REINHOLD ENVIRONMENTAL Ltd.

2017 NOx-Combustion-CCR Round Table Presentation

February 27 & 28, 2017, in Cleveland, OH / Hosted by FirstEnergy

BENEFITS, IMPACTS & COSTS OF USING DSI TO REDUCE SCR MINIMUM OPERATING TEMPERATURES

WORKSHOP 1
2017 NOx-Combustion-CCR/PCUG Meeting
February 27, 2017
Cleveland, Ohio

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AGENDA

DSI and applications with hydrated lime

Benefits of DSI: compliance and beyond

SCR MOT: limitations, concerns & considerations

Business case for pre-SCR hydrate DSI

Applications and Case Study

Discussion/Questions

Hydrate DSI

>Low installed capital cost

> Relatively easy to retrofit to most plants

> Small equipment footprint

> Mechanically simple system

> Short installation schedule ~1 yr award to installation

> Low consumable requirements

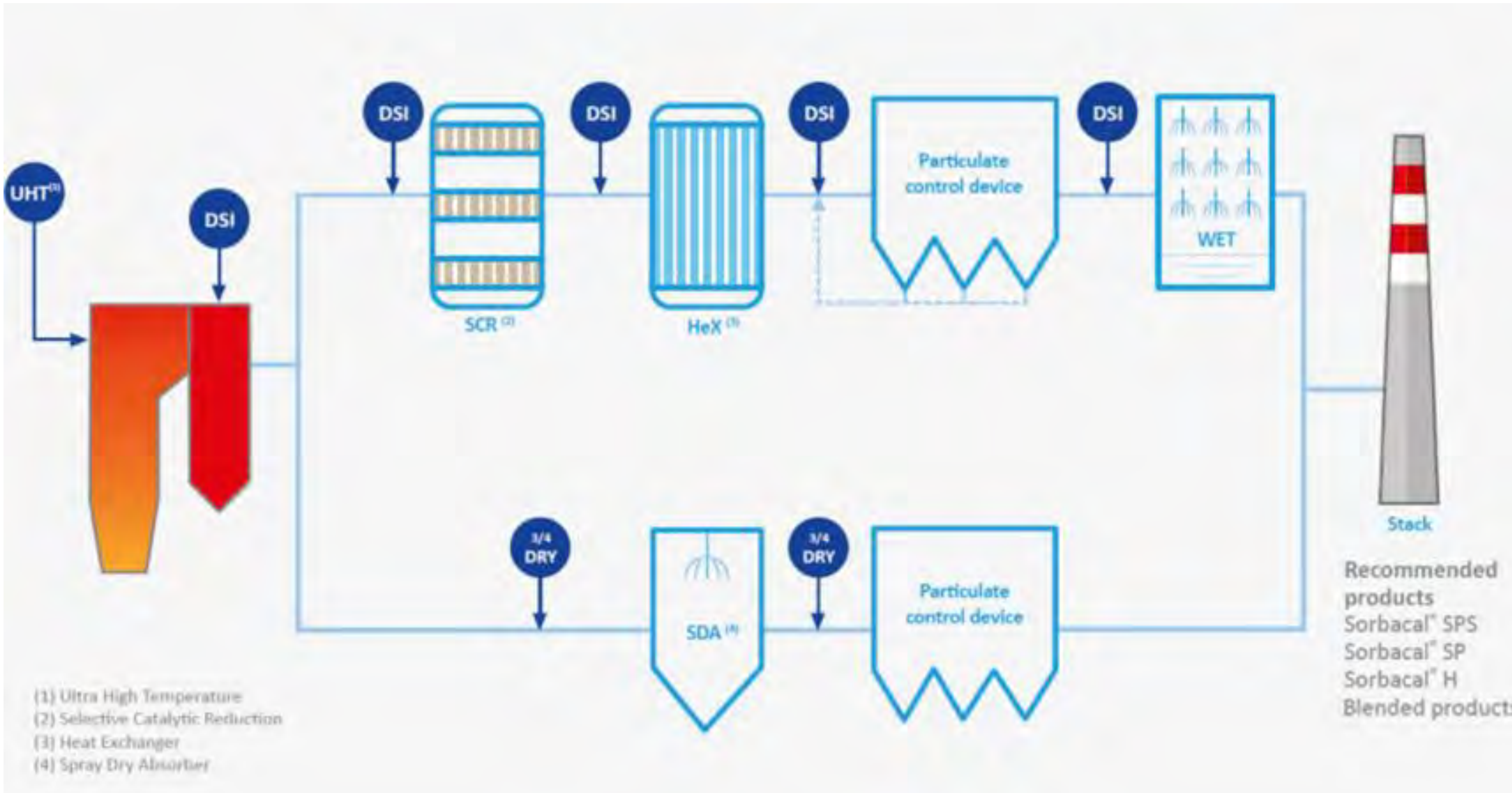
> Mature technology, advancements

> Operational Flexibility

> Removal performance significantly advanced for calcium sorbents over the last 5+ years

