REINHOLD ENVIRONMENTAL Ltd.

2019 NOx-Combustion-CCR Round Table Presentation

February 11 & 12, 2019, in Salt Lake City, Utah / Hosted by PacifiCorp

Hydrated Lime Use for Economic Benefit

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DISCOVERING WHAT'S POSSIBLE WITH CALCIUM

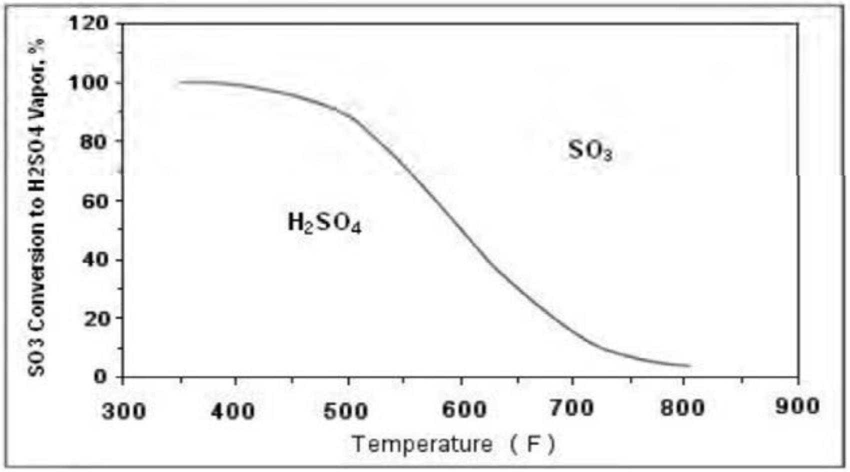
February 11, 2019   **Reinhold Winter Conference, Salt Lake City, UT**

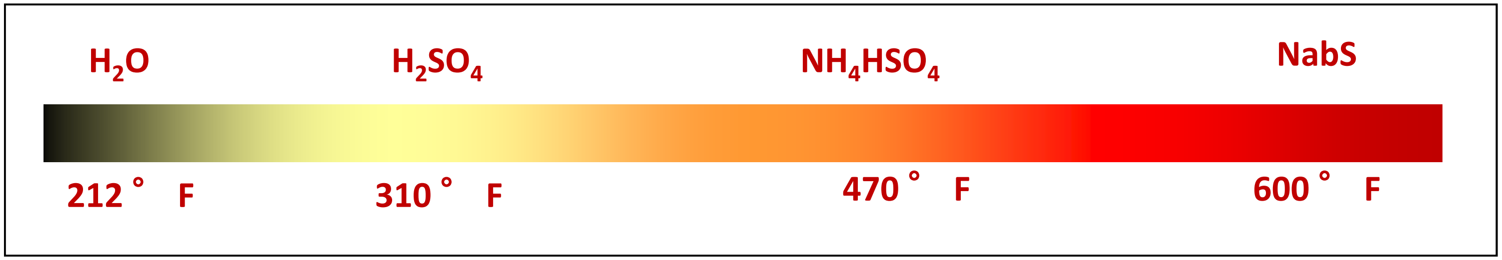
Acid Gas Overview

What is “Acid Gas"

- We think in terms of “SO_3”, but what is it really?

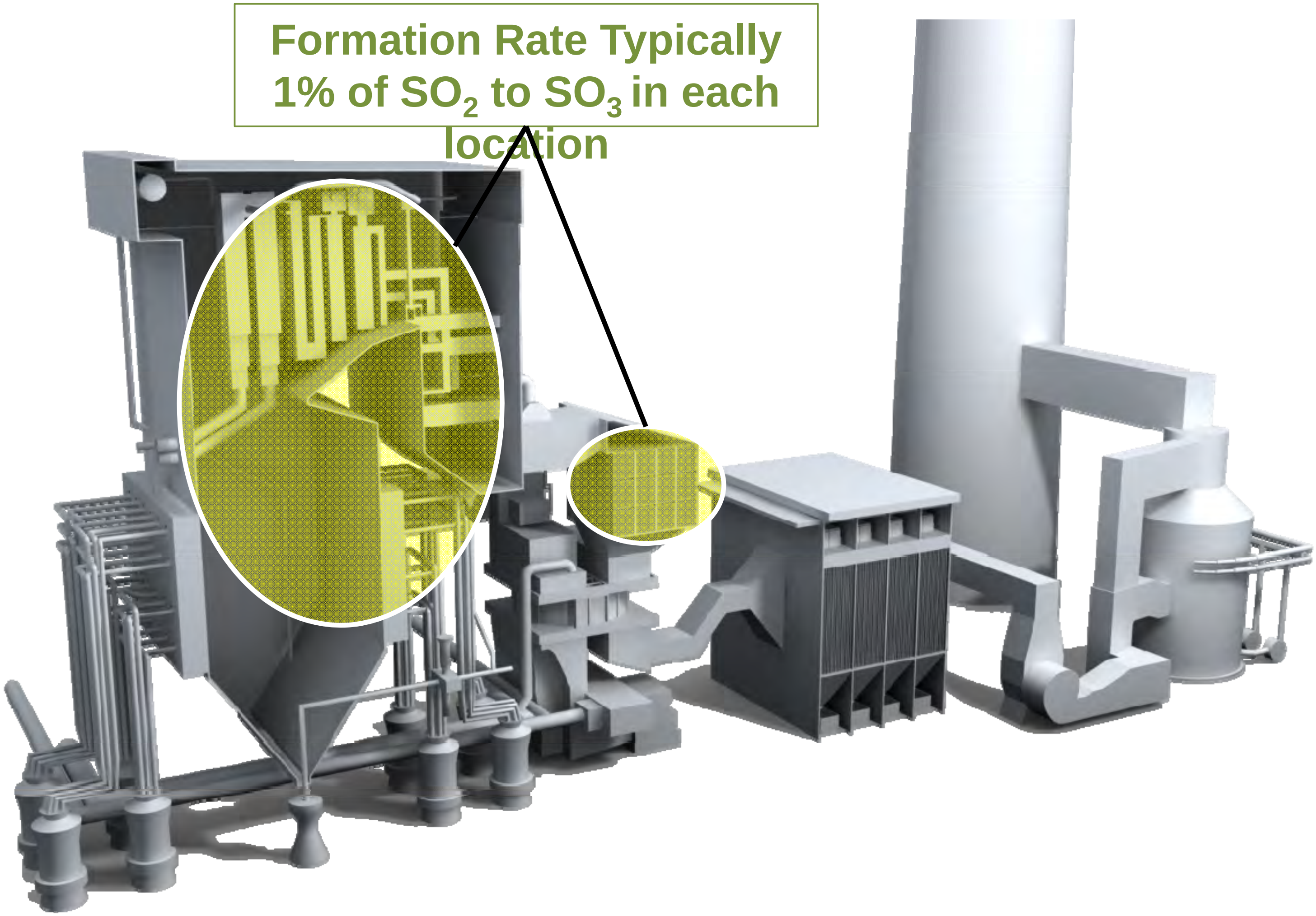
$SO_3 + H_2O \rightarrow H_2SO_4$





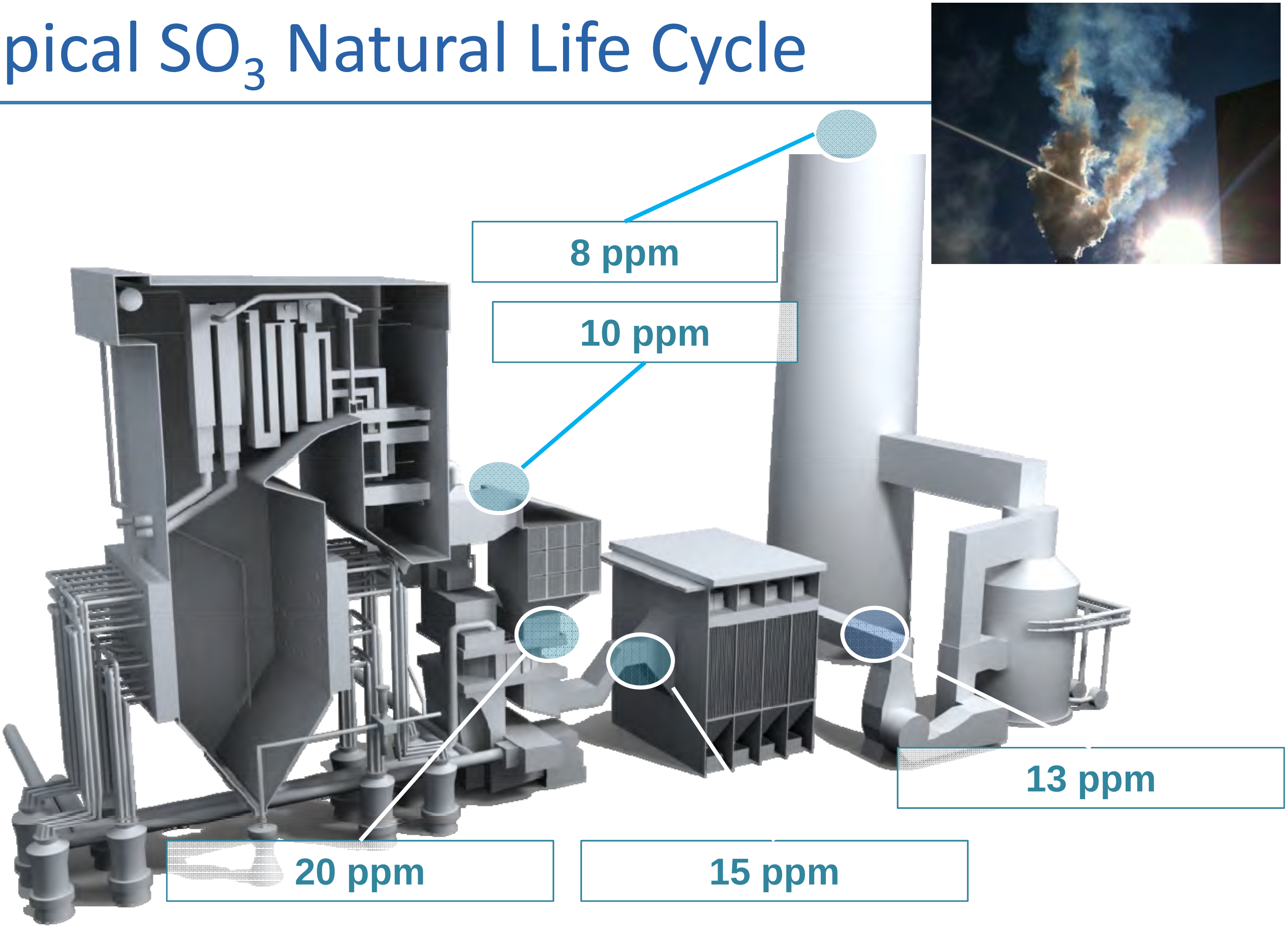
The same device measures condensables across the spectrum!

Typical SO_3 Natural Life Cycle



Formation Rate Typically 1% of SO_2 to SO_3 in each location

Typical SO_3 Natural Life Cycle



8 ppm

10 ppm

13 ppm

20 ppm

15 ppm

For 1000 ppm SO_2 Concentration

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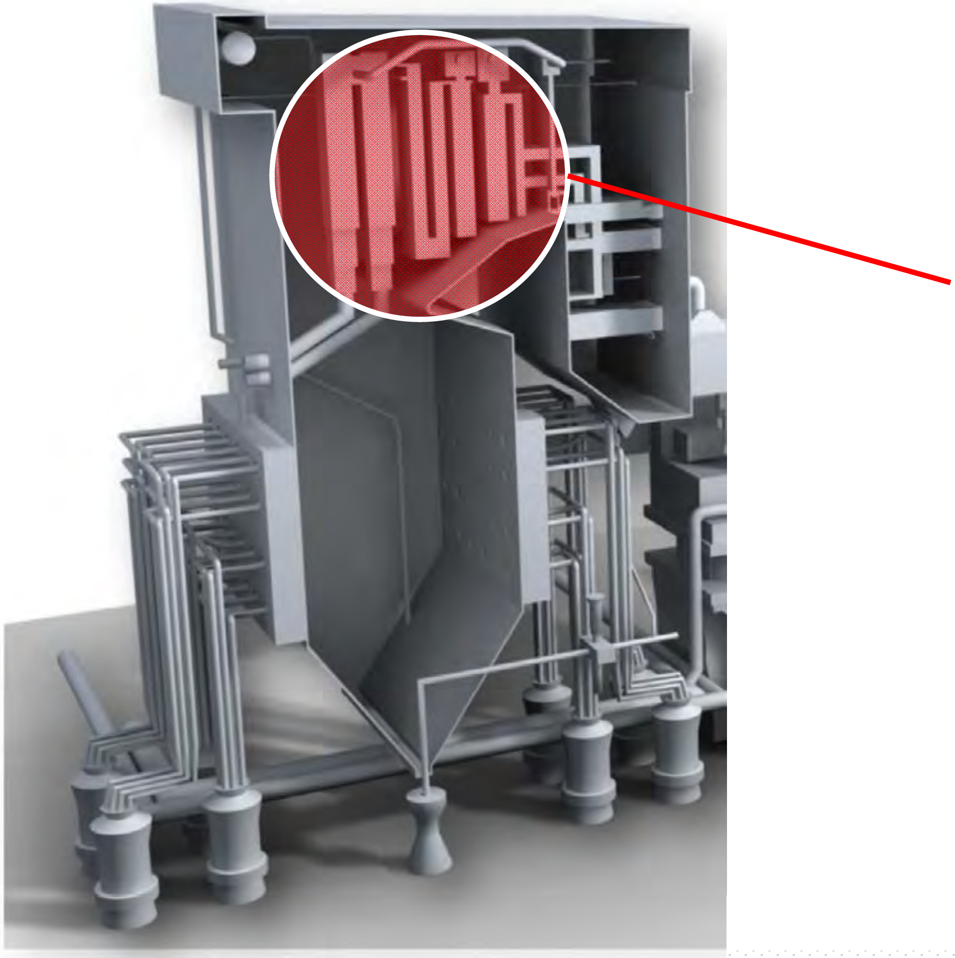
Acid Gas Generation

