Reinhold Environmental Ltd.

2006 APC Round Table & Expo Presentation

July 16-18, 2006, Columbus, OH

Mercury Control and Measurement

Reinhold Fabric Filter/ESP Roundtable

July 17, 2006

Sharon Sjostrom

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Near-Term Mercury (2005-2008) Drivers

State Regulations:

Massachusetts: 85% removal by 2008; 95% by 2012:

New Jersey: 90% removal by 2008

Additional States with Regs. – Connecticut and Wisconsin

New States announcing Regs. In 2006 – Maryland and Minnesota

States considering Regs. – NC, DE, NH, PA, IN, MN, MI, VA, GA, and IL

*"**Illinois** Governor seeks 90% mercury reduction: Coal plants would have to comply by '09" Chicago Tribune January 5, 2006*

*"**Pennsylvania** Would Demand Big Mercury Cuts from Power Plants under New Proposal" (80% by 2010 and 90% by 2015); AP February 22, 2006*

***Maryland** Department of the Environment (MDE) unveiled Governor Ehrlich's proposed Clean Power Rule*

Consent Decrees:

Wisconsin, Colorado, Illinois, New Mexico

New Power Plants:

20 to 80 new coal-fired power plants moving forward

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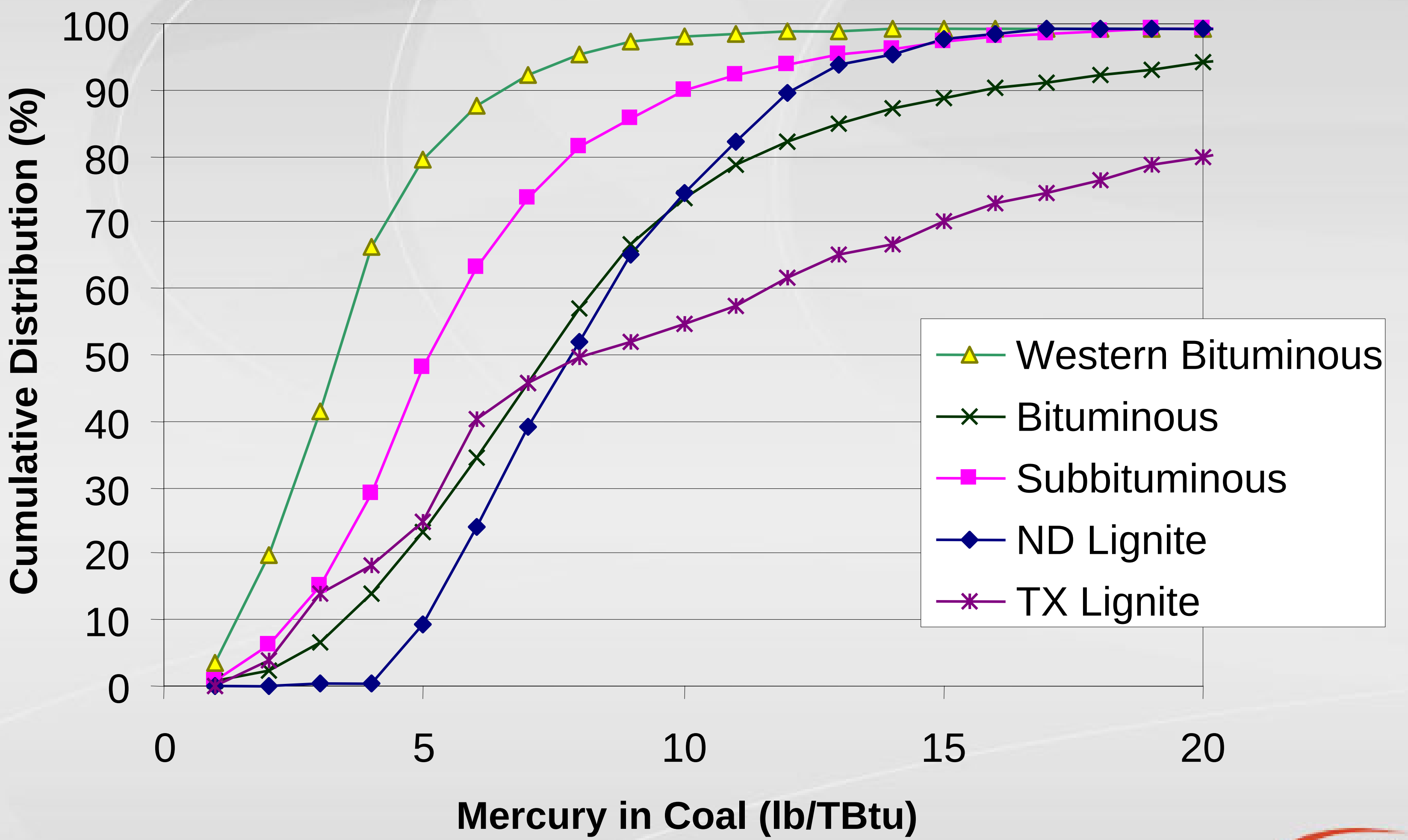
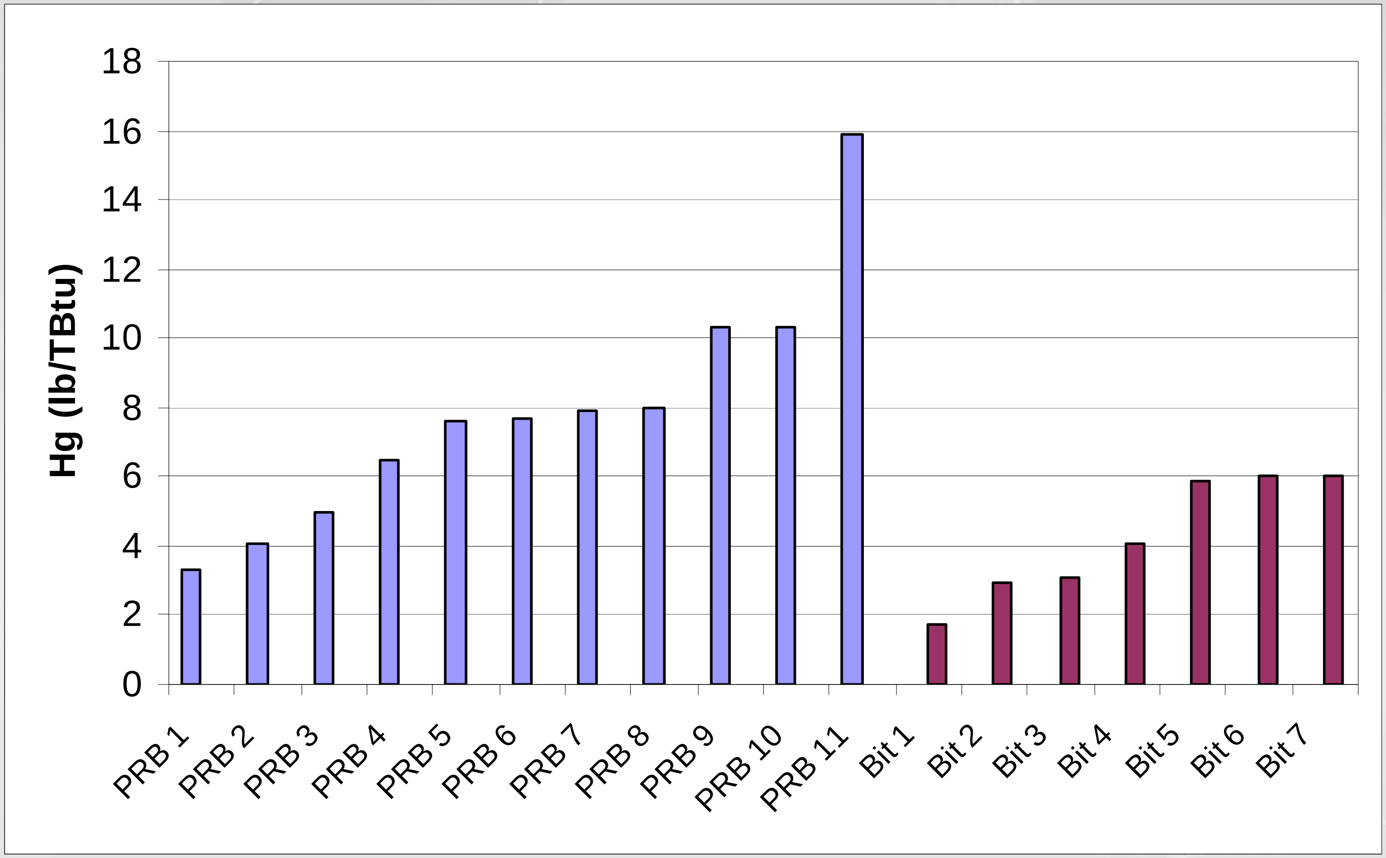
Mercury Control

- Native Removal
- Co-Benefits
  – FGD
  – SCR
- Sorbent Injection
  – Low sulfur coals
  – High SO_3 flue gas

Distribution of Mercury in Coals



Process Variability: Coal from One Fleet



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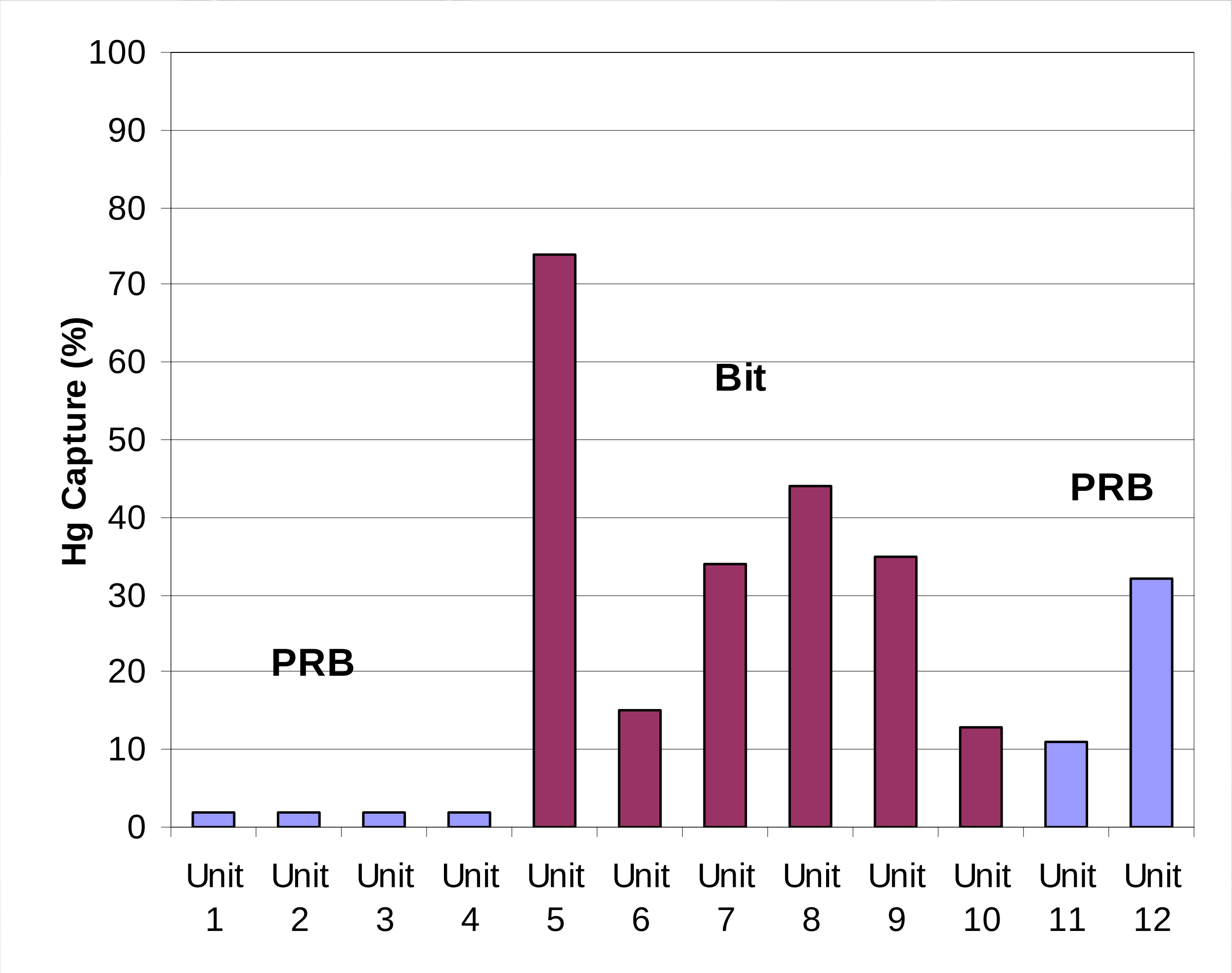
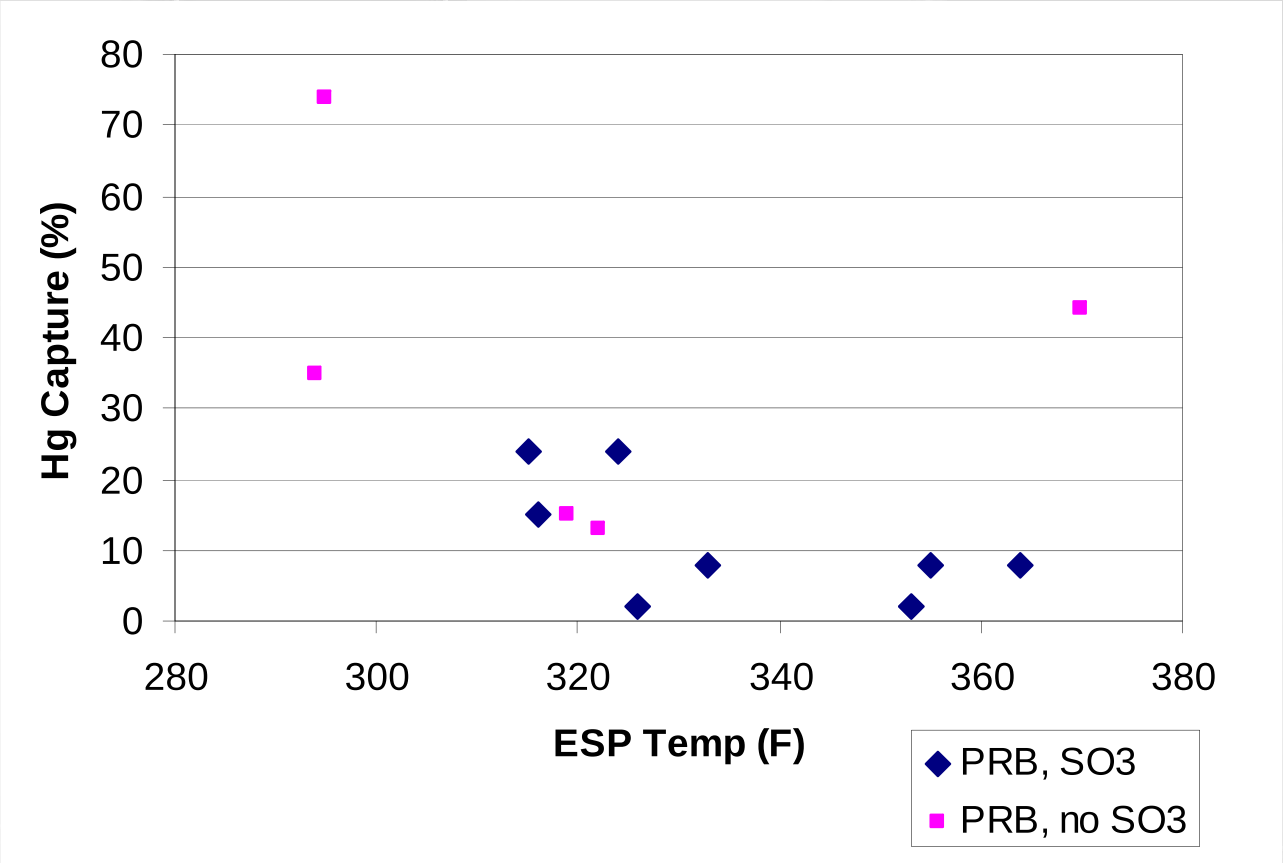
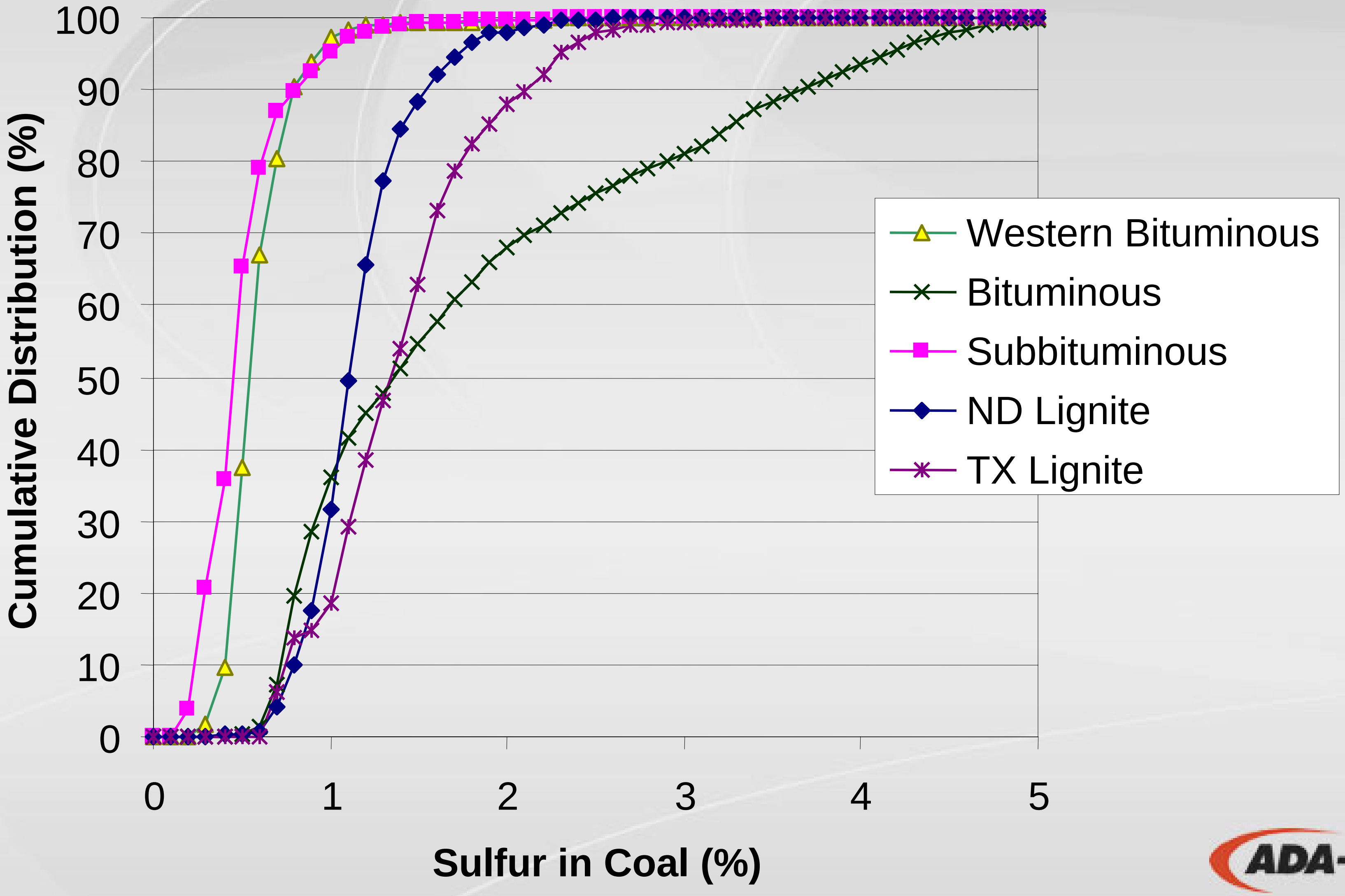
Native Capture Variability in One Fleet



Process Variability: Temperature



Distribution of Sulfur in Coals



Mercury Fundaments: Speciation

- Mercury forms into different species in the boiler
  - Elemental mercury
  - Non-elemental mercury
- We cannot identify different forms of non-elemental Hg
- The amount of non-elemental mercury depends on:
  - Coal chemistry
  - Equipment characteristics (exposure to catalytic surfaces)
    - For example, tubular APH seem to have greater percentages of non-elemental Hg than rotary APH
  - Increases as the gas moves downstream
- Some of the non-elemental mercury can be removed in a wet scrubber while other forms pass through scrubbers

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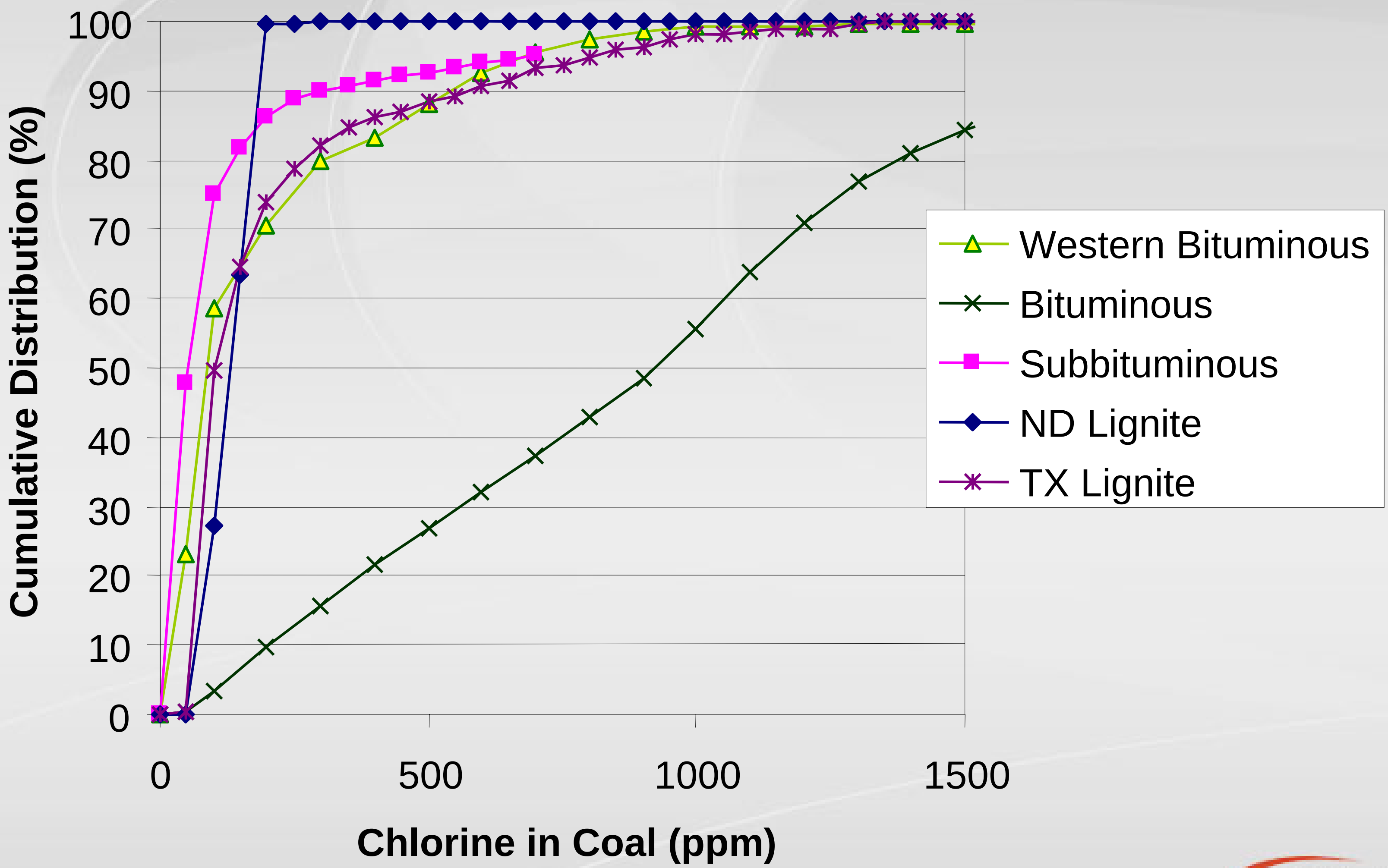
Distribution of Chlorine in Coals



