Worldwide Pollution Control Association

Duke Energy Seminar
September 3 – 5, 2008
Concord, NC

Vist our website at www.wpca.info

Wet Scrubber System Fundamentals

Vic Adamson

WPCA/Duke Seminar
September 3-5, 2008

In what decade was the first wet FGD system commissioned?

The 1930s

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Where was the first wet FGD system commissioned?

Battersea Power Station in London

FUN

When, where, and by whom was the first US WFGD system commissioned?

1968 in Lawrence, Kansas by Alstom

Agenda

- Introduction
- Major Process Equipment
- Operation
- Secondary Emissions
- Summary

US FGD Systems

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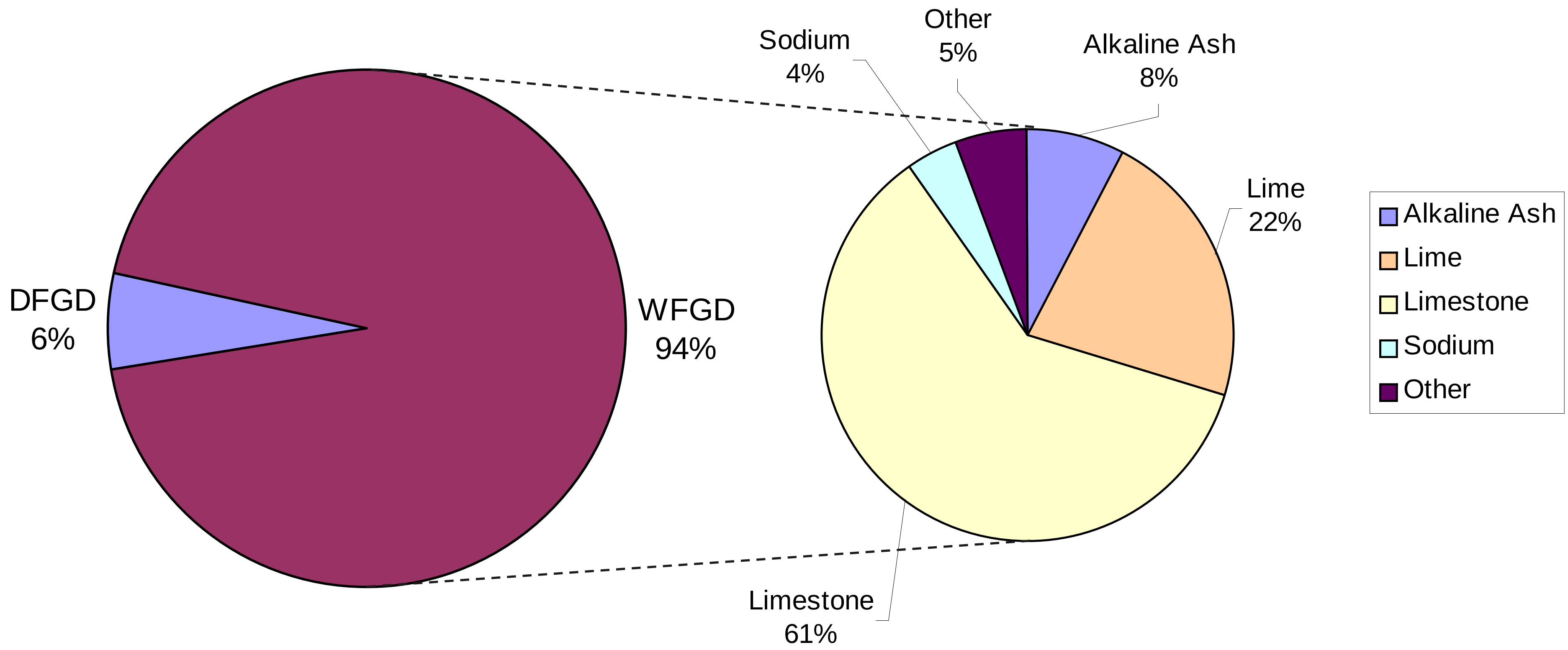
Total US Scrubbed Capacity – Approx. 100 GW



US WFGD Experience

- Over 94 GW of WFGD systems in US; first units installed in 1960s
- SO2 removal efficiencies greater than 98%
- Availability greater than 98%
- Experience with wide range of fuels
- Reagent flexibility (lime, limestone, ammonia, alkaline ash)
- Marketable product or landfill

