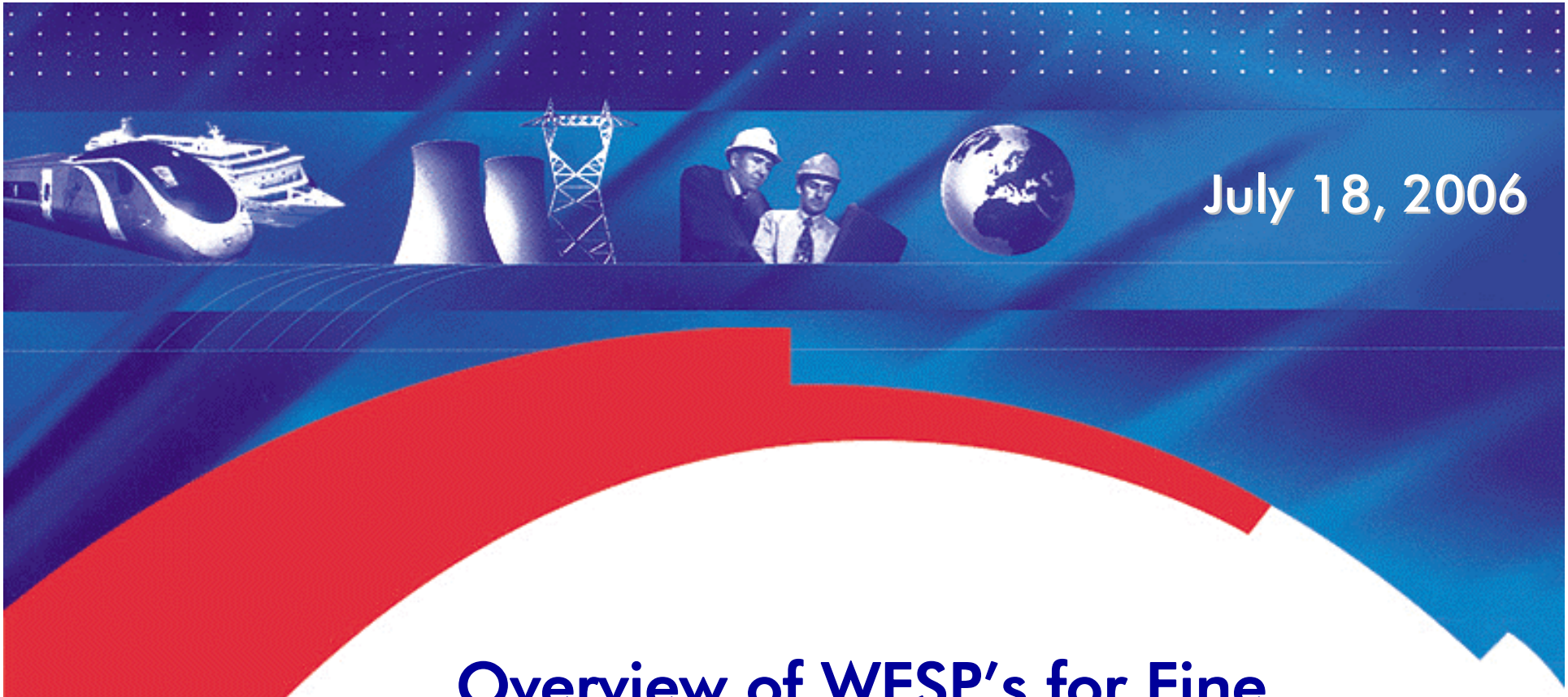
Reinhold Environmental Ltd.

2006 APC Round Table & Expo Presentation

July 16-18, 2006, Columbus, OH



July 18, 2006

Overview of WESP's for Fine Particulate and H_2SO_4 Collection

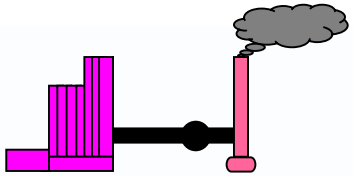
Steve Francis

ALSTOM

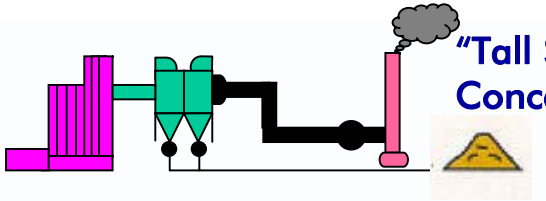
Agenda

- Emissions Limitations
- SO_3 (H_2SO_4) Formation
- Reduction of SO_3 (H_2SO_4)
- WESP Designs
- WESP Arrangements
- WESP Wash Water Systems
- WESP Installation Details
- Summary & Conclusions

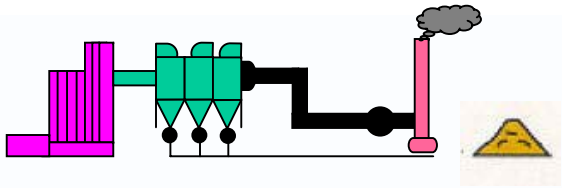
AIR POLLUTION CONTROL EVOLUTION



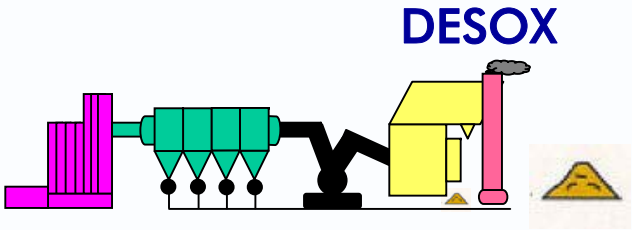
1950s



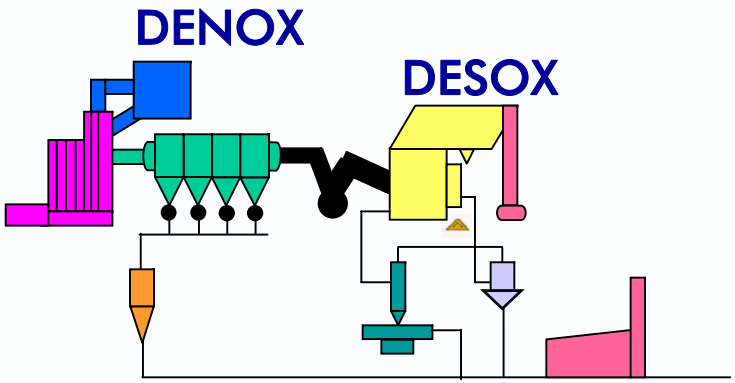
1960s



1970s



1980s



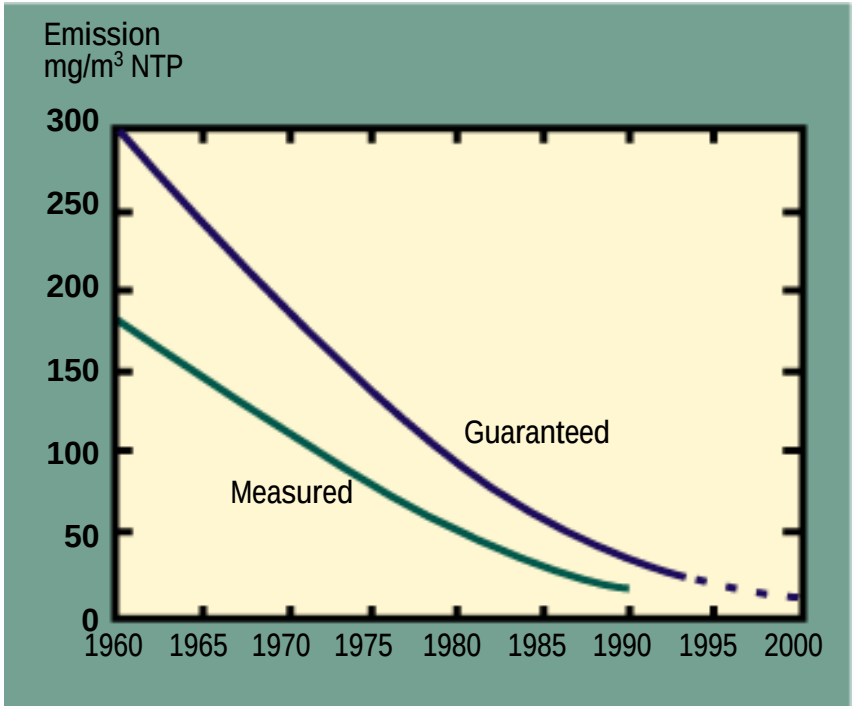
1990-Today End Product Recovery and Utilization

MASS & VISIBLE EMISSION LIMITS ARE BEING REDUCED

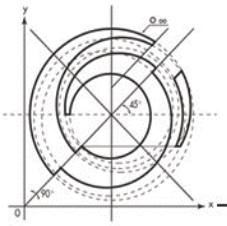
EMISSIONS REQUIREMENTS

Trends:

- Guarantees Are Now As Low As 10 mg/Nm³ (0.005 gr/SCF)
- Trend Toward 5 mg/Nm³ (0.0025 gr/SCF)
- Increased Emphasis on Removal of Fine Particles (PM 2.5)
- Particulate Emissions Including Condensibles
- More and More Emphasis on Removal of Mercury and HAP's



