REINHOLD ENVIRONMENTAL Ltd.

2019 NOx-Combustion-CCR Round Table Presentation

February 11 & 12, 2019, in Salt Lake City, Utah / Hosted by PacifiCorp

Mercury Control in the US: 2018 Year in Review

Advancing Cleaner Energy

Sharon Sjostrom –Year in Review

Joe Wong and Robert Huston - Development of New Activated Carbons

Reinhold NOx-/Combustion-CCR, February 12, 2019

Disclaimer

This presentation includes general information on coal and coal-fired boilers intended for education and illustration purposes only. All information is provided "AS-IS" and without warranty or liability of any kind.

Mercury Control 2018 Year in Review

How are we doing?

- What's working?
- What's not working?
- What's new?

Methodology

- Query EPA Air Markets and EIA Databases for boilers subject to MATS reporting Hg emissions
- 12 months ending November 2018 for operations, January – December 2018 for mercury emissions
- Calculate daily and monthly average mercury emissions, and monthly average coal source (mine and region), heating value mercury and sulfur by EGU
- Categorize each boiler by air pollution control type and primary fuel
- Abbreviations used:
  - CESP – cold-side ESP
  - FF – Fabric filter
  - SCR – Selective catalytic reduction
  - Hg controls
    - PAC – Powdered Activated Carbon
    - CA – Coal Additives (i.e. bromine or iodine)
    - RC – Refined Coal (IRS designation) *EGUs included here use iodine or bromine as a coal additive*
  - BIT – Bituminous Coal
  - SUB – Subbituminous Coal
  - LIG – Lignite Coal
  - WFGD – Wet FGD
  - DFGD – Dry or semi-dry FGD
  - DSI – Dry Sorbent Injection

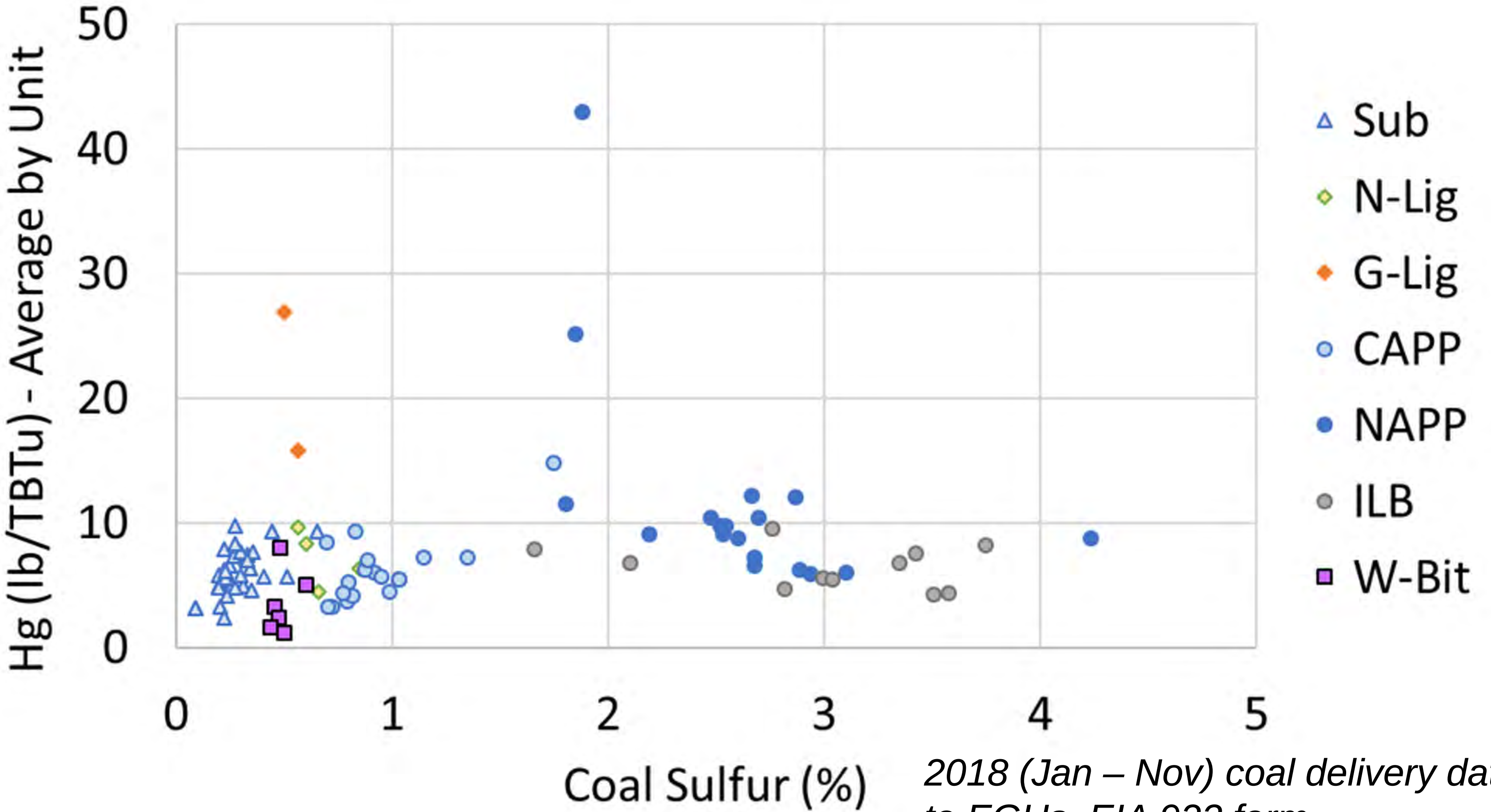
Primary Factors that Affect Mercury Emissions and Mercury Control Selection

- Coal properties
  - Mercury, halogens, sulfur
- Air Pollution Controls (NOx, SOx, PM)
  - FF generally better than ESP
  - FGD helps if there's enough halogen
  - SCR helps oxidize Hg on scrubbed units
  - Reducing SO_3 on medium and high sulfur units will help
- Other Considerations
  - Economics
  - Balance-of-plant impacts
  - Environmental constraints (e.g. ancillary emissions or effluent discharges)

Primary Factors that Affect Mercury Emissions and Mercury Control Selection

- Coal properties
  - Mercury, halogens, sulfur
- Air Pollution Controls (NOx, SOx, PM)

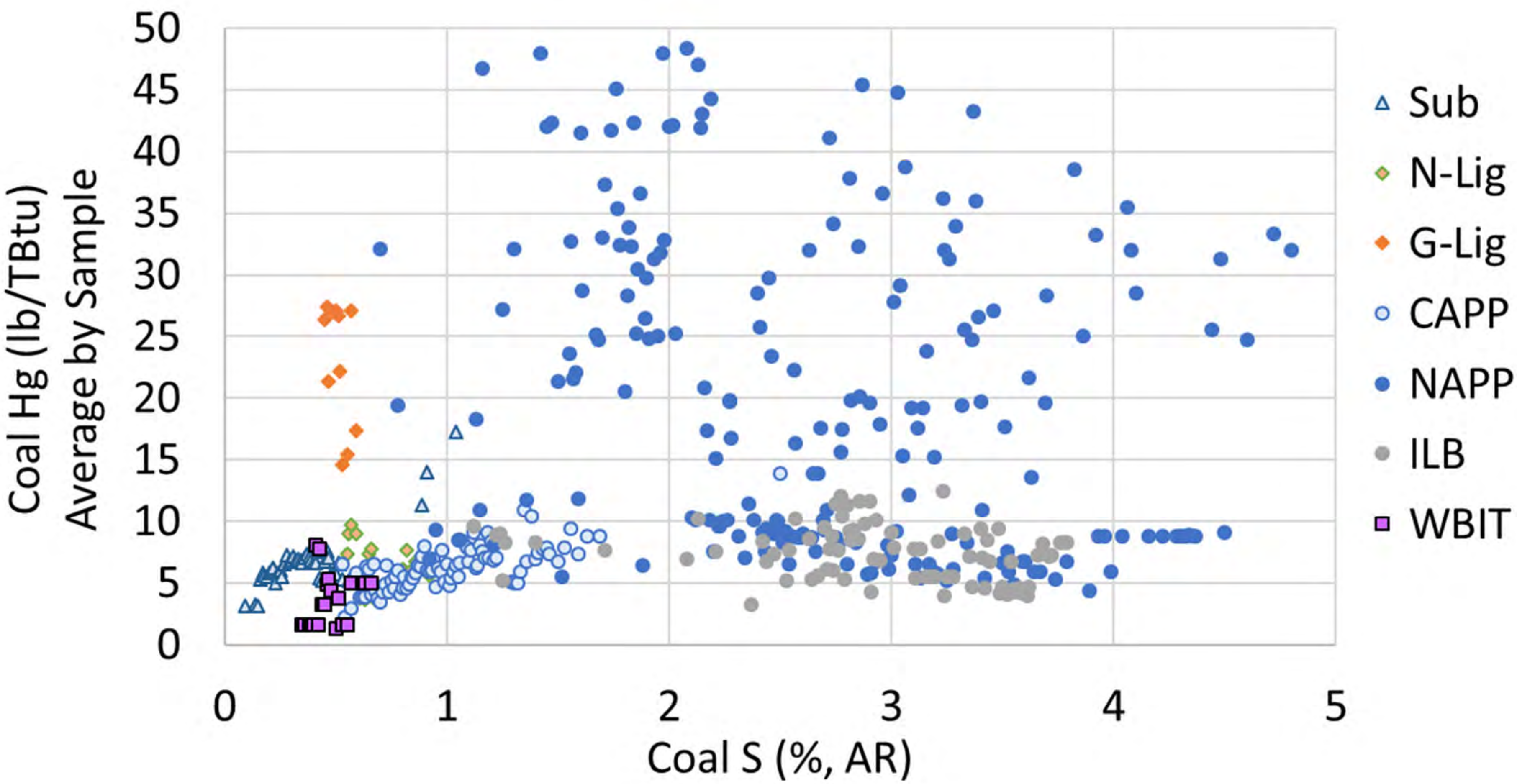
Coal Mercury and Sulfur – Unit Averages



2018 (Jan – Nov) coal delivery data to EGUs, EIA 923 form

- ➢Northern Appalachian: Higher Hg required for some plants
- ➢NAPP and ILB: Sulfur may make controls more challenging