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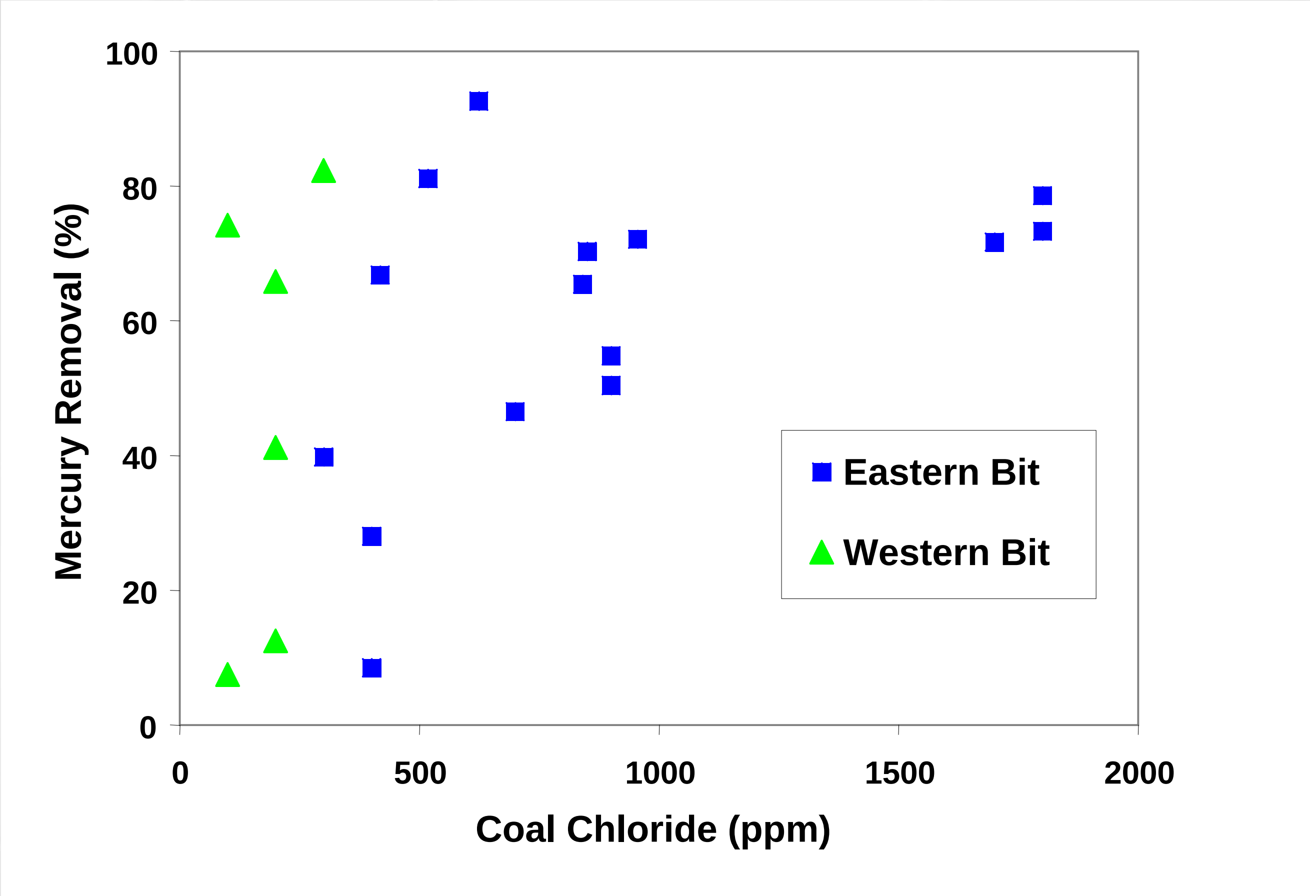
Control of Mercury in Wet FGD Scrubbers

- Oxidized Mercury is water soluble and can be captured in wet scrubbers
  - ~70 to 90% typically removed
  - Some captured mercury gets re-emitted
- Elemental mercury cannot be captured by scrubbers

Mercury Removal in Wet Scrubbers for Bituminous Coals



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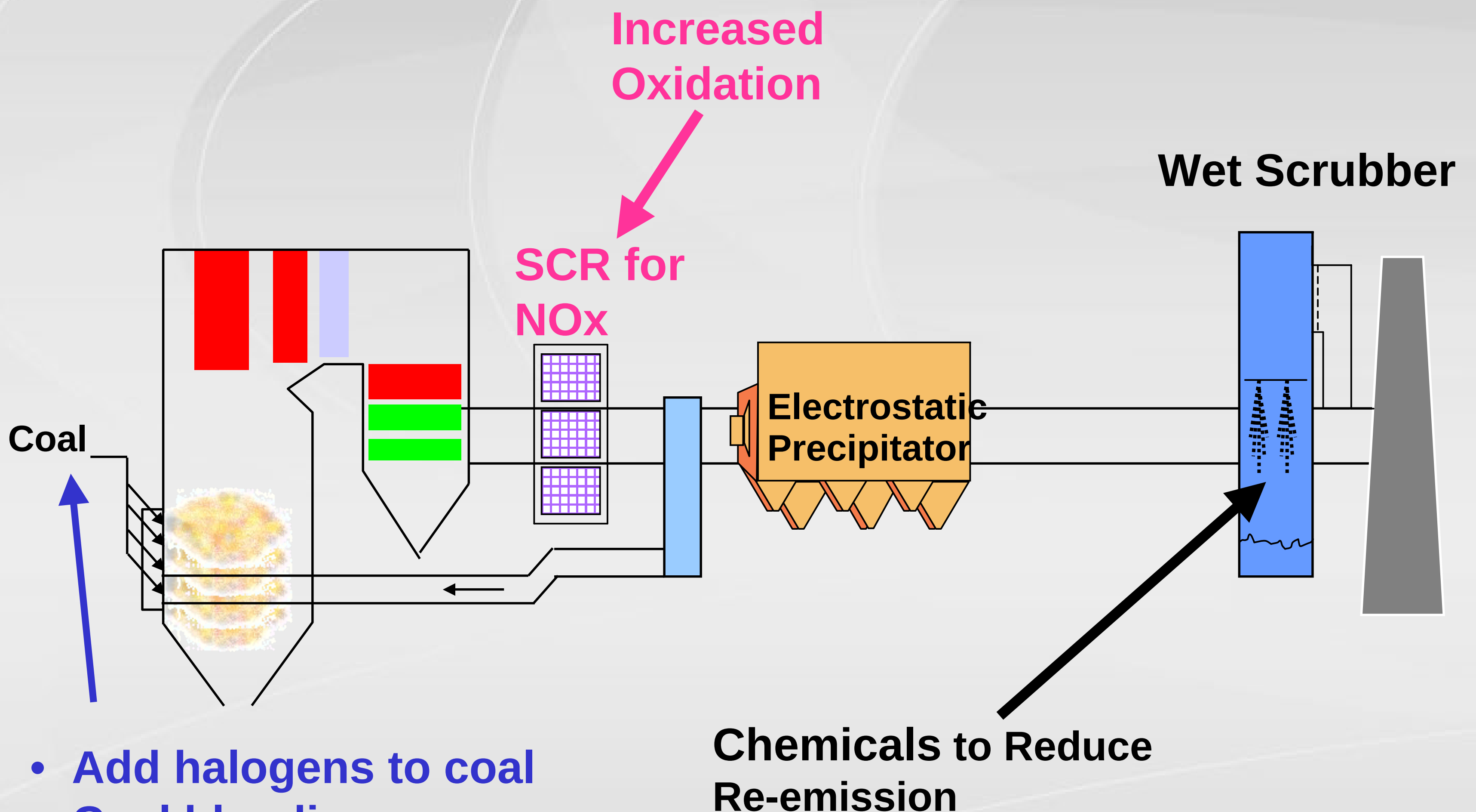
Enhancing Capture of Hg in Wet Scrubbers: Increase Amount of Oxidized Hg



- Add halogens to coal
- Coal blending

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Effectiveness of SCR-FGD Systems

~ 70 to 90% of oxidized mercury removed in FGD

- No SCR:
  - Bituminous: 50 to 90+% oxidized mercury
  - Subbituminous: <25% oxidized mercury
- With SCR:
  - Bituminous: >90% oxidized mercury
  - Subbituminous: <25% oxidized mercury

SCR increases Hg oxidation for units firing bituminous coals, increasing overall Hg removal

SCR does not appear to significantly increase fraction of oxidized mercury or improve Hg removal for units firing subbituminous coals

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Coal Additives to Increase Oxidation

- PRB coals
  - Halogens (bromine and/or chlorine) introduced onto coal results in increased mercury oxidation
  - Additional oxidized mercury does not appear to be effectively removed in SDA (ESP or FF)
  - Increased Hg removal observed in presence of high LOI
- Bituminous Coals
  - Halogens introduced onto coal results in increased mercury oxidation at some sites *(may also improve effectiveness of SCR for oxidation)*
  - Additional oxidized mercury appears to be effectively removed in WFGD

Unburned Carbon (LOI) and Mercury Removal

- LOI can be effective at removing mercury
  - LOI properties and capture can vary with changes to process conditions
  - LOI has a capacity for mercury that is ten to a hundred times lower than activated carbon
- LOI suffers from the same interferences as activated carbon (e.g. SO_3)

Activated Carbon Injection (ACI)

- ACI as primary mercury control
  - Injection upstream of Fabric Filters or ESPs
  - Injection upstream of SDAs
  - TOXECON^{TM} (injection between ESP and polishing FF)
  - TOXECON II^{TM} (injection between ESP fields)
- ACI as supplementary or “trim” mercury control
  - Injection upstream of ESP or FF followed by WFGD
  - TOXECON II^{TM} followed by WFGD

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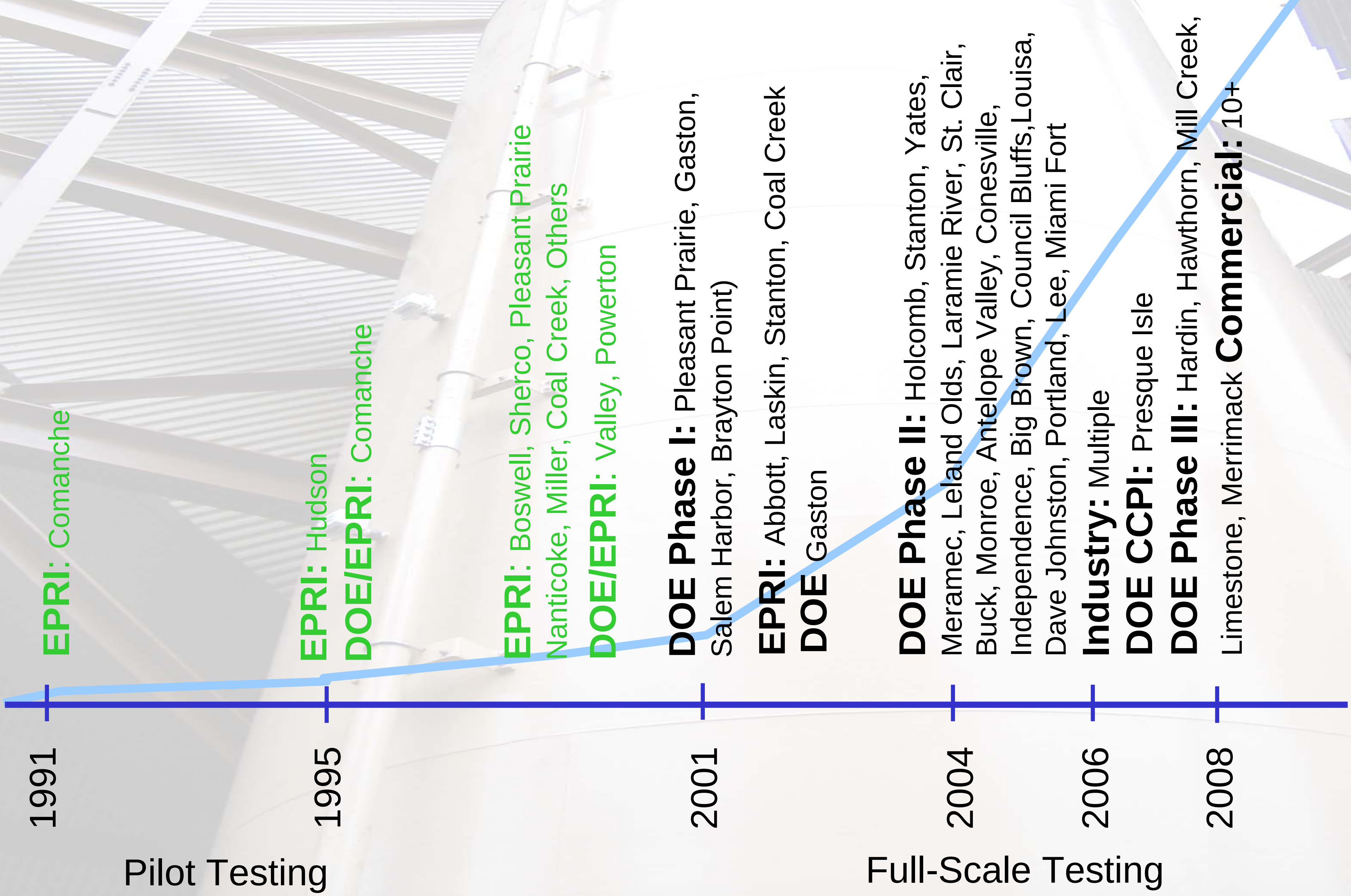
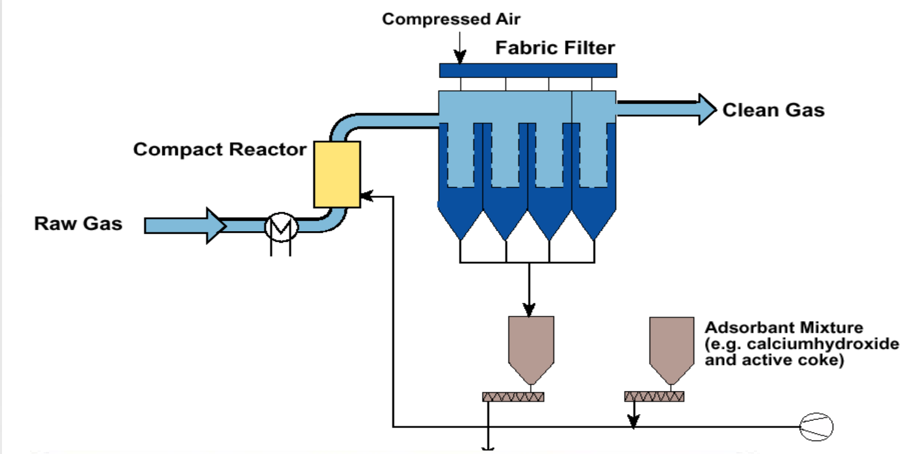
Mercury Control Evaluations: ACI Timeline



ACI Has Been Used for Mercury Control in the Waste Industry for Over 15 Years

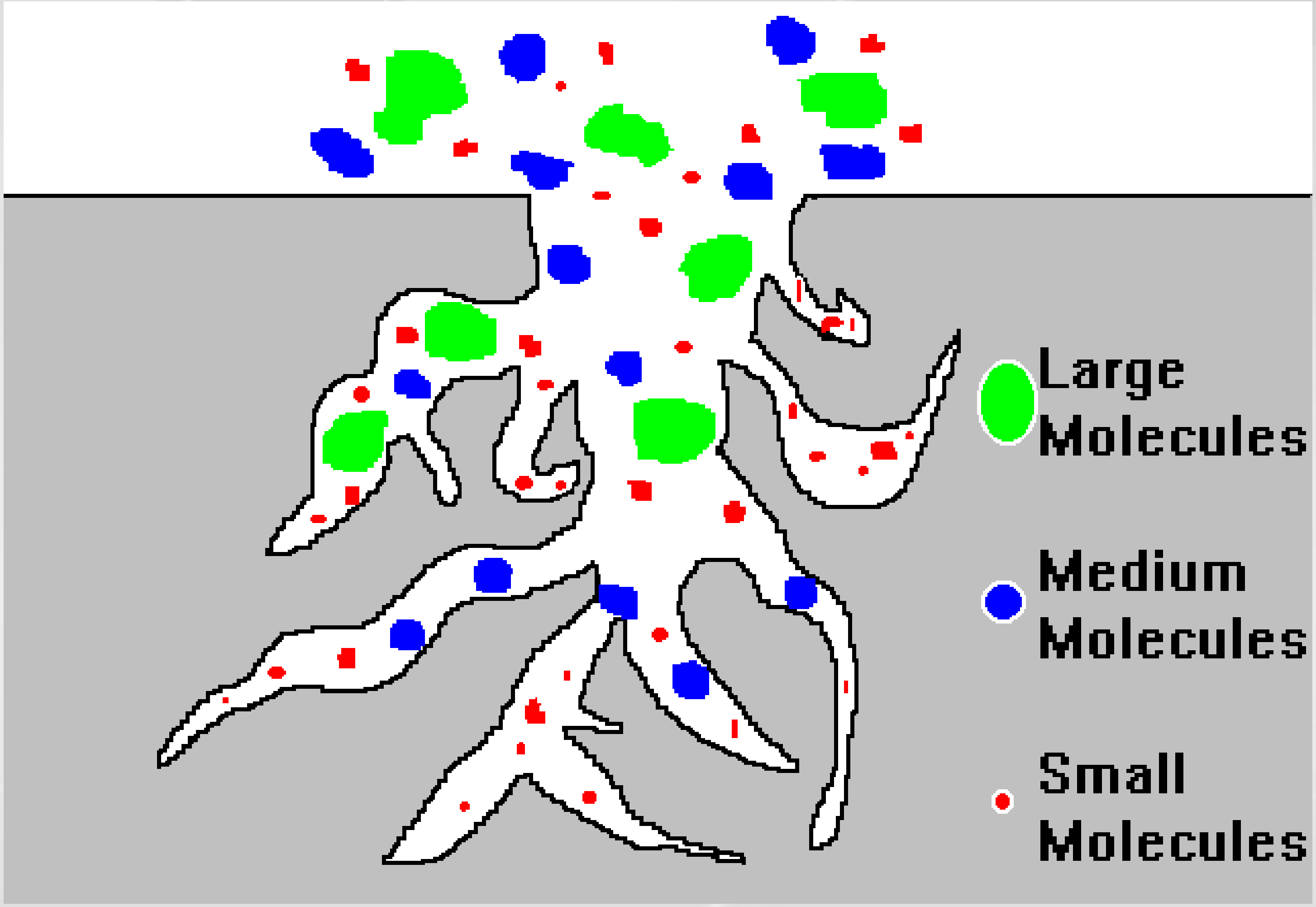
- **Commercialized mercury removal technology for the European WtE industry**
- **Sorbent injection upstream of dedicated FF**
  - Systems installed during early 1990s in Europe and the US
    - Utilize activated carbon/coke
    - ALL have operated reliably for more than 10 years
    - ALL achieve between 80 - 90% mercury removal
    - ALL capture both elemental and oxidized mercury



What is activated carbon?

