REINHOLD ENVIRONMENTAL Ltd.

2018 APC & Wastewater Round Table & Expo Presentation

July 23 & 24, 2018 in Lexington, KY / Hosted by East Kentucky Power Coop

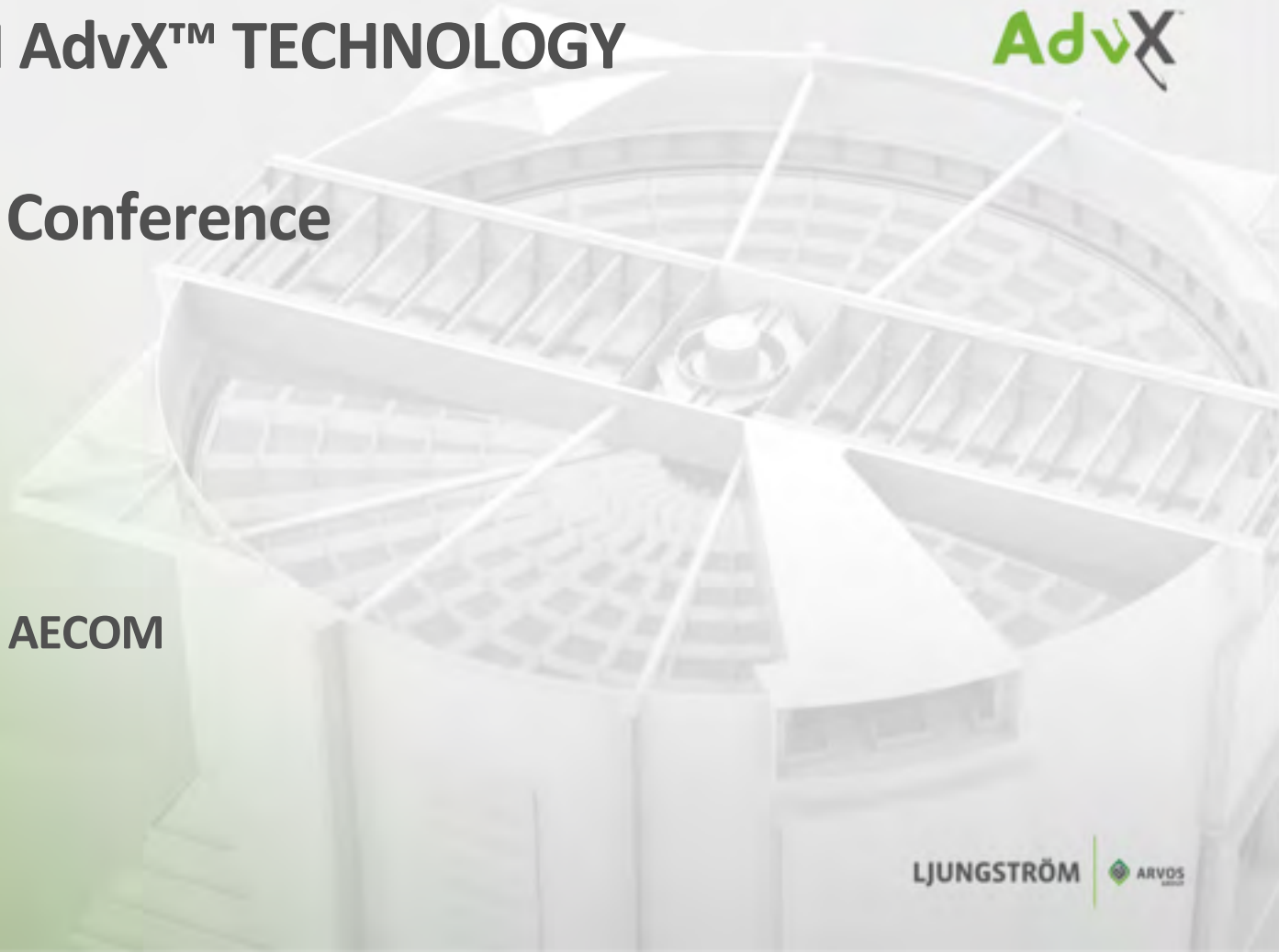
LJUNGSTRÖM AdvX™ TECHNOLOGY

Reinhold APC Conference

July 24th, 2018

Dr. Jonas Klingspor

In partnership with AECOM



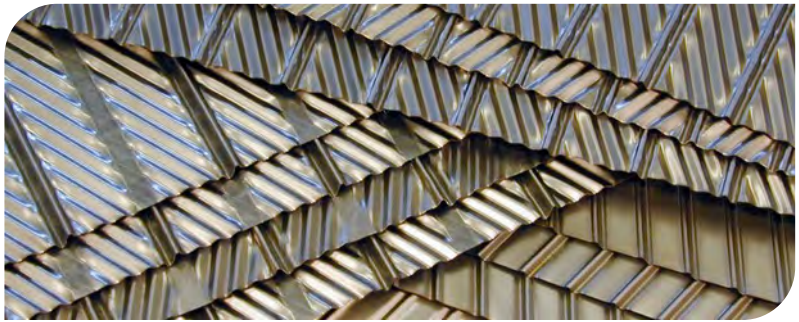
PRESENTATION OUTLINE

LJUNGSTRÖM | ARVOS

- Ljungström Overview
- What is AdvX™
- Heat Extraction
- Beneficial use of Energy
- SO_3 Reduction and Benefits
- BREF Compliance
- Next Steps

LJUNGSTRÖM OVERVIEW

- AdvX™ Heat Recovery Technology
- Traditional Air Preheaters
- Gas-Gas Heaters
- Element Profiles
- Enameled Elements
- EPC provider
- Comprehensive BREF Compliance



Exclusive provider of AdvX™ Heat Recovery Solutions

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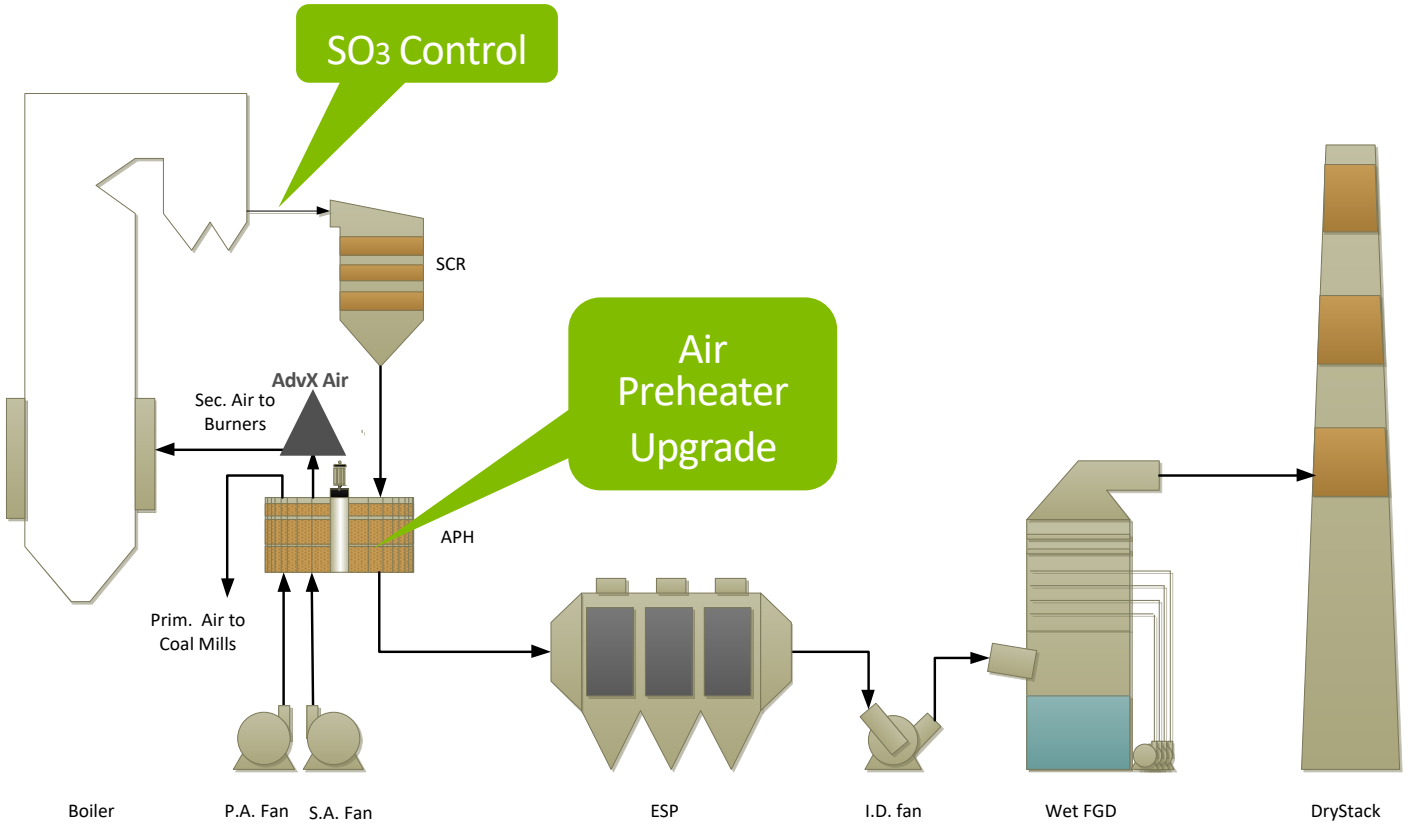
AdvX™ FOR AIR & WATER COMPLIANCE



WHAT IS AdvX™?