Duke Energy
Marshall Units 1-4
Terrell, NC

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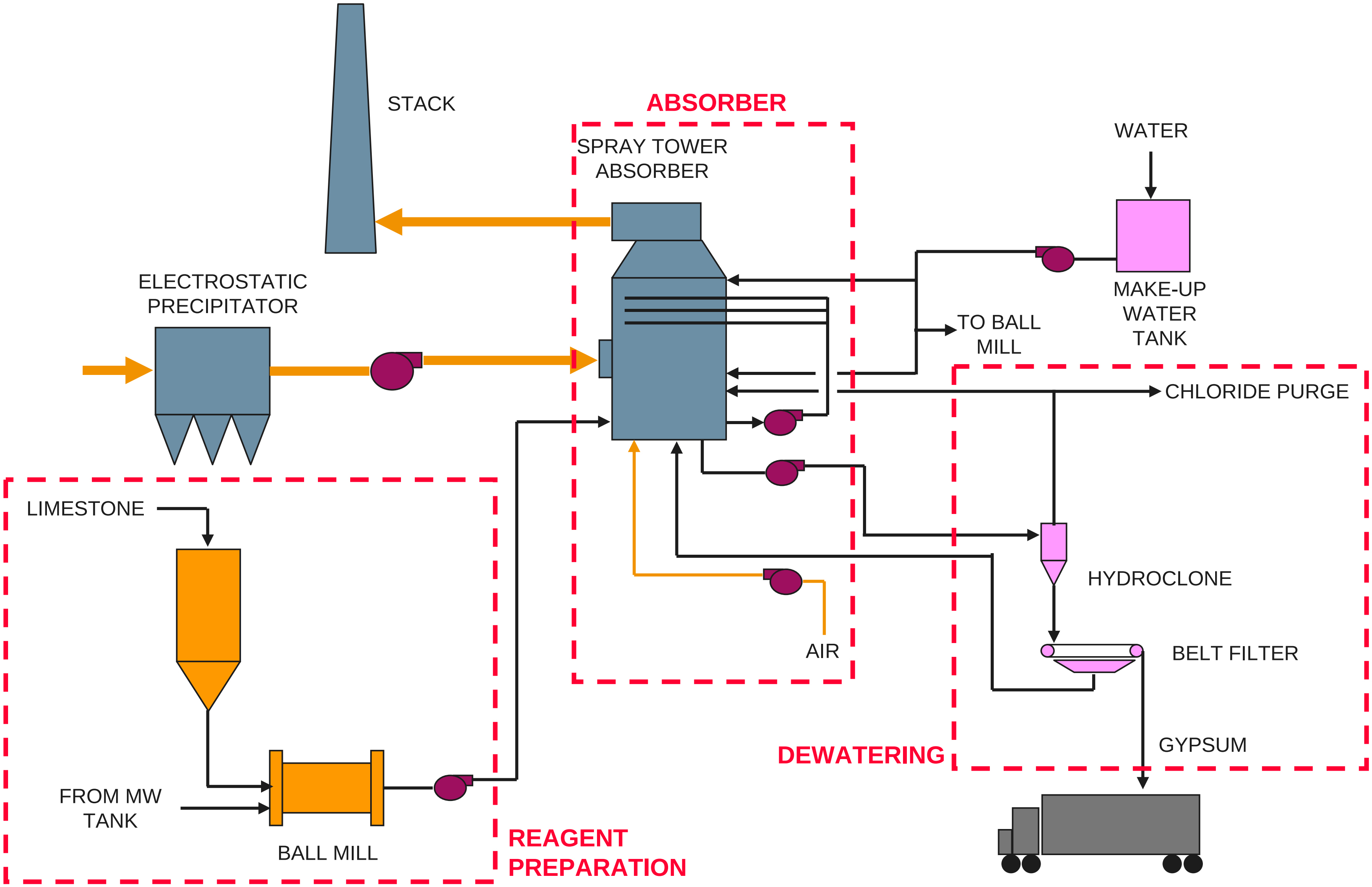
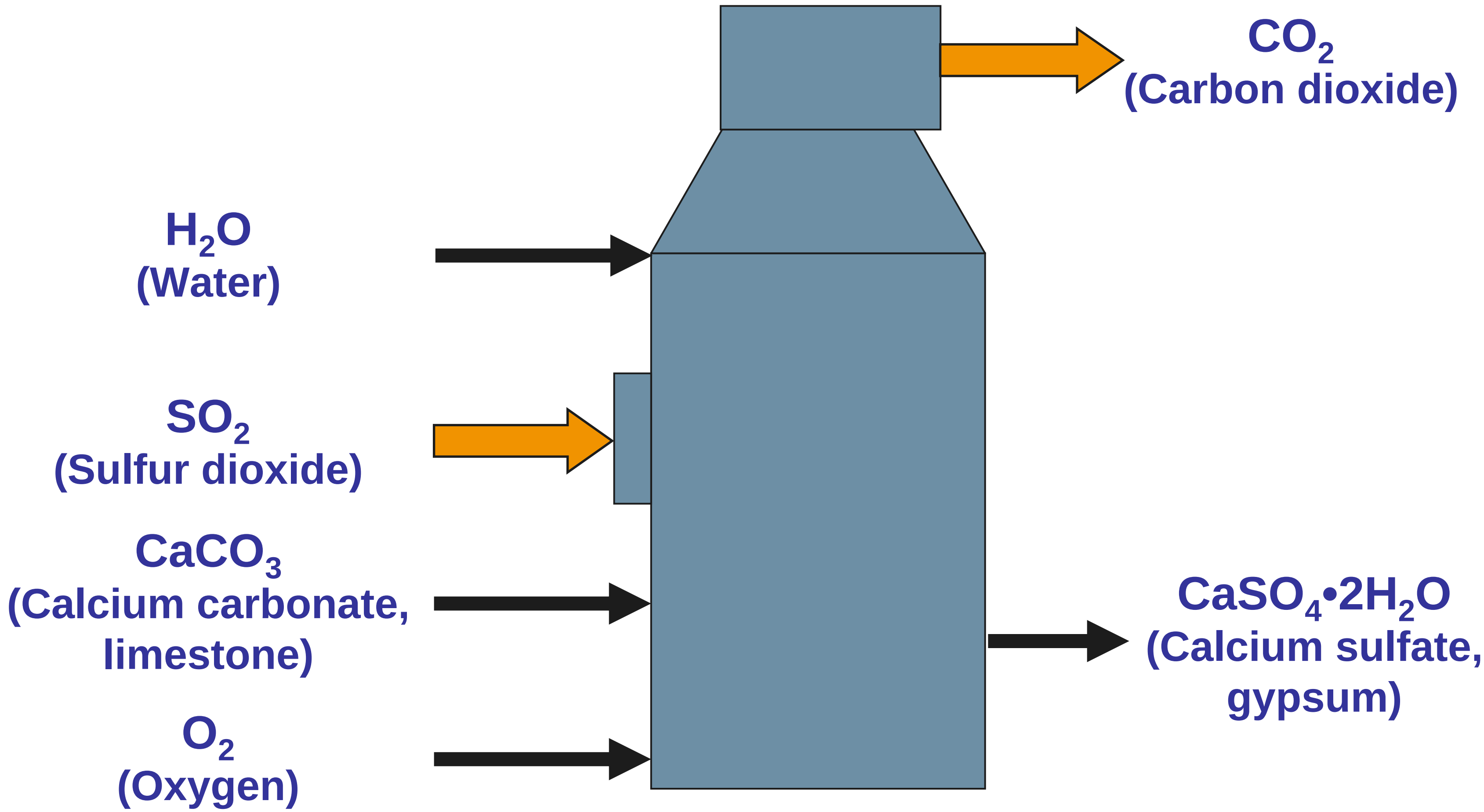
LSFO Process Diagram