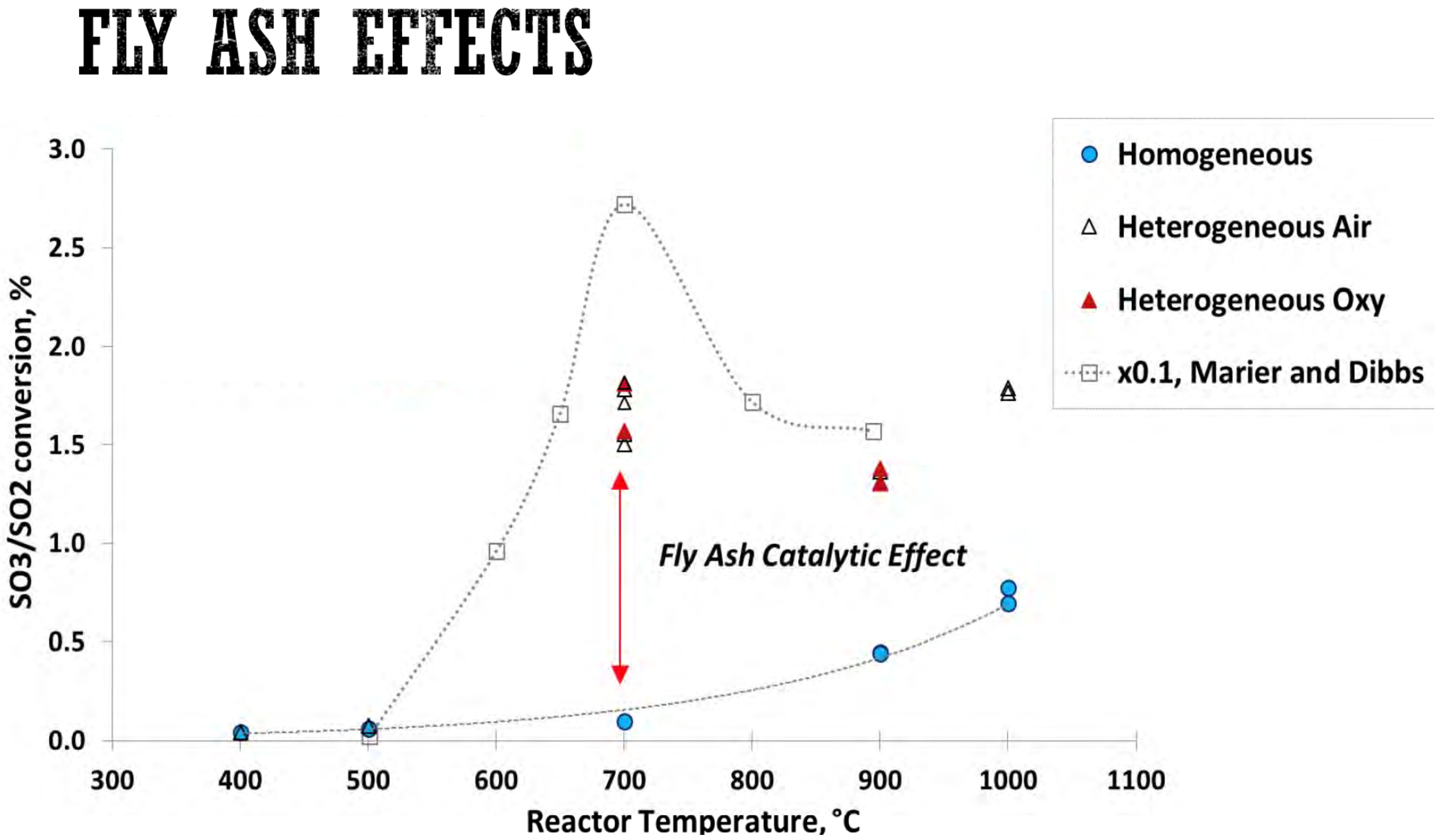
Furnace Impact

SO_2:SO_3 Conversion Happens Here!



The bulk of Furnace SO_2:SO_3 conversion happens in the convective zone in the presence of iron, oxygen and suitable temperature

SO_2:SO_3 in the Furnace



O_2 Impact

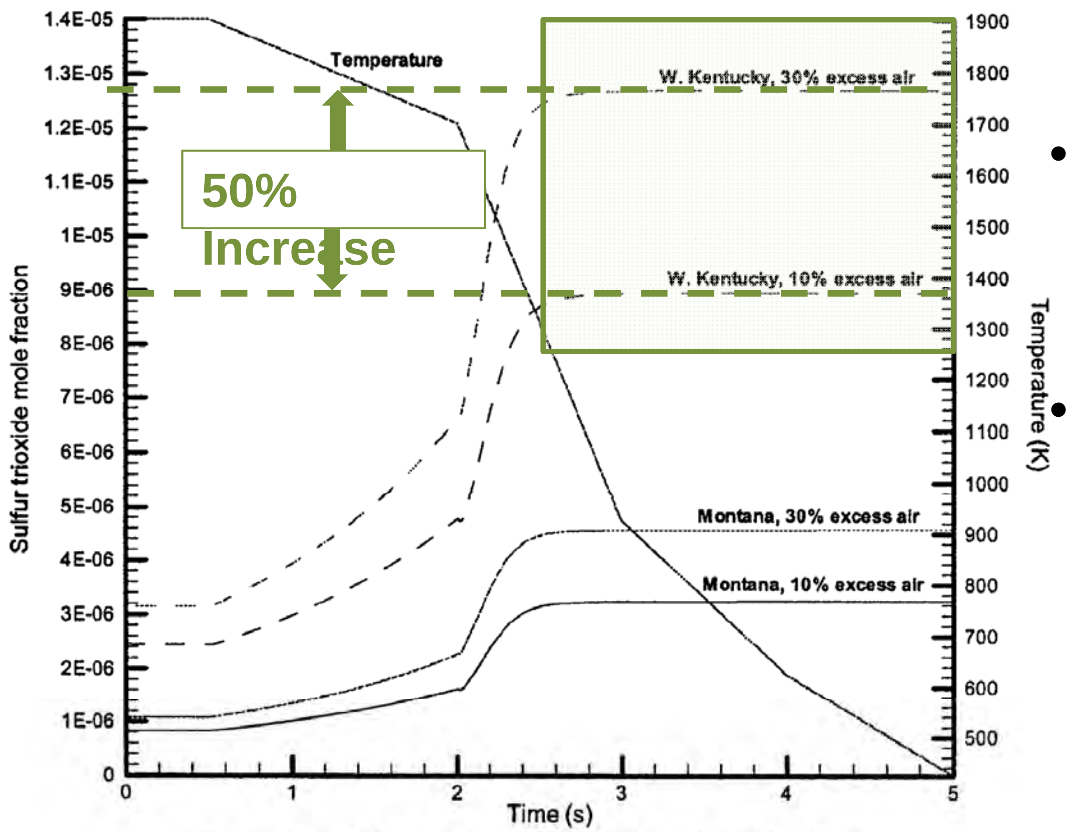


Figure 4a SO3 produced during coal combustion.

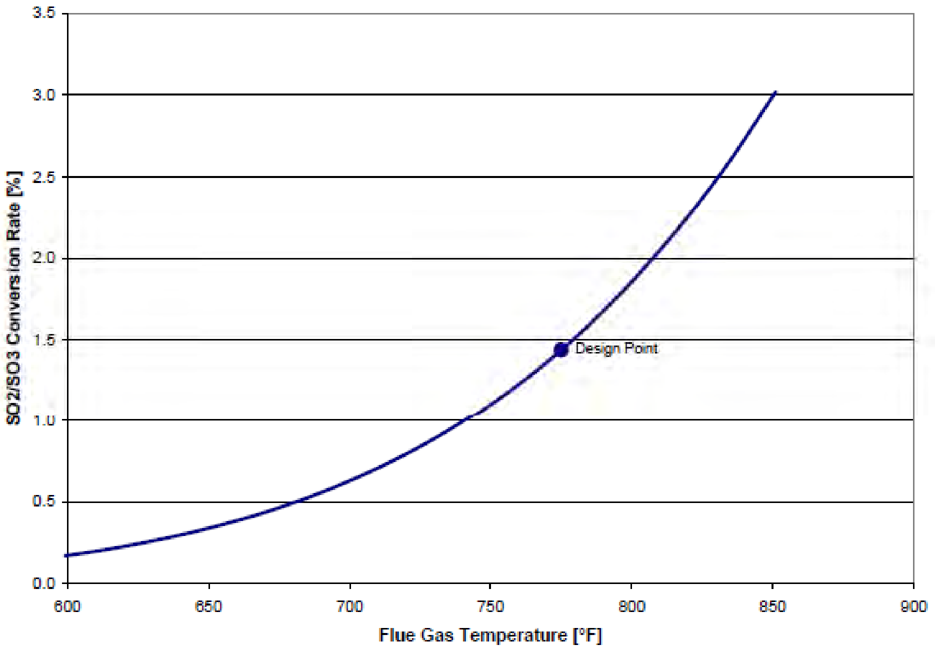
- **SO_2 Conversion is highly dependent on O_2 and temperature**
- **A change in O_2 from 2% to 5% can cause a 50% increase in SO_2**

Acid Gas Generation

SCR Impact

SO_2 Conversion Rate vs. Temperature

- **SO_2 Conversion Rate Increases Exponentially with Temperature**



If you do not know the temperature basis for your conversion rate, you do not know your conversion rate.

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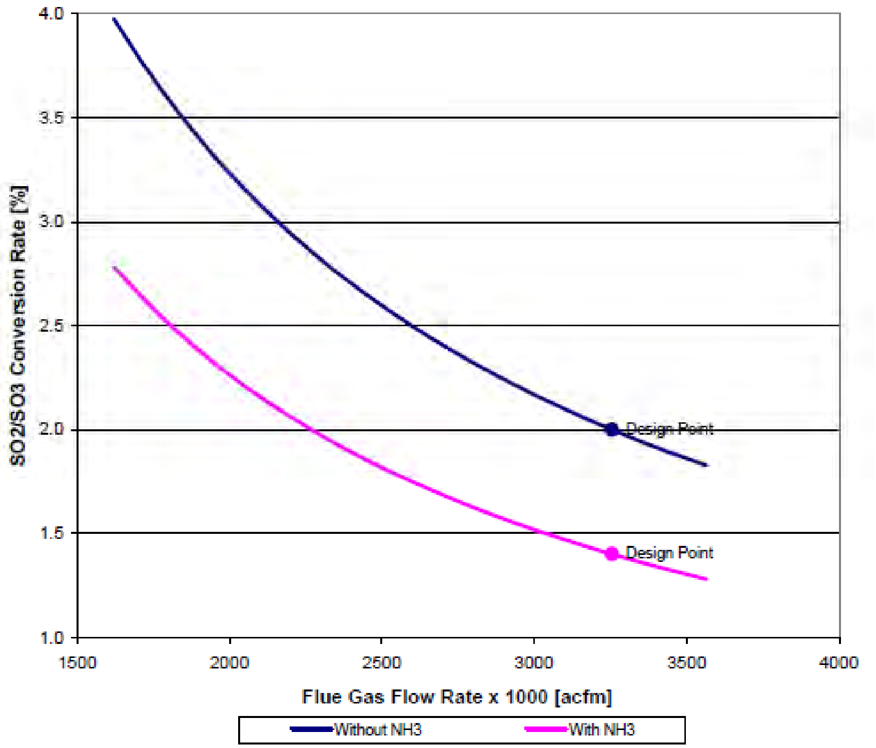
SO_2 Conversion vs. NH3/Gas Flow

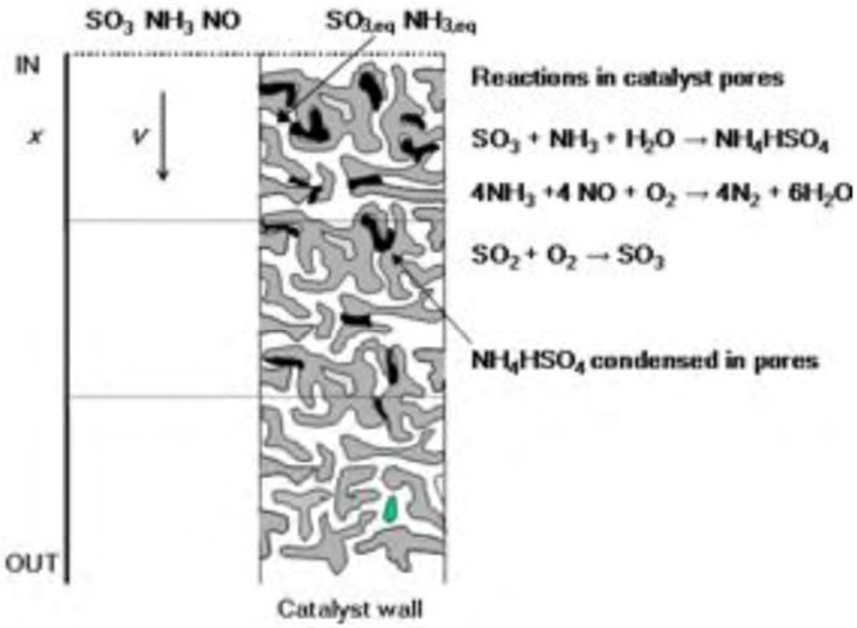


- SO_2 Conversion increases without Ammonia present
- SO_2 Conversion increases with reduced gas flow

Acid Gas Interaction

SCR Catalyst-Sub MOT Operation

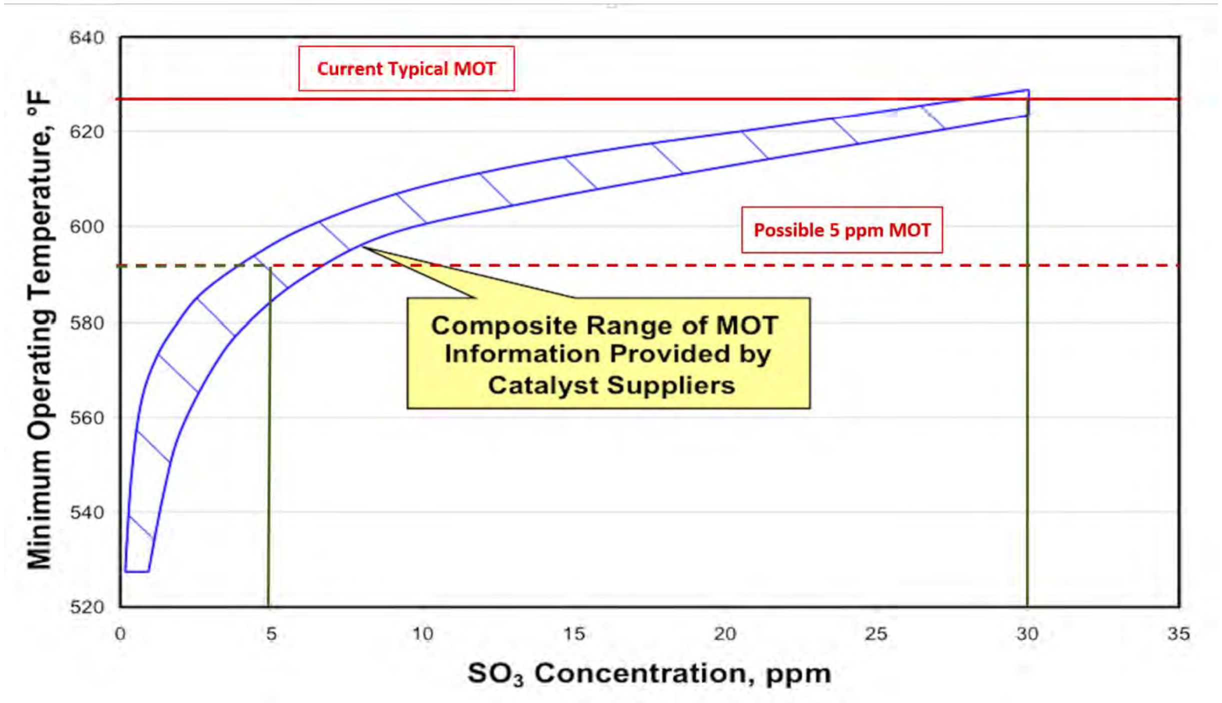
The Catalyst’s Weak Spot



- Depending on Catalyst Inlet SO_3 levels, it is probable that some portion of the ammonia introduced will interact with SO_3/H_2O and form an ammonia salt.
- While Ammonium Sulfate (AS) is the expected species due to stoichiometry, kinetics favor ABS before AS. Some ABS may condense, via capillary condensation, in the catalyst pores

