REINHOLD ENVIRONMENTAL Ltd.

RE

2012 APC Round Table & Expo Presentation

July 16-17, 2012, in Baltimore, MD / Hosted by Duke Energy, Entergy, FirstEnergy, Southern Company & TVA

An Unbiased Comparison of Dry Scrubber Technologies

2012 APC Roundtable – Training Session

July 2012

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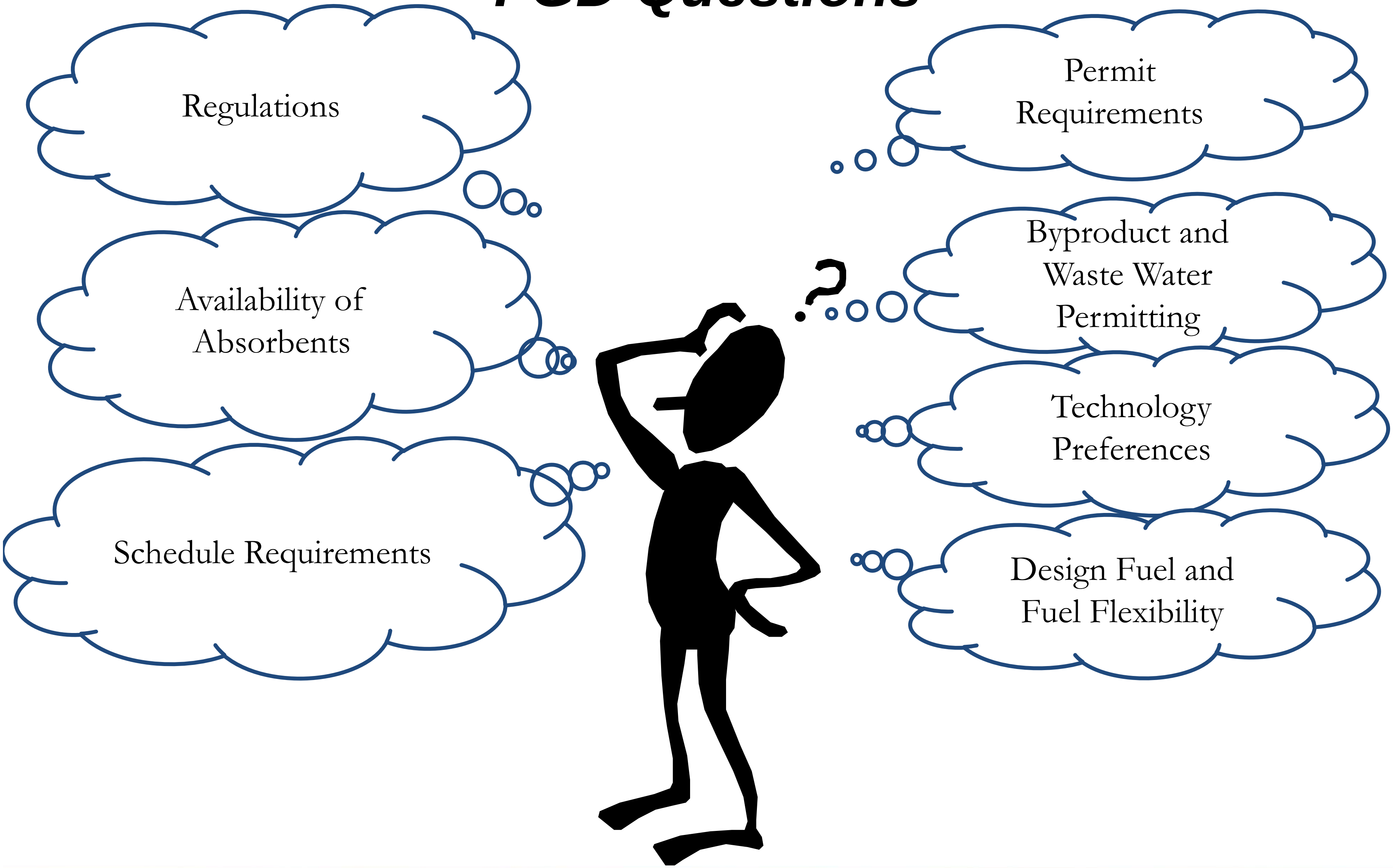
Agenda

- Dry Sorbent Injection Overview
- Spray Dry Absorber Overview
- Circulating Dry Scrubber / Transport Reactor Overview
- Compare and Contrast Technologies
- Summary

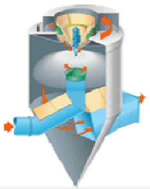
FGD Questions



Dry Flue Gas Desulfurization and Acid Gas Control

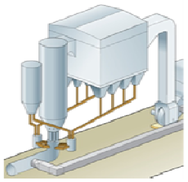
Dry Sorbent Injection (DSI)

- Usually lime or sodium based
- Injected before particulate control device
- Used for SO_2,SO_3, HCl control



Spray Dry FGD System

- Up to 98% SO_2 removal
- Traditionally <1.5% sulfur coal, but with hydrated lime, virtually unlimited
- Dry product for landfill
- Uses lime



Circulating Dry Scrubber/ Transport Reactor

- Up to 98% SO_2 removal
- More fuel flexibility
- Dry product for landfill
- Uses lime which can be hydrated on site

Some Common Key Terminology

- **Saturation Temperature**
  - *Moisture condenses out of the gas (wet bulb temperature)*
- **Approach to Saturation**
  - *Temperature margin at SDA or CDS outlet above saturation*
- **Spraydown**
  - *Temperature difference between absorber inlet and outlet*
- **Stoichiometry**
  - *Ratio of lime to SO_2 at absorber inlet or SO_2 removed from flue gas*

Agenda

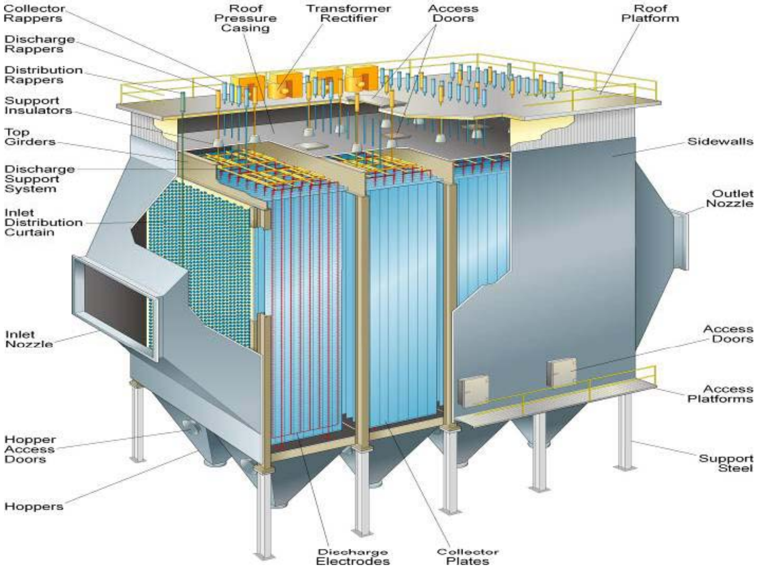
- **Dry Sorbent Injection Overview**
- **Spray Dry Absorber Overview**
- **Circulating Dry Scrubber / Transport Reactor Overview**
- **Compare and Contrast Technologies**
- **Summary**

DSI Technology Overview

- DSI = Dry Sorbent Injection
- DSI is based on dilute phase pneumatic conveying technology
- Major components are:
  - Truck/rail unloading
  - Silo
  - Weigh hopper/Rotary feeder
  - Transport Air Blowers
  - Reagent milling (optional)
- Not a new technology
  - Used for SO_2 since 1980s
- Current applications for SO_2, SO_3, HCl, condensables and Hg
- Mobile test units available

DSI Evaluation – Overall System Approach

- When using DSI, overall system needs evaluated
- Which pollutants to target?
- Removal or emission limit required?
- Is the particulate control device affected?
  - How will additional loading affect it?
  - How do sorbents impact flyash?
- What is the best sorbent to use?
- Is there enough residence time?
- Is a trial warranted?



DSI Reagent Options

- Trona (dry) for SO_2, SO_3, or HCl
- Milled Sodium Bicarbonate (dry) for SO_2, SO_3, or HCl
- Hydrated Lime (dry) for SO_3 or HCl
- Hydrated Lime (dry) plus Humidification for SO_2
- Milled Trona or SBC should be considered for higher removal efficiency: >70% SO_2

Mobile test units available

What is Trona?

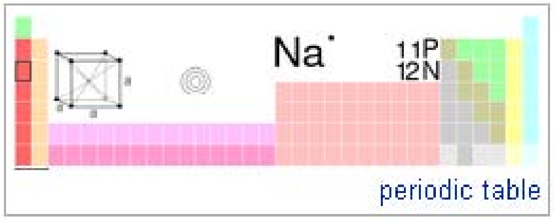
- **Chemically formula:**

$$Na_3(CO_3)(HCO_3)\bullet 2(H_2O)$$

- **Refined into soda ash, sodium bicarbonate (baking soda) and sodium phosphates (detergents).**

Trona

- **Calcines in the flue - increases surface area and reactivity.**
- **May improve Dry ESP performance by reducing the resistivity of the ash**
- **Increases sodium content of flyash ⟶ high flyash pH.**
  Metals such as Se may leach at high pH's.
- **Potential material handling problems due to exposure to high temperature or moisture**
  - **Calcination of trona in the transport line resulting in lower reactivities**
  - **Release of waters of hydration causing product scaling**



Sodium Bicarbonate

- Chemical Formula: $NaHCO_3$
- Mean Size: 100+ microns
- Delivered in crystalline form
- Produced from Trona
- Suppliers: Solvay, $Natron_x$

Sodium Bicarbonate

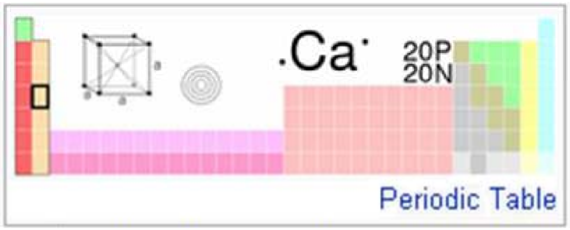
- Sodium bicarbonate (SBC) is the most effective dry sorbent for mitigating acid gases, but is typically only used for SO_2 due to cost
- SBC also calcines in the flue causing a "popcorn" effect which increases the surface area and reactivity.
- SBC has the fewest material handling issues
- SBC must be milled to achieve high reactivity

