# Reinhold Environmental Ltd.


## 2008 APC Round Table & Expo Presentation

***July 13-15, 2008, in Savannah, GA***


# Wet FGD Training Workshop

**APC Conference**

**July 13, 2008**


# Worldwide Pollution Control Association

**A non-profit organization whose mission is to improve pollution control through better technical communication.**


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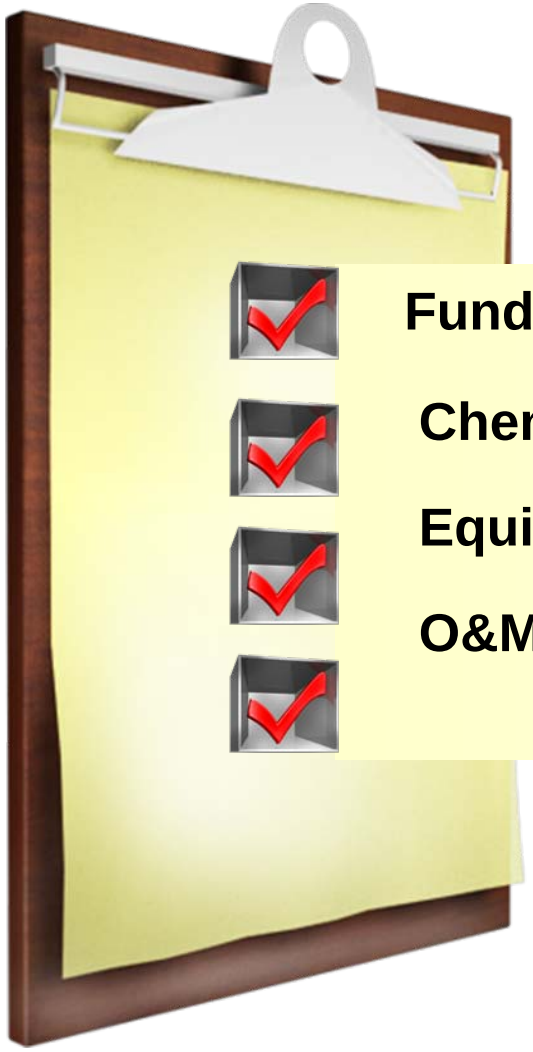
# *Wet FGD Training Outline*



- **Fundamentals – Greg Bielawski, B&W**
- **Chemistry - Gordon Maller, URS**
- **Equipment and  O&M intro – Tony Licata, BPI**
- **O&M Panel – Rich Staehle, Marsulex (chair)**

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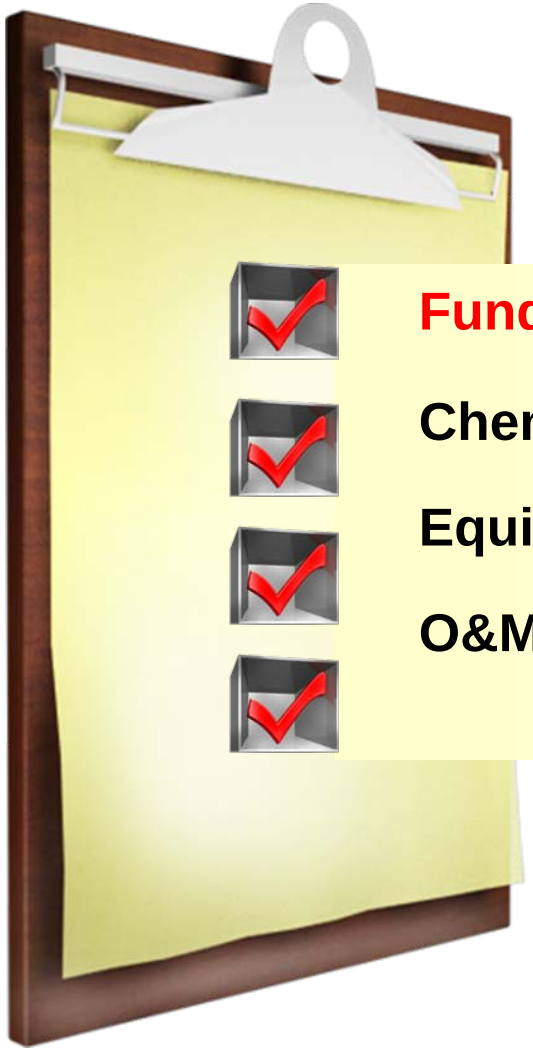

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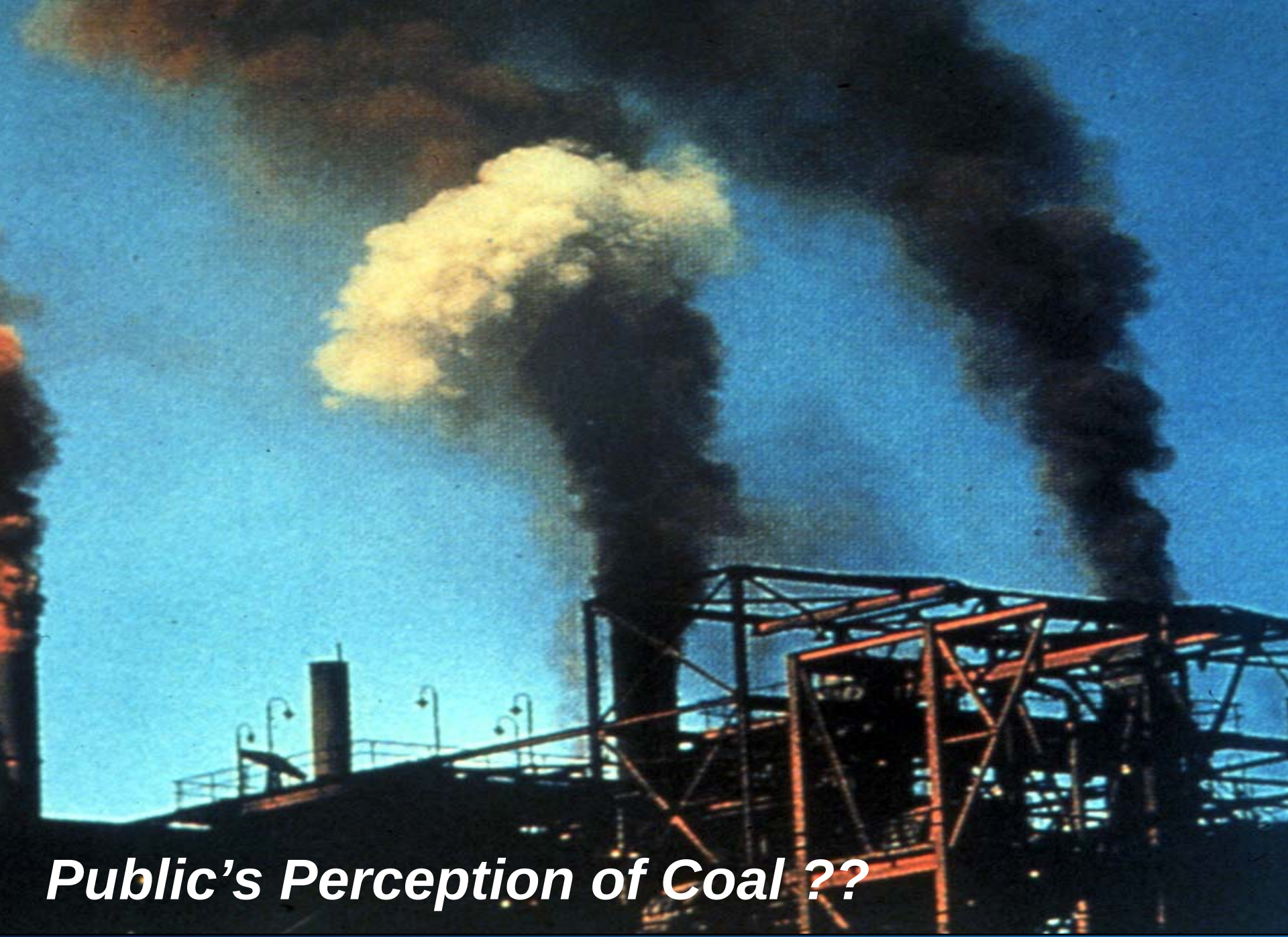
# Wet FGD Fundamentals

- What's the issue and progress
- Overview of major types of utility FGD system
- General description of wet limestone forced oxidized (LSFO) system
- Basic types and configurations of commercially available LSFO FGD technology
- Detailed description of LSFO FGD absorber
- Materials of Construction



# *Public's Perception of Coal ??*

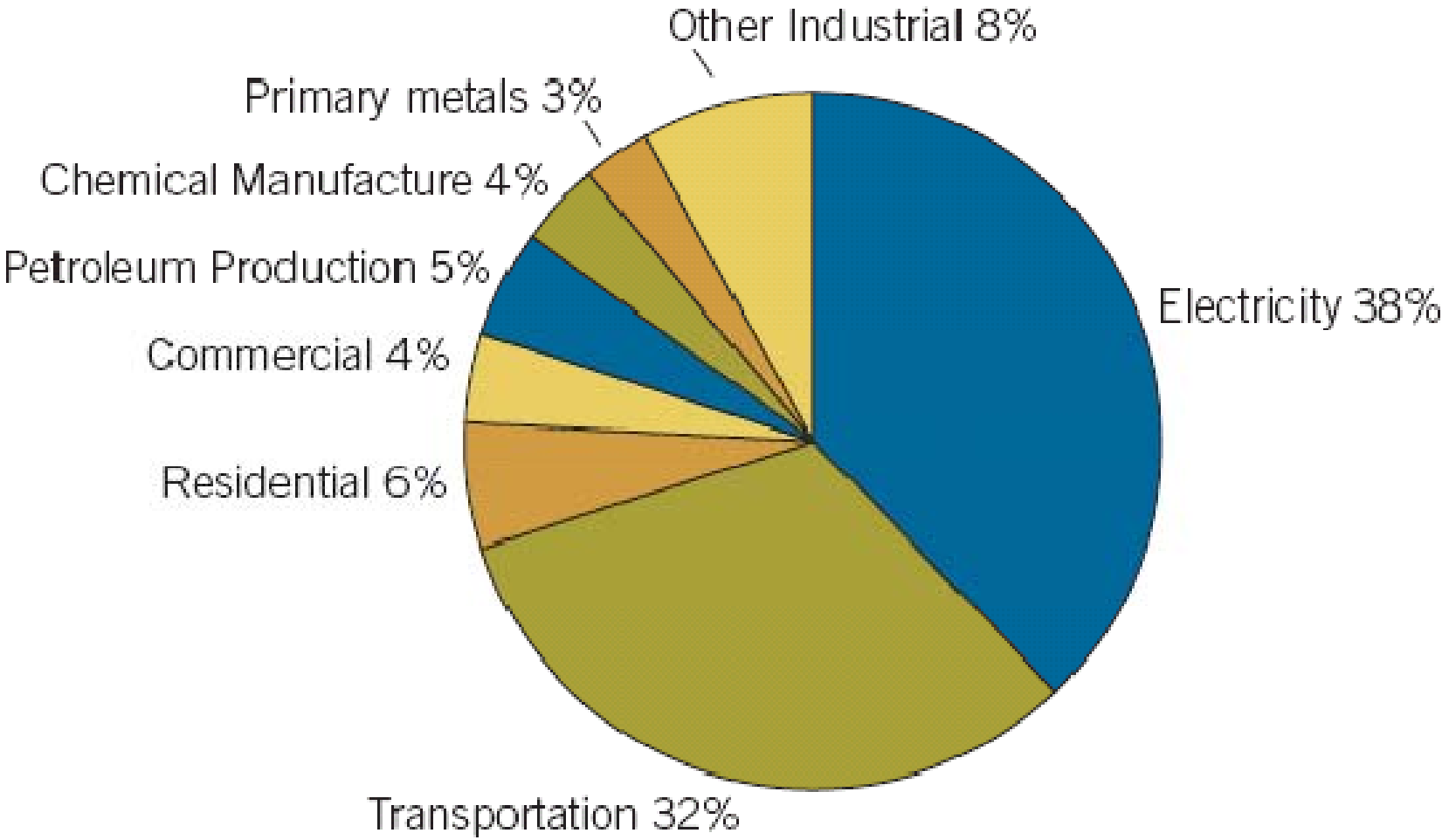
# *Environmental Issues / Fuel Choice Driver*

- **Acid rain**
- **By-product utilization of sulfur oxides**
- **Selective catalytic reduction for nitrogen oxides as nitric acid precursors**
- **Sulfuric Acid Mist**
- **Mercury**


- **Coarse particulate**
- **Acid rain**
- **Scrubbers for sulfur oxides as sulfuric acid precursors**
- **Combustion control for nitrogen oxides as nitric acid precursors**

- **$CO_2$**
- **Other Air toxics**
- **PM 2.5 (fine particulate matter less than 2.5 microns)**

# Sources of U.S. $CO_2$ Emissions



# *Environmental Regulations*

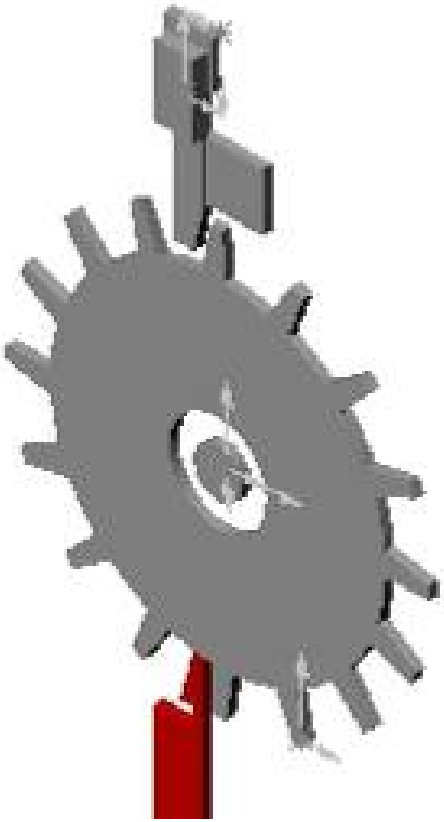
- **Clean Air Act**
- **Clean Air Interstate Rule (CAIR) – Vacated**
- **Clean Air Mercury Rule (CAMR) - Vacated**
- **Clean Air Visibility Rule (CAVR)**
- **Potential Future Carbon Dioxide Limits**

# *Clean Air Act*

**Q: How much reduction is enough?**

**A: The law is designed to ratchet down the level of allowable emissions to the best that achievable with the available, demonstrated technology.**

**As new technology is demonstrated, the limit goes lower.**

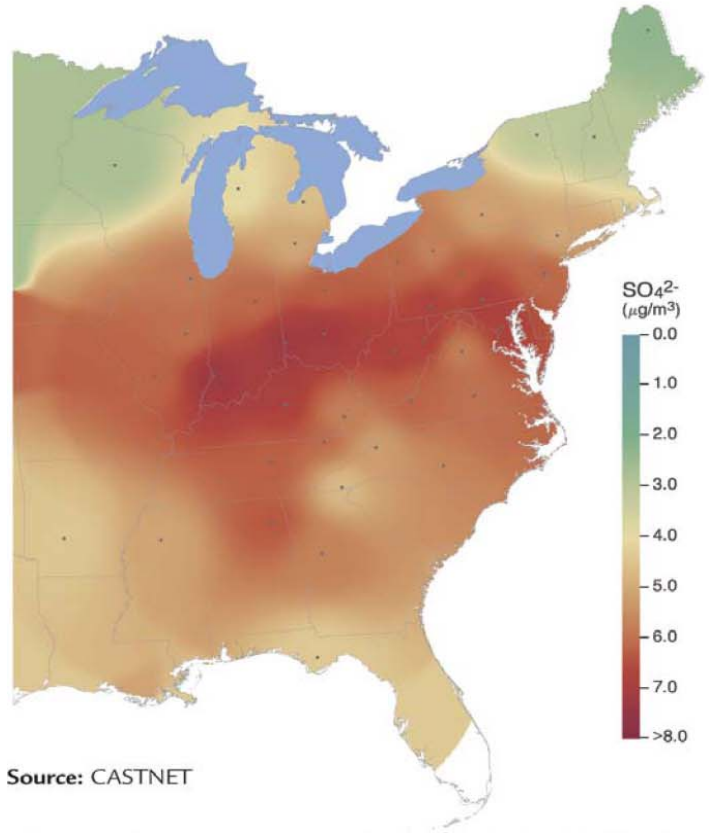


***Ratchet Gear***

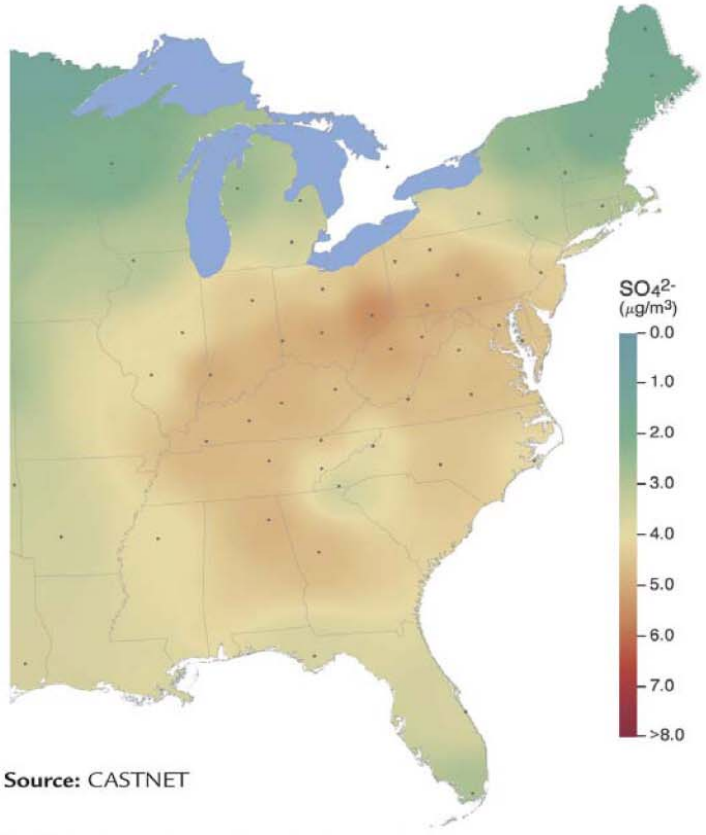
# Achieved Reductions in Sulfate Concentration

## Annual Ambient Sulfate Concentration

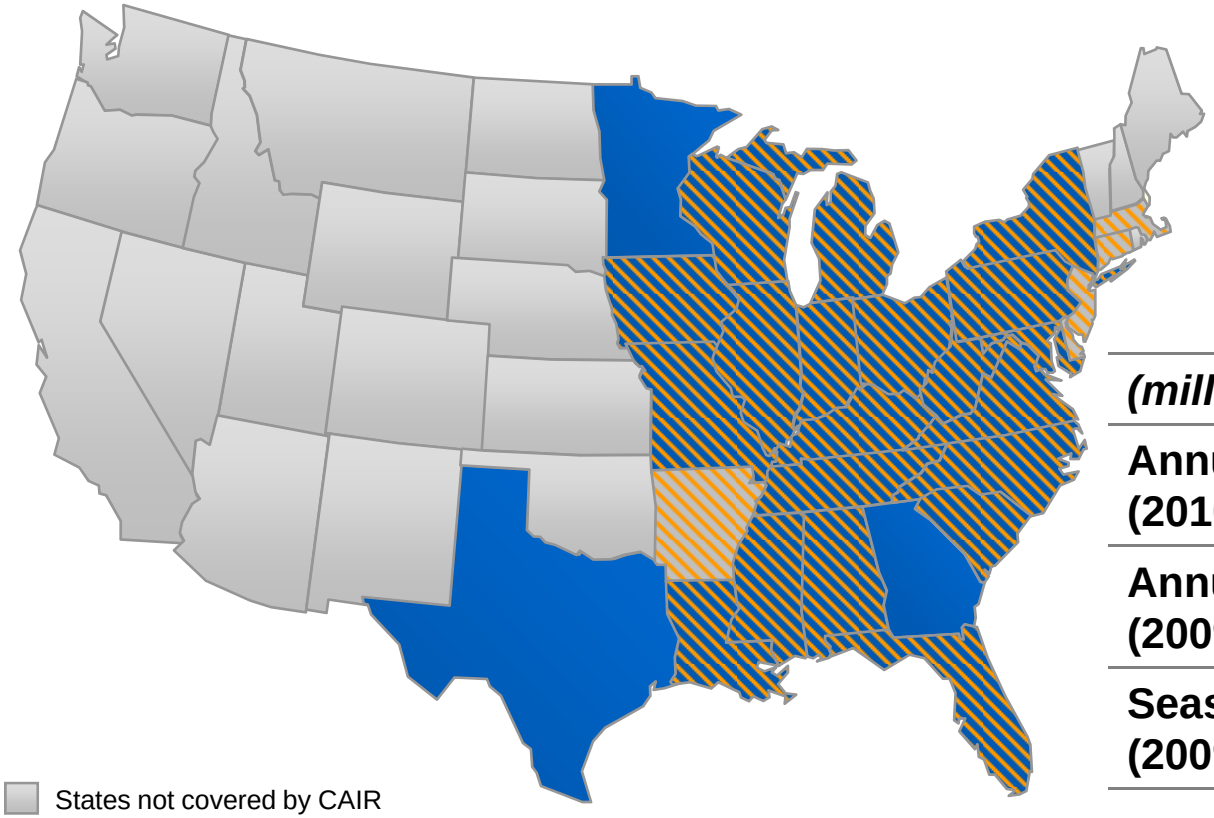
**1989 - 1991**




**2003 - 2005**



# *Clean Air Interstate Rule (CAIR) - Vacated*
# *Affected Region and Emission Caps*



States not covered by CAIR

States controlled for ozone (ozone season NOx)

States controlled for fine particles (annual $SO_2$ and NOx)