- Enabling Technologies
  - Extraction of additional energy - AdvX™
  - Removal of SO_3 ahead of the SCR - SBS
- Emission compliance
  - NO_x
  - PM,
  - Hg,
  - SO_3
- Substantial reduction in water consumption
- Increase in heating element life
- Reduced corrosion of ductwork and ESP

- Beneficial use of extracted energy
  - Improved boiler heat rate
  - Stack gas reheat
  - Zero liquid discharge

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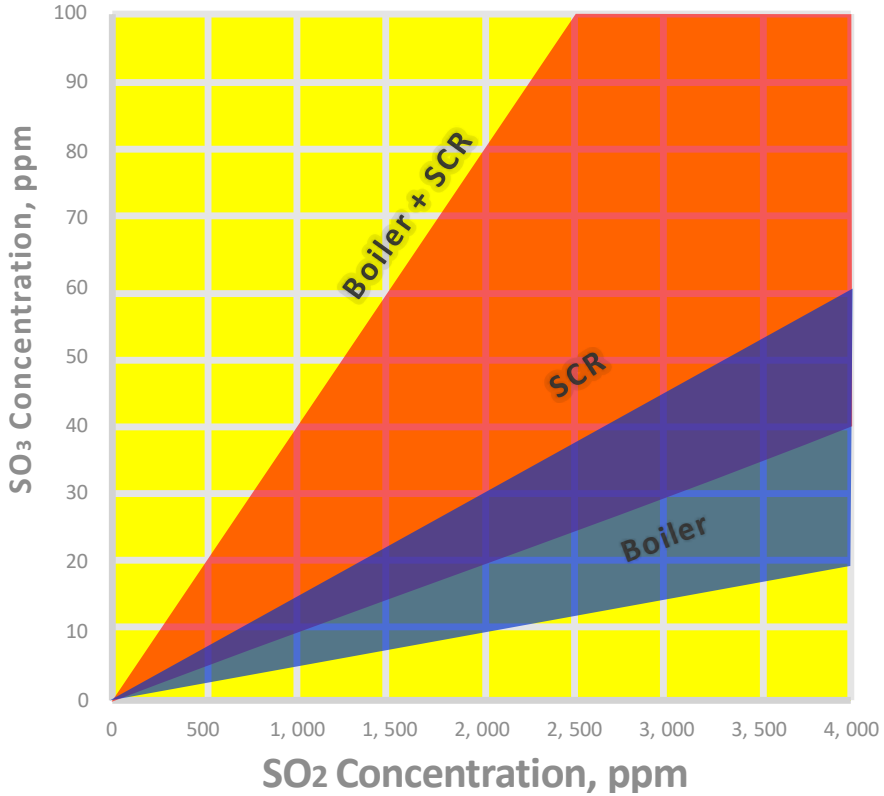
SO_3 FORMATION



- Boiler
  - ½ - 1 ½ percent SO_2 to SO_3 oxidation
- SCR
  - 1/3 percent SO_2 to SO_3 oxidation per catalyst layer
- Operation Limitations
  - Minimum SCR operating temperature
  - Minimum APH operating temperature
- Negative impact starts at 10 mg/m^3

ADVX™ SYSTEM OVERVIEW

LJUNGSTRÖM | ARVOS

AdvX™

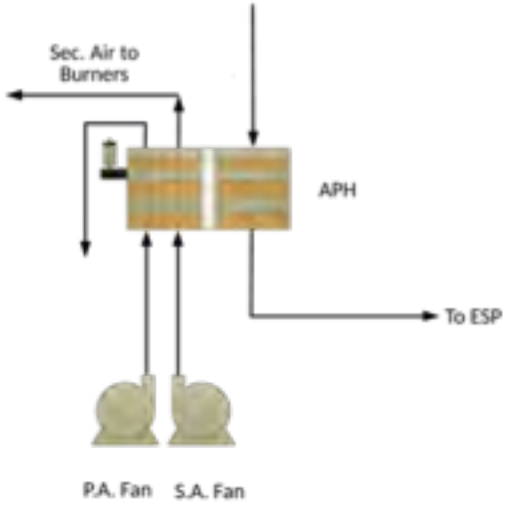
- High efficiency heating elements
- Additional heating element depth
- X-ratio shift
  - Increased secondary air flow or
  - Reduced flue gas flow, APH bypass & HTE

DN8

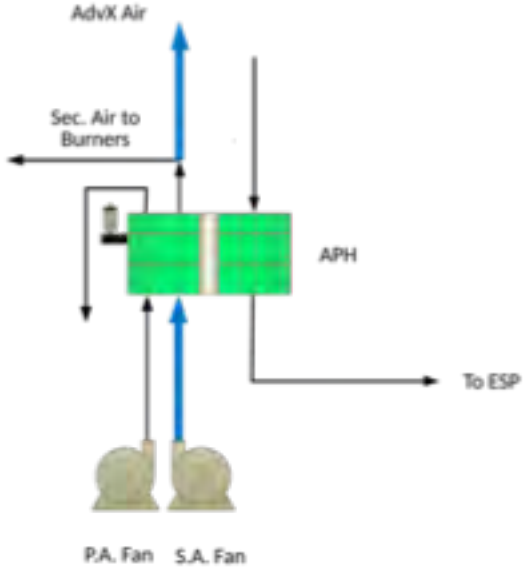
ADVX™

$$X - Ratio = \frac{air}{flue\ gas}$$

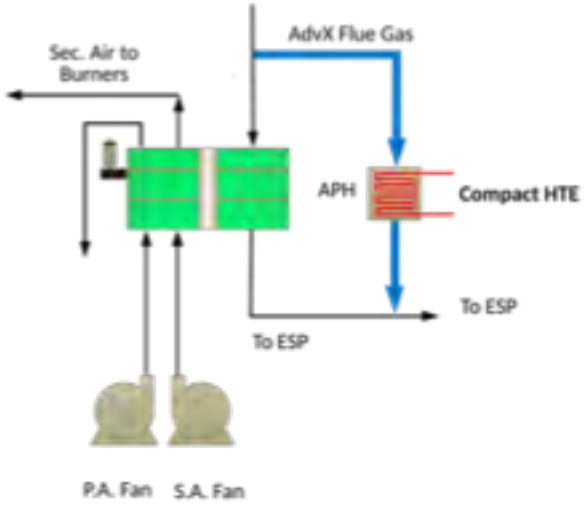
LJUNGSTRÖM | ARVOS



Typical APH

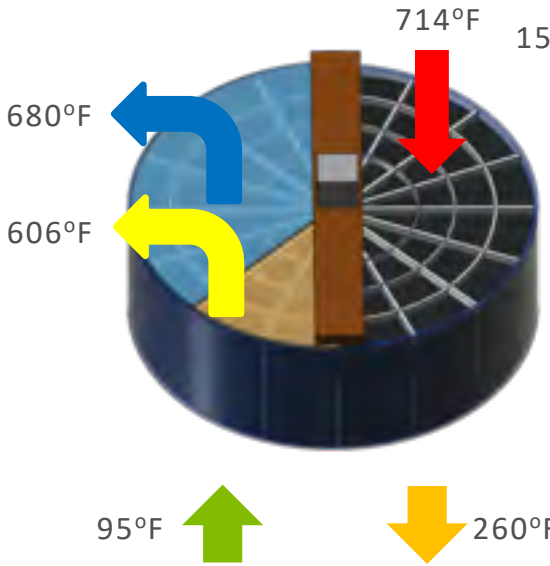


AdvX™ Option 1

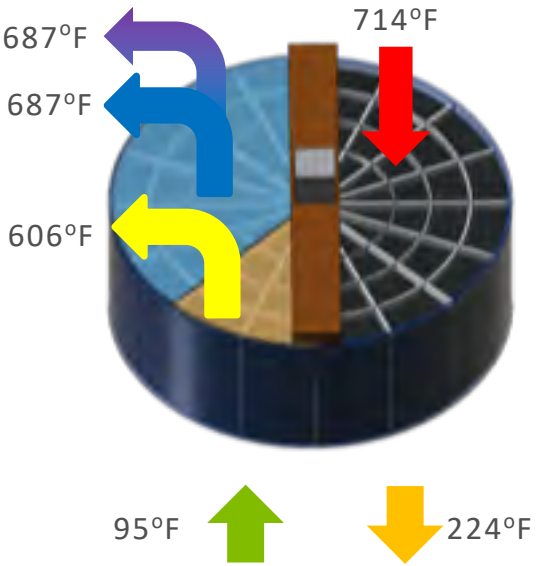


AdvX™ Option 2

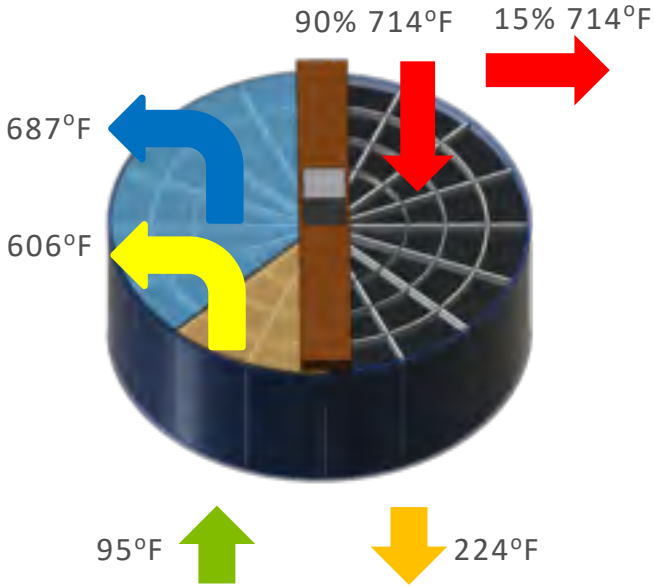
ORIGINAL APH vs ADVX™ HEAT RECOVERY SOLUTION