Hydrated Lime

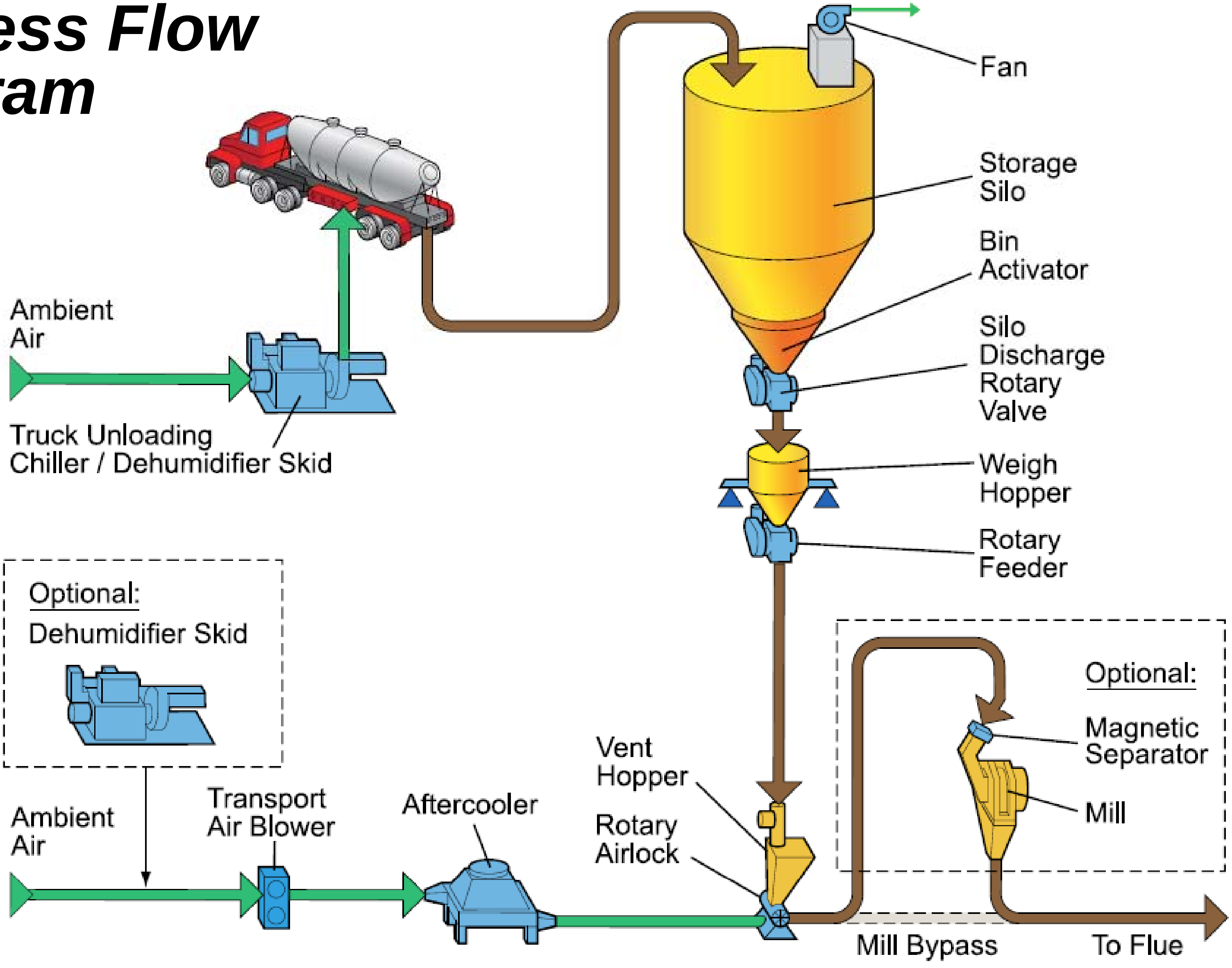
- **Chemical Formula: $Ca(OH)_2$**
- **Mean Size: 2-3 microns**
- **Vendors: Mississippi Lime, Lhoist, Carmeuse**
- **Surface area (>20 g/m^2) and available $Ca(OH)_2$ should be considered in any evaluation**

Hydrated Lime

- **Less reactive than sodium-based sorbents.**
- **Longer residence time than sodium sorbents to maintain similar SO_3 reduction**
- **Injection typically does not impact ash sales**
- **May negatively impact dry ESP performance by increasing resistivity of flyash**
- **CO_2 can react with hydrated lime in the convey line and cause scaling**
- **Line plugging issues are exacerbated with moisture and high temperatures**



Process Flow Diagram



When to mill reagent?

Sodium Bicarbonate

- **Milling required**
  - **As received D50 ~100-120μ**

Trona

- **SO_2 / HCl with ESP recommended**
- **SO_2 / HCl with PJFF**
  - **Desired especially for SO_2 removal over 70%**
- **As received D50 ~35-45μ**

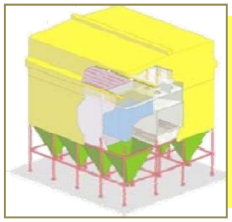
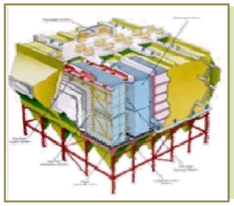
Hydrated Lime – not required

Conveying Line Splitters

DSI for Multi-Pollutant Control

Performance

- Removal rates are variable depending on sorbent, sorbent particle size, flue gas temperature and residence time

	*Pulse Jet Fabric Filter (PJFF)*	SO_2 removal 80+% and 95%+ capture of H_2SO_4 and HCl
	*Electrostatic Precipitator (ESP)*	SO_2 up to 70% and 90%+ capture of H_2SO_4 and HCl

- Hg control improvement by mitigating H_2SO_4
- Condensable PM control by mitigating H_2SO_4 and HCl

Considerable Interest in DSI with Hydrated Lime: but it is not a cure-all !!

<table>
<tr><th></th><th colspan="3">ESP</th><th colspan="3">PJFF</th></tr>
<tr><th></th><th>SO_2</th><th>HCl</th><th>H_2SO_4</th><th>SO_2</th><th>HCl</th><th>H_2SO_4</th></tr>
<tr><td>Bituminous Coal (Med – High Sulfur)</td><td></td><td></td><td rowspan="5">Post ESP and pre-WFGD preferred</td><td></td><td></td><td></td></tr>
<tr><td>Bituminous Coal (Low Sulfur)</td><td></td><td rowspan="5">ESP must be evaluated for desired rate</td><td></td><td></td><td></td></tr>
<tr><td>PRB Blends (>80%)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>PRB</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Lignite</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Biomass</td><td></td><td></td><td></td><td></td><td></td></tr>
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Forget Lime for SO_2!

DSI Capabilities – Trona / Sodium Bicarbonate

	ESP			PJFF		
	SO_2	HCl	H_2SO_4	SO_2	HCl	H_2SO_4
Bituminous Coal (Med – High Sulfur)						
Bituminous Coal (Low Sulfur)						
PRB Blends (>80% Blend)						
PRB						
Lignite						
Biomass						

Red & Yellow zones due to large volume of material to be injected and ash leachate / toxicity issues.

ESP Performance & Disposal

	ESP Performance	Ash
Trona / milled Trona	Lowers resistivity SO_3 mitigation – improves performance SO_2 mitigation – need to be careful of breakthrough	SO_3 mitigation – sodium may affect flyash sales, if ponding may affect pH of pond SO_2 mitigation – could have 8-10% NaO in flyash
Sodium Bicarbonate	Lowers resistivity SO_2 mitigation – need to be careful of breakthrough but half as much is used compared to Trona	SO_2 mitigation – increased NaO in flyash
Hydrated Lime	Increases resistivity Good for large precip's May try dual injection (pre-ESP and pre-WFGD)	Usually does not affect ash sales

Performance Guarantees – SO_2

% removal and/or emission limit

	ESP	PJFF	Comment
Trona	50% overall system	80% overall system	Milled trona likely required
Sodium Bicarbonate	50% overall system	80%+ overall system	90% removal with PJFF being investigated

HCl and H_2SO_4 removal could be included with this guarantee

HCl and SO_2 Relationship

- **H_2SO_4 first and readily reactive**
- **HCl / SO_2 somewhat competing**
  - **Good coverage and high >1 s residence time ensure high removals**
- **HCl only with no SO_2 in the stream is removed readily**
- **HF is removed more readily than HCl**

Performance Guarantees – Halides

% removal and/or emission limit

	ESP	PJFF	Comment
Trona	70 - 90% overall system	90%+ overall system	Milled trona likely required
Sodium Bicarbonate	70 - 90% overall system	90%+ overall system	
Hydrated Lime	70% overall system	90%+ overall system	

R&D ongoing to finalize required injection rates, max removal, etc.

Advantages and Disadvantages of DSI

Advantages

- Simple process
- Limited equipment
- Easy to retrofit
- Limited space needed
- No fluework changes needed

Disadvantages

- Limited removals
- May impact existing particulate control device
- May impact ash sales
- Many vendors do not understand full impacts of system

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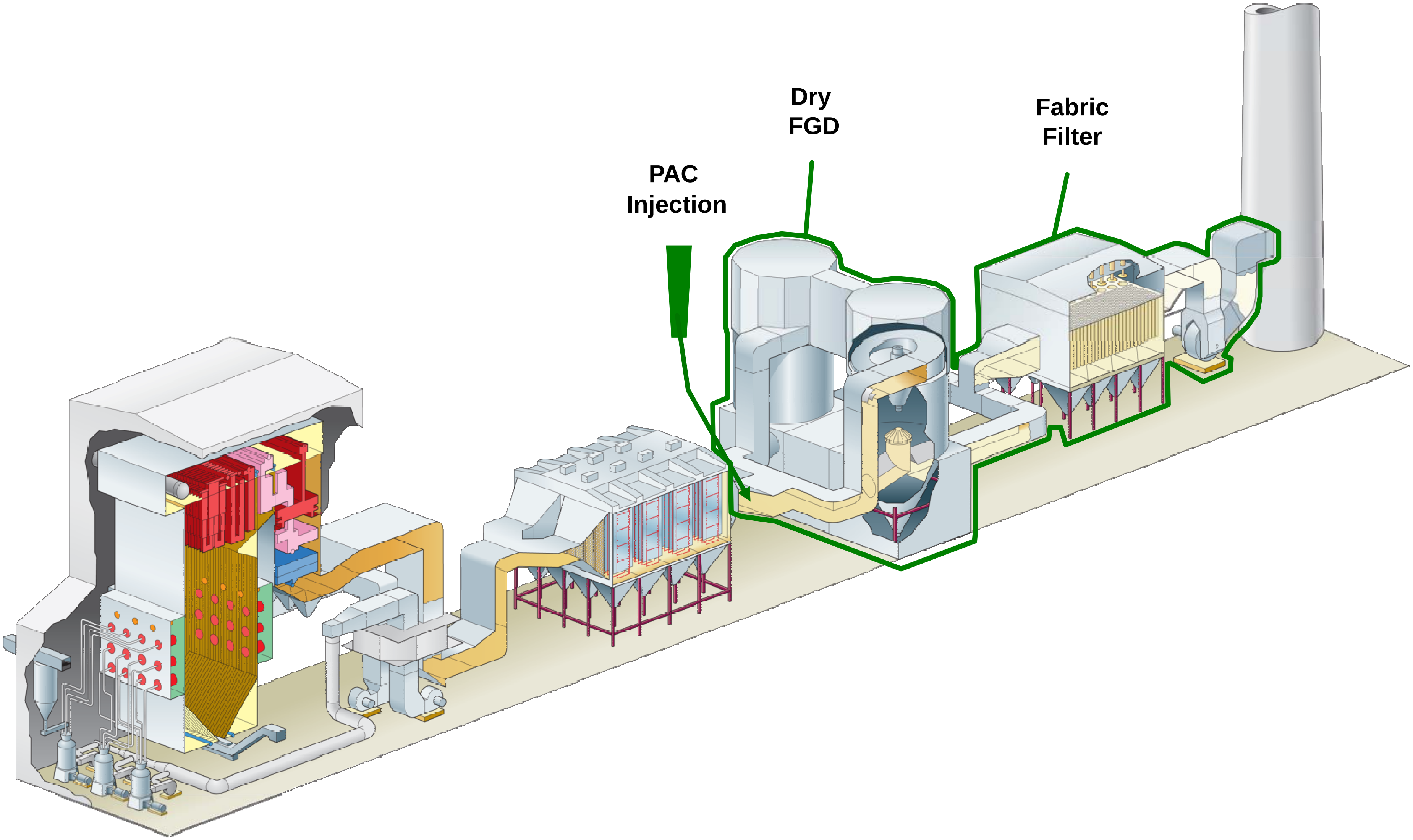
Typical Spray Dry Absorber Configuration