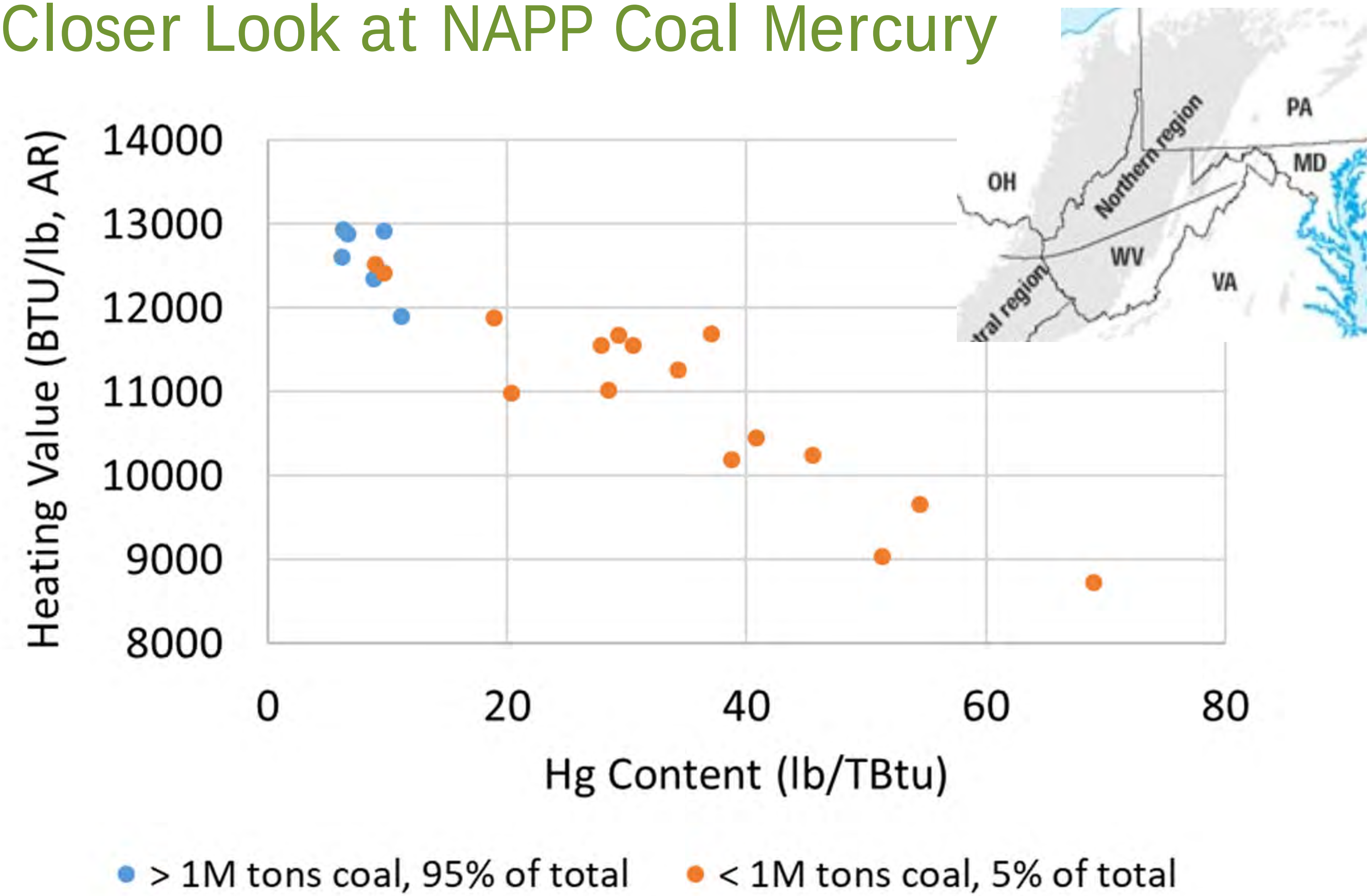
Variability in Mercury and Sulfur



➢ Northern Appalachian: Significant scatter

2018 (Jan – Nov) coal delivery data to EGUs, EIA 923 form

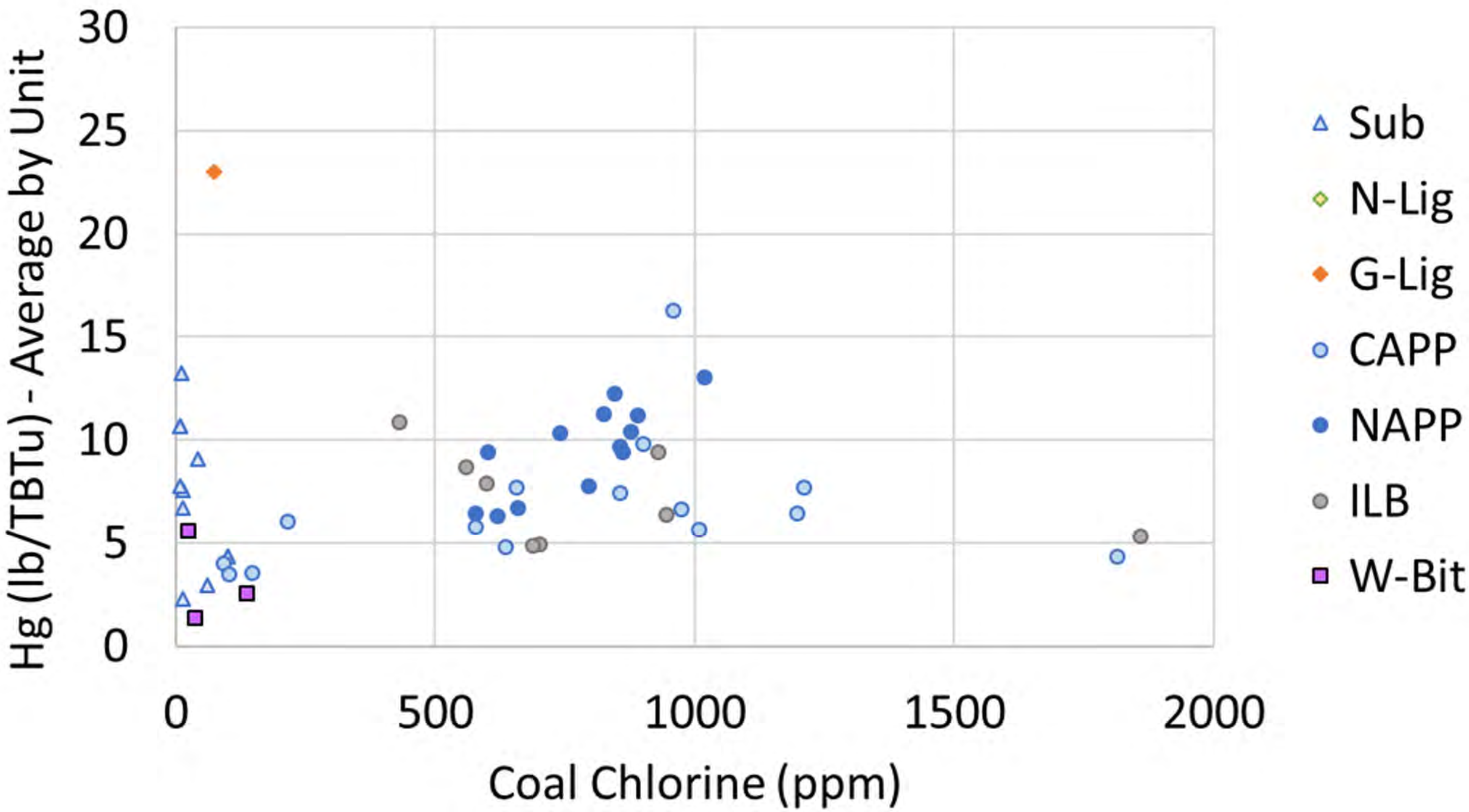
Closer Look at NAPP Coal Mercury



➤Most NAPP delivered is high HV with lower mercury content

Chlorine and Mercury in Coal

- Subbituminous, Western Bituminous, Gulf-Lignite and some CAPP may benefit from halogen addition (ND lignite too)