Original APH



Option 1
Increased Air Flow



Option 2
Flue Gas Bypass / HTE

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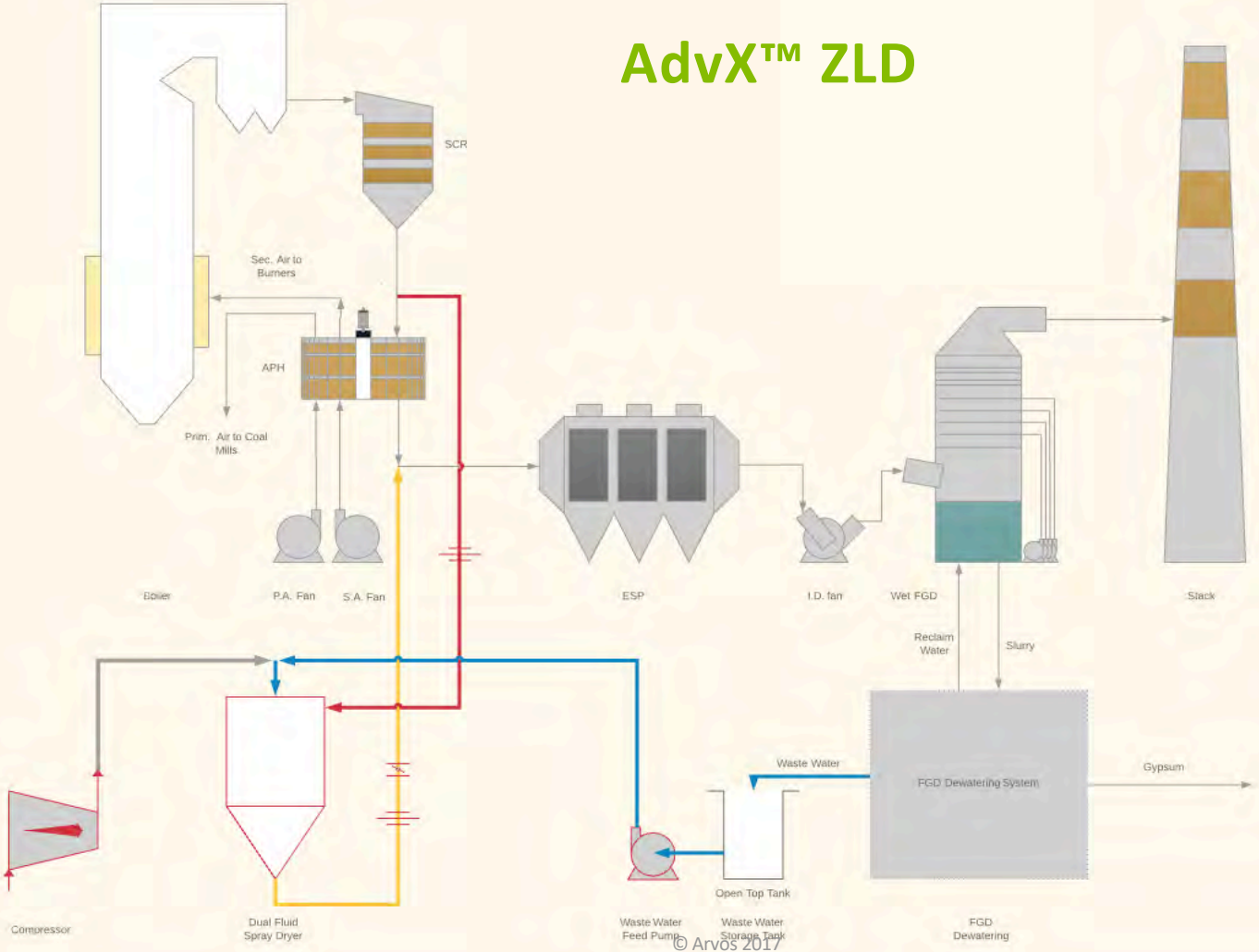
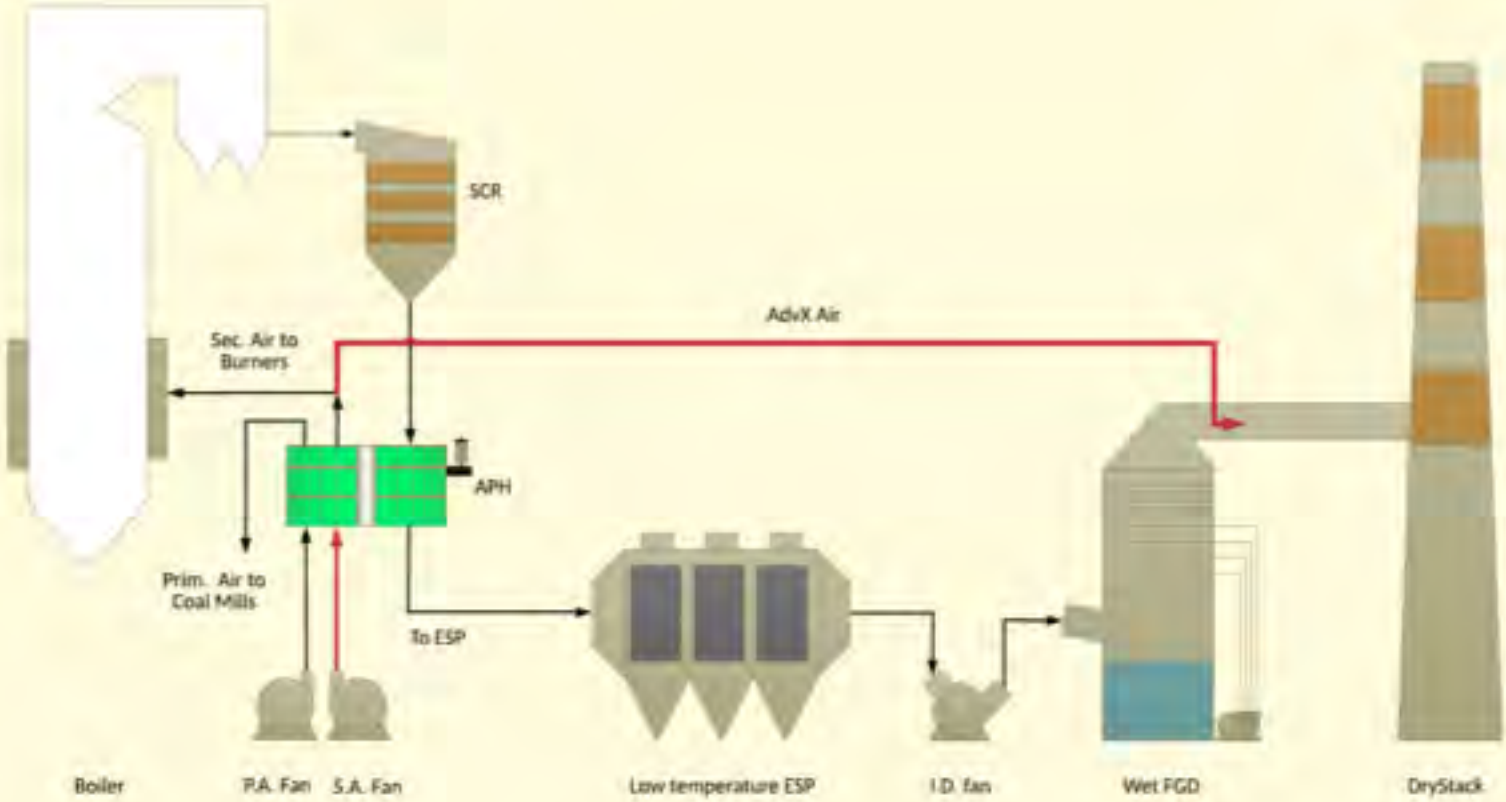
AdvX™ ZLD