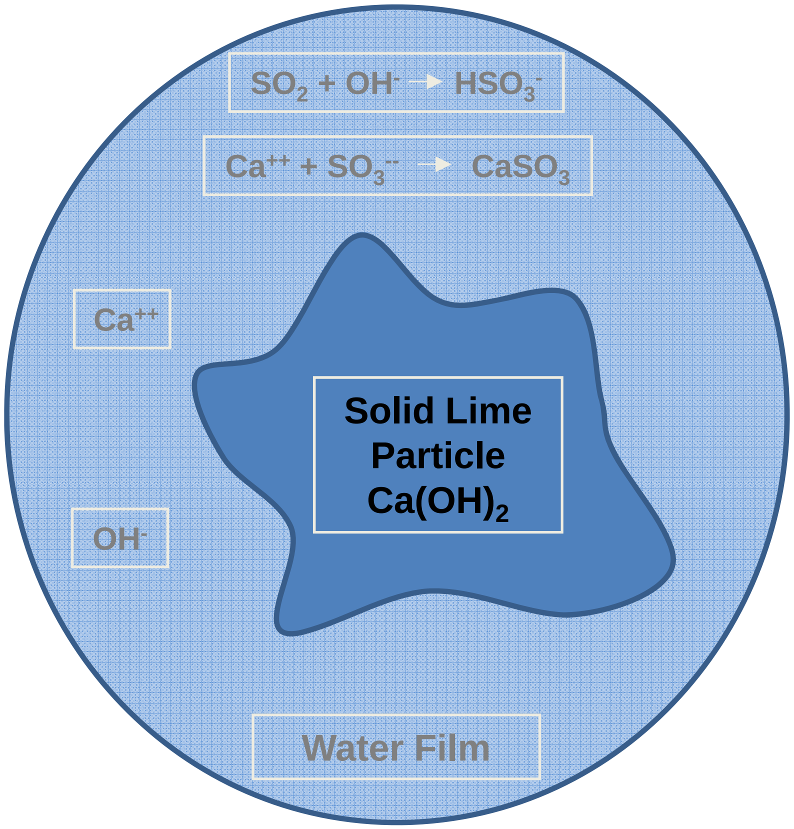


SDA Chemistry

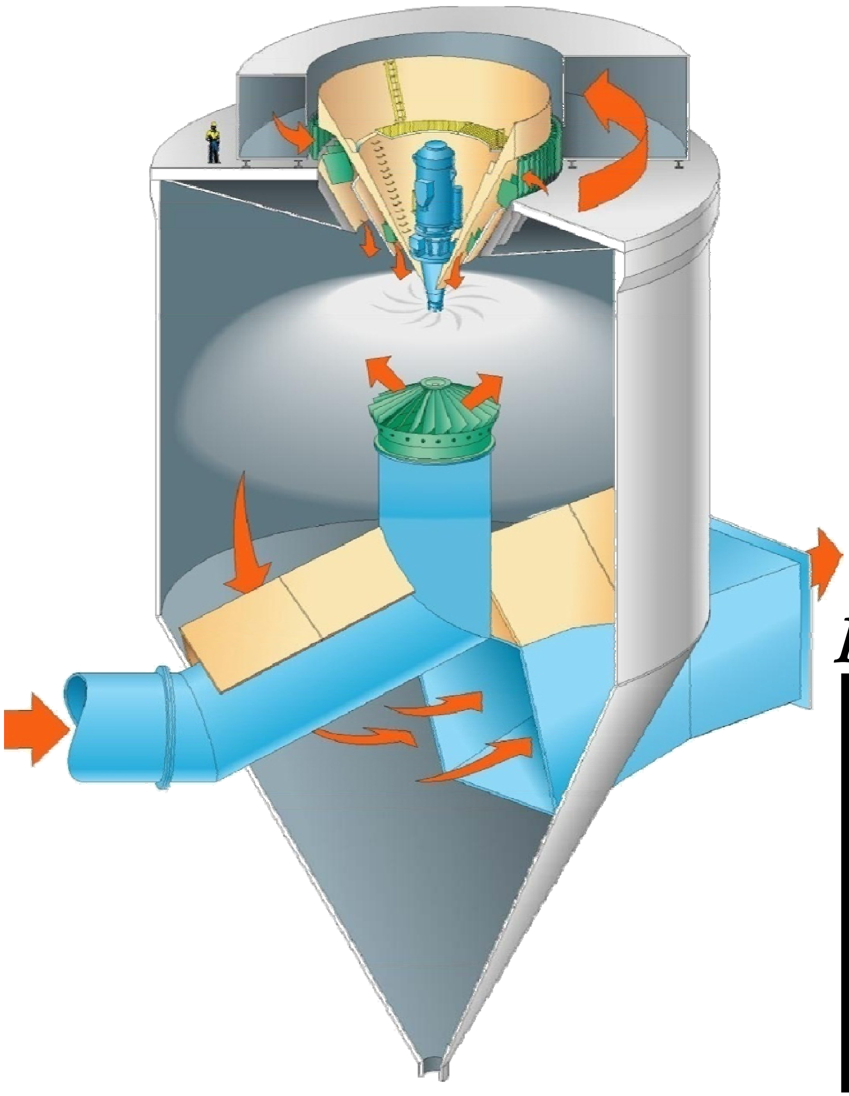
Reactions:		Products:
SO_2/SO_3	+ $Ca(OH)_2$	$CaSO_3$ / $CaSO_4$ + H_2O
2HCl	+ $Ca(OH)_2$	$CaCl_2 + H_2O$
2HF	+ $Ca(OH)_2$	$CaF_2 + H_2O$

SO_2 Absorption

- Absorption of acid gases most rapid when water is present
- High reagent solubility and drop pH promote absorption
- Inert solids provide more surface area and enhance gas/reagent contact
- Enhanced by good distribution of high surface area reagent



