REINHOLD ENVIRONMENTAL Ltd.

2019 REINHOLD Round Table Presentation

June 24 & 25, 2019, in Birmingham, Alabama / Hosted by Southern Company

AdvX™ ZERO LIQUID DISCHARGE SYSTEM

26th Reinhold Round Table & Expo

June 24, 2019

Blake Stapper

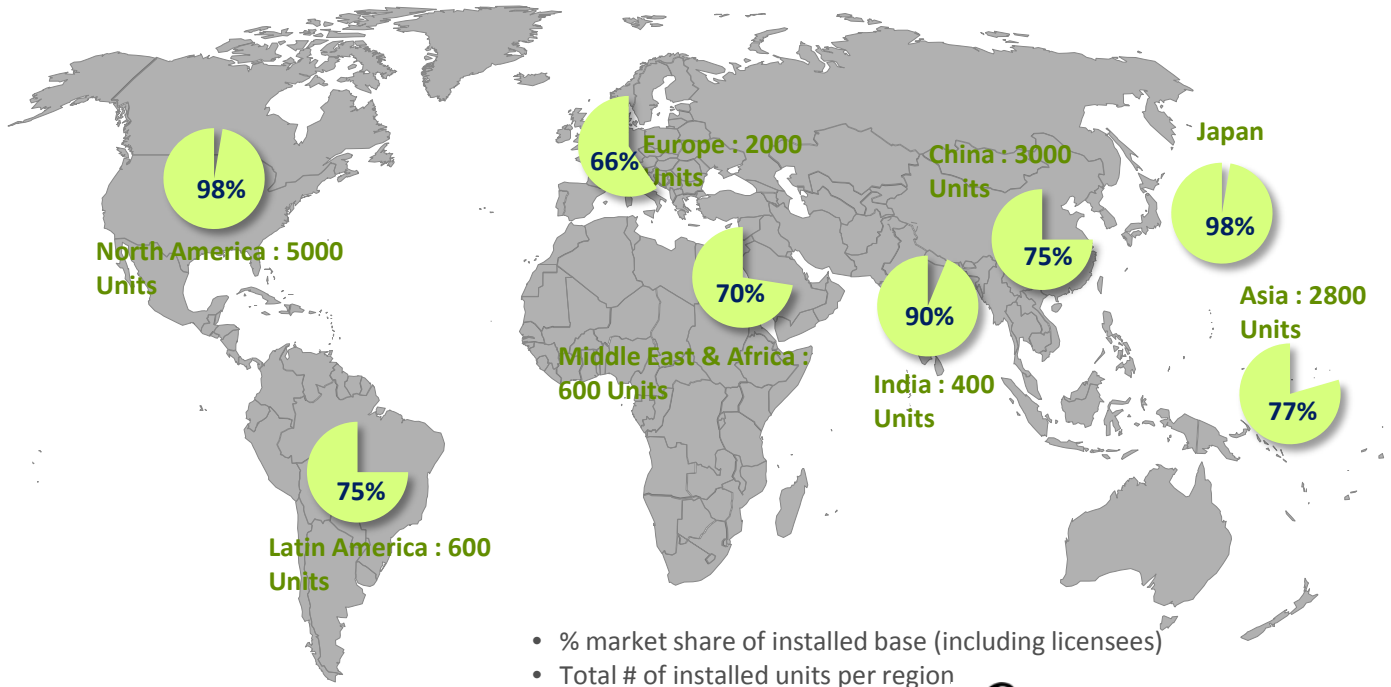
LJUNGSTRÖM

LJUNGSTRÖM HISTORY

LJUNGSTRÖM | ARVOS GROUP

1920	Frederik Ljungström invents the *Ljungström* air preheater in **Sweden**
1925	The **Air Preheater Corporation** is created in the **USA**
1927	Gadelius Shokai in **Japan** becomes a licensee
1934	Kraftanlagen Heidelberg in **Germany** becomes a licensee
1965	První brněnská strojírna (**PBS**) in **Czeck Republic** becomes a licensee
1967	Stein Industrie in **France** becomes a licensee
1977	Air Preheater Equipamentos Ltd (**APEL**) is established in **Brazil**
1995	ABB acquires and combines all APH interests from USA, Japan, Germany, Czech Republic & Brazil
1997	ABB acquires all global IPR to the *Ljungström*® technology
1999	Creation of joint venture ABB ALSTOM Power
2000 – 2013	ALSTOM acquires ABB's JV share and operates the business as part of ALSTOM Power
2014	ARVOS Group acquires the air preheater business and forms the LJUNGSTRÖM Division

APH & GGH REFERENCES

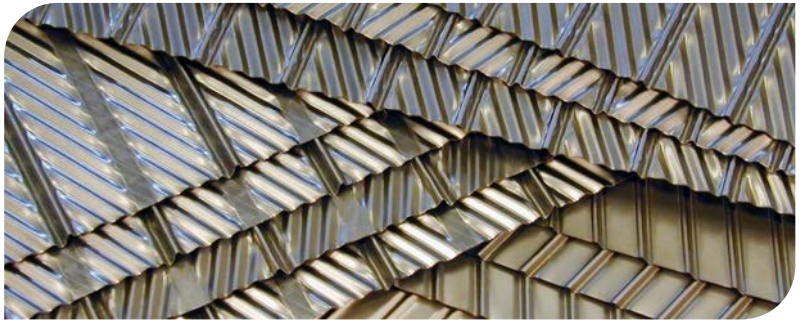


- % market share of installed base (including licensees)
- Total # of installed units per region

Worldwide leader through experience

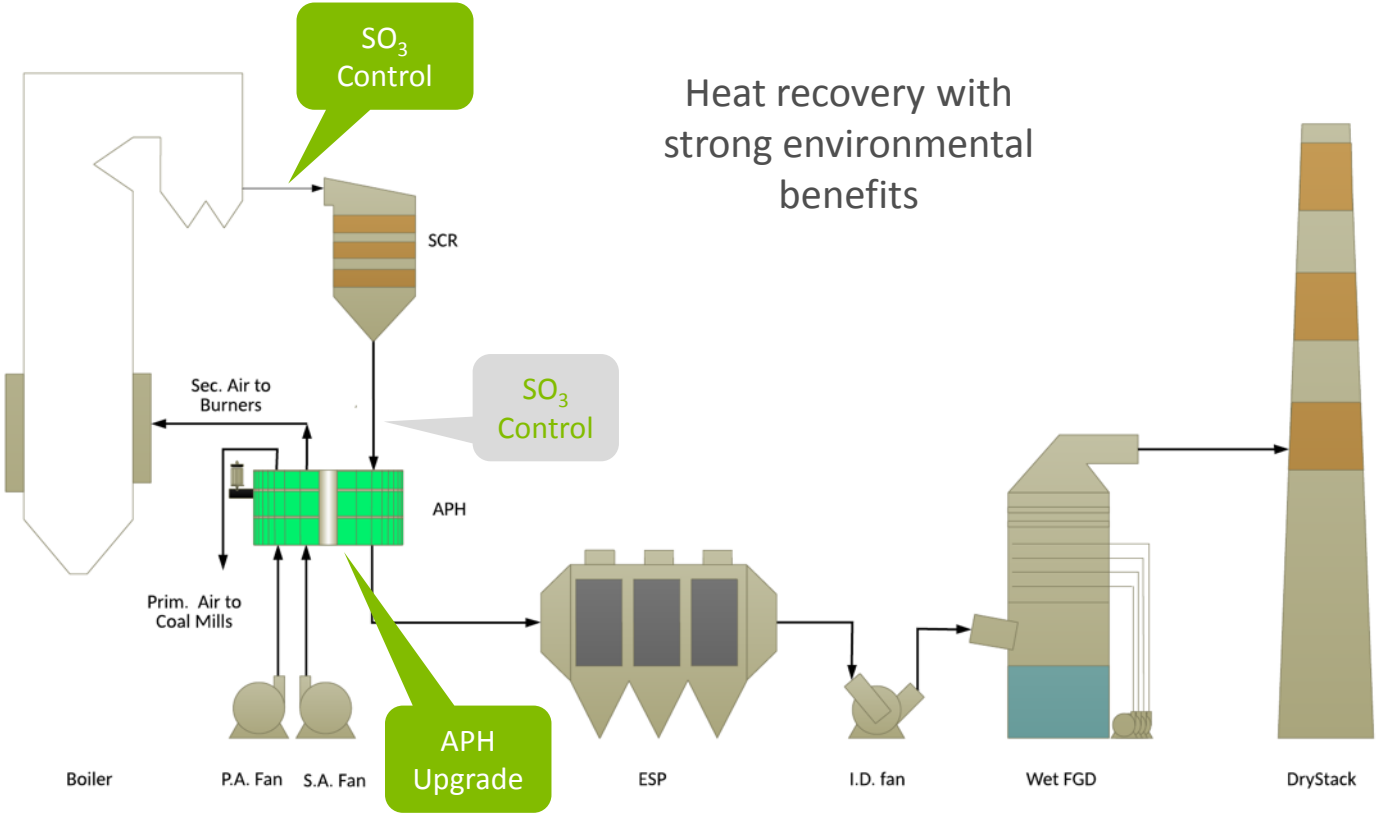
LJUNGSTRÖM OVERVIEW

- EPC Provider
- Traditional Air Preheaters
- AdvX™ Heat Recovery Technology
- Gas-Gas Heaters
- Element Profiles
- Enameled Elements
- SO_3 Control
- Engineered Upgrades
- Surface Technology Solutions



