REINHOLD ENVIRONMENTAL Ltd.

2014 NOx-Combustion Round Table & Expo Presentations

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Balancing LNB vs SCR Catalyst Layers

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Overview of Tradeoffs in a New Era

2014 Reinhold NOx-Combustion Round Table
Charlotte, NC

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Overview

- Historical Background – How We Got Here
- What Has Changed
- Options & Trade-Offs Going Forward
- Conclusions/Recommendations

Historical Background

- Vast Majority of Fuels – Bituminous
  - Some Powder River Basin
  - Other Fuels
    - Pet Coke
  - Fuel outlook seemed more certain except for units that were not scrubbed yet
  - Major Issues
    - Arsenic
      - High Arsenic Concentrations with Low Calcium Concentrations
      - European Experience
    - SO_3 Emissions
    - LPA

Historical Background

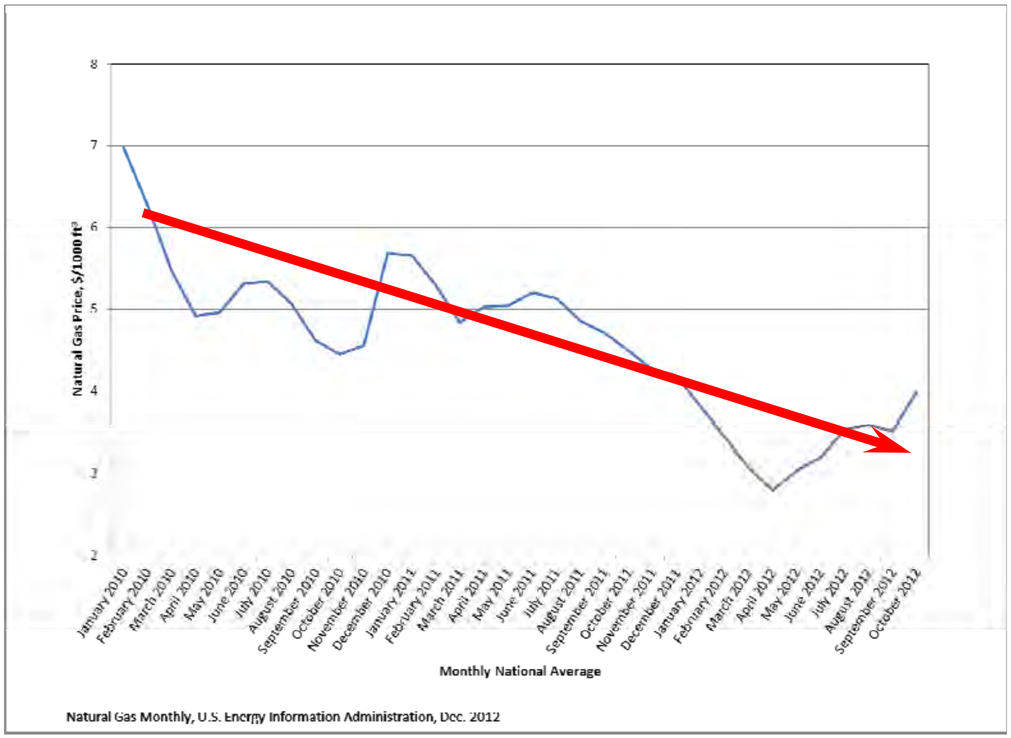
- Operational Considerations
  - Ozone season and year round
  - All new catalyst (HC, plate, corrugated)
  - Base loaded
  - European and Japanese experience base for maintenance expectations
- Reagent
  - Anhydrous
  - Big Shift to Urea
    - Issues with Surrounding Community
  - Aqueous
    - Smaller Units

New (and Renewed) Issues

- Fuels
  - Western Bituminous
  - Powder River Basin
  - Greater Deactivation Levels prevalent on Staged Combustion Units
- Mercury Emissions
  - SCR Hg Oxidation as a Co-Benefit
- Lower SO_3 Levels
  - Effect of SO_3 on Powder Activated Carbon Usage
  - Opacity Issues With SO_2 Control Equipment
    - Wet Scrubbers
  - Higher need to balance with catalyst life & Co-benefit drivers
- Longer initial catalyst life expectations
  - Up to 32k hours vs. 16-24k hours

