REINHOLD ENVIRONMENTAL Ltd.

2014 APC Round Table & Expo Presentation

July 14-15, 2014, in Louisville, KY / Hosted by LG&E/KU

URS / Gore

Gore Mercury Control System (GMCS)

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July 15 2014

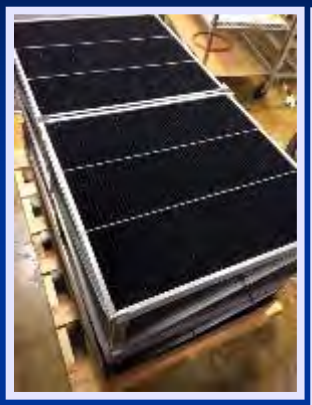
Outline

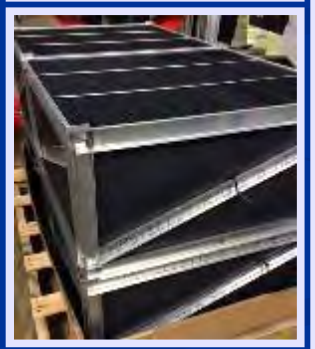
- GMCS Introduction / Overview
- Test Capabilities (Lab, Field)
- Commercial Systems
- Hybrid Systems

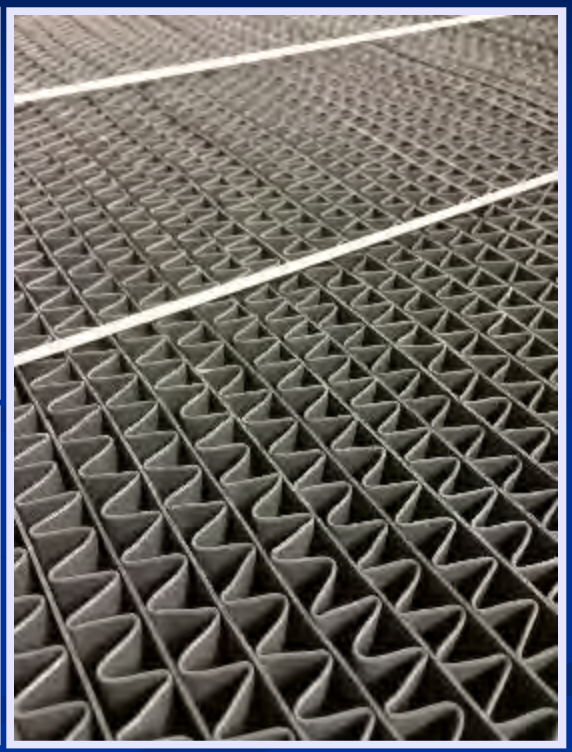
GORE™ Mercury Control System (GMCS)

Fixed Sorbent Technology

- Low pressure drop sorbent modules
  - ✓ No moving parts, no adjustments – simple, passive operation
- Able to operate on saturated gas streams containing acid gases
  - ✓ No gas pre-conditioning required
- Low Process Impact
  - ✓ No injection of sorbents or chemicals
- Continuous mercury capture
  - ✓ No regeneration required



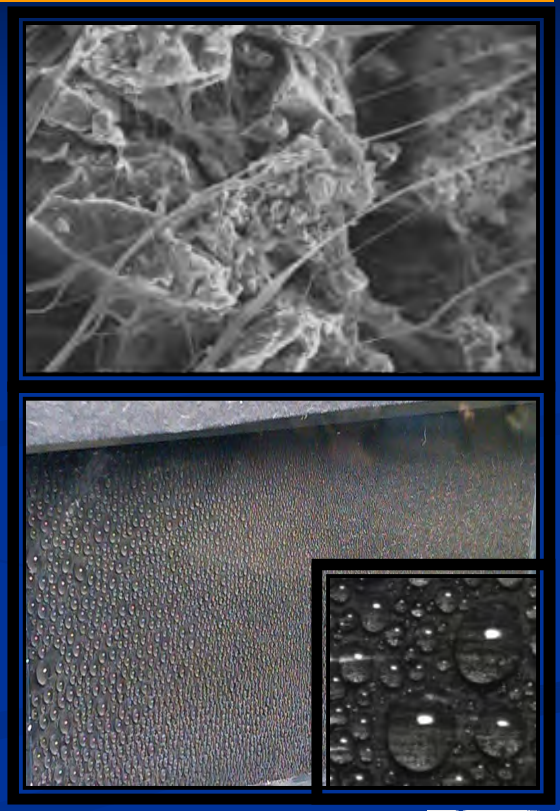




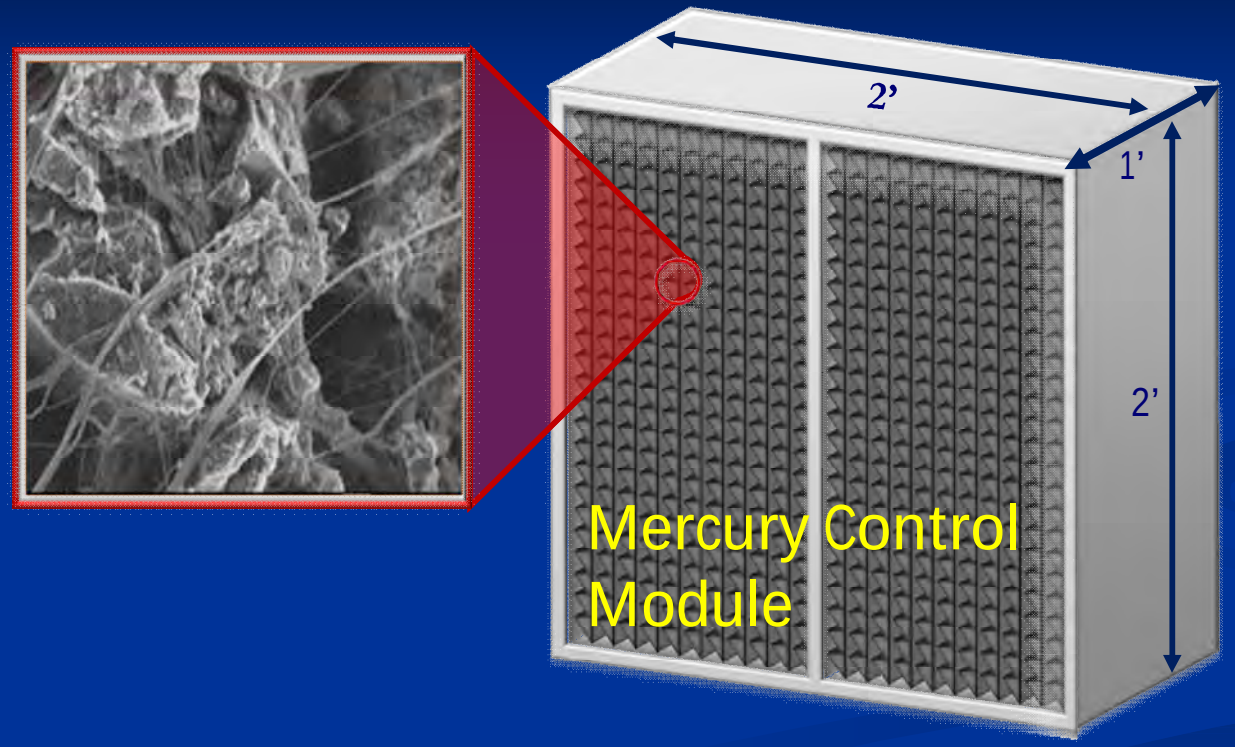
Sorbent Polymer Composite (SPC)

Unique Fluoropolymer Composite Material

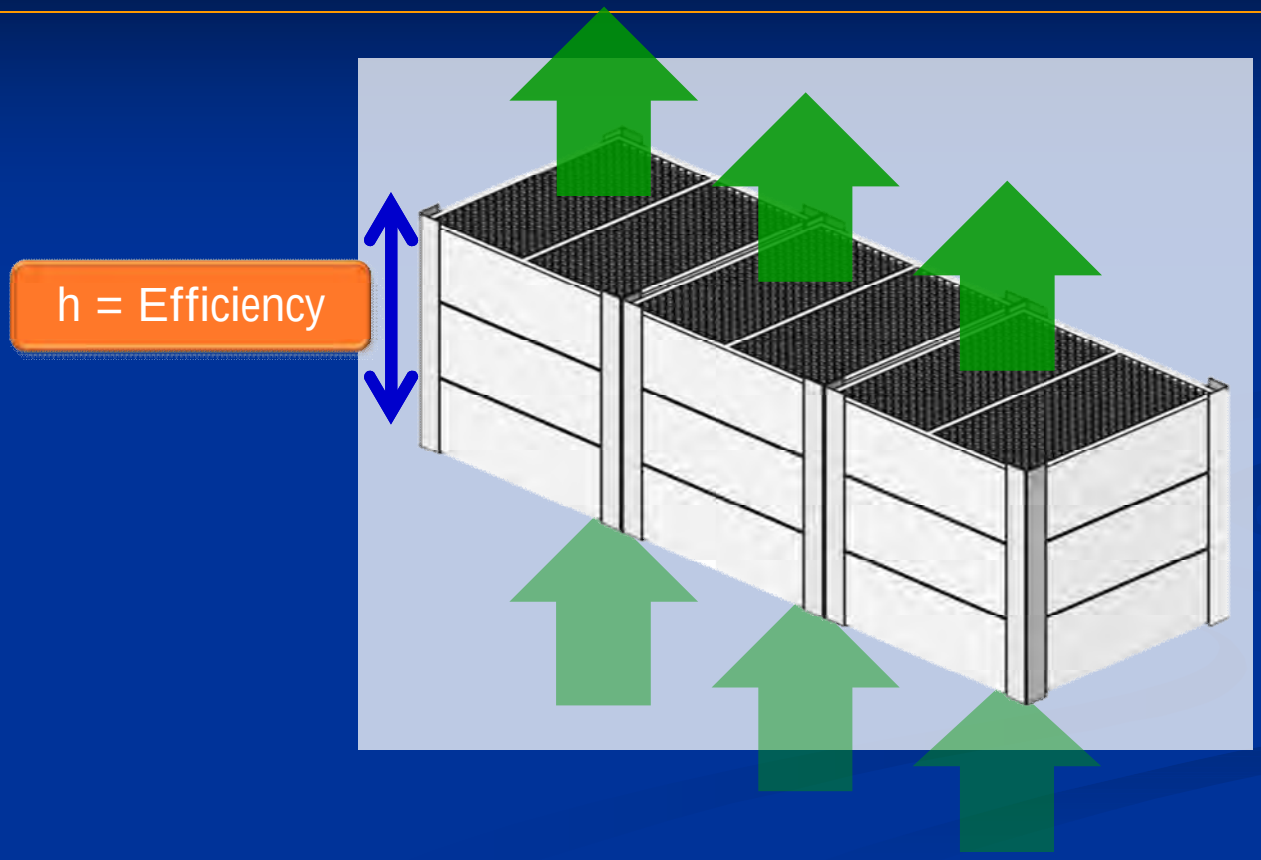
- Efficiently captures both elemental and oxidized mercury
- Very high capacity for mercury storage
  - Long module lifetime
- SO_2 is converted into sulfuric acid
  - SO_2 removal co-benefit
- Hydrophobic structure prevents “flooding” and expels acid to outer surface of SPC
  - Does not require regeneration



Sorbent Polymer Composite (SPC)