- **Staying above the capillary dew point will avoid ABS condensation in the catalyst pores. Catalyst suppliers refer to this as staying above the Minimum Operating Temperature of MOT)**

SCR Minimum Operating Temperature (MOT)



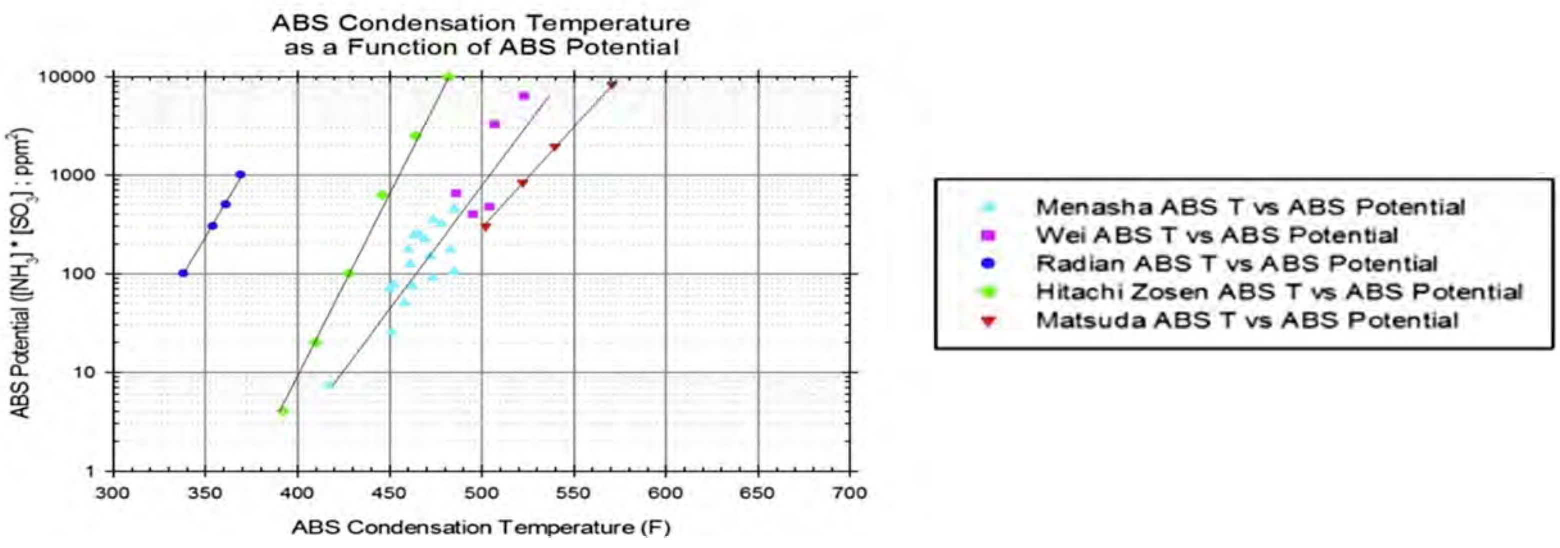
For a quick estimate of SCR MOT reduction value, we assume that a reduction in SO_3 from its native level to 5 ppm will eliminate SCR MOT constraints and will provide a 30F reduction in desired SCR Inlet temperature

The actual relationship between SCR Inlet SO_3 (ppm) and the SCR Minimum Operating Temperature (MOT) is very plant specific. The design curve from the catalyst supplier is required to determine the true potential impact of SCR Inlet SO_3 reduction.

Lets explore some current perspectives on MOT

Identifying MOT – The Theoretical

L. Muzio et al. / Fuel 206 (2017) 180–189



The combined Wei/Menasha work can be defined by the formula below:

$$P_{NH3}(atm) * P_{SO3}(atm) = 2.97 * 10^{13} * e^{(-54{,}950/RT)}$$

- R is the universal gas constant (1.987 cal/K-mol)
- T is the flue gas temperature in degrees Kelvin (K).

Identifying MOT – Theoretical #2

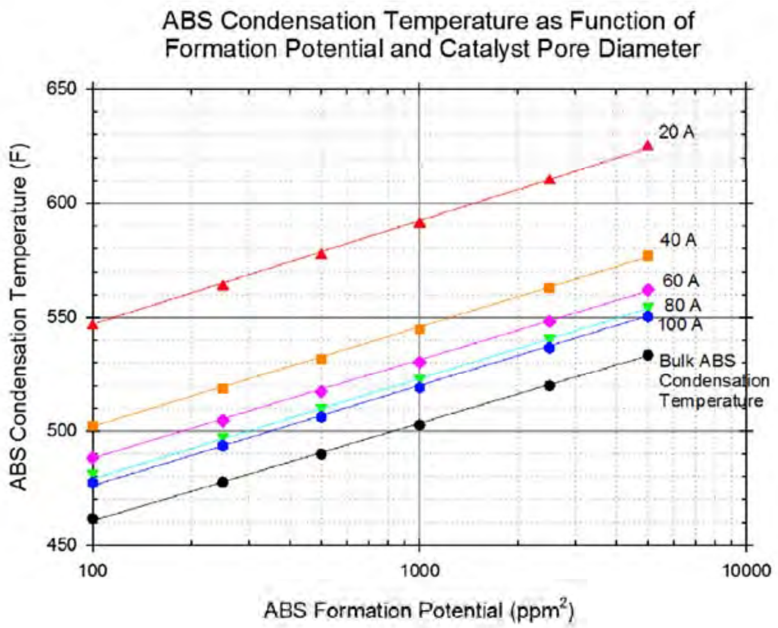
From our earlier example:

- SO_3 = 30 ppm, NH3 = 300 ppm / ABS Potential = 9,000

From the above chart using the Wei/Menasha Curve:

- ABS Condensation Temperature = 540F

But the actual condensation temperature in the catalyst is also a function of pore size as illustrated in the graph to the right:


ABS Condensation Temperature as Function of Formation Potential and Catalyst Pore Diameter

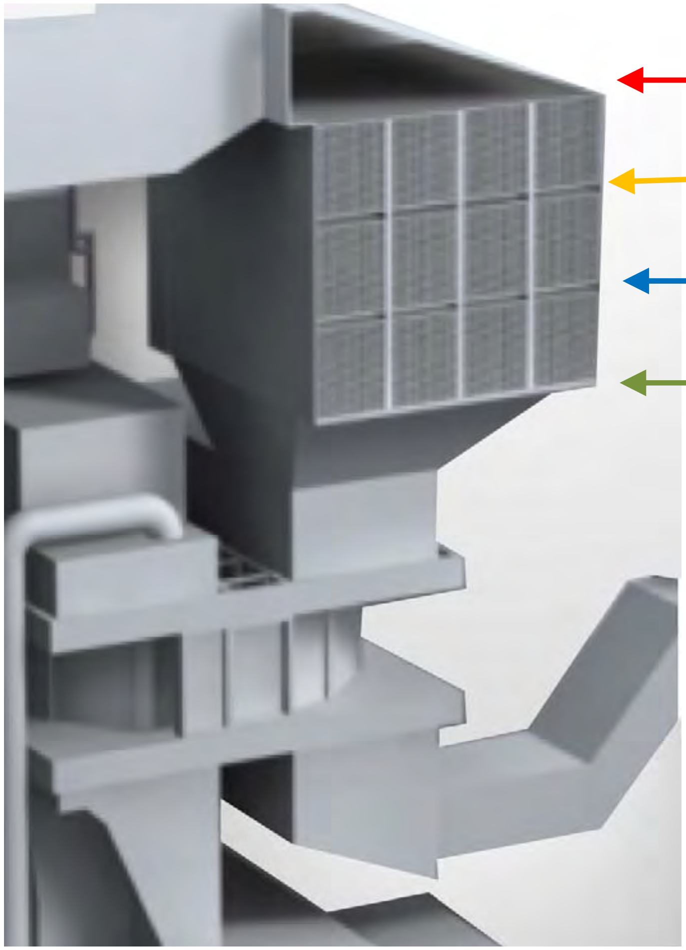
Reference for this slide and the preceding slide:


Ammonium bisulfate formation and reduced load SCR operation

Lawrence Muzio[a], Sean Bogseth[a], Richard Himes[b], Yu-Chien Chien[c], Derek Dunn-Rankin[c,*]

[a] Fossil Energy Research Corporation (FERCo), Laguna Hills, CA 92653, United States
[b] Electric Power Research Institute (EPRI), Palo Alto, CA 94304, United States
[c] Department of Mechanical and Aerospace Engineering, University of California, Irvine, CA 92697-3975, United States

Some Math Exercises



	NH_3	SO_3	Bulk $F_m t$
Inlet:	150 ppm	20 ppm	523F
2nd layer:	50 ppm	27 ppm	507F
3rd layer:	10 ppm	34 ppm	482F
Outlet:	2 ppm	40 ppm	457F

After Hydrate Injection

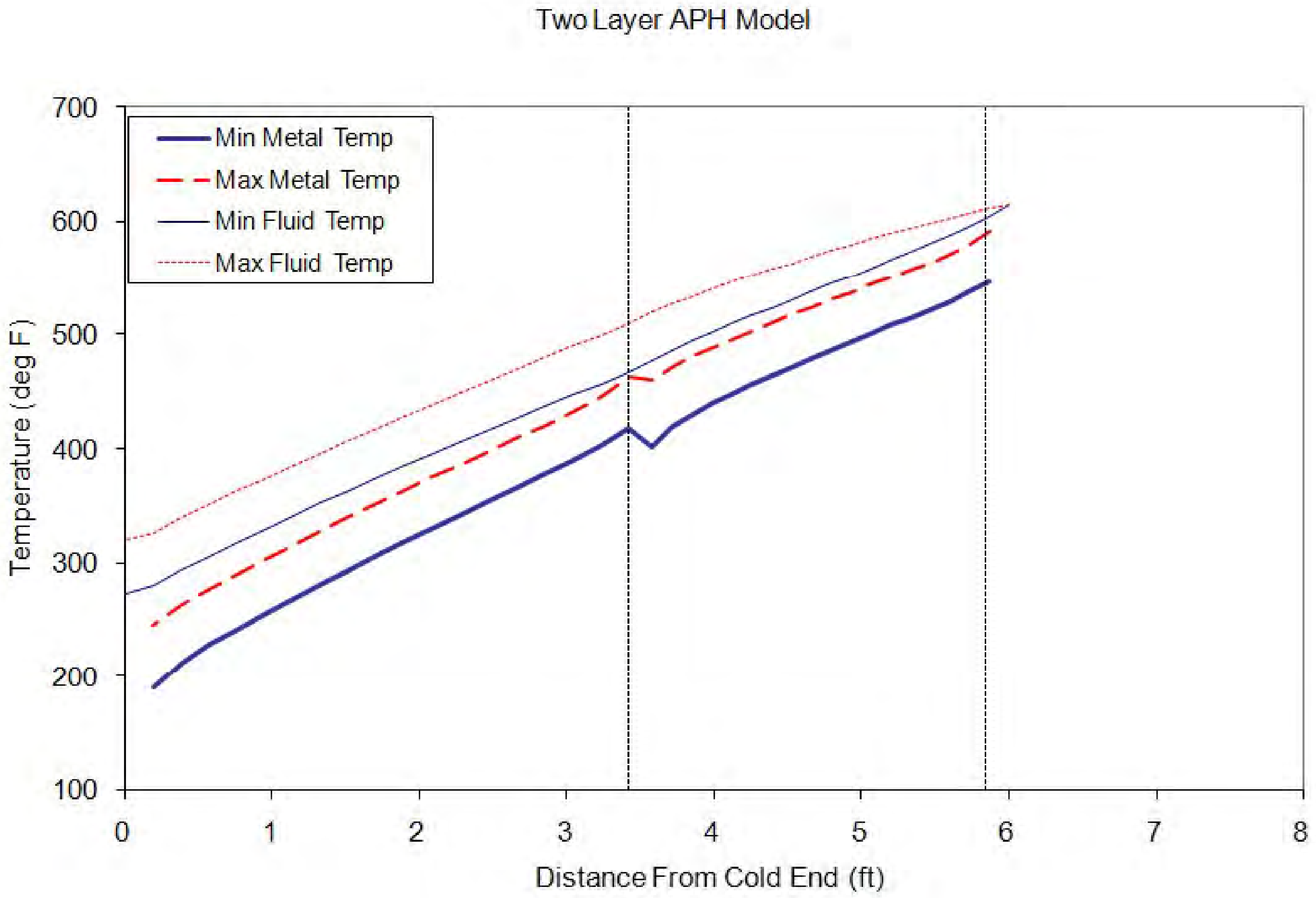
	NH_3	SO_3	Bulk $F_m t$
Inlet:	150 ppm	5 ppm	496F

Mitigating SO3 at the SCR Inlet Allows a 25F or more drop in SCR Minimum Operating Temperature

Acid Gas Interactions

Air Heater

Air Heater Dynamics – the Basics



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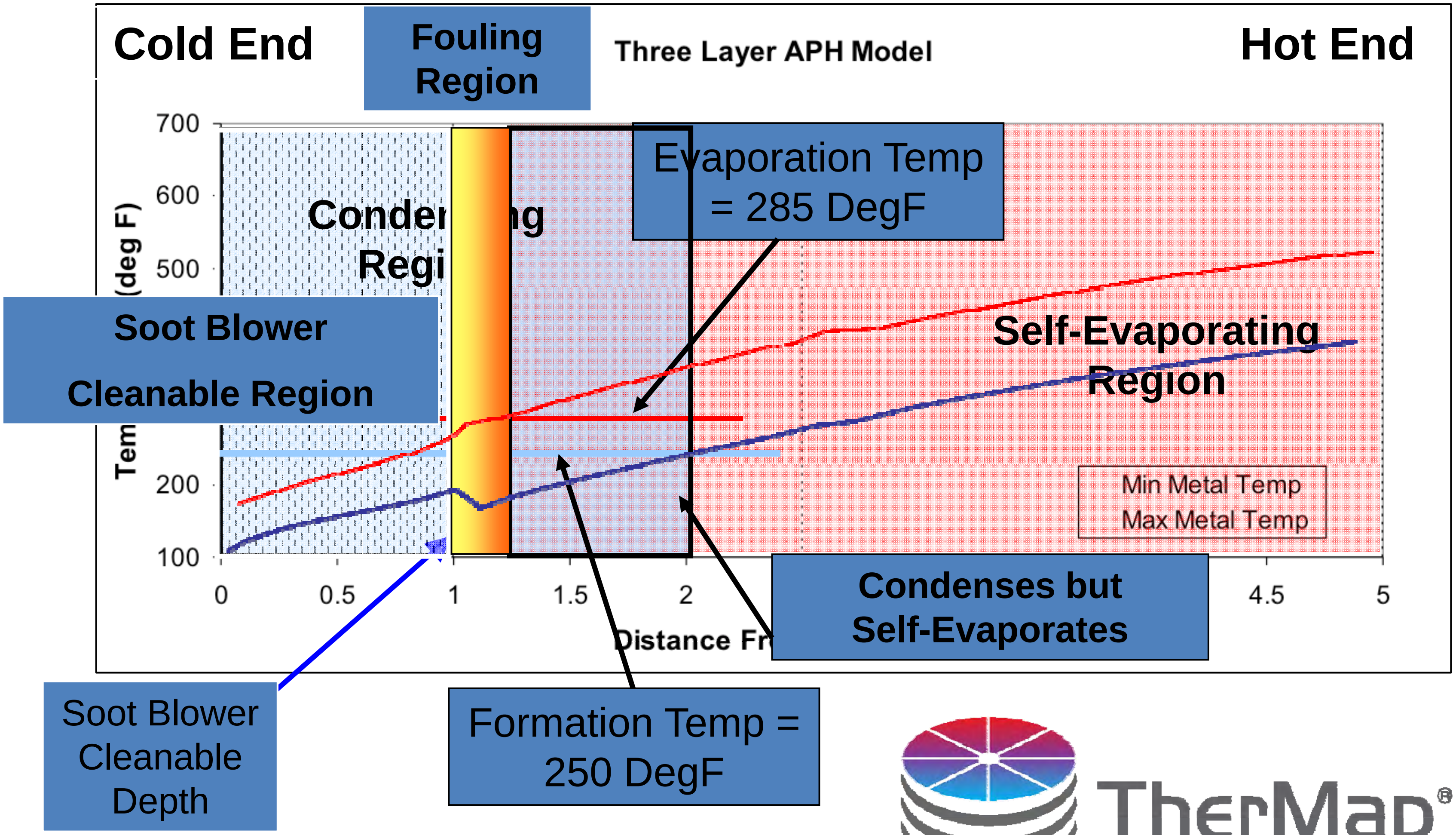
AH Model and Deposition



