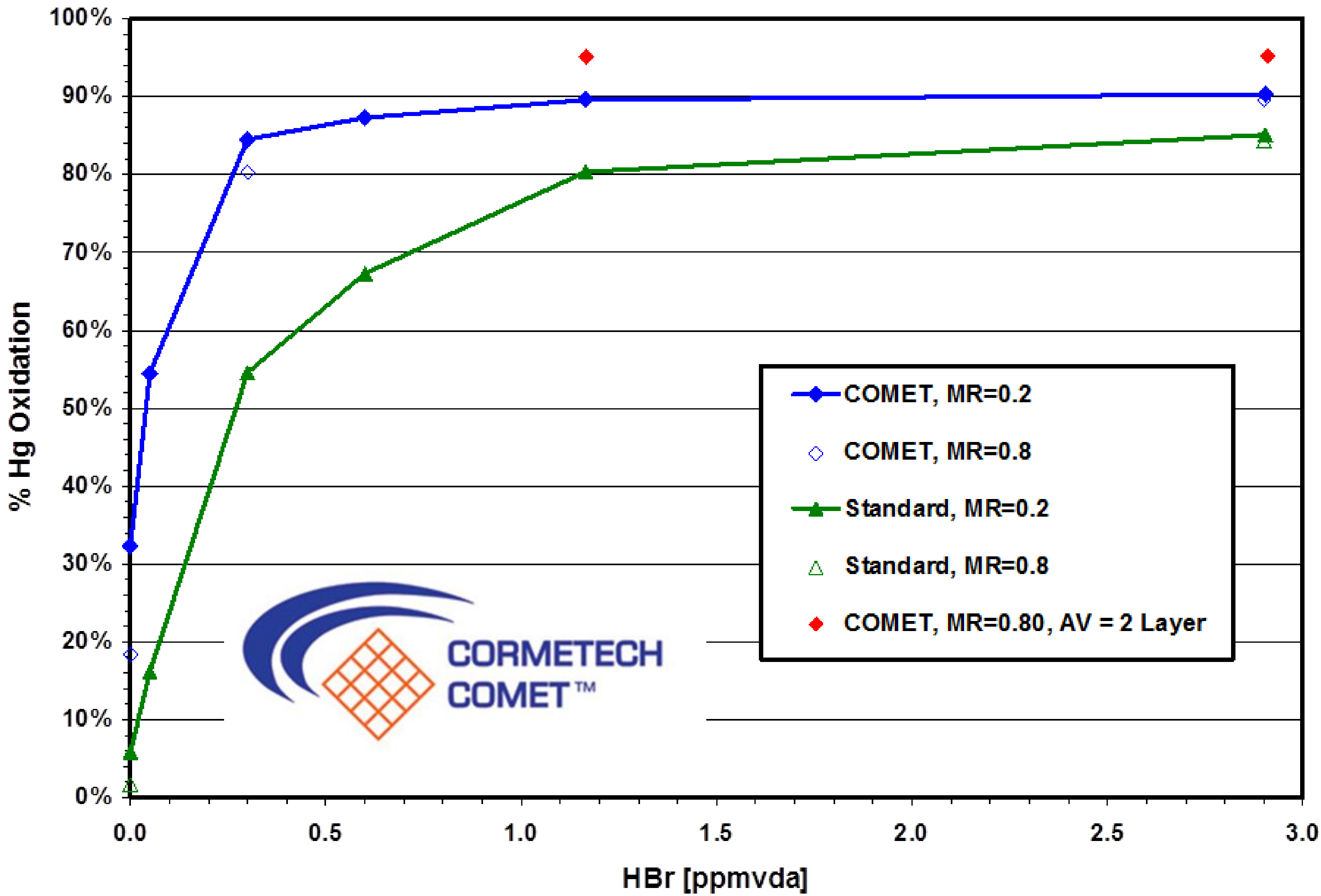


NH3	**ppm**	**0**	**0**	**0**	**0**	**0**	**21**	**21**	**21**	**21**	**86**
CO	**ppm**	**0**	**100**	**0**	**100**	**0**	**0**	**0**	**100**	**0**	**0**
HBr	**ppm**	**0**	**0**	**0.1**	**0.1**	**1**	**0**	**0.1**	**0.1**	**1**	**0**

From 50% to 400% higher Hg ox Activity
With 10% higher DeNOx Activity
SO_2 conversion maintained & lowered sensitivity to reducing species

Levers can be custom balanced to reduce SO_2 conversion with same DeNox activity, etc.

