



# Dual Flue Gas Conditioning Processes, Technology and Experience

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# *$SO_2$ Flue gas Conditioning ( $SO_3$ FGC)*

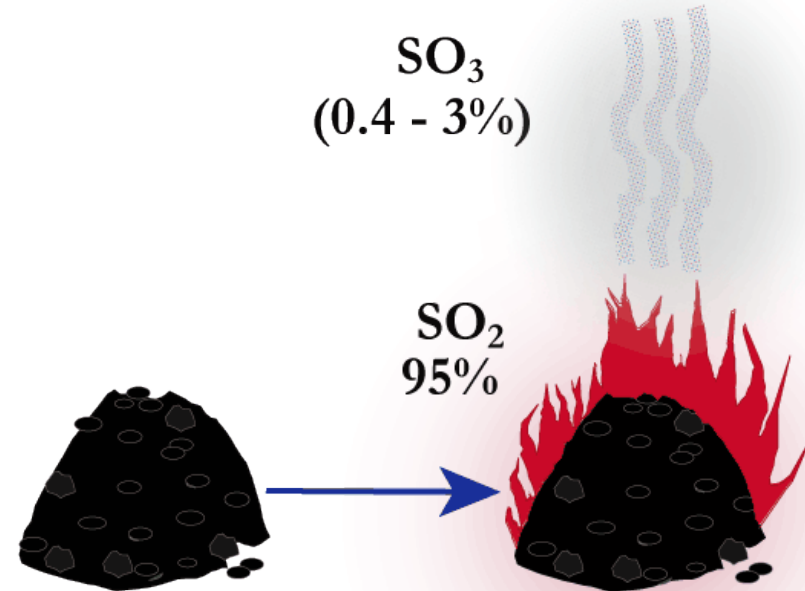
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# SO<sub>3</sub> FLUE GAS CONDITIONING

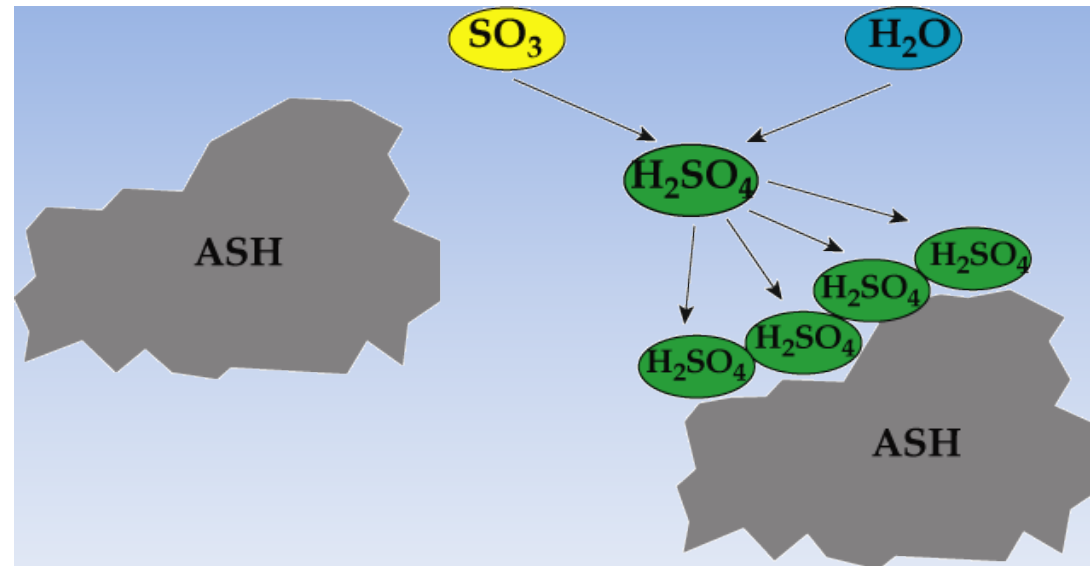
When coal is subjected to pulverized fuel combustion, the sulphur it contains is converted to the oxides of sulphur in the gas phase



During coal combustion only a small fraction of SO<sub>2</sub> appears as SO<sub>3</sub> (0.4 - 3%)

# SO<sub>3</sub> FLUE GAS CONDITIONING

- SO<sub>3</sub> and H<sub>2</sub>O combine in the flue gas to form H<sub>2</sub>SO<sub>4</sub>
- H<sub>2</sub>SO<sub>4</sub> and H<sub>2</sub>O are adsorbed on the surface of the fly ash particles at flue gas temperatures below 204 °C (400 °F)

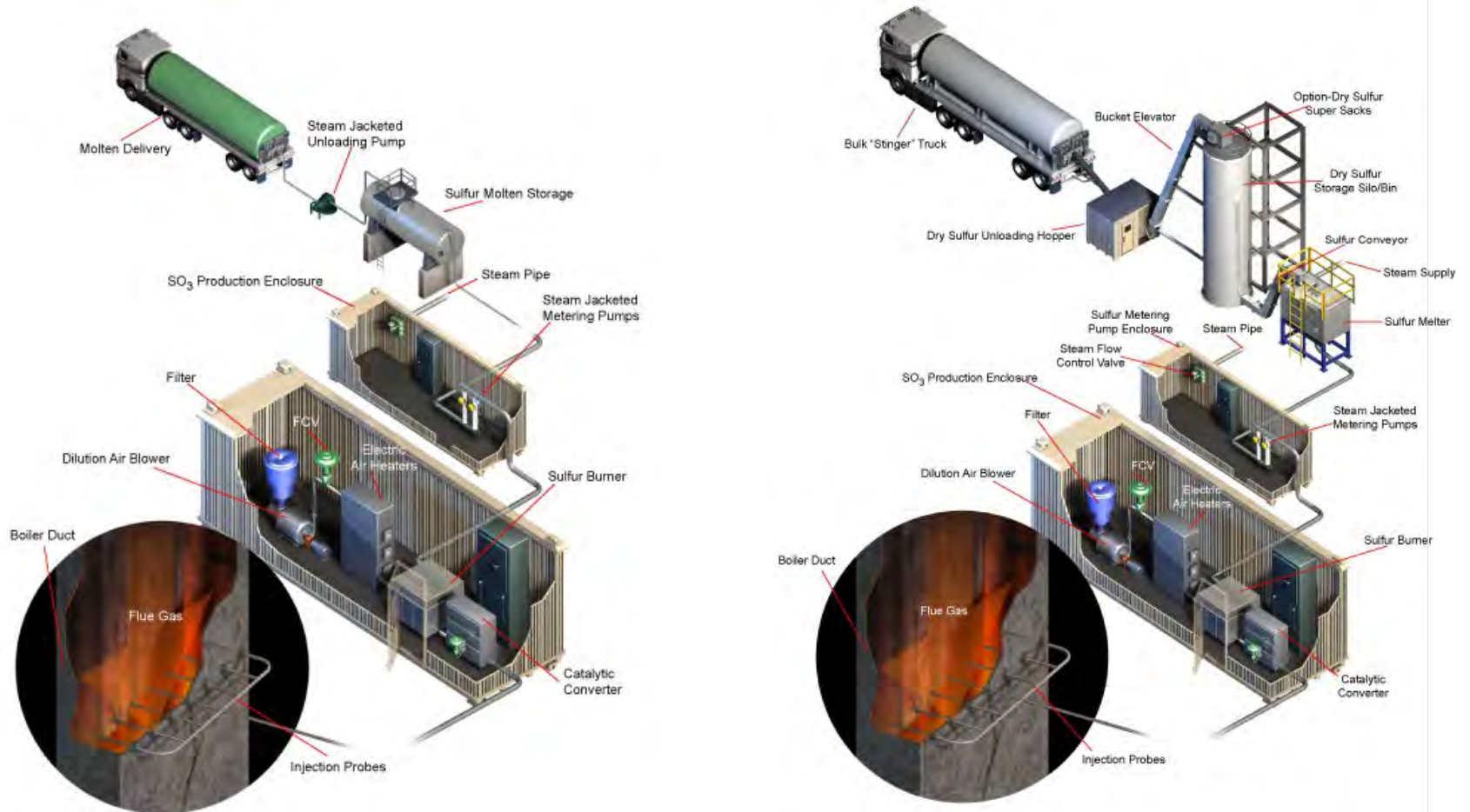


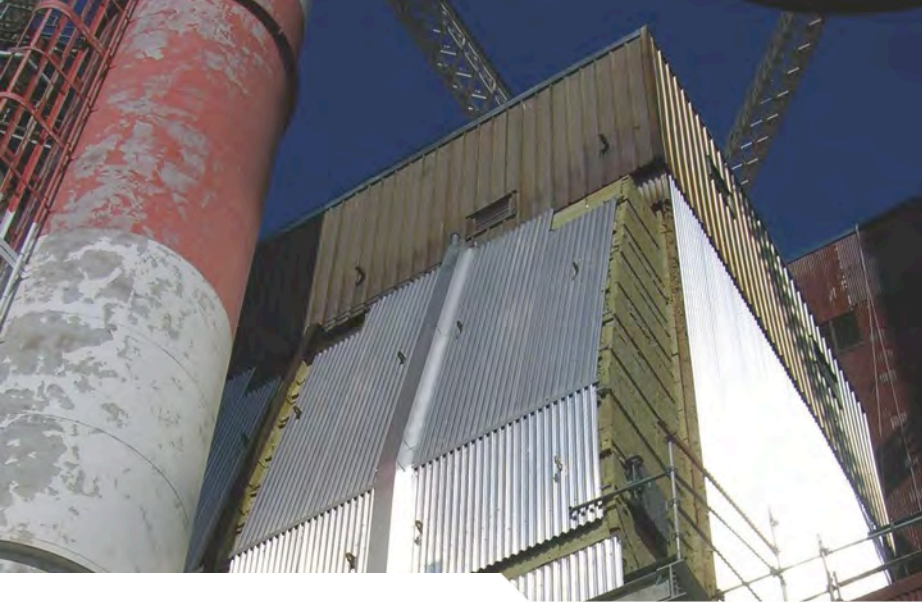
# ***SO<sub>3</sub> FLUE GAS CONDITIONING***