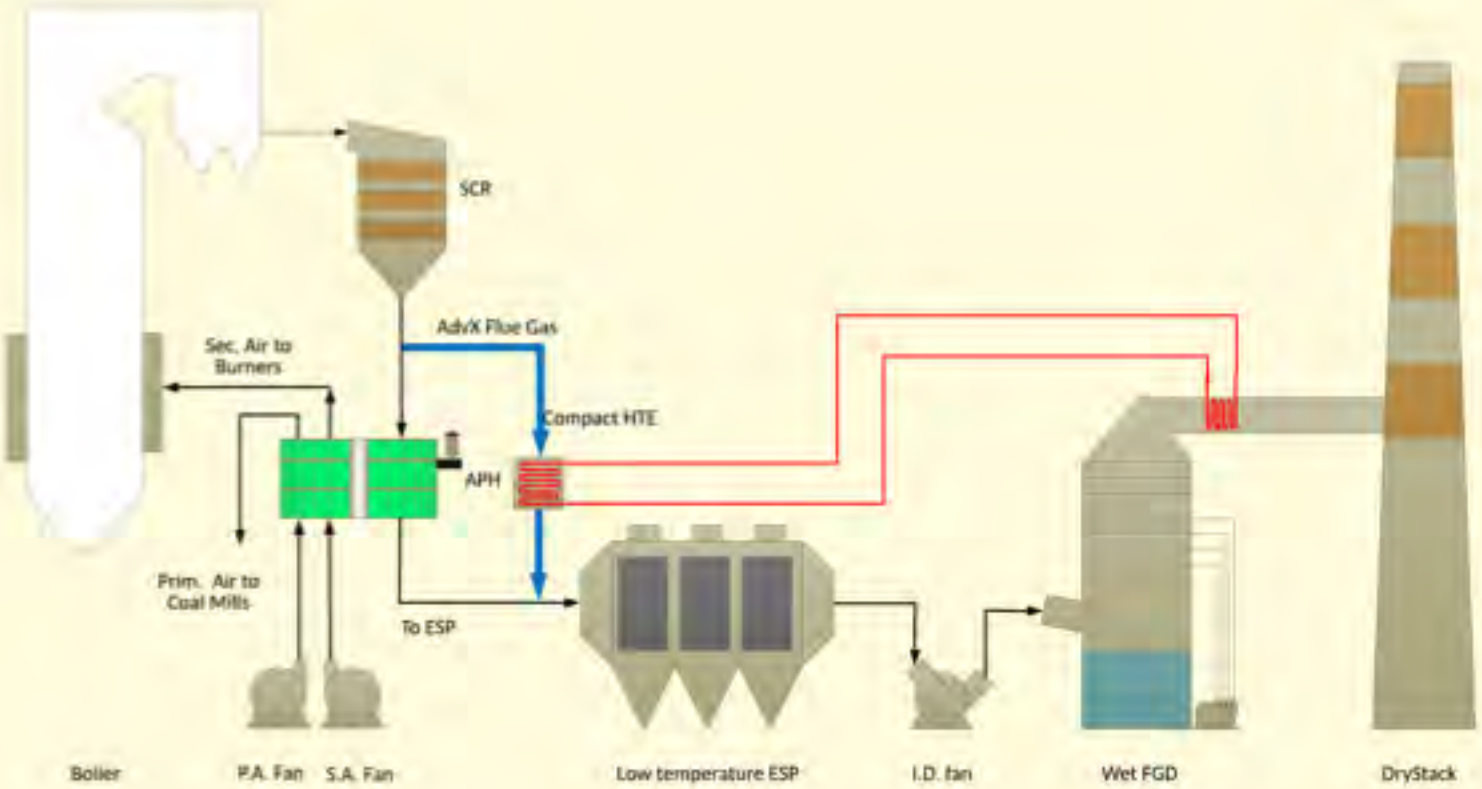


- Rule of Thumb
  - A 500 MWe plant can evaporate ~200 gpm of waste water
  - No additional fan
  - No impact on boiler heat rate
  - No product disposal
  - No discharge limits
  - Forever compliant

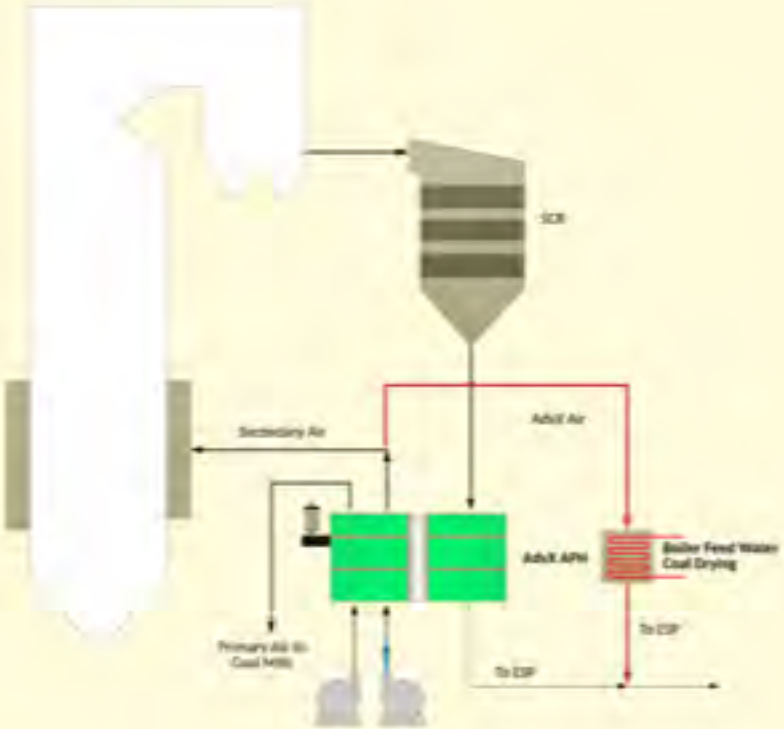
ADVX™ DIRECT FLUE GAS REHEAT WITH AIR



ADVX INDIRECT FLUE GAS REHEAT WITH FLUE GAS



COAL DRYING



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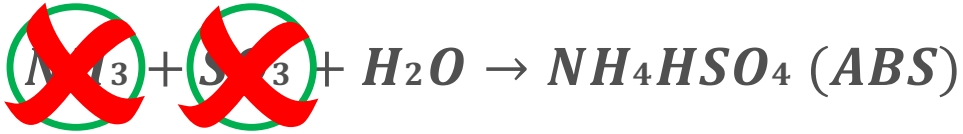
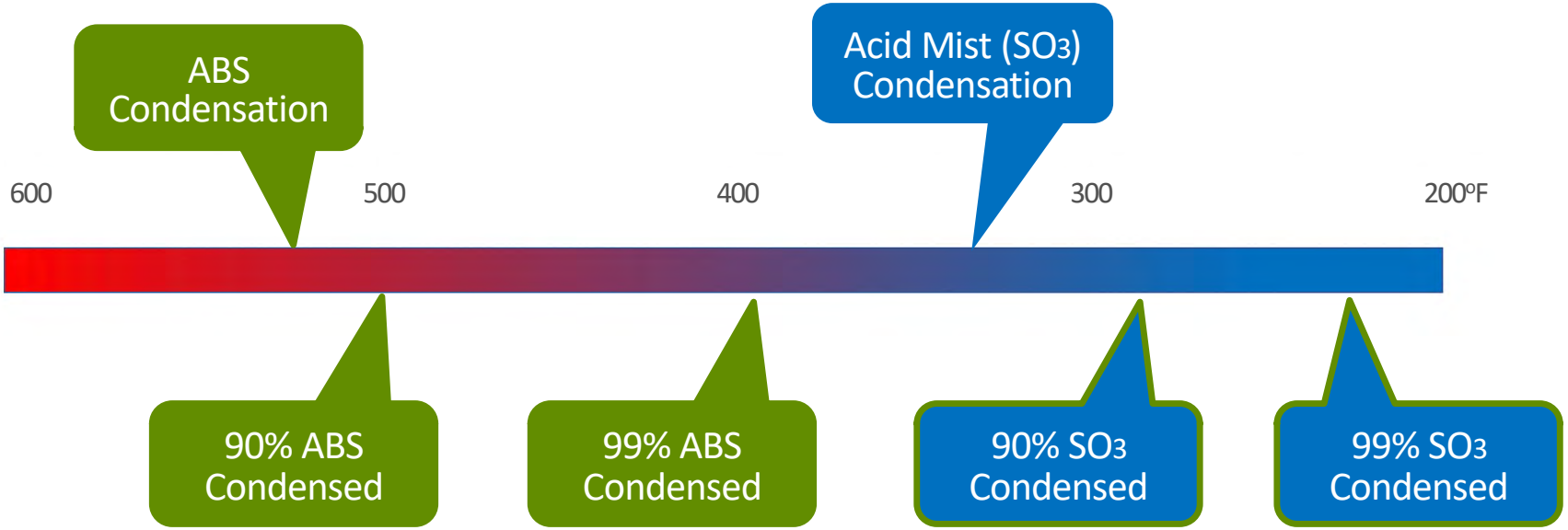
KEEPING THE APH CLEAN – SBS BENEFITS



- Limiting Ammonia Slip
  - Limited ABS fouling of APH

- Removing SO_3 enables many benefits
  - NO SO_3 fouling
  - No ABS fouling of SCR and APH
  - BREF Compliance
    - NO_x, SO_3, PM and Hg emissions
  - Flexible SCR performance
  - Reduced WFGD water consumption
  - Reduced WWT demand
  - No corrosion of ductwork and ESP

FOULING TEMPERATURES



Increasing the APH exit Temperature from 175 to 200 doesn't resolve ABS scaling
Only solution is to Remove SO_3 with SBS