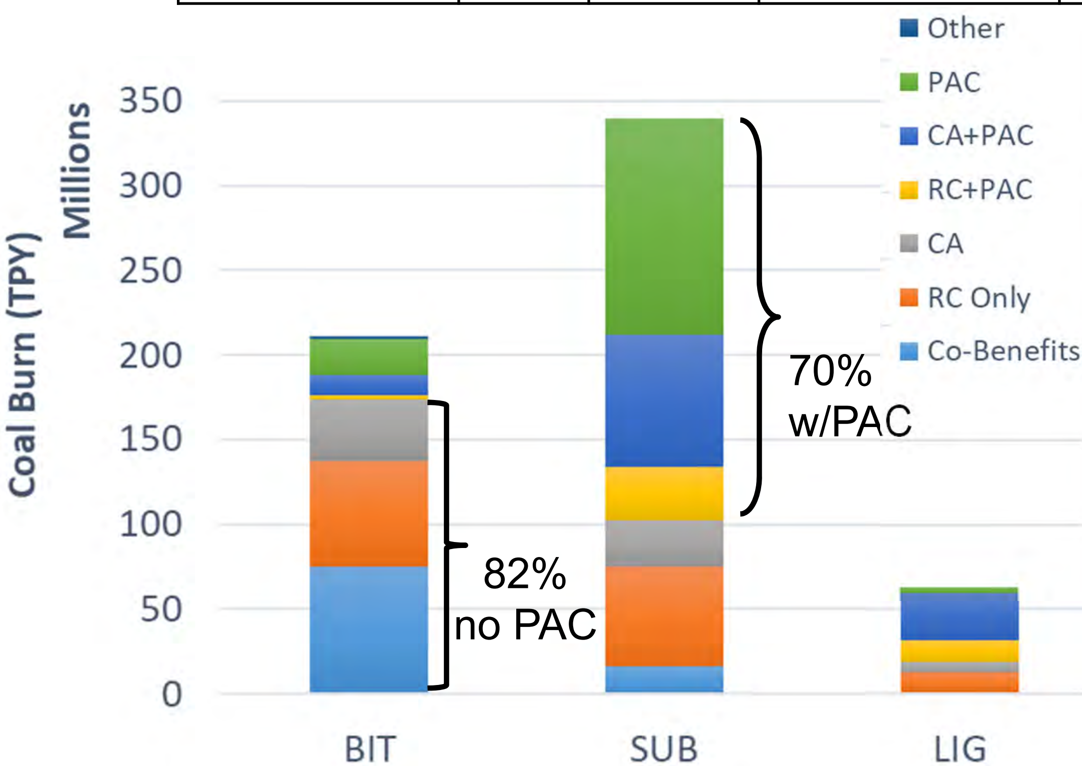


Mercury Control Strategies

- **Reported to EPA**
  - Powdered Activated Carbon (PAC)
  - Halogenated Activated Carbon (HPAC)
  - Coal Additives (CA)
  - Fuel blending
  - Halogen Coal Additive + PAC (CA+PAC)
  - Alkaline sorbents for acid gas mitigation (DSI)
- **Not Reported**
  - Combustion modifications to enhance Hg removal through unburned carbon
  - Scrubber Re-emission chemicals
  - Amount of PAC or CA used, or specific type (beyond PAC-HPAC)

Preferred Hg Controls by Coal Type

Primary Coal	GW	EGUs	Coal (MMtpy)	Capacity Factor
BIT	119	270	218	38%
SUB	111	268	333	51%
LIG	12	28	52	65%
WC	1	6	5	64%
Total	**243**	**572**	**619**	



- Bituminous-fired plants are operating at lower capacity factor, on average
- 82% of bituminous coal controlled by co-benefits or halogen coal additives*
- 70% of subbituminous and lignite coal controlled with PAC*
- High level averages don't tell the whole story

** Based on information reported to CAMD and EIA*

Primary Factors that Affect Mercury Emissions and Mercury Control Selection

- Coal Rank
- Air Pollution Controls (NOx, SOx, PM)

Coal and Air Pollution Control

Operating Units Per Configuration (566 Units Total)

		BIT			SUB			LIG		
		No NOx	SCR	SNCR	No NOx	SCR	SNCR	No NOx	SCR	SNCR
CESP	No SOx	2	1	6	**57**	10	8			
	Dry*	2			3	3	2	1		
	WFGD	26	**122**	13	19	20	2	8		5
FF	No SOx			1	21	4	4			
	Dry*	7	10	9	29	24	1	6		3
	WFGD	14	13	2	14	8			2	1
Other	No SOx				9		1	1		
	Dry*	1	4		6	7	2			
	WFGD	12	22	3	8	5	1	1		

**Dry: Primarily DFGD, but includes DSI and fluidized bed boilers*

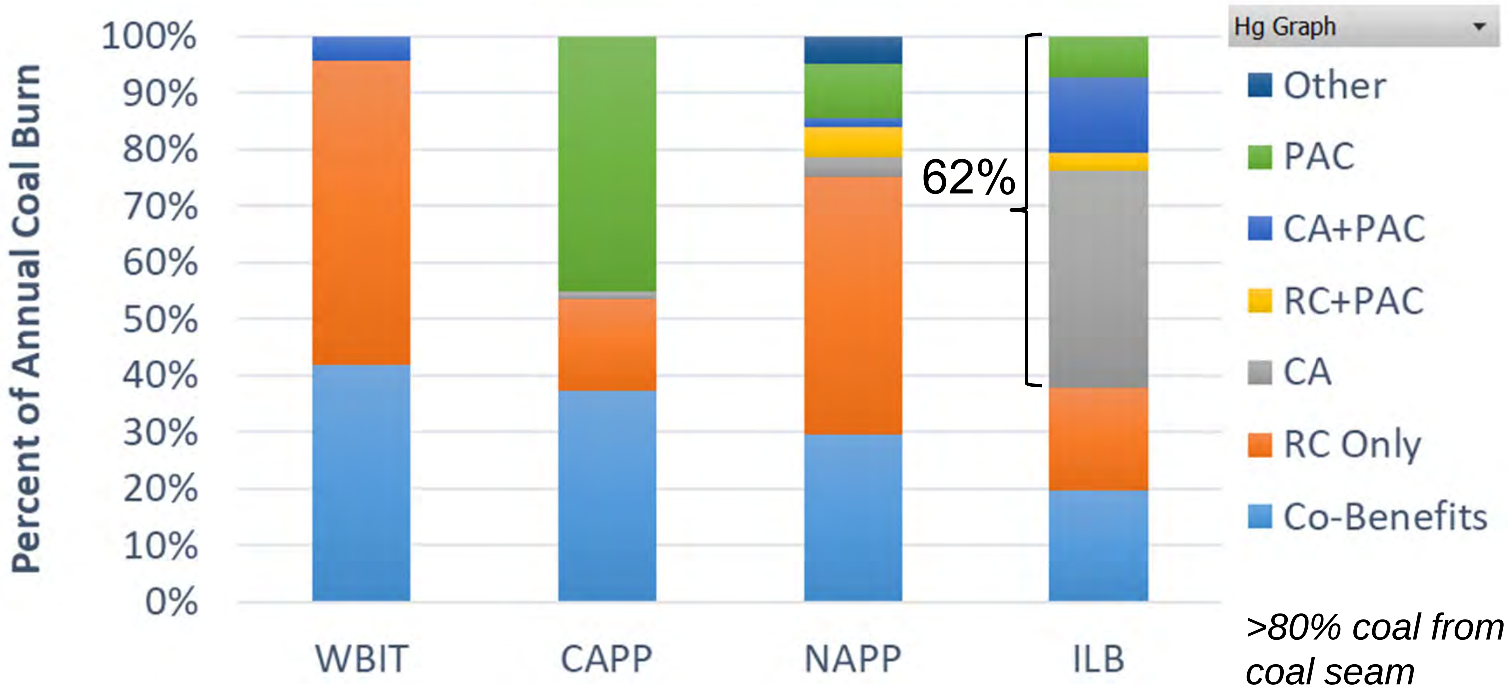
Most popular:

- Bituminous:
  - ✓ **45% SCR+CESP+WFGD**
  - ✓ 10% CESP+WFGD
  - ✓ 5% FF + WFGD
  - ✓ All others < 5% of all Bit units
- Subbituminous:
  - ✓ 21% CESP
  - ✓ 11% DFGD + FF
  - ✓ 9% SCR + DFGD + FF
  - ✓ 8% FF
  - ✓ 7% SCR+CESP+WFGD
  - ✓ 7% CESP + WFGD

Focus on Bituminous Units

- 63% (by coal fired) report no Hg-specific controls
  - *Down to 34% if RC is included as Hg control*
- Most (76% by coal burned) have SCRs
- Almost all (95% by coal burned) have wet FGDs
- Most (76% by coal burned) have CESPs

