

REINHOLD ENVIRONMENTAL Ltd.



2016 APC-Wastewater Round Table & Expo Presentation

July 18 & 19, 2016 in Dearborn, MI / Hosted by DTE Energy

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*Creative Technologies
Worldwide*

Fixed Sorbent System Installations and Lessons Learned

Jeff Kolde

W.L. Gore and Associates, Inc.

Reinhold APC Conference

July 18/19, 2016

Outline

1. Gore's Fixed Bed Technology Overview
2. Benefits / Co-Benefits
3. Installation Approach and Experience
4. Lessons Learned from Commercial Installations
 - Performance Information
 - Process Residuals
 - Wash System Designs

Fixed Bed Mercury Control

Pack Beds for Mercury Control

- Activated Carbon Granules with various chemical treatments
- Installed downstream of particle collection, and possibly after gas conditioning
- Adsorption / Chemisorption of mercury on granules
- Bed is run until saturation and then replaced

- ✗ High pressure drop
- ✗ Requires significant footprint on-site
- ✗ If saturated gas stream, requires gas drying
- ✗ Sensitive to residual dust in process stream

Generally considered not viable for power production applications

Most Common Strategies for Power Applications

Activated Carbon Injection

- Powdered carbon sorbent continuously injected into duct
- Adsorption of Hg on carbon
- Remove mercury-containing spent carbon in particle collector
- Disposal w/ ash

- ✘ Ash contamination – loss of sales + disposal costs
- ✘ Additional burden on particulate collector
- ✘ Sensitivity (SO₃, Hg species, duct configuration)
- ✘ High Operating Cost

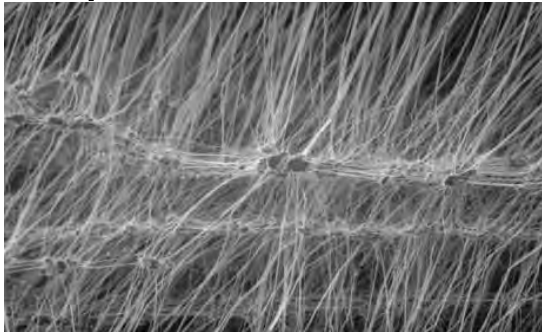
Oxidizing Additives + Wet Scrubber

- Halogens applied at the front of the process (i.e., coal treatment)
- Converts Hg to soluble Hg²⁺ form
- Absorption of Hg²⁺ in a wet scrubber
- Hg²⁺ removed in waste water treatment system

- ✘ Additives can cause corrosion of process equipment (APH, wFGD)
- ✘ Waste water treatment concerns (i.e., Br, Se)
- ✘ Potential Hg Re-emissions from scrubber

W.L. Gore & Assoc. → 40 years in Industrial Filtration

Expanded PTFE (ePTFE)



GORE® Filter Bags

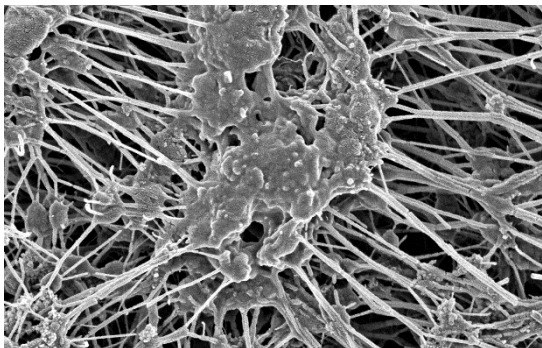
GORE® Filter Cartridges

GORE® Liquid Filtration Products



Particulate Filtration

Filled ePTFE



Catalytic Filter Bags

SPC Technology

PM + Dioxin/Furan

PM + NOx

???

Mercury Capture

SOx Removal

???



GORE
Creative Technologies
Worldwide

GORE™ Mercury Control System

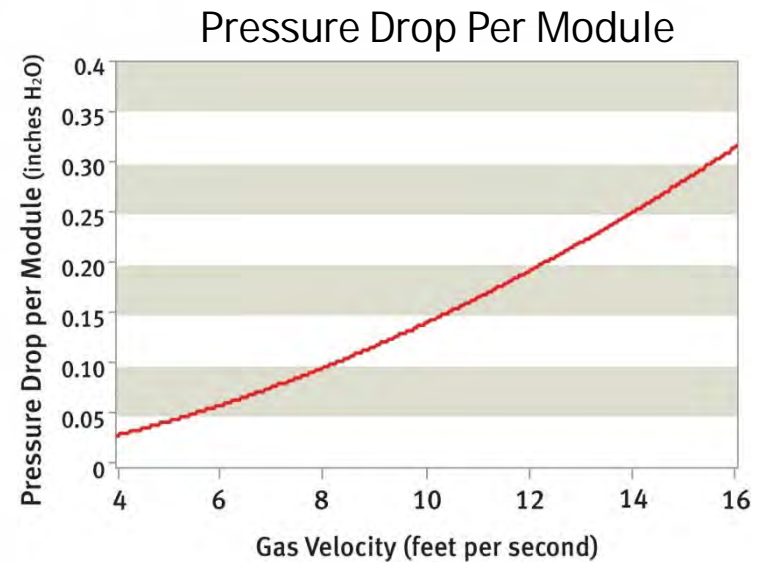
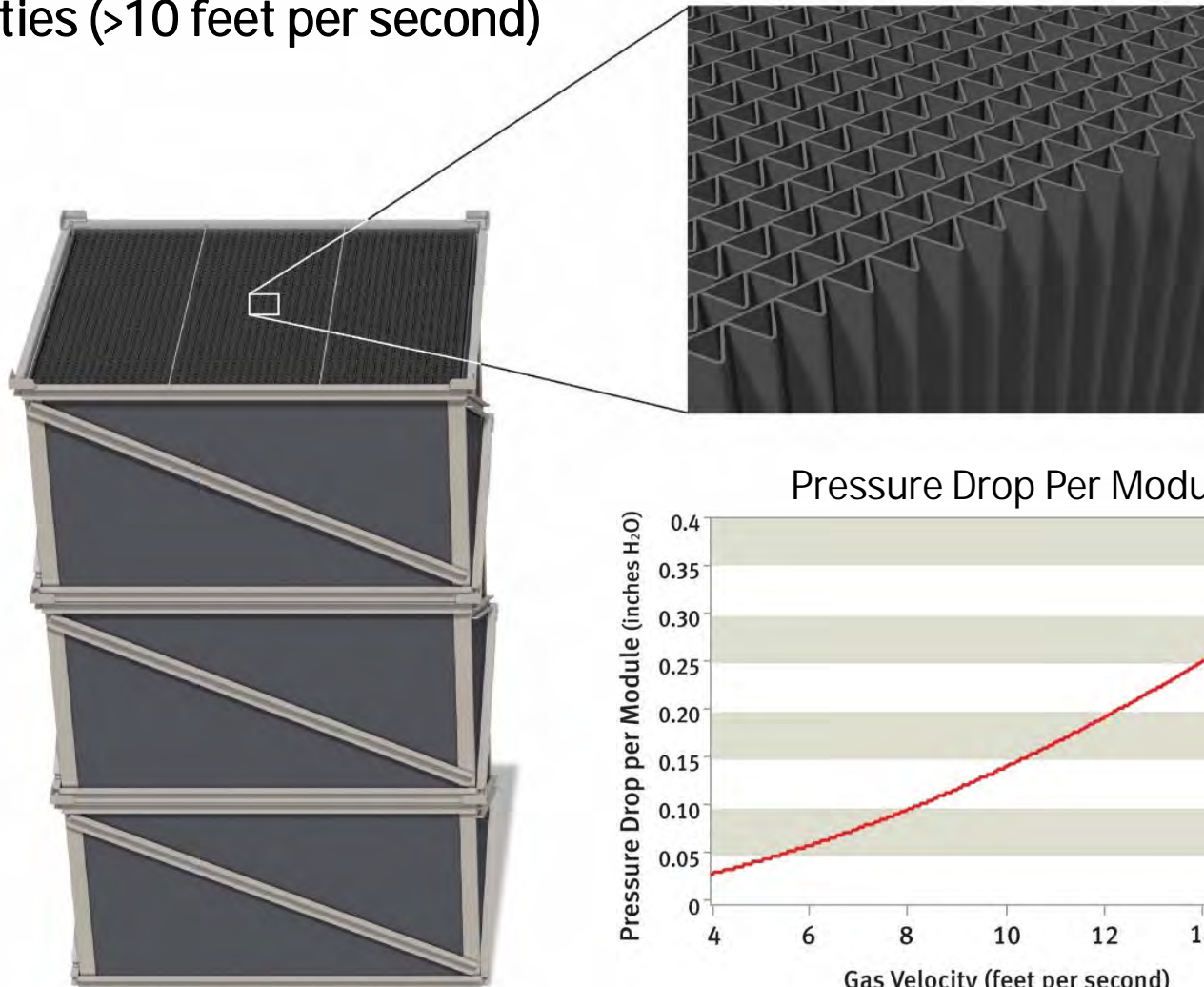
Based on Fixed Sorbent Technology

- Low pressure drop sorbent modules
 - Simple Passive Operation
- Able to operate in saturated gas streams containing acid gases
- Does not require any injection of sorbents or chemicals
 - Low impact
- Continuous mercury adsorption for long period of time without deactivation
 - Low operating cost

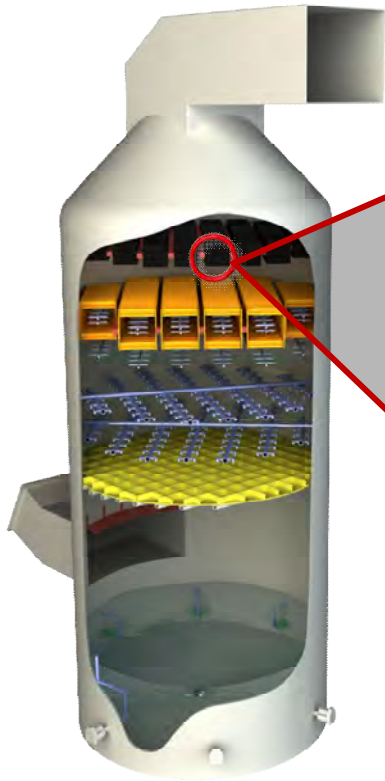


Module Design

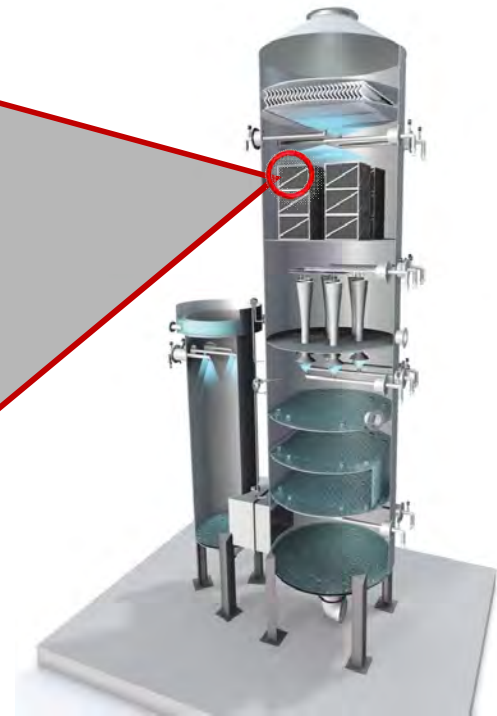
Low Pressure Drop design allows for high velocities (>10 feet per second) to be used



Installations in Wet Scrubbers



**ZERO FOOTPRINT
INSTALLATION**



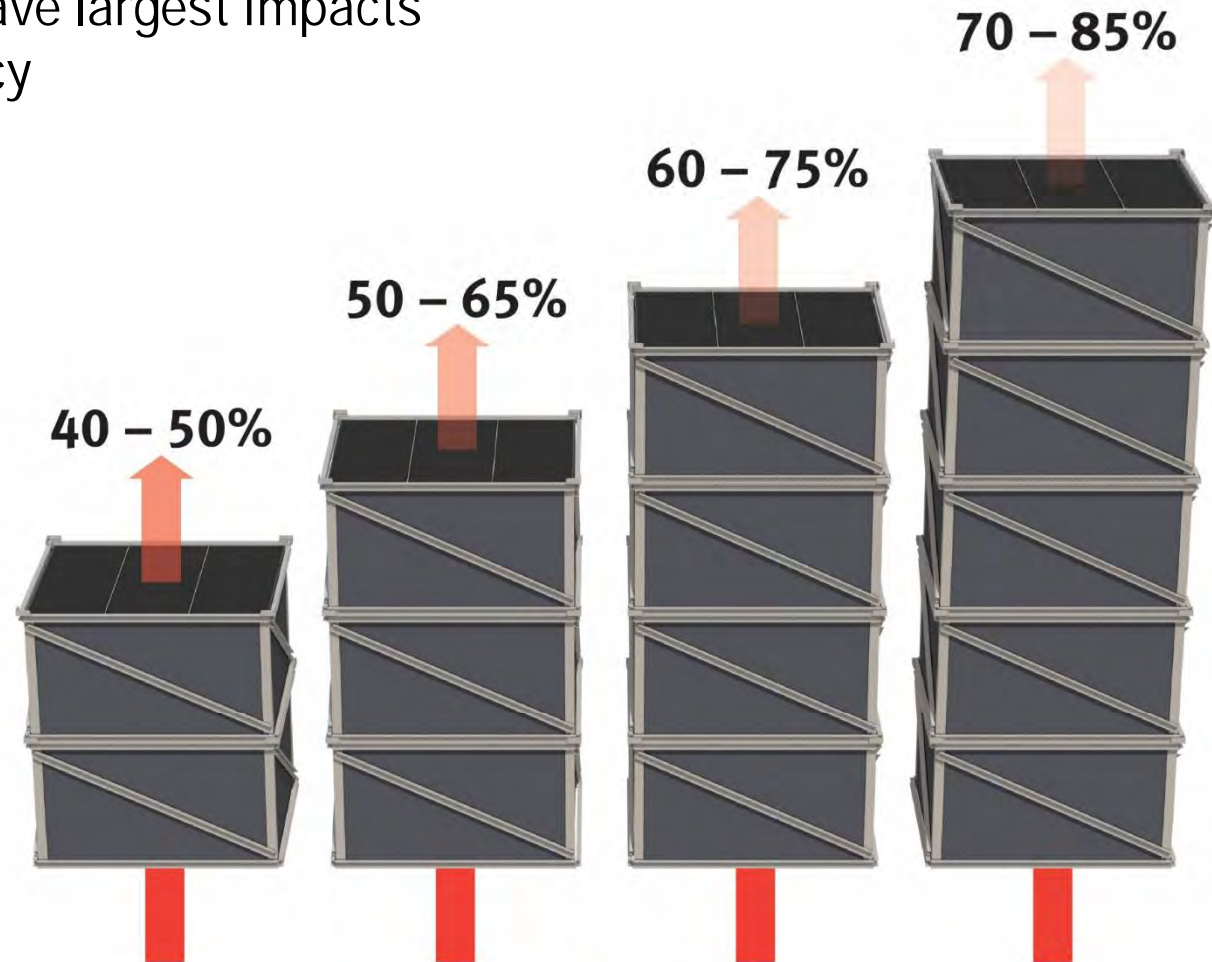
**Wet Venturi Scrubber
(i.e., sludge incineration)
15 installations to date**



Technology for in-scrubber installations licensed from EPRI

Removal Efficiency is Scalable

Residence Time (Module Stack Height and Gas Velocity) have largest impacts on removal efficiency



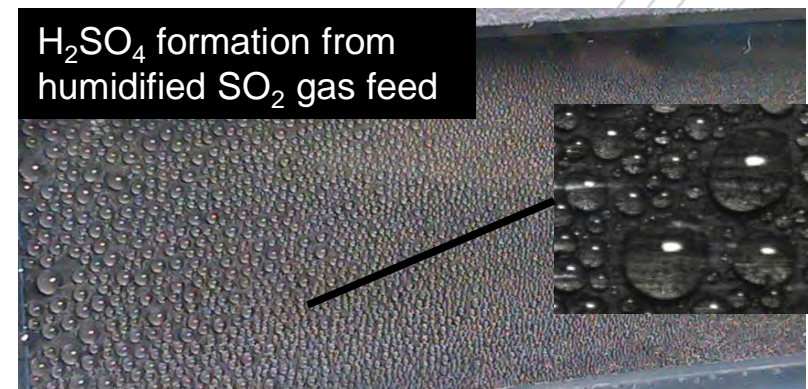
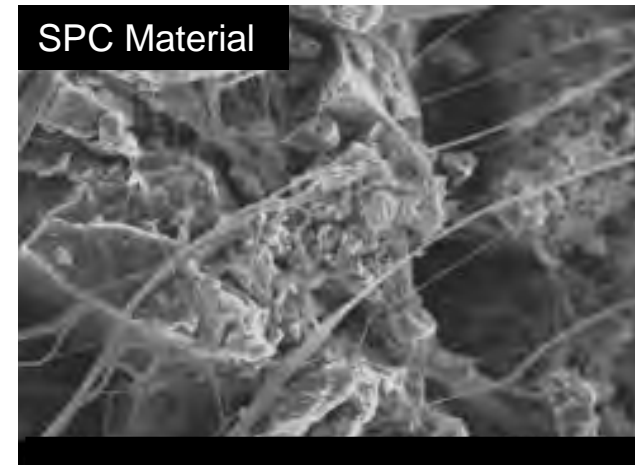
Example of Mercury Removal Efficiencies at Typical Scrubber Gas Velocities

Hg

Sorbent Polymer Catalyst (SPC)

Fluoropolymer composite material

- Chemisorption of gas phase mercury (even in wet gas stream)
 - Elemental and oxidized mercury capture
 - High capacity for mercury storage
 - Does not require regeneration
- Catalytic conversion of SO_2 (without generating solid waste)
 - Dilute sulfuric acid solution created
 - Highly hydrophobic structure expels acid to SPC outer surfaces
 - Continuous sulfuric acid weeping helps minimize impact of solids