TREND TOWARDS LOWER EMISSIONS



EMISSIONS REQUIREMENTS

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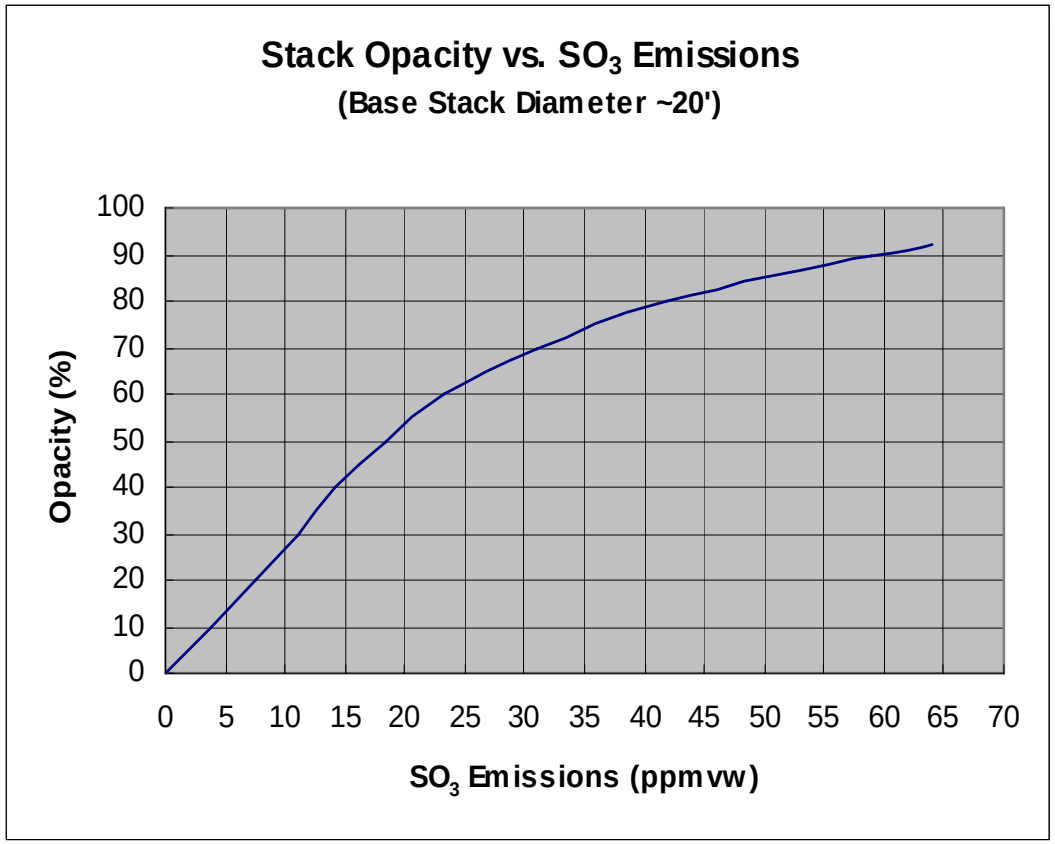
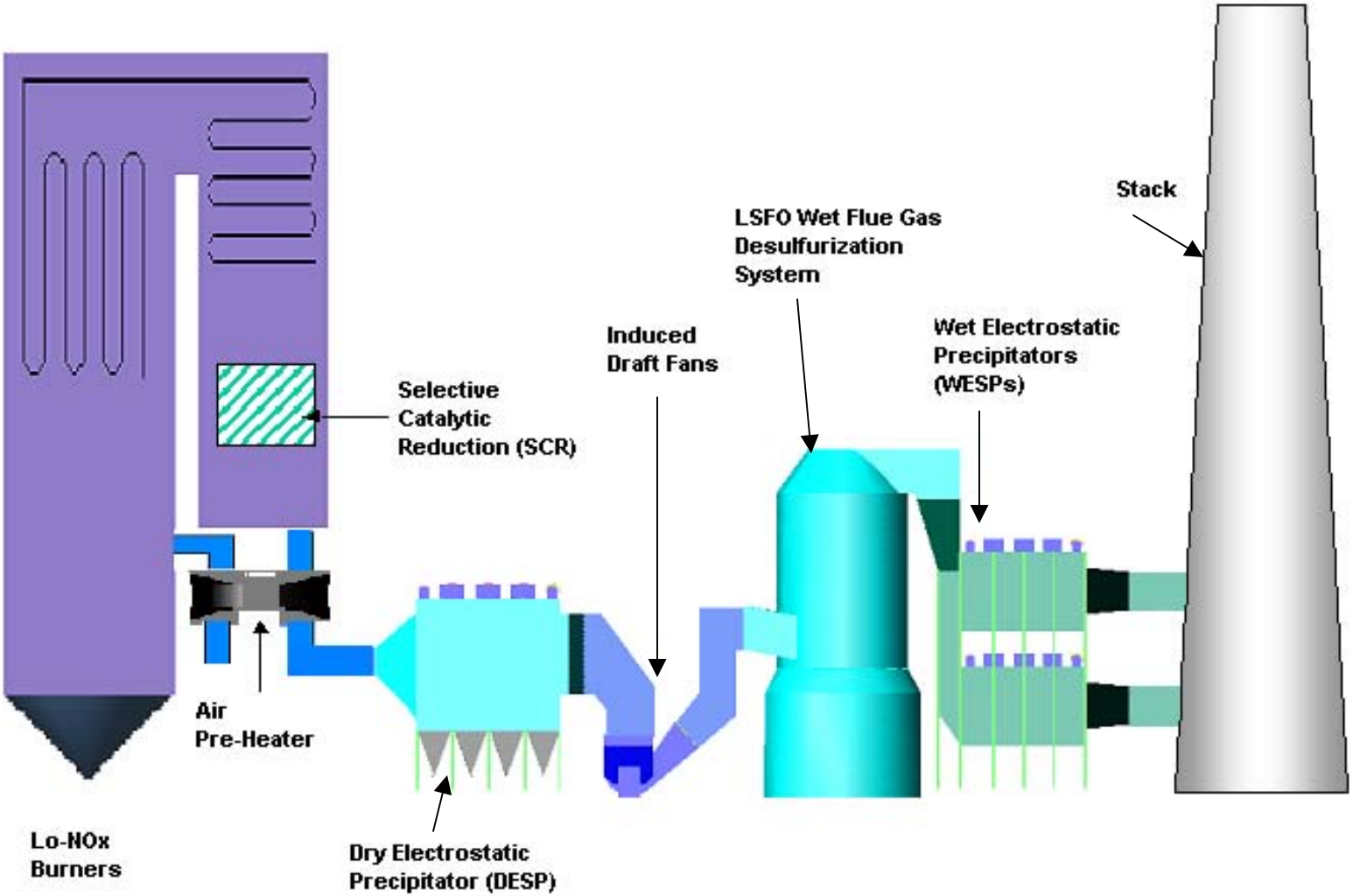
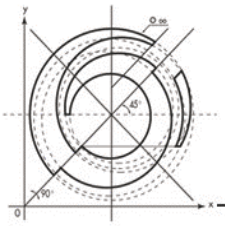
Trends:

- Visible plume from stacks becoming an increasing concern
- Sub-micron particulate and SO_3 emissions are very visible
- Even with very low particulate emissions there may still be a plume associated with as little as 5 ppm of SO_3



Current Back-End APC Design





SO_3 Formation

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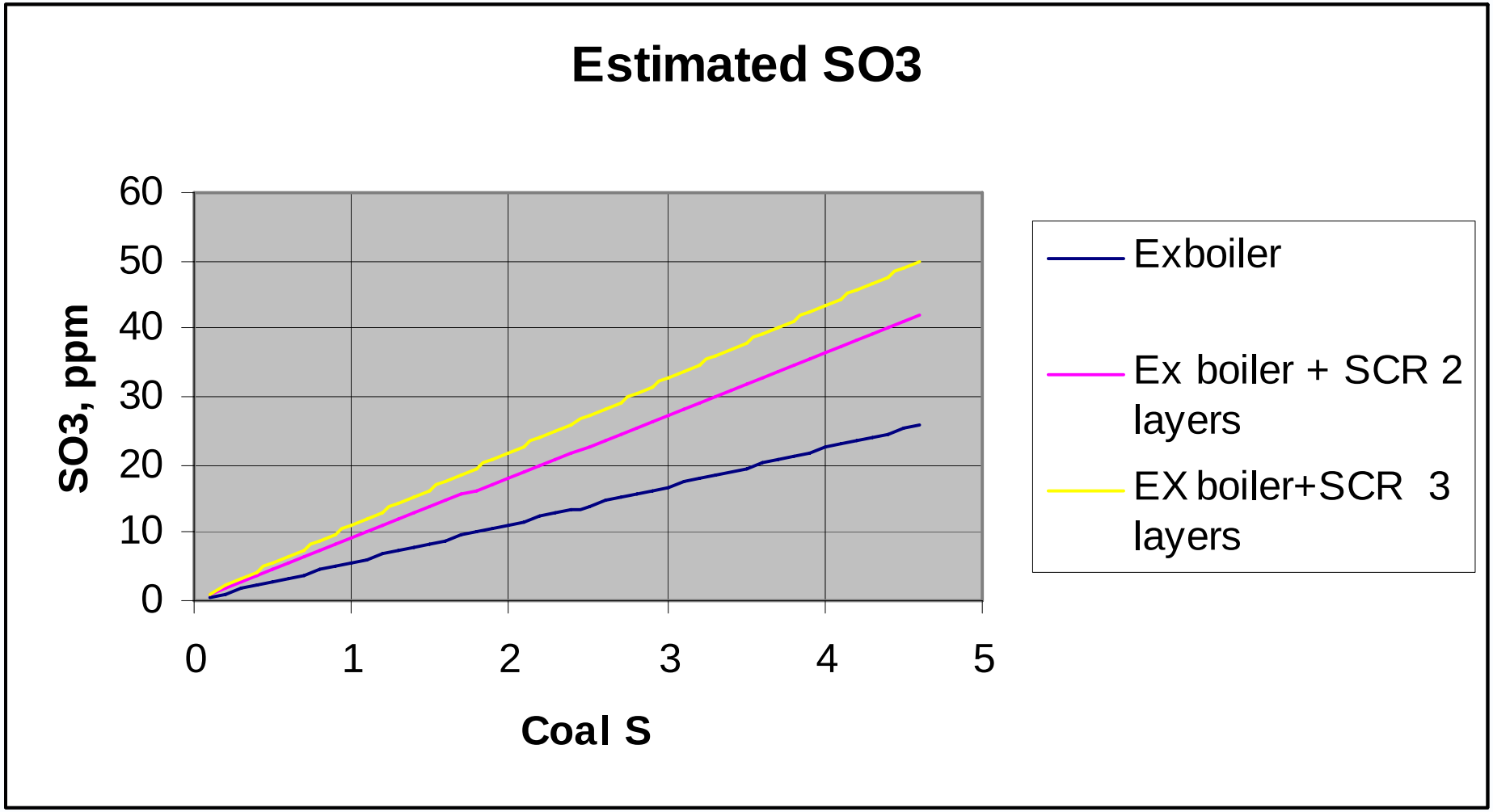
- Amount of oxidation in the boiler depends primarily on the coal composition and the excess air in firing
- Result is that SO_3/SO_2= 0.5%/0.7% at 10/30% excess air
- In practical engineering boiler engineers frequently use 1% flat figure, which most often probably is an overestimate
- A portion of the SO_3 is absorbed in the ash and in the APH
- SCR Catalyst manufacturer balances activity to get efficient NOx reduction and limited SO_3 formation
- Typical SCR SO_3 formation is ~0.25 % oxidation per layer