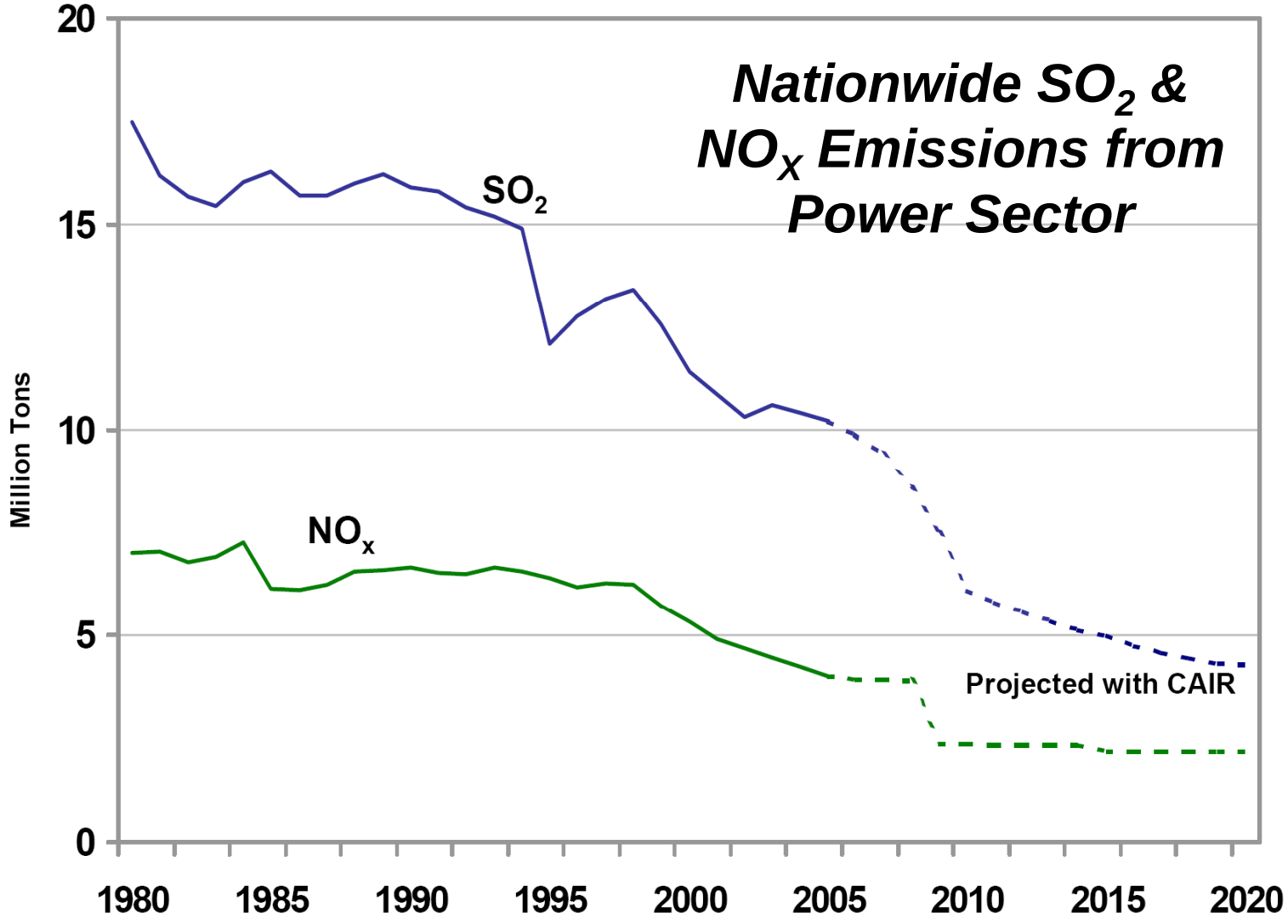
States controlled for both fine particles (annual $SO_2$ and NOx) and ozone (ozone season NOx)

***Emission Caps****

| *(million tons)* | 2009-10 | 2015 |
|---|---|---|
| Annual $S0_2$ (2010) | 3.6 | 2.5 |
| Annual NOX (2009) | 1.5 | 1.3 |
| Seasonal NOX (2009) | .58 | .48 |

***Source: Briefing by Sam Waltzer, EPA Clean Air Market Division, 3/29/2005***

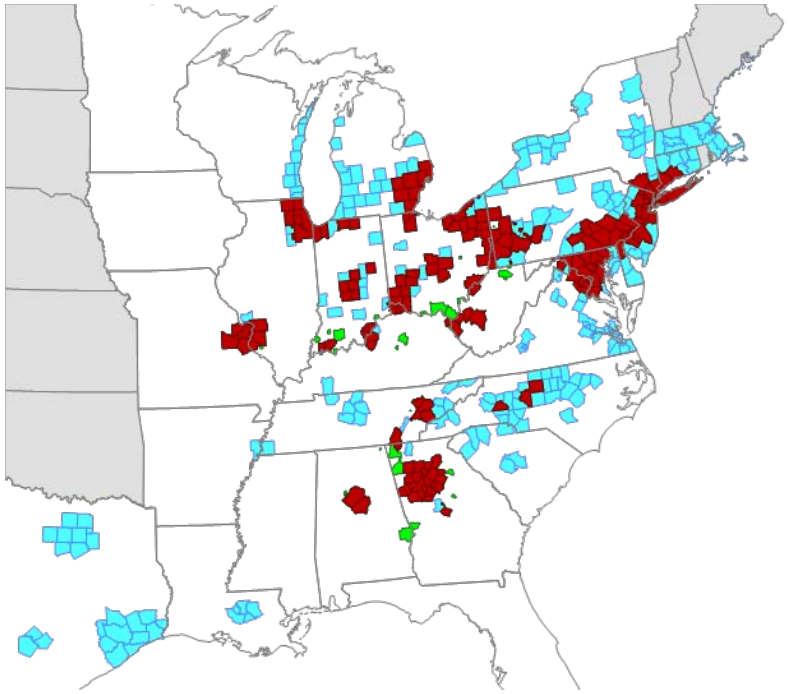
# CAIR Accelerated 35 Years of Clean Air Progress



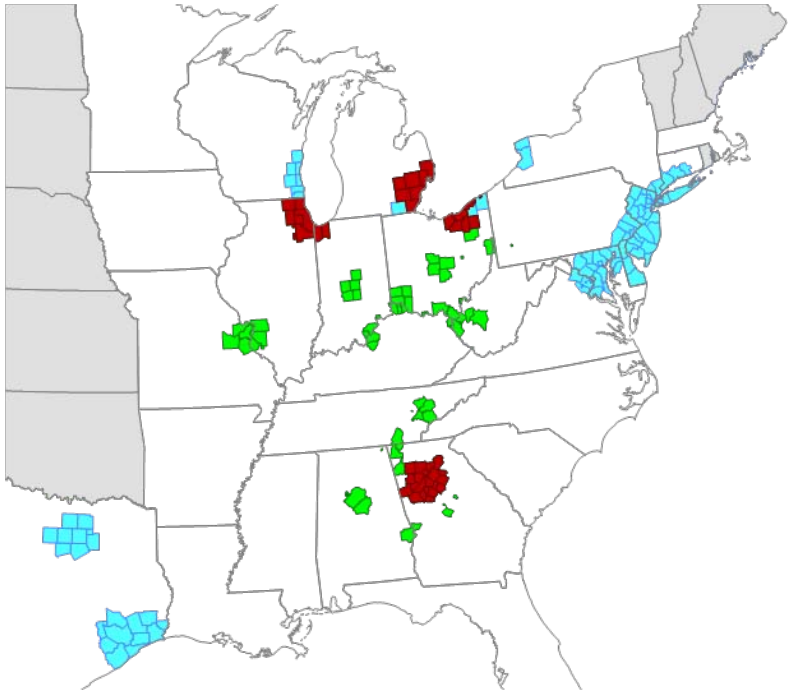

*Source: EPA*

# *Ozone and Particle Pollution under CAIR*
# *2005 vs 2010*

**Ozone and Fine Particle Nonattainment Areas (March 2005)**



**Projected Nonattainment Areas in 2010 after Reductions from CAIR and Existing Clean Air Act Programs**



Nonattainment areas for 8-hour ozone pollution only

Nonattainment areas for fine particle pollution only .

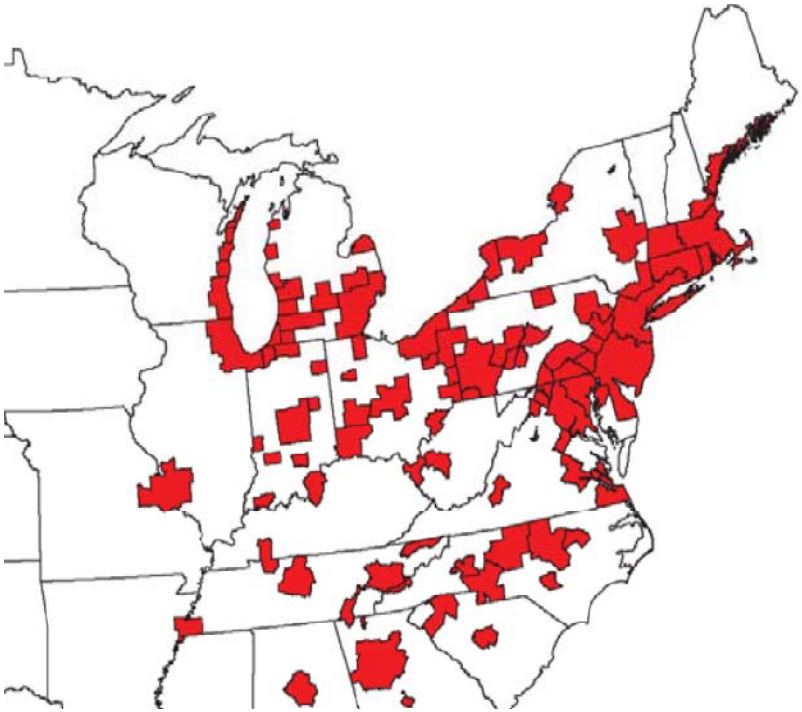
Nonattainment areas for both 8-hour ozone and fine particle pollution

*Source: Briefing by Sam Waltzer, EPA Clean Air Market Division, 3/29/2005*

# *Achieved Reduction in Ozone Exposure, Following SCR Construction*

## 2003

**8-Hour Ozone Nonattainment Areas,**



## 2005

**Areas Remaining Above Standard**

**Nearly 70 percent of the areas out of attainment in 2003 are now below the ozone standard in 2005. Power plant NOx reductions is the major contributor to this improvement.**

# *Sulfur in Coal to $SO_2$*

**3.0% Sulfur; 12,000 BTU/LB coal**

$$\frac{3.0 \text{ lb Sulfur}}{100 \text{ lb coal}} \times \frac{1 \text{ mole Sulfur}}{32 \text{ lb Sulfur}} \times \frac{1 \text{ mole } SO_2}{1 \text{ mole Sulfur}} \times$$

$$\frac{64 \text{ lb } SO_2}{1 \text{ mole SO2}} \times \frac{1 \text{ lb coal}}{12{,}000 \text{ BTU}} \times \frac{1{,}000{,}000 \text{ BTU}}{\text{Million BTU}}$$

$$= \frac{5.0 \text{ lb } SO_2}{\text{Million BTU}}$$

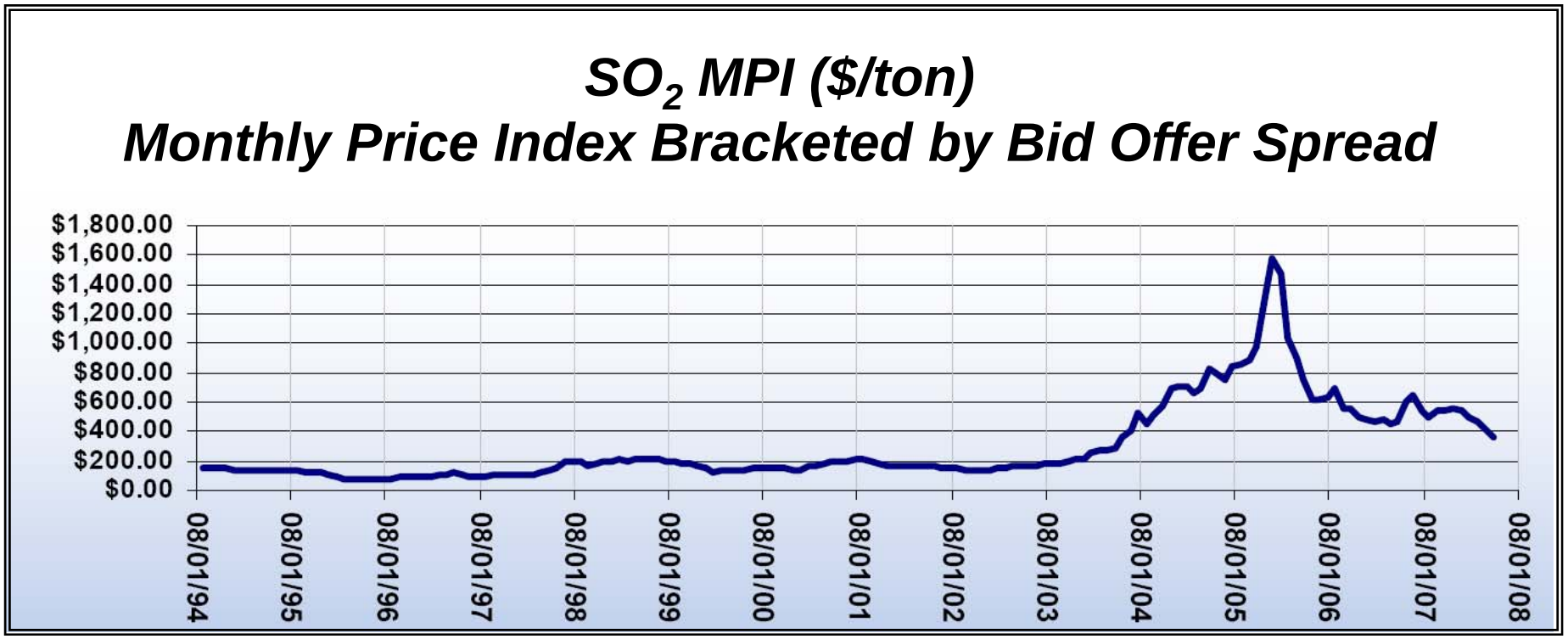
**Also known as a "5 Lb Coal"**

- **2624 ppmvd @ 3% $O_2$**
  **(parts per million by volume dry at 3% oxygen in flue gas)**
- **6240 mg per DSCM @ 6%$O_2$**
  **(milligrams per dry standard cubic meter, 0 degrees C) (2.38 x ppm)**

# *Reactions to $SO_2$ Regulations*

- **Buy credits**
- **Switch to lower sulfur coals**
  - **Powder River Basin**
- **Install scrubbers**
  - **Dry scrubbers - lower sulfur applications**
  - **Wet scrubbers - higher sulfur applications**
- **Earn credits / bank credits / sell credits**
- **Upgrades to Existing Scrubbers to Increase $SO_2$ Removal**

# $SO_2$ Allowance Prices




Source: Cantor Environmental Brokerage www.emissionstrading.com

# Wet FGD Fundamentals

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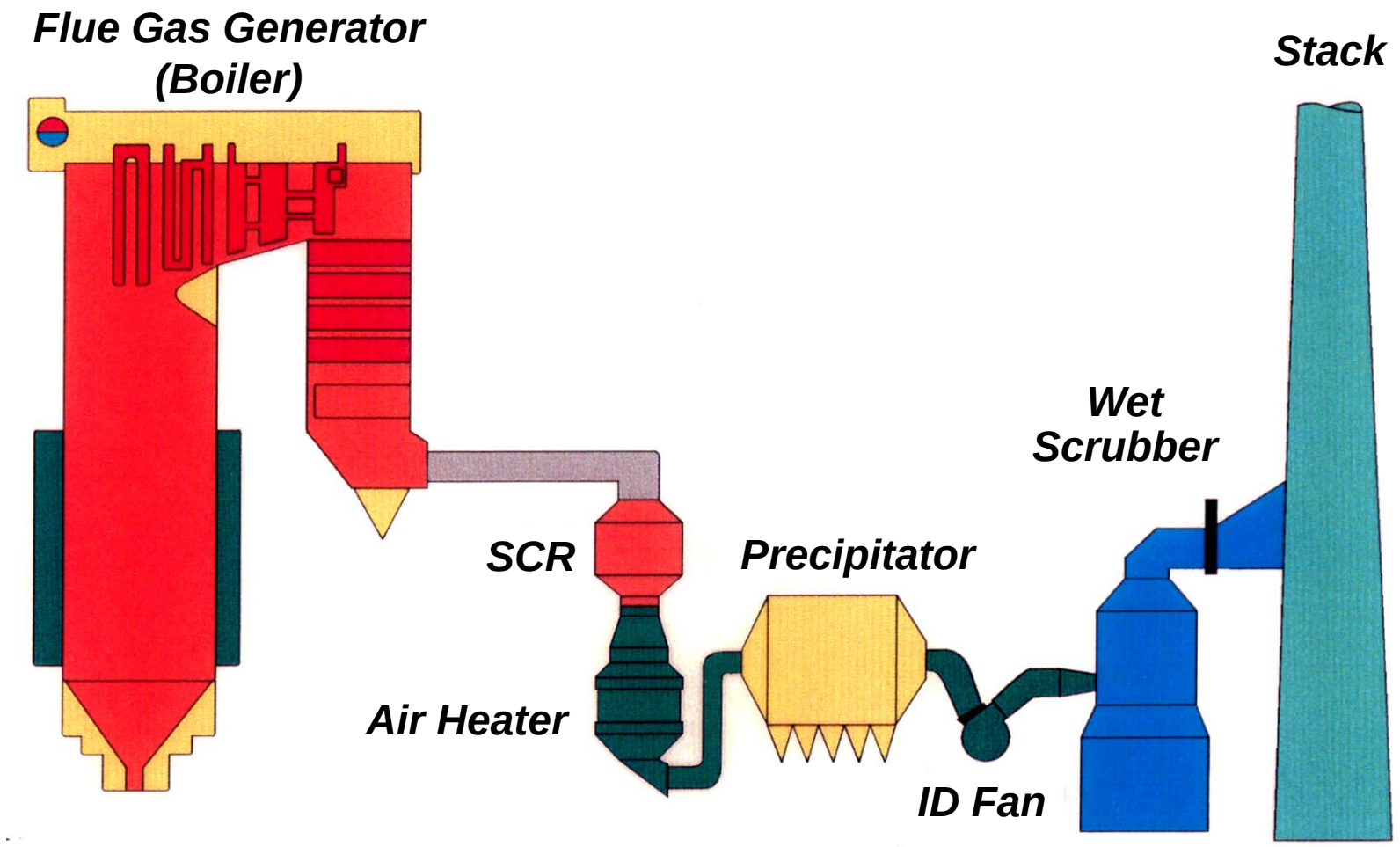
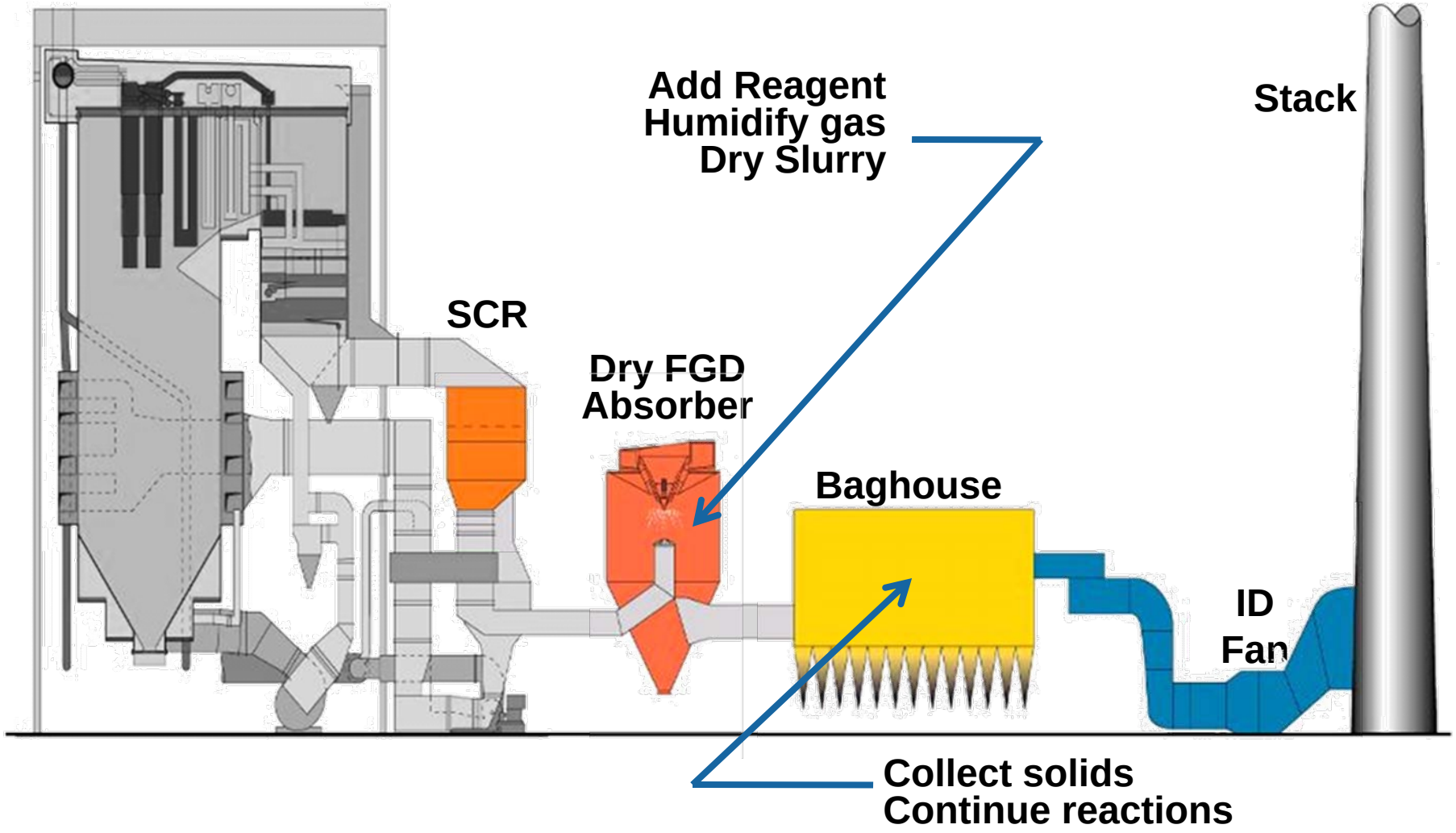
# Typical Wet FGD Configuration



# Typical Dry FGD Configuration



# *Wet FGD* Vs *Dry FGD*

- **Typically >1.5% sulfur coal**
- **>95% $SO_2$ removal**
- **More fuel flexibility**
- **Marketable byproduct**
- **Typically uses limestone ($5-15/ton)**

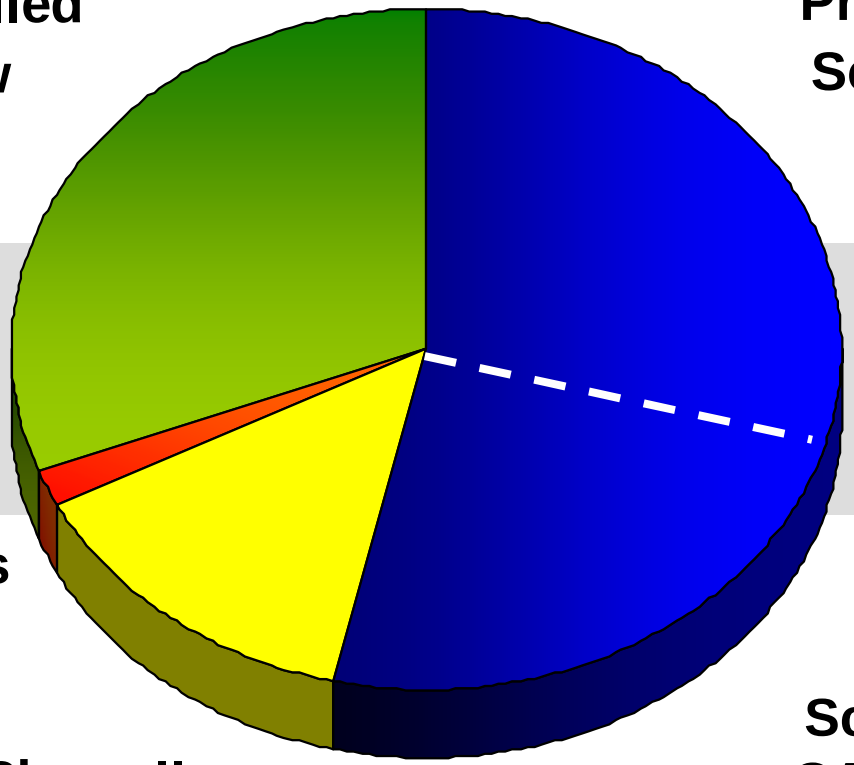
- **Typically <1.5% sulfur coal**
- **≤ 95% $SO_2$ removal**
- **Dry Product for Landfill**
- **Uses lime ($50-70/ton)**
- **Carbon Steel Construction**
- **System Simplicity, but Multiple Absorbers**
- **Final Filter last (Baghouse)**

# *Typical Wet vs Dry FGD Comparison*

| | WFGD | DFGD w/BH |
|---|---|---|
| Capital cost, D&E ($/KW) | 300-400 | 75% of WFGD |
| Reagent | | |
| Limestone, tons/hr @ $10/ton | 25 | |
| Lime, tons/hr @ $70/ton | | 12 |
| Water (gpm) | 560 | 430 |
| Power, incl. portion of ID fan (KW) | 8,000 | 6,000 |

- 600 MW unit, 1.7% S Bit coal, 95% $SO_2$ Removal
- Capital costs are very site specific and vary widely !

