REINHOLD ENVIRONMENTAL ®

2024 Reinhold/PCUG Round Table Presentation

Hosted by LG&E/KU and Co-hosted by Southern Co. and TVA

in The Marriott Resort Lexington Griffin Gate Hotel, Lexington, KY on June 24-25, 2024

Dry Sorbent Injection Compliance, Conveying, and Cost Optimization

Curt Biehn and Cal Lockert

Reinhold Conference – Lexington KY

June 25, 2024

MLC™

AN HBM COMPANY

Introductions and Qualifiers

Safety - Clearing Hydrated Lime Line Plugs

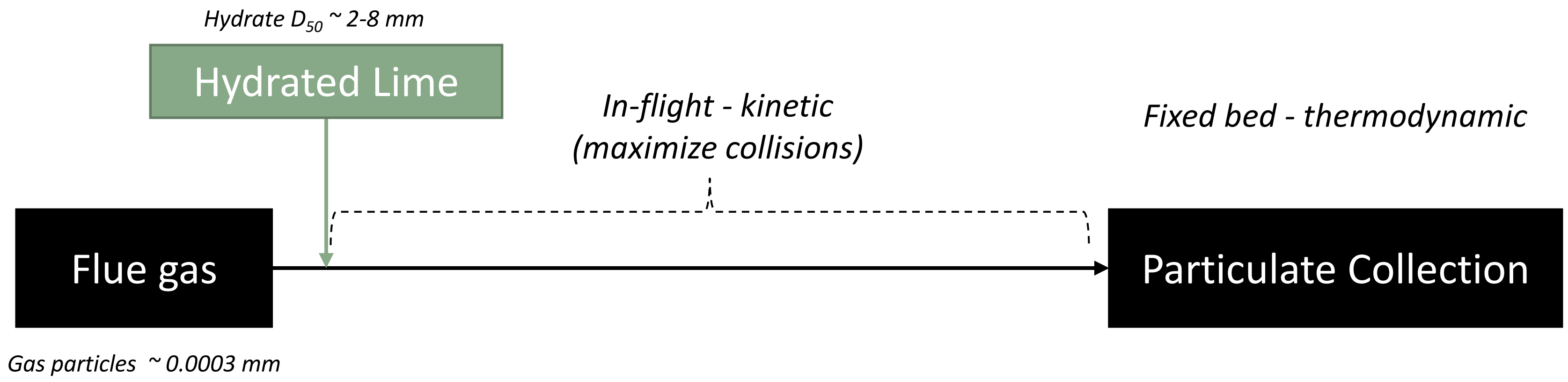
KNOWN RISK FOR **SEVERE EYE INJURIES**

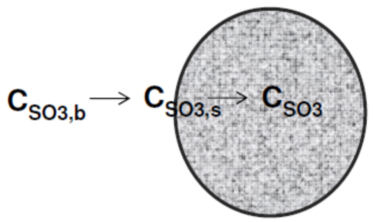
- Wear the **proper PPE**
  - Protect your **face and eyes**. Goggles, dust mask, and face mask should be worn
  - Consider the **buddy system** – if overcome by exposure; one may need assistance
- **Eliminate any pressure** in line before attempting to break the line
  - Position yourself to be protected in event of **unexpected discharge**
  - When breaking seal, **act as if the line is pressurized**

Full face respirator or PAPR

T-valve for pressure relief

Hydrated Lime for Control of Acidic Gases





Neutralization on surface is fast
Absorption into the core is relatively slow

Benson, NalcoMobotec, DHUG 2012

Typical Coal-fired flue gas components

N_2 : 72-77%
CO_2 : 12-14% (reacts with hydrated lime)
H_2O : 8-10%
O_2 : 3-5%

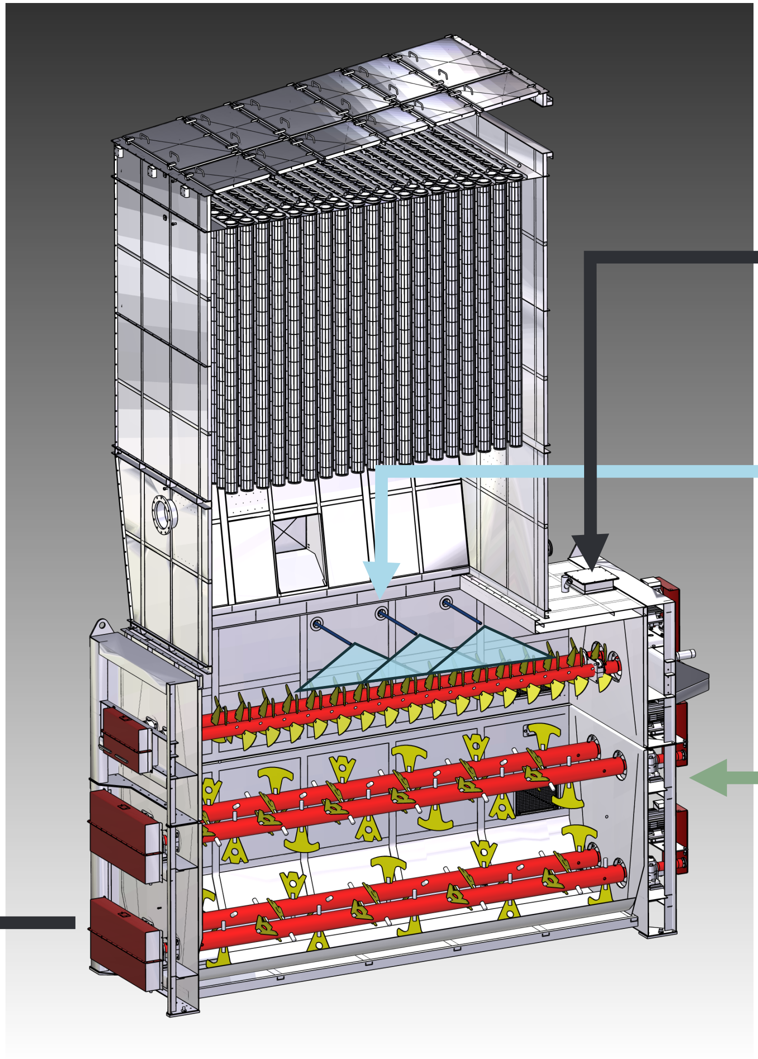
SO_2 : 300 – 2000 ppm (0.03-0.2%)
SO_3 : 10-100 ppm
HCl : 1 – 100 ppm

Targeted acid gases are diluted in flue gas

Factors Affecting Performance

- Hydrated lime quality
- Conveying system consistency
- Distribution of hydrate in flue gas

Hydrated Lime Production



$CaO_{(s)}$

Quicklime

Water

Multi-pass hydrator

Standard **Enhanced**

$Ca(OH)_2$

Hydrated Lime

Post processing
(if necessary)

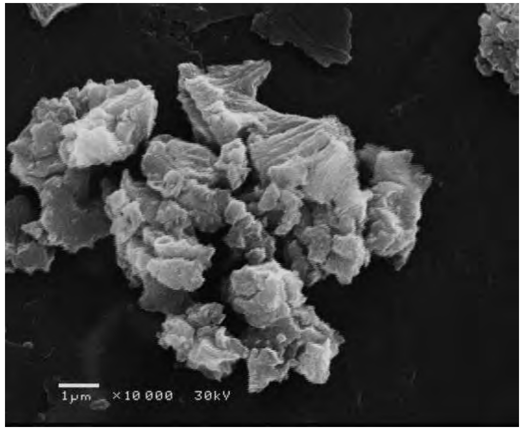
Courtesy of Cimprogetti

What Makes a Hydrated Lime "Enhanced"

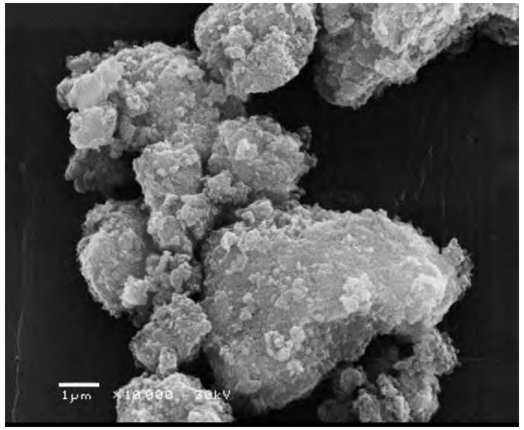
Lime supplier has **modified the manufacturing process** to **consistently** produce a hydrated lime that has **more active sites for neutralization of acids**

Think in terms of "effective surface area"
J.A.H. Oates, "Lime and Limestone"

1. The specific surface area (BET)
2. Total volume and size of pores
3. Particle size
4. Degree of agglomeration



Enhanced hydrate



Standard hydrate

~60-80% of hydrated limes used in Air Pollution Control market are enhanced hydrates

Key Characteristics

Physical & Chemical	Reactivity
• Moisture • Available $Ca(OH)_2$ • -325 mesh • Bulk Density • pH	• BET Surface Area • Particle size and distribution • Pore size and volume (Enhanced hydrates)

Caveats:

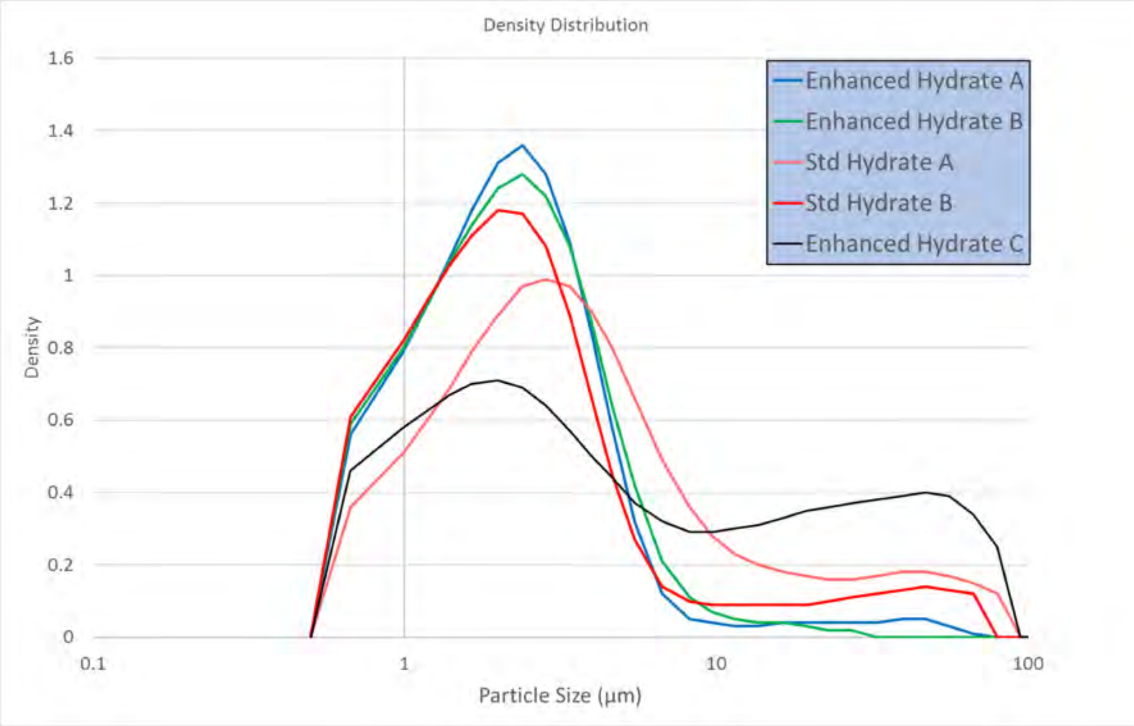
1. Enhanced hydrates are patented or proprietary technology
   - ➢ Comparing suppliers is not simple
2. Specifications are good, but **proof of performance comes in plant evaluations**

Hydrate Particle Sizing – Baghouse Questions

About 20% of units using DSI for SO_3 control use baghouses

Several U.S. Utilities use hydrate DSI for SO_2 control in conjunction with baghouses.

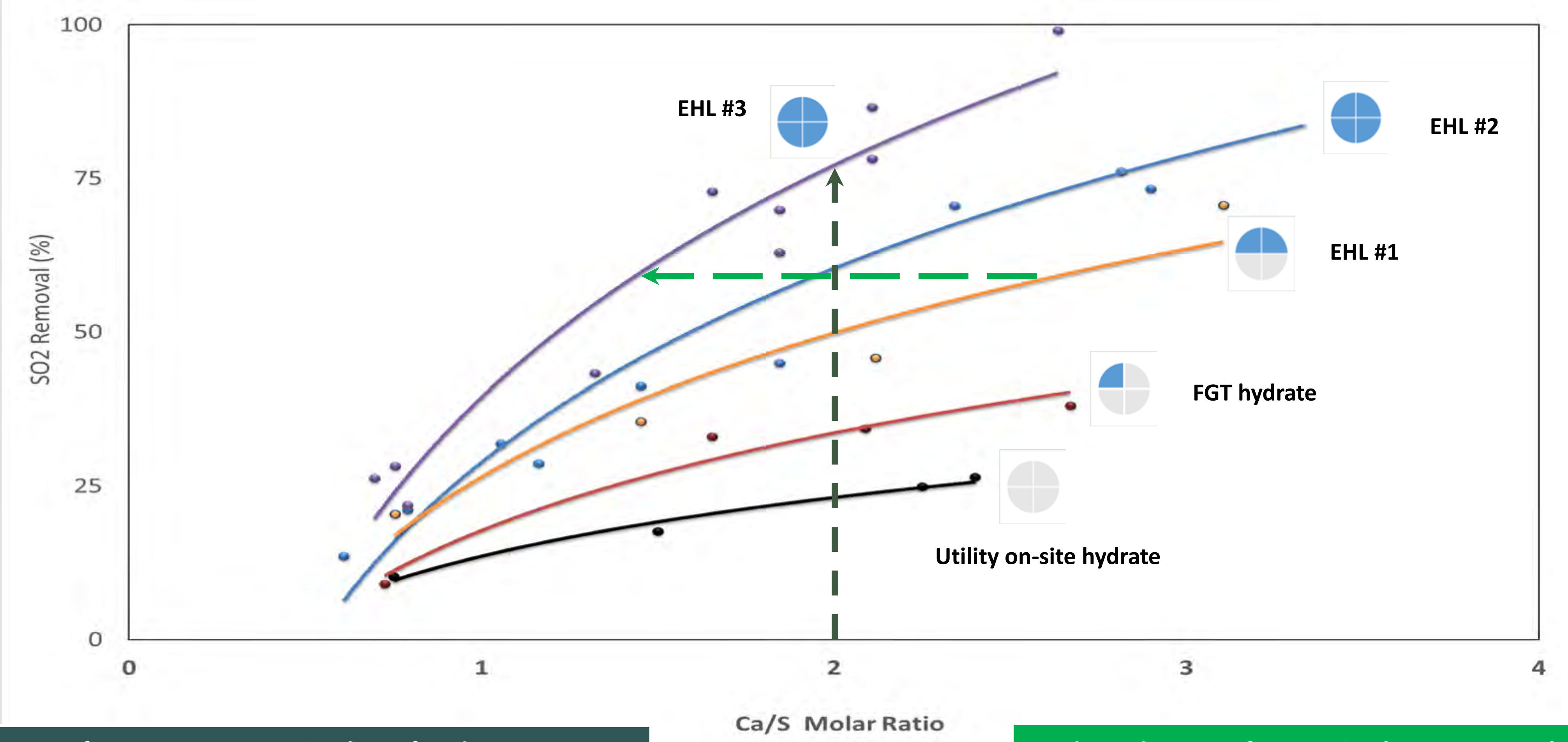
Several Circulating Dry Scrubbers use purchased enhanced hydrates for SO_2 mitigation



No reported baghouse issues related to hydrated lime particle sizing

Performance Comparison in Pilot Plant

Benefits of Enhanced Hydrates based upon meeting the four criteria of Oates (pie charts)
Note that this chart is for SO_2 removal; **curves will be different for SO_3 and HCl**

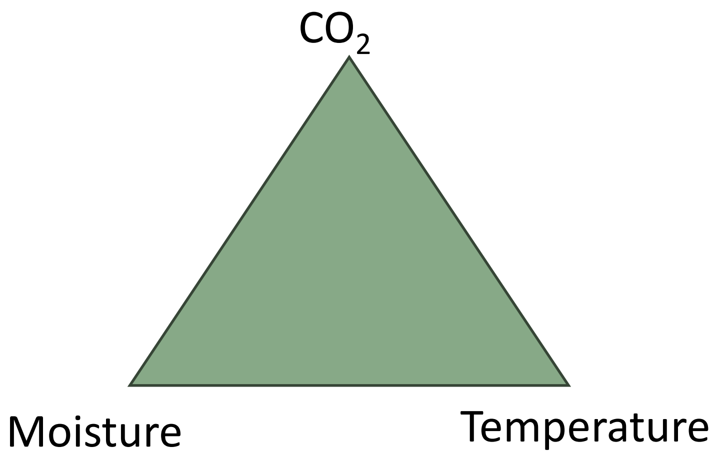


Higher performance at equivalent feed

Reduced usage for equivalent removal rate

Conveying System Issues – Deposit in Piping

- Hard Scale
  - Short term formation – convey air effects
    - Quality
    - Quantity
  - Long term formation
    - Minimize physical ‘hot spots’
      - Unions and elbows
- Soft scale (hydrated lime)
  - Saltation velocity ~2,400 ft/min
  - Target 3,300-4,000 ft/min to keep hydrate suspended