- Carbon-based materials
  - Lignite, coal, wood, coconut shells
- Treated with heat and steam
- A highly porous material
- Highly capable of adsorbing or entrapping contaminants out of a liquid or gas stream.
- Can be combined with coatings to enhance performance

Activated Carbon Pore Structure



Activated Carbon Pore Volume

- Total volume of all pores inside a particle of activated carbon in ml/g
- Calculated from density data

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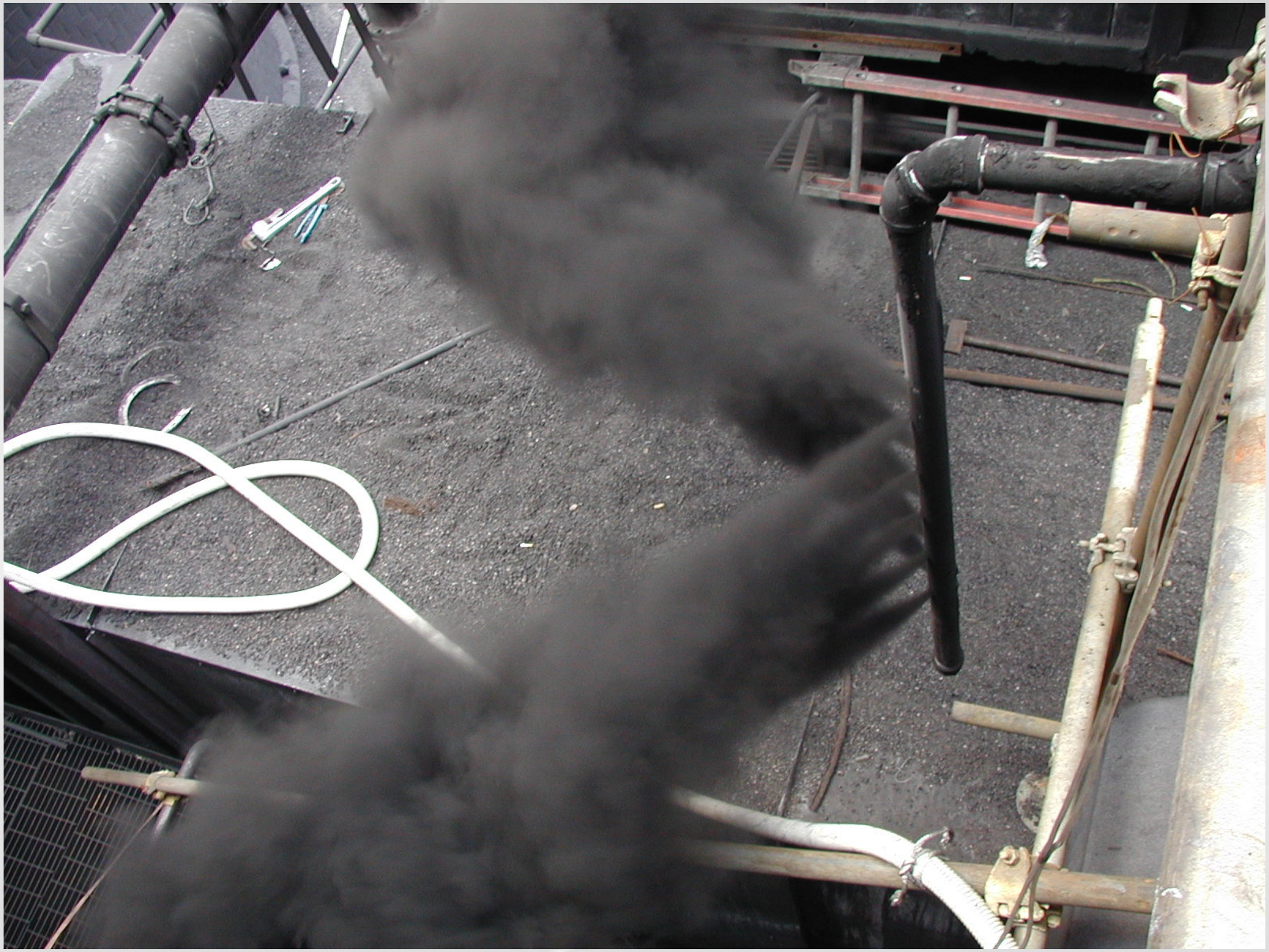
Powdered Activated Carbon Specifications

- Particle size: (15-25 µm).
- Surface Area: Typical PAC > 500 m^2/g.
- Treated sorbents for low-halogen flue gas applications such as PRB-fired units with ESPs or SDA/FFs
- Emerging PAC sorbents for high SO_3 flue gas

Powdered Activated Carbon Injection



Factors Affecting ACI Performance

- Coal Type
  - Halogen content (Cl, Br, other)
  - Sulfur content
- Acid Gases (HCl, SO_2, $SO_{3,}$)
- Flue Gas Temperature
- APC Configuration
- ACI Design
  - Distribution
  - Residence time
  - Sorbent characteristics

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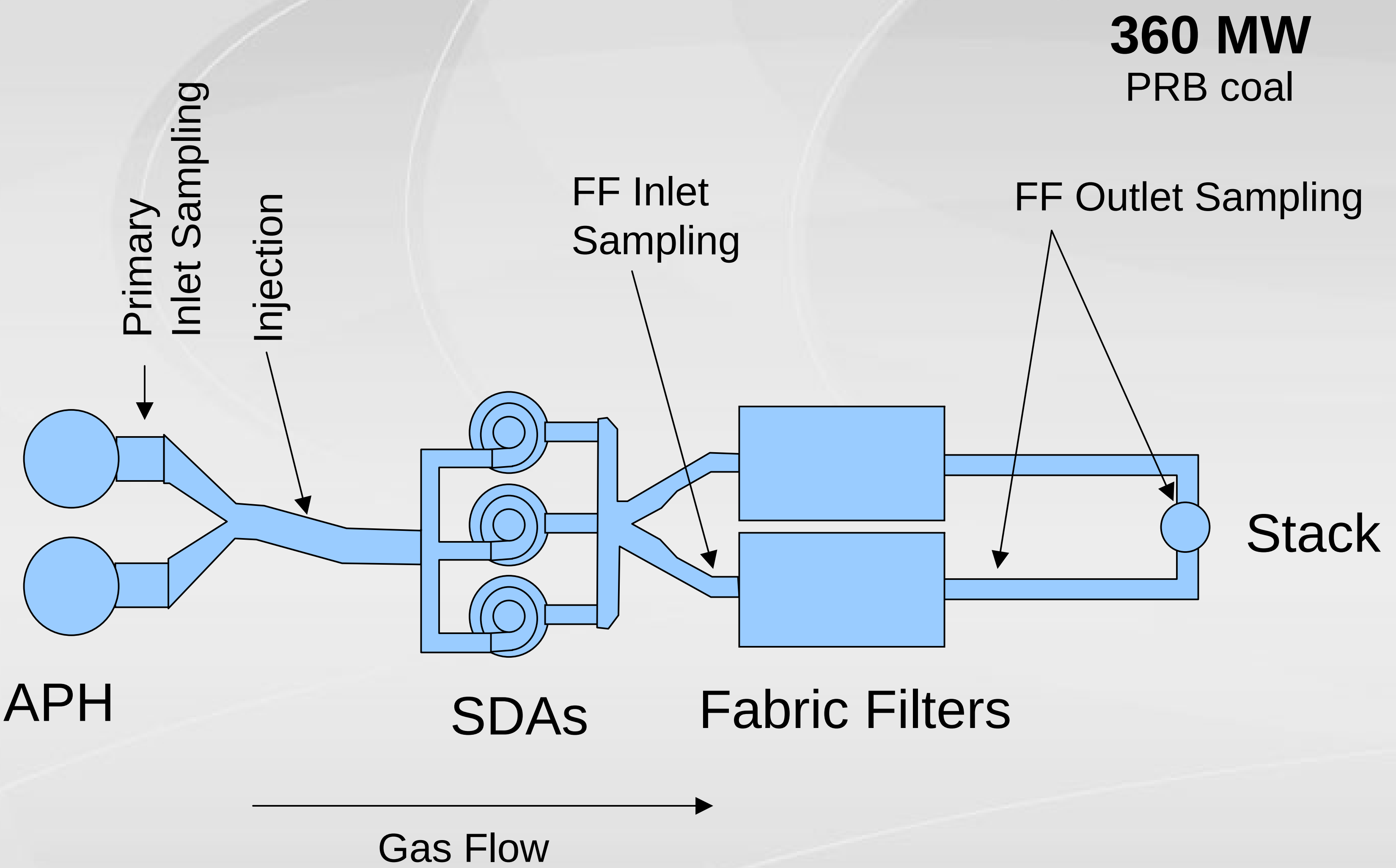
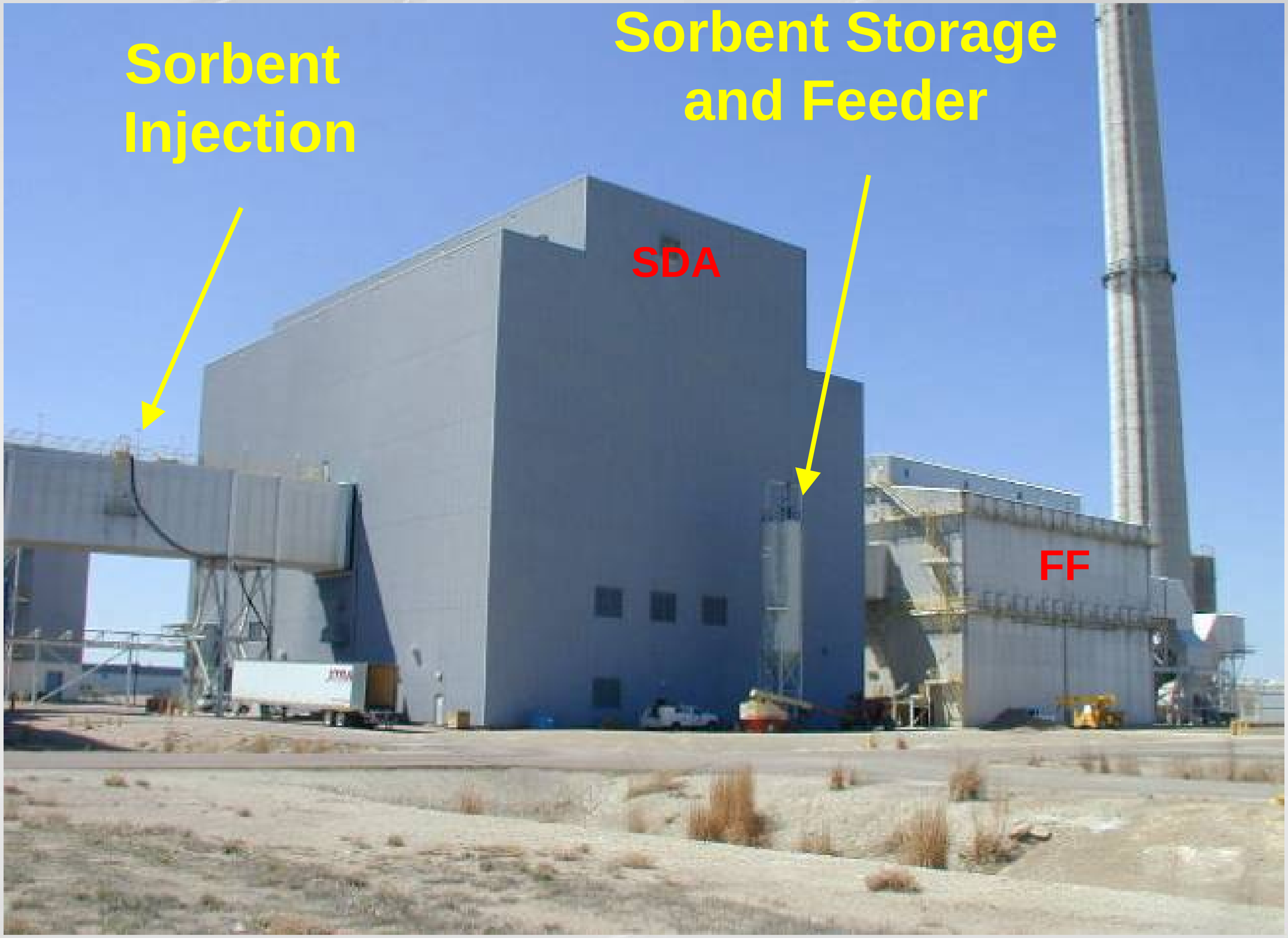
Review of Full-Scale ACI Results

- Low sulfur coals (PRB, lignite, low S bit)
  - SDA + FF
  - ESP
  - Toxecon™
  - Toxecon II™
- High sulfur coals and high SO_3 sites
  - ESP
  - ESP + WFGD

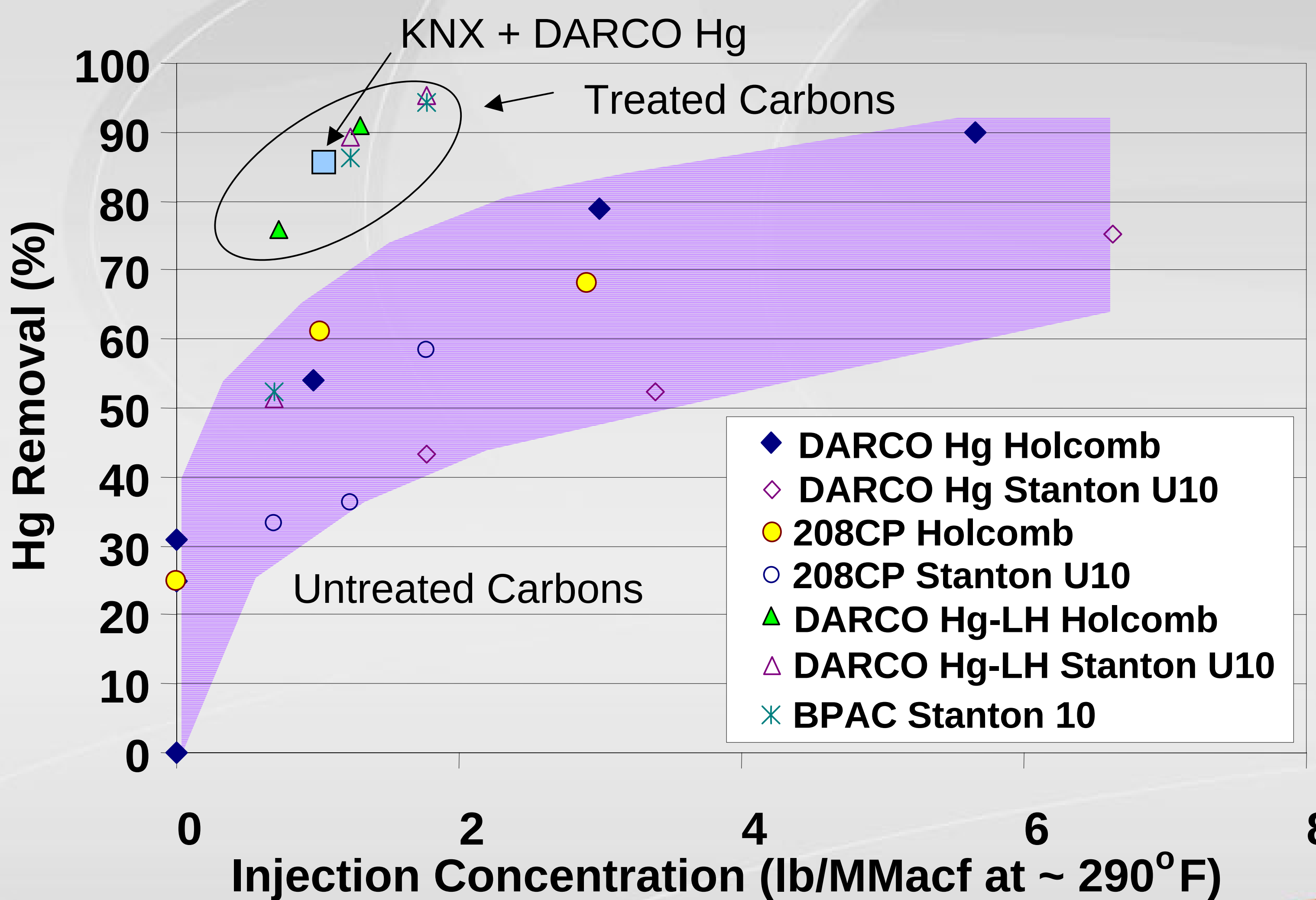
Holcomb Overall Layout



ACI System at Holcomb



SDA Results, PRB and Lignite Fuels



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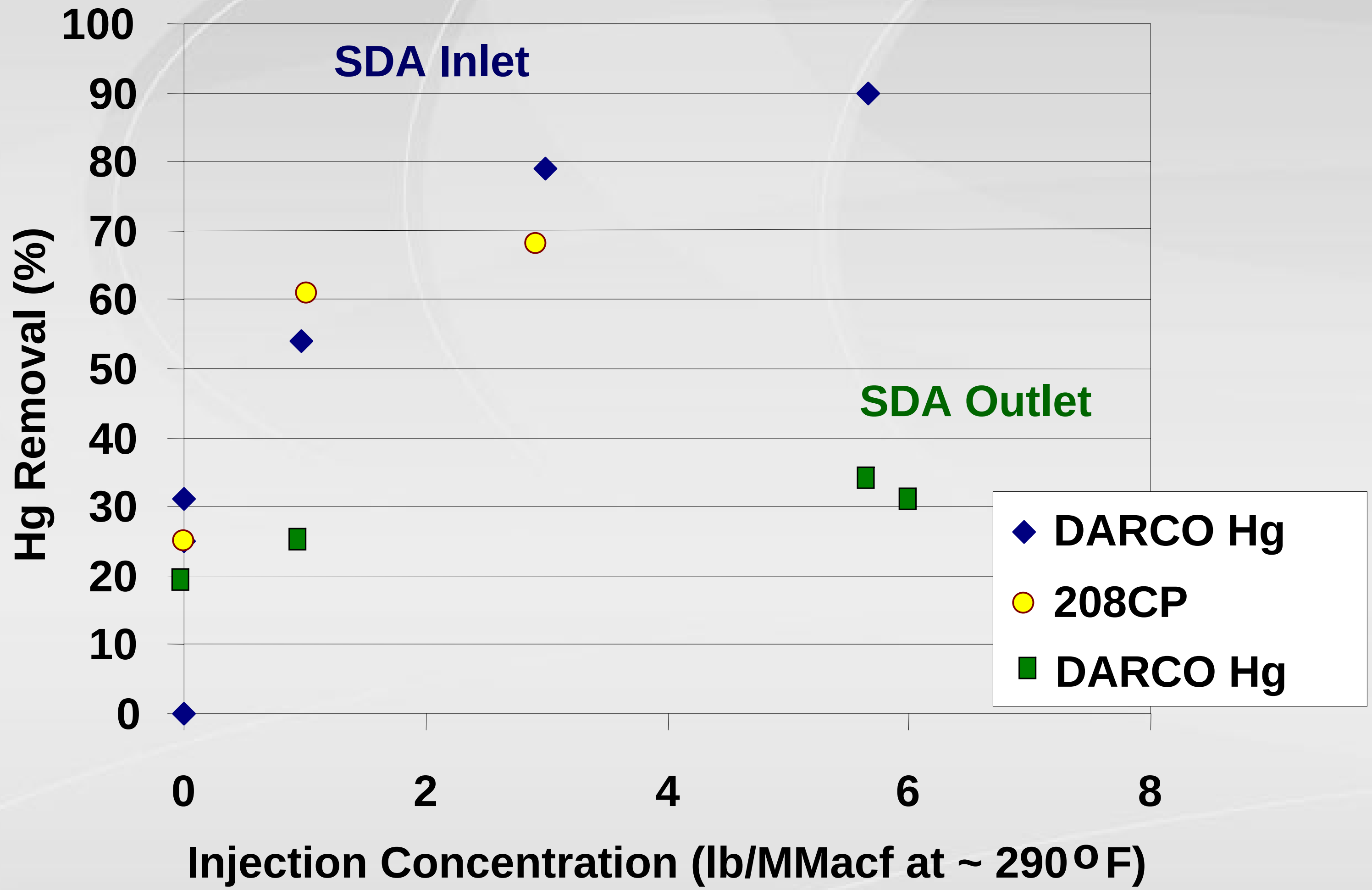
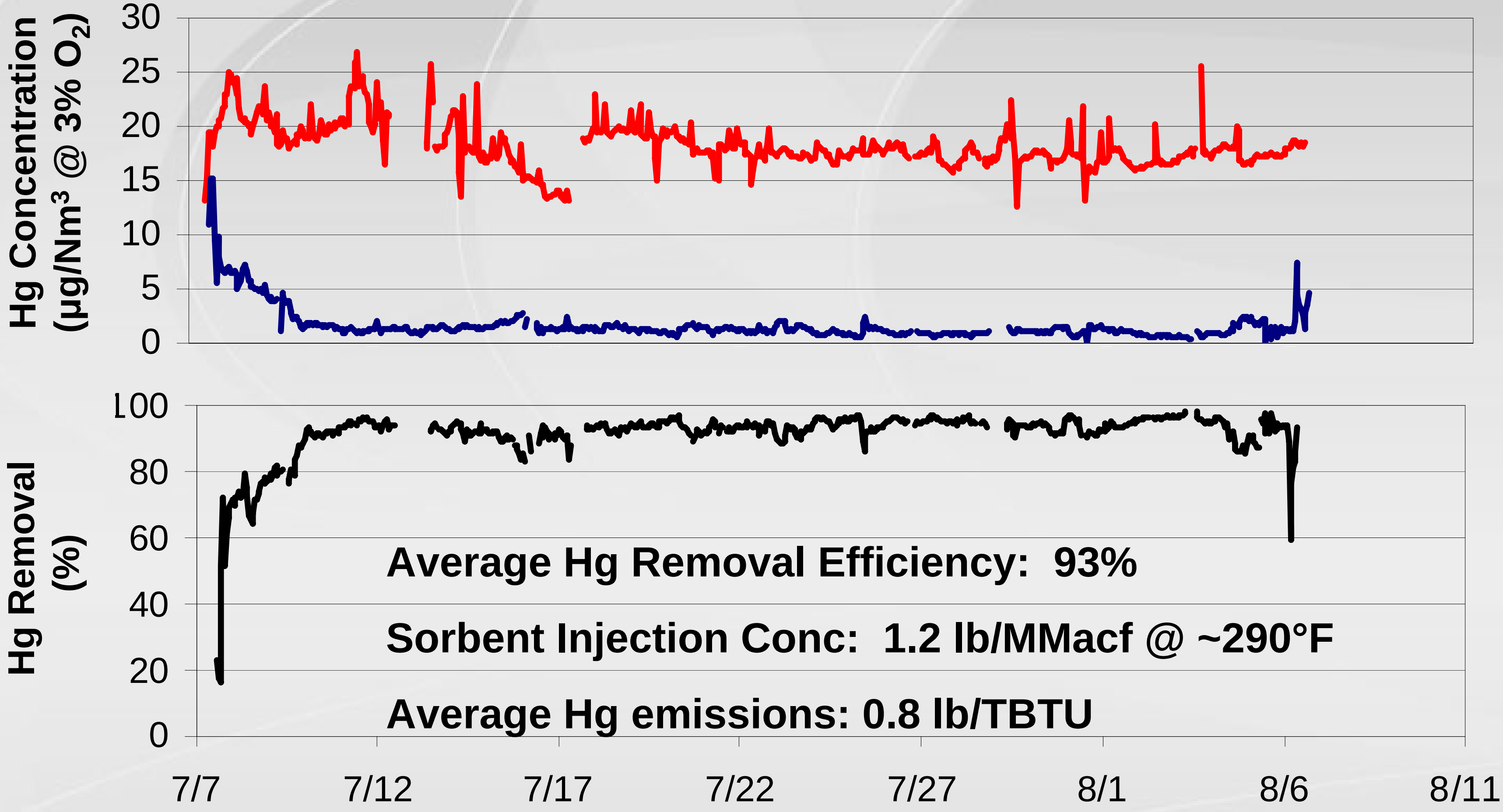
Alternative Sorbent Performance
SDA Inlet Injection, Holcomb Station