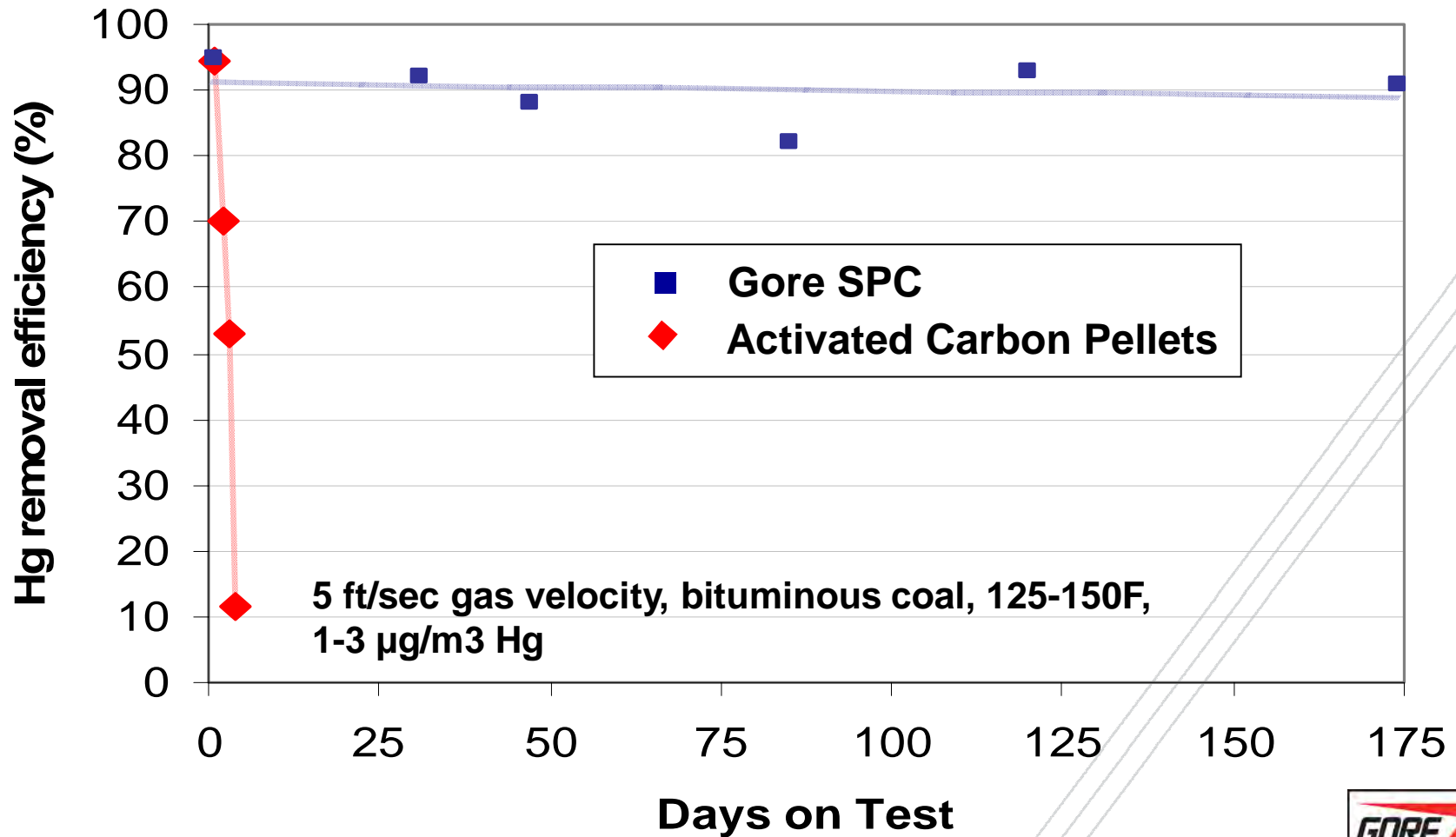


Slip Stream Testing at U.S. Power Plant

Southern Company Plant Yates

Pilot installed downstream of Wet Scrubber

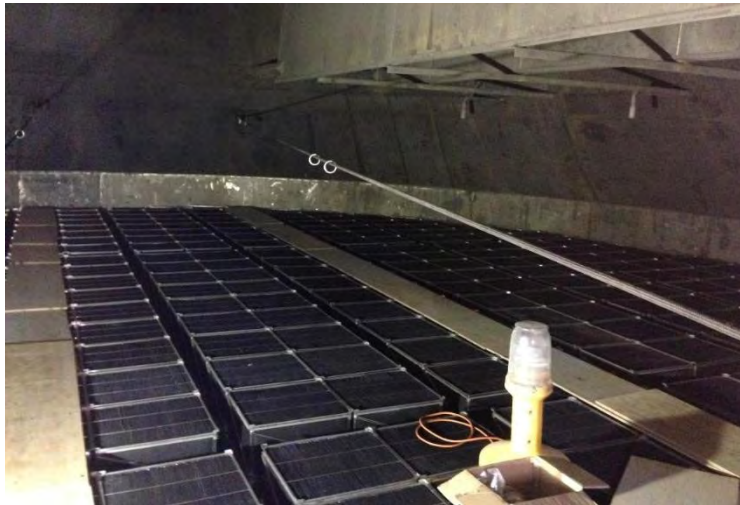
Demonstrates resistance to poisoning/fouling by flue gas constituents including moisture



Simple Operation

Passive Control System

- No adjustments in use
- No moving parts
- No regeneration required
- No need to remove SO_3
- No need to reheat gas stream (unlike carbon fixed beds)



Low Process Impact

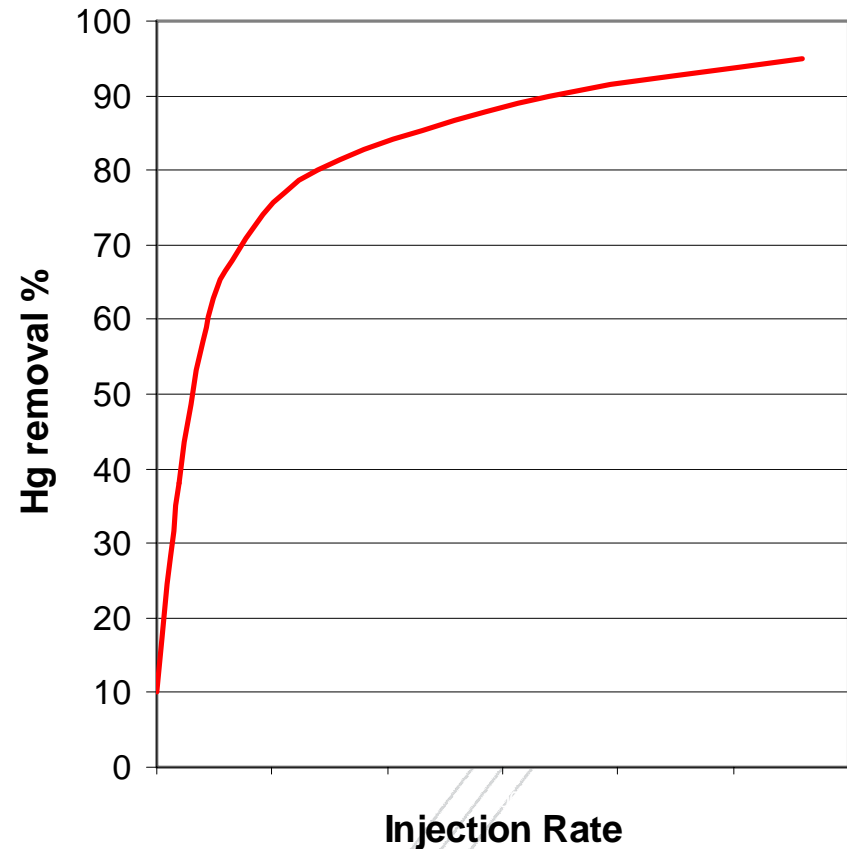
Tail Pipe Solution



- No impact on dust fly ash
 - ✓ Preserves fly ash sales
- No additional particulate matter introduced
- No impact on gypsum
 - ✓ Preserves gypsum sales
- No concern from halogen-induced corrosion of equipment
- No impact on WWT system
- Can work in complementary fashion with existing injection systems

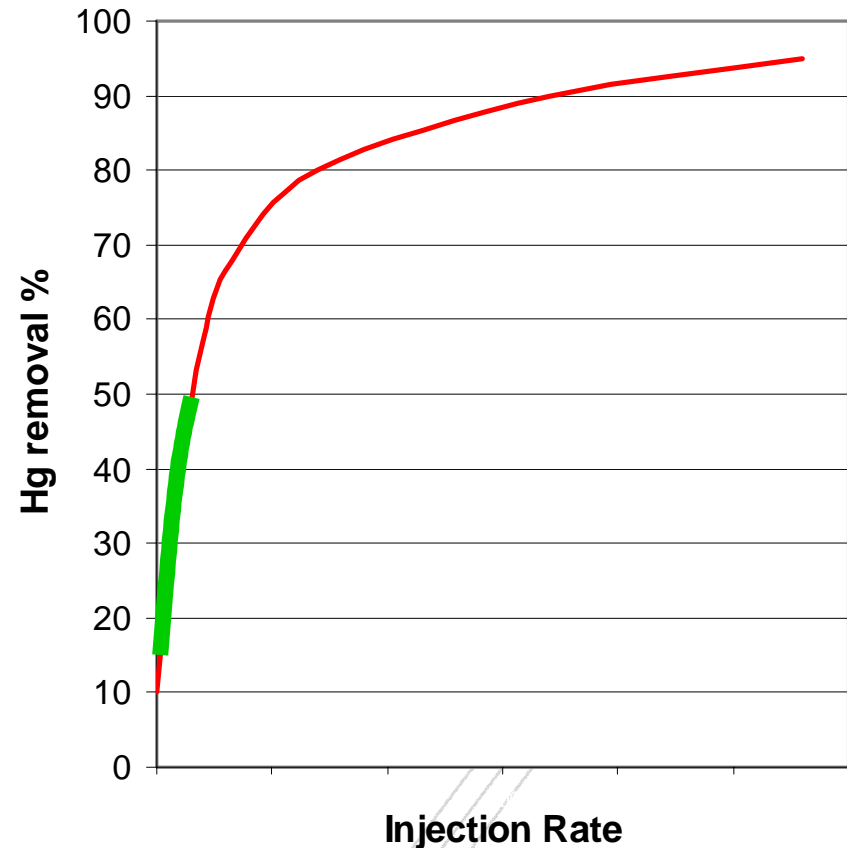
Diminishing Returns with Injection

- Injection Systems such as ACI or Bromides typically show similar behavior in terms of removal efficiency



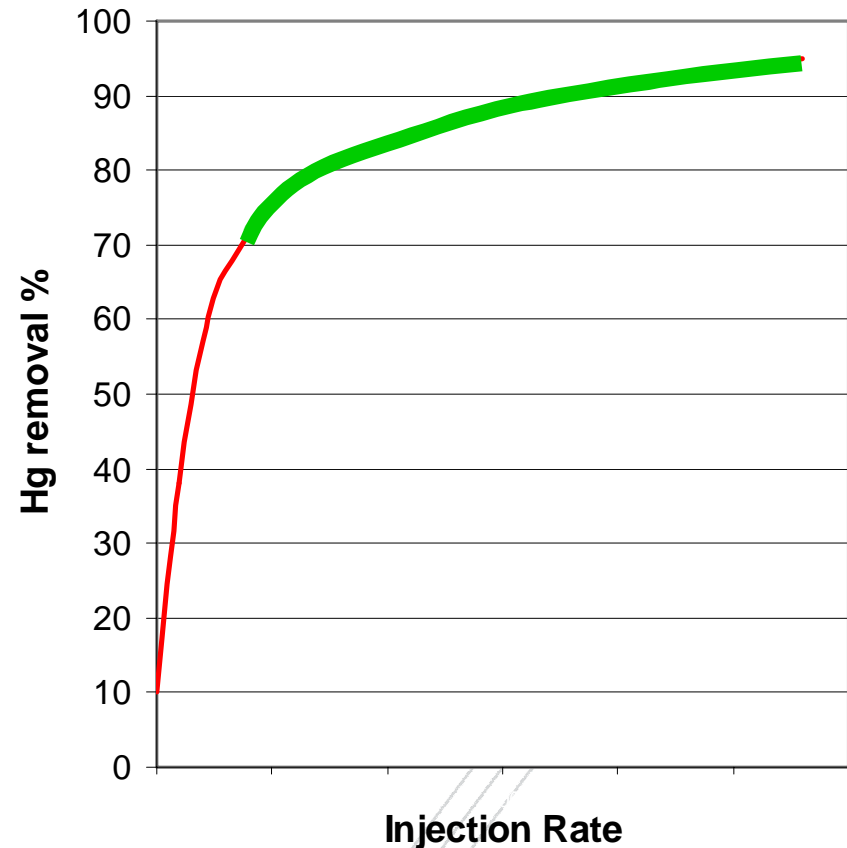
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 - Easy to achieve initial 20-40% Hg removal



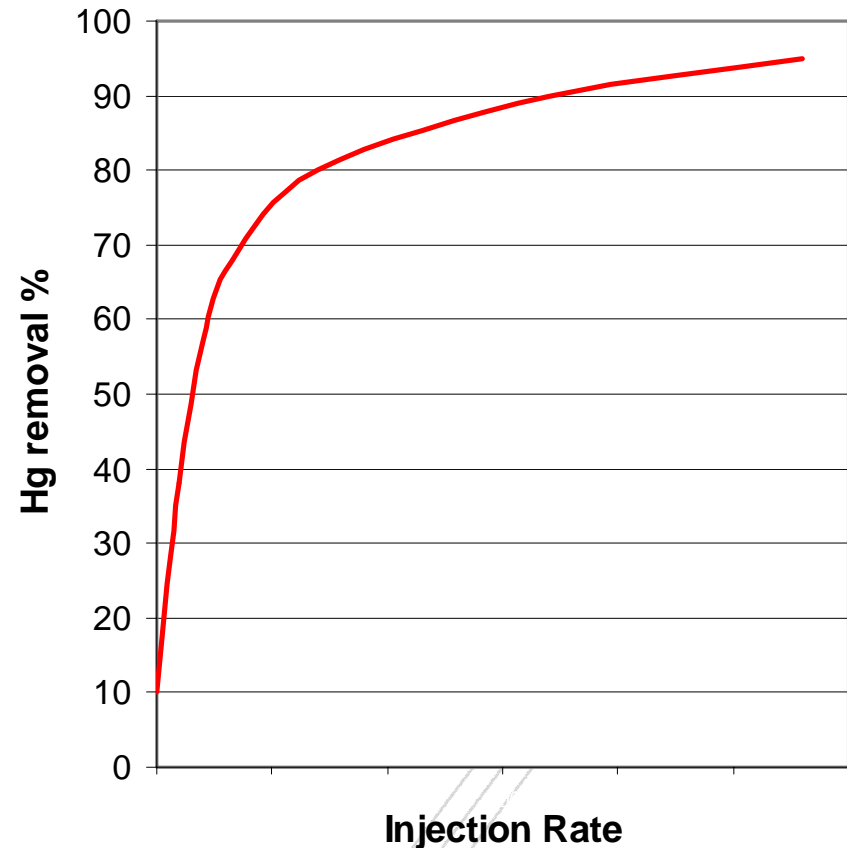
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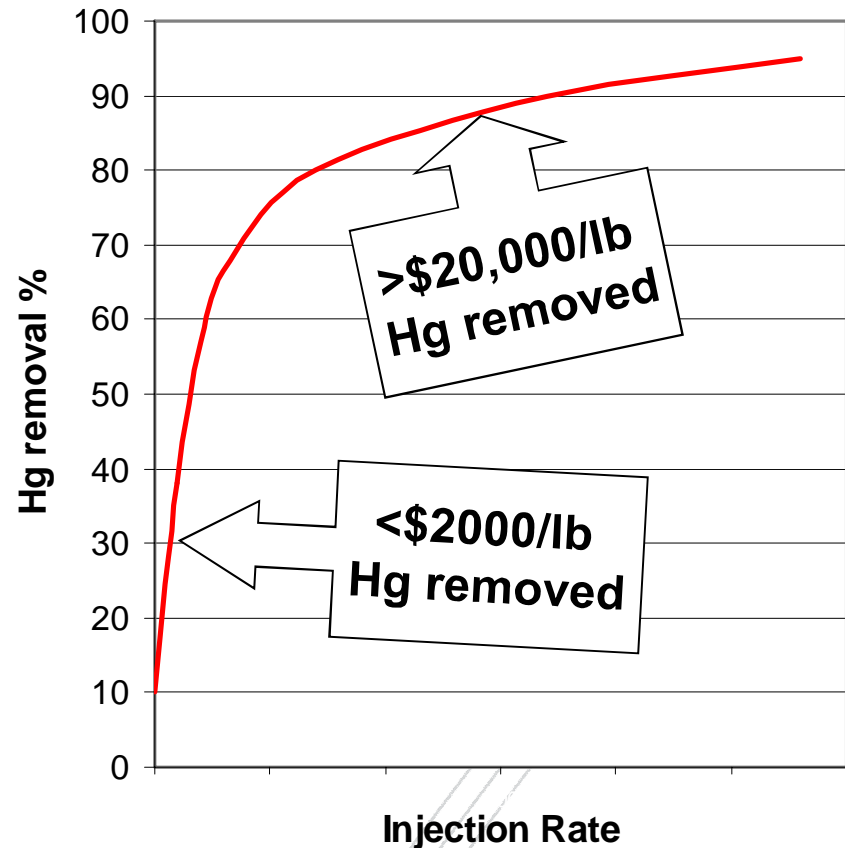
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 - Difficult to achieve the last 20-40% Hg removal
- Result: high operating cost for plants that have significant Hg reduction needs



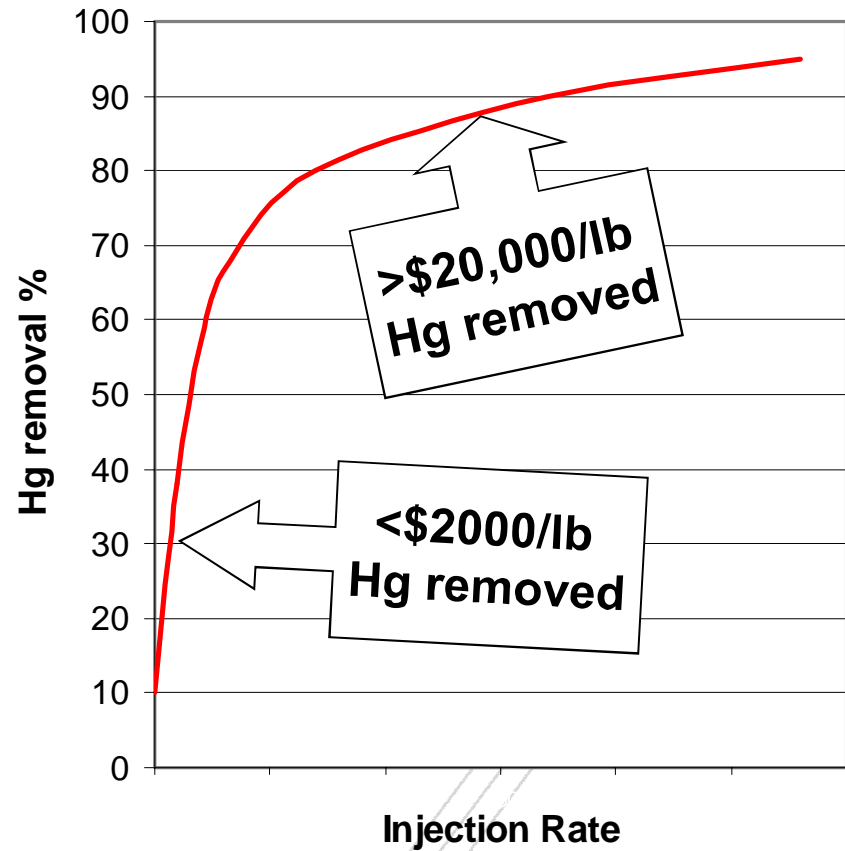
Diminishing Returns with Injection

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Diminishing Returns with Injection

- Additional concern over high reagent usage
 - ACI:
 - Fly ash contamination
 - Overloading ESP
 - Bromine
 - APH Corrosion
 - Wastewater treatment issues