Fouling Region

Evaporation Temp = 285 DegF

Soot Blower

Cleanable Region

Condenses but Self-Evaporates

Soot Blower Cleanable Depth

Formation Temp = 250 DegF

TherMap®

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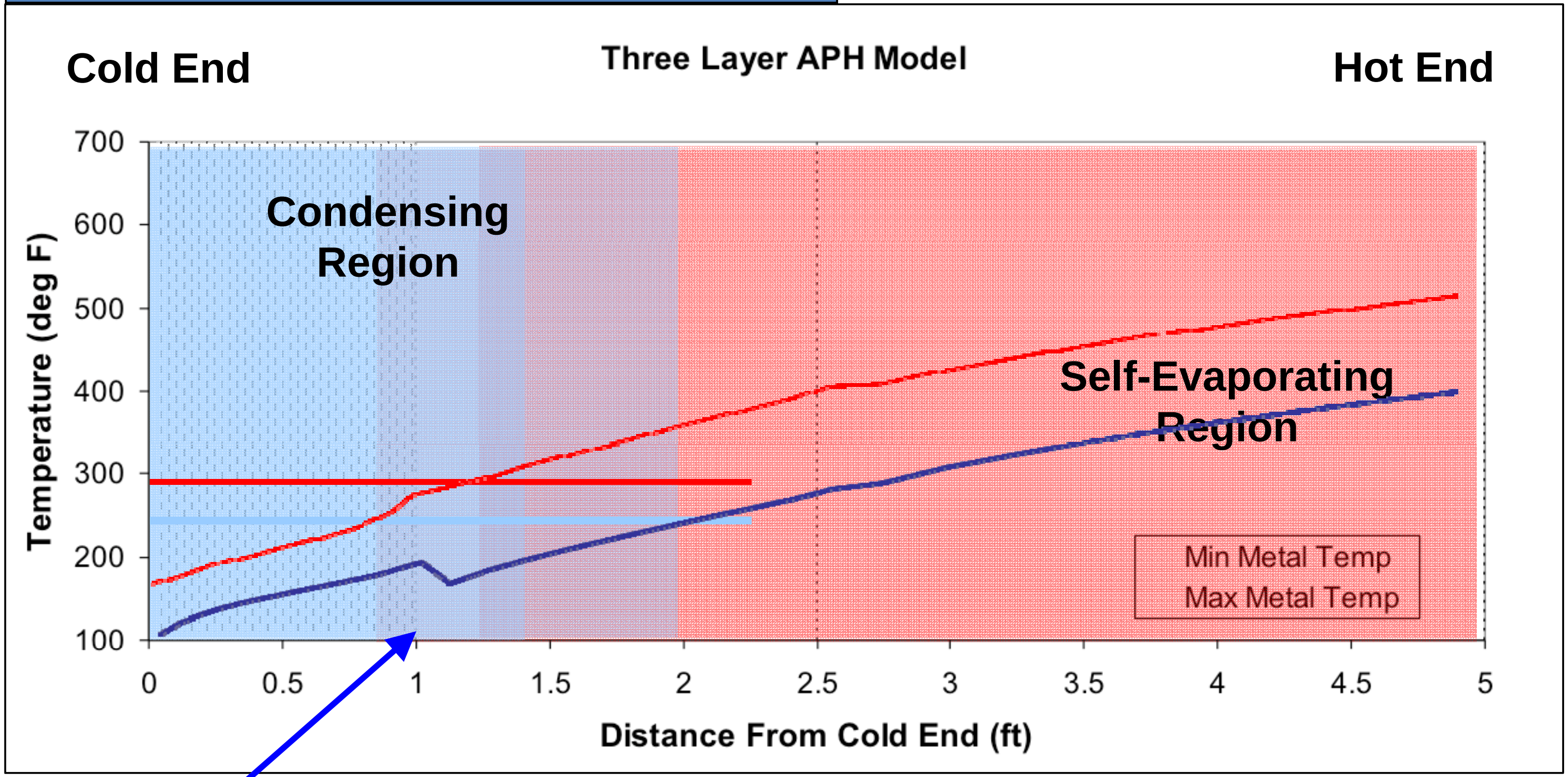
* AH Model Licensed from EPRI; developed by Lehigh

What can you do?

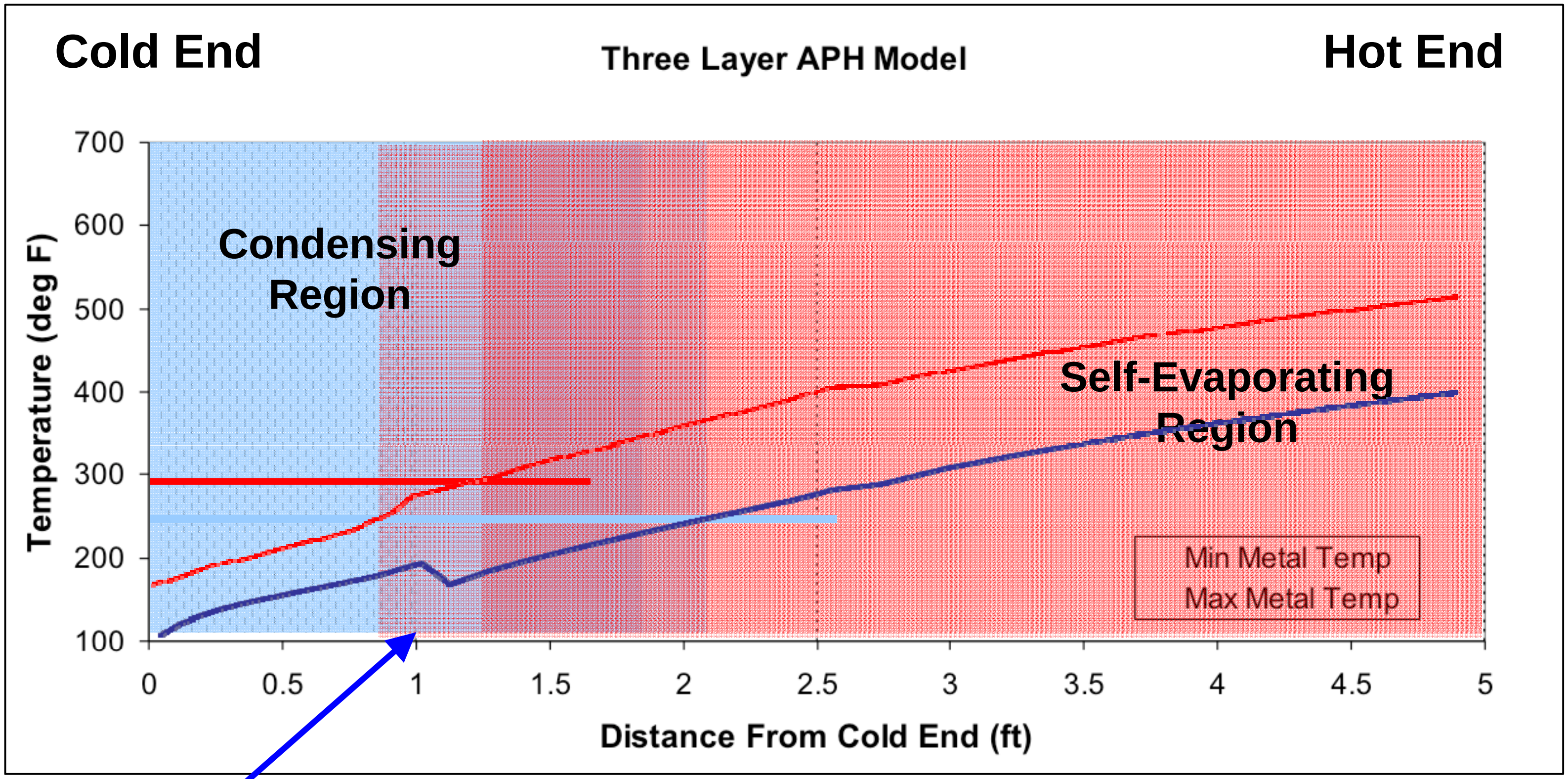
Increase Average Cold End Temp



Soot Blower Cleanable Depth

What can you do?

Reduce NH3 / SO_3



Soot Blower Cleanable Depth

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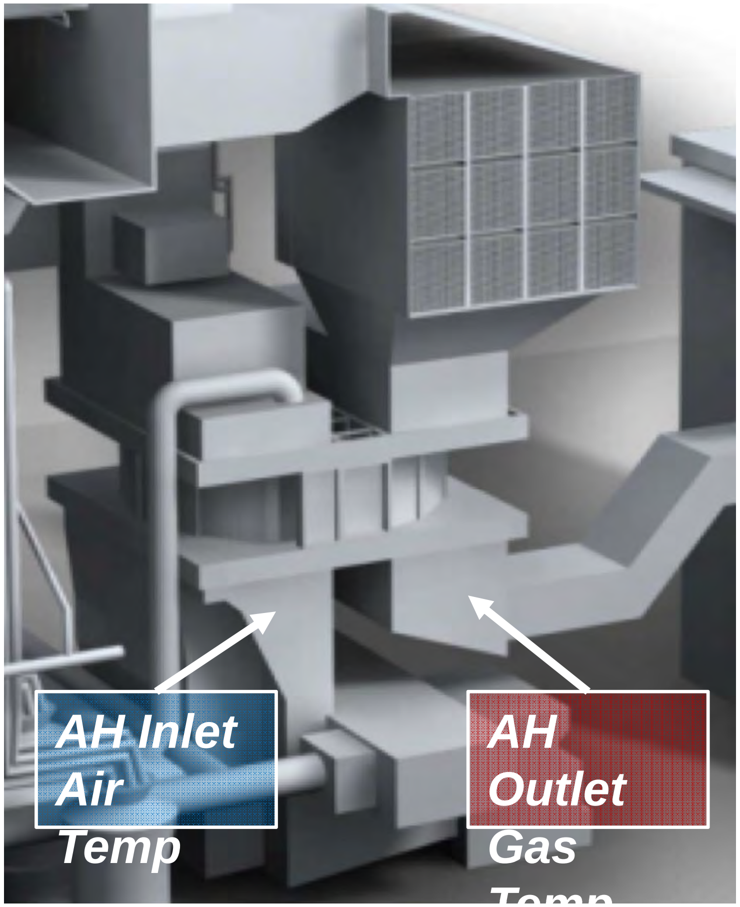
Air Heater – Steam Coil Impact



AH Outlet Gas Temp is Key

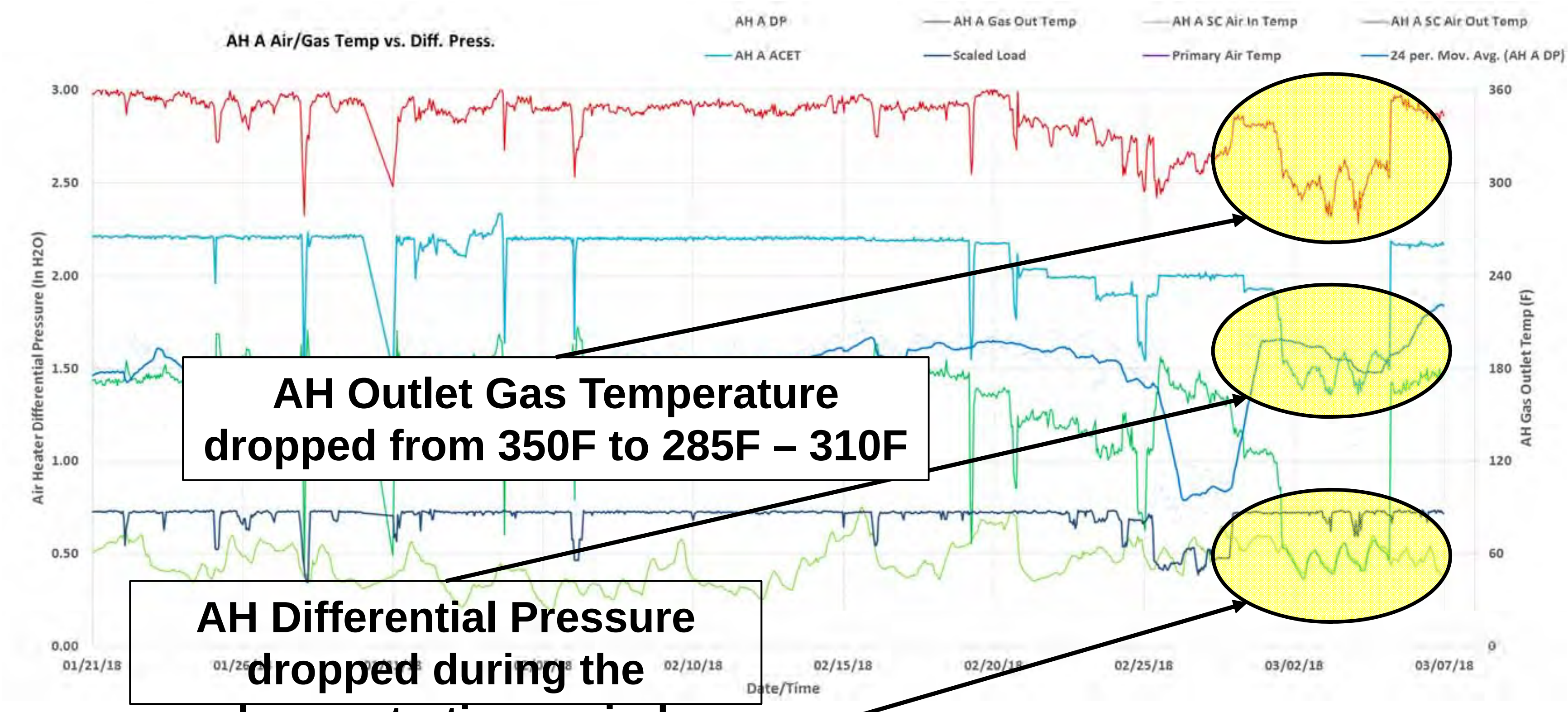
- Inlet air temp is adjusted via Steam Coils to maintain a desired AH Outlet gas temp
- Outlet gas temp is set to avoid condensable fouling
- It takes 0.24 BTU to raise 1 Lb of Inlet air by 1 degree F

