REINHOLD ENVIRONMENTAL ®

2022 Reinhold/PCUG Round Table Presentation

Hosted by Duke Energy in the Charlotte Sheraton/Le Meridien Hotel, Charlotte, NC on June 27-28, 2022

MISSISSIPPI® LIME

Discovering what's possible with calcium

Quantifying Operational Benefits from the Use of Enhanced Hydrated Lime

Mississippi Lime Company

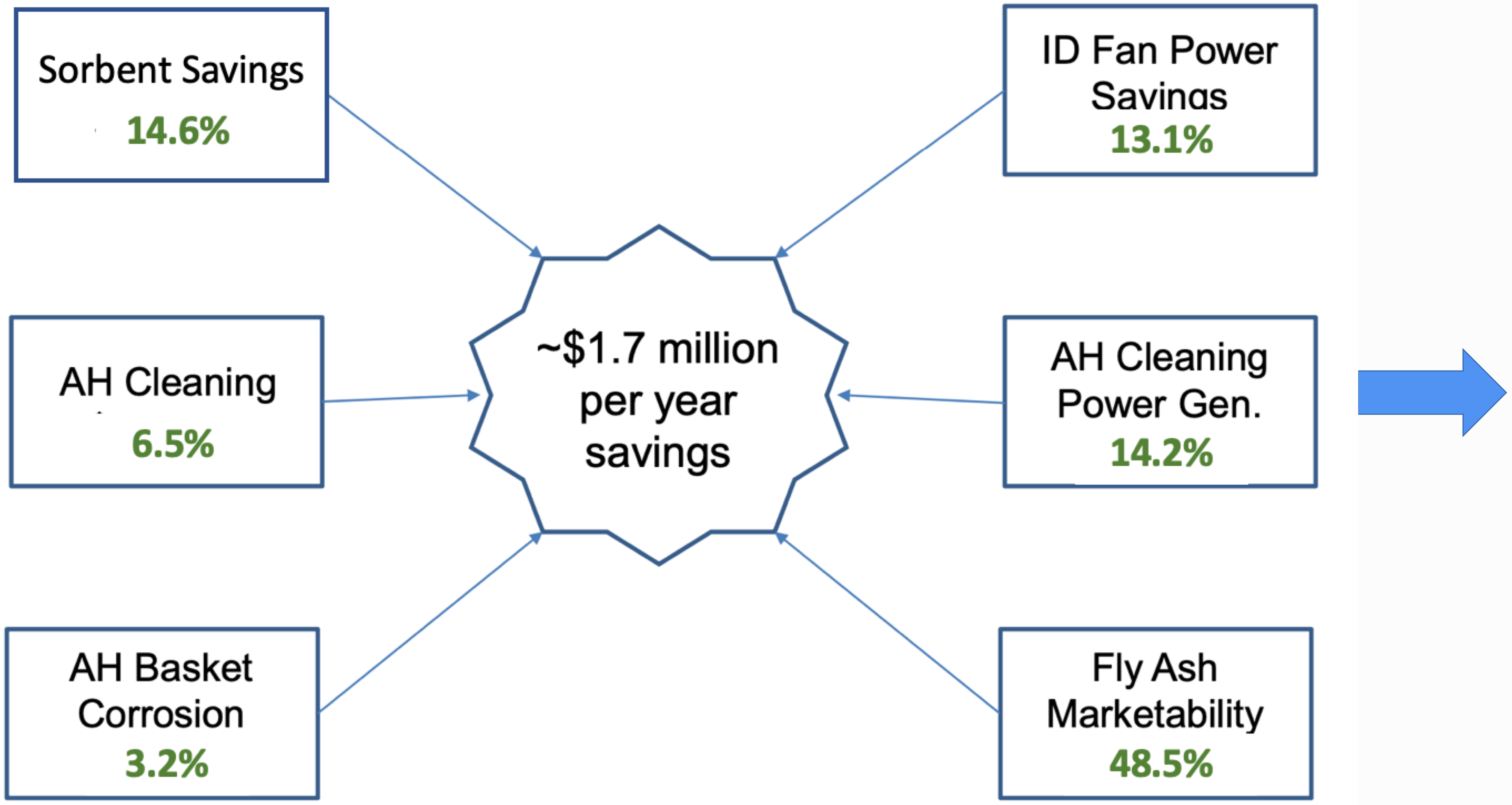
June 28, 2022

MISSISSIPPI LIME™

Discovering what's possible with calcium™

Program Objectives

From Project Submission



Fly Ash Marketability: 48.5%

Sorbent Savings: 14.6%

MW Gain/Heat Rate 14.2%

ID Fan Power 13.1%

AH Cleaning 6.5%

AH Basket Corrosion 3.2%

Fly Ash Marketing

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Fly Ash Marketing Pg. 1

Traits of Marketable Fly Ash

- LOI lower than 6%
- SO_3 content less than 5%
- Sulfur Species – Sulfate vs. Sulfite
- Low Chloride Content
- Sodium less than 1.5%

	Hydrated Lime	Trona
Oxide	Result (%)	Result (%)
SiO2	35.68	40.6
Fe2O3	27.12	22.4
Al2O3	14.37	15.5
CaO	12.81	7.4
SO3	3.99	4.6
K2O	2.54	2.4
TiO2	1.15	1.1
MgO	0.63	0.6
Na2O	0.54	4.2
BaO	0.24	0.2
V2O5	0.17	0.1
Cl	0.17	0.3
ZnO	0.1	0

High Sodium precludes Ready Mix Applications

–

Trona is the source of the Sodium

High Chlorides preclude Kiln Feed Application

-

Lack of Beneficial Use Drives Increased Disposal Cost

Fly Ash Marketing Pg. 2

- Pre-SCR Injection changed the temperature of the sorbent/acid gas reaction zone, favoring SO_3 over Chlorides.
- High Reactivity Hydrated lime is calcium, not sodium, based.

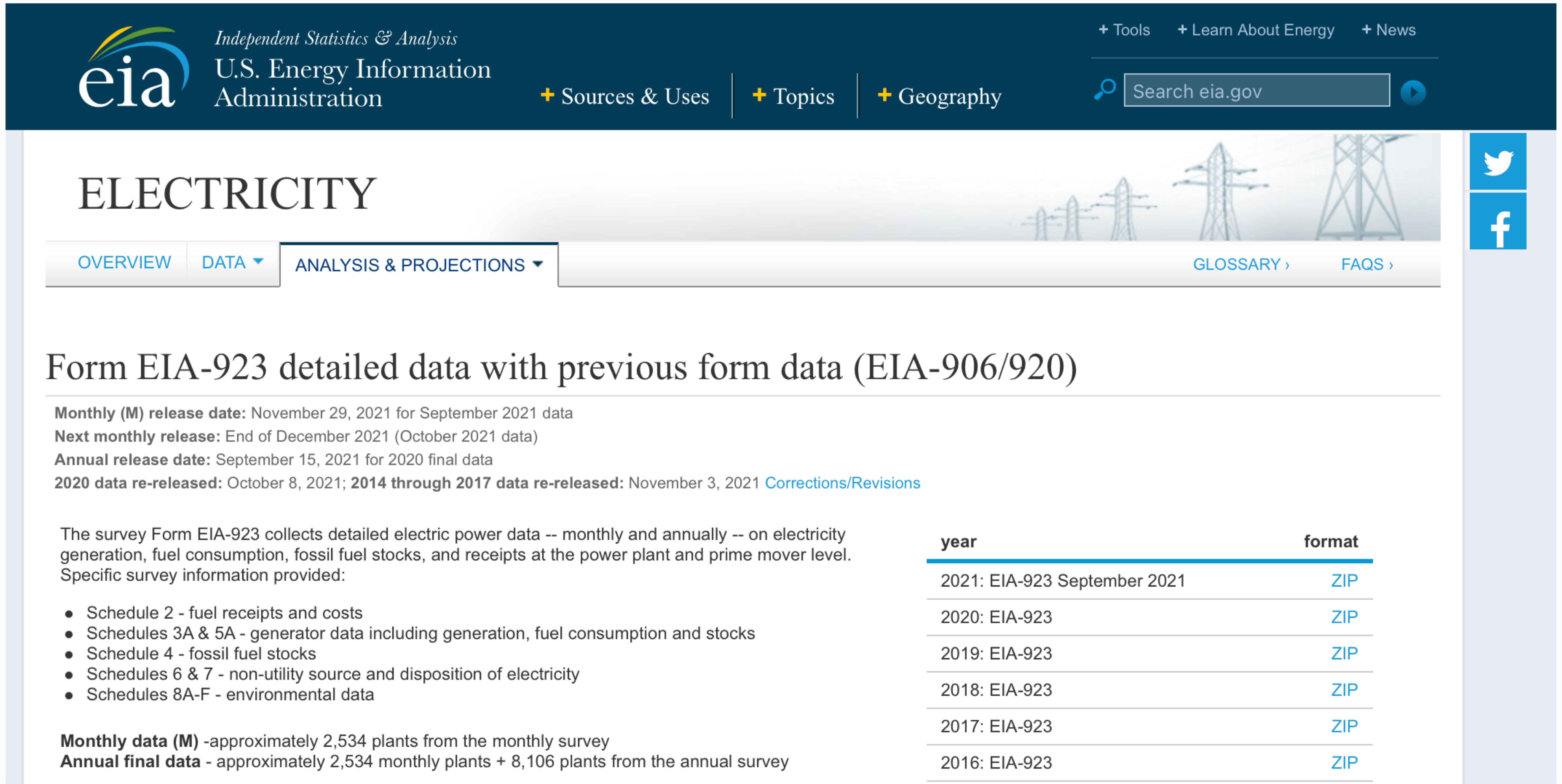
- **Net Result of Sorbent/Location move was a reduction in sodium and chlorides, allowing material to be used for kiln feed applications**
- **Landfill avoidance Value = Approx. $11.50/Ton**
  - **Year 1 Benefit = $724,500**
  - **Year 2 Benefit = $891,250**

Improvement in Flyash LOI to <3% could more than double the marketable value. Combustion Improvements needed to attain this.