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- **In general, SO<sub>3</sub> is formed by a catalytic conversion of gaseous sulfur dioxide (SO<sub>2</sub>).**
- **The SO<sub>2</sub> usually comes from an "external" source (feedstock) by either evaporating liquid sulfur dioxide or by burning molten or solid sulfur.**

# SO<sub>3</sub> FLUE GAS CONDITIONING





# *Indigenous Flue Gas Conditioning (iCON™) Concept & Operation*

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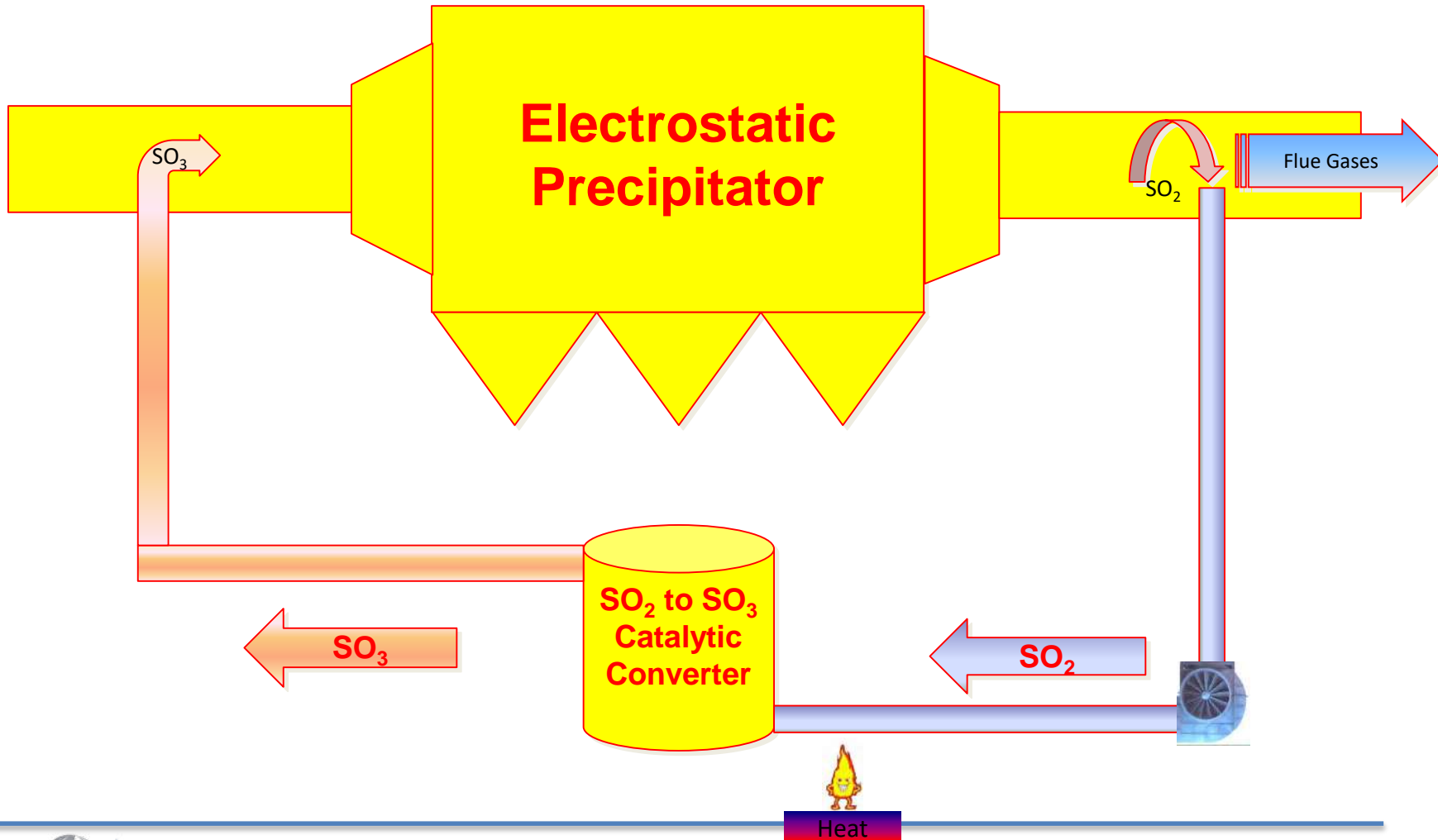


# FROM TODAY TO TOMORROW...

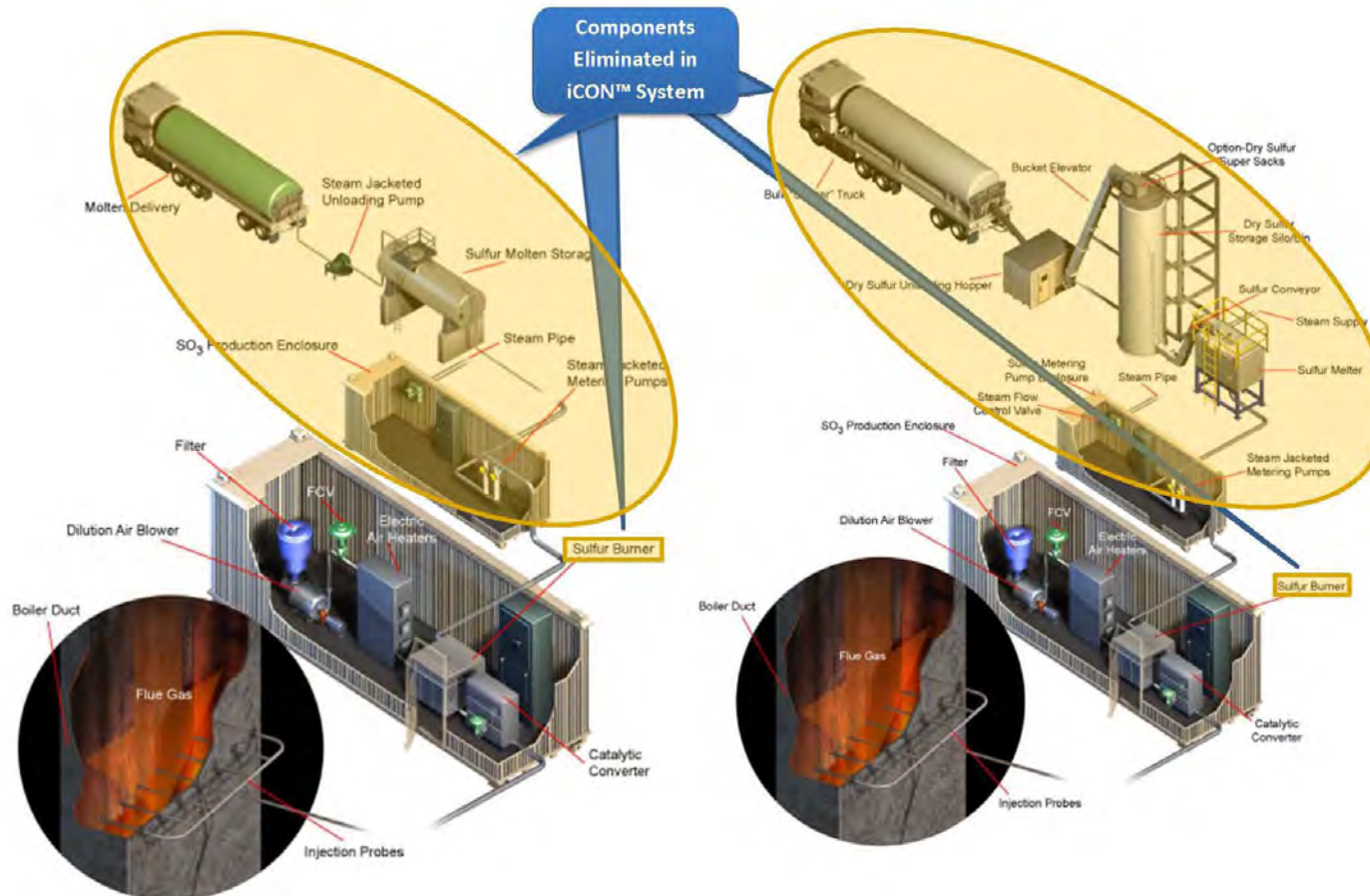
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- **Conventional flue gas conditioning systems have two major drawbacks:**
  - they require an external continuous supply of a feedstock and
  - in the process of operation these systems slightly increase SO<sub>2</sub> emissions
- **Another approach to create SO<sub>3</sub> is to utilize a "native" SO<sub>2</sub> formed during combustion of sulfur contained in fossil fuels as a feedstock for a subsequent conversion to SO<sub>3</sub>**

## INDIGENOUS FLUE GAS CONDITIONING



# INDIGENOUS FLUE GAS CONDITIONING



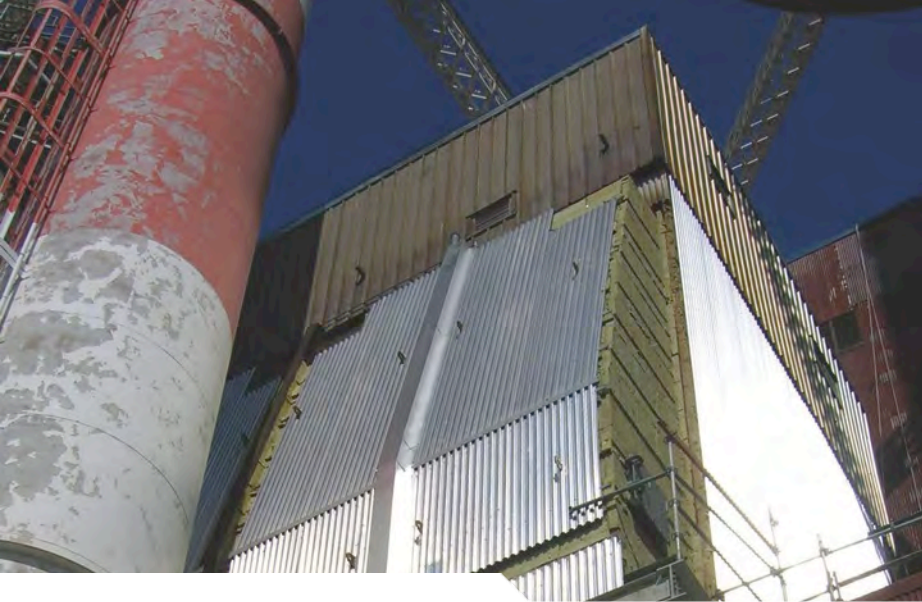
Conventional FGC with Molten Sulfur Feedstock