# *U.S. Coal-Fired Generating Capacity by Scrubber Status*



# Megawatts with FGD – Worldwide (1999)

| | USA | Non-USA | Total | % |
|---|---|---|---|---|
| Wet FGD | 82,859 | 116,374 | 199,233 | 87 |
| Dry FGD | 14,386 | 11,008 | 25,394 | 11 |
| Other | 2,798 | 2,059 | 4,857 | 2 |
| Total | 100,043 | 129,441 | 229,484 | 100 |
| Total[2] Coal-Fired Units | ~320,000 | ~530,000 | ~850,000 | |

**Source:**
**1 Status of SO2 Scrubbing Technologies, Jozewicz and Singer ARCADIS Geraghty & Miller, Inc., Srivastava and Tsirigotis, EPA, 1999 MegaSymposium, Atlanta, GA**
**2 B&W Internal Data**

# Megawatts with Wet FGD – Worldwide (1999)

| | $MW_e$ | % |
|---|---|---|
| Limestone | 163,330 | 82 |
| Lime | 31,514 | 16 |
| Other | 4,389 | 2 |
| Total | 199,233 | 100 |

Source:
Status of SO2 Scrubbing Technologies, Jozewicz and Singer ARCADIS Geraghty & Miller, Inc., Srivastava and Tsirigotis, EPA, 1999 MegaSymposium, Atlanta, GA

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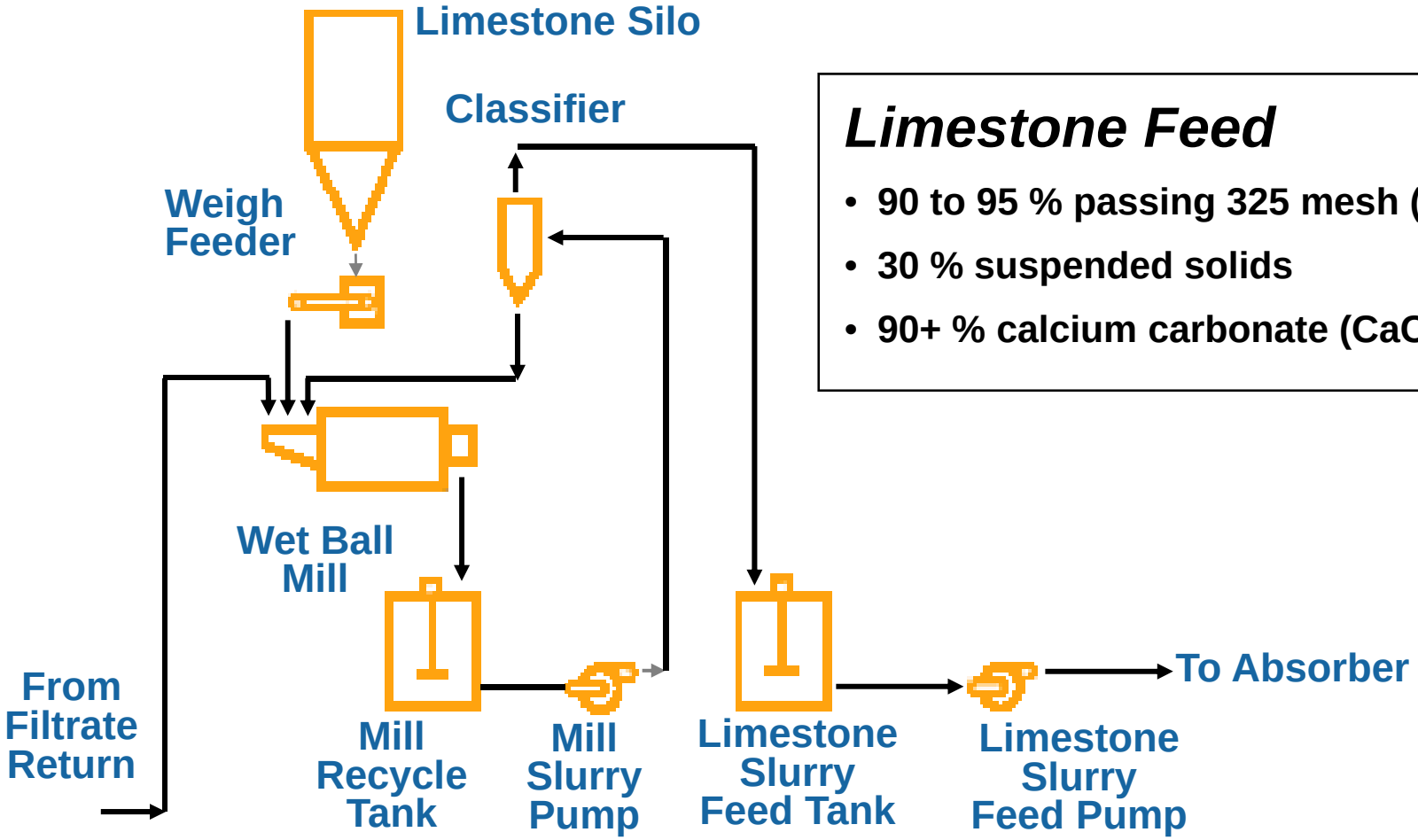
# *Characteristics of Wet FGD Systems*

- **Coal sulfur levels of 0.2 to 8 %**
- **Inlet $SO_2$ ranges from 200 - 6500 ppmv**
- **Removal efficiencies up to 99 %**
- **98% removal typically required today**
- **Mature Technology: 4th Generation**
- **One tower per boiler; even 1300 MW units**
- **Added benefit: ability to remove oxidized mercury**
- **Availability better than the boiler today**

# *Wet FGD Process Overview*

- **Prepare reagent (such as limestone, lime, or soda ash)**
- **Quench / Humidify the Flue Gas**
- **Absorb $SO_2$**
- **React $SO_2$ with reagent**
- **Oxidize to Gypsum**
- **Remove slurry from flue gas**
- **Separate product (ie, gypsum) from water slurry (dewater)**

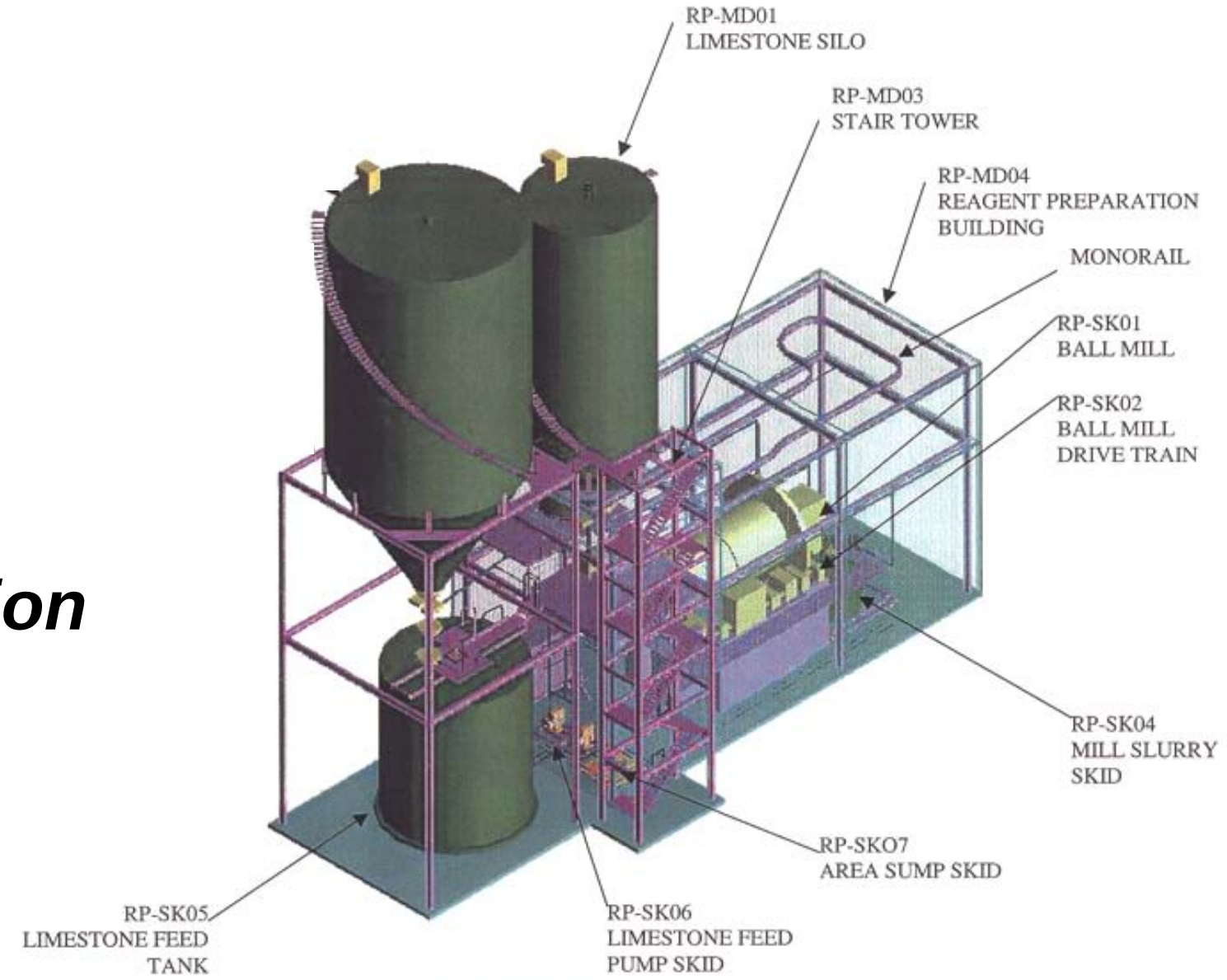
# Limestone Preparation System




## Limestone Feed

- 90 to 95 % passing 325 mesh (44 microns)
- 30 % suspended solids
- 90+ % calcium carbonate ($CaCO_3$)

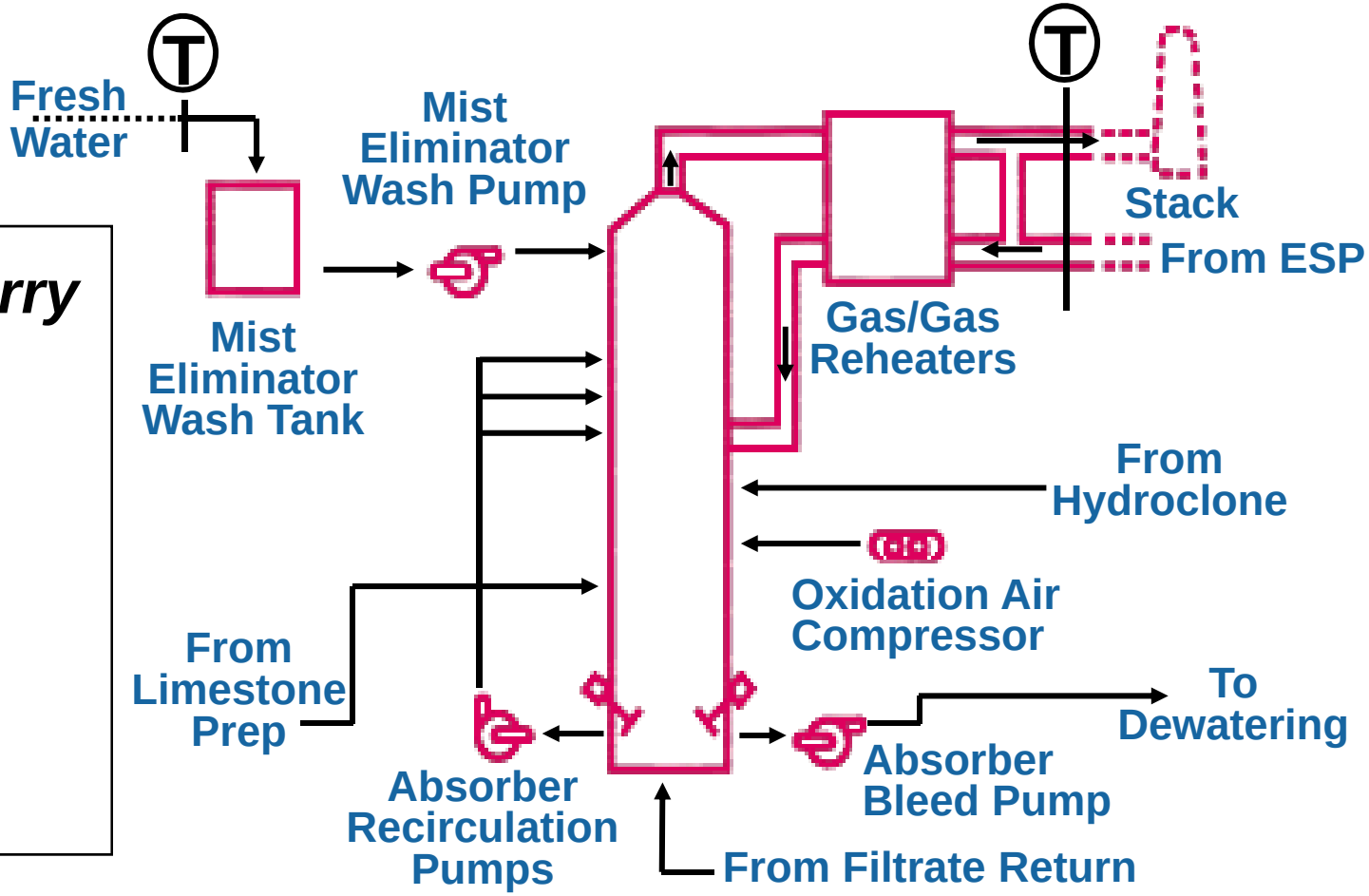
# *Reagent Preparation Area*



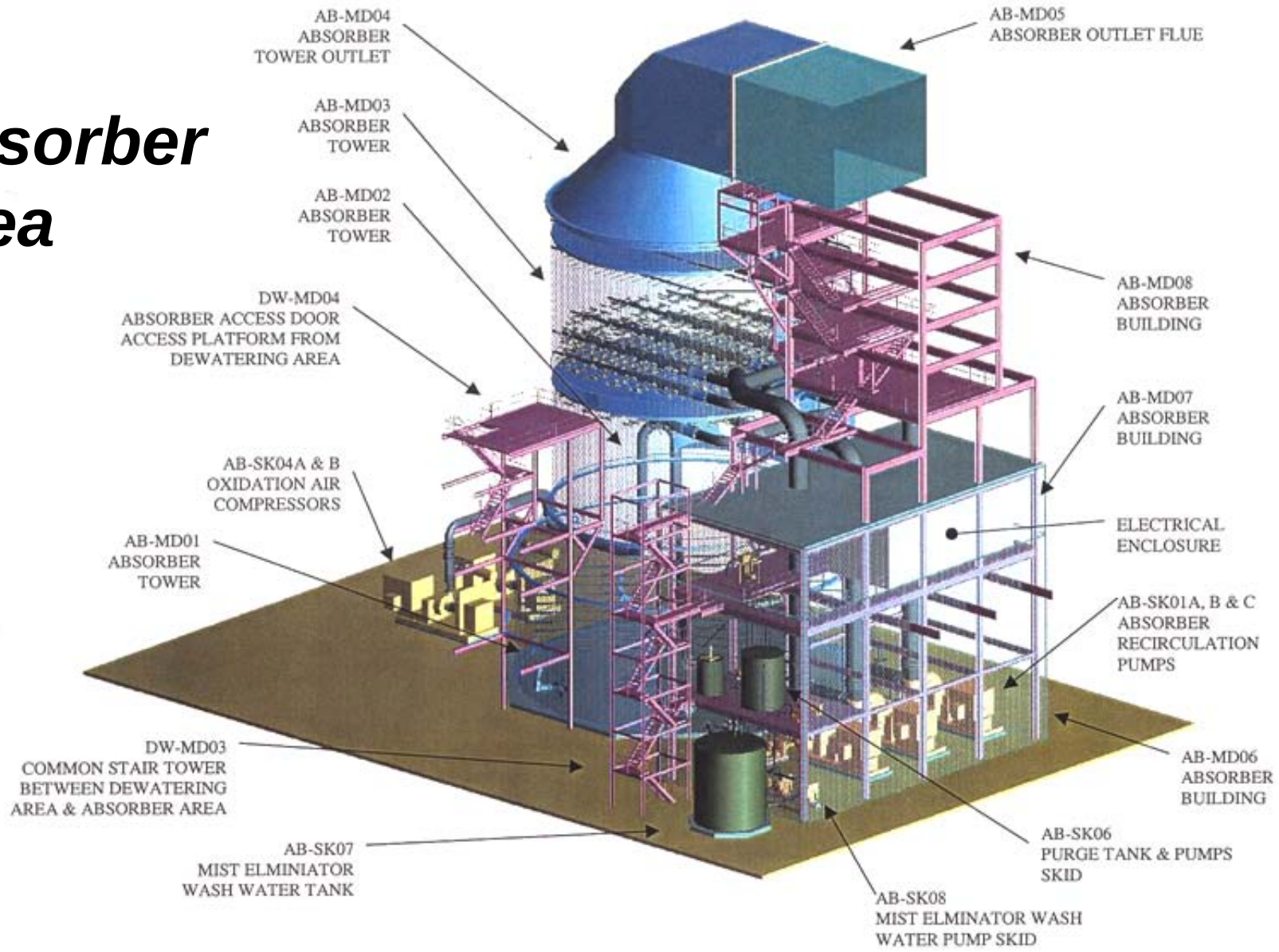
# Absorber System

## Absorber Slurry

- 15 - 20 % suspended solids
- 92%+ gypsum (calcium sulfate, $CaSO_4 \cdot 2H_2O$)
- Residual calcium carbonate, inerts and flyash



# Absorber Area



# *In a Wet FGD Absorber: A Very Heavy Rainstorm !*

**Imagine the heaviest rainstorm you have experienced, which might be 6 inches of rain per hour.**

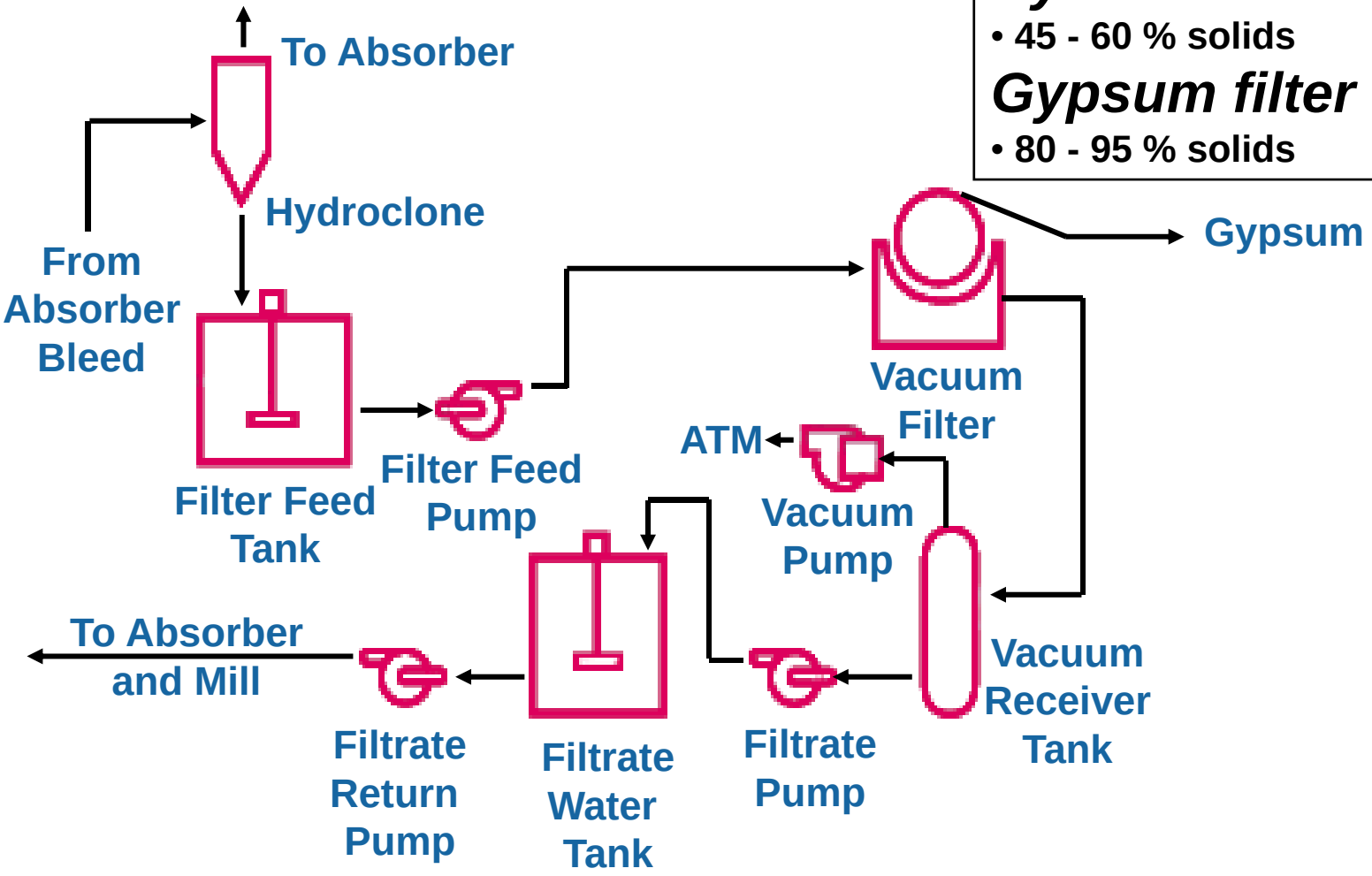
**100 L/G (gal/1000 $ft^3$ of flue gas) in a Wet FGD absorber operating at a typical 12 foot per second superficial gas velocity is equivalent to 6929 inches per hour !**