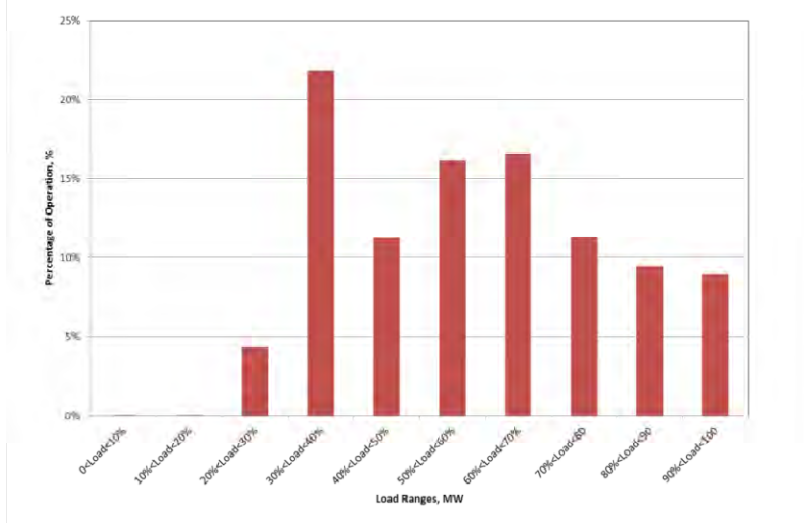
New (and Renewed) Issues

- Operational Considerations
- Base Loaded Units Being Run at Lower Load
  - Natural Gas Pricing & Renewables



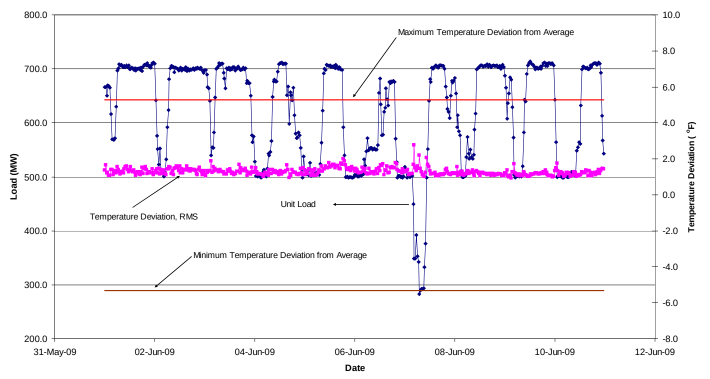
New (and Renewed) Issues

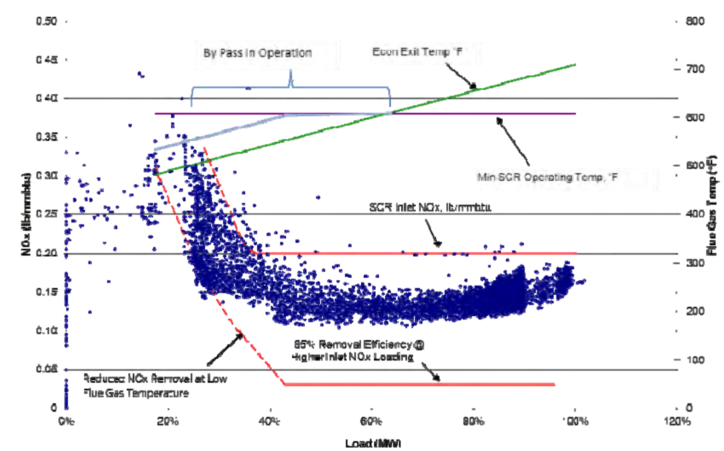
- Short-Term to intermediate-term SCR layup
  - Boiler shutdown
  - SCR bypass (tonnage vs. rate)
- Reagent
  - Renewed Interest in Aqueous and Anhydrous Ammonia