Fixed Sorbent System / Hybrid System

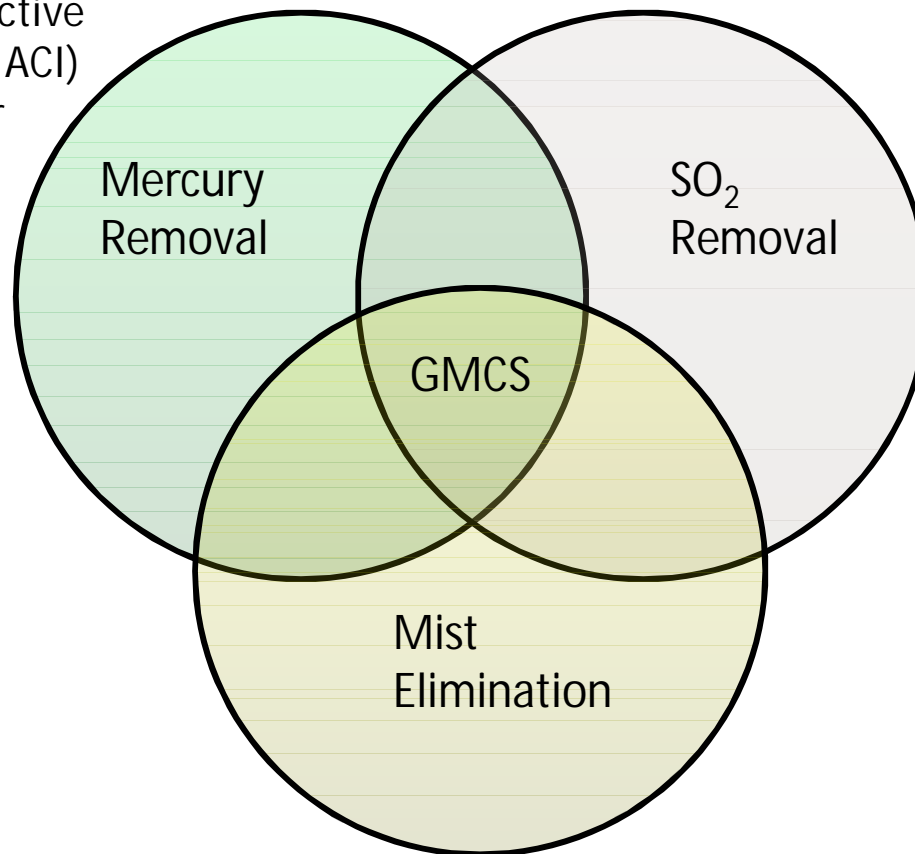
- Fixed Sorbent System has a **constant \$/lb** mercury removed
 - Sorbent remains in flue gas until it reaches capacity for Hg capture
 - Each modules has the capacity to capture ~2 lb of mercury
- Can work in complementary fashion with an injection system
 - Use injection system for “easy-to-get” mercury
 - Injection system is always upstream of fixed sorbent system
 - Use fixed sorbent system for “difficult-to-get” mercury
- Hybrid system (i.e., ACI + Modules) minimizes overall operating cost and unwanted plant impacts

Hybrid = Active and Passive Control

- Hybrid system provides robust mercury control
 - Modules operate during start-up / shut-down
 - No impact due to seasonal variation
 - Higher mercury removal efficiency by modules at low load
 - Lower velocity = higher residence time
 - Turn off injection system during low load?
 - Re-emissions captured by modules
 - May provide fuel flexibility
 - SO₂ and Hg removal capabilities

Multi-Pollutant Control System

- Primary Mercury Control
- Complementary to Active Control System (i.e., ACI)
- Effective solution for Re-Emissions

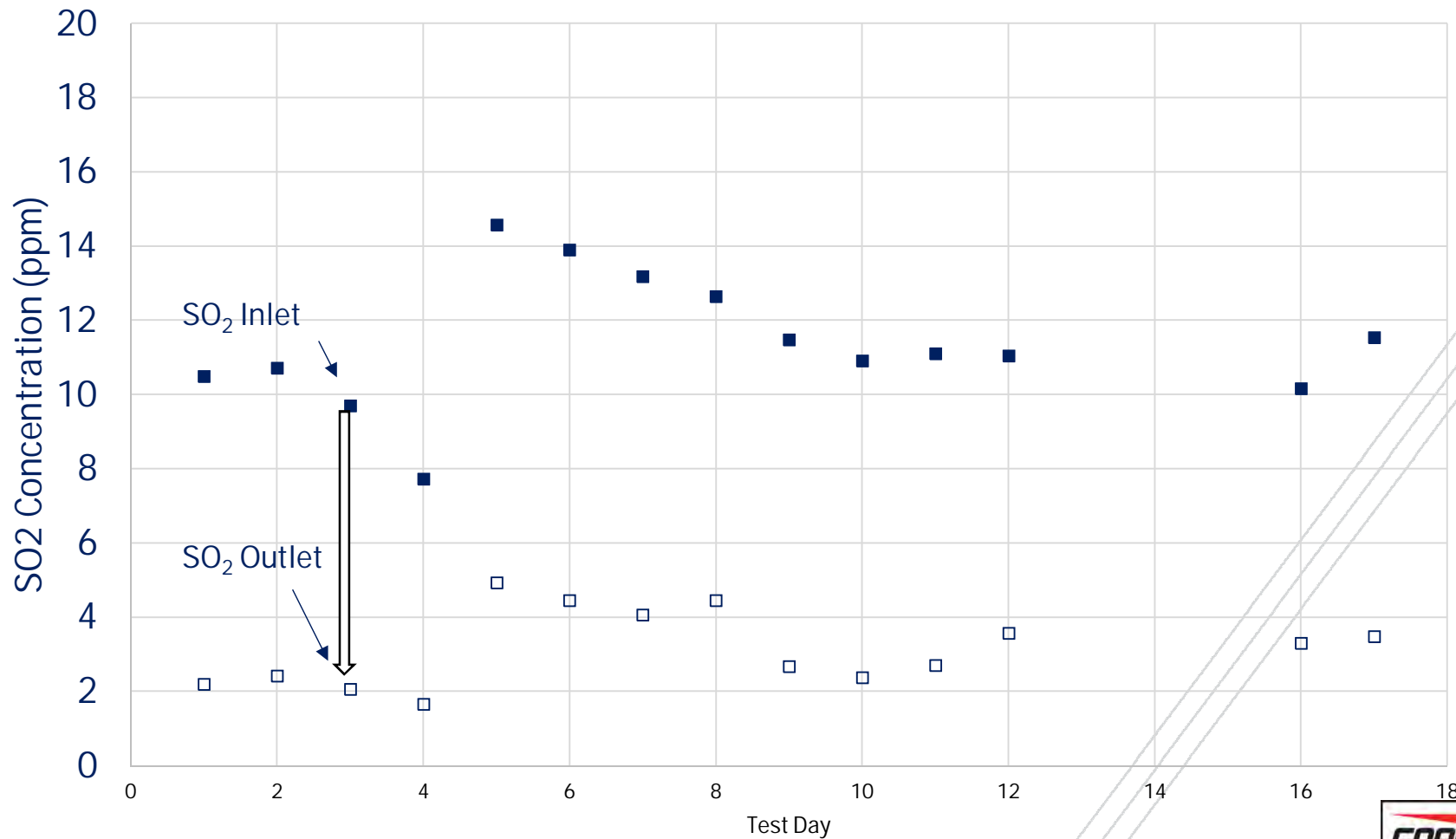


- Current or future SO₂ regulations
- Can eliminate need for scrubber upgrade
- Potential power savings from detuning scrubber

- Significant additional mist elimination (1-10 µm droplets) provided by modules

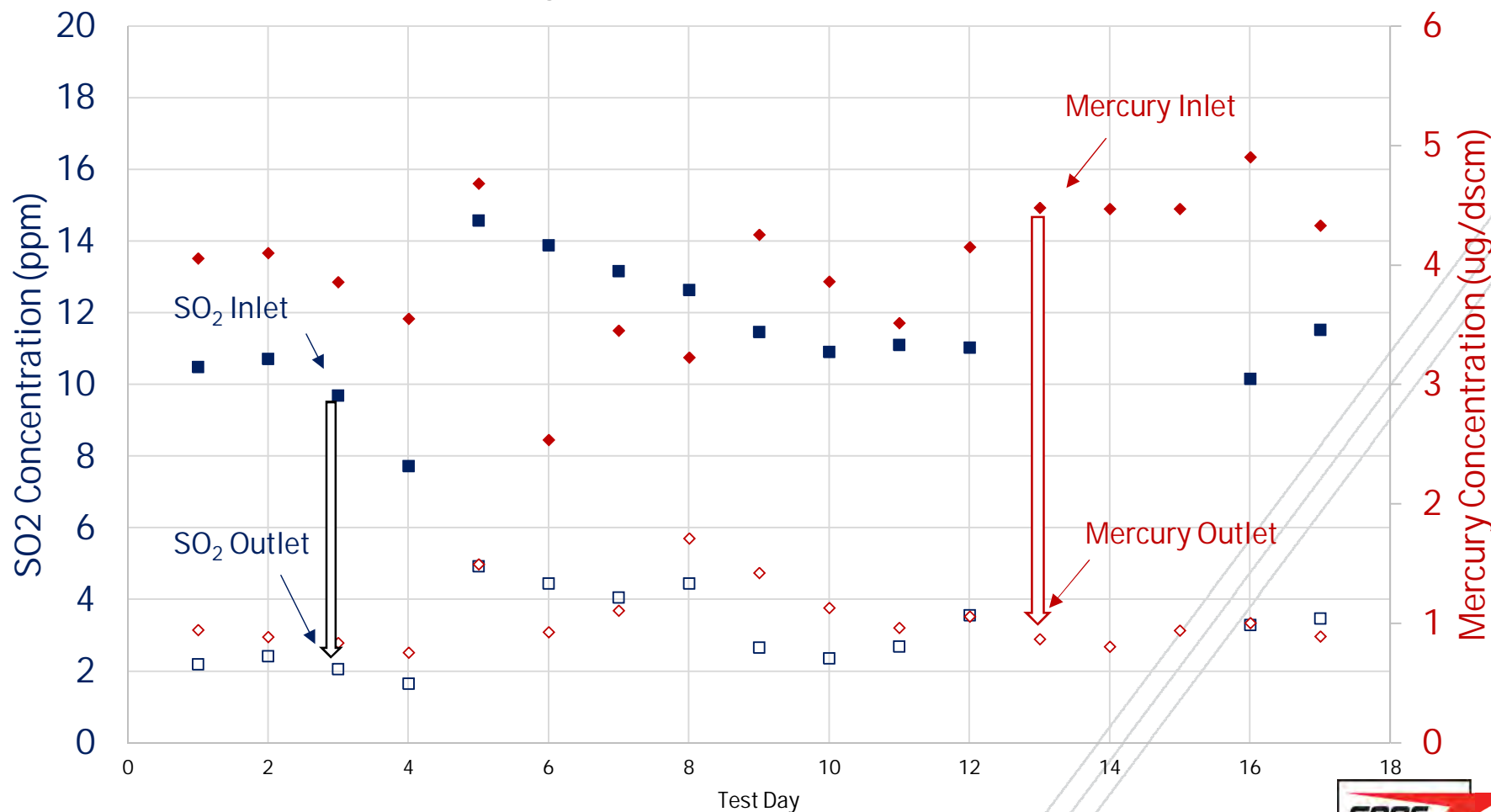
Simultaneous Removal of Mercury and SO₂

Data from iron ore refining application



Simultaneous Removal of Mercury and SO₂

Data from iron ore refining application

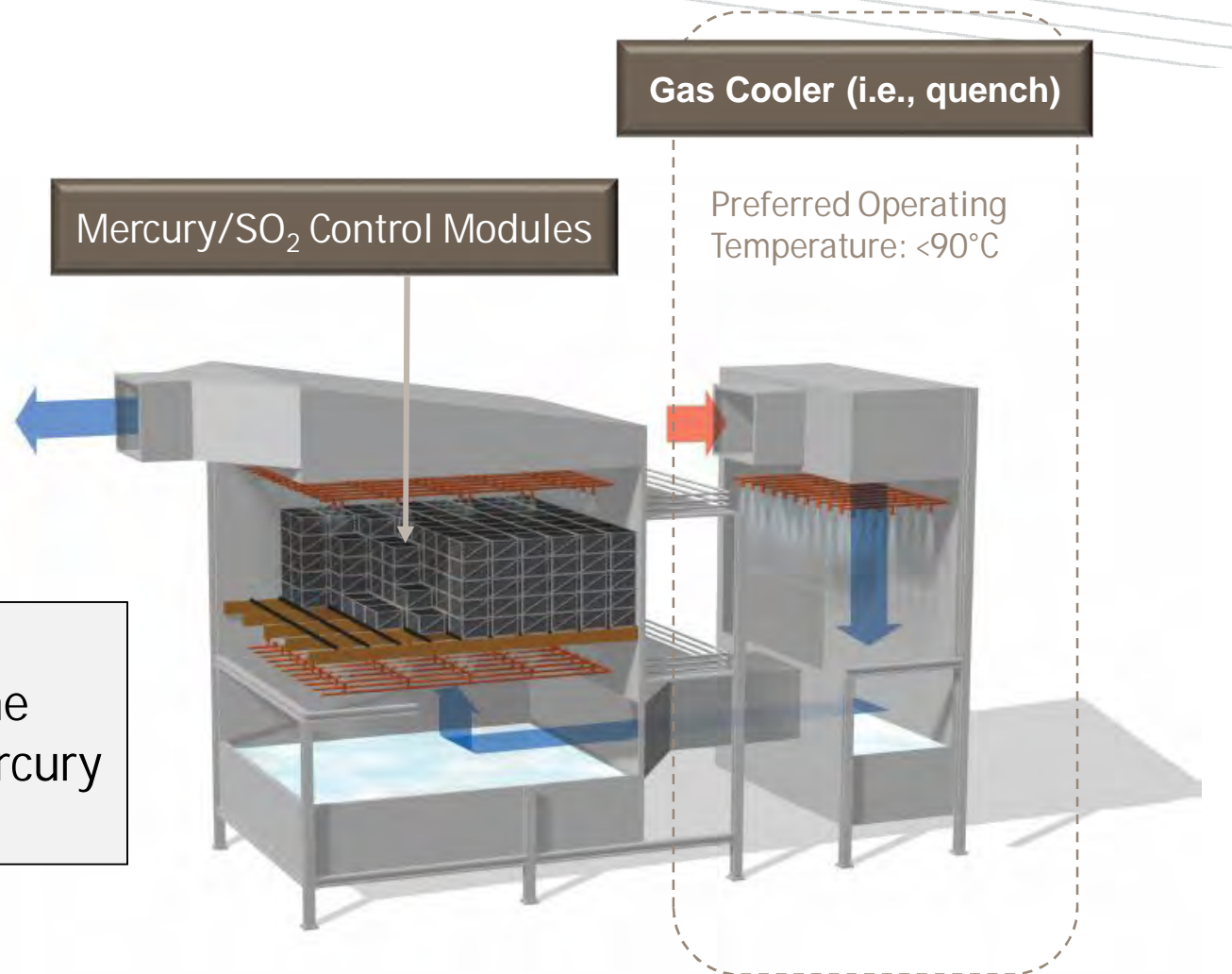


Stand-alone Installation

Applications without wet scrubbers:

- ✓ Cement
- ✓ Metals
- ✓ Incinerators
- ✓ Industrial Boilers
- ✓ Coal-fired power, unscrubbed
- ✓ Coal-fired power, with dry scrubber

SO₂ removal can be the primary function in some applications, with a mercury removal co-benefit



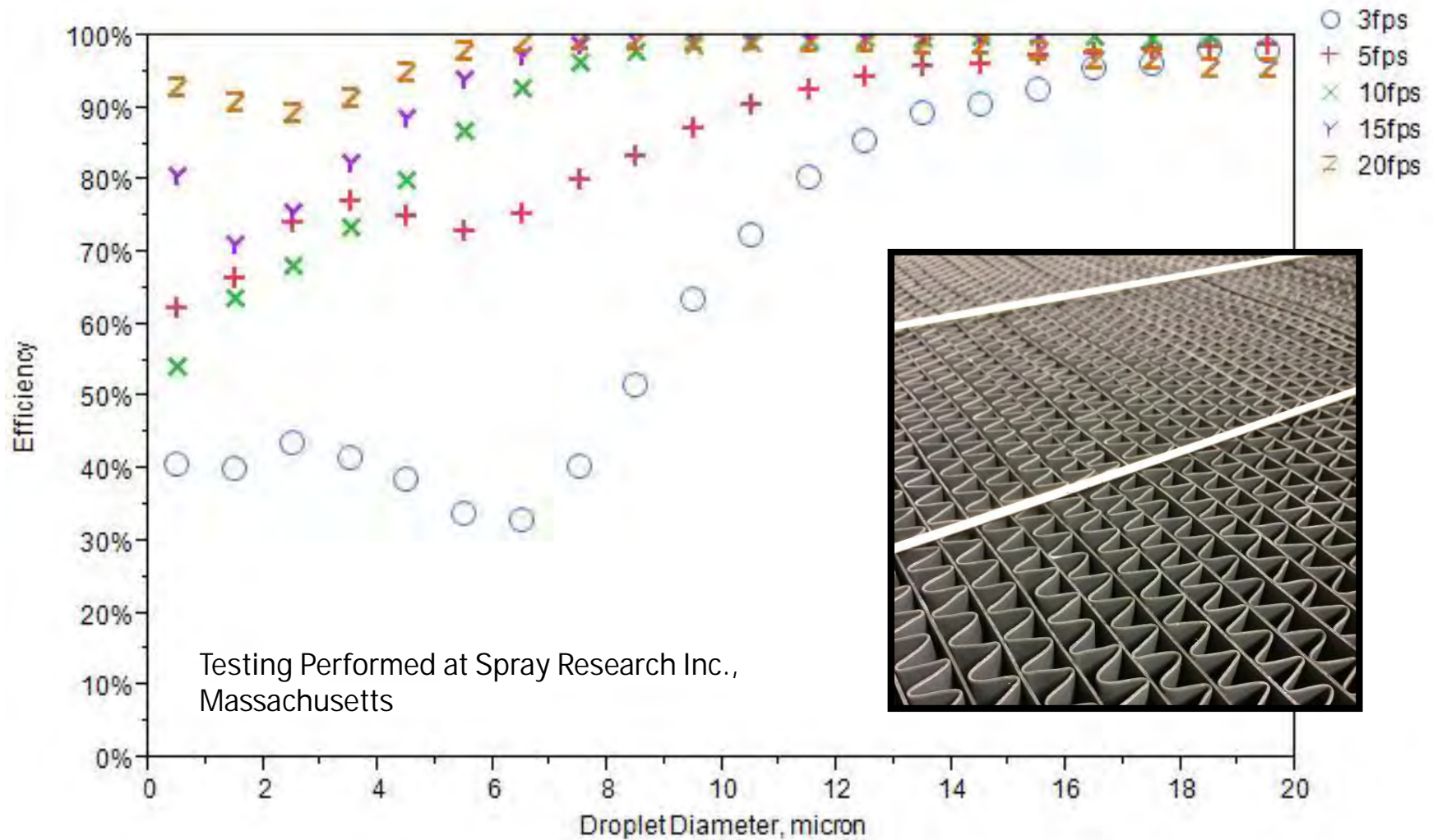
Passive SO₂ Scrubber

- Catalyst-based reaction
 - No reagent injected for SO₂ removal
 - Neutralization, use, or sale of acid
 - No power for pumps
 - Low pressure drop across system
- Simple operation
 - No moving parts
 - No reagent supply / prep / solids disposal
- Very low operating cost
- Significantly lower capital cost than a new scrubber
- Ideally suited for applications requiring 50-80% SO₂ removal



Mist Elimination Co-Benefit

Droplet Collection Efficiency by PDPA Gore Mercury Modules (30 inch)