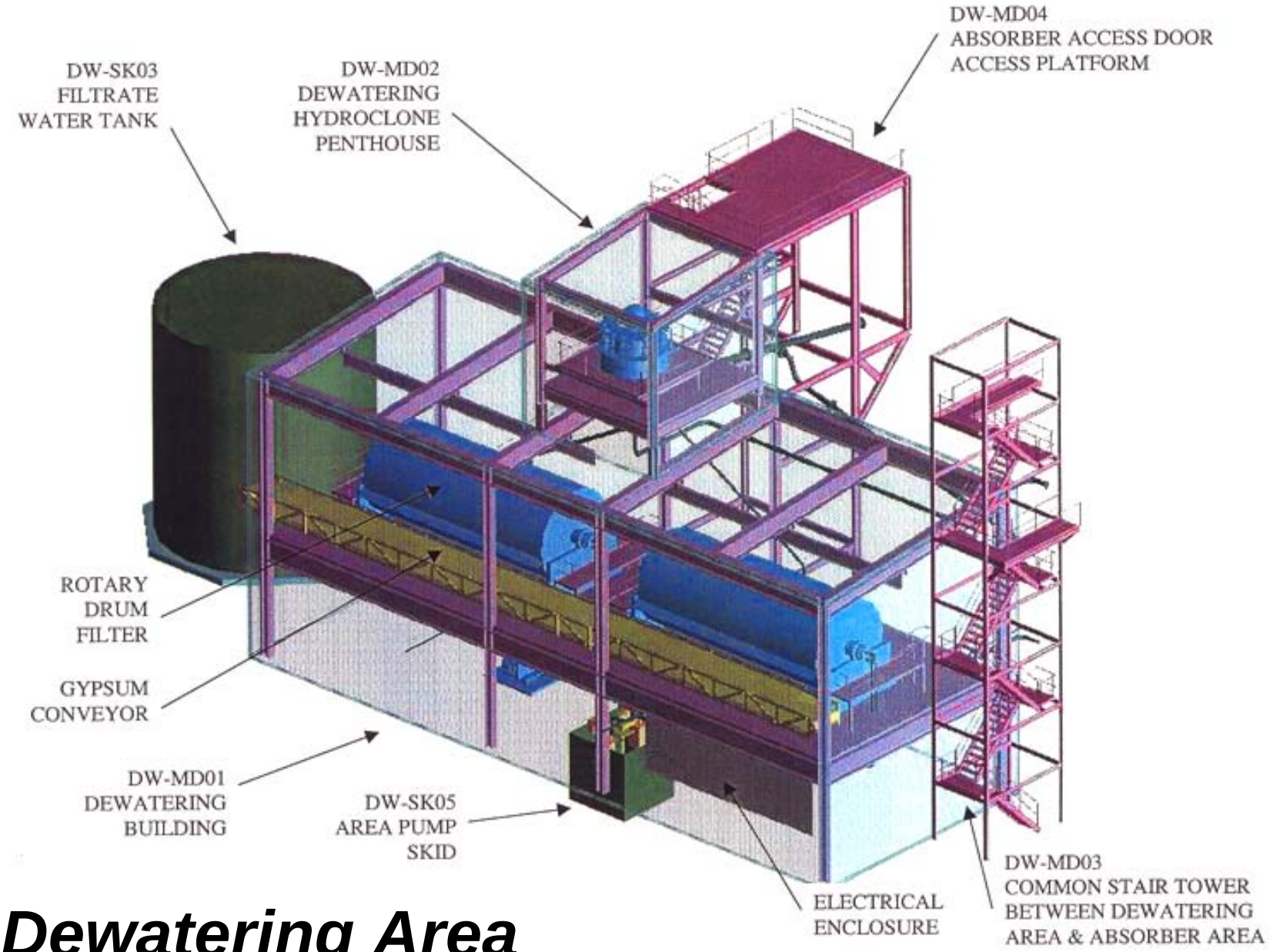
# Dewatering System

***Absorber Bleed***
- 15-20 % solids

***Hydroclone Underflow***
- 45 - 60 % solids

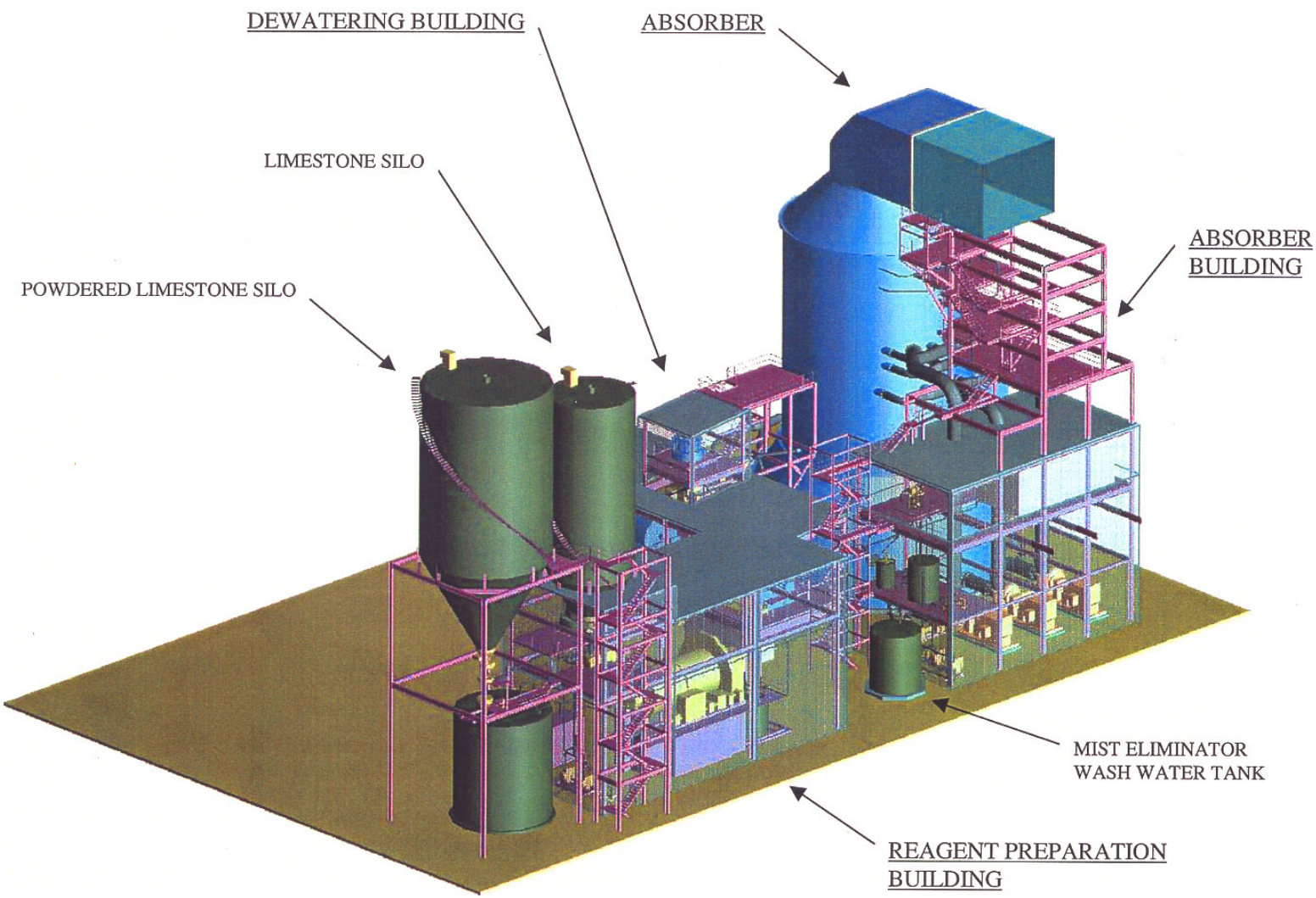
***Gypsum filter cake***
- 80 - 95 % solids






# *Dewatering Area*

# Example of Compact Plant Arrangement



# *Wet FGD Equipment Terminology*

**Reagent Preparation** - A system for preparing the reagent slurry used for sulfur dioxide (SO2) removal, typically with grinding mills for limestone or slakers for lime.

**Absorber or Absorber Tower** - Also called a scrubber, the vessel where the flue gas passes through a slurry spray for SO2 absorption and removal.

**Absorber Spray** - A system of spray nozzles to administer a distributed spray of slurry within the absorber tower.

**Contact Device** - A perforated plate installed in the absorber to increase contact between the flue gas and the slurry.

**Recirculation Tank** - A vessel which receives and stores the slurry which has been sprayed into an absorber. The slurry from this tank is recirculated to the spray nozzles.

**Mist Eliminator** - A device used to separate slurry droplets from the scrubbed flue gas at the absorber outlet.

# *Wet FGD Equipment Terminology (cont'd)*

**Absorption** - Process by which SO2 is transferred from the gaseous state to the liquid state.

**Slurry** - A pumped mixture of solids (reaction products with added limestone or lime) and water.

**pH** - A measurement of the relative acidity or alkalinity in a liquid. Neutral on the pH scale is 7; below 7 is acidic, above 7 is alkaline. Typical operating pH is 5.5 .

**L/G ("L over G")** - The ratio of recirculated slurry sprayed into the absorber, in gallons per minute (gpm) per 1000 actual cubic feet per minute (ACFM) of saturated flue gas treated.

**Forced Oxidation** - A process where compressed air is injected into the recirculation tank to oxidize the sulfite present in the slurry to sulfate. Some natural oxidation occurs as the result of molecular oxygen in the flue gas.

**Stoichiometry** - The ratio of reactive components in the reagent (limestone or lime) to the amount of sulfur dioxide being removed.

**Carry-over** - Solids or liquid which pass through a mist eliminator and escape into the outlet flues and up the stack.

# *Wet FGD Equipment Terminology (cont'd)*

**Dewatering** - A system where the water is removed from the reaction products and inerts. The reclaimed water is reused. Dewatering is normally accomplished in two steps:

**Primary dewatering** from about 15 % solids to approximately 50 % solids is normally accomplished by the centrifugal forces of a hydroclone; older systems relied on gravitational forces in a thickener.

**Secondary dewatering** to approximately 90 % solids for forced-oxidized gypsum is normally accomplished with a vacuum filter or centrifuge. The gypsum can be washed for use as a byproduct. Naturally oxidized product with a higher calcium sulfite content is more difficult to dewater and is normally filtered to about 65 % solids. This material is normally disposed as a fly ash admixture in a landfill.

***Please pickup a Lexicon!***

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# *Wet FGD Absorber Types*

**Configuration**

- **Open Spray Tower**
- **Spray Tower with Tray**
- **Double Contact Flow Scrubber**
- **Bubbling reactor**
- **Packed tower**

**Method**

- **Once-through**
- **Regenerable**

**Reagent**

- **Calcium-based - limestone or lime**
- **Sodium-based - soda ash, caustic soda**

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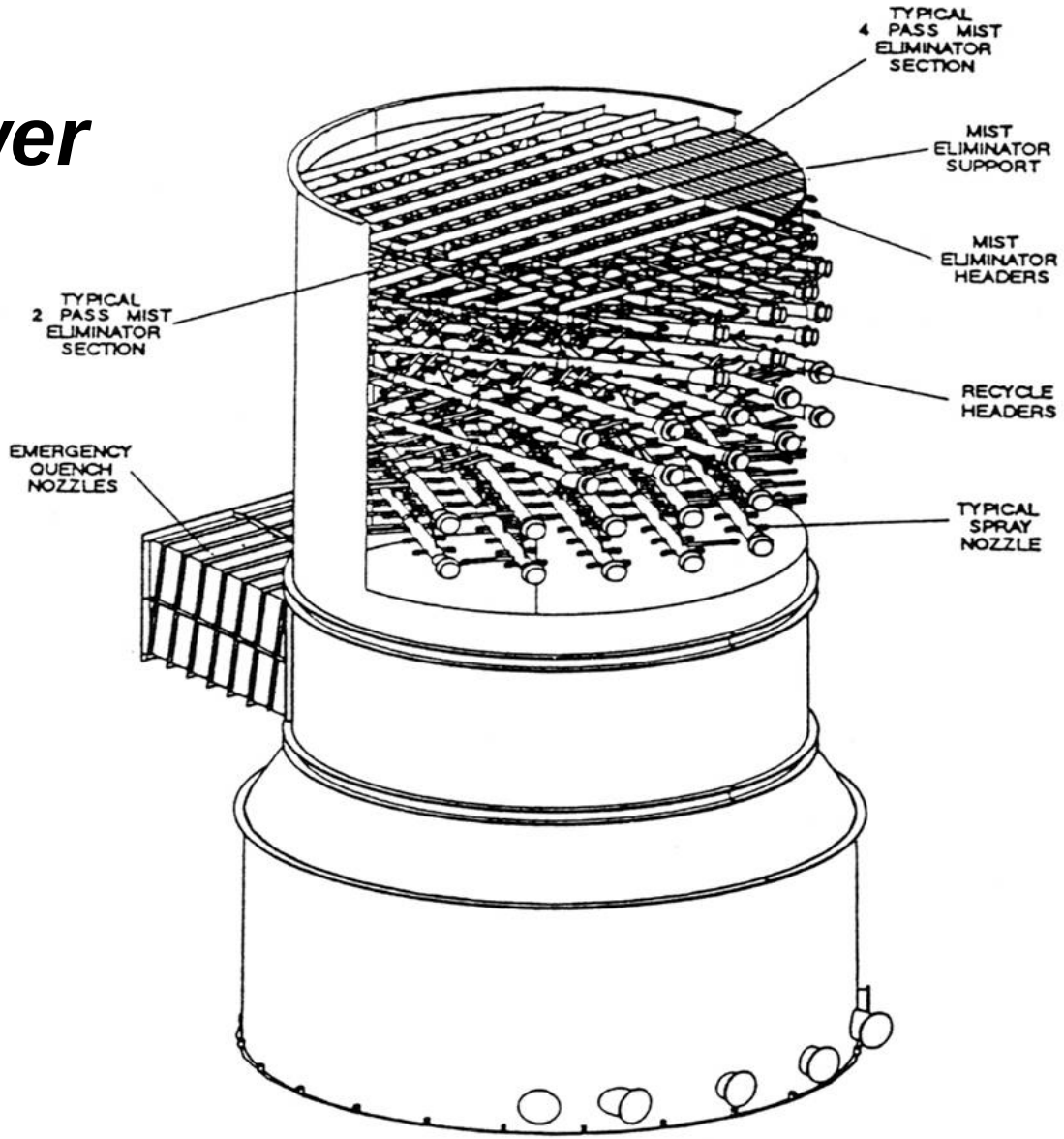
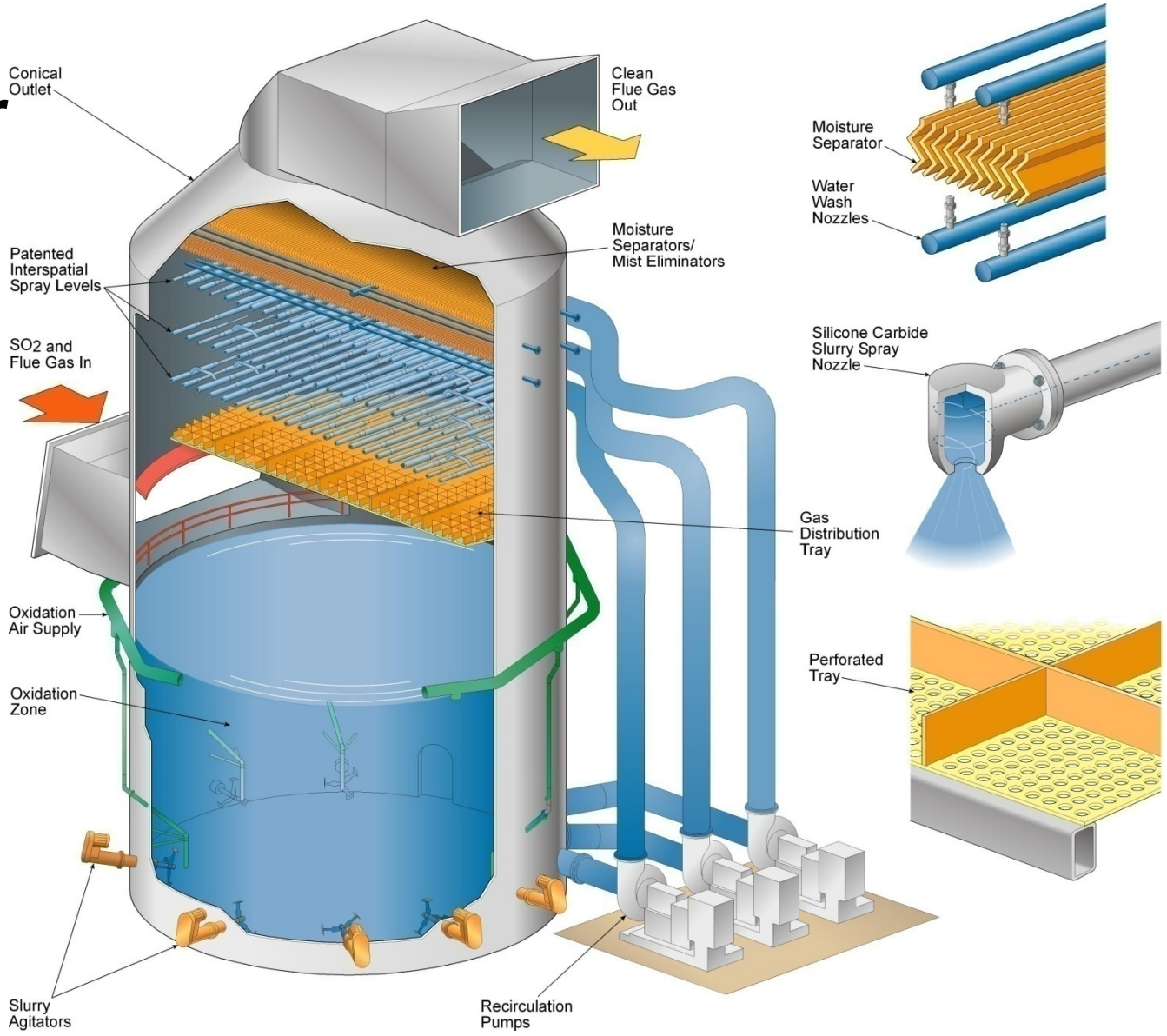
# *Typical Open Spray Tower with or without Wall Rings*