>SO_3
>HCl, HF
>SO_2
> And, …. broad applicability

Hydrate DSI Applications



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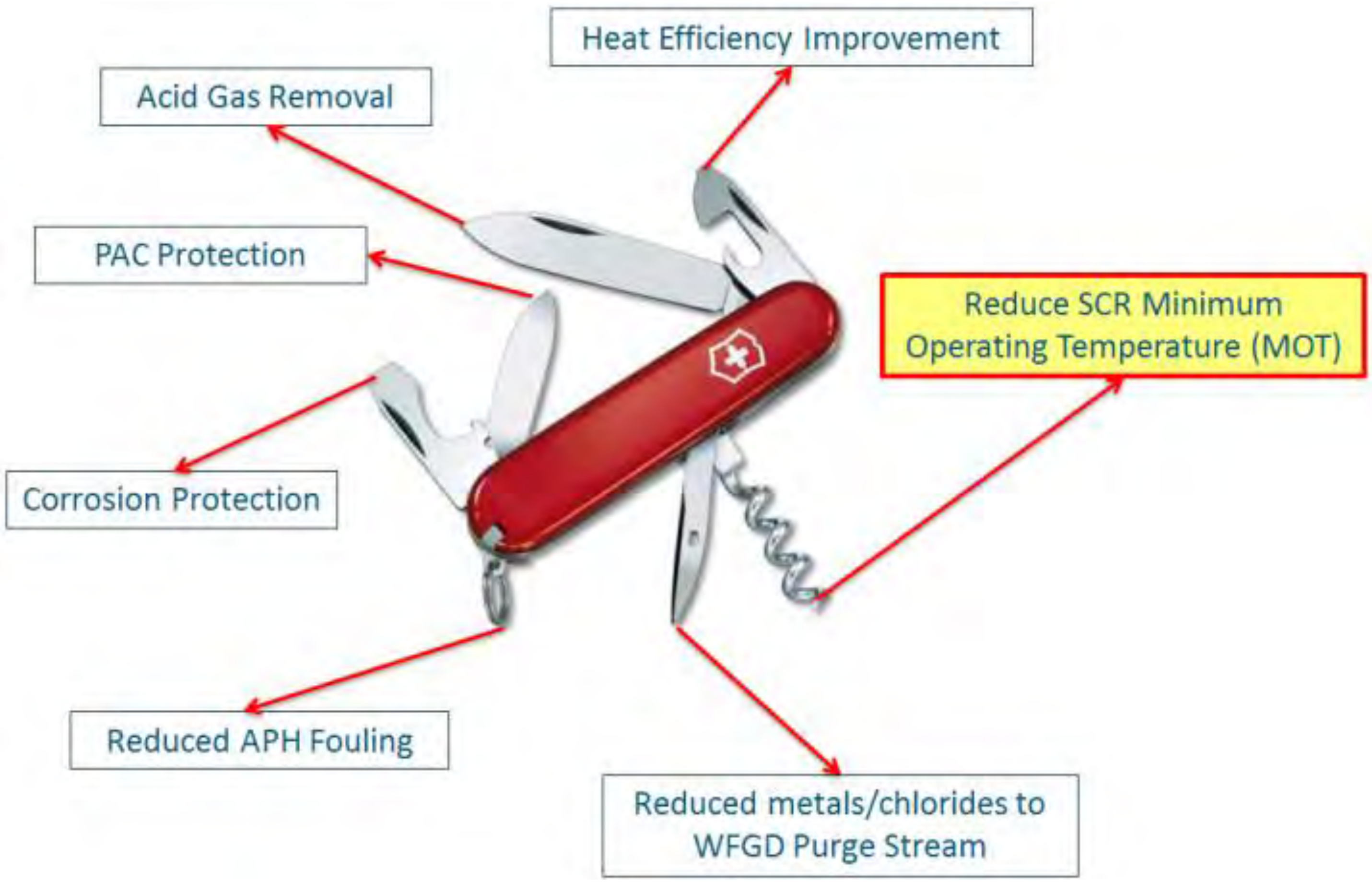
Swiss Army Knife® of Emissions Control Options



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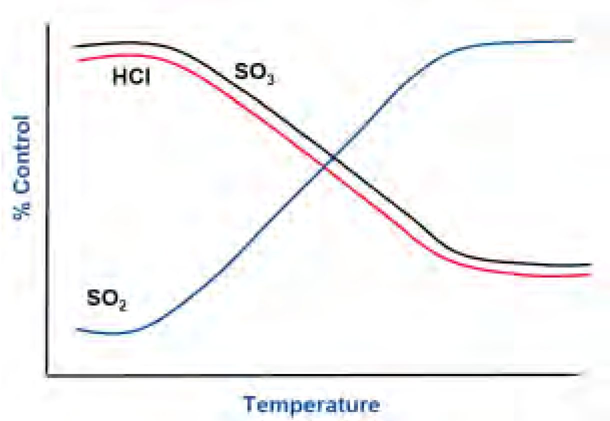
Hydrate DSI for SO_3 Control

Hydrate DSI can be applied across a full range of operating temperatures

The reactivity sequence between calcium hydroxide and select pollutants:
$SO_3 > HF > HCl >> SO_2 > CO_2$

Source: Karpf, Rudi H., Basic Features of the Dry Absorption Process, Paper, Germany, 2015



Source: Lhoist North America © 2017

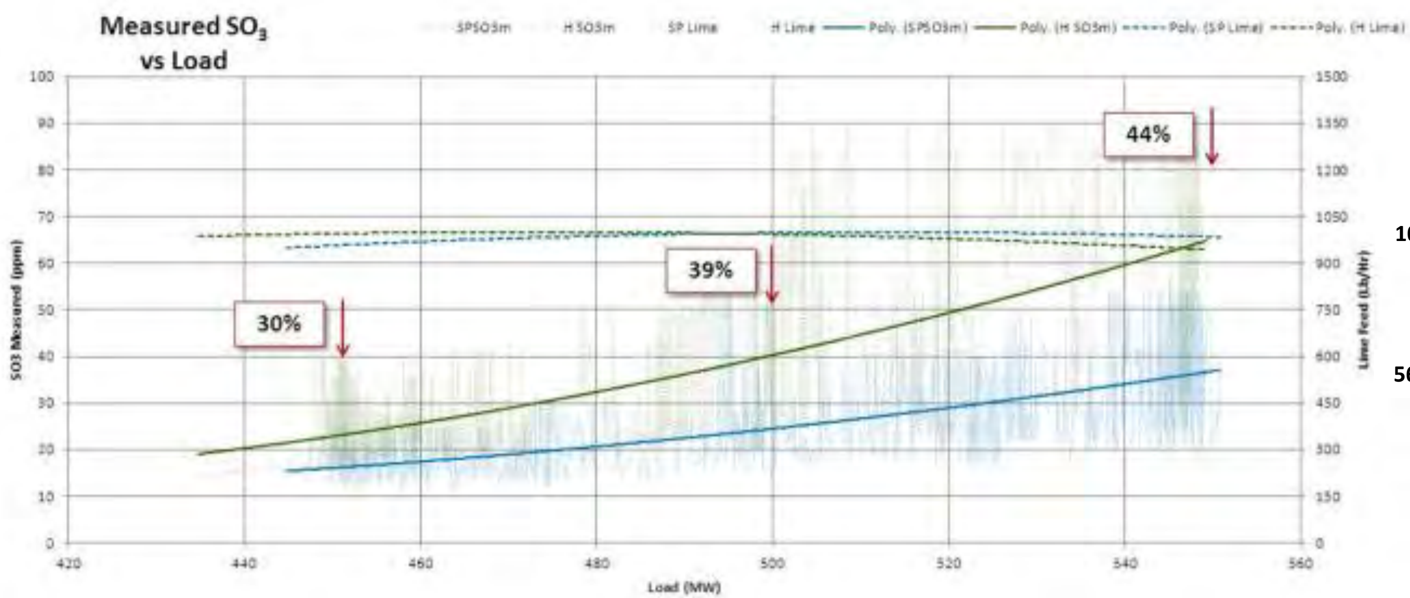
The impact of temperature on the relative control efficiency of hydrate for specific pollutants