Mercury Control Strategies

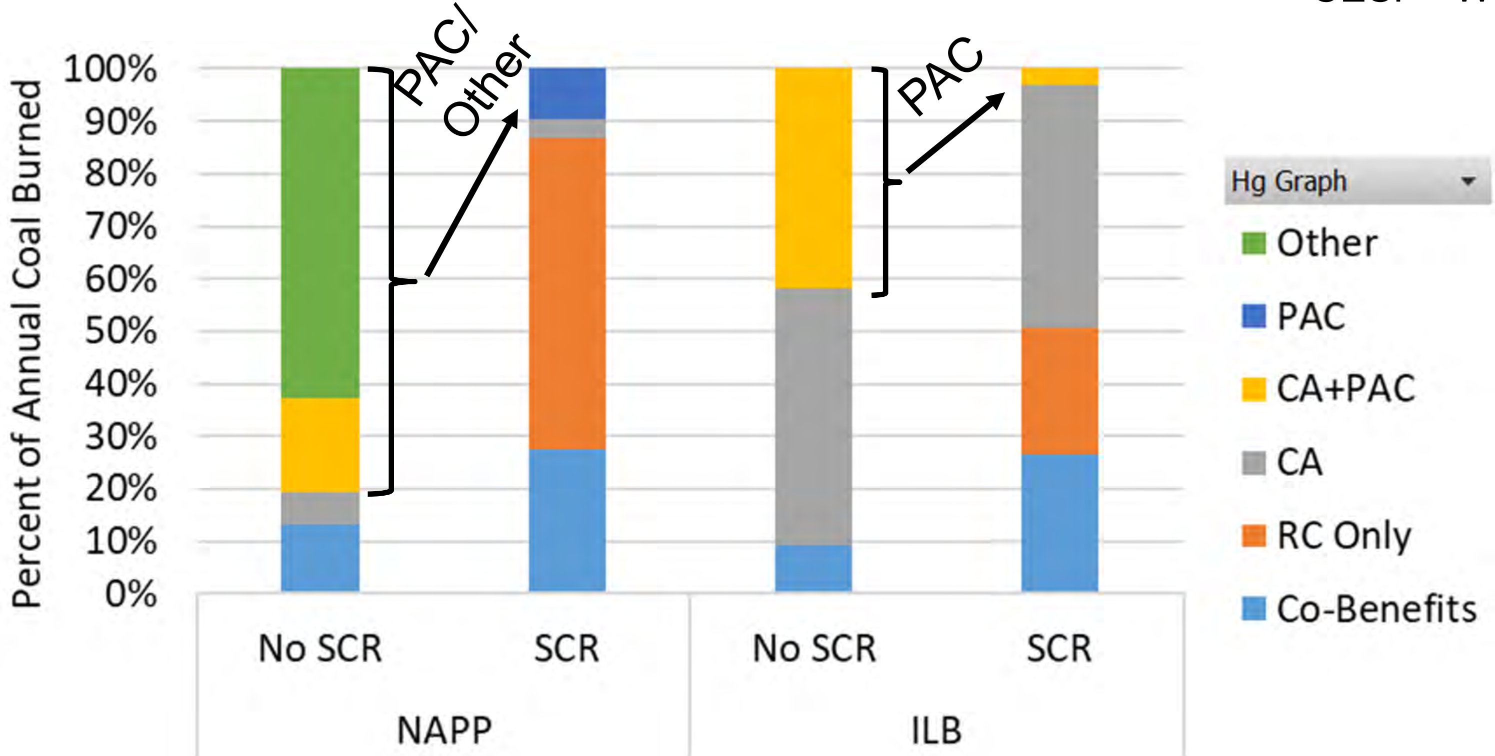


>80% coal from this coal seam

	WBIT	CAPP	NAPP	ILB
% SCR (by coal fired)	6%	32%	86%	83%
% WFGD (by coal fired)	91%	31%	90%	99%
% Fabric Filter (primary)	54%	33%	10%	11%
Avg Coal Sulfur	0.5-0.6	0.7-1.8	1.8-4.2	2.1-3.8
Avg Coal Cl	11-138	92-1814	576-1019	431-1858

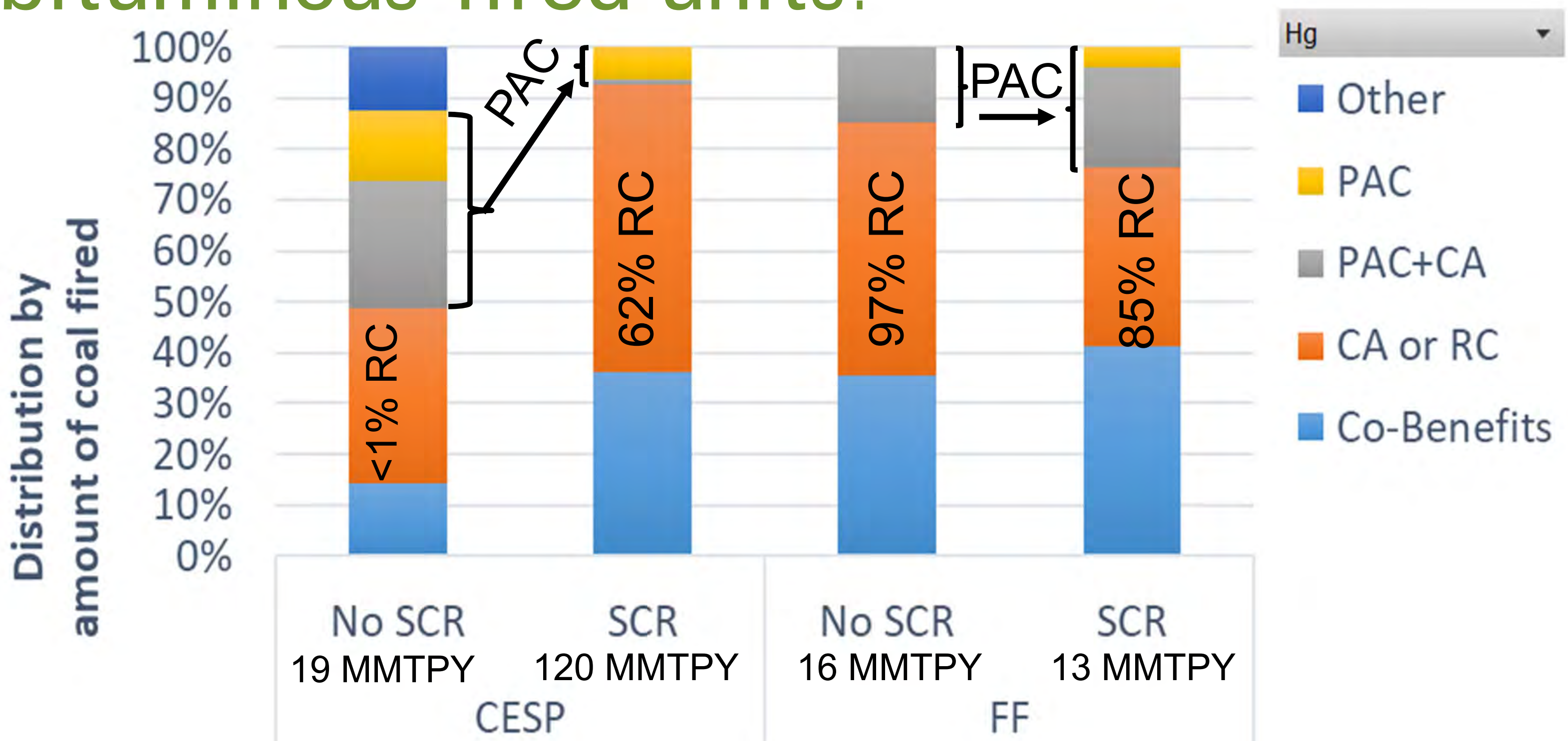
How does an SCR influence Hg controls on bituminous-fired units?

EGUs with CESP+ WFGDs



- An SCR decreases reliance on PAC (or other) for ILB and NAPP units
  - NAPP: 81% PAC or "Other" → 10% PAC
  - ILB: 42% PAC → 3% PAC

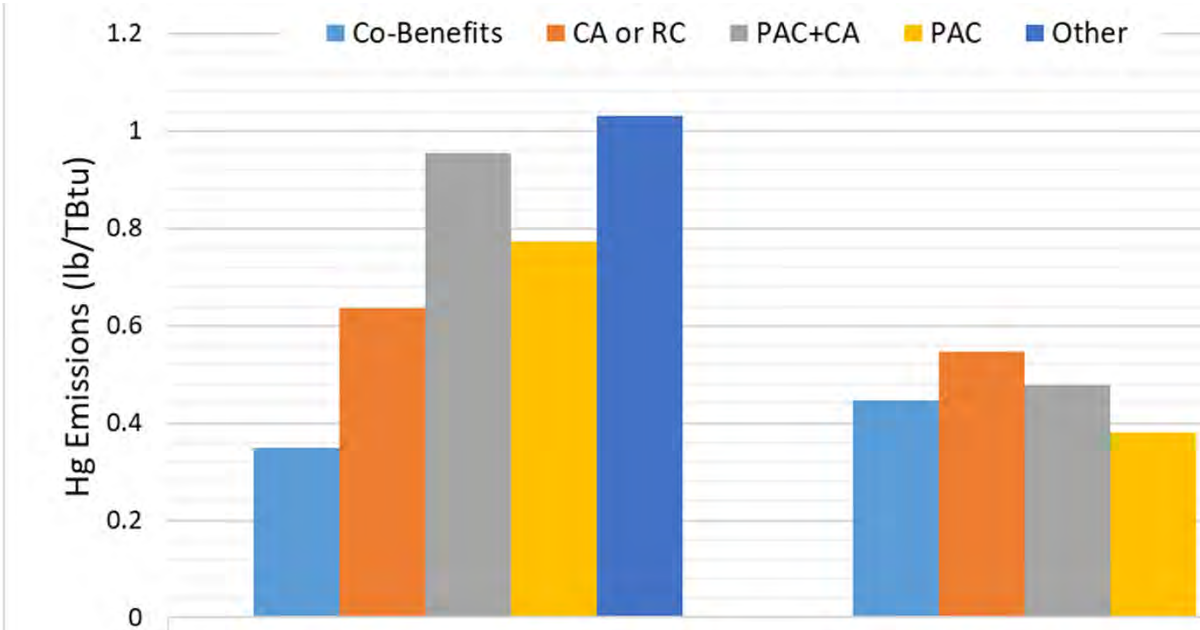
How does an SCR influence Hg controls on bituminous-fired units?



