

Reinhold Environmental Ltd.



2007 NOx Round Table & Expo
Presentation

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SO₃ Mitigation/NO_x Perspective

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URS
Corporation



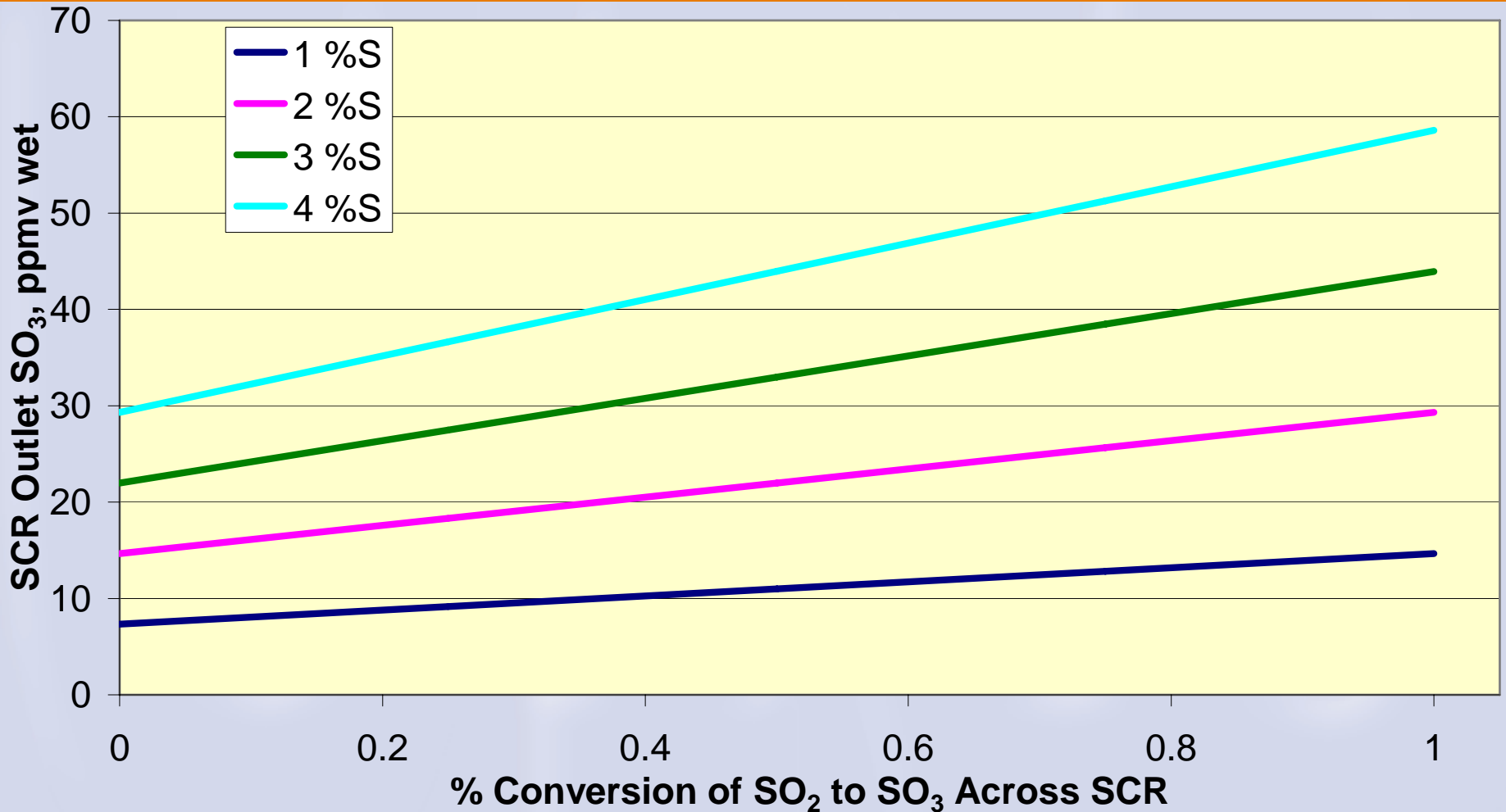
Background

- Boilers firing bituminous coal convert ~0.5 to 1.5% of SO_2 to SO_3
- SCR can convert an additional 0.25 to >1% of SO_2 to SO_3
- Resulting sulfuric acid (H_2SO_4) and/or ammonium bisulfate (NH_4HSO_4) can cause problems:
 - SCR catalyst fouling
 - Air heater plugging or reduced plant efficiency
 - Reduced mercury capture in ESP/baghouse
 - Back-end corrosion
 - Baghouse performance issues
 - Plume opacity

Presentation Outline

- Background
 - Effects of SCR on flue gas SO₃ concentrations
 - Adverse effects of SO₃ in flue gas
- SO₃ Control Technologies
 - Effects of location in gas path
 - +/- attributes of technologies
 - Typical process flow diagram
 - Typical performance curves
- Example SO₃ Control Technology Costs

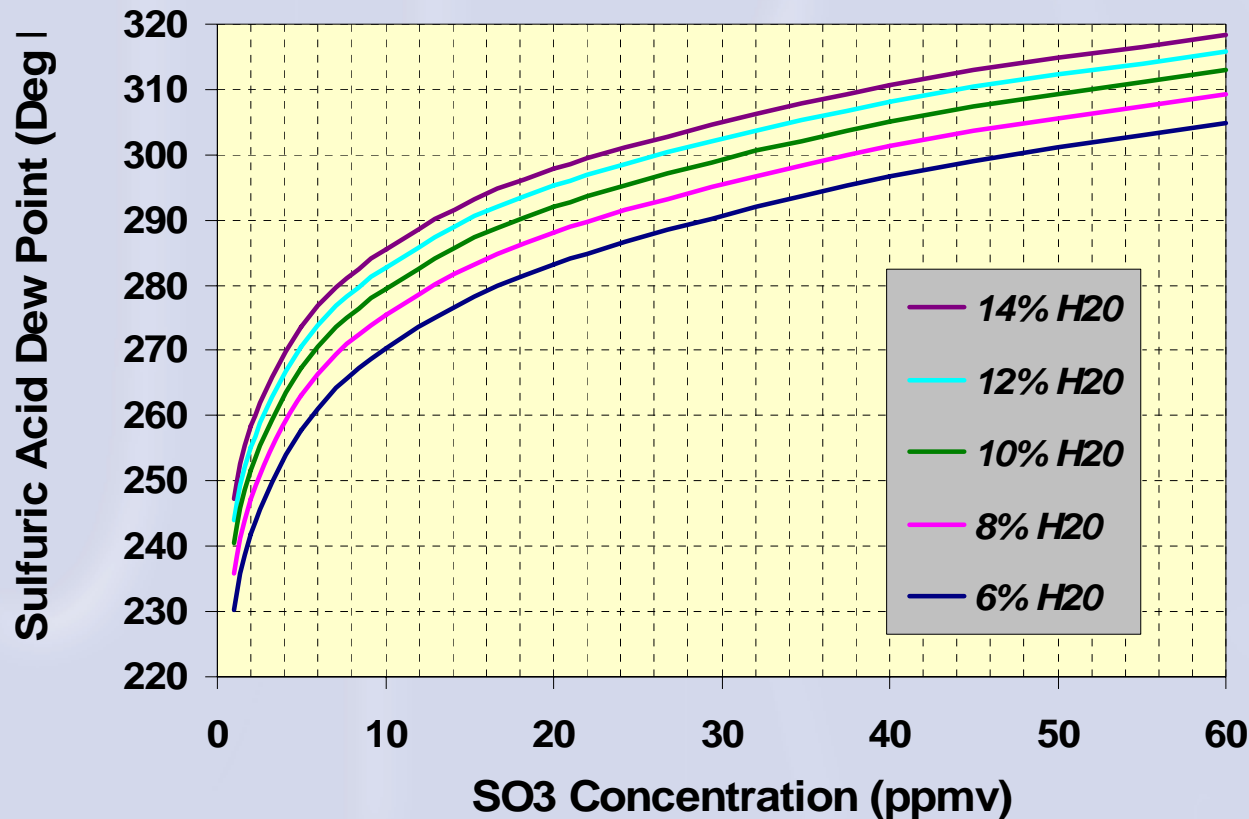
Effect of SCR Conversion on Air Heater Inlet SO_3 Concentration*



*Assumes 1% boiler conversion of SO_2

Impacts Created by Presence of SO_3

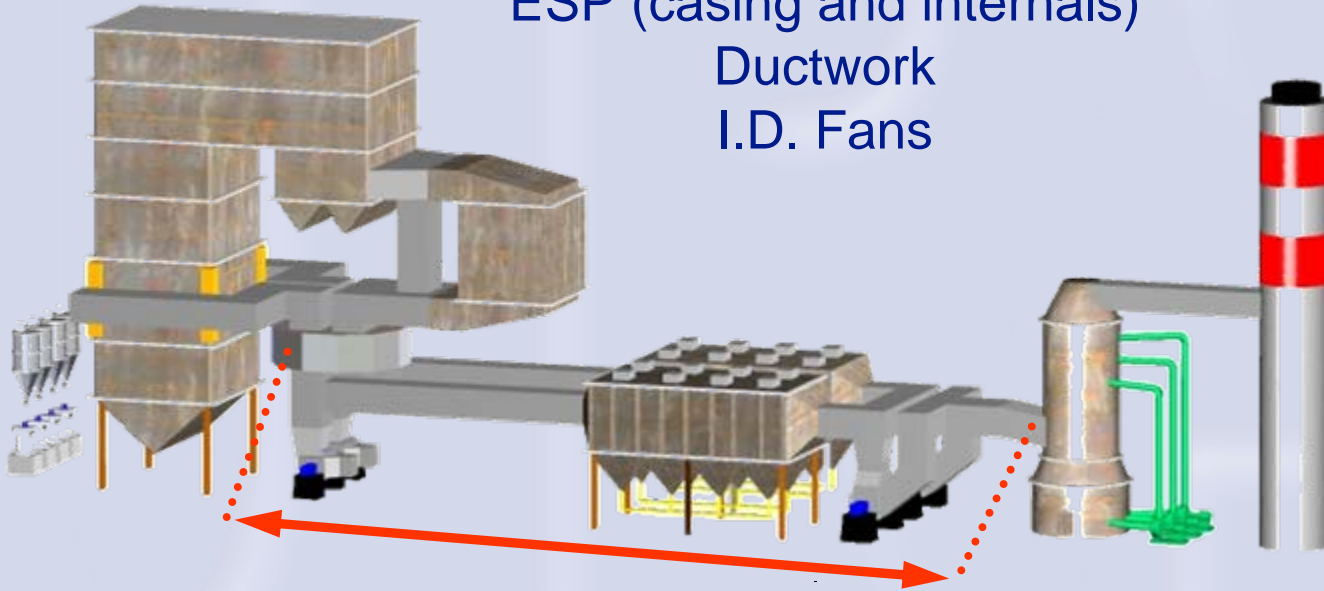
Effect of SO_3 on Sulfuric Acid Dew Point