TYPICAL FOULING TEMPERATURES

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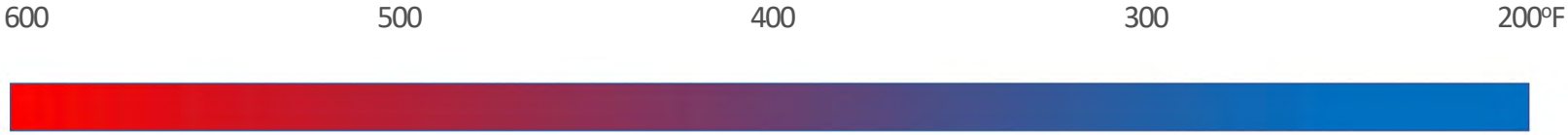
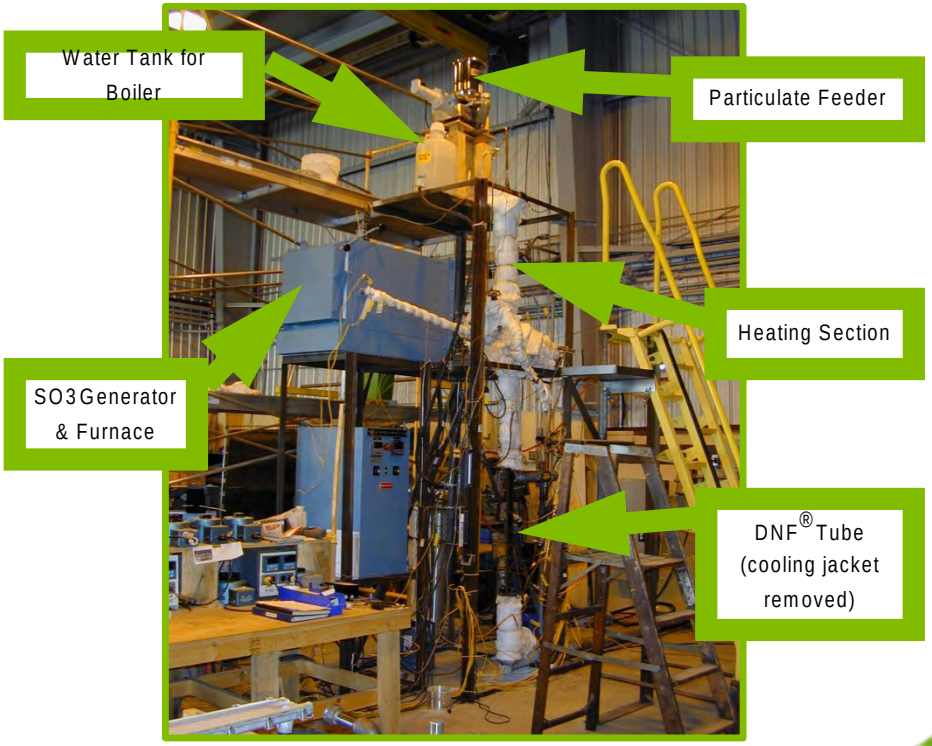
$$NH_3 + SO_3 + H_2O \rightarrow NH_4HSO_4\ (ABS)$$

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



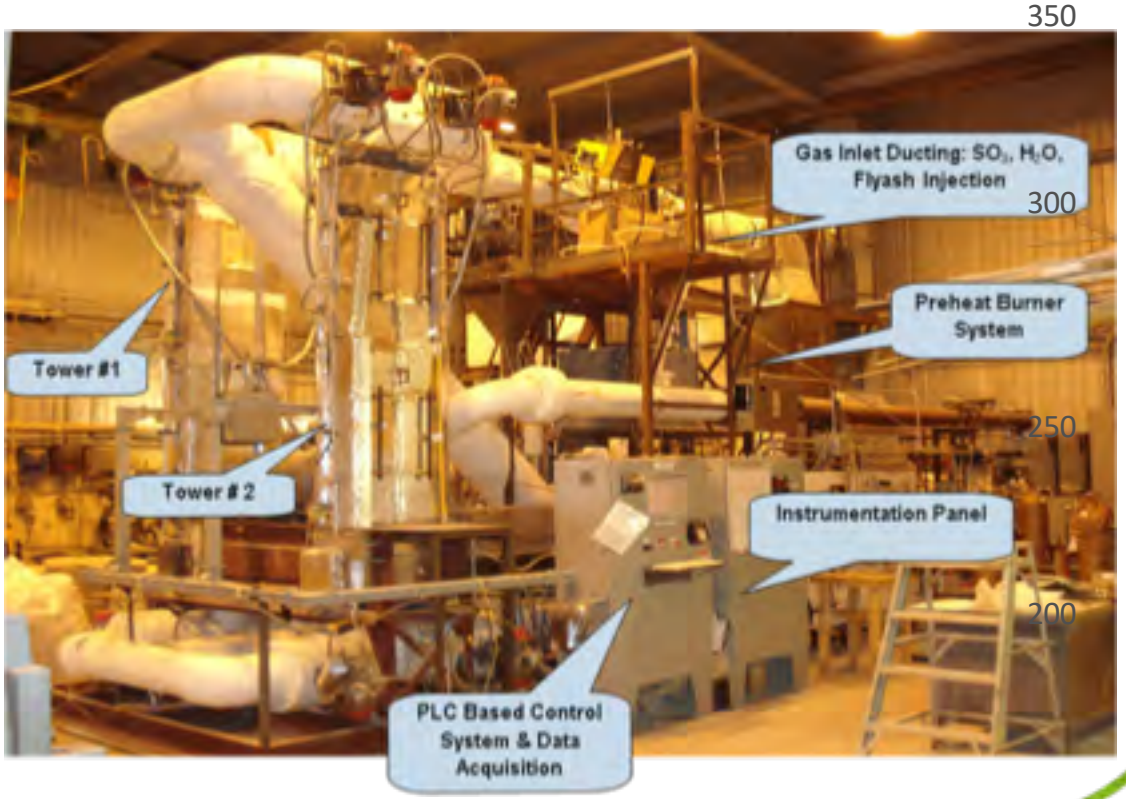
DEVELOPMENT HISTORY

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

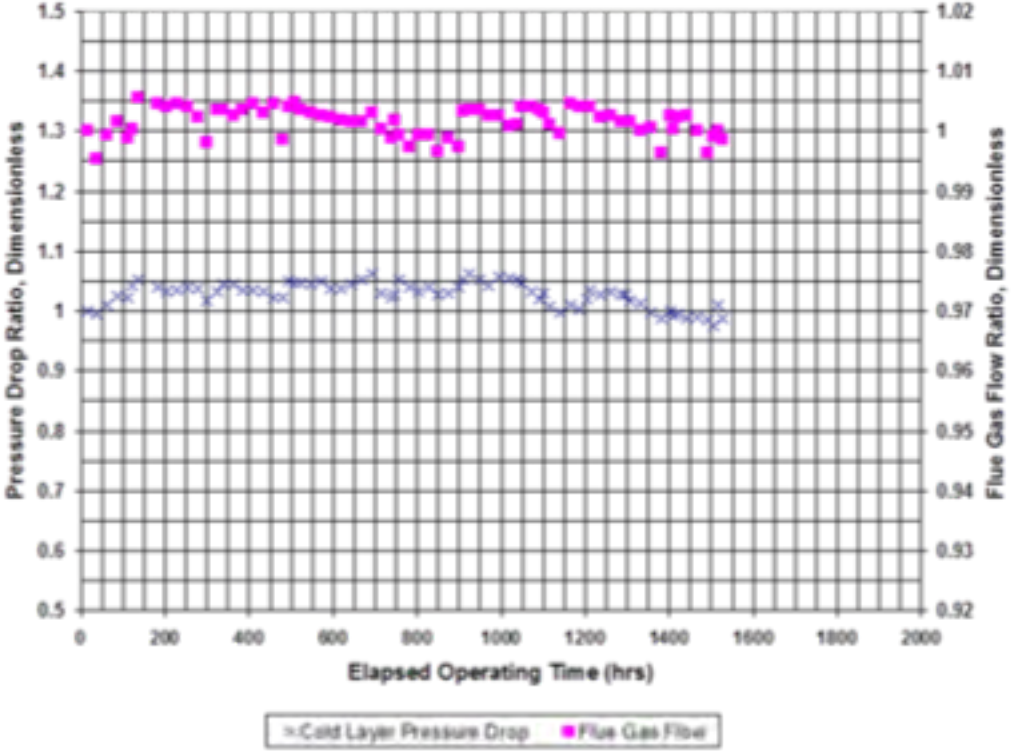


PILOT PLANT

- Simulated Flue Gas
  - U.S. eastern bituminous coal ash used for testing with various levels of ash
  - 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 SO3 to ash ratio varied
  - Flue gas outlet temperature held at 219°C
- On-line cold end soot blowing every 8 hours (compressed air)