- **Potential Benefit to over $2,000,000/Yr.**

Sorbent Savings

Source of Analytical Data



1. HRH captured Sulfur data was taken from the first 7 months of 2021
2. Trona captured Sulfur data was taken from the first 10 months of 2019
3. Trona use was supplied by plant
4. HRH use was taken from MLC records on actual deliveries to plant

Tons of Sulfur was derived by totalizing monthly fuel use (tons) X monthly Sulfur %

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Annual Savings from Hydrate

20% Improvement against target

Sorbent Comparison for 2019 EIA Data

Total Sulfur Tons per EIA923-2019	Trona Reqd per Ton Sulfur	HRH Reqd per Ton Sulfur	Tons Sorbent Required	Sorbent Cost per Ton	Annual Sorbent Cost
66,430	0.061174358		Confidential	Confidential	Baseline
66,430		0.057293143	Confidential	Confidential	Baseline – 16.4%

Additionally, plant operations has provided data supporting a 10% decrease in O&M costs associated with physical injection of sorbent.

Sorbent Cost Savings – 15% Over Target (Target = 14.6%)	16.4%
Sorbent O&M Savings	1.1%
Total Annual Sorbent Related Savings	17.5%

Annual Savings from Hydrate

As a parting thought on this point:

The plant operating permit requires maintenance of "no visible plume". So no data on actual stack emission limits exist other than both materials, when in operation, met this operational objective

However, the plant reported that operational problems often took the trona injection system offline. Detailed data was not available on the amount of downtime.

The plant reports that conversion to HRH injection resulted in "significantly" higher system availability, leading to more injection hours.

Plant management believes that if the total trona use accounted for more operational hours the actual use, and cost, of trona would have been much higher.

Sorbent Performance

Plant Injection Plan

- Experience with Injection resulted in the following dual-mode injection plan being implemented

MW Trigger Point (MW)	Feedrate (lbs/hr)		
150	U1	U2	U3
	200	200	200
	350	385	350

- Essentially 200 Lb/Hr at loads below 150MW and 350 Lb/Hr at loads above 150 MW

Load Code Definition

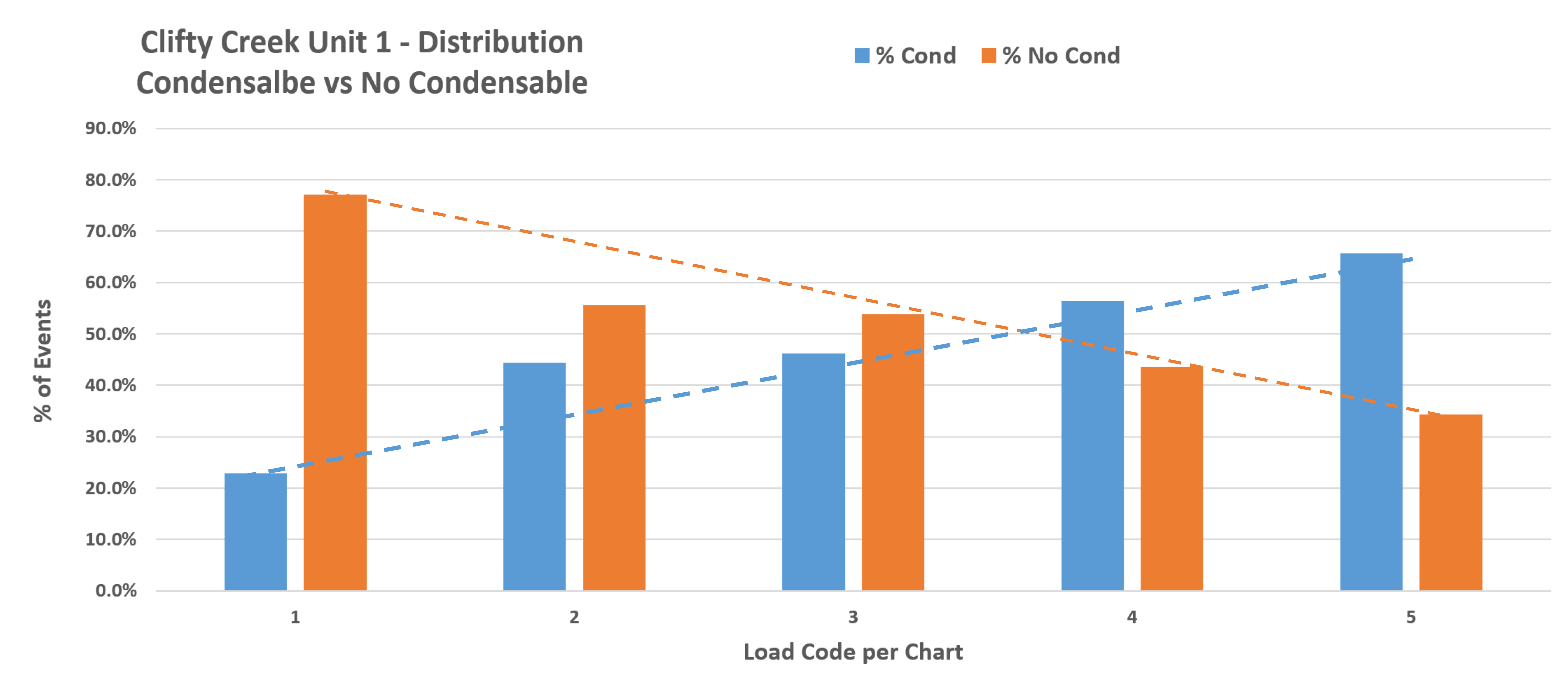
- Load Codes (buckets) were established to provide data groups as follows:

Code	Load Pt
1	85
2	105
3	185
4	200
5	210

- Load Code 0 (not plotted here) covers all gross loads below 85 MW.
- Load Code 1 (LC1) covers 85 – 105 GMW, and so forth.
- The goal of the injection plan was to provide an acid concentration at, or below, 10 ppm at the AH Inlet.

Probe Response vs. Load Codes

- The following bar chart shows the percentage of readings from the Breen probe (located at the AH Inlet location) that registered “no Condensable” versus valid Condensable. “No Condensable” (NC) means the reading was below the detection point.



Inspection shows that:

- 77% of the readings reported NC at low load (LC1)
- 65% of the readings at high load reported valid condensable readings

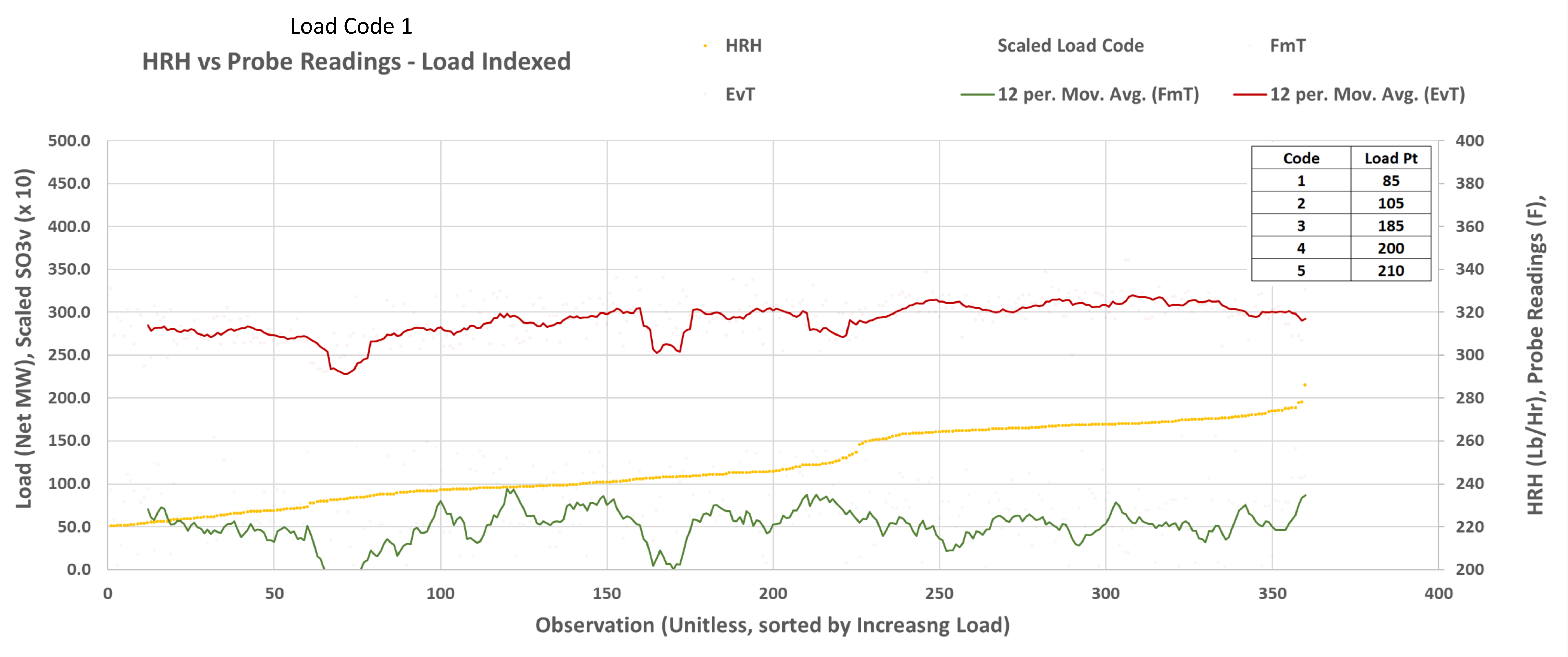
Acid Load/HRH Load

- Combustion Calculations were executed on the fuel generally burned. Assumptions for SO_2:SO_3 conversion were:
  - Furnace – 1%
  - SCR – 1%