Options for Low Load and Start UP NOx Control

- Oversize SCR/Catalyst for Increased NOx Removal
- Flue Temperature Control
  - Flue Gas Bypass, Water Side Bypass, etc. → Impact on Heat Rate
- Reduced Temperature Variation
- Reduced NOx Removal at Lower Load
  - ABS Formation Temperature = Function (H_2O, SO_3, NH_3)
  - Lower Ammonia Concentrations Reduces Minimum Operating Temperature





Options for Low Load and Start UP NOx Control

- Transient SCR Operation – Temporary Operating Below ABS Formation Temperature
- Additional Combustion Control For When SCR is Not in Operation
- Extended Range For Gas Firing
- Reduction in Number of Start Ups

Brief NOx Reduction Technology Comparison

Technology	LNB/OFA	SNCR	SCR
Reduction, %	30-60	20-50	90+
Advantages	• Cost • simplicity	• Cost	• Reduction and emissions • Pot. Hg co-benefits
Disadvantages	• LOI • corrosion • limited reduction	• Limited reduction • Risk of NH_3 slip • poor reagent util.	• Cost • SO3 conversion • pressure loss

Note: Technologies can be used in combination

Unit Design Basis

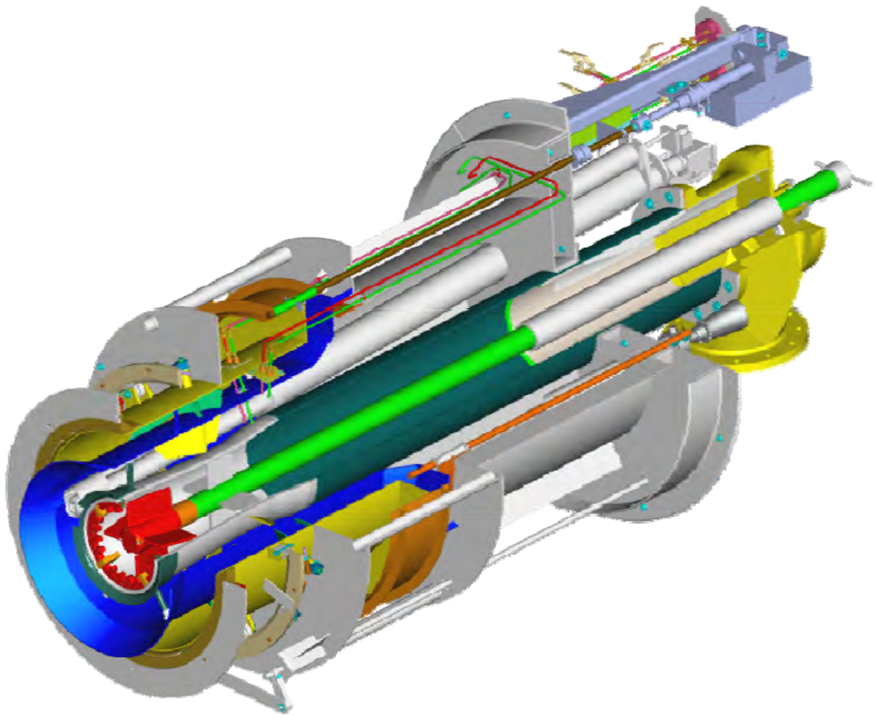
- 500 MW
- 9,500 Btu/Kwh
- Flue Gas Temperature at MCR – 670 ^{o}F
- Ammonia Slip – 2 ppm
- Arrangement – High Dust SCR, ESP/Baghouse, WFGD

Uncontrolled NOx (lbs/Mmbtu)

Fuel	Wall Fired	Tangential Fired
PRB	0.42	0.35
Western Bituminous	0.63	0.48

Combustion Modifications

- Reduced Catalyst & potential reactor cost
  - Incremental Cost of Increased NOx Reduction on SCR
- Proven Technology
- Reduced Reagent Cost
- Reduced Catalyst Cost
- NOx removal at Low Load/Start Up
- Combustion Control Impact on Catalyst Life



VS III® (Venturi Series)

Typical Low NOx Burner and Over fired Air Results

Coal Type	Wall Fired		Tangential Fired	
	Lbs./Mmbtu	%	Lbs./Mmbtu	%
PRB	0.22	47.6%	0.17	51.4%
Western Bituminous	0.32	49.2%	0.23	52.1%