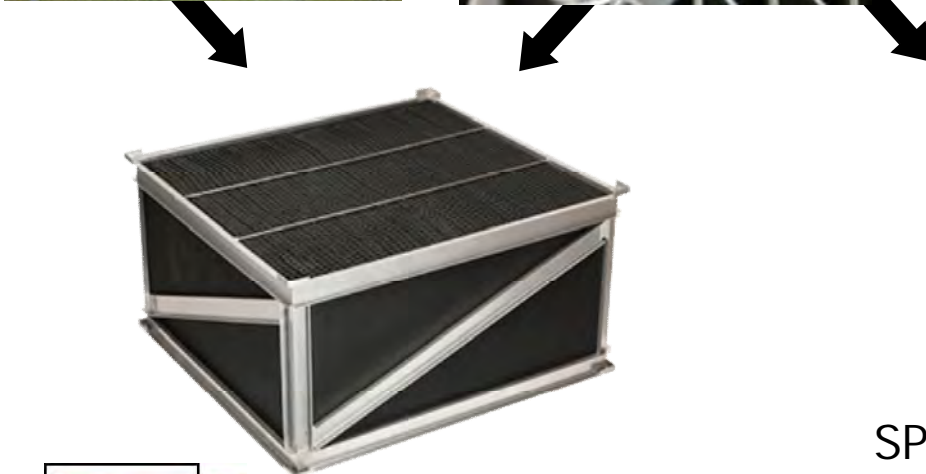
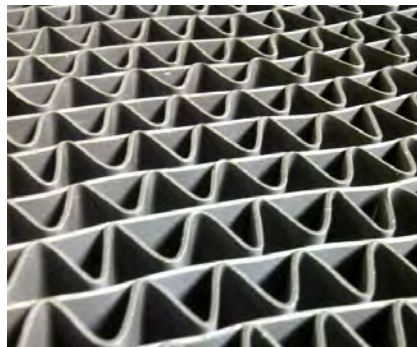
Module Disposal

- Mercury is sequestered inside the SPC via chemisorption
- At end of module lifetime, SPC is removed from frame and sent out for disposal
- SPC disposal via encapsulation/landfill (“debris” waste standard): <\$50/module
- Significantly lower quantity of solid waste generation compared to sorbent injection, assuming sorbent is not beneficially used

C22 Tray
(Re-used)



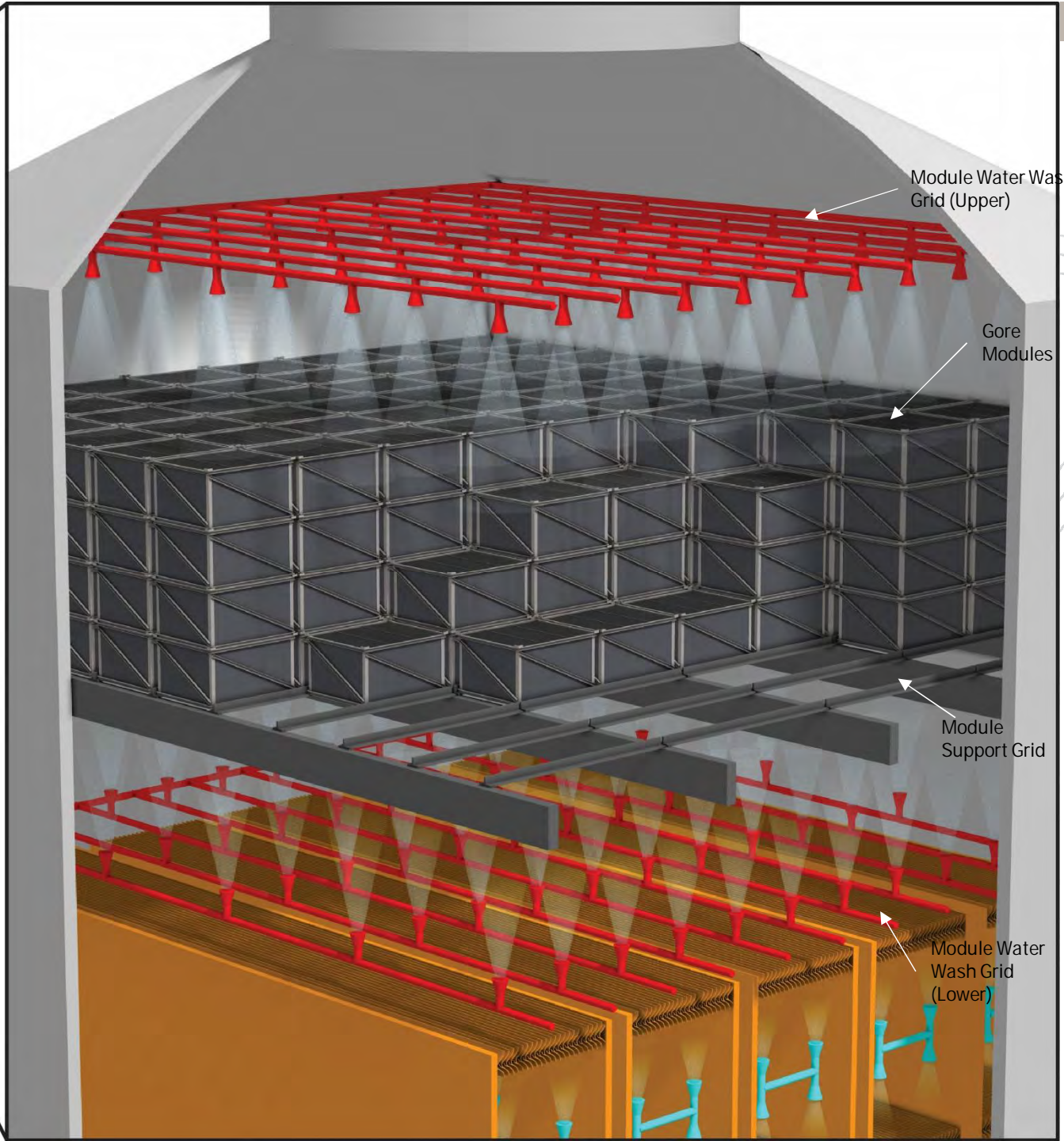
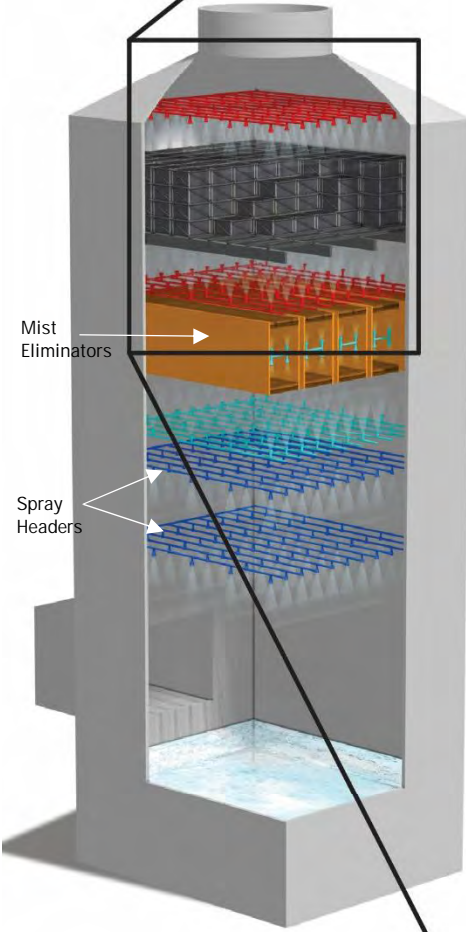
SPC Media
(Consumable)



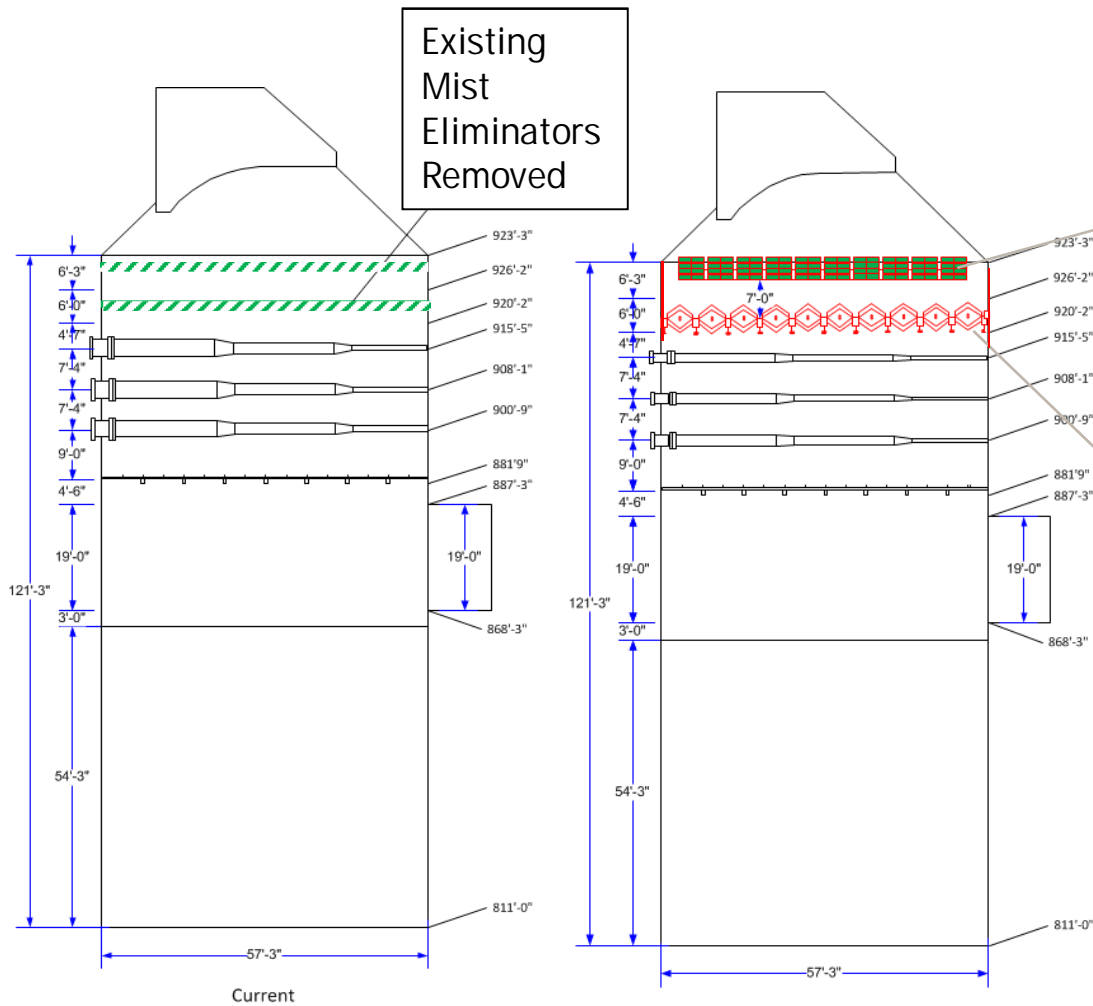
SPC Media from one entire module (25” W x 27” L x 13” H) – compact shipping/disposal

Installation Approaches and Experience

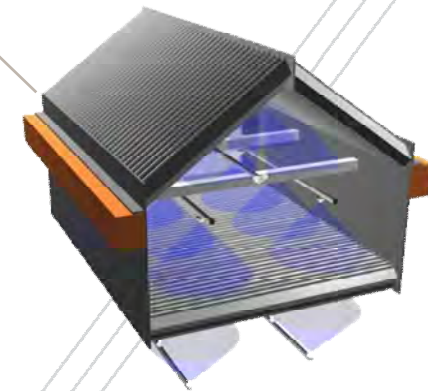
Coal-Fired Power Plant: wet FGD Installation



Installing modules in an existing wet FGD scrubber



Modules installed above Mist Eliminators



New compact Mist Eliminators installed to create space for Modules

Commercial Installations in Coal Fired Power Plants

~2100 MW Installed to Date

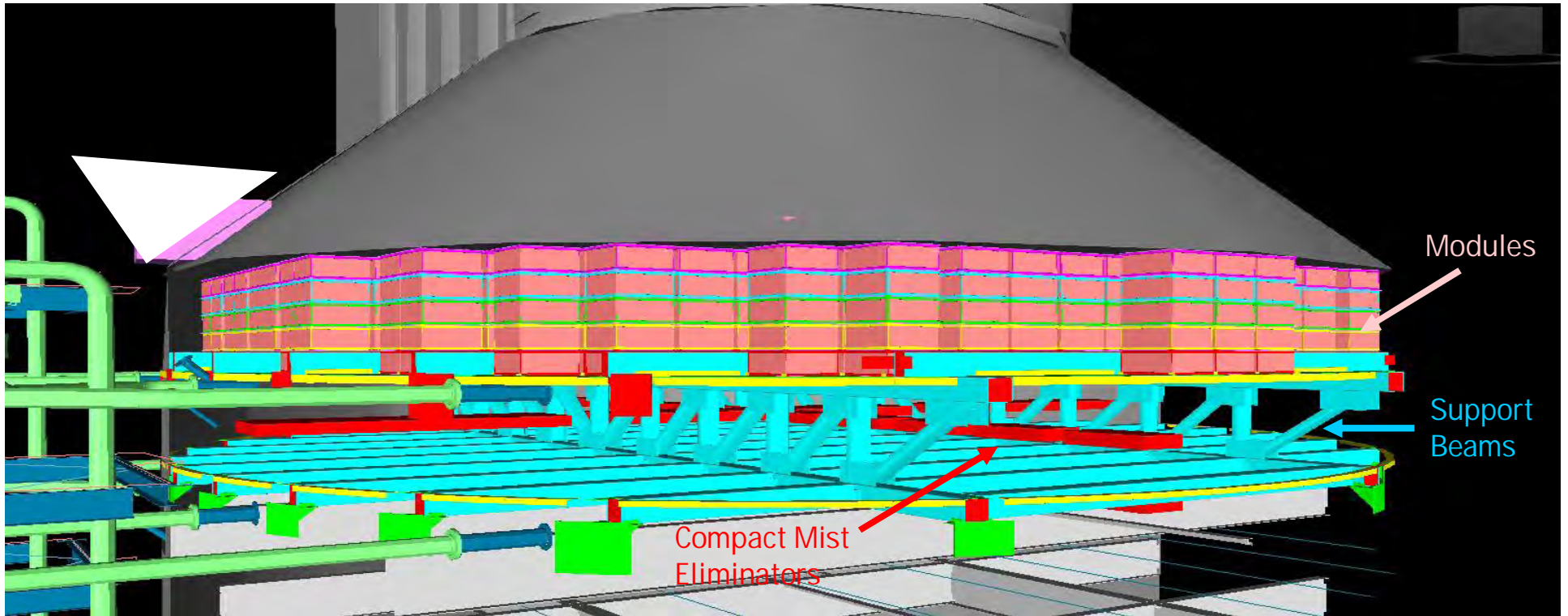
- 1) FirstEnergy Ft Martin Unit 1 (2014)
 - Single Absorber, ~550 MW
- 2) Cayuga Operating Company (2014)
 - Single Absorber, ~150MW
- 3) AEP Conesville Unit 6 (2015)
 - Two Absorbers, ~220 MW each

2016 Installations:

- 4) AEP Conesville Unit 5 (Spring '16)
 - Two Absorbers, ~220MW each
- 5) FirstEnergy Ft Martin U2 (Spring '16)
 - Single Absorber, ~550MW

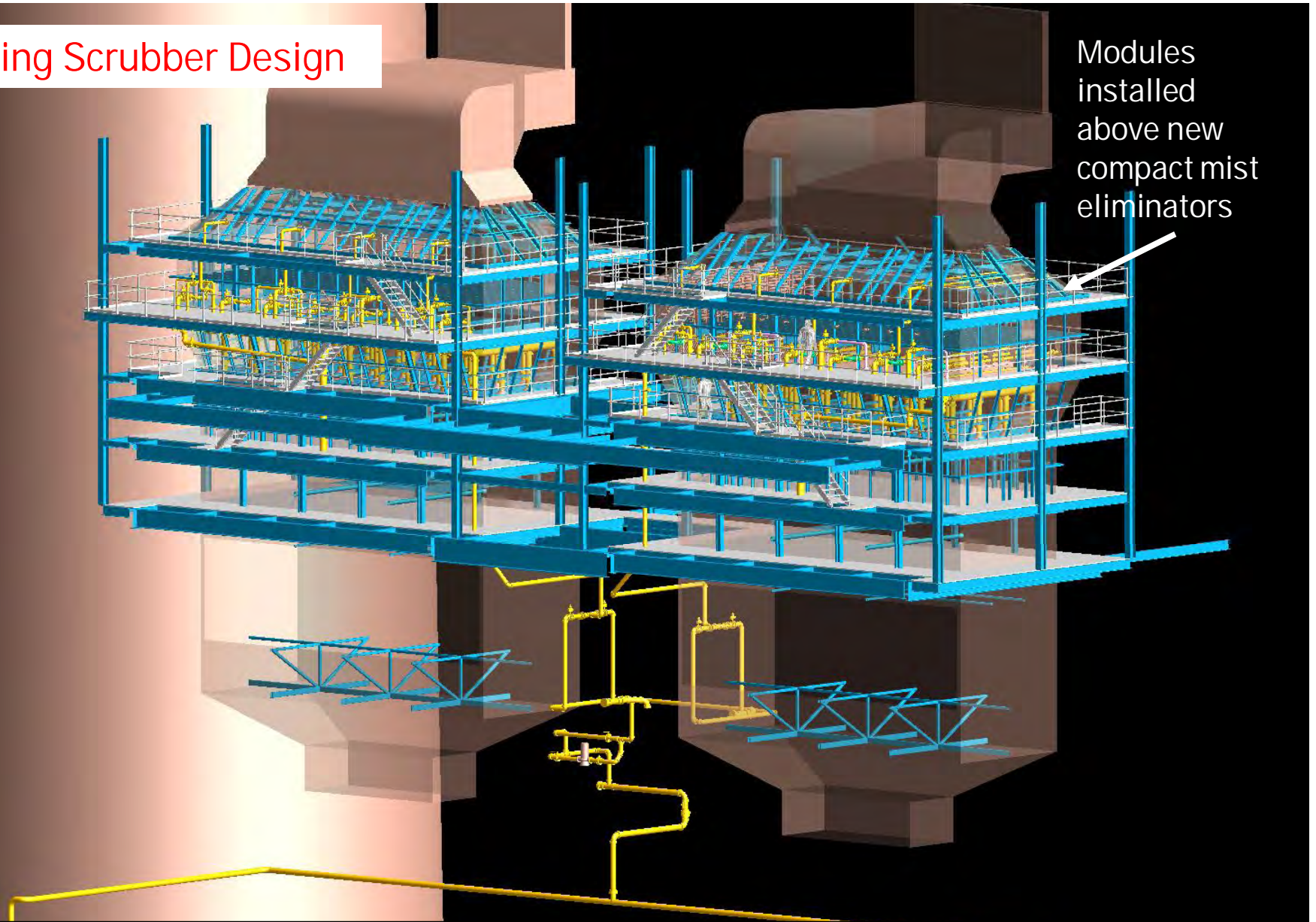


MonPower (FirstEnergy) Fort Martin Installation Approach



EPC performed by AECOM

Existing Scrubber Design



Modules
installed
above new
compact mist
eliminators

American Electric Power (AEP): Conesville Station (Ohio) Units 5/6
Two rectangular absorber vessels per unit