- Full Load Acid Load = 268 Lb/Hr
- Full Load HRH Projected = 563 Lb/Hr
- Full Load NSR = 2.1

- Low Load Acid Load = 127 Lb/Hr
- Low Load HRH Projected = 260 Lb/Hr
- Low Load NSR = 2.1

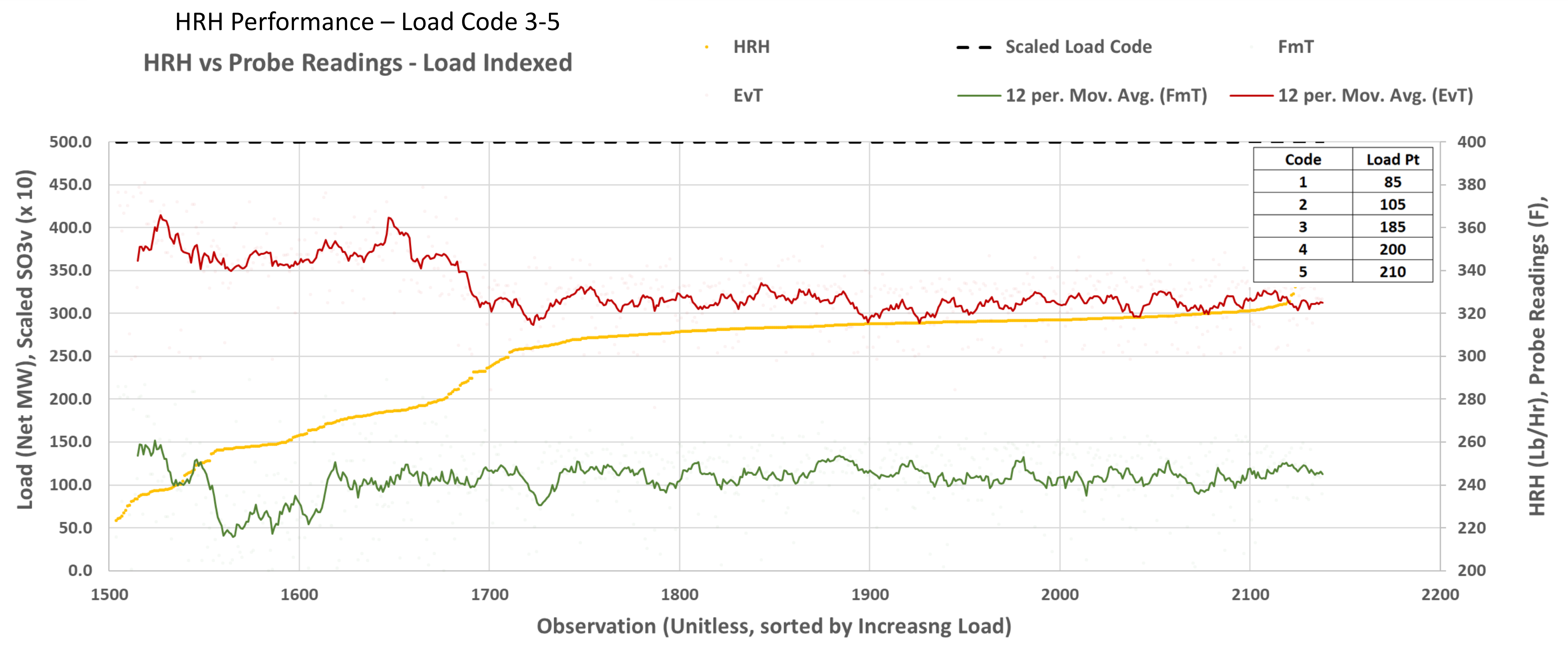
Low Load HRH Performance



This graph shows the relationship between varying injection rates at low load and detected condensable matter at the AH Inlet.

- With injection rates between 220 Lb/Hr and 280 Lb/Hr Formation temperatures below 240F were reported. This is below the 10 ppm target set point
- With 77% of the readings below the detection level, the target of 260 Lb/Hr is believed to be in excess of the amount required

High Load HRH Performance



This graph shows the relationship between varying injection rates at high load and detected condensable matter at the AH Inlet.

- With injection rates between 220 Lb/Hr and 300 Lb/Hr ABS was detected at the AH Inlet location. This is to be avoided.
- With Injection rates above 310 Lb/Hr, ABS was generally eliminated and Formation Temperatures around 250F were reported. This is consistent with the 10 ppm target
- With 65% of the readings above the detection level, the target of 350 Lb/Hr is believed to be generally correct but was never actually demonstrated at full load

High Load HRH Performance

As a parting thought on this point:

In preparation for the 2022 CSAPR regulation changes, the plant experimented with changes in mill configuration at various load point.

Where 350 Lb/Hr at full load was controlling AH Inlet SO_3 levels previously, that is no longer the case

The plant is currently exploring a three tier injection protocol to deal with increased acid loading with certain mill deployments

Initial results suggest that somewhere between 400 and 450 Lb/Hr is the actual requirement at full load for this unit.

Heat Rate/Fuel Savings

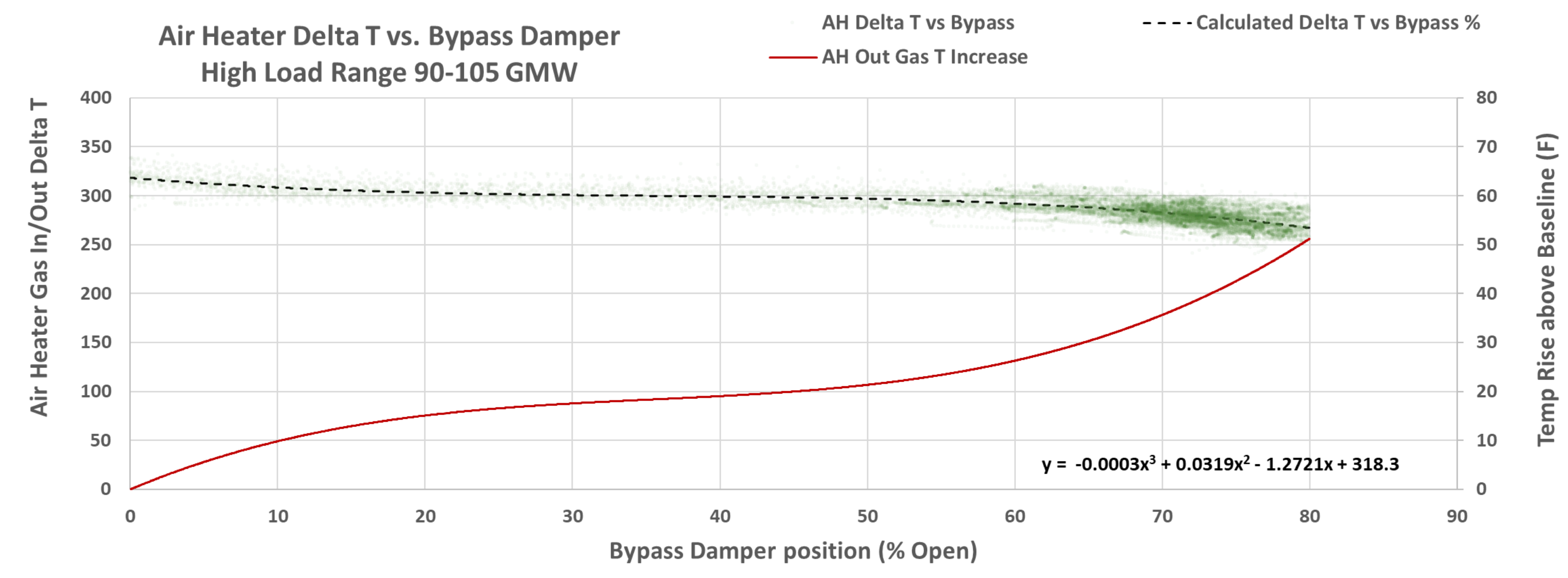
Fuel Savings Potential

1. Hot gas loss improvement from reduced use of Air Heater Bypass Dampers
2. Excess Fuel Use at Minimum Load (Min Load Reduction)
3. ID Fan Power Consumption

Hot Gas Loss – Bypass Dampers

Rule of Thumb:
40F in AH Outlet Gas Temp = 1% in Heat Rate

Impacts of Bypass Dampers



High Resolution	
0	75
0.5	90
1	105
2	115
3	125
4	135
5	145
6	165
7	185
8	200
9	210
10	220

The data set provided by the plant (covering 4/1/21 – 8/26/21) was subdivided into 10 (eventually 11) “load codes” as shown on the table to the right, above.

From those data subsets, the relationship between damper position and the gas temperature increase at the AH Outlet for each load group could be determined.

A typical graph for LC 1 is shown, for example, above.

Data Metrics

The curve developed for each load code was defined as a third order polynomial and the coefficients for each curve used to define the expected gas temperature differential at any given load and any given damper position.