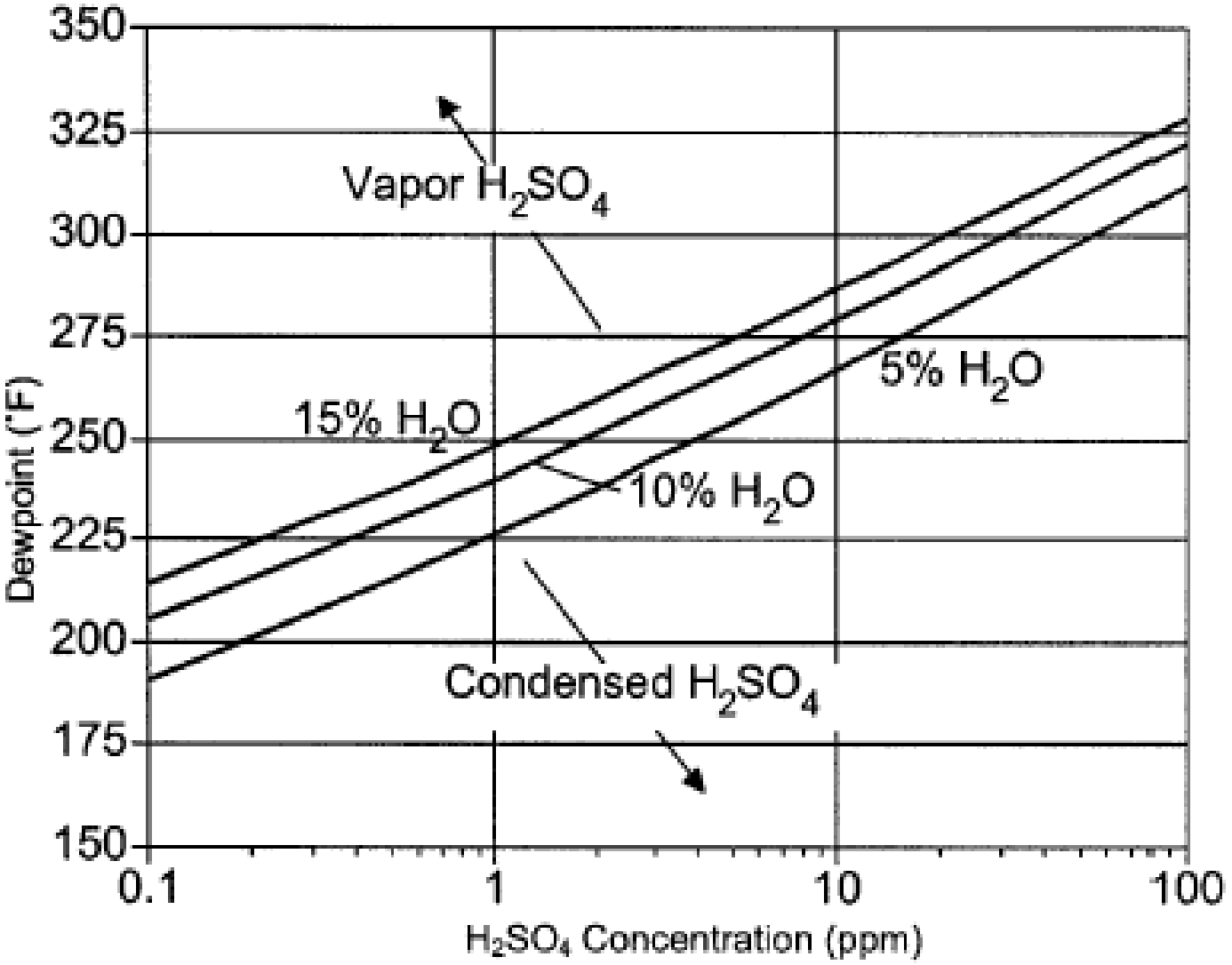
Coal S %	1	3
SO_2, ppm	600	1800
SO3 inlet SCR ppm	5	15
SO3 after 1st layer, ppm	6.5	19
SO3 after 2nd layer, ppm	8	24
SO3 after 3rd layer , ppm	10	30

- Low opacity requires <2-3 ppm SO_3 (drops) in the stack!

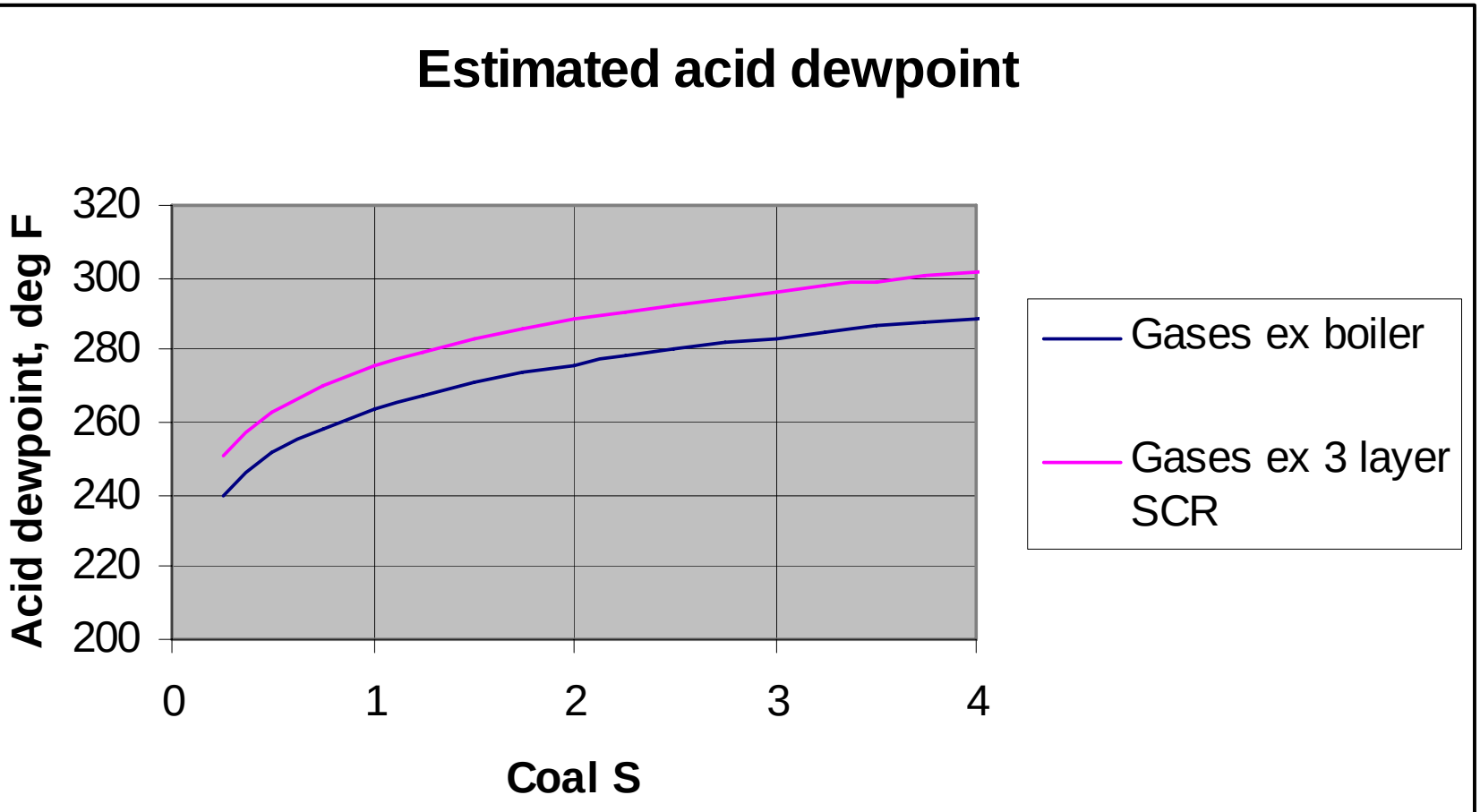
Estimated SO_3 for Different Coals



Acid Dewpoint

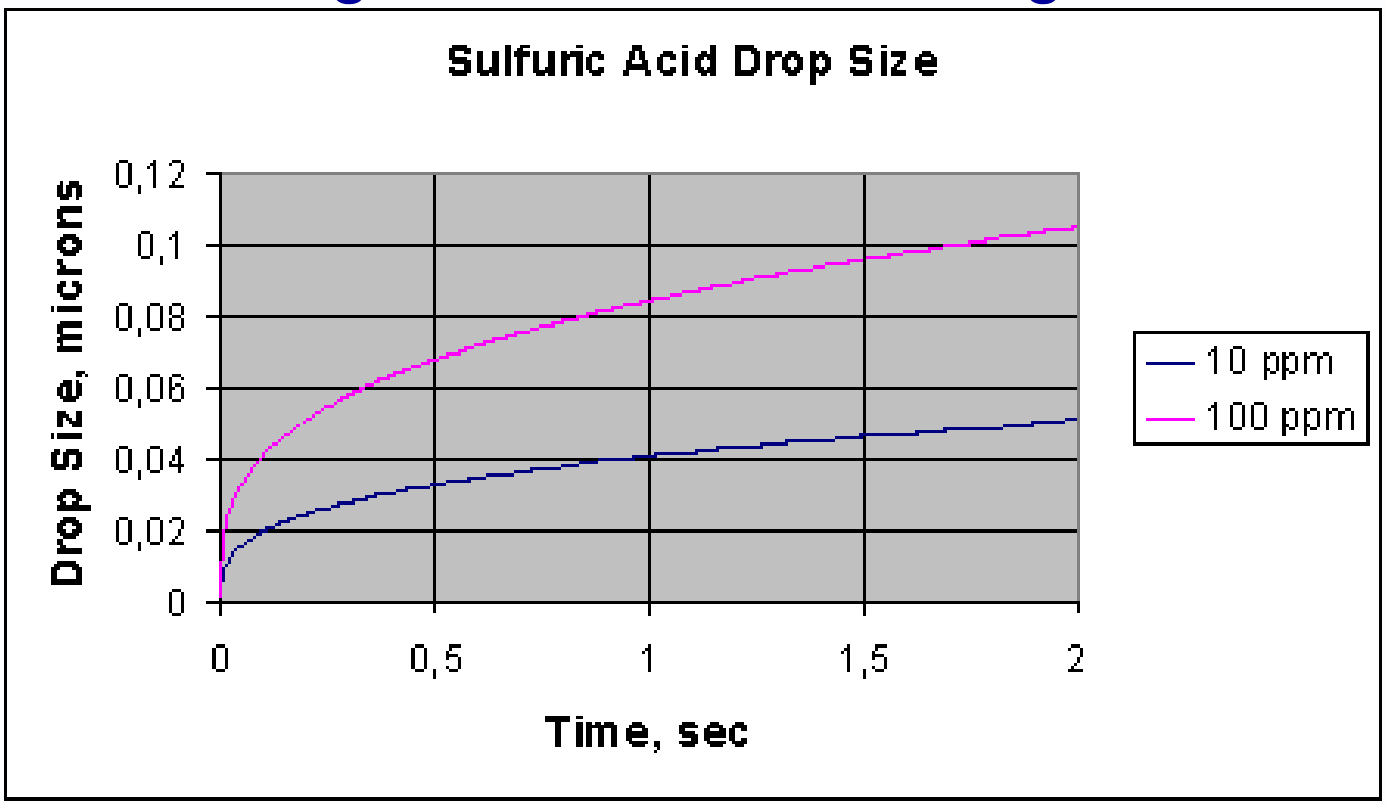


Estimated Dewpoint for Diffrent Coals



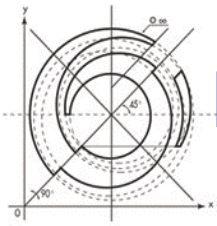
SO_3 (Actually it is H_2SO_4)

- Cooling below acid dewpoint creates high supersaturation and creation of extremely fine H_2SO_4 mist, 0.05 μm size
- This fine mists grows as a result of coagulation:



H_2SO_4 emitted from Open Spray Tower FGD

- Picture is from Cumberland, TN: 1300 MW SCR, ESP, WFGD, 3% S coal
- SO_2 efficiency=95% SO_3 efficiency=18%
- SO_3 emission of 15 ppm gives persistant plume after OST scrubber



Non-WESP Methods for SO_3 Control

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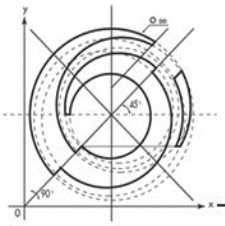
1. Boiler injection : low utilization due to bad distribution & competition with SO_2. Impacts slagging & fouling in the boiler.
2. Ammonia injection downstream ESP. Works fine, low cost, but system produces stinking ash. Not an option for most systems due volume of ash problem.
3. Sorbent injection downstream of the economizer. Several chemical systems possible.
4. GGH together WFGD. Little experience (no high S in DE & JP where GGH's are used for other reasons).