Holcomb: 30-day Long Term Results DARCO Hg-LH Injection



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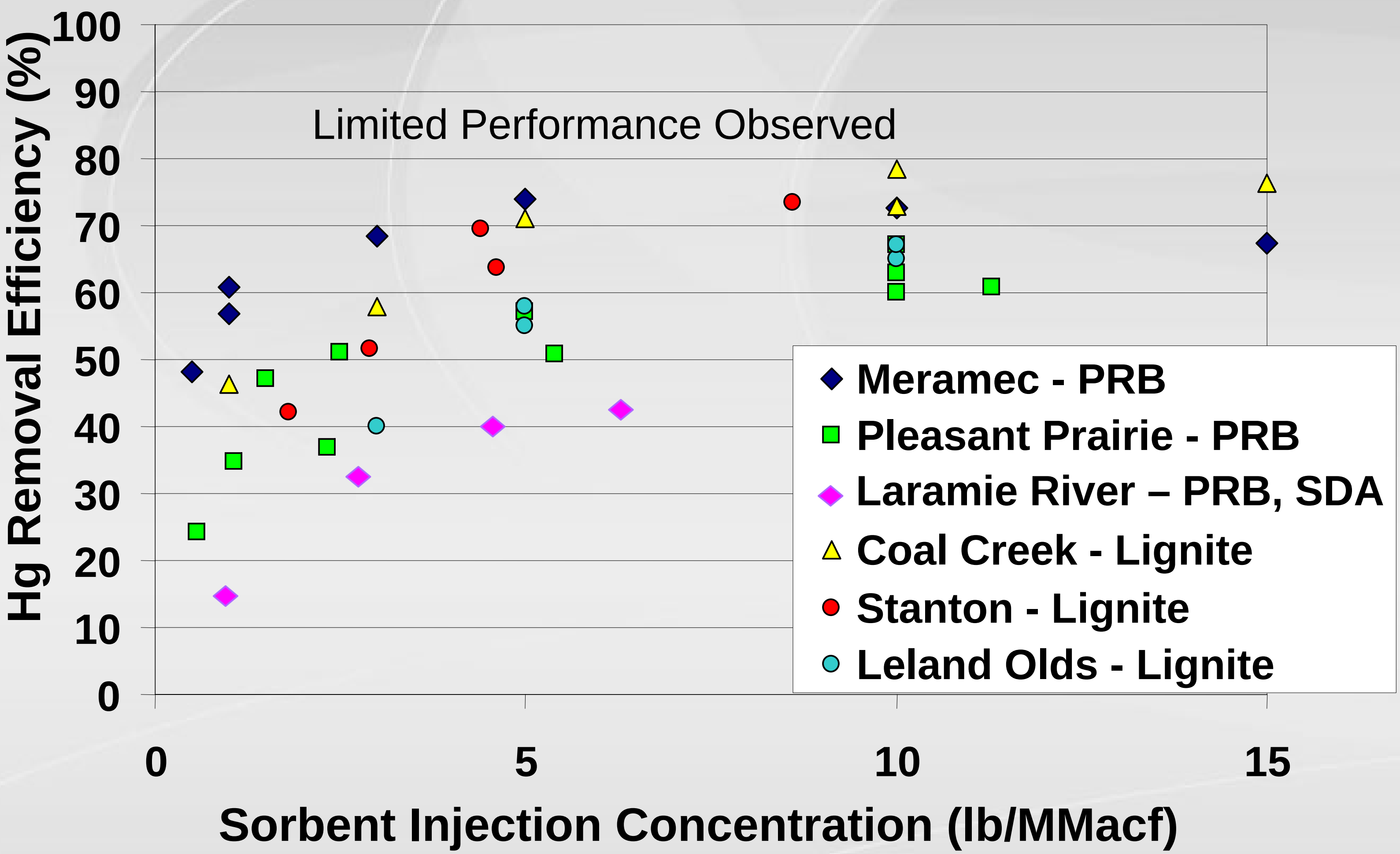
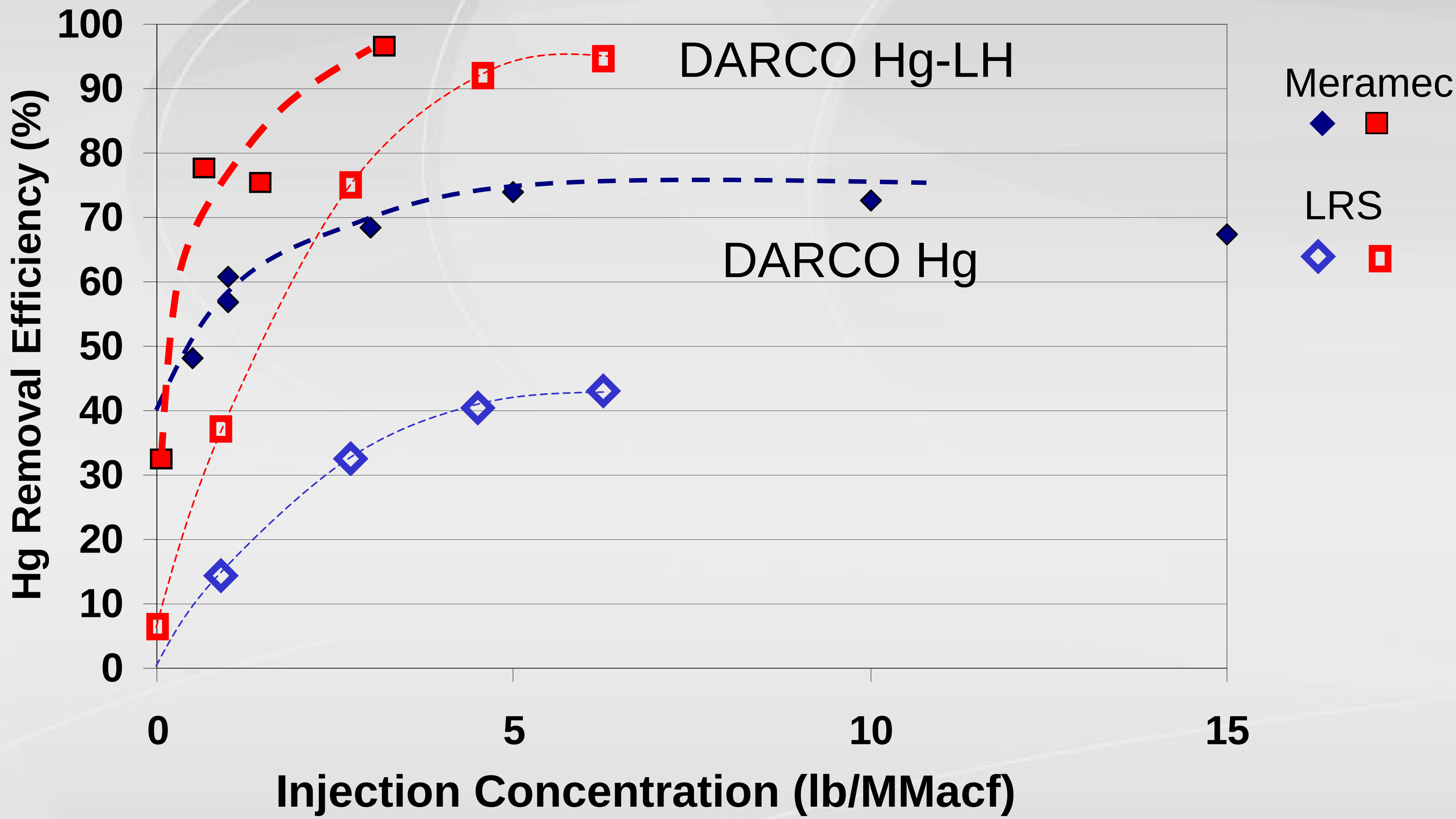
Untreated PAC Injection into ESP PRB and Lignite Coals



PRB/ESP Parametric Results



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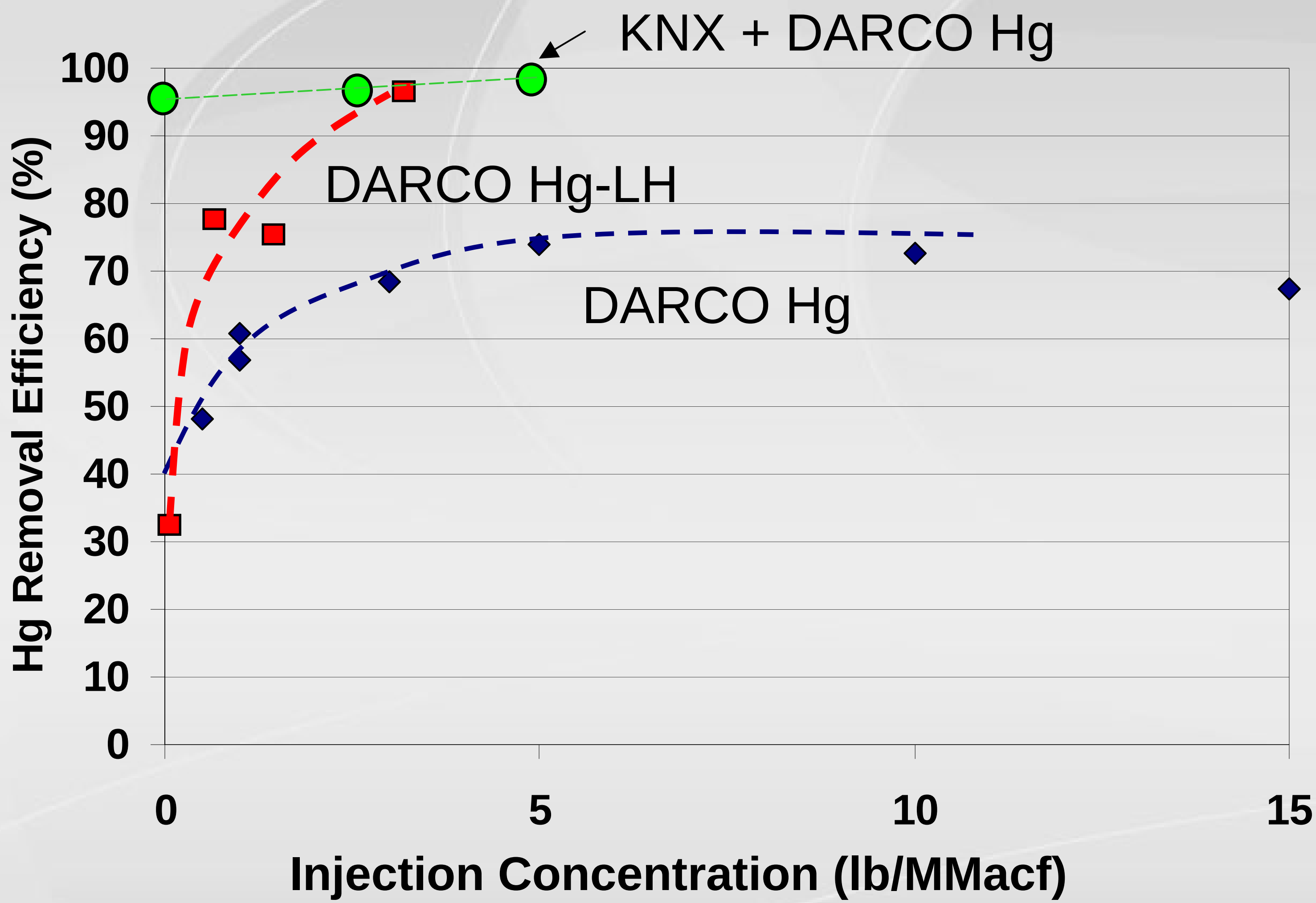
PRB/ESP Parametric Results: Coal Additive



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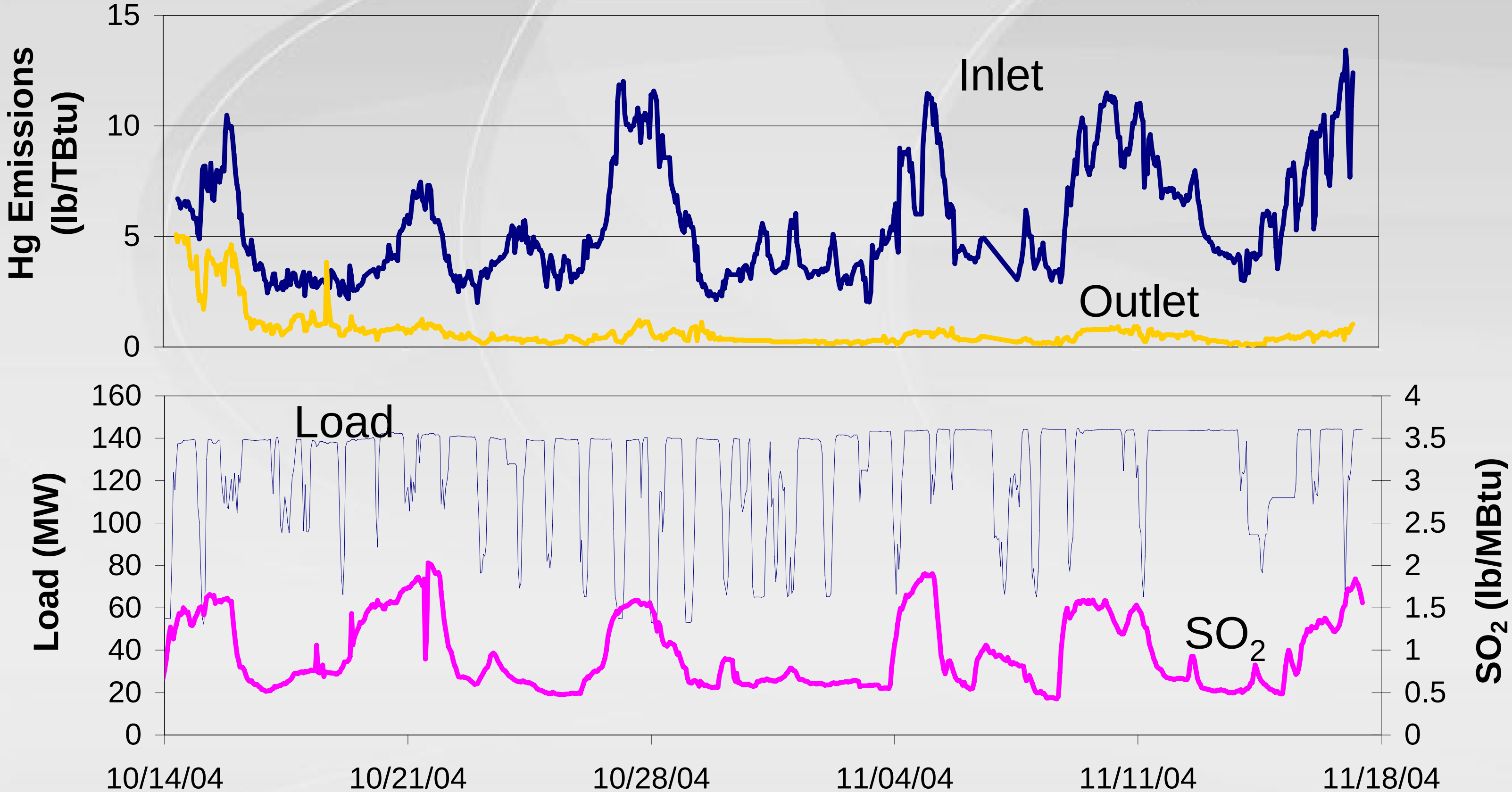
PRB, ESP Long-Term Results Meramec, DARCO Hg-LH



Average Hg Removal Efficiency: 93%

Sorbent Injection Concentration: 3.3 lb/MMacf

Average Hg emissions: 0.44 lb/TBTU

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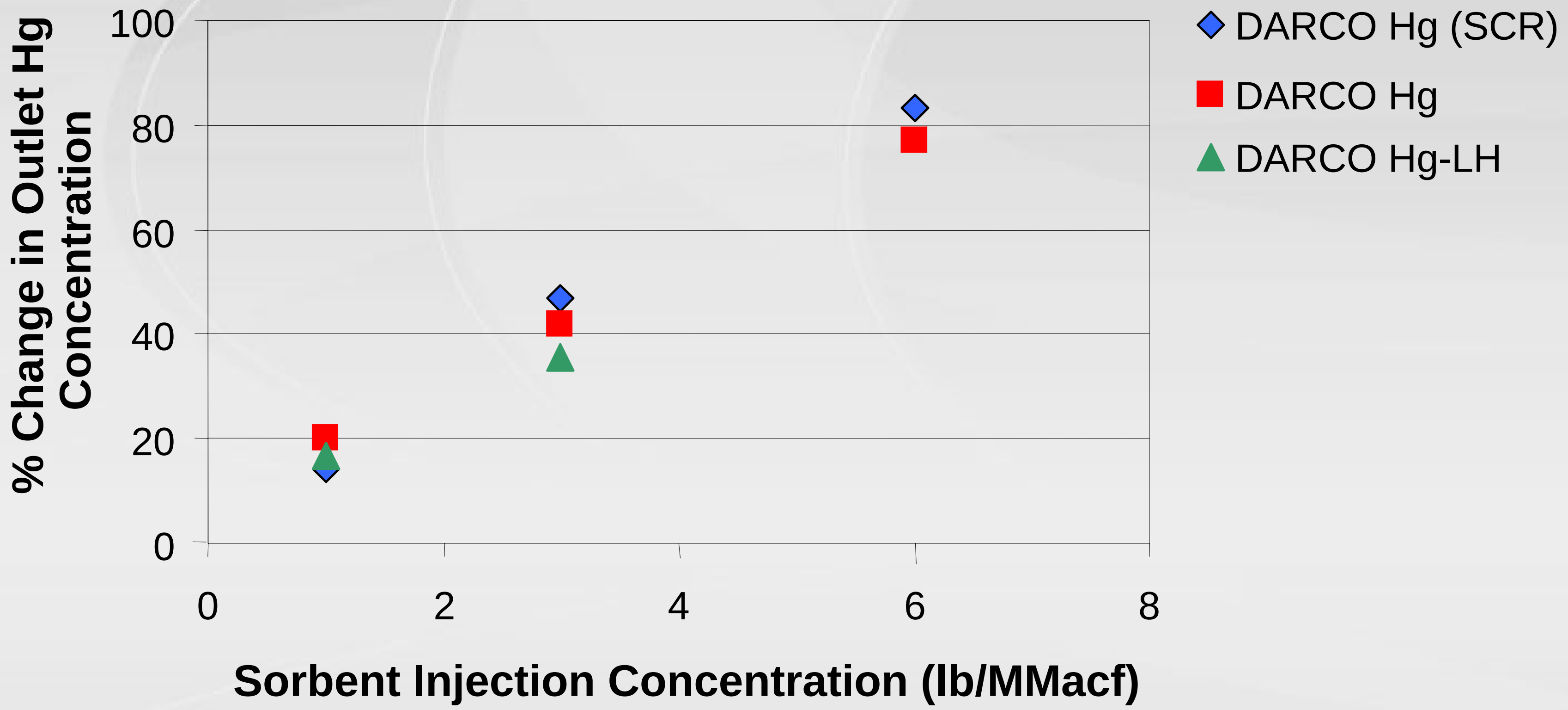
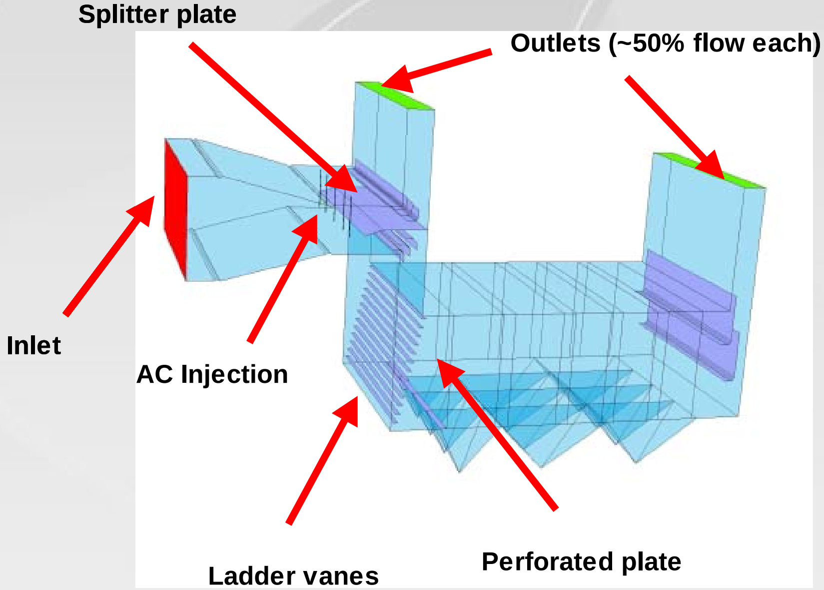
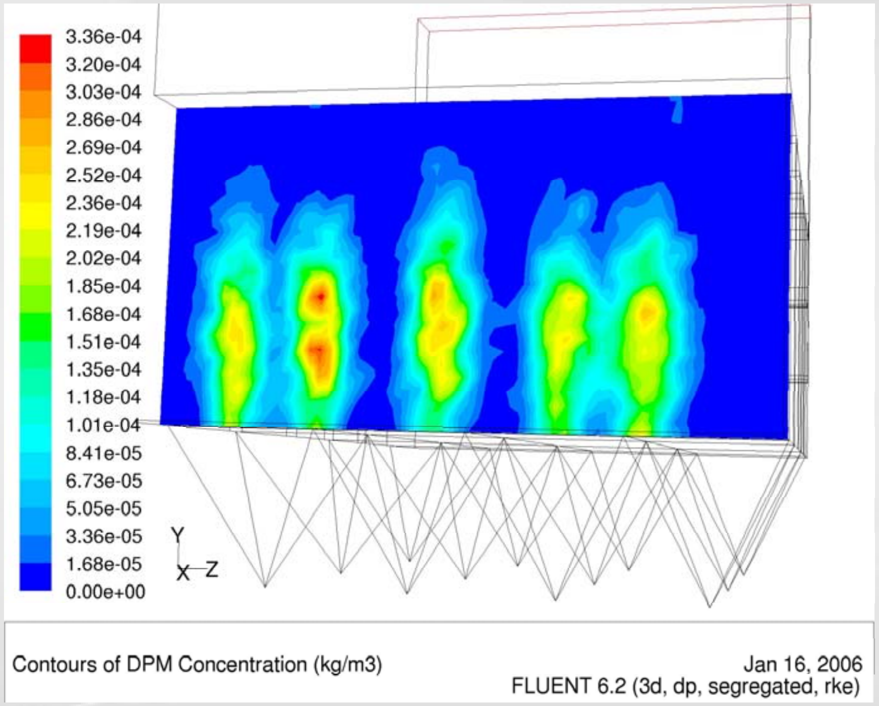
Standard vs. Brominated AC at Monroe ESP, 60:40 Blend PRB:Bit



CFD Modeling of Injection (Monroe)



Predicted Sorbent Mass Distribution at ESP Inlet



Model predicts non-uniform mass distribution

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Balance-of-Plant and Coal Combustion Byproducts (CCB)

- **No impacts on ESP or FF performance at most sites tested**
- **No secondary stack emissions measured due to treated sorbent injection**
- **The mercury captured by activated carbon, LOI carbon, and ash appears to be very stable and unlikely to reenter the environment.**
- **The presence of activated carbon in ash will most likely prevent sale for use in concrete.** *Impacts approximately 30% of the affected units*
  - **Several developing technologies to address the problem**