Mercury Control Modules



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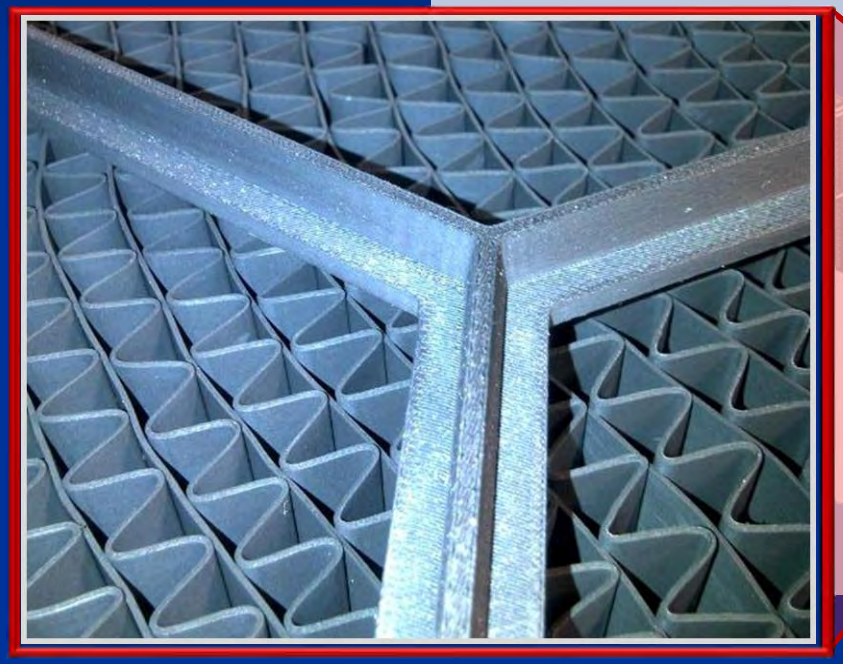
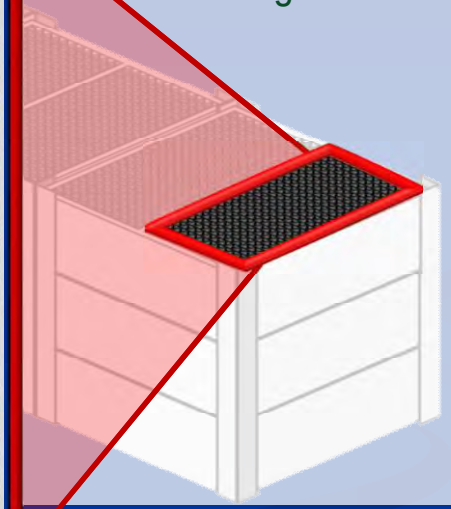
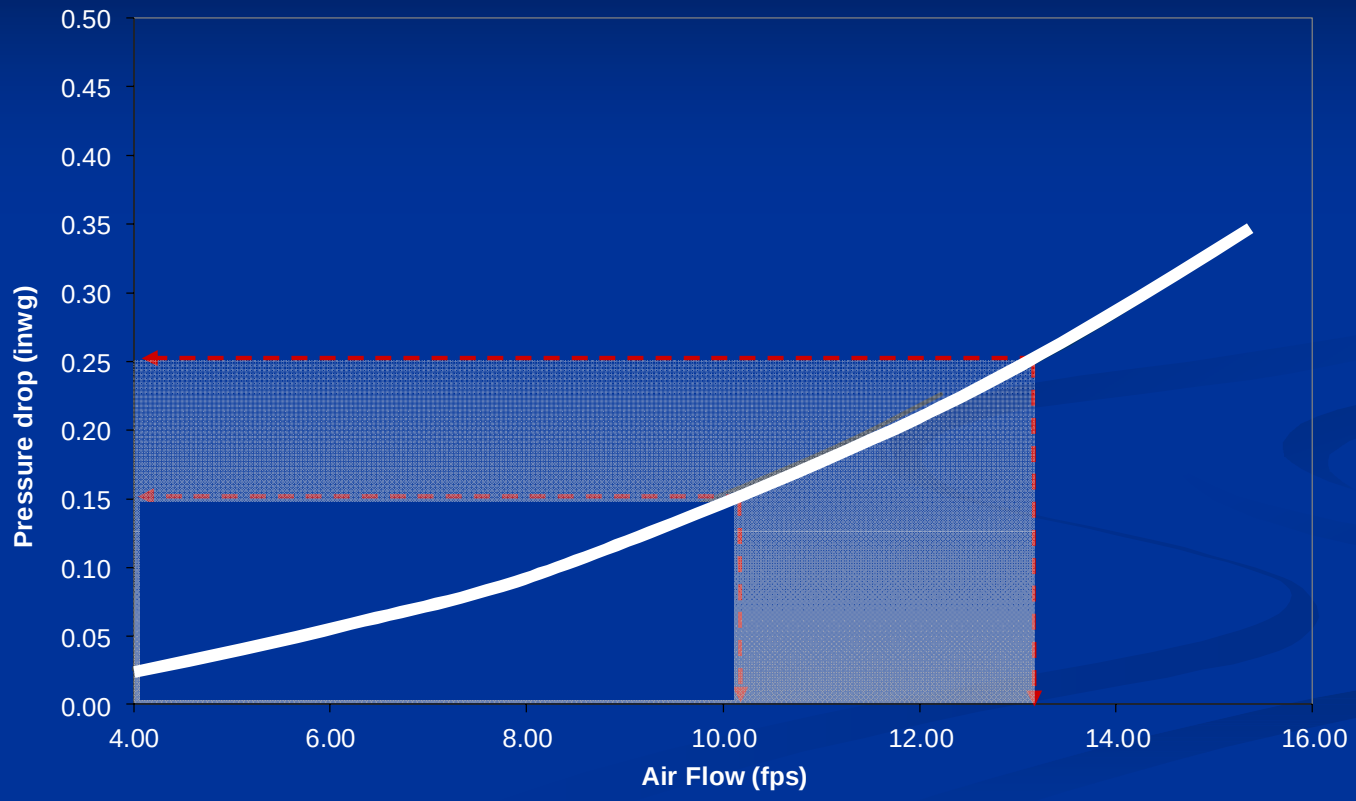


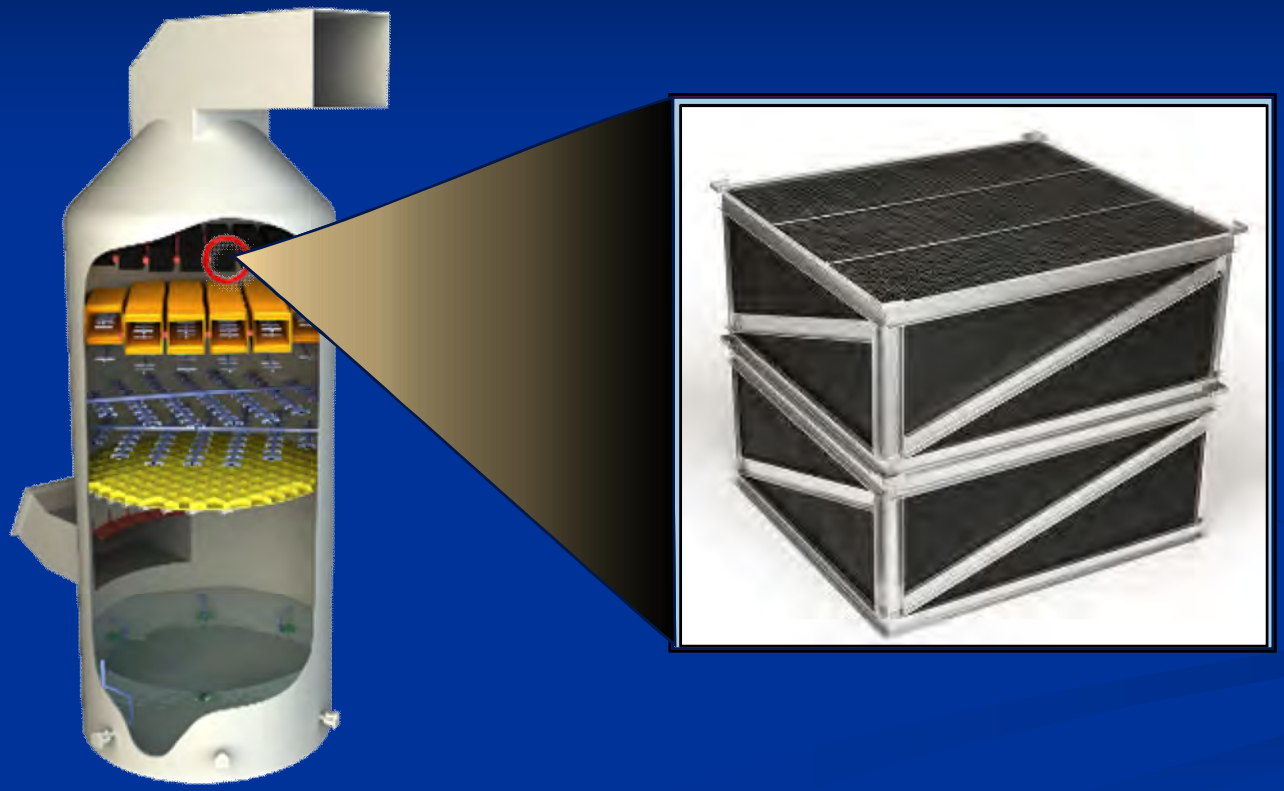
- Low Pressure Drop
- Fouling resistance



Pressure Drop Across Single Module

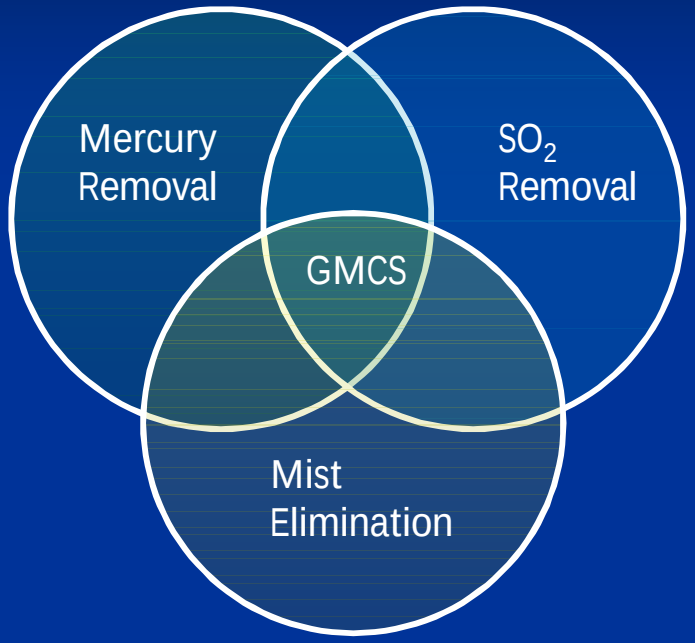


Installation in Wet Scrubber



"Zero-footprint"

Multi-pollutant Control System



Hg: Elemental and Oxidized mercury capture

SO_2: Additional SO_2 polishing

ME: Order of magnitude reduction in carryover

Where is GMCS the best fit?