Exclusive provider of AdvX™ Heat Recovery Solutions

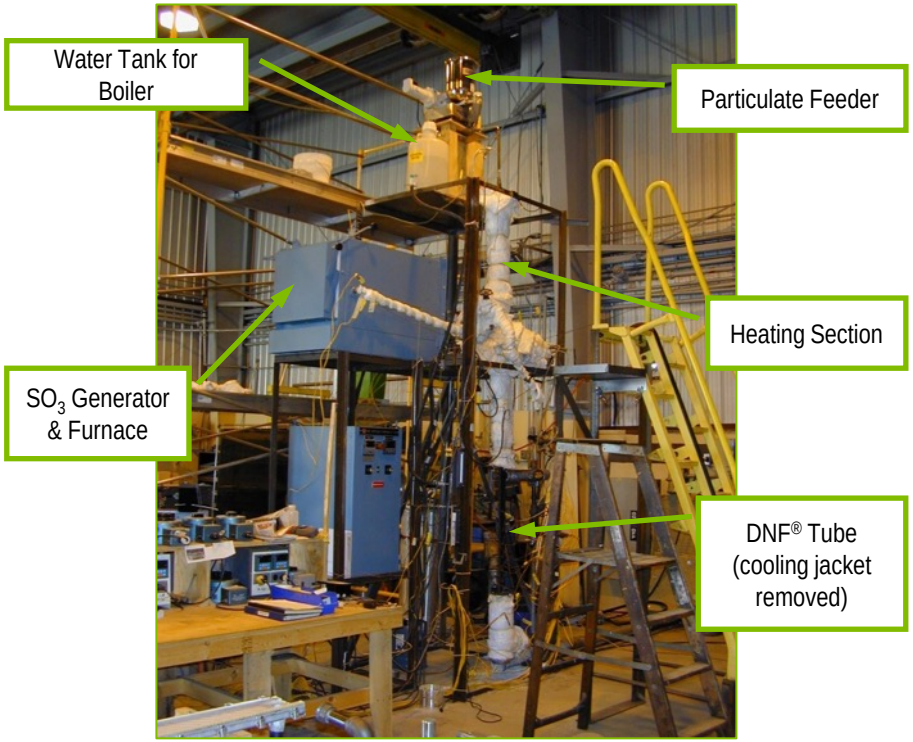
TWO TECHNOLOGIES



Heat recovery with strong environmental benefits

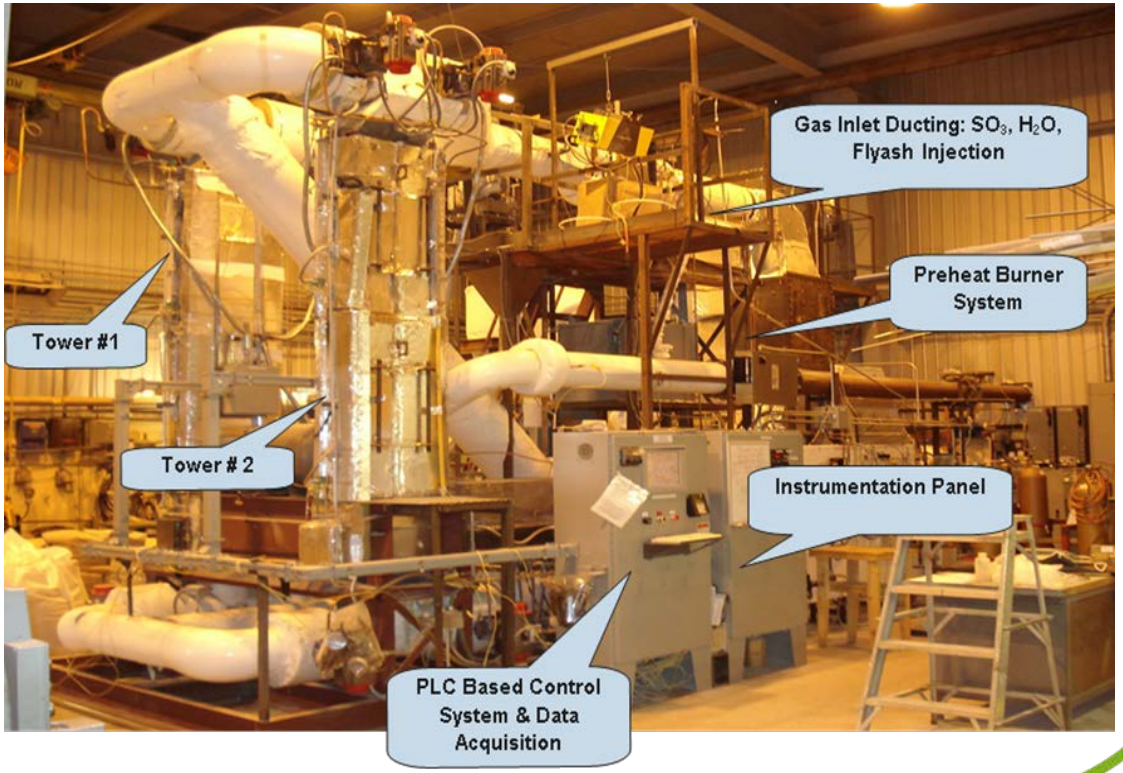
DEVELOPMENT HISTORY

- 2006 – 2008 Bench Scale Testing
- 2008 – 2009 Construction of Pilot Plant
- 2009 – 2103 Pilot Plant testing
- 2015 – 2016 Full-scale demonstration

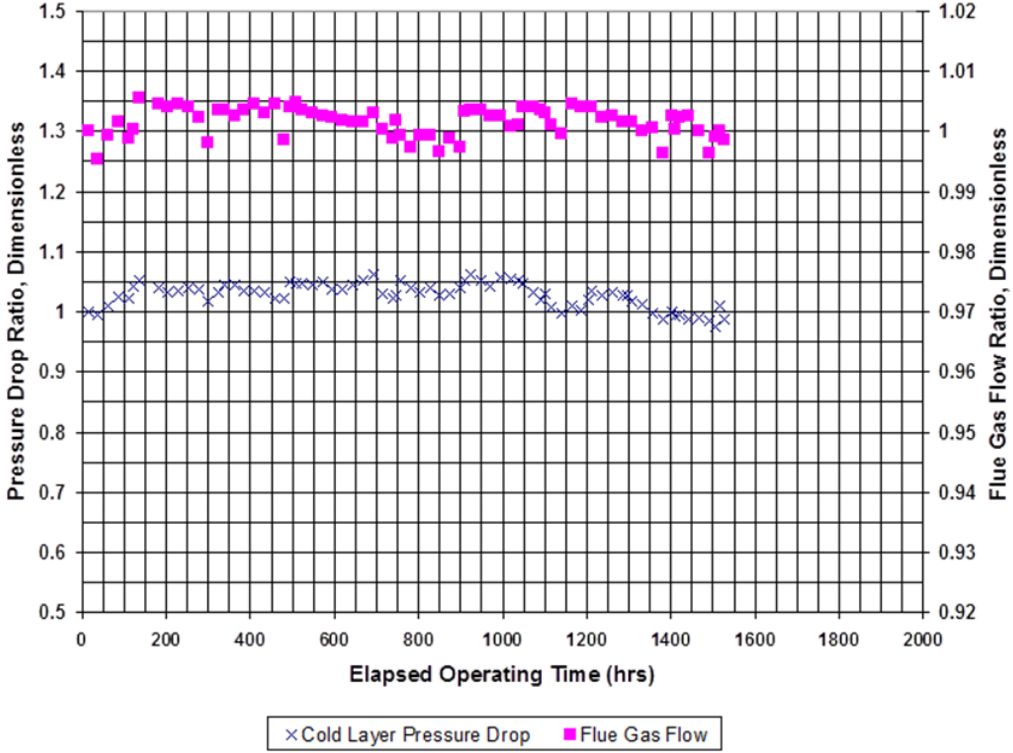


PILOT PLANT

- U.S. eastern bituminous coal ash used for testing
- Milled sodium sulfate added to the ash to simulate byproduct of upstream SO_3 mitigation from 60 ppm down to 5 ppm
- SO_3 content set at 5 ppm
- Flue gas outlet temperature held at 104°C
- On-line cold end soot blowing every 8 hours (compressed air)



LJUNGSTRÖM PILOT TESTS AT 104°C NO dP INCREASE



DNF® Element After the Test

THREE COMPONENTS

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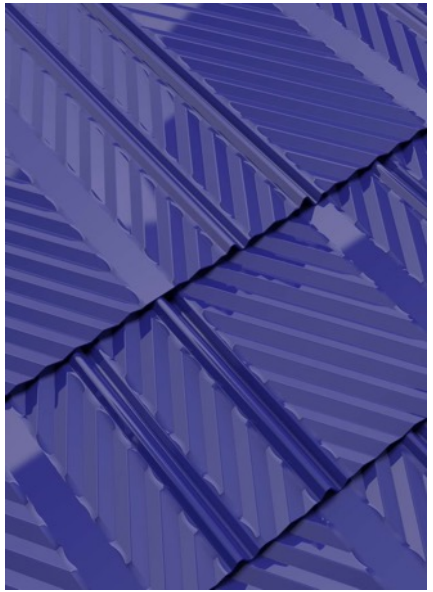
AdvX™