SDA Module Design

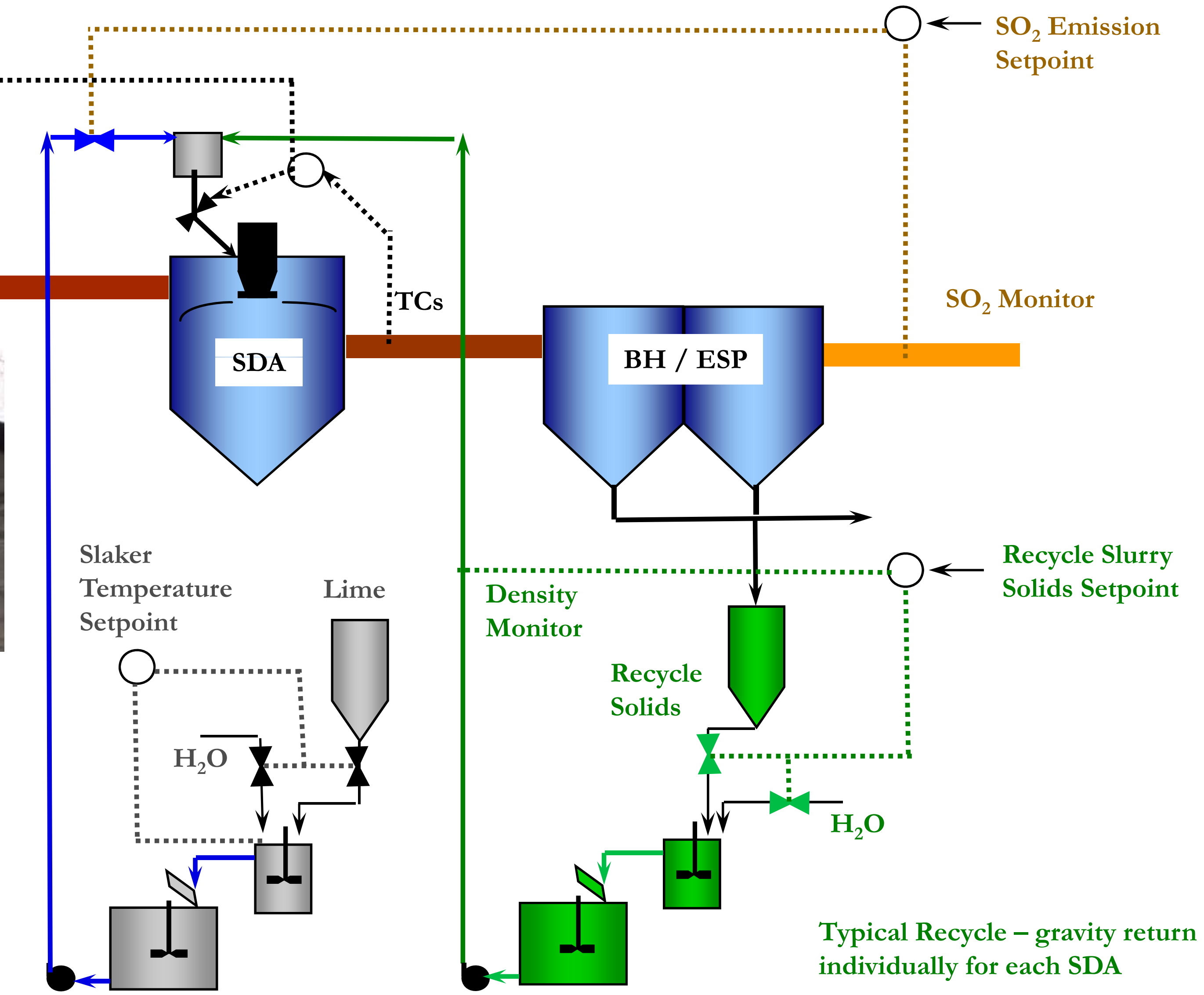


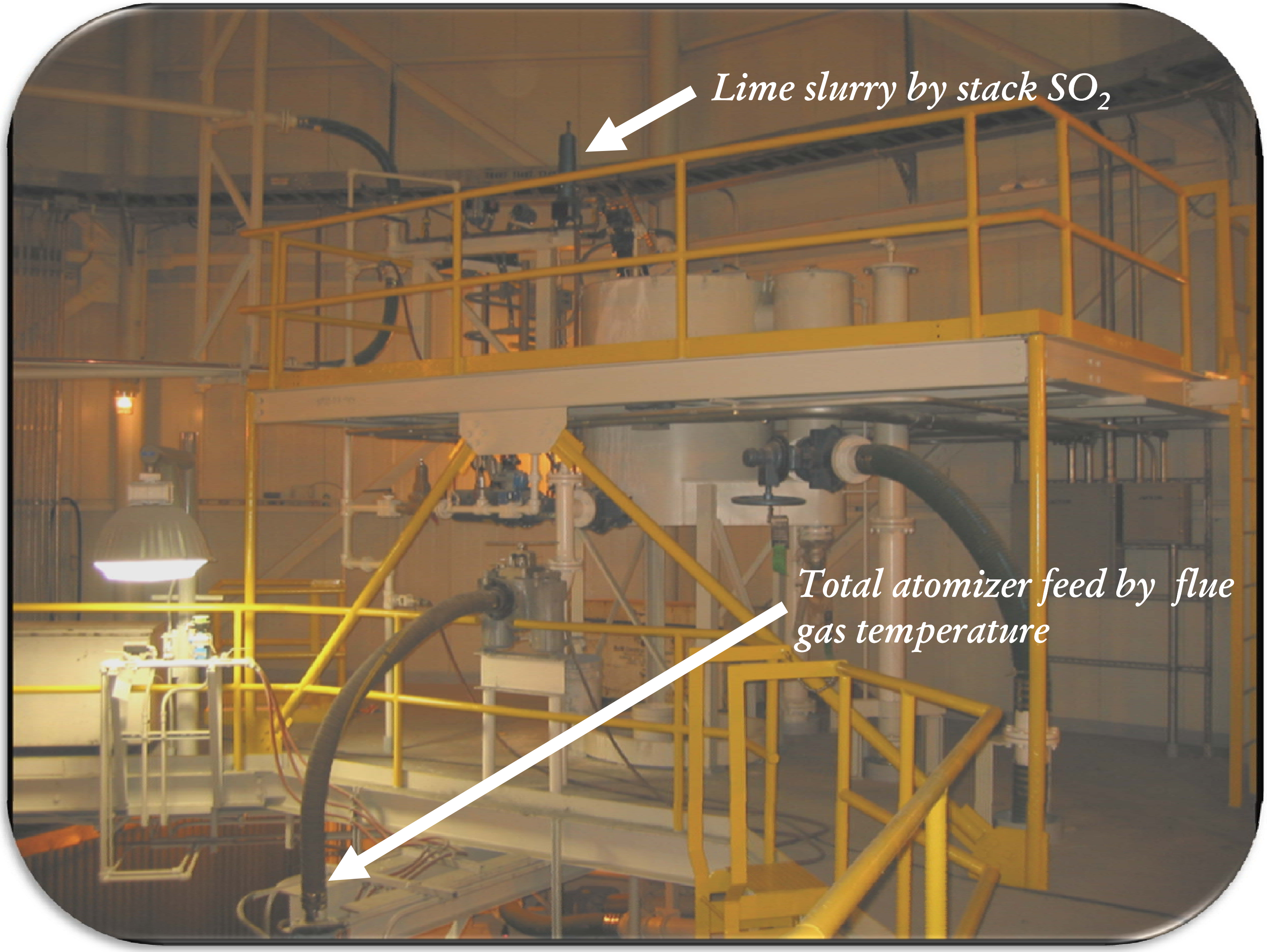
SDA module size is based on the flue gas flow rate (not SO_2 removal efficiency)

Roof Gas Disperser

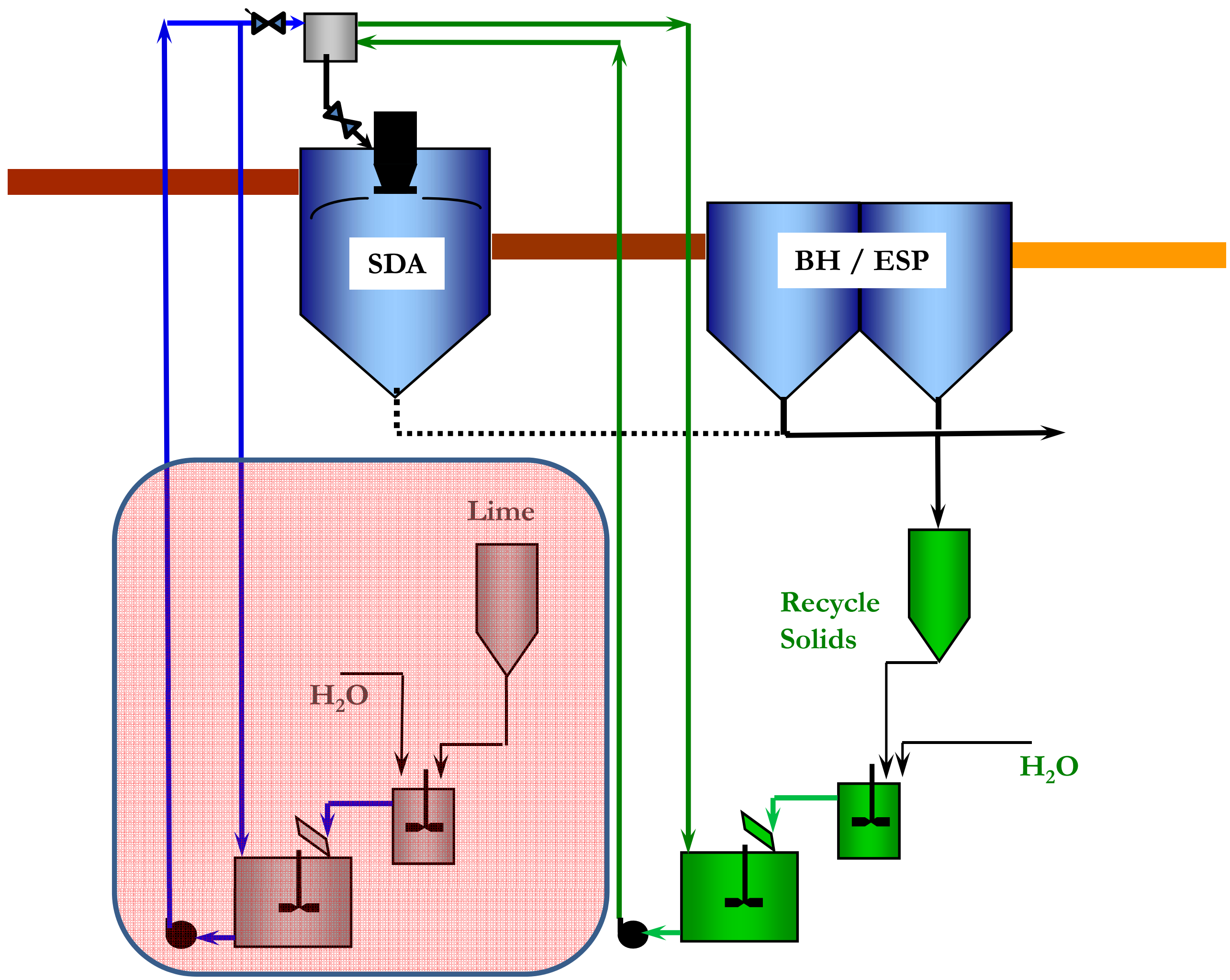
Central Gas Disperser

Process Flowsheet and Control Basics




Lime slurry by stack SO_2
Total atomizer feed by flue gas temperature

Lime Slurry Preparation System



Lime Slaking

Horizontal Ball Mill

Detention Slaker

Vertical Ball Mill

Lime Slurry Preparation System
Horizontal Ball Mill

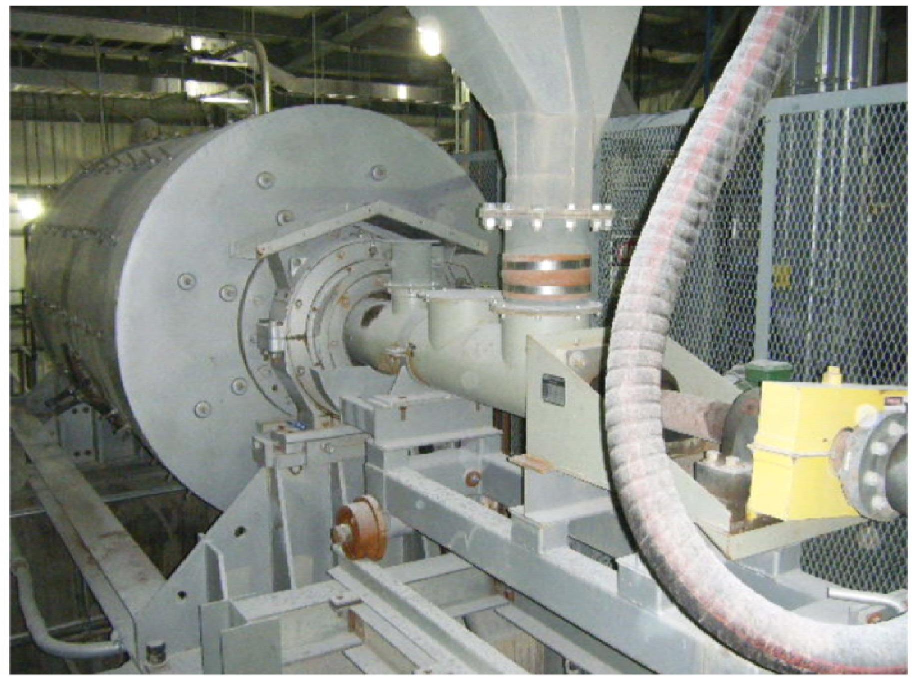
Larger Capacities for Supplying Multiple SDAs

Highest Capital Cost

Higher Maintenance Costs

High Operating Noise

No Grit Disposal Required



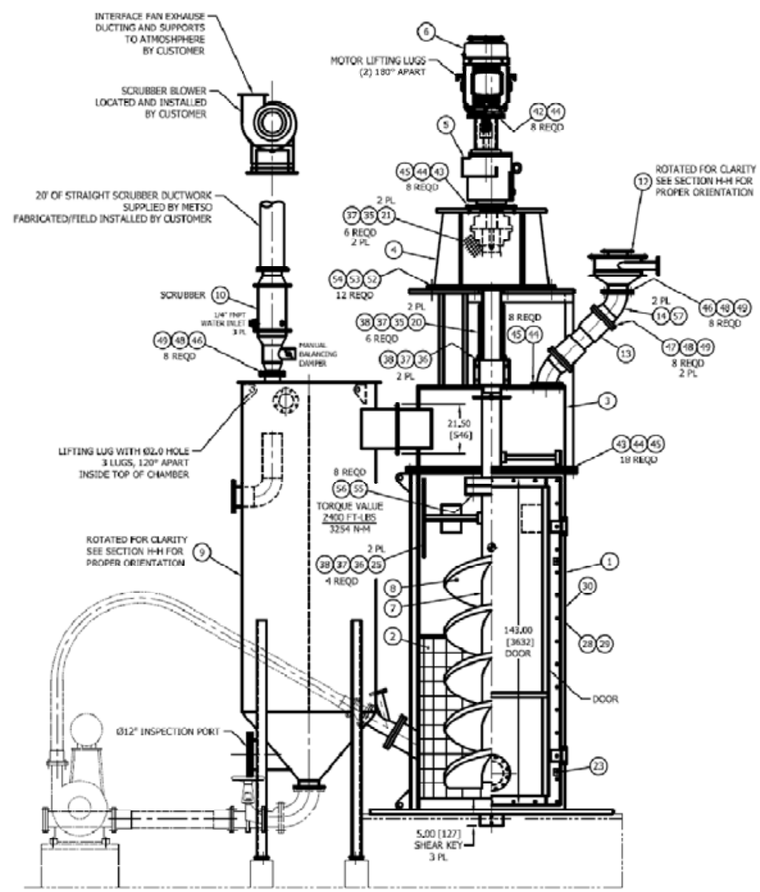
Lime Slurry Preparation System
Vertical Ball Mill