Temperature impacts on SO_3 removal efficiency are low for temperature between 300 °C and 400 °C

Source: Chen, Peng et al, Experimental Study of the Reactivity of Ca-Based Matters with SO3, Power and Energy Engineering, Asian-Pacific Conference (APPEEC), 2011

Hydrate DSI Performance for SO_3 Control

Enhanced hydrates like Sorbacal® SP result in lower mass loading for equivalent performance



1025 lb/hr of Sorbacal® H

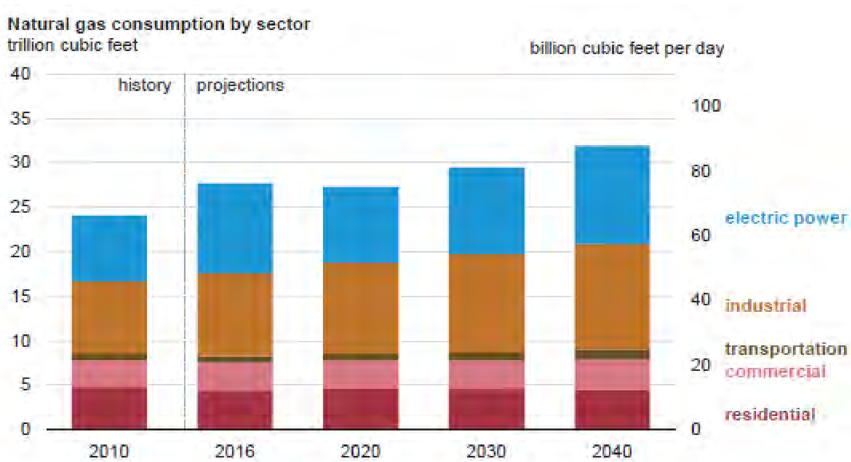
565 lb/hr Sorbacal® SP

Note: Data obtained by third-party during post-SCR injection. Use for illustrative purposes

Dispatch/Demand-based Impacts on Coal-fired Generation

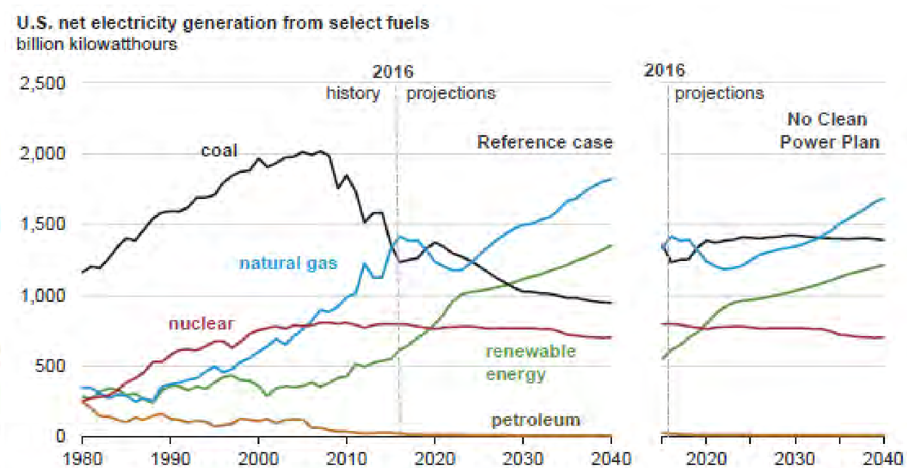
- **Economic dispatch**
  - base load plants forced to operate to cycle load or
  - Availability requirements force extended periods at low load operation
- **US utility market has shifted from coal generation to gas generation due to costs of fuel**
- **Underlying metrics for coal-fired plant**
  - Reliability, availability and low operating costs
  - Load flexibility
- **Fuel is primary cost driver impacting economically viable**

NG consumption for Generation projected to increase in the future



Source: U.S. Energy Information Administration, *Annual Energy Outlook* 2017, January 5, 2017

Coal Generation projected to stay flat or decrease in the future



Source: U.S. Energy Information Administration, *Annual Energy Outlook* 2017, January 5, 2017

Lower Demand Implies More Low Load Operation

- **SCR minimum operating temperature (MOT) requirements drive the unit low-load floor**
- **Reducing MOT requires:**

  Inlet reduction in condensables (SO_3 and/or NH_3) or
  Economizer by-pass

- **Hydrate DSI = Best solution for SO_3 reductions**
- **Economizer bypass negatively impacts boiler efficiency**

296 electricity generating units in the U.S. have SCR installed as a NOx control strategy

Options to Allow Lower MOT

- **Combustion Optimization**

  In the furnace, SO_2 is converted to SO_3 through reactions with oxygen and catalytic reactions with tube deposits

  Conversion depends on the
  - fuel's composition,
  - flue gas temperature,
  - excess air in the furnace, and
  - ash content of tube deposits.