- Plants that value ash sales
- Plants with high SO_3 levels
- Plants where ACI and/or Bromine are not highly effective
  - High injection rates required = high operating costs, potential for negative impacts on other equipment
- Plants that need both Hg and SO_2 reduction
- Plants with challenging re-emission problems
- Plants with variable speciation (i.e., coal variation, SCR catalyst aging)

Gore Mercury Control System

- Testing Capabilities

Establishing Test Capabilities

- Traditional approaches to mercury control have developed standardized, accepted test platforms
  - Refined over many years
  - Lab tests, pilot tests in field
- Gore Mercury Control Modules represent a new category of mercury control technology
  - New test methods had to be developed

Establishing Test Capabilities

$$	Small-Scale Lab Tests		X	X	X	X	X	X		
$	Material Characterization	X	X		X		X		X	X		
		2008	2009	2010	2011	2012	2013	2014	2015

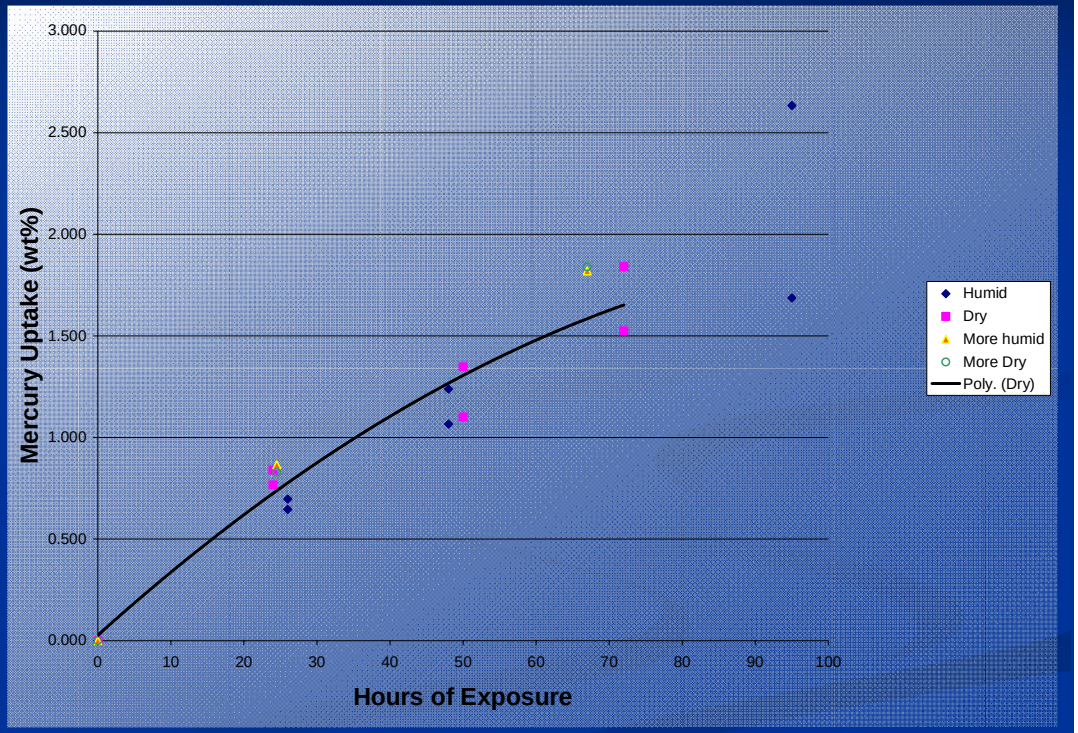
Evolution of Small Scale Lab Testing

Material Characterization (sorbents, composites)

Evolution of Small Scale Lab Testing

Material Characterization (sorbents, composites)

Low velocity, high Hg concentration flow over SPC disc, dry air



Evolution of Small Scale Lab Testing

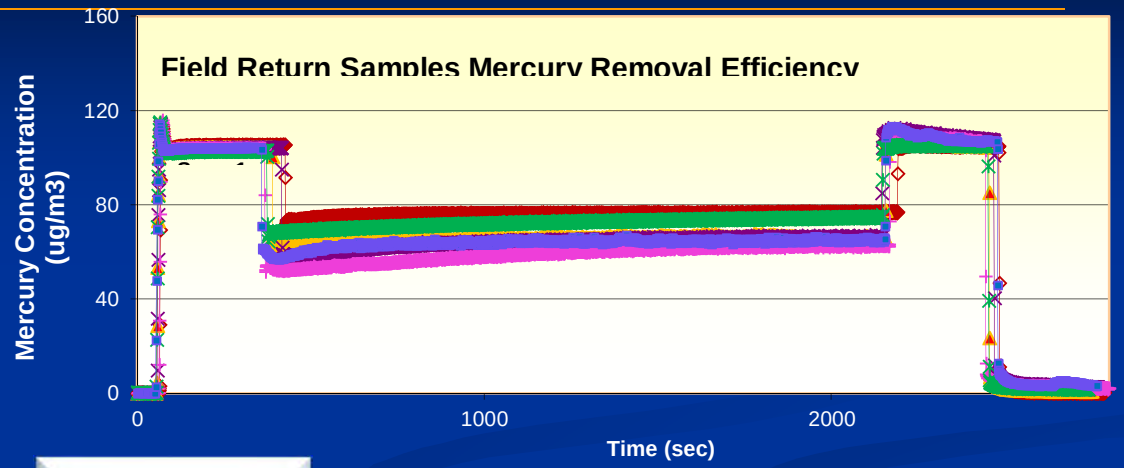
Material Characterization (sorbents, composites)

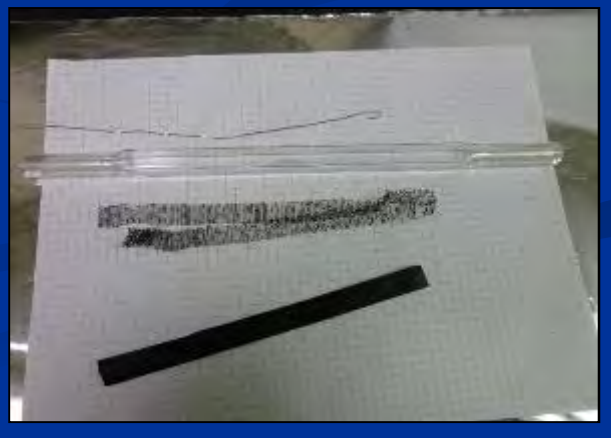
↓

Low velocity, high Hg concentration flow over SPC disc, dry air

↓

High velocity, lower Hg concentration flow over 6” long SPC flat strip → Add Humidity





Evolution of Small Scale Lab Testing

Material Characterization (sorbents, composites)

Low velocity, high Hg concentration flow over SPC disc, dry air

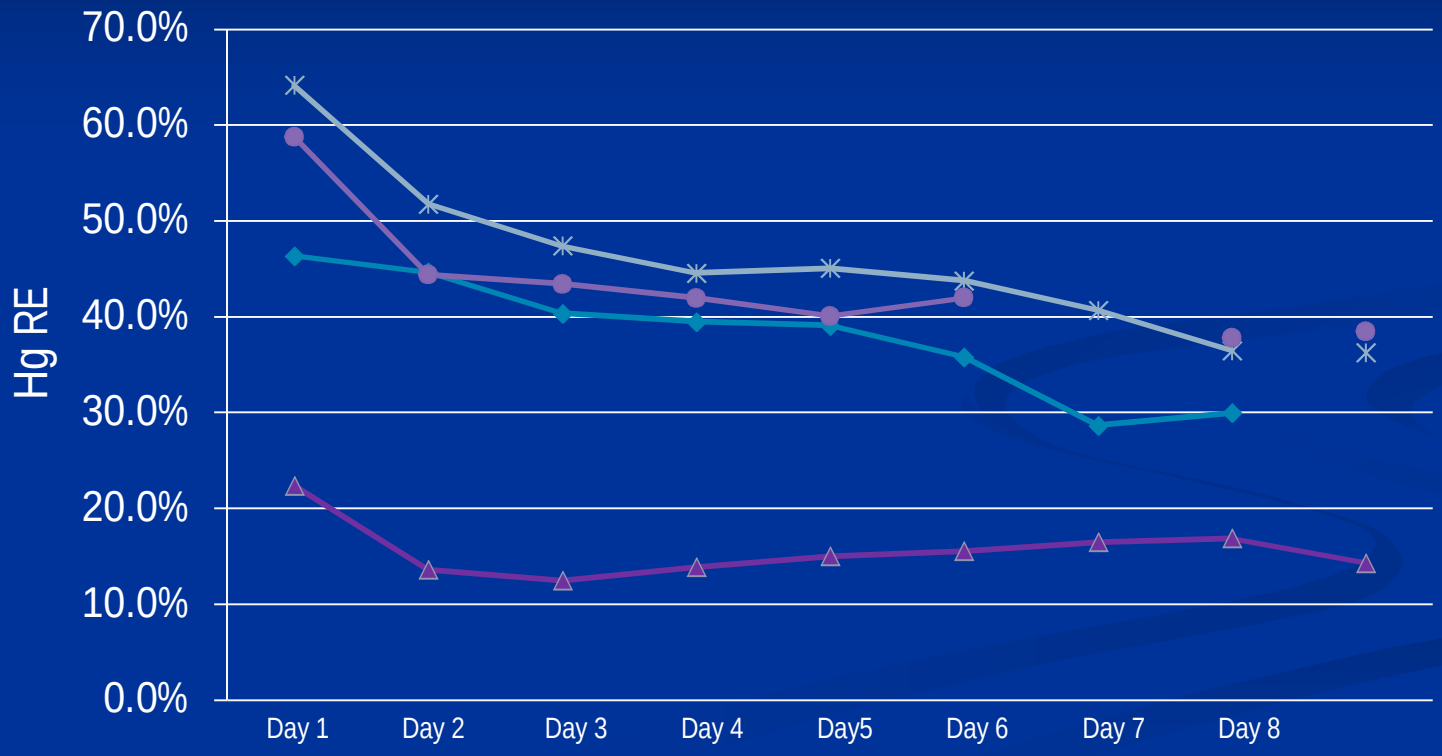
High velocity, lower Hg concentration flow over 6" long SPC flat strip → Add Humidity

High velocity, low Hg concentration flow through 12" long triangular channel → With Humidity and SO_2

Single Channel Test Fixture

Small Scale Single Channel Testing

12” long, triangular channel, upflow 10 fps, 60C, 90%RH, 20 ppm SO2, 10 µg/Nm^3 Hg



Establishing Test Capabilities

$$$$$	Full-Scale						X	X X	X X X X
$$	Small-Scale Lab Tests		X X	X	X	X	X		
$	Material Characterization	X X		X	X	X	X	X	
		2008	2009	2010	2011	2012	2013	2014	2015

URS

Full-Scale Installations

- Average Full-Scale Installation requires 2-4 modules / MW
  - Average scrubber size, at least several hundred MW

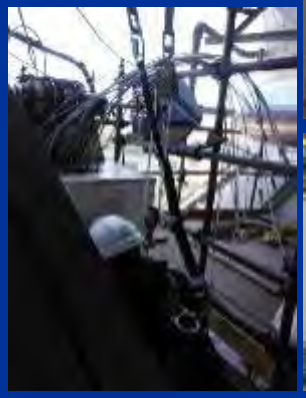
Establishing Test Capabilities

		2008	2009	2010	2011	2012	2013	2014	2015
$$$$$	Full-Scale						X	X X	X X X
$$$$	Slip-Stream Pilot		X	X X	X	X X	X X	X X	
$$	Small-Scale Lab Tests		X X	X	X	X	X		
$	Material Characterization	X X		X	X	X	X	X	

URS

Pilot Testing

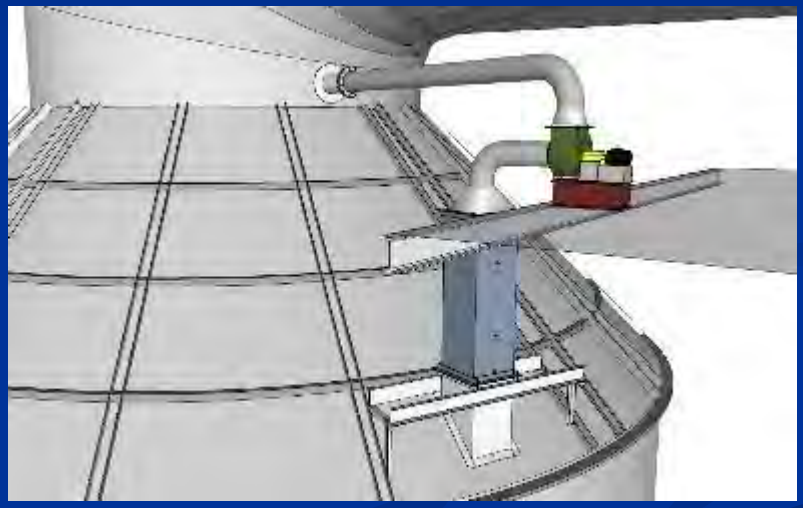
- Coal-Fired Power
  - 3 completed
  - 3 in progress
- Minerals/Metals
  - 5 completed
  - 1 starting soon
- Incinerators
  - 2 completed
  - 1 in progress