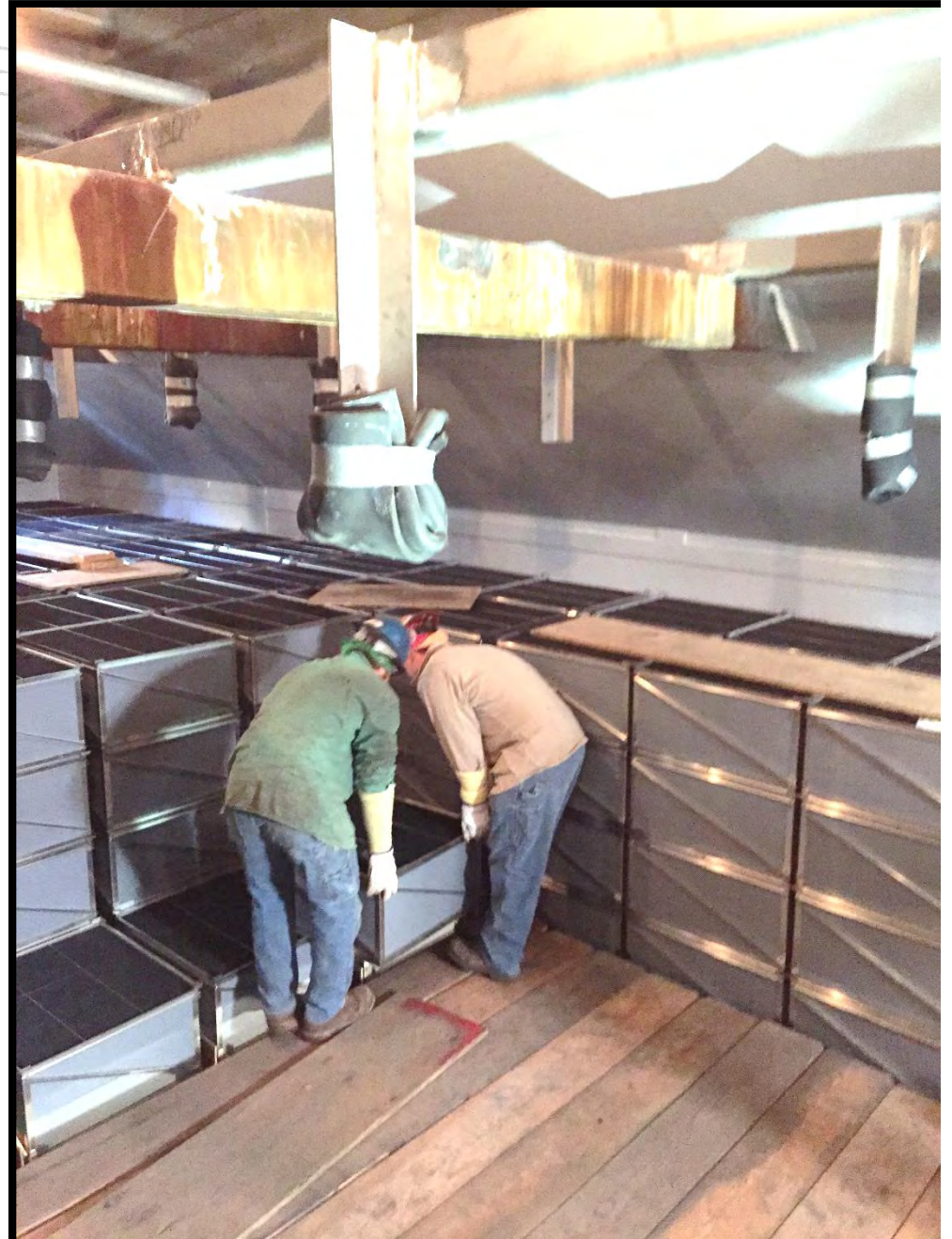


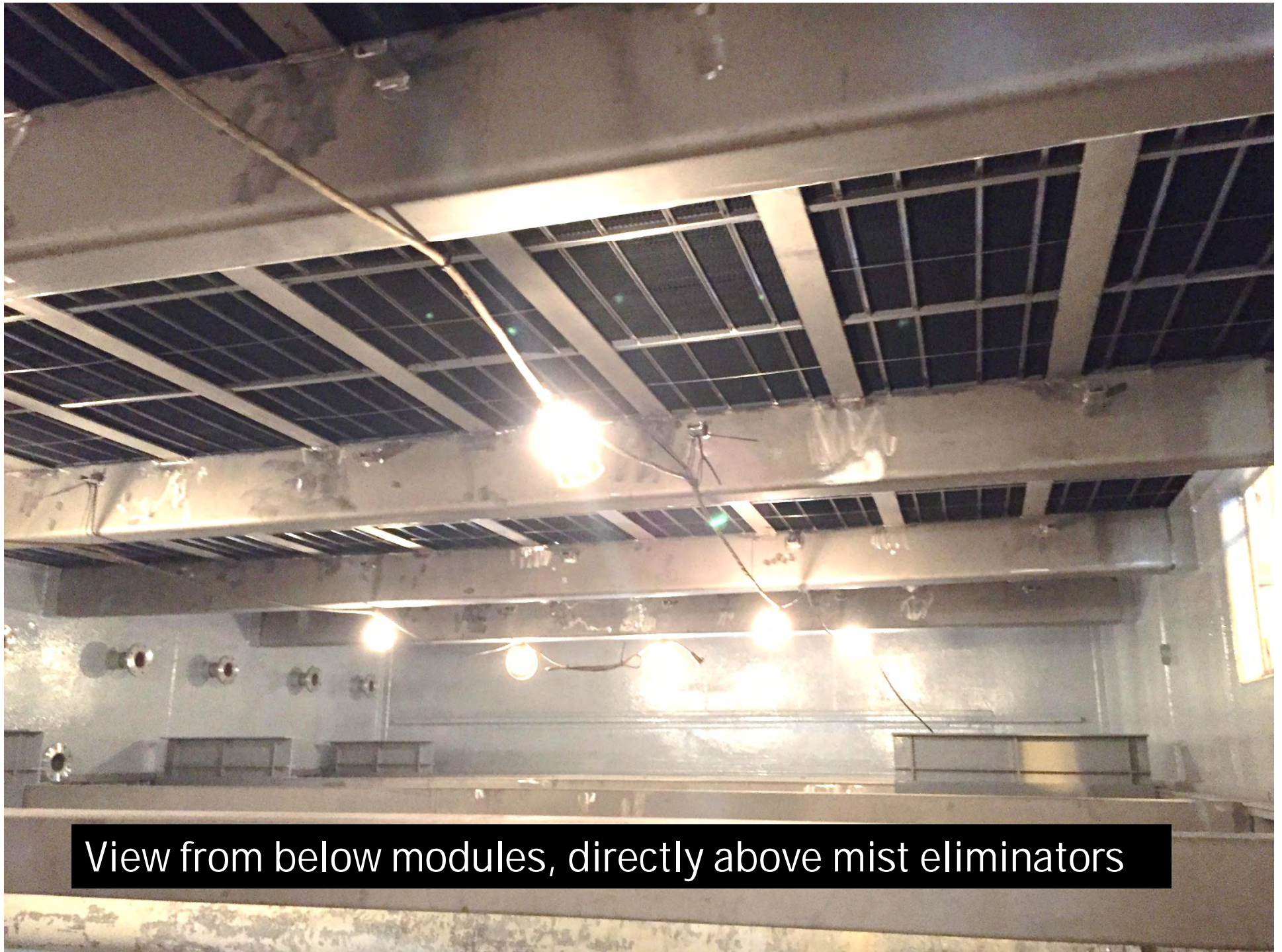
Module Support Grid





Modules Staged at Elevation, Ready for Installation





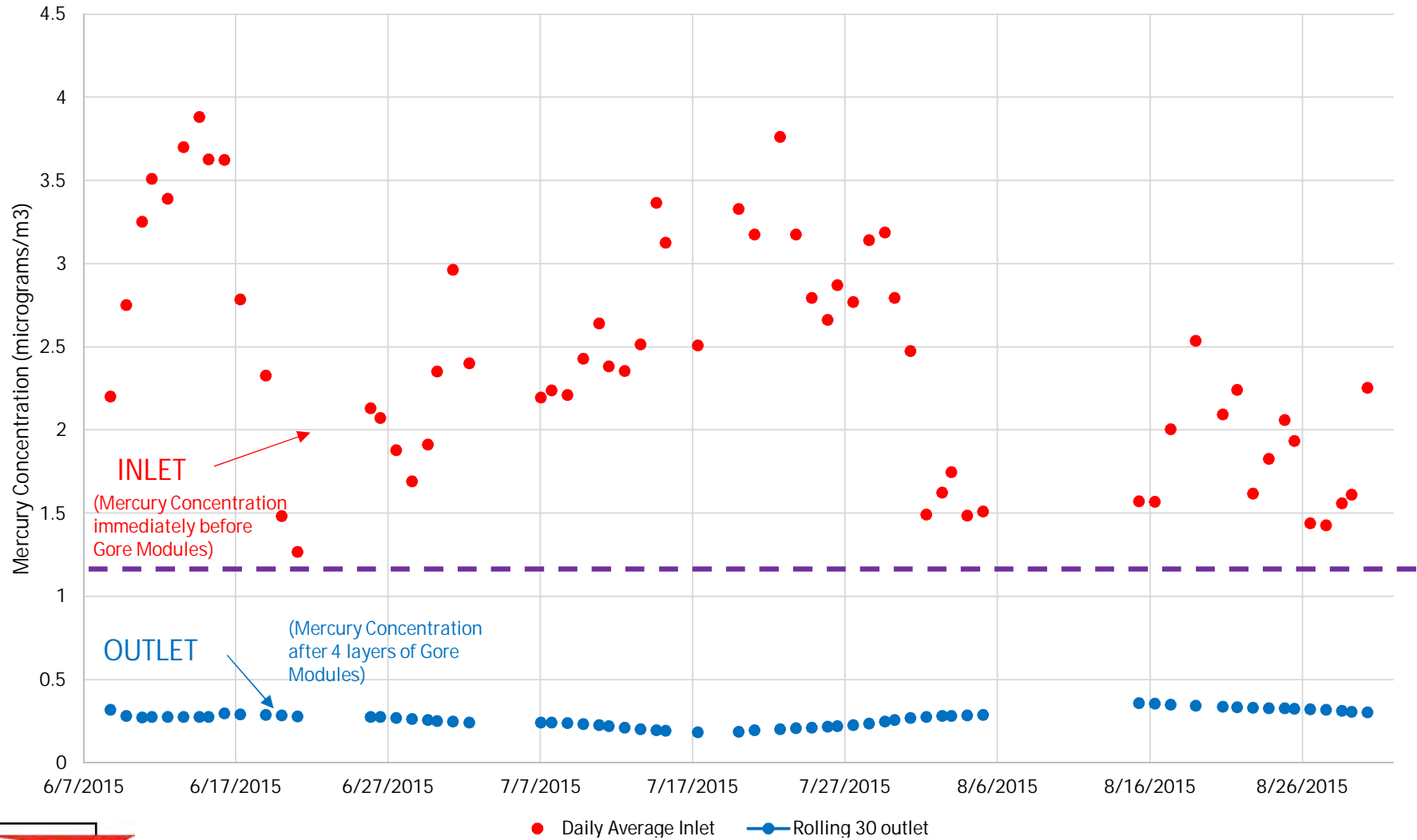
View from below modules, directly above mist eliminators



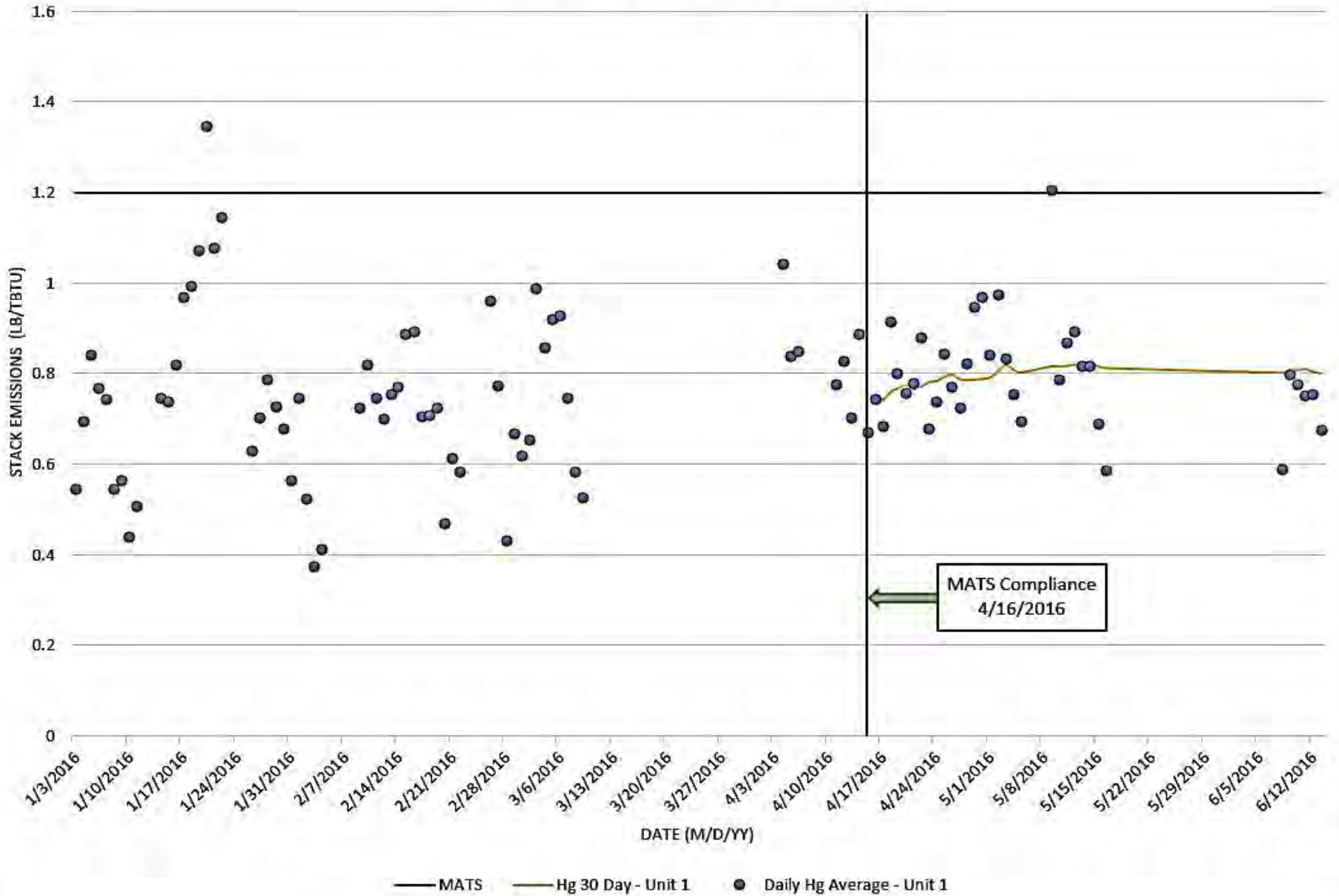
View from above modules, including top rinse system

Full-Scale Results

AEP CV6, Conesville OH



Ft Martin GMCS Performance - 2016 YTD



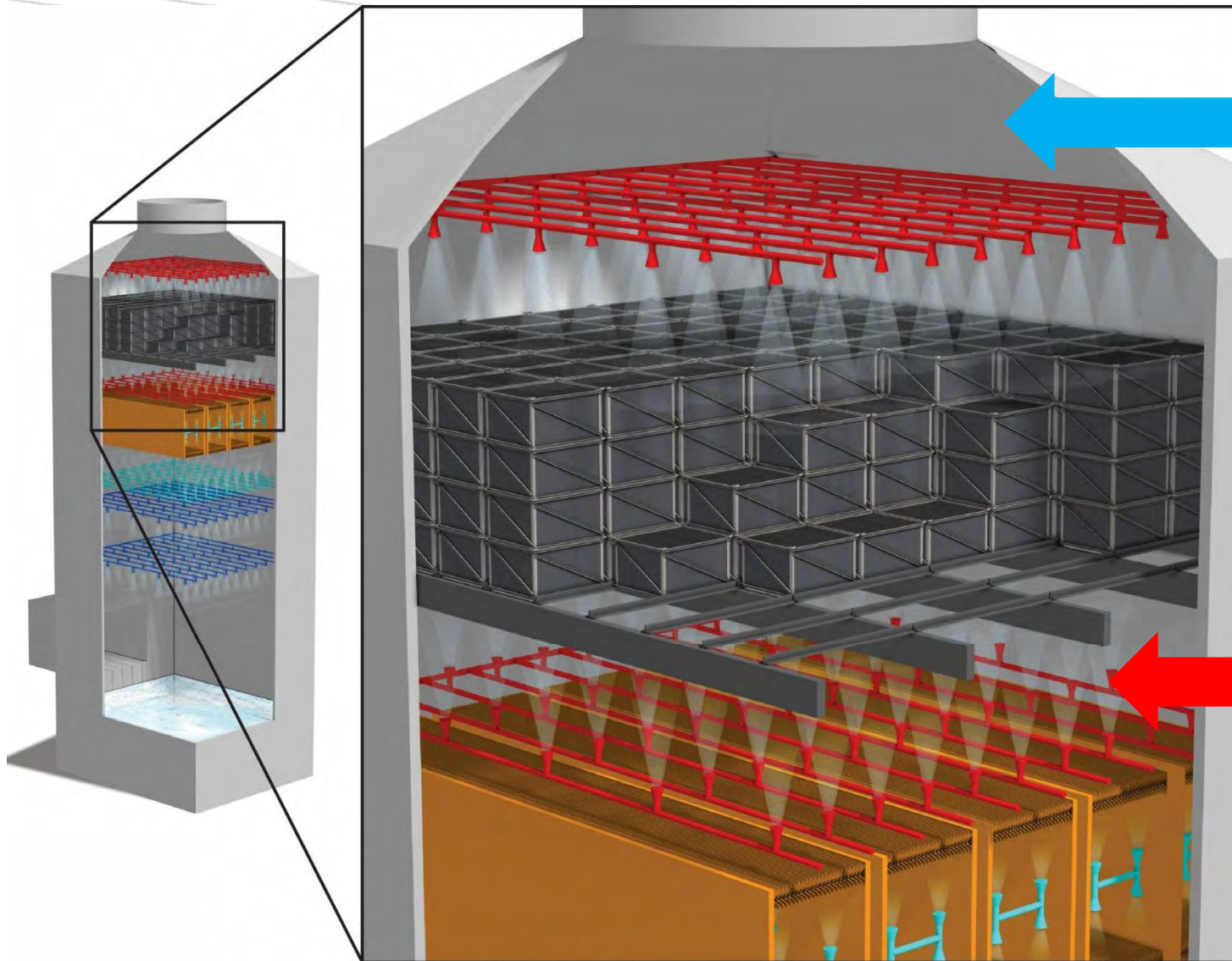
MATS Compliance
4/16/2016

— MATS — Hg 30 Day - Unit 1 ● Daily Hg Average - Unit 1

Lessons Learned

Performance Information

- Difficult to study module performance in the field
 - Modules installed in scrubber can only be accessed during an outage
 - Can't change operating conditions
 - Typically, only outlet (stack) mercury emissions are measured by the plant
 - Doesn't provide module efficiency values
 - Mercury measurements only provide aggregate performance indications
 - Can't monitor performance of individual modules or module stacks
- Desire for additional information
 - Diagnosing health of modules
 - Determining impact of changes to operating conditions
 - Testing next generation SPC formulations