1. **Improved heat transfer**
   - High efficiency heating elements
   - Additional heating element depth
     - Shallow baskets
     - Available space
2. **X-ratio shift**
3. **SO_3 control**

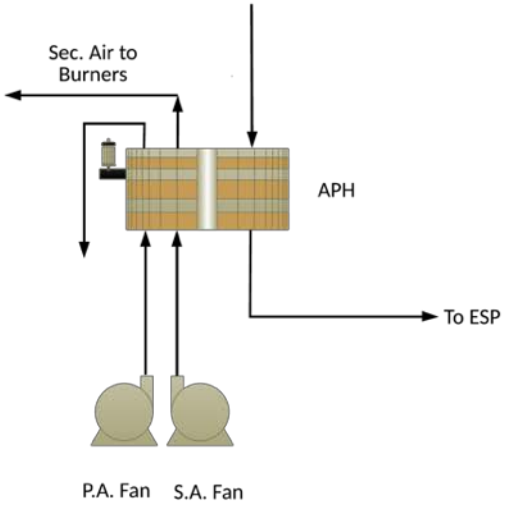
DN8



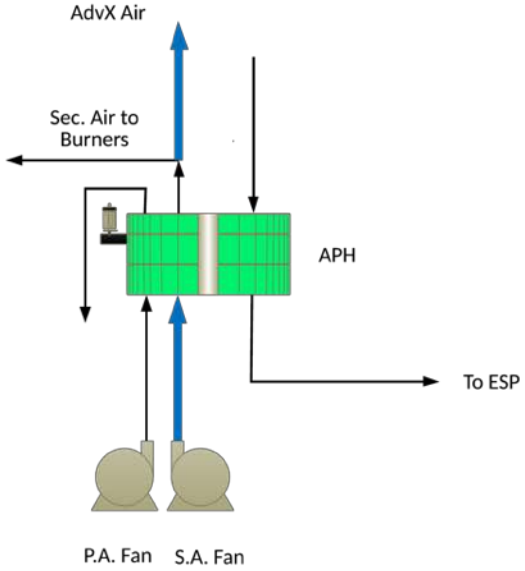
TF4

X-RATIO SHIFT

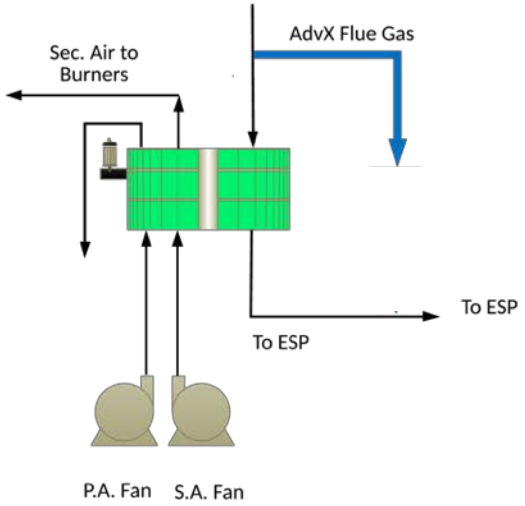
$$X - Ratio = \frac{Air}{Flue\ Gas}$$



Typical APH



AdvX™ Option 1



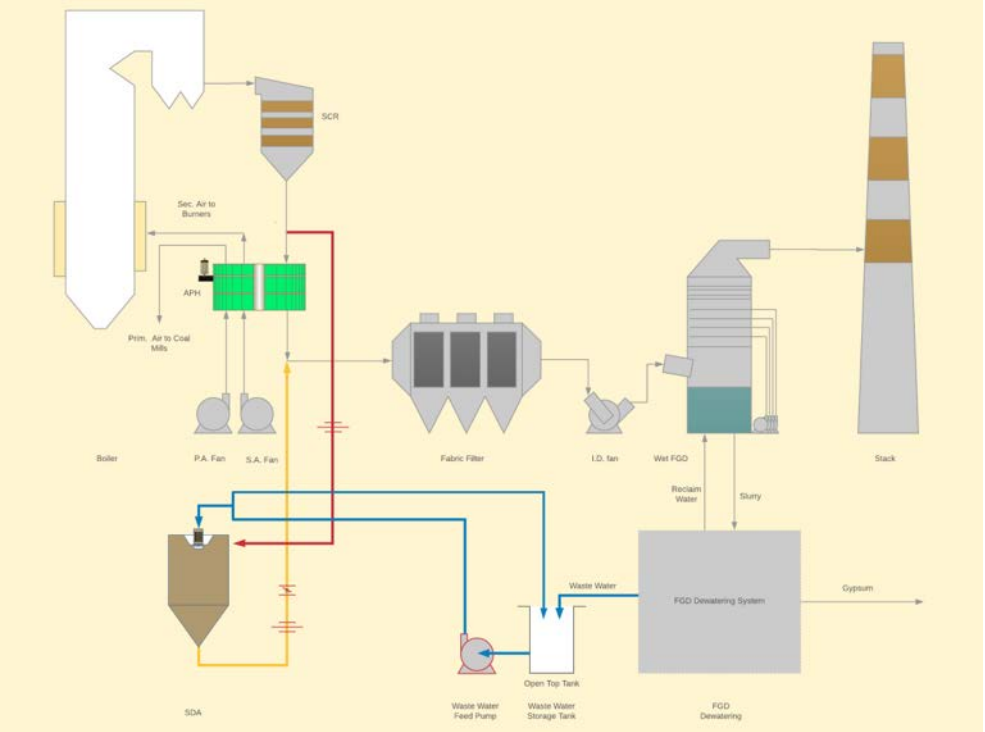
AdvX™ Option 2

OPTIONS FOR RECOVERED AdvX™ ENERGY

1. Zero liquid discharge
2. Boiler feed water preheat
3. Maximize thermal performance
4. Reheat
   - Direct (mixing of air and flue gas)
   - Indirect (close coupled heat exchangers)
   - Tail-end SCR gas reheat
   - GGH Non-leak upgrade (replacement of GGH internals)
5. Coal drying

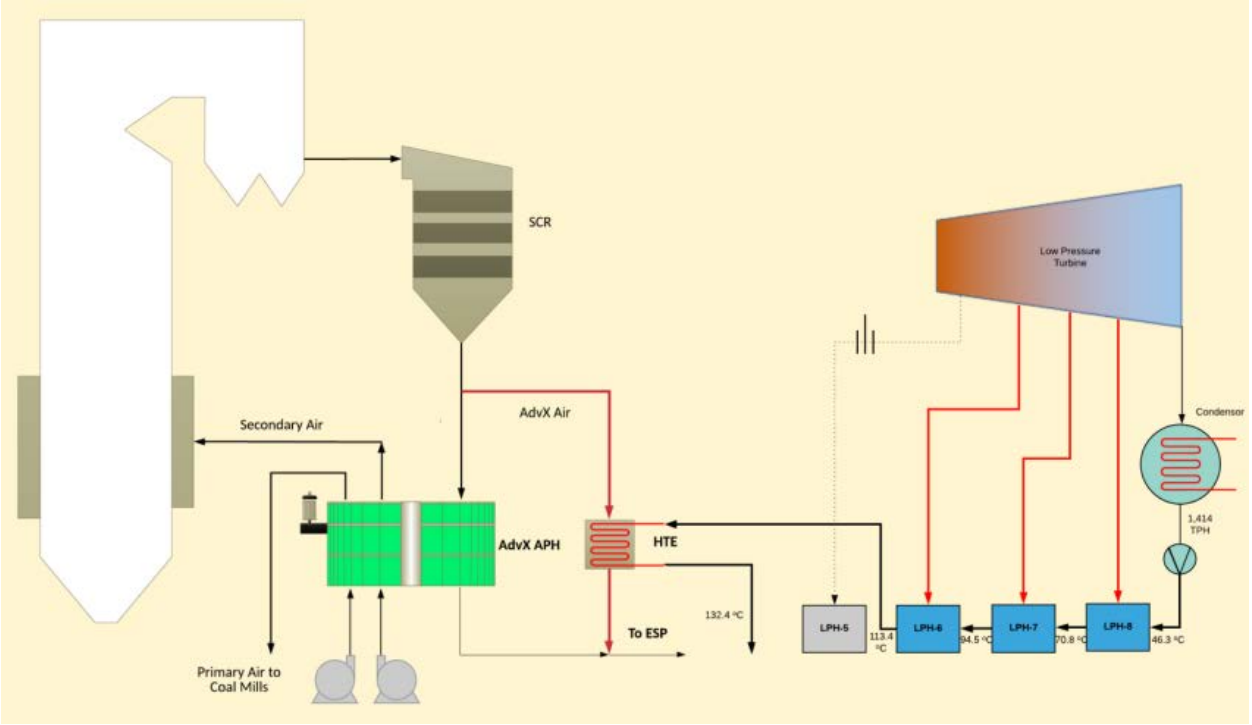
ZLD SYSTEM

- No boiler derate
- Improved ESP performance
- No waste water
  - No discharge limits
  - Forever compliant
  - No product disposal
    - Co-collected in ESP/FF
  - Proven Spray Dryer Evaporator (SDE) technology
    - Variable speed rotary atomizer