Conventional FGC with Dry Pelletized Sulfur Feedstock

## **INDIGENOUS FLUE GAS CONDITIONING**

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- There is **NO NEED FOR AN “EXTERNAL” FEEDSTOCK** (dry/pelletized or molten sulfur, SO<sub>2</sub>, H<sub>2</sub>SO<sub>4</sub>, etc.)
- **VERY LOW COST** of operation and maintenance
- **iCON™** is offering virtually **INSTANTANEOUS ON-DEMAND AVAILABILITY**



# *Ammonia Flue Gas Conditioning*

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# AMMONIA FLUE GAS CONDITIONING

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- First reports of the *intermittently* successful use of ammonia as a conditioning agent were reported in Australia by Watson and Blecher in 1966.
- The results of their study showed effectiveness of using the ammonia as a conditioning agent.
- There, the SO<sub>3</sub> flue gas conditioning was proven to be ineffective due to the highly acidic ash (pH of 3.5-4)

# AMMONIA FLUE GAS CONDITIONING

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- **Fundamental explanations of the effects of ammonia conditioning have assumed that the chemical compounds formed are:**
  - **ammonium bisulfate  $\text{NH}_4\text{HSO}_4$  or,**
  - **if the stoichiometric ratio is appropriate, the normal sulfate  $(\text{NH}_4)_2\text{SO}_4$**

# AMMONIA FLUE GAS CONDITIONING

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- The chemical reactions postulated by Rendle and Wildson suggested that ammonia will react with any sulfur trioxide and moisture present to produce ammonium bisulfate
  - $NH_3(gas) + SO_3(gas) + H_2O(gas) \rightarrow NH_4HSO_4(semi-liquid)$
- In the presence of excess ammonia this reaction will slowly continue to produce ammonium sulfate
  - $NH_3(gas) + NH_4 + HSO_4(liquid) \leftrightarrow (NH_4)_2SO_4(solid)$

# AMMONIA FLUE GAS CONDITIONING

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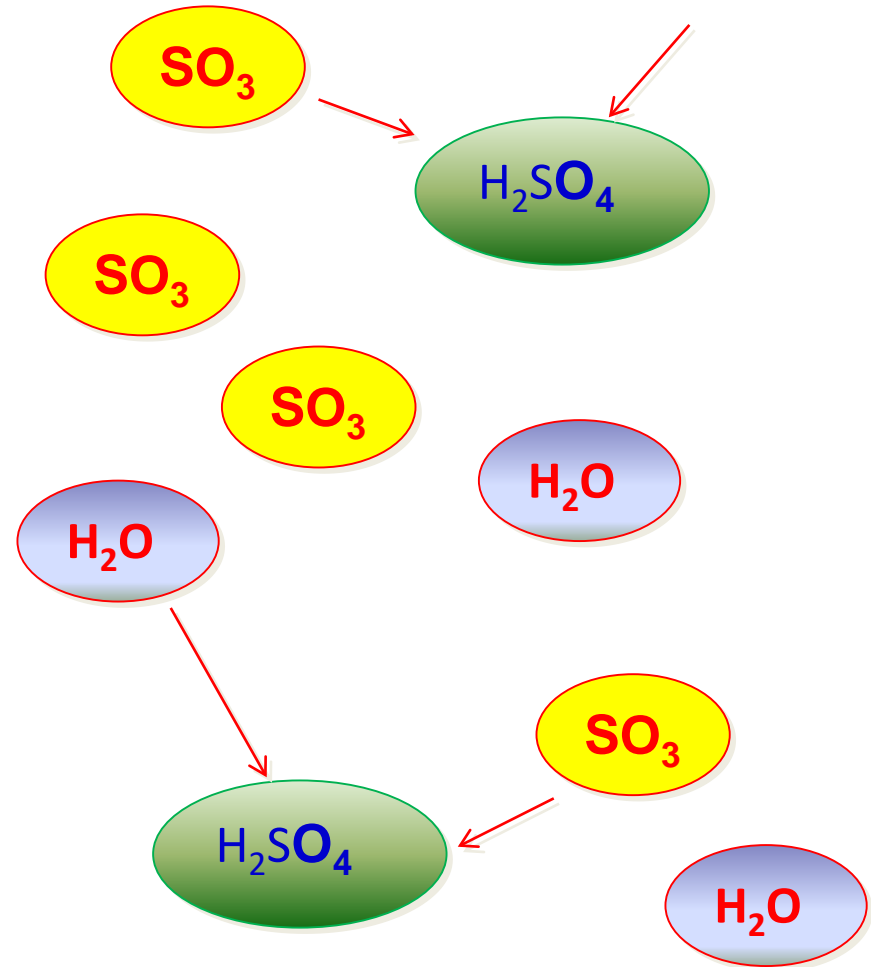
- **Melting point of ammonium bisulfate ( $NH_4HSO_4$ ) is 146.9°C (297°F)**
- **Therefore, lacking excess ammonia or as cooling occurs the liquid ammonium bisulfate will freeze at temperatures below 147°C (297°F) into a sticky solid**
- **It is this adherent nature of the resultant that is thought to play a major role in the precipitator performance improvement**

# AMMONIA FLUE GAS CONDITIONING

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- In fact, ammonia works as a scavenger, hunting down each free molecule of the  $\text{SO}_3$  producing several ammonium salts

# AMMONIA FLUE GAS CONDITIONING



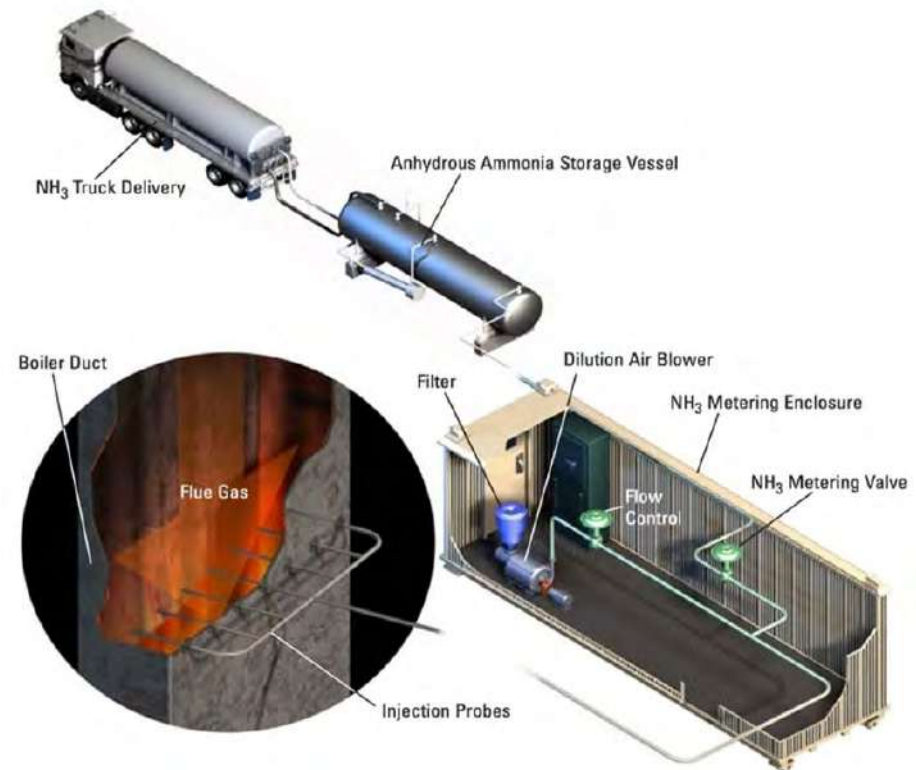
# AMMONIA FLUE GAS CONDITIONING

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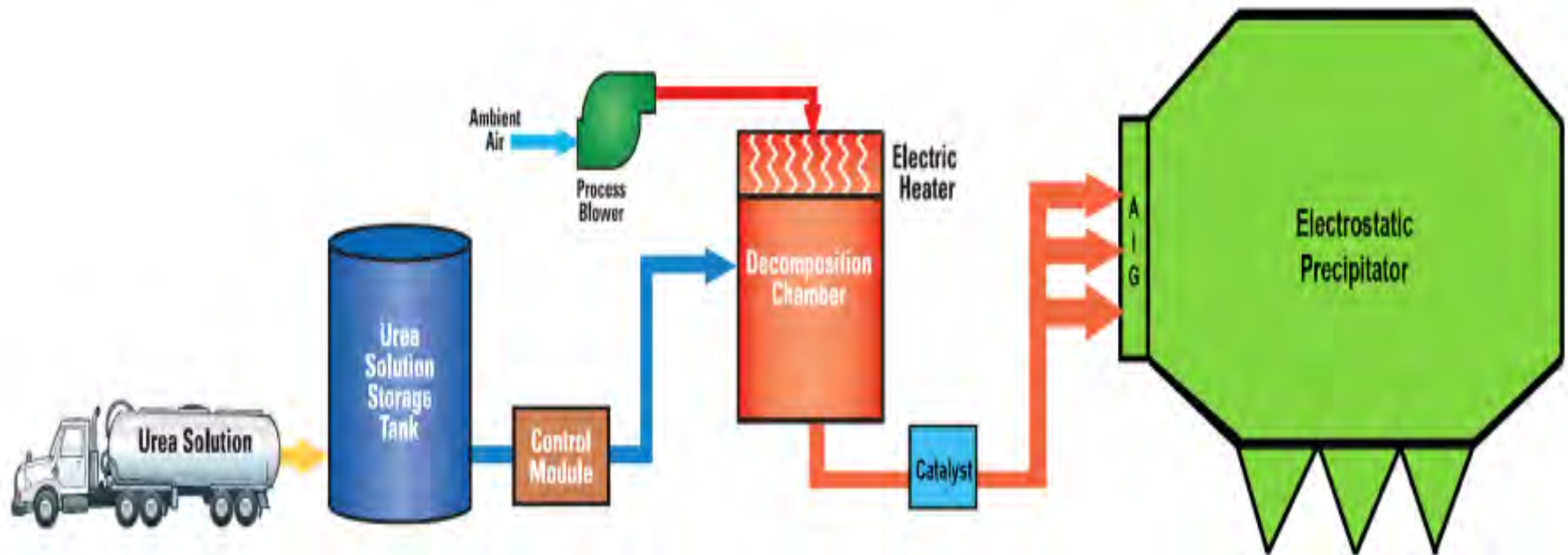
- Because the presence of  $H_2SO_4$  reduces the amount of  $SO_3$  available in the flue gas to react with  $NH_3$ , formation of the sulfuric acid
  - $SO_3 + H_2O \leftrightarrow H_2SO_4$
- Was noted as, perhaps, the most important principle chemical reaction for the formation of ammonium bisulfate, since it tends to reduce the ammonium bisulfate formation temperature