LC	Load Range		X3	X2	X	Constant		Count
0	0	**90**	coefficients for AH Temp Rise vs Bypass Damper %					
1	90	105	**-0.0003**	**0.0319**	**-1.2721**	**319.3**		**19063**
2	105	115	**0**	**-0.0045**	**-0.1639**	**316.99**		**3279**
3	115	125	**0**	**-0.0026**	**-0.3469**	**320.67**		**1350**
4	125	135	**0**	**-0.0093**	**0.0525**	**319.37**		**1411**
5	135	145	**0**	**-0.0043**	**-0.2294**	**319.91**		**945**
6	145	165	**0**	**-0.0039**	**-0.2792**	**323.96**		**1600**
7	165	195	**0**	**0.0002**	**-0.5339**	**329.73**		**1279**
9	195	200	**0**	**-0.0015**	**-0.3923**	**330.44**		**1642**
9	200	210	**0**	**-0.0046**	**-0.0365**	**324.29**		**1592**
10	210	220	**-0.0005**	**0.0563**	**-1.9377**	**343.29**		**572**

For consistency of data, heat input at any given gross load was determined from a curve based on the heat input and gross megawatts reported to the EPA Acid Rain database for 2021

The cost of fuel was similarly determined from the EIA923 report, again 2021.

Bypass Damper Valuation

EIA923 Fuel Quality	
0.01156	mmBTU/Lb

Heat Input vs Load (mmBTU/GMW)		
-0.0024	9.8355	73.617

Deg F for 1% Heat Rate	40

Min in 1 Year	525,600
Min In Data Set	212,550
Data % of Year	40.4%

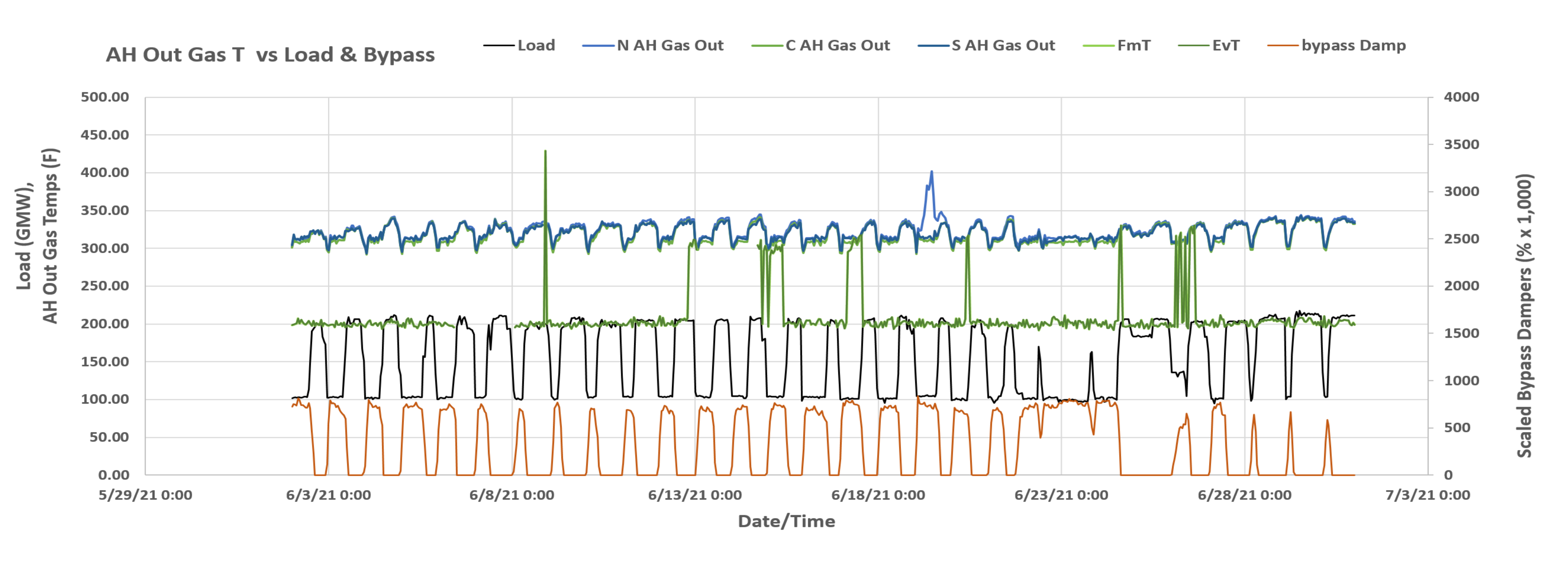
EPA Fuel Projection	4,999,730.3	0.28%	Heat Rate Penalty
Projected Fuel Penalty from Bypass Dampers	14,209.7	$83,629.09	Value of Penalty at Cost

	Load	North AH Bypass	Baseline Gas Out T 319.37		
Timestamp (Local)	G1GROSSMW-IEL.UNIT1@NET1	B1NAIRHTRBYP-ODE.UNIT1@NET1	Calc Increase in Outlet Gas T	Heat Input (mmBTU)/3 Min	mmBTU Saved from Bypass
4/1/21 0:00	102.26	76.21	44.5	52.7	0.6
4/1/21 0:02	102.26	76.21	44.5	52.7	0.6
4/1/21 0:05	102.26	76.2	44.4	52.7	0.6
4/1/21 0:08	102.26	76.2	44.4	52.7	0.6
4/1/21 0:11	102.32	76.09	44.3	52.7	0.6

The box above is a snapshot of the top of the calculation worksheet. Items of Importance:

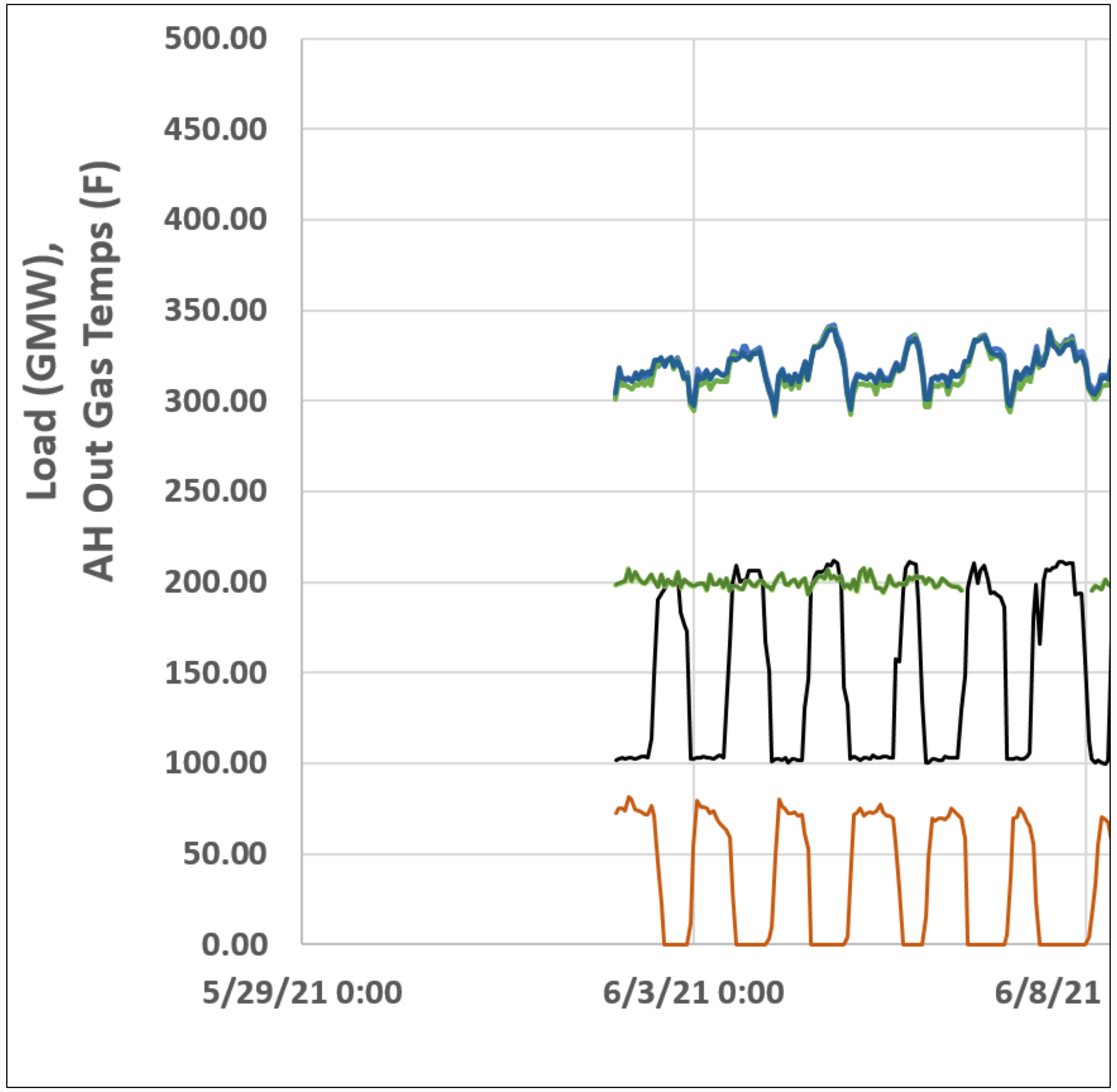
- Projected fuel penalty based on 2021 data annualized — 14,210 mmBTU
- Projected Heat Rate Penalty — 0.28%
- Value of fuel penalty at 2021 cost — $83,630
- CO_2 Emissions from Fuel Penalty (@.103 tons/mmBTU) — 1,463 Tons

Impact on AH Gas Temps



The box above is a snapshot of Load, Bypass Damper use, AH Outlet Gas Temperatures and Breen probe Formation/Evaporation Temperatures. There is a lot going on here so the next slide will cover it in detail.

Impact on AH Gas Temps –Pg. 2



This is a close-up of the left hand side of the previous graph.