BFW PREHEAT SYSTEM

- Eliminate at least one BFW heater
- Improved net unit heat rate
- Enhanced ESP performance



ANCILLARY BENEFITS

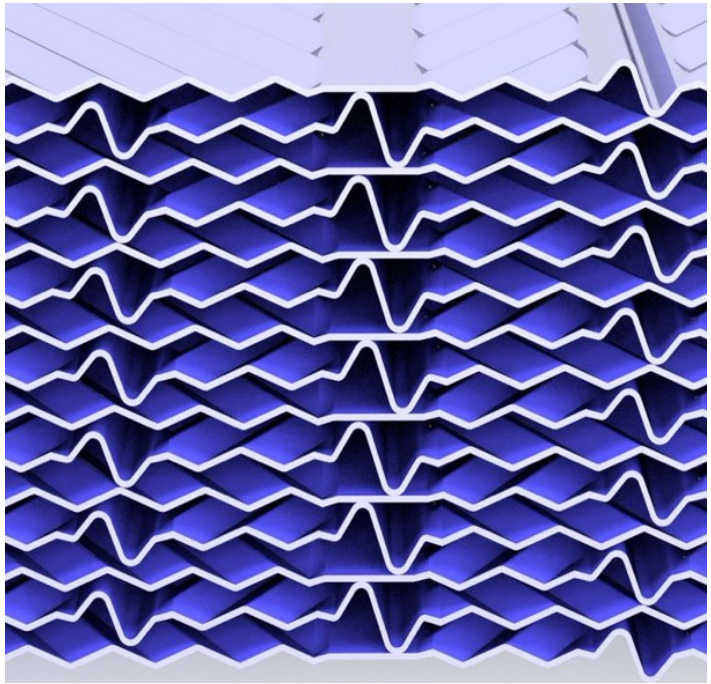
- Additional benefits to lower AH gas outlet temperature
  - Increased PM capture in ESP
  - Improved heat rate and reduced CO_2 emissions
- Additional benefits to removal of SO_3
  - Reduced SCR MOT and bypass, with lower boiler minimum load
  - Potential to operate post-combustion controls with higher NH_3 slip to increase NO_x removal efficiency, extend catalyst life, or eliminate a layer of catalyst
  - Better Hg capture by native ash
  - Reduction in HCl, leading to less scrubber blowdown and WWT
  - Eliminate AH corrosion and need for periodic washing
  - Eliminate visible emissions

COMMERCIAL RESULTS – 550MW UNIT

Parameter	Units	Before	After
Hard Coal Sulfur	percent	4.5	4.5
APH Inlet SO_3	ppm	> 70	< 5
Stack SO_3 Emissions	ppm	>20	< 0.5
APH Outlet Temperature	°C	175	125
CO_2 Reduction	percent	base	2%
SCR MOT	°C	325	280
HCl Removal by SBS	percent	<10	>40
Se Removal by SBS	percent	<10	>60
SCR Catalyst	# of beds	3	2
Boiler Efficiency Increase	percent	base	2
Hg Emissions	µg/m³	>2	<0.5
Hg Removal by SBS	percent	20	>75

PLANT A

- 380 MW unit
  - Existing lime injection system
  - Seeking compliance with ELG
- Solution – Spray dryer ZLD
  - 9% additional heat extracted
  - Modified x-ratio
  - New heating elements
  - Additional heating element depth added using shallow basket frames
  - Relocate lime injection to upstream of air heater



PROPOSED APH UPGRADE

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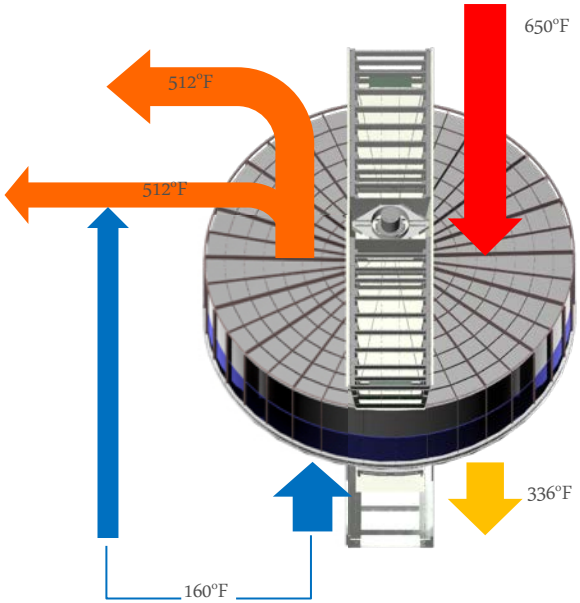
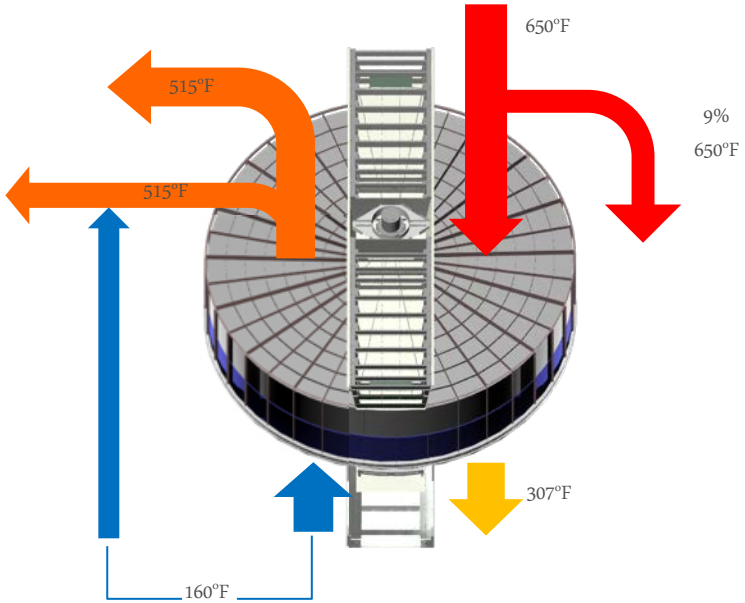
ORIGINAL APH