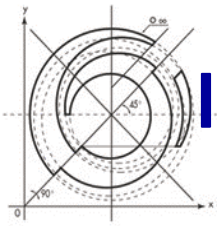


Sorbent Injection Performance

Consider SCR case , 3% S with SO_3 amounts (ppm).

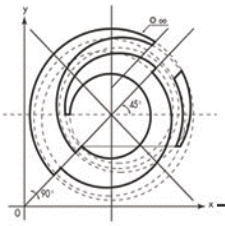
	Non-controlled	Controlled
After economizer	38	38
After ESP	33	4
After scrubber	16	2

Sorbent injection needs to achieve 90% efficiency to meet opacity goal!



Injection Methods for H_2SO_4 Control

- Low capital cost, corresponding tolerance for higher per lb operational cost
- The segment is 0.8% < S< 1.5% - WESP is selected for higher S
- Technical/ market candidate technologies:
  - SBS patent by URS, injection of liquid upstream APH
  - Trona injection – patent by AEP
  - APH cooling + $CaCO_3$
  - $Ca(OH)_2$ injection
  - MgO injection



Sorbent Injection: Issues/Concerns

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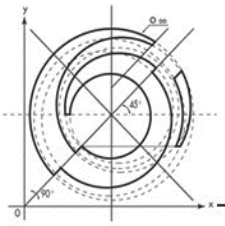
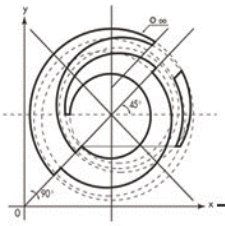
- Performance can be impacted by sorbent particle size and too short contact time
- Uniform injection of dry material in large ducts is a technical challenge
- Handling of some sorbent materials can be tricky
- Some sorbent materials can impact the nature of the ash such that ESP performance is reduced
- Some sorbent materials may impact the sale of the ash



GGH

ALSTOM

- GGH before/after scrubber reheats gas to 210 °F
- 1 ppm SO_3 (gas), 2 ppm SO_3 (drops) at stack
- 6 ppm upstream scrubber needed (scrubber efficiency 50%)
- GGH cooling side needs to reduce 80-85% from 33 ppm May be possible.
- ALSTOM's experience from Niles (only known GGH on high S coal) is that yes, acid is indeed collected
- Effect not quantified
- Benchmark cost $14/kW. Press drop 4" H_2O, capitalizes to about $0.4/kW/yr. Spares and soot-blowing add to operating cost.
- GGH's not a proven solution for SO_3 control for opacity reduction on high S coals



Cost Comparison

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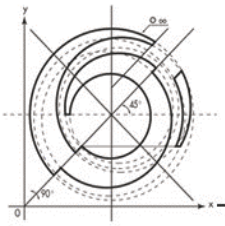
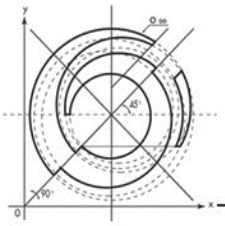
System	Capital $/kW	Operation $/kW/yr.	Notes
$Ca(OH)_2$	2	3	Impacts ash
MgO	3	1.2	Estimated
SBS	5	0.75	Demonstrated
GGH	14	0.5	Available??
WESP	10-15	0.3	MgO neutr.



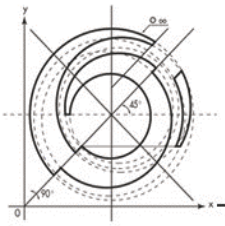
Why WESP?

- Highest capital cost solution
- Added power consumption
- May impact plant H_2O usage
- Consumes valuable plant area
- Requires maintenance
- May require acid neutralization system (i.e. additional consumables)
- Requires significant time to integrate into plant operations



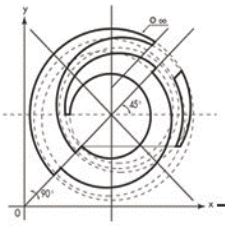
Why WESP?

- Many Installations in Japan
  - Nakoso Power Station
  - Himeji Power Station
  - Shin-Nagoya Power Station
- Existing units in NA with WESP's
  - AES – Deepwater
  - Xcel Energy – Sherco Station
  - Dakota Gasification
  - New Brunswick Power – Dalhousie
  - New Brunswick Power – Coleson Cove



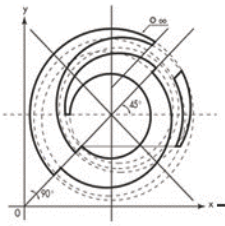
Why WESP?

- **Active projects in NA including WESP's**
  - WE Energies Elm Road
  - EKP Spurlock Unit 1
  - EKP Spurlock Unit 2
  - Trimble County Unit 2
  - Dallman Power Station Unit 4



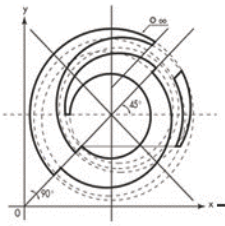
Why WESP?

- WESP's have been used for collection of H_2SO_4 Mist for nearly 100 years in industrial applications
- There is little doubt that they will effectively collect acid mist exhaust from coal fired boilers
- WESP's are excellent at collection of fine particulate
  - Increased input power
  - Virtually no re-entrainment
  - Minimal pressure drop
- The addition of a WESP does not create other problems in the APC system (such as impacting the ash properties)



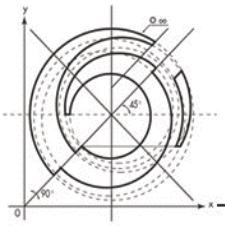
Addressing the Negatives

- **The high cost issues of WESP's are being addressed**
  - Lower conversion rate catalyst
  - Improved H_2SO_4 mist collection in the scrubber (Flowpac)
  - Larger size HF power supplies resulting in fewer bus sections
  - Lower cost alloy usage with the use of re-circulation system and acid neutralization system
- **The latest arrangement for the WESP's consumes less plant area – centralized water recirculation system**
- **Liquid blowdown from the WESP system used in the WFGD system**



WESP Advantages

- **WESP's can collect more than acid mist and ash particulate matter**
  - Oxidized mercury
  - Sulfur dioxide
  - Hydrogen chloride
  - Hydrogen fluoride
  - HAP's such as arsenic, cadmium, chromium
- **The addition of a WESP provides added fuel flexibility**
  - Not as sensitive to variations in ash properties as dry ESP's
  - Dry ESP's work better with high S coals (lower resistivity)



TYPES of WESP DESIGNS

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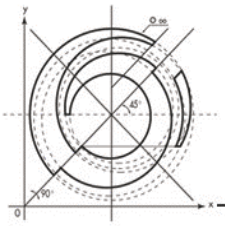
WESP types available:

- **Vertical flow designs**
  - Round Tubes
  - Square Tubes
  - Rectangular Tubes
  - Hexagonal Tubes
  - Concentric Rings
  - Flat Plates
- **Horizontal flow flat plate type**
  - Rectangular casing
  - Round casing



TYPES of WESP DESIGNS

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WESP configurations:

- Vertical Flow Types - Non-Condensing
  No mechanical means are used to help precipitate the mist/liquid from the gas stream

- Vertical Flow Types – Condensing WESP™(Wheelabrator)
  Cool liquid is used to lower the temperature of the collecting surface to promote condensation of the warm, moist gas on the collector interior surface

TYPES of WESP DESIGNS

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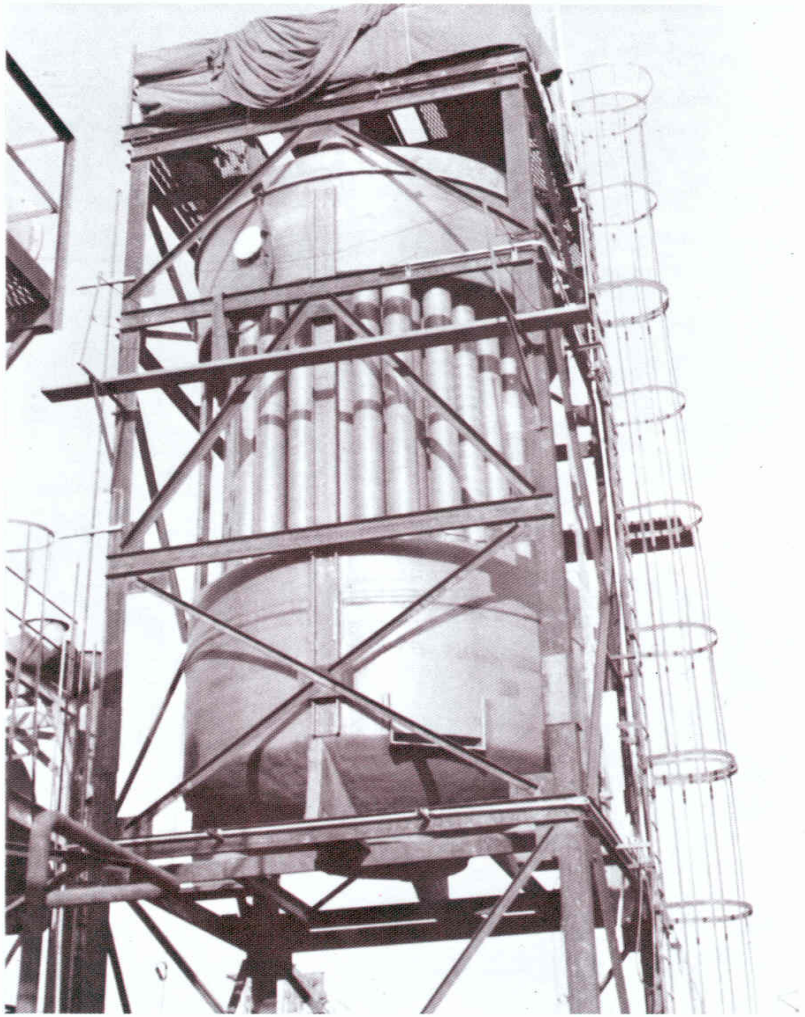
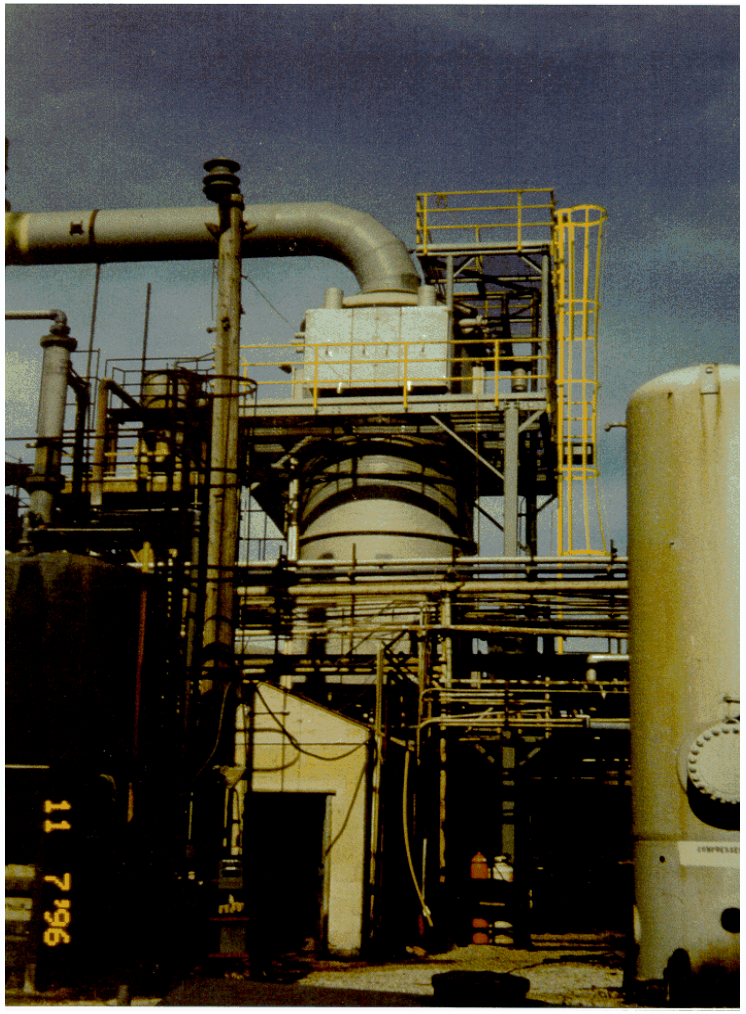