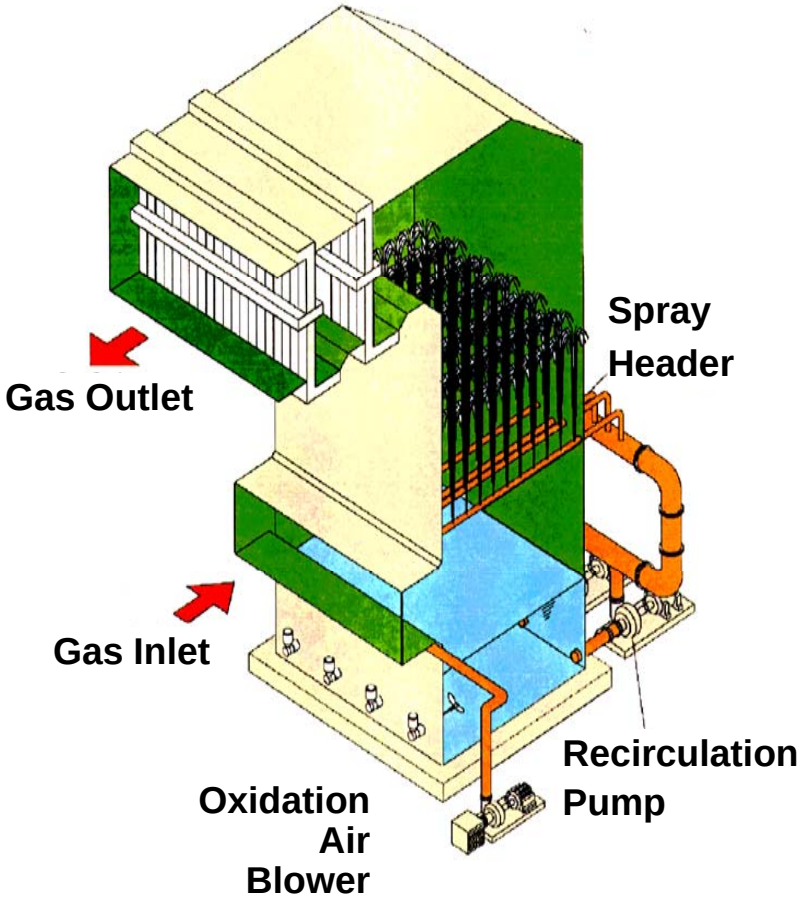
# Open Spray Tower

**Source:**
**Babcock Power Inc.**

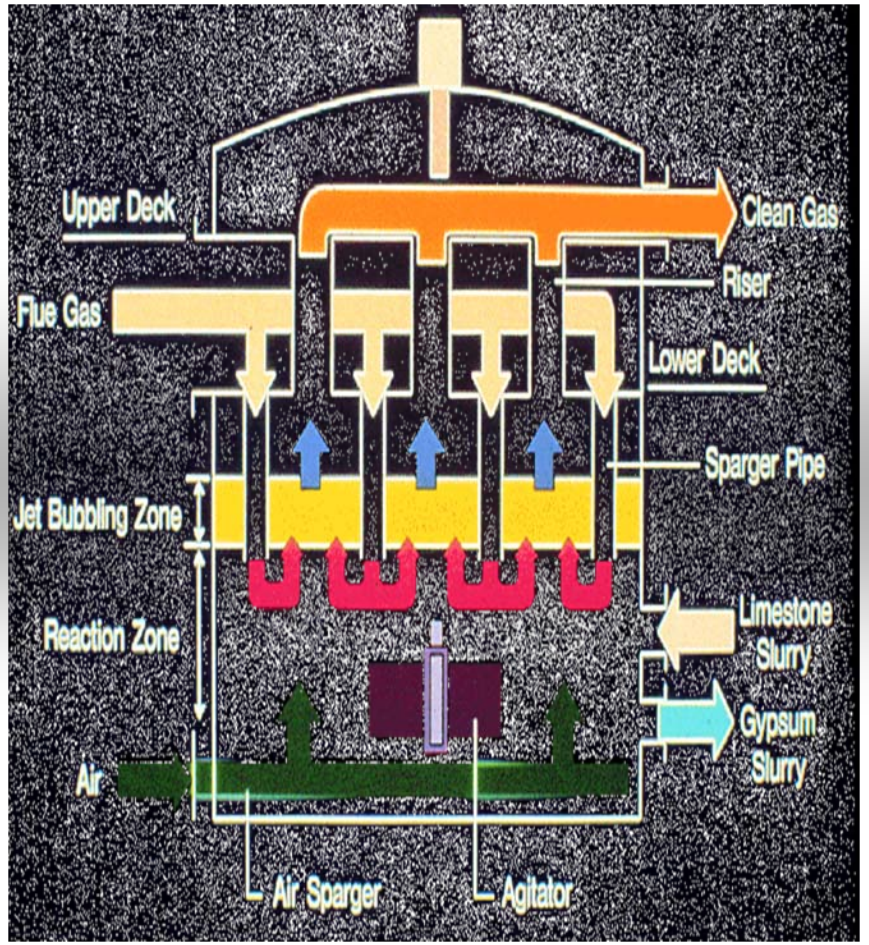
# B&W Spray Tower Absorber with Tray

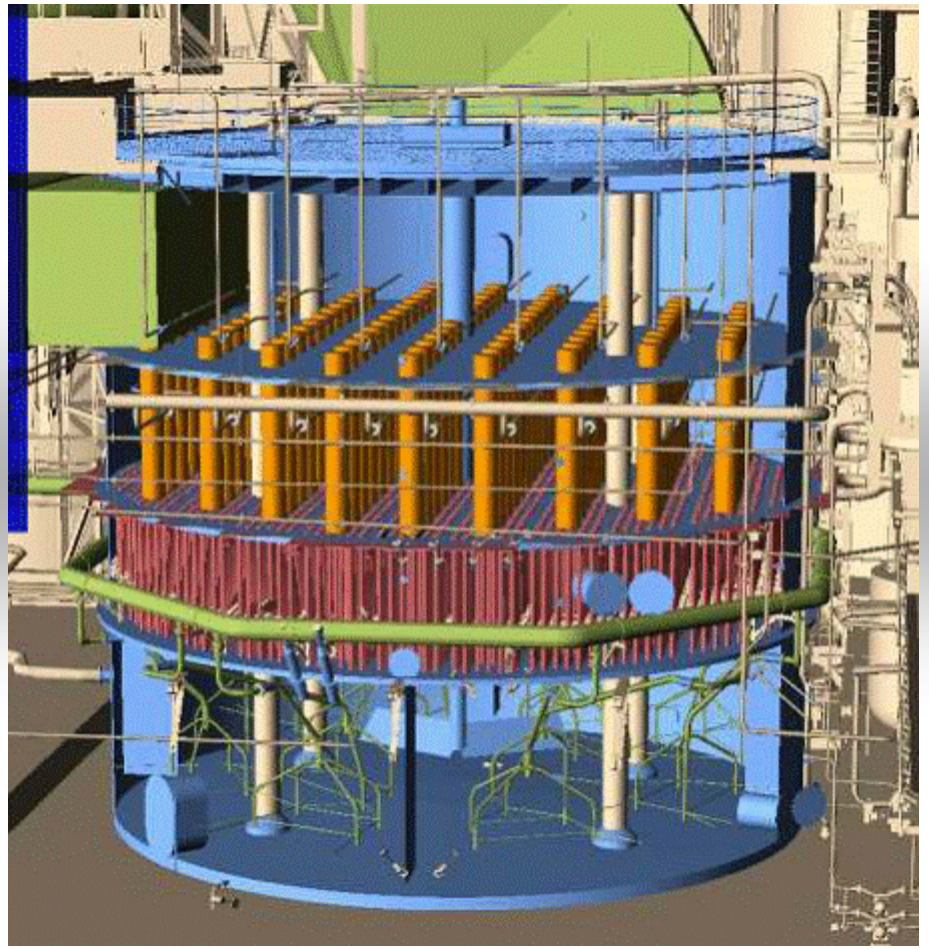


# Double Contact Flow Scrubber MHI - Advatech




# 千代田化工建設 (Chiyoda) - Jet Bubbling Reactor



# Packed Towers - No Longer Used

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# *Absorber Tower Sizing*

## Diameter or Cross-section

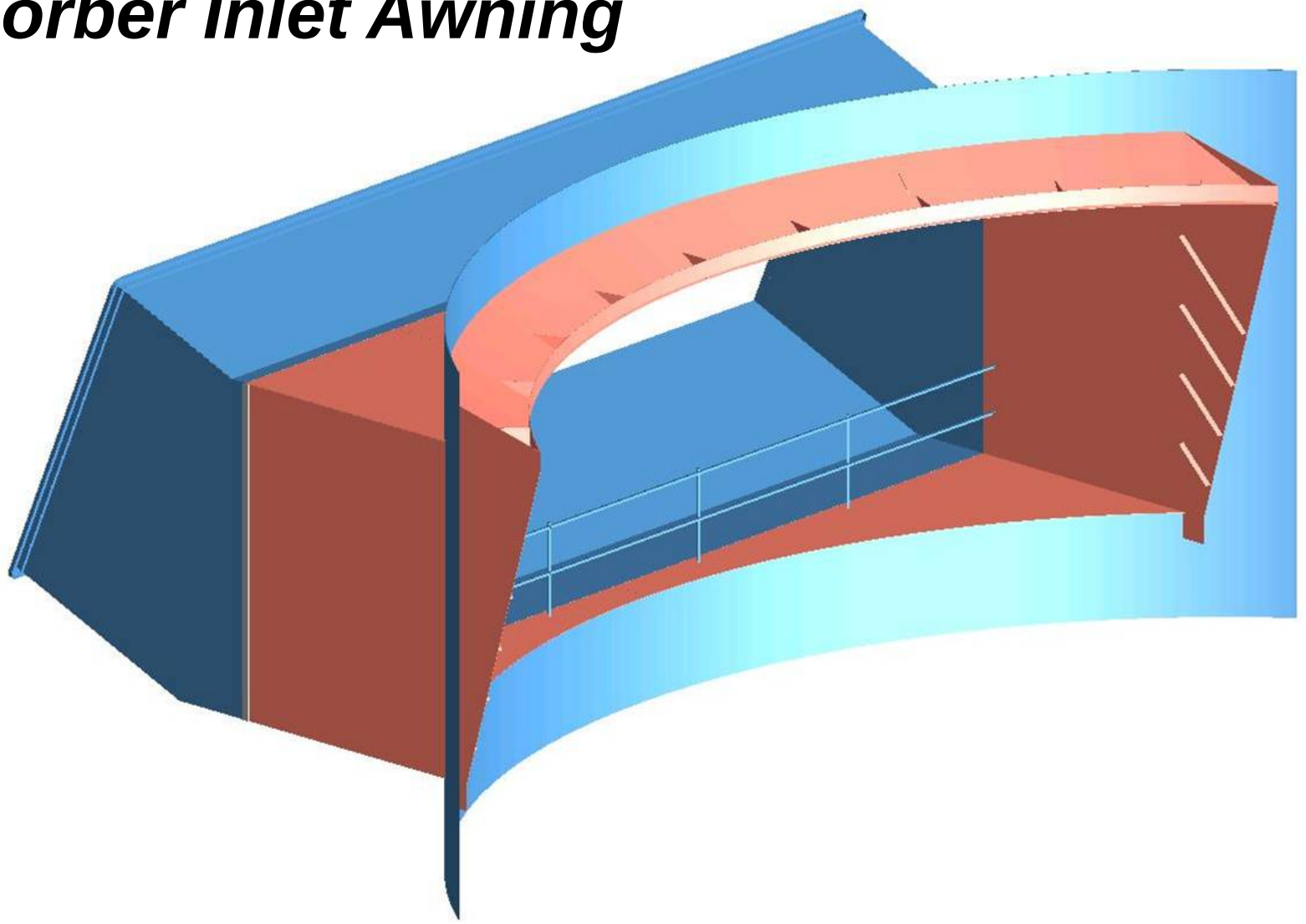
- Set by gas flow
- Set for proper gas contact & to prevent mist carryover
- Usually 10-14 FPS superficial gas velocity, higher with MHI design, lower with Chiyoda

## Height

- Gas flow and inlet opening width sets inlet
- Number of headers sets absorption zone height
- L/G & Retention Time sets recirculation tank volume
- Mist eliminator height or depth is fixed

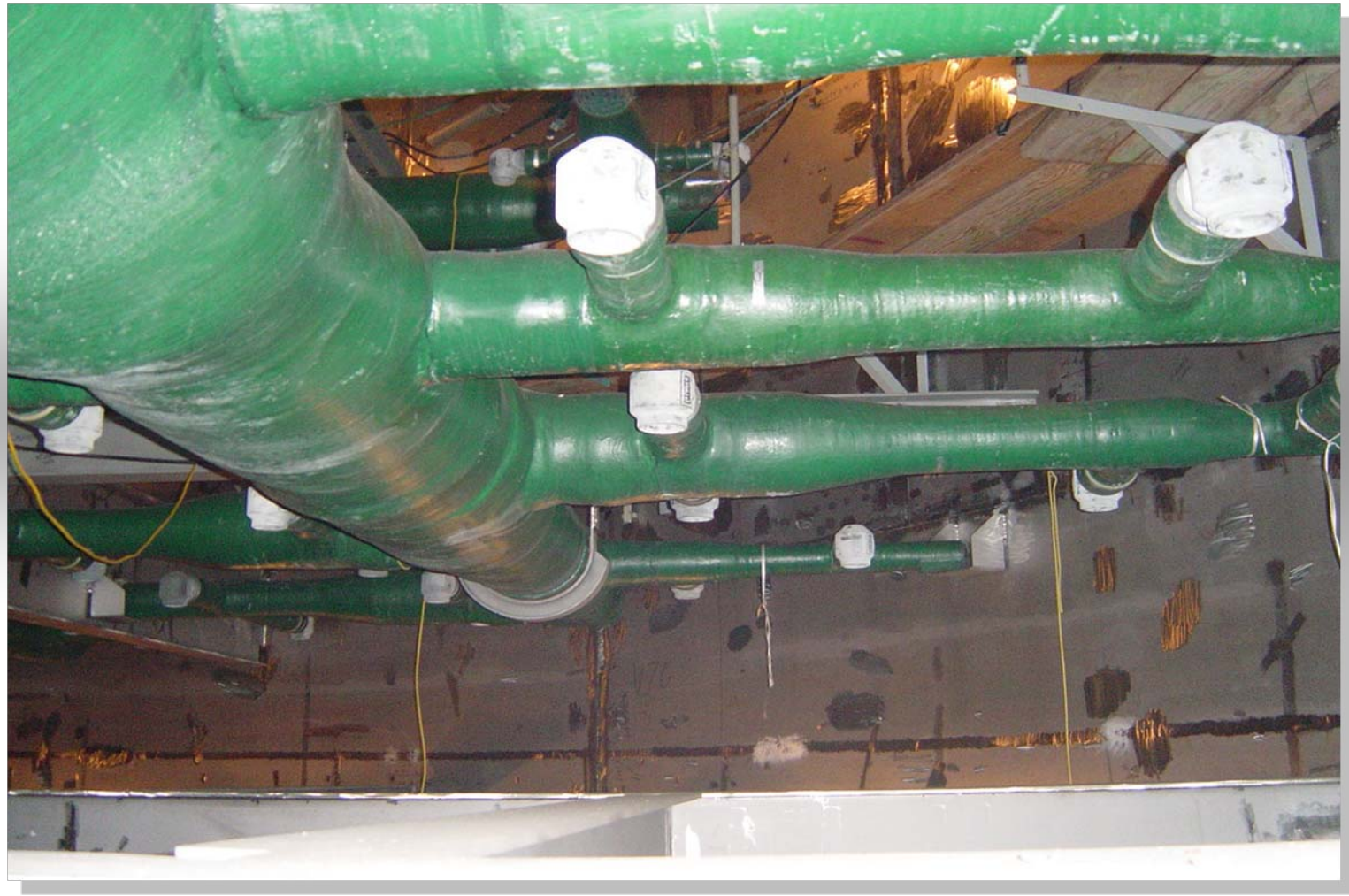
**Note: Higher $SO_2$ removal efficiency and $SO_2$ inlet concentration increases the required Liguid to Gas Ratio (L/G) and hence increases the number of headers, spray zone height and recirculation tank retention time and volume.**

# Absorber Inlet Awning

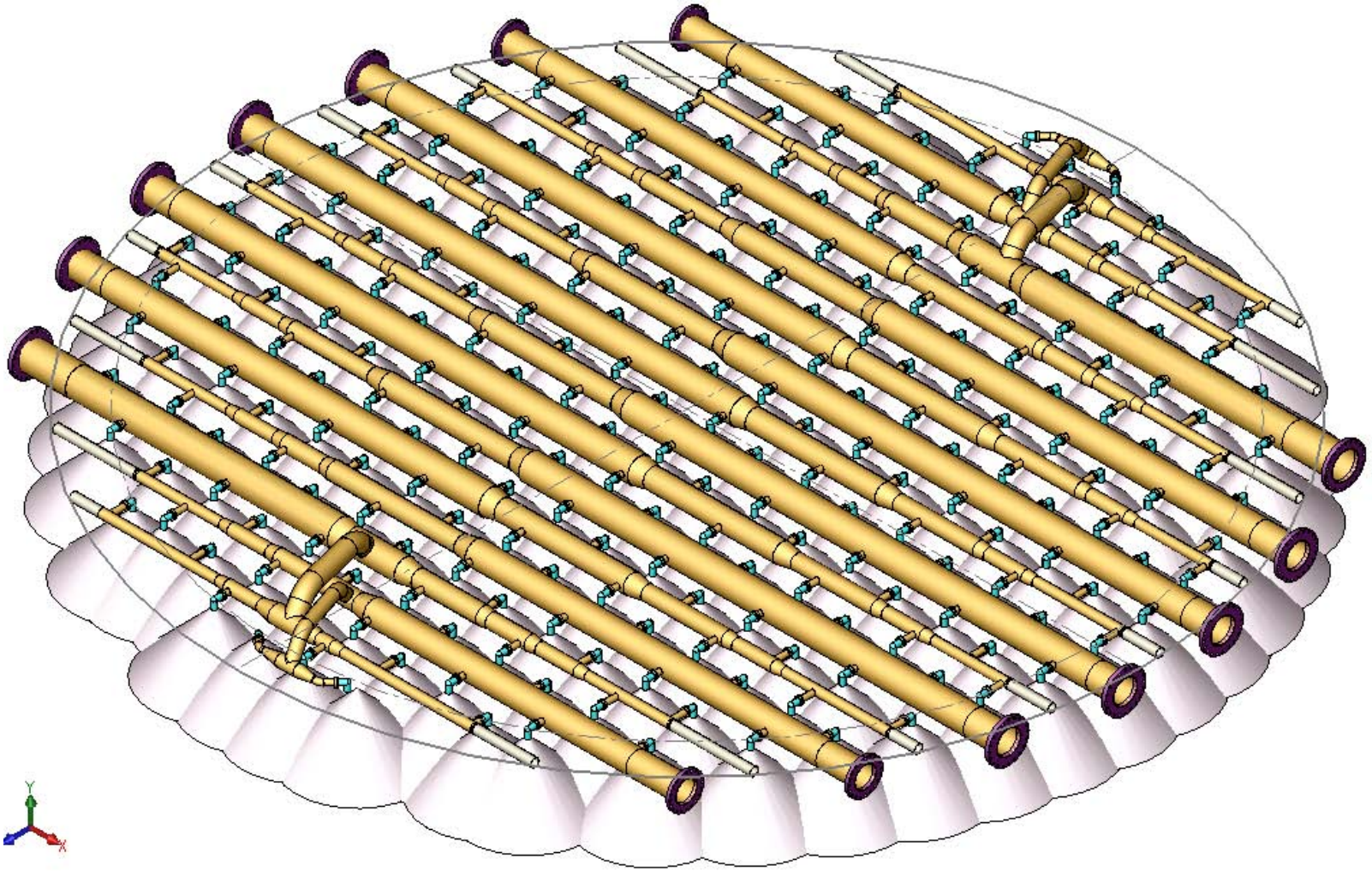


# *Alloy Spray Headers*

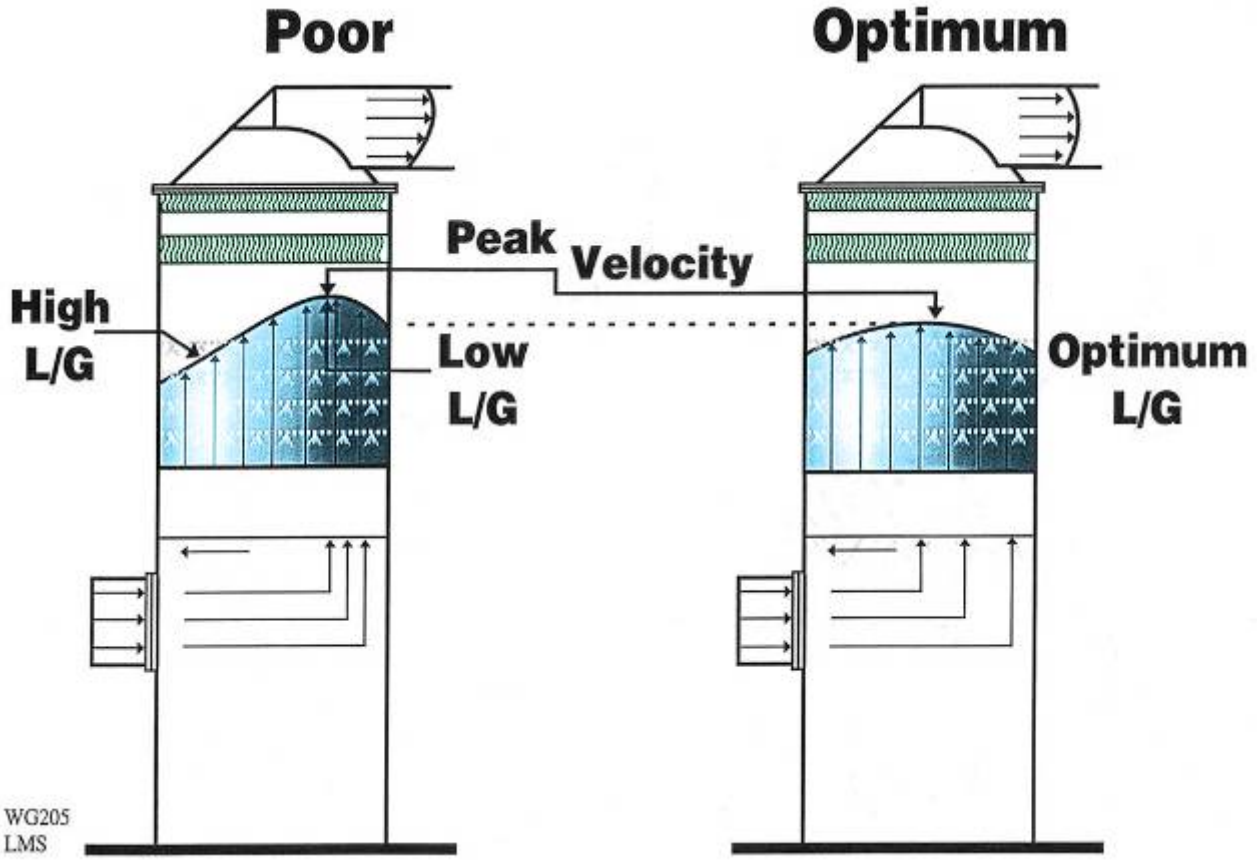
# FRP Spray Headers



# Spray Headers & Nozzles: Full Coverage



# *Importance of Gas Flow Distribution*




- Improved $SO_2$ removal
- Less carryover to ME

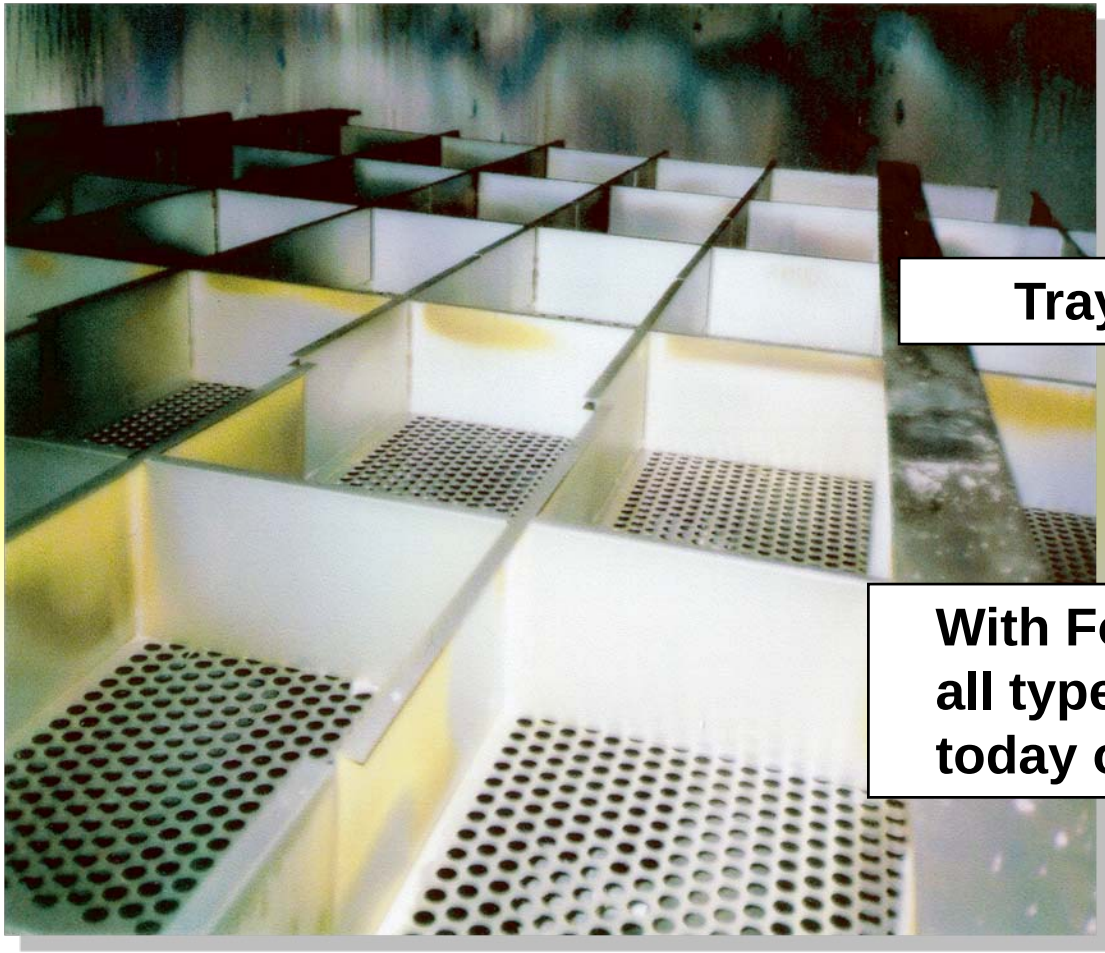
# Gas Distribution Tray

# Absorber Gas Inlet with Tray

# Absorber Spray Headers & Tray

***Taiwan Power Unit 5 – One-year Inspection***

# *Absorber Tray*



**Trays Stay Clean**

**With Forced Oxidation, all types of FGD systems today operate scale-free**

# Absorber Tray

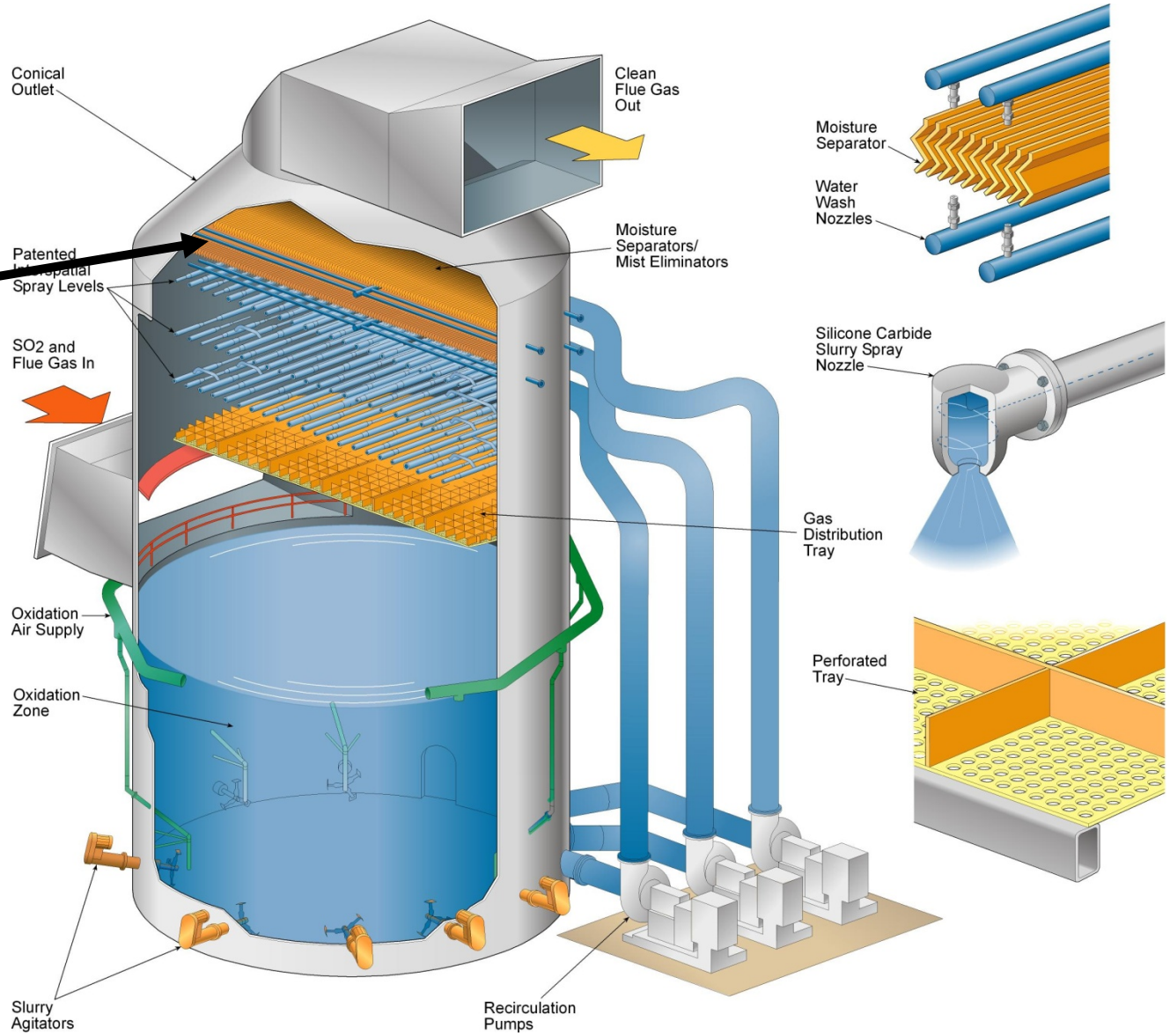
**Two-Year Outage Inspection (No-cleaning)**