Pilot Test Approach

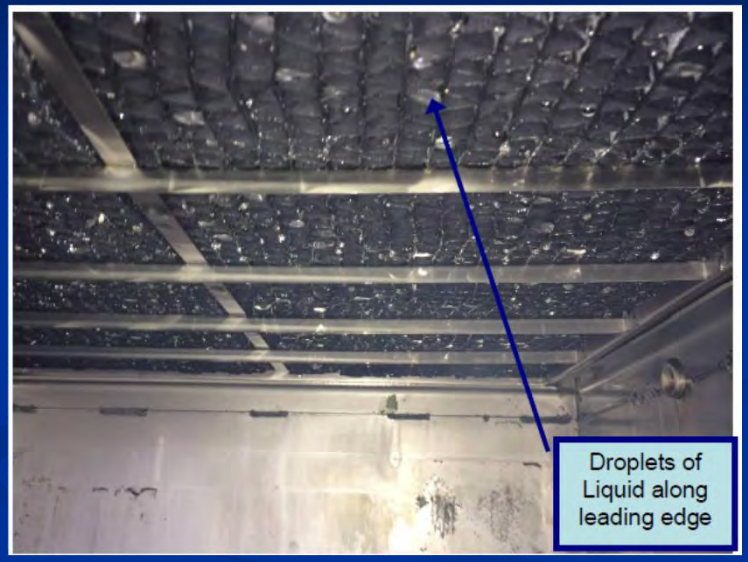
Coal-Fired Power, In-Scrubber Installations

- ~3000 acfm slip stream pulled from actual location where modules will be placed
  - Above the final stage of mist eliminators
- Single stack of full-size modules
  - 3-6 modules high
- External fan after modules used to pull air through modules
  - Velocity matched to that of final installation
- Mercury concentrations measured before and after module stack
  - Can also measure concentrations between modules



3000 acfm slip stream pilot

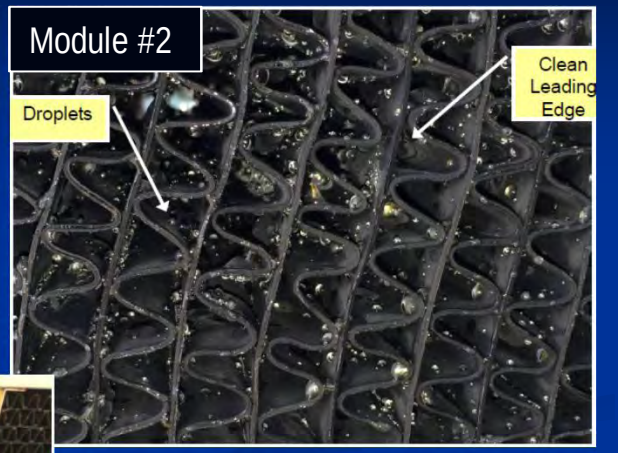
Anonymous site
Eastern Bituminous High Sulfur Coal

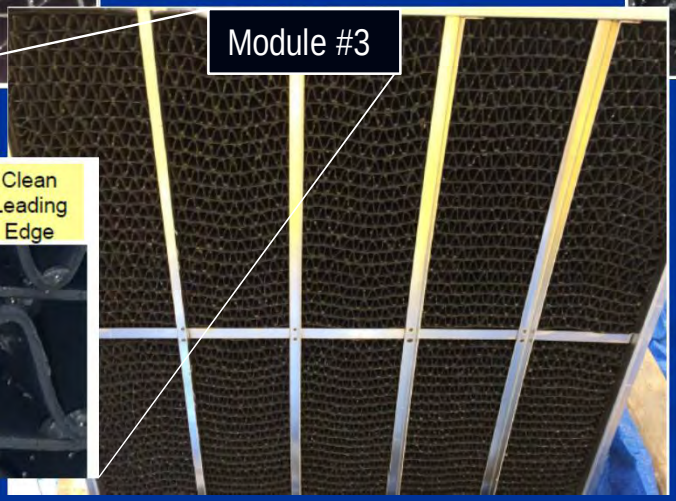


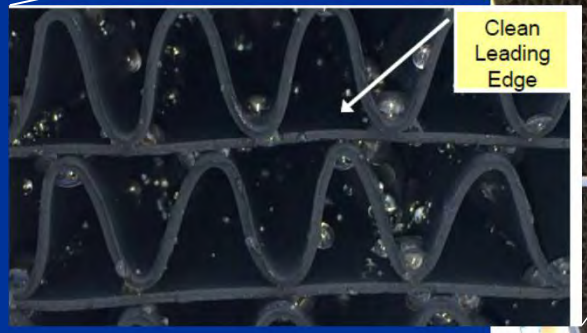
Modules in operation

Modules after 3 months of operation

Modules remain very clean
No build-up observed

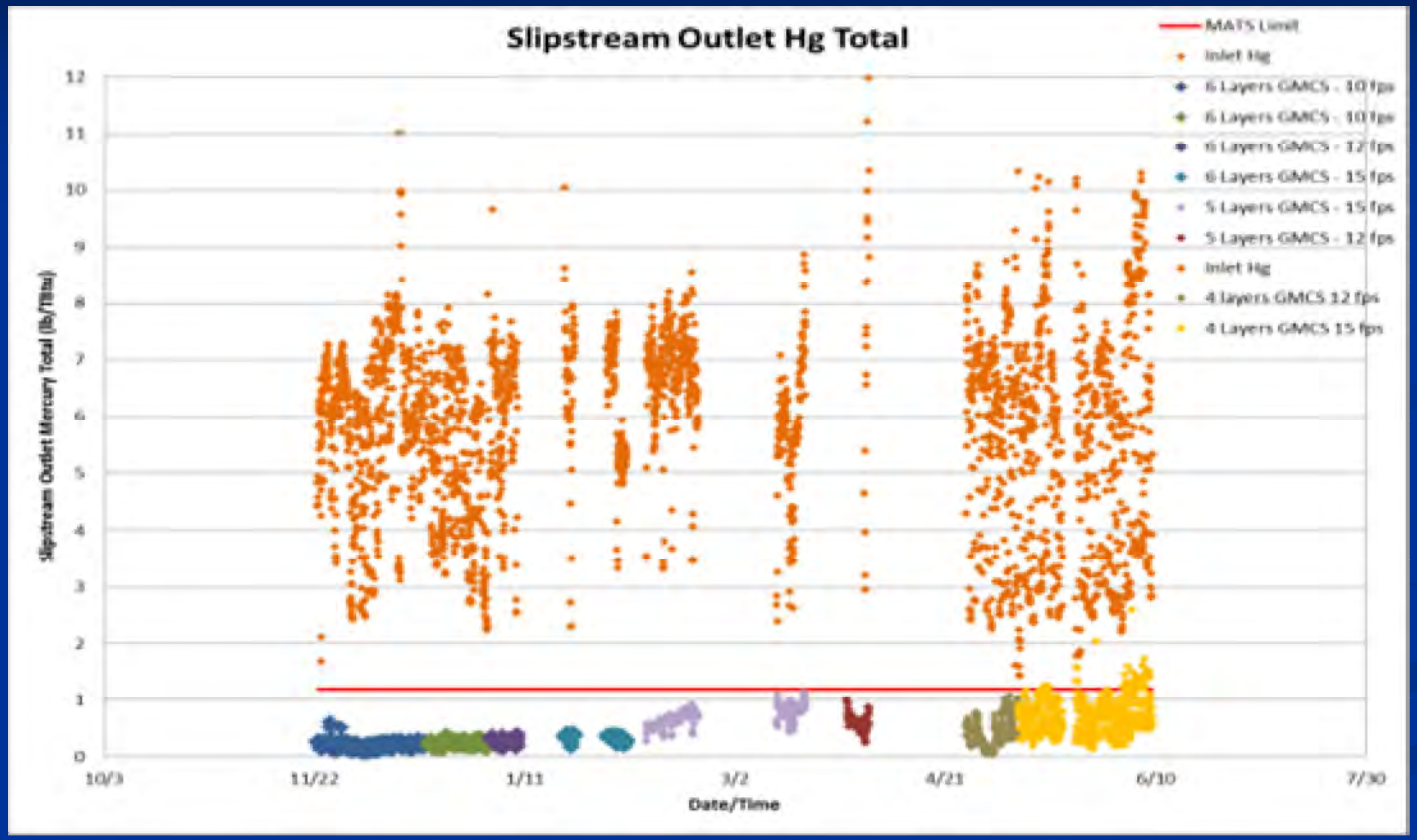






Slip-Stream Pilot Results

85-95% Hg removal efficiency across
4 – 6 modules at 10-15 fps



Pilot Testing Pros and Cons

- Pros:
  - Modules exposed to real-world conditions
    - Real flue gas, not simulated
    - Includes scrubber carryover, ash, potential catalyst poisons (?)
- Cons:
  - Can't change or control process conditions
  - Equipment fairly expensive ($300K+)
  - Challenging work environment

Establishing Test Capabilities

	2008	2009	2010	2011	2012	2013	2014	2015
$$$$$ Full-Scale						X	X X	X X X
$$$$ Slip-Stream Pilot		X	X X	X	X X	X X	X X	
$$$ Mini-module Lab Test						X		
$$ Small-Scale Lab Tests		X X	X	X	X	X		
$ Material Characterization	X X		X	X	X	X	X	