- An SCR decreases reliance on PAC for CESP units
  - No SCR: 39% use PAC
  - SCR: only 8% use PAC
- An SCR has little impact on PAC usage for FF units
  - 15% vs 23% use PAC

Reminder:
76% (by coal burned) have SCRs

How does an SCR influence Hg controls on bituminous-fired units?



No SCR + CESP

SCR + CESP

39% report using PAC

8% report using PAC

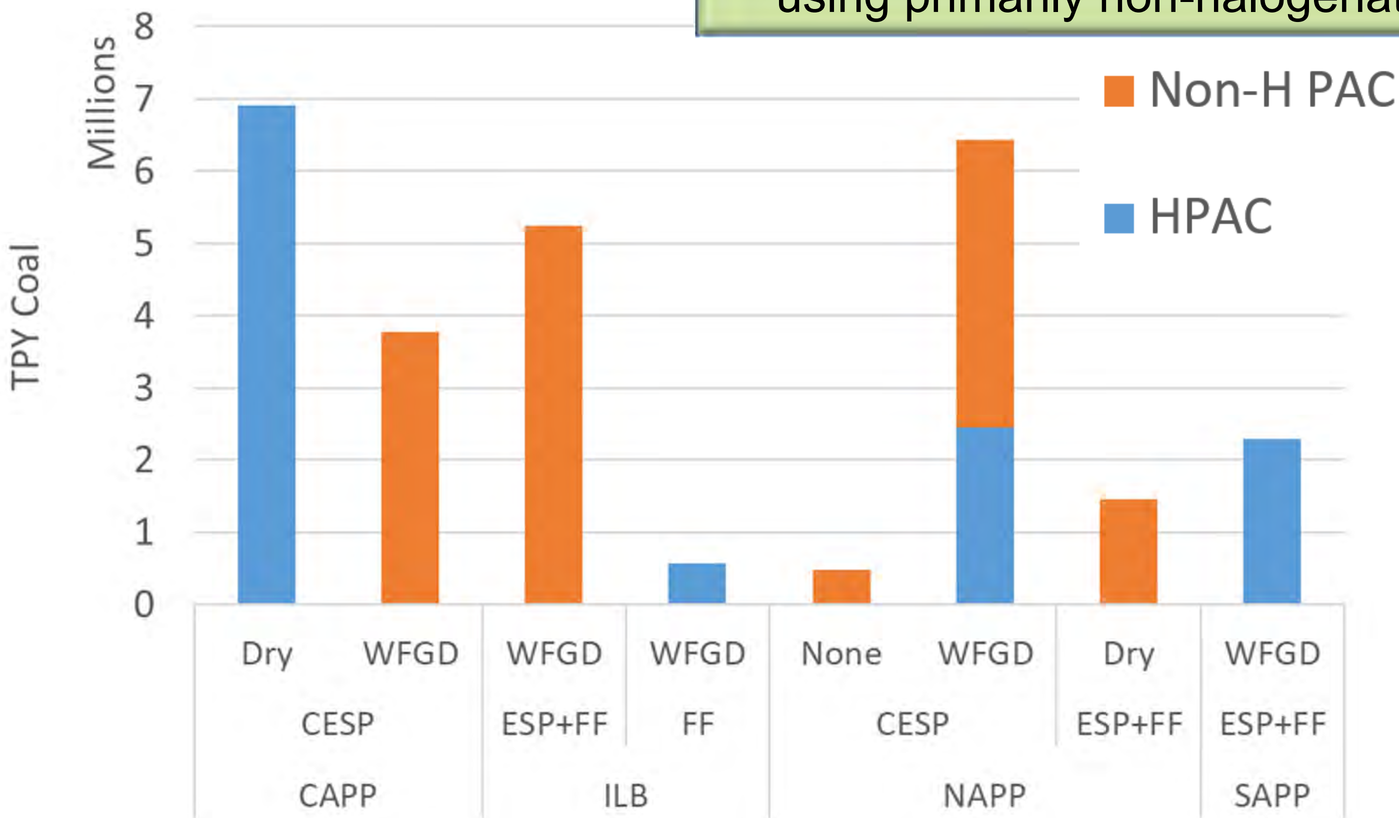
CESP + WFGD Units

- SCR units: Low average emissions (<0.6 lb/TBtu). PAC and CA may be on-site as a backup, but how often are they used for compliance?
- Non SCR units: Higher emissions suggest need to rely on PAC and CA more frequently

Reminder: 76% (by coal burned) have SCRs

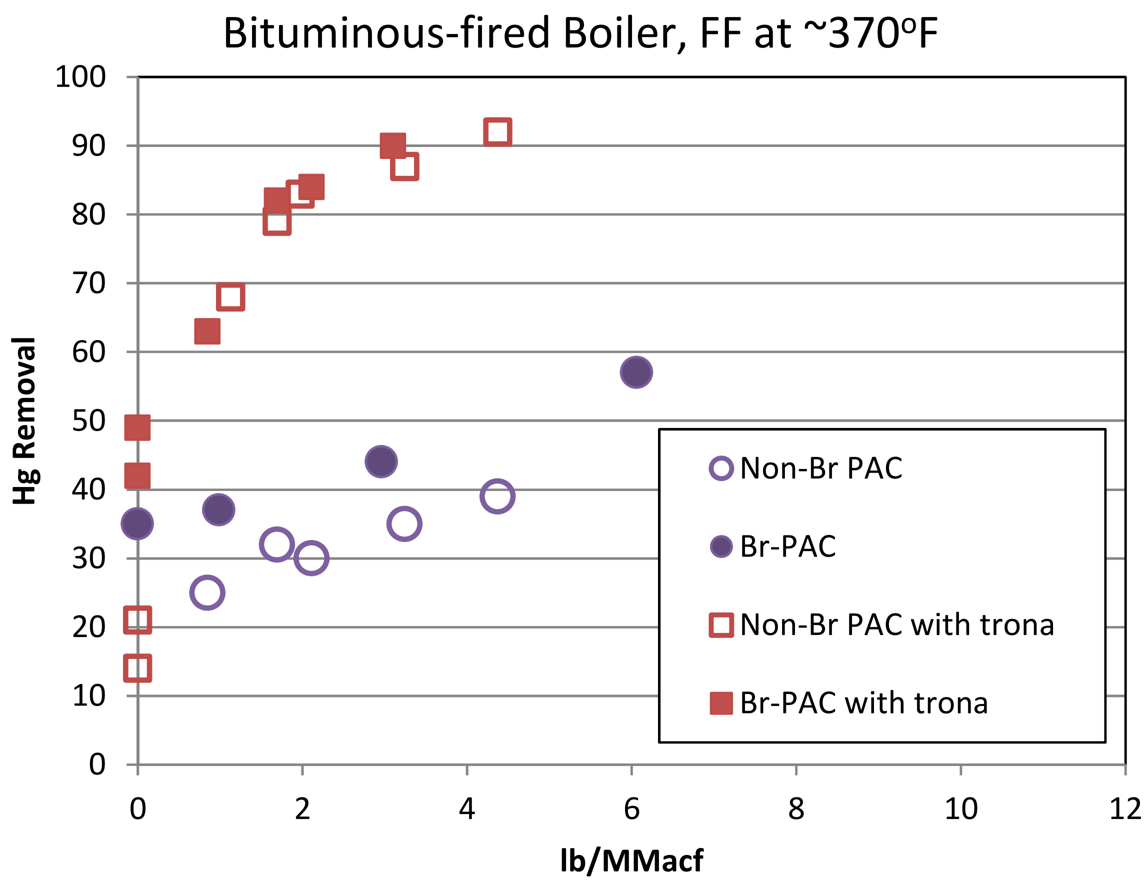
What type of PAC is used on bituminous-fired units?