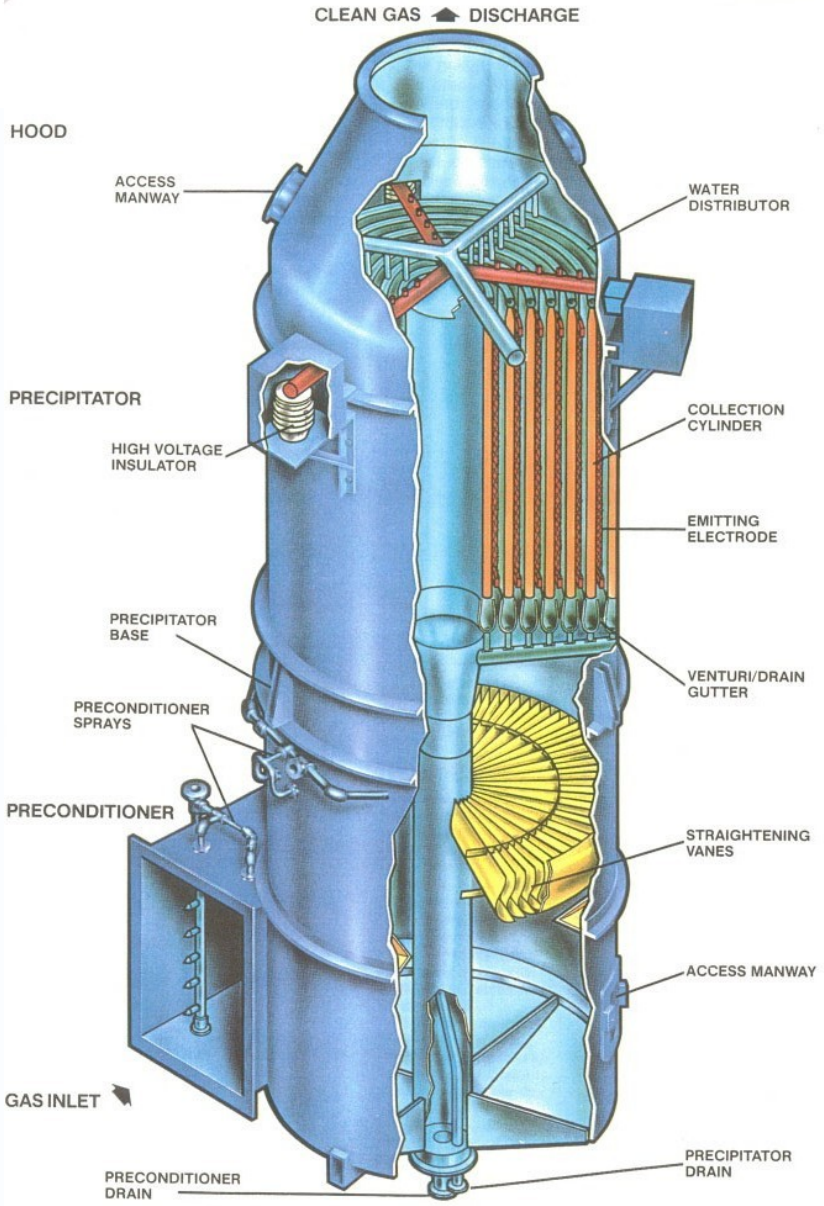


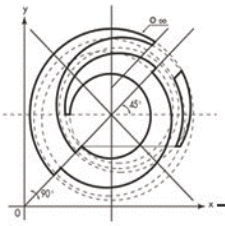
Old and New Style Tubular Vertical Flow WESP's

TYPES of WESP DESIGNS

Concentric Ring Style

Vertical Flow WESP



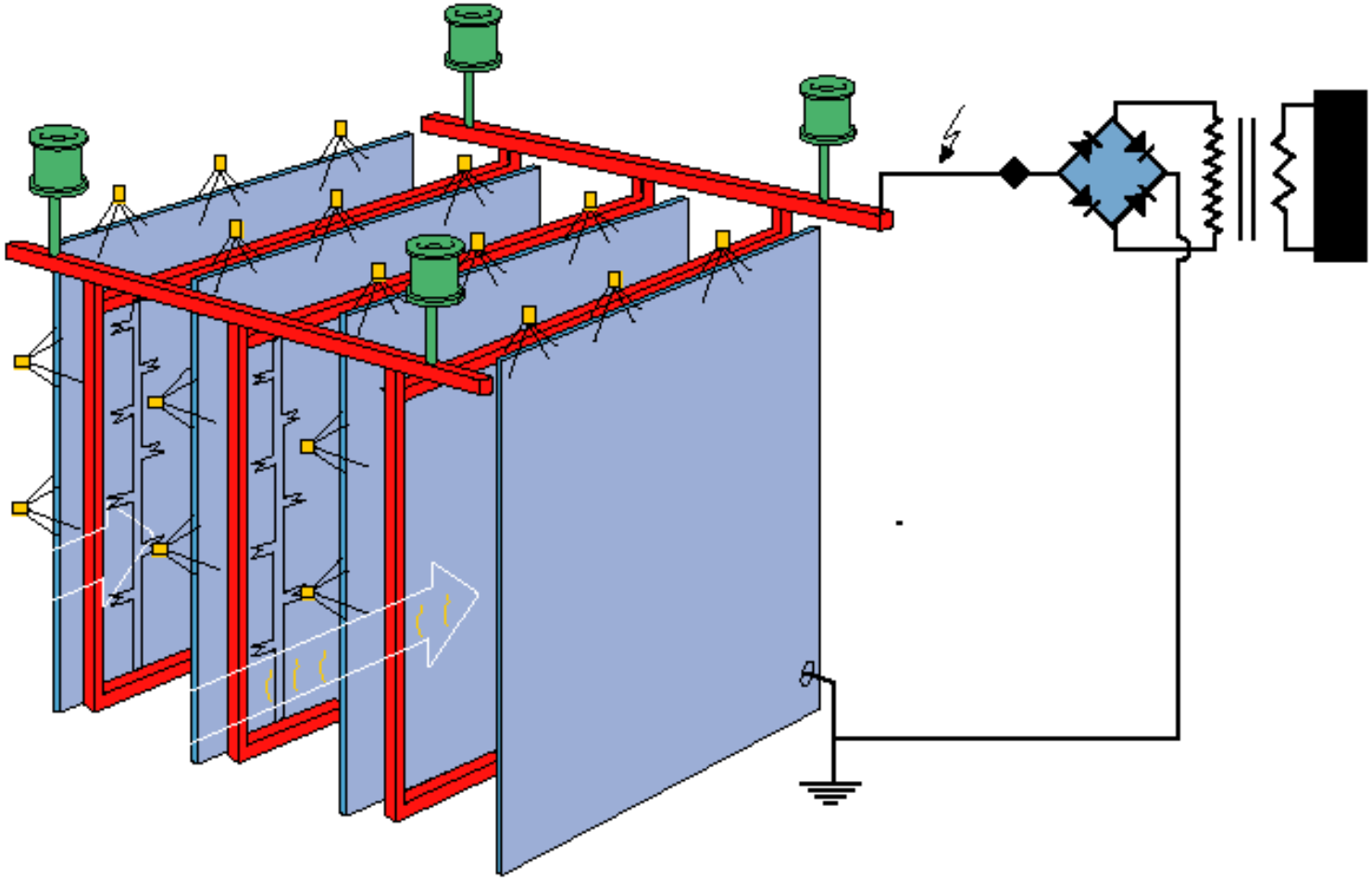


TYPES of WESP DESIGNS

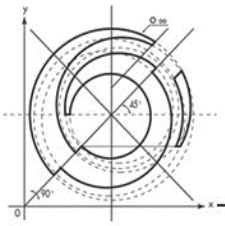
- WESP configurations (continued):
  Horizontal Flow Designs:
  Flat Plate Non-Irrigated – No added liquid on the collecting surfaces - intermittent washing
  Flat Plate Irrigated – a stream of liquid covers the collecting surface to wash them clean
  Flat Plate Flushed (washed) – washing sprays are used continuously to clean the collecting and discharge electrodes

All Horizontal Flow Designs are: Non-Condensing Type

TYPES of WESP DESIGNS



Basic Design of Horizontal Flow WESP with sprays
in front of and over the precipitation zone



WESP ARRANGEMENTS

- **WESP Arrangements:**
  - Multiple Vertical Flow Units in Parallel – to address large gas flows
  - Multiple Vertical Flow Units in Series – to address high removal efficiencies
  - Horizontal Flow Units with multiple cells and collecting fields in one casing to address large gas flows and high removal efficiencies
- **WESP's after WFGD Systems:**
  - Mounted in or on the top of the wet scrubber
  - Grade mounted installations – VFWESP's
  - Grade mounted installations – HFWESP's