Catalyst Improvements



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Key factors: Hg in Coal
(% Removal @ 1.2 lb/TBTU emission)

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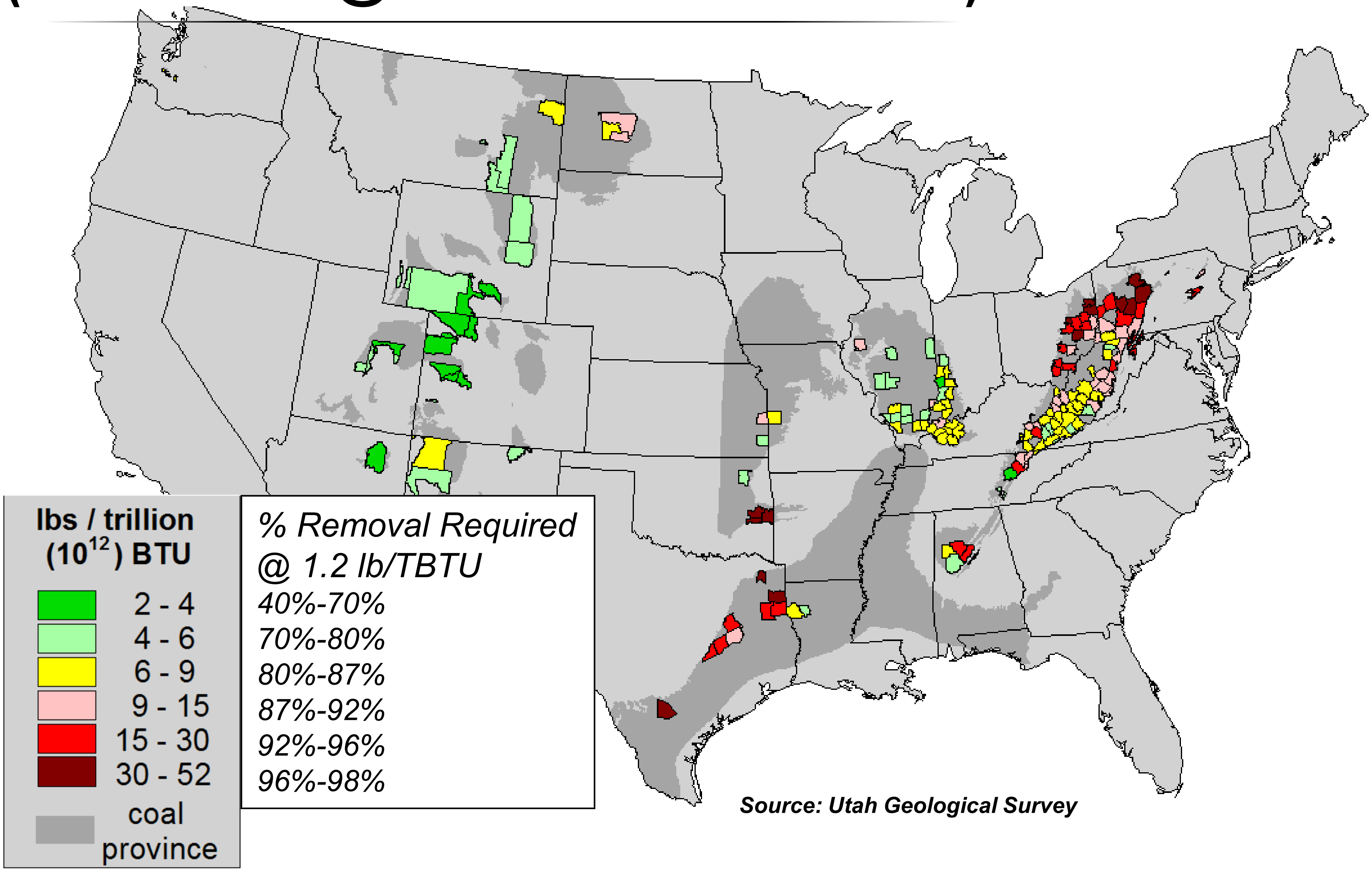