Eliminating condensable material via hydrated lime injection eliminates the need for steam coils

The Real World

Air Heater Impacts

Something You’ve Seen Before



AH Outlet Gas Temperature dropped from 350F to 285F – 310F

AH Differential Pressure dropped during the demonstration period

SCAH Power “OFF” from 3/3 – 3/5

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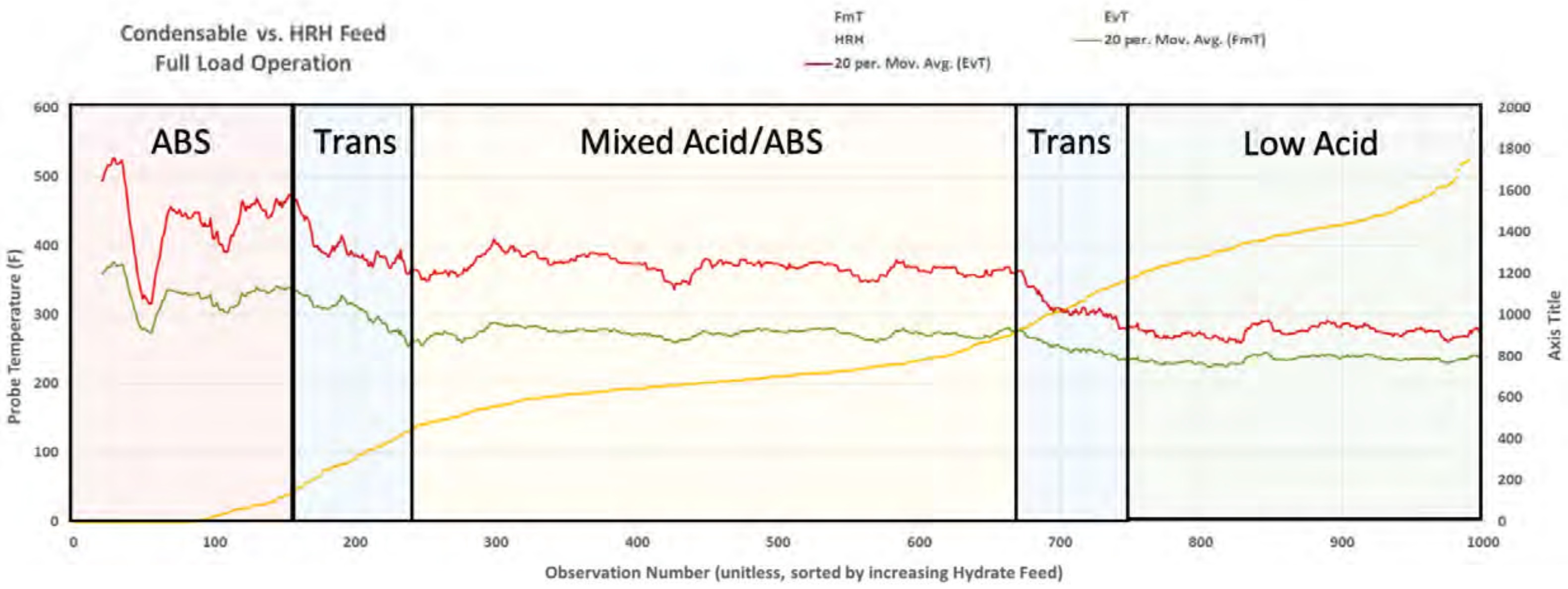
Projecting and Optimizing HRH Utilization

There is no “one size fits all” answer

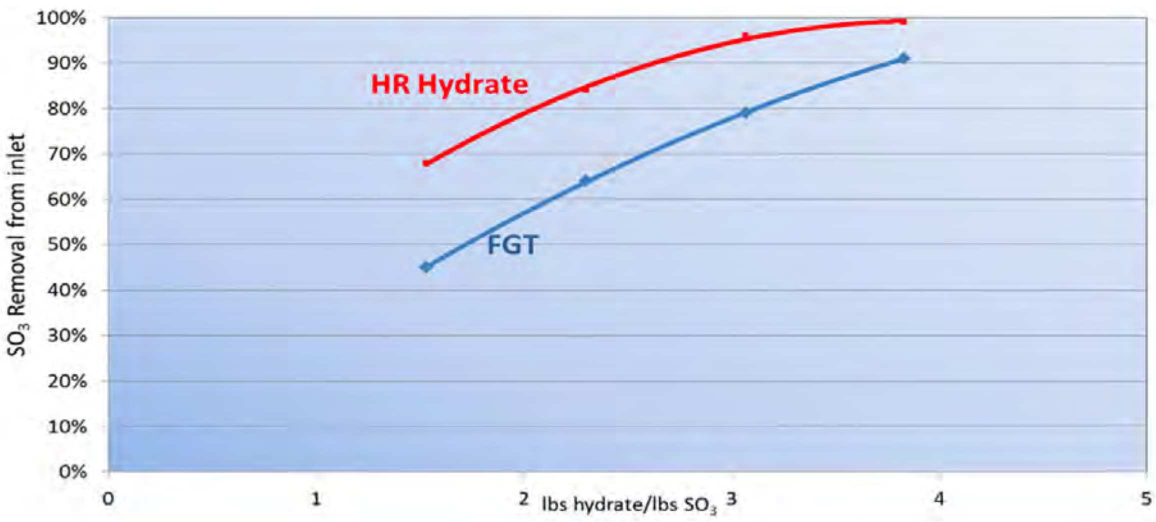
Condensable vs. HRH Usage



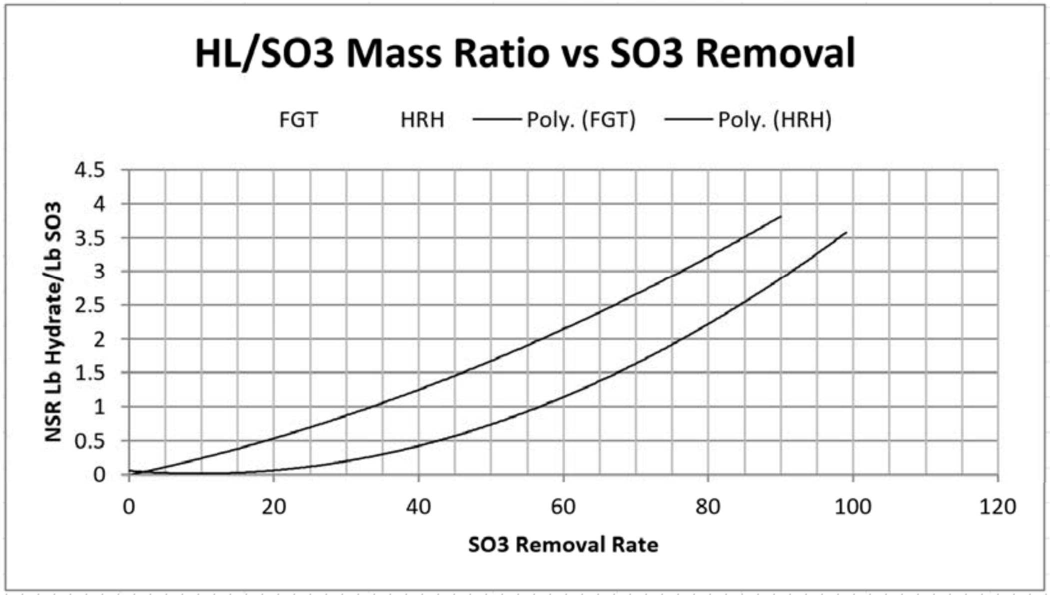
This is also a much-published curve showing condensable state and concentration against varying levels of HRH injection

The overall optimization process requires a knowledge of the expected and the actual before work can be done to reconcile the two

Published Performance Curves



This is the published curve on SO3 removal rate vs HRH Stoichiometry.



This is the same curves but plotted to show HRH required to achieve a desired removal rate

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Some work in Progress

Projections from Public & Plant

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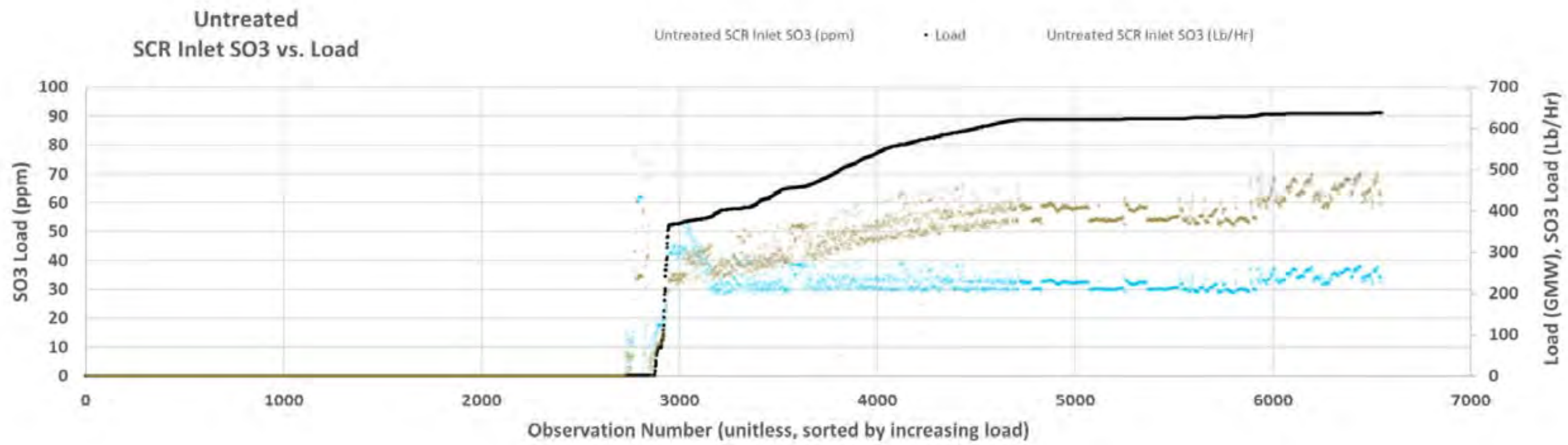
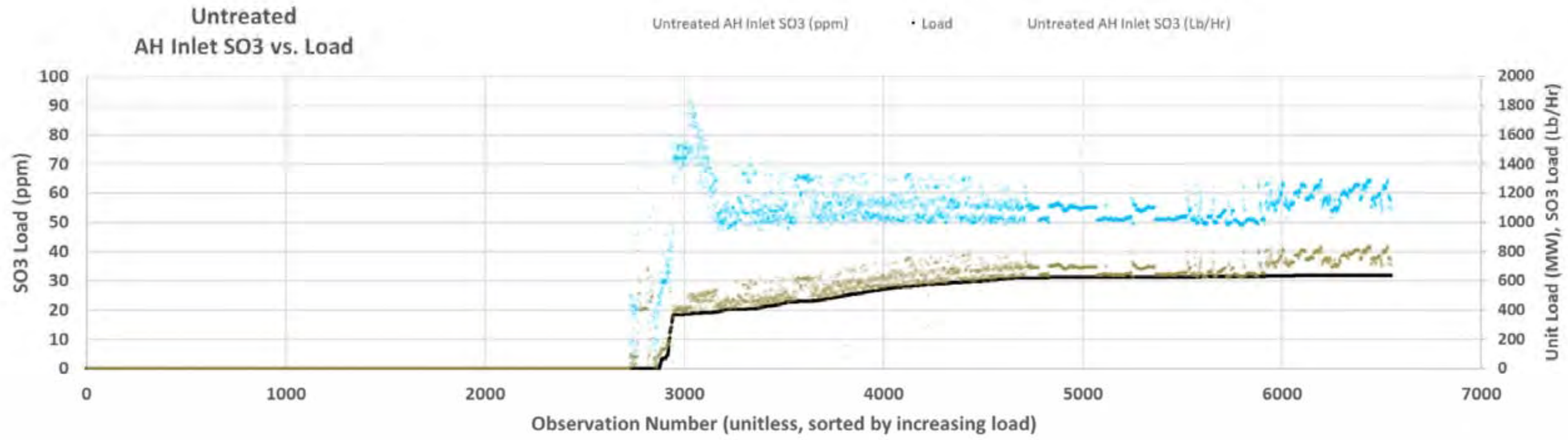
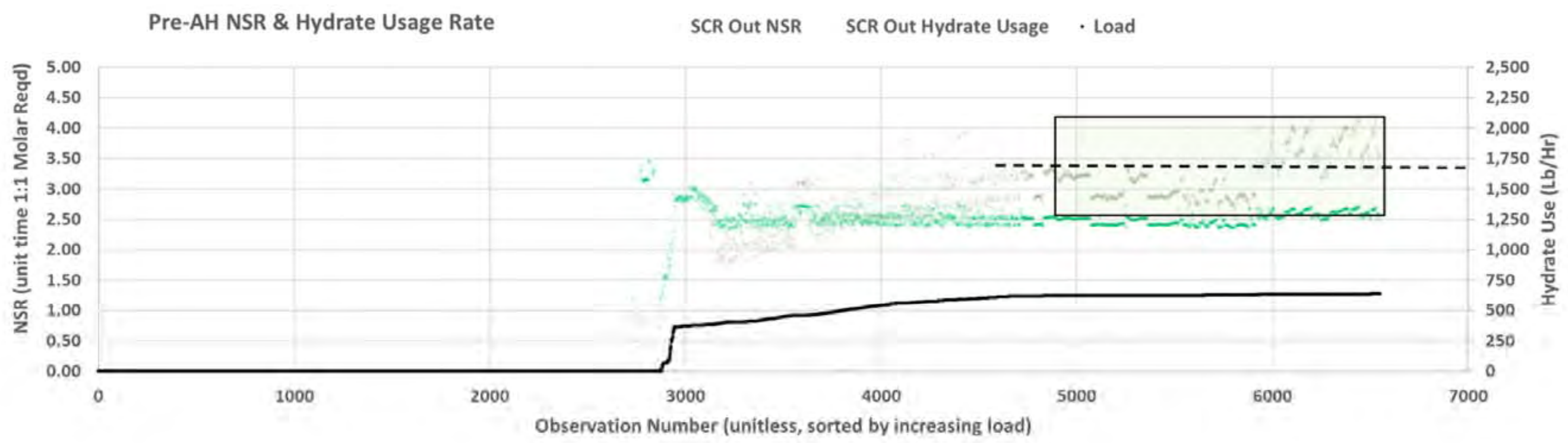


Furnace Conversion Rate could be adjusted so that calculated concentration matches wet chemistry testing. In this case the assumed 1% conversion matched wet chemistry