# AMMONIA FLUE GAS CONDITIONING

- Anhydrous  $\text{NH}_3$  feedstock requires least energy input
- Anhydrous system utilizes uninsulated carbon steel piping for transport to the injection probes for lowest cost installation
- 2,000 gallon tank is under the threshold for Risk Management Plans and intensive safety requirements



# ULTRA™ UREA TO AMMONIA PROCESS

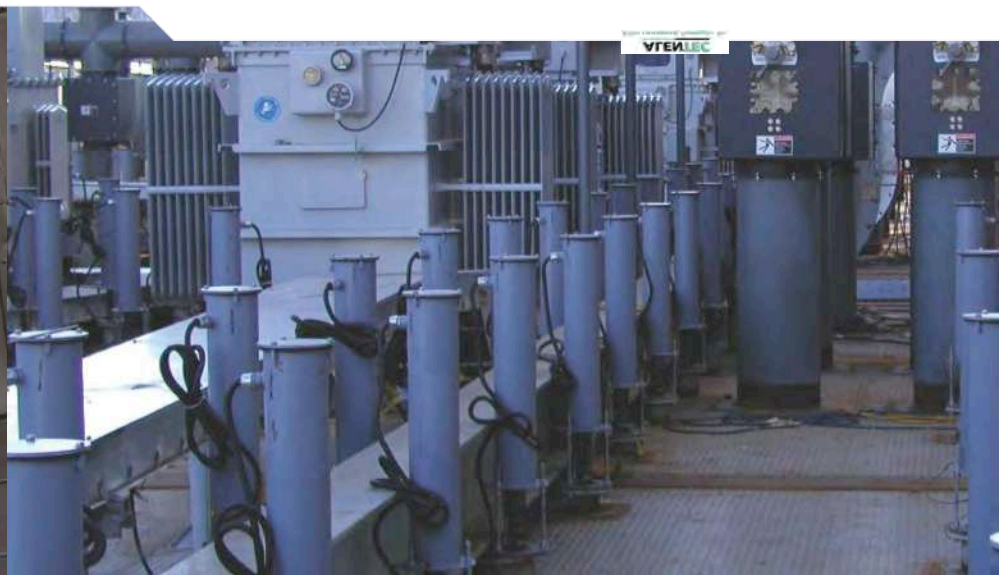




# *Ammonia FGC & Fly Ash Resistivity*

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# AMMONIA FGC & FLY ASH RESISTIVITY

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- **The reaction of ammonia with sulfur trioxide to produce ammonium sulfate or ammonium bisulfate appears to have been a key event in the occurrence of either type of conditioning process**
- **Dr. Dismukes and his team investigated concentrations of ammonia, sulfur oxides, and water vapor found at the inlets ESP fields**
- **In each instance, the injection of ammonia lowered the concentration of sulfur trioxide**

# AMMONIA FGC & FLY ASH RESISTIVITY

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- Subsequently, direct measurements of resistivity were made with a point-to-plane probe in situ as described by Dr. White
- Comparative values of the data obtained with ammonia injected at concentrations of 7 to 20 ppm by volume show no significant change in resistivity due to ammonia conditioning

# AMMONIA FGC & FLY ASH RESISTIVITY

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- Thus, it had been demonstrated that fly ash shows no significant change in resistivity as a result of ammonia conditioning
- However, ammonia does improve the efficiency of fly ash precipitation through two mechanisms:
  - the first: consisting of a space-charge effect, and
  - the second: involving an increase in the cohesiveness of fly ash.



# *Dual Flue Gas Conditioning (DFGC)*

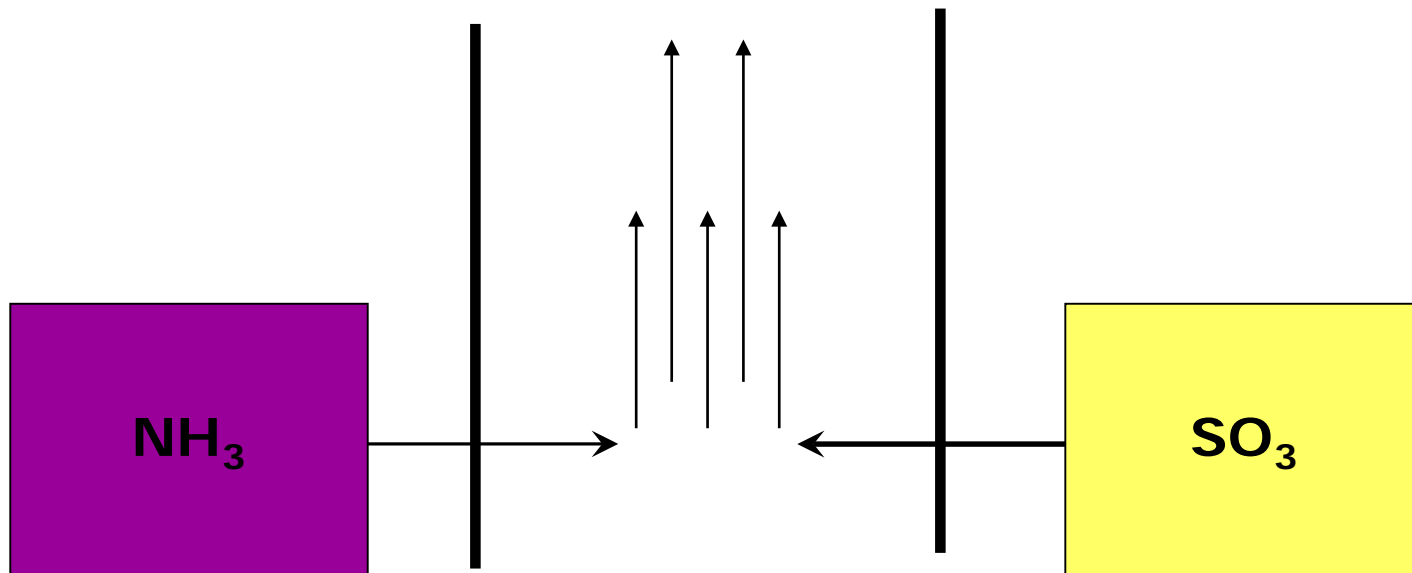
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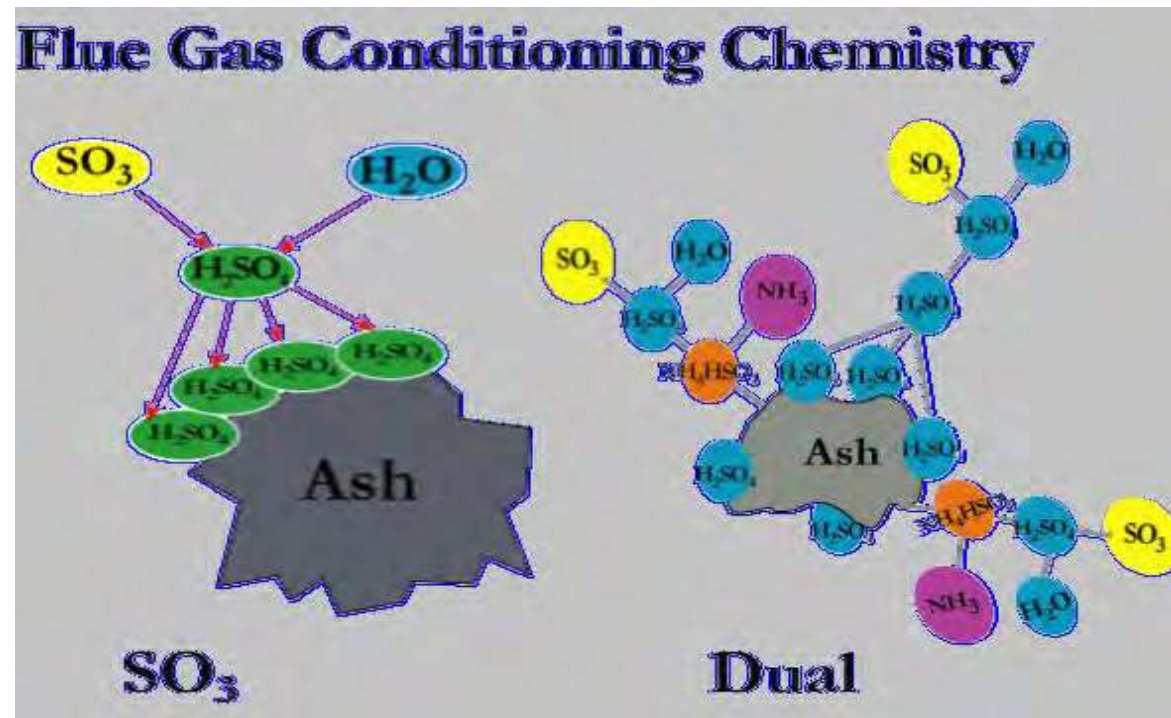
# DUAL FLUE GAS CONDITIONING

A DFGC system, by providing the independent and simultaneous injection of  $\text{SO}_3$  and  $\text{NH}_3$  in strictly controlled stoichiometric ratios, allows for a further collection efficiency improvement when compared to  $\text{SO}_3$  injection on its own



# DUAL FLUE GAS CONDITIONING

The injection of ammonia promotes improved utilization (uptake) of the  $\text{SO}_3$ , forming ammonium bisulfate resulting in more effective resistivity control



# DUAL FLUE GAS CONDITIONING

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- Depending on the  $\text{NH}_3$  to  $\text{SO}_3$  stoichiometric rates, ammonia can produce low melting point substances
- DFGC by producing ammonium bisulfate increases the cohesiveness of fly ash particles and thus *reduces the reentrainment of ash deposited on the collection electrodes*
- Cohesion has a positive effect on the electrostatic precipitator efficiency by:
  - Increasing the average particle size (the larger particles are easier to collect in the electrostatic precipitator)
  - Reducing the re-release of particles on the plates.