Source: Utah Geological Survey

Key factors: Chlorine in Coal

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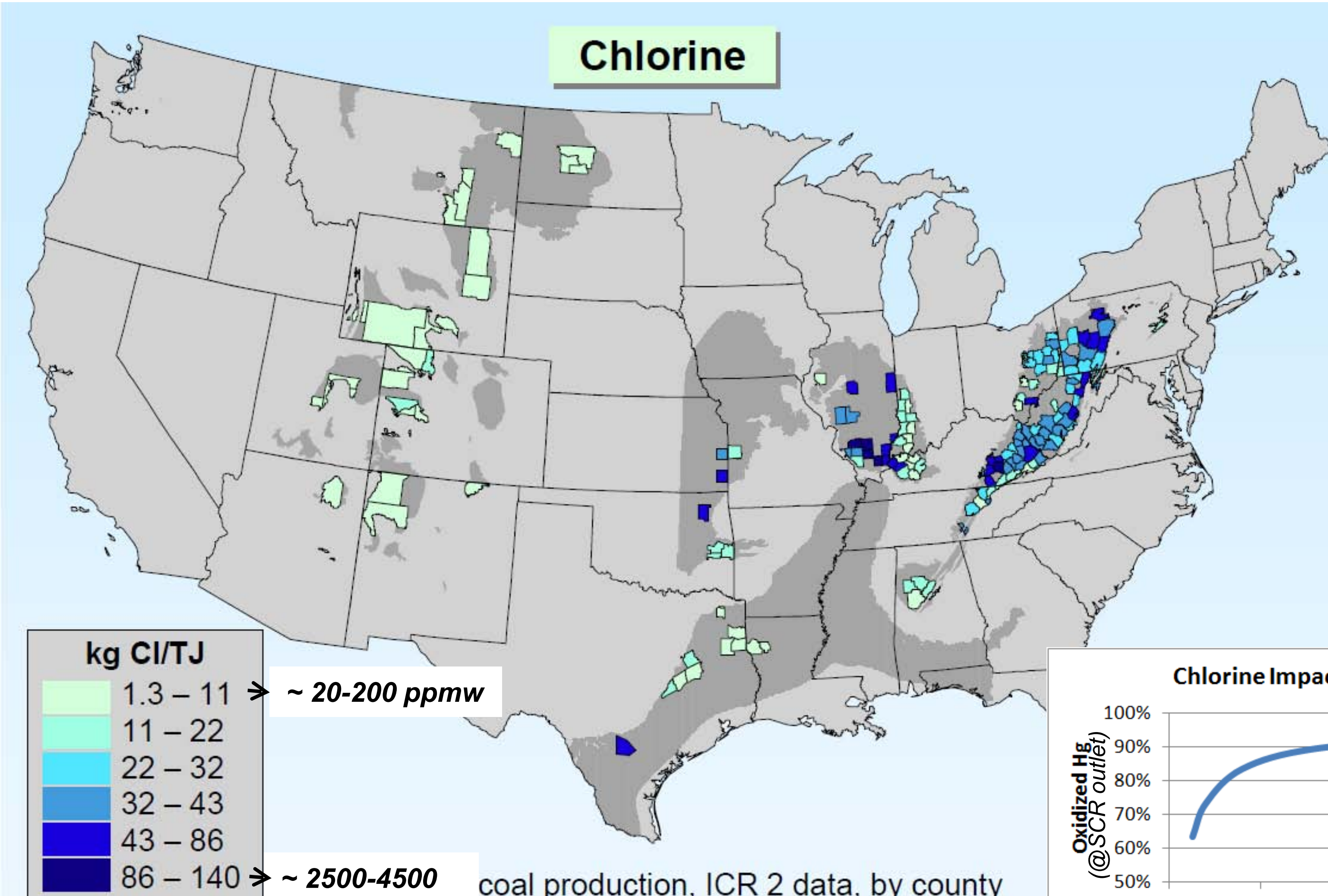
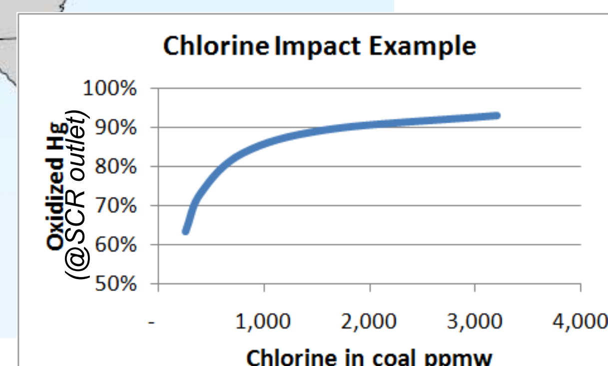


~ 20-200 ppmw

~ 2500-4500 ppmw

Source: Utah Geological Survey



Background: Key Factors Impacting Hg Emissions with Co-Benefits (ACI separate)