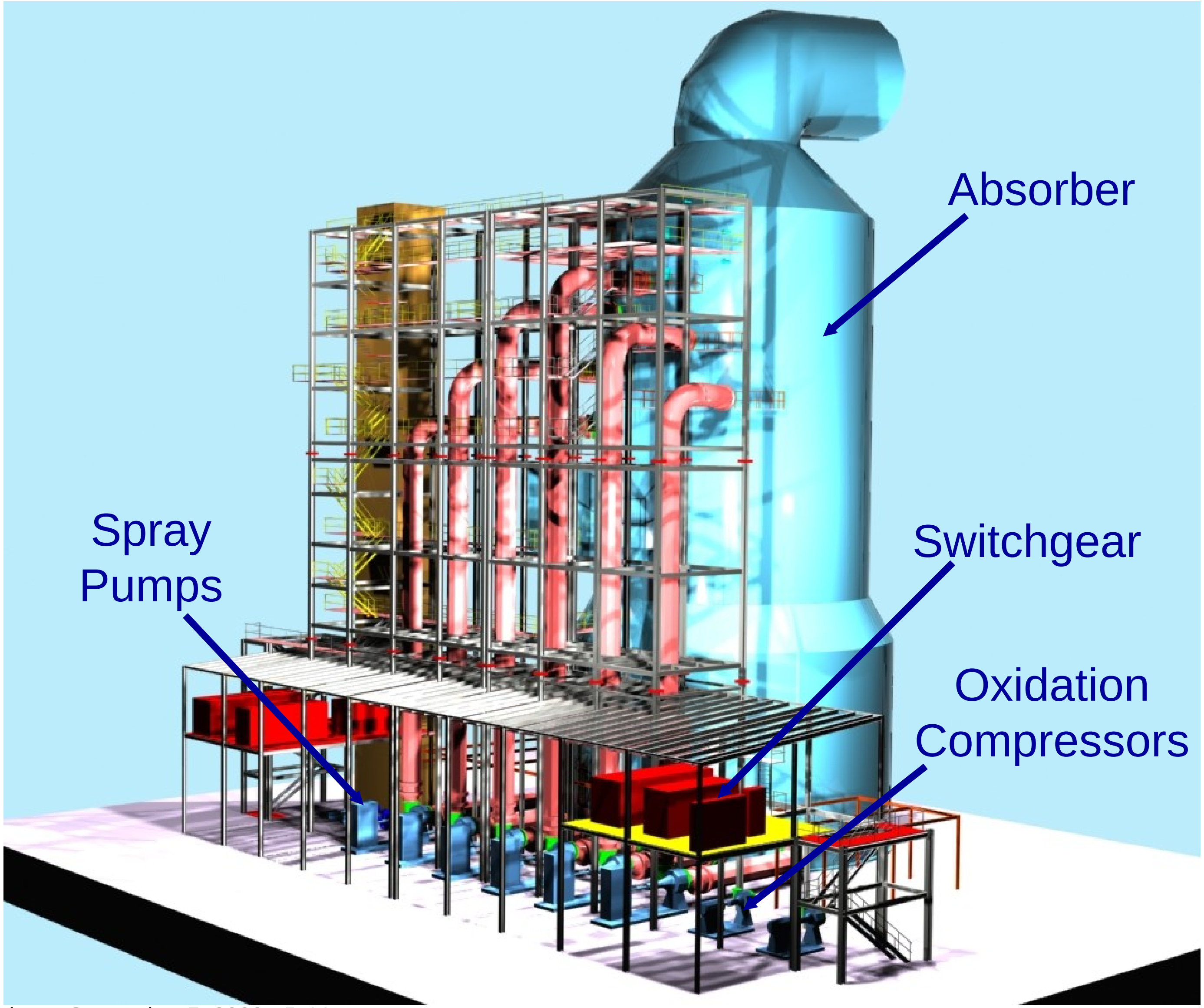


Limestone/Forced Oxidation



$$SO_2 + CaCO_3 + \tfrac{1}{2}O_2 + H_2O \rightarrow CaSO_4 \cdot 2H_2O + CO_2$$

Absorber Island



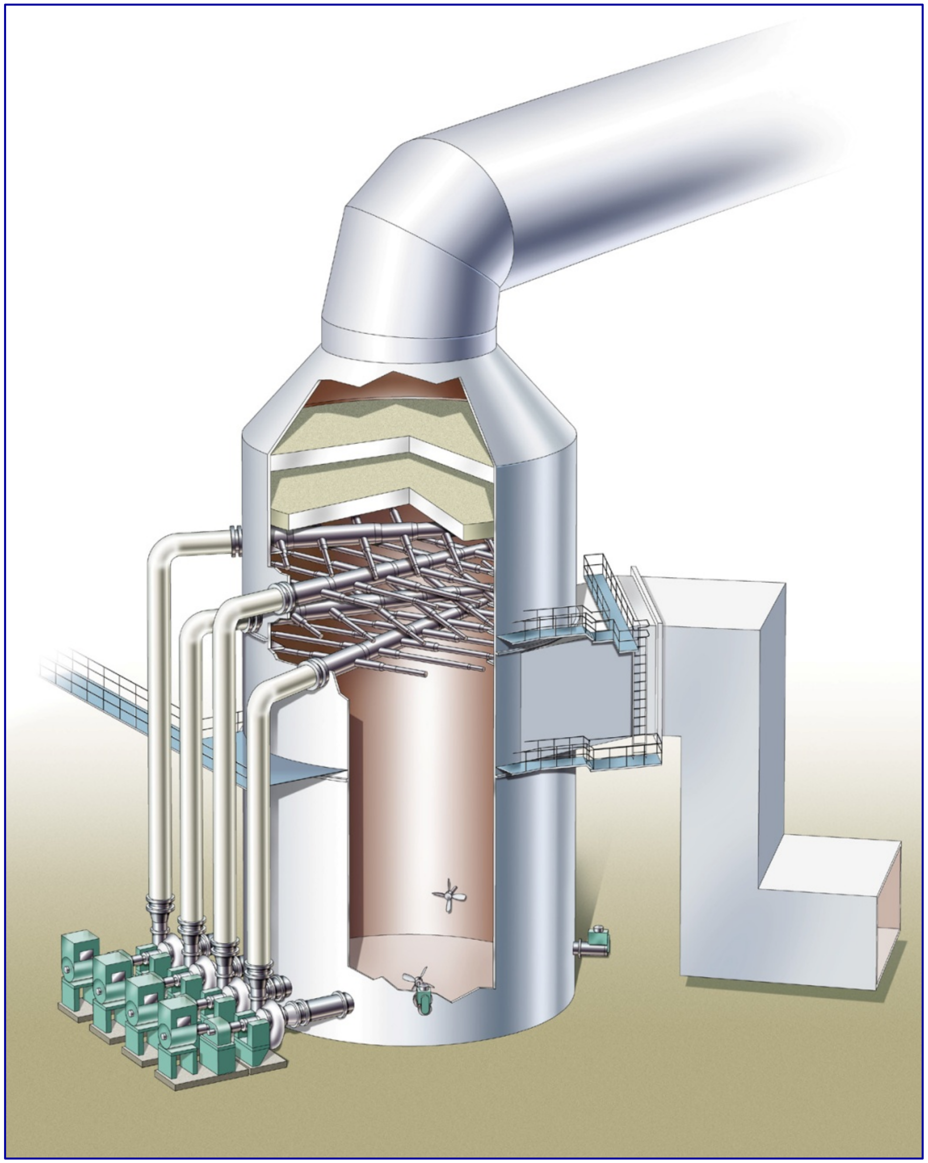
Absorber Unit Operations

Unit Operations

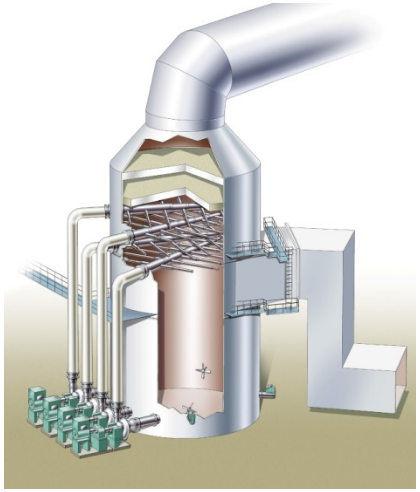
- Inlet – gas distribution, humidification
- Spray zone – gas/liquid contact
- Mist eliminator zone – liquid/gas separation
- Reaction tank – oxidation, dissolution, crystallization

Design Goals

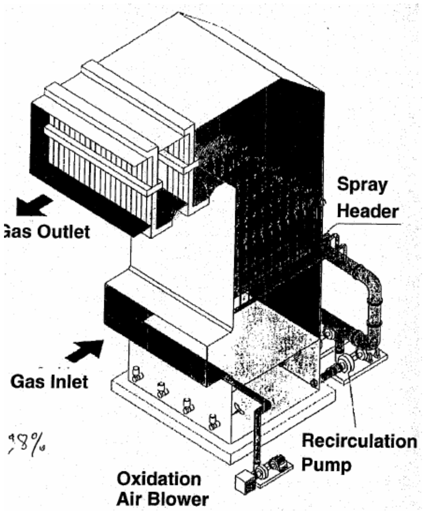
- Lowest lifecycle cost
  - Capital
  - O&M
- High reliability



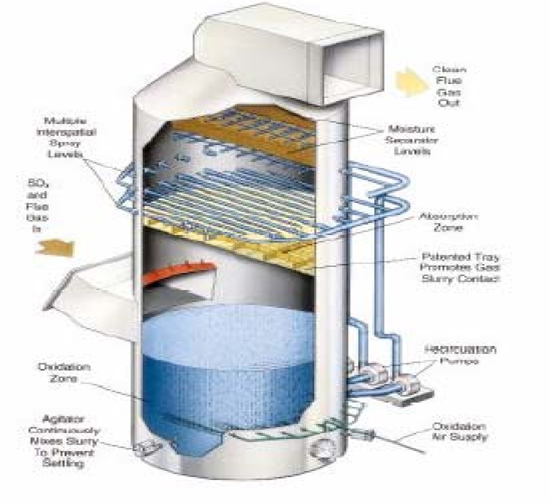
Absorber Designs



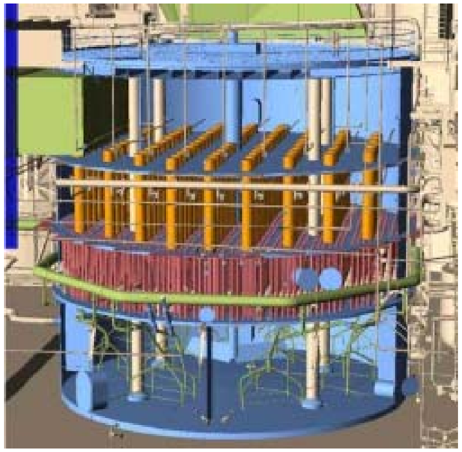
Open Spray Tower



Fountain Tower



Tray Tower



Jet Bubbling Reactor

Spray Headers

- Materials
  - Stainless steel
  - Alloy
  - FRP
  - Rubber-lined carbon steel
- Self-supporting or internal support beams or trusses
  - Absorber diameter
  - Material of construction
- Staggered arrangement