Increased SO_3 : Acid Dew Point Implications

Increased Acid Corrosion of all Back-end Components

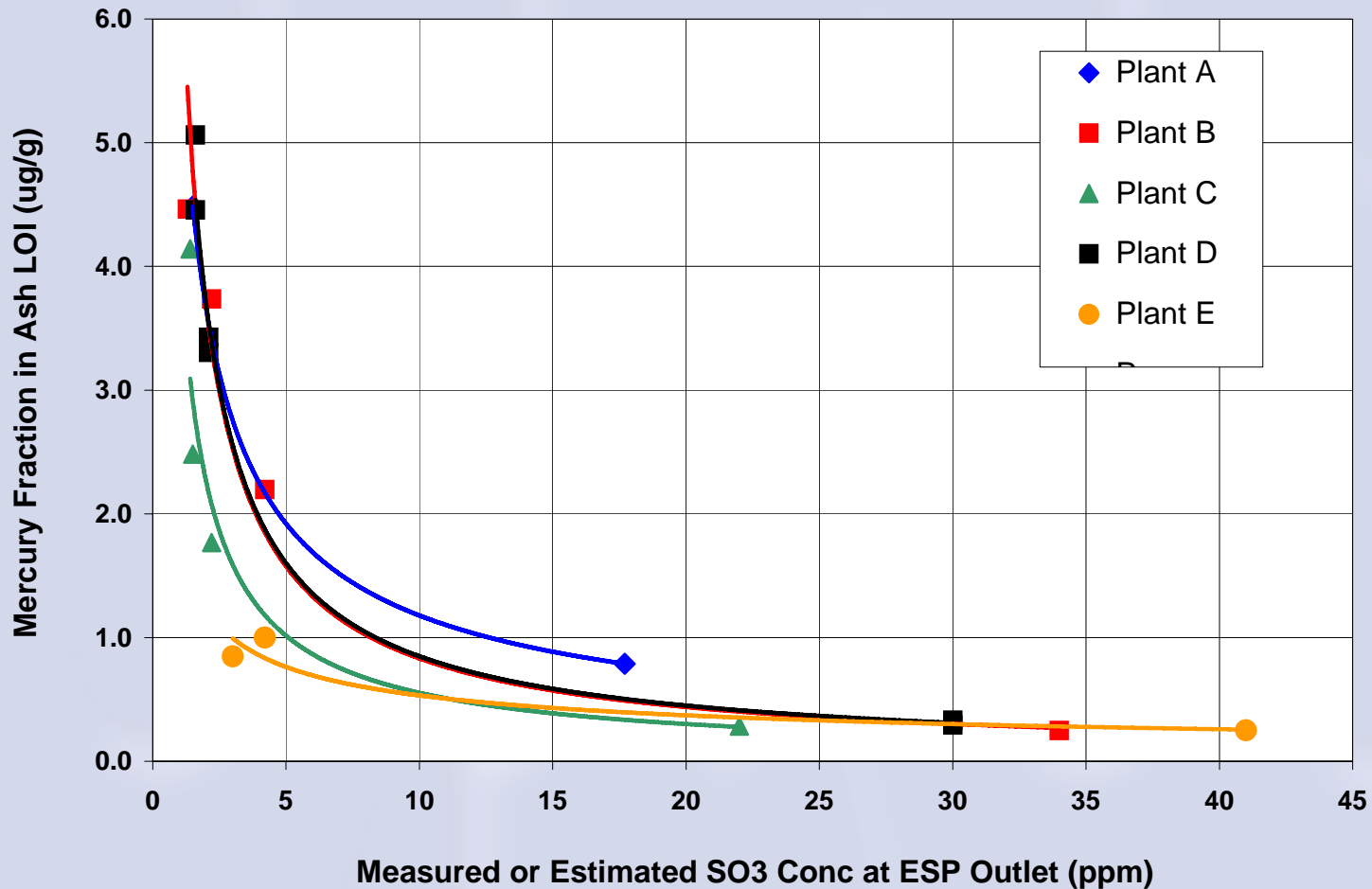
Air heater cold-end baskets
ESP (casing and internals)
Ductwork
I.D. Fans



Increasing air heater outlet temperature negatively affects plant heat rate (Change of 35°F ~ 1% change in heat rate)

Full-Scale Impact of SO₃ on Hg

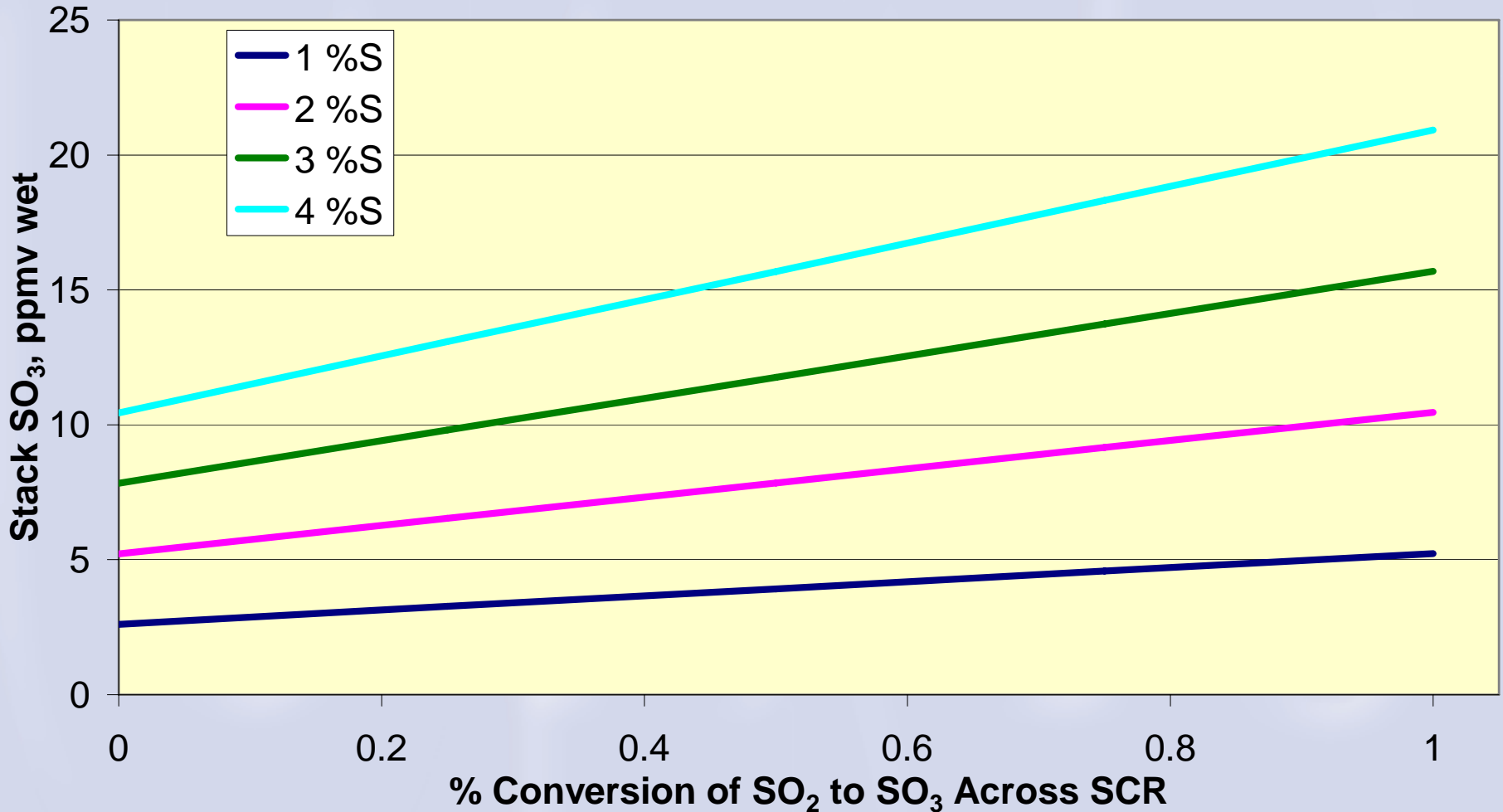
Mercury Removal By Carbon in Ash with SBS Injection



SO₃ Control

- Existing air emission controls do not collect SO₃/sulfuric acid at high efficiency:
 - 10-20% removal typical across air heaters and cold-side ESPs
 - mostly adsorption, condensation
 - actual percentages vary widely
 - Widely varied removal across wet scrubbers
 - measured range <10% to >80%
 - 50% is “typical” for limestone forced oxidation absorbers designed for >90% SO₂ removal

Effect of SCR Conversion of SO₂ on Stack SO₃ Concentration*



* Assumes 10% air heater and ESP removal, 50% FGD removal

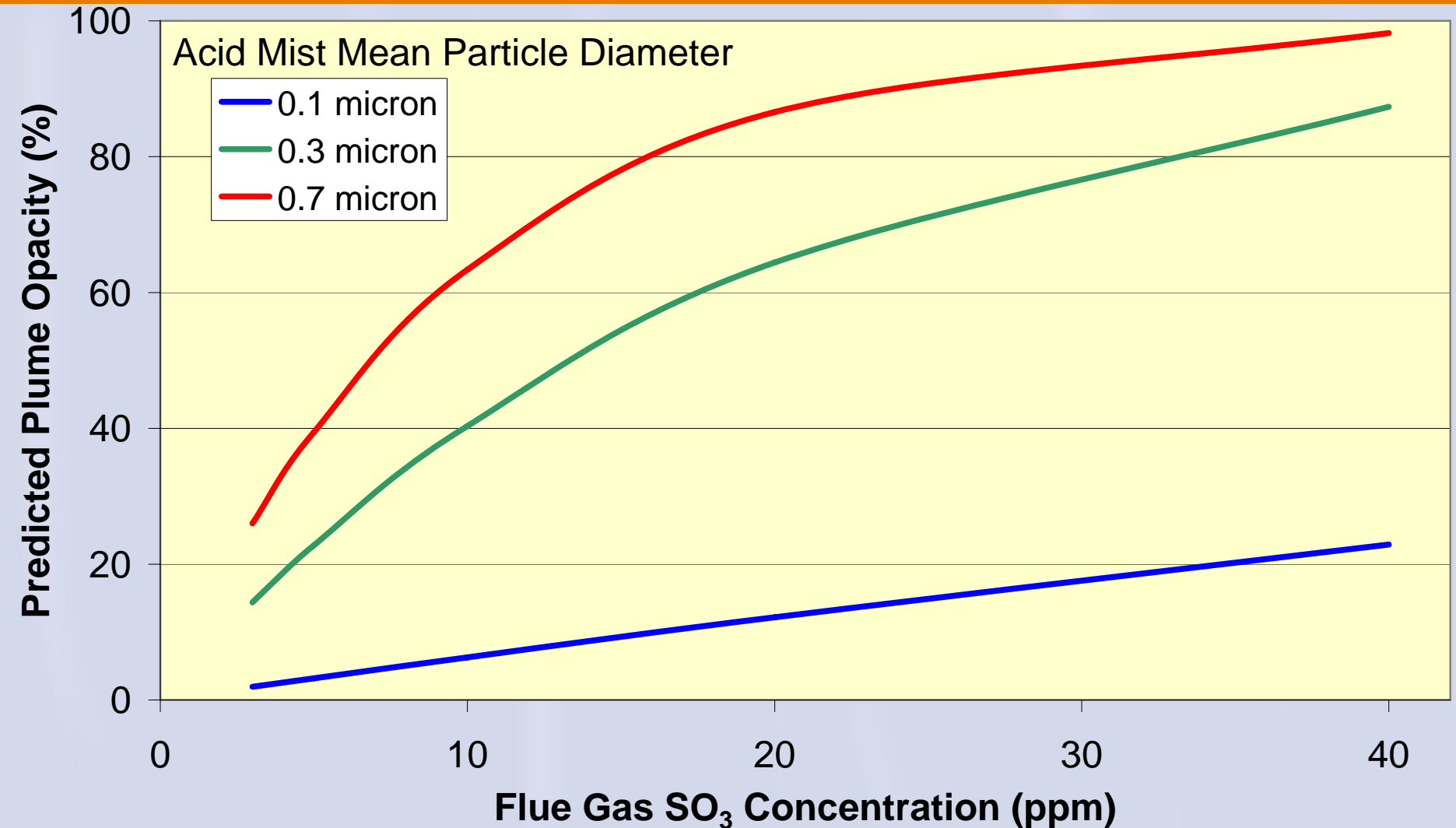
Impacts Created by Presence of SO_3

- Plume Opacity Issue: Coloration of plume from light scattering effects of sub-micron sulfuric acid aerosols