# DUAL FLUE GAS CONDITIONING

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- In addition, injection of ammonia ( $\text{NH}_3$ ) into the flue gases in the presence of  $\text{SO}_3$  results in the formation of submicron particles of ammonium sulfates
- DFGC improves the ESP performance due to an additional space charge, which alters the electrical characteristics of the flue gas in a precipitator



# Case Studies

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# *Shenhua Zhungeer Power Station*

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# ***SHENHUA ZHUNGEER POWER STATION***

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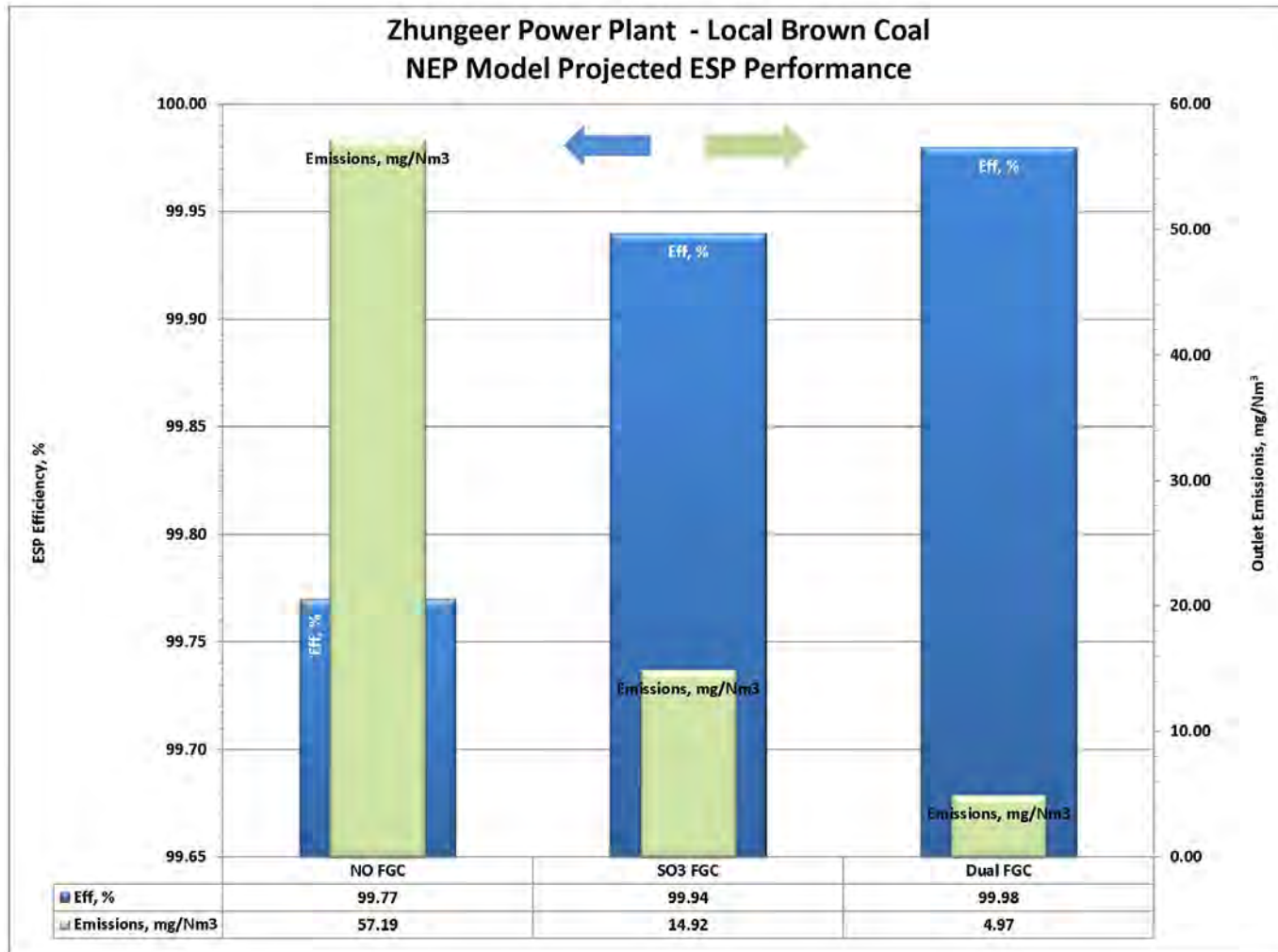
- **Zhungeer Power Station is a 1,570-megawatt (MW) coal-fired power plant located at the suburbs of Jungar, Ordos (E'erduosi) Prefecture, Inner Mongolia Autonomous Region**
- **The local coal is being delivered from the Zungeer mine**
- **It is thought that Zhungeer coal ash is one of the most difficult to collect in electrostatic precipitator**

# SHENHUA ZHUNGEER POWER STATION

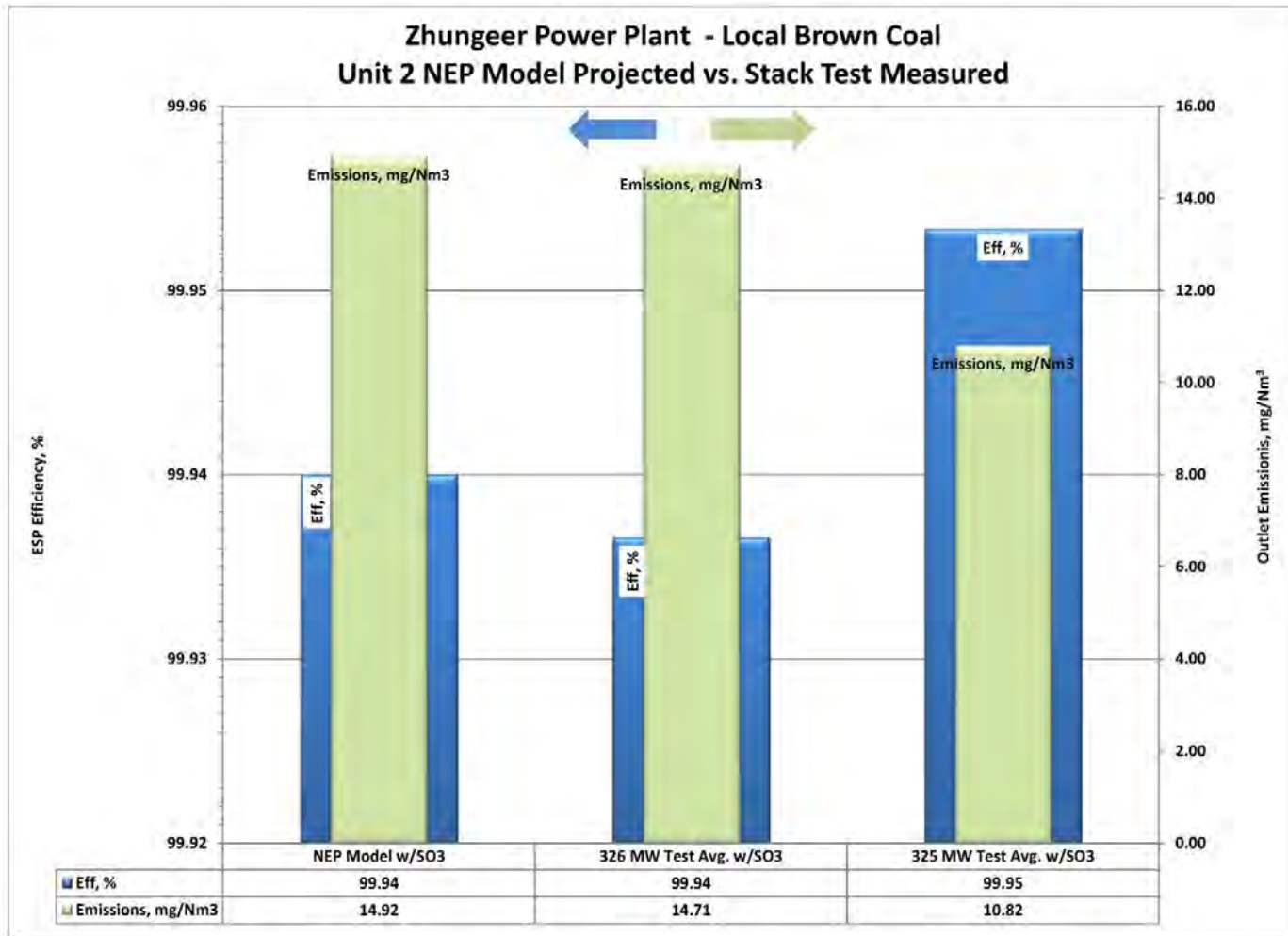
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- There is one (1) ESP with two (2) chambers, two (2) cells per each unit
- Each cell houses forty-seven (47) gas passages on 305 mm (12 inches nominal) centers
- Each ESP has five (5) mechanical fields in the direction of the gas flow:
  - first three fields are 3.00 m (9.85 ft.) in length, and
  - last two fields are 3.5 m (11.47 ft.) each
- Collecting plates are 15.24 m (50.00 ft.) tall
- The SCA is 151 m<sup>2</sup>/m<sup>3</sup>/s (767 ft<sup>2</sup>/kacfm)