Catalyst Design Basis

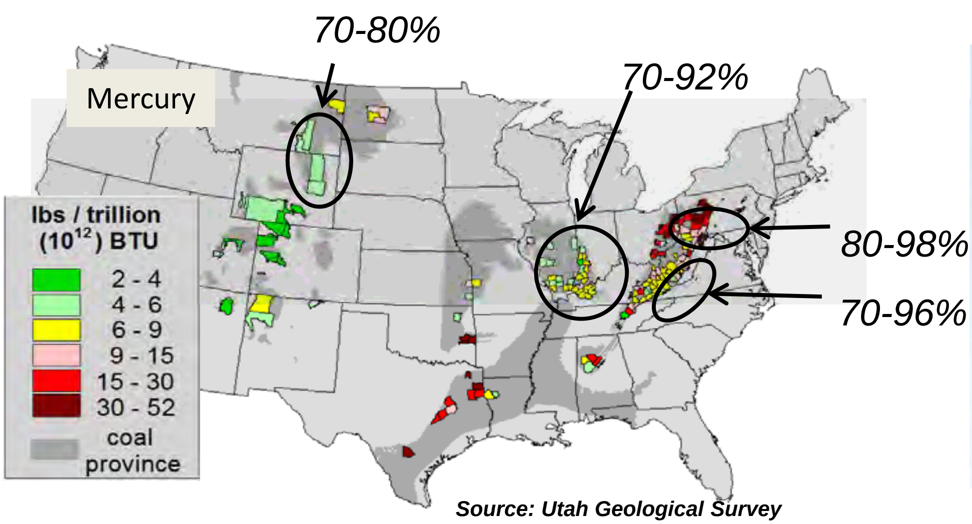
- Fuel – PRB or Western Bituminous
- Initial Catalyst Life – 24,000 hours
- Initial Catalyst SO_2 Conversion Rate
  - 1% PRB
  - ½% Western Bituminous
- Catalyst Pitch = 8 mm (optional 7 mm)
- Inlet NOx & Removal Efficiency → variable based on LNB/OFA Configuration with Outlet NOx = 0.05 lb/mmbtu
- Distributions
  - NH3:NOx 5% RMS
  - Temperature +/- 20 ^{o}F
  - Velocity 15% RMS

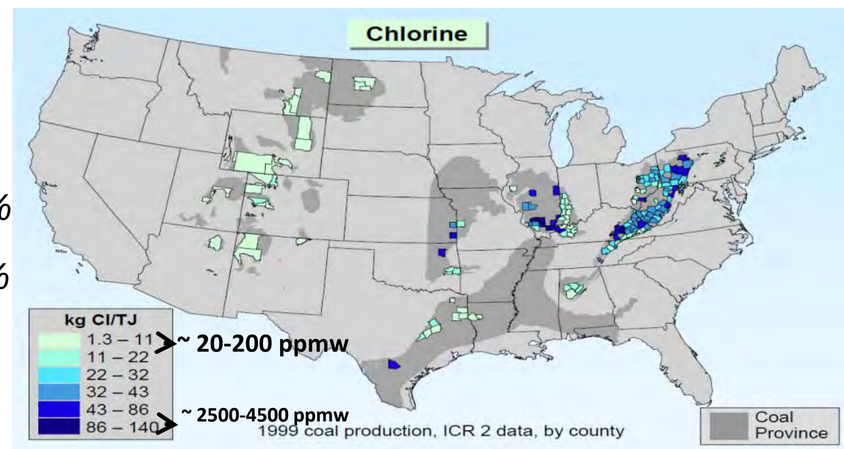
Economic Evaluation Basis

- Electric Cost - $0.05/Kw-hr
- Plant Life – 15 years
- Plant Load Factor – 90%
- Discount Value – 8%
- Ammonia Cost $500/Ton
- Catalyst Cost $5,500/$m^3$
- Burner with Over Fired Air Cost $12,000/MW
- Impact to PAC, halogens or other additive cost (not included)