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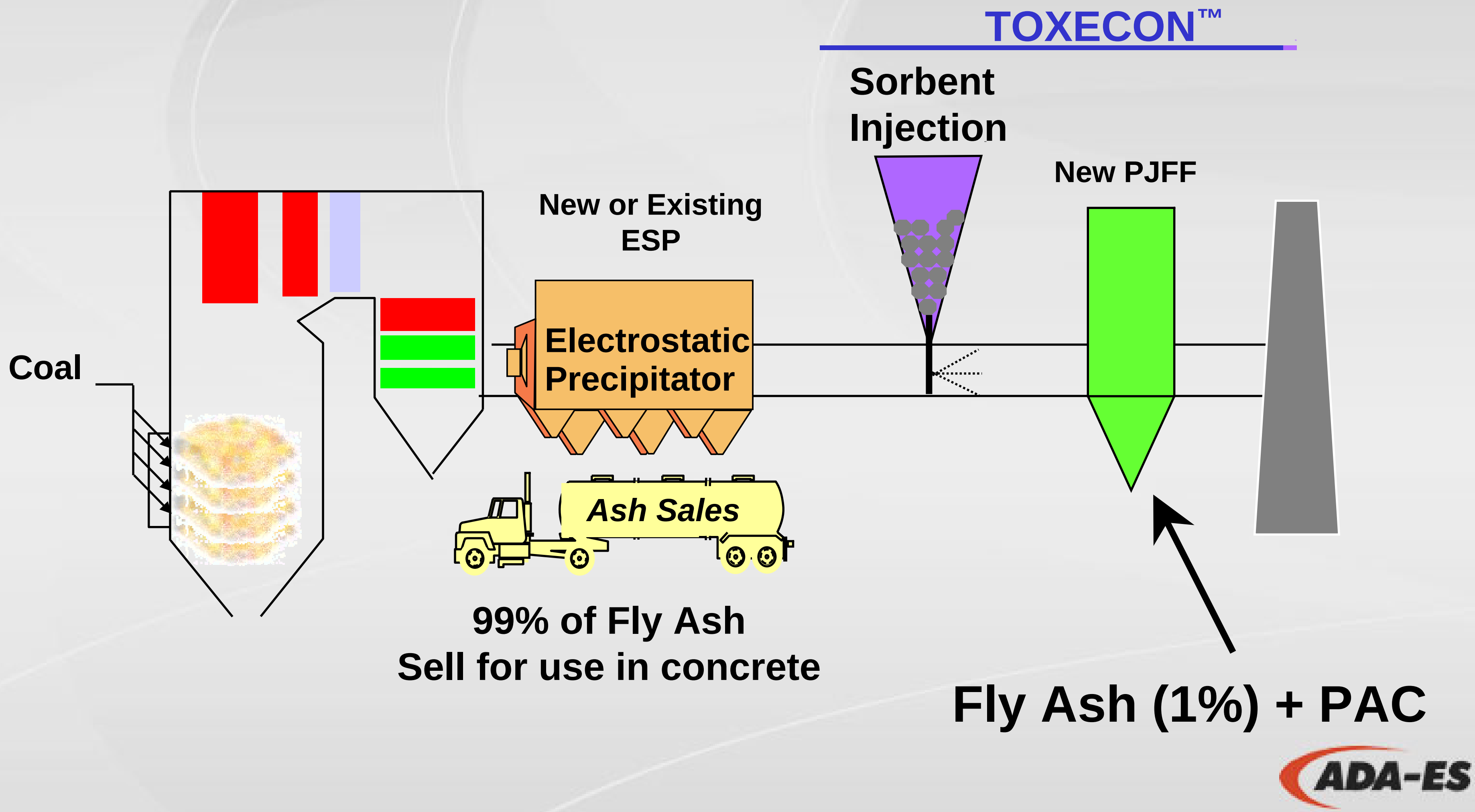
Options for Preserving Ash sales

- TOXECON™
- TOXECON II™

EPRI TOXECON™ Typical Configuration



Typical TOXECON™ Configuration

Likely ACI Injection Location

Alabama Power E. C. Gaston Unit 3

- 270 MW firing a variety of low-sulfur, washed eastern bituminous coals
- Particulate collection:
  - Hot-Side ESP; SCA = 274 ft^2/kacfm
  - COHPAC™ baghouse @ 8:1
- Wet ash disposal to pond
- Primary funding from DOE/NETL with co-funding provided by:
  - Southern Company
  - PG&E NEG
  - Ontario Power Generation
  - TVA
  - Kennecott Energy
  - We Energies
  - EPRI
  - FirstEnergy
  - Hamon Research-Cottrell
  - Arch Coal

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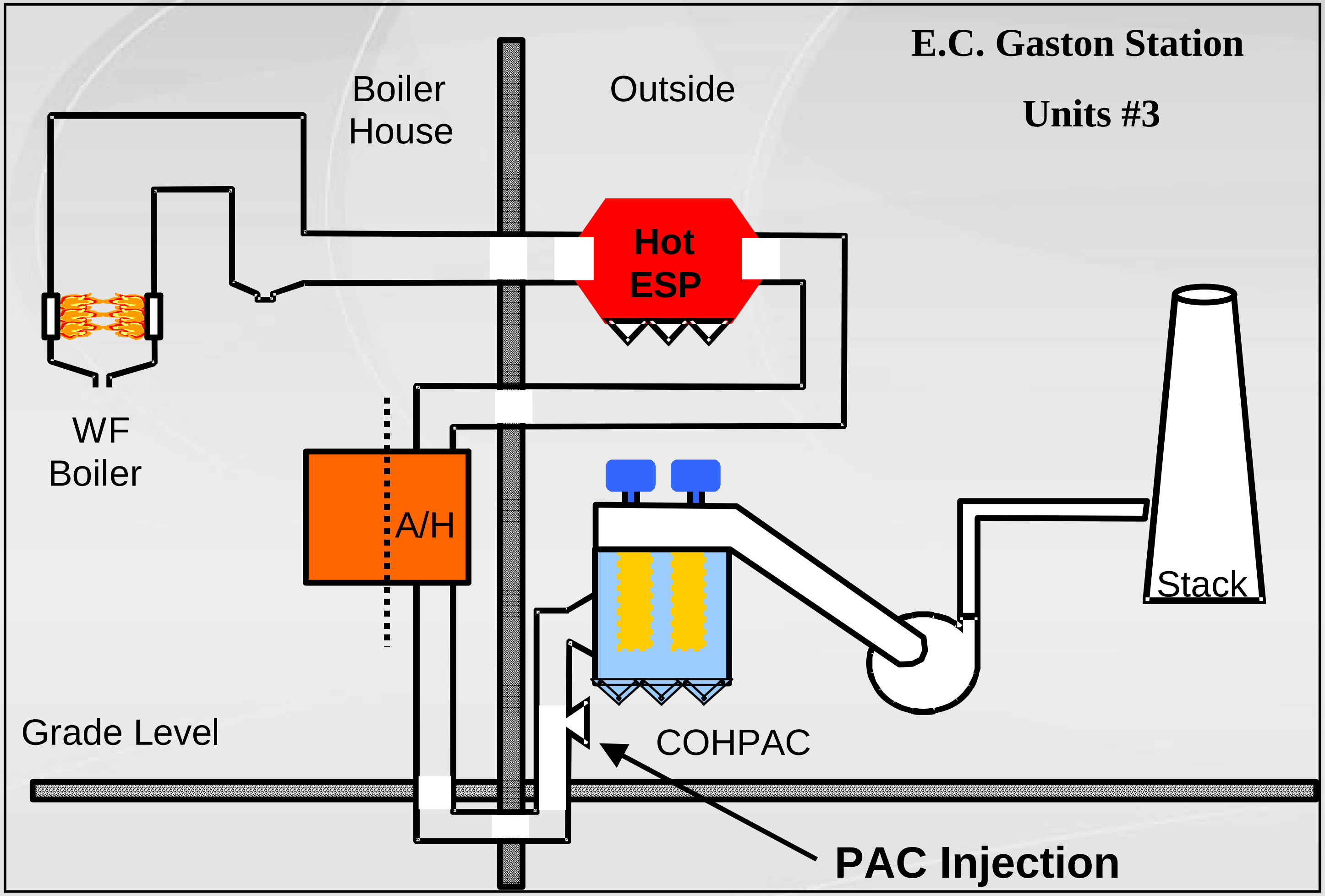
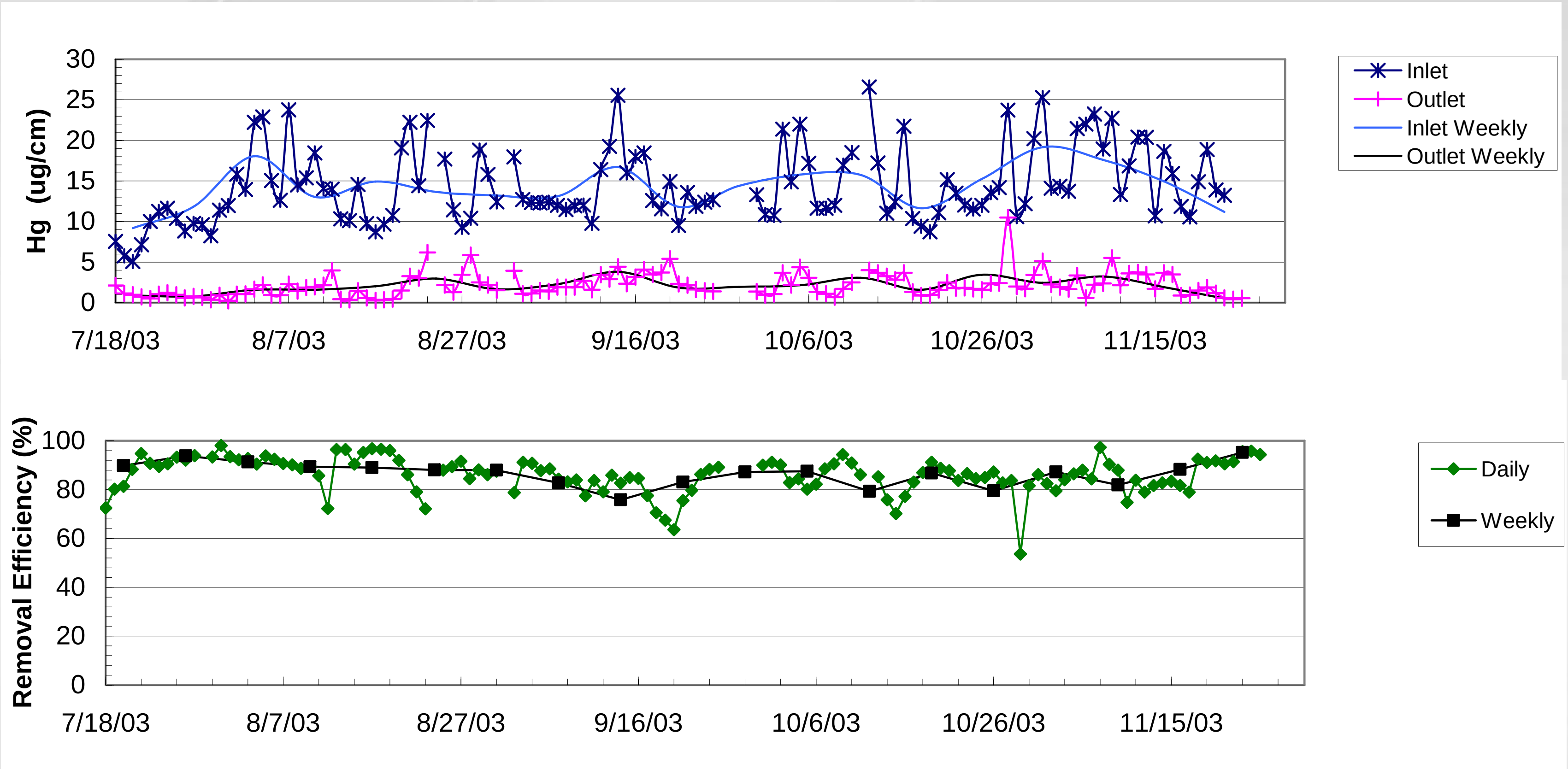
Alabama Power Installation



Long-Term Testing of TOXECON™ at Alabama Power Gaston Station



Overall Hg Removal > 85% @ 8:1 A/C

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PAC Impacts on Fabric Filters

- PAC may higher pressure drop when compared to some fly ash – COHPAC/TOXECON FFs should be sized with PAC in mind
  - Recommended A/C ratio < 6 ft/min
- Typical, additional grain loading of PAC for a baghouse application will be 0.01 – 0.2 gr/acf

First Commercial Hg Control System Presque Isle Power Plant

- **$50 Million program funded by We Energies and DOE**
- **Units 7 – 9 (270) MW on PRB Coal**
- **System designed for 90% Hg control**

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PIPP Project Goals

- Achieve at least 90% mercury removal.✓
  >90% demonstrated in parametric testing @ 2 lb/MMacf (Darco Hg)
- Increase collection efficiency of PM, especially during upset conditions. ✓
- Demonstrate mercury CEMs as a reliable mercury measuring system. ✓
- Determine viability of sorbent injection for SO_2 and NO_X control.
- Recover at least 90% of mercury captured in the ash.
- Minimize waste disposal with a target of 100% utilization.

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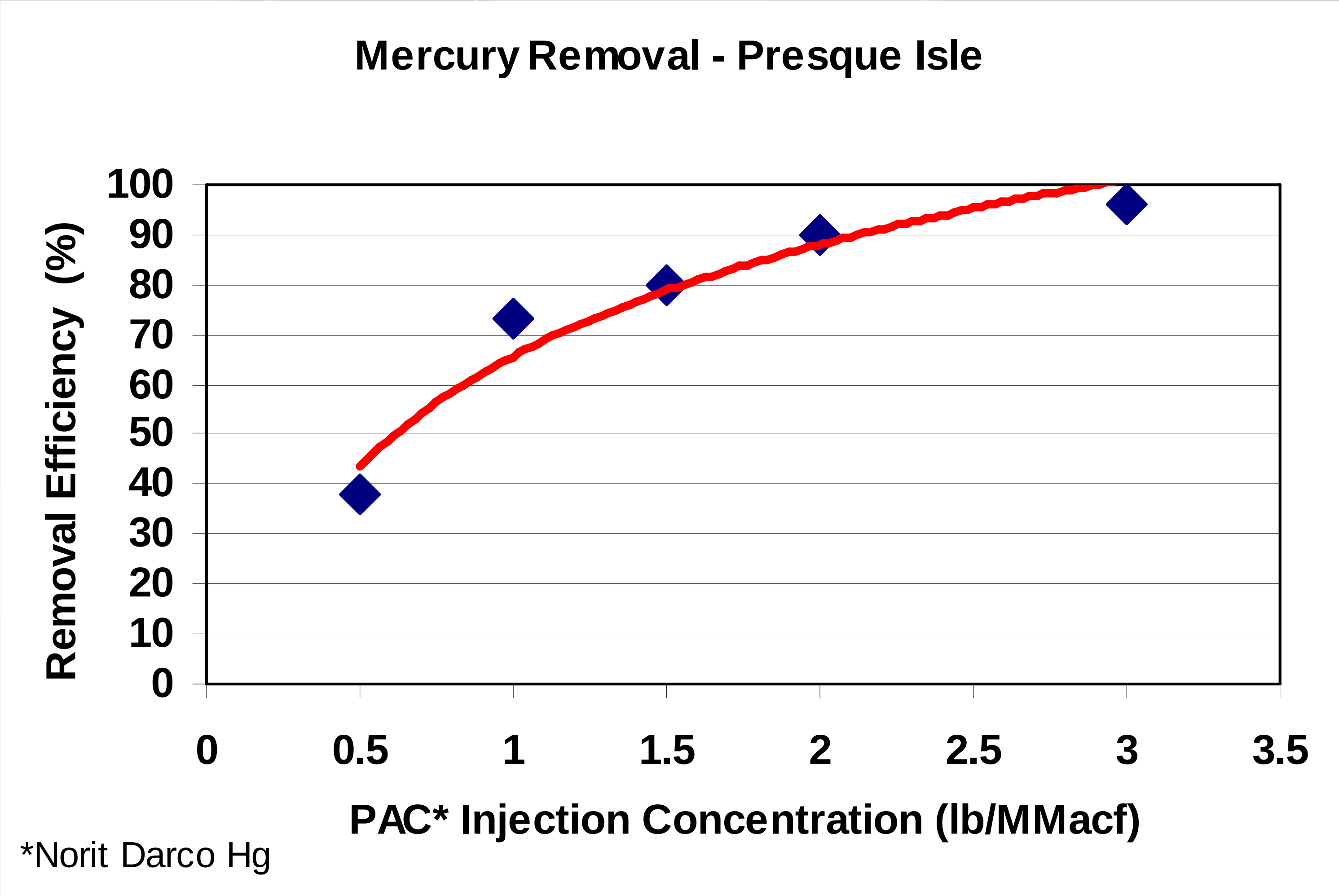
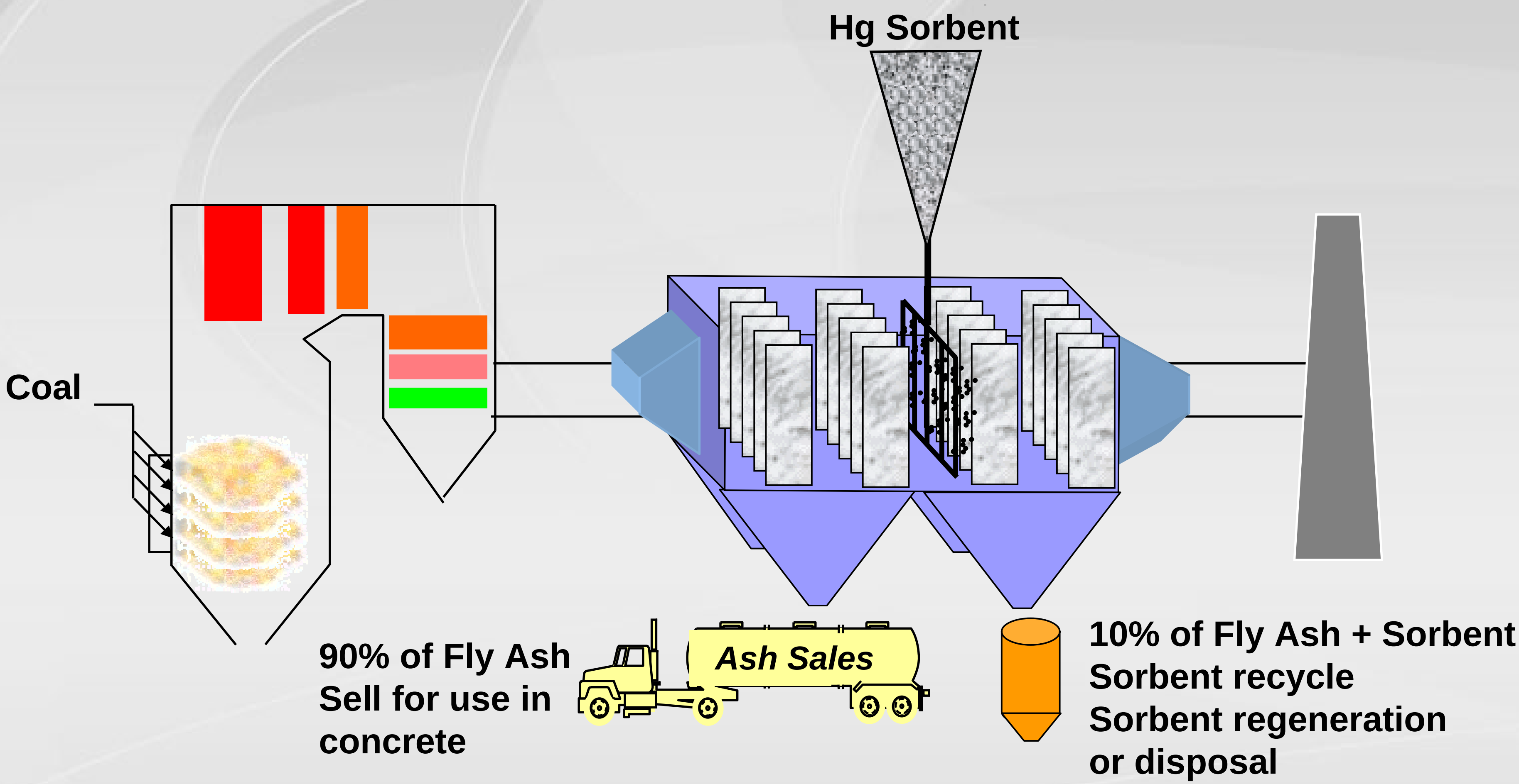
ADA-ES ACI System at We Energies Presque Isle (270MW) TOXECON™

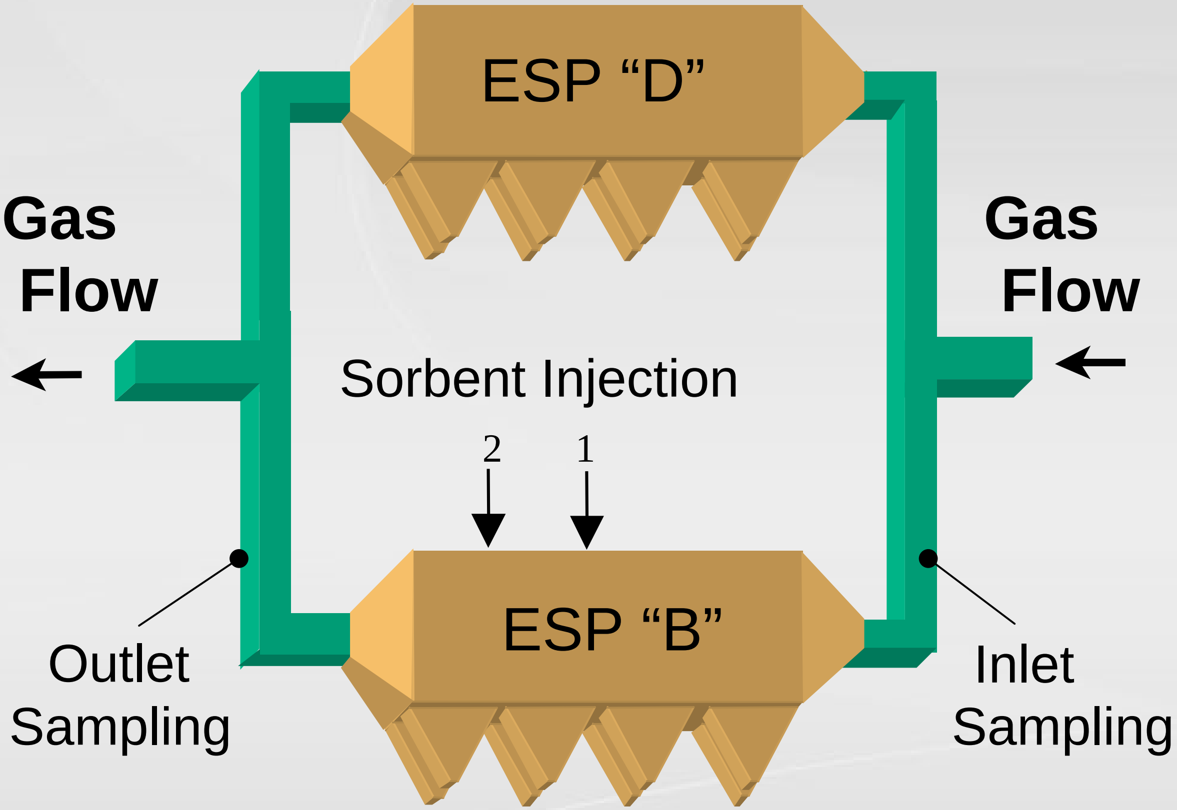
Parametric Results from Presque Isle TOXECON