Notes:

1. When Load drops to minimum (black trace), the bypass dampers (brown trace) are generally opened to 75% of their capacity,
2. AH Outlet Gas Temperatures (green, blue and red traces at top – all basically overlapping) initially drop then rise to roughly 320F.

ACET Cost

1. **AH Outlet gas temp seems to be set at 320F.**
2. **Reduction in outlet gas to 290F (actual plant mgmt. target) could provide 0.75% Improvement in gross heat rate**
3. **What Value is 0.75% Heat Rate to the plant (at Minimum Load)**

The answer to question 3 has a lot to do with how the heat rate improvement is implemented

i.e., Steam Coils or bypass dampers

And whether the unit is regulated or non-reg.

Saving Fuel at Min load also calculates into less NOx generated and that, from and ACET perspective, may be the bigger deal

Minimum Load Reduction

In Other Words Operating Flexibility

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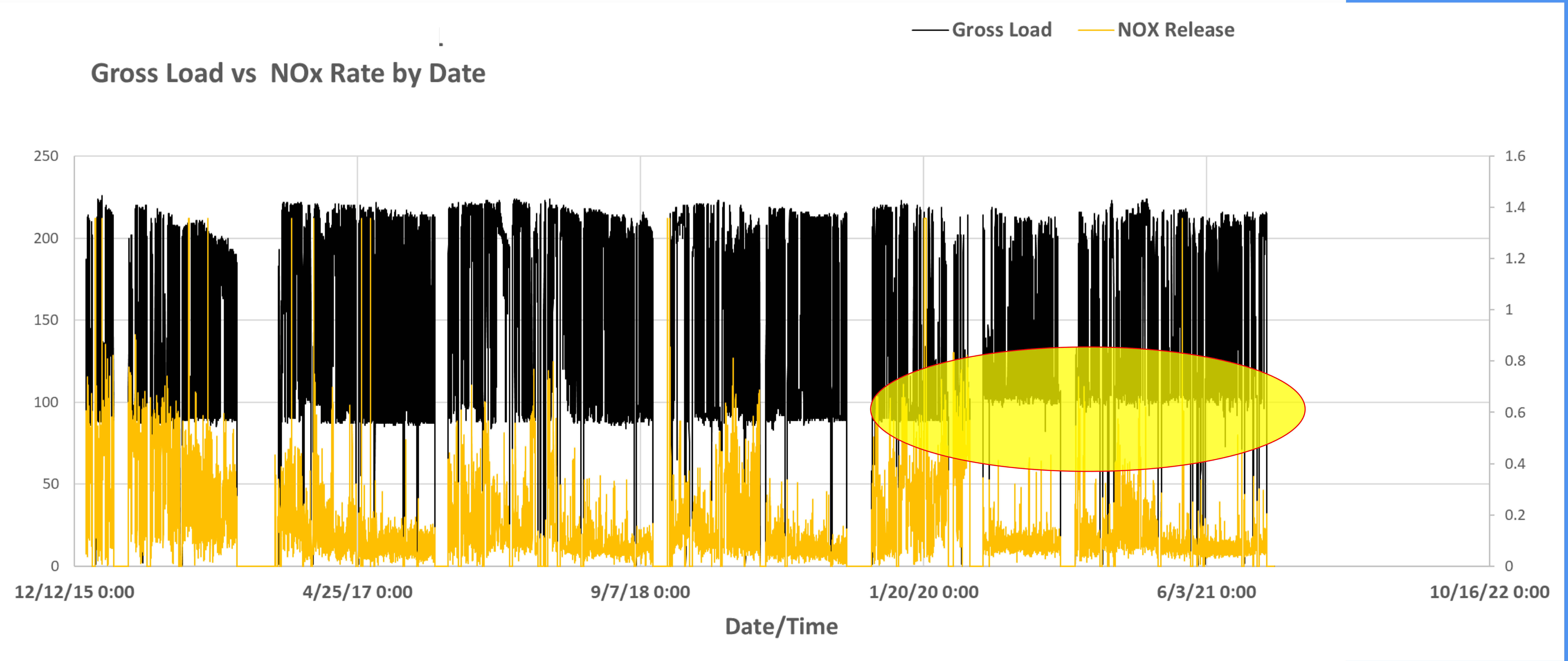
What Defines Unit Minimum Load?

1. SCR Minimum Operating Temperature
2. Number of Mills in Service
3. Number of Feedwater Pumps

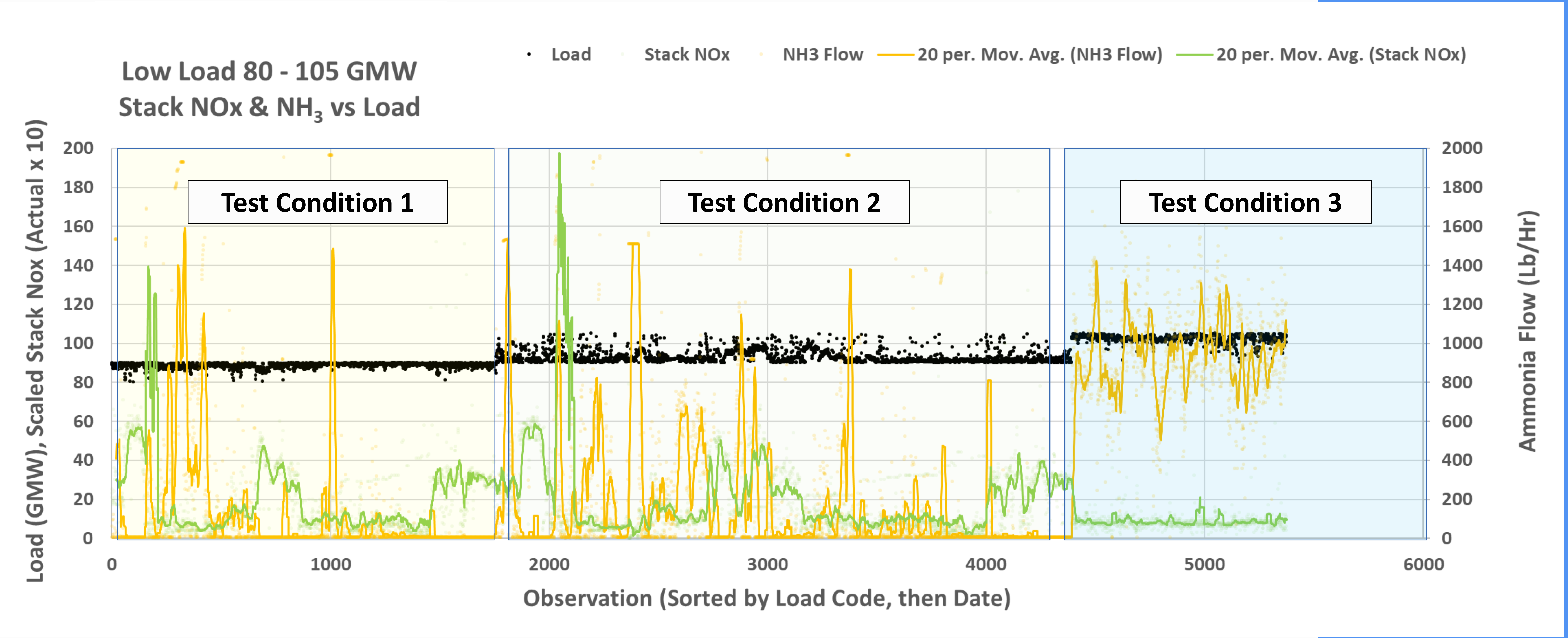
- DSI Enables elimination of SCR MOT as an operating constraint
- Mill Deployment can be impacted by DSI
- Feedwater Pumps are generally a different issue and not open to DSI Improvement

Load Profile 2016 - 2021



Operations suggested that Mill considerations drove the min load increase?

Impact of Min Load Change



See next page for test conditions on total fuel and NH_3 Increase.

Impact of Minimum Load Increase

Test Condition	1	2	3	4	5
Avg Minimum Load (GMW)	88.6	93.0	102.25		
Avg Ammonia Feed (Lb/Hr)	143	190	934	1763	2062
2019 Min Load Hrs. (Baseline) – 2,226 Hr					
Average GMW Penalty			9.25		
Average NH3 Penalty Lb./Hr. (Adj. for 17% act. Loss)			711		
Gross MW Penalty vs. 2019			**20,600**		
Ammonia Feed Penalty (Tons)			**791**		