WESP ARRANGEMENTS

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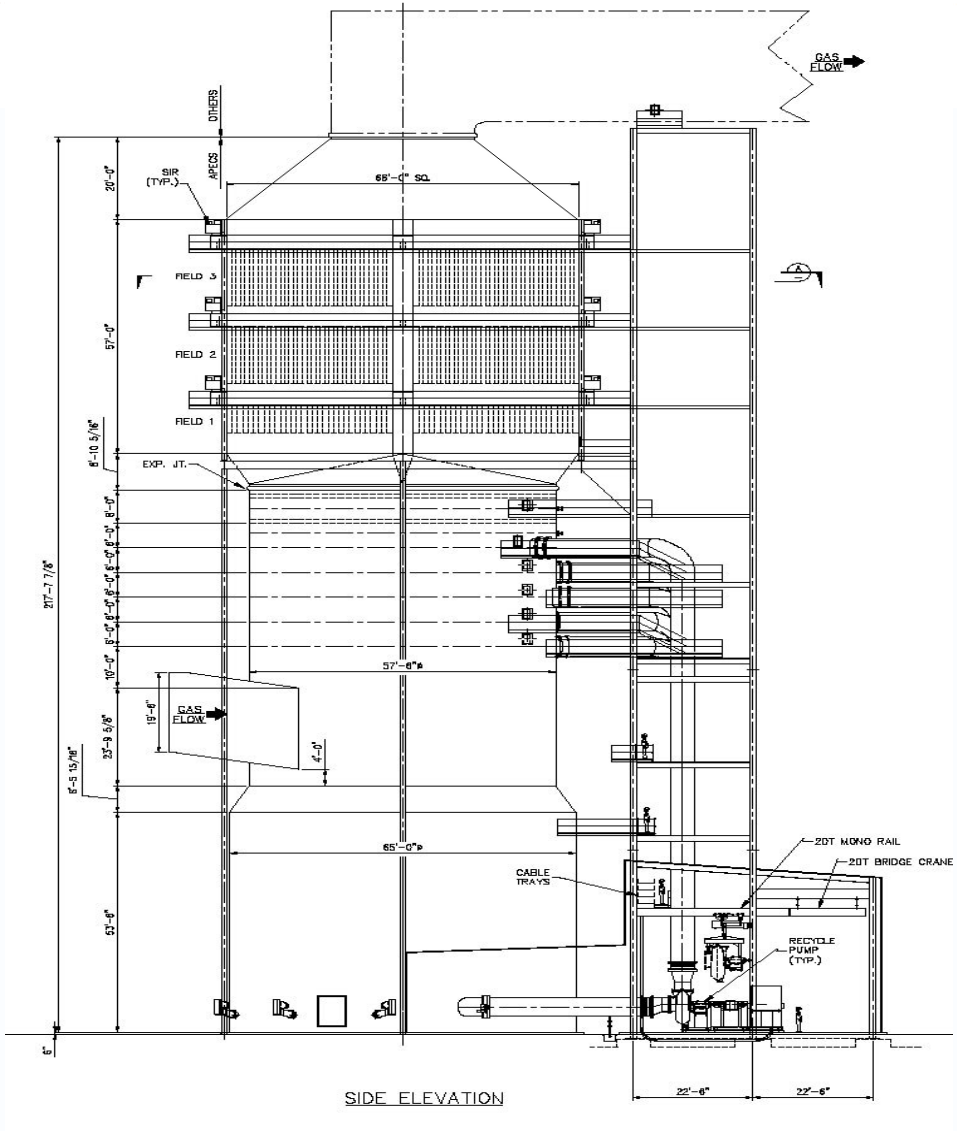
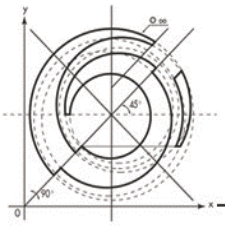
VFWESP In Scrubber Vessel Design



WESP ARRANGEMENTS

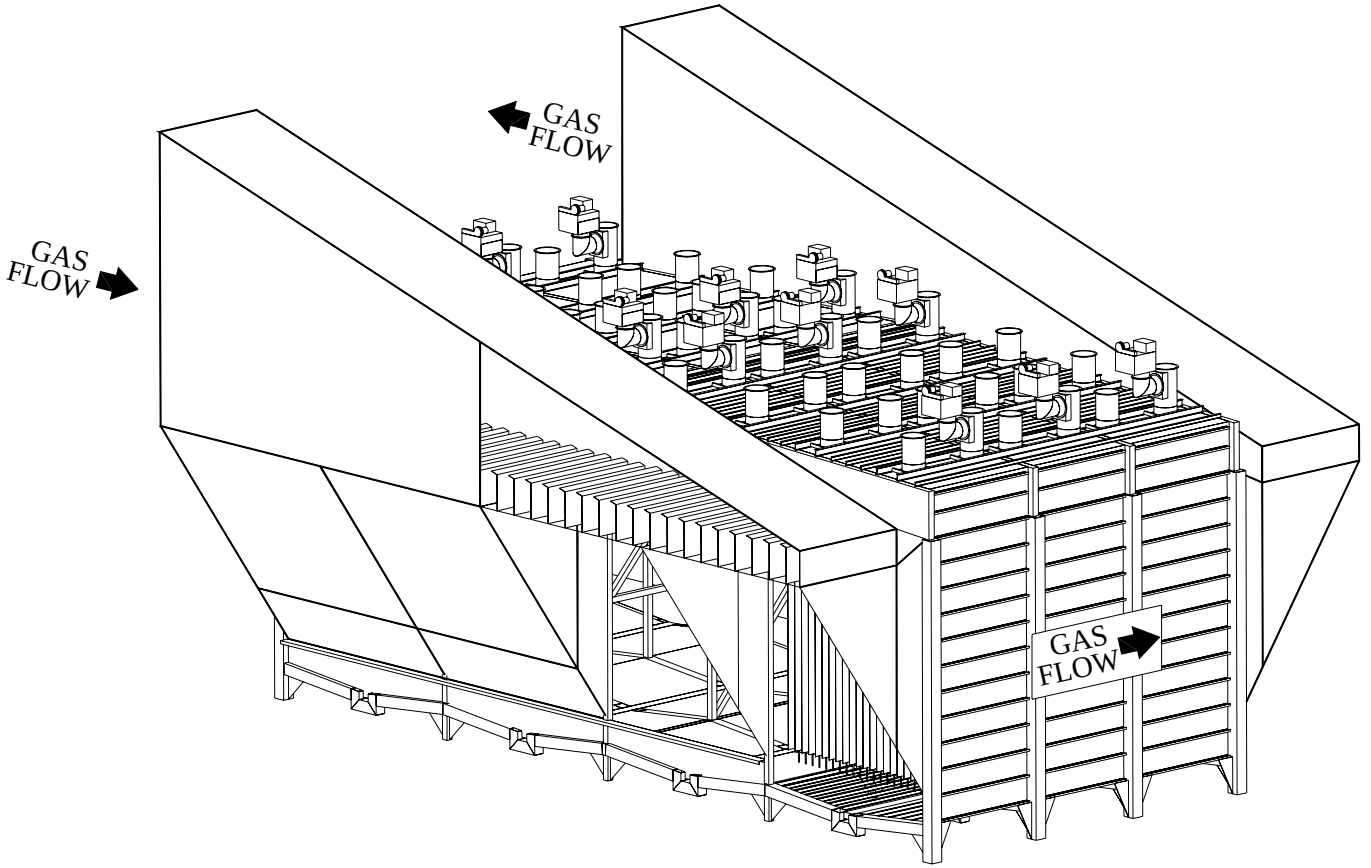
Tubular Vertical Flow WESP Arrangement



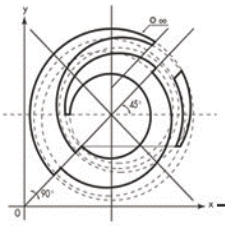
HFWESP DESIGN

- Electrode spacing is 250 mm or 300 mm (10″ or 12″)
- Designed to meet conditions for WET environment with controlled water flow to reduce sparking
- Designed to reduce risk for corrosion including spray systems to keep all surfaces wet
- Maximum height of collecting plates is 9 meters (29.5′)
- Discharge electrodes designed to increase current
- Wash water recirculation to reduce water consumption
- Design allows continuous flushing of internals

HORIZONTAL FLOW WESP DESIGN



Horizontal Flow WESP with multiple cells wide and multiple fields long in one casing



WESP MATERIALS of CONSTRUCTION

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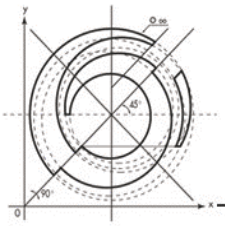
CHOICE OF MATERIALS DEPENDING ON PROCESS AND GAS COMPOSITION

MATERIAL is a major part of WESP cost

- Mild Steel
- Coated Mild Steel
- Wall Papered Mild Steel
- Fiberglass
- Corrosion Resistant Alloys……



WESP MATERIALS

RISK FOR CORROSION

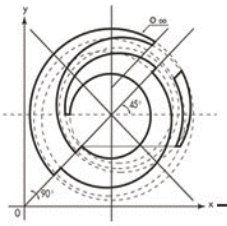
Alloy Materials

	Material & fabrication/Lb
– 316L	$3.50
– 2205	$4.25
– 317LMN	$5.00
– AL6XN	$6.00
– 904L	$6.00
– C276	$16.00

MATERIAL

INCREASED COST

- Design to prevent corrosion
- Keep wash water at reasonable pH
- Control liquid chloride content
- Continuous flushing of all internals
- Keep ALL surfaces wet at all time

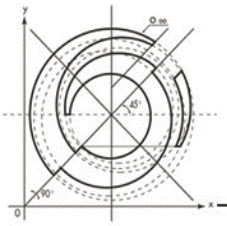


WESP INTERNALS CLEANING SYSTEMS

ALSTOM

CHOICE OF WASH WATER ARRANGEMENTS

- **Once through system**
  - Used on smaller size WESP systems
  - Used on low dust load systems
  - Most efficient cleaning system
  - Consumes large quantities of water
- **Re-circulation system**
  - Used on larger size WESP systems
  - Used on high dust load systems
  - Minimizes water consumption

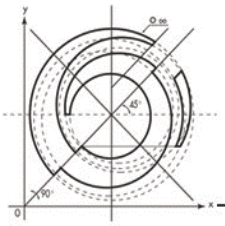


WESP INTERNALS CLEANING SYSTEMS

ALSTOM

WATER RE-CIRCULATION SYSTEM DESIGN

- **Complete contained systems provided**
  - Tanks
  - Pumps, piping and valves
  - Control system
- **Adjustable blow-down & make-up water**
  - Used to control % solids in re-circulation water
  - Used to control re-circulation water pH and chlorides content