Smaller Footprint than Horizontal Ball Mill

Lower Capital Cost than Horizontal Ball Mill

High Operating Noise

No Grit Disposal Required



Lime Slurry Preparation System
Detention Slaker

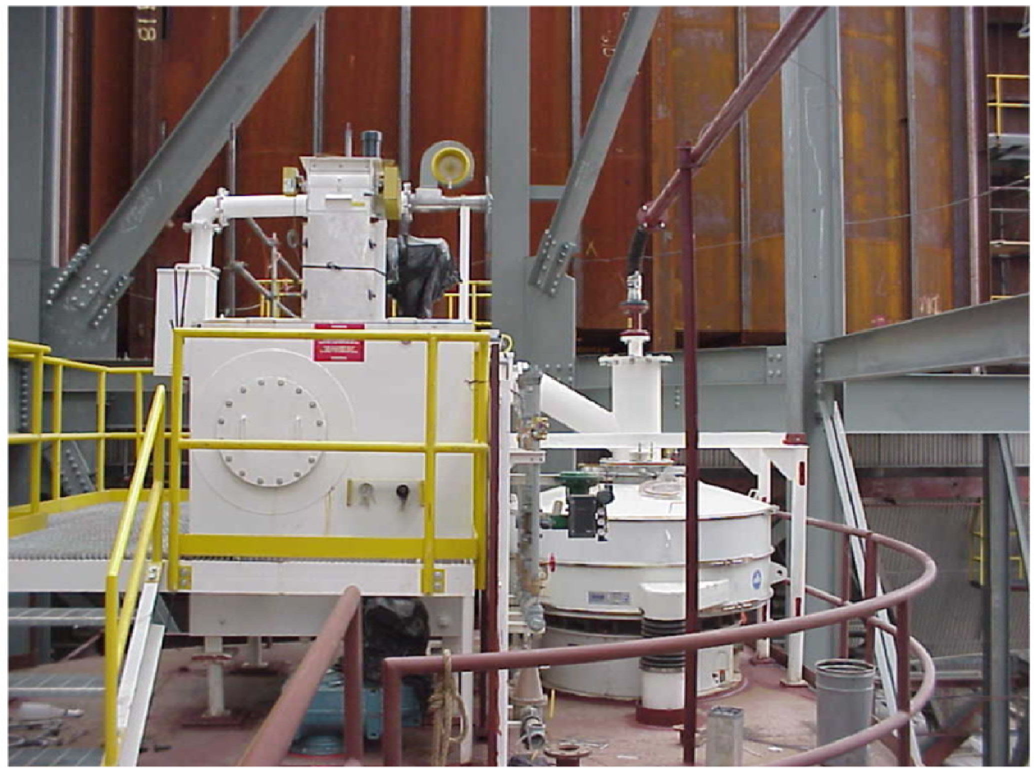
Simple Slaker Design

Lowest Capital Cost

Lower Maintenance Costs

Relatively Quiet Operation

Grit Disposal Required

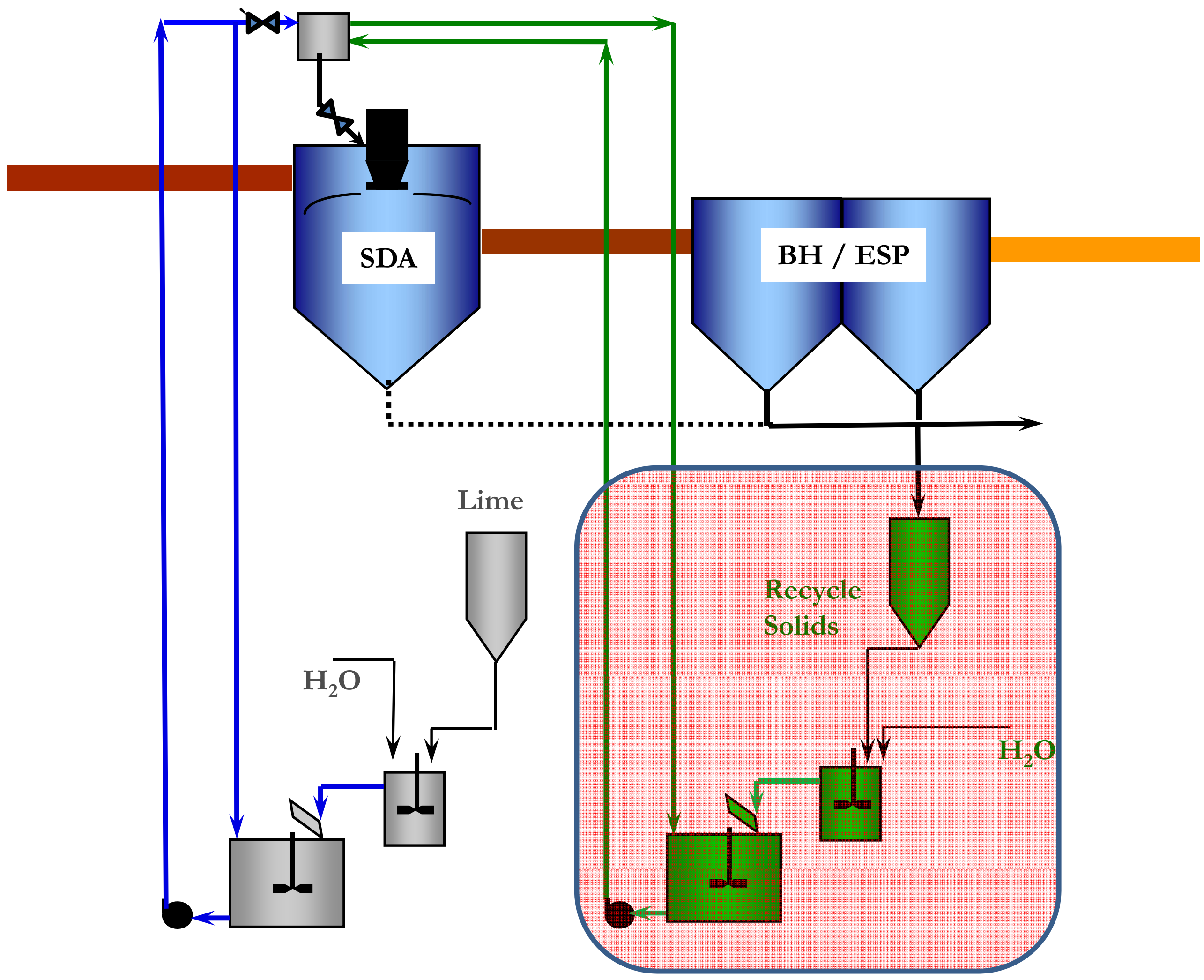


Lime Slurry Preparation System

Water Control Panel

Slaking Water Heater

Recycle Slurry Preparation System



Recycle Ash Storage Silo

Top of recycle silo showing bin vent with pressurized flyash transport system

Recycle Ash Storage Silo Discharge

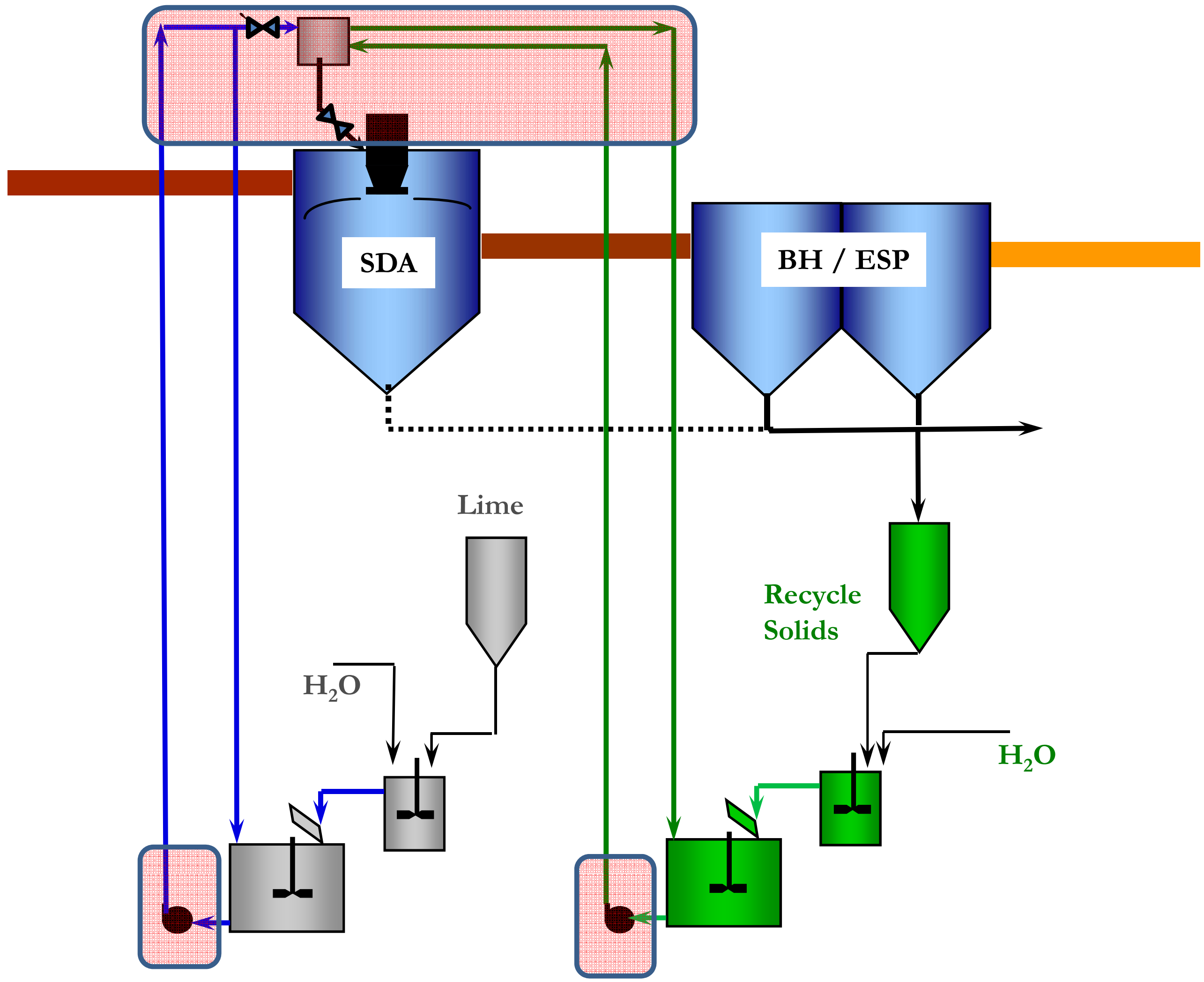
Recycle Slurry Mix Tanks

Two x 100% capacity trains for a 500 MW installation

Recycle Ash Preparation System

Wetting Box, Mix Tank, and Dust & Vapor Removal System

Slurry Feed System

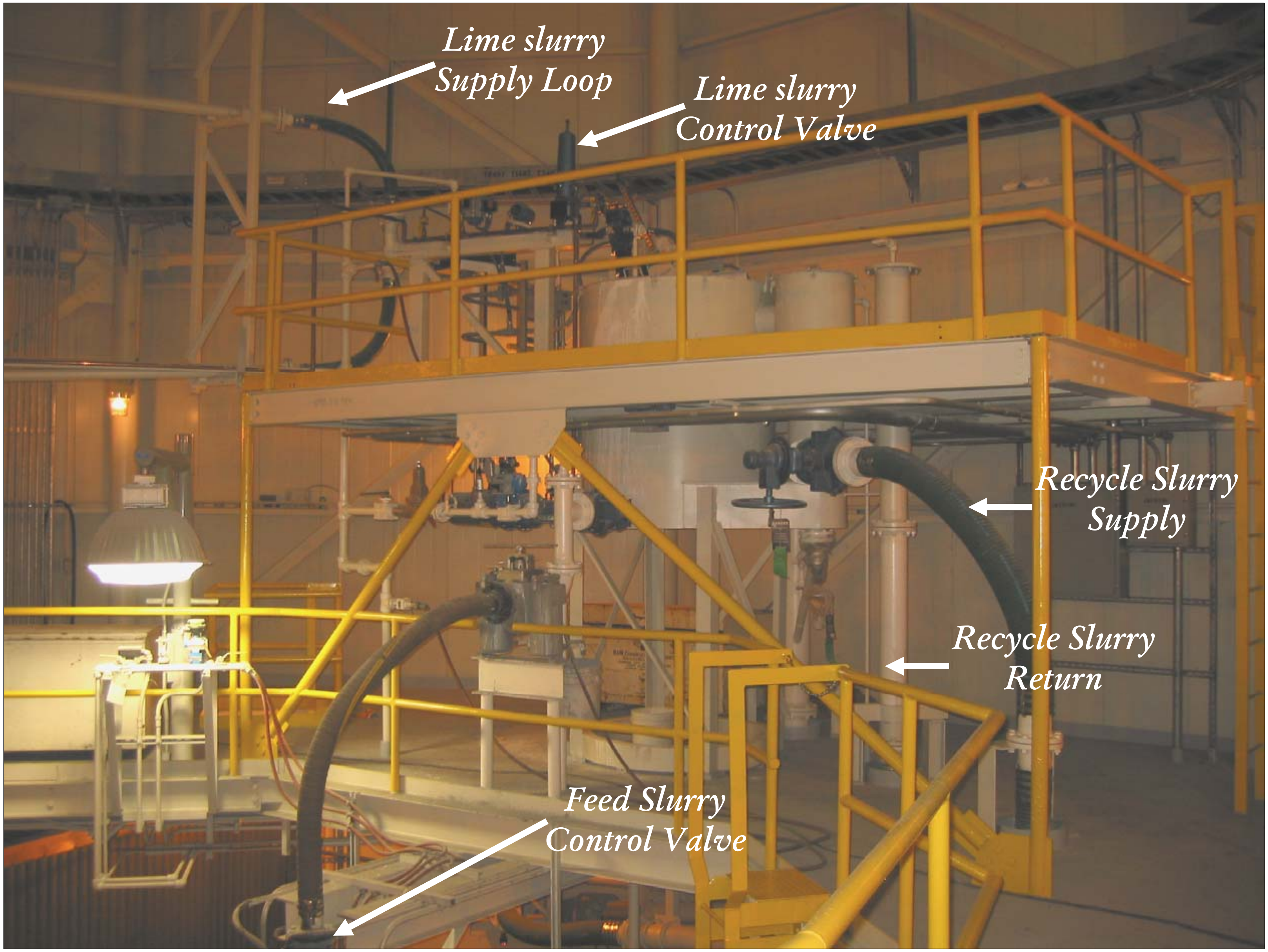


Slurry Feed Pumps

Direct-drive, laminar flow

Belt-drive, centrifugal

Fast Response Head Tank


Lime slurry
Supply Loop
Lime slurry
Control Valve
Recycle Slurry
Supply
Recycle Slurry
Return
Feed Slurry
Control Valve