# SHENHUA ZHUNGEER POWER STATION



# SHENHUA ZHUNGEER POWER STATION



# SHENHUA ZHUNGEER POWER STATION

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- **The final emissions were tested with SO<sub>3</sub> FGC only and the results were as follows:**
  - **Unit 1 achieved 18 mg/Nm<sup>3</sup> (0.00786 gr./dscf) at ESP outlet**
  - **Unit 2 achieved 17 mg/Nm<sup>3</sup> (0.00743 gr./dscf) at ESP outlet**



# ***NRG Energy – Morgantown Power Station***

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# **NRG ENERGY – MORGANTOWN POWER STATION**

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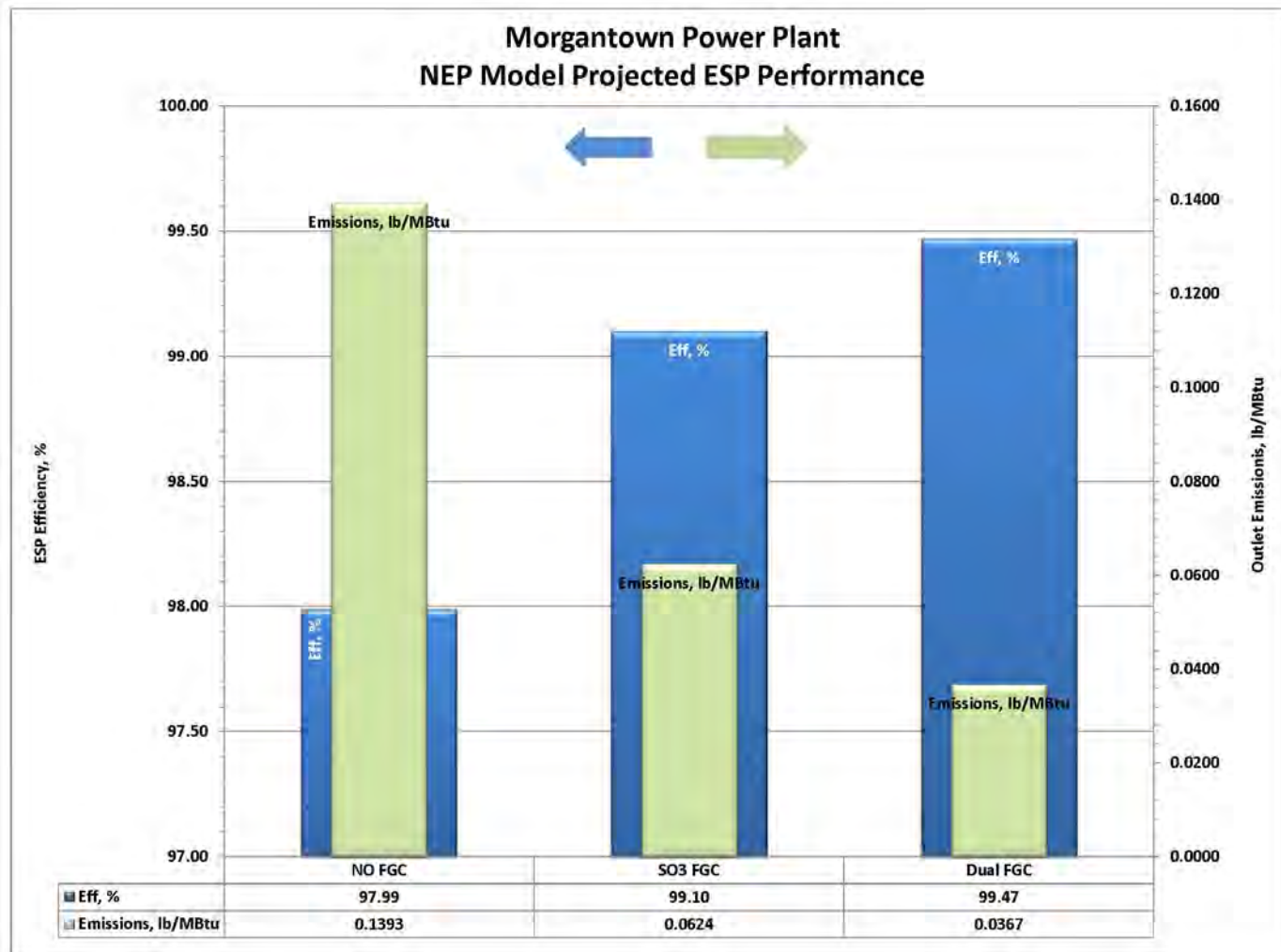
- **Morgantown Generating Plant is located in Newburg, Washington, D.C. area in Charles County, Maryland on the Potomac River**
- **The boilers, manufactured by Combustion Engineering (CE), are rated at 640 MW**
- **Each boiler is a tangentially coal fired supercritical unit with a superheater, single reheat and economizer**
- **Its capacity is 1,492 megawatts at base load**
- **Unit № 1 was placed in service in 1970, and Unit № 2 following in 1971**

# **NRG ENERGY – MORGANTOWN POWER STATION**

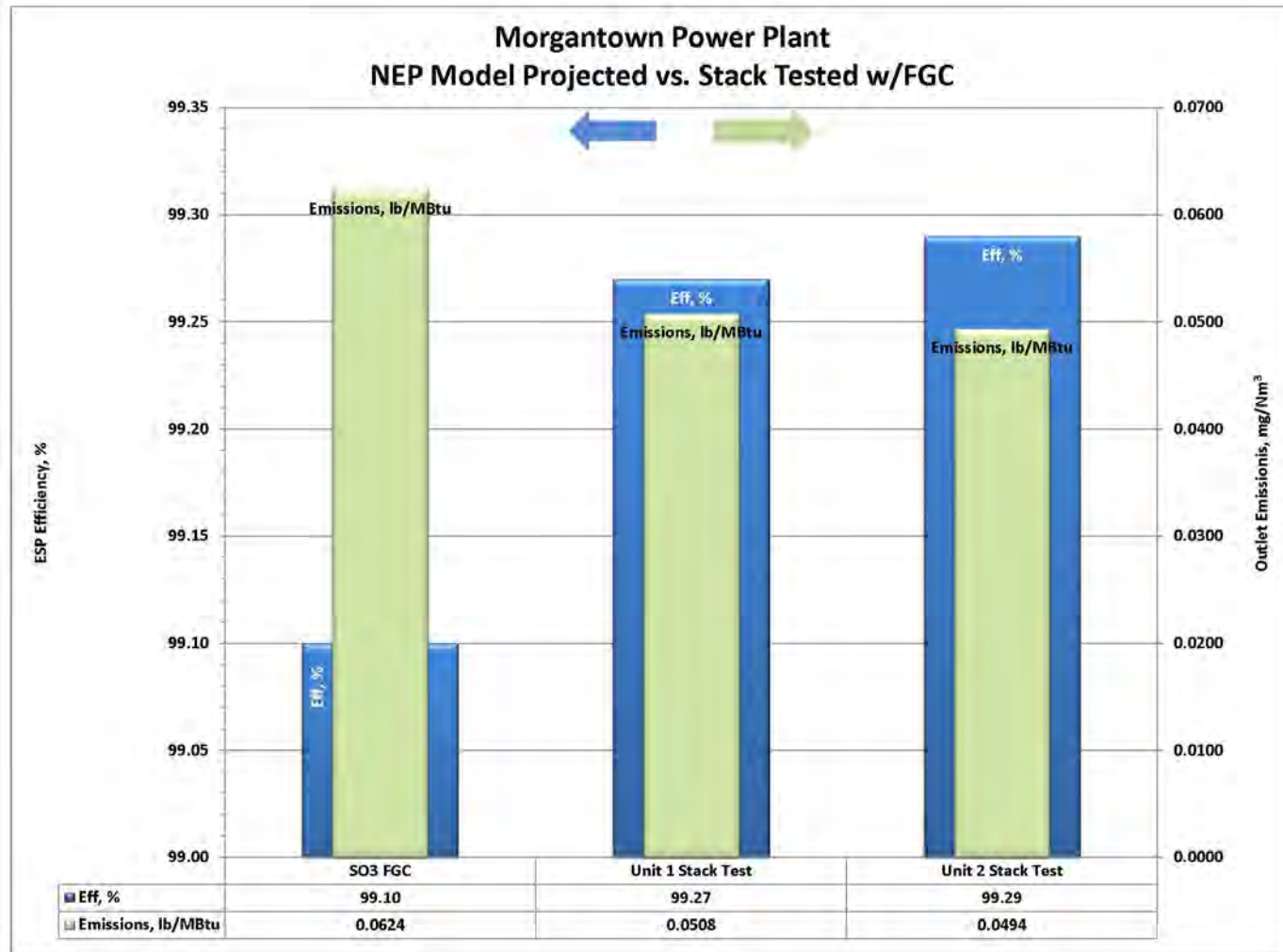
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- **The project team identified a comprehensive two-phase approach to reduce the stack opacity:**
  - **(a) Phase I included the Numerical Electrostatic Precipitator (NEP) model, and**
  - **(b) Phase II consisted of ESP upgrade (split 1<sup>st</sup> fld.) and DFGC.**
- **The latter resulted in a significant recovery of the power generation:**
  - **Unit 1 recovered 25 MW**
  - **Unit 2 recovered 45 MW**

# NRG ENERGY – MORGANTOWN POWER STATION



# NRG ENERGY – MORGANTOWN POWER STATION





# *Minnesota Power - Taconite Harbor Energy Center*

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## TACONITE HARBOR ENERGY CENTER

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- Taconite Harbor Energy Center is a coal-fired power station near Schroeder, Minnesota
- The facility is a coal-fired steam electric utility generating plant located on the north shore of Lake Superior
- The plant burns western bituminous and sub-bituminous coal, which is received by boat and stored in an outdoor storage pile