Existing
Sampling Port:
Outlet of wFGD
or stack

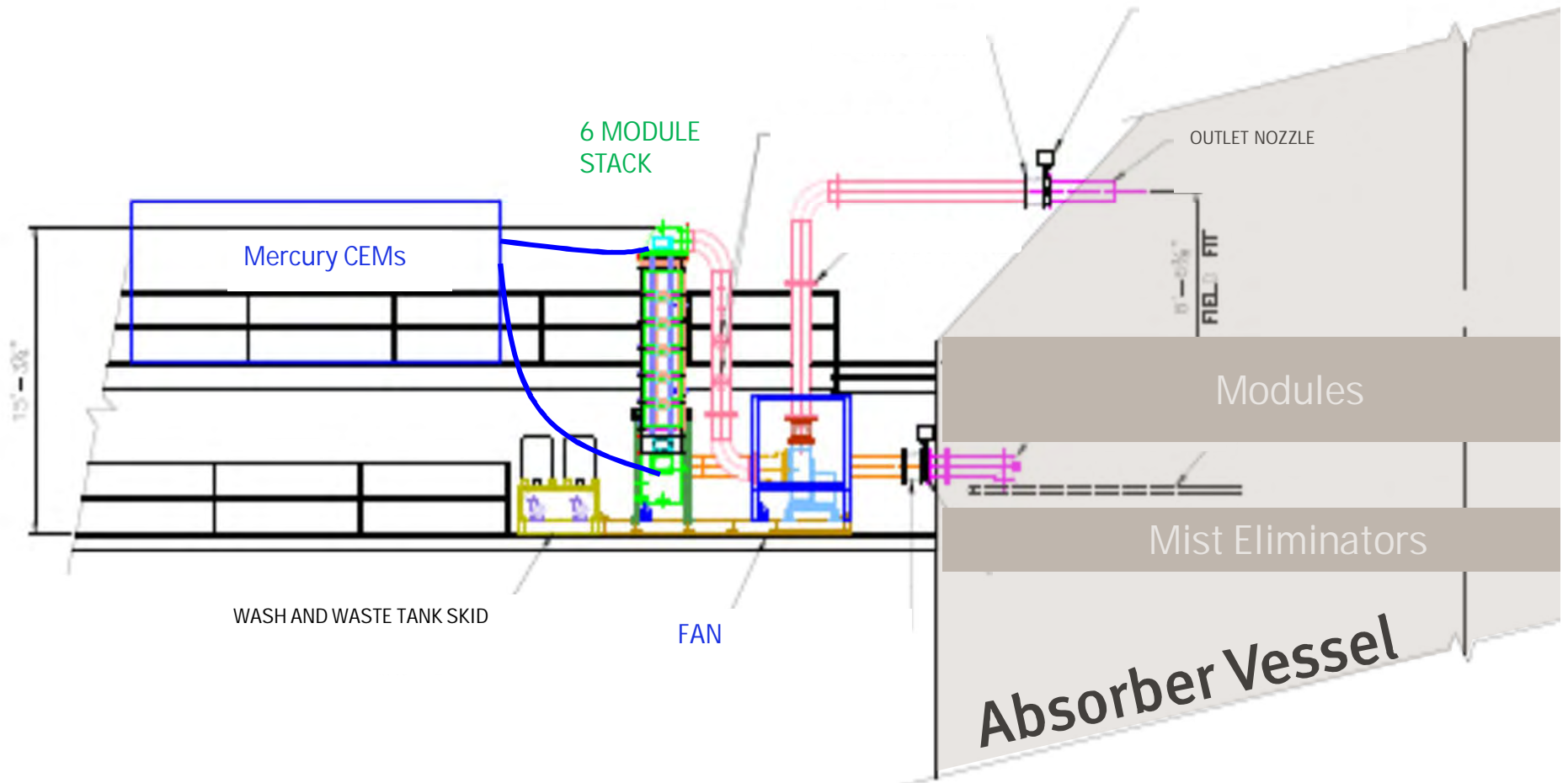
Additional
Sampling Port:
Inlet to
Modules

Slip Stream Pilot Testing

- Over the past 4 years, slip stream pilots conducted at 8 different power plants plus 12 non-power application sites
- ~3000 acfm slip stream, single stack of full-size Modules
- Mercury concentrations measured before and after Module stack



Slip Stream Pilot on wFGD







Slip Stream Pilot Testing

- Over the past 4 years, slip stream pilots conducted at 8 different power plants plus 12 non-power application sites
- ~3000 acfm slip stream, single stack of full-size Modules
- Mercury concentrations measured before and after Module stack

- ☑ Testing in very representative conditions
- ☑ Use of External Fan allows for study of impact of velocity
- ☑ Pilot can be shut-down at any time to analyze or change modules

- ☒ Investment required to construct, install, and operate the pilot plant
- ☒ Experiments need to be run in series. Difficult to study long-term impacts
- ☒ Some effects difficult to simulate in a single stack of modules (zone washing)



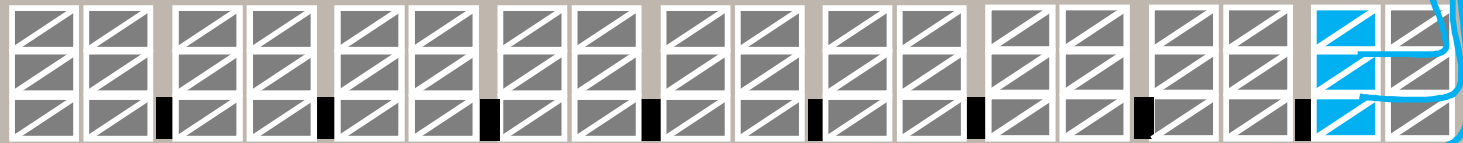
In-Scrubber Monitored Stacks

Overall Performance

Monitored Stack

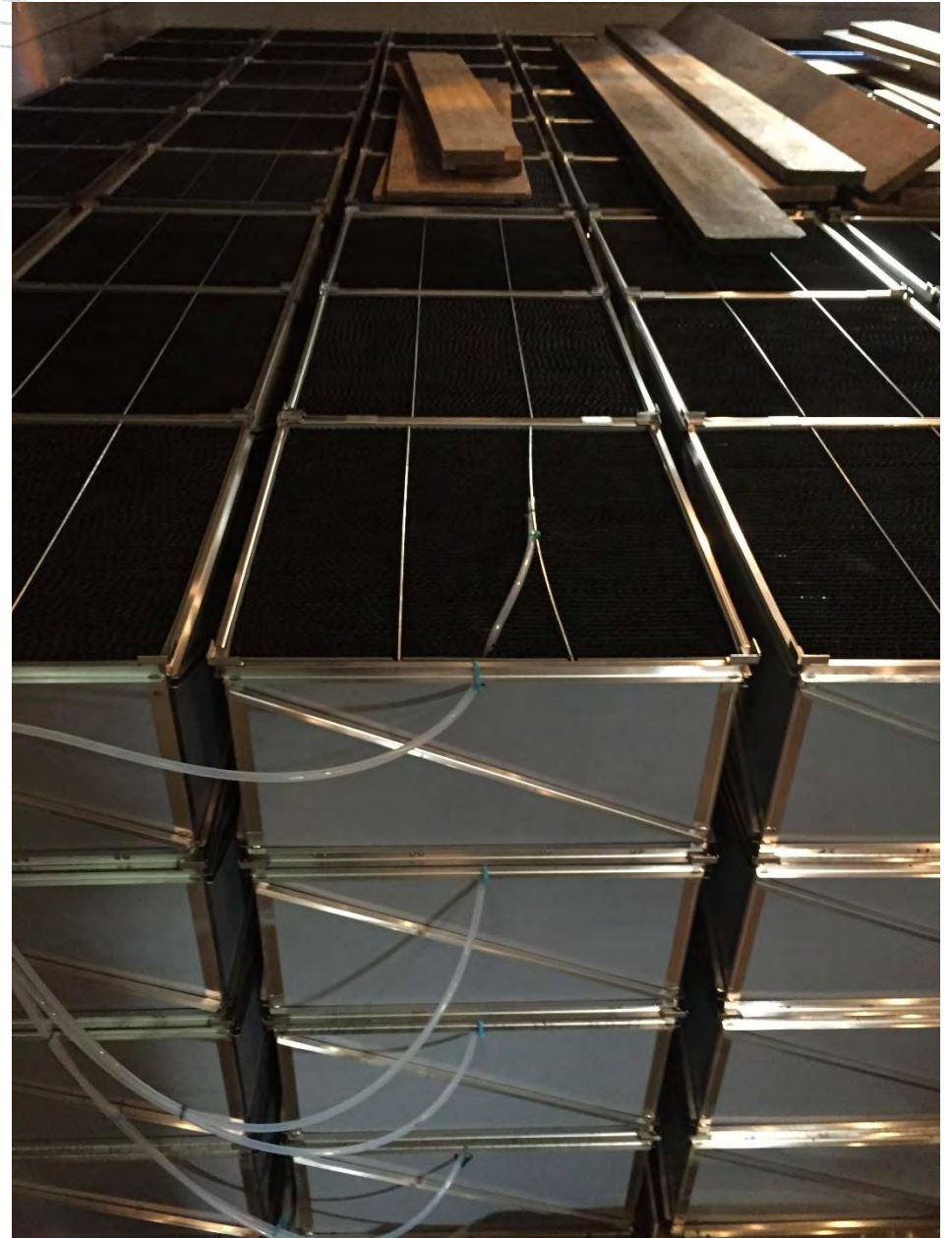
OUTLET

INLET



Mist Eliminators

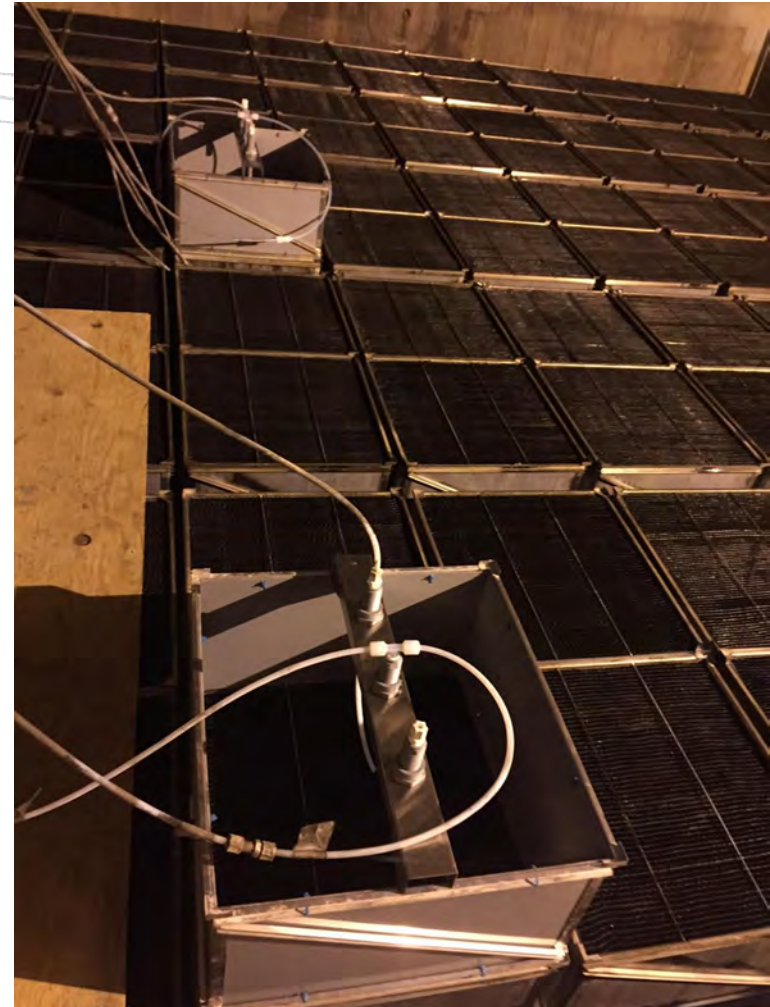
In-Scrubber Test Stacks / Monitored Stacks



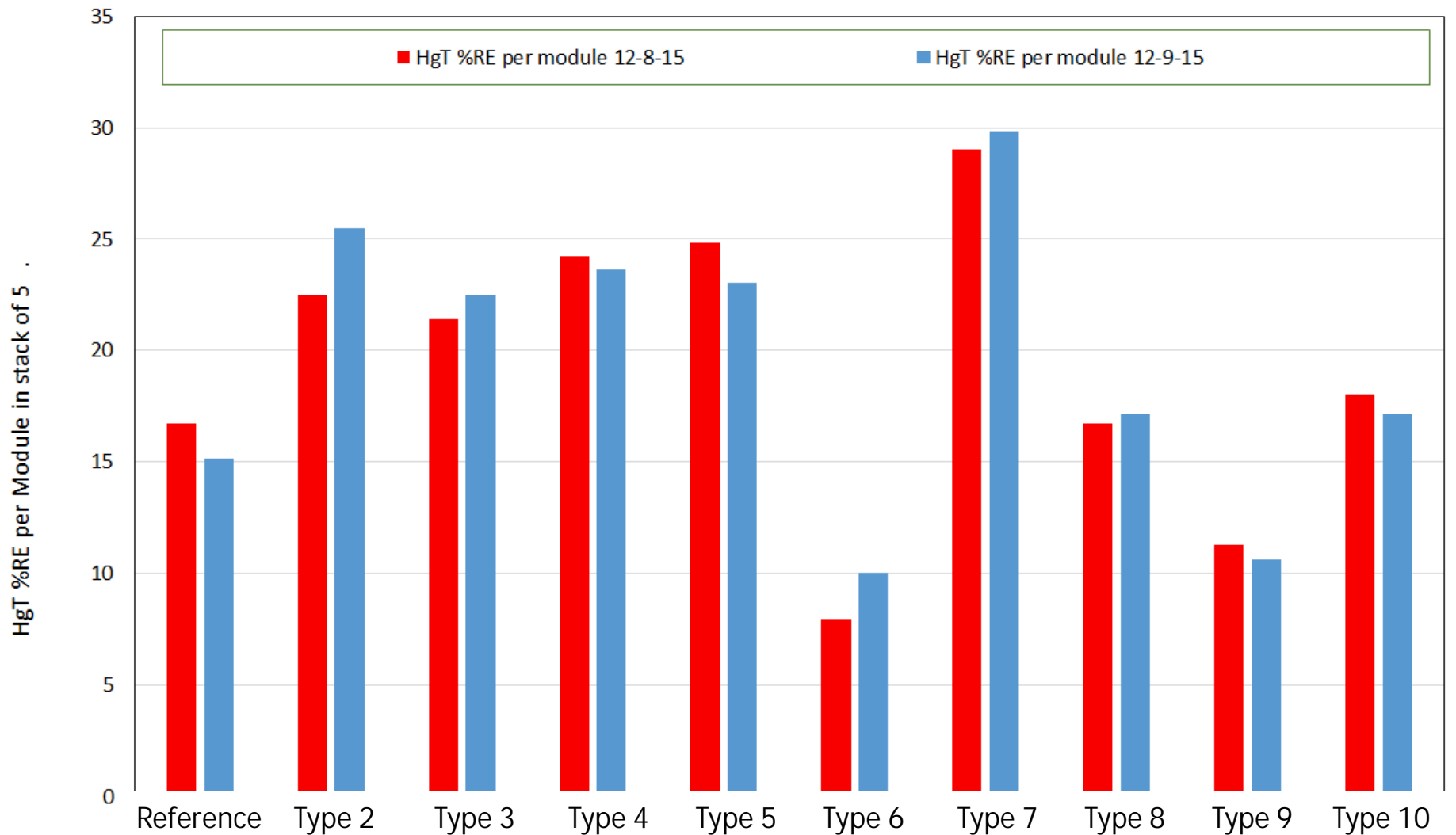


In-Scrubber Test Stacks

- Very low cost to install, no cost to operate
 - ✓ Periodic performance measurements
- Performance over time of individual test stacks
 - ✓ Wash system optimization
- Performance over time of individual modules
 - ✓ First layer performance vs. top layer performance
- Performance of next generation SPC formulations
 - ✓ Tested alongside standard formulations



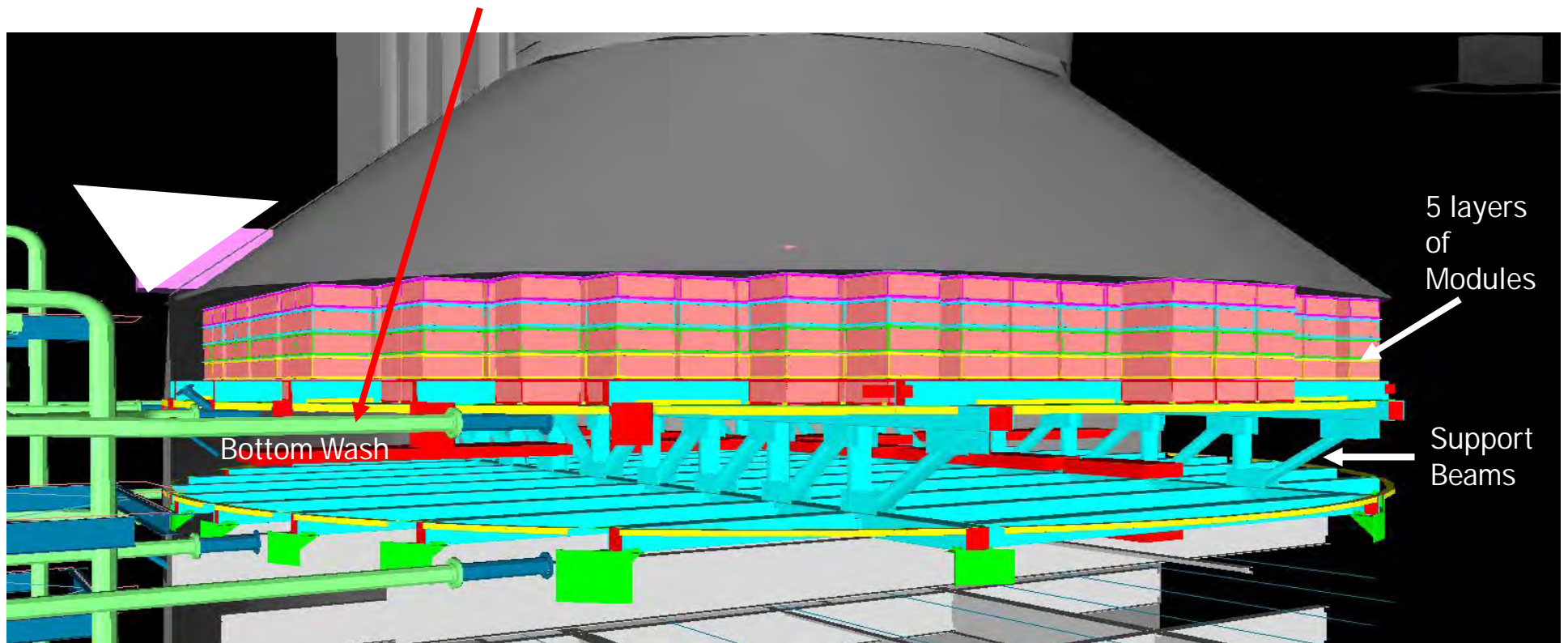
In-Scrubber Test Stacks Hg Performance Measurement



10 monitored stacks (out of total of ~400 installed stacks in scrubber):
Experimental formulations evaluated for Hg and SO₂ removal performance