Spray Zone

- Dedicated recirculation pump at each spray header
- Performance enhancement plates
- Excellent gas / liquid contact assures high SO_2 removal efficiencies
- Lowest draft loss
- Highest reliability
- Low scaling potential
- Excellent turndown reduces operating costs over 100–0% load range

Spray Nozzles

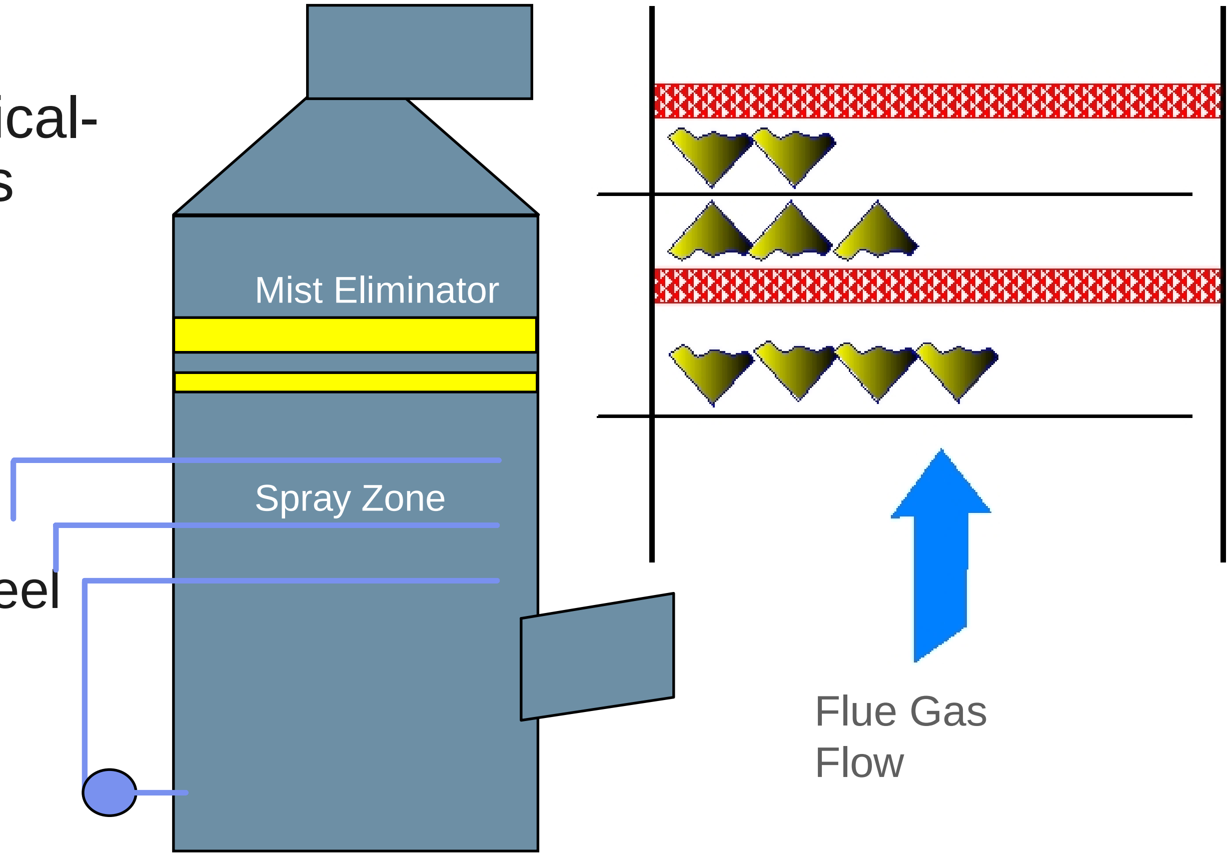
- Multiple counter-current spray elevations
- Nozzle type
  - Top elevation—single orifice hollow cone
  - Lower elevations—dual orifice hollow cone
- Sauter mean droplet diameter of ~2,000 micron at 8 psig
- Silicon carbide construction

Reaction Tank

- Functions
  - Limestone dissolution
  - Oxidation
  - Gypsum crystallization
- Side entry agitators with air lances for oxidation
  - 4–6 agitators/lances
  - Simple, reliable and proven design
  - Excellent turndown at lower boiler loads and inlet SO_2 loading
  - Minimizes plugging potential
  - Easy inspection during scheduled outages

Mist Eliminator

- Two stages of vertical-flow chevron vanes
- Construction
  - Polypropylene
  - Polysulfone
  - FRP
  - Alloy/stainless steel



Mist Eliminator Wash System

- Fresh water wash on intermittent basis
  - First stage washed from below (1.5 gpm/ft^2) and above (0.75 gpm/ft^2)
  - Second stage washed from below (0.75 gpm/ft^2)
- Construction
  - Piping: FRP, polypropylene, alloy/SS
  - Nozzles: polypropylene, alloy/SS

Absorber Recycle Pump

- Typical size: 50,000–85,000 gpm at 55–85 TDH
- Pump Efficiency: 87–90+%
- 800–1,500 hp (~1 MW)
- Horizontal, centrifugal
- Rubber-lined casing
- Metal Impeller
- Mechanical Seal

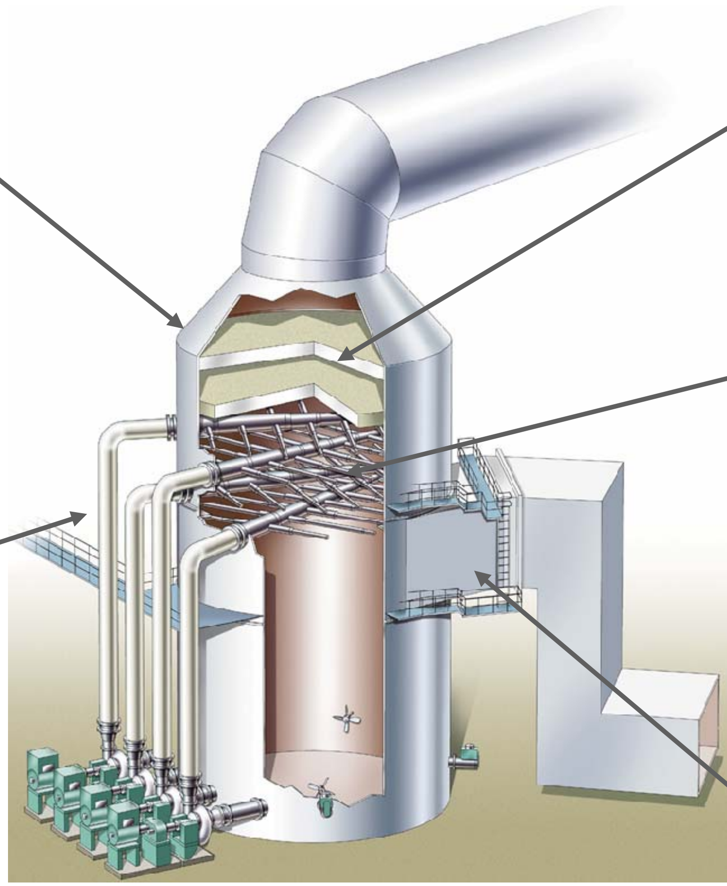
Materials of Construction

Shell

- Rubber-lined carbon steel
- Flakeglass-lined carbon steel
- Stainless steel (317LMN)
- Duplex stainless steel (2205, 255)
- Nickel-based alloy
- Roll-clad alloy
- Lined concrete (tile, rubber)