ADVX™ UPGRADE

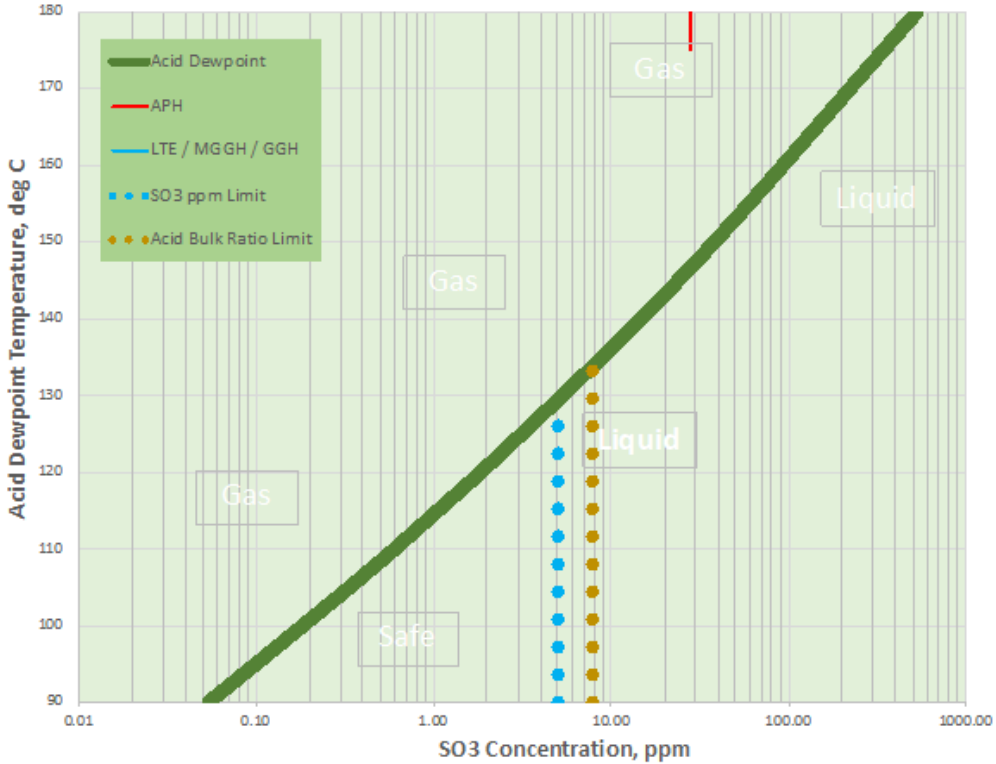


APH – CURRENT OPERATION

- Chemical Reactions

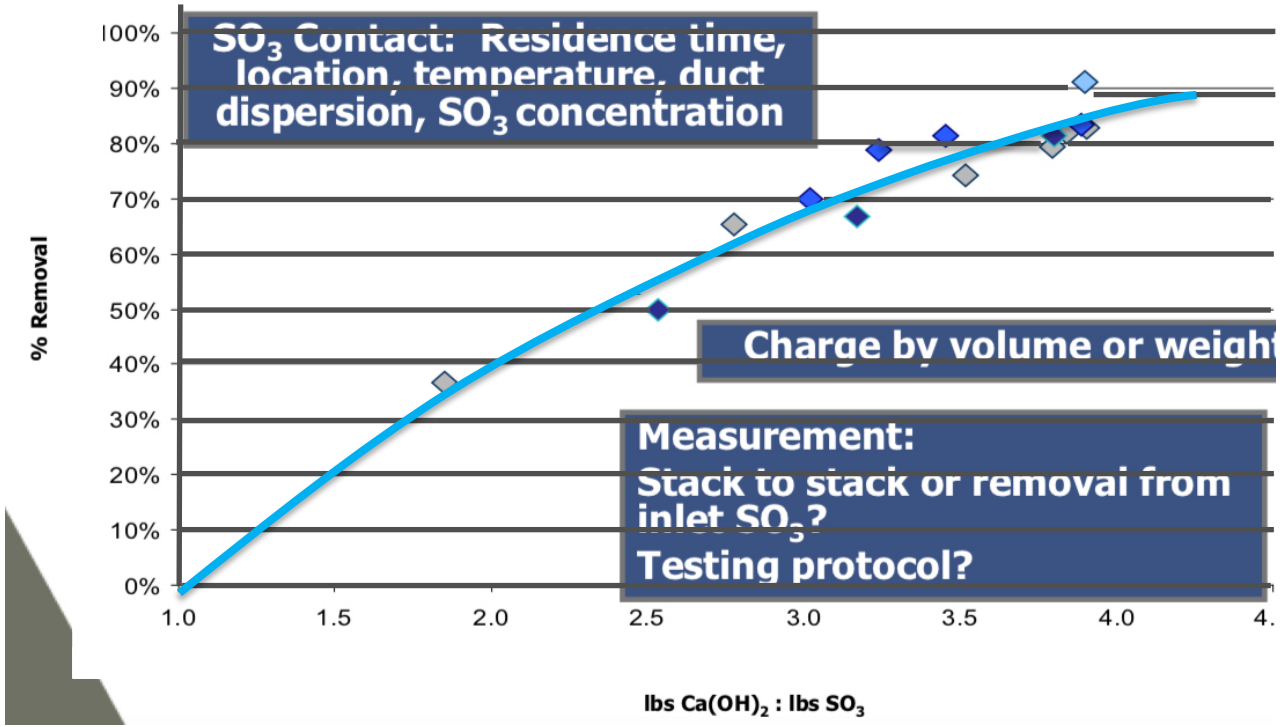
  $SO_3 + H_2O \Rightarrow H_2SO_4$
  $H_2SO_4(g) \Rightarrow H_2SO_4(l)$

- Current operation is above the dewpoint
  - No acid condensation related problems anticipated



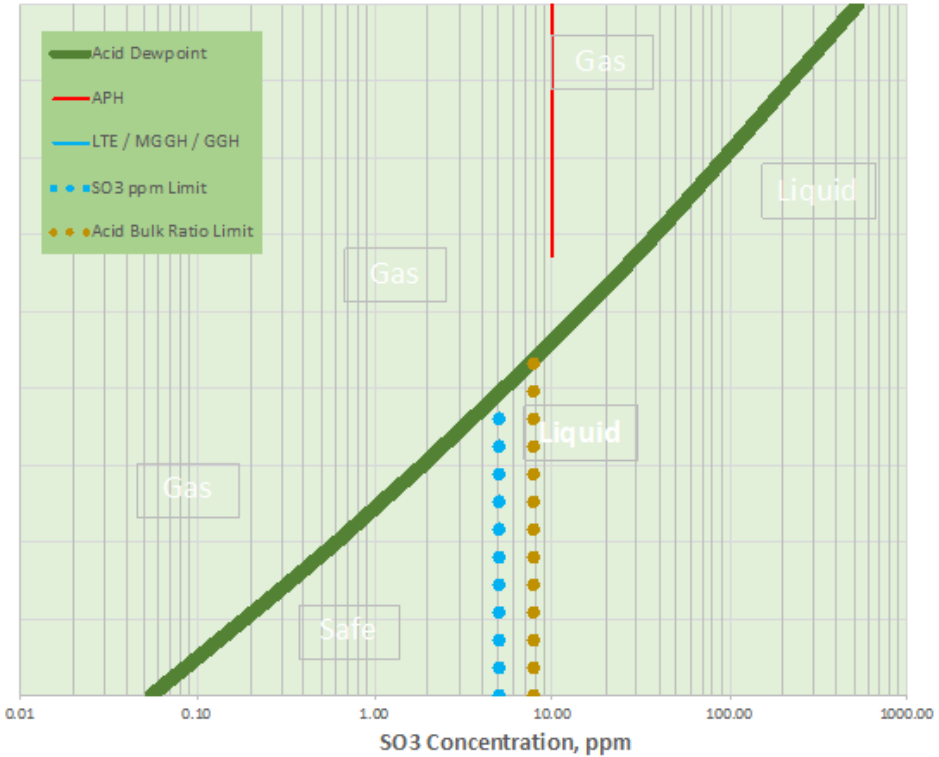
REMOVAL DATA (MISSISSIPPI LIME)

- Removal Possible
  - 1.8 – 37%
  - 2.5 – 55%
  - 3.0 – 68%
  - 3.5 – 79%
- Removal required to protect APH
  - 50%
  - Not a stretch for a lime based SO_3 control system



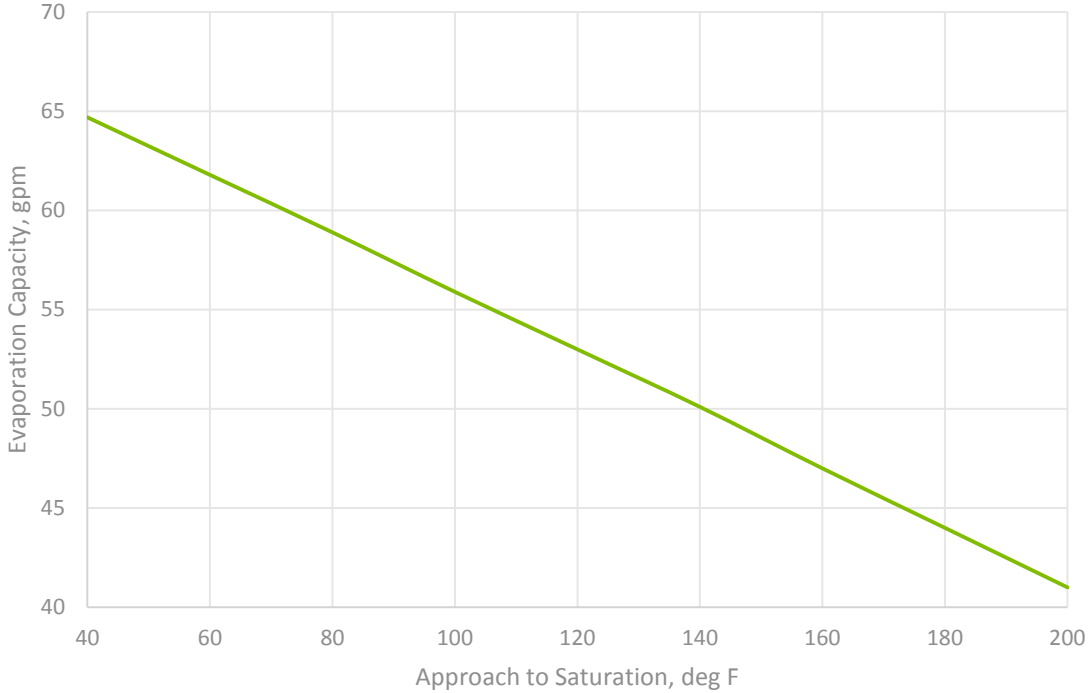
PROPOSED FUTURE OPERATION

- Chemical Reaction
  $Ca_2CO_3(s) + SO_3 \Rightarrow Ca_2SO_4(s) + CO_2$
- Removal of SO_3 to less than 24 ppm ahead and 20 ppm after the APH
- SO_3 removal capability between 50 to 80 percent
  - 50 percent assumed
- Proposed Operation is above the acid dew point
  - Sufficient margin maintained
  - No change in APH operation anticipated



OPERATIONAL FLEXIBILITY

- Significant turndown flexibility on waste water feed rate
- Maximum feed rate 65 gpm
- Fabric filter ash loading increased by 10%
- When no evaporation, SDE will be kept warm
  - Above calcium chlorides deliquescent temperature