## TACONITE HARBOR ENERGY CENTER

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- Due to the installation of a Lime Based Sorbent and other agents used to lower SO<sub>x</sub> and NO<sub>x</sub> emissions (Mobotec Process), particulate load had increased
- The exiting hot-side ESP was not able to handle the speed of gas flow to effectively collect the excess and highly resistive fly ash
- Government regulations required the facility to reduce opacity

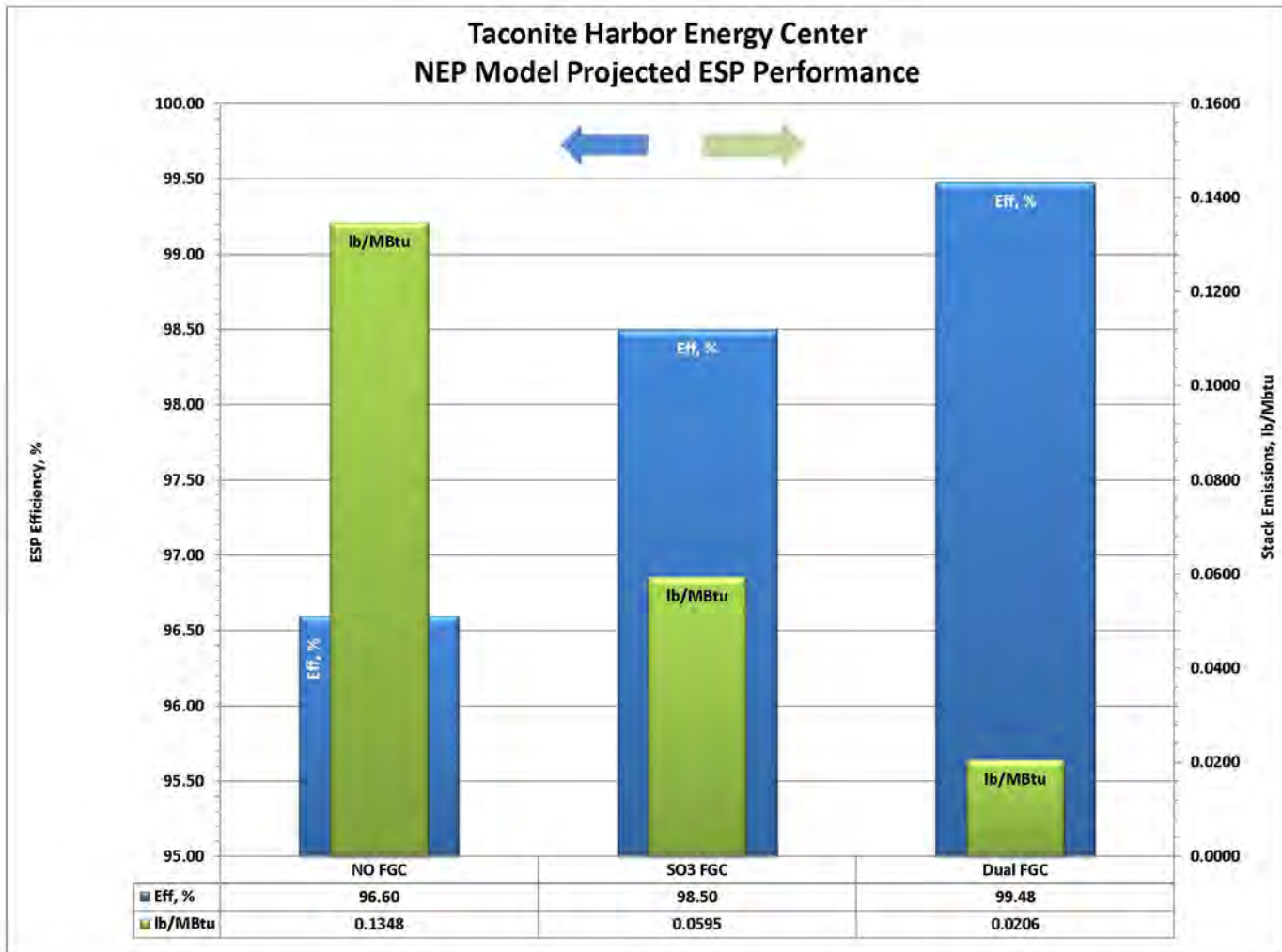
## TACONITE HARBOR ENERGY CENTER

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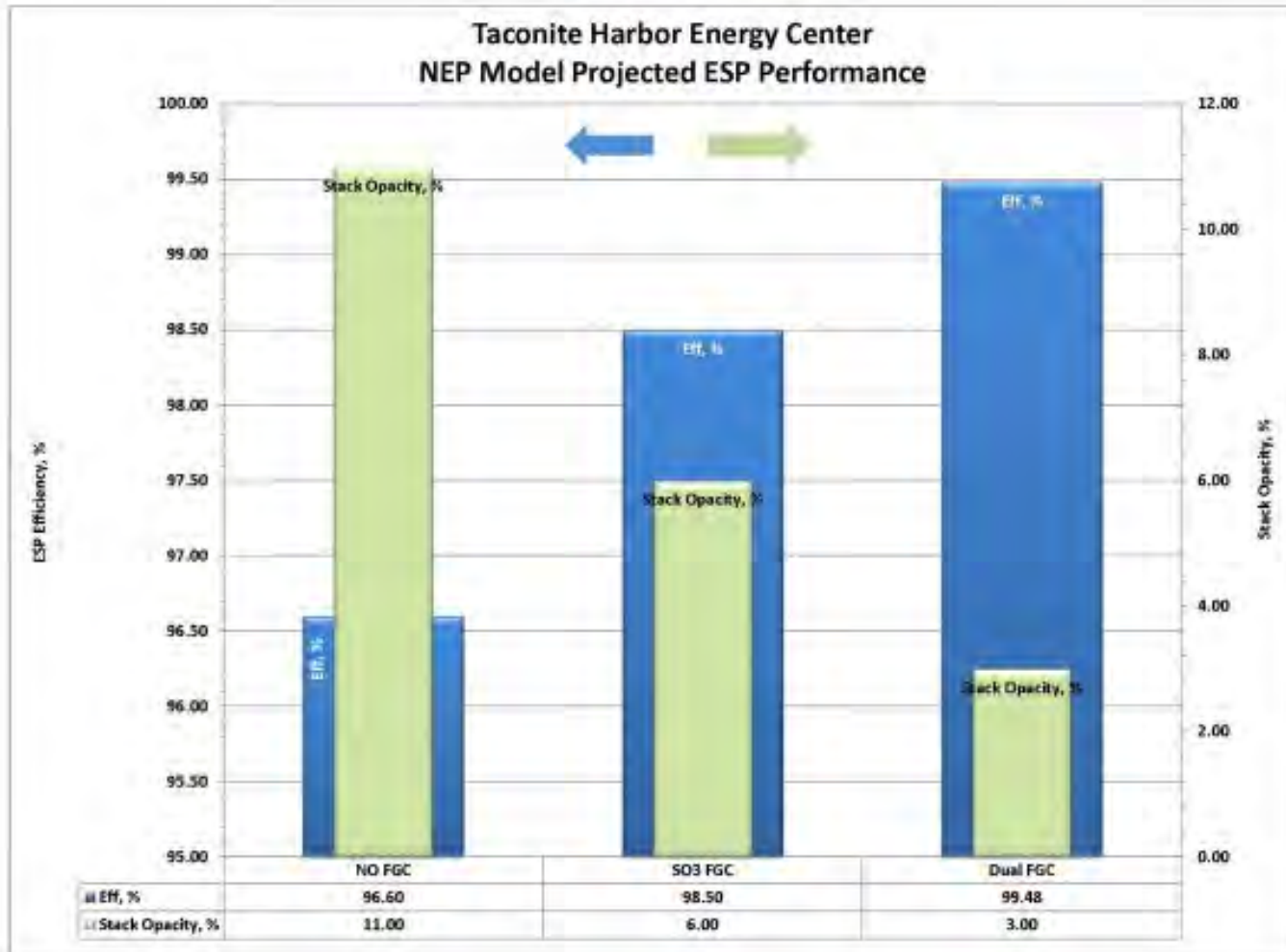
- **The chosen cold-side ESP design had:**
  - **one (1) ESP with two (2) chambers, single cell per each unit**
  - **each cell houses eighteen (18) gas passages on 305 mm (12 inches nominal) centers**
  - **ESP has six (6) electrical and three (3) mechanical fields in the direction of the gas flow:**
    - **electrical fields are 1.37 m (4.5 ft.) in length and**
    - **mechanical fields are 2.7 m (9.0 ft.) each.**
  - **Collecting plates are 9.14 m (30.00 ft.) tall.**
  - **The SCA is 32.8 m<sup>2</sup>/m<sup>3</sup>/s (167 ft<sup>2</sup>/kacfm).**

- The successfully performed hot-to-cold retrofit augmented by the use of DFGC, enabled the plant to outperform the 0.03 lbs./MBtu (22.61 mg/Nm<sup>3</sup>, wet) outlet emissions
- The equipment upgrade also resulted in an improved reliability and performance

# TACONITE HARBOR ENERGY CENTER



# MINNESOTA POWER TACONITE HARBOR ENERGY CENTER





# ***Current & FUTURE DFGC APPLICATIONS***

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# ***CURRENT & FUTURE DFGC APPLICATIONS***