Comments on Conveying System Components

Feed bin

- Can hold multiple truck loads
- Loss in wt vs volumetric
- Fluidization

Convey air → Feeder → Convey pipe → Splitter(s) → Injection

Convey air

- Maintain convey velocity through injection
- Low hydrate to air ratio can cause scale
- Chiller/dehumidifier/after cooler solves many issues

Feeder

- Most use rotary feeders
- Screw conveyors can flood
- Closed end rotors preferred over open ended
- Shallow pocket valves can help in certain cases

Convey pipe

- Minimize shelves where scale can form
- Minimize # of bends
- Hoses at elbows can reduce scale events

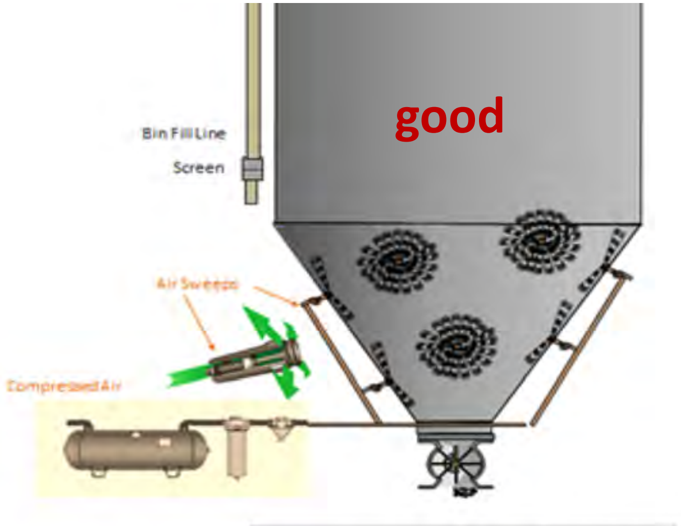
Splitter(s)

- Vary by vendor
- MLC prefers conical splitters from upward flow
- Equal pressure for each leg; simplest is to have each leg the same length
- Provisions for maintenance

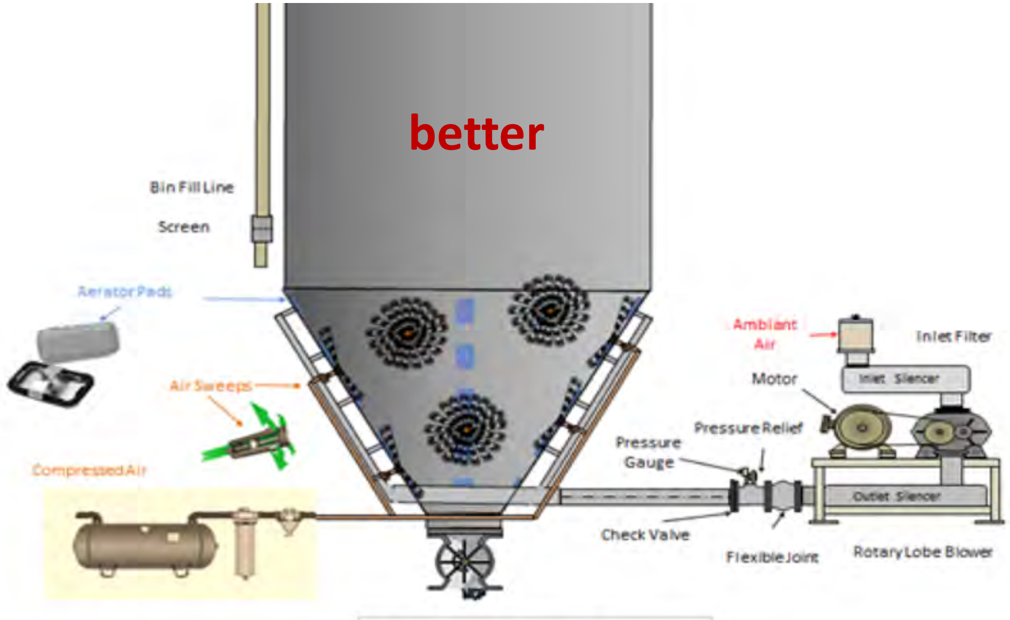
Injection

- Vary by vendor
- Minimize pluggage
- Increase distribution in flue gas

Improve Consistency of Material Flow from Silo



Storage Silo + Air Sweeps

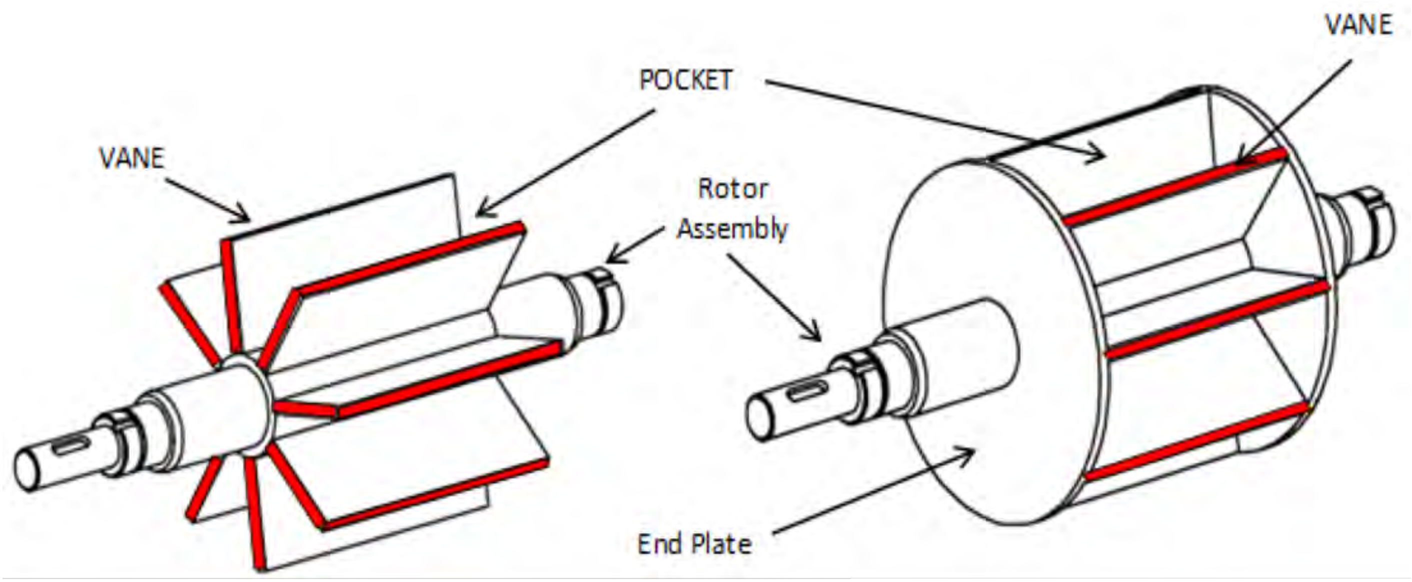


Storage Silo + Air Sweeps + Air Pads

1. Air sweeps break bridges that may form due to cohesiveness of hydrate

2. Addition of air pads gives a consistent bulk density of hydrate entering the feeder

Rotary Feeders



Open End Rotor

Three contact points with housing

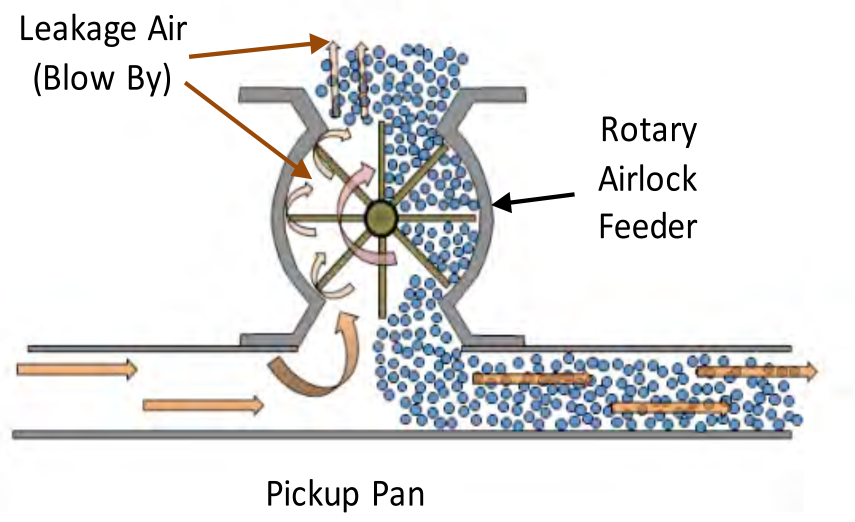
- Prone to air leakage
- Prone to wear
- Prone to squealing

Closed End Rotor

One contact point with housing

- Tighter clearances
- Reduced wear & leakage
- **Recommended for hydrate**

Leakage Air at Rotary Feeder



Abrasion & Erosion
Scoring
Vane edge
Housing wall

Rotary feeder air leaks reduce conveying air velocity

1. Product deposits in conveying line
2. Gradual increase in conveying air pressure
3. Periodic spikes in conveying pressure

Why & Where to Capture Acid Gas

Where to treat the gas is a function of what you want to achieve

Where is a Function of Why

1 point each for Matching Result with Injection Location

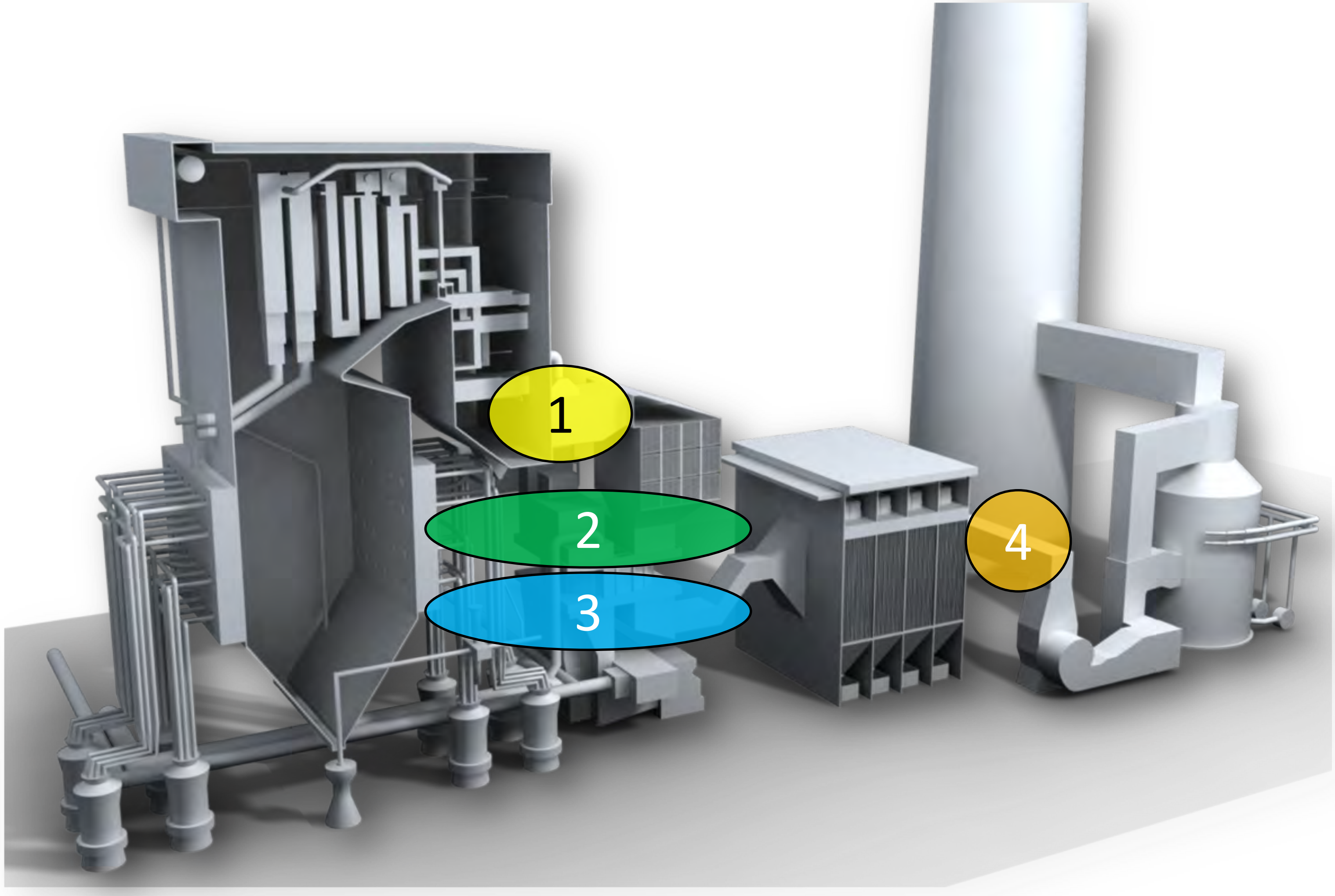
A: Ash Quality

B: Differential Pressure Control

C: Eliminate Steam Coil Dependence

D: MOT Control

E: Visible Plume Control

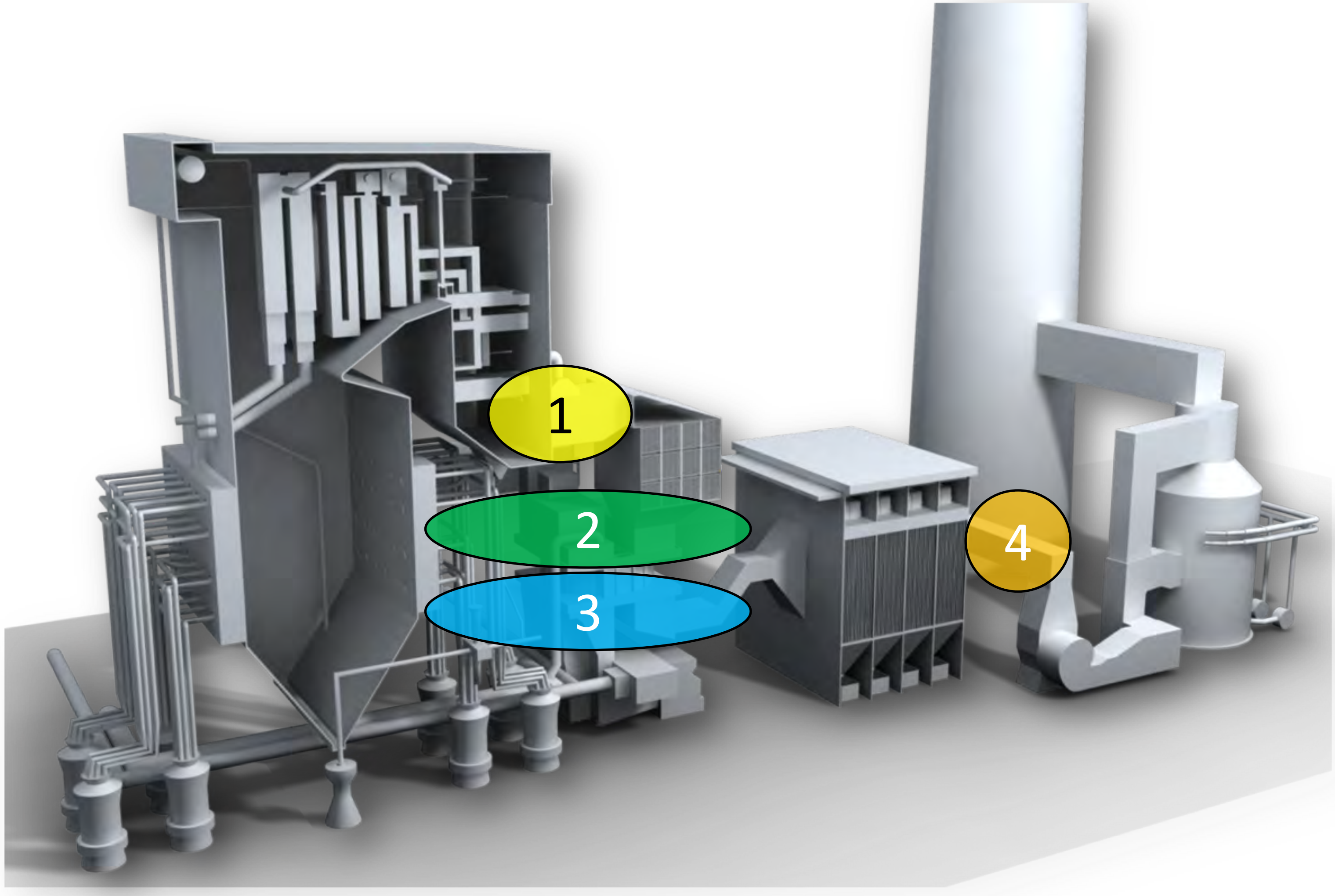


Where is a Function of Why

A – 4
B – 2
C – 2
D– 1
E – 3

Extra credit:

Why would you inject at location 2 & 4?