External Spray Piping

- FRP
- Rubber-lined carbon steel
- SS/alloy



Mist Eliminators

- FRP
- Polypropylene
- Polysulfone
- SS/alloy

Headers

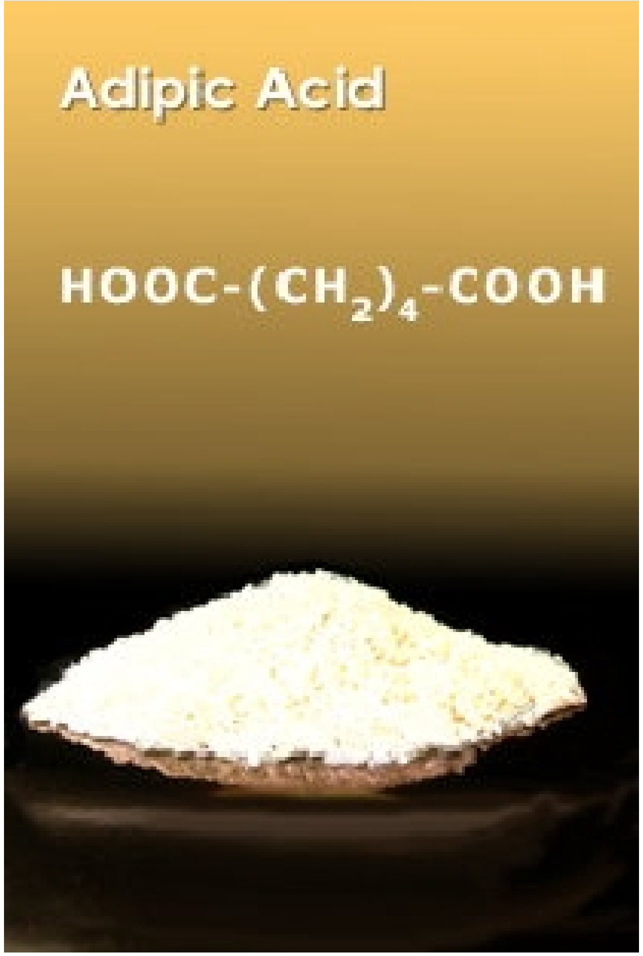
- Rubber-lined carbon steel
- FRP
- Stainless steel (317LMN)
- Duplex stainless steel (2205, 255)
- Nickel-based alloy

Inlet

- C-276

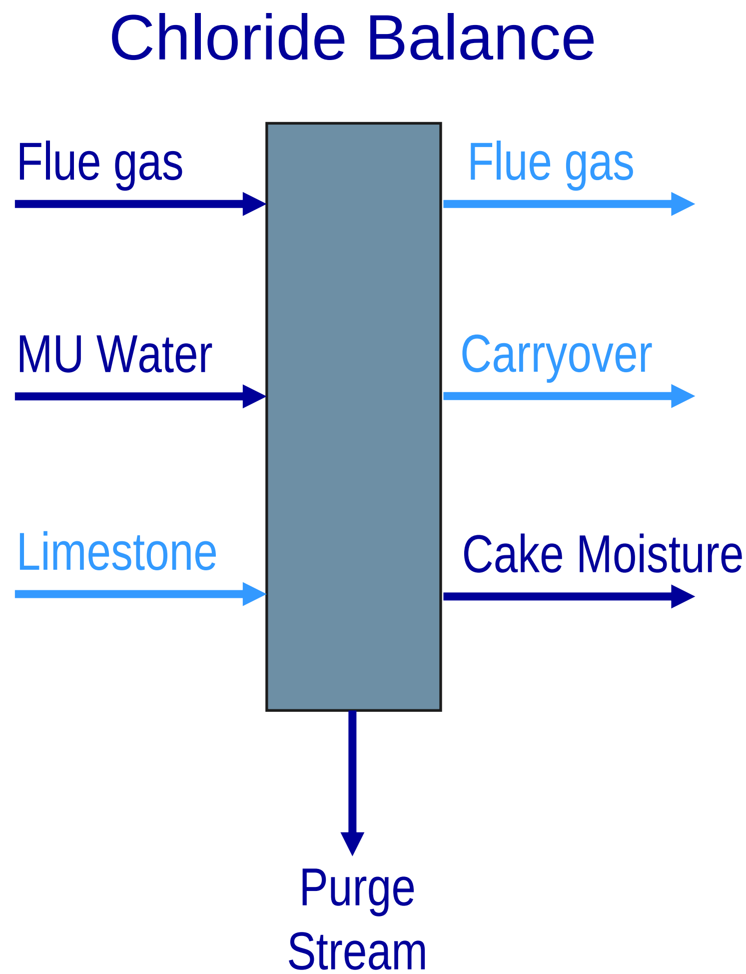
Organic Acid Enhancement

- Organic acids (e.g. adipic, dibasic) increase the scrubbing capacity of limestone slurry
- Relatively low dosage rates (e.g. 300 - 700 ppm)
- Can be used to improve efficiency or reduce operating costs
- Most effective for high sulfur fuels
- Widely used commodity chemical
  - Nylon manufacture
  - Food additive
  - Curing agents/plasticizers
- Environmentally friendly
  - Initial use promoted by US EPA
  - Approved by US FDA as food additive



Chlorides in WFGD Systems

- Chlorides concentrated in WFGD system due to evaporation
- Chlorides leave WFGD system via:
  - Moisture in gypsum filter cake
    - Disposal gypsum
    - Wallboard gypsum
  - Liquid carryover from absorber (insignificant)
  - Unabsorbed HCl (insignificant)
- Purge stream required for wallboard gypsum production