Hydrated Lime Injection with SDA

- Inject hydrated lime upstream of the SDA
- Decouples the lime addition from the water addition
- Removes the prior limitations of the SDA system
- Extends inlet sulfur range and increases removal rates

Typical Required SDA Performance

	Recent Projects (lb/MBtu)
SO_2	0.06 to 0.10 lb/Mbtu
SO_3 (as H_2SO_4)	0.0040
HCl	0.0029
HF	0.0009
Hg	0.8 to 3 lb/TBtu
PM_{10} (filterable)	0.008 to 0.012
PM_{10} (total)	0.018 to 0.025
Opacity	5 to 20%

Advantages and Disadvantages of SDA

Advantages

- Mature product
- Recycle usage lowers lime consumption
- Carbon steel construction
- Low water usage
- No wastewater treatment
- No wet stack required

Disadvantages

- Typically limited to lower sulfur coals
- Slurry Handling
- Byproduct disposal requires care
- Fairly high quality water required for slaking

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- Spray Dry Absorber Overview
- **Circulating Dry Scrubber / Transport Reactor Overview**
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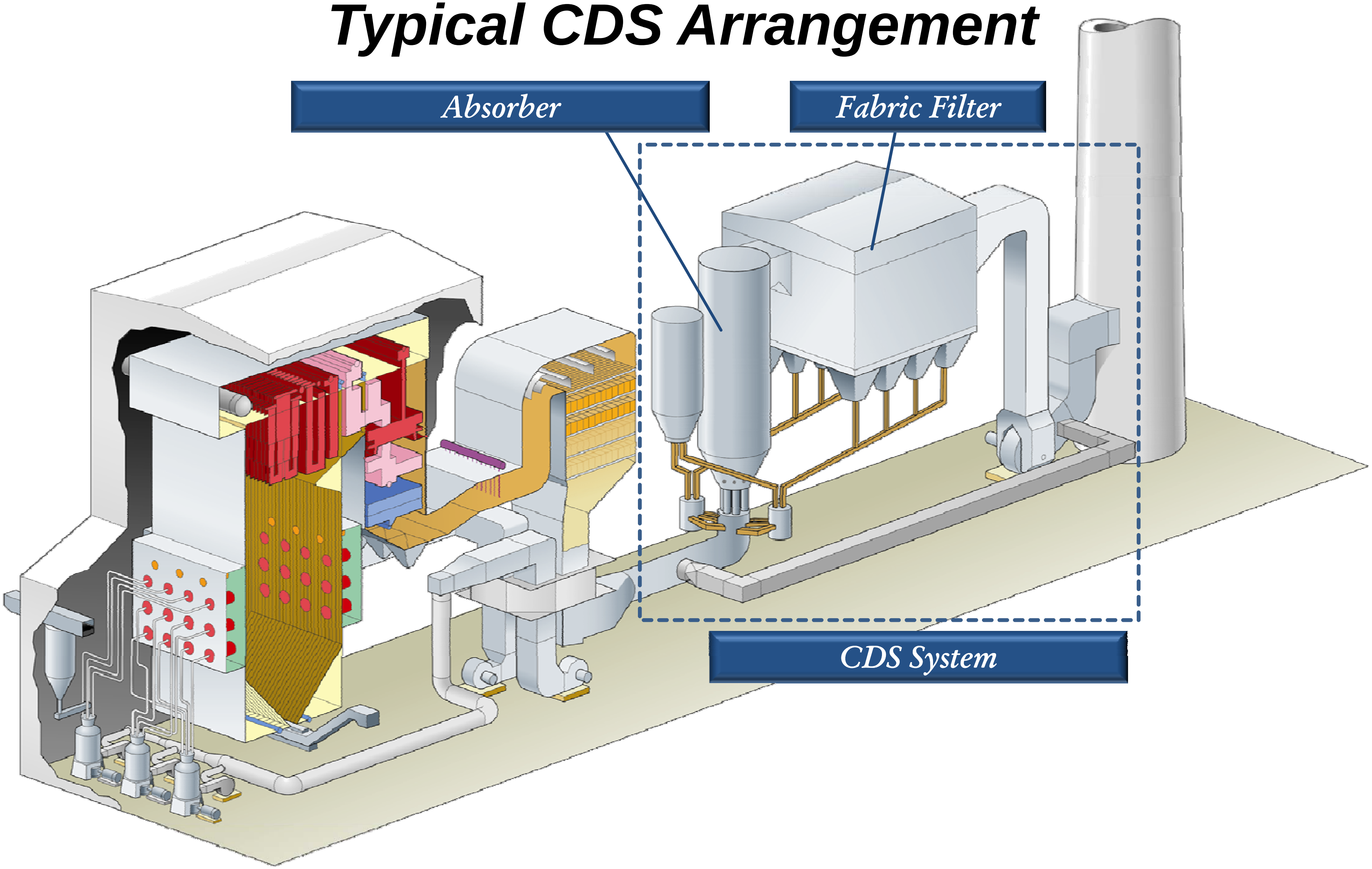
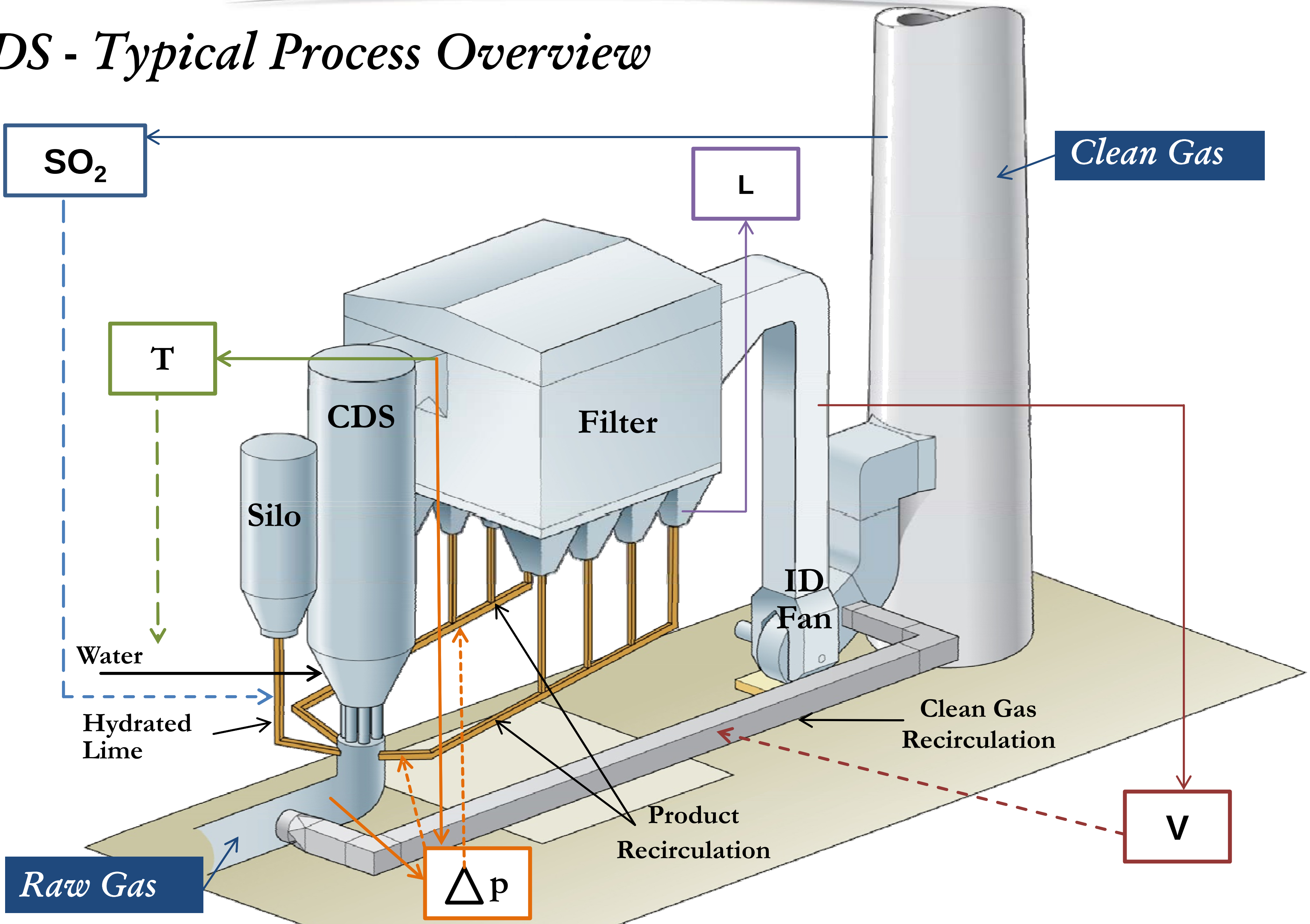
CDS Process Chemistry