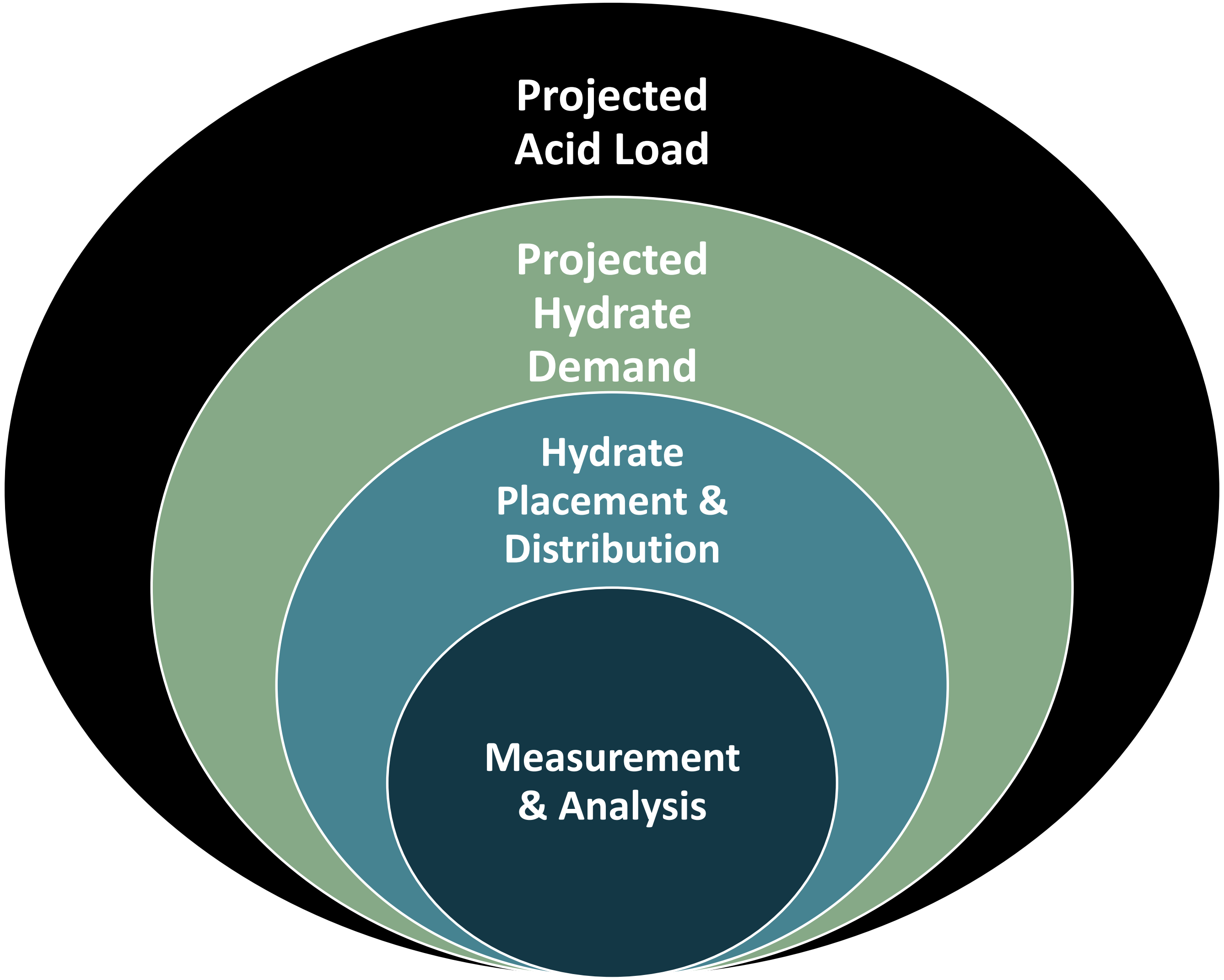


A Quick Course in Acid Gas Capture

High Level Overview of the SO_2/"SO_3 Life Cycle

- General SO_2 Load in Lb/Hr
- Typical SO_3 Load in Lb/Hr
- Native SO_3 Loss rates
- Impacts on NSR
- Measurement/Trial Considerations

Steps to Effective Acid Gas Control



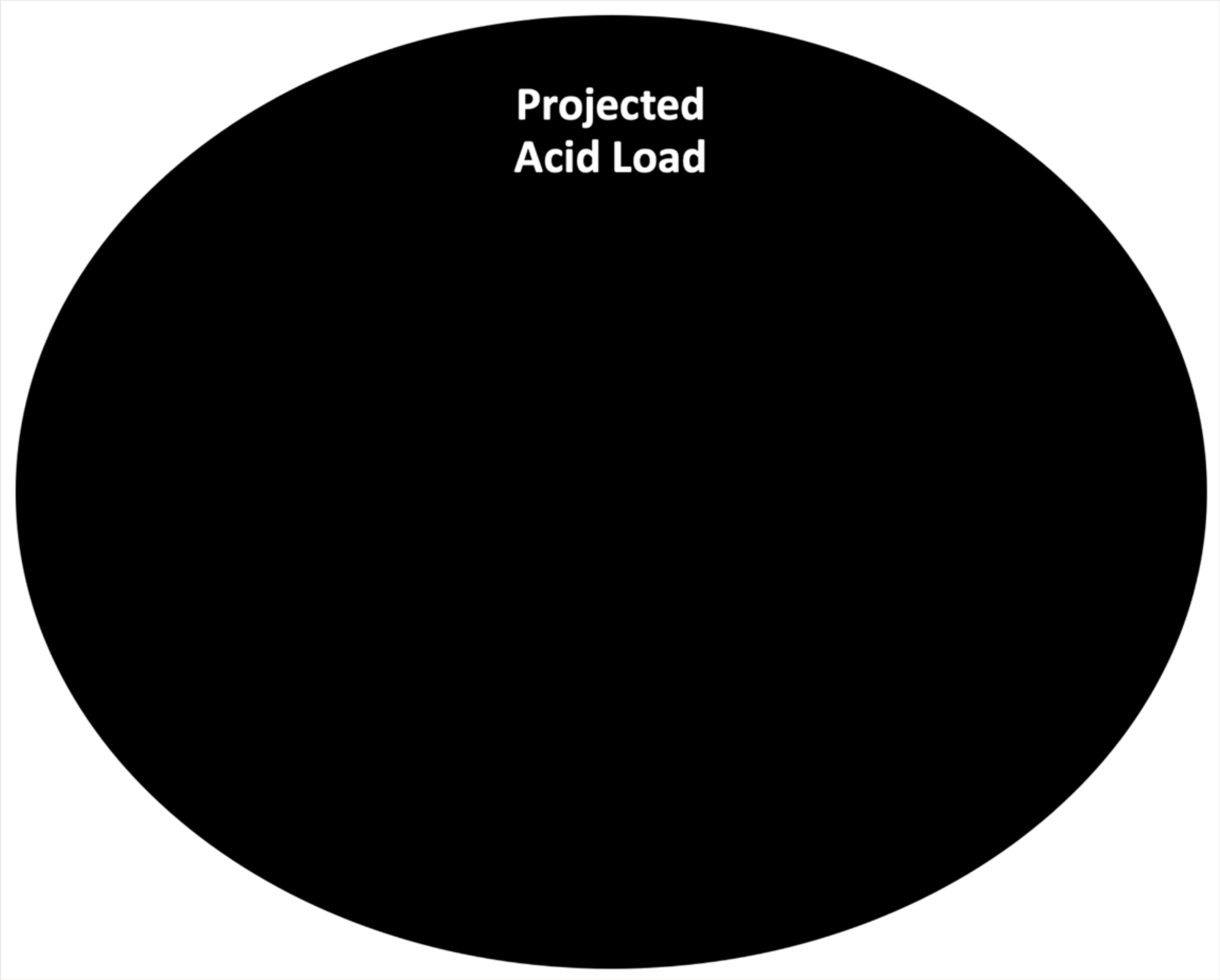
Acid gas management demands a calculation of the project acid load in Lb/Hr. at the Injection Point

Perfect hydrate demand is based on a 1:1 molar ratio of hydrate to acid

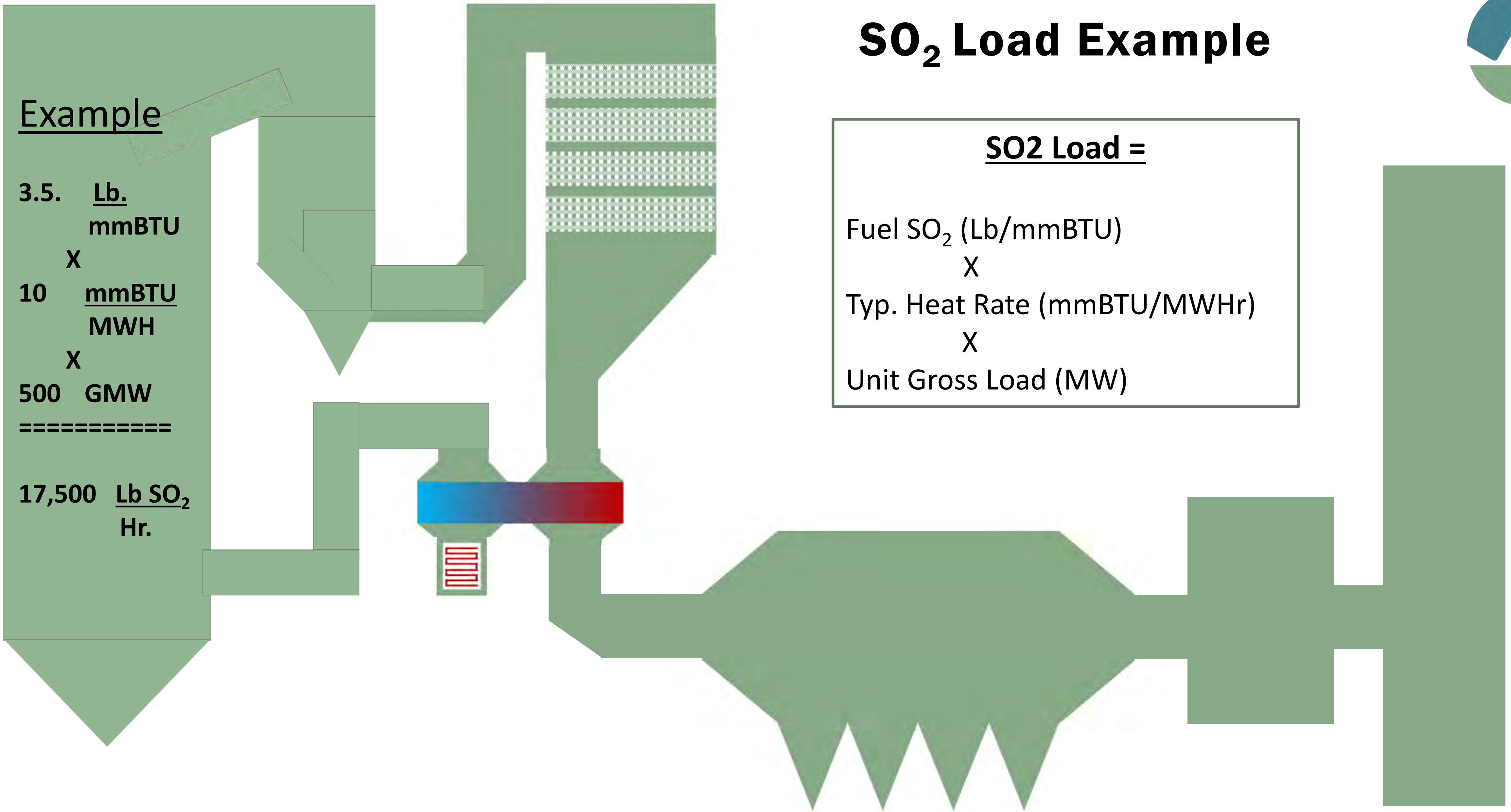
Acid Gas-Hydrate mixing is NOT perfect. Some additional Hydrate is needed to improve interaction. This is termed NSR

Determination of system performance demands a numerical understanding of process variables

How Much Acid is There



SO_2 Load Example



<u>Example</u>

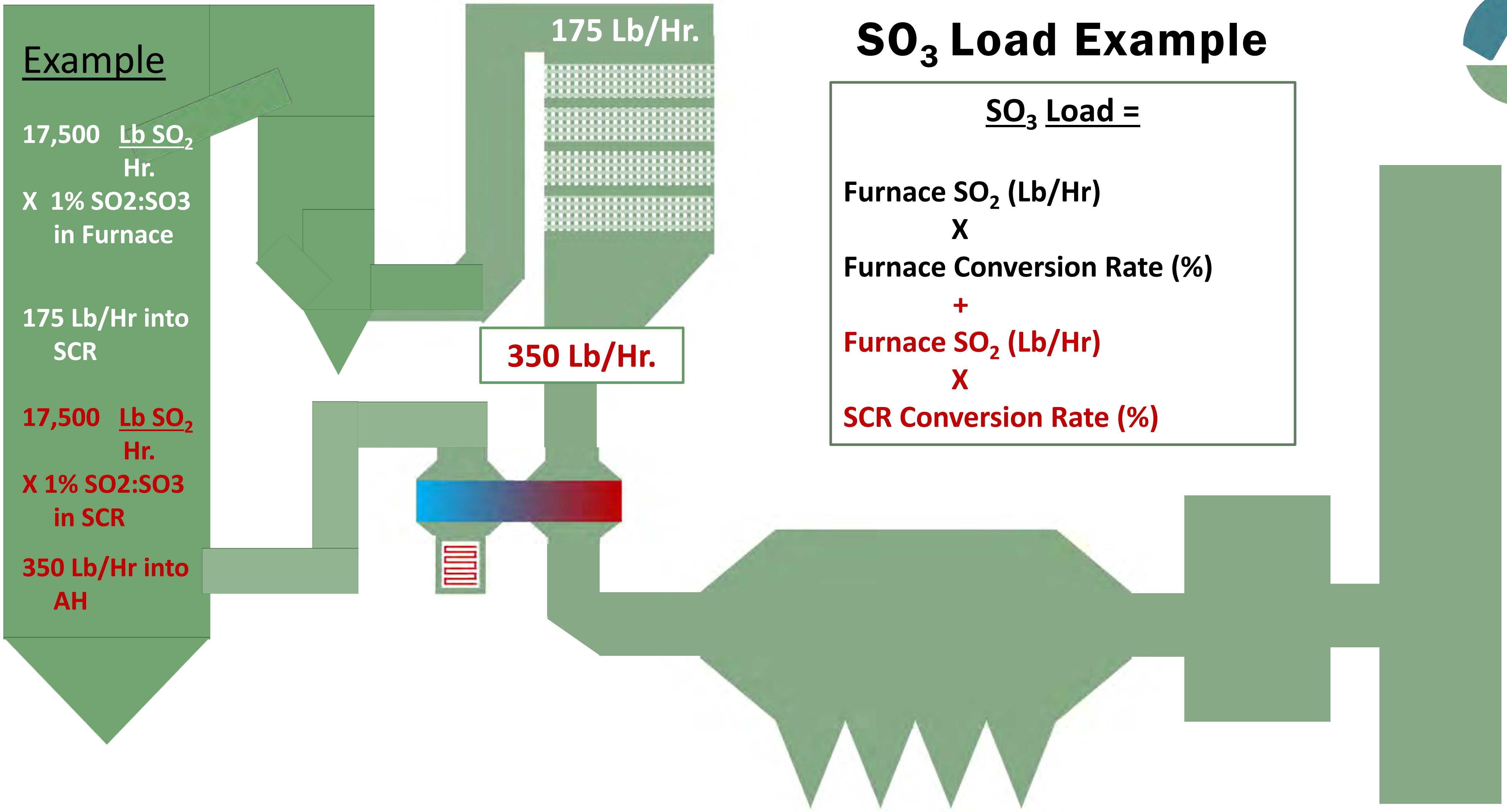
3.5. <u>Lb.</u>
mmBTU
X
10 <u>mmBTU</u>
MWH
X
500 GMW
===========

17,500 <u>Lb SO_2</u>
Hr.