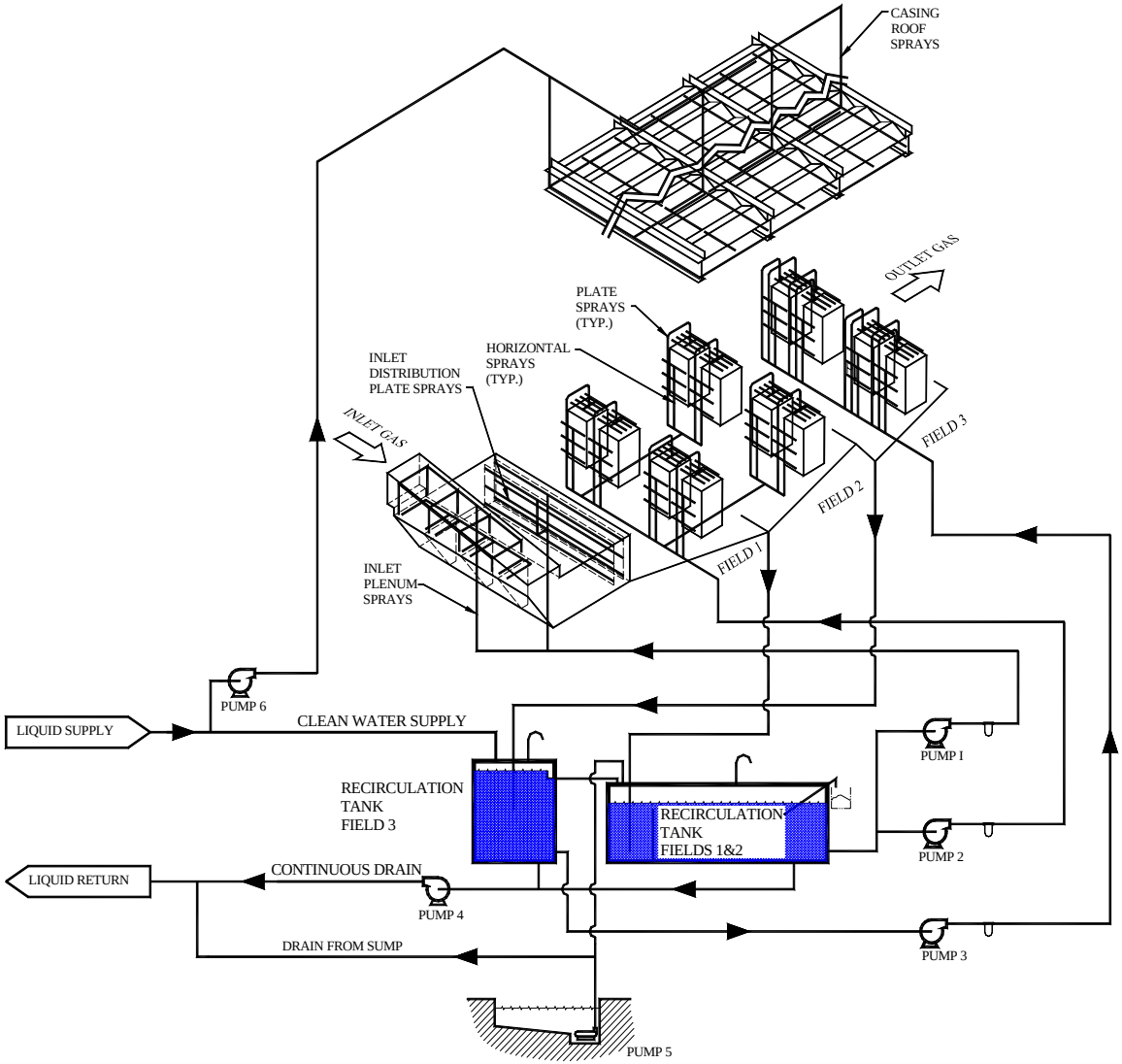
WESP INTERNALS CLEANING SYSTEMS

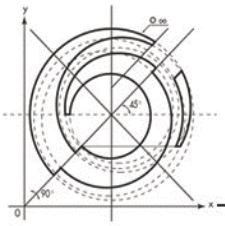
ALSTOM

WATER RE-CIRCULATION SYSTEM DESIGN

- Segregated arrangement available if required
- Cleaner water in outlet
  - Lowers risk of dust carry-over
  - Lowers corrosion risk in outlet C.E. & D.E. fields
- Cleaner water for corrosion protection
  - Used to keep materials wet and flushed clean
  - Used to reduce casing/housing material corrosion risk

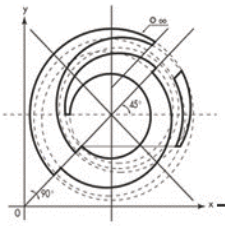
WESP INTERNALS CLEANING SYSTEMS





WESP SPRAY NOZZLE WASHING DESIGNS

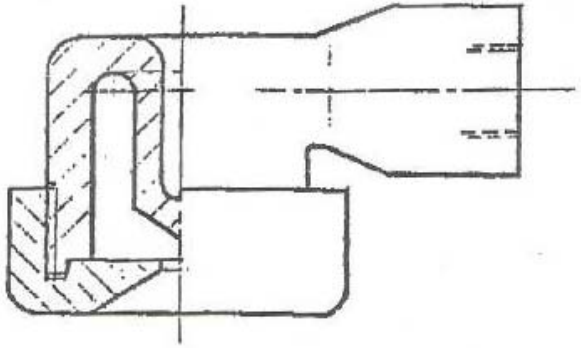
- Proprietary Centrifugal Nozzle
- Helix Spiral Nozzle
- Flat Jet Nozzle



WESP SPRAY NOZZLE WASHING DESIGNS

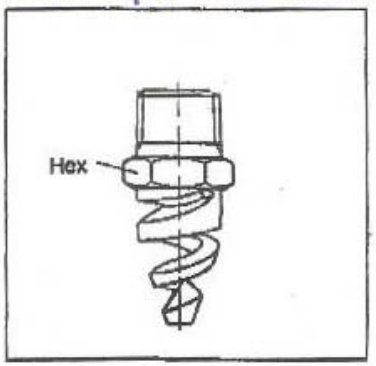
ALSTOM

Centrifugal Nozzle ALSTOM Design



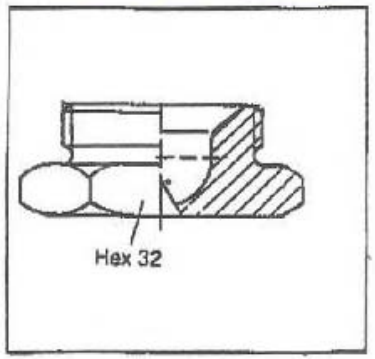
- HORIZONTAL SPRAYS
- VERTICAL PLATE SPRAYS

Helix Spiral Nozzle



- HORIZONTAL SPRAYS

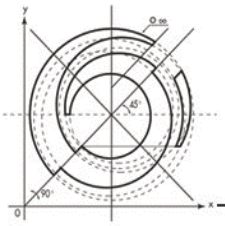
Flat Jet Nozzle



- VERTICAL PLATE SPRAYS

HFWESP WASH WATER SYSTEM

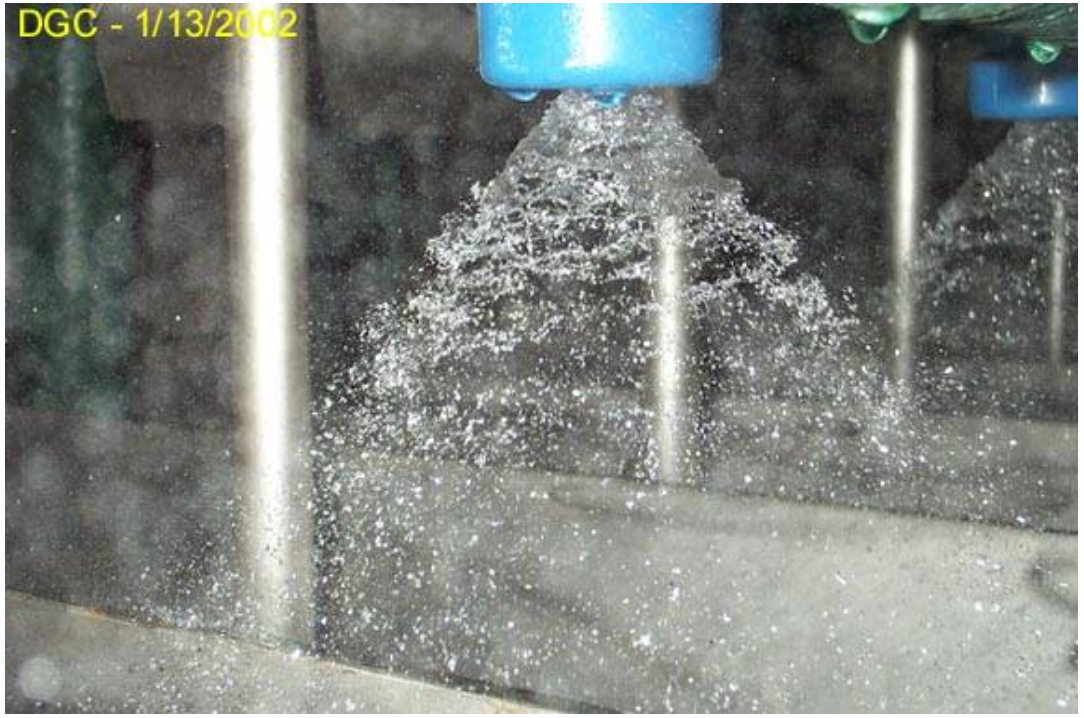
- **Horizontal flow wash water system**
  - Ensures completely saturated gas stream
  - Adds free moisture to gas stream that assists with precipitation and cleaning
  - May be operated continuously or intermittently

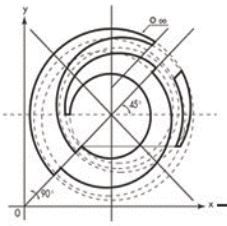


HFWESP WASH WATER SYSTEM

ALSTOM

- **Top water sprays used to keep C.E.s clean**
  - Uniform flow of liquid over entire C.E. surface
  - Variable volume depending on process, typically 0.43 gpm/ft^2 or less
  - May be operated continuously or intermittently