- 19% of bituminous units report that PAC is part of their control strategy
- Higher chlorine bituminous units report using primarily non-halogenated PAC



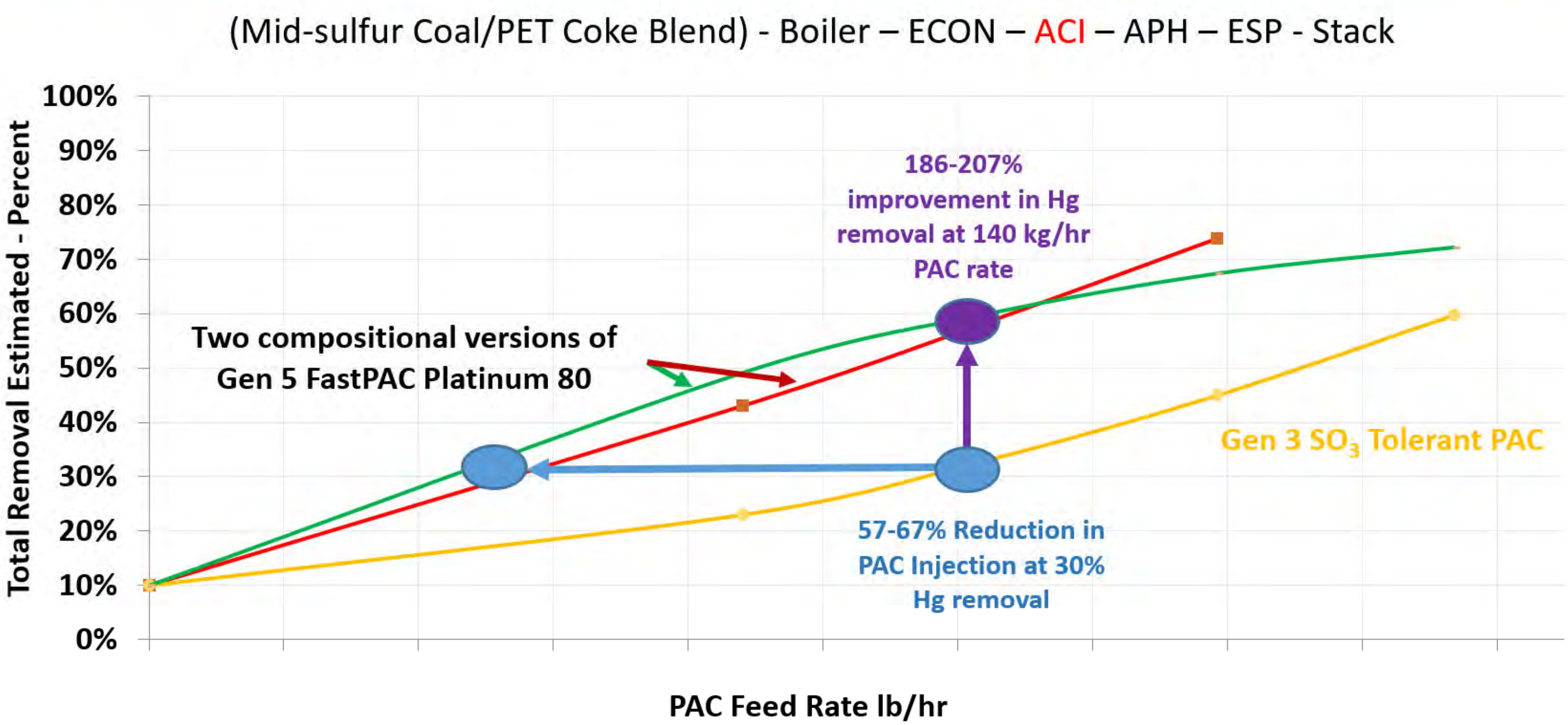
Improving Performance with PAC:
Use Alkaline Sorbents (DSI) to Lower SO_3

- Sodium or calcium DSI sorbents can be used to remove SO_3 and increase effectiveness of PAC
- Example: Bituminous-fired boiler with FF, ~20 ppm SO_3 uncontrolled



Developing More Effective PACs for Bit Units

EGU Collaboration - 150 MW Mid-Sulfur Coal Blend with 15-20 ppm SO_3



- Highly collaborative engagement with contracted EGU with full data interchange and pilot testing of Coal Blend at Southern Research Institute's 1 MW Combustor
  - Both versions of Gen 5 FastPAC Platinum 80 achieved 60% Hg removal with turn-up capability as needed
- PAC injection rate was reduced by at least 30% and will be implemented commercially as part of our optimization

Developing More Effective PACs for Bituminous Units

- R&D efforts can result in significant performance improvements
- Performance: 80-85% total Hg removal in high SO_3 flue gas

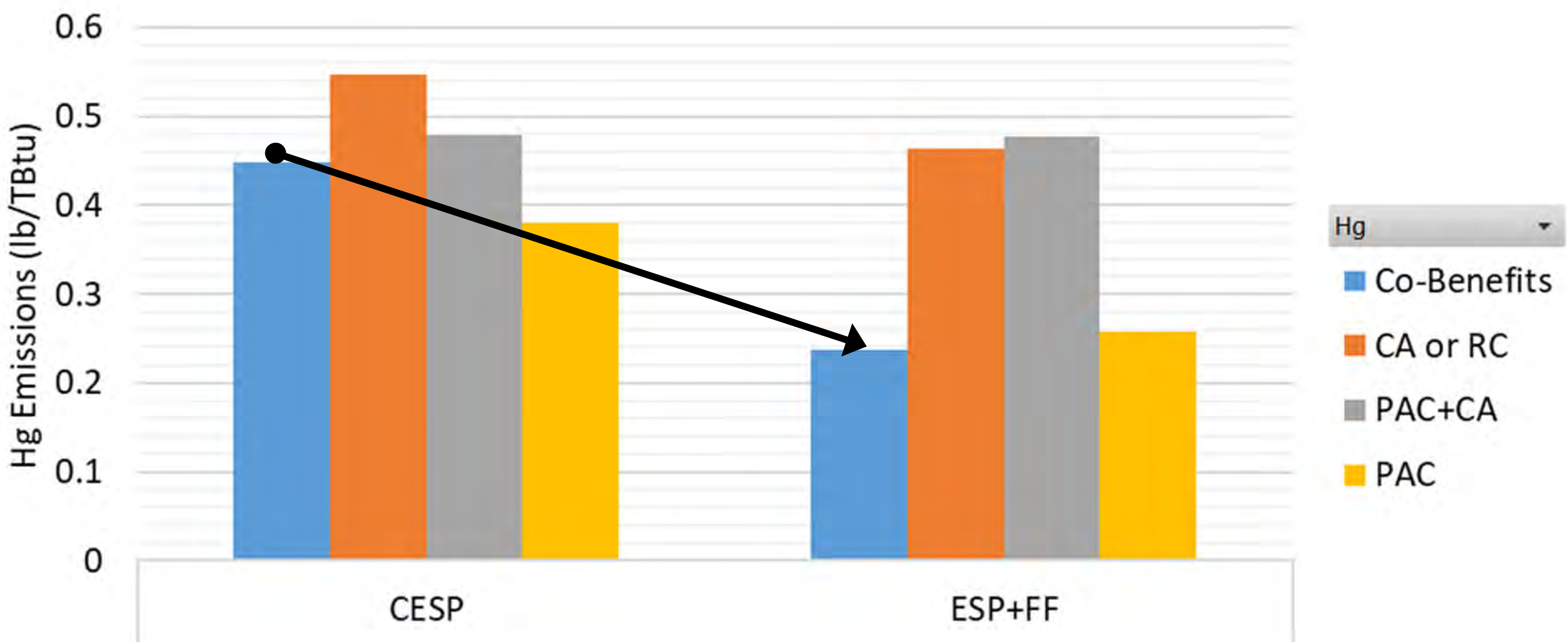
High Sulfur Fuel Blend (18-24 ppm SO_3)

PAC	Description	Contact	Conversion	Capture	% Hg Removal
1	Gen 2 FastPAC Premium	x	x	x	28-38%
2	SO_3 sacrificial additive	xx	x	x	38%
3	Improved oxidation and SO_3 barrier	xx	x	x	37%
4	Improved oxidation and SO_3 tolerant	xx	x	xx	52%
5	Improved oxidation and catalytic additive	xx	xx	x	48%
6	Improved oxidation, SO_3 suppression and catalytic additive	xx	xx	x	52%
7	Improved oxidation and optimized catalytic additive	xx	xx	xx	62%
8	Improved oxidation, SO_3 suppression and optimized catalytic additive	xx	xx	xxx	62%
9	Enhanced oxidation through improved processing	xx	xxx	xx	60%
10	Enhanced oxidation, SO_3 suppression and optimized catalytic additive	xx	xxx	xxx	63%
11	Enhanced oxidation and enhanced SO_3 suppression Generation 4 PACs	xx	xxx	xxxx	80-85%