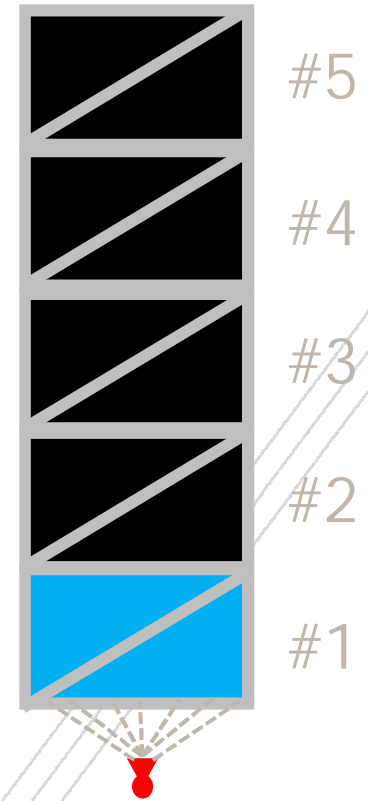
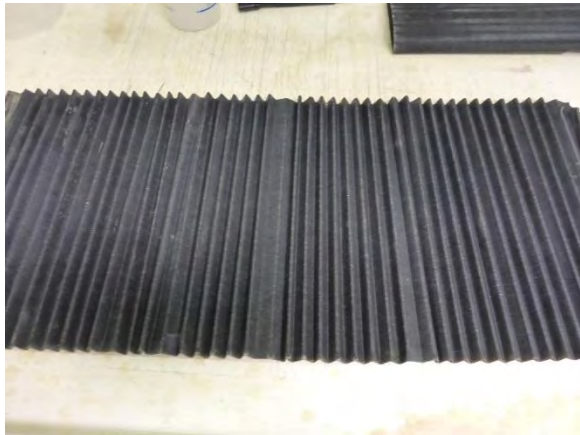
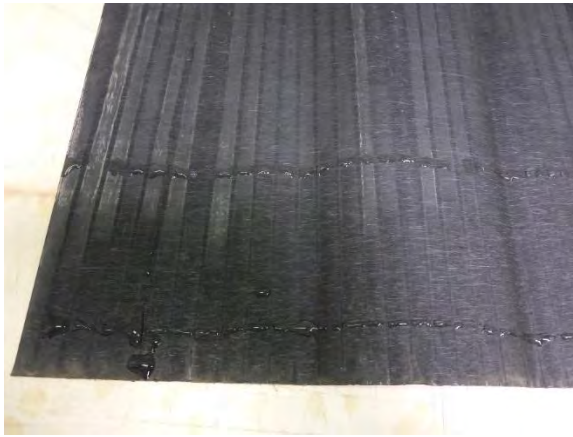
Process Residuals and Wash System Design

Fort Martin Original Design: Bottom wash grid only

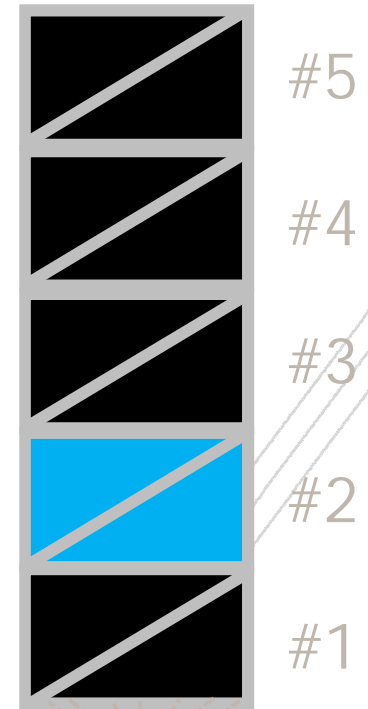
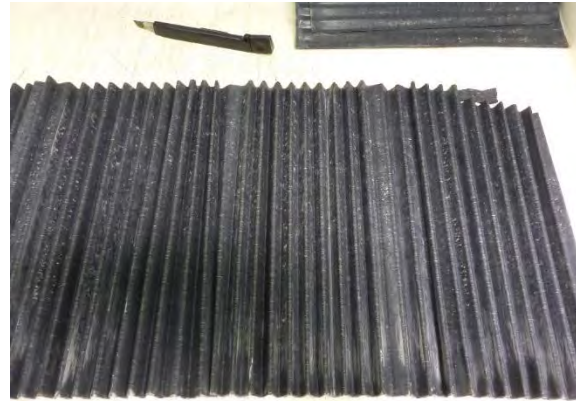
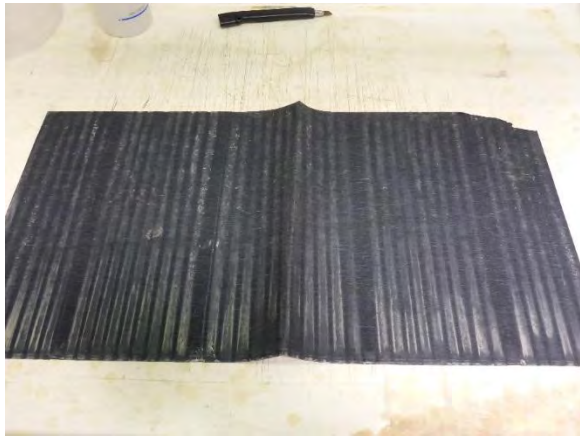


Engineering/Construction by AECOM

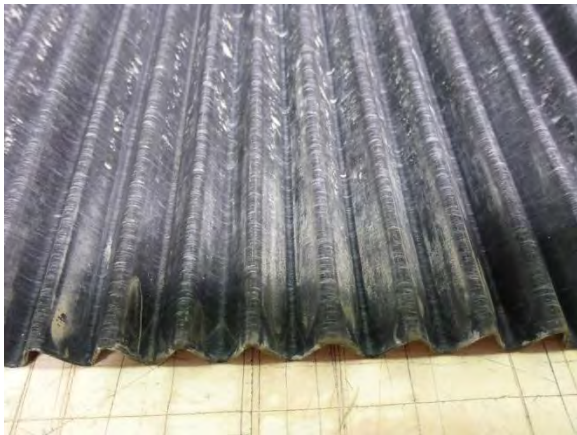
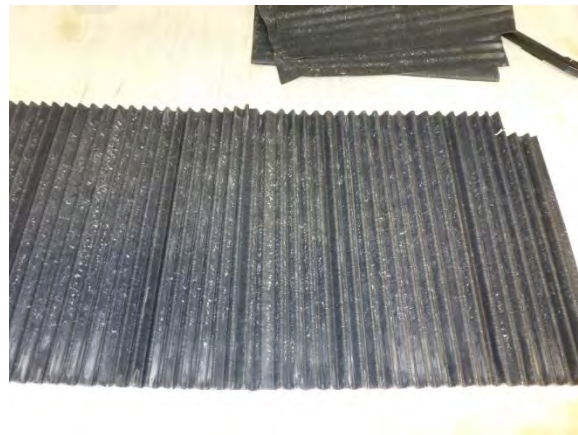
Module 1 after several months of operation



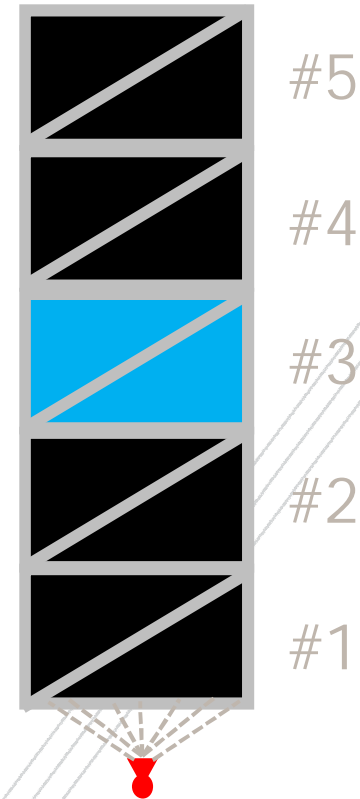
Module 2 after several months of operation



Module 3 after several months of operation

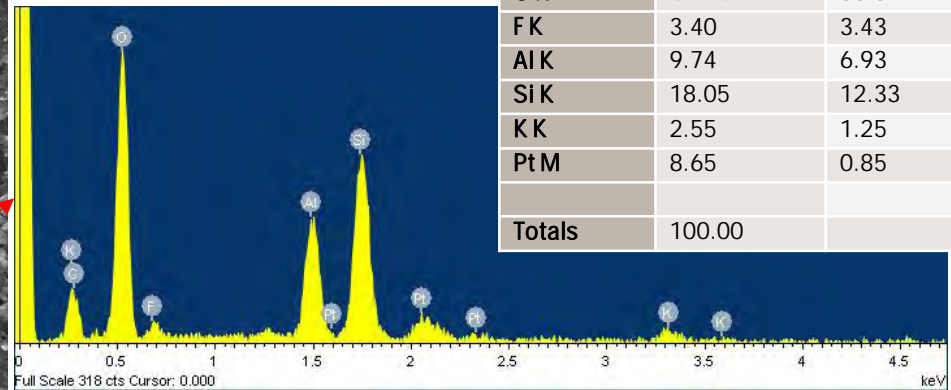
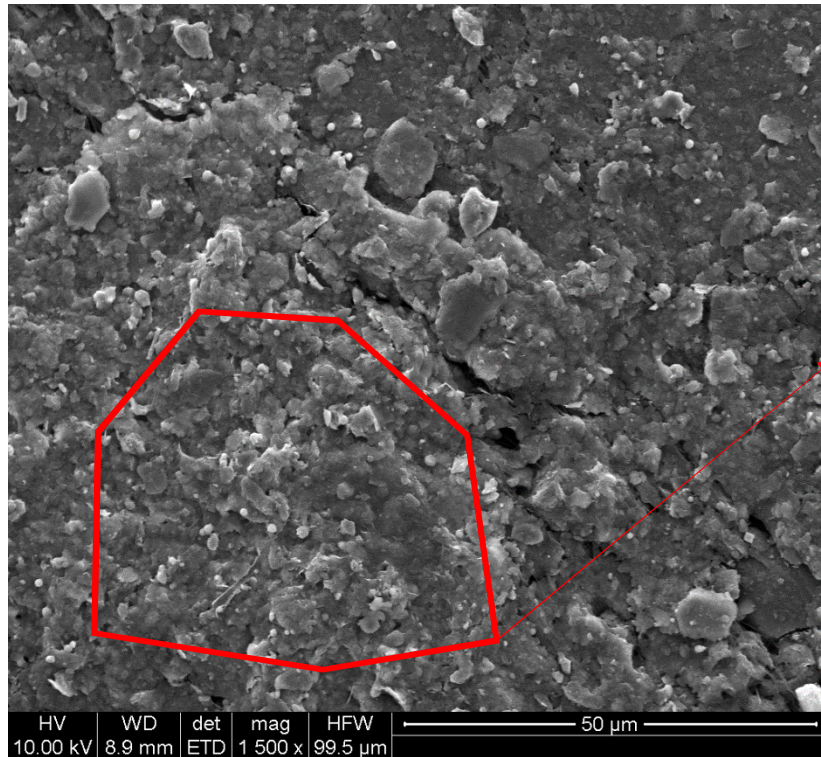


Bottom Washing System is not effective at cleaning top 3 layers of modules



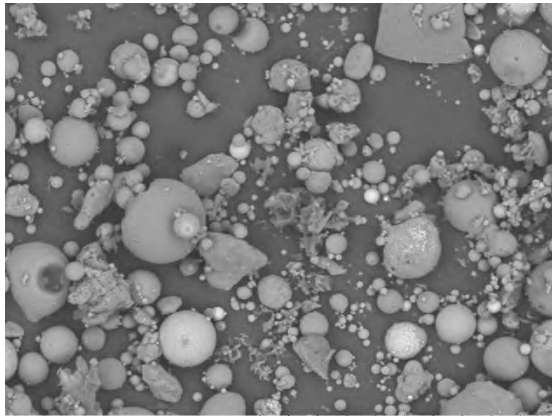
Characterization of Solids present on SPC material by X-Ray Diffraction and Electron Microscopy

- Silica and Alumina

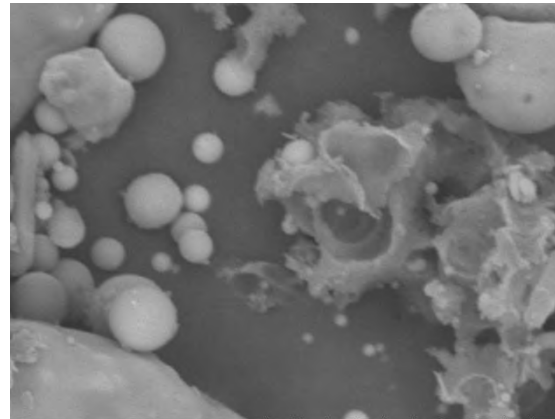


Element	Weight%	Atomic%
C K	15.47	24.70
O K	42.14	50.52
F K	3.40	3.43
Al K	9.74	6.93
Si K	18.05	12.33
K K	2.55	1.25
Pt M	8.65	0.85
Totals	100.00	

Comparison of particulates to Fly Ash from ESP hopper

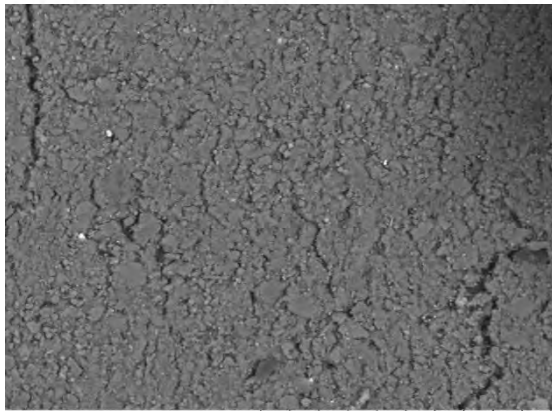


10256-1812 2015/07/09 x1.0k 100 um

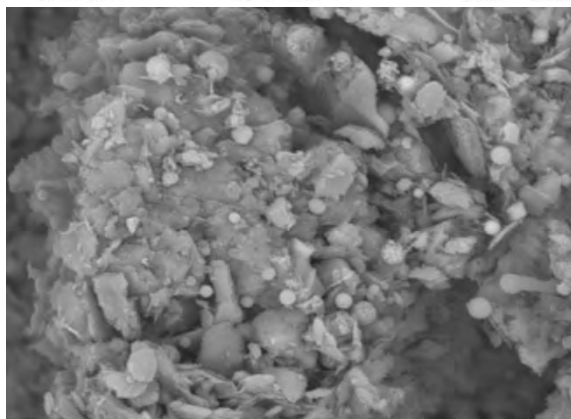


10256-1812 2015/07/09 x5.0k 20 um

Fly Ash from ESP hopper



10442-70-1 2015/09/09 x1.0k 100 um

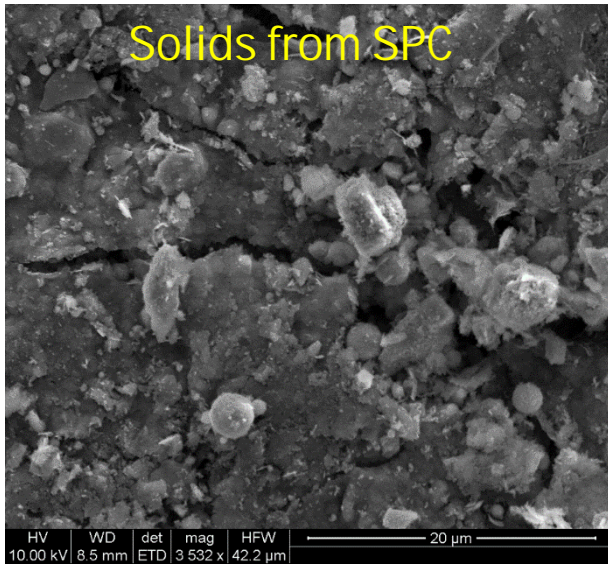


10442-70-1 2015/09/09 x5.0k 20 um

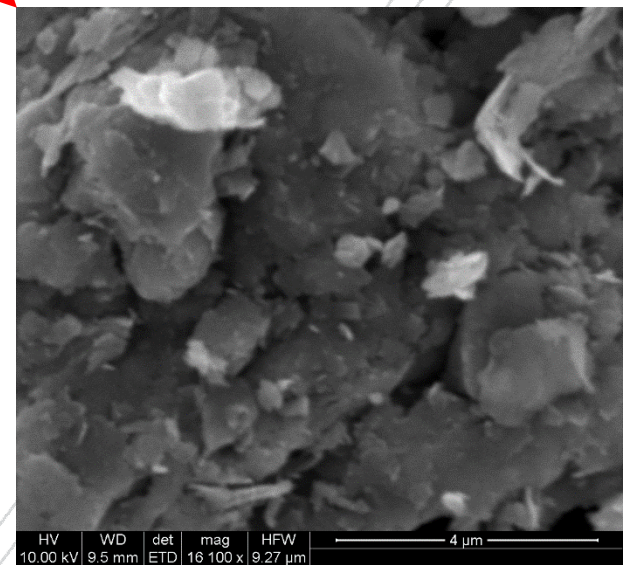
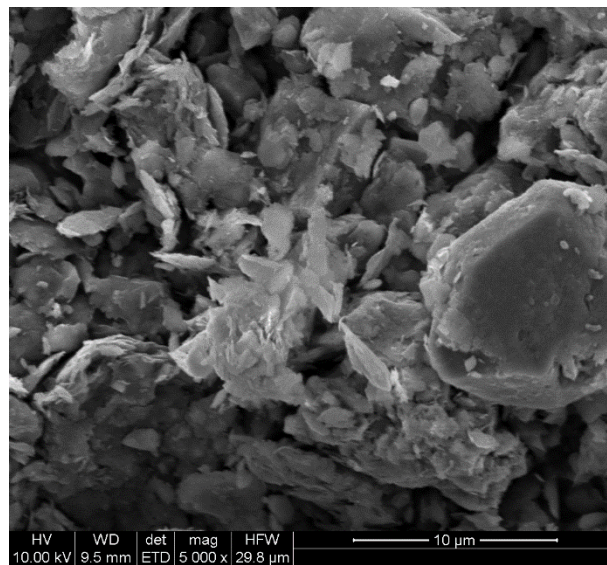
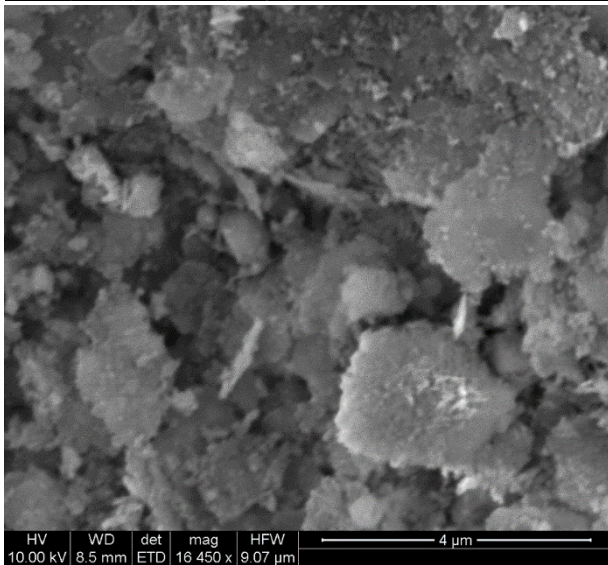
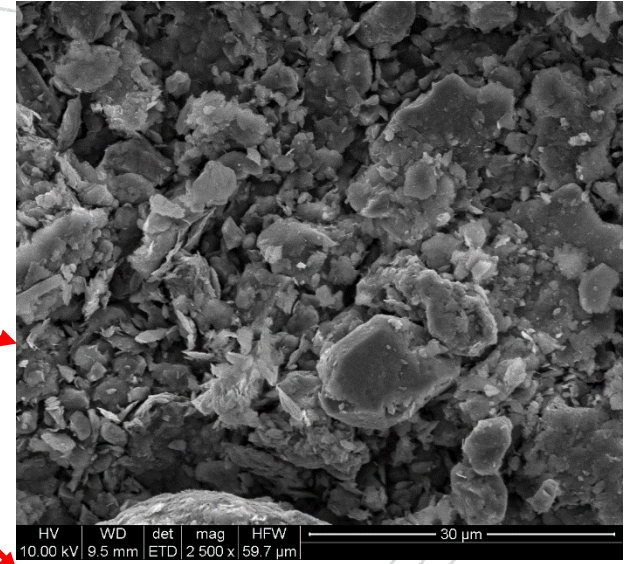
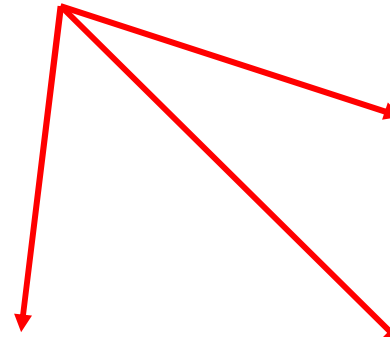
Particulate collected from modules

Very Different Morphology Observed

What is the source of the small particles with not very well defined shape?