  1% to 3% of the fuel bound sulfur can be converted to SO_3 in the combustion process

- **Optimize Ammonia Feed at Lower Load Operation**

  Less potential for condensable formation

  Reduced NOx removal rate

- **DSI Injection**

  Hydrated lime injection is a proven method for SO_3 reduction

  Injection up/s of SCR has been practiced

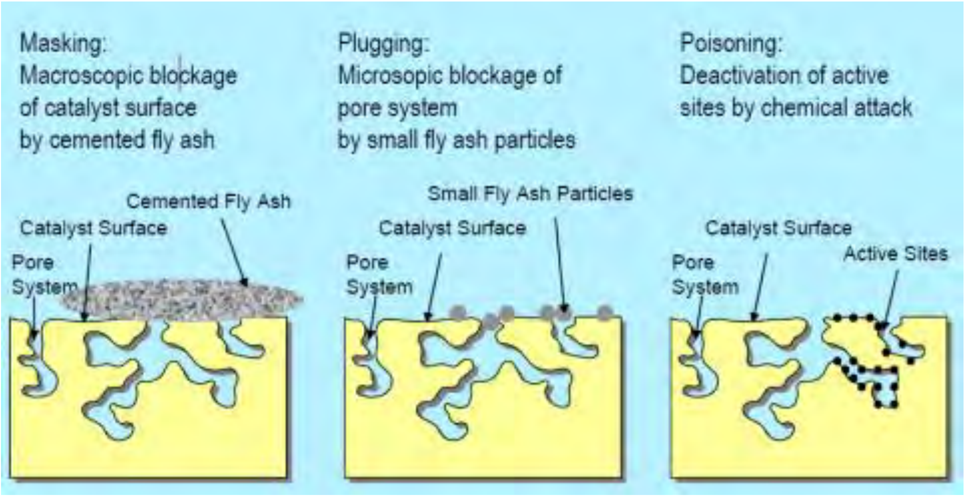
  Load-dependent sorbent injection

SCR Catalyst Deactivation

- **Alkali Metals – Sodium poisoning is known to be a problem**
  - Poisoning: Adsorption of catalyst poison at Active Sites
  - Plugging: Soluble material absorb moisture at the Pore System opening and plug the Pore System
- **Alkaline Earth Metals - What about Calcium**
  - CaO in ash can accumulate on the catalyst
  - Reaction with SO_3 to form $CaSO_4$
  - Masking: Potential to mask Pore System

Relative strength of poison oxides: Na2O > > CaO

Source: Guo, Xiaoyu, "*Poisoning and Sulfation on Vanadia SCR Catalyst*" (2006). *All Theses and Dissertations.* Paper 439, pp 26



Source: ARGILLON, *SCR Catalyst Selection and Design*, K. Jeffers, 2008

Sorbent Loading and Catalyst Operation

- **Most coal boiler SCR systems operate in 'high-dust' environments**
  - High-dust SCR configuration, ash levels can approach 20% of the flue gas; dependent on coal type
  - Very high-dust flue gases require special considerations to minimize blockage and erosion
- **DSI typically adds less than 5% to the total solids loading of the flue gas**

Business case for pre-SCR Hydrate DSI

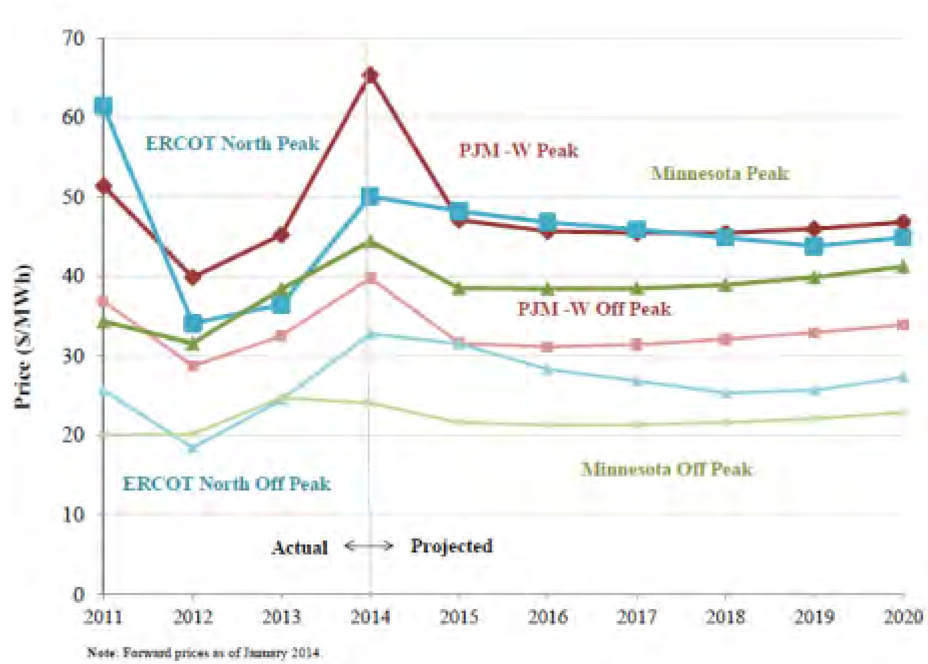
A Basic Approach

- **Scenario Analysis**
- **Clear definition action and operation benefit**
- **Key Performance Indicator (KPI) for Potential Benefits**
  - Define the benefit formula – how to represent value
  - Identify which factors illustrate success
- **Economic Risk of "No Investment"**
- **Establish Alignment with Strategic Goals**

Business case for pre-SCR Hydrate DSI

Scenario Analysis

- 500 MW (nominal) coal fired- unit
- Existing DSI system located at site (MATS/Haze)
- Projected distressed operation due to dispatch pressure
- Increased load-load operations
- Forward power prices continue to be low in coal-heavy regions due to low gas prices and depressed load conditions