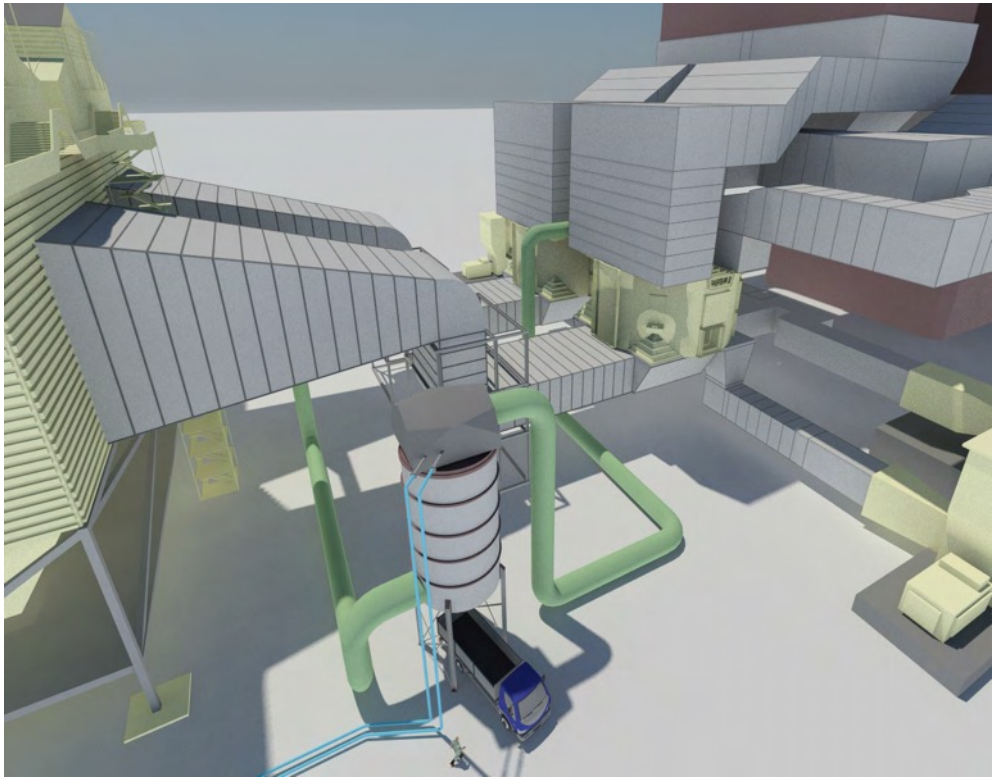


SPRAY DRYER EVAPORATOR

- Proven technology in this application
- Rotary Atomizing type
  - Negligible clogging tendency
  - turndown capability better than multi-nozzle design - 50%
  - Complete atomizing assembly removable for inspection and maintenance
  - Higher solids handling capability
- Design flowrate:
  - Flue Gas Flowrate: 200,000 lb/hr
  - FGD Waste Water Flowrate
    - 37 to 65 gpm @100F
    - 4,000 ppm Chlorides, 3% TSS, 50,000 TDS

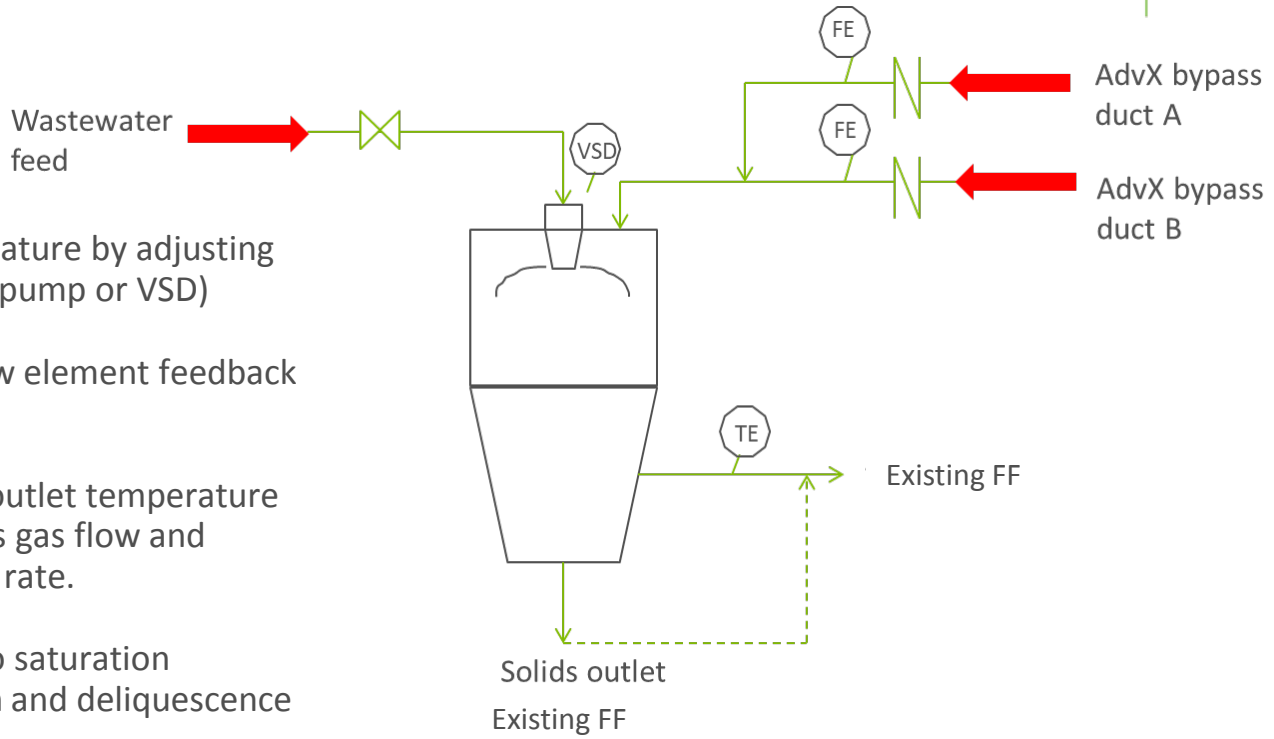
SDE SYSTEM

- Multiple suppliers
- Footprint requirements
  - Evaporation vessel
    - 30 to 40 feet in diameter
    - Final size dependent on flowrate and operating strategy (batch vs. continuous)
  - Additional considerations
    - Feed tank (shop fabricated FRP)
    - Transfer pumps
    - Solids handling equipment
    - After treatment equipment
    - Enclosure
  - Total footprint ~ 60’ x 40’ x 80’



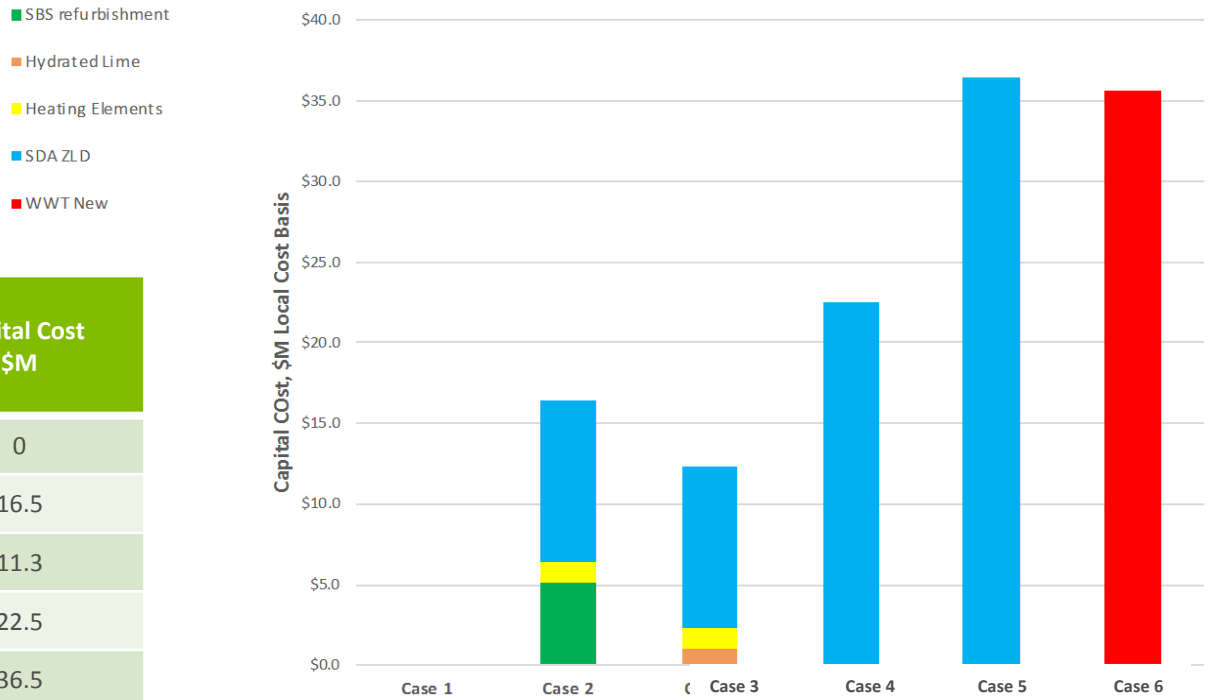
ADVX SPRAY DRYER CONTROL

- Maintain the gas outlet temperature by adjusting the liquid feed rate. (Via valve, pump or VSD)
- Bypass gas flow balance via flow element feedback to dampers
- Alternative - Maintain the gas outlet temperature by regulating the AdvX™ bypass gas flow and keeping a constant liquid spray rate.
- Critical to maintain approach to saturation temperature to avoid corrosion and deliquescence
  - Always keep minimum gas flow to maintain temperature