<u>SO2 Load =</u>

Fuel SO_2 (Lb/mmBTU)
X
Typ. Heat Rate (mmBTU/MWHr)
X
Unit Gross Load (MW)

SO_3 Load Example



SO_3 Load =

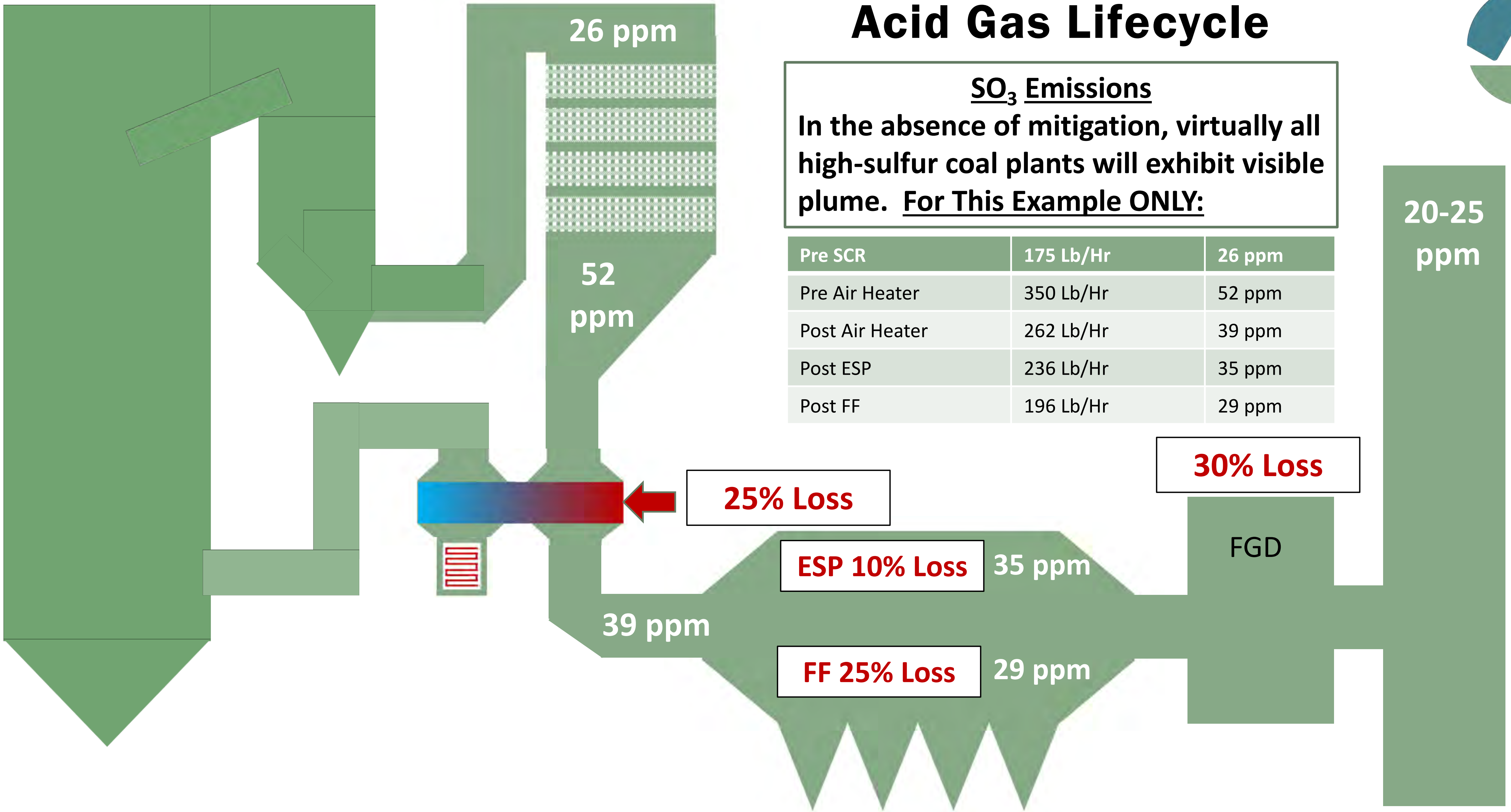
Furnace SO_2 (Lb/Hr)
X
Furnace Conversion Rate (%)
+
Furnace SO_2 (Lb/Hr)
X
SCR Conversion Rate (%)

Acid Gas Lifecycle

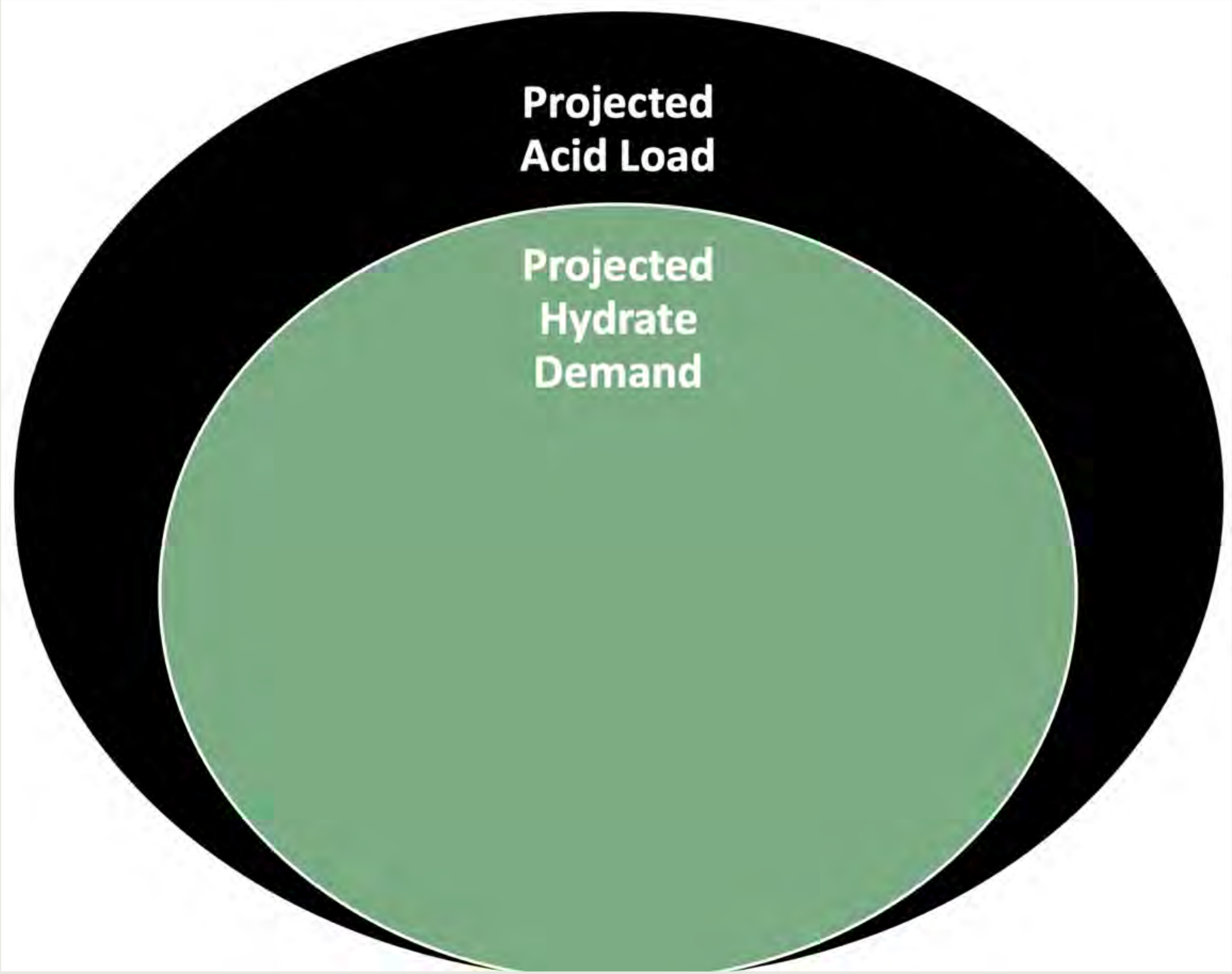
<u>SO_3 Emissions</u>

In the absence of mitigation, virtually all high-sulfur coal plants will exhibit visible plume. <u>For This Example ONLY:</u>

Pre SCR	175 Lb/Hr	26 ppm
Pre Air Heater	350 Lb/Hr	52 ppm
Post Air Heater	262 Lb/Hr	39 ppm
Post ESP	236 Lb/Hr	35 ppm
Post FF	196 Lb/Hr	29 ppm



How Much Acid is There



Hydrated Lime for Control of SO_3

$Ca(OH)_2(s) + SO_3(g) \longleftrightarrow CaSO_4(s) + H_2O(g)$

Molecular Wt. 80.06

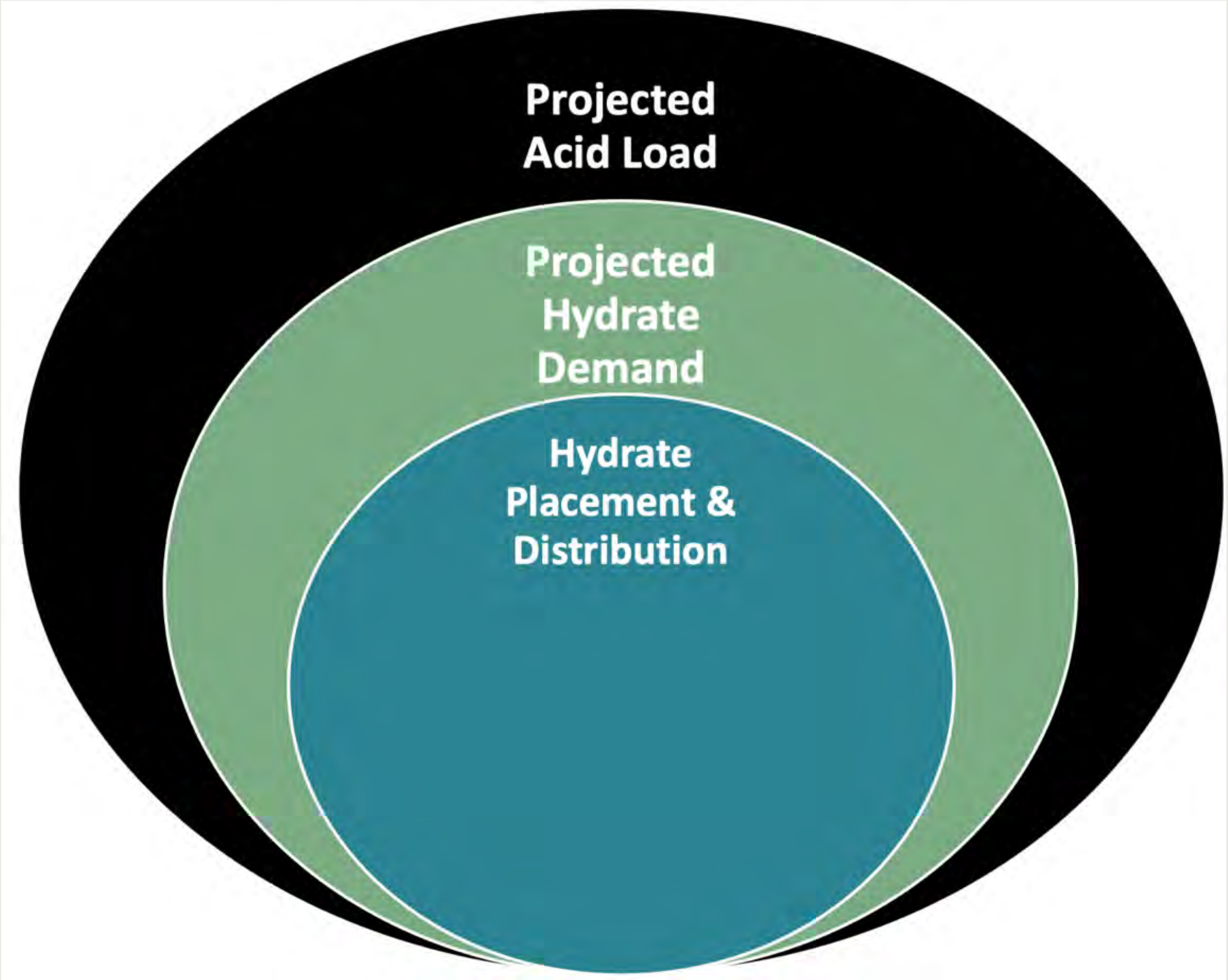
Molecular Wt. 74.093

1 point each for Required Hydrate at 1:1 Molar Ratio

Location	Acid Load	1:1 Hydrate
Pre SCR	175 Lb/Hr	163 Lb/Hr
Pre Air Heater	350 Lb/Hr	326 Lb/Hr
Post Air Heater	262 Lb/Hr	244 Lb/Hr
Post ESP	236 Lb/Hr	219 Lb/Hr
Post FF	196 Lb/Hr	182 Lb/Hr

- **Under perfect conditions it takes 0.93 pounds of Hydrated Lime to neutralize 1 pound of SO_3**
- **But flue gas ducts are NOT perfect conditions**

How Much Acid is There



So Why Is the NSR >1?

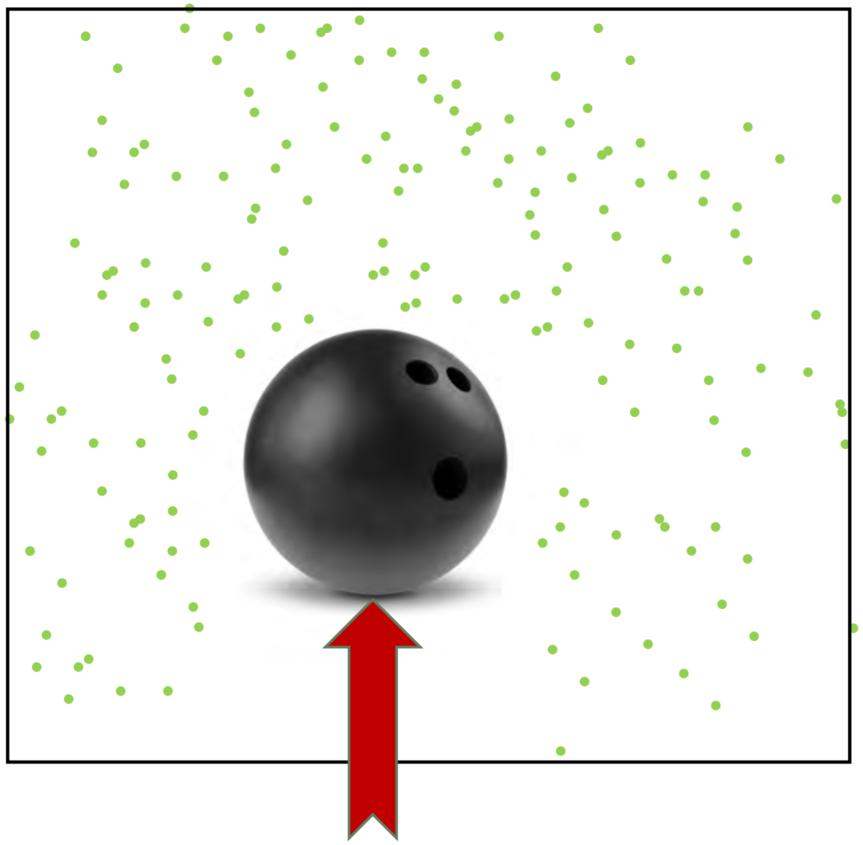
1. **Distribution of Hydrate within the Duct**