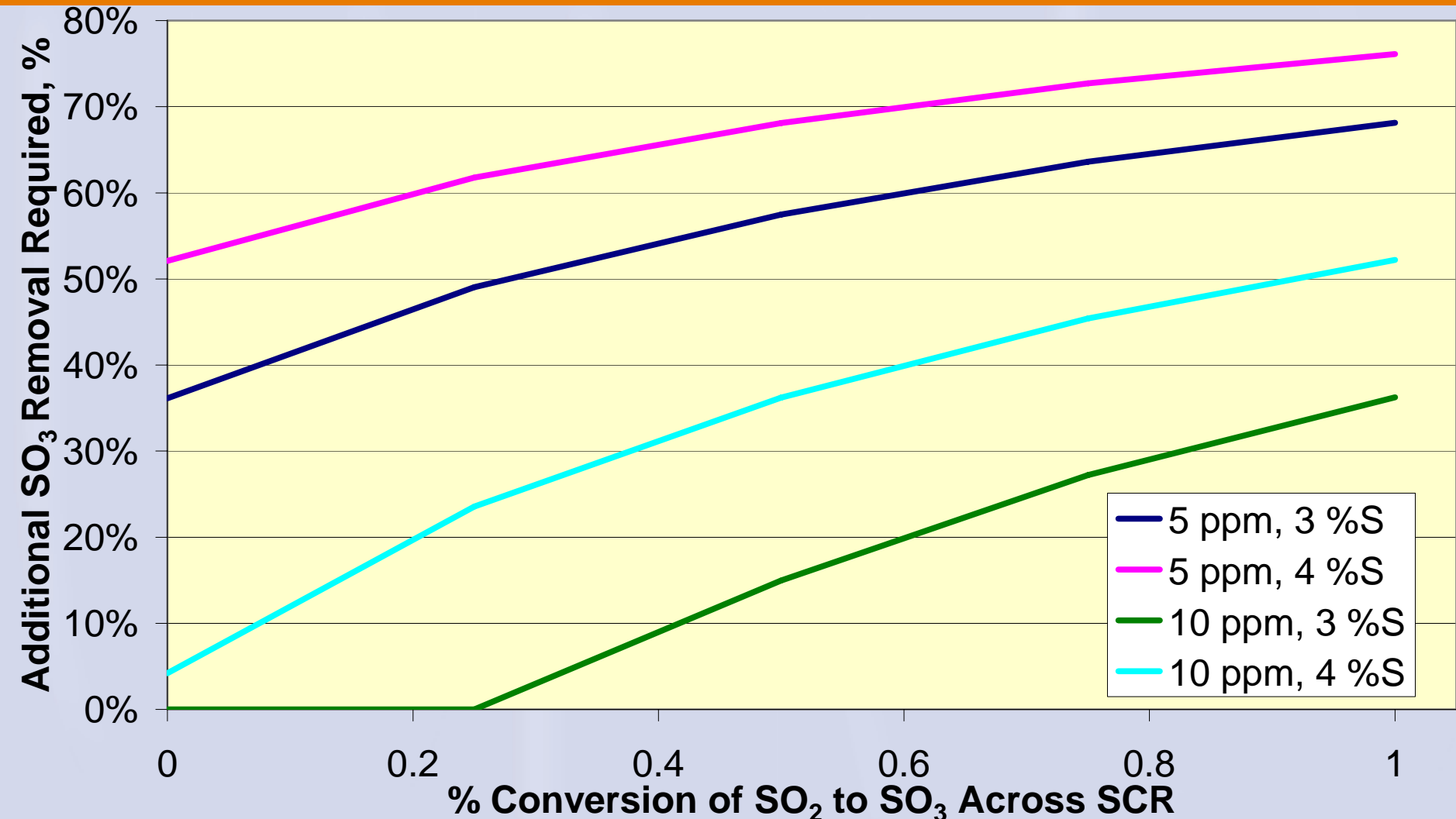
Sulfuric acid opacity can be visible when $\text{SO}_3 > 5\text{ppm}$