Hg Oxidation Considerations

- Performance goals
  - 40% to 80+% Hg removal (not SCR Oxidation)
  - Considering APH, PM device, FGD influences translates to an SCR oxidation requirement of 20-80%





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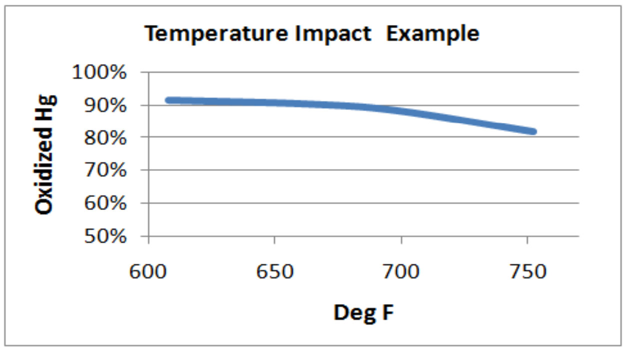
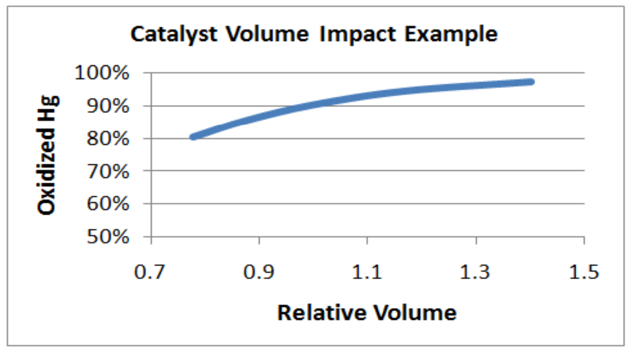
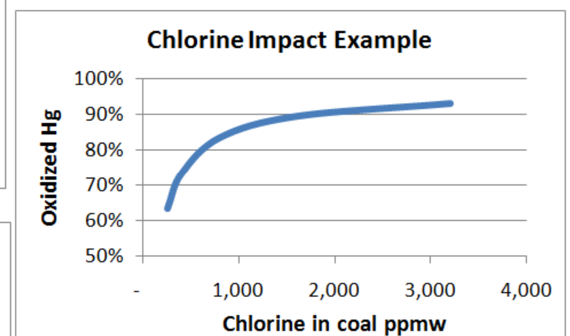
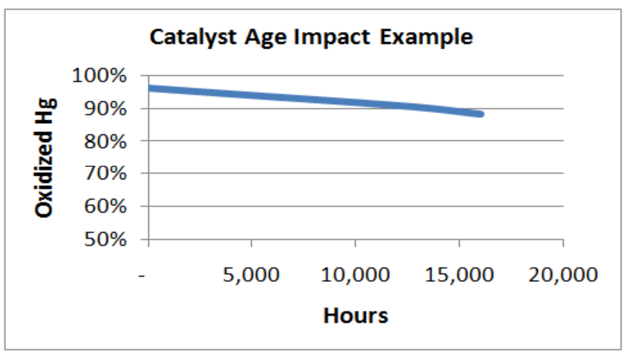
Hg Oxidation Considerations

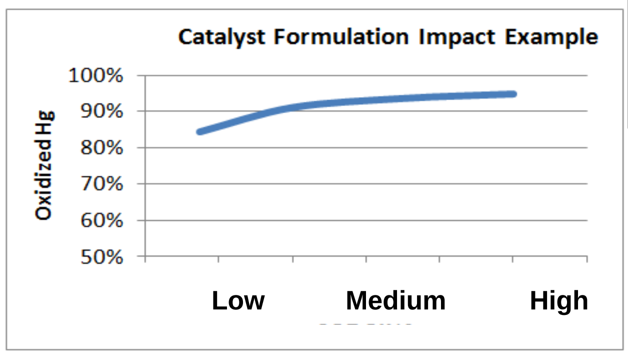
- Influences on performance











Others: H_2O, O_2, CO, HC's, NOx, NH3

(All values at SCR outlet)

*(Note: Specific **<u>example</u>** cases shown above to illustrate tendencies.)*