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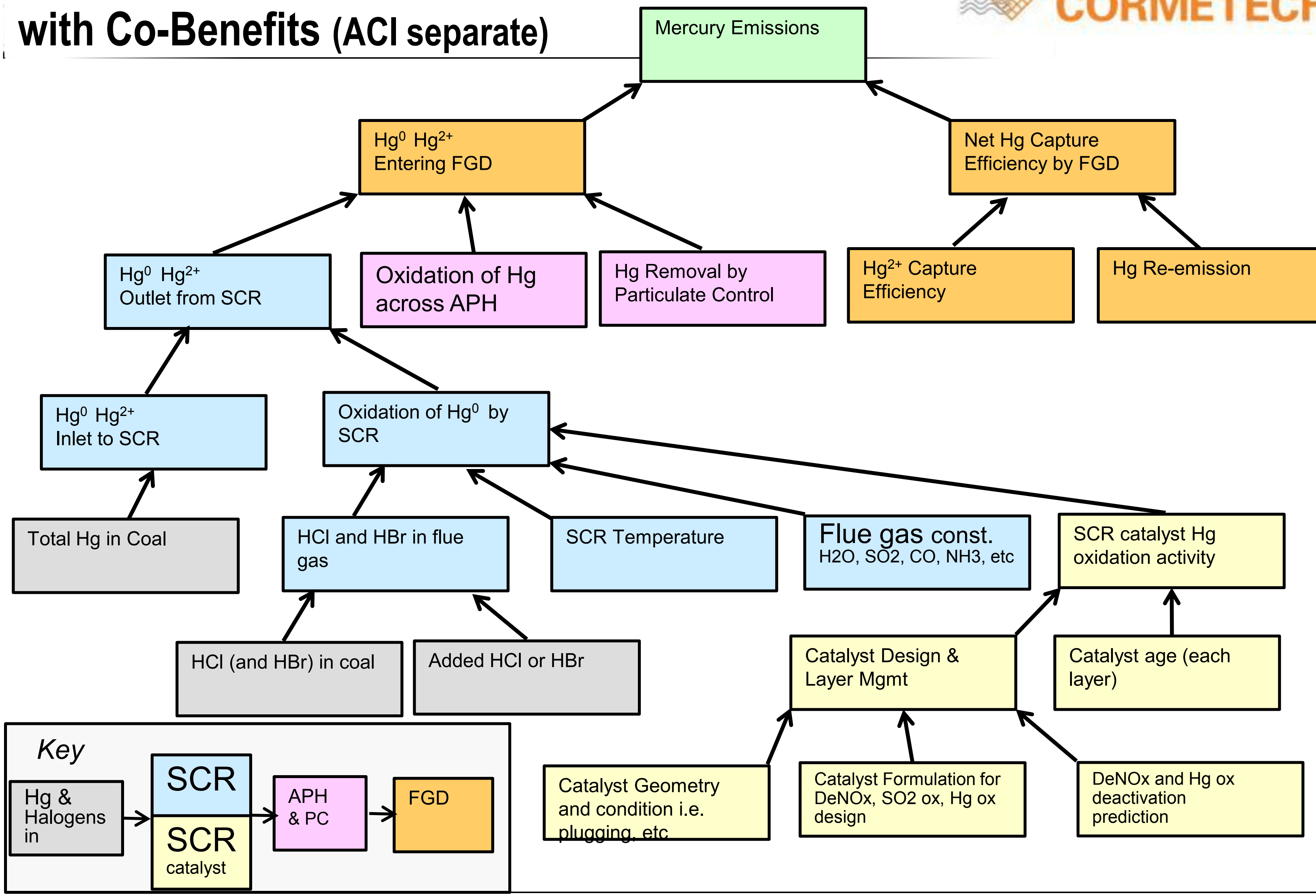

Evaluation to set Catalyst Targets

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No Halogen, ACI or DSI

lb/Tbtu	Inlet	SCR	APH	PM/ACI	FGD	Net Reduction/Outlet	Notes
	10						
SCR							
Oxidation efficiency		84%					
Oxidized in device		8.37					
Elemental from device		1.63					
APH							
Oxidation efficiency			35%				
Oxidized in device			0.57				
Elemental from device			1.06				
Total oxidized			8.94				
ESP/Baghouse + optional ACI	**no ACI**						
Oxidation efficiency				10%			
Oxidized in device				0.11			
Elemental from device				0.95			
Total oxidized				9.05			
Particulate removal % elemental				10%			
Particulate removal % oxidized				10%			
Net elemental from device				0.86			
Net oxidized from device				8.14			
WFGD							
Collection efficiency					96%		
Oxidized available for collection					8.14		
Elemental					0.86		
Outlet (No credit for PM bound)						**88.0%**	
						1.2	Outlet Hg elemental + oxidized
						10.00	balance check

Note: No halogen injection in this case therefore no additional Hg Ox benefit taken for interaction

Evaluation to set Catalyst Targets

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With DSI -- No Halogen, or ACI

lb/Tbtu	Inlet	SCR	APH	PM/ACI	FGD	Net Reduction/Outlet	Notes
	10						
SCR							
Oxidation efficiency		81%					**may also benefit SCR cat act.**
Oxidized in device		8.05					
Elemental from device		1.95					
APH							
Oxidation efficiency	**w/ DSI**		50%				**lower APH outlet temp**
Oxidized in device			0.97				
Elemental from device			0.97				
Total oxidized			9.03				
ESP/Baghouse + optional ACI	**w/o ACI**						
Oxidation efficiency				10%			
Oxidized in device				0.10			
Elemental from device				0.88			
Total oxidized				9.12			
Particulate removal % elemental				10%			
Particulate removal % oxidized				10%			
Net elemental from device				0.79			
Net oxidized from device				8.21			
WFGD							
Collection efficiency					95%		
Oxidized available for collection					8.21		
Elemental					0.79		
Outlet (No credit for PM bound)						**88.0%**	
						1.2	Outlet Hg elemental + oxidized
						10.00	balance check

Note: No halogen injection in this case therefore no additional Hg Ox benefit taken for interaction