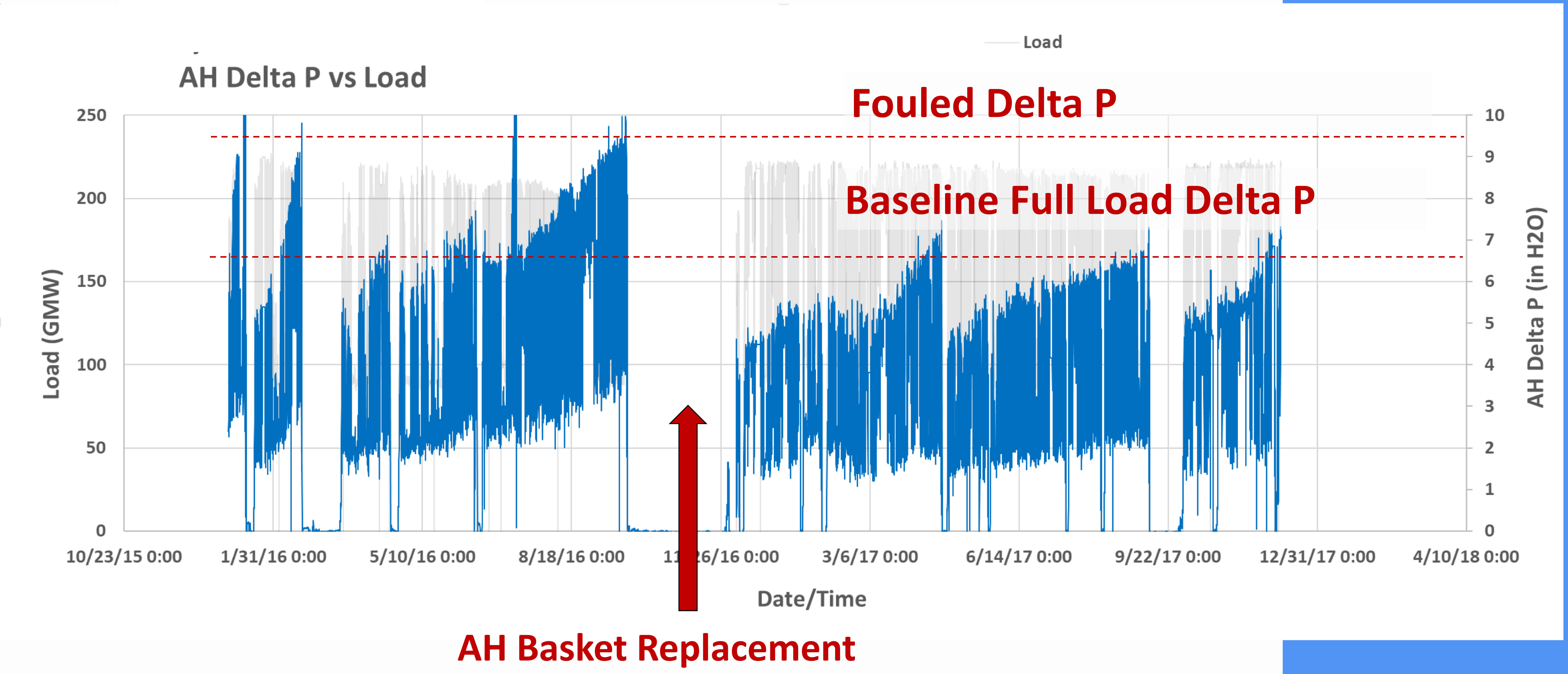
1. **@ 10 mmBTU/MWHr and $2.35/mmBTU, the GMW Penalty has a value of $484,000**
2. **@$100/ton, the ammonia flow penalty has a value of $79,100**

Test Conditions 4 & 5 are 200 – 220 GMW covering all Data from 2018 – 2019, and only data from 2021 respectively

ID Fan Power

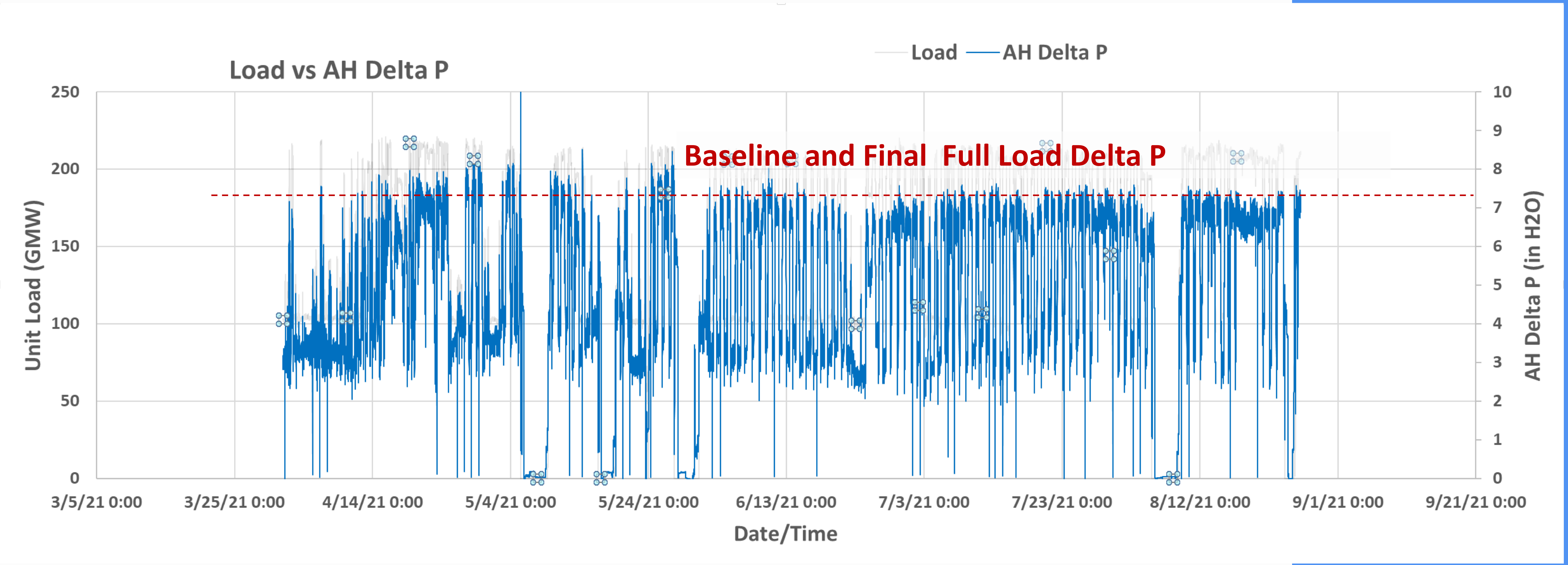
AH Delta P – Trona Feed

Pre-Basket Changeout Conditions



Prior to basket replacement, the pressure drop increase of 6-8 weeks is nearly 3"

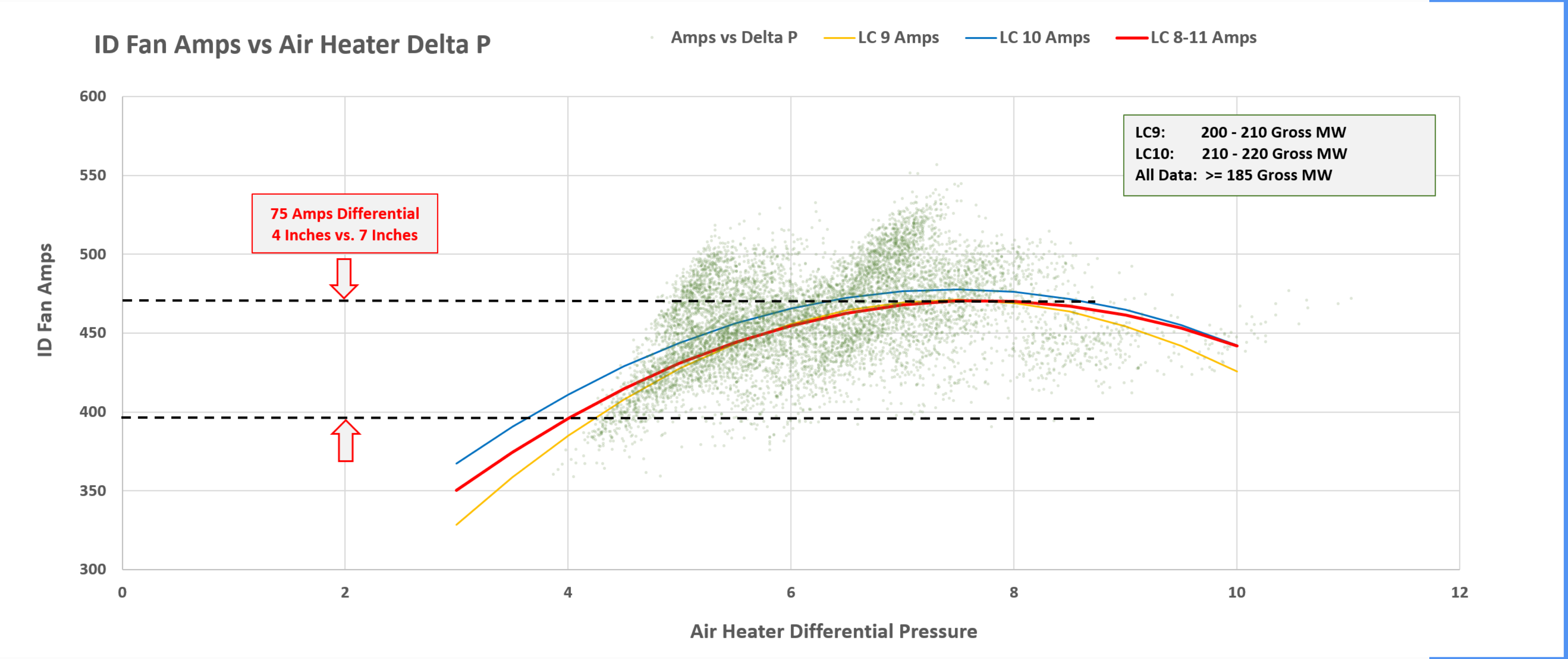
AH Delta P – HRH Feed



While the baseline full load Delta P is similar to the pre-replacement level of 2016, over four months of operation there was zero increase in pressure drop.

An improvement of 1.5" – 2.0" average load avoidance on ID fan is realized

ID Fan Amps vs AH Differential



Eliminating AH Differential Pressure increased can provide a 10% reduction in ID Fan parasitic power that could be sold to the grid.

Impact of ID Fan Power Gain

- The ID Fan Uses between 200 and 525 Amps at 13,200KV
- This Projects to a typical parasitic load of 4 to 11 MW
- Applying the projected Reduction in Current to 2019 actual data shows a savings in parasitic load of 3,750 Gross MWHrs.