- **Pebble Lime (CaO) or Hydrated Lime**
  - $CaO + H_2O \rightarrow Ca(OH)_2$ + Heat
- **Theoretical Stoich Ratios (mol Ca/mol acid)**
  - SO_2 1:1 , HCl ½:1, HF ½:1 , SO_3 1:1
- **Actual stoich typically between 1.4 – 1.9 for SO_2**
- **Water – Humid flue gas increases the efficiency of the lime/acid gas interaction**
- **Option: PAC injection removes mercury, dioxins, and furans**
- **Dry Byproduct – 60% flyash, 20% $CaSO_3$, 5 %$CaSO_4$, 2% $Ca(OH)_2$, 5% $CaCO_3$, <5% $CaCl_2$**

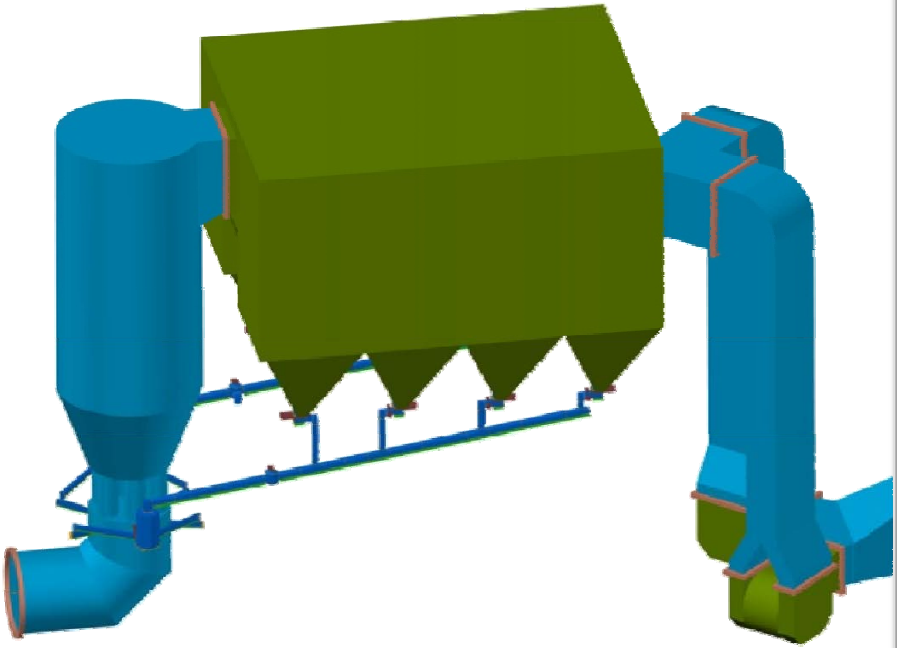
Typical CDS Arrangement



CDS - Typical Process Overview



Fabric Filter for CDS *Applications*



- Lower ATC ratio
- Designed for reduced velocities
  in filtration zone
- Pulse air supply designed for high cleaning rate
- Larger hopper outlet opening
- Trough hopper design to minimize vertical height and accommodate high recirculation rate

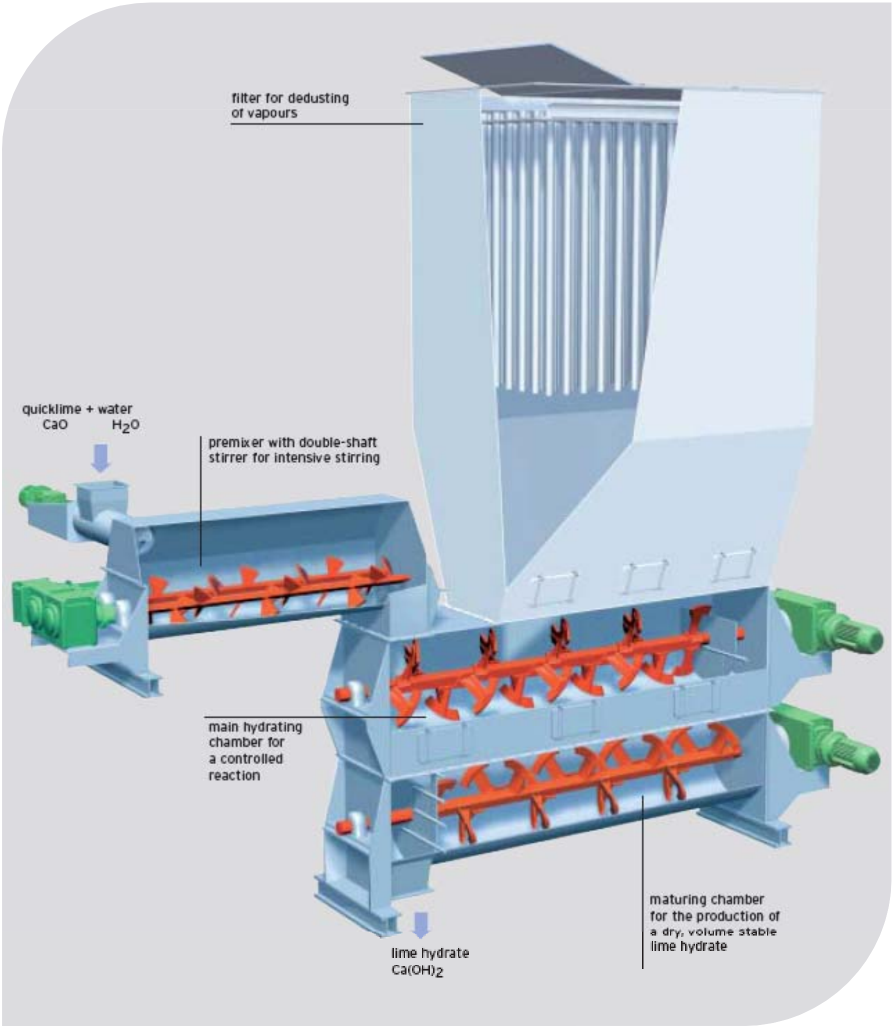
Reagent Preparation Typical Equipment

- **Pebble Lime Silo**
- **Rotary Feeder**
- **Screw Feeder**
- **Lime Hydrator with Vent Filter****
- **Water pumps for hydration**
- **Pneumatic Conveying to Hydrated Lime Day Bin**

****Some plants have hydrated lime delivered to site**

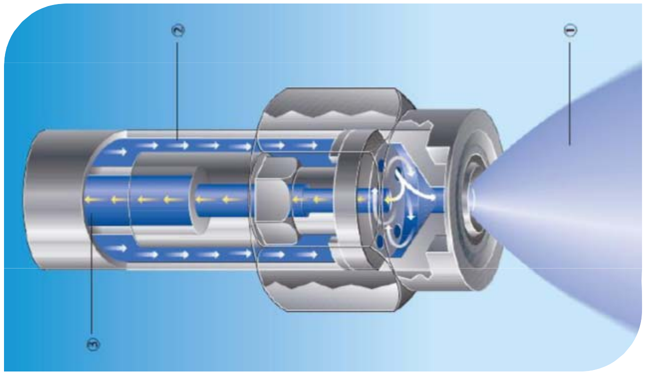
Lime Hydrators

- **Pebble lime breaks up as it is hydrated**
- **Exothermic Reaction**
- **Continuous operation**
- **Dry product controlled by temperature**



Lime Hydrator

Water Supply and Injection System



- **Single fluid atomization**
- **Droplets less than 250 micron**
- **One water injection per venturi**
- **Online removal and replacement**
- **Adjustable depth for optimization**
- **10:1 Turndown**
- **Flow to absorber regulated by recirculation flow control**

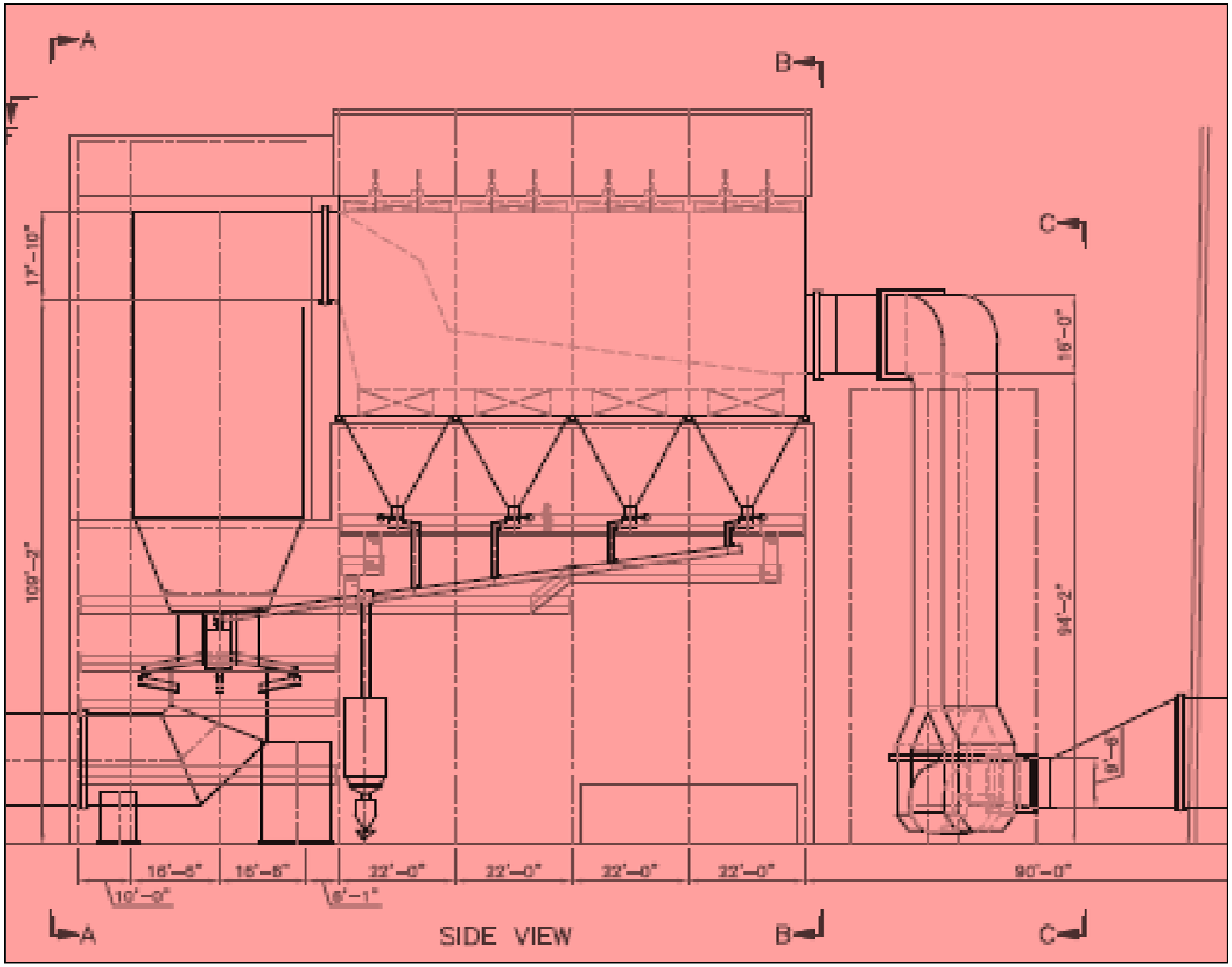
High Pressure Water Pumps

Byproduct Handling System

1. **Recirculation air slide system**
   - **Returns solids to the absorber**
   - **Air slides, flow control gates, distribution bins**
2. **Byproduct removal**
   - **Removes solids for landfill**
   - **Pressure or Vacuum system**
   - **Pressure system can be dilute or dense phase**

Solids move easier when they are dry and free flowing!