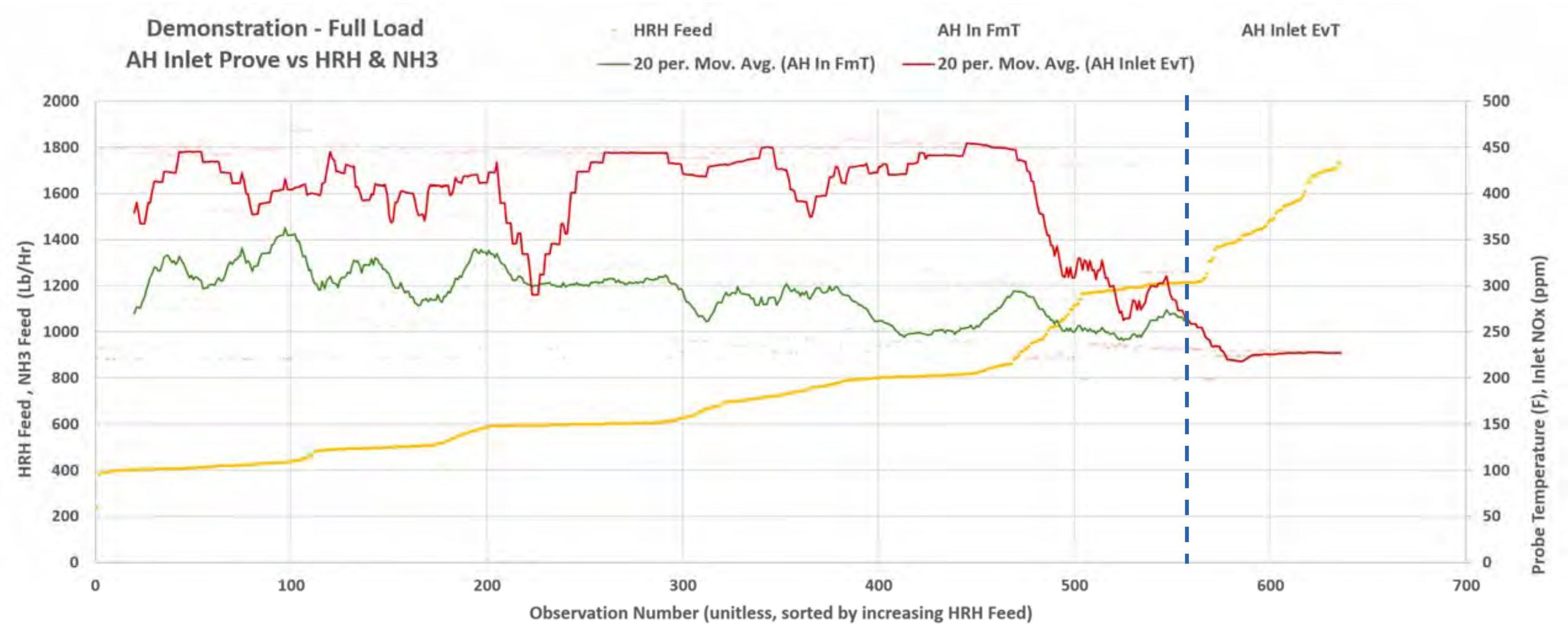
Projections from Public & Plant Data

Using the published HRH Performance Curve to project HRH requirement provides the graph below. In this case a target of 10 ppm at the AH Inlet (H2SO4) was used.



- Projections suggested that 1700 Lb/Hr of HRH would be required to control the total Unit Acid Gas to 10 ppm at the AH Inlet.
- Testing was conducted on a single duct to minimize variables.

Performance Curve During Trial



Demonstration testing provided Performance Insight:

1. **1,200 Lb/Hr was required to control the acid compared to the 850 Lb/Hr projected (for each single duct)**
2. **While Increased HRH consistently dropped the Formation Temperature (FmT), the Evaporation Temp (EvT) remained elevated until roughly 1,100 Lb/Hr. This suggests high level of ammonia slip through the SCR**

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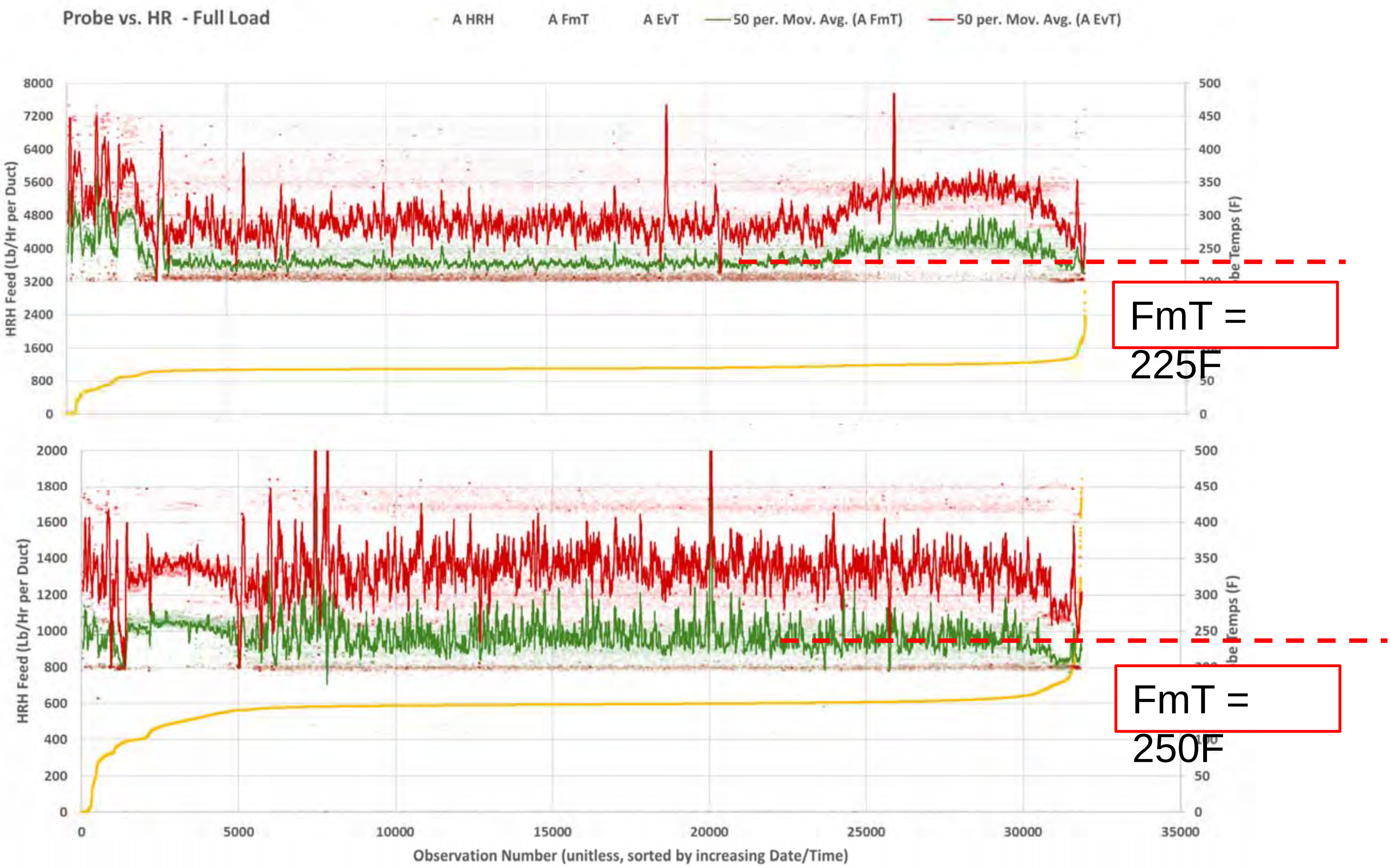
Control Capabilities – Monitor Acid



FmT = 225F

FmT = 250F

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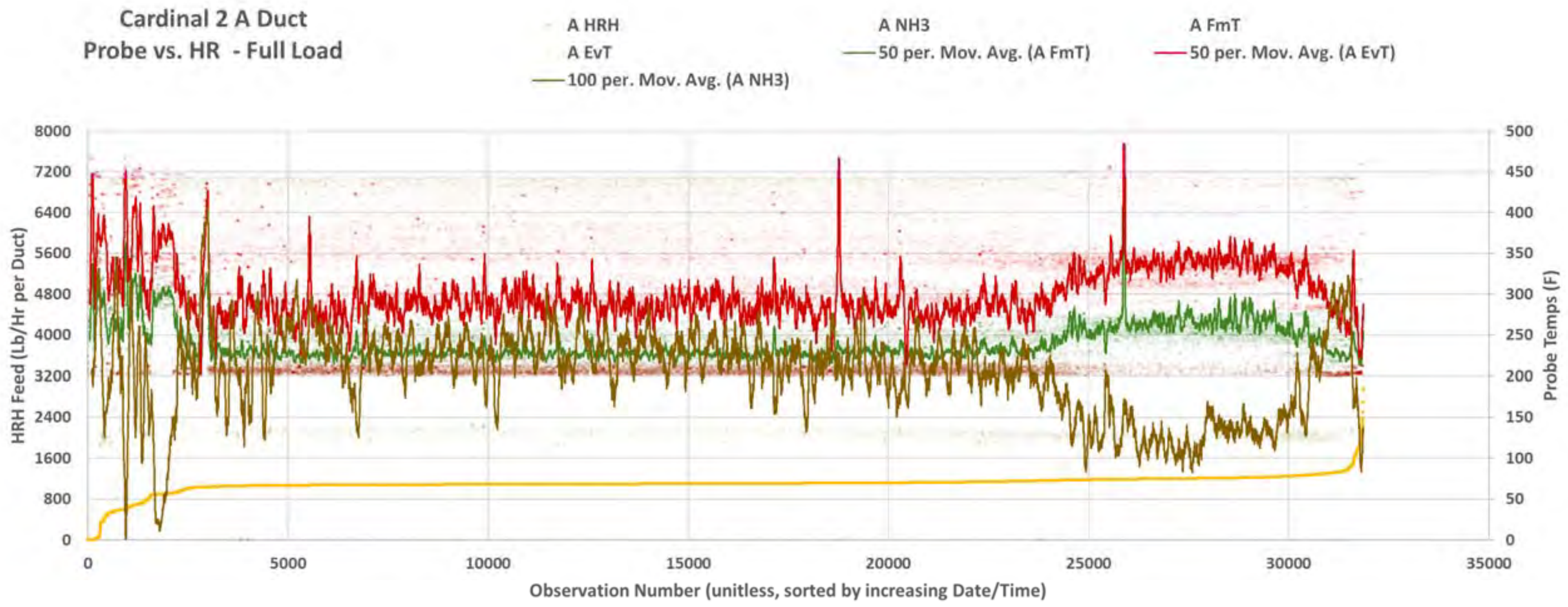
Troubleshooting



Ammonia Interaction with Acid Gas:

“A” Duct experiences wide variations in Ammonia Feed due to Dumping of Hydrolyzer overflow

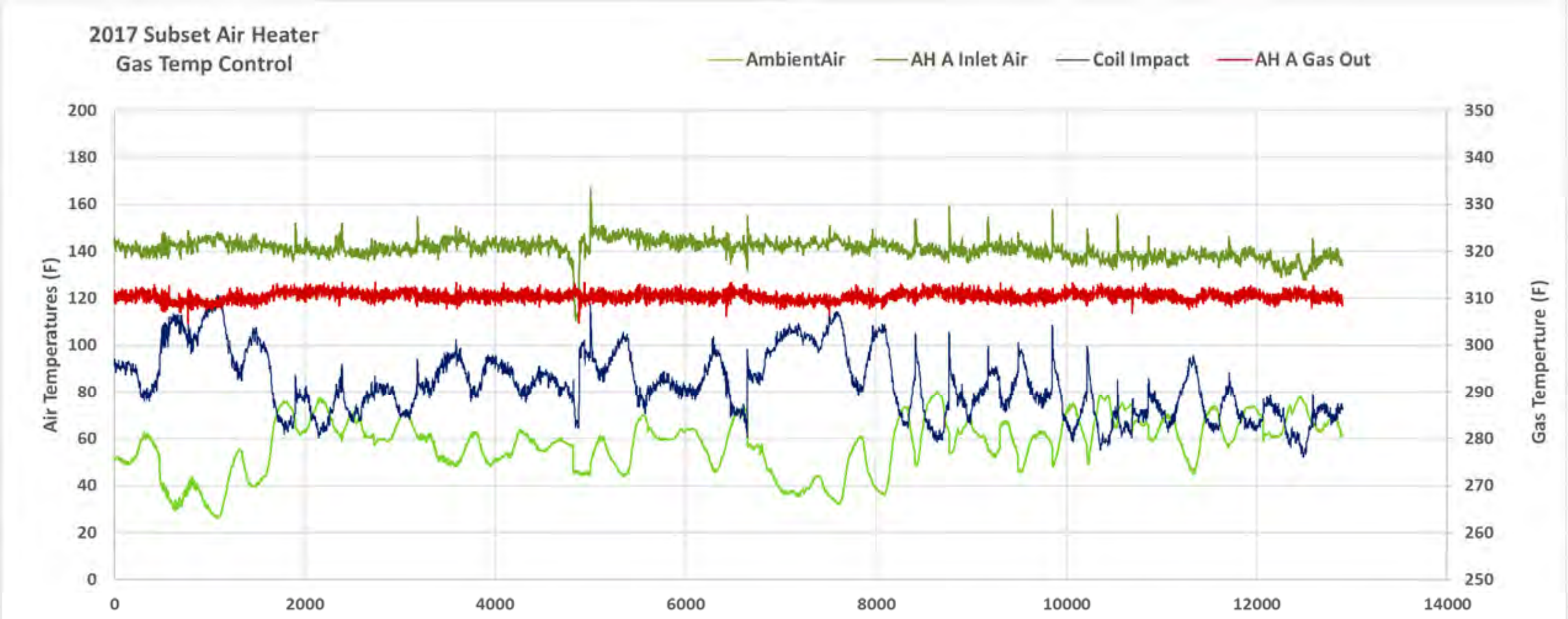
Notice that a DROP in average ammonia resulted in and INCREASE in Acid Gas Concentration. NH_3 reduces free SO_3, but raises the propensity for Ammonium Bisulfate.