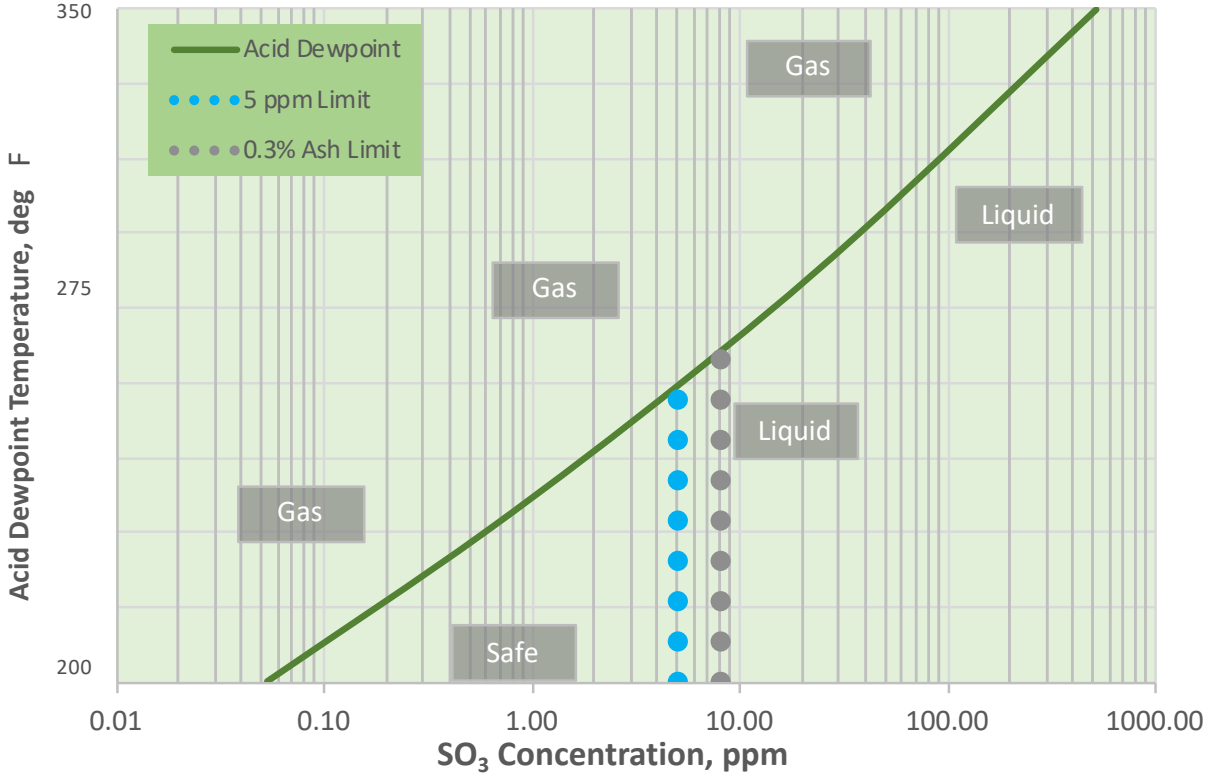


LJUNGSTRÖM PILOT TESTS AT 219°F NO dP INCREASE



- Results showed that to operate with no fouling, the flue gas must comply with two design conditions (whichever is more stringent):
  - SO_3 levels at air heater inlet must be below 5 ppm
  - SO_3 / fly ash ratio must be below 0.3 percent

IMPROVED APH EFFICIENCY – NO SO_3 FOULING



- Reduce APH outlet temperature from ~300°C to 230°C
  - Increase boiler efficiency by 2%
  - Reduced coal consumption by 2%
  - Reduced PM emissions
  - Reduce Hg emissions
  - Reduced FGD water consumption

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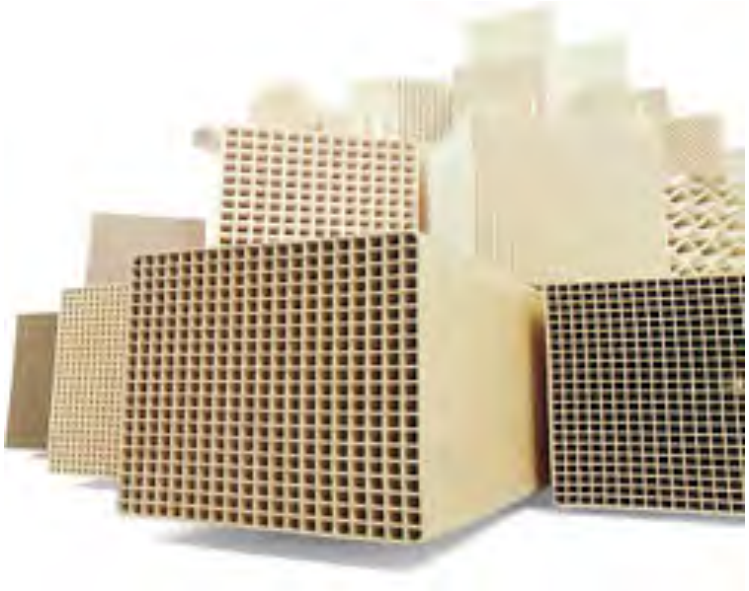
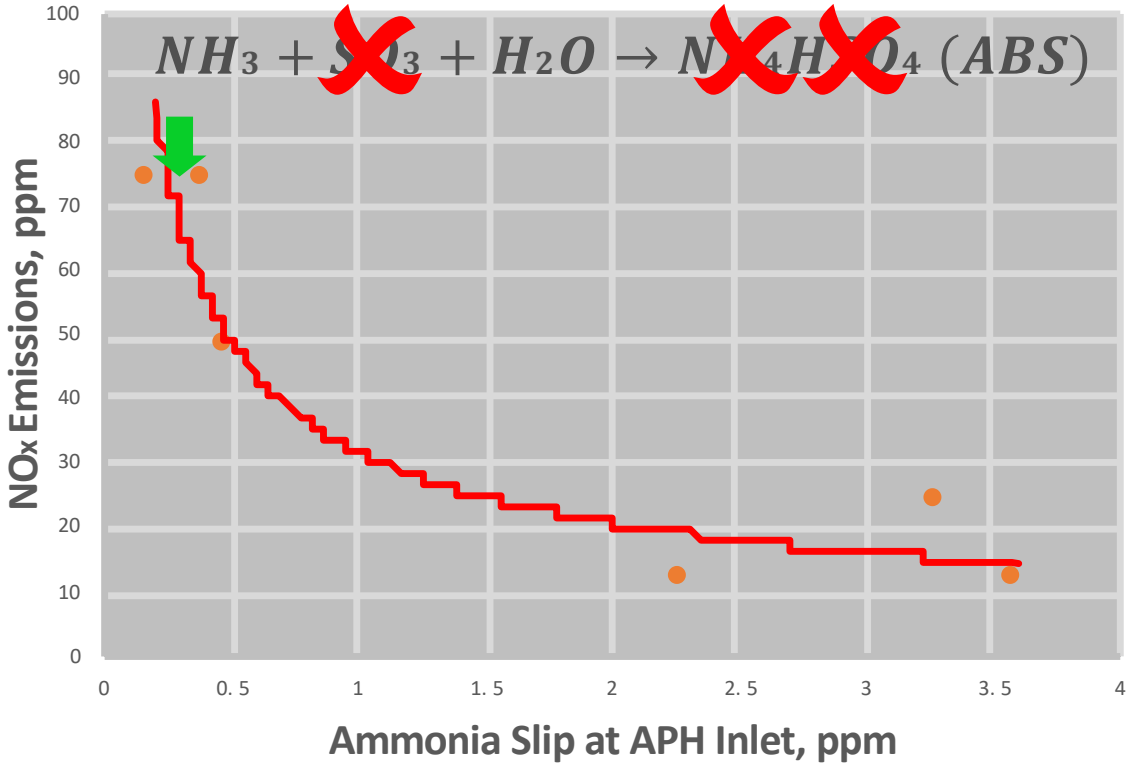
INJECTION AHEAD OF SCR EXPERIENCE

- Haldor Topsoe
- Hitachi
- Cormotech (Mitsubishi)
- Johnson Matthey (formally Argillon and Siemens)
- IBIDEN (formerly Ceram)
- KW