Source: The Brattle Group, *Coal Plant Retirements and Market Impacts*, 2014

Business case for pre-SCR Hydrate DSI

Connection between action and operational benefit

- DSI injection upstream of the SCR
- Proven to lower SO_3 in the flue gas
- Lower SO_3 means lower condensables
- Lower condensables eliminates the requirement for elevated MOT

KPI for Potential Benefits

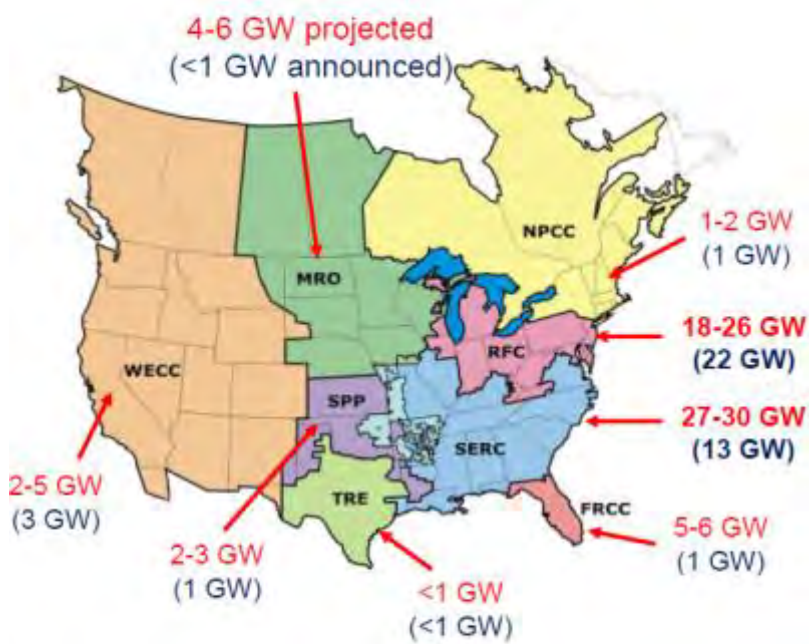
- The cost of current low load operation
- Plus, the cost of SO_3 mitigation
- Plus, the cost of new low load operation including improve APH operation

Business case for pre-SCR Hydrate DSI

Economic Risk of "No Investment"

> A 2012 study predicted 59-77 GW of coal plant capacity at risk for retirement during 2012-2016

> EIA published in 2017 a projection for increasing coal plant retirements



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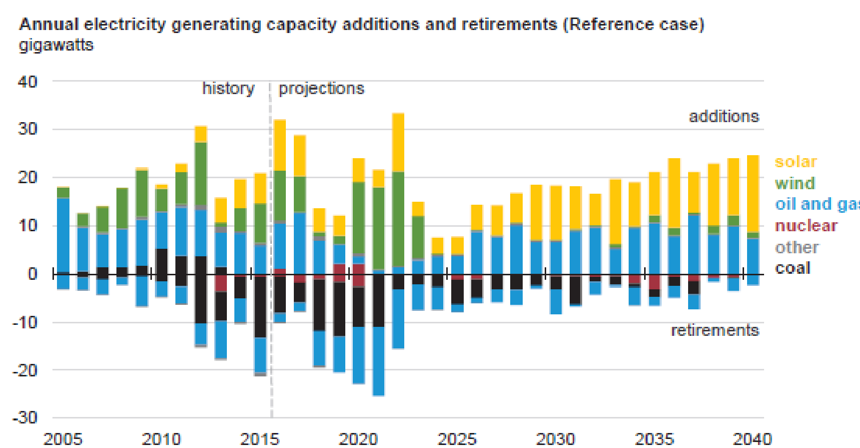


Source: U.S. Energy Information Administration, *Annual Energy Outlook* 2017, January 5, 2017

Business case for pre-SCR Hydrate DSI

Assumptions	
Boiler Capacity (Mw)	500
Fuel Heating Value (Btu/lb)	10,000
Fuel Cost ($USD/ton)	$68
SCR Inlet SO3 concentration, High Load (ppmv)	40
SCR Outlet SO3 concentration, High Load (ppmv)	60
SO3 %RE (w/ Ca(OH)2)	90%
Target SO3 concentration (ppmv)	6
SCR Inlet SO3 concentration, Low Load (ppmv)	4

COST

SO3 Mitigation Cost	
Sorbent ($USD/ton delivered)	$200
Sorbent Injection Rate, Full Load (lb/hr)	2,800
Sorbent Injection Rate, Low Load (lb/hr)	500
Annual Hours of Operation	
Full Load (hr)	5,000
Low Load (hr)	3,000
Outage (hr)	760
Estimated SO3 Mitigation Cost ($USD)	($1,250,000)

Summary of Savings[1]	
Estimated SO3 Mitigation Cost ($USD)	($1,250,000)
Sum of Avoided Expenese ($USD)	$ 15,816,117
Estimated Net Avoided Expense ($USD)	$ 14,566,117

Avoided Expense

Air Heater Fuel Savings Savings	
Decrease in Temp at APH (degF)	-20
Heat Rate Improvement (BTU/kWh)	150
Fuel Savings (tons)	30,064
Estimated Fuel Savings ($USD)	$ 2,044,352

Low Load Fuel Savings	
Reduced MOT Temp SCR (degF)	60
Associated Load Reduction (MW)	132
Low Load Operation (hr/yr)	3,000
Fuel Savings (tons)	202,035
Estimated Fuel Savings ($USD)	$ 13,738,353

ID Fan Savings	
ID Fan Power Consumption (MW)	2
Power Savings (Kw)	360
Annual Hours of Operation	8,000
Fuel Savings (tons)	490
Estimated Fuel Savings ($USD)	$ 33,412
Sum of Avoided Expenese ($USD)	$ 15,816,117