Evaluation to set Catalyst Targets

With ACI -- No Halogen, or DSI

lb/Tbtu	Inlet	SCR	APH	PM/ACI	FGD	Net Reduction/Outlet	Notes
	10						
SCR							
Oxidation efficiency		78%					
Oxidized in device		7.75					
Elemental from device		2.25					
APH							
Oxidation efficiency			35%				
Oxidized in device			0.79				
Elemental from device			1.46				
Total oxidized			8.54				
ESP/Baghouse + optional ACI	**w/ACI**						
Oxidation efficiency				40%			**low-med ACI usage/effect**
Oxidized in device				0.58			
Elemental from device				0.88			
Total oxidized				9.12			
Particulate removal % elemental				10%			
Particulate removal % oxidized				10%			
Net elemental from device				0.79			
Net oxidized from device				8.21			
WFGD							
Collection efficiency					95%		
Oxidized available for collection					8.21		
Elemental					0.79		
Outlet (No credit for PM bound)						**88.0%**	
						1.2	Outlet Hg elemental + oxidized
						10.00	balance check

Note: No halogen injection in this case therefore no additional Hg Ox benefit taken for interaction

Evaluation to set Catalyst Targets

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With ACI & DSI -- No Halogen

lb/Tbtu	Inlet	SCR	APH	PM/ACI	FGD	Net Reduction/Outlet	Notes
	10						
SCR							
Oxidation efficiency		56%					**may also benefit SCR cat act.**
Oxidized in device		5.61					
Elemental from device		4.39					
APH							
Oxidation efficiency	**w/ DSI**		50%				**lower APH outlet temp**
Oxidized in device			2.19				
Elemental from device			2.19				
Total oxidized			7.81				
ESP/Baghouse + optional ACI	**w/ACI**						
Oxidation efficiency				60%			**mod. ACI use/effect (lower SO3)**
Oxidized in device				1.32			
Elemental from device				0.88			
Total oxidized				9.12			
Particulate removal % elemental				10%			
Particulate removal % oxidized				10%			
Net elemental from device				0.79			
Net oxidized from device				8.21			
WFGD							
Collection efficiency					95%		
Oxidized available for collection					8.21		
Elemental					0.79		
Outlet (No credit for PM bound)						**88.0%**	
						1.2	Outlet Hg elemental + oxidized
						10.00	balance check

Note: No halogen injection in this case therefore no additional Hg Ox benefit taken for interaction

Target Summary

Inlet Hg lb/Tbtu		10	10	10	10	20
	Outlet Hg lb/Tbtu					
SCR Requirement	1.2	84%	81%	78%	56%	91%
SCR Requirement	1.0	88%	86%	84%	68%	97%
DSI		✗	✓	✗	✓	✓
ACI		✗	✗	✓	✓	✓
APH		✓	✓	✓	✓	✓
PM		✓	✓	✓	✓	✓
FGD		✓	✓	✓	✓	✓

Note: No non-SCR halogen injection benefit or Hg PM slip assumed in scenarios shown

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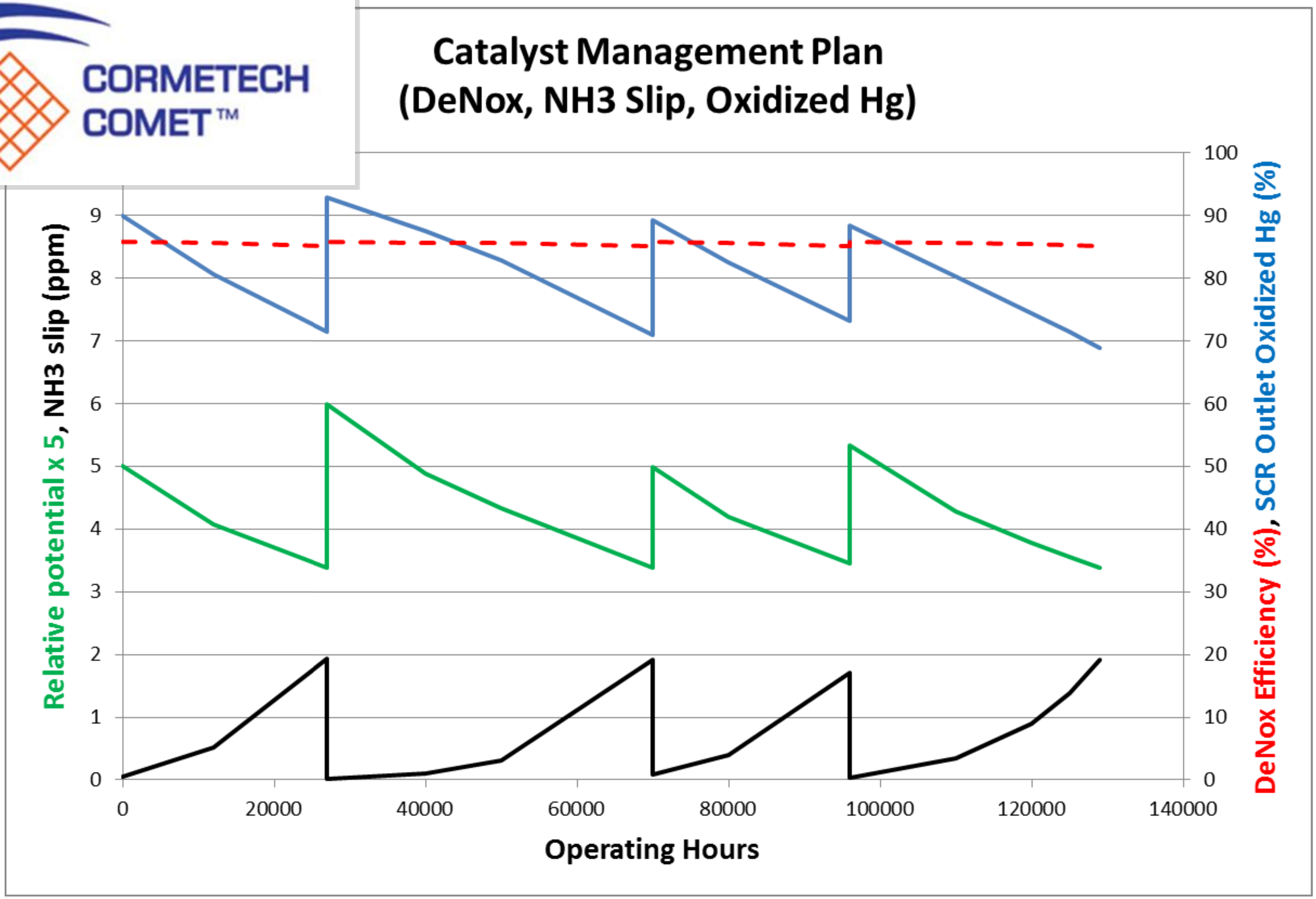
Management Plan w/ DeNox Potential & Hg Oxidation