2. **Particle Size & Pore Structure**

The Hydrate MUST Collide with the Acid Gas

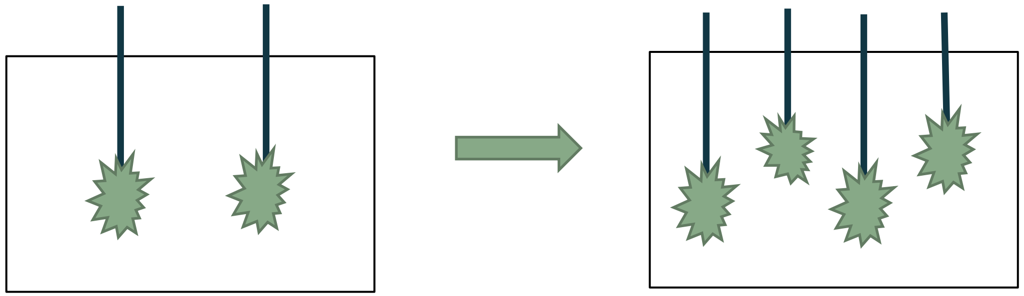
Pretty Easy Contact

Many Collisions Required

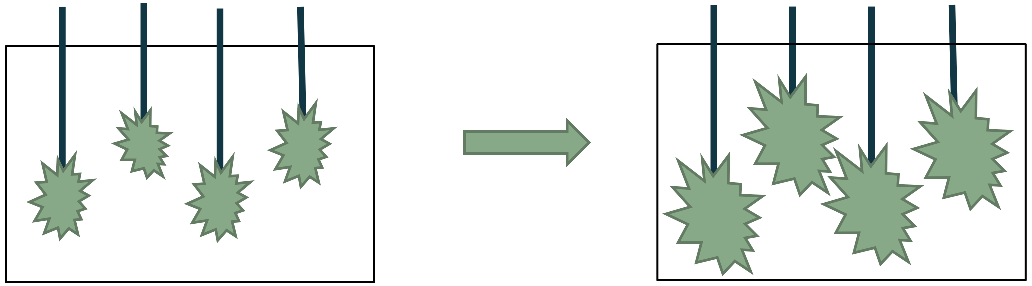


Improving DSI Flue Gas Coverage Summary

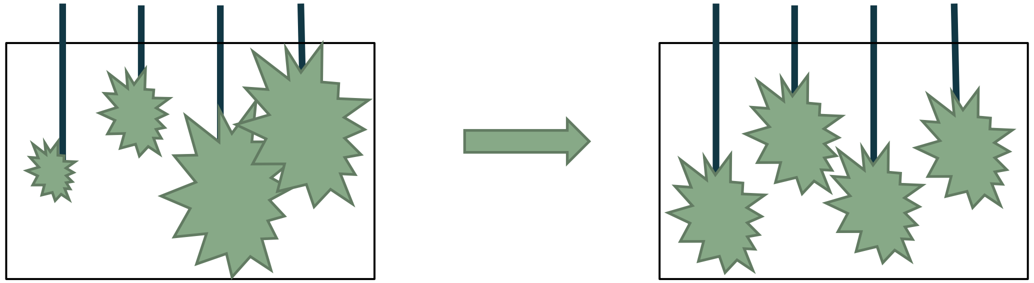
Add injection points



Use mechanical methods to better disperse EHL



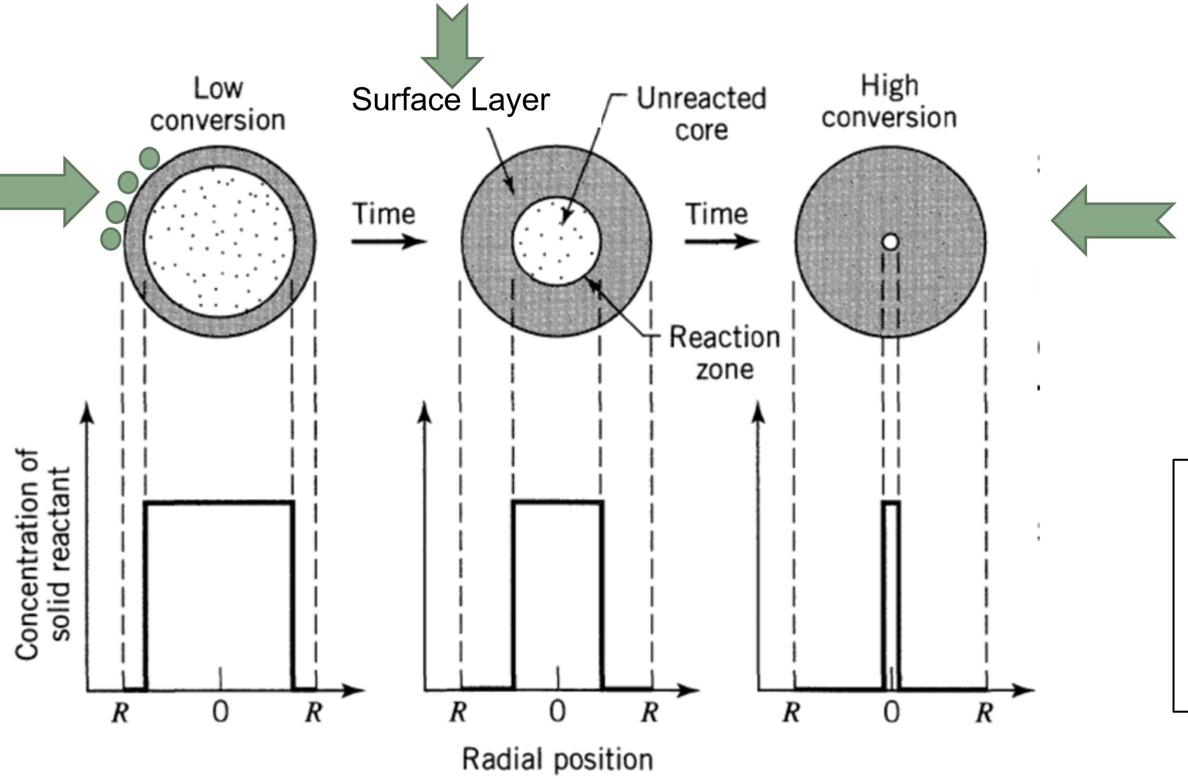
Correct distribution errors



Particle Design and Unreacted Hydrate

2. Captured Material Moves through the Surface Layer to Unreacted Hydrate

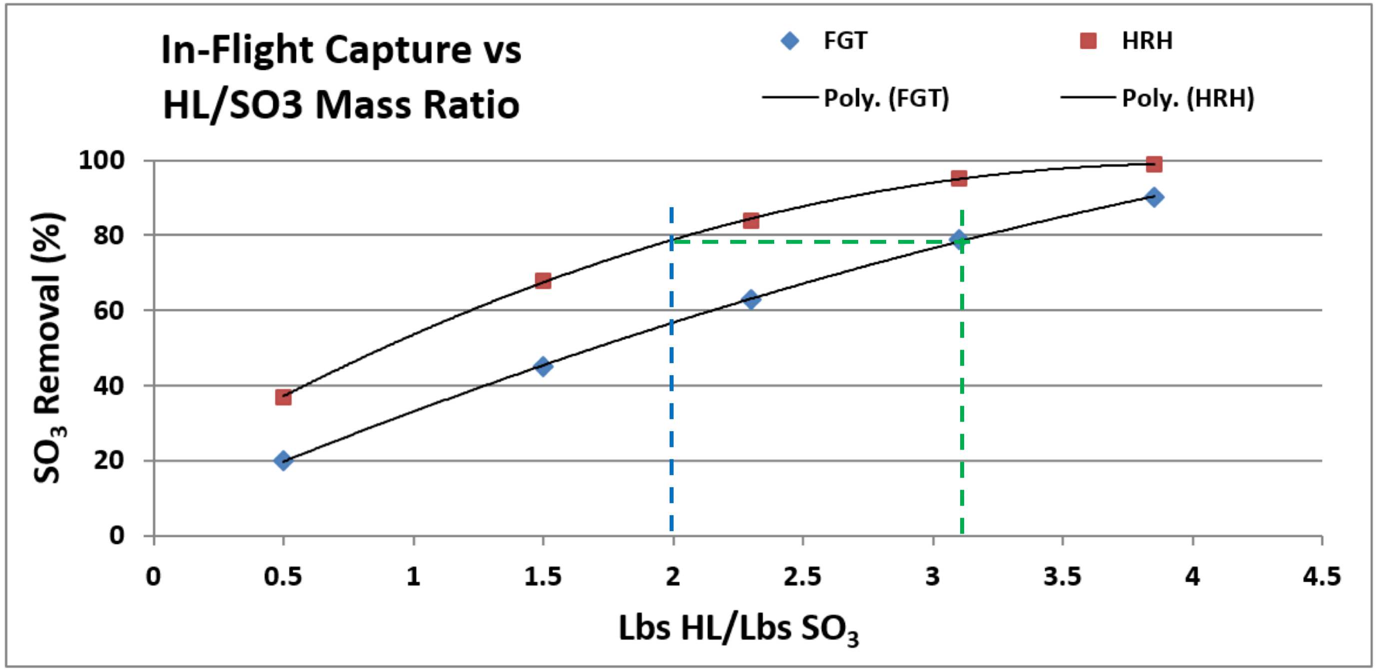
1. Acid gas Impacts with Surface



3. The Unreacted Core shrinks as it is consumed, eventually becoming unreachable

Smaller initial particle size coupled with closely controlled pore sizing creates differences in overall hydrate performance

Hydrated Lime for In-Flight Control of SO_3

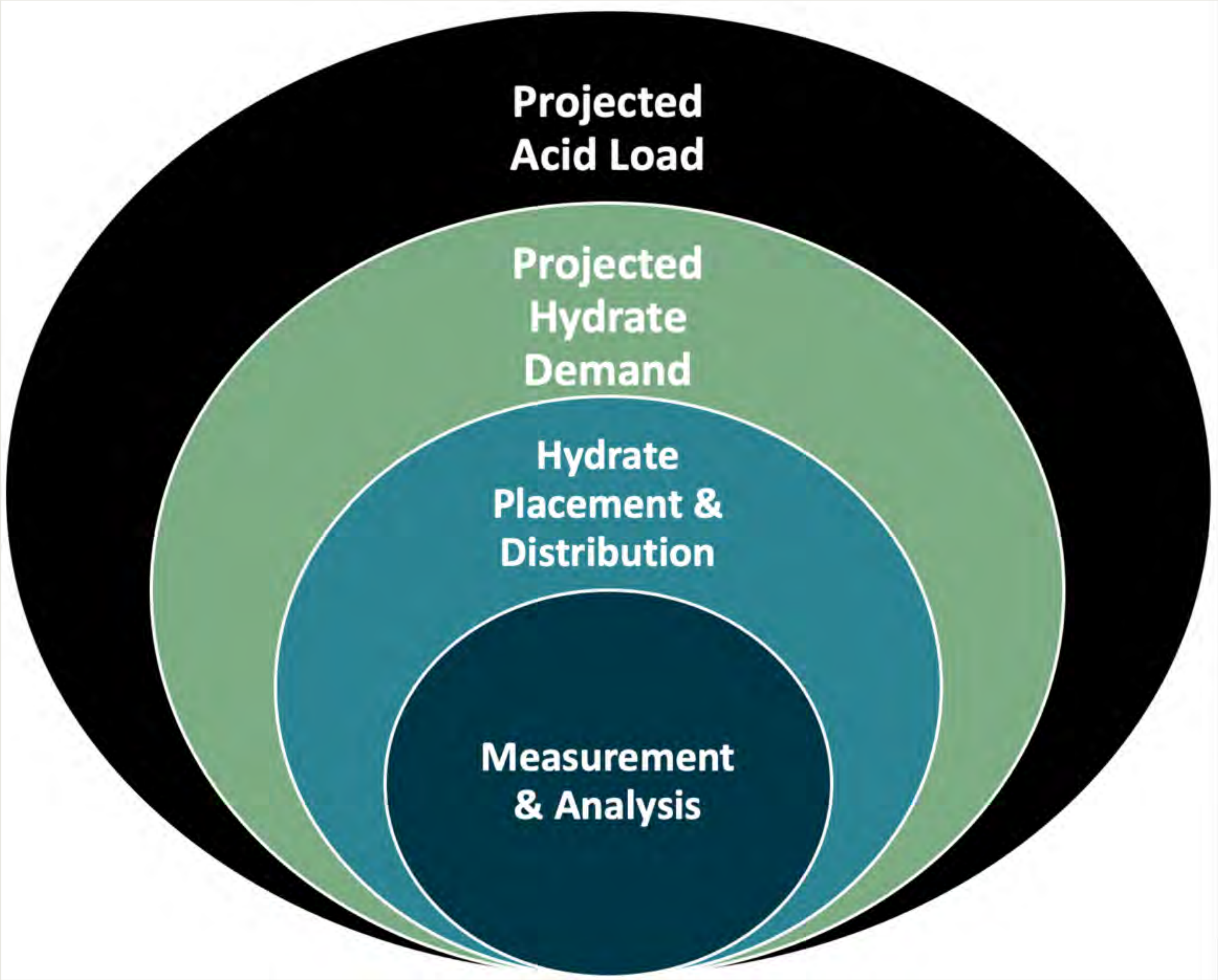


NSRs are Unique to Each Site

- **At this site an NSR of 2.0 provided 75% capture of SO3**
- **Differing grades of Hydrate have differing NSR demands**
- **Standard hydrates could require as much as 50% more material to achieve the same capture rate**

Also competing reaction with CO_2

How Much Acid is There

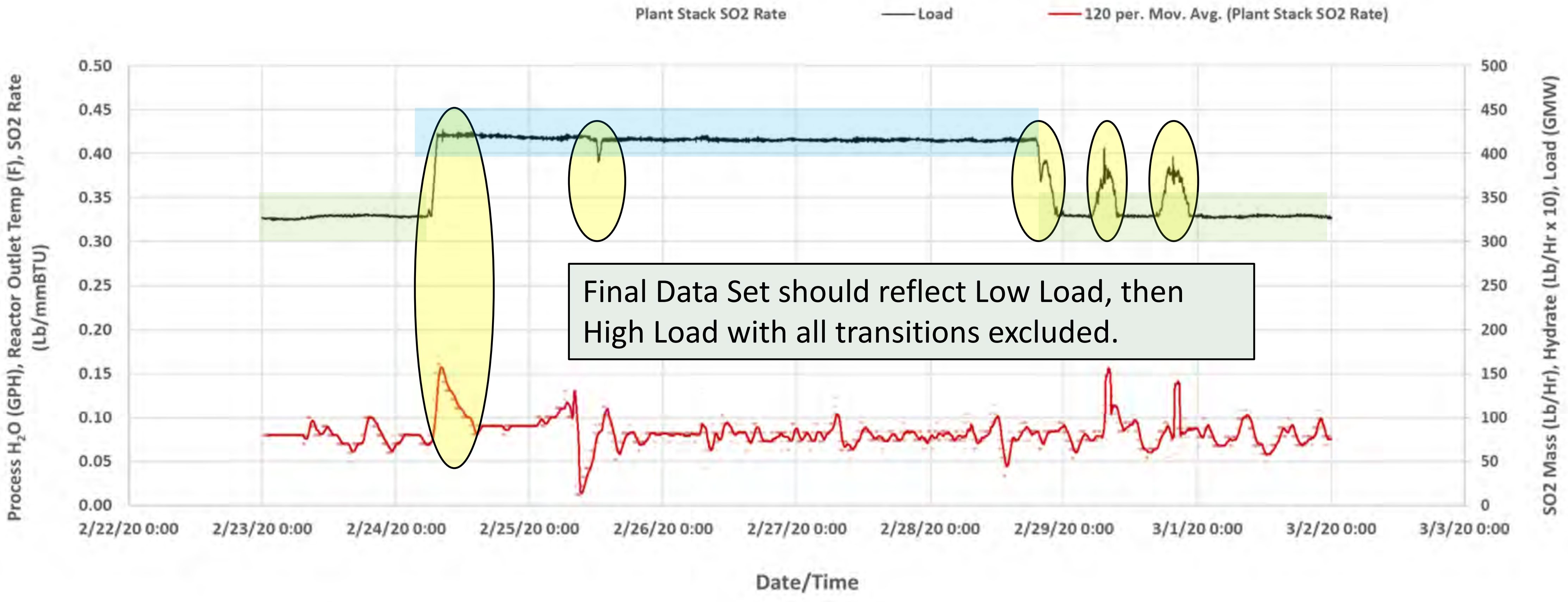


How Do We Know if We Succeeded?

1. To compare performance, all variable (or as many as humanly possible) MUST be held constant
   1. Load
   2. Burner Configuration
   3. Coal/Gas blend
2. All Transient Conditions MUST be understood and eliminated from possible influence

An Example Data Set

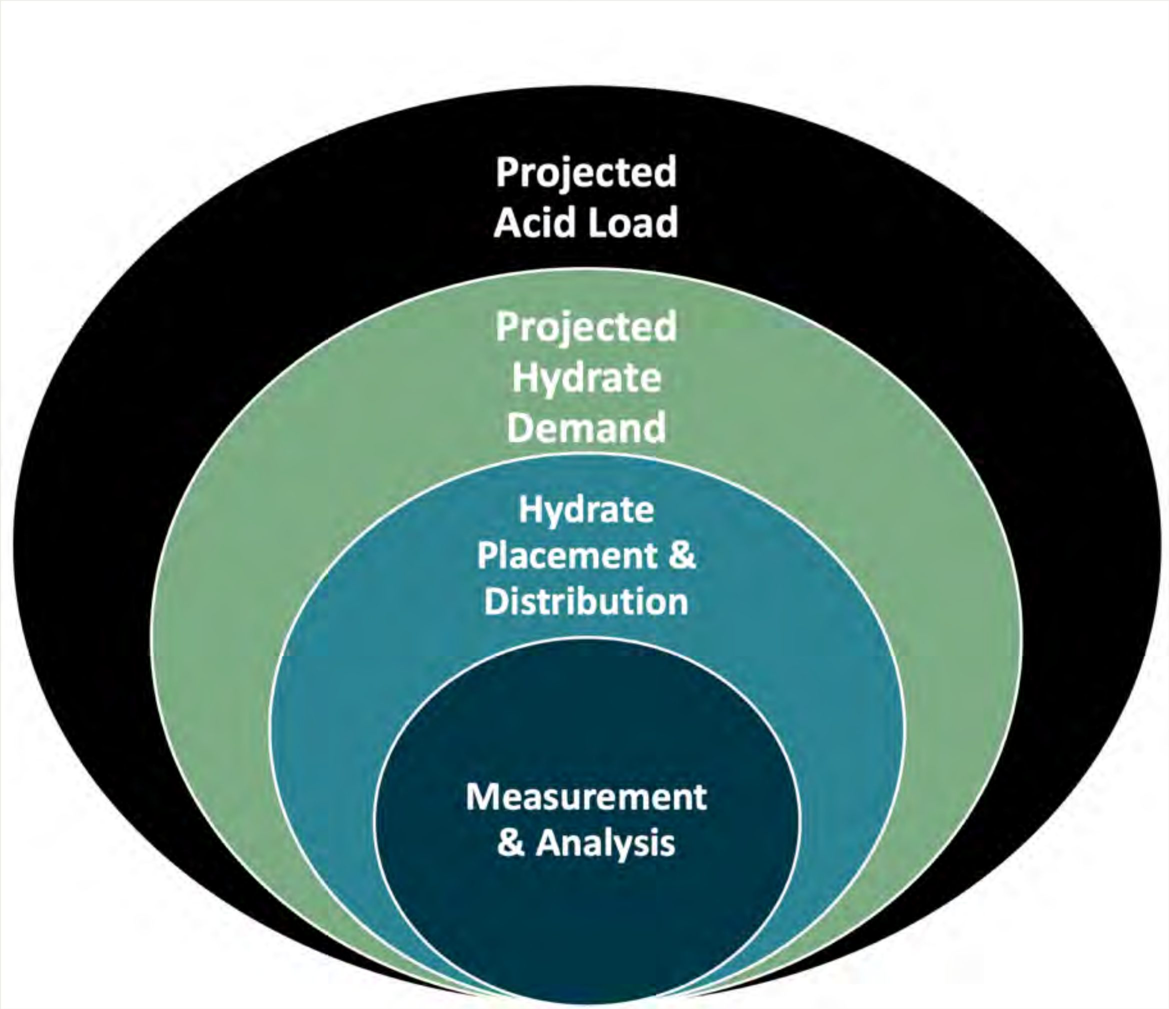
Transient Condition
High Load Condition
Low Load Condition



Final Data Set should reflect Low Load, then High Load with all transitions excluded.