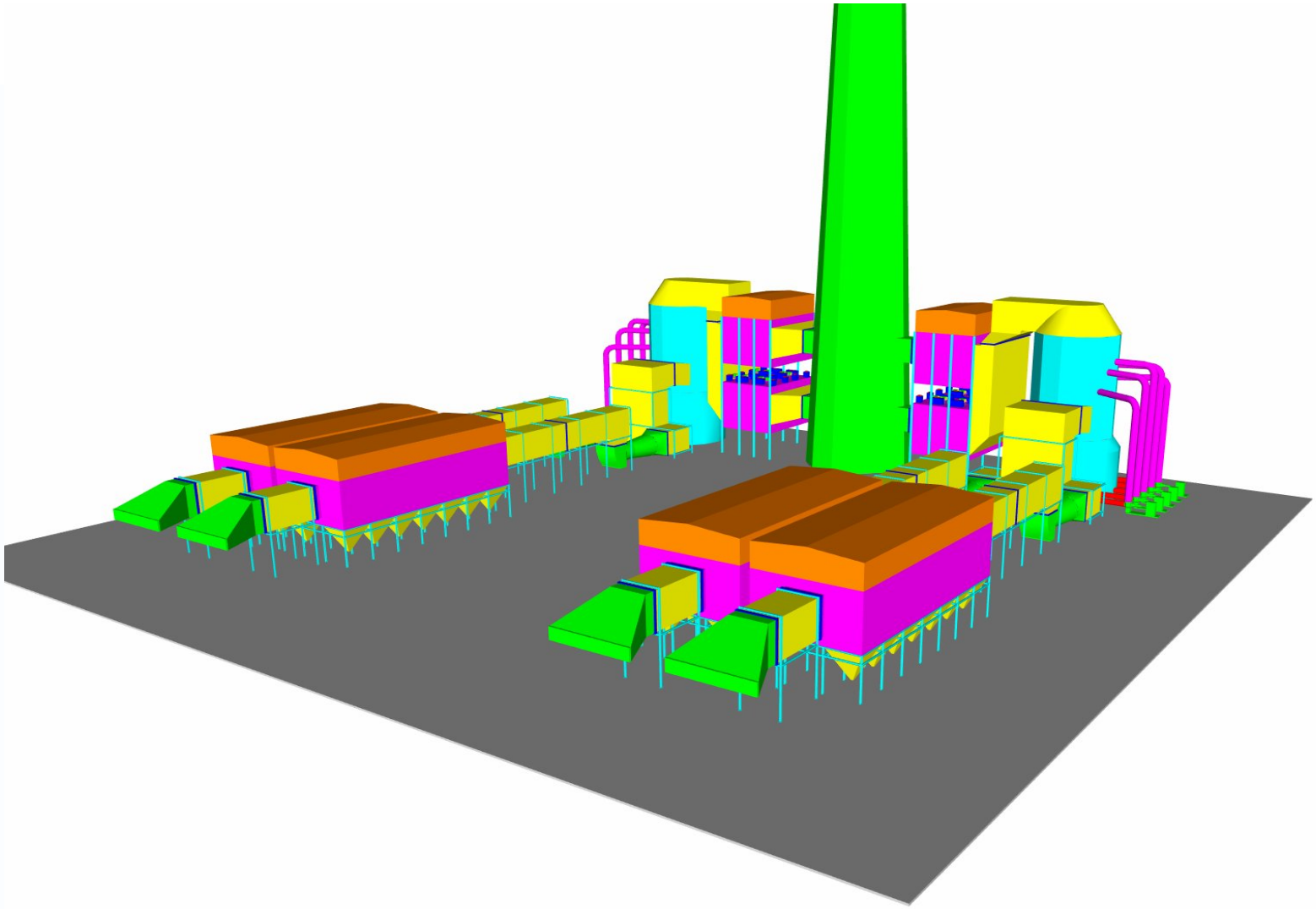


HFWESP INSTALLATIONS

HFWESP REFERENCES

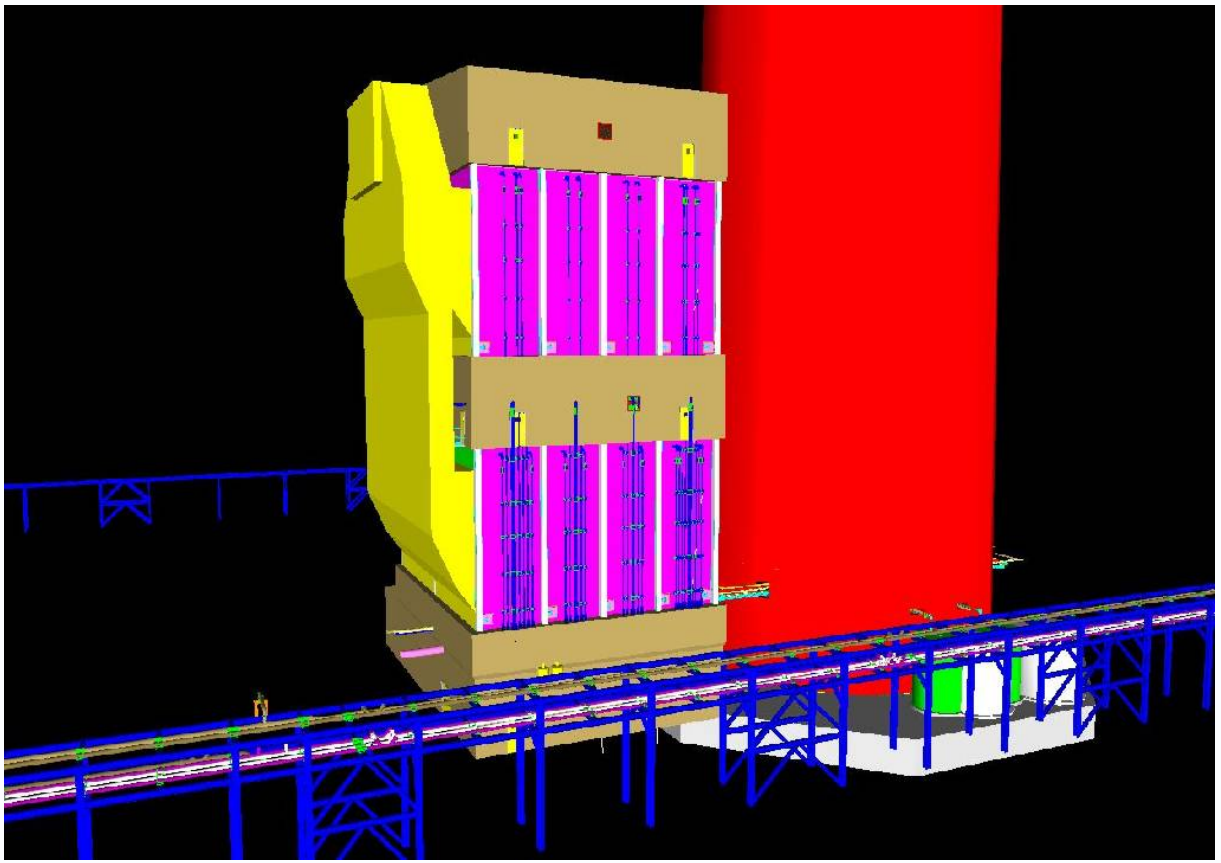
- **After coal fired boiler, ELM ROAD**
  - 650 MWe capacity system/boiler
  - Preceded by wet limestone scrubber
  - Design gas flow 720 Am^3/s (1,530,000 ACFM)/boiler
  - 2 WESP's/boiler, 4 fields in series, 2 bus sections wide
  - Materials used 2205 and AL6XN
  - Gas velocity >2.46 m/s (>8.2 f.p.s.)
  - Outlet emissions: sized for 5.2 mg/Nm^3 (0.0017 gr/scf)

APC System for Elm Road 2 X 650 MW

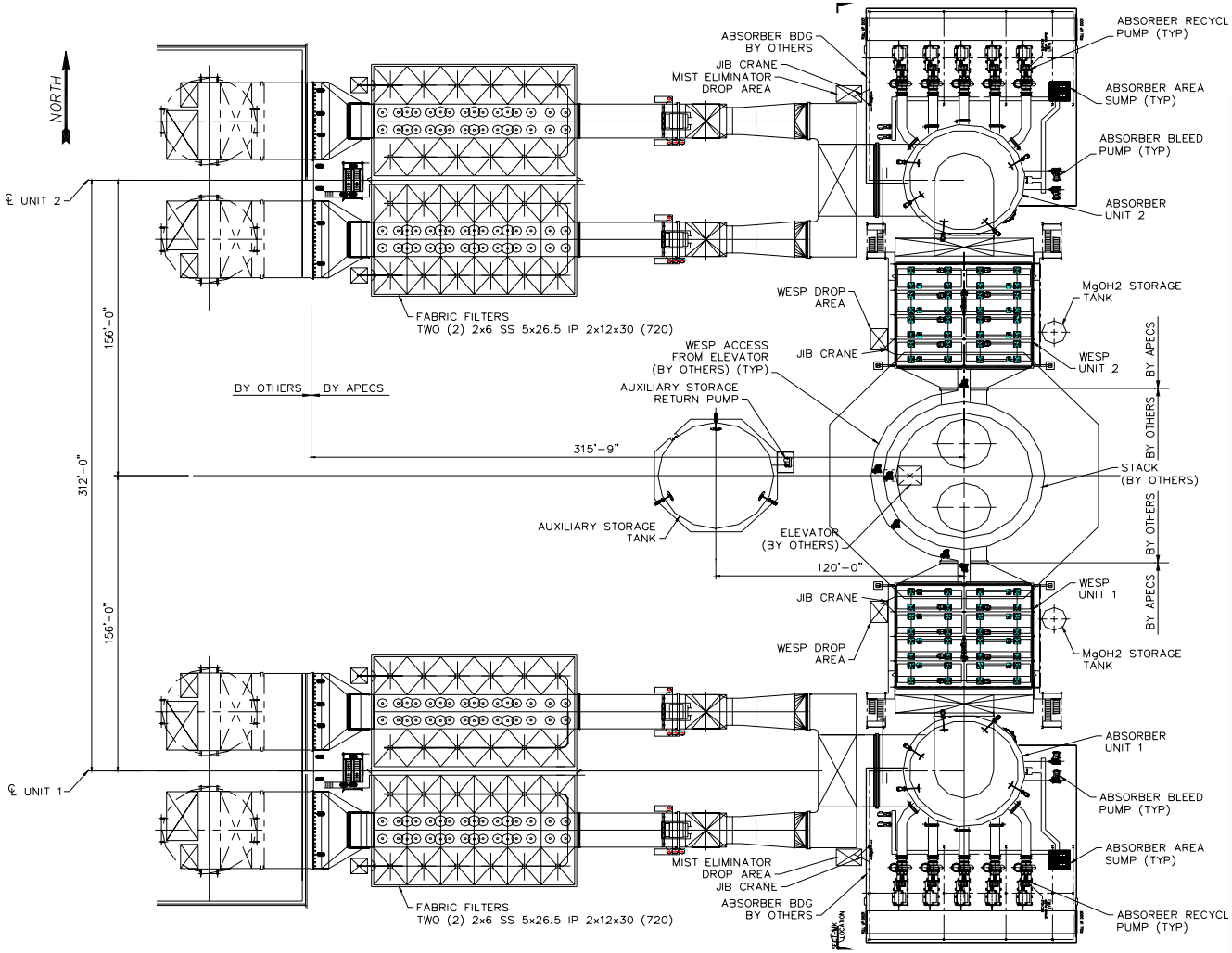


WET ESP

ELM ROAD, 2 WESP STACKED/BOILER



WESP for 2 x 650 MW Boilers



HFWESP MODULARIZATION

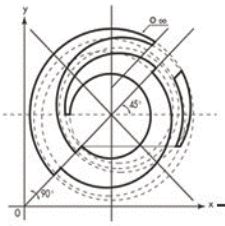
HFWESP INSTALLATIONS

VFWESP INSTALLATIONS

Grade Mounted Vertical Flow WESP System

VFWESP INSTALLATIONS

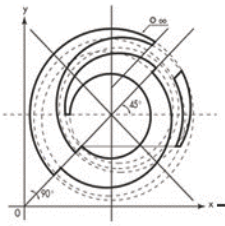
Vertical Flow WESP in WFGD



SUMMARY & CONCLUSIONS

ALSTOM

- There exists an installed base of WESP's that provides excellent design knowledge for future projects
- WESP's have demonstrated excellent collection of sub-micron particulates, aerosols and fumes
- WESP's with multiple fields have demonstrated very high removal efficiencies
- WESP's may be arranged to suit site limitations
- HFWESP's, being very similar to DESP's in configuration, are ideal for use on high volume applications
- WESP's will collect condensed mercury and HAP's
- The use of a WESP system will not impact other APC equipment



CONCLUSION

ALSTOM

THANK YOU!

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