Adding a Polishing Fabric Filter Bituminous-Fired Units

SCR+WFGD+CESP Units

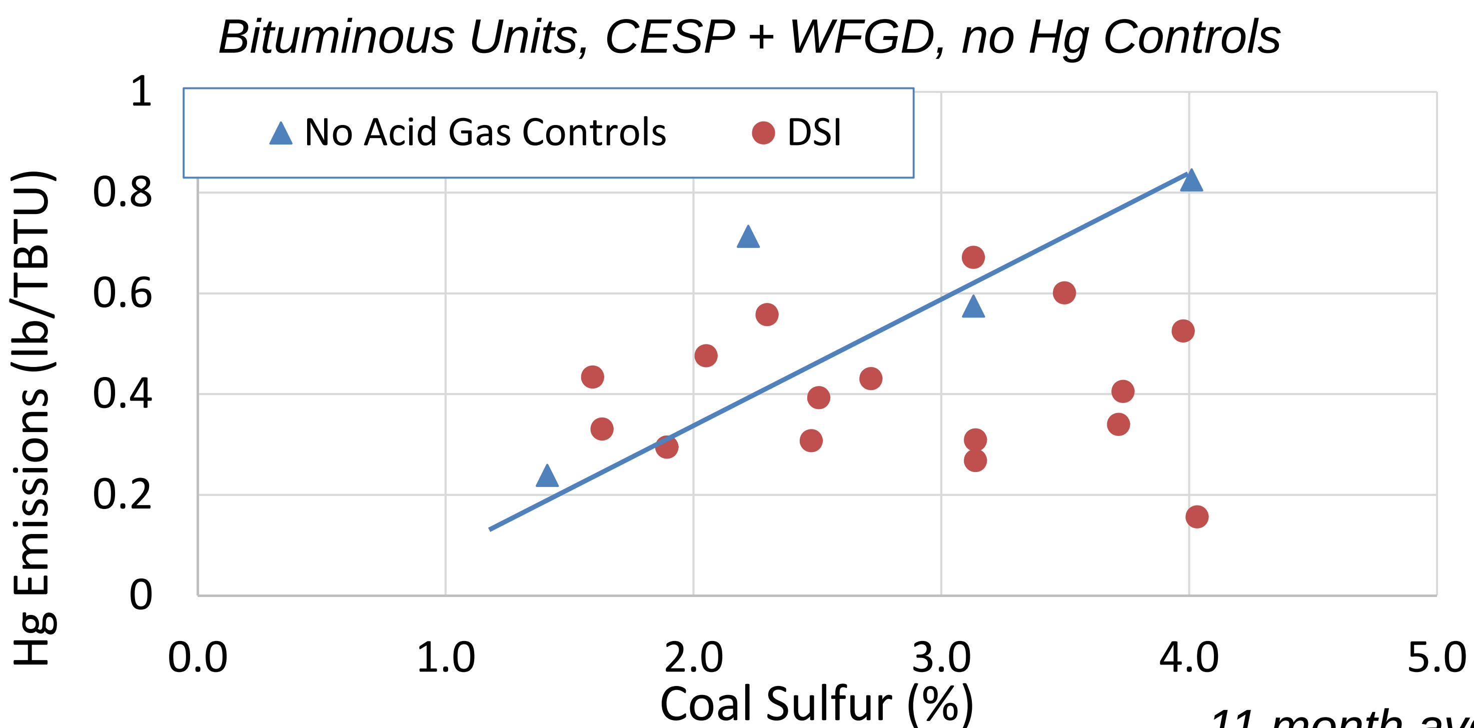
- 7% of bituminous units: SCR+CESP+**FF**+WFGD
- Adding a FF appears to increase native removal and effectiveness of coal additives



Bituminous EGUs with SCR+WFGDs

How does Coal Sulfur Influence Hg emissions without PAC?

- Clear correlation between coal sulfur and Hg emissions for units not using acid gas controls
- No correlation between coal sulfur and Hg emissions for units using DSI for acid gas control
  - ✓ Controls appear to mitigate impacts

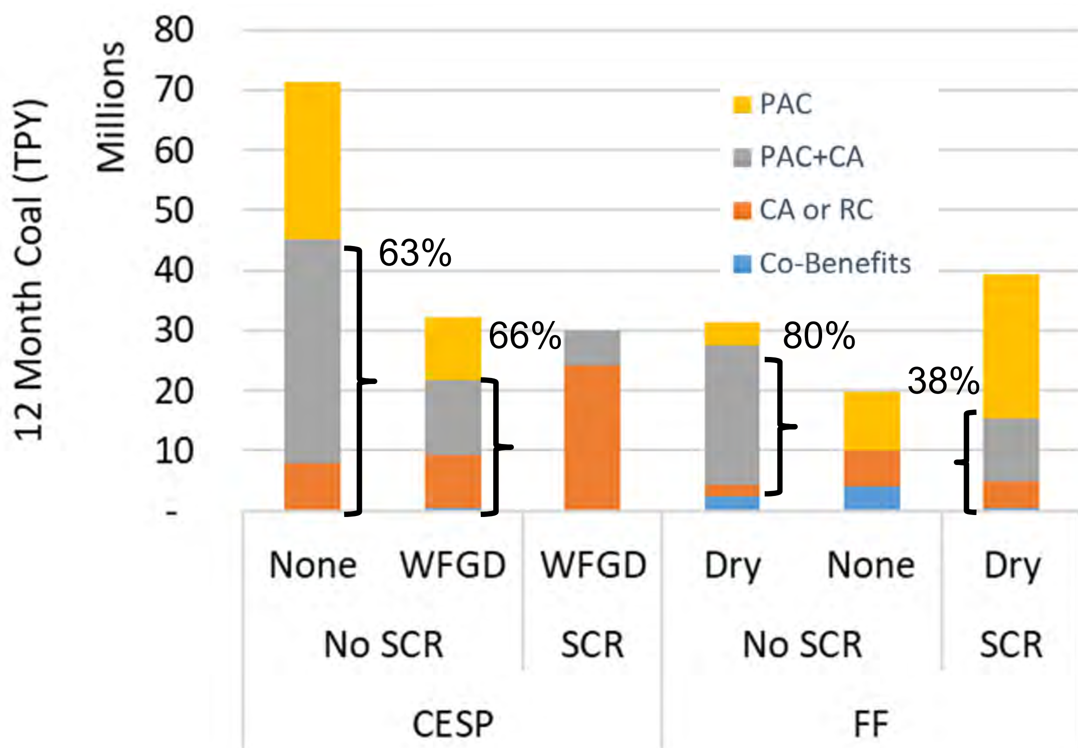


11 month avg by unit

Focus on Subbituminous Units

- 95% (by coal fired) have some Hg control (including RC)
- 38% (by coal burned) have an SCR for NOx control
- 76% (by coal burned) are scrubbed (including DSI, DFGD, WFGD)
- 56% (by coal burned) have CESPs

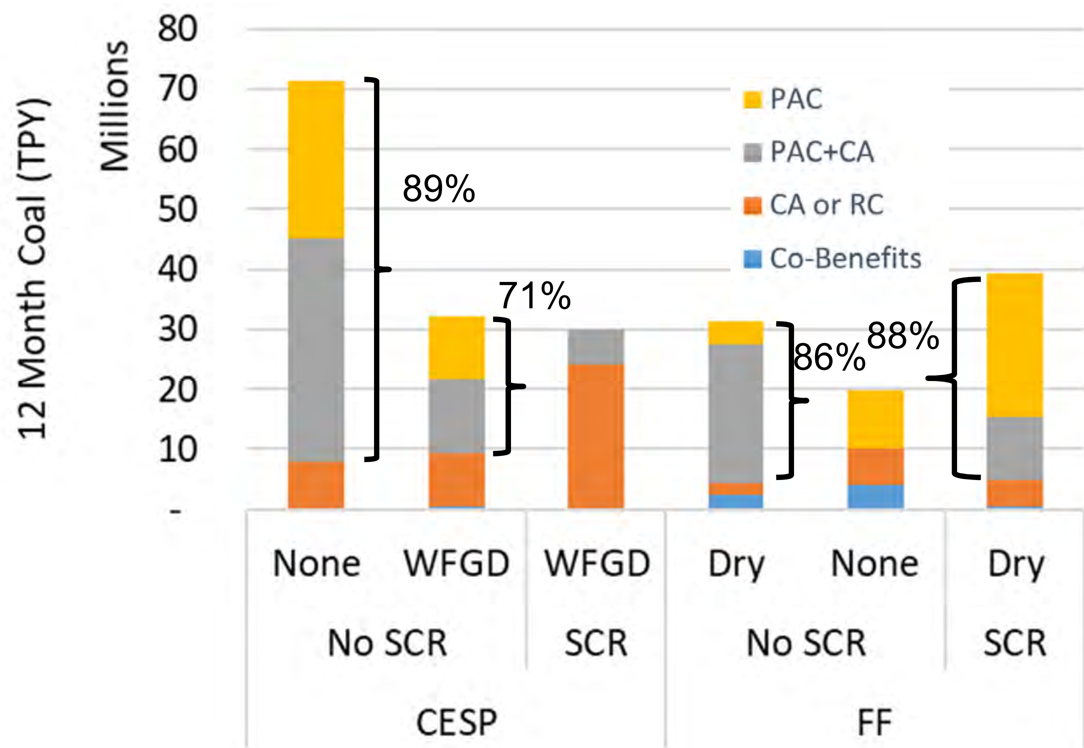
Mercury Control on Subbituminous Units



Influence of SCR and Scrubbers on CA Use

- An SCR increases reliance on CA for units with CESP
  - No SCR: 63% - 66% use CA
  - SCR + WFGD: 100% use CA
- An SCR decreases reliance on CA for dry scrubbed units with FFs
  - No SCR: 80% use CA
  - SCR + DFGD: 38% use CA