Effect of Chlorides on Process

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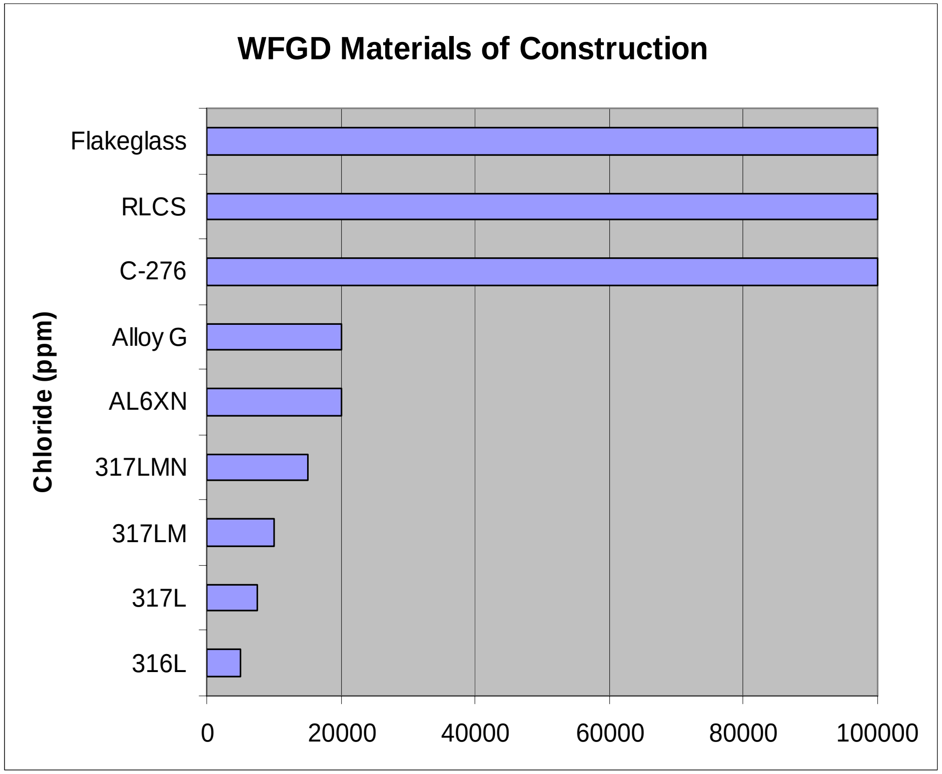
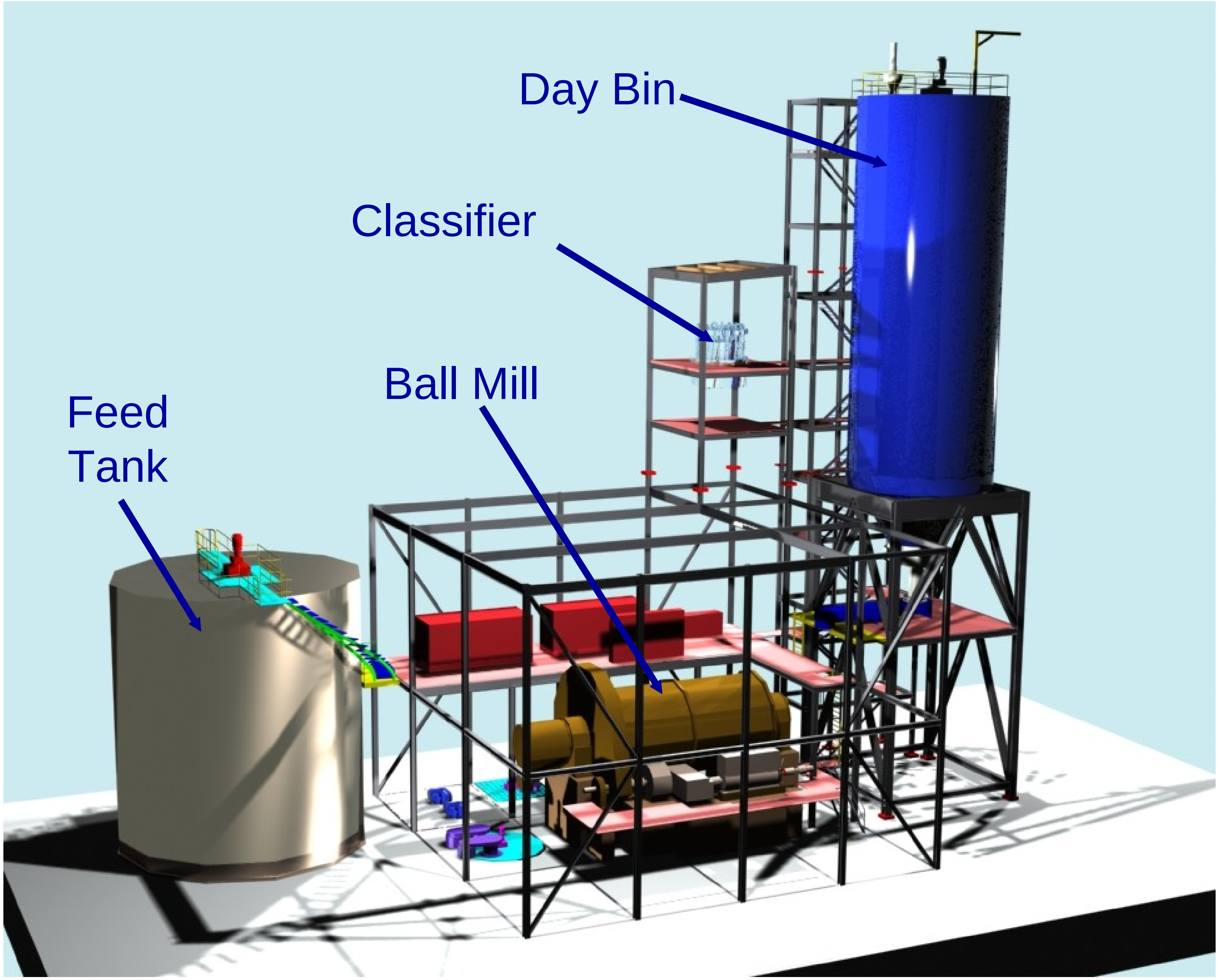
- Impact on SO_2 removal
  - Chloride from flue gas accumulates as soluble $CaCl_2$
    $2HCl + CaCO_3 \rightarrow CaCl_2 + CO_2 + H_2O$
    $CaCl_2 \rightarrow Ca^{+2} + 2Cl^{-}$
  - High Ca^{+2} concentration depresses pH and alkaline species such as $HCO3^{-}$, $SO3^{-2}$, $HSO3^{-}$
  - Result is lower removal efficiency/higher L/G
  - Chlorides that accumulate as NaCl (e.g. from make-up water) have much less impact

Effect of Chlorides on Materials

- Soluble chlorides known to attack steel/alloys
  - General corrosion
  - Pitting
  - Stress corrosion cracking
- Aggravated by
  - Low pH
  - Deposits
  - Stagnant liquids
- Material selection must consider
  - Service/operating conditions
  - Availability requirements
  - Cost



Reagent Preparation Island



Limestone Delivery/Storage

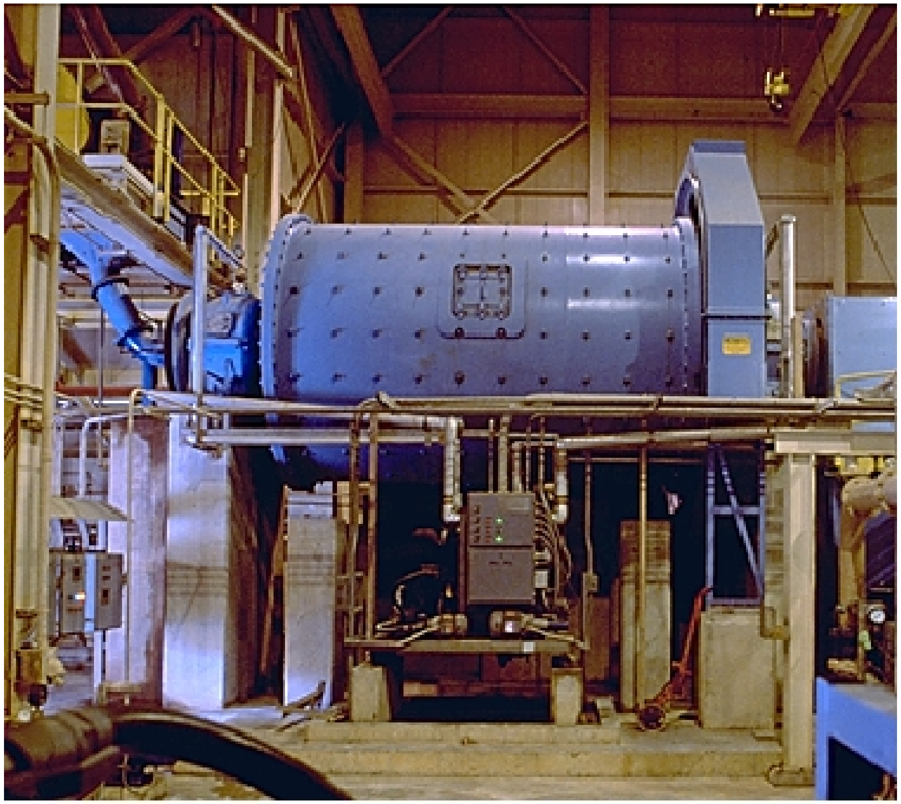
- Truck, rail, or barge delivery
- ¾" x 0" (20 x 0 mm) crushed limestone
- Outdoor long-term storage feasible in most areas
- Indoor storage in harsh/wet climates