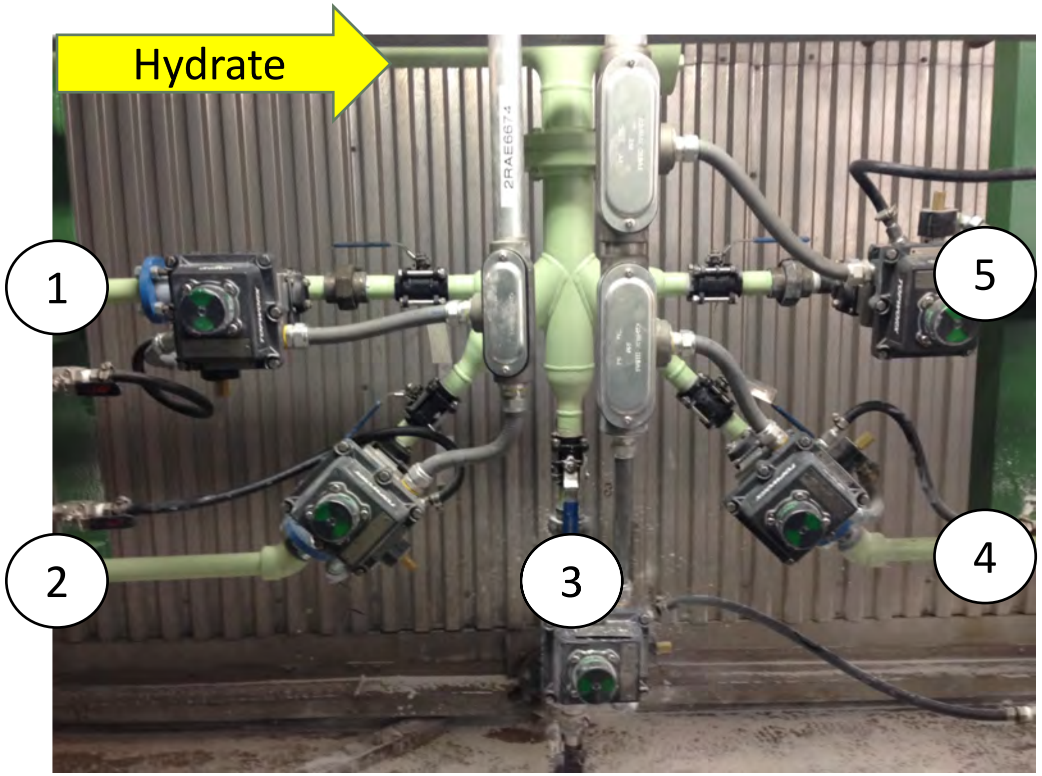
Troubleshooting Trial Results

Always Follow the Process:



Quiz #1

- **Acid Load Has Been Calculated Correctly**
- **Excessive Hydrate seems to be Required, beyond Expectations**
- **SO3 Measurements are not Equal Across the Duct**



For 5 Points Each:

1. **Which outlet leg sees the most hydrate flow?**
2. **Which outlet leg sees the least Hydrate flow**

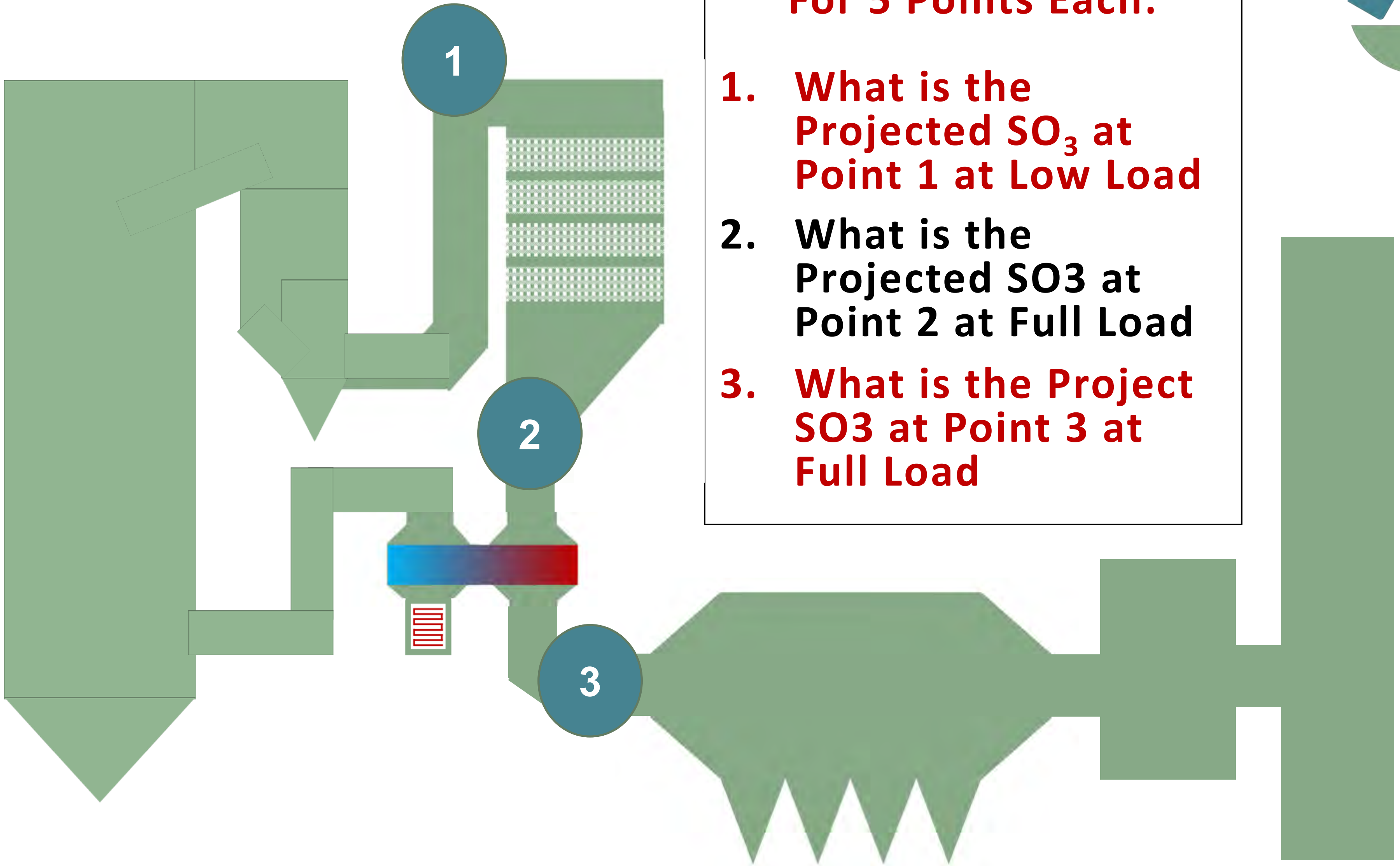
Quiz #2A

- Fuel SO_2 = $\frac{5\ Lb}{mmBTU}$
- Ht Rate = (Full Load) $\frac{9\ mmBTU}{GMW}$
- Ht Rate = (Low Load) $\frac{11\ mmBTU}{GMW}$

- Full Load = 500GMW
- Low Load = 200 GMW

- Furnace Conv = 1%
- SCR Conv = 1%

- AH Loss = 25%

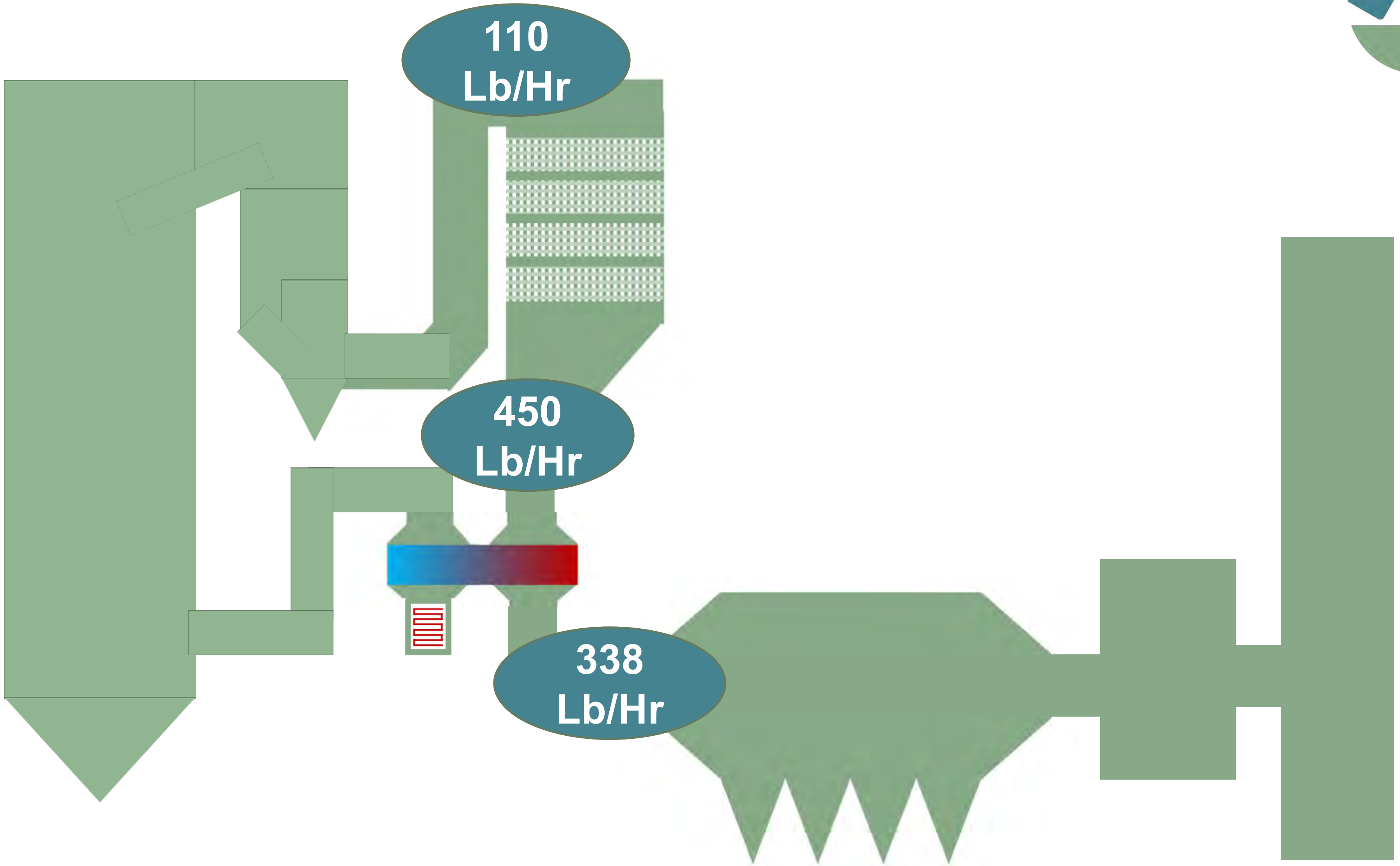


For 5 Points Each:

1. What is the Projected SO_3 at Point 1 at Low Load
2. What is the Projected SO3 at Point 2 at Full Load
3. What is the Project SO3 at Point 3 at Full Load

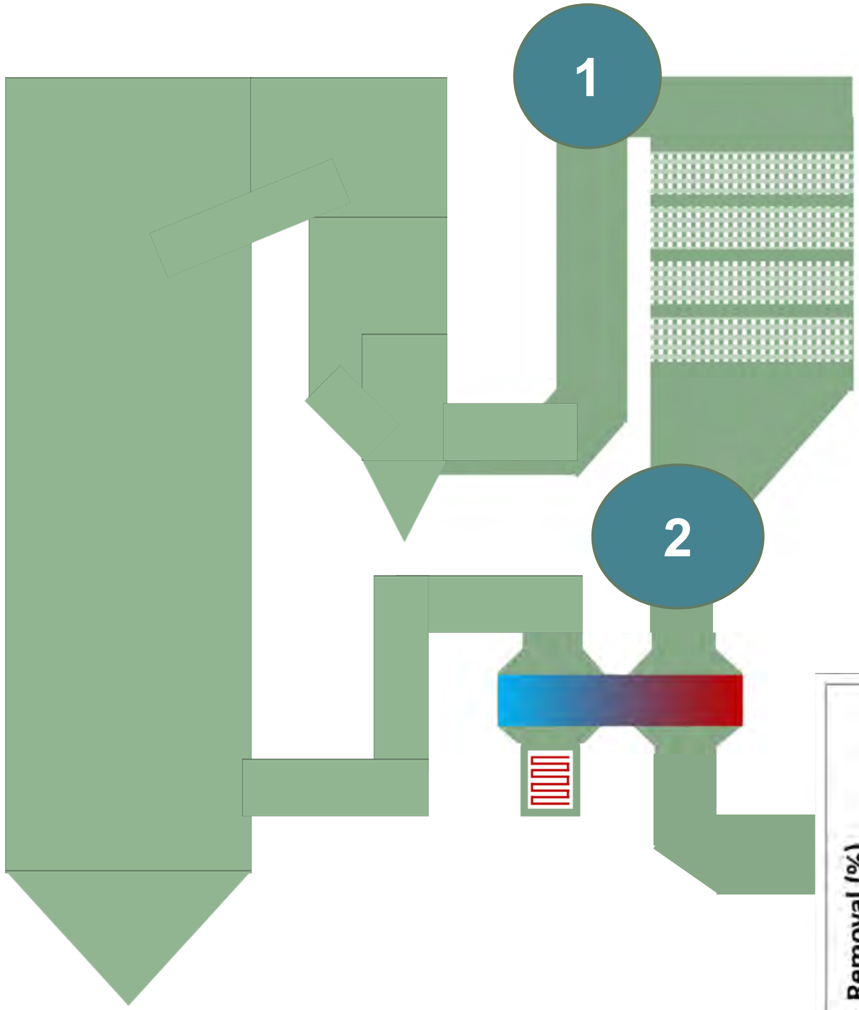
Quiz #2A Answers

1. Low Load SO3 at SCR_{Inlet} = *110 Lb/Hr*
2. High Load SO3 at AH_{Inlet} = *450 Lb/Hr*
3. High Load SO3 at ESP/FF_{Inlet} = *338 Lb/Hr*