Management Plan w/ DeNox Potential & Hg Oxidation

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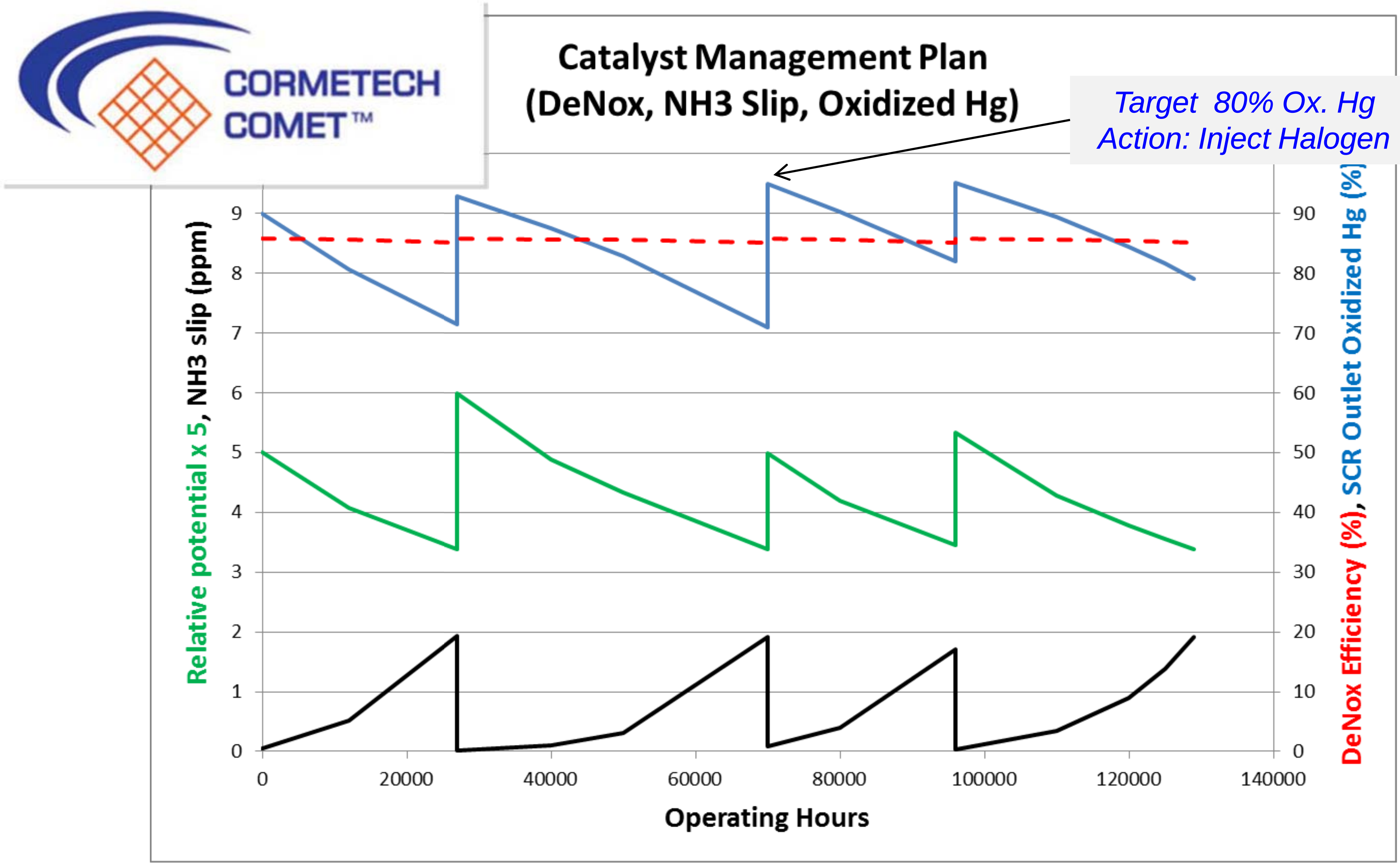