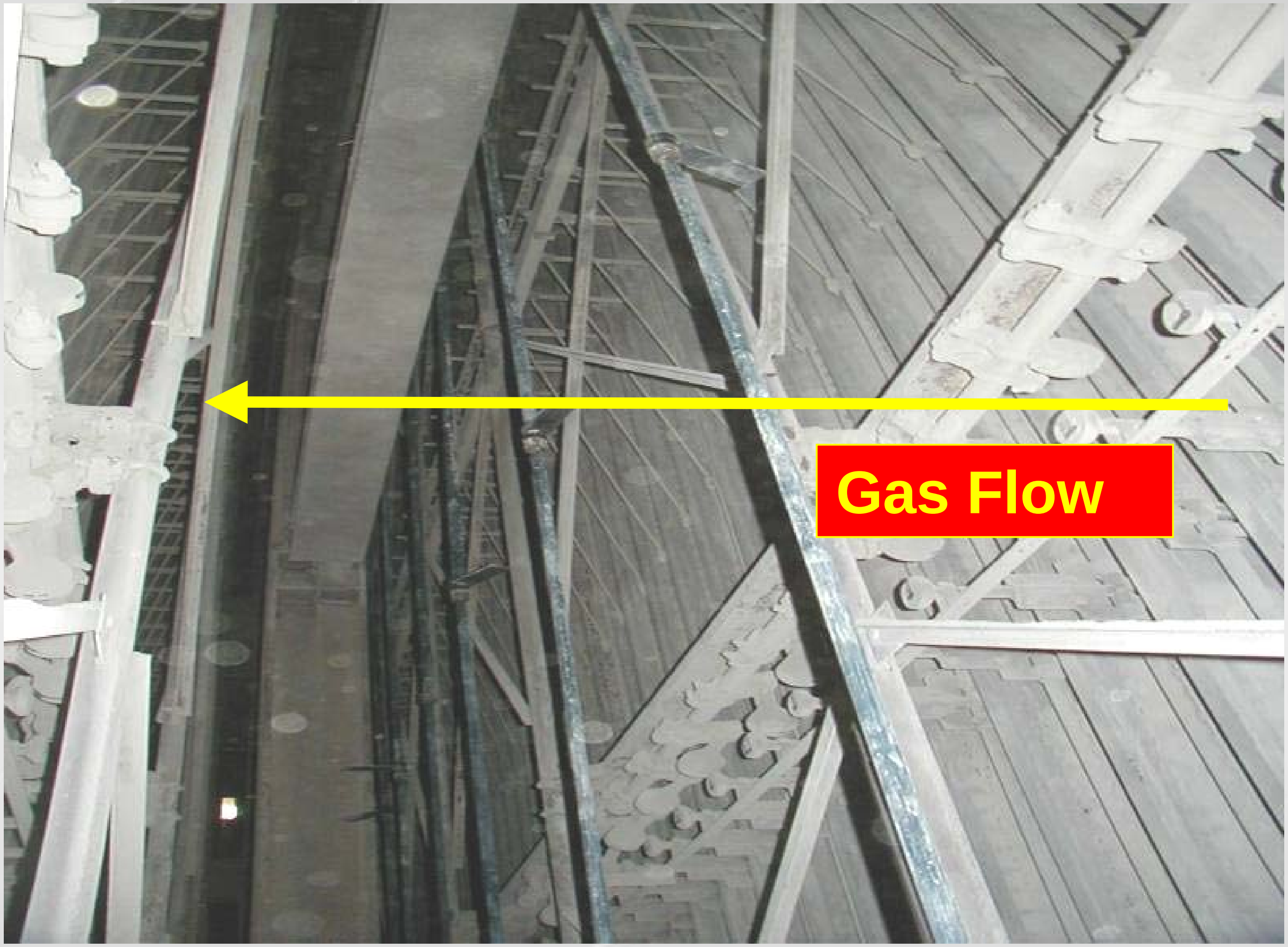
EPRI TOXECON II™ Configuration



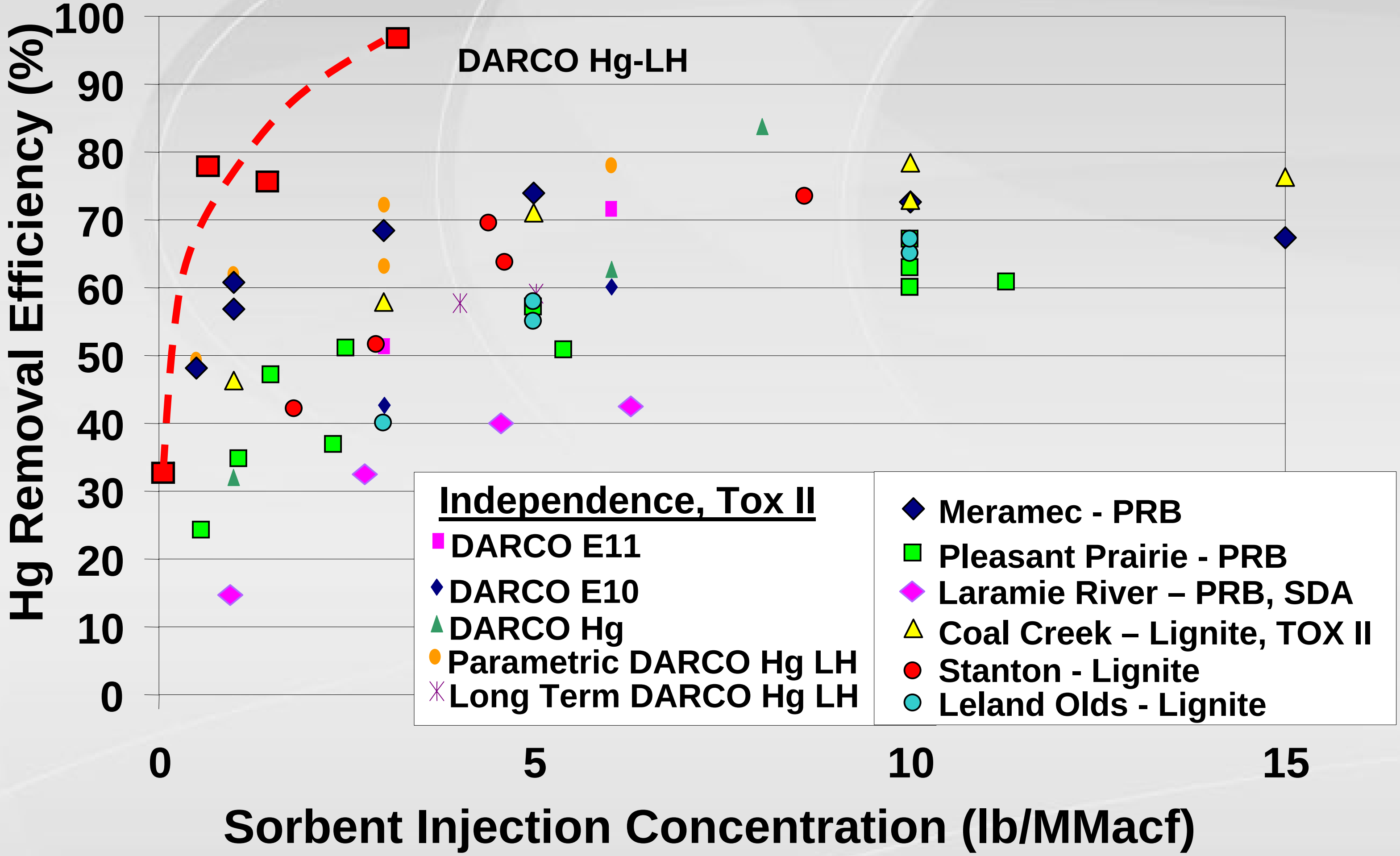
Entergy Independence TOXECON II ™ ESP General Arrangement



Grid Layout



TOXECON II™ Performance



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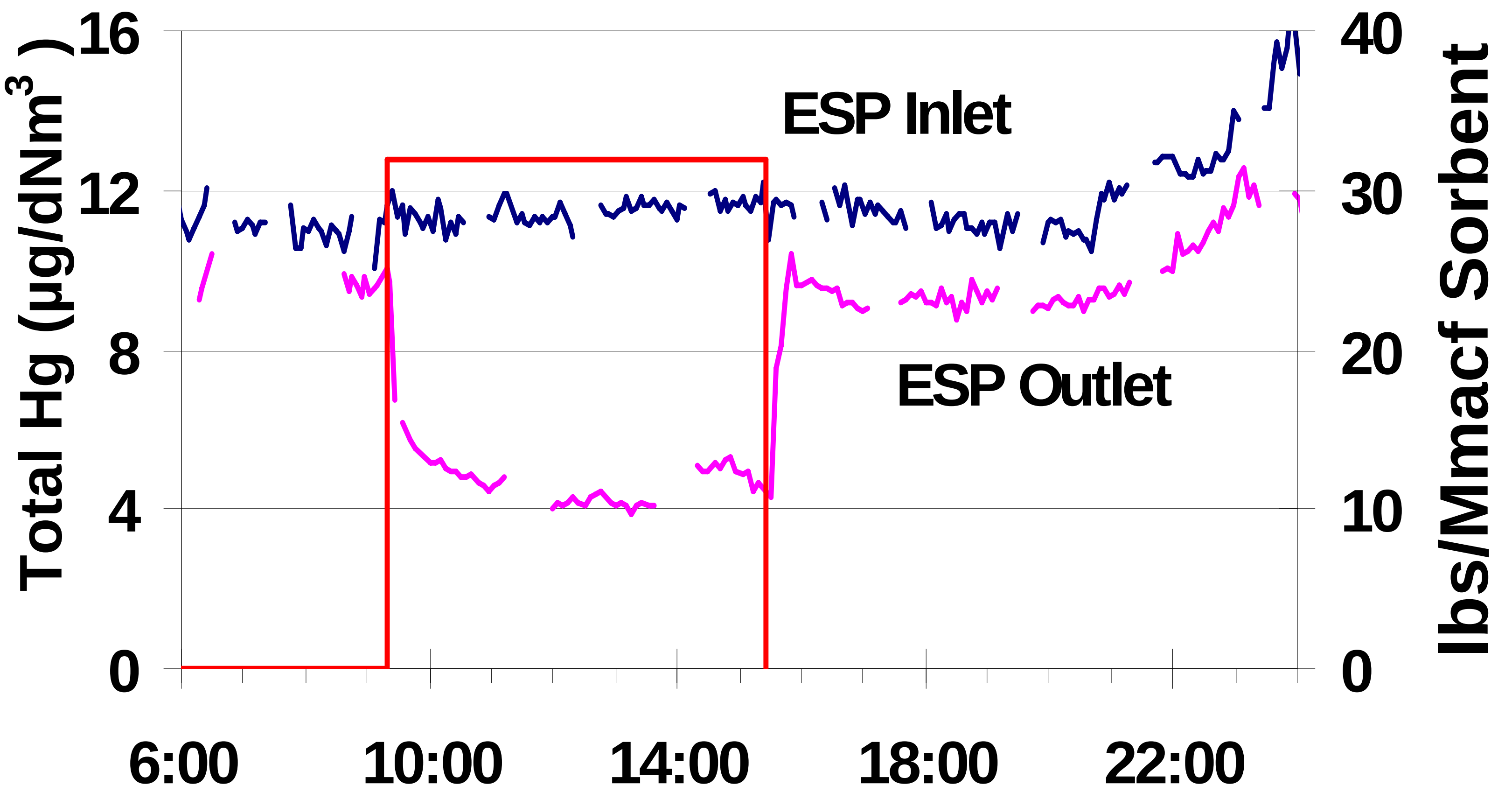
Optimizing ACI Performance

- Good distribution is critical for maximizing capture and minimizing sorbent requirements
  - Critical for an ESP where in-flight capture is primary
  - Less critical for FF because most capture is on the bags
- Residence time is important for in-flight capture
  - Provides time for contact between flue gas Hg and sorbent
  - Provides time for oxidation Hg on surface of sorbent
  - Enhances distribution

In-Flight vs. Secondary Capture of Hg in an ESP



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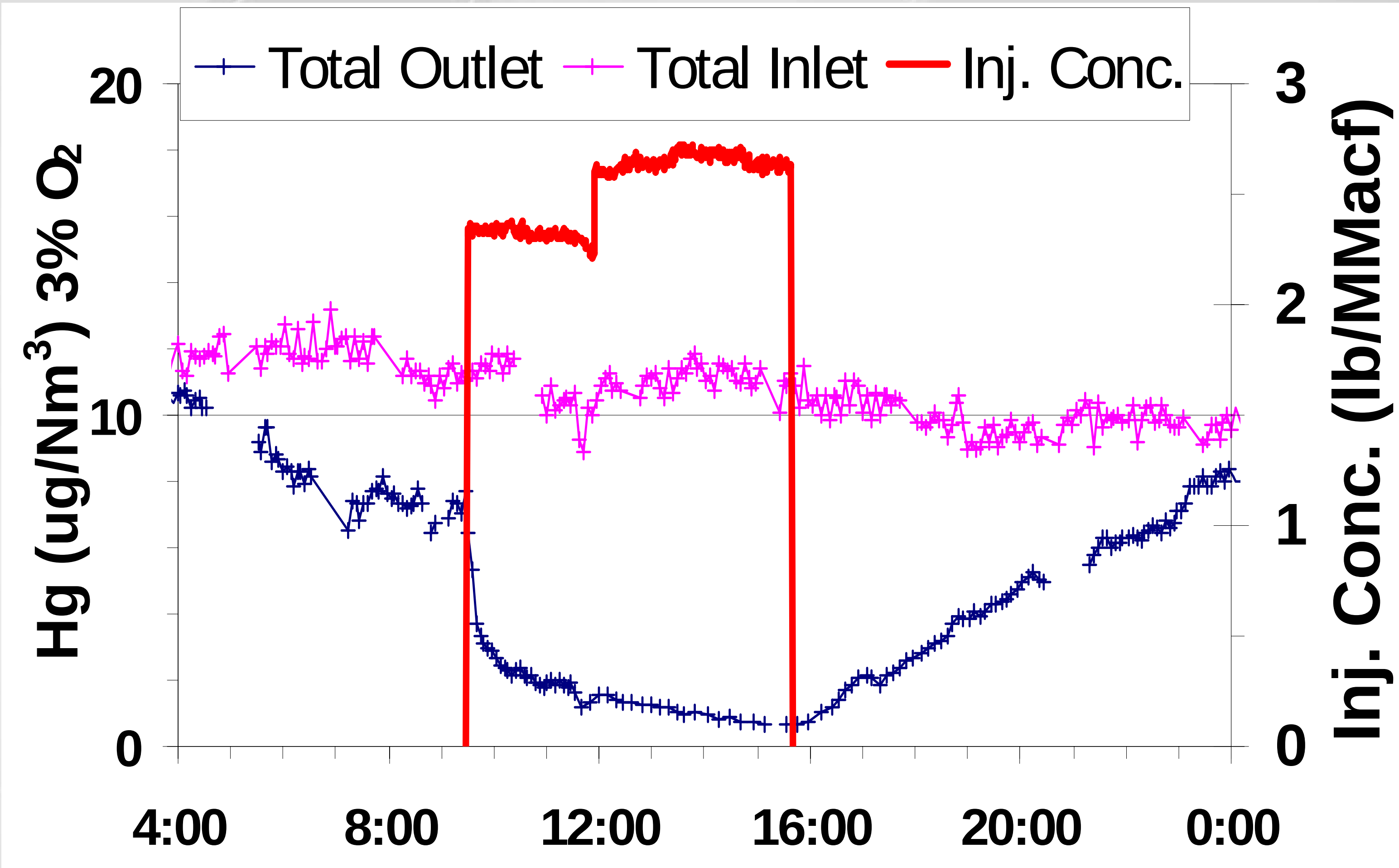
In-Flight vs. Secondary Capture of Hg in a Fabric Filter



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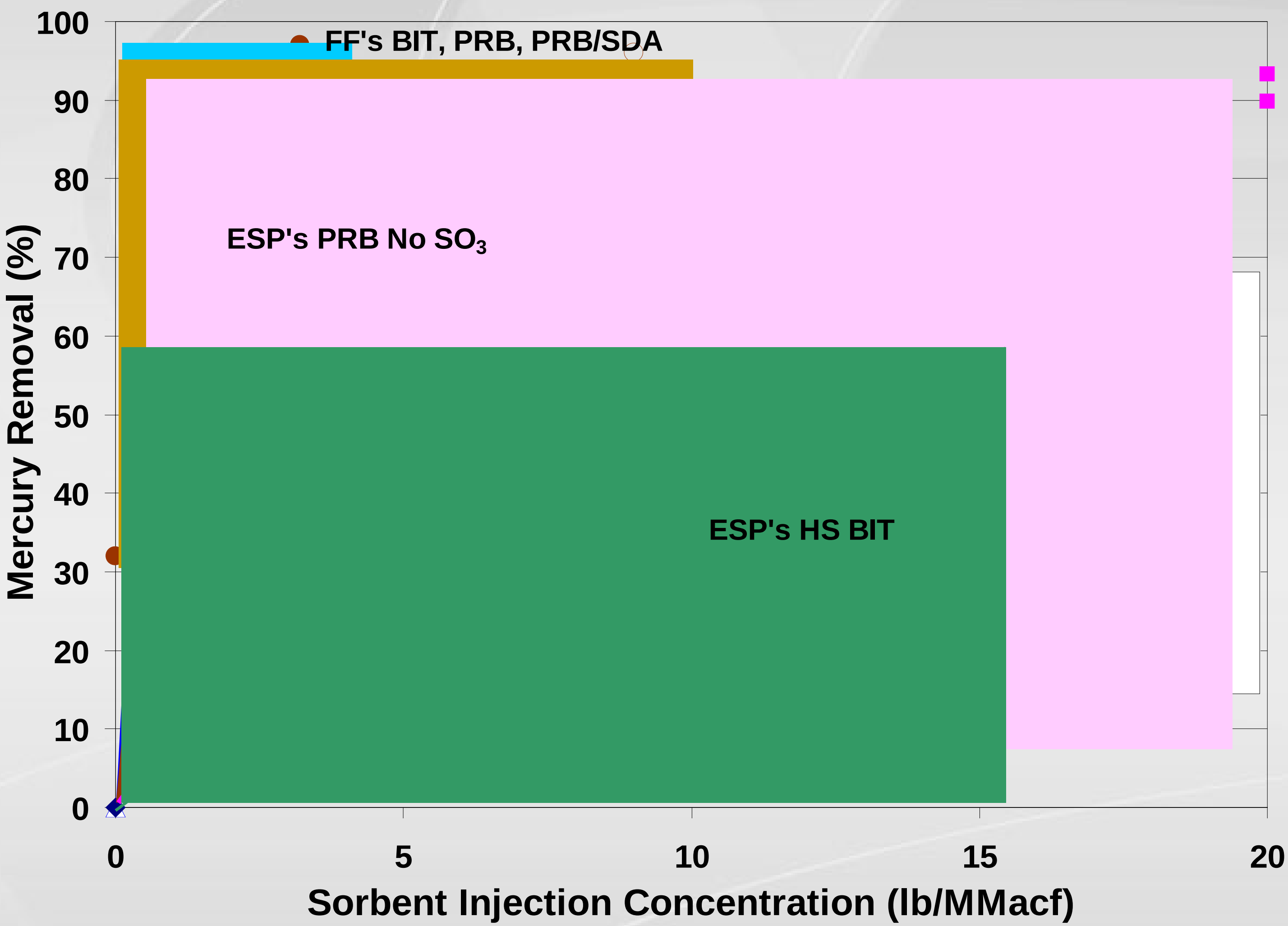
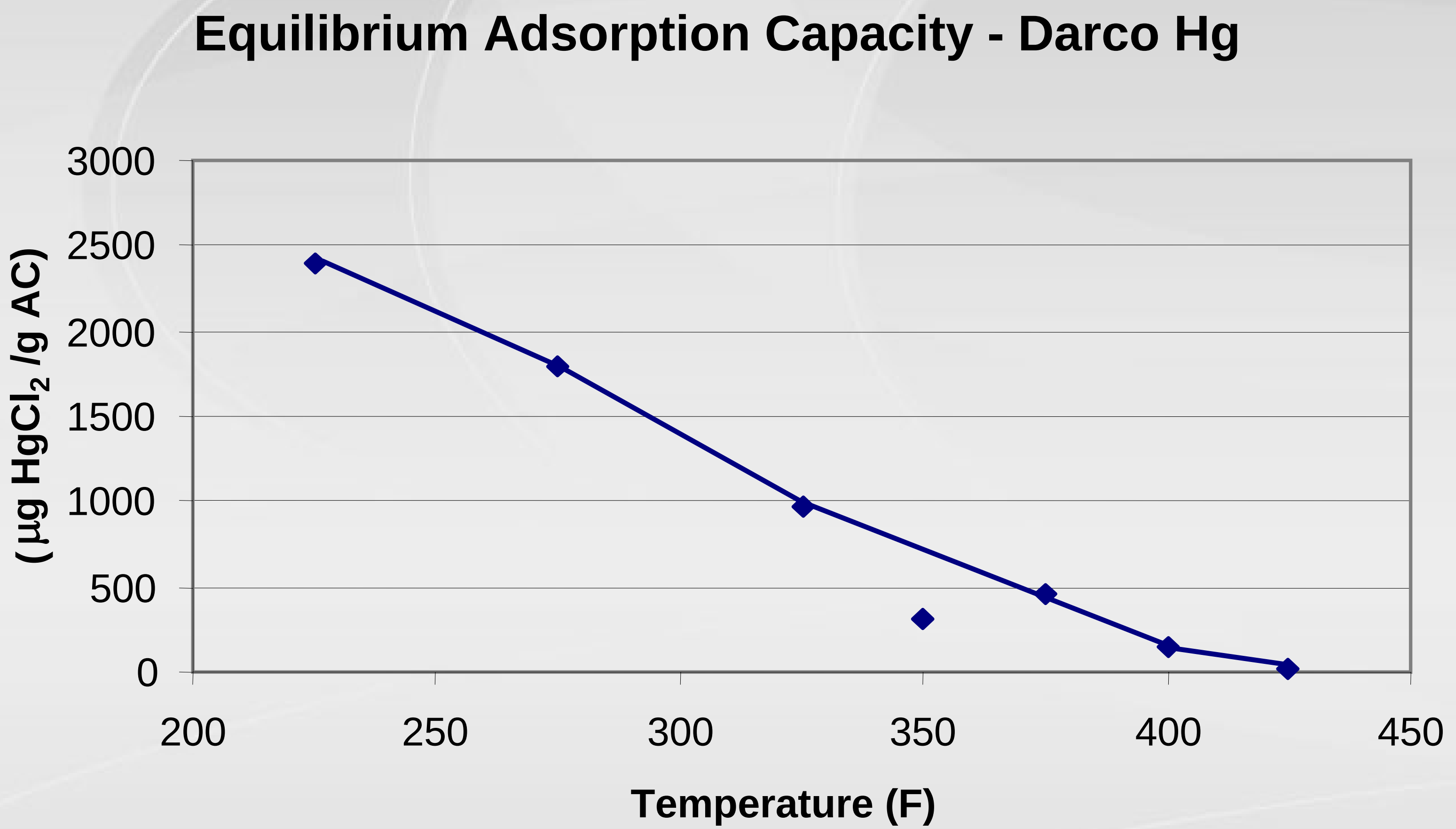
Mercury Reduction Trends with ACI on FF's and ESPs