Predicted Effects of SO₃ on Plume Opacity*



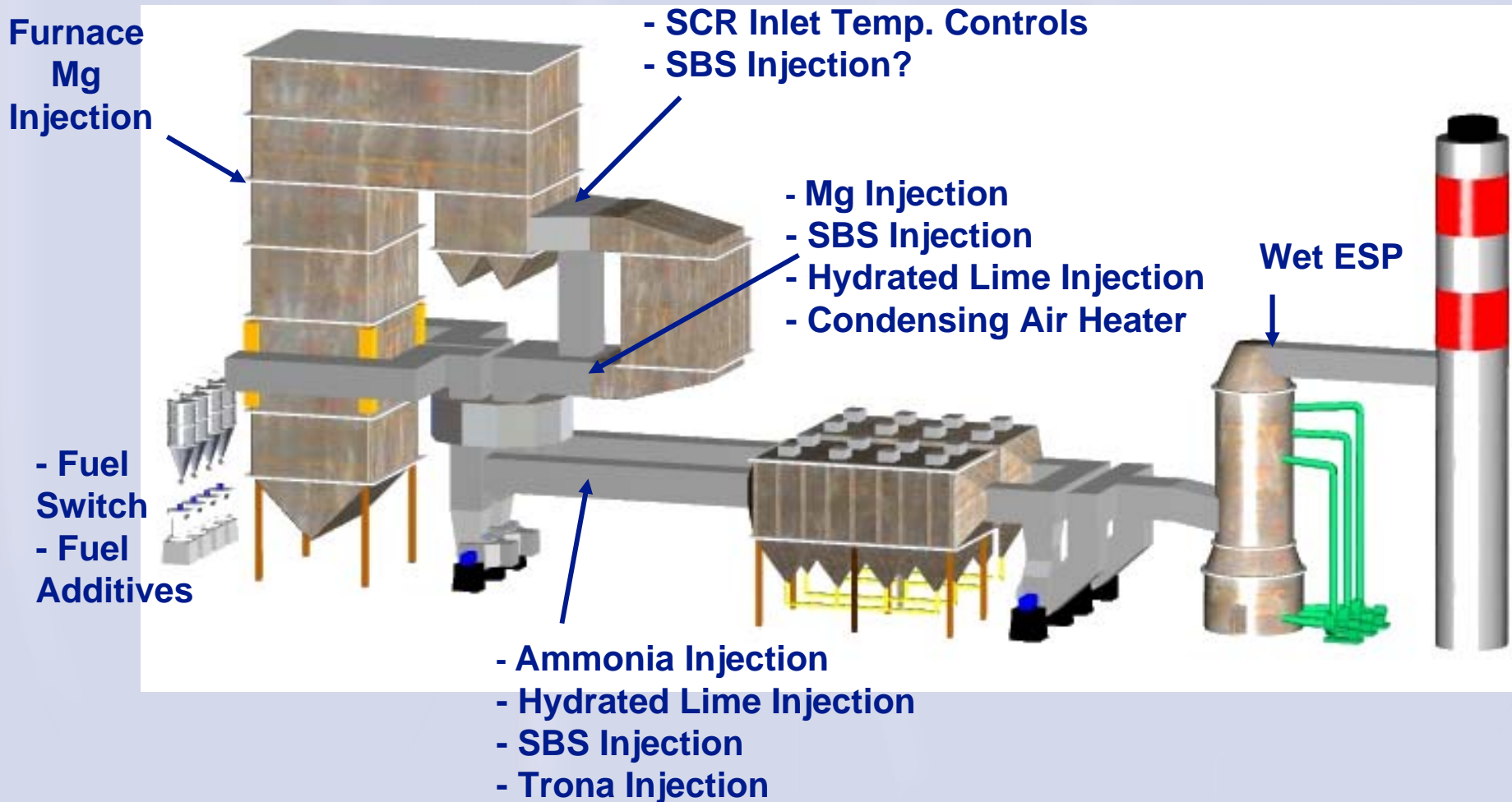
*25-ft stack diameter

Required SO₃ Removal (to achieve target SO₃ concentrations)*



*Assumes 10% removal across air heater & ESP, 50% across wet FGD

Potential Sulfuric Acid Control Options



Benefits of SO₃ Control Locations

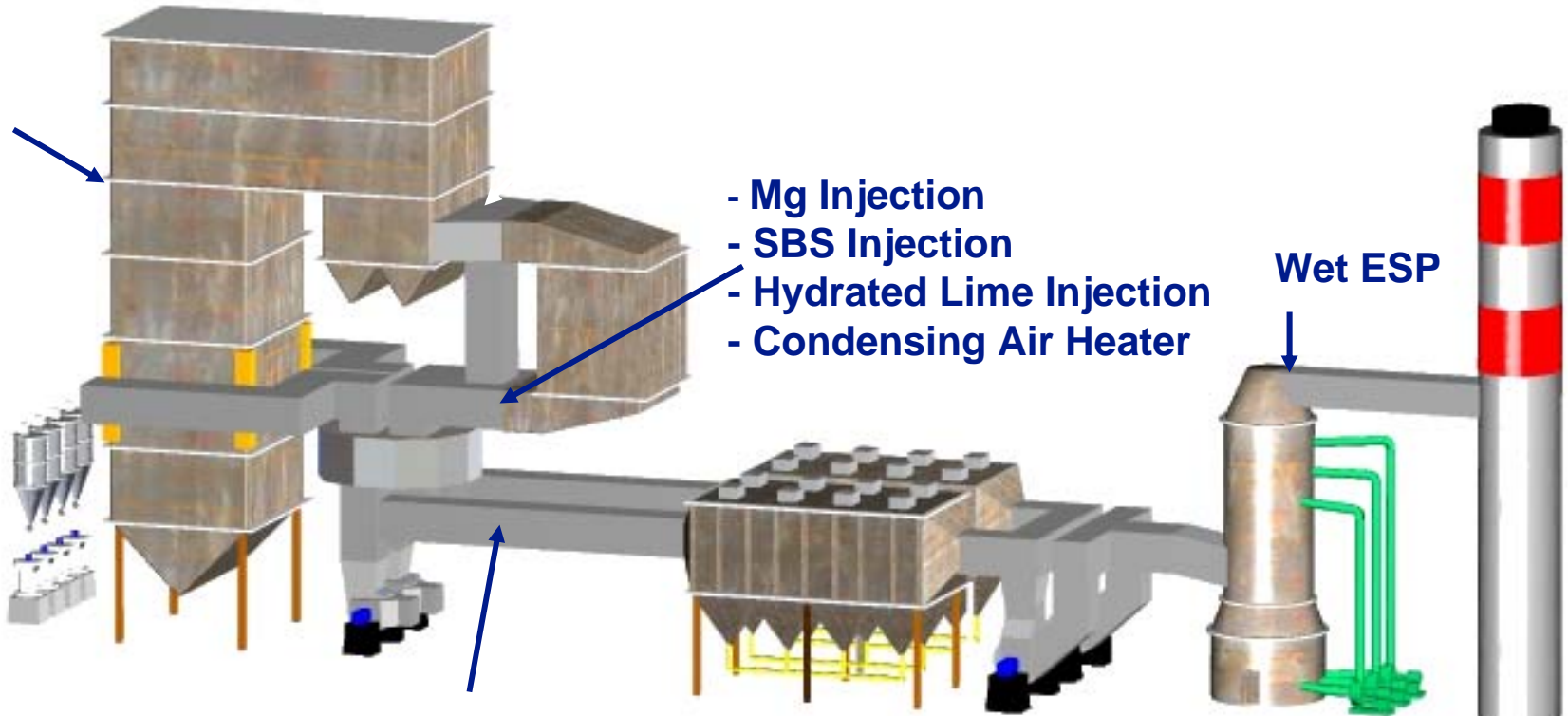
- Upstream of SCR:
 - Improved SCR turn-down (avoid capillary condensation at low unit load)
 - May not be as effective removing SCR-formed SO₃
- Between SCR and air heater:
 - Avoid SO₃ deposition in AH or heat rate impacts
 - Can allow increased NH₃ slip from SCR if SO₃ removal is very high
 - Low SO₃ limits ABS formation
 - Allows longer catalyst life and/or higher NO_x removal
 - Improved Hg capture by fly ash, activated carbon
 - Downstream benefits otherwise similar to control upstream of ESP/baghouse

Impacts of SO₃ Control Locations

- Upstream of ESP/Baghouse:
 - Helps avoid baghouse impacts (bag life, bag weight, pressure drop)
 - Mixed impacts on ESP, range from positive (lower ash resistivity) to negative (increased resistivity, space charge effects)
 - Potentially improves Hg capture by activated carbon
- Downstream of FGD (wet ESP):
 - No adverse effects on ESP or on byproducts (fly ash, gypsum)
 - Polishing control of Hg and fine particulate
 - Does not realize any upstream benefits, though (e.g., air heater, corrosion, Hg control, NH₃ slip)

Potential Sulfuric Acid Control Options Discussed Today

Furnace
Mg
Injection



- Fuel
Switch
- Fuel
Additive

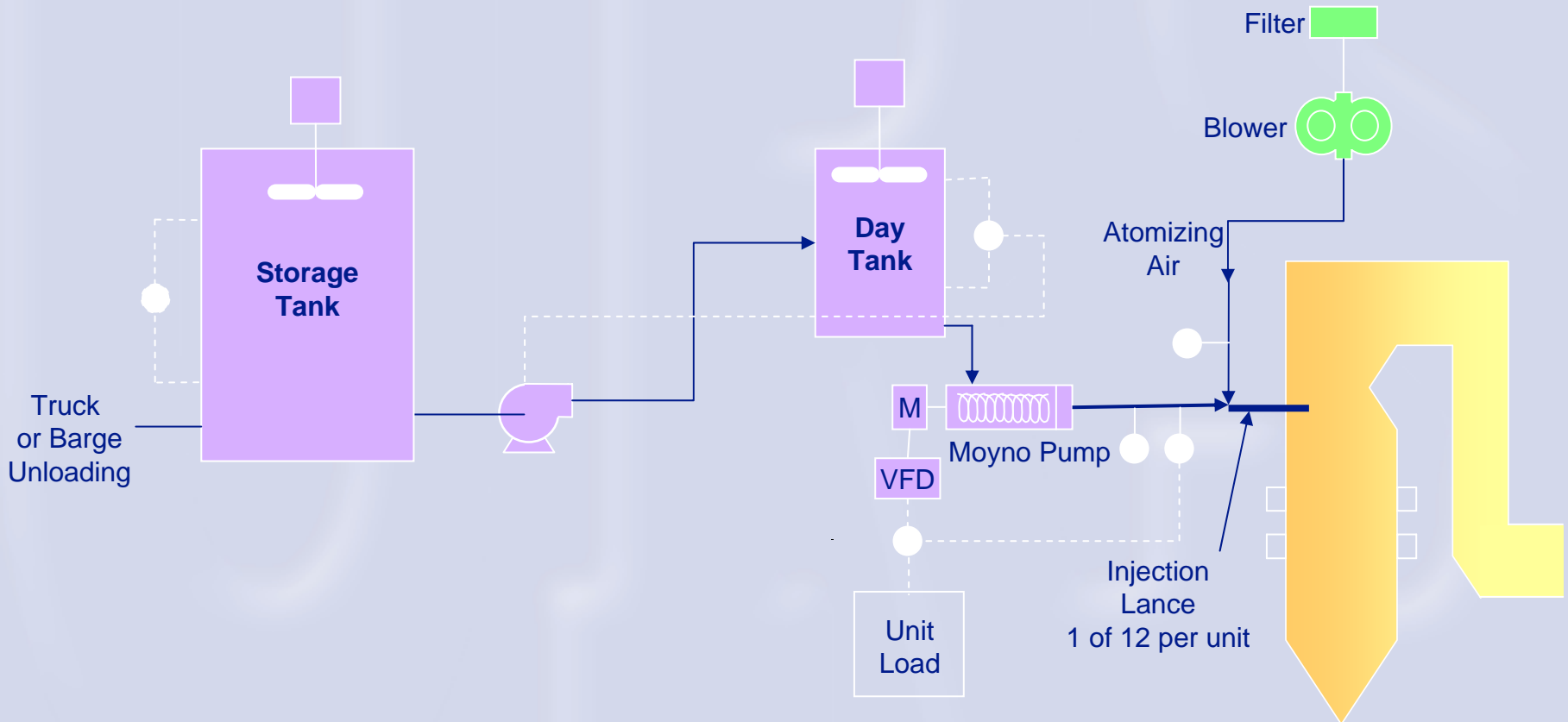
- Mg Injection
- SBS Injection
- Hydrated Lime Injection
- Condensing Air Heater

- Ammonia Injection
- Hydrated Lime Injection
- SBS Injection
- Trona Injection

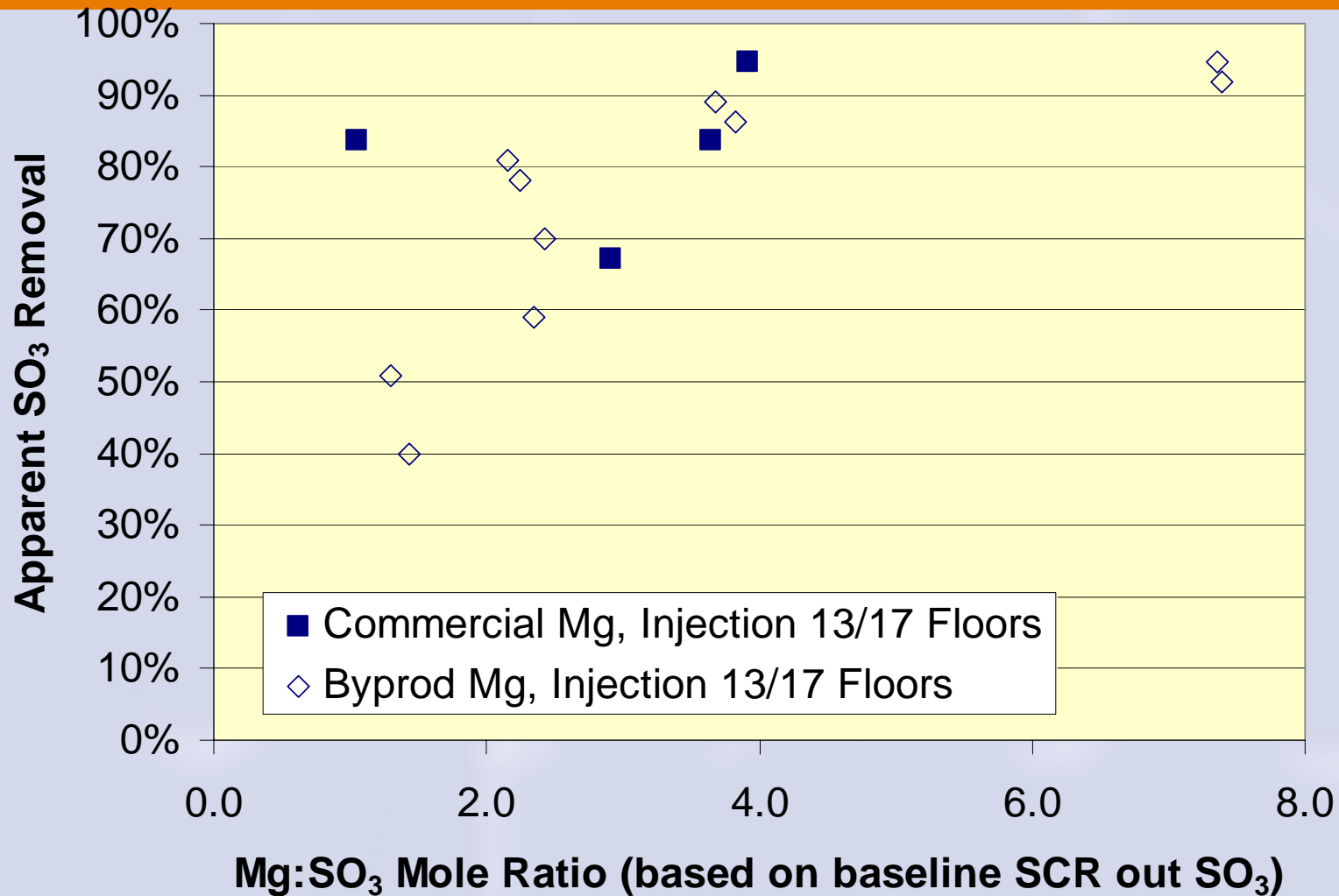
Furnace Injection of Mg Hydroxide Slurry

- Full-scale experience at AEP Gavin, Cinergy Zimmer, others
 - High control percentage of furnace SO_3
 - Limited control of SCR-formed SO_3
 - Potential benefits to slagging in furnace
 - Relatively high sorbent costs