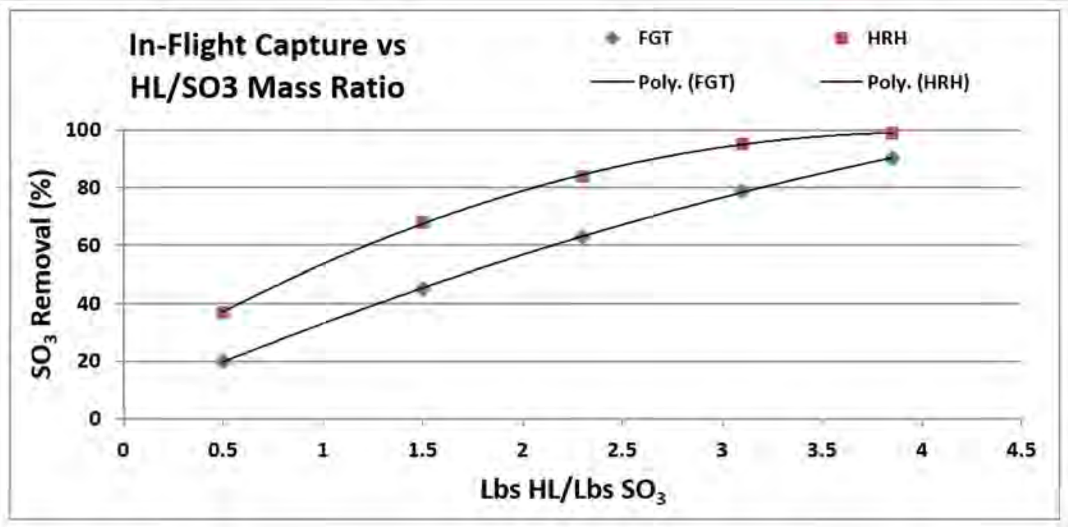
Quiz #2B

1. Low Load SO3 at SCR_{Inlet} = *110 Lb/Hr (or) 8 ppm*
2. High Load SO3 at AH_{Inlet} = *450 Lb/Hr (or) 33 ppm*
3. High Load SO3 at ESP/FF_{Inlet} = *338 Lb/Hr (or) 25 ppm*



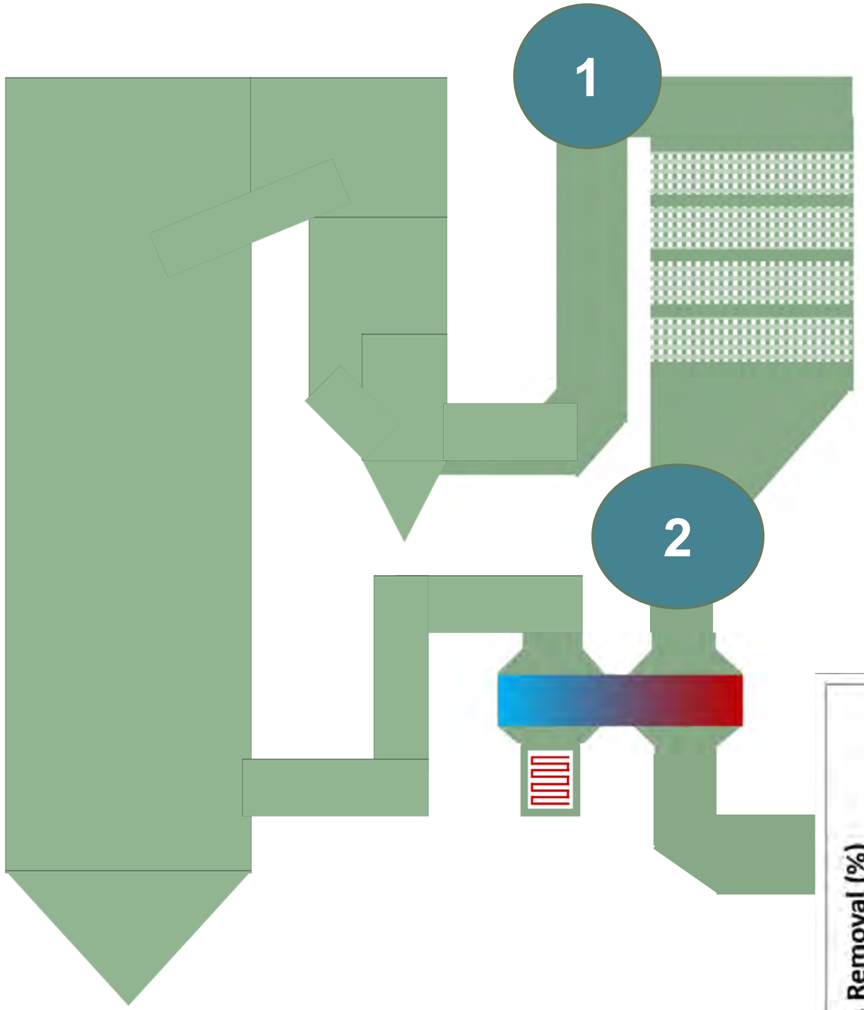
For 5 Points Each (Using the HRH curve below):

1. How Much Hydrate is need to achieve 2 ppm at Point 1
2. How much Hydrate is needed to achieve 10 ppm at Point 2



Quiz #2B Answers

1. Low Load SO3 at SCR_{Inlet} = *110 Lb/Hr (or) 8 ppm.*
    1. *75% Reduction*
    2. *2 Lb HRH/Lb SO3*
    3. *220 Lb/Hr HRH*
2. High Load SO3 at AH_{Inlet} = *450 Lb/Hr (or) 33 ppm*
    1. *70% Reduction*
    2. *1.5 Lb HRH/Lb SO3*
    3. *675 Lb Hr HRH*



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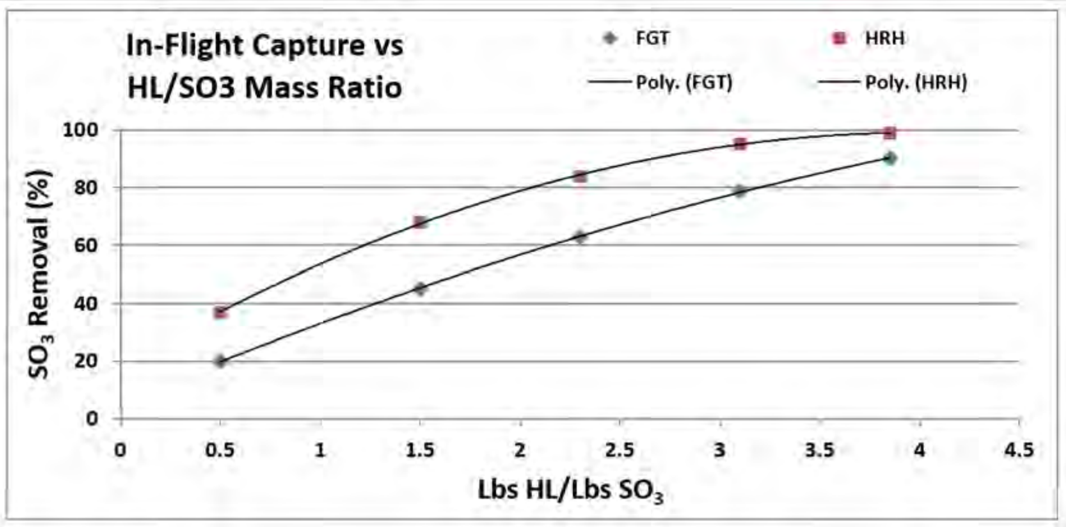
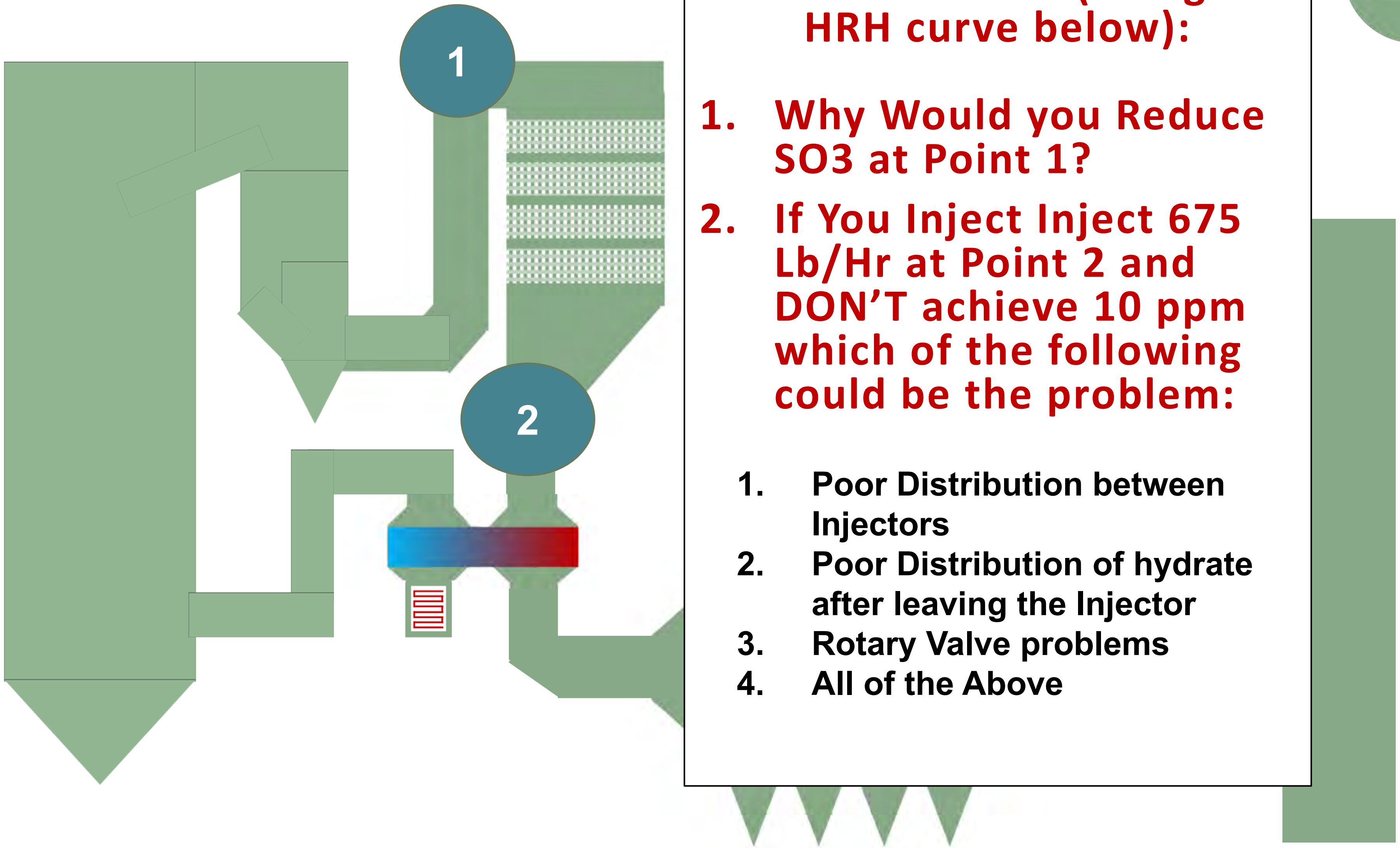


Quiz #2C



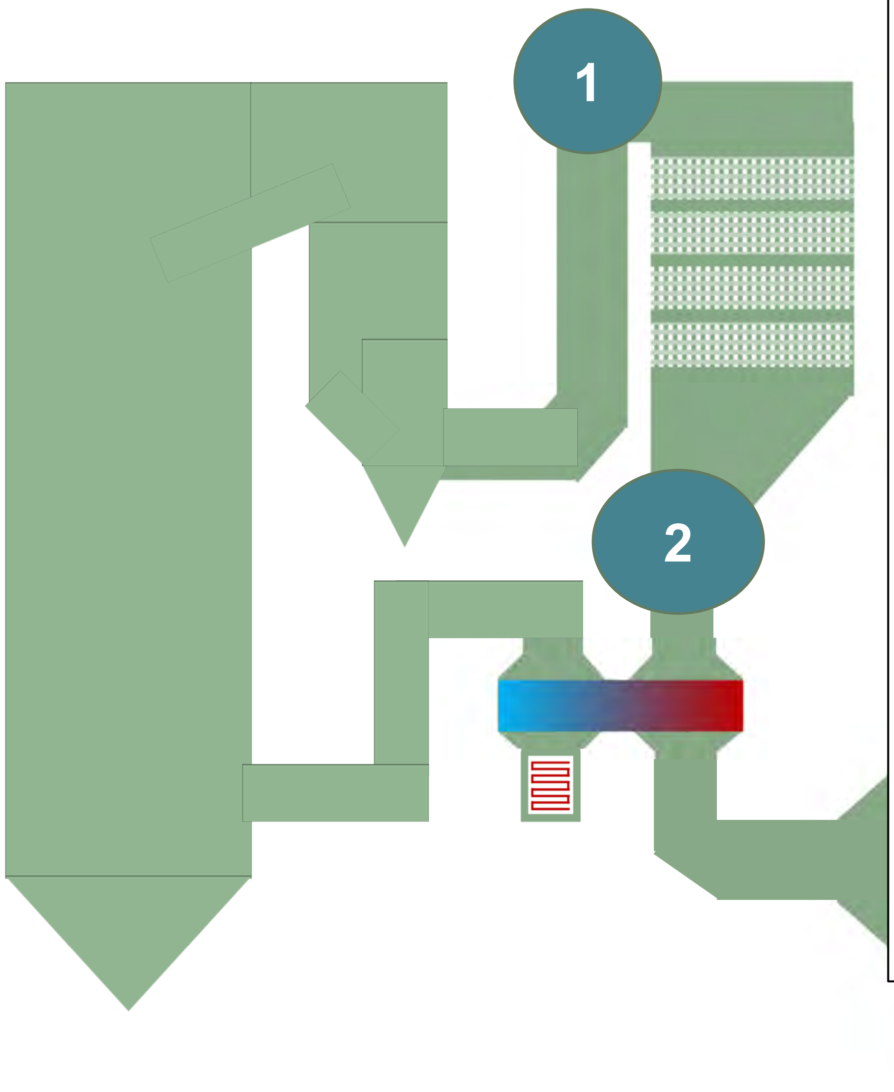
For 5 Points Each (Using the HRH curve below):

1. **Why Would you Reduce SO3 at Point 1?**
2. **If You Inject Inject 675 Lb/Hr at Point 2 and DON'T achieve 10 ppm which of the following could be the problem:**

   1. Poor Distribution between Injectors
   2. Poor Distribution of hydrate after leaving the Injector
   3. Rotary Valve problems
   4. All of the Above

Quiz #2C

1. Reduction in SCR MOT results in lower minimum unit load
2. Answer 4, "All of the Above" could contribute to unexpected results



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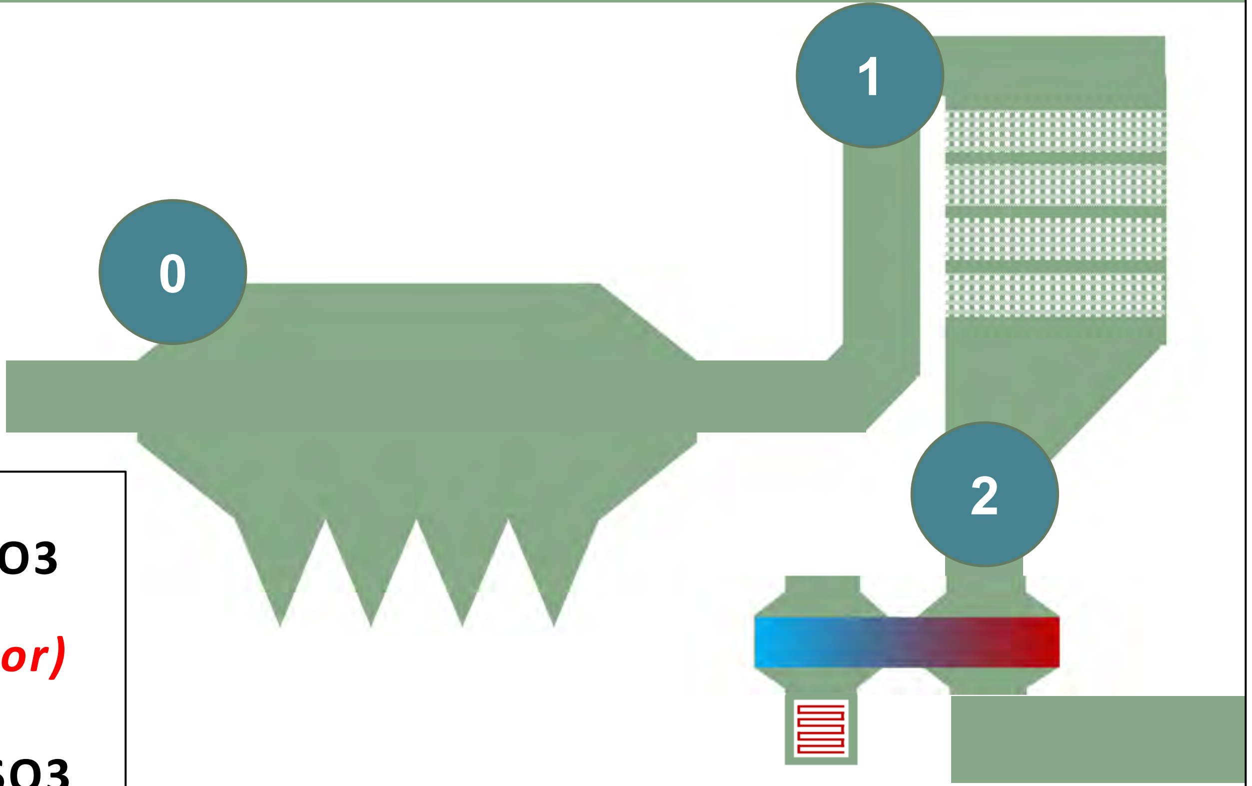
   4. All of the Above