Limestone Silo

- Provide buffer between limestone pile and ball mill operation
- 16-24 hr capacity
- Carbon steel construction with polymer or stainless steel hopper lining
- Fluidized bottom/mechanical activation
- Vent filter for fugitive dust control

Limestone Preparation

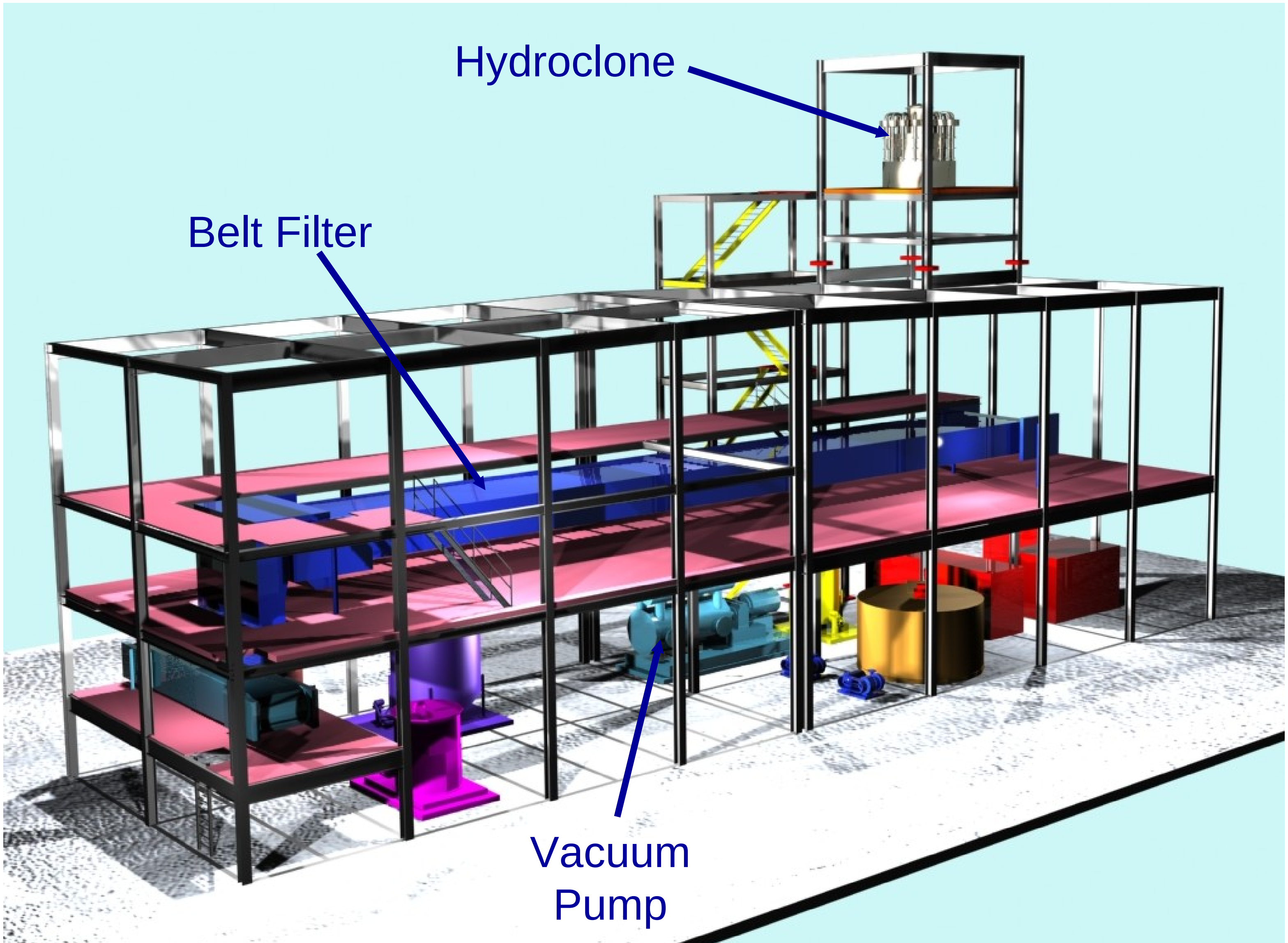
- Limestone grinding
  - Horizontal/vertical wet ball mills
  - On-site vs. off-site preparation
- Product ground to 90-95% < 40 μ; 30-35% solids
- Rubber-lined with hardened steel balls



Pre-Ground Limestone Injection

- Dry, pre-ground limestone feed options
  - Pneumatic injection into reaction tank below slurry level
  - Pre-slurry in small tank
- Advantages
  - Low capital cost (i.e. no ball mills, auxiliary equipment, buildings, etc.)
  - Less equipment to maintain
- Disadvantages
  - Higher delivered cost
- Lifecycle cost evaluation on case-by-case basis

Dewatering Island



Dewatering

- Primary dewatering:
  - Hydrocyclone
  - Absorber - 15% solids
    Overflow - 3% solids
    Underflow - 55% solids
- Secondary dewatering:
  - Commercial gypsum – vacuum belt filter @ 10% moisture
  - Landfill gypsum – vacuum drum filter @ 15% moisture

Wallboard Gypsum

- Typical specification:
  - >95% $CaSO_4 \bullet 2H_2O$
  - <0.5–1.0% $CaSO_3 \bullet ½H_2O$
  - <100 ppm Cl
  - <10% moisture
  - pH 6–8
  - 30–40µ MMD
- Requires:
  - High purity limestone (95–96%)
  - High efficiency ESP/FF
  - 99+% oxidation
  - Belt filter
  - Cake washing

Gypsum Storage/Handling

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- Covered storage options
  - Direct discharge to bunker/ manual reclaim
  - Convey to dome/manual reclaim
  - Convey to building or silo/ automated reclaim
- Open pile
  - Feasible
  - Possible issues: moisture, fugitive dust, leaching
- Selection depends on:
  - On-site storage requirement
  - Gypsum contract

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Centralia Operations Summary

- Start-up
  - Unit 2 and common equipment – October 2001
  - Unit 1 – July 2002
- 100% availability on both units since start-up
- Emissions and performance well within required limits
- Absorber opened for first time during planned Unit 2 boiler/turbine outage in April 2003