2 Ducts are Never the Same

- The total HRH required, at the pre-SCR location is currently 1,700 Lb/Hr as projected.
- However the split between the ducts is radically different.
- The plant has agreed that there is a significant gas flow imbalance between the two ducts that needs attention for a multitude of reasons

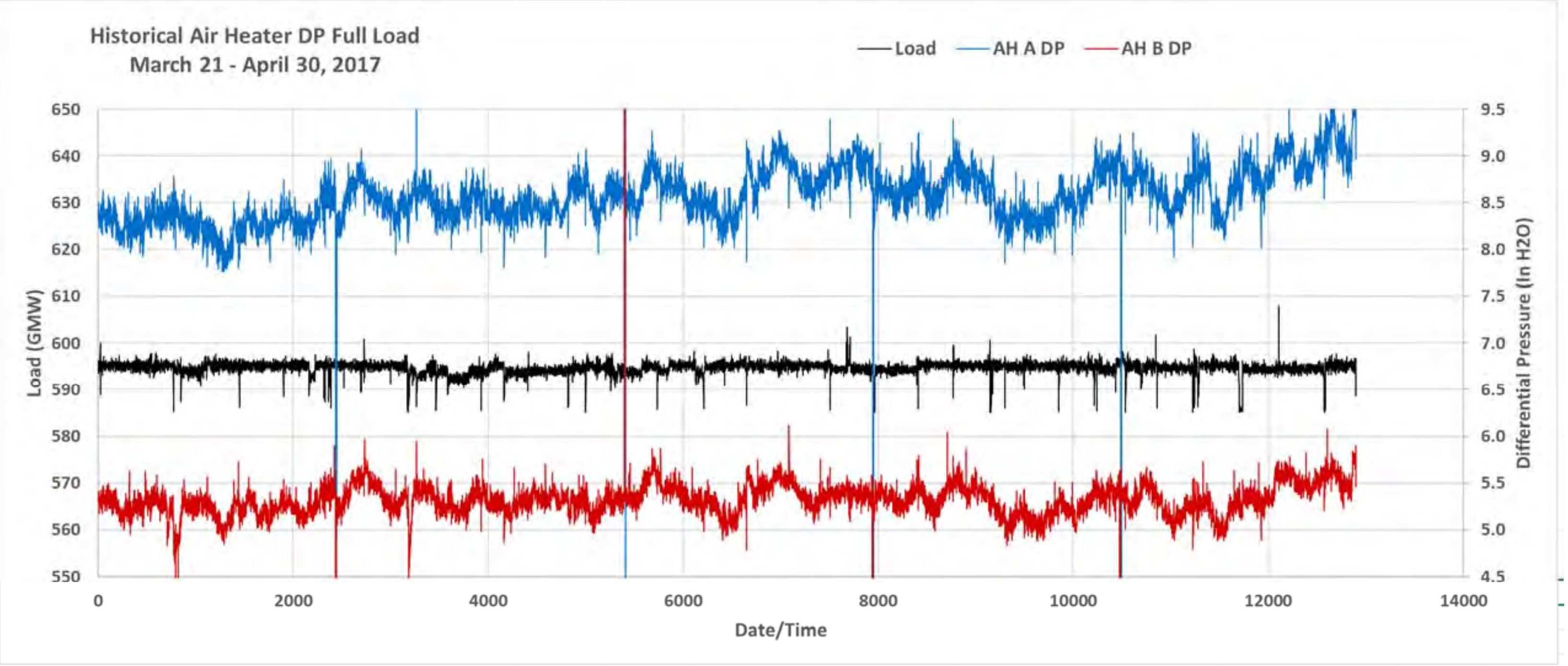
Plant Improvements

Something New: A Duct AH Historical



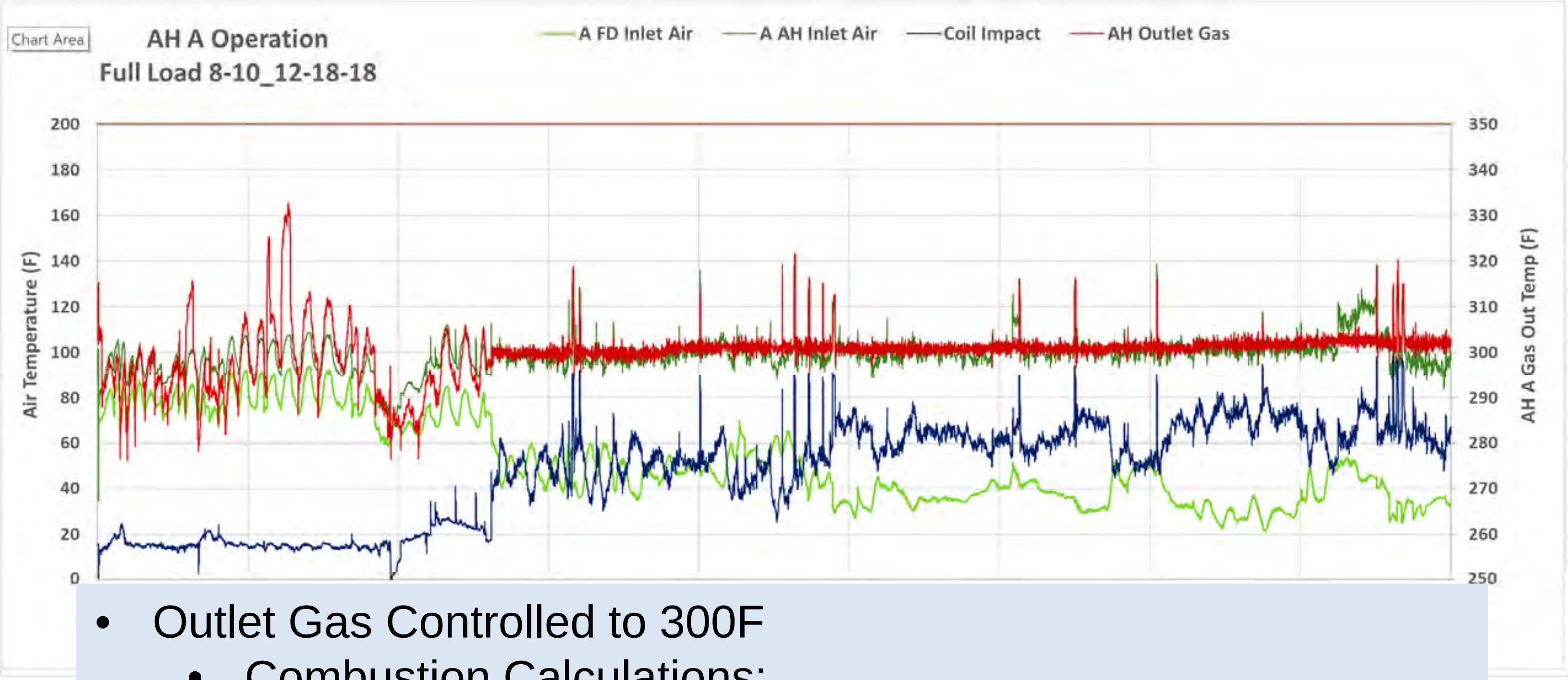
- Outlet Gas Controlled to 310F
  - Combustion Calculations:
    - Net Heat Rate = 9.676 mmBTU/MWHr
    - Total Heat Input Used in Period = 3,700,617 mmBTU
    - Total Air use = 10.49 Lb Air/Lb Coal
    - Total Heat Input used in Coils = 48,004 mmBTU
  - Fuel used in Coils = 1.29% of total Heat Input

Historical Operation Differential Press



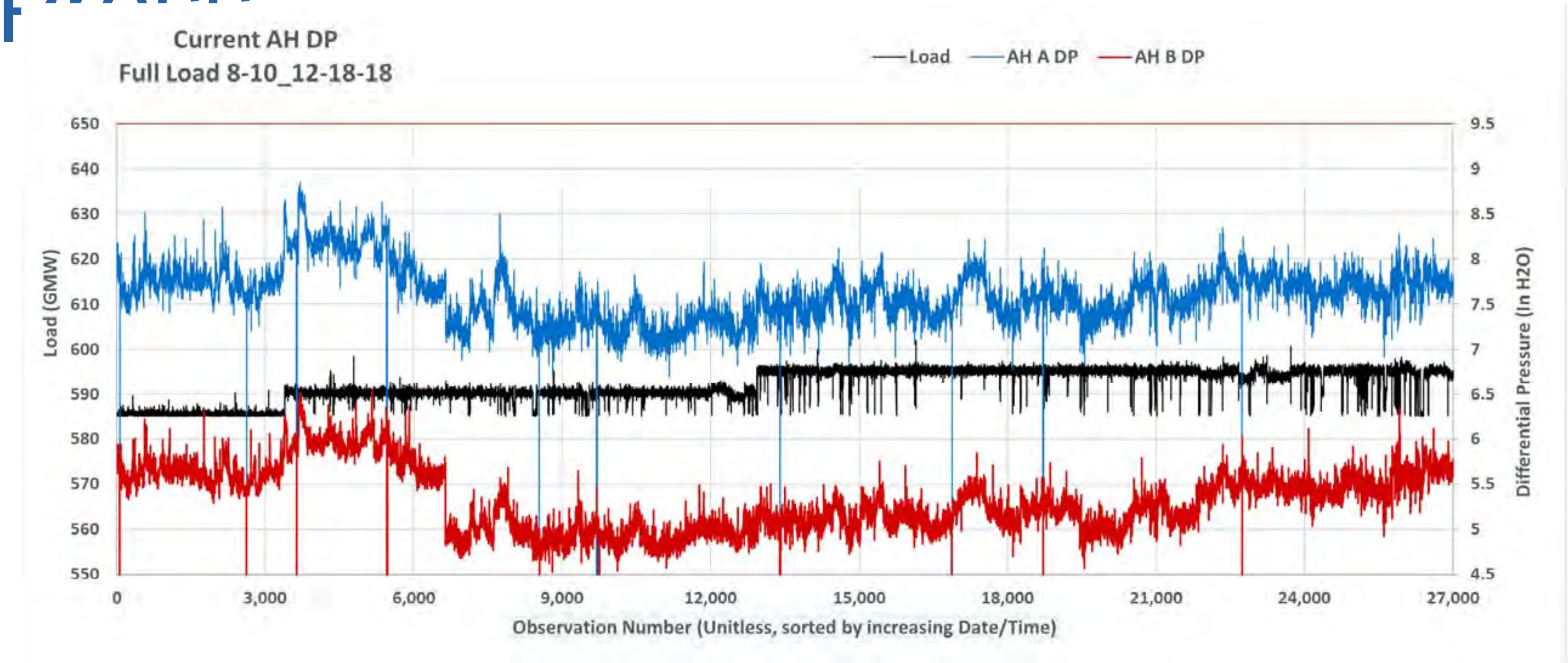
- Significant DP bias toward A Duct
- 32 Days of operation –
    - 0.75” Increase on A Duct
    - 0.25” Increase on B Duct

A Duct AH Current



- Outlet Gas Controlled to 300F
  - Combustion Calculations:
    - Net Heat Rate = 9.676 mmBTU/MWHr
    - Total Heat Input Used in Period = 5,859,540 mmBTU
    - Total Air use = 10.49 Lb Air/Lb Coal
    - Total Heat Input used in Coils = 52,150 mmBTU
  - Fuel used in Coils = 0.89 % of total Heat Input

Current Operation Differential Press



- Significant DP bias toward A Duct
- Actual HRH bias of 2.5:1 A vs. B Duct
- 102 Days of operation –
  - 0.50” Increase on A Duct
  - 0.75” Increase on B Duct

Results to Date

The plant has achieved:

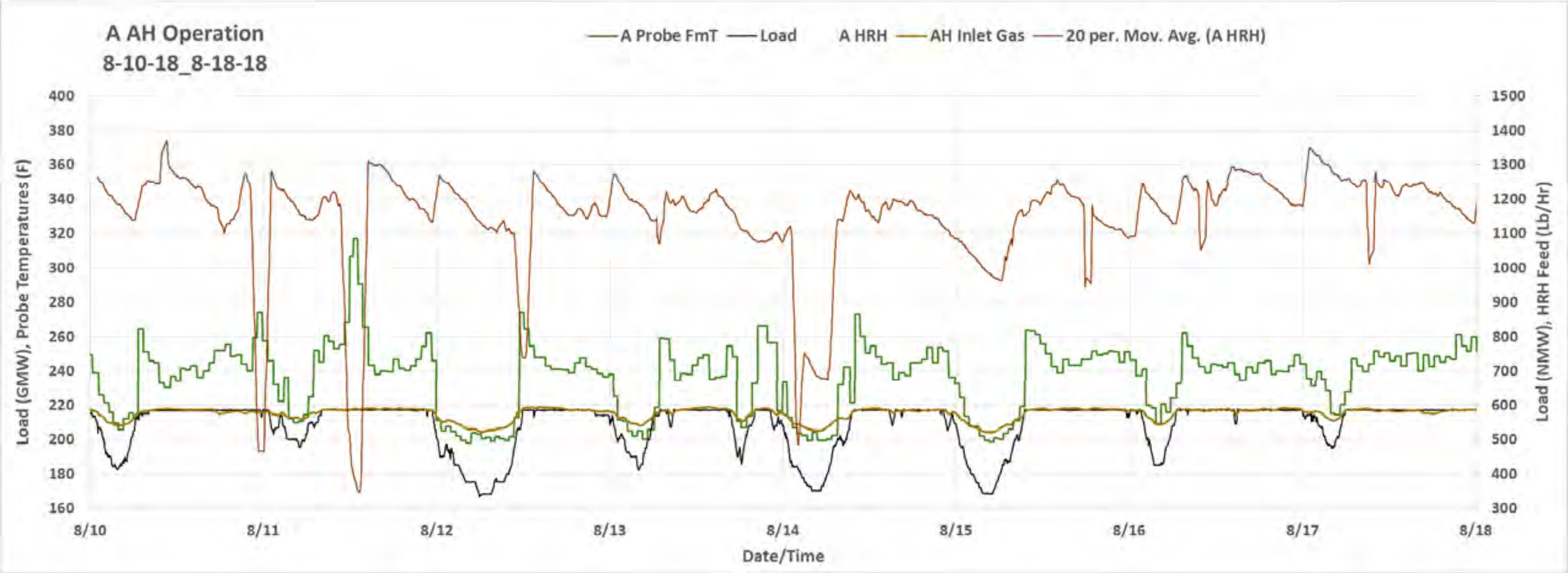
- A reduction in average Air Heater Outlet gas temperature (Heat Rate)
- A reduction in differential pressure buildup although buildup still exists

- More work needs to be done to understand the NH3 overload and distribution issues

Turndown & MOT Reduction

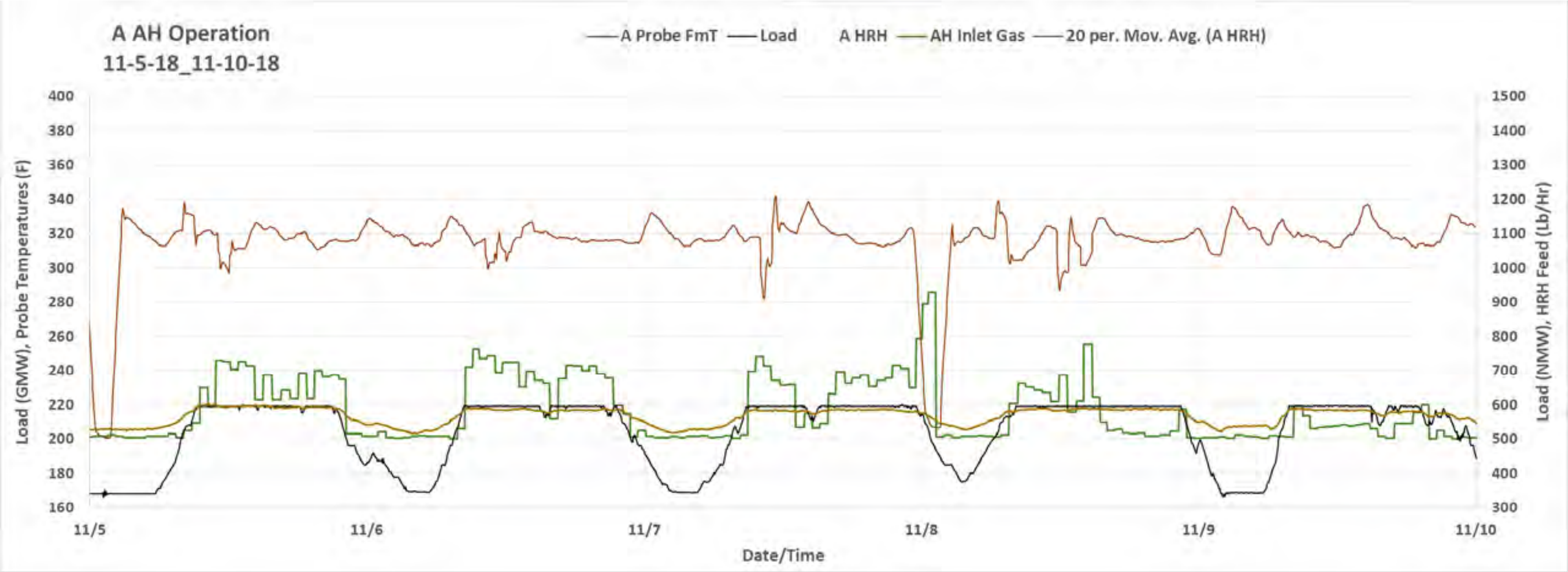
Acid Gas Implications

Morning Sickness



- Desired Control point is 240 – 250F Formation Temperature
- Early System Feed control issues resulted in acid release at morning ramp. An indication of ABS presence in the catalyst pores