Quiz 3 - Low Dust SCR Considerations



1. Low Load SO3 at SCR_{Inlet} = *110 Lb/Hr (or) 8 ppm*
2. High Load SO3 at AH_{Inlet} = *450 Lb/Hr (or) 33 ppm*

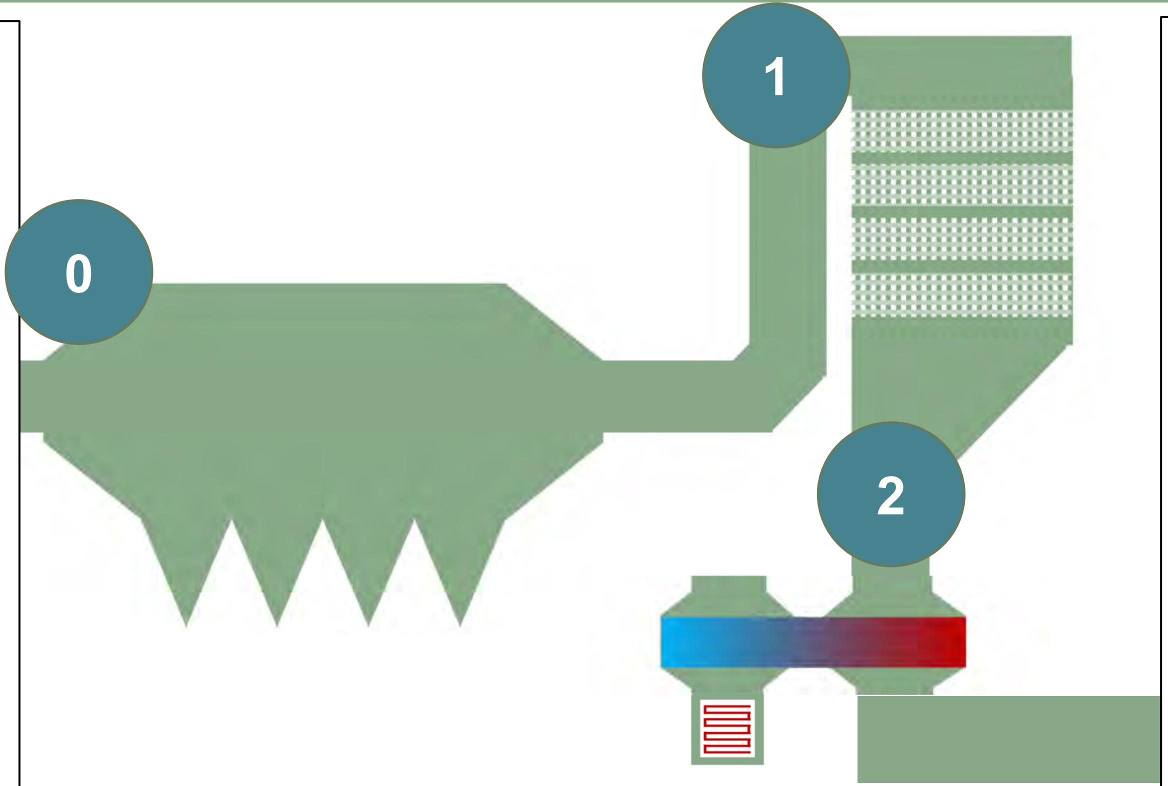
For 5 Points Each:

Your Goal is to mitigate Visible Plume.

1. If you inject the theoretical amount at point "0" do you succeed?
2. If no, why not?
3. If you inject at point "1", do you succeed?
4. If No, why not?
5. If Yes, are there any potential unexpected results

Quiz 3 Answers - Low Dust SCR

1. No, you do not
2. You mitigate the Furnace SO3, but the ESP captures the hydrate and the SCR SO3 is still present
3. Yes you will, maybe
4. Low Dust SCRs have small pitch and may be subject to plugging
5. If there are FGD issues, the particulate may pass through to the stack



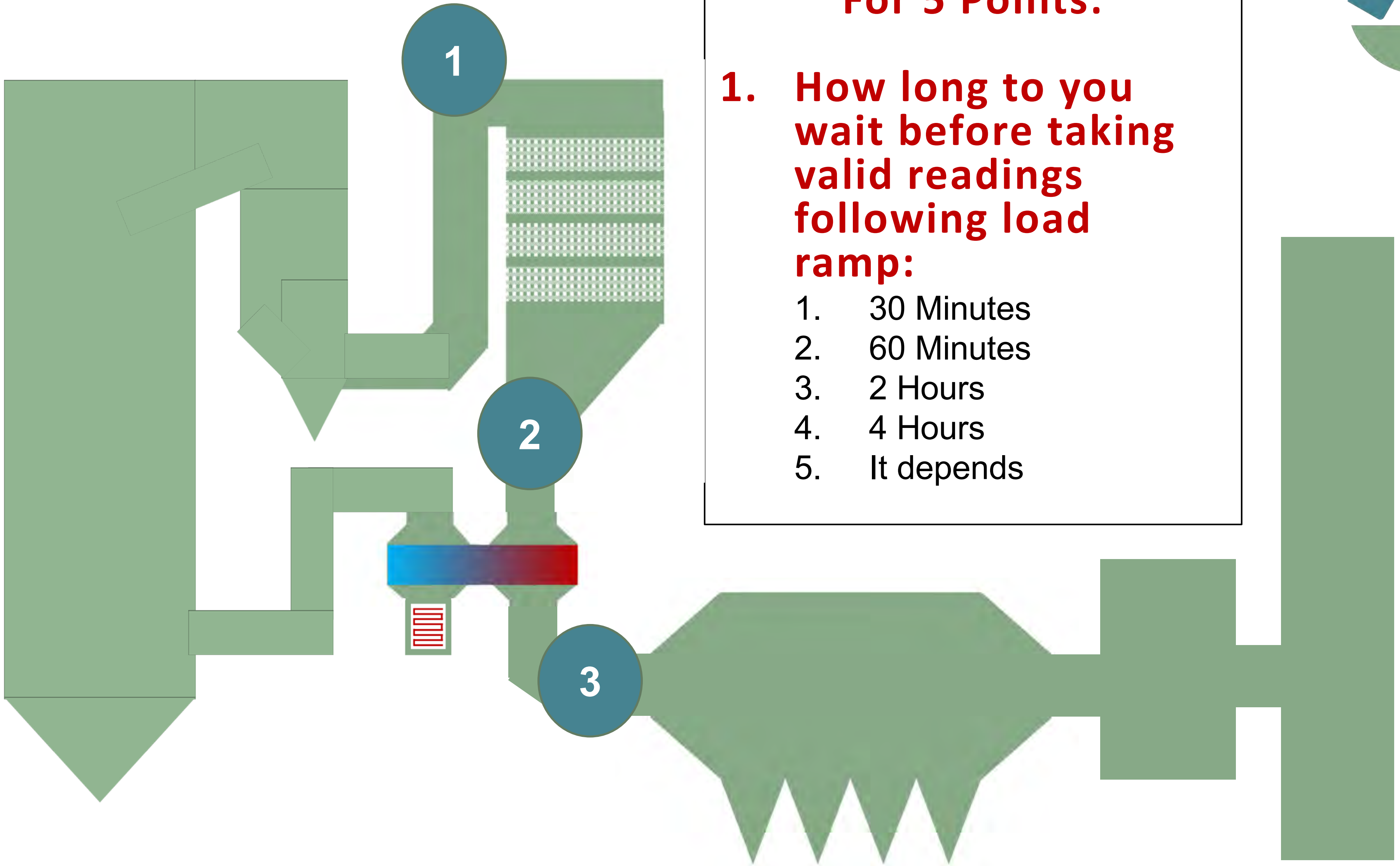
For 5 Points Each:

Your Goal is to mitigate Visible Plume.

1. If you inject the theoretical amount at point "0" do you succeed?
2. If no, why not?
3. If you inject at point "1", do you succeed?
4. If No, why not?
5. If Yes, are there any potential unexpected results

Quiz #4

- You Start a trial of HRH at a pre-SCR or pre-AH location
- You are exploring low load impact on MOT and full load impact on AH differential pressure.
- To assess success you are running some form of SO_3 measurement at the AH Inlet following the injection points

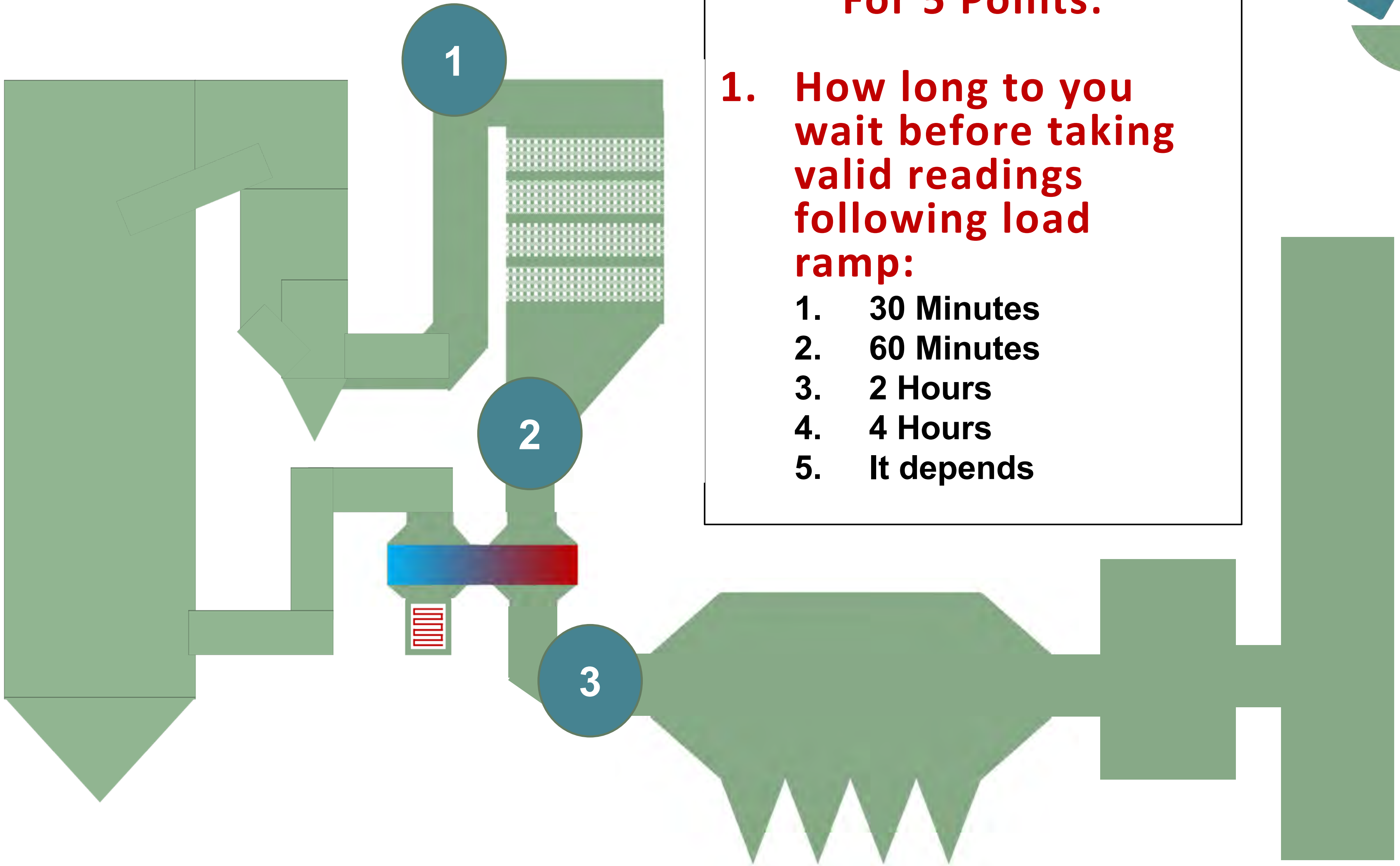


For 5 Points:

1. **How long to you wait before taking valid readings following load ramp:**
    1. 30 Minutes
    2. 60 Minutes
    3. 2 Hours
    4. 4 Hours
    5. It depends

Quiz #4 Answers

- *It Depends*
- Load Ramp generates increased levels of SO3.
- For Extra Credit (1 Point for each valid answer)
- What Does the wait time depend on?

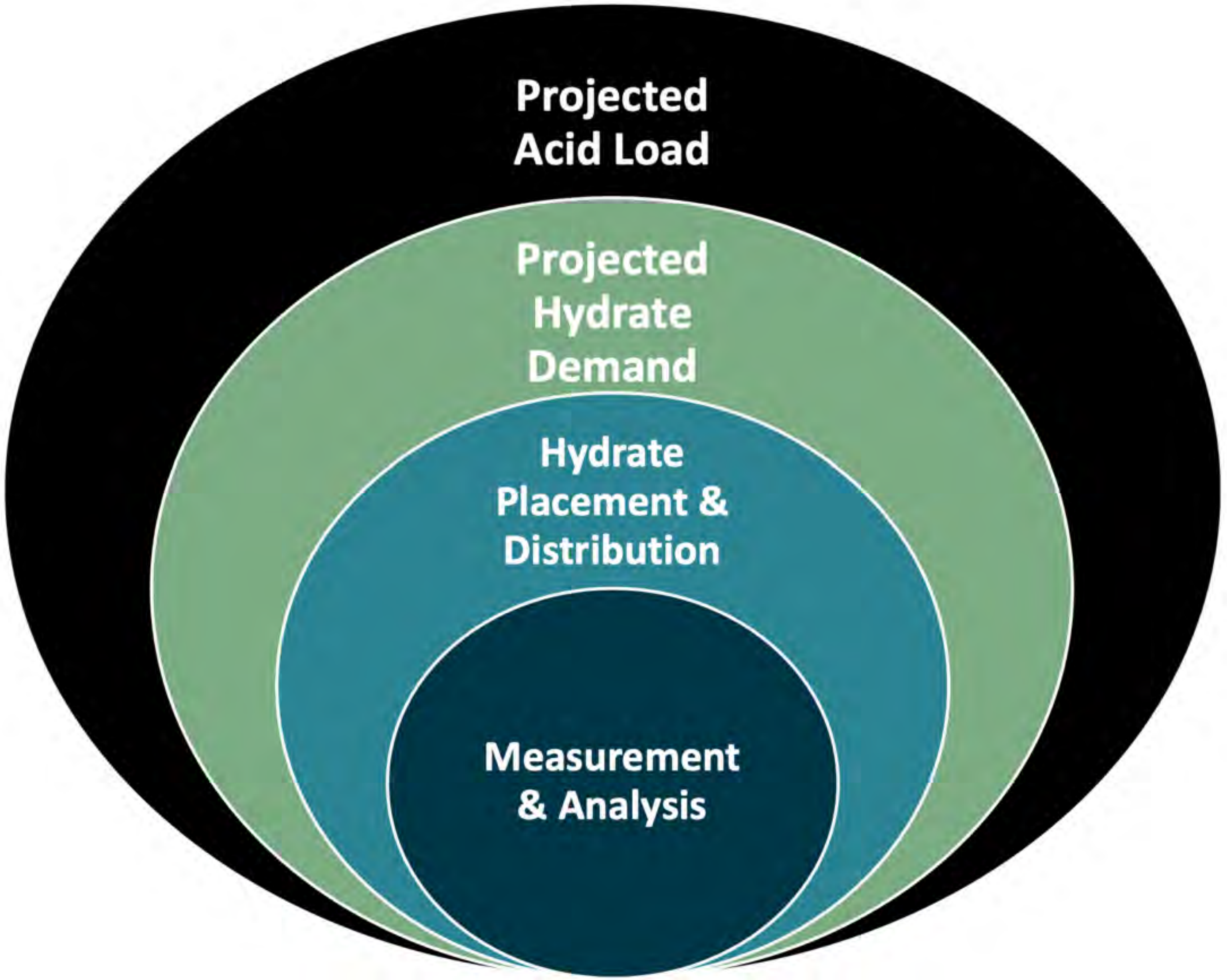


For 5 Points:

1. How long to you wait before taking valid readings following load ramp:
   1. 30 Minutes
   2. 60 Minutes
   3. 2 Hours
   4. 4 Hours
   5. It depends

Projecting and Verifying DSI Performance

Conclusions



Insights into Dry Sorbent Injection

- Projecting Acid Load and Theoretical Demand is straight forward,
- Projecting Distribution and Hydrate Utilization Impacts is less straightforward
- Finally, understanding how to normalize data so that direct comparisons are possible requires attention to detail;.
- A basic understanding of the DSI process will help but, in the end, there is a lot to be said for Experience

MLC is Here to Help

Questions for the Professors?

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