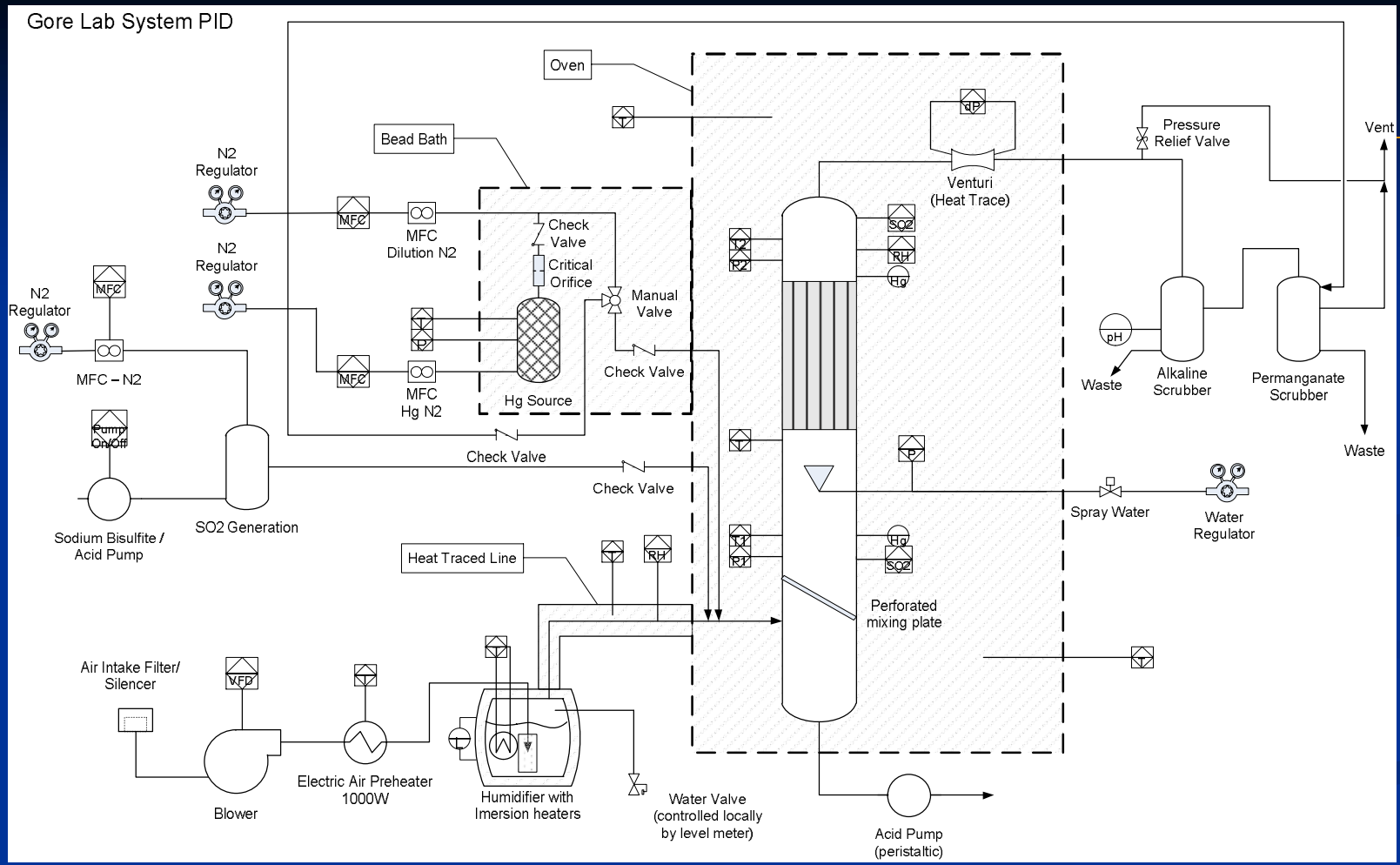
URS

New testing platform: Mini-Module Testing

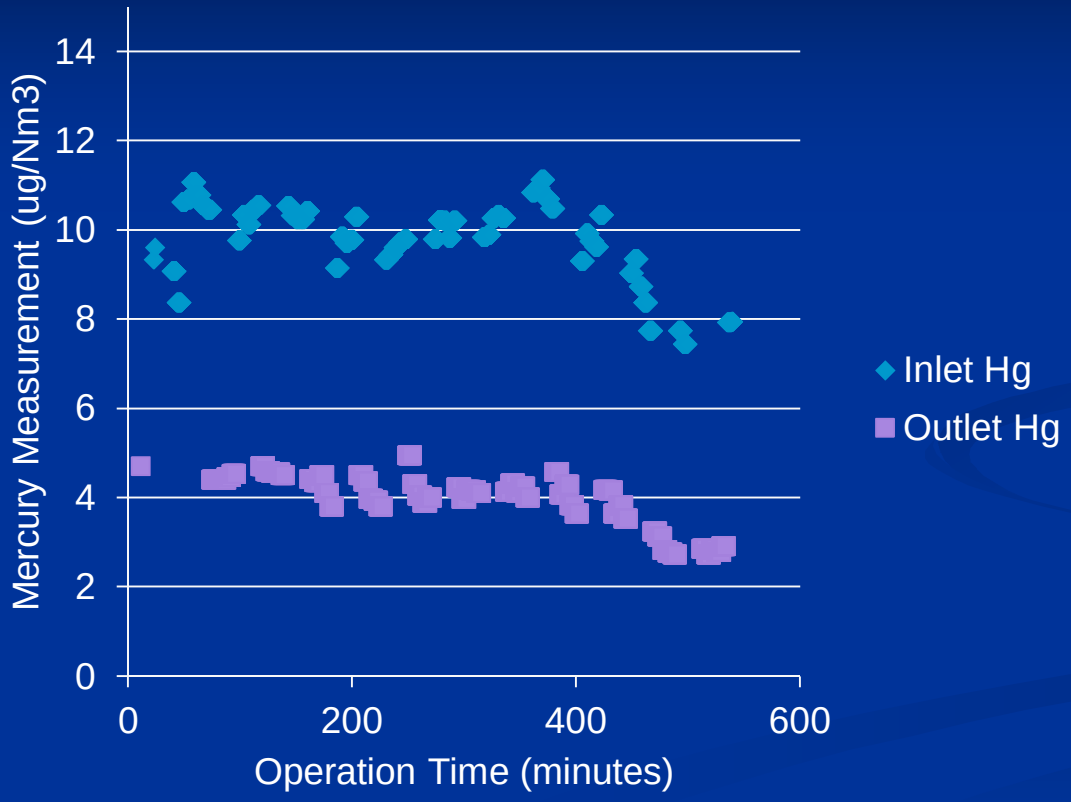
Collaboration between Gore and URS

- Located in URS labs (Austin, Texas)
- 2”x2” cross-sectional area, 12” high mini-module
  - Approximately 36 channels
- Up to 33 cfm flow rate
- Variables: [Hg], [SO_2], RH, flow rate (velocity)
- Glass module housing – allows visualization of acid generation mechanism
- On-line water spray (simulated washing)
- URS-designed mercury generator, SO2 generator, and effluent treatment systems

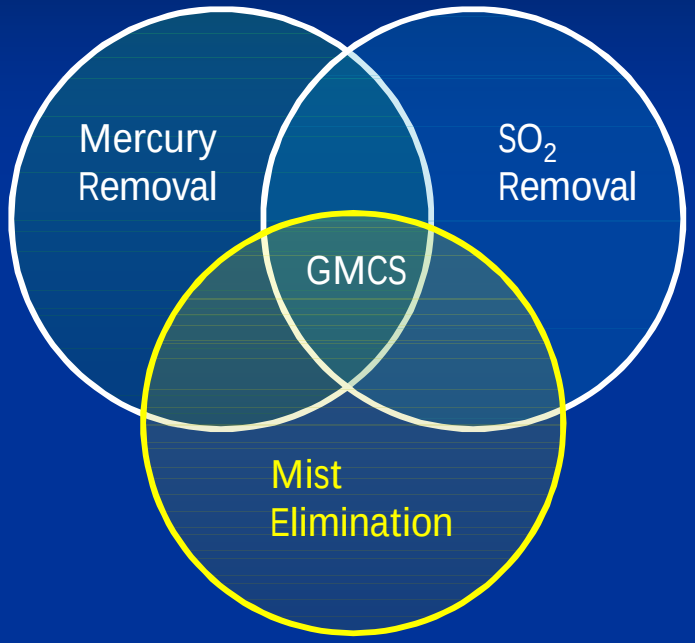
Gore Lab System PID



Example of data from Mini-Module Testing



Mist Elimination Co-Benefit

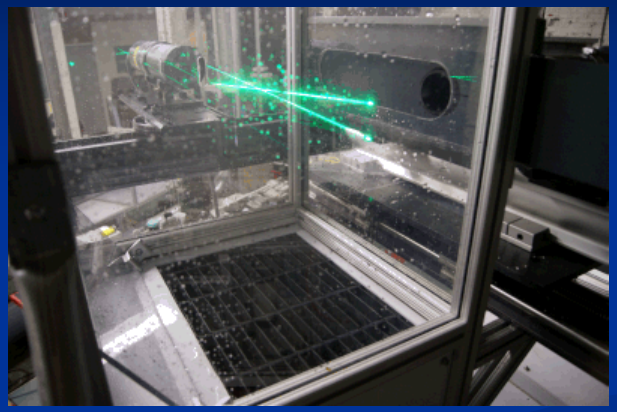


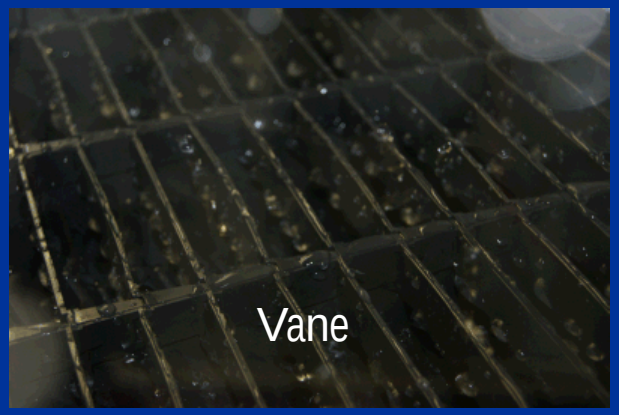
Hg: Elemental and Oxidized mercury capture

SO_2: Additional SO_2 polishing

ME: Order of magnitude reduction in carryover

Measuring Droplets in Lab with Phase Doppler Particle Analyzer (PDPA)





Droplet Collection Efficiency by PDPA

Commercial Vane Mist Eliminator (6 inch)

Ave Efficiency	U=3 fps	U=5 fps	U=10 fps	U=15 fps	U=20 fps
0-10 μm	68.4%	55.3%	66.7%	81.4%	75.1%
0-20 μm	70.9%	68.1%	79.1%	89.1%	86.3%

Gore Modules (30 inch)

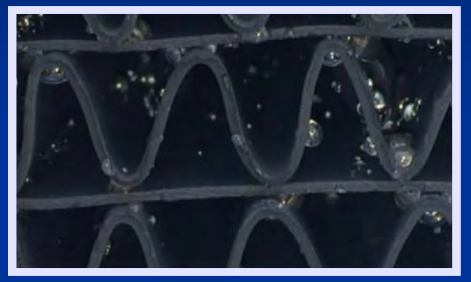
Ave Efficiency	U=3 fps	U=5 fps	U=10 fps	U=15 fps	U=20 fps
0-10 μm	42.7%	75.5%	81.3%	88.8%	95.5%
0-20 μm	66.3%	85.7%	90.0%	93%	96.7%

Mist Elimination Co-Benefit

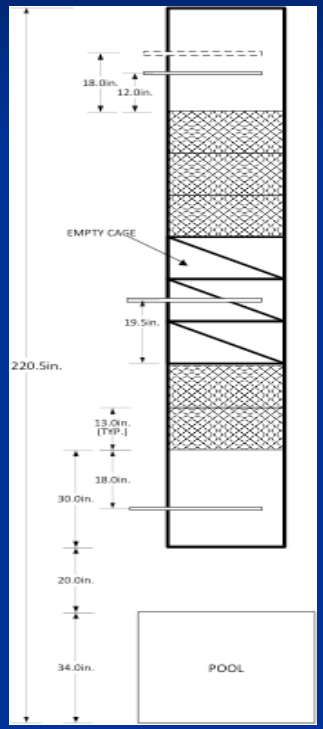
- SRI was contracted to measure liquid carryover before and after the Gore modules in a slipstream pilot
  - 5 modules installed for this test
- Video Droplet Analyzer (VDA) utilized
- Accurately detects droplets down to 80 microns in size
  - Some ability to detect down to 20 microns
- Testing showed on average an order of magnitude reduction across GMCS (grains/ft^3)
- Testing done both with ME wash active and inactive
  - Outlet of GMCS showed comparable liquid levels in both cases
  - GMCS performance was not affected

Ash and Carryover Impacts on Modules

- Two mechanisms available to keep modules clean
  1. SO_2 in flue gas → sulfuric acid generation
     - Self-cleaning mechanism
  2. Wash system installed below/above modules
     - Periodic spray of water into modules
- SO_2 concentration is not really a variable we can control
- Gore/URS are studying improved wash systems for sites that have high PM and/or low SO_2 concentrations