Example Process Flow Diagram for Commercial Magnesium Injection into the Furnace

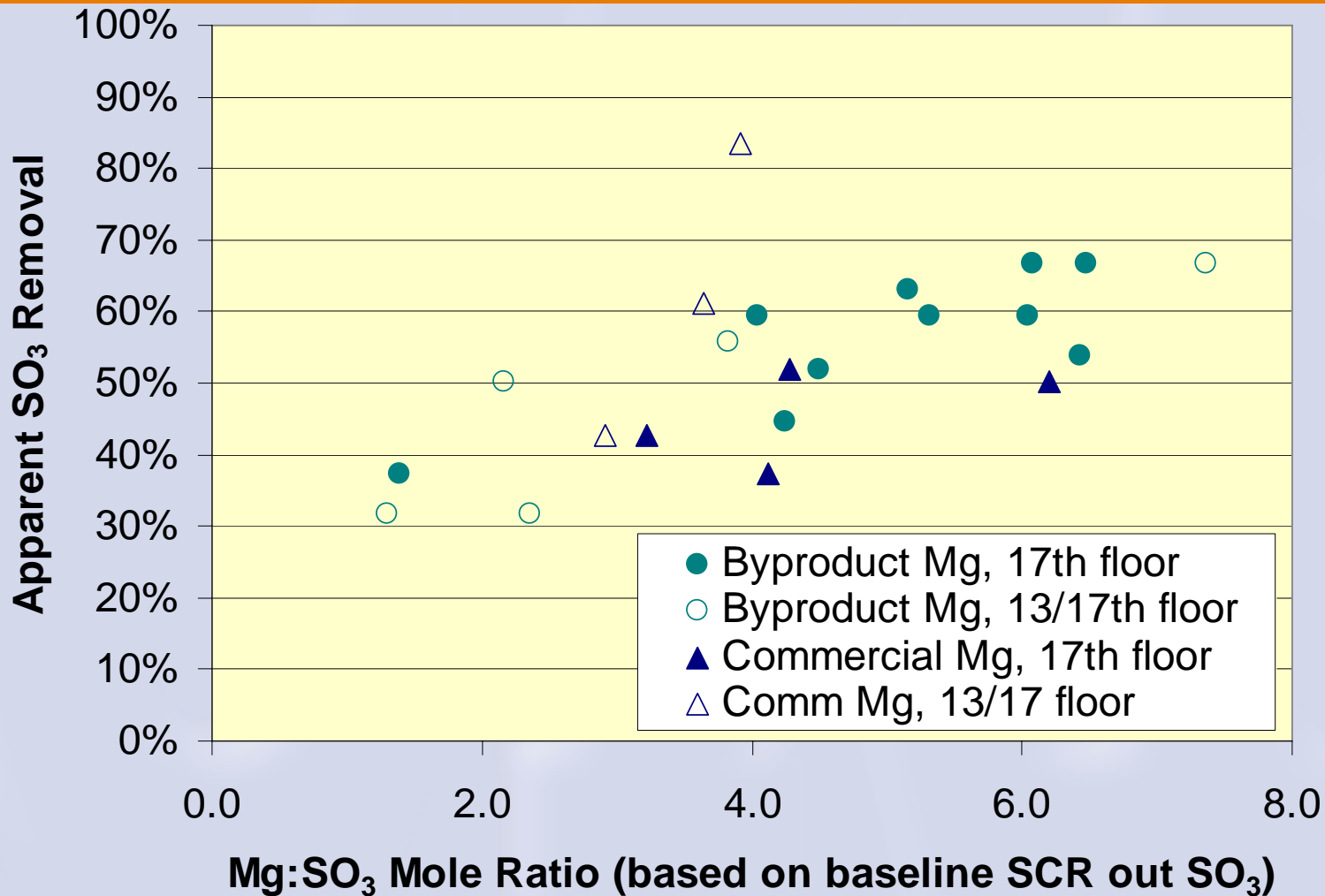


Gavin Mg(OH)₂ Injection Results - SO₃ Control at Economizer Outlet*



Note: these results were not optimized through CFD modeling of injection locations

Gavin $\text{Mg}(\text{OH})_2$ Injection Results - SO_3 Control at ESP Outlet*



Note: these results were not optimized through CFD modeling of injection locations

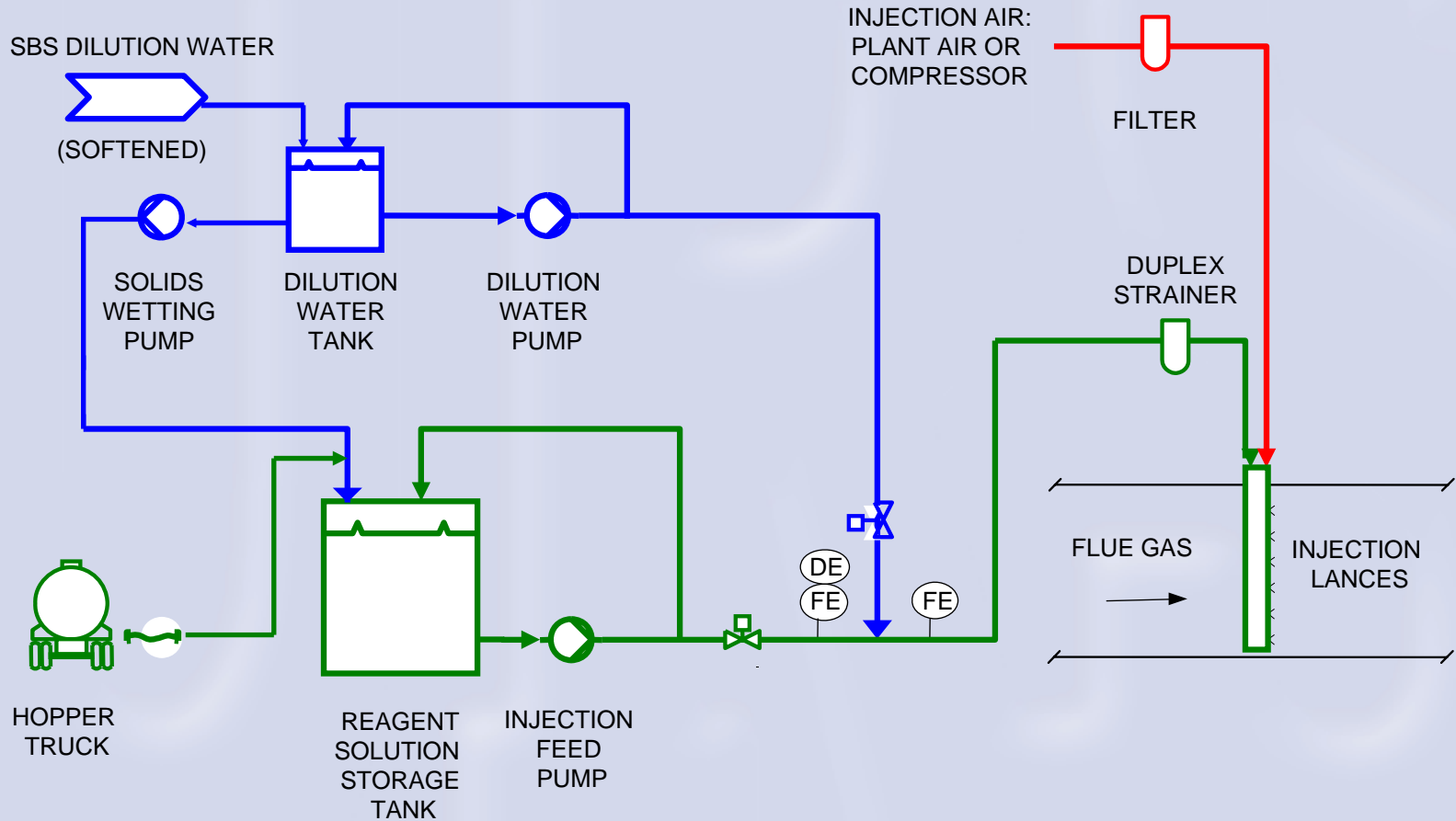
Injection of Mg Powder at SCR Outlet Duct

- Limited performance data published for high SO_3 levels
- Can be combined with furnace Mg injection for higher SO_3 control (e.g., FuelTech TIFI/TIDI)
- Potential adverse effects on ESP at high control efficiencies

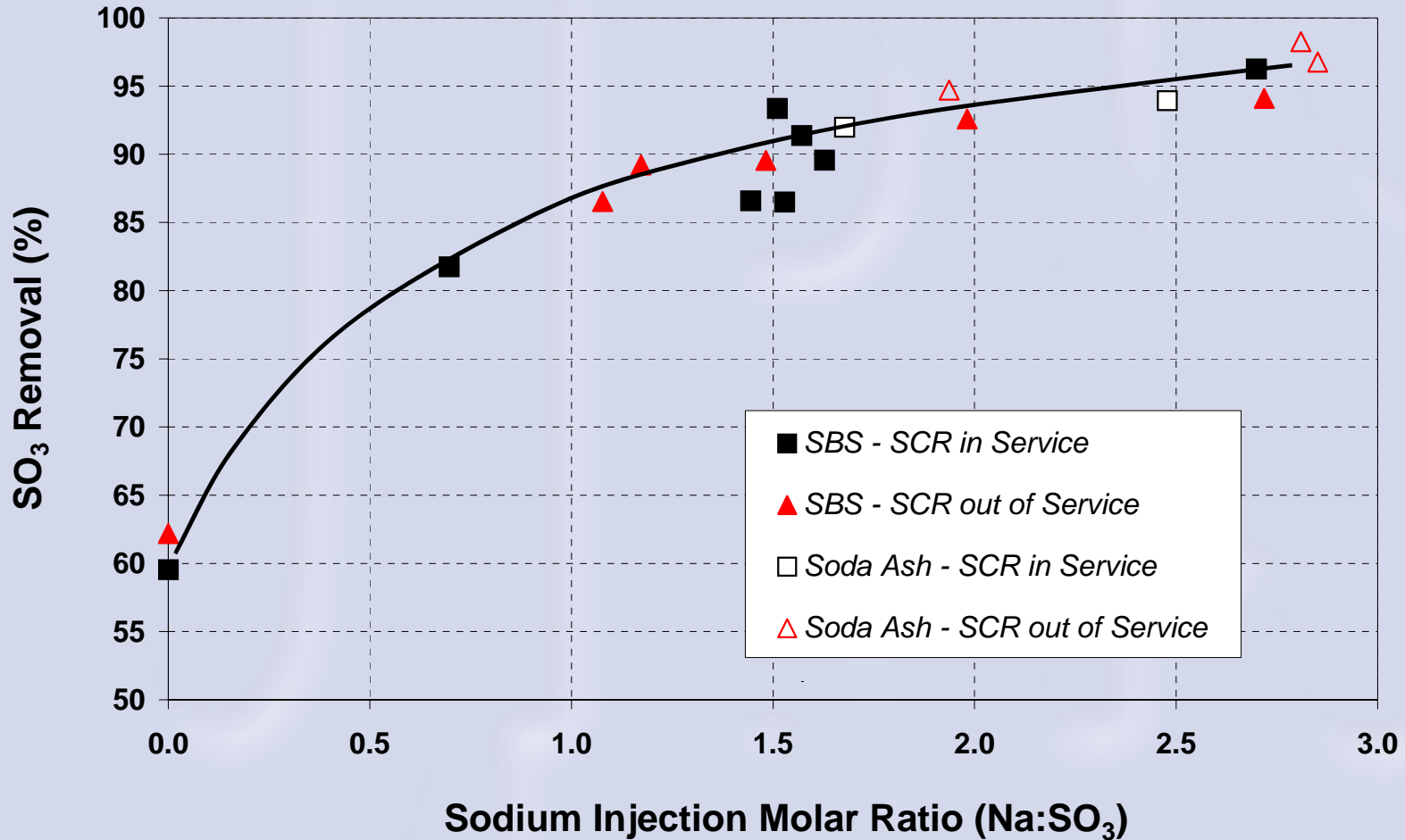
SBS Injection

- 6 commercial installations (13 units, 8500 MW)
- Codan Technologies patent, URS partner
- Can implement up- or downstream of air heater
- Can meet high SO₃ removal targets, clear stack
 - Potential heat rate benefits if high SO₃ control can be achieved upstream of air heater
 - Possible SCR, ESP, Hg control benefits
- Requires diligent maintenance to reliably inject aqueous solutions in duct
- Sodium can lower ash resistivity
- Adds sodium to fly ash (~1%), could impact ash sales