At a variable cost of generation of $25/GMWHr this projects to $93,750/Year in Parasitic Load Reduction

Summary of Fuel, Heat Rate & Min Load

• Artificial ACET	$90,000/yr.
• Min Load Reduction	> $500,000/yr.
• ID Fan Parasitic Load	$100,000/yr.

This total of approx. $700,000/year is significant, but may actually pale compared to the reduction in NOx generation (tons) and the increase in available fan capacity during summer operation

Some Real World Considerations

The Basics - Heat Rate Improvement

- **A reduction of 30 degrees F on air heater exit gas temp is approximately a 1% savings in unit heat rate**

- **Improved heat rate has benefits beyond coal cost**
  - Decreased fuel handling
  - Decreased ash & waste handling and stabilization
  - Decreased CO_2 emissions
  - Better native Hg capture
  - Better ESP performance
  - Decreased emissions overall
- **Sustainability**
  - People, Planet, and Profits

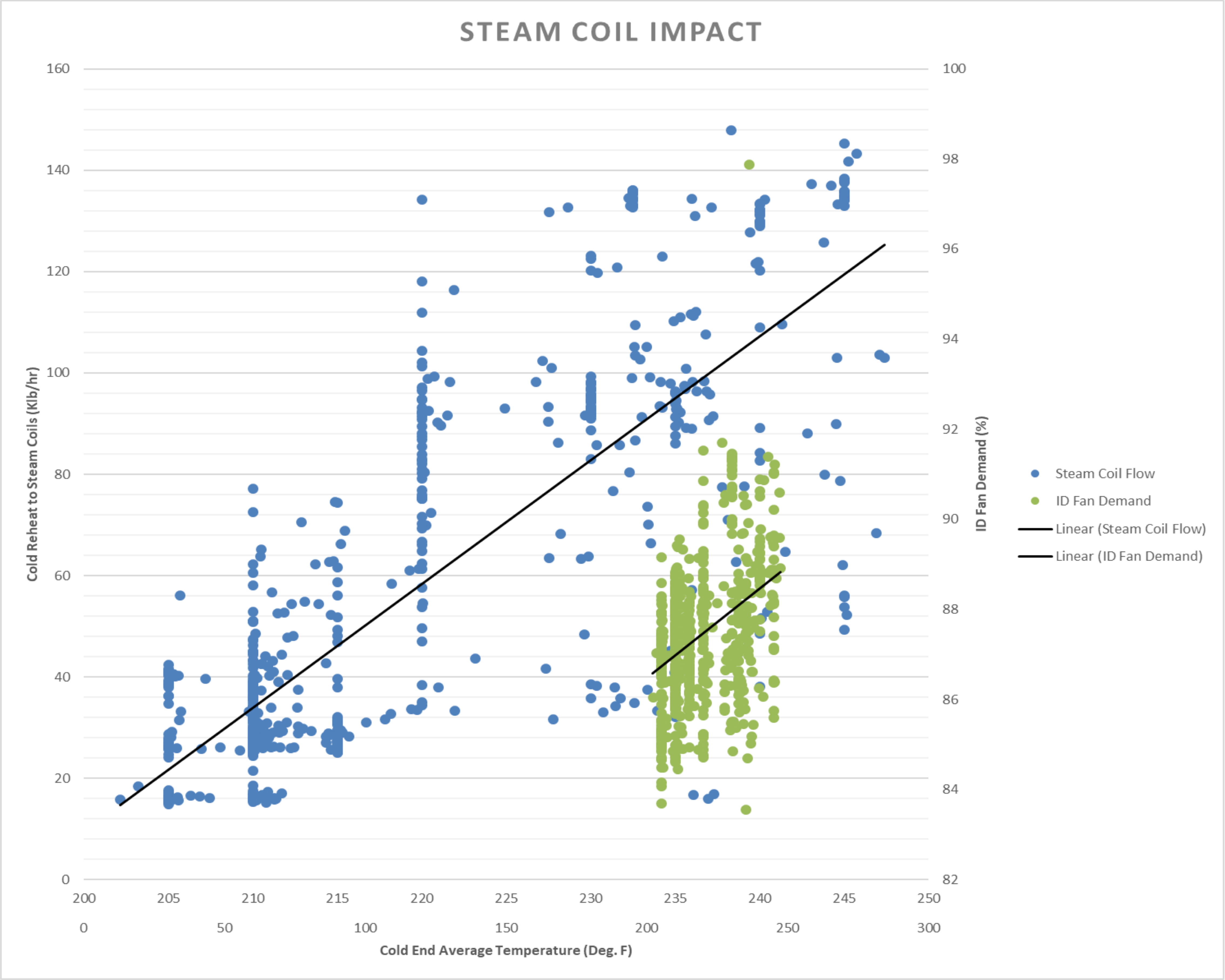
	Baseline	Less 1% HR	Savings
Heat Rate (BTU/KWh)	10,000	9,900	100
Yearly Fuel (TN's)	1,368,750	1,355,063	13,688
Yearly Ash (TN's)	109,500	108,405	1,095
Coal & Ash Cost ($'000)	87,600	86,724	876
CO_2 Emissions (TN's)	3,367,125	3,333,454	33,671

Assumptions:

500 MW Unit
12,000 BTU/lb fuel heating value
75% Capacity Factor
$60/ton coal cost
10% ash content
$50/ton ash processing cost
205 lb/Mmbtu CO_2 Emissions per EIA

Plant Examples – ID Fan Demand

- **Water and steam coils installed in series providing additional FD plenum DP**
- **Steam coils at East Bend are fed from Cold Reheat**
- **Station typically operates in the 230-240 deg. F cold end average temperature range**
- **Hydrated lime injection trial prior to the air heater in August '16 showed reliable operation down to 205 deg. F ACET**
- **Air heater DP's dropped during this time and the unit was currently operating fan limited prior to the testing which cleared up with the reduced ACET**
- **Improved volumetric efficiency with lower air/gas temperatures results in efficiency improvements**



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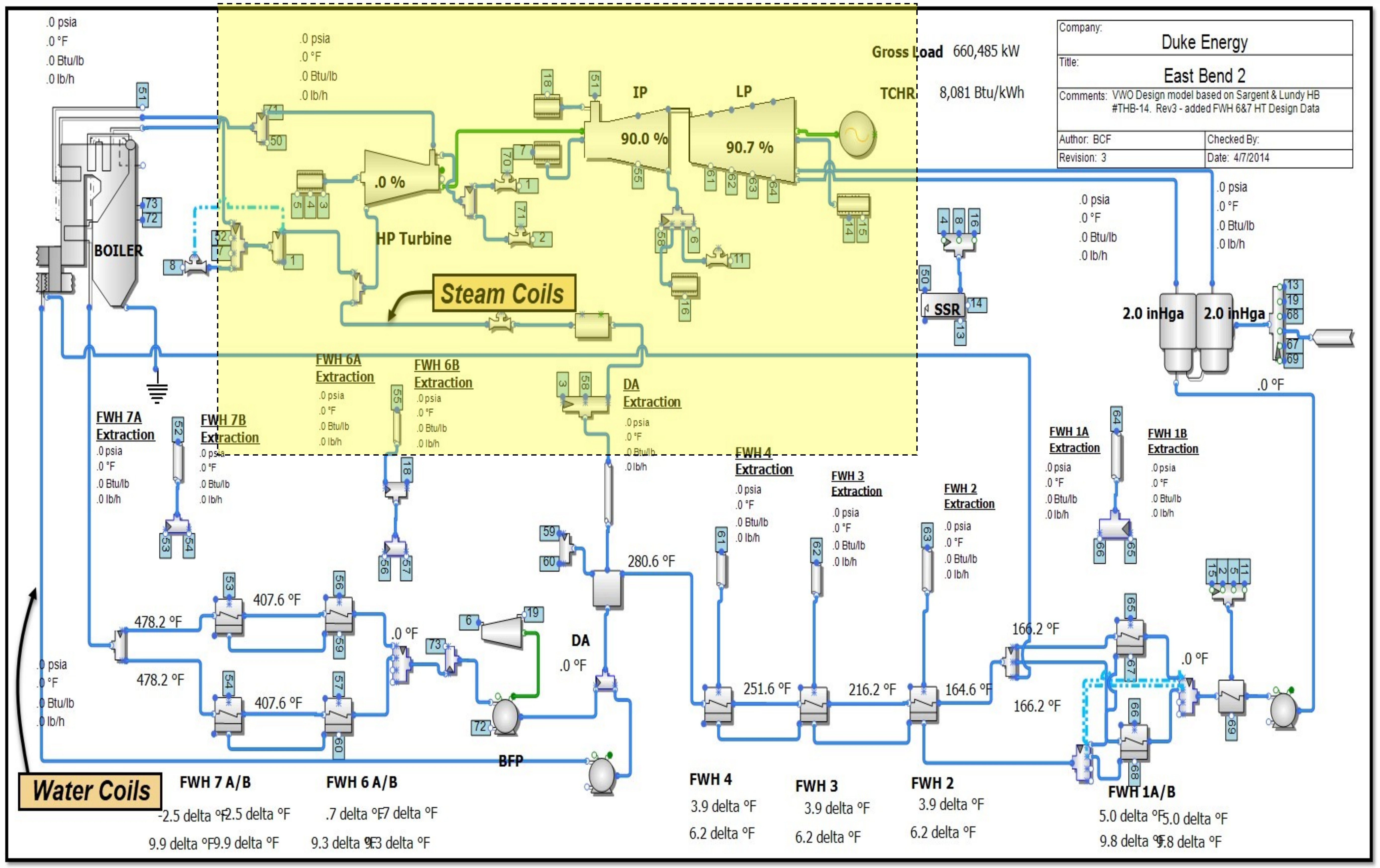
Plant Examples – Steam & RH Spray Demand