Wash Testing at Alden Research Lab



Commercial Installations

Anonymous Site A Unit 1, Startup May 2014

Anonymous Site A Unit 2, Startup Fall 2015

Site A: Design Overview

- Single tower
- 1,200 / 2000 Gore Modules (3 / 5 layers)
- Number of Layers
  - 3 initially
  - 5 if needed
- Design inlet Hg 4.5 lb/TBtu
- Guarantee 1.0 lb/TBtu
- Started operation early June 2014
- Encouraging performance, guarantee testing shortly

Scope of Work

- SOW
  - Turnkey firm fixed price EPC with guarantees
  - Demolition of existing mist eliminator and supports
  - New Munters two-stage, two pass mist eliminator on one support level with wash headers
  - Gore system structural supports
  - Gore system wash headers
  - Gore modules
  - Absorber lining

Materials of Construction

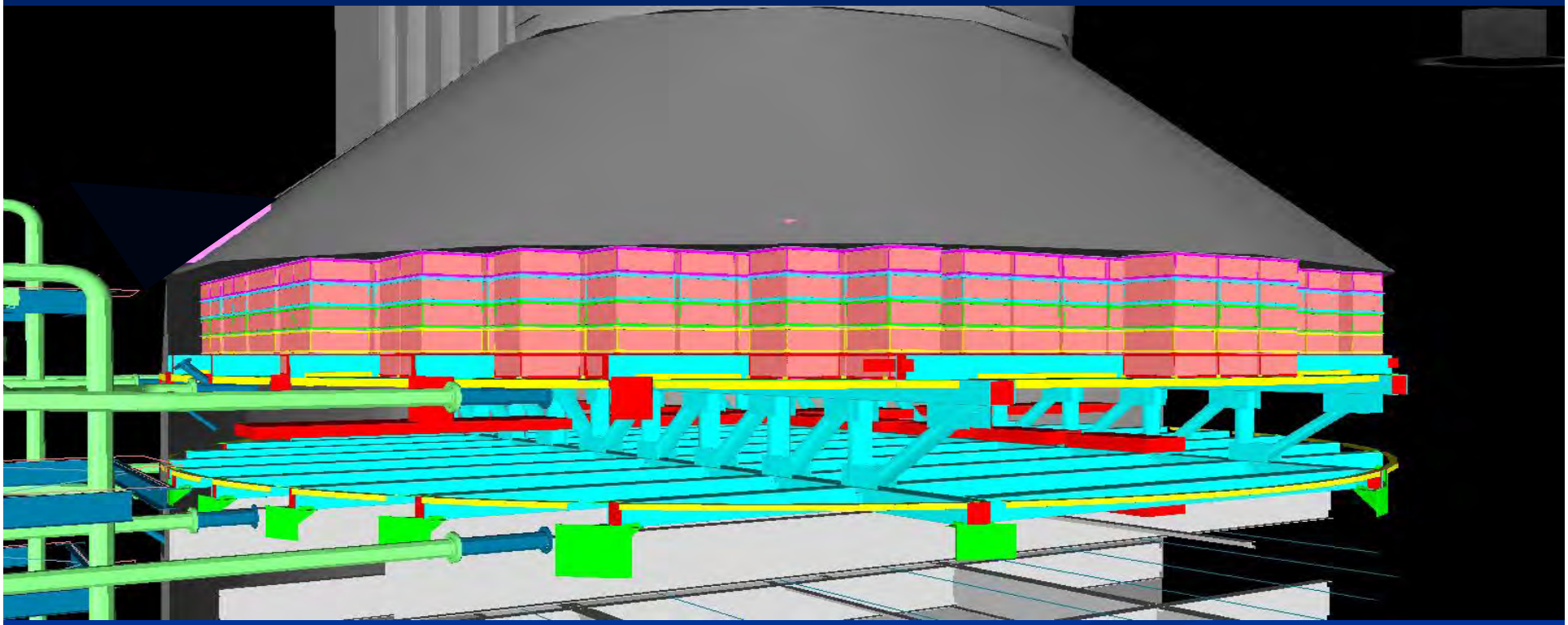
Item	Material
ME Wash Headers	FRP
ME Wash Nozzles	Polysulfone
ME vanes	Polysulfone
ME structure	Polypropylene
Gore Module Structural Support	C-276
Absorber liner	Blome Flakeglass
Gore Module Cage	C-276
Gore Material	SPC Gen 1.5
Gore Wash Header	FRP
Gore Wash Nozzles	Polysulfone

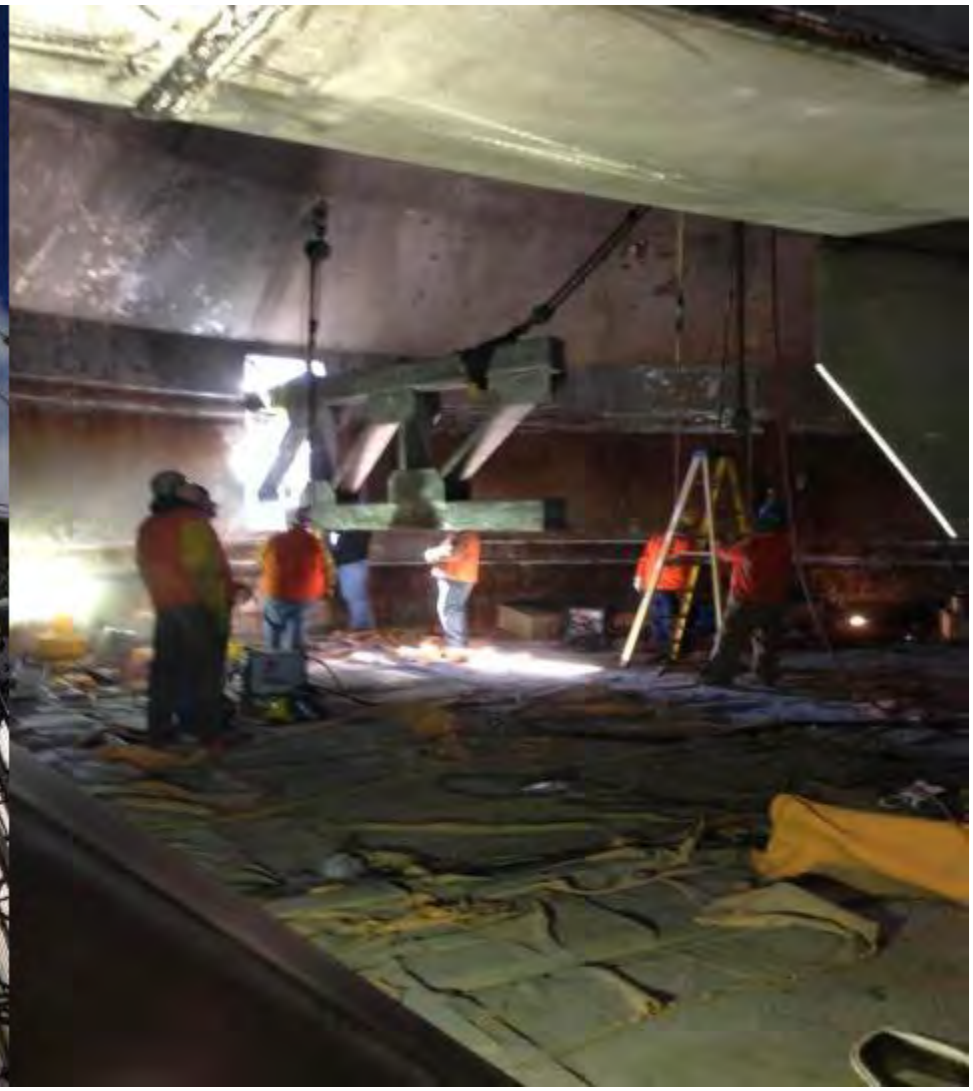
Construction

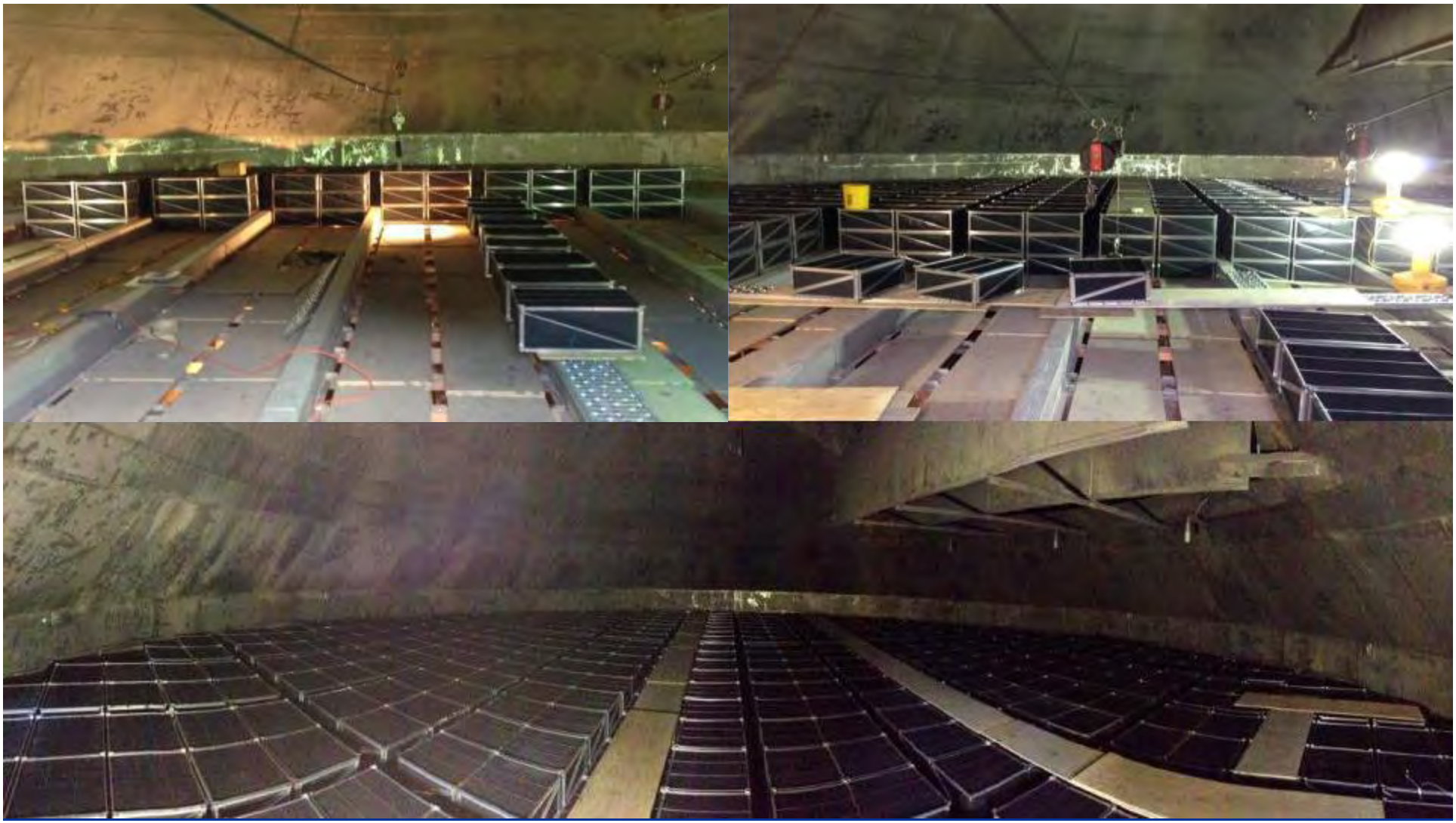
- 4-Week Outage
  - Ahead of schedule
  - Below budget
  - Zero recordable injuries
  - Zero safety incidence
  - Zero change orders
- Construction subcontracted to Bowen Engineering, a URS partner