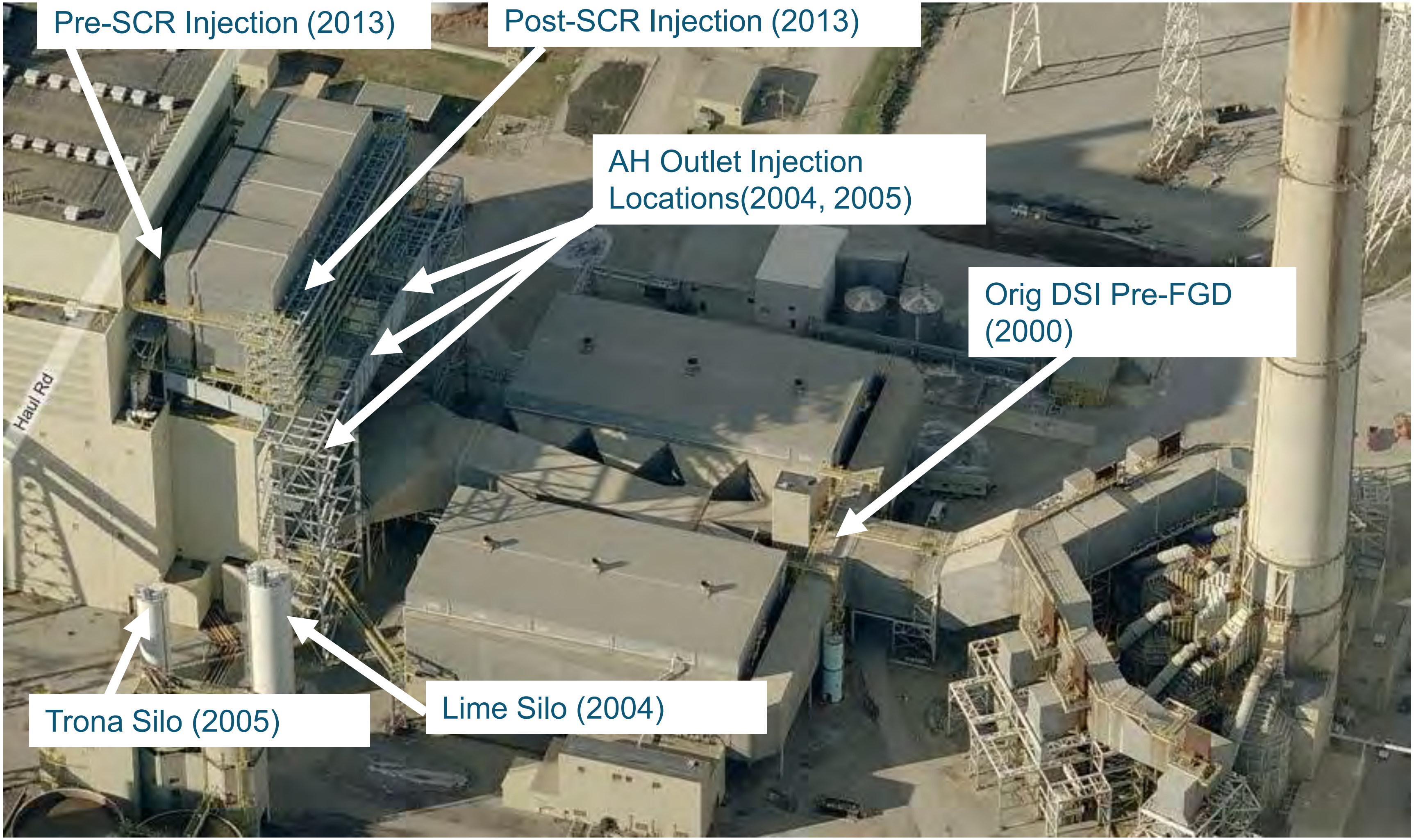
1 Savings are shown for illustrative purposes and do not include amortization for capital expenses associated with DSI system, nor are offset power/electricity revenues considered for normal low-load MOT and effective low-load MOT with hydrate injection.

Applications & Case Study

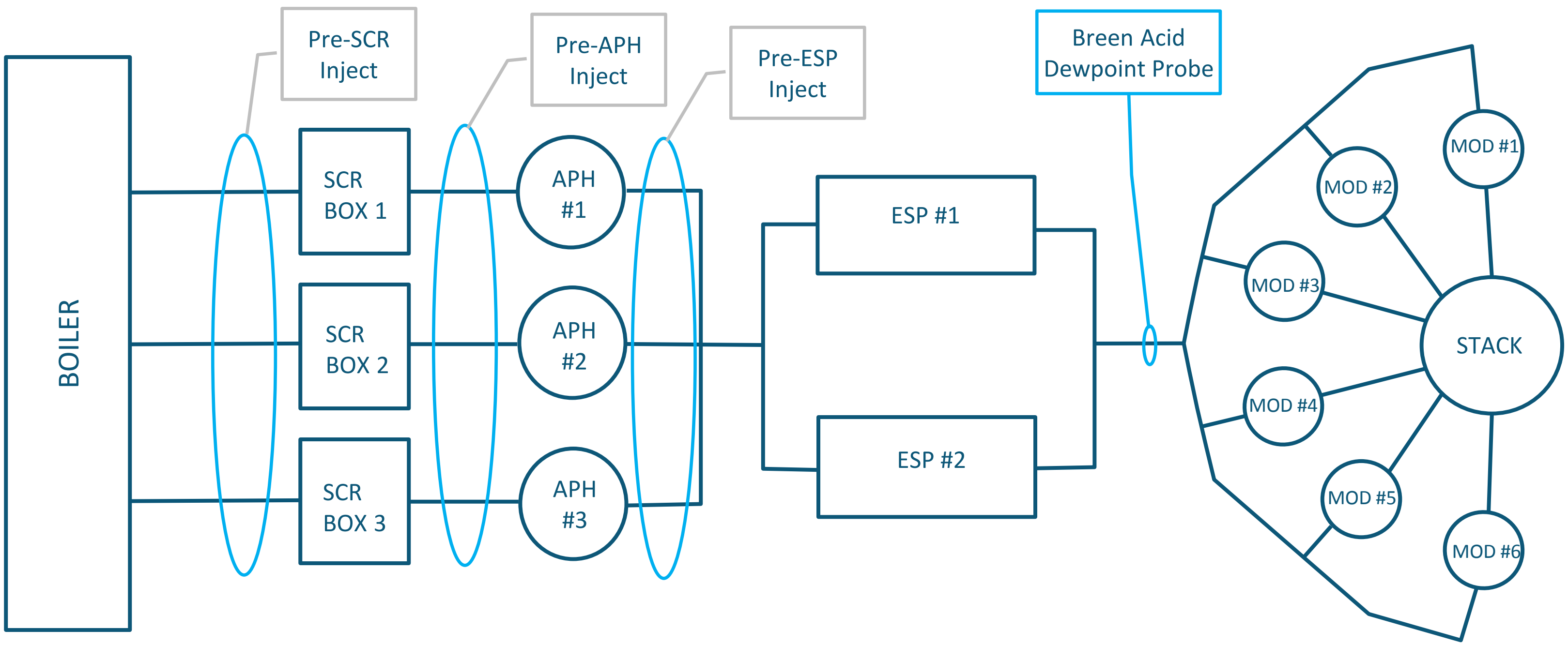
Benefits, Impacts & Costs of Using DSI to Reduce SCR MOT