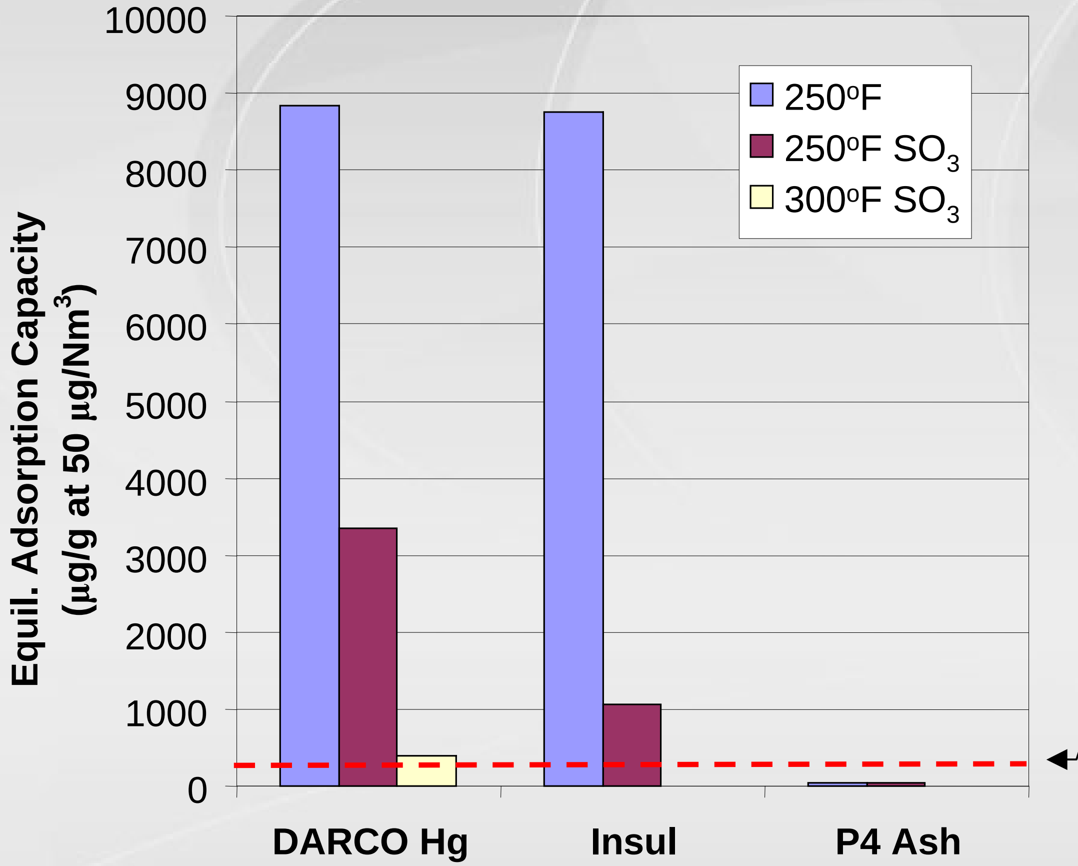
Challenges for PAC

- High Temperature
- High SO_3
  - High sulfur coal
  - SO_3 for FGC
  - SO_3 from SCRs

Adsorption Capacity vs. Temperature



Effect of SO_3 on Sorbent Capacity: Fixed-bed results



EPRI tests indicate capacity > 300 µg/g is needed for good Hg capture

Equilibrium Adsorption Capacities Upstream and Downstream of SO_3 Injection for FGC

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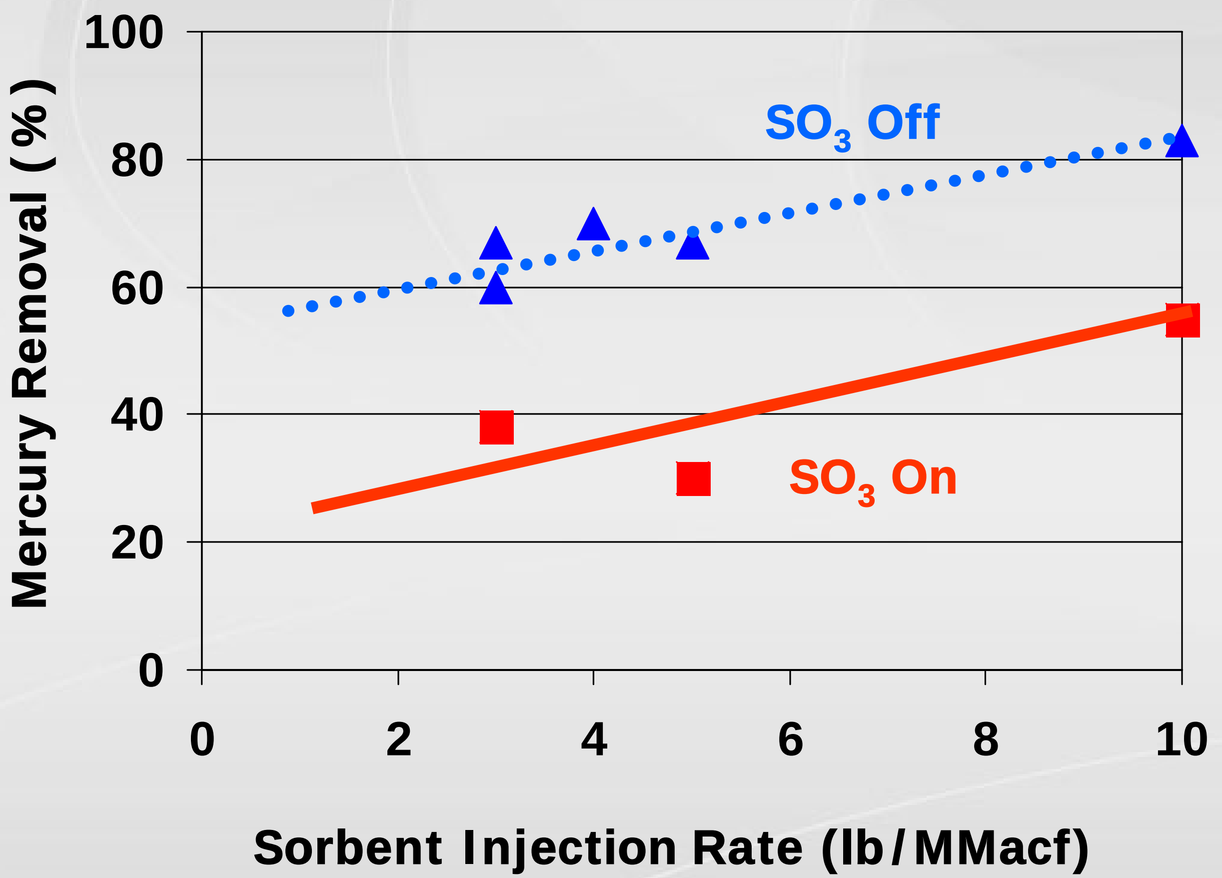
Flue Gas Conditioning and ACI Effectiveness: Full-Scale Injection

Mississippi Power Plant Daniel
Low sulfur bituminous coal



High Sulfur Coal and Sorbent Effectiveness

- Conesville Station (3.5 to 4% sulfur coal)
  - – Fixed-bed screening
    - 46 sorbents from 14 suppliers
  - – Full-scale injection tests
    - 15 sorbents from 5 suppliers

Poor mercury removal performance for all sorbents tested (carbon, non-carbon, virgin, treated)

DOE NETL testing 2006

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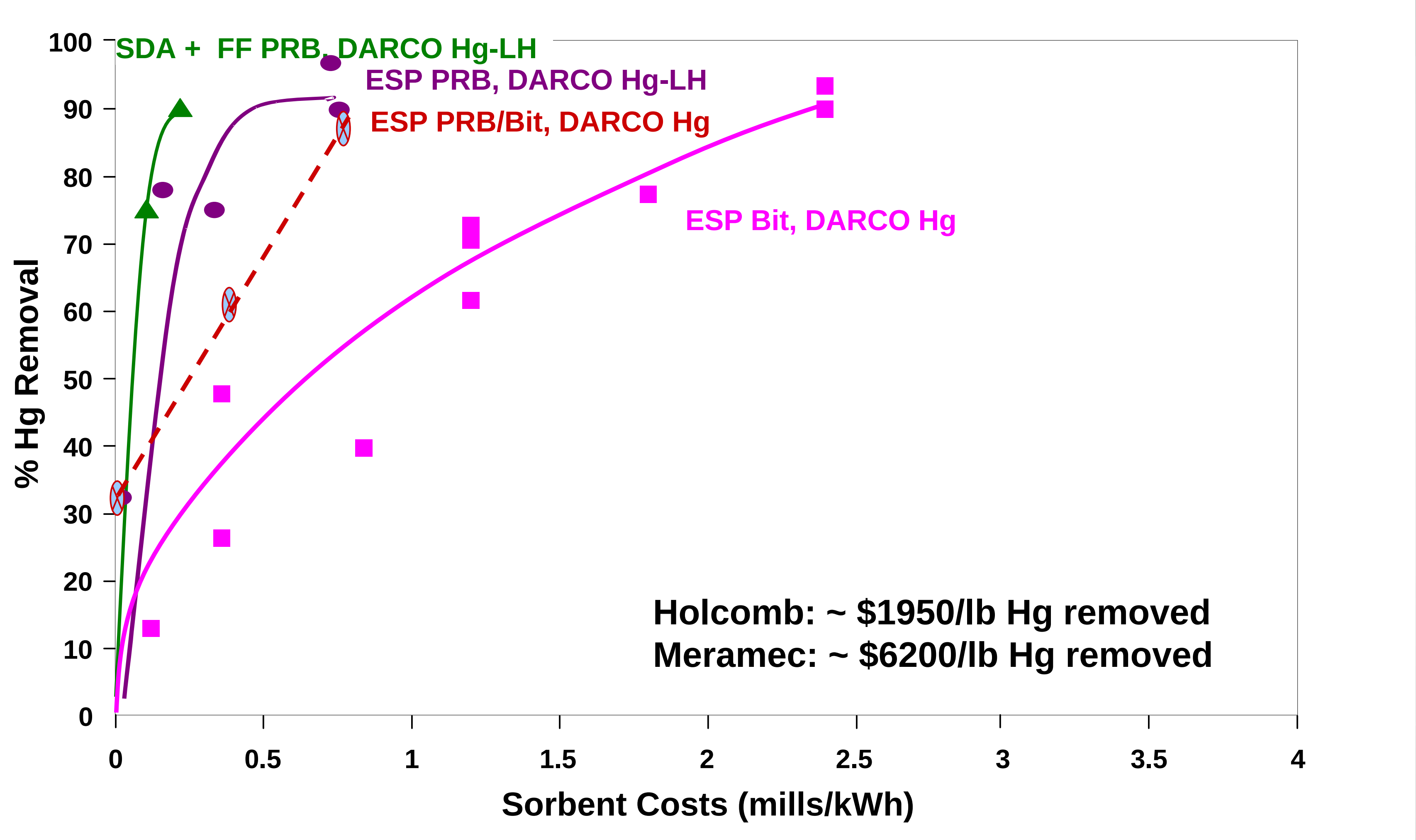
Options for Addressing SO_3 Issues

- SCR Catalysts designed for low sulfur oxidation
- Sorbents to capture SO_3
- Activated carbons designed to resist SO_3 interference
- Inject AC upstream of SO_3 FGC
- Use liquid-based (non- SO_3) conditioning

Effect of Flue Gas Characteristics on PAC: Summary

- The capacity of activated carbon to capture mercury decreases at higher temperatures
  - <280ºF – minimal impact
  - 375ºF > and > 280ºF – increased effect, may need brominated carbon
  - 650ºF > and > 375ºF – some success with brominated carbons
  - >650ºF – opportunity for product development
- Chlorine, SO_3, and other trace acid gases play a significant role in the performance of activated carbon
  - Low halogen = reduced capacity: halogen addition using treated sorbent or process additive required
  - High SO_3 (from SCR, FGC or high sulfur coal) = reduced capacity: products being developed

Sorbent Cost Comparison



Worst Case Sorbent Injection Costs

- **ESP sized for 10 lb/MMacf injection rate**
  - At maximum injection rate, assuming $0.65/lb delivered = $9.57/kW annual PAC cost.
  - ESP expected to achieve 30-50% Reduction

- **PJFF sized for 5 lb/MMacf injection rate**
  - At maximum injection rate, assuming $0.65/lb delivered = $4.78/kW annual PAC cost.
  - PJFF expected to be <3 lb/MMacf for 80-90% reduction due to greater intimate contact of Hg to PAC in filter cake or $2.87/kW annual PAC cost.

Commercial ACI Systems: Permitted or Installed

Plant Size MWs	Location	Coal	APC	New/Retrofit	Regulatory Driver
270	Midwest	PRB	TOXECON	Retrofit	Consent Decree
740	Midwest	PRB	SDA/FF	New Plant	New Construction Permit
550	Midwest	PRB	SDA/FF	New Plant	New Construction Permit
350	West	PRB	SDA/FF	Retrofit	Consent Decree
350	West	PRB	SDA/FF	Retrofit	Consent Decree
800	West	PRB	SDA/FF	New Plant	New Construction Permit
350	East	Bituminous	ESP	Retrofit	State Regulation
350	East	Bituminous	ESP	Retrofit	State Regulation
650	Midwest	PRB	SDA/FF	New Plant	New Construction Permit

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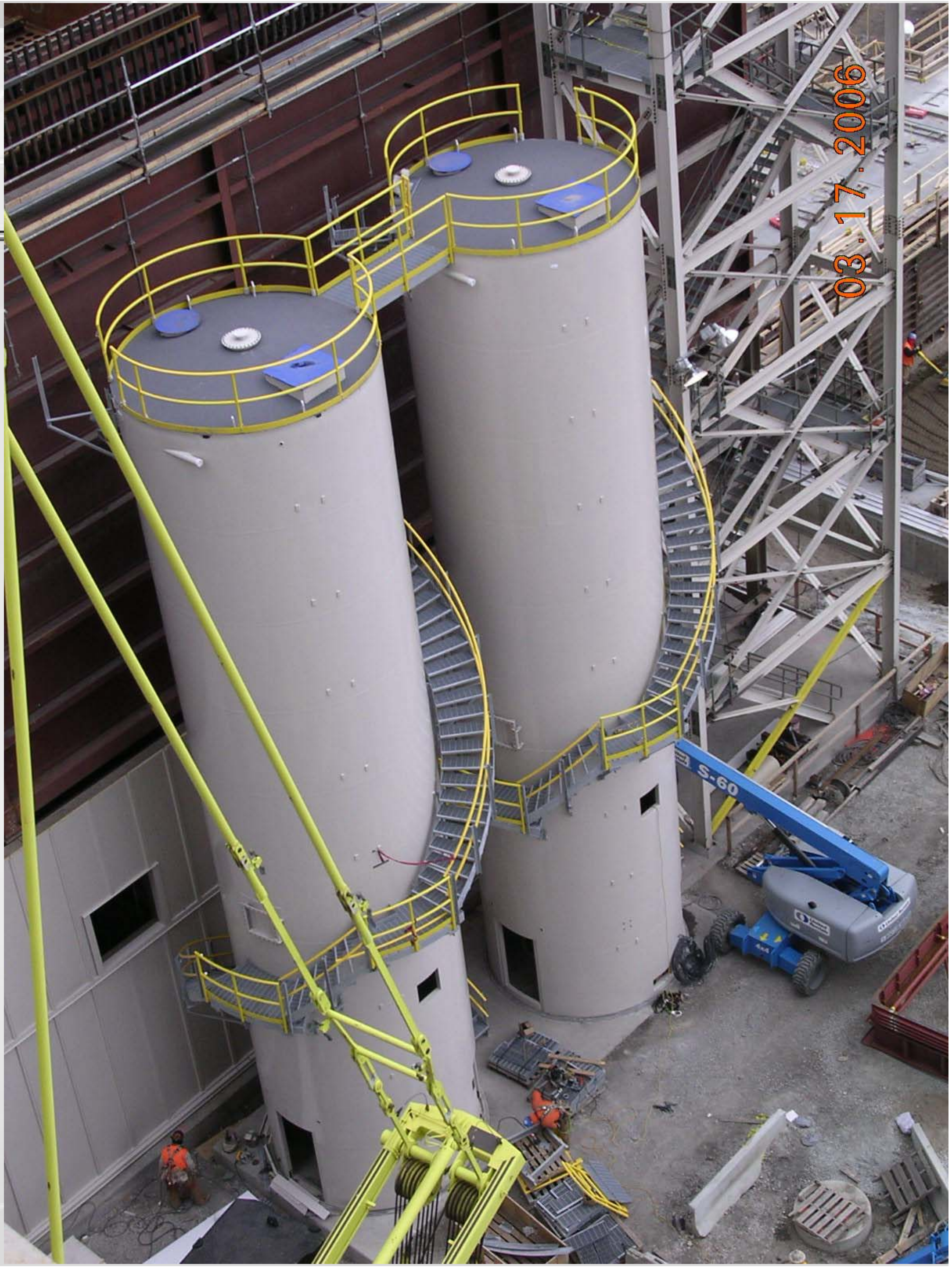
Council Bluffs Installation With Spiral Staircases Installed For Access



Guidelines on Hg Removal/Emissions Guarantees

- Plant-specific and coal-specific
- Fabric filters: >90% possible
- ESPs alone: fuel specific (30-80% expected)
- SDA/FFs: 80 to 90+% with halogenated sorbents
- Sorbent screening and full-scale tests reduce uncertainties in providing guarantees

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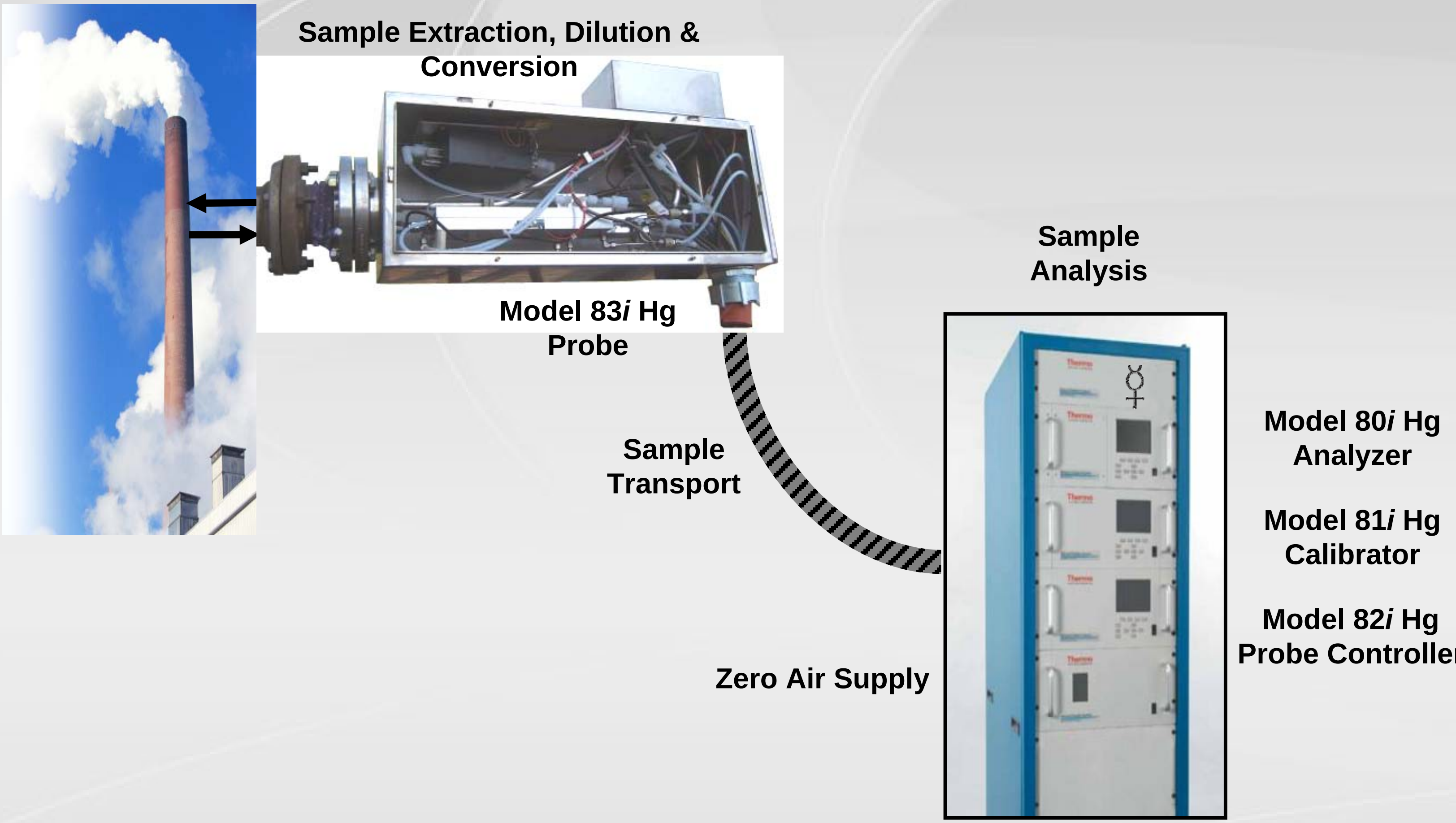
Mercury CEM