Elevation – Structural Support, ME and GMCM

GMCS Layout



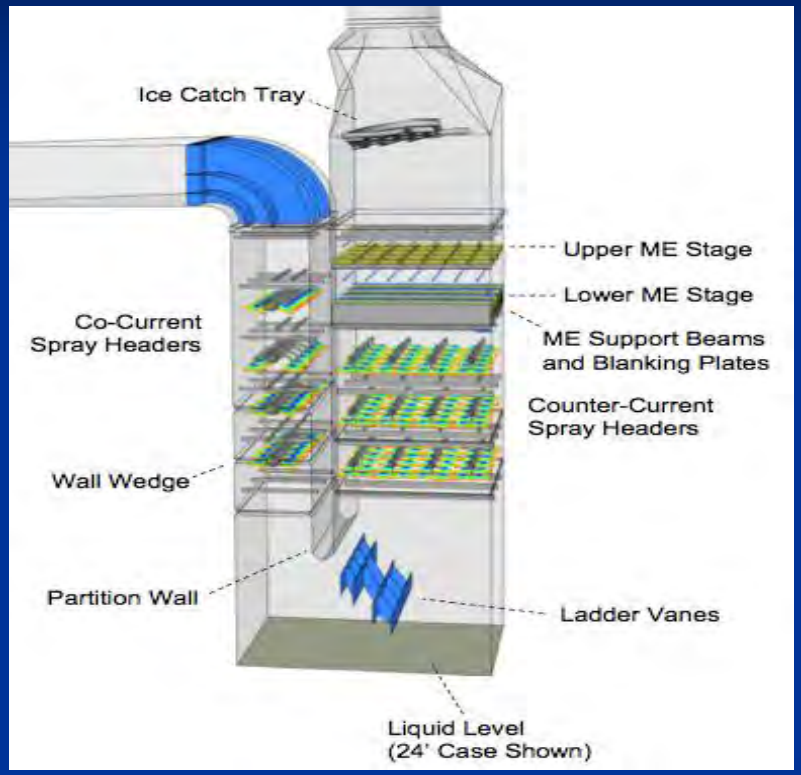


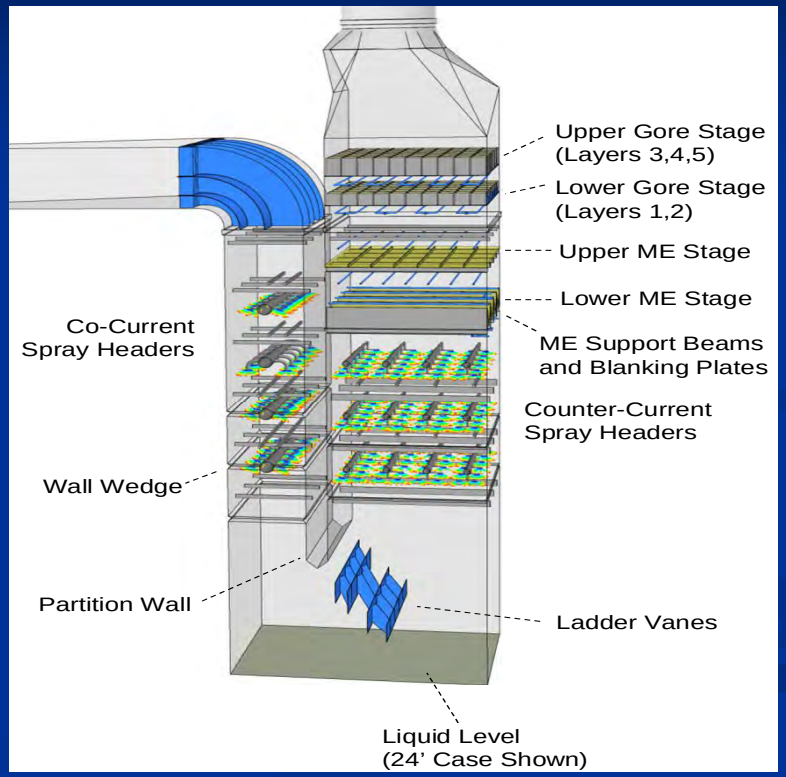


Commercial Installations

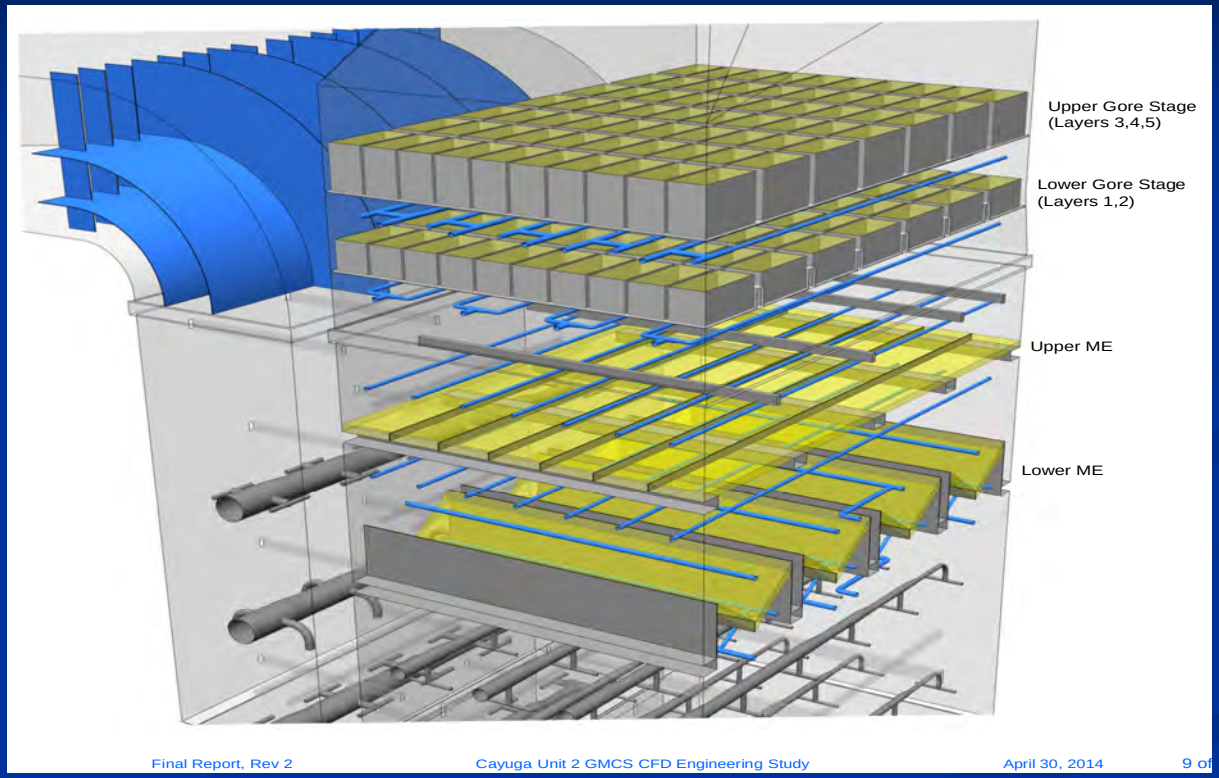
Cayuga Unit 2, Startup October 2014

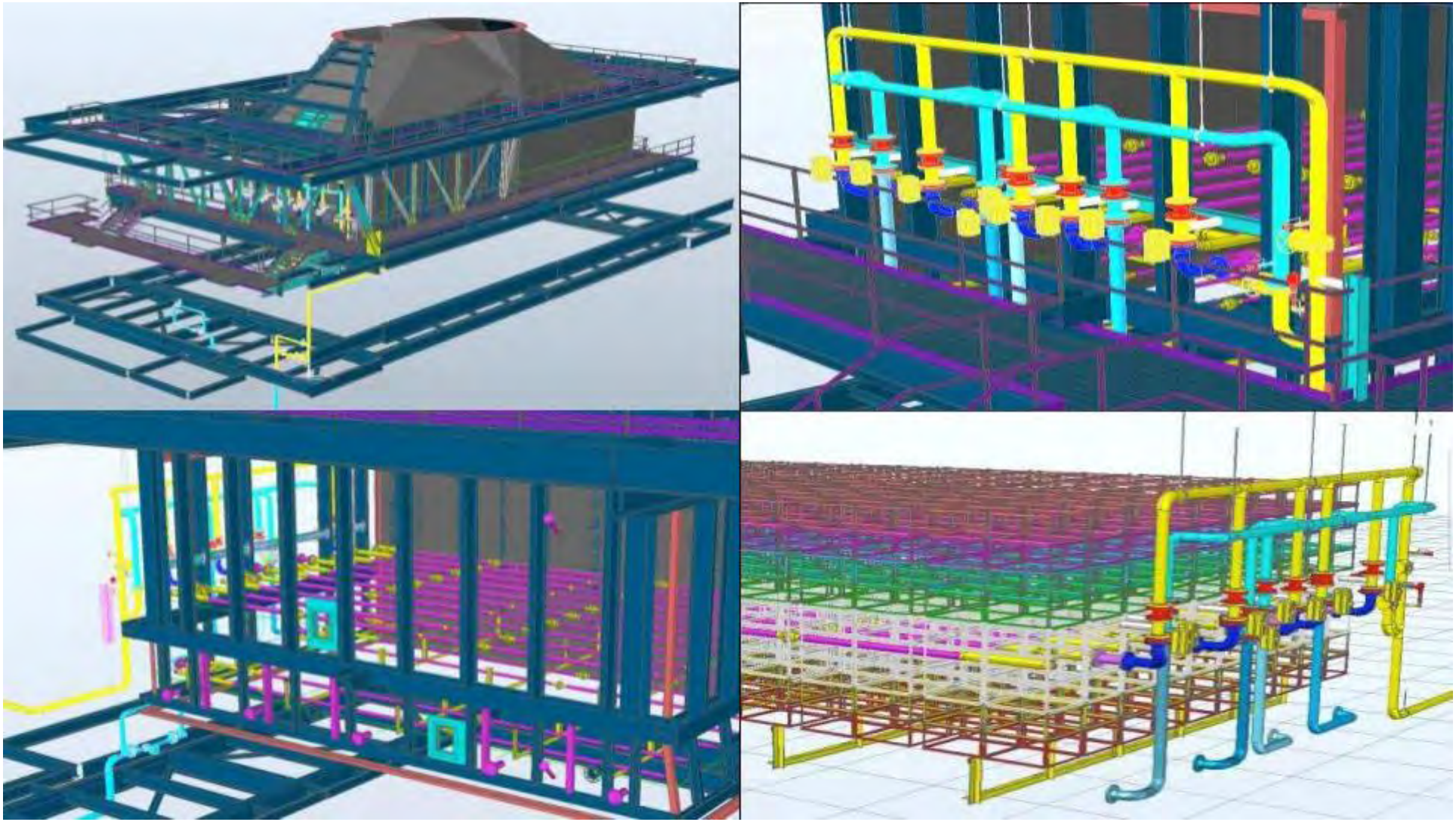
Cayuga – Before and After





Cayuga – 2 modules + 3 modules, Intermediate Washing





Design Overview

- Single tower
- 700 / 840 Gore Modules, (5 / 6 layers)
- Number of Layers
  - 5 initially
  - 6 if needed
- Design inlet Hg 2.5 lb/TBtu
- Design 0.58 lb/TBtu

Scope of Work

- SOW
  - Turnkey firm fixed price EPC
  - Gore system structural supports
  - Gore system wash headers
  - Gore modules
  - Outlet duct lining