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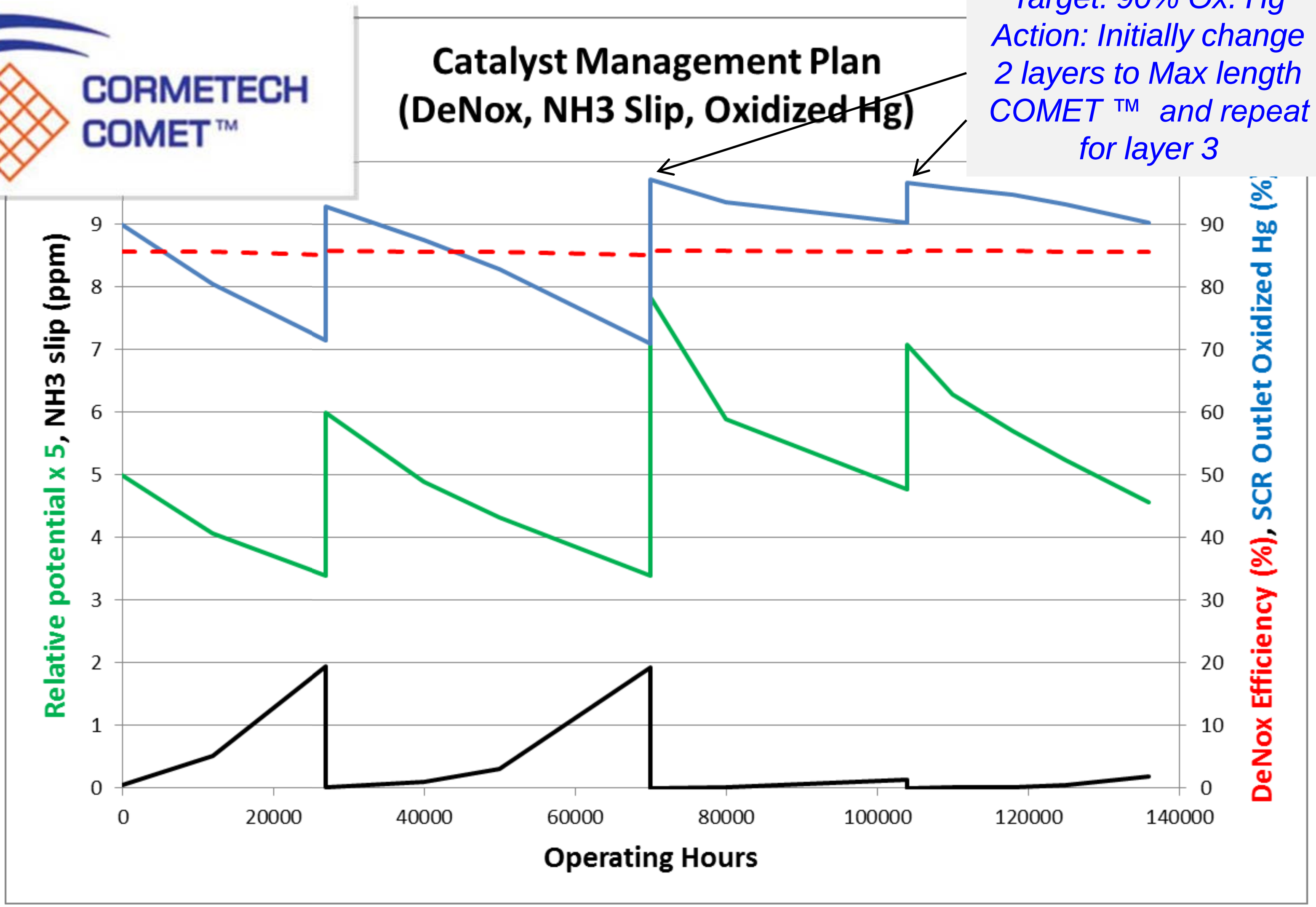
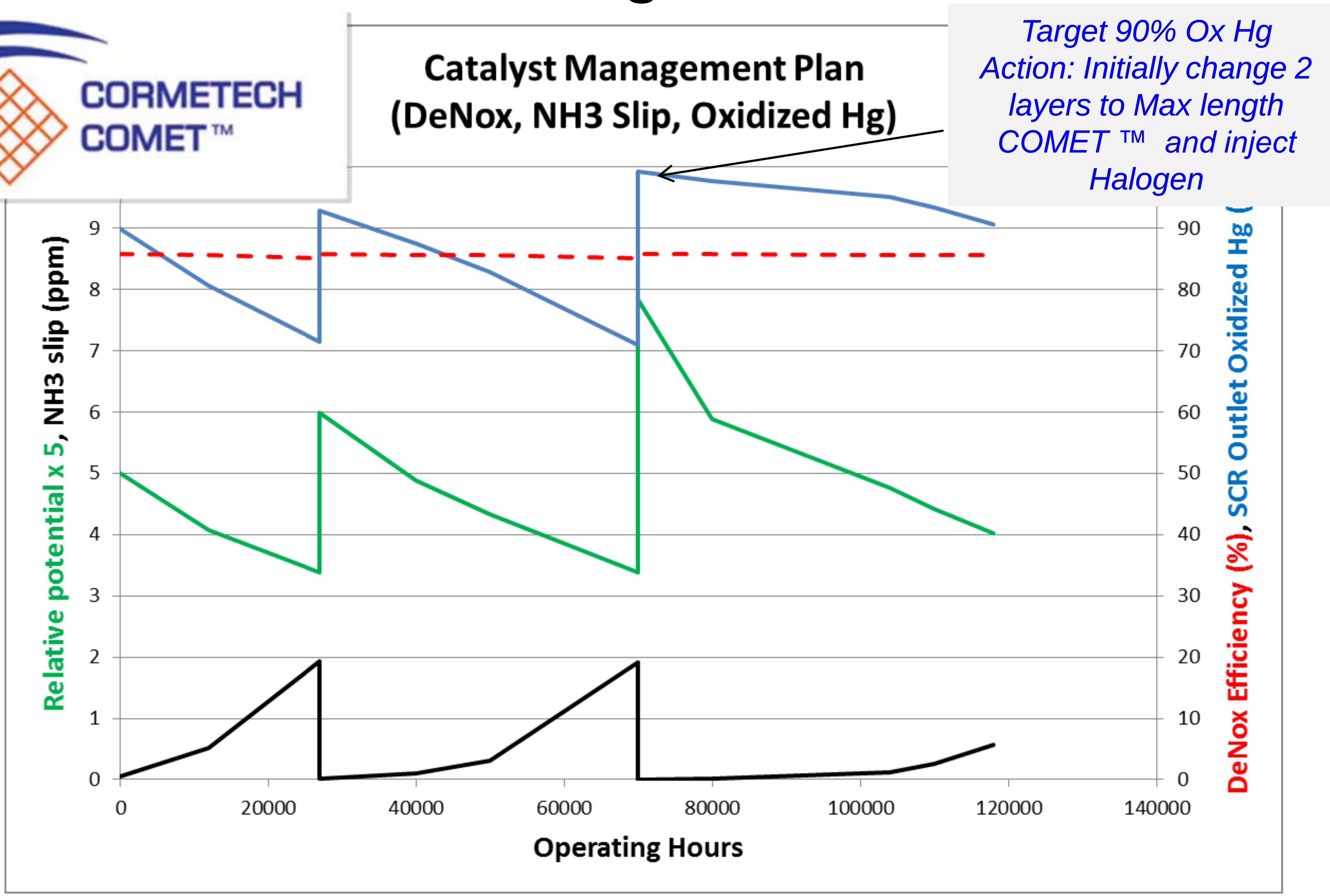