- Dynegy Zimmer Power Station
- Moscow, Ohio
- 1440 Mw Gross
- Worlds Only Nuclear to Coal Conversion
- In Service 1991 with Wet FGD
- SCR Added 2004

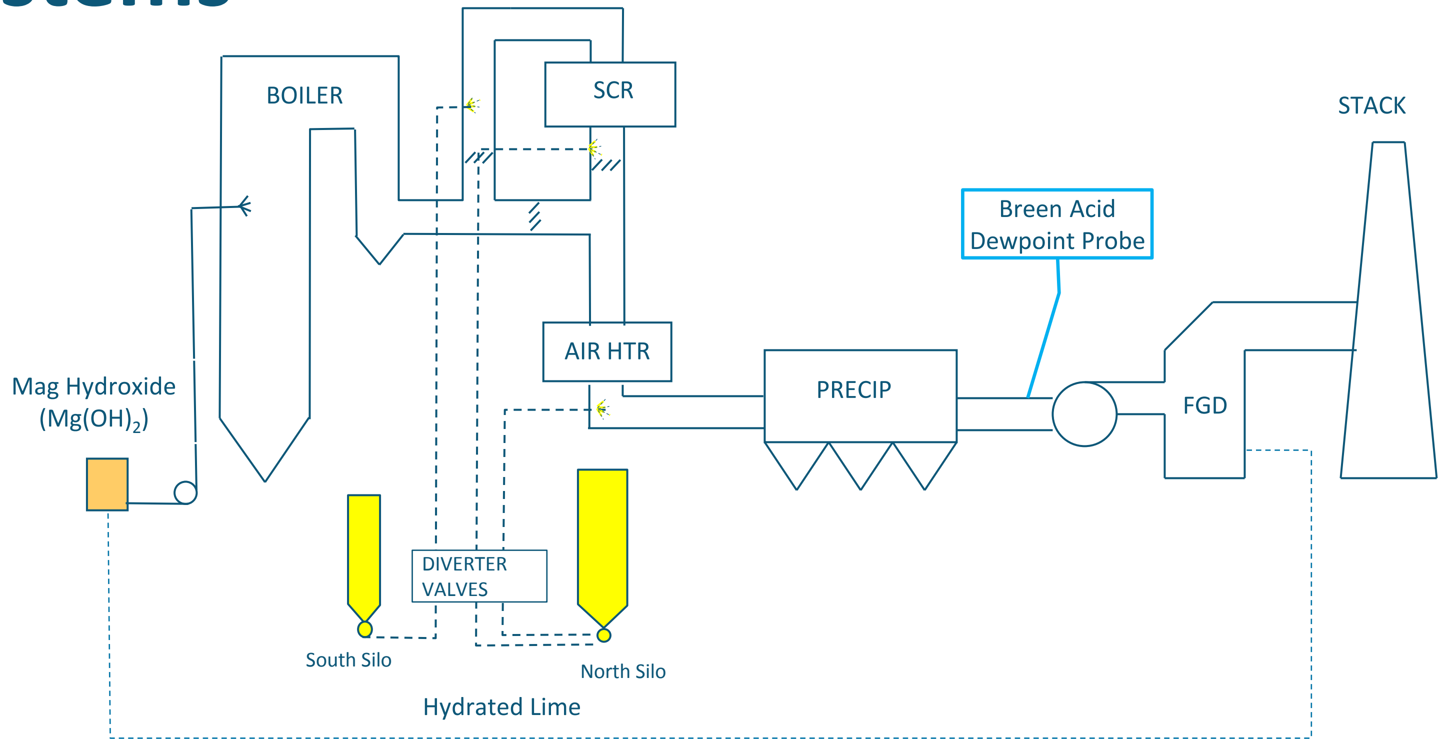
Zimmer DSI Systems History



Zimmer Power Station AQCS Config and Sorbent Injection Locations



Zimmer Power Station SO_3 Mitigation Systems



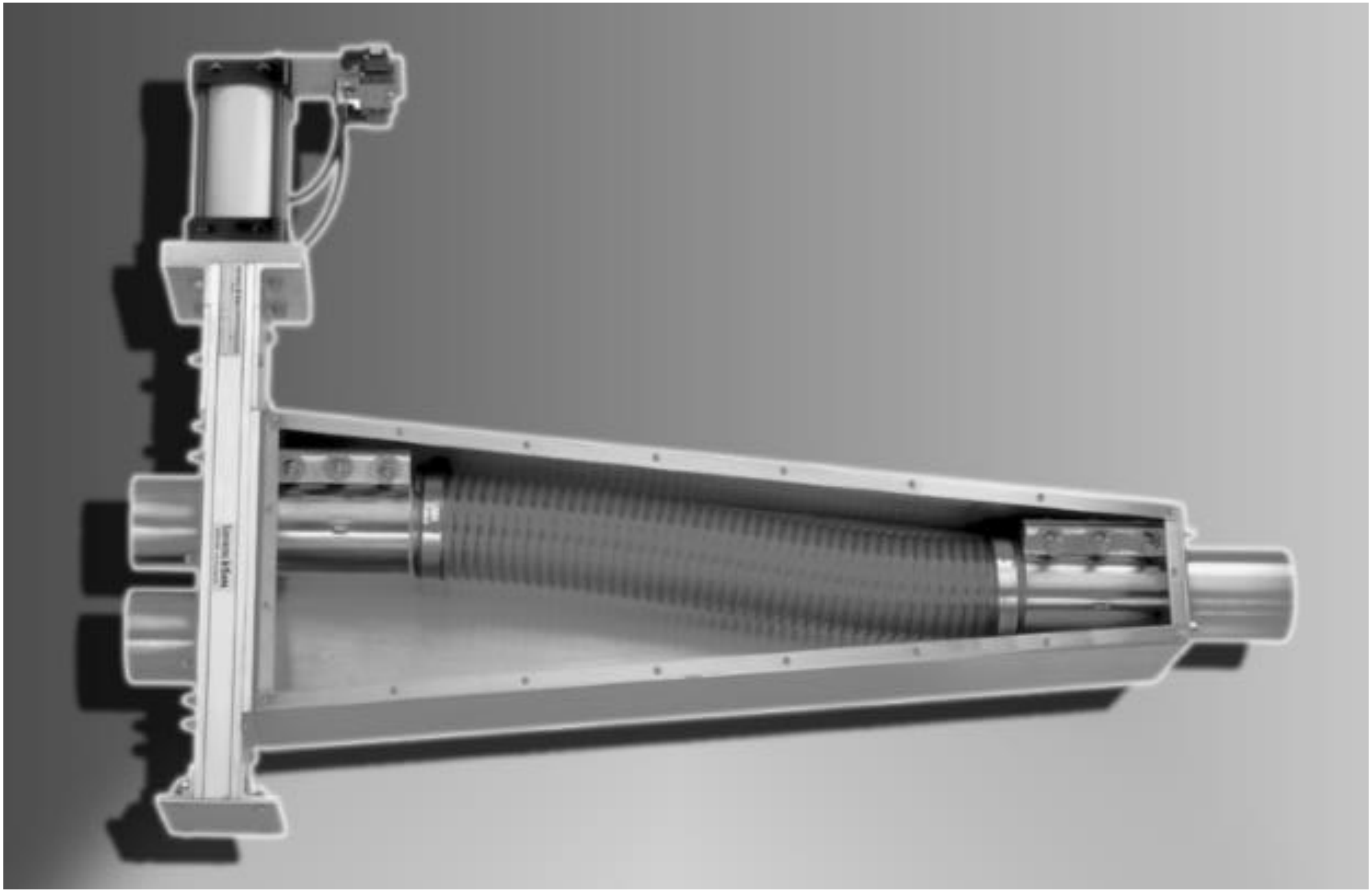
Pre-SCR Injection

- **Initially Installed to resolve APH Pluggage Problem**
- **Location Selected for Simplicity**
- **Initially Injected Continuously Pre-SCR**
- **Added Post-SCR/ Pre APH Injection**
  - Switched to Dual Injection
- **Currently Inject Pre-SCR only at Low Load**

NH_3 Injection Grid

NH_3 Injection Nozzle & Delta Wing™ Mixers (4 Per duct)

Diverter Valves



Diverter Valves

Effect on SCR Operations

- **Lowered Min Temps by >30F**
  - Allows significant lower Min Load
  - Not require Low Load Gas Temp Mods
  - Based on Reducing SO3 to ~5ppm @SCR Inlet
  - Currently Use Tiered DeNOx @ Lower Loads
    - > Can Likely Push to Lower Temps

Catalyst Impacts

- **No Accelerated Catalyst Deactivation**
- **Slight Catalyst CaO Increase**
- **No Catalyst Pluggage**
  - From Buildups or Ash/Lime Falls
- **No Increased Catalyst Erosion**
- **No Deposits after 6 Month Outage w/o Layup Air heating thru Winter Season**
- **No Negative Impacts on Hg Oxidation**