CAPITAL AND OPERATING COSTS

Case	Annual Operating Cost $M	Capital Cost $M
Case 1	3.7	0
Case 2	3.4	16.5
Case 3	2.1	11.3
Case 4	4.5	22.5
Case 5	2.8	36.5
Case 6	3.6	35.6

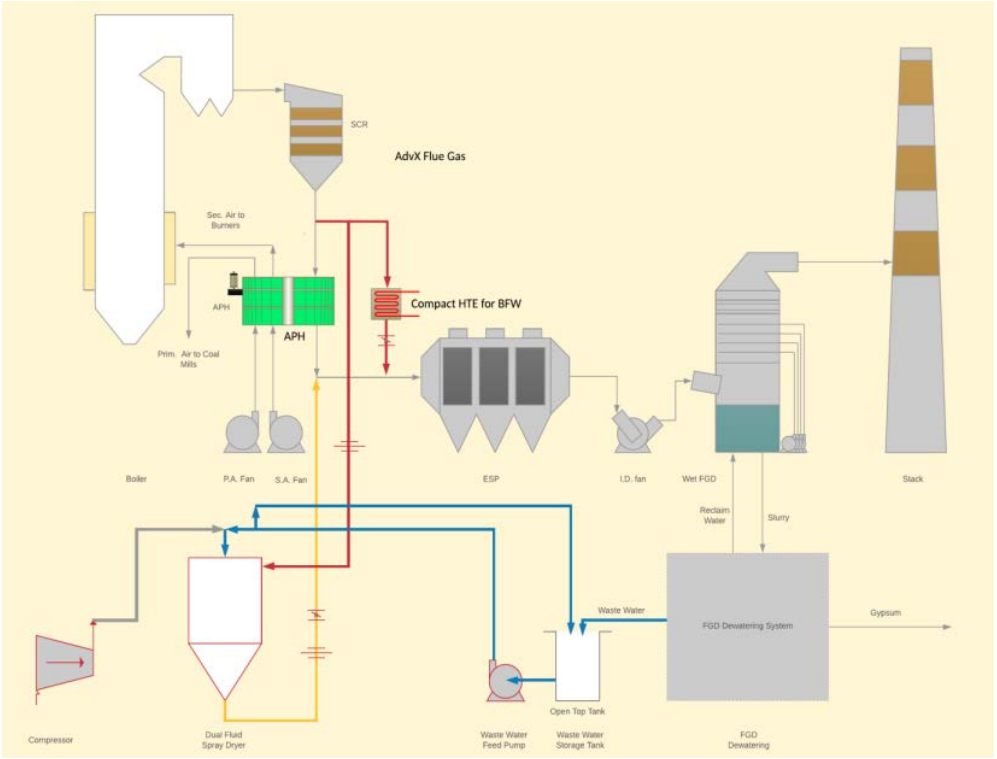


PLANT B

- 580 MW unit firing 0.8% sulfur coal
  - Significant air heater fouling requires frequent washing resulting in waste water generation
  - SCR bypass for reduced load operation
  - Minimum load using SCR bypass is still 46 MW above design
- Solution – Combined ZLD and BFW heating system
  - 15% additional energy can be extracted
  - Modified x-ratio
  - New heating elements
  - SBS Injection™

ZLD + BFW

- No boiler derate
- Eliminate frequent AH washing
- No wastewater
- Remove SCR bypass
- Restore design minimum load
- Reduction in net unit heat rate
- Enhanced ESP performance
- Improved native Hg capture



PROPOSED APH UPGRADE

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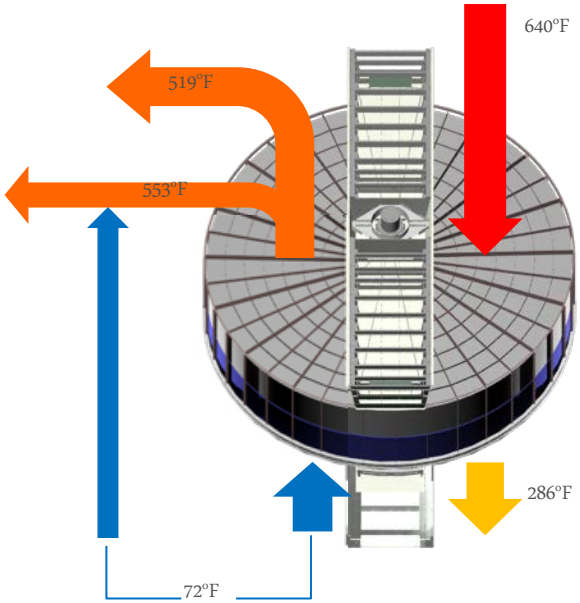
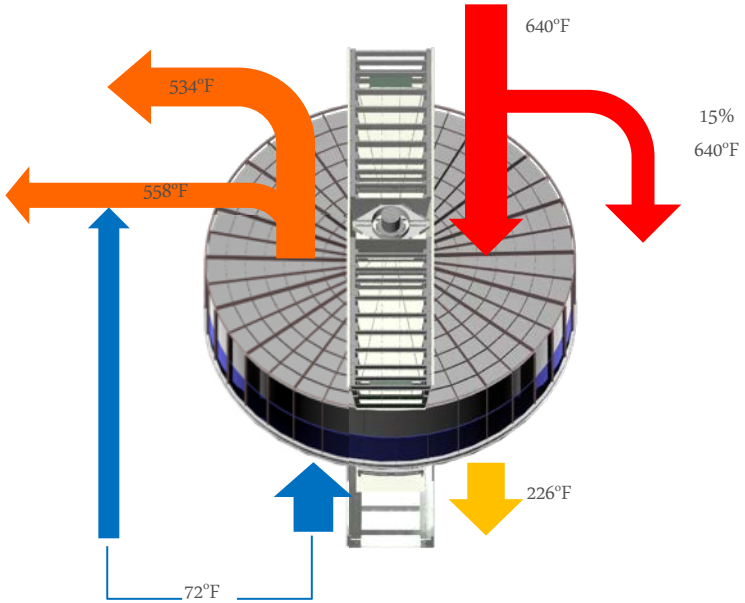
ORIGINAL APH