Simplified Process Flow Diagram



Example SO₃ Removal Results





Unit 1 (without SBS)

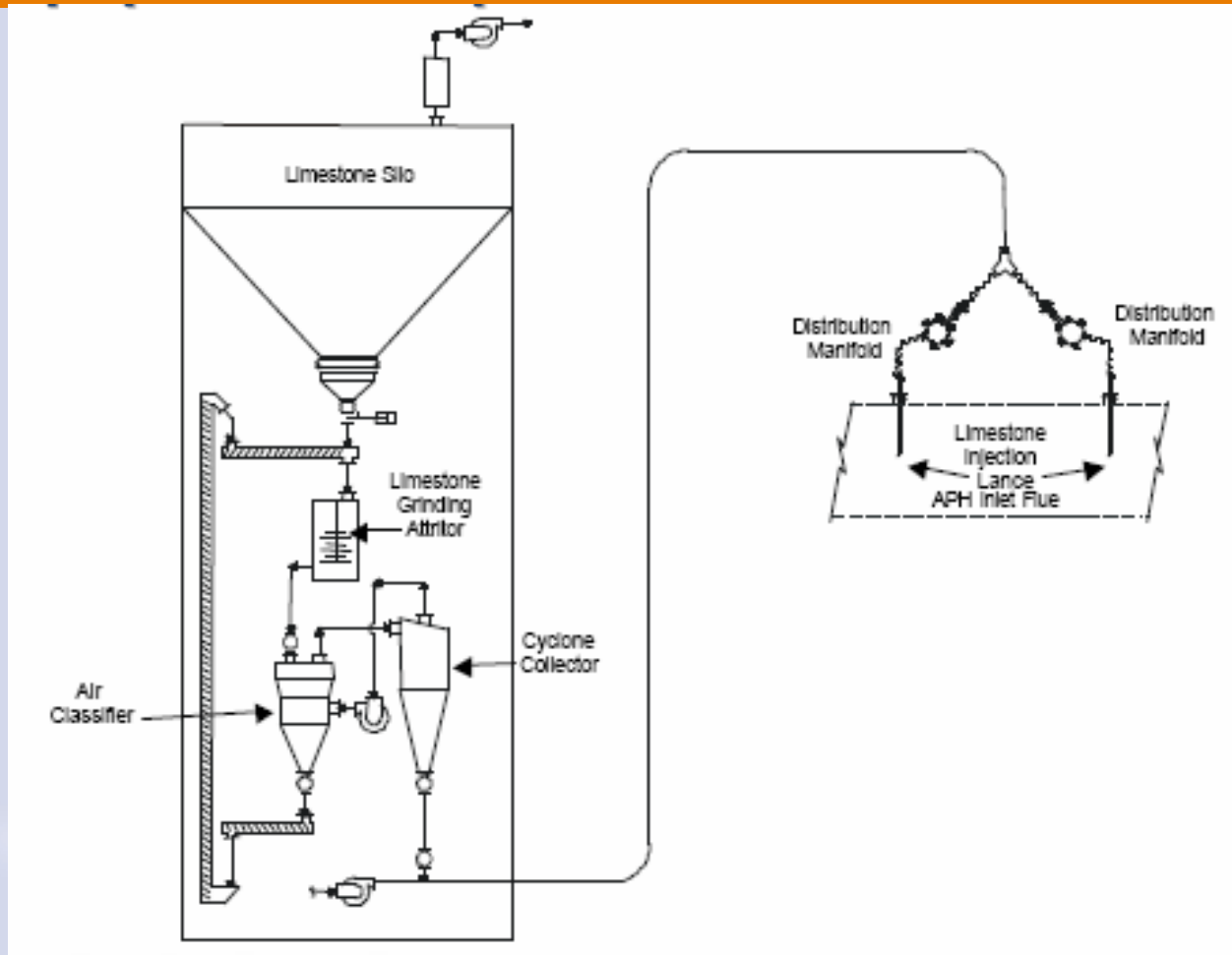
Unit 2 (with SBS)

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CleanStack™ Condensing Air Heater

- Developed by Marsulex, Alstom Air Preheater, UNDEERC
- Lower air heater exit temperature to condense sulfuric acid
- Add micronized (2-3 μm) limestone to provide surface area for acid condensation, neutralize

CleanStack™ Condensing Air Heater



Source: Bowes et al, 2006 Mega Symposium

CleanStack™ Condensing Air Heater

- Potentially significant heat rate benefits if air heater outlet temperature is lowered
- Possible benefits to Hg capture due to removal of SO₃, lower flue gas temperature
- However, only limited full-scale test results have been reported to date

CleanStack™ Condensing Air Heater – Short-term Test Results*

Limestone Injection Rate, lb/hr	0	500
Distance from APH Inlet, ft	93	93
Measured SO ₃ Concentration, ppmv	12-13	5-8
Approximate SO ₃ Removal Percentage	-	48
Estimated Limestone Injection Ratio, lb/hr/kacfm	0	0.8

*Based on data presented by Bowes, et al, 2006 Mega Symposium

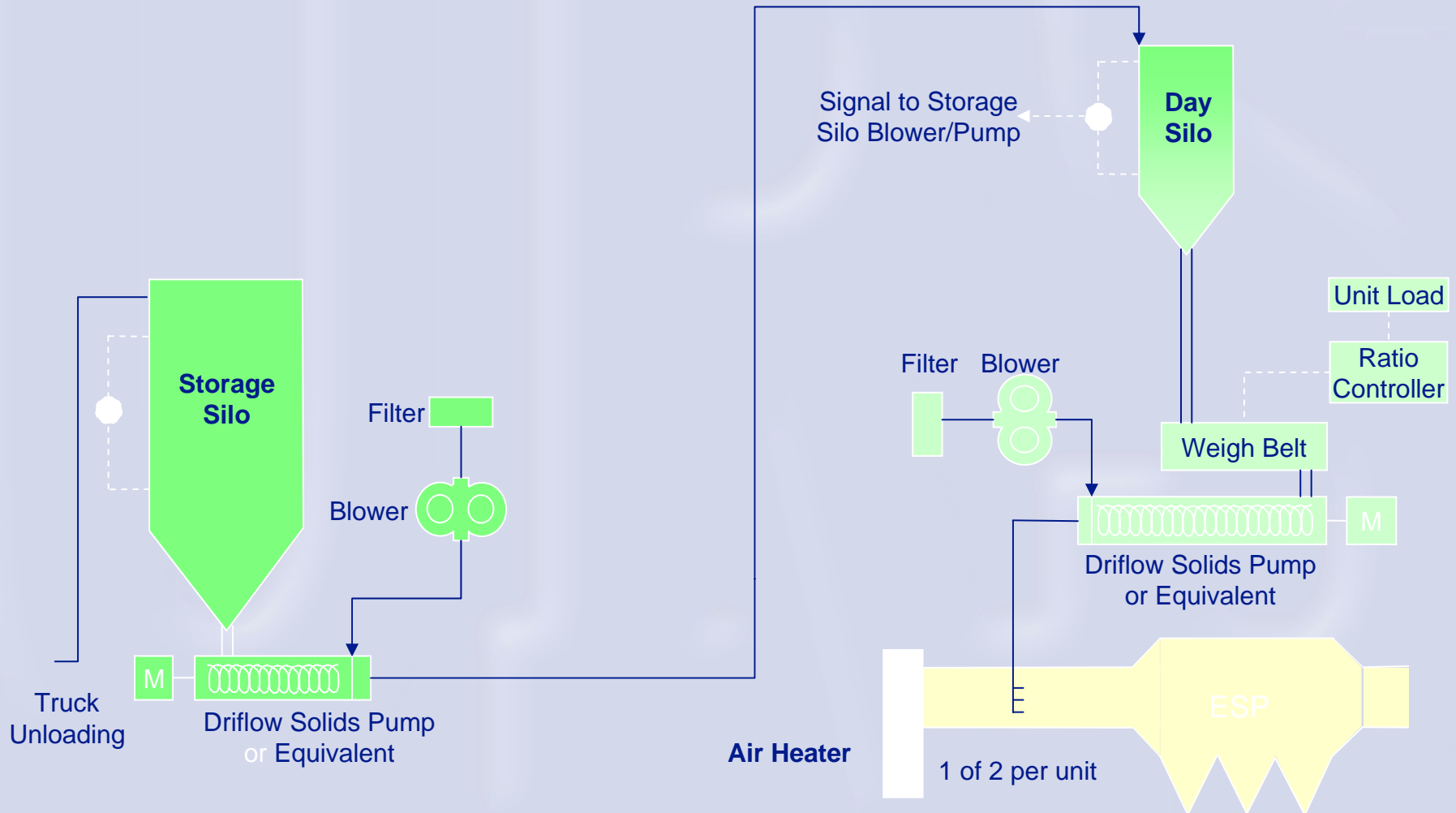
Ammonia Injection Downstream of Air Heater

- Ammonia is already available at SCR sites
- High SO₃ removal capability at ~stoichiometric injection rates
- Low capital and reagent costs
- Possible space charge effects on first field of ESP (addition of many small particles)
- Probable adverse effect on fly ash handling, disposal, reuse (odor, free ammonia in leachate, ammonia release at pH>7)