Byproduct Handling



Recent B&W CDS/FF Proposal Performance Requirements

	Recent Projects (lb/MBtu)
SO_2	0.06 lb/Mbtu
SO_3 (as H_2SO_4)	0.0040
HCl	0.0016
HF	0.000
Hg	0.80 to 3 lb/Tbtu
PM_{10} (filterable)	0.012
PM_{10} (total)	0.015
Opacity	5 to 20%

Typical for PRB and PRB Blends

Advantages and Disadvantages of CDS

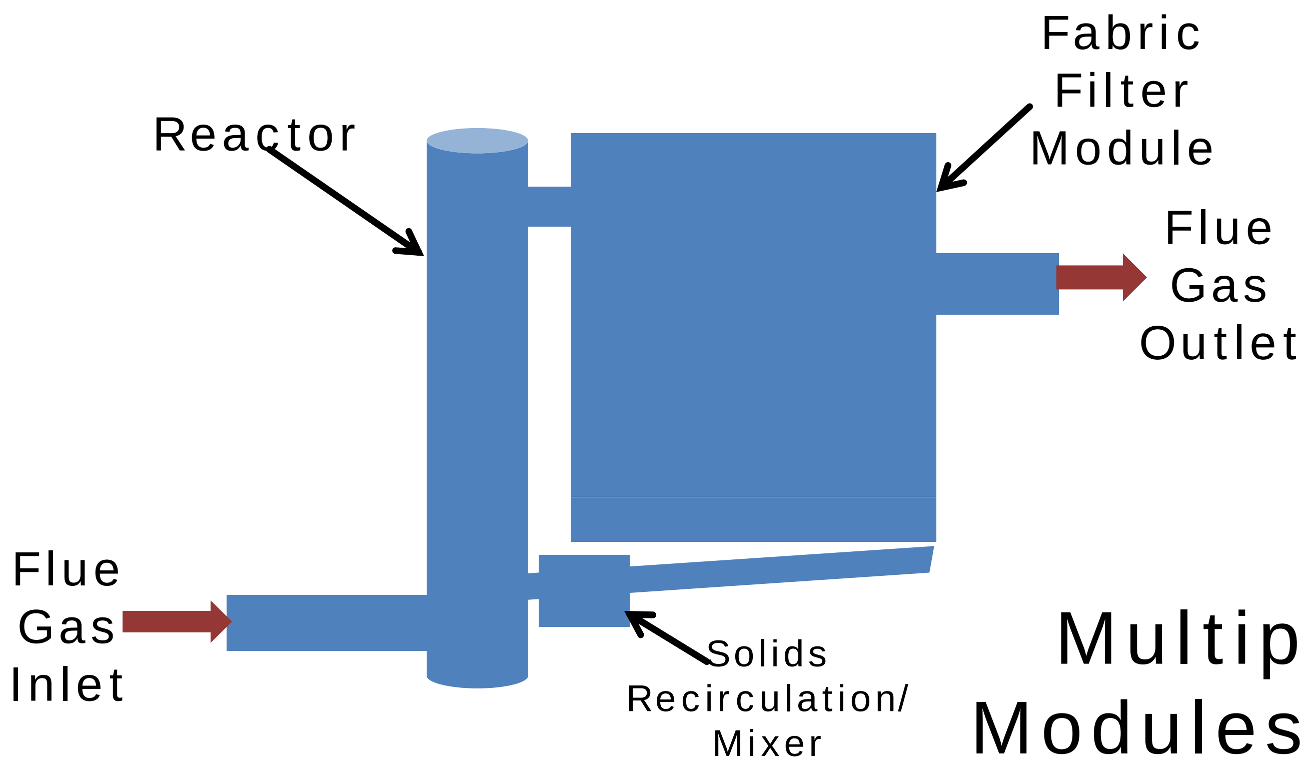
Advantages

- Water evaporation independent of lime feed rate
- Carbon steel construction
- Few moving parts
- Low water usage
- No wastewater
- No wet stack required

Disadvantages

- Higher pressure drop
- Significant solids handling
- Flue gas recirculation required at low loads
- Byproduct transport requires care

Transport Reactors



Solids mixers are proprietary to each supplier

Multiple Modules per Unit – "Modular Design"

Transport Reactors

- **For units larger than ~80MW, multiple reactors needed**
- **Each reactor has its own mixer/hydrator**
- **Mixer/hydrator is proprietary to each vendor**

Advantages and Disadvantages of Transport Reactors

Advantages

- Water evaporation independent of lime feed
- Carbon steel construction
- Low water usage
- No gas recirc needed
- Typically has an installed spare
- No wastewater
- No wet stack required

Disadvantages

- High pressure drop
- Significant solids handling
- Few installations on PC fired units
- Many reactors needed for a unit

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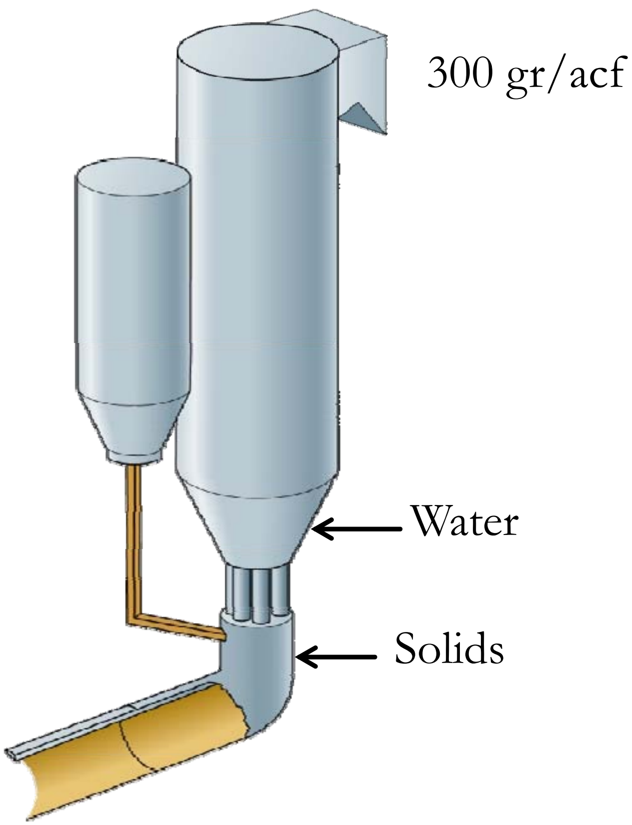
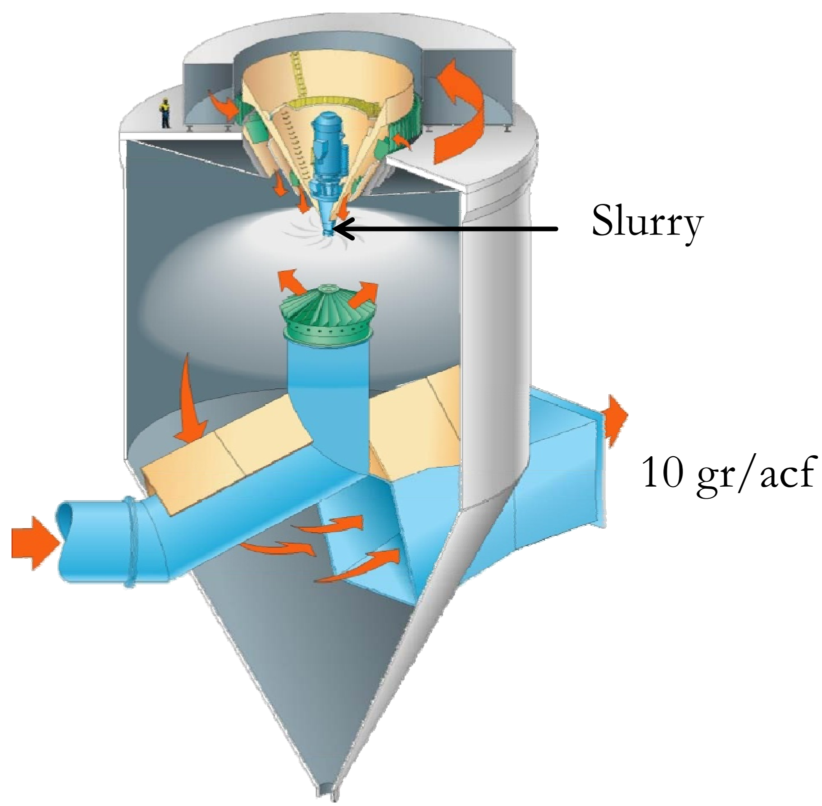
CDS vs. SDA – Process Difference

Circulating Dry Scrubber → CDS	Spray Dryer Absorber → SDA
Spray water and solids independently	Spray slurry – solids in water





Absorber Configuration Comparison

	DSI	SDA	CDS	Transport Reactor
Size Constraints (MW)	NA	~350-400 per absorber	~400 per vessel	~50-90 per reactor
# Absorbers / Unit Examples: 1000MW 350MW	NA	3 SDAs & 1-2 PJFF 1 SDA & 1 PJFF	3 CDSs & 3 PJFF 1 CDS & 1 PJFF	14-16 reactors & PJFFs 4-6 reactors & PJFFs

Consumable Comparison
(other than reagent)

	DSI	SDA	CDS	Transport Reactor
Pressure Drop	Lowest	Low	Higher than SDA	Higher than SDA
Power Consumption (no fans)	Lowest	About equal	About equal	About equal
Water Consumption	None	Since use same approach to saturation temperature, water consumption should be equal		

Reagents

	DSI	*SDA*	*CDS*	*Transport Reactor*
Reagent Preparation Method – Pebble Lime Delivered	**N/A**	**Slaker**	**Hydrator**	**Hydrator**
Reagent Preparation Method – Hydrated Lime Delivered	**N/A**	**Mixing**	**No prep needed**	**No prep needed**

Performance Comparison

	DSI	*SDA*	*CDS*	*Transport Reactor*
Stoichiometric Ratios for PRB Coals	**High stoich needed**	**Lower stoich**	**Higher Stoich**	**About equal to CDS**
Stoichiometric Ratios for Higher Sulfer Coals	**High stoich needed**	**About equal to CDS**	**About equal to SDA**	**About equal to CDS**
SO_2 Removal	**Low**	**95%+**	**95%+**	**95%+**
HCl/HF Removal	**N/A**	**99%+**	**99%+**	**99%+**

By-Product Streams

	DSI	*SDA*	*CDS*	*Transport Reactor*
Solids Composition	**Based on reagent**	**Fly ash** $CaSO_3$ $CaSO_4$ $CaCl_2$ $CaCO_3$	**Fly ash** $CaSO_3$ $CaSO_4$ $CaCl_2$ $CaCO_3$	**Fly ash** $CaSO_3$ $CaSO_4$ $CaCl_2$ $CaCO_3$
Water Treatment	**N/A**	**N/A**	**N/A**	**N/A**

Agenda

- Dry Sorbent Injection Overview
- Spray Dry Absorber Overview
- Circulating Dry Scrubber / Transport Reactor Overview
- Compare and Contrast Technologies
- **Summary**

Should you choose a technology prior to RFQ?

- **How would you decide?**
- **Why do you want to decide?**
- **What is your evaluation criteria and weighting methodology?**
  - **Experience?**
  - **Consumables consumption?**
  - **O&M? How?**

Preferred Methodology from a Vendor Perspective

- **Performance specification**
  - **Site preferences**
  - **Reagent selection**
  - **Details on evaluation criteria**
- **Vendor to select best technology based on detailed evaluation criteria**
- **Let the vendors be creative!**

Summary of Dry FGD Comparisons

No “one size fits all”
Chemistry of the various technologies is similar
DSI is not a “magic bullet”
Site specific requirements may drive technology decision
Let the vendors be creative

Thank You.