Centralia Steam Plant

Absorber After 11,000 Hours

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September 2001

April 2003

Unit 2 Absorber Outage

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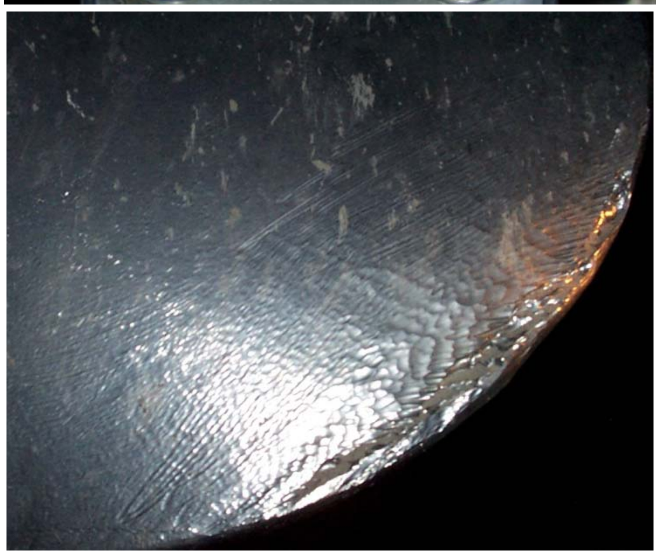

Unit 2 Absorber Outage

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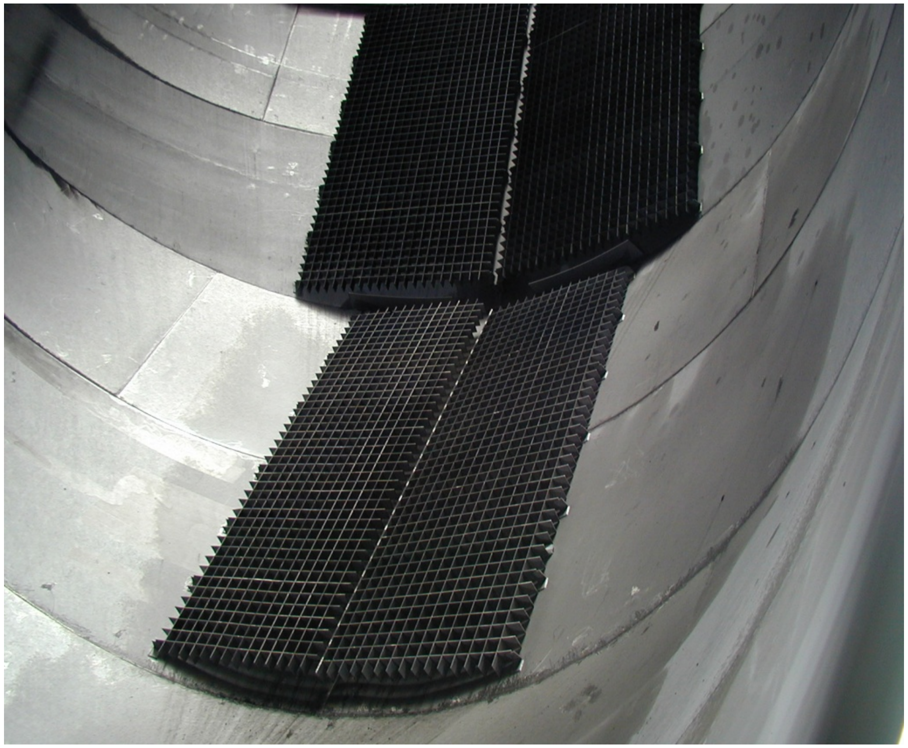

WFGD Operations Staff

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Position Description	No.	Coverage
FGD Supervisor	1	1 shift, 5 days/week
FGD Operator	1	3 shifts, 7 days/week
FGD Mechanic	1	1 shift, 5 days/week
FGD Computer Tech	1	1 shift, 5 days/week
FGD Specialist	1	1 shift, 5 days/week
FGD Material Handling	1	3 shifts, 7 days/week

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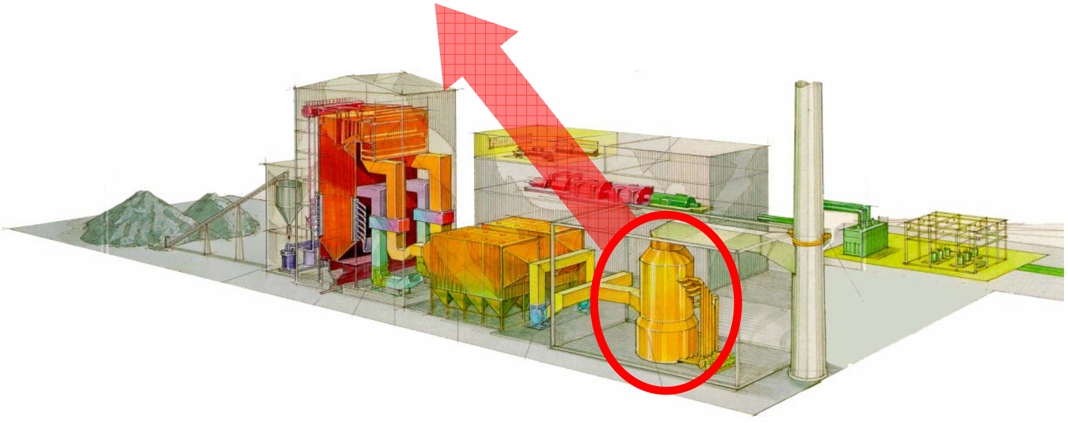
Sulfuric Acid Mist

- SO_3 inlet concentration
  - <1 ppm for western sub-bituminous coal
  - >50 ppm for eastern bituminous
- Sulfuric acid (H_2SO_4) mist created due to rapid quenching of flue gas in absorber
- Fine droplets (< 0.5 micron) are difficult to collect
- Control techniques
  - Alkali injection (e.g. lime, trona, sodium carbonate
  - Wet electrostatic precipitator

Mercury

- WFGD systems remove 70-90% of incoming $HgCl_2$, but very little Hg^o
  - $HgCl_2$ water soluble and is absorbed efficiently
  - Removal not strong function WFGD design
- Effluent flue gas contains mostly elemental, vapor-phase Hg
- Mercury can also enter WFGD with limestone and/or make-up water
- Fate of mercury
  - Purge stream
  - Gypsum
- Do WFGD systems re-emit Hg?



Mercury

- Oxidized mercury readily absorbed by WFGD system; elemental mercury is not
- Oxidized Hg entering WFGD is a function of:
  - Fuel (i.e. Hg, Cl, Br)
  - Boiler operating conditions (e.g. unburned carbon)
  - Upstream equipment (e.g. SCR, ESP, FF)
- Oxidized mercury captured by WFGD can be reduced to elemental mercury and re-emitted
  - Re-emission additives
  - Oxidation/reduction potential
- Fate of mercury
  - Gypsum
  - Purge stream

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WFGD Rules of Thumb

Limestone Usage	1.7 ton limestone/ton SO_2 removed
Limestone Cost	$10-20/ton
Gypsum Production	3.1 ton gypsum/ton SO_2 removed (95% purity, 10% moisture)
Gypsum Value	-$10 to +$5/ton
Water Consumption	1.5-1.8 gpm/MW
Power Consumption	Low S – 1.2-1.5% generation High S – 1.5-2.0% generation

600 MW WFGD System

Unit Size	600 MW
Number of Units	1
Fuel Sulfur Content	1.5 %
SO2 Loading	18,000 lb/hr
SO2 Removal Efficiency	98 %
Limestone Purity	96 %
Limestone Consumption	30,000 lb/hr
Gypsum Purity	95 %
Gypsum Production @ 10% Moisture	55,000 lb/hr
Water Consumption	960 gpm
Power Consumption	9 - 12 MW
Cost	90.0 MUSD

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