Materials of Construction

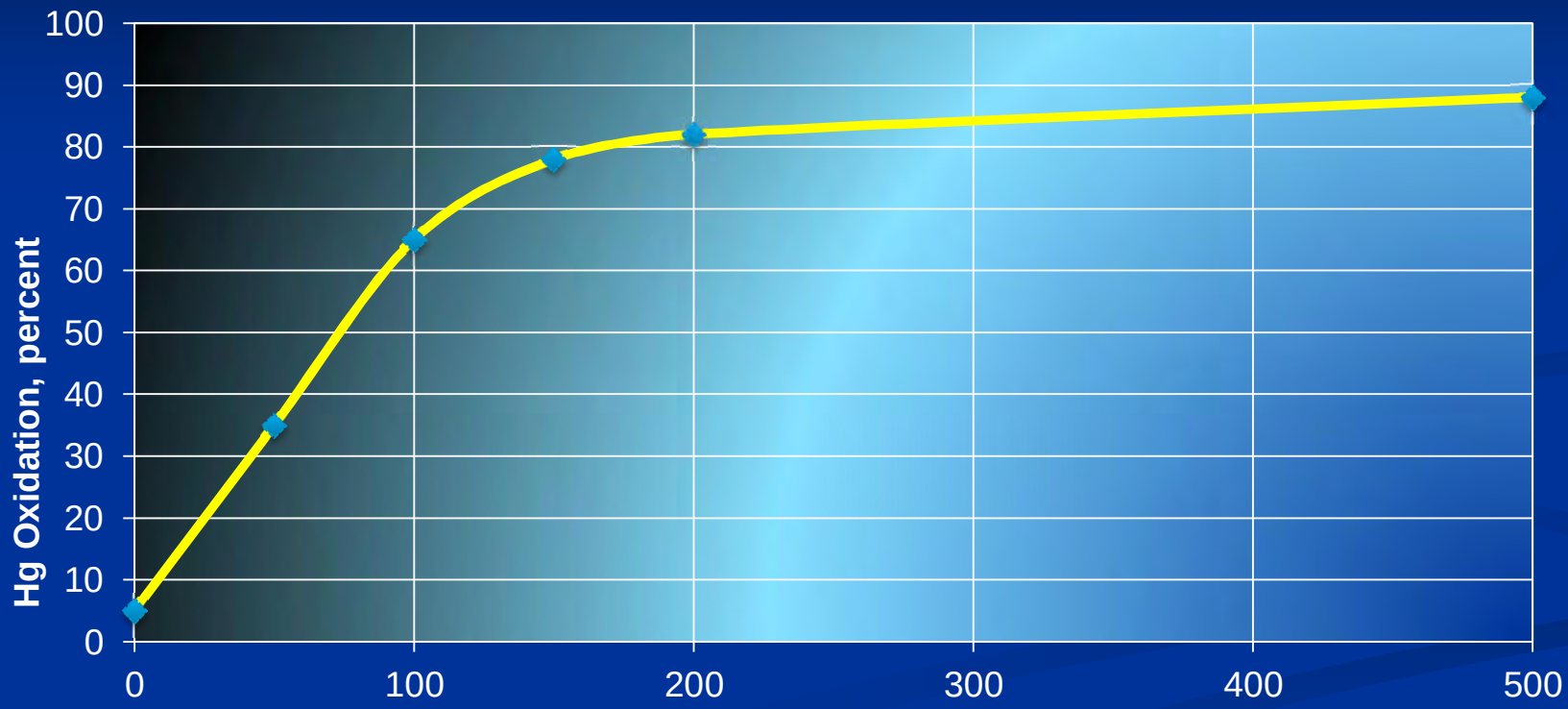
Item	Material
Gore Module Structural Support	C-276
Absorber liner	Blome Flakeglass
Gore Module Cage	C-276
Gore Material	SPC Gen 1.5
Gore Wash Header	FRP
Gore Wash Nozzles	Polysulfone

Combined Halogen Injection and Gore Mercury Control System

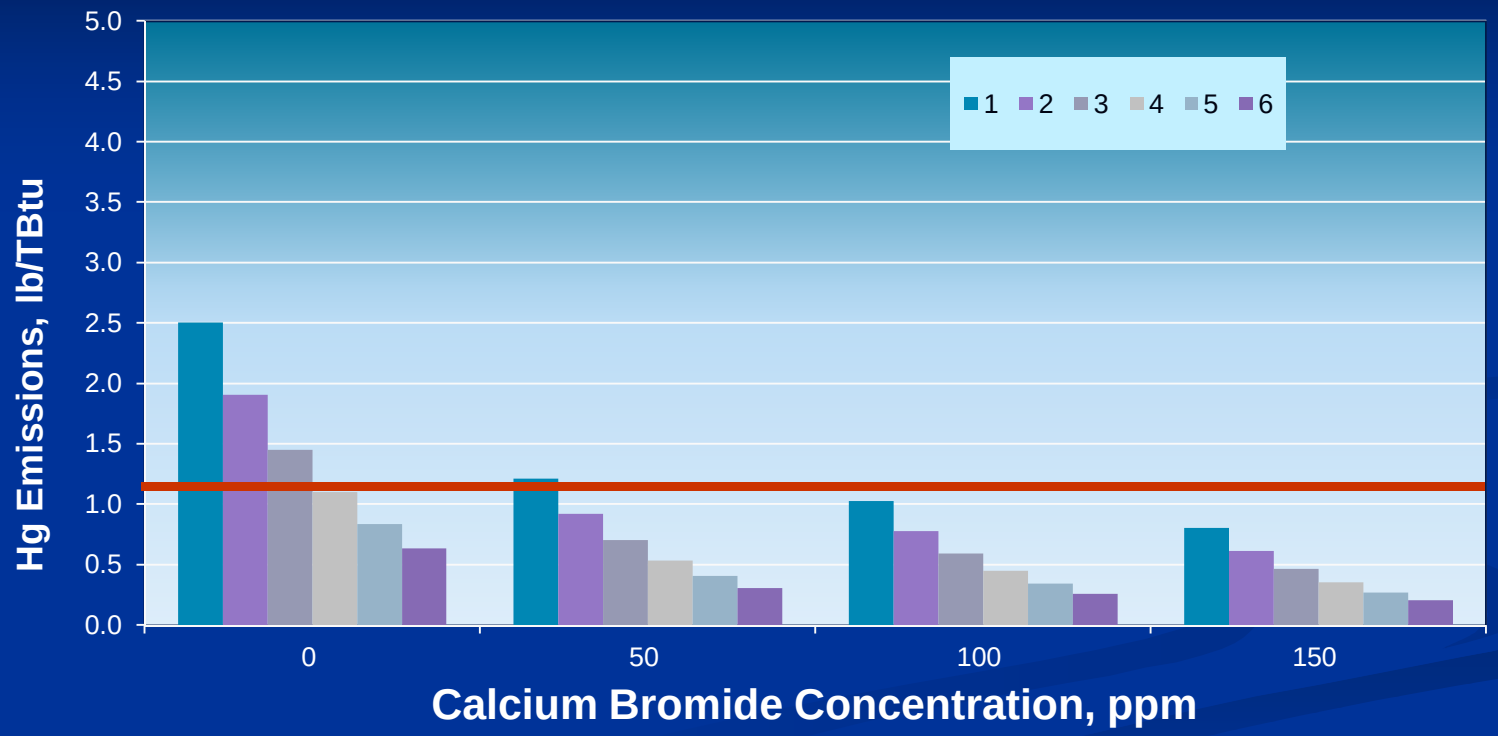
Two-stage System – Gore & Calcium Bromide

- Concept
  - Halogen injection
    - Provides active operator control
    - Injection rate below corrosion threshold
  - Gore mercury control system
    - Reduces number of Gore layers
    - Provides re-emission control
  - Potentially Lower Cost Approach

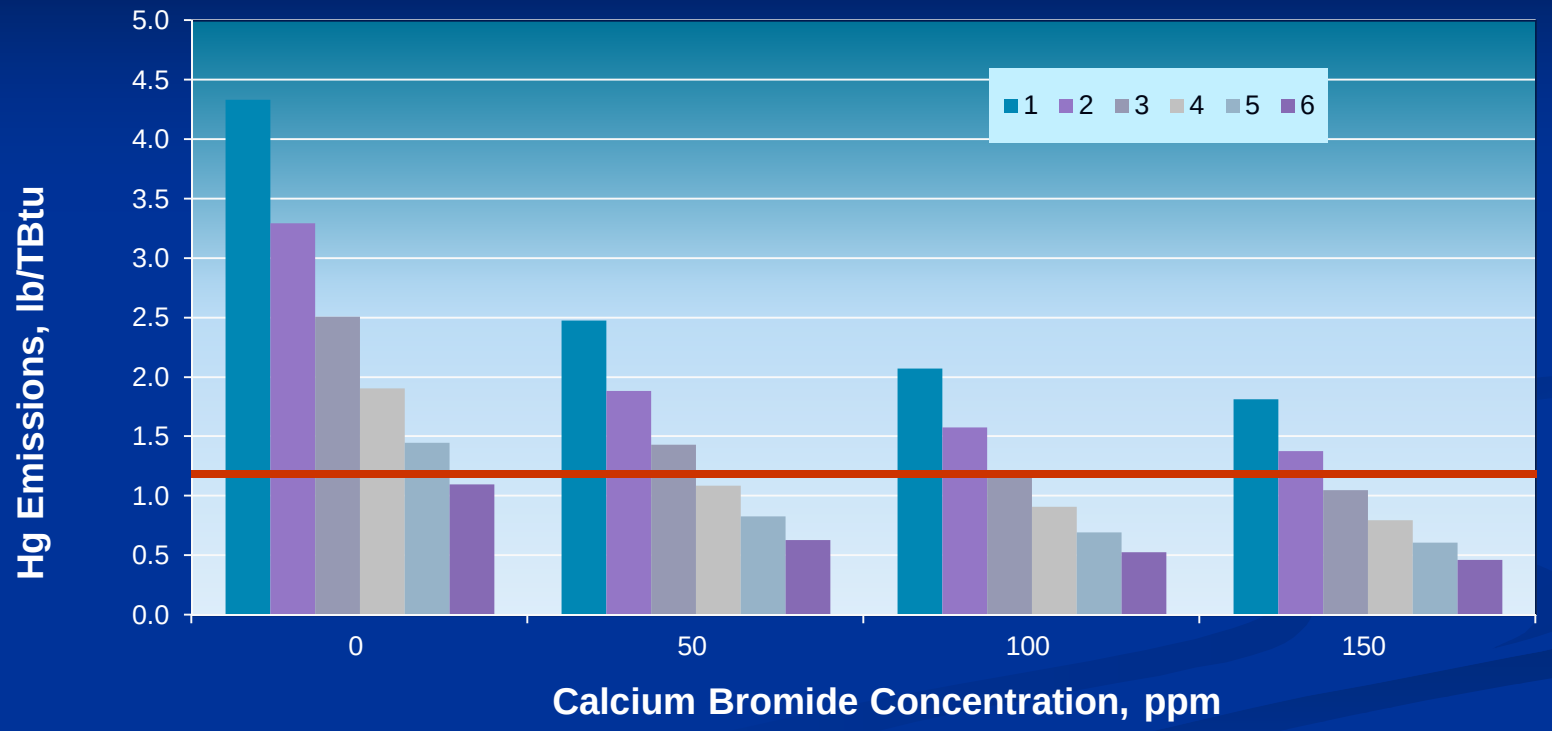
Calcium Bromide Injection – Typical Test Data



3.3 lb/TBtu – Gore/Bromine Combo



6.6 lb/TBtu – Gore/Bromine Combo



Summary

- Gore Mercury Control System is an attractive alternative to ACI or bromine
  - Hybrid system also possible
- Extensive lab and field testing over past 10 years
- Full-scale installations underway

Thank You

Questions?