Clean Coal Partnership

- ADA-ES partnered with Thermo Electron to develop mercury CEM
- ADA-ES installed systems at Presque Isle NETL mercury demonstration project (PIPP) and has conducted measurements at 6 other plants for >25,000 hours of operation.
  - PRB, LS E. Bit, HS E. Bit, Wet FGD, upstream and downstream of APC
- Thermo CEMs have passed EPA certification tests

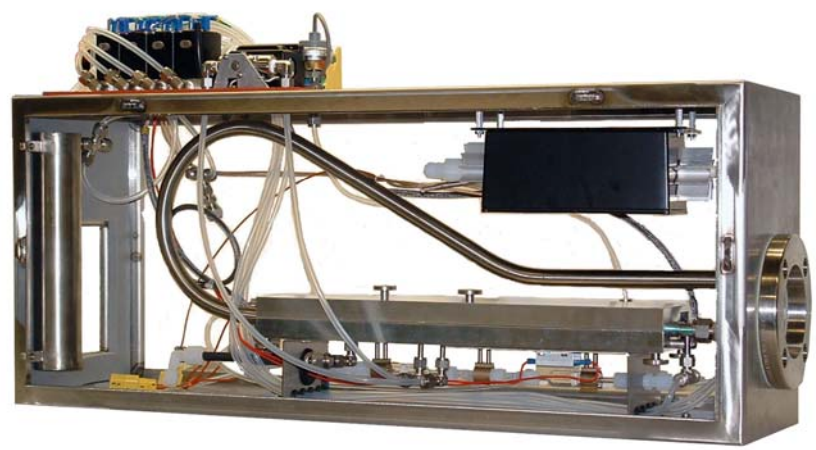
Mercury CEMS Overview



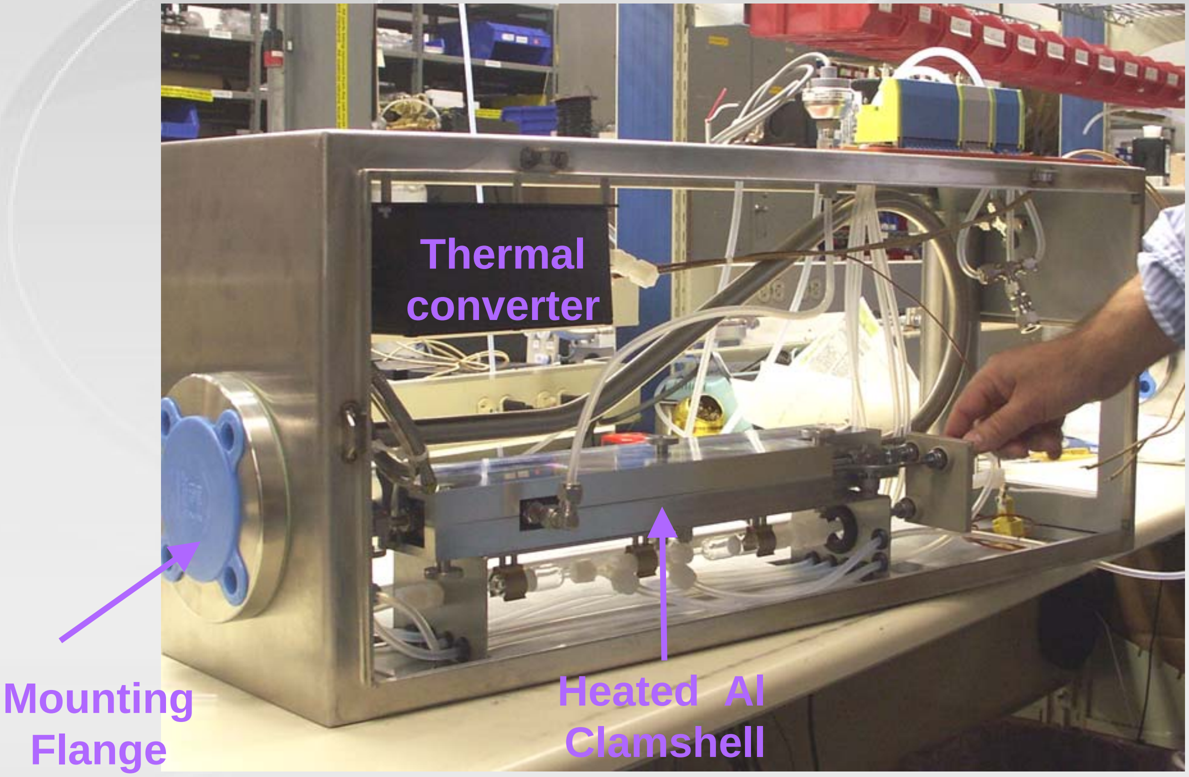
Thermo Electron *Mercury Freedom System*™

Model 83*i* Probe/Converter

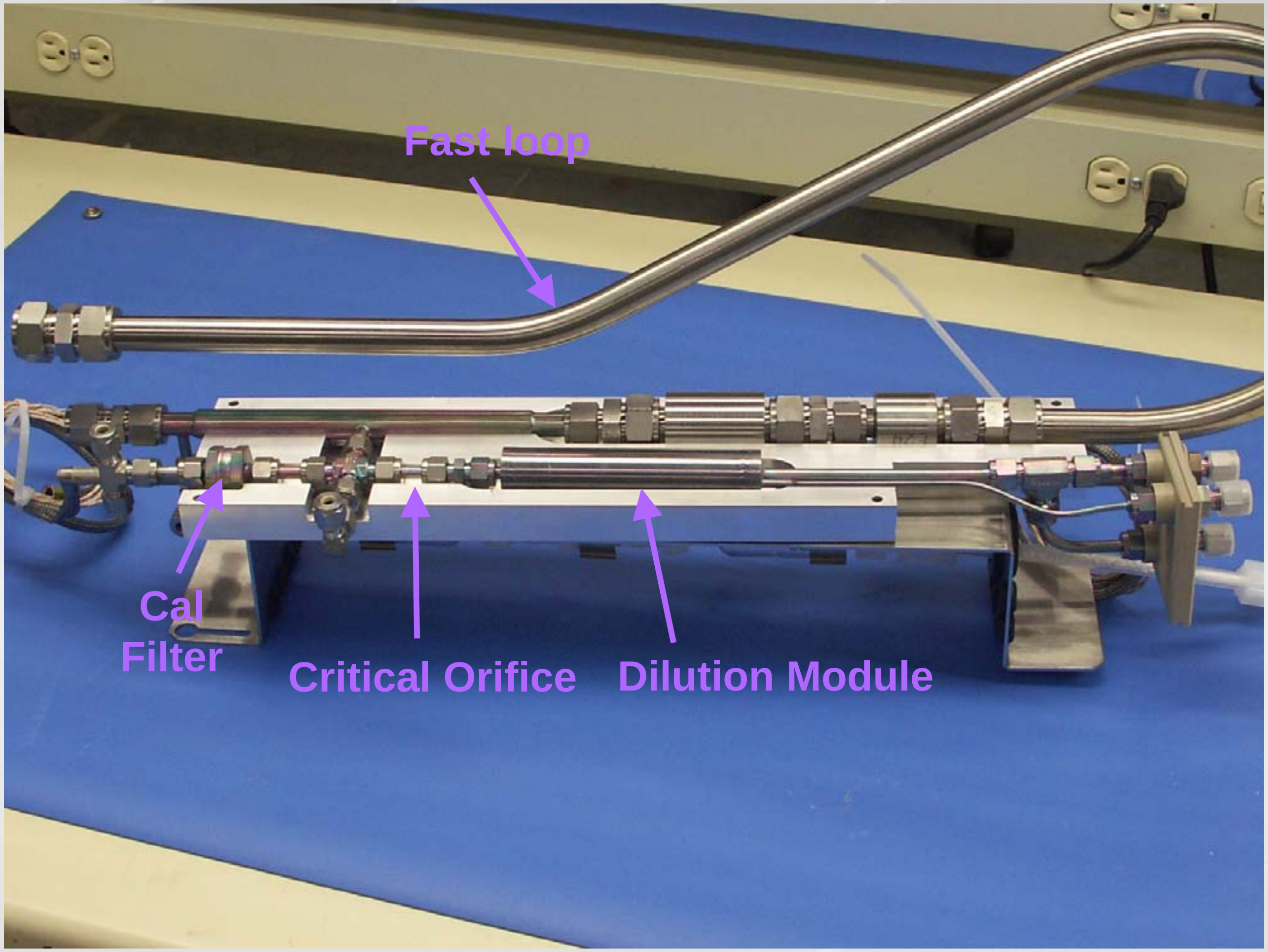
- Designed for serviceability
- Elimination of cold spots
- Integrated Converter
- Dilution Module



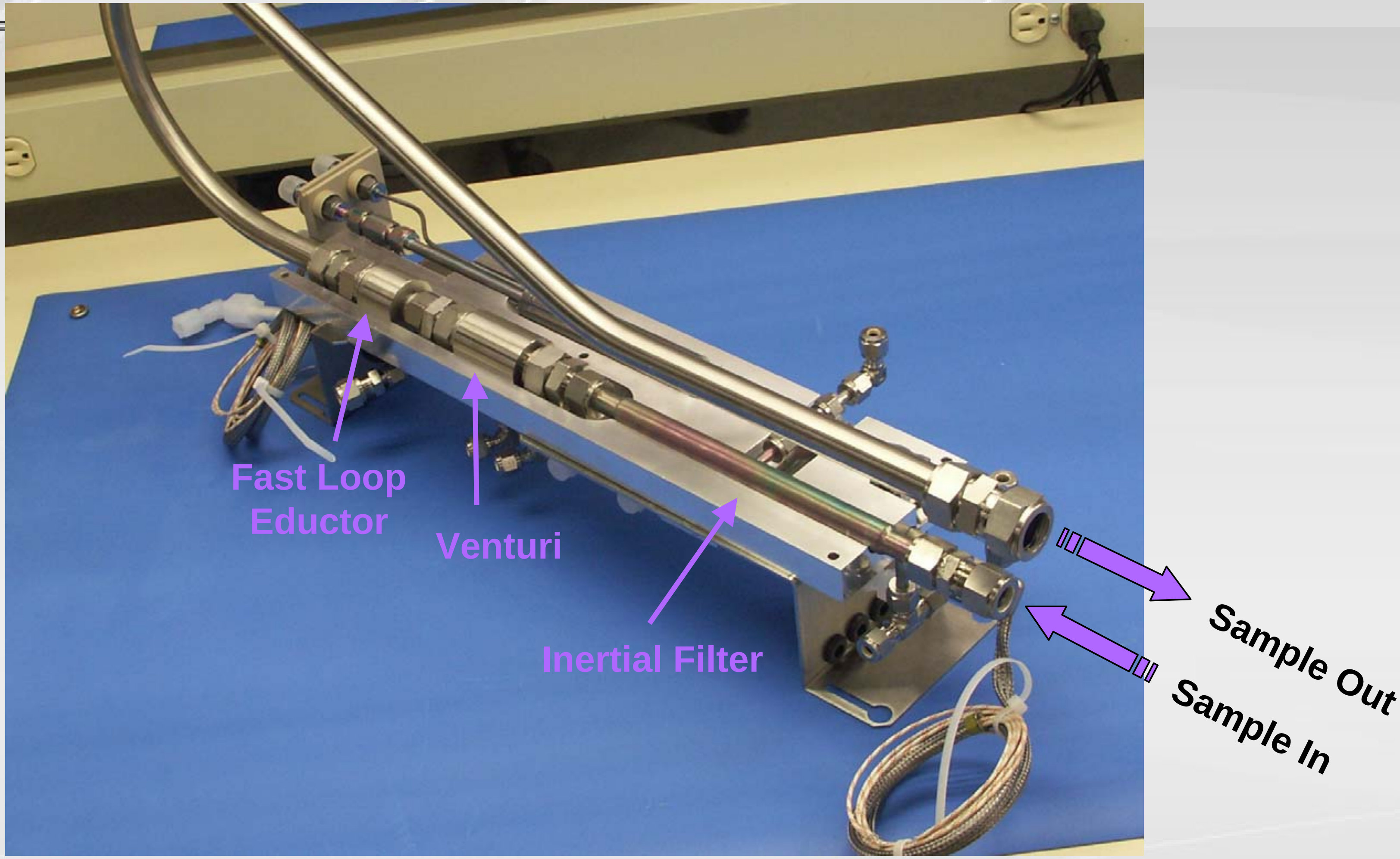
Converter/Inertial Filter Probe



Inertial Filter/Dilution Module

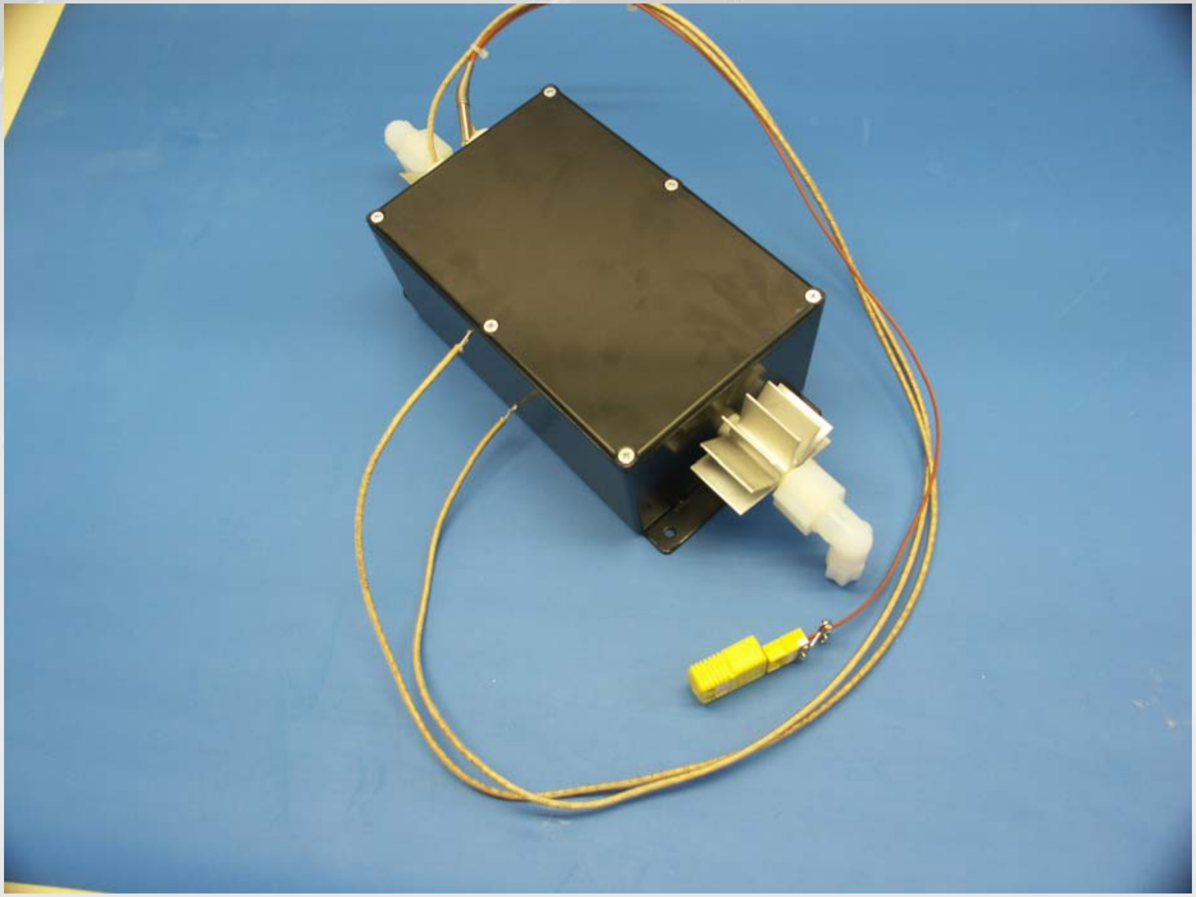


Fast Loop Inertial Filter



Total Mercury Converter

Then



Now

Hg CEMS – Presque Isle, MI

Results of 7-day Calibration Error Test

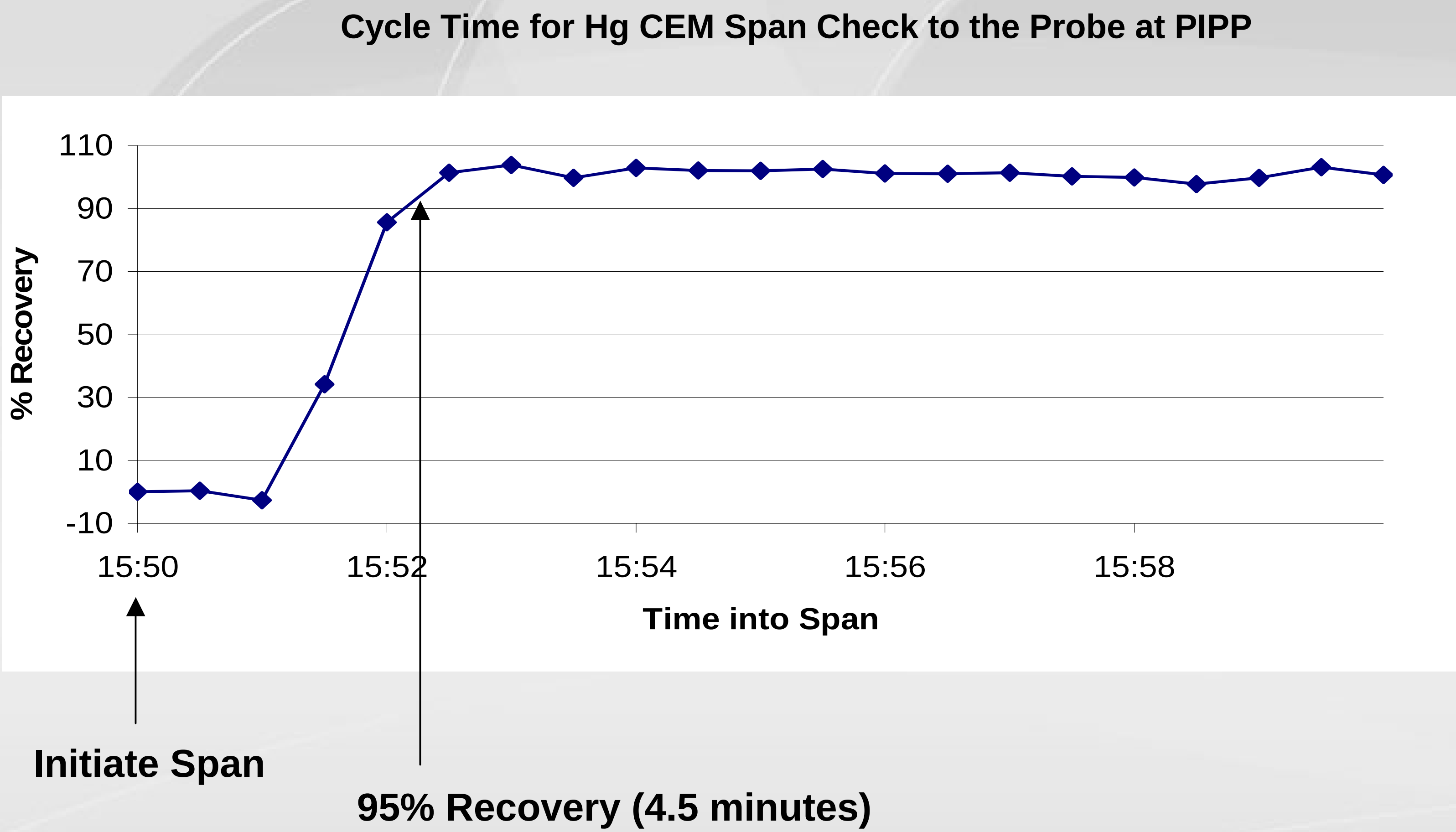
DAY	DATE	TIME START	TIME END	SPAN	CEMS	% ERROR -or- ABS DIFF		PASS/FAIL
1	10/21/2005	6:30		9.94	9.92	0%	0.02	PASS
2	10/22/2005	12:54	13:05	9.99	10.02	0%	-0.03	PASS
3	10/23/2005	16:25	16:47	9.99	9.6	4%	0.39	PASS
4	10/24/2005	16:40	16:55	9.82	9.55	3%	0.27	PASS
5	10/25/2005	13:45	14:15	9.87	9.87	0%	0	PASS
6	10/26/2005	15:20	15:45	9.85	10.09	-2%	-0.24	PASS
7	10/27/2005	14:45	15:15	9.84	10.2	-4%	-0.36	PASS

Hg CEMS – Presque Isle, MI

Results of 3-Point Linearity Check

PT	DATE	TIME START	TIME END	SPAN	CEMS	% ERROR -or- ABS DIFF		PASS/FAIL
1	10/27/2005	14:30	14:45	0	0	-	0	PASS
2	10/27/2005	15:25	15:50	4.92	4.63	6%	0.29	PASS
3	10/27/2005	14:45	15:15	9.84	10.2	-4%	-0.36	PASS

Hg CEMS – Presque Isle, MI



Hg CEMS – Presque Isle, MI

Results of STM testing at PIPP

Start Time	Stop Time	STM 1* µg/dNm³	STM 2 µg/dNm³	Thermo** µg/dNm³	% error** (STM 2)
08/03/05 10:41	08/03/05 11:41	NA	6.01	6.47	
08/03/05 12:03	08/03/05 13:35	5.94	5.91	6.39	-8.1
08/03/05 14:03	08/03/05 14:42	6.48	5.98	6.51	-9.0
08/03/05 15:24	08/03/05 16:06	6.81	6.22	6.22	6.2
08/03/05 16:20	08/03/05 16:55	7.65	6.74	6.32	-1.6

* Dry basis, 0°C.

** Totalizer on STM 1 malfunctioning intermittently. All error calculations based upon STM 2

Strategic Planning

Strategic Planning Program

- Characterize Mercury Emissions
  - Assess the current mercury emissions of each plant in the fleet
  - Project future emissions based on fuel usage
  - Project future (co-benefit) emissions based on planned flue gas desulfurization retrofits
- Review Options for Additional Control
  - Develop capital and operating cost projections for each unit

Analysis of Air Pollution Control Options

- Integrate mercury control with other APCs
- Evaluate specific retrofit technologies
- Evaluate coal/blending opportunities
- Project economic/compliance costs
- Plan strategy for one unit or whole fleet

ADA-ES

More Information

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http://www.netl.doe.gov/technologies/coalpower/ewr/mercury/index.html