# Basic Wet FGD Controls

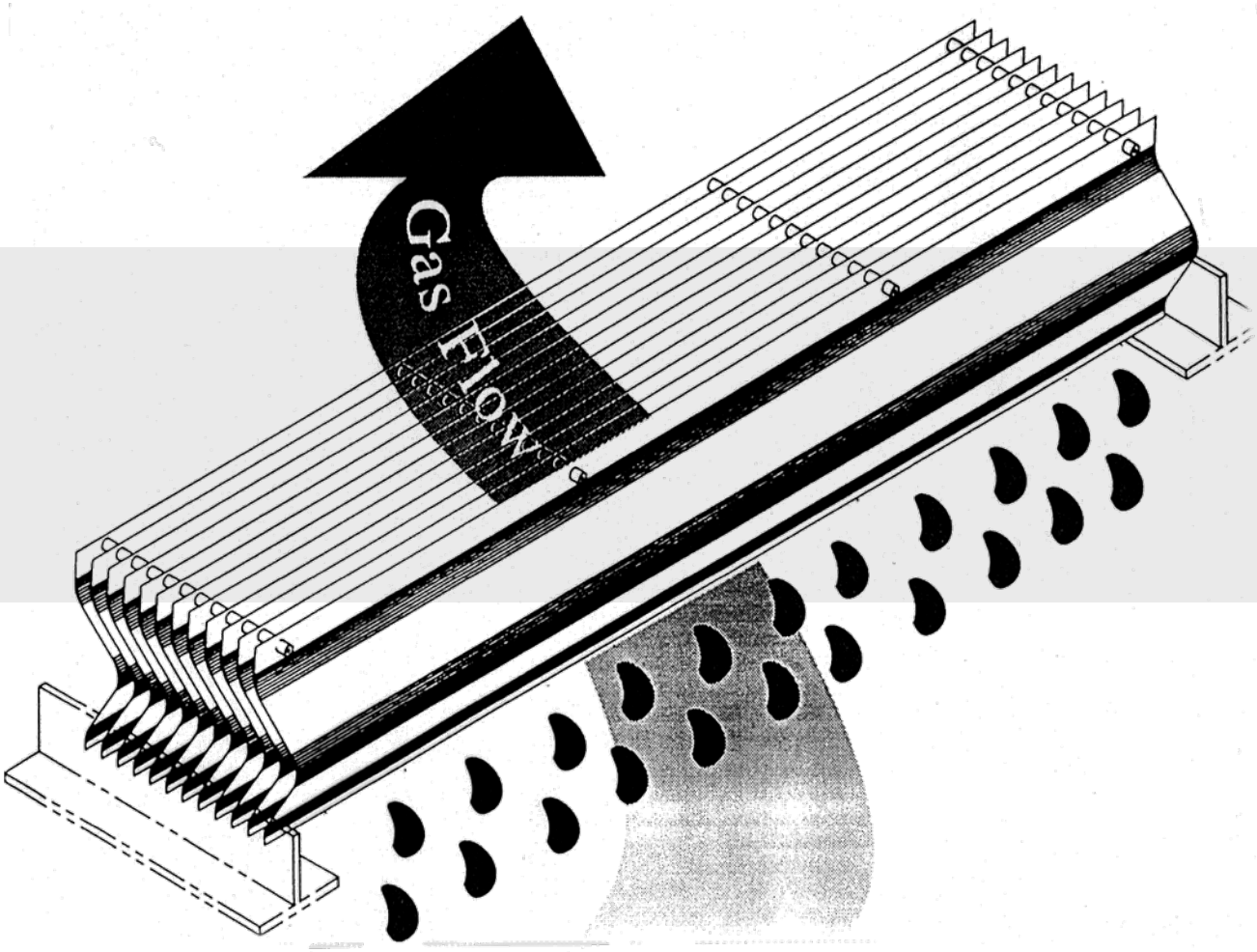
- **pH control -**
  Feed limestone slurry

  Use $SO_2$ inlet and boiler load as feed forward
- Absorber T**ank Level** -
  Turn on bleed pump
- **Density -**
  Add water thru mist eliminators
- Milling system - batch operation