Limestone inerts



Comparison to Mag Lime Site

SPC after extended operation at mag lime site with top washing system: Very clean appearance

Stack PM emissions similar between mag lime site and limestone site

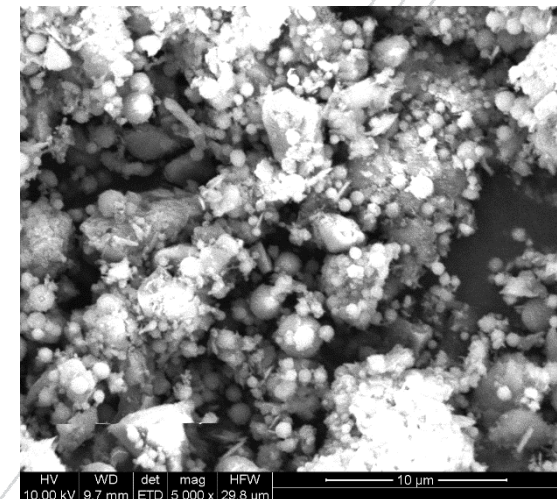
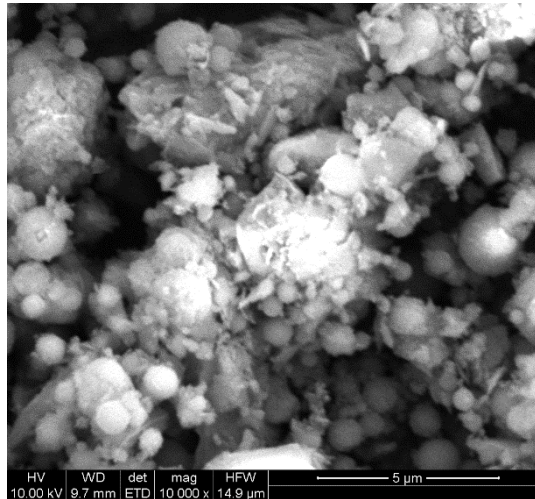
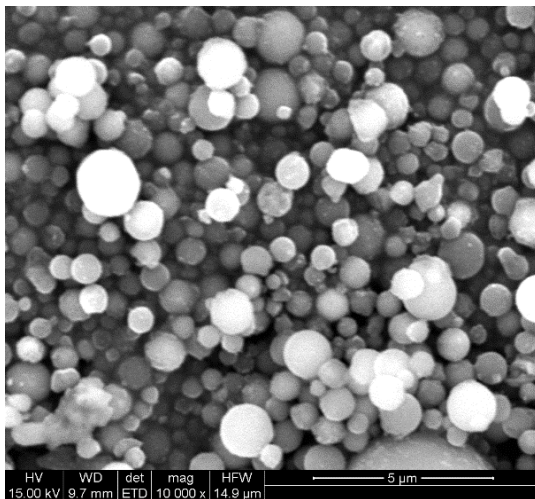
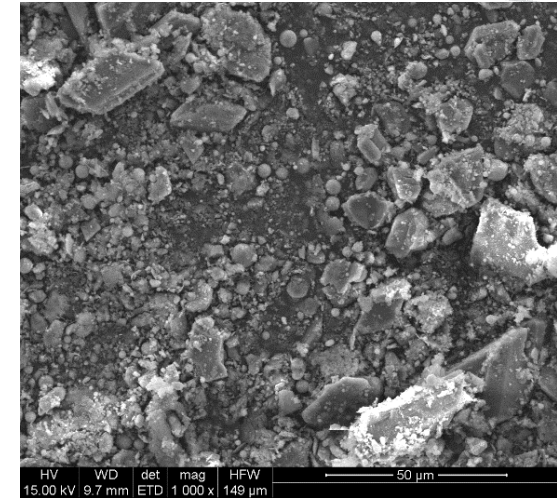
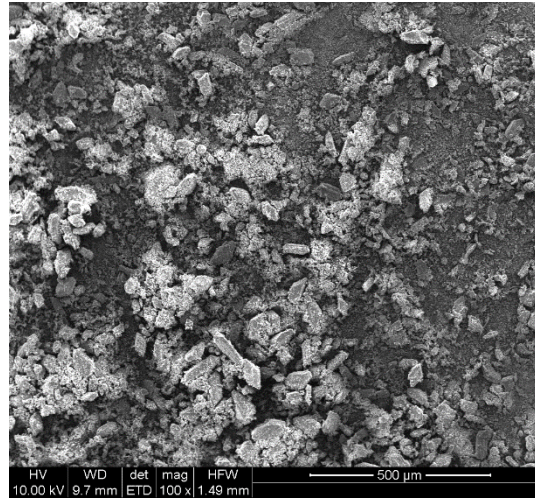
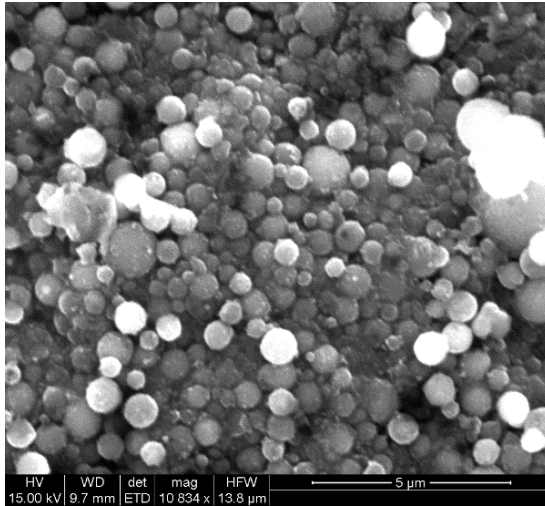
Combined impact of top wash system AND much lower level of inert material in lime



Particulates collected outside the modules at Mag Lime site & Limestone site

Mag Lime Site

Limestone Site

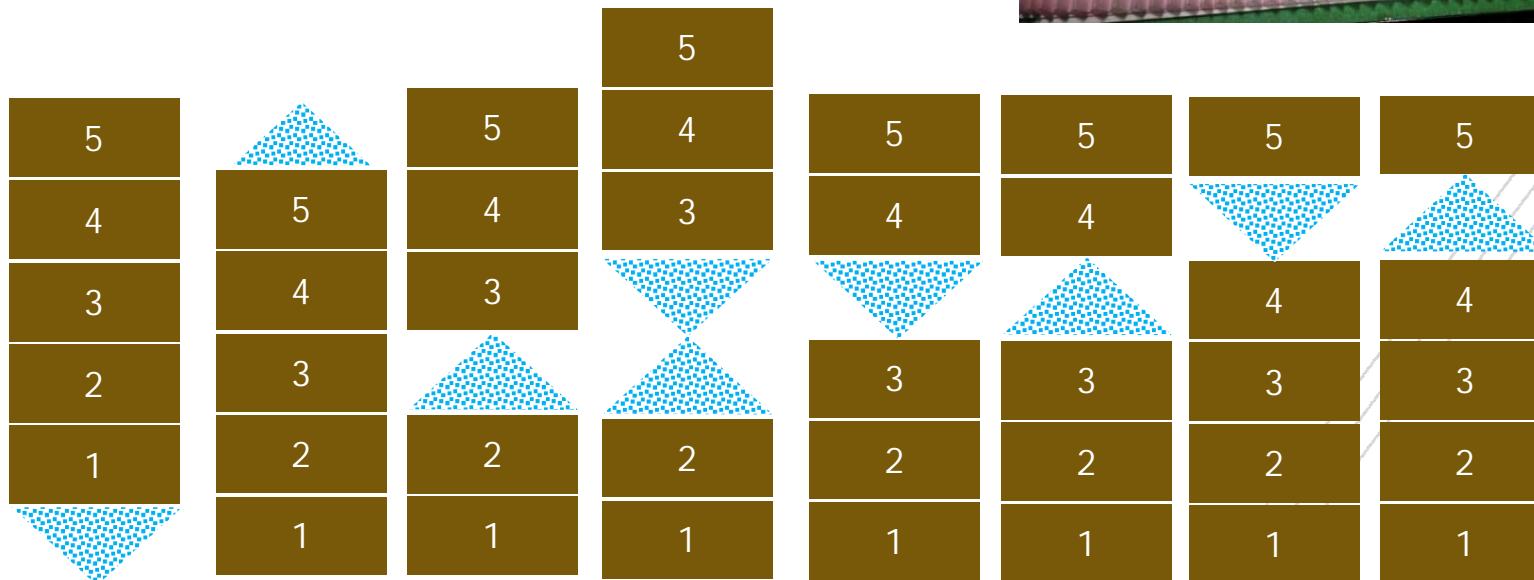


Solids Analysis Conclusions

- Solids found on SPC from limestone sites is a combination of fly ash and an aluminosilicate material that appears consistent with limestone inerts
- SPC samples from Mag Lime site with top wash system were very clean with only a very few spherical fly ash particles
- Improved washing may be needed to keep limestone inerts from accumulating on SPC
- Washing study commenced at Alden Labs to optimize wash system design

Alden Labs Wash Studies

- Evaluated effectiveness of washing (wash water penetration) using colored dyes
 - Location of wash
 - Direction of wash
 - Type of wash nozzle (angle, volume)
- Evaluated liquid carryover during washing as a function of velocity
- Determined optimum wash system design

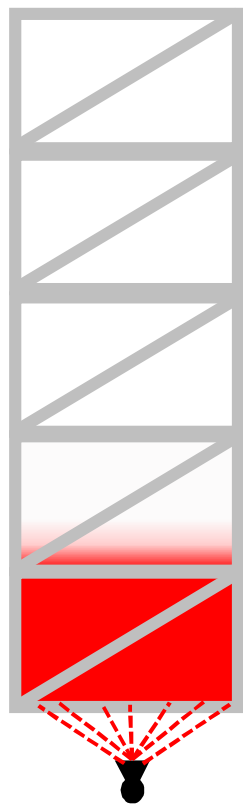


W. L. Gore & Associates

Various Configurations Tested

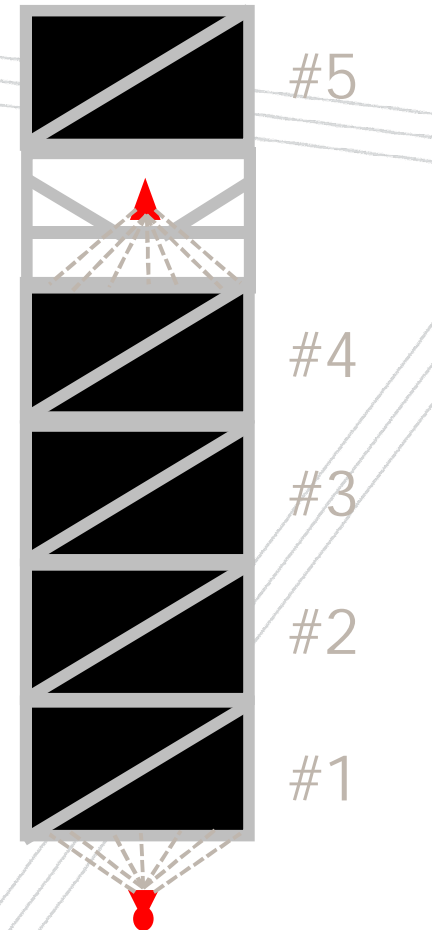


Ft Martin Unit 1: Wash system modified Fall 2015



Original Wash Design

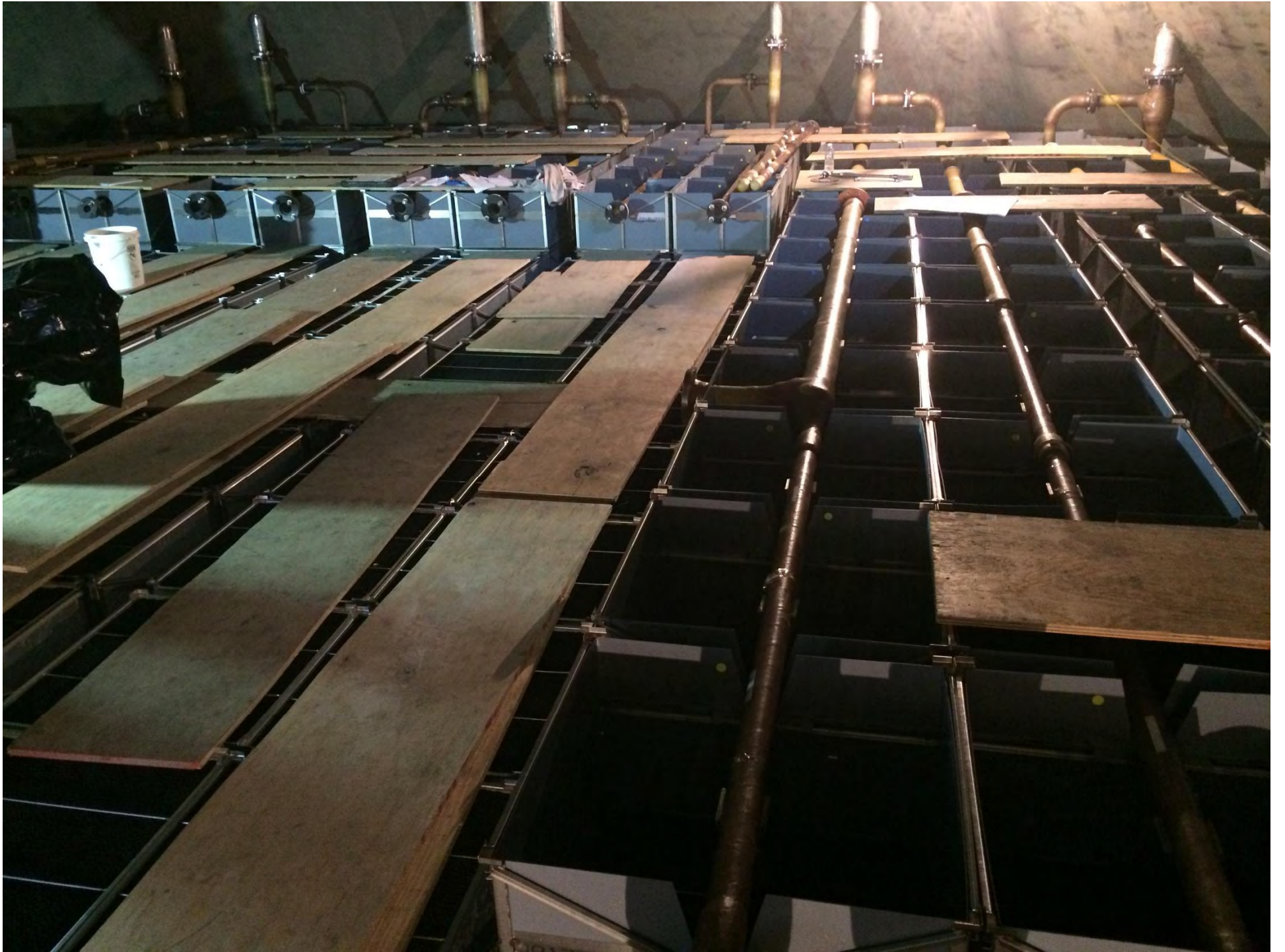
- Fifth layer raised, inter-module wash grid installed
- Significant improvement in removal efficiency after wash system installed
- Ft Martin Unit 2 installed same modified wash design



Modified Wash Design

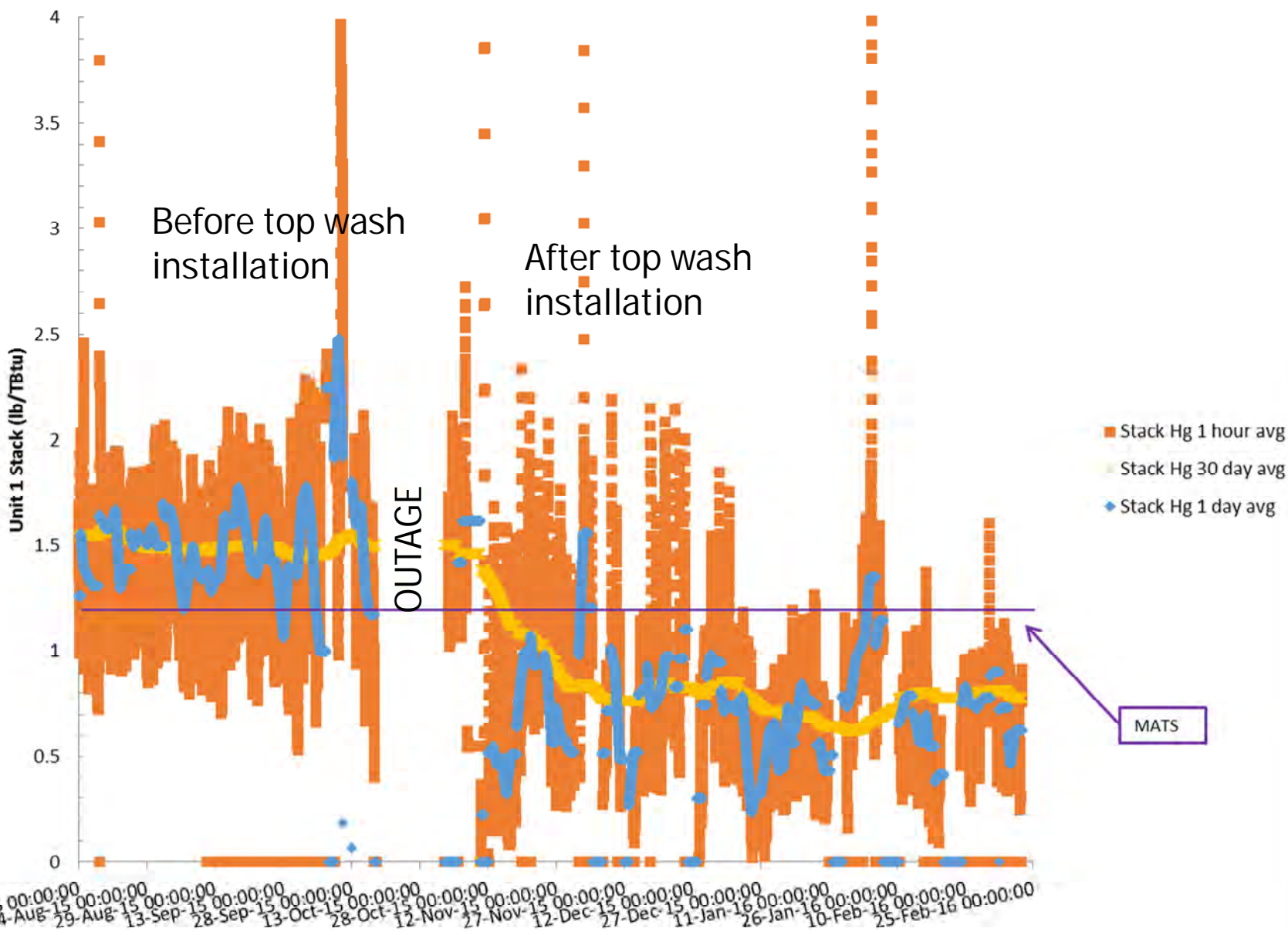








FirstEnergy Fort Martin Unit 1 GMCS



Thank You!

Questions?

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