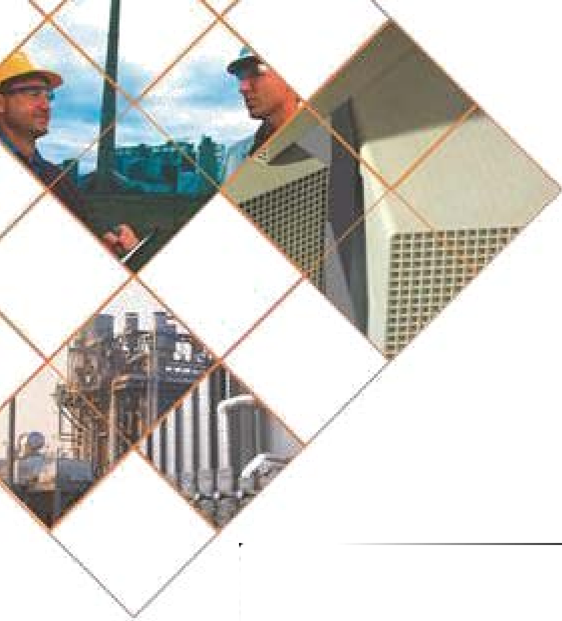
Management Plan w/ DeNox Potential & Hg Oxidation



Summary

- Catalyst additions and replacements can be managed to maintain Hg oxidation in a manner analogous to that for DeNOx, but with a few key differences:
  - Perf. Threshold (dependency on downstream equipment)
  - Layer dependency
    - Layer location and NH_3 inlet to each layer must be considered
  - More factors are needed in setting design conditions
    - HCl, HBr, CO; and more significant impacts of Temperature, O_2, and H_2O
- Understanding these dependencies, factors, requires thorough demonstrated testing capability, catalyst technology and application knowhow

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



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Thank You!

Questions/Discussion

Scot Pritchard

Cormetech, Inc.

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