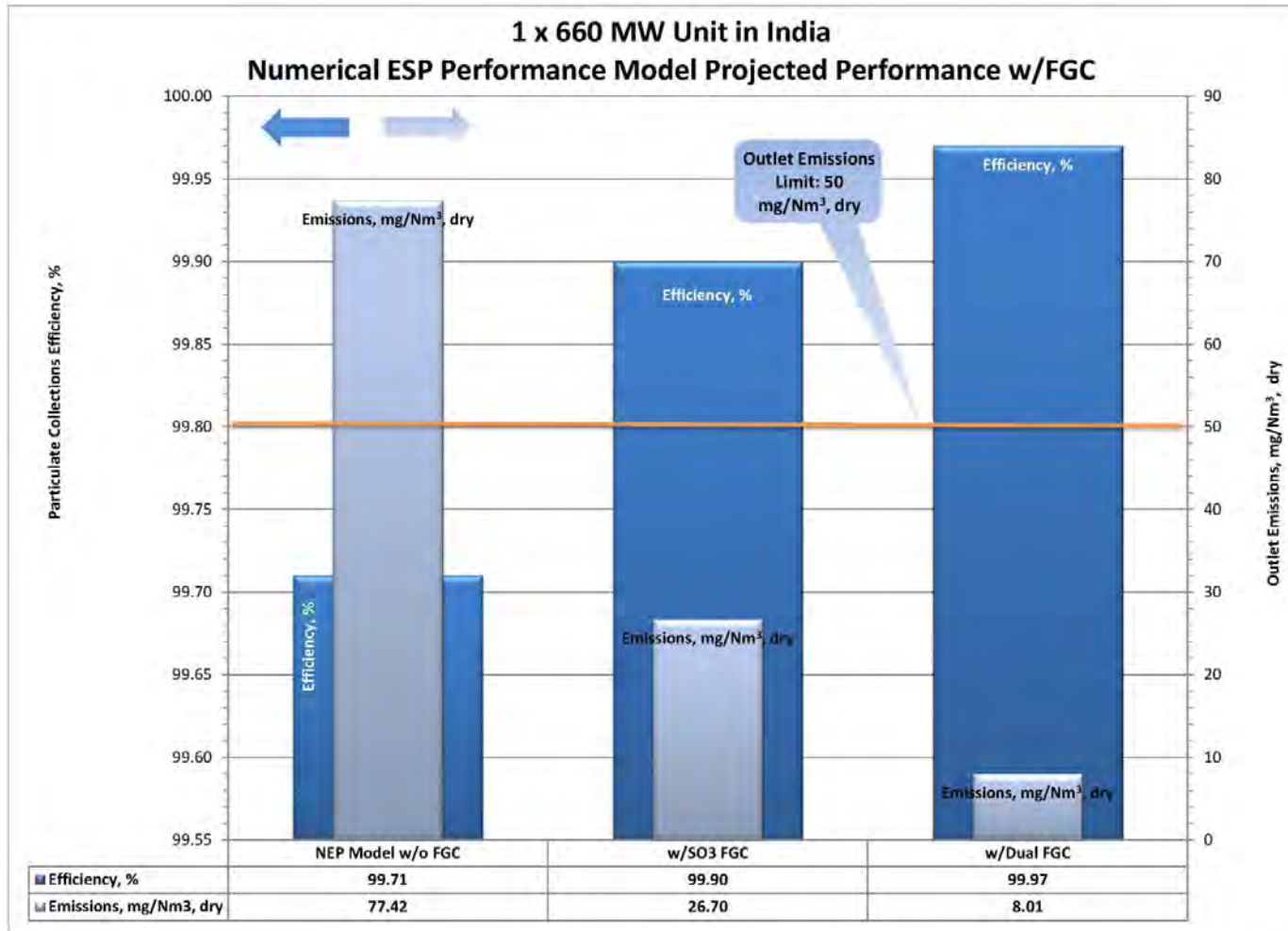
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- **Indian power plant**
- **Super critical 660MW unit**
- **Eight (8) fields ESP**
- **Moderate SCA of 91.23 m<sup>2</sup>/m<sup>3</sup>/s**

# CURRENT & FUTURE DFGC APPLICATIONS

FGC Option === >			w/o SO <sub>3</sub>		w/SO <sub>3</sub>		w/Dual FGC	
ITEM			English	Metric	English	Metric	English	Metric
Inlet Conditions	Temperature	Deg. F - Deg. C	285	140.7	285	140.7	285	140.7
	Flue Gas Flow, actual	acfm - Am <sup>3</sup> /s	2,048,294	966.79	2,048,294	966.79	2,048,294	966.79
	Fly Ash Concentration	gr./scf - g/Nm <sup>3</sup> , dry	11.66	26.70	11.66	26.70	11.66	26.70
ESP Design Param.	ESP/Blr	No.	2	2	2	2	2	2
	Chambers/ESP	No.	2	2	2	2	2	2
	Cells/CH	No.	2	2	2	2	2	2
	Gas Passages/Cell	No.	21	21	21	21	21	21
Collecting El.	Spacing (Plate-to-Plate)	in - mm	15.75	400	15.75	400	15.75	400
	Fields 1-5	ft. - m	11.48	3.50	11.48	3.50	11.48	3.50
	Height	ft. - m	49.21	15.00	49.21	15.00	49.21	15.00
Details	Total Collecting Area	sq. ft. - m <sup>2</sup>	949,377	88,200	949,377	88,200	949,377	88,200
Values Efficiency	SCA	sq. ft./k acfm - m <sup>2</sup> /m <sup>3</sup> /s	463.50	91.23	463.50	91.23	463.50	91.23
	Estimated Eff.	%	99.71	99.71	99.90	99.90	99.97	99.97
Emissions	Fly Ash Concentration	gr./scf - mg/Nm <sup>3</sup> , dry	0.0338	77.42	0.0117	26.70	0.0035	8.01

# CURRENT & FUTURE DFGC APPLICATIONS





# Summary

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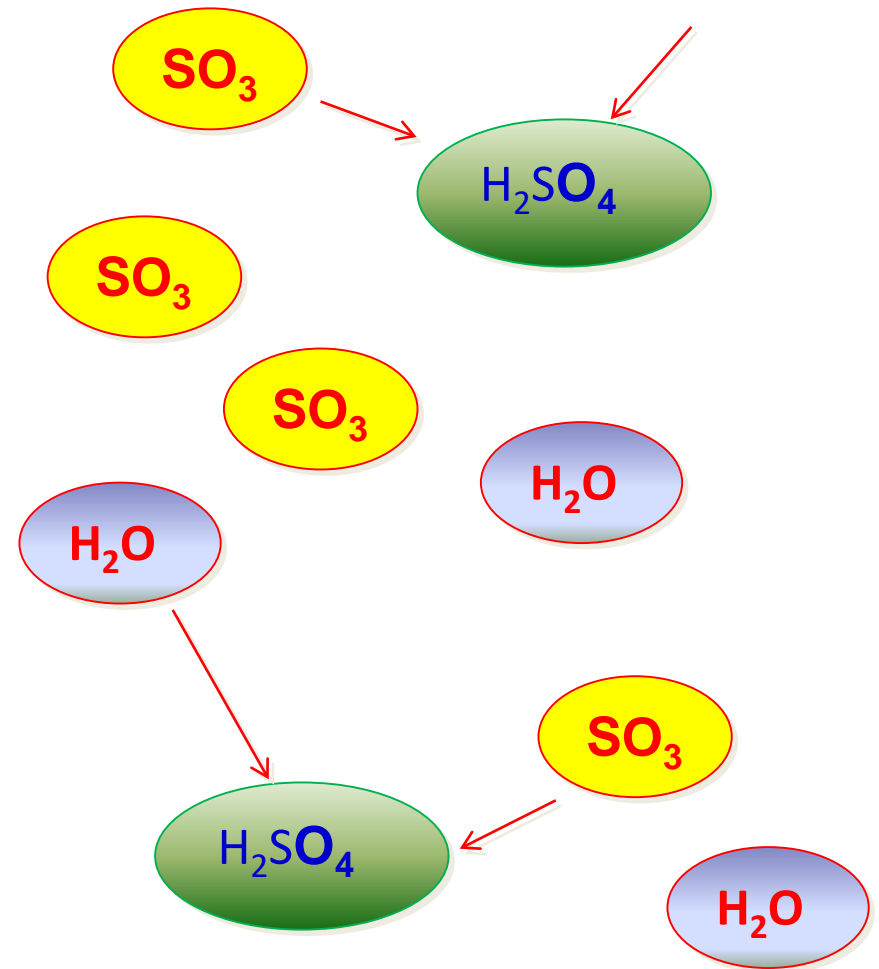
  
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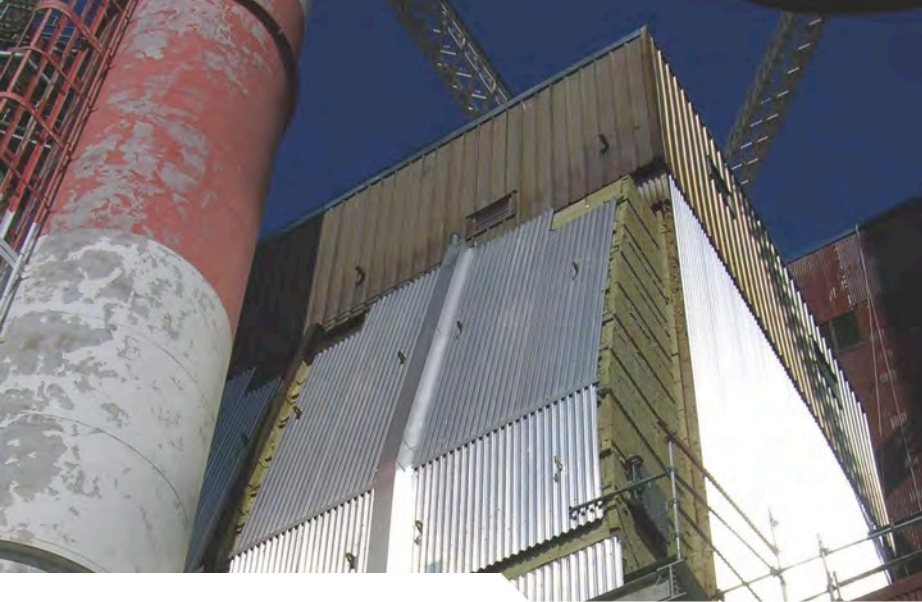
# SUMMARY

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- In conclusion, in properly designed and implemented DFGC system (at appropriate stoichiometric ratio), ammonia will, in effect, scavenge  $\text{SO}_3$  thus creating various ammonia salts
- While  $\text{SO}_3$  will be working on improving the fly ash resistivity, the ammonia salts will be working on improving particles agglomeration and cohesivity, eliminating rapping losses, and the enhancing the electric field to further improve the particle migration velocity

# FLUE GAS CONDITIONING: SUMMARY





# *Questions & Answers*

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