MOT Control



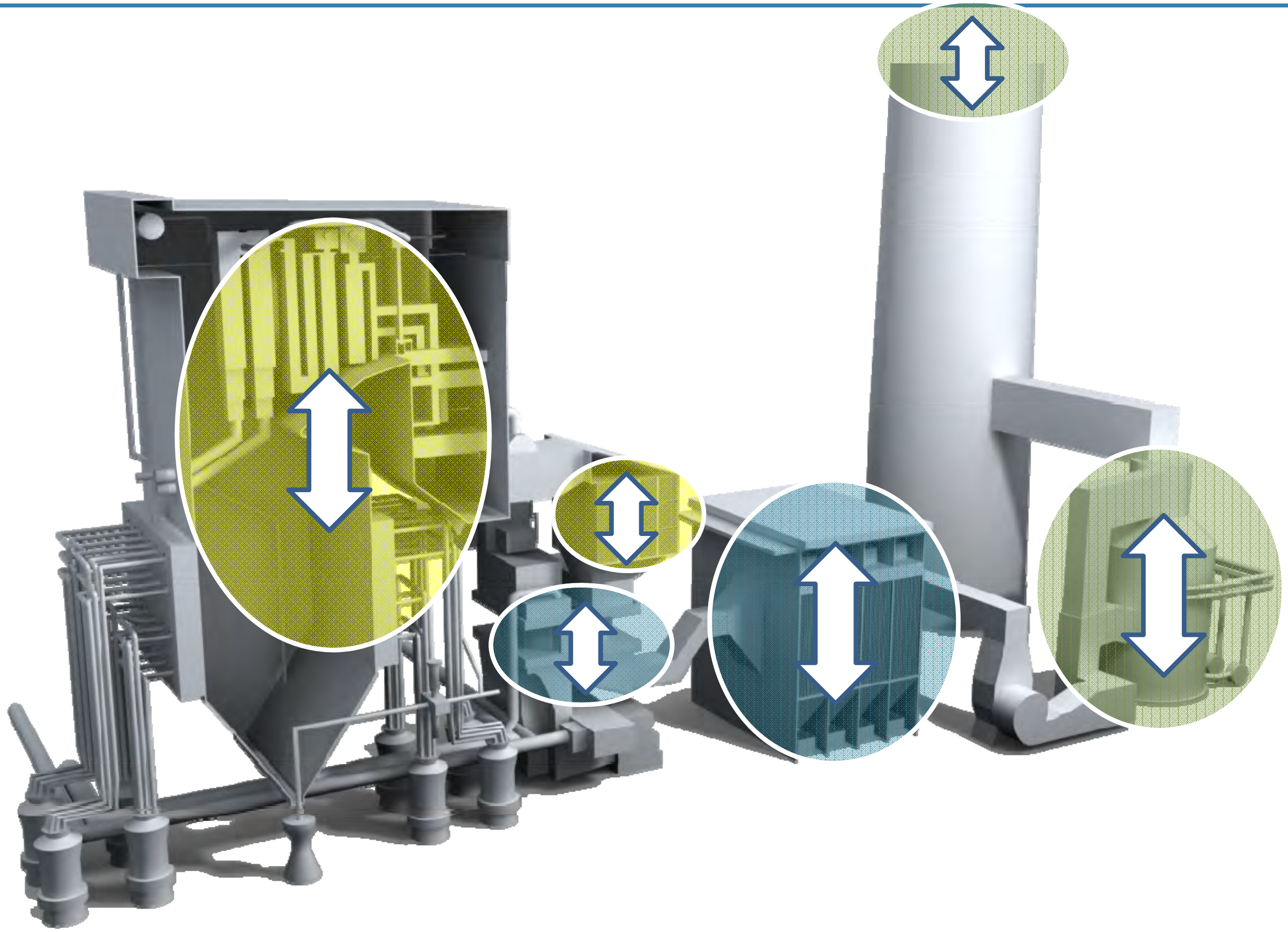
3 months into operation:

- More consistent feed provides operation at target Formation Temperatures with Reduced turndown
- 85 MW reduction in Minimum load (1,000 Hr/yr.):
  - $2 Million/Yr. in Fuel Savings (@$2.50/mmBTU)
  - 3,000 Tons/Yr. Ash Disposal avoidance
  - Reduced SCR/FGD Operating Costs

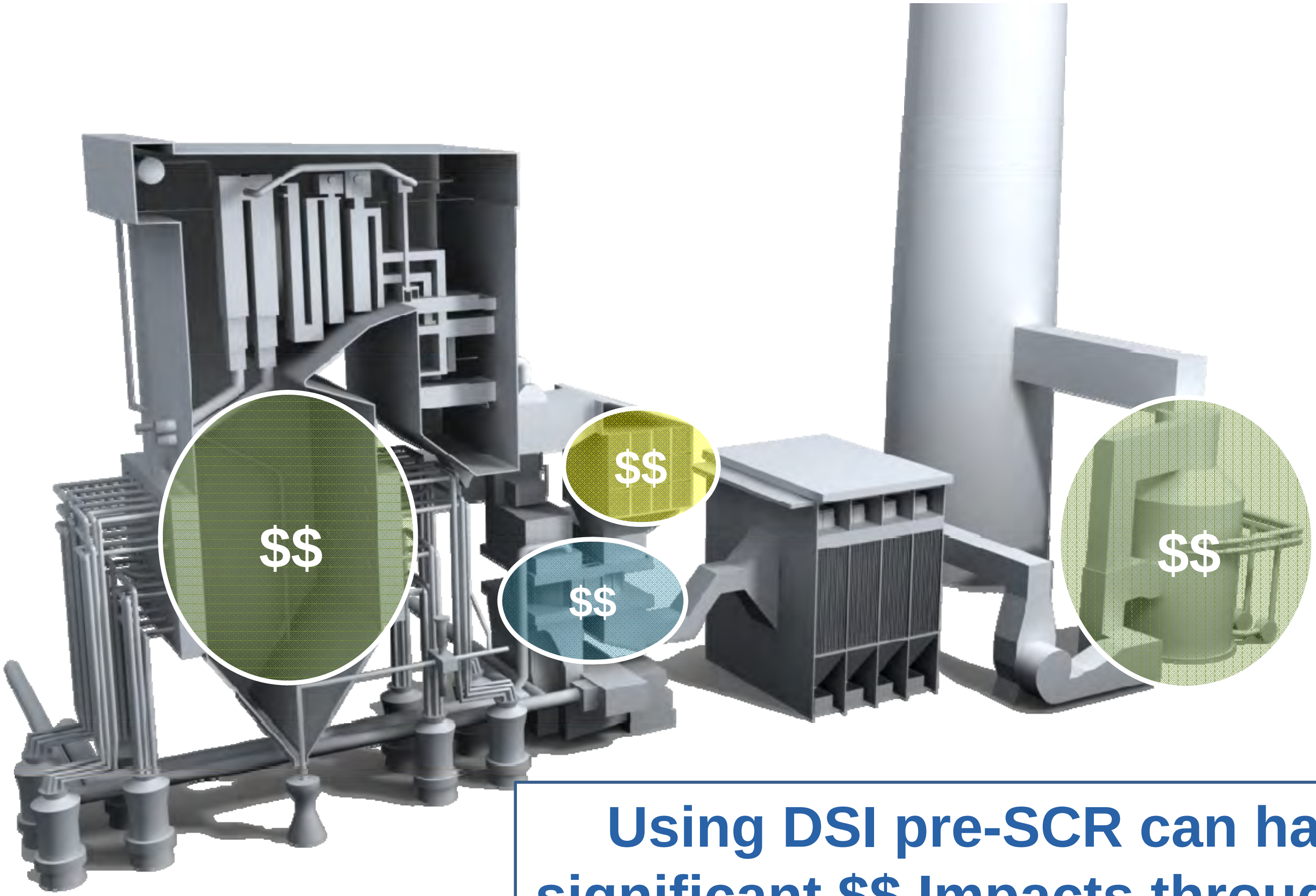
Summary & Conclusion

Acid Gas Implications

Acid Gas Impacts Everything



Pre-SCR DSI Operational Impacts



Using DSI pre-SCR can have significant $$ Impacts throughout the plant

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Operating Benefits from DSI

Obvious:

- Reduced Loss to Steam Coils
- Reduced Air Heater Outlet Gas Temp
- Reduced Minimum Load

Not so Obvious:

- Reduced Ash/Gypsum Disposal
- Revenue Potential from Ash Sales
- Reduced SCR Operating Cost
- Reduced FGD Operating Cost
- Reduced ESP/Wet ESP Operating Cost
- Reduced AH Basket Corrosion/Loss
- Reduced Duct Corrosion
- Reduced Pulverizer Cost
- Reduced ID Fan Loading

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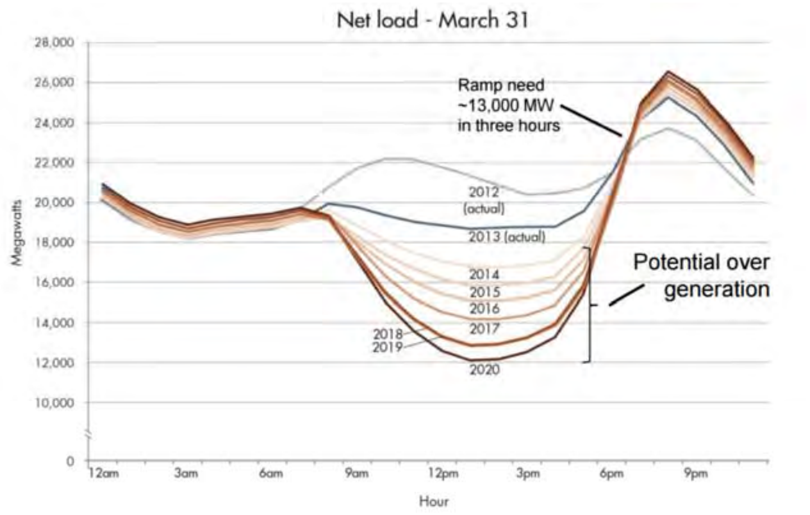
For Consideration

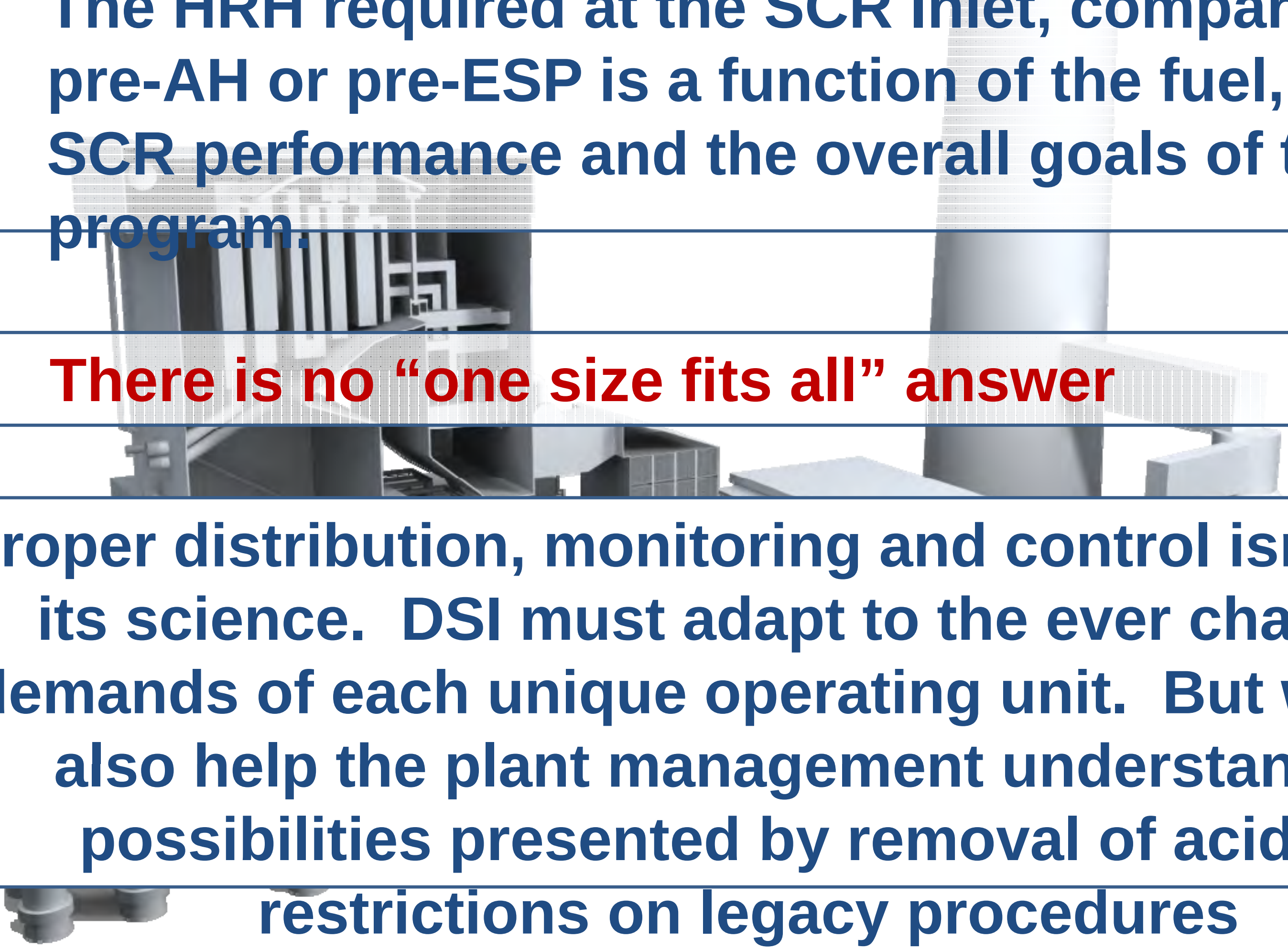


To Remain Viable and Competitive, Coal plants **MUST** evaluate their Operating Cultures.

Many **EXISTING** Paradigms will need to be discarded in favor of more **DYNAMIC** operating paradigms, to:

- Improve Fuel Flexibility
- Improve Minimum Load Constraints
- Improve Ramp Constraints

Pre-SCR DSI Operational Impacts



- The HRH required at the SCR Inlet, compared to pre-AH or pre-ESP is a function of the fuel, the SCR performance and the overall goals of the program.

- There is no “one size fits all” answer

- Proper distribution, monitoring and control isn’t an art its science. DSI must adapt to the ever changing demands of each unique operating unit. But we must also help the plant management understand the possibilities presented by removal of acid gas restrictions on legacy procedures

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