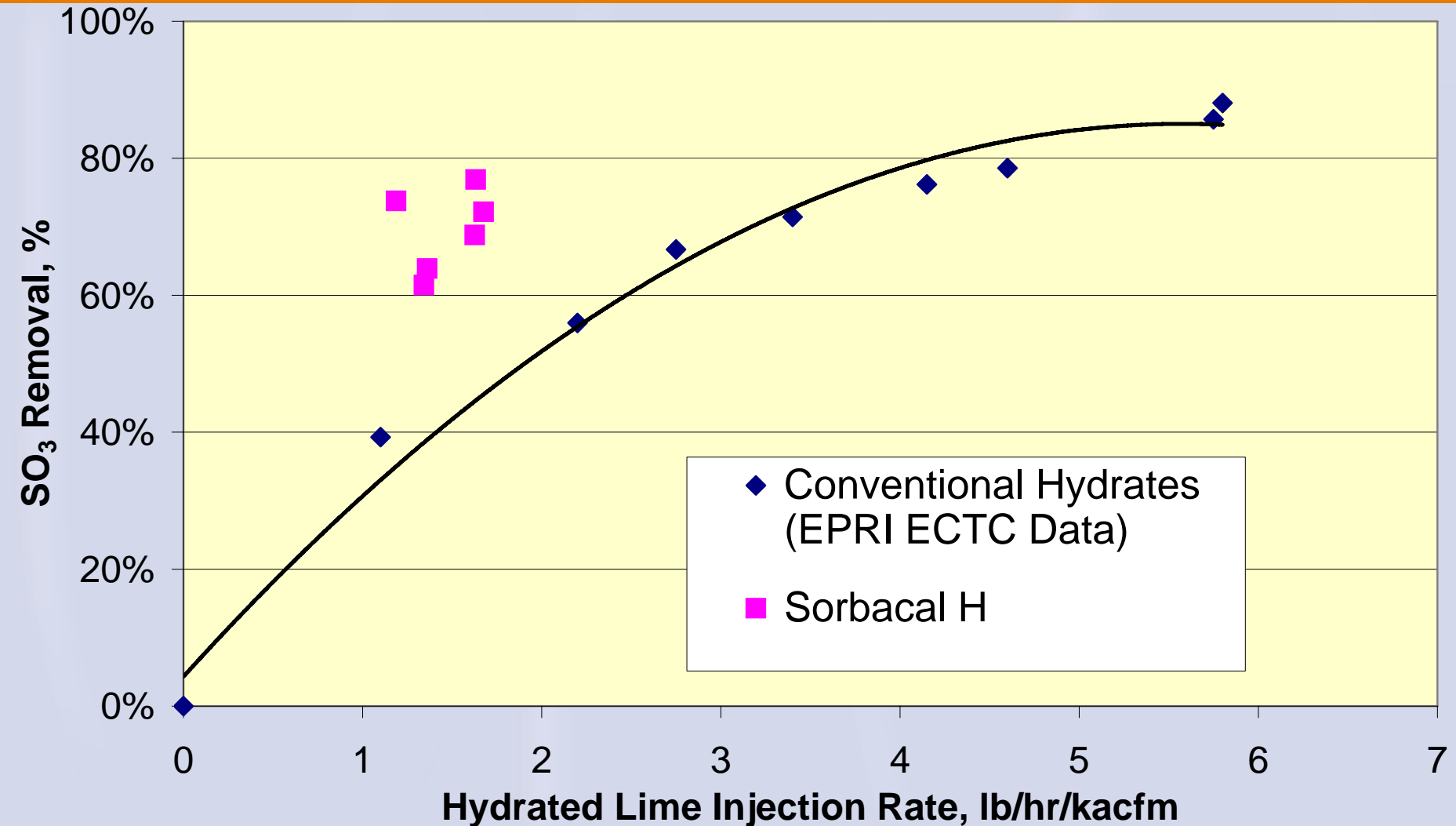
Hydrated Lime Powder Injection

- Traditionally injected downstream of air heater, but recent testing has combined injection upstream to improve effectiveness
- Potentially high sorbent injection rates to achieve high SO₃ removal percentages
 - High surface area, high pore volume hydrates (Chemical Lime) can reduce sorbent requirements, though
- Adverse effects on ESP at high control percentages (removal of SO₃ + addition of high resistivity material)
 - Advanced sorbents may reduce this effect

Example Process Flow Diagram for Hydrated Lime Injection Upstream of the ESP



Example Hydrated Lime Injection Data*

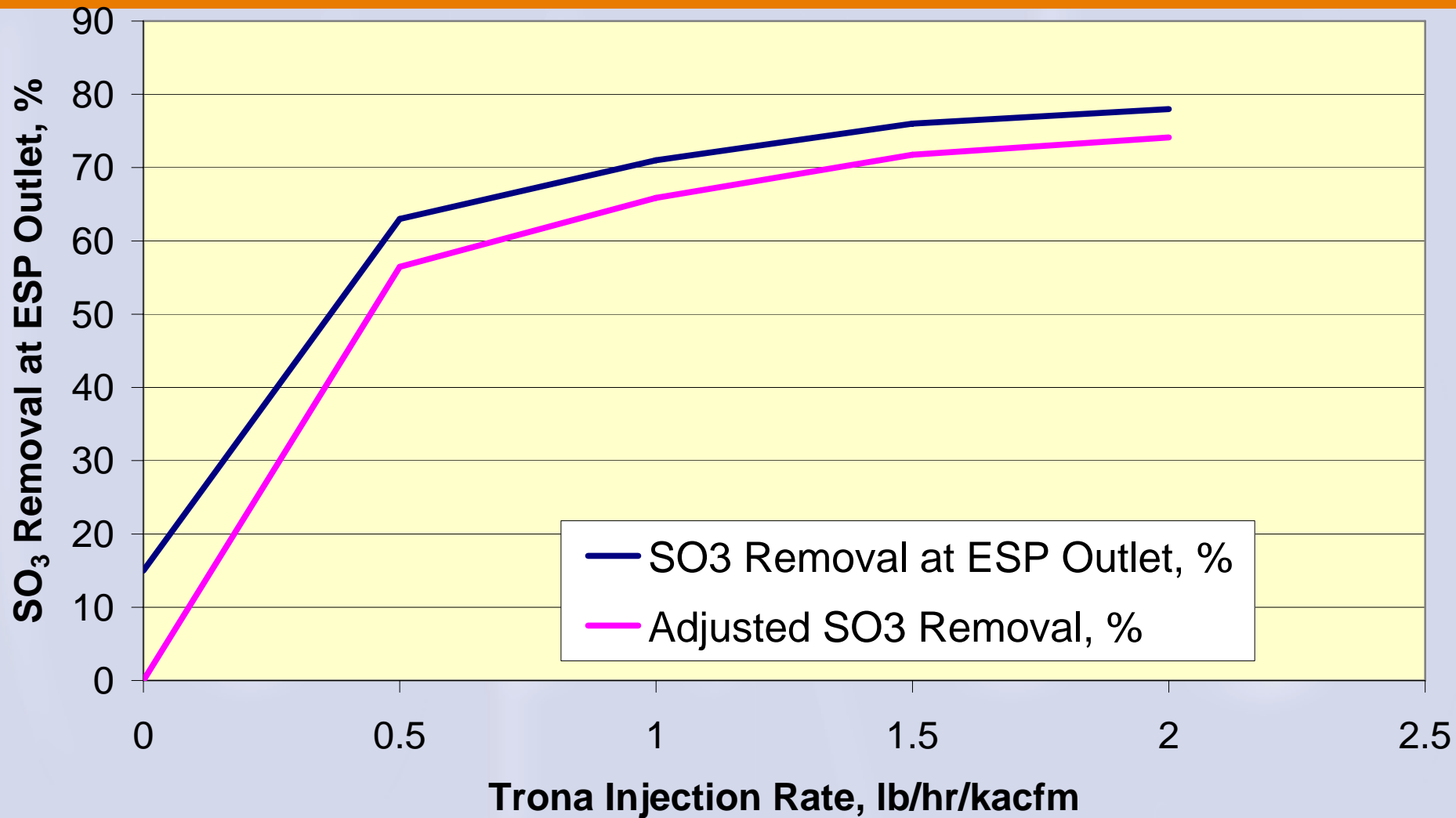


*Data source: Sorbacal H - Nolan et al, 2006 Mega Symposium; Conv. Hydrates – EPRI SO₃ Mitigation Guide, 1994

Trona Injection Downstream of Air Heater

- Trona is the raw material for sodium bicarbonate production, mined in Wyoming ($\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$)
- Process developed, patented by AEP (licensed to B&W, possibly others)
- Low injection rates for moderate removal, high injection rates to achieve high removal levels
- Temperature and moisture sensitive (handling properties, duct deposition)
- Can benefit ESP performance (lower resistivity)
- Can impact fly ash sales (increased Na content)

Example Trona Performance Data



Source: Ritzenthaler and Maziuk, 2004 Mega Symposium

Wet ESP Downstream of FGD Absorbers

- Higher capital cost (\$30 to \$70+/kW vs. \$5-\$10/kW for sorbent injection processes)
 - Development of polymer-based collecting membranes can lower cost
- Longer lead time, outage required to install
- No upstream benefits on SCR, air heater, baghouse, cold side corrosion
- Potential benefits from control of fine particulate emissions, stack spitting, Hg
- No impacts on fly ash or gypsum
- Not well demonstrated for high S coal, SCR, wet FGD combination

Estimated “Green Field” Cost for Wet FGD Integrated with FGD*

Design SO ₃ Removal, %	Number of Fields	Estimated Capital Cost, \$/kW
50	1	20
80	2	30
95	3	40

*Source: Staehle et al, 2003 Mega Symposium

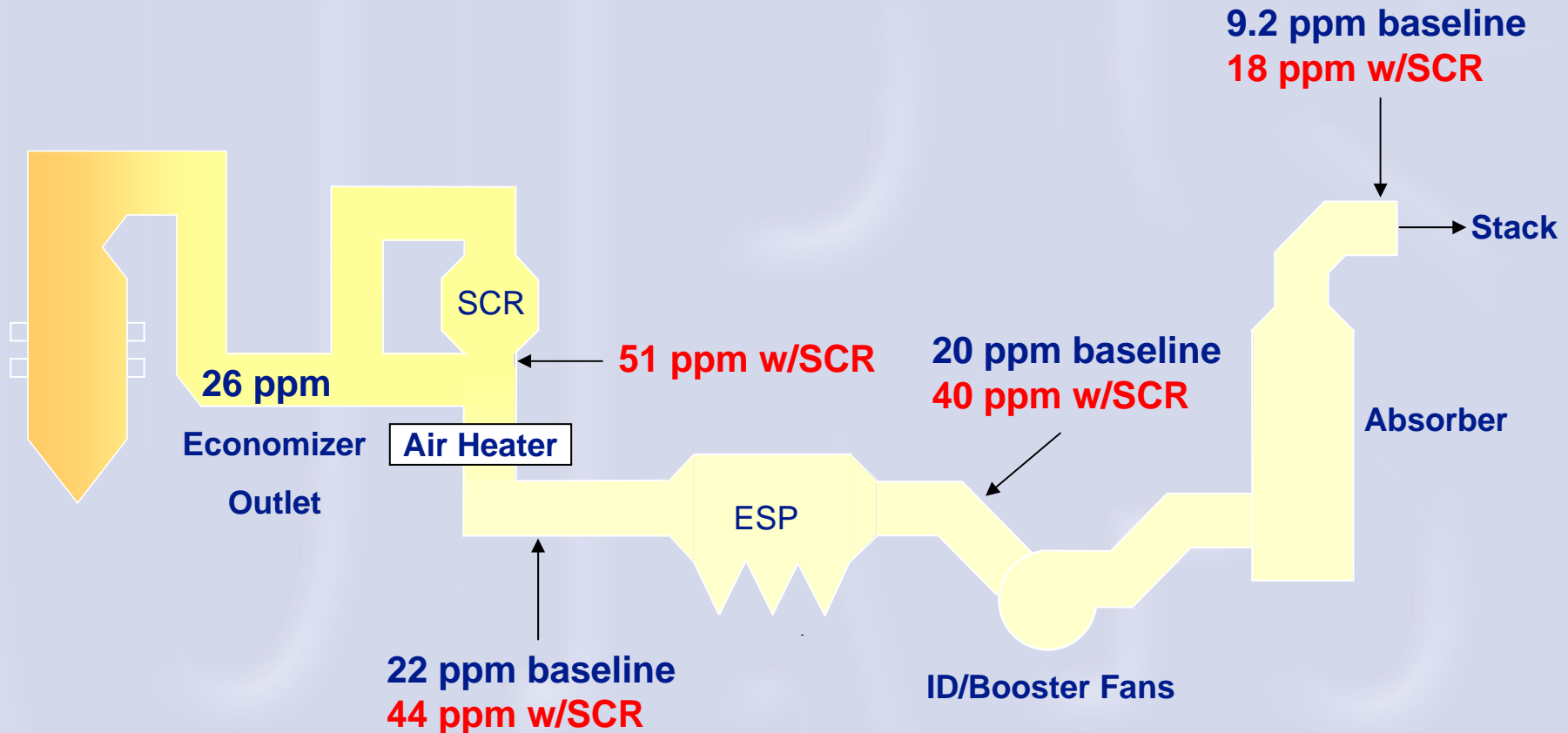
Assumes 6% Mo internals

Not escalated to 2007 alloy and construction costs

Example SO₃ Control Economics

- Hypothetical plant (high S coal, SCR retrofit)
- Data from literature used to estimate SO₃ control performance of technologies
- Material balance calculations used to estimate reagent and utilities consumption, size major equipment
- Capital cost estimates developed from factored estimates on major equipment purchase cost (except wet ESP, used \$/kW)