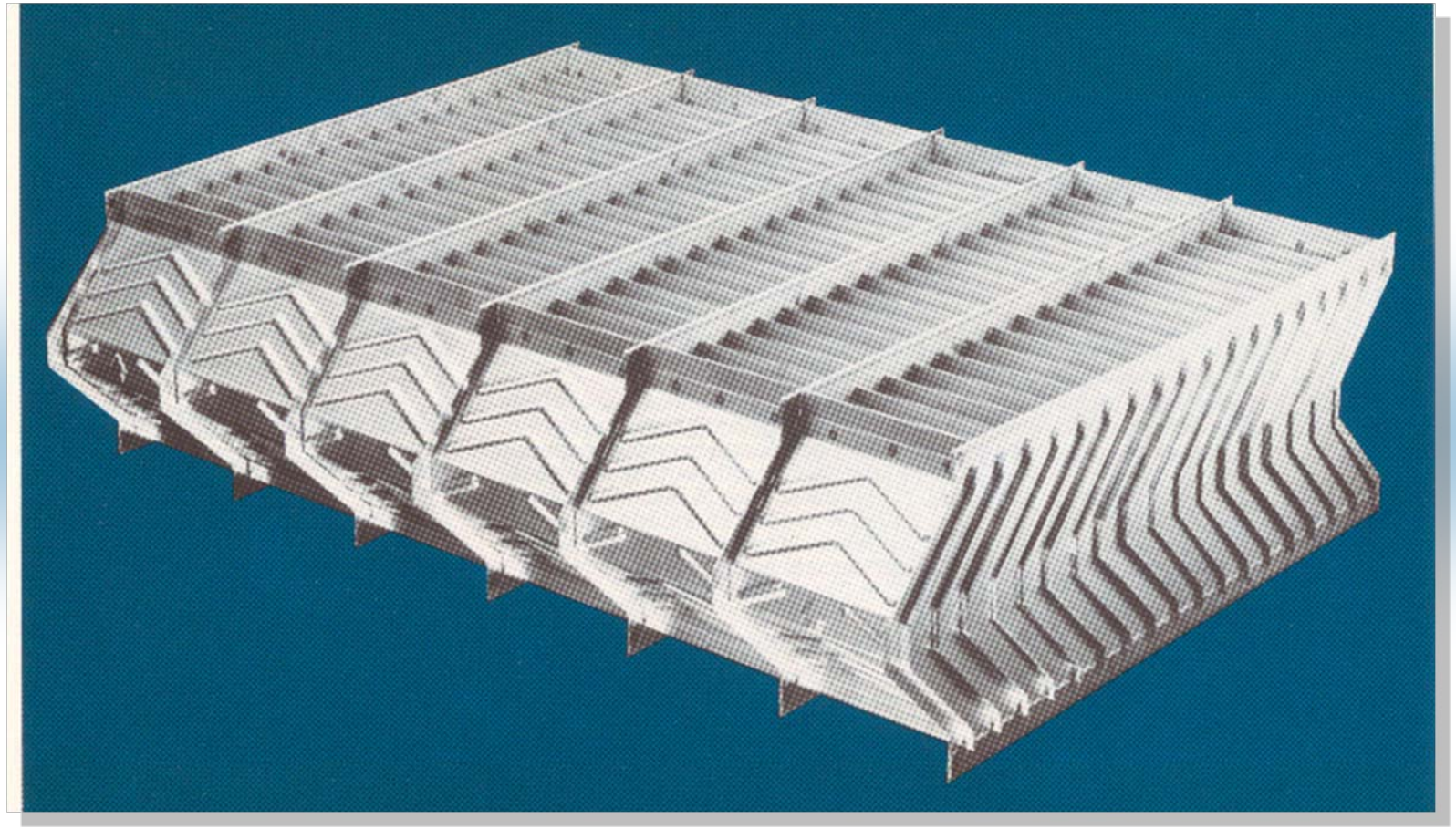
# *Absorber Tower: Mist Eliminators*



# Vertical Flow Mist Eliminator

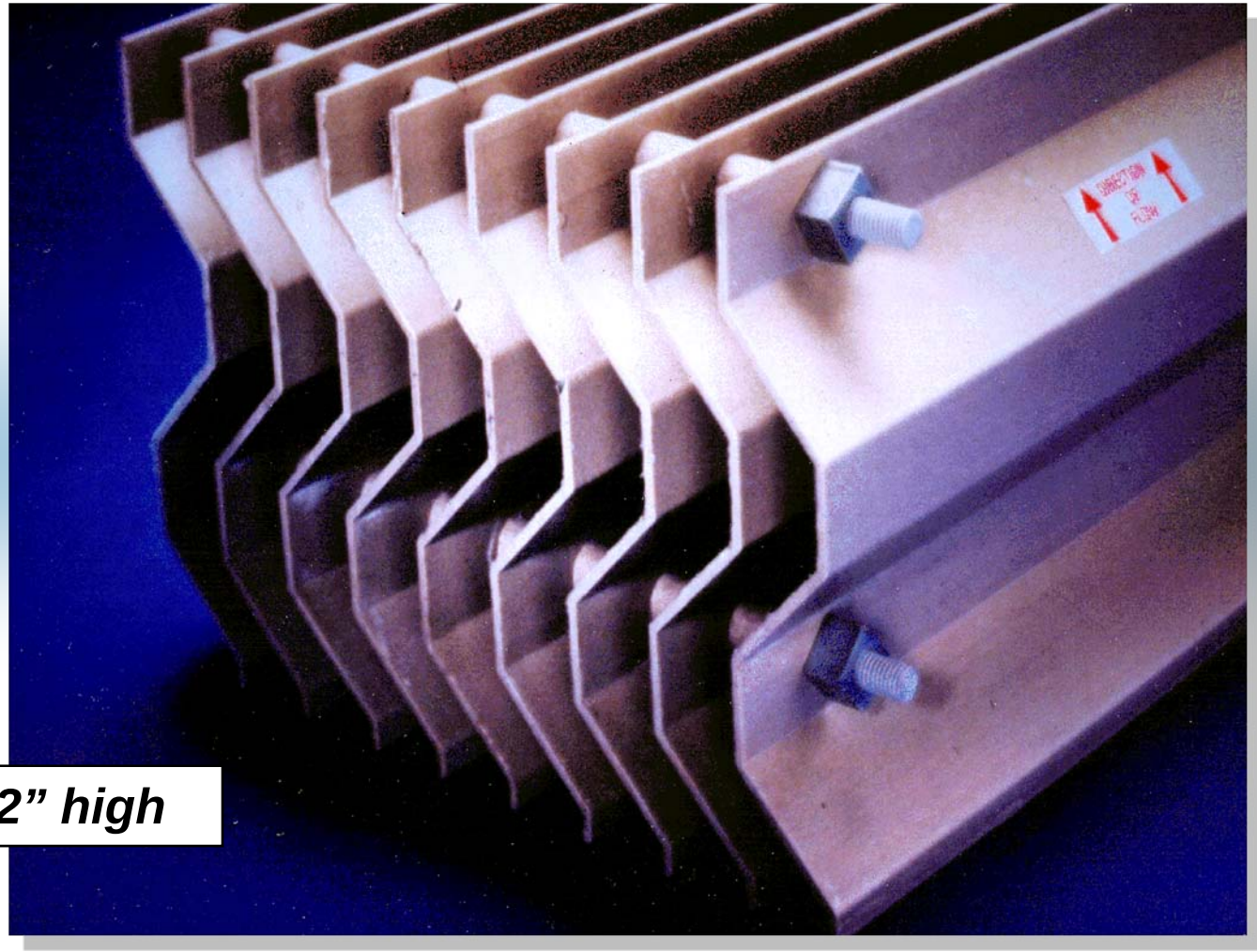


# *One type of Mist Eliminator*



**Source: Munters**

# *Another type of Mist Eliminator*

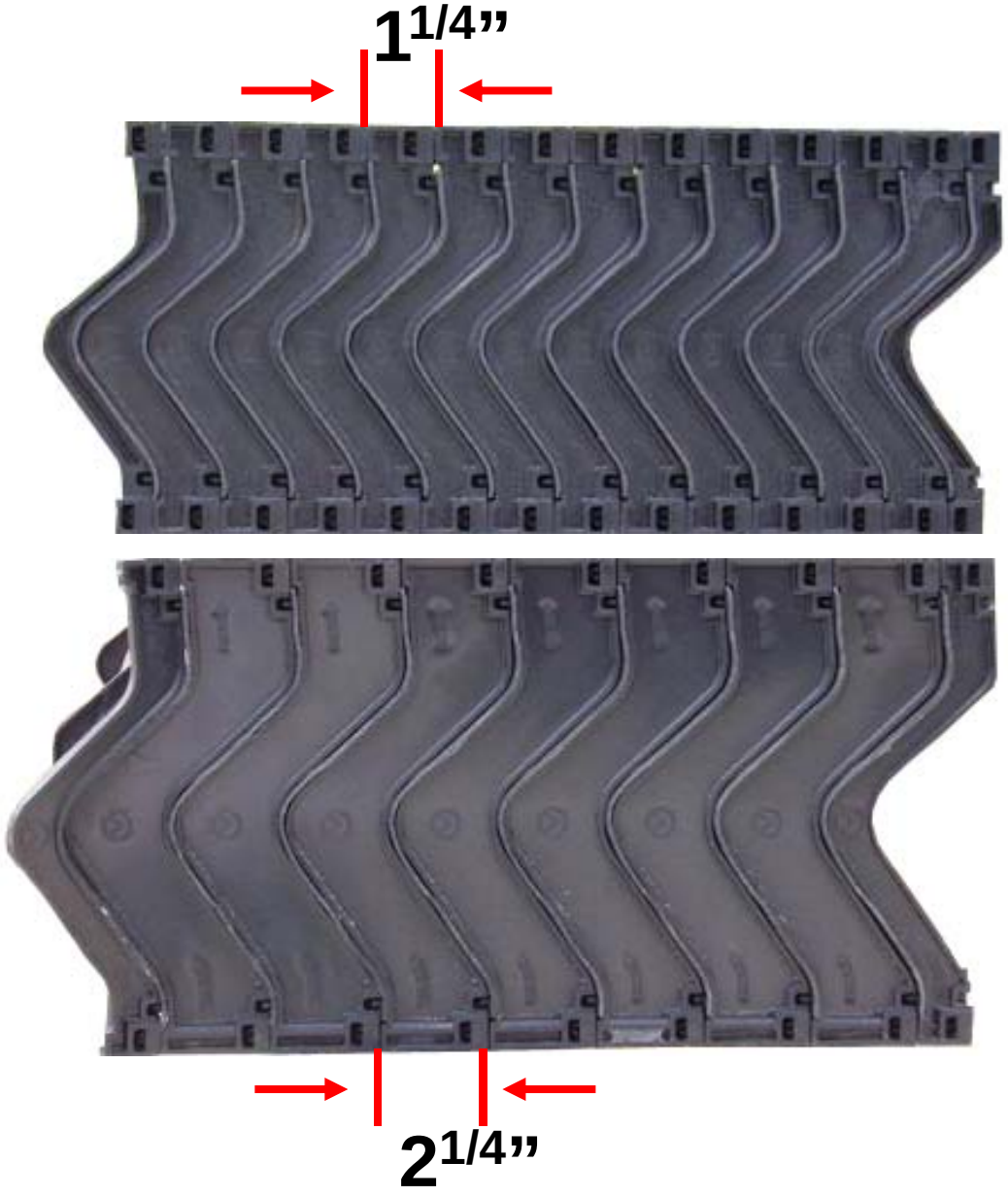


***9” to 12” high***

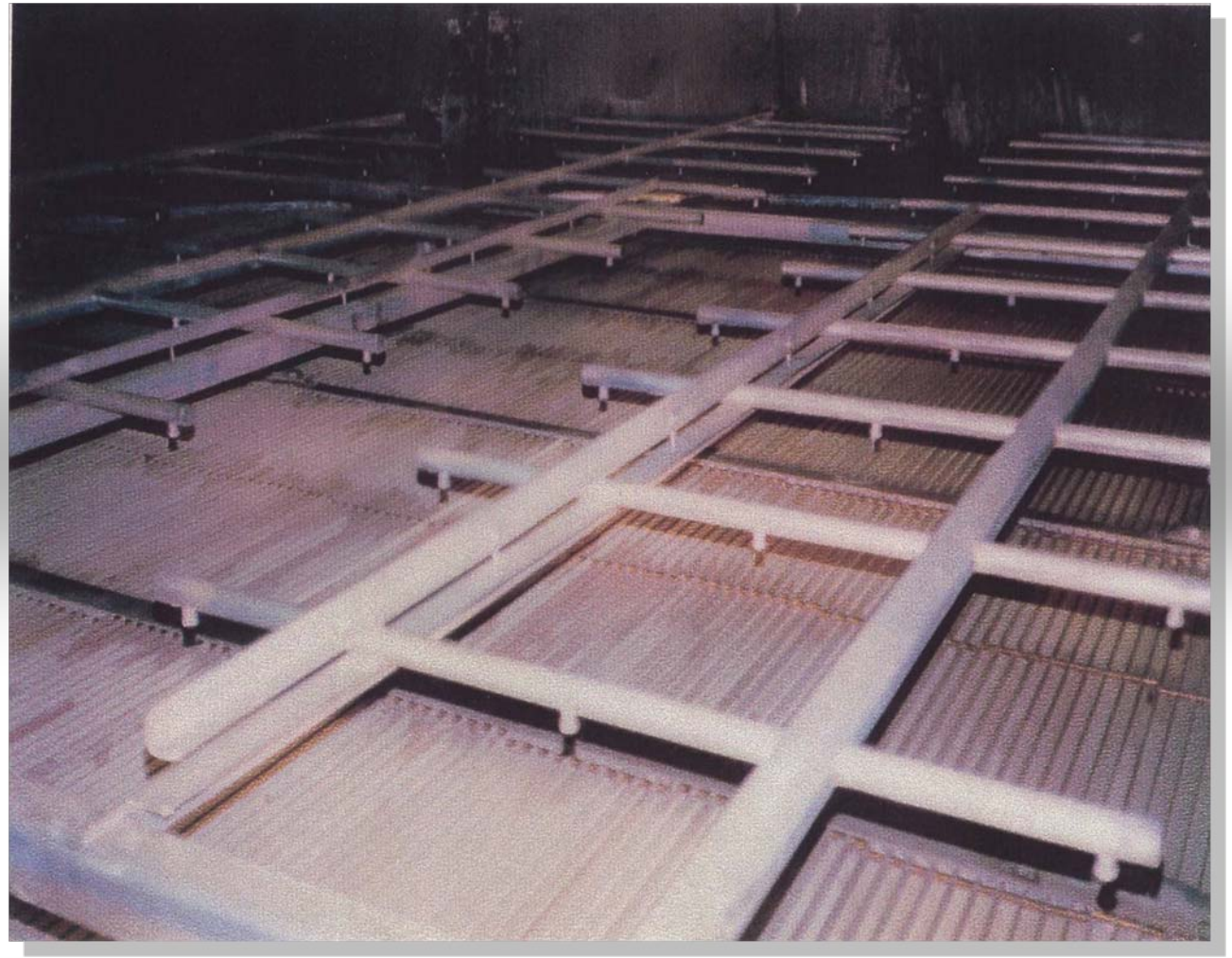
# *Mist Eliminator, Typical Spacing*

***Upper Mist Eliminators***

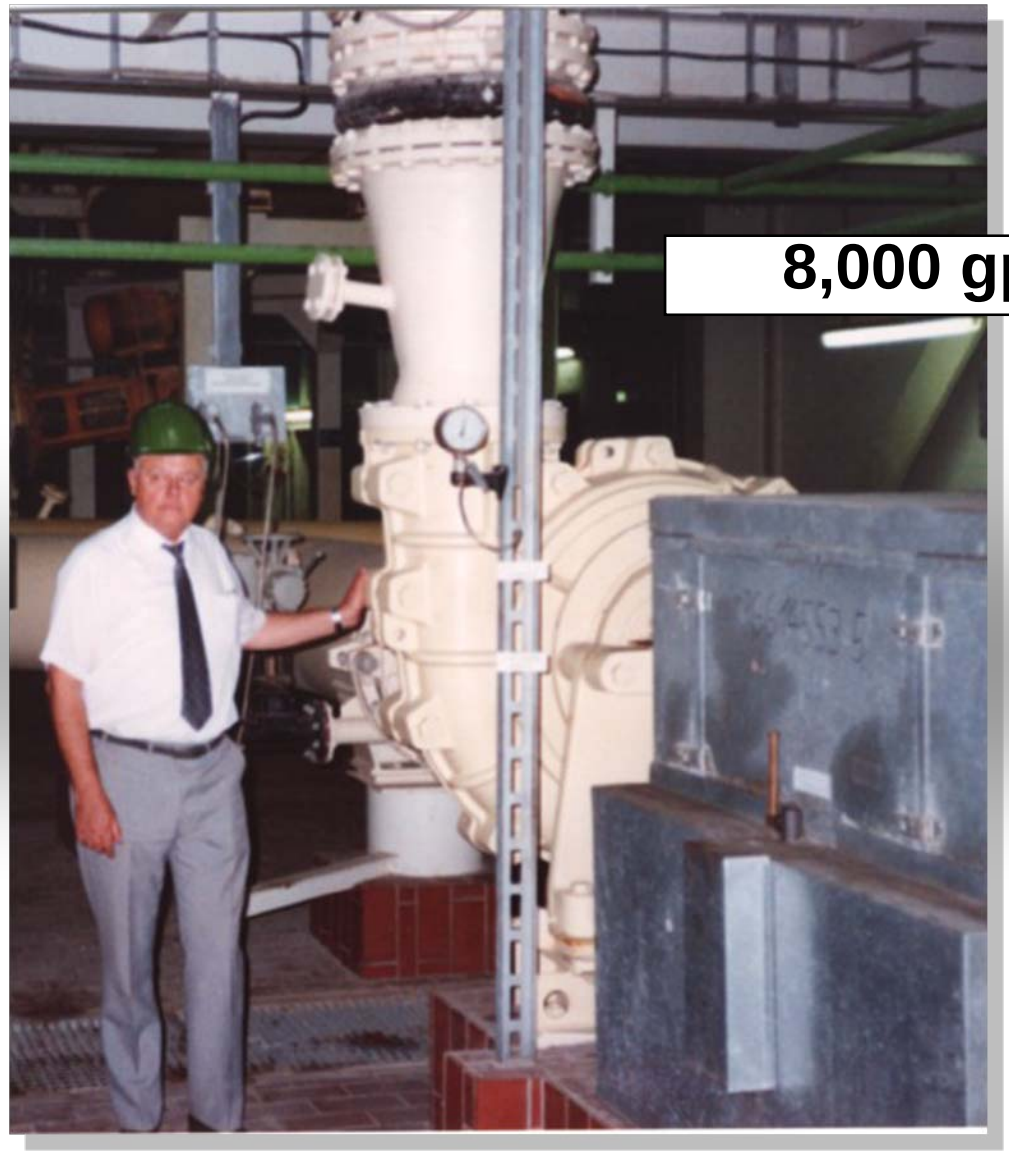
***Lower Eliminators***



# Top of Level of Mist Eliminators w/ Wash Header



# *Absorber Pumps - Yesterday*



**8,000 gpm**

**Source: Weir Pumps**

# Absorber Pumps - Today

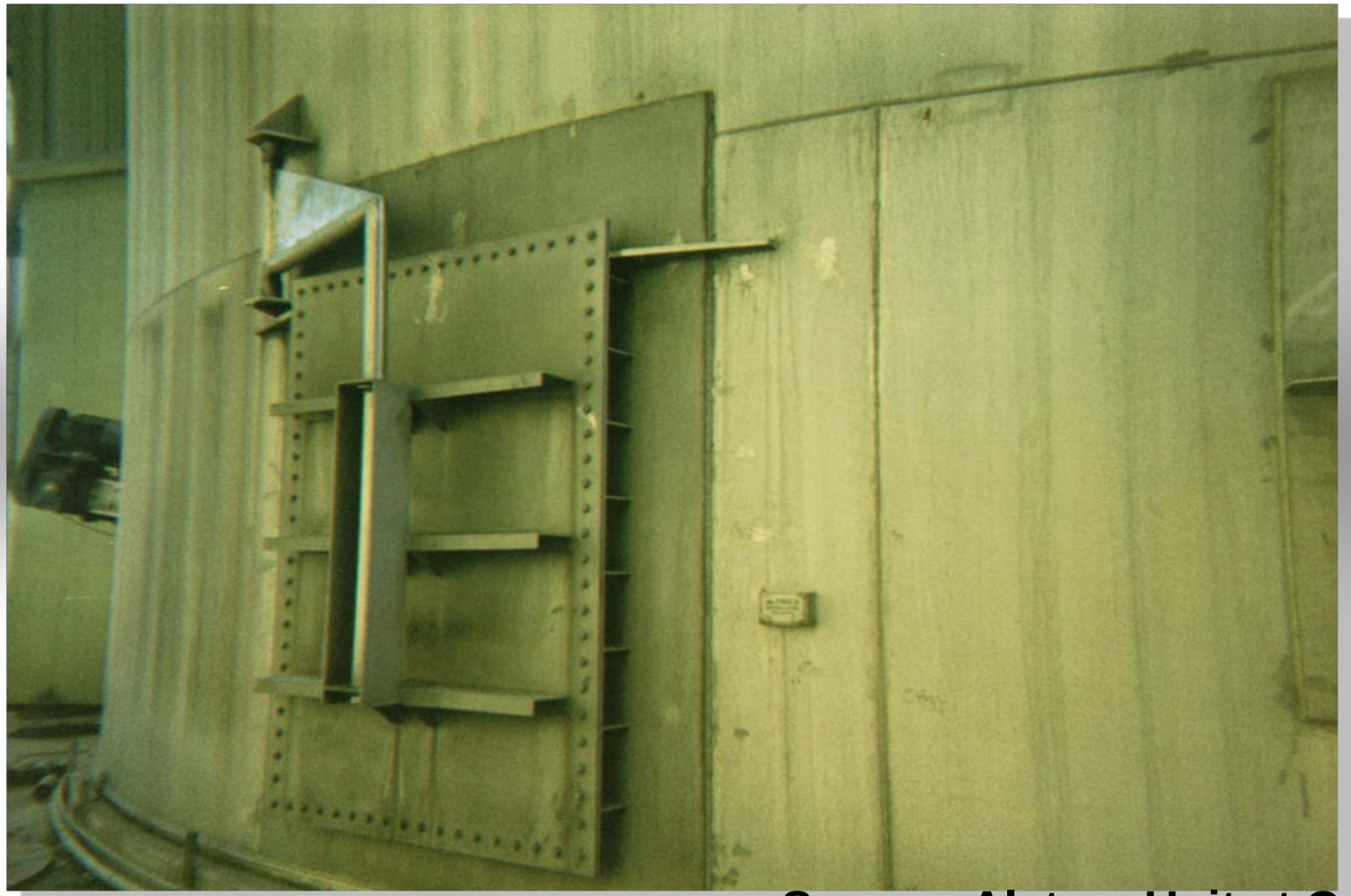

**70,000 gpm**

**Source: Weir Pumps**

# Absorber Pump with FRP Pipe

**Note Supports**

# Absorber Tank Access Door



**Source: Alstom Unit at Centralia**

# Yesterday: Natural Oxidation

$$CaCO_3 + SO_2 + H_2O \longrightarrow CaSO_3 \cdot {}^1/_2H_2O + CO_2\uparrow$$

(Gas-to-Sorbent Reaction)

Calcium Carbonate - active ingredient in limestone

Calcium Sulfite

$$CaSO_3 \cdot {}^1/_2H_2O + O_2\downarrow + H_2O \longrightarrow CaSO_4 \cdot 2H_2O$$

20-50% Complete

(Natural Oxidation Reaction)

Calcium Sulfate or Gypsum

# Today: Forced Oxidation

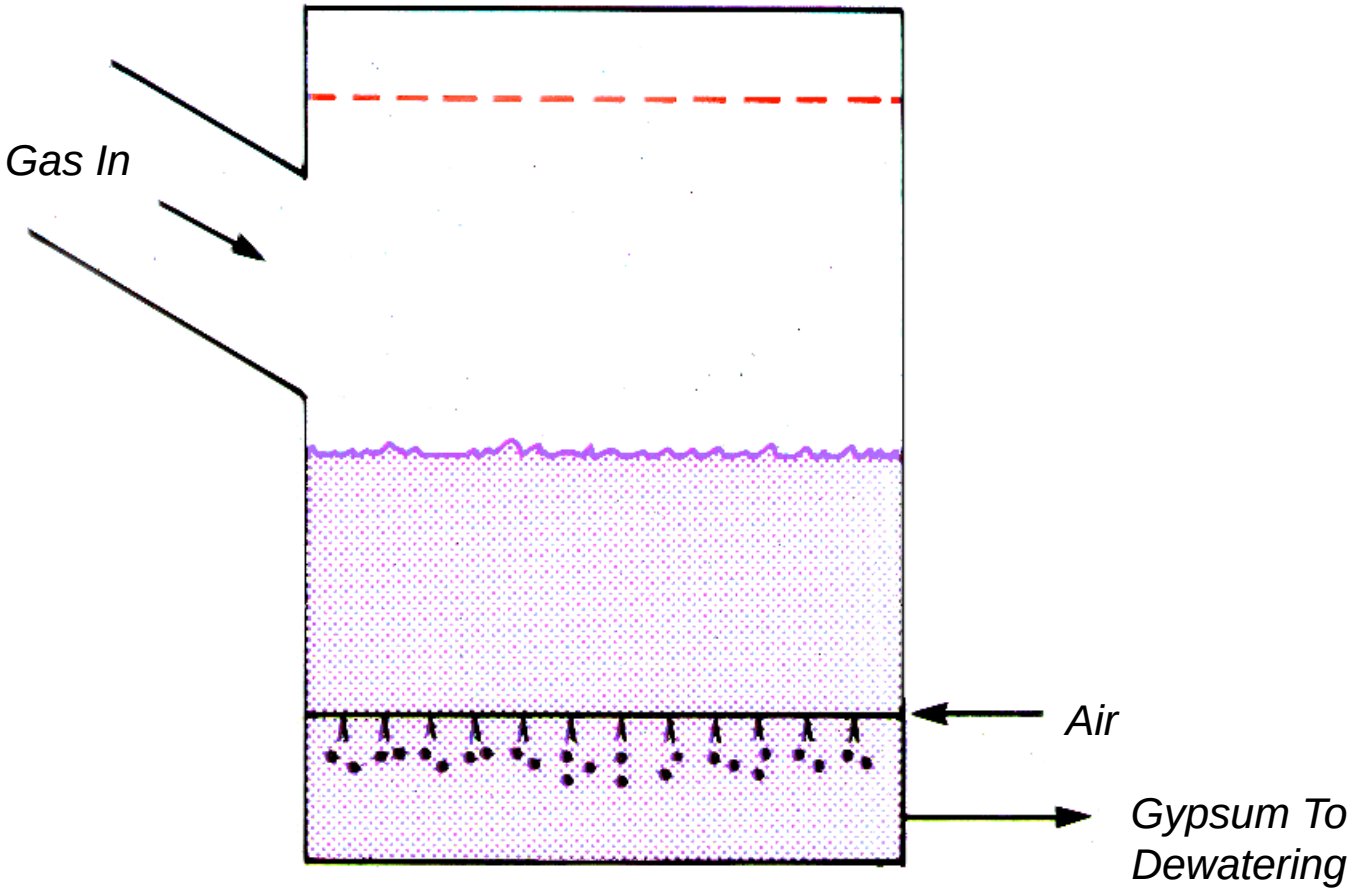
$$CaSO_3 \cdot {}^1/_2H_2O + O_2\downarrow + H_2O \longrightarrow CaSO_4 \cdot 2H_2O$$

~100% Complete

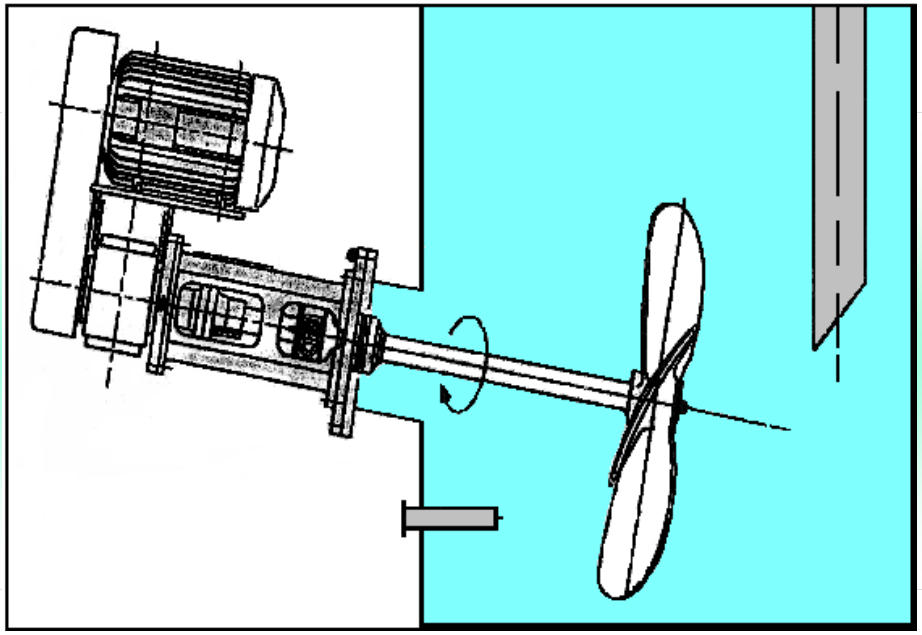
(Forced Oxidation Reaction)

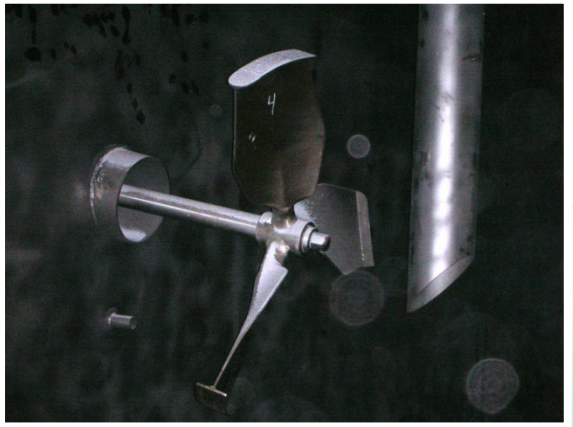
Calcium Sulfate or Gypsum

# Forced Oxidation - Sparge Header



# Forced Oxidation Agitator with Lance





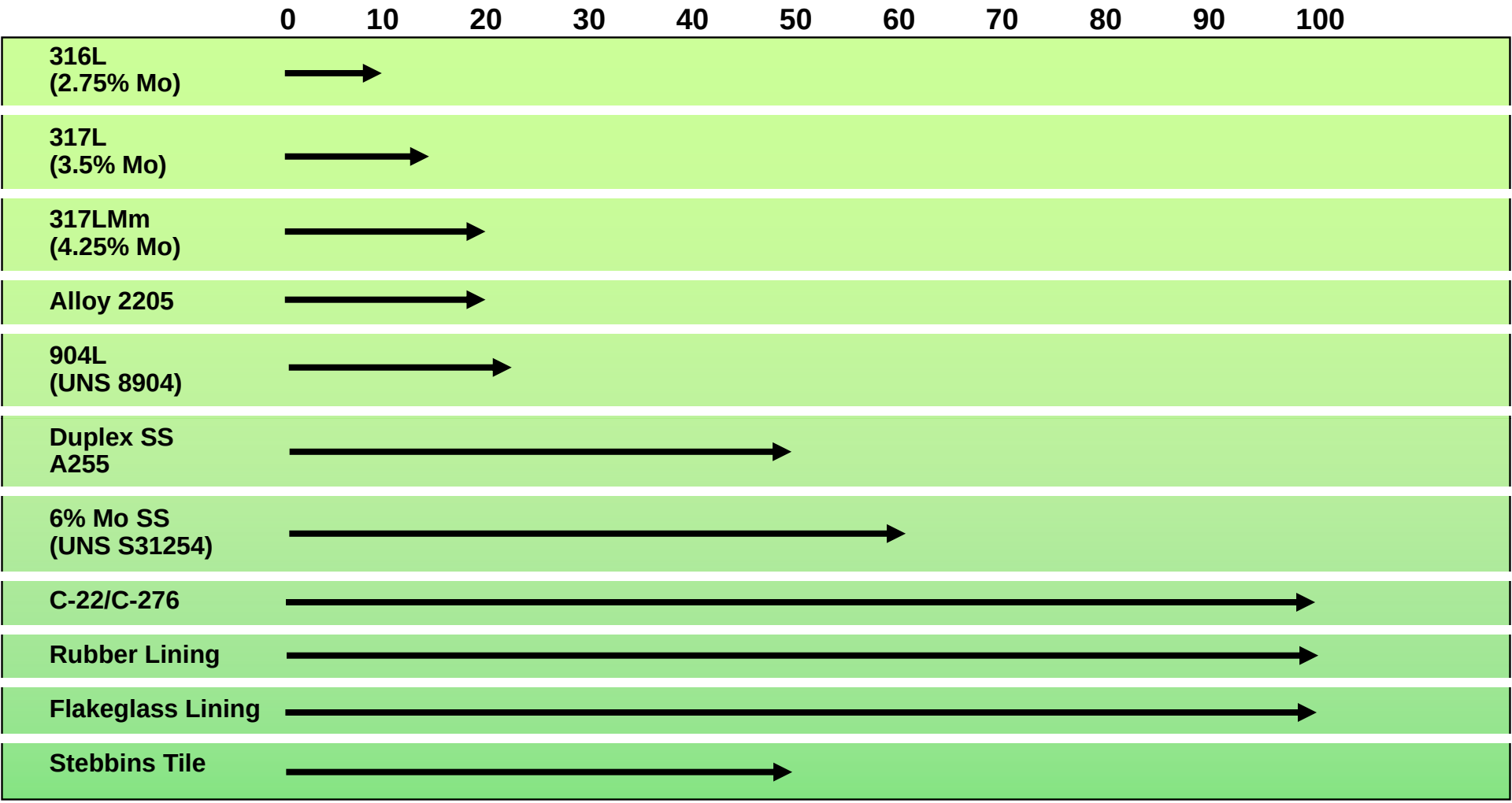
# *Lance Oxidation*

# *Wet FGD Fundamentals*

- What's the issue & progress
- Overview of major types of utility FGD system
- General description of wet limestone forced oxidized (LSFO) system
- Basic types & configurations of commercially available LSFO FGD technology
- Detailed description of LSFO FGD absorber
- Materials of Construction

# Absorber Material Selection

## Chloride Ion Concentration, 1000's ppm



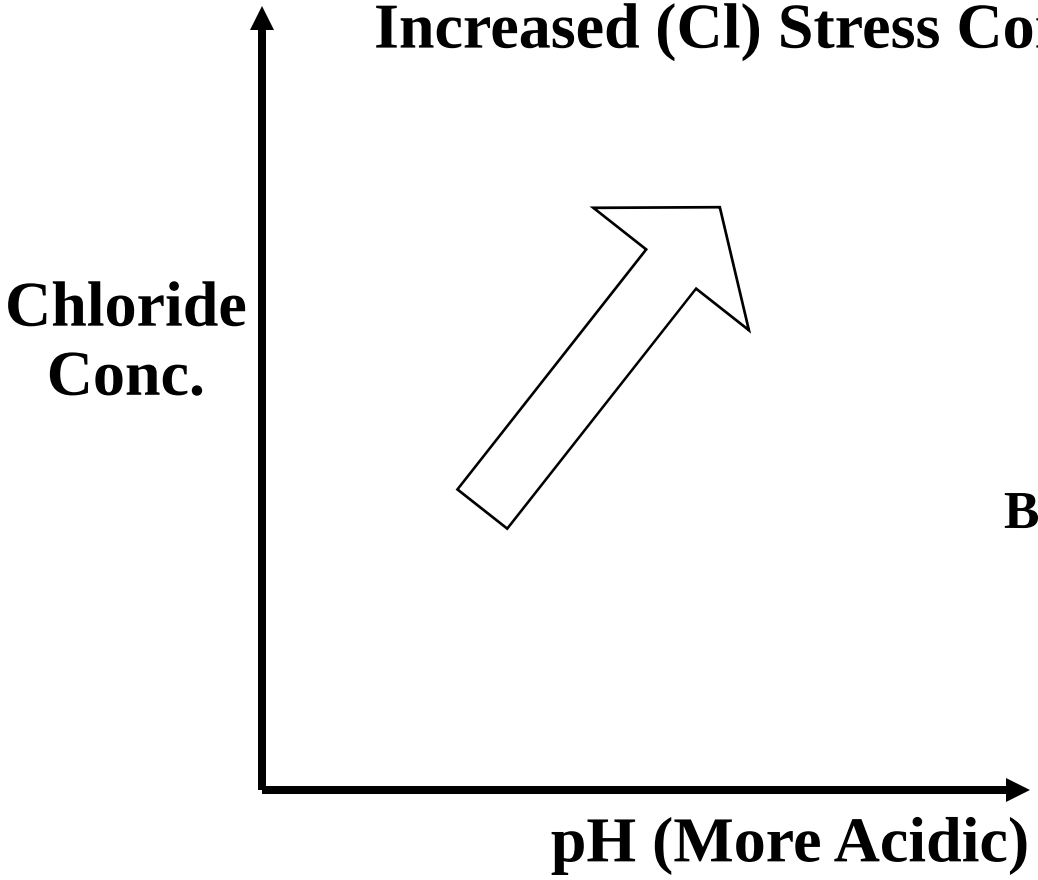
# *Wet FGD Alloys and Key Constituents*

| Alloy | UNS | Cr | Moly | Nickel | N | $Cl^-$ (ppm) service |
|---|---|---|---|---|---|---|
| **316L** | S31603 | 16.0 | 2.0 | 10.0 | 0.00 | **10,000** |
| **317L** | S31703 | 18.0 | 3.0 | 11.0 | 0.00 | **15,000** |
| **317LMN** | S31726 | 17.0 | 4.0 | 13.5 | 0.10 | **20,000** |
| **2205** | S32205 | 22.0 | 3.0 | 4.5 | 0.10 | **30,000** |
| **255** | S32550 | 24.0 | 2.9 | 4.5 | 0.10 | **45,000** |
| **254-SMO** | S31254 | 19.5 | 6.0 | 17.5 | 0.18 | **55,000** |
| **AL-6XN** | N08367 | 20.0 | 6.0 | 23.5 | 0.18 | **55,000** |
| **C-22** | N06022 | 20.0 | 12.5 | 50.0 | 0.00 | **100,000+** |
| **C-276** | N10276 | 14.5 | 15.0 | 51.0 | 0.00 | **100,000+** |

# Alloy Selection Criteria

**Increased Pitting & Crevice Corrosion Potential**

**Increased (Cl) Stress Corrosion Cracking Potential**




**Need**

**Pitting & Crevice Corrosion Resistance**

**SCC Resistance**

**Both Shop & Field Fabricate-ability**

**Weld-ability**

**Availability**

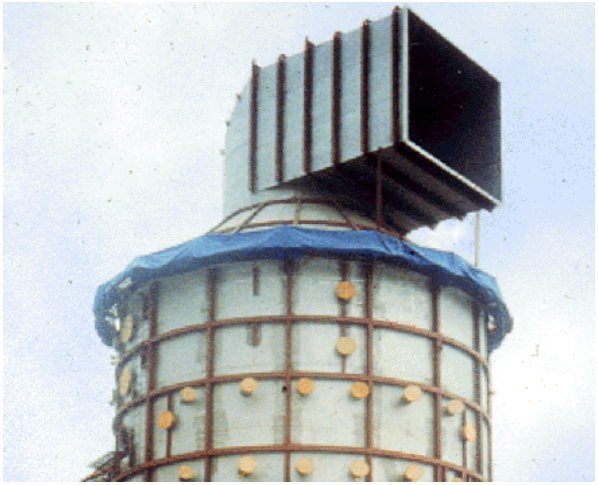
***Economics***

***Source: Babcock Power***

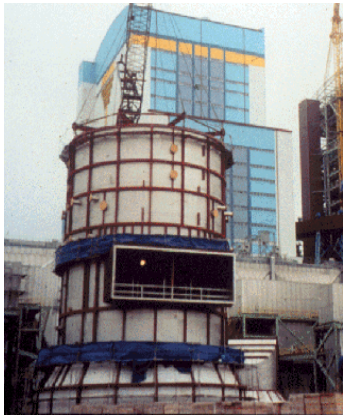
| Materials of Construction | Design Chloride Limits (ppm) | GPM Wastewater |
|---|---|---|
| 317LMN Stainless Steel (S31726) | 8,000 | 287 |
| Duplex 2205 Stainless Steel (S32205) | 12,000 | 141 |
| Super Duplex 255 Stainless Steel (S32550) | 20,000 | 115 |
| Super Austenitic 6% Mo Stainless Steel (N08367) | 40,000 | 57 |
| C-276 (N10276) | 50,000 | 46 |
| Carbon Steel/Glass Lined | 50,000 | 46 |
| Carbon Steel/Rubber Lined | 50,000 | 46 |
| Concrete/Tile Lined | > 50,000 | 46 |
| Concrete/PP Lined | 50,000 | 46 |