ADVX™ UPGRADE

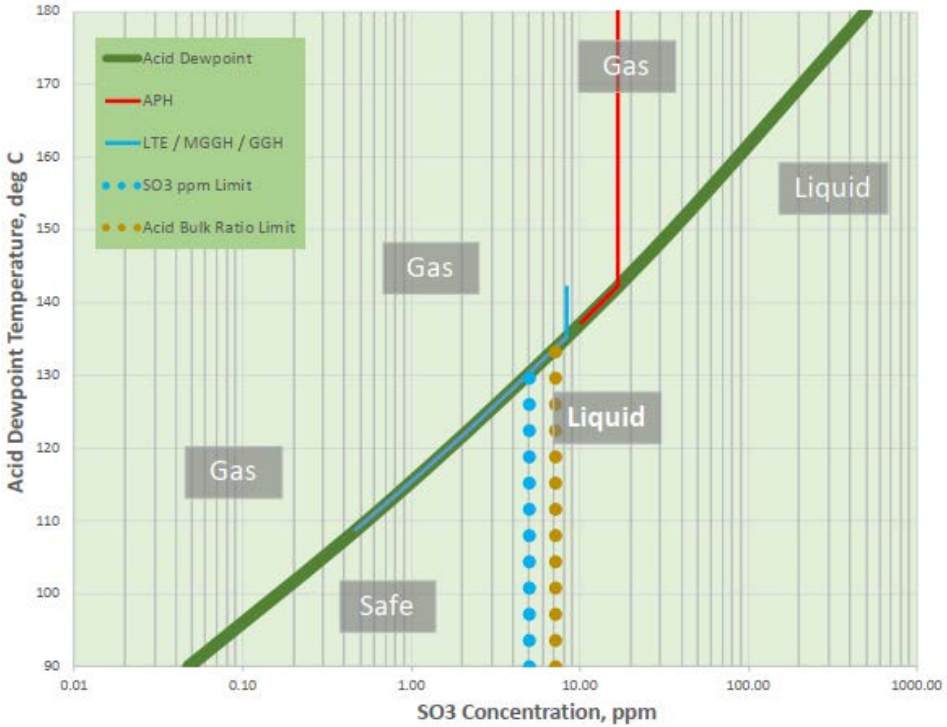


APH – CURRENT OPERATION

- Chemical Reactions

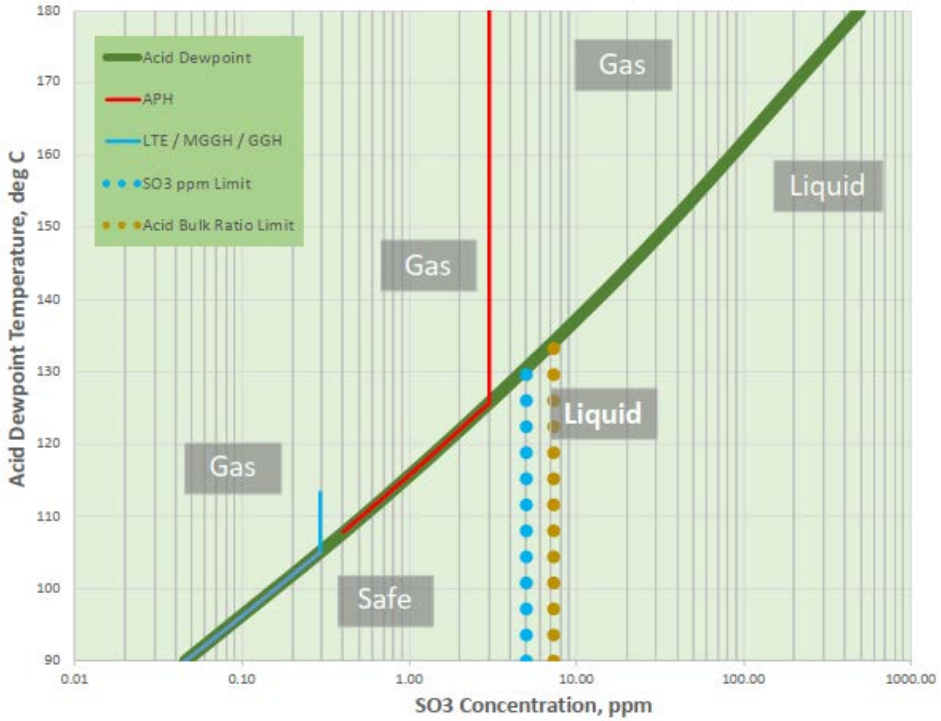
  $SO_3+H_2O \Rightarrow H_2SO_4$
  $H_2SO_4(g) \Rightarrow H_2SO_4(l)$

- Condensation of sulfuric acid
  - Fouling
    - APH condensation
    - GGH condensation
    - Excessive sootblowing leading to erosion of heating elements
  - Corrosion
    - Loss of heating element surface

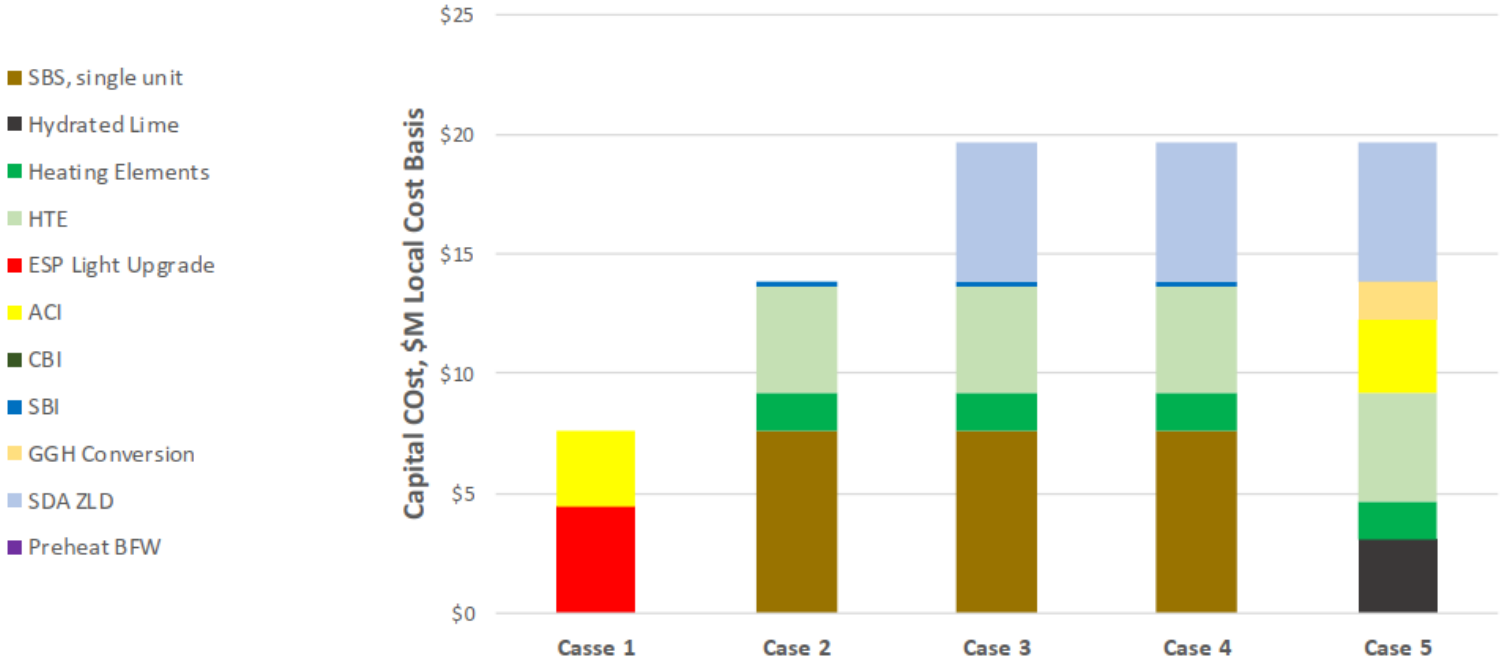


PROPOSED FUTURE OPERATION

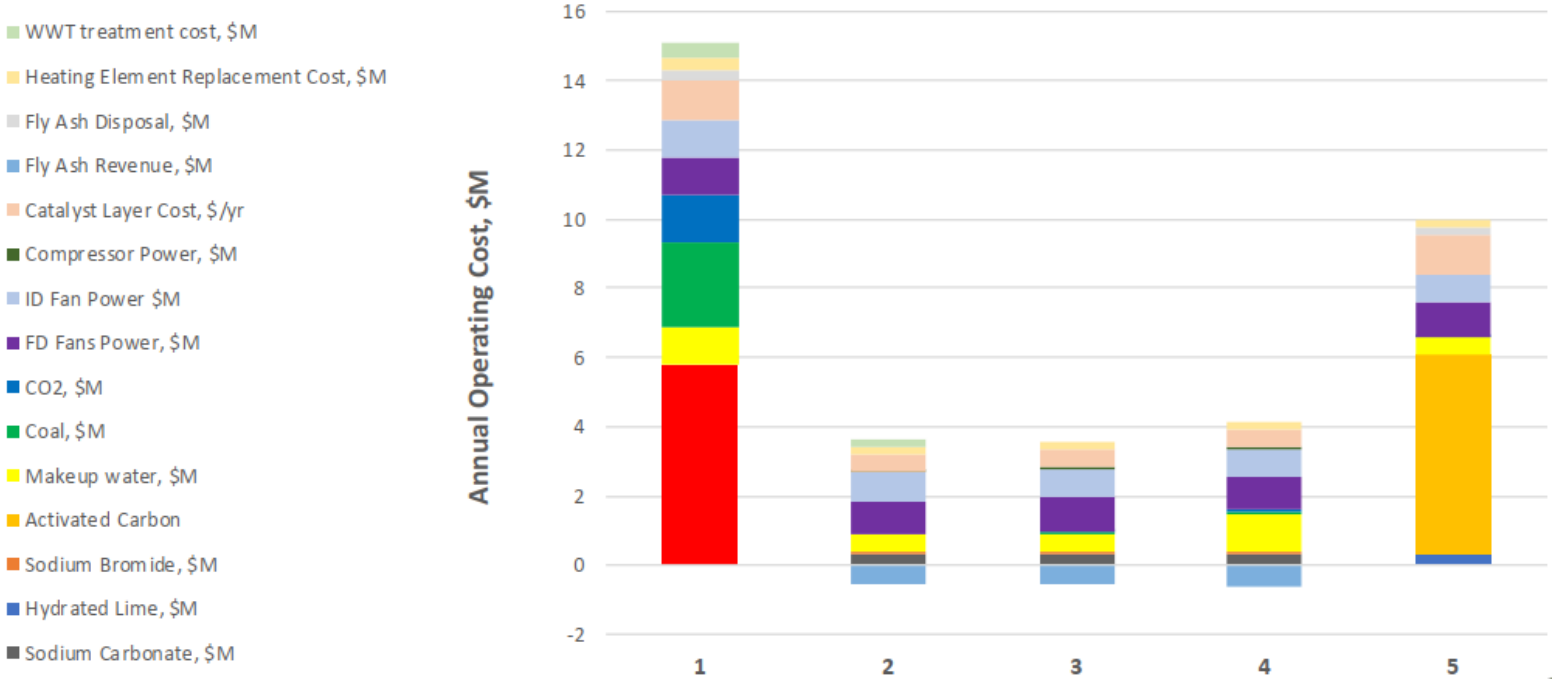
- Chemical Reaction
  $Na_2CO_3(s) + SO_3 \Rightarrow Na_2SO_4(s) + CO_2$
- Removal of SO_3 to less than 5 ppm ahead of APH using SBS Injection™
  - Most of the remaining SO_3 will condense on fly ash
- No fouling, no corrosion
  - Constant pressure drop
  - Less APH cleaning, better reliability
  - Increased heating element life
  - Maintain boiler efficiency
  - Minimal condensation in GGH



CAPITAL COST



OPERATING COST



QUESTIONS?

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