- **Boiler thermal model was created to determine the impact of the steam coils on plant efficiency**
- **Heat sync was added to simulate the steam demand of the steam coils on the cold reheat**
- **Additional reheat spray is needed to prevent reheater overheating due to reduced steam flow that is being diverted to the steam coils**



Plant Examples – Steam & RH Spray Demand

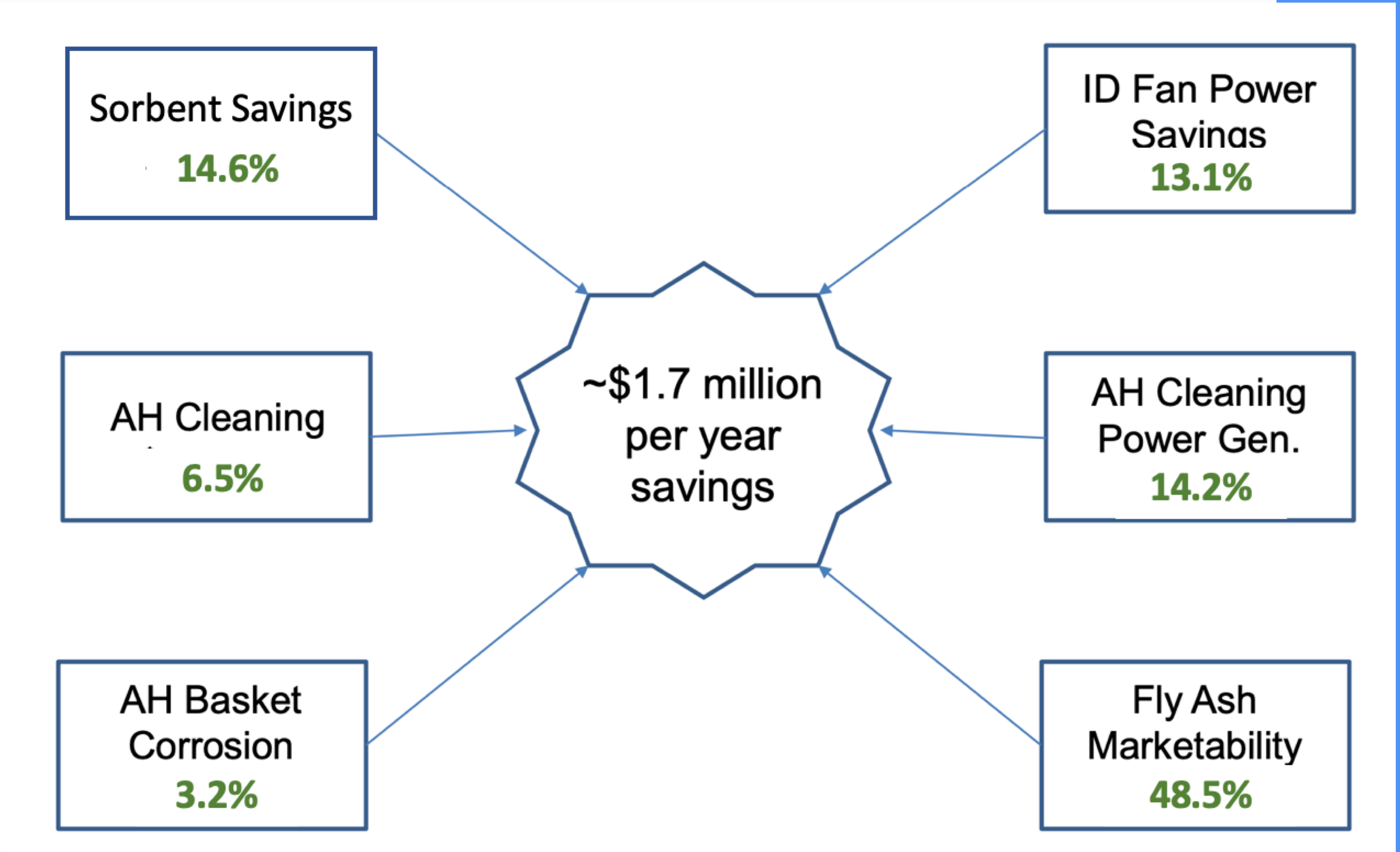
- Station regularly operates at 130-150kpph of preheat coil steam in the winter months
- At 150kpph there is ~ 228btu/kwhr heat rate impact and approximately a 10.5MW load impact
- Reheat spray flow of 38kpph is directly attributed the loss of cold reheat flow and the necessary atemperation required
- Assumes water coil operation is constant

Effects of Lost Steam Flow Going to Steam Coils

					Deviations	
	Steam Coil Flow (kpph)	RH Spray Flow (kpph)	Gross Load (kW)	NUHR (BTU/kWh)	Gross Load (kW)	NUHR (BTU/kWh)
Base Case	-	-	**671.0**	**9,753**	-	-
Case 1	10	5.5	670.9	9,763	-0.1	10
Case 2	30	11.7	670.0	9,787	-1.0	35
Case 3	50	13.5	667.8	9,823	-3.2	70
Case 4	70	13.2	665.9	9,851	-5.2	98
Case 5	100	14.0	663.1	9,895	-7.9	142
Case 6	115	17.0	661.9	9,921	-9.2	168
Case 7	130	23.2	661.1	9,945	-9.9	193
Case 8	150	38.0	660.5	9,981	-10.5	228

Summary & Conclusion

There are MULTIPLE Sources of Operational Benefits



Summary & Conclusions

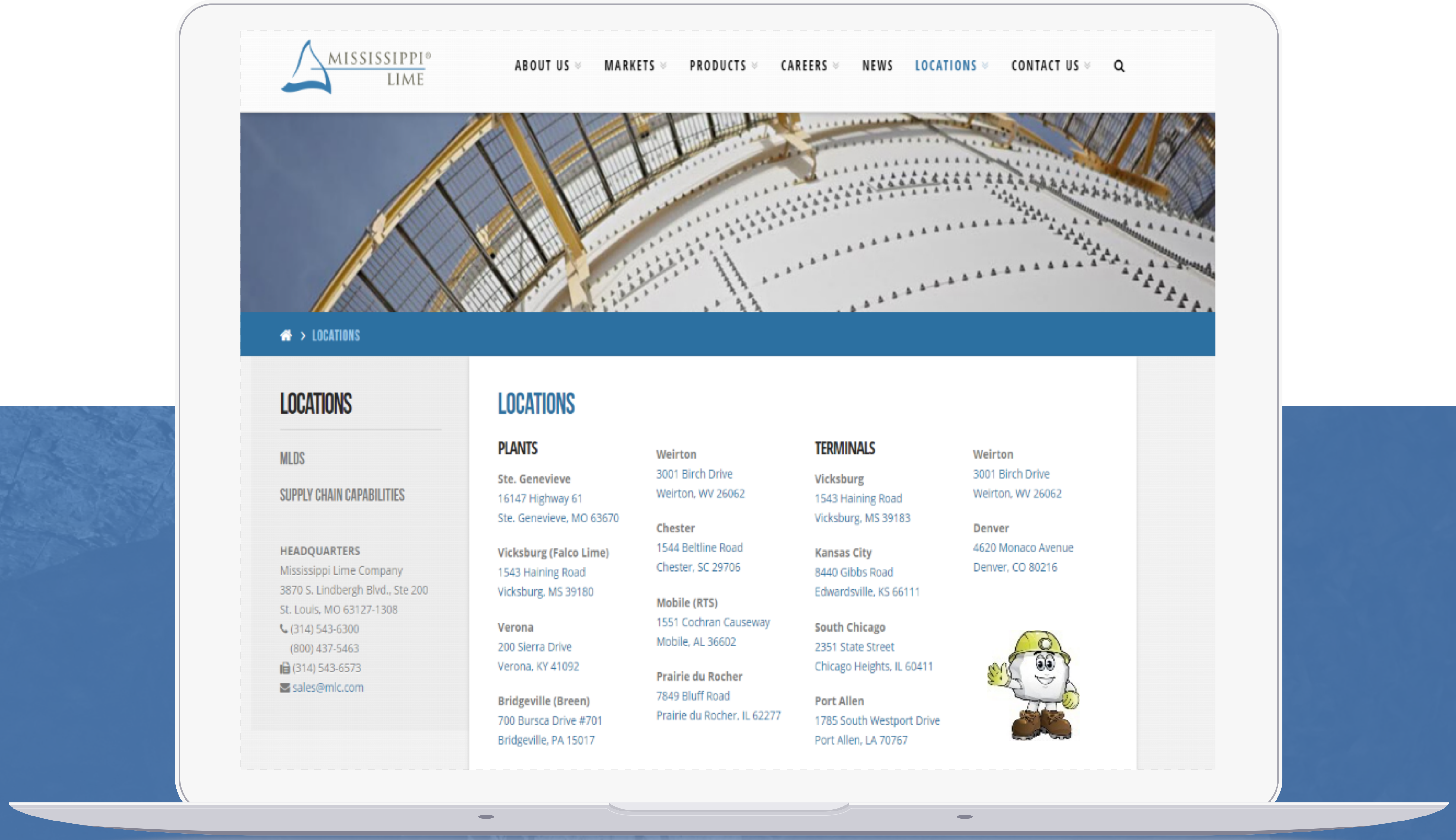
The Key Takeaways

- Clearly Identify your objectives for Operational Improvement
- Engage ALL aspects of Plant Management in the discussion and Educate them in the Sources and Sinks for Acid Gas
- Identify the focus for "Heat Rate" Improvement
    - Reduced Fuel Cost, or
    - Increased Generation

- Follow up with all stake holders to monitor progress against Objectives

Questions

Contact



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