***Source: Babcock Power***

# Alloy Construction Flexibility




***Korea Electric Power (10 x 500 MW)***

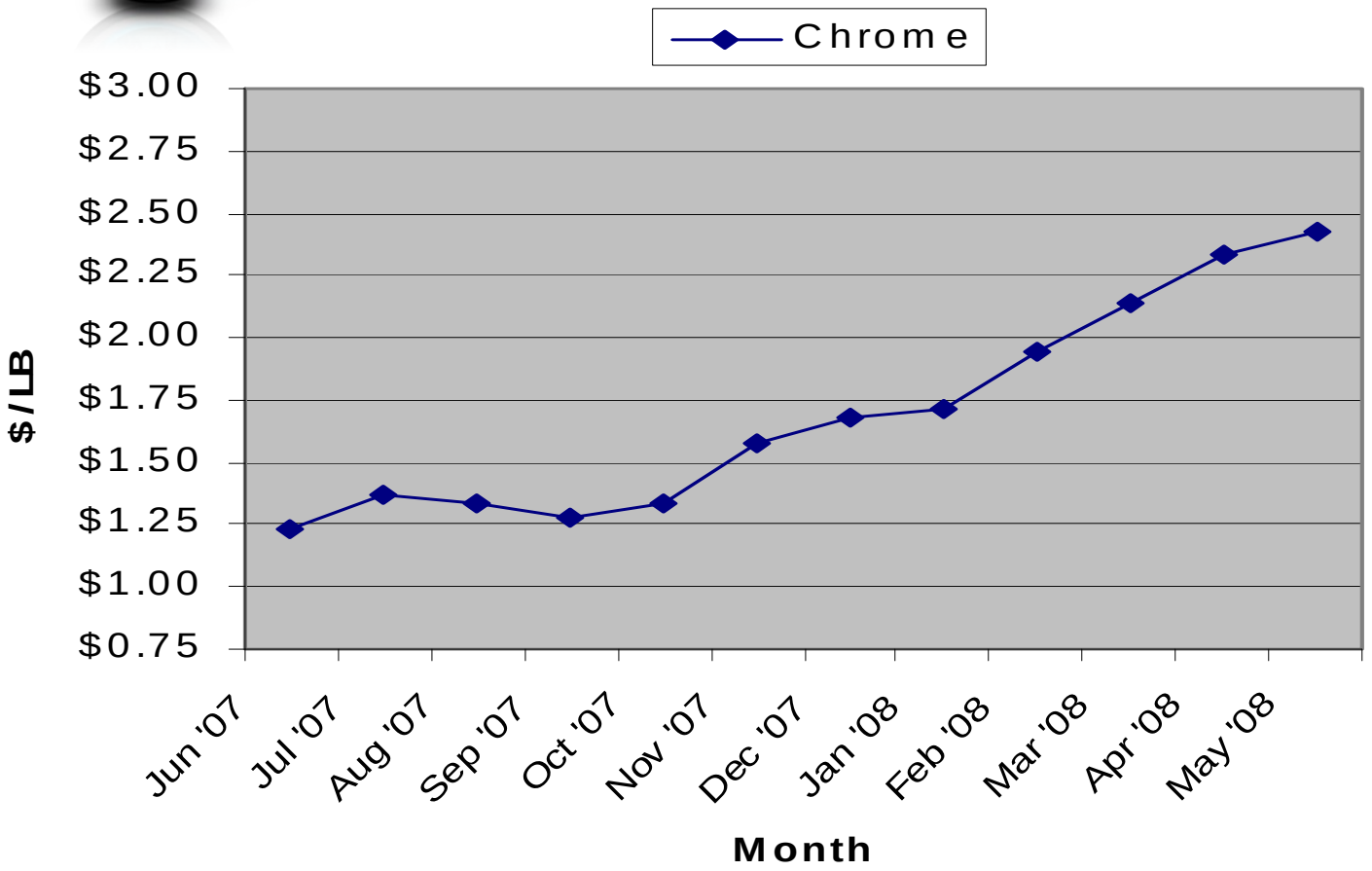


# Alloy 2205 Absorber Modules: Shop Assembled

# Alloy 2205 Absorber Sections: Moving to Site

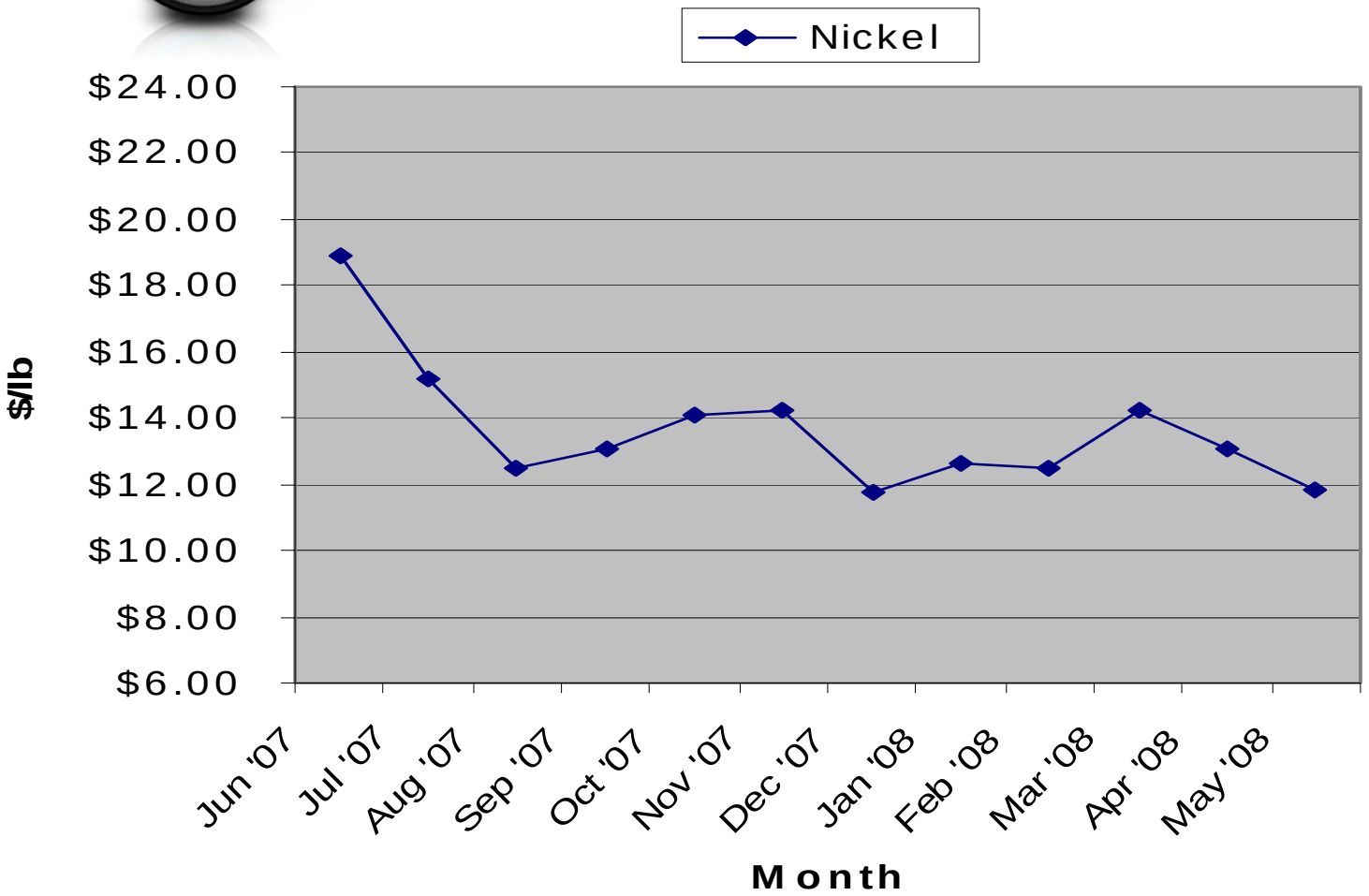
# Chromium Pricing

## July 2003: $0.48/LB



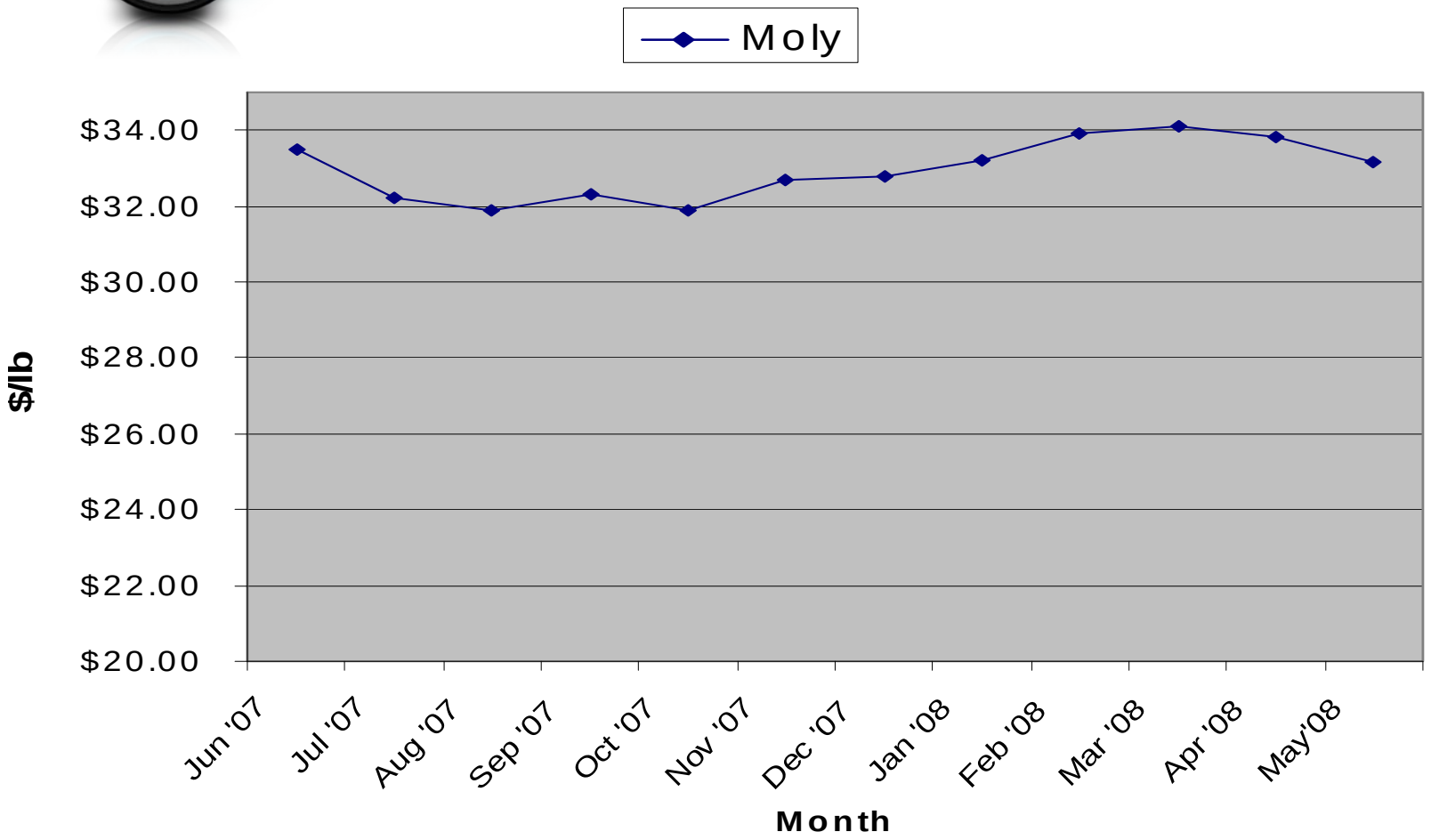
# Nickel Pricing

## July 2003: $4.00/LB.

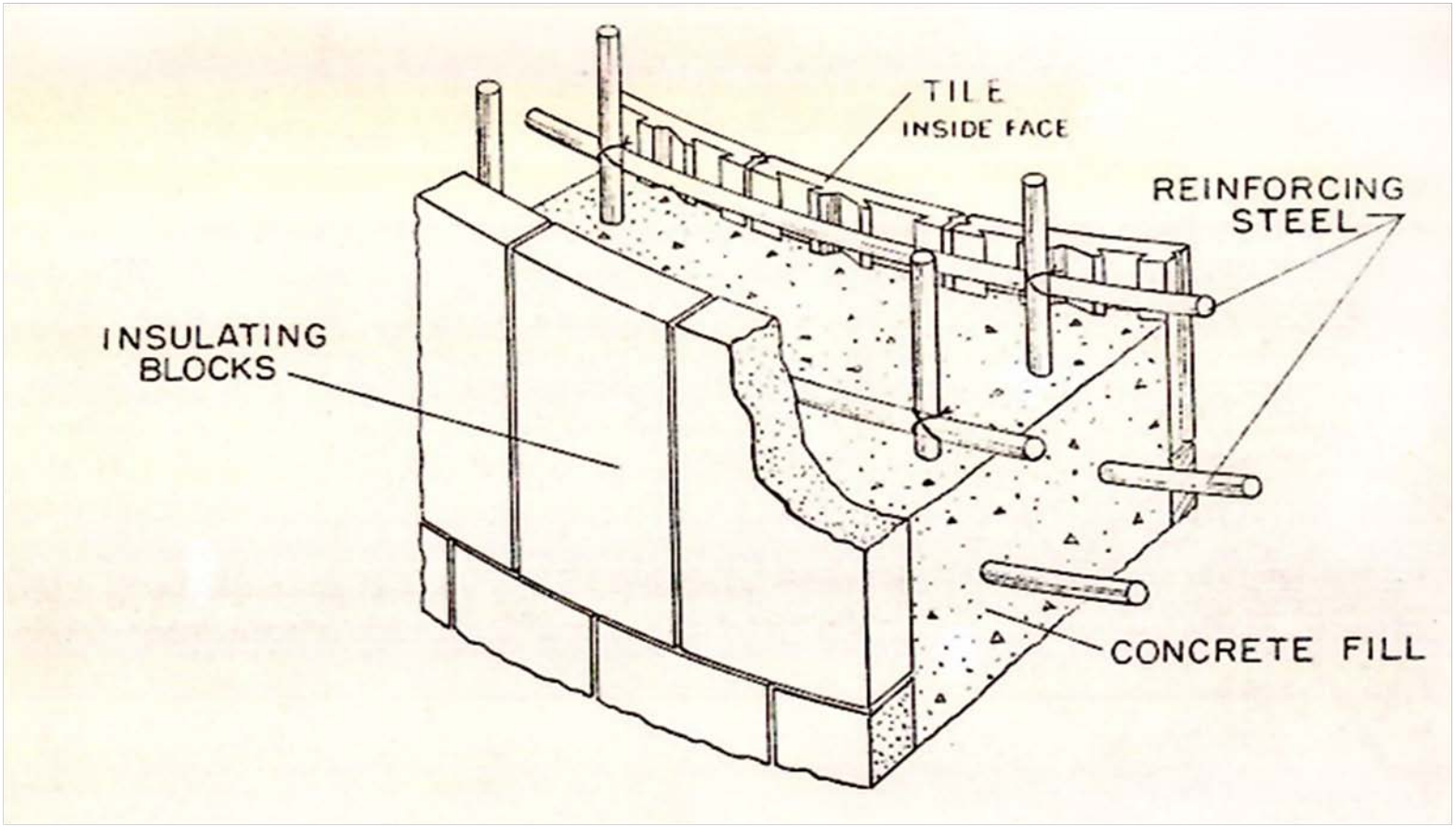


# Molybdenum Pricing

## July 2003: $5.75/LB

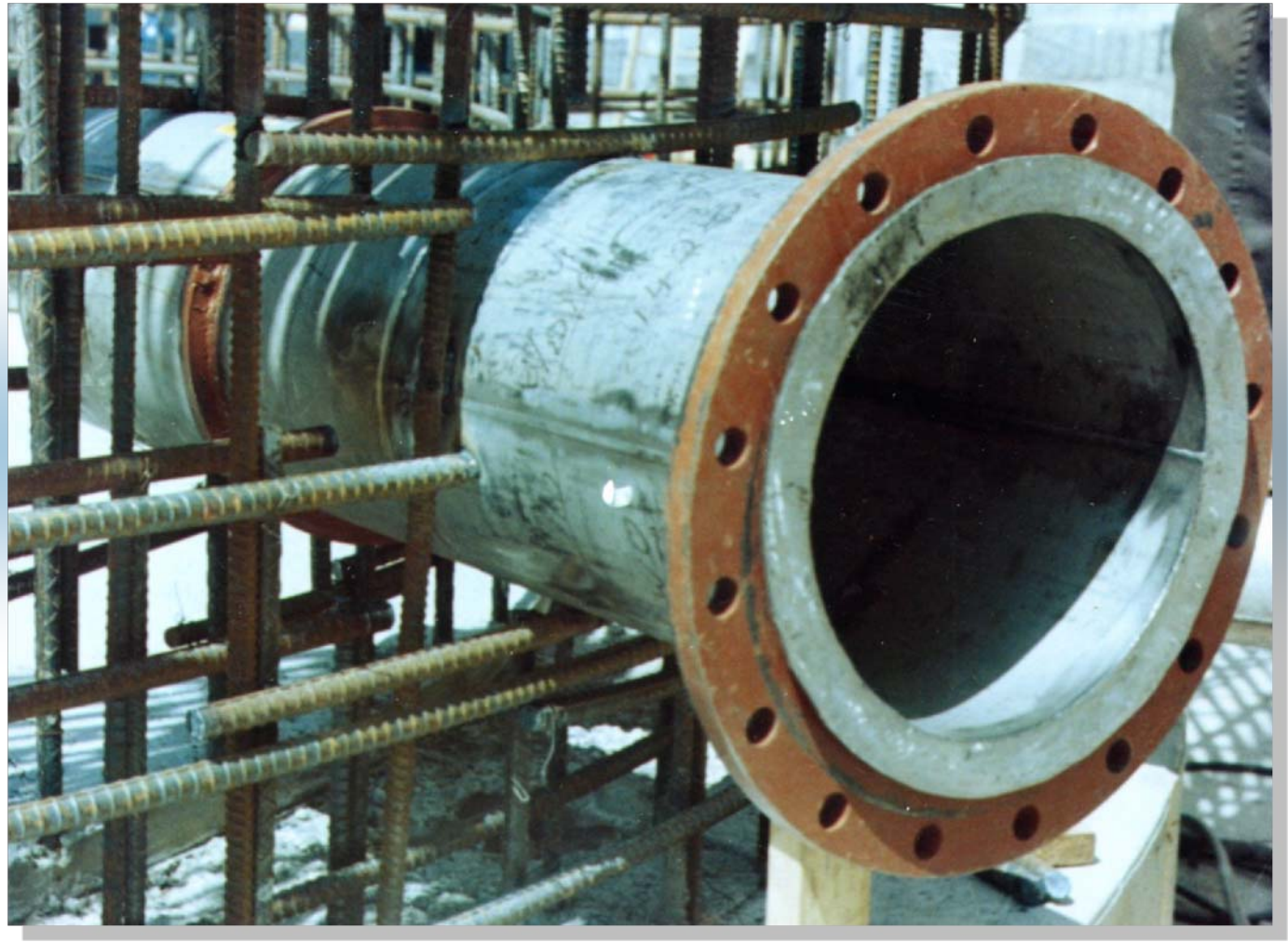


# Stebbins Tile & Concrete Construction




Insulated Reinforced Masonry Wall

# Nozzle Placement in Stebbins Tower

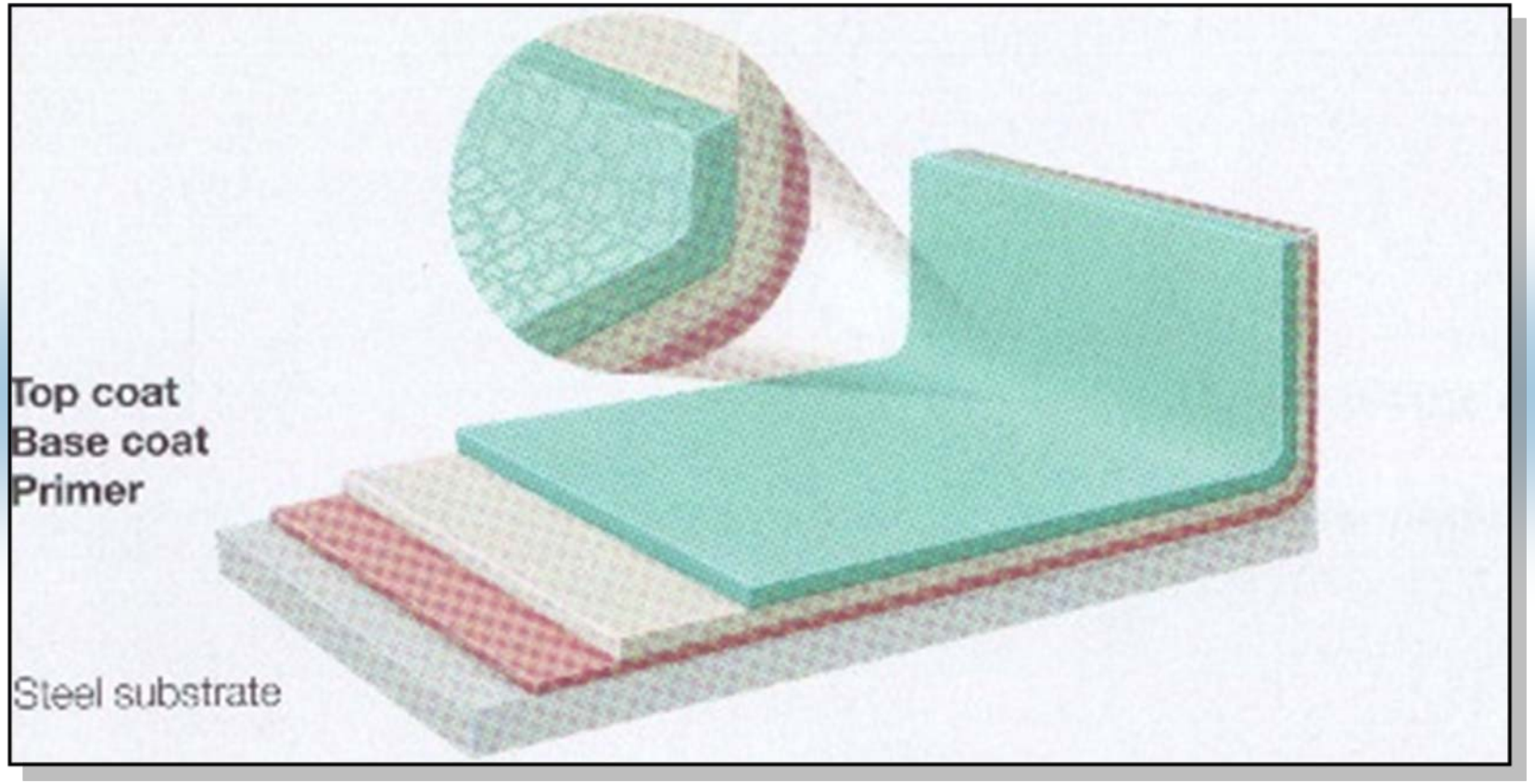


# Stebbins Absorber Tower

# Rubber Lining Application

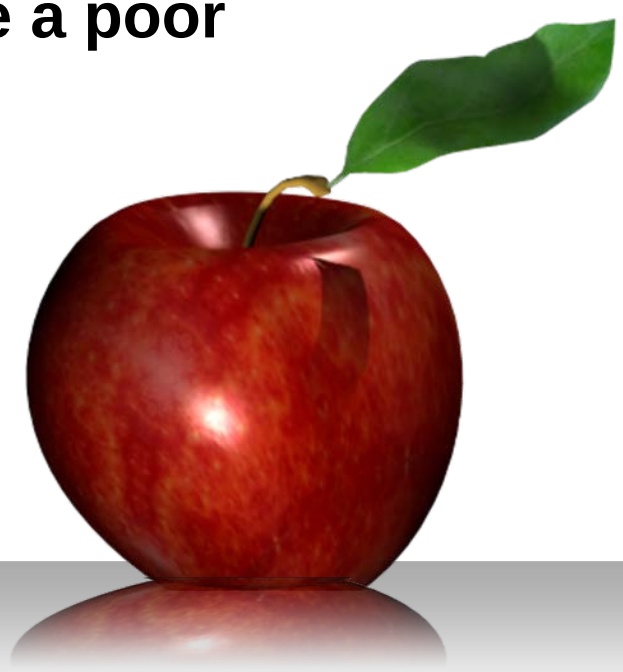
# *Flakeglass Lining Application*

# Flakeglass Lining Application



# *Words of Wisdom*

**An excellent lining/coating material selection will not overcome a poor application, nor will an excellent application overcome a poor lining/coating material selection.**



# *Thank You*