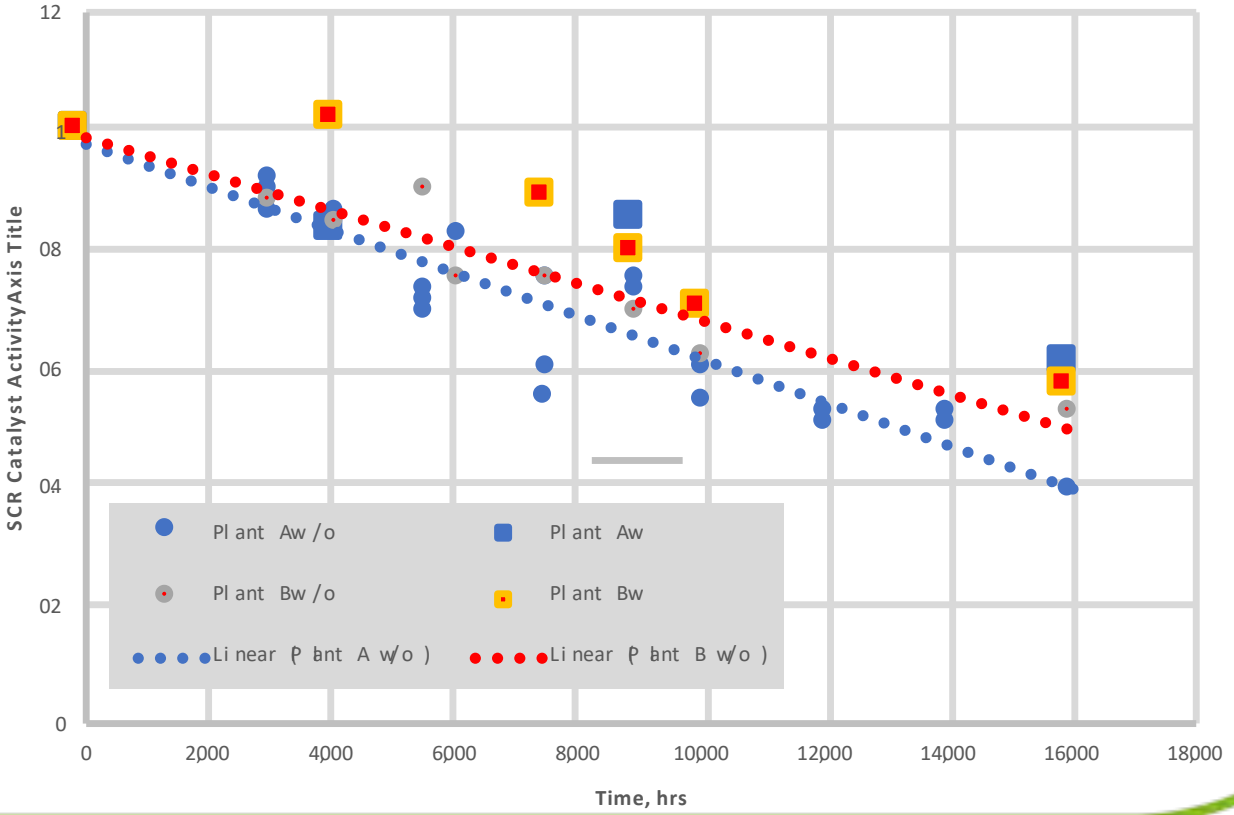
SCR OPTIMIZATION



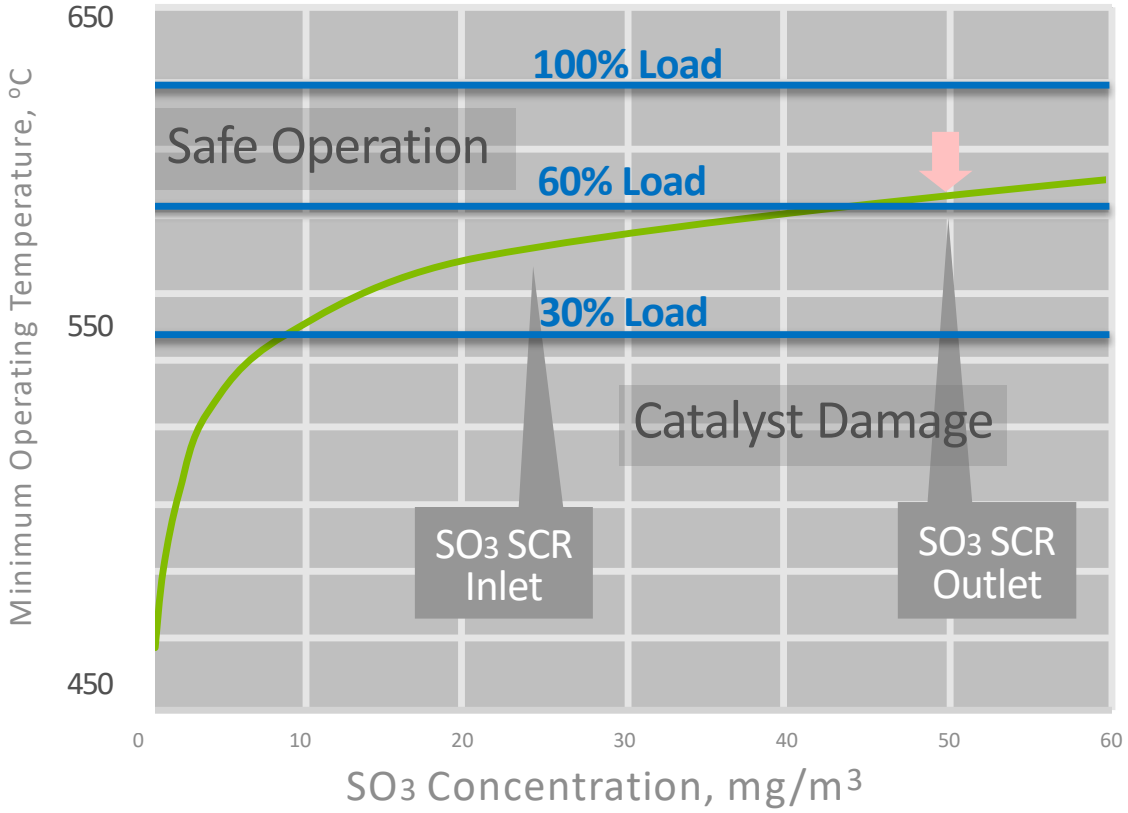
- Increased ammonia slip – no ABS scaling
- 80 to 90% reduction in NO_x emissions
- Remove one catalyst layer and maintain NO_x emissions
- Double catalyst life by gradually increasing ammonia slip over time
- SCR flexibility

UTILITY LONG-TERM SCR TEST RESULTS

- 17 installations
- 8,000 MWe
- Longest run time, 9 years
- No negative impact on SCR catalyst
  - Possible slight enhancement



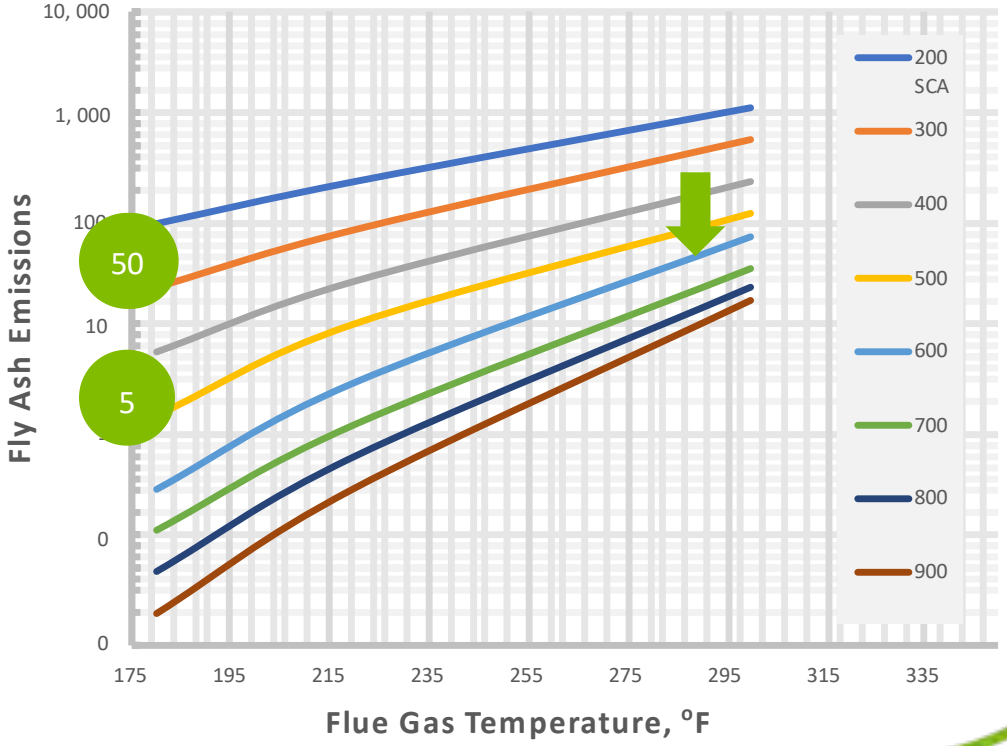
IMPROVED SCR OPERATING FLEXIBILITY



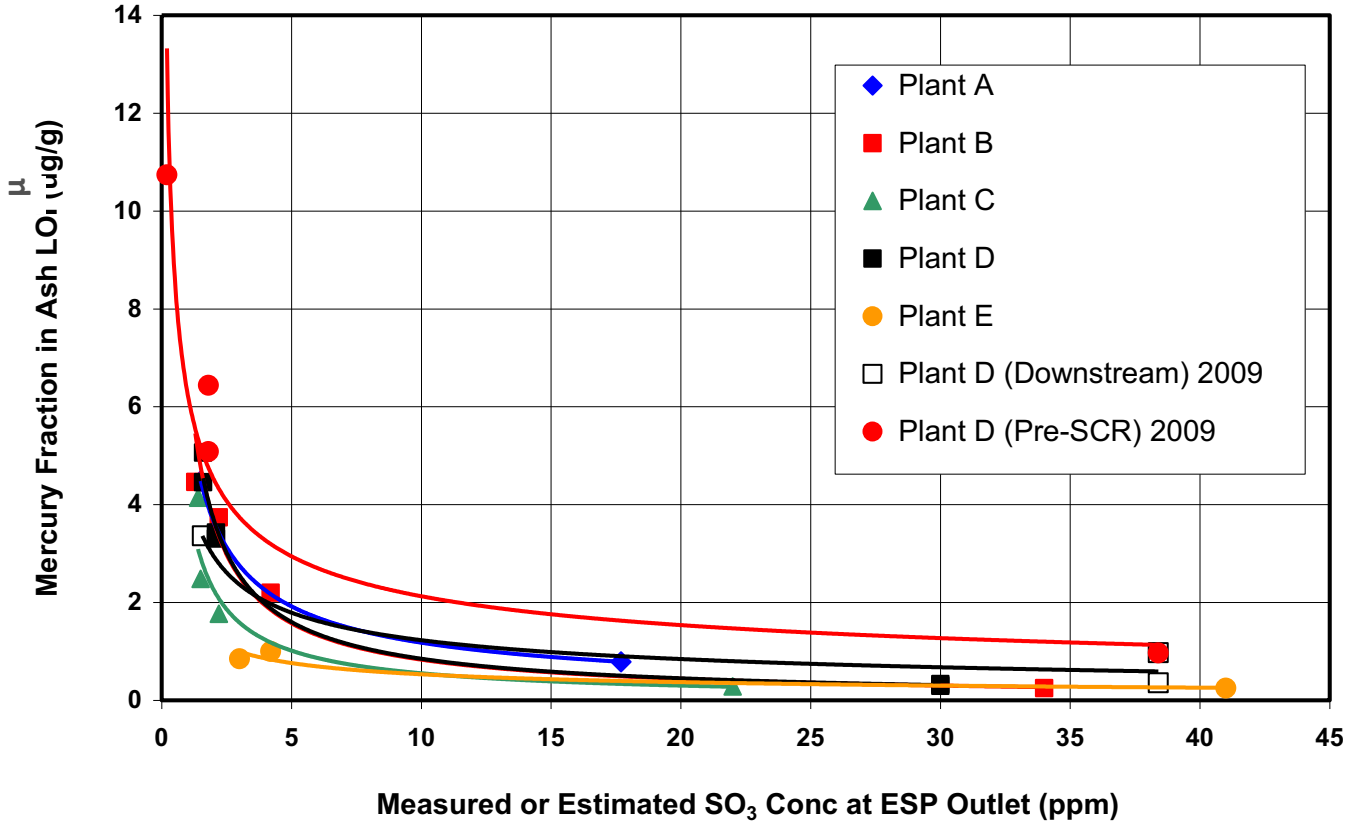
- SCR temperature is reduced at lower boiler loads
  - Risk of ABS scaling
- SO_3 concentration sets minimum boiler load limit
  - 60% load is typical
- SO_3 removal allows operation at lower loads
  - 30% is typical
  - Greater operating flexibility
  - Large savings in operating cost