SCR Design With and Without LNB and OFA

- Firing Powder River Basin
- SO_2 Conversion Rate = 1%

Coal Type	Wall Fired		Tangential Fired	
	Without LNB-OFA	With LNB-OFA	Without LNB-OFA	With LNB-OFA
Required SCR NOx Reduction	88.1%	77.3%	85.7%	70.6%
Ammonia Flow, lbs/hr	690	320	560	227
Catalyst Volume, %	100%	129%	92%	108%
Flue Gas Pressure Drop, iwg	1.3	1.6	1.2	1.4

Complexity of Hg oxidation performance threshold must be evaluated on a case specific basis → lower NH_3 assists however potential for higher deactivation may offsets.

Savings With and Without LNB and OFA

Wall Fired Firing PRB Fuel

Case	SCR Only	LNB & OFA	Difference
Power NPV	$1,450,000	$1,780,000	$330,000
Ammonia NPV	$12,000,000	$5,600,000	($6,400,000)
Cost of LNB & OFA	N/A	$6,000,000	$6,000,000
Catalyst			$3,200,000
Total			$3,130,000

Additional cost assessment criteria for Hg oxidation may include one or all of the following; alternate catalyst, halogen addition, PAC.

Savings With and Without LNB and OFA

Tangential Fired Firing PRB Fuel

Case	SCR Only	LNB & OFA	Difference
Power NPV	$1,300,000	$1,560,000	$260,000
Ammonia NPV	$9,450,000	$3,800,000	($5,650,000)
Cost of LNB & OFA	N/A	$6,000,000	$6,000,000
Catalyst			$2,500,000
Totals			$3,110,000

Additional cost assessment criteria for Hg oxidation may include one or all of the following; alternate catalyst, halogen addition, PAC.

SCR Design With and Without LNB and OFA

- Firing Western Bituminous
- SO_2 Conversion Rate = ½ %
- 10 X 15 Catalyst Arrangement, 3 initial Layers

Coal Type	Wall Fired		Tangential Fired	
	Without LNB-OFA	With LNB-OFA	Without LNB-OFA	With LNB-OFA
Required SCR NOx Reduction	92.1%	84.4%	89.6%	78.3%
Ammonia Flow, lbs/hr	1080	504	800	338
Relative Catalyst Volume, %	100%	98%	79%	78%
Flue Gas Pressure Drop, iwg	1.8	1.7	1.5	1.4

Complexity of Hg oxidation performance threshold must be evaluated on a case specific basis → lower NH_3 assists however potential for higher deactivation may offsets.

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Savings With and Without LNB and OFA

Wall Fired Firing Western Bituminous Fuel

Case	SCR Only	LNB & OFA	Difference
Power NPV	$1,560,000	$1,470,000	($90,000)
Ammonia NPV	$18,200,000	$8,500,000	($9,700,000)
Cost of LNB & OFA	N/A	$6,000,000	$6,000,000
Catalyst			$800,000
Totals			($2,990,000)

Additional cost assessment criteria for Hg oxidation may include one or all of the following; alternate catalyst, halogen addition, PAC.

Savings With and Without LNB and OFA

Tangential Fired Firing Western Bituminous Fuel

Case	SCR Only	LNB & OFA	Difference
Power NPV	$1,200,000	$1,200,000	($100,000)
Ammonia NPV	$13,500,000	$5,700,000	($7,800,000)
Cost of LNB & OFA	N/A	$6,000,000	$6,000,000
Catalyst			$650,000
Totals			($1,250,000)

Additional cost assessment criteria for Hg oxidation may include one or all of the following; alternate catalyst, halogen addition, PAC.

Conclusions/Recommendations

- Each unit will be case specific
- For Western Bituminous fuels, the installation of LNB/OFA will assist in the overall compliance cost
- However for PRB fuels, the installation of LNB/OFA may not assist in compliance cost if higher catalyst deactivation rates are not mitigated
- Optimization of staging level should be explored:
  - Reduce catalyst deactivation and related volume
  - Balance against increased ammonia/reagent cost
  - Consider impact on Hg oxidation potential
  - Consider impacts of additives (Halogen, poison mitigation, PAC) through cost/benefit analysis

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