Balance-of-Plant Effects & Findings

- **Elimination of APH Fouling for 4 Years**
- **Permits More HR Benefit @ Low Load**
  - Eliminate need for APH Air Side Bypass
  - Reduced Combust Air Pre-Heat >>Lower SCR In Temps
- **Proportionally Less Sorbent Needed at Low Load due to lower SO3 at Low Load**
  - Case Specific
- **HCl Capture more efficient w/ Pre SCR Injection**
- **SO3 Capture more efficient w Post SCR/ Pre APH**

Sorbent Mixing

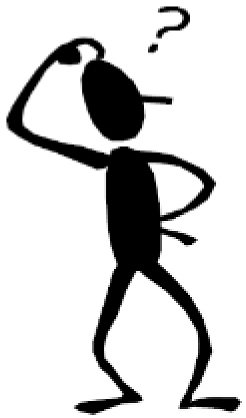
- **Sorbent Mixing Critical**
  - More Important near MOT/ MIT
  - Need to good coverage to prevent localized ABS formation
- **Similar Issues as NH_3 Mixing**
  - Added Erosion & Buildup Potential
  - Practical Limit on Number of Lances

Other Considerations

- **DSI System Redundancy**
  - Silos, Feeders, Distribution Piping, Lances, Etc
- **SCR Bypass Duct & Dampers Configuration & Ops**
- **Controls & Operating Procedures**
- **Econ Gas or Water Bypass for SCR Inlet Temp Control**
  - Reduced Maintenance or Eliminate Need for
- **Preheat Coil Operation**
- **Ash Sales (Chloride Limits, Calcium Limits)**

Summary & Conclusions

- So Far No Negatives
- Significant Unit Turndown Improvement
- Air Heater Fouling Elimination
- Additional Advancements Under Evaluation



Discussion/Questions?

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