BREF COMPLIANCE - PM

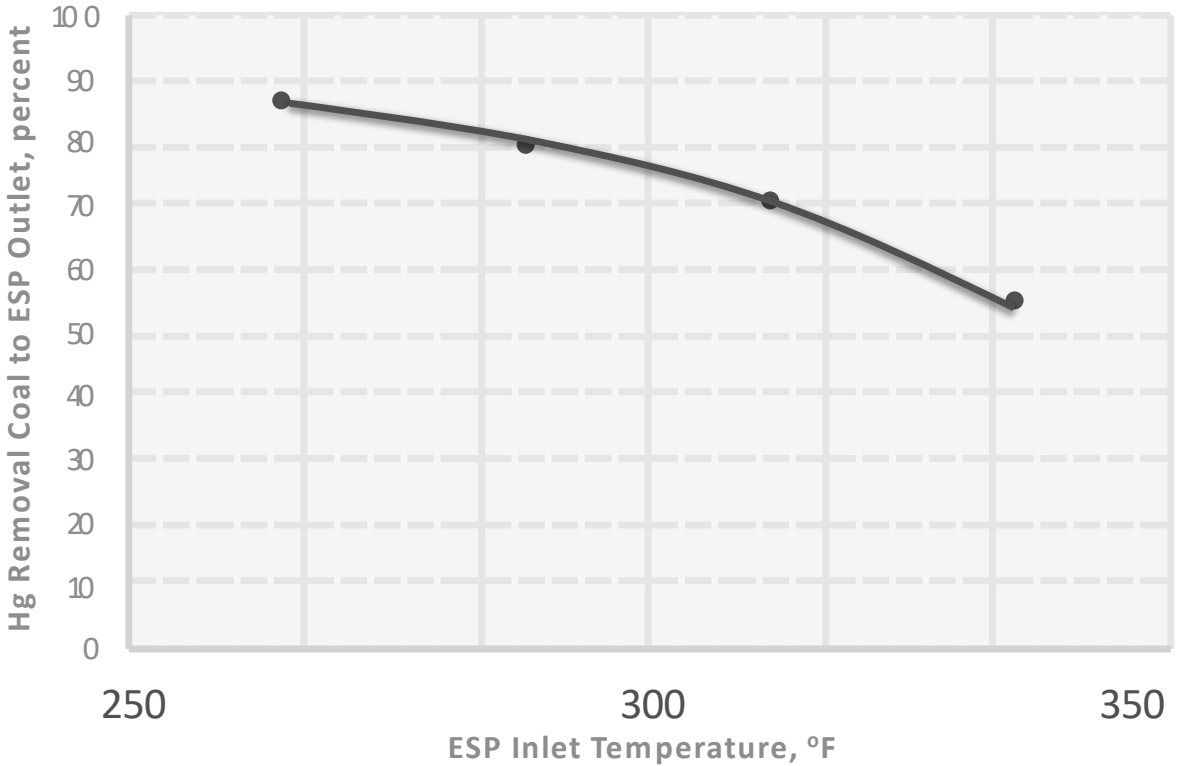
- Reduction in flue gas temperature leads to a reduction in fly ash resistivity which result in a reduction in fly ash emissions:
  - A temperature reduction from 150ºC to 100ºC reduce fly ash emissions by 84%
  - 280ºC to 210ºF by 80%
  - 265ºC to 210ºF by 71%
  - 250ºC to 210ºF by 60%



Hg REMOVAL BY FLY ASH



REDUCED TEMPERATURE INCREASE HG REMOVAL



- Unburnt carbon (LOI) is natural activated carbon in fly ash
- Unburnt carbon adsorbs SO_3
- When SO_3 is removed by SBS, the unburned carbon removes mercury
- Provides compliance with BREF
- Can be combined with HBS to boost Hg removal

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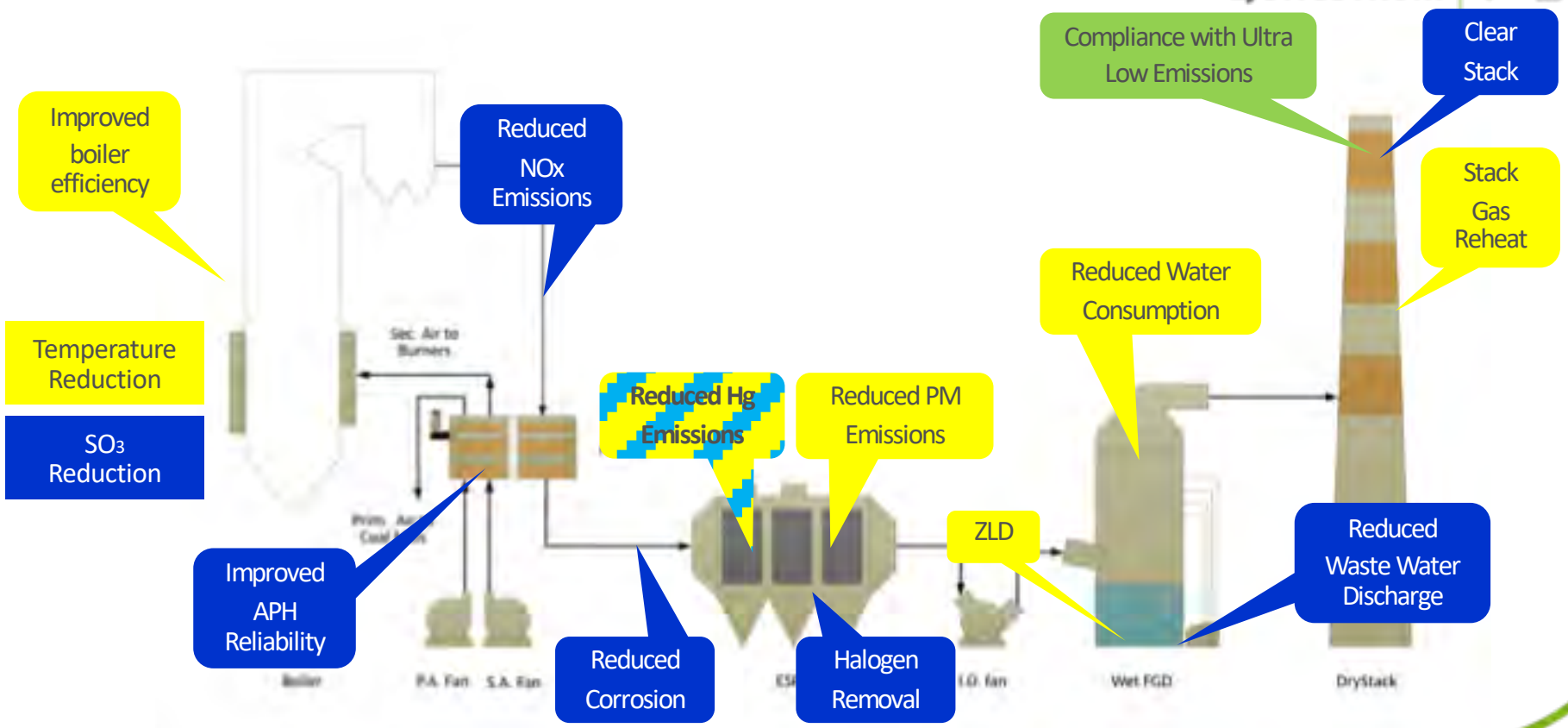
BENEFITS OF ADVX™ TECHNOLOGY



FULL-SCALE ADVX™ OPERATING RESULTS

AdvX™ OPERATING TUNING		
Temp.	ESP temperature	Reduced from 345°F to 255°F
SO3	SO3 Removal	>99.8 percent
	Stack SO3 Emissions	Decreased from 70 ppm to <0.5 ppm
HEAT RECOVERY		
Boiler	Coal consumption Improvement	Reduced by 2 percent
	CO2 Reduction	Reduced by 2 percent
BREF COMPLIANCE		
NOx	NOx Removal	80 percent additional NOx reduction
	Stack NOx Emissions	Decreased from 80 mg/m^3 to 15 mg/m^3
	Ammonia Slip	Increased from 0.5 ppm to 3 ppm
	SCR MOT	Decreased from 620°C to 540°C
	SCR Flexible Operation	Minimum load reduced from 60 percent to 30 percent
PM	ESP Temperature	Reduced from 350°F to 255°F
Hg	Hg Removal	Increased from 20 to 85 percent
	Stack Hg Emissions	Reduced from 2 µg/m^3 to <0.2 µg/m^3
OTHER BENEFITS		
HCl & HF	Removal ahead of FGD	Increased from 10 to as high as 70 percent ahead of FGD
Water	Water Consumption	Reduced by 50 percent

1 Equivalent AdvX APH Experience

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