Example Plant SO₃ Concentrations - Before and After SCR Retrofit (1% SO₂ to SO₃ Conversion)



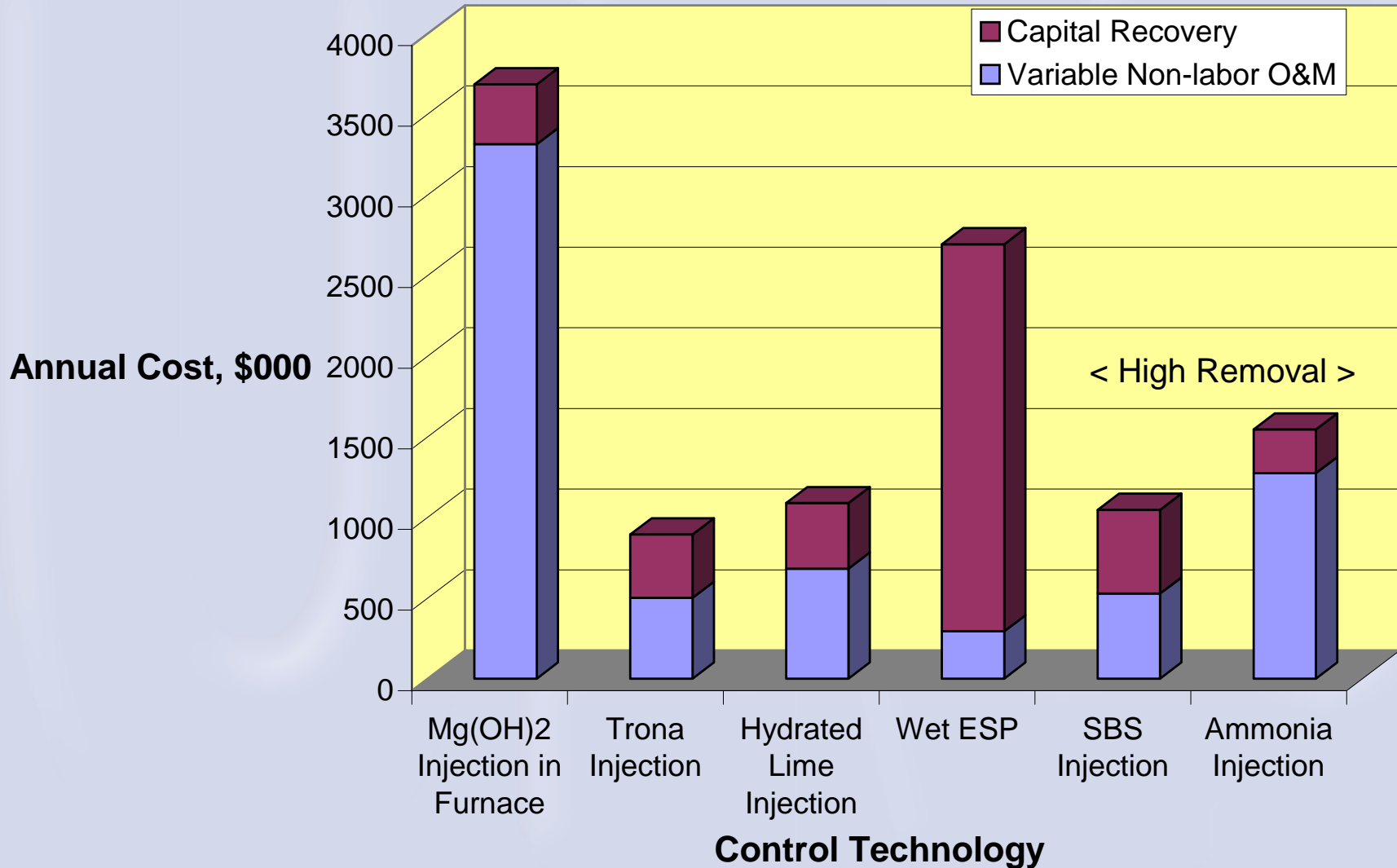
Example Plant for Comparing SO₃ Control Technologies

Parameter	Value
Unit Load (gross MW)	500
Gross Plant Heat Rate (Btu/hr/KW)	9200
Capacity Factor (%)	85
Flue Gas Flow Rate (acfm at economizer outlet)	2.07 x 10 ⁶
Coal Sulfur Content (%)	3.5
Flue Gas SO ₂ Content (ppmv wet at economizer outlet)	2790
NO _x Season Duration (months/yr)	12
Target Stack Sulfuric Acid Concentration (ppmv, dry basis):	
For lower SO ₃ removal percentage target	9.2 (50% removal)
For higher SO ₃ removal percentage target	4.0 (78% removal)

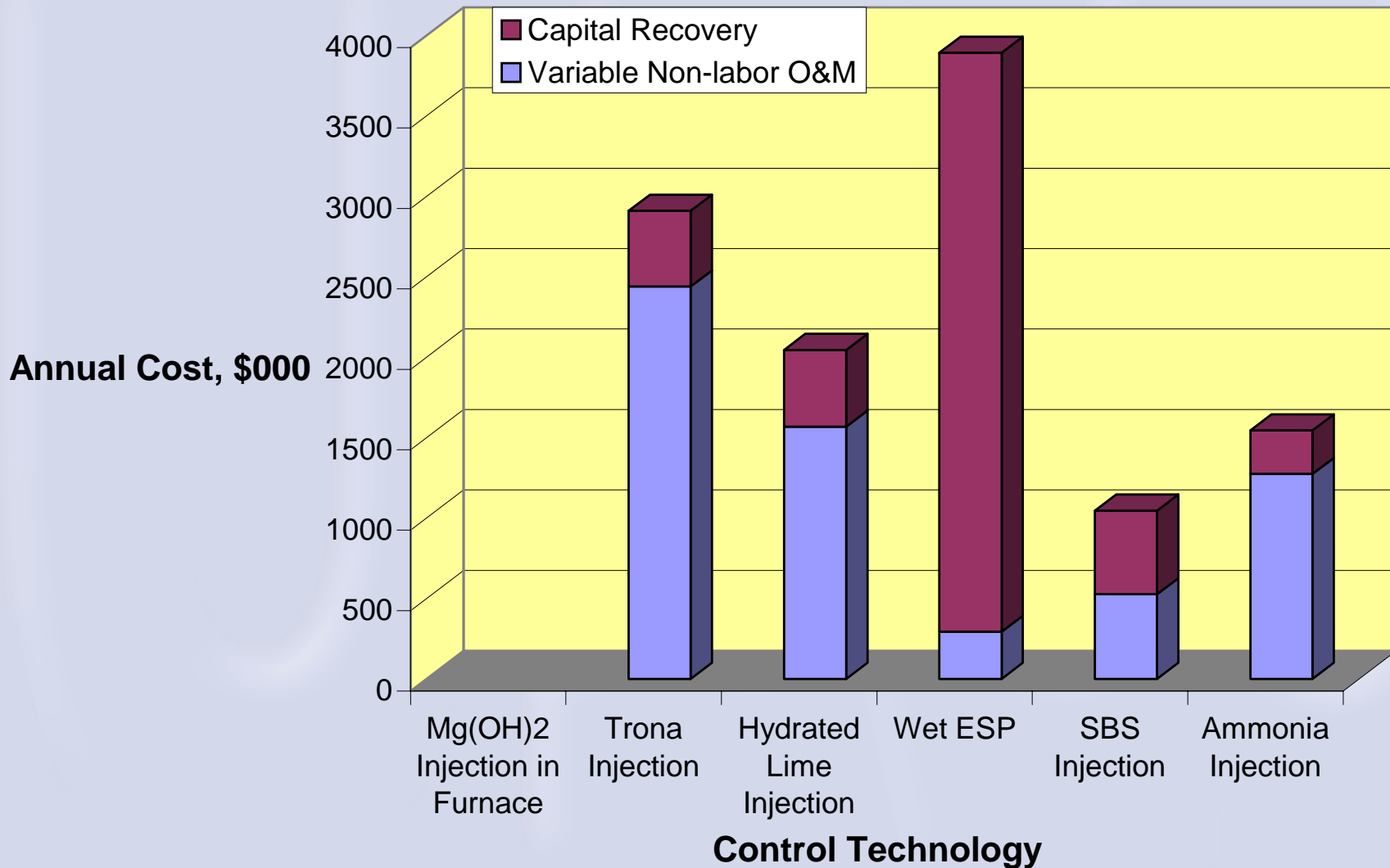
Cost Factors for Comparing SO₃ Control Technologies

Factor	Value Used
Trona, delivered (\$/ton)	150
Commercial Mg, delivered (\$/dry ton Mg(OH) ₂), shipped at 58 wt%	450
Sodium carbonate, delivered (\$/dry ton available Na as Na ₂ SO ₃)	250
Ammonia, delivered from existing plant system (\$/ton)	300
Hydrated Lime, delivered (\$/ton)	120
Truck Transit Costs (\$/ton-mile)	0.15
Plant Water Cost (\$/1000 gal)	0.40
Plant Softened Water Cost (\$/1000 gal)	2.30
Plant Auxiliary Power (\$/kwh)	0.05
Gypsum & Fly Ash Byproduct Values (\$/ton, f.o.b. plant)	5.00
Incremental Landfill Disposal Costs (\$/ton)	5.00

Cost Estimate Comparisons for SO₃ Control Technologies for 9 ppm Stack



Cost Estimate Comparisons for SO₃ Control Technologies for 4 ppm Stack



Conclusions

- Technologies are available to remove SO_3 /sulfuric acid from flue gas from coal firing, but:
- More full-scale results are needed to allow utilities to evaluate performance, cost, reliability, balance of plant impacts
- The technology of choice will likely be very site specific