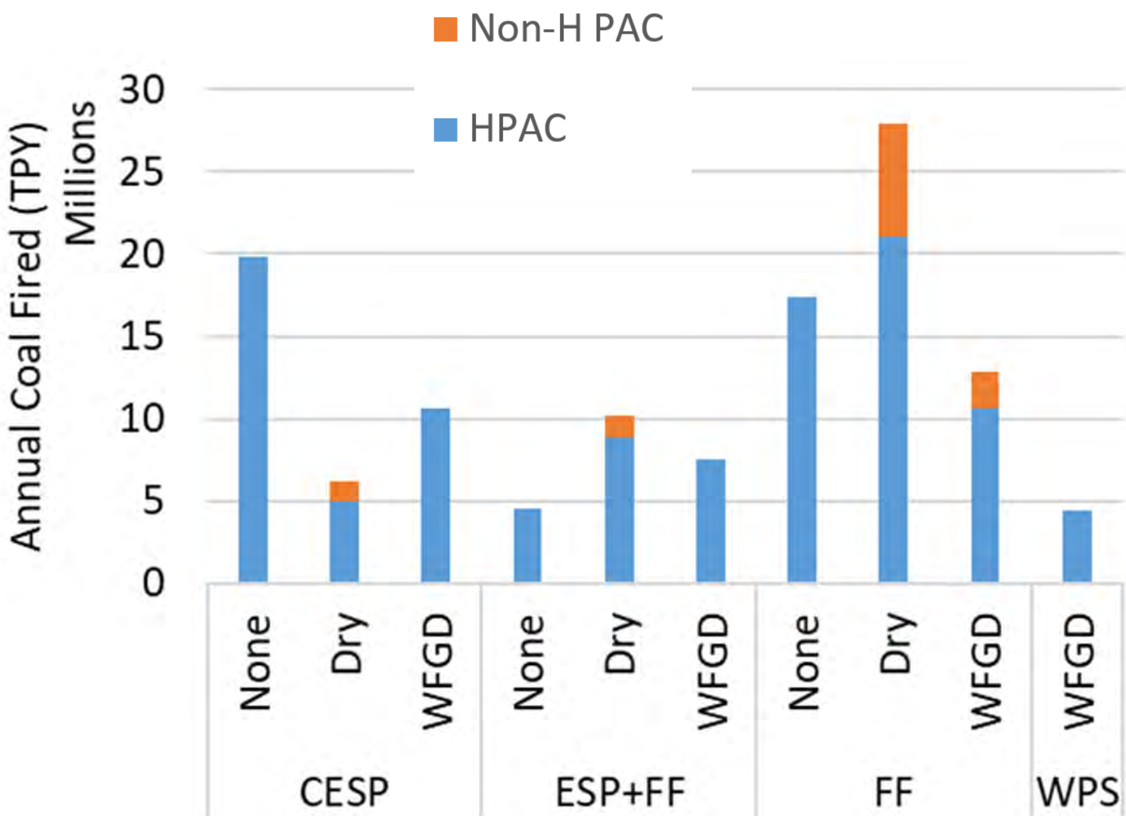
Mercury Control on Subbituminous Units



Influence of SCR and Scrubbers on PAC Use

- An SCR decreases reliance on PAC for CESP units
  - No SCR, No SOx: 89% use PAC
  - No SCR, WFGD: 71% use PAC
  - SCR + WFGD: only 20% use PAC
- An SCR does not reduce reliance on PAC for units with FFs

What Type of PAC is used on subbituminous units?

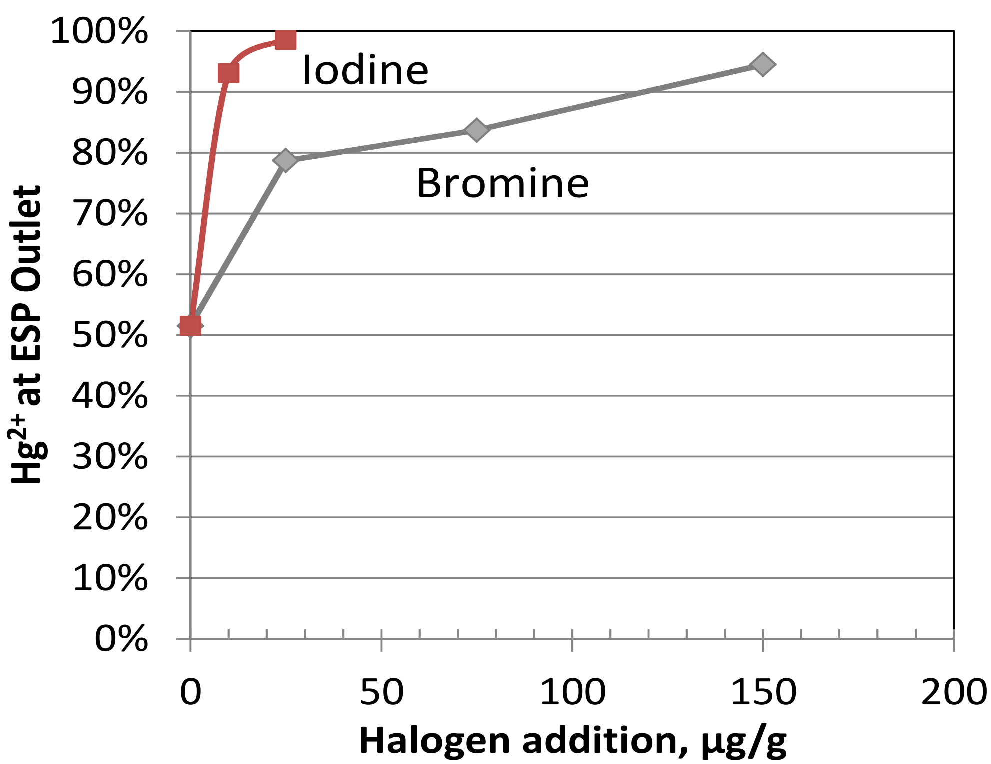


- Subbituminous units report using primarily halogenated PAC (HPAC)
- More non-halogenated on Dry+FF units (recall many of these use CA)

Bottom line:

Most subbituminous units use halogens, either through CA or HPAC

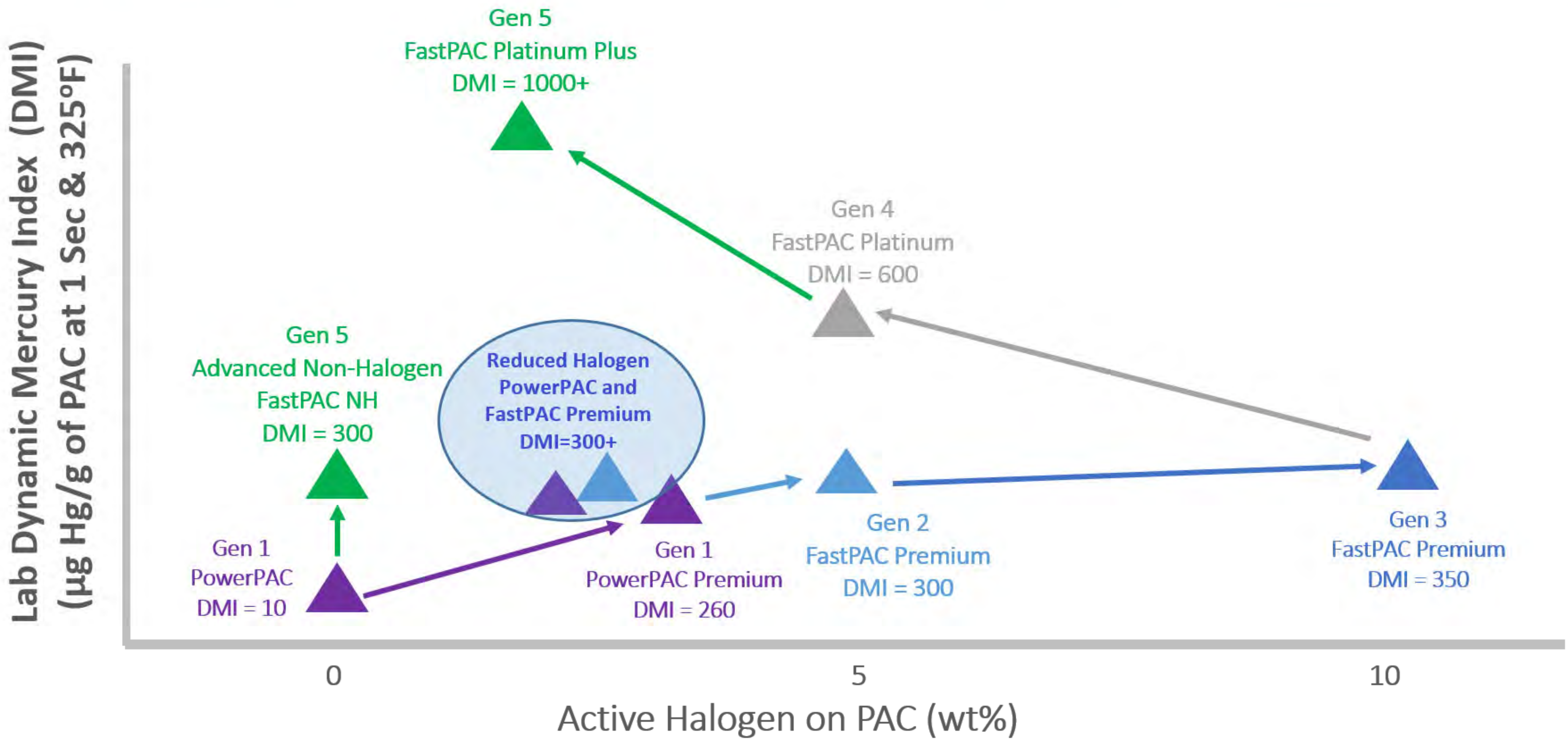
Relative Effectiveness of Halogens for Mercury Oxidation



- Iodine is more effective than bromine at oxidizing Hg, often requiring 1/10th the halogen concentration[1]
- ~ 19% of halogen treated coal is treated with iodine[2]
- High levels of halogens can cause corrosion and other balance-of-plant impacts[3]

1.Gadgil, 2015
2.Based on plants reporting RC d CA use
3.EPRI's Balance of Plant Effects Study of Bromine-based Mercury Controls, 2016

Maximize Hg Removal Performance and Minimize BOP Impacts via Highly Advanced Reduced and/or No Halogen PACs



Through advancing base PAC properties and halogen technologies, we can provide better Hg removal with minimal BOP impacts

Advanced Non-Halogen PAC Technology for Mercury Removal

ADA CARBON SOLUTIONS

New advanced non-halogen PACs can be just as effective as Gen 2 halogenated PACs in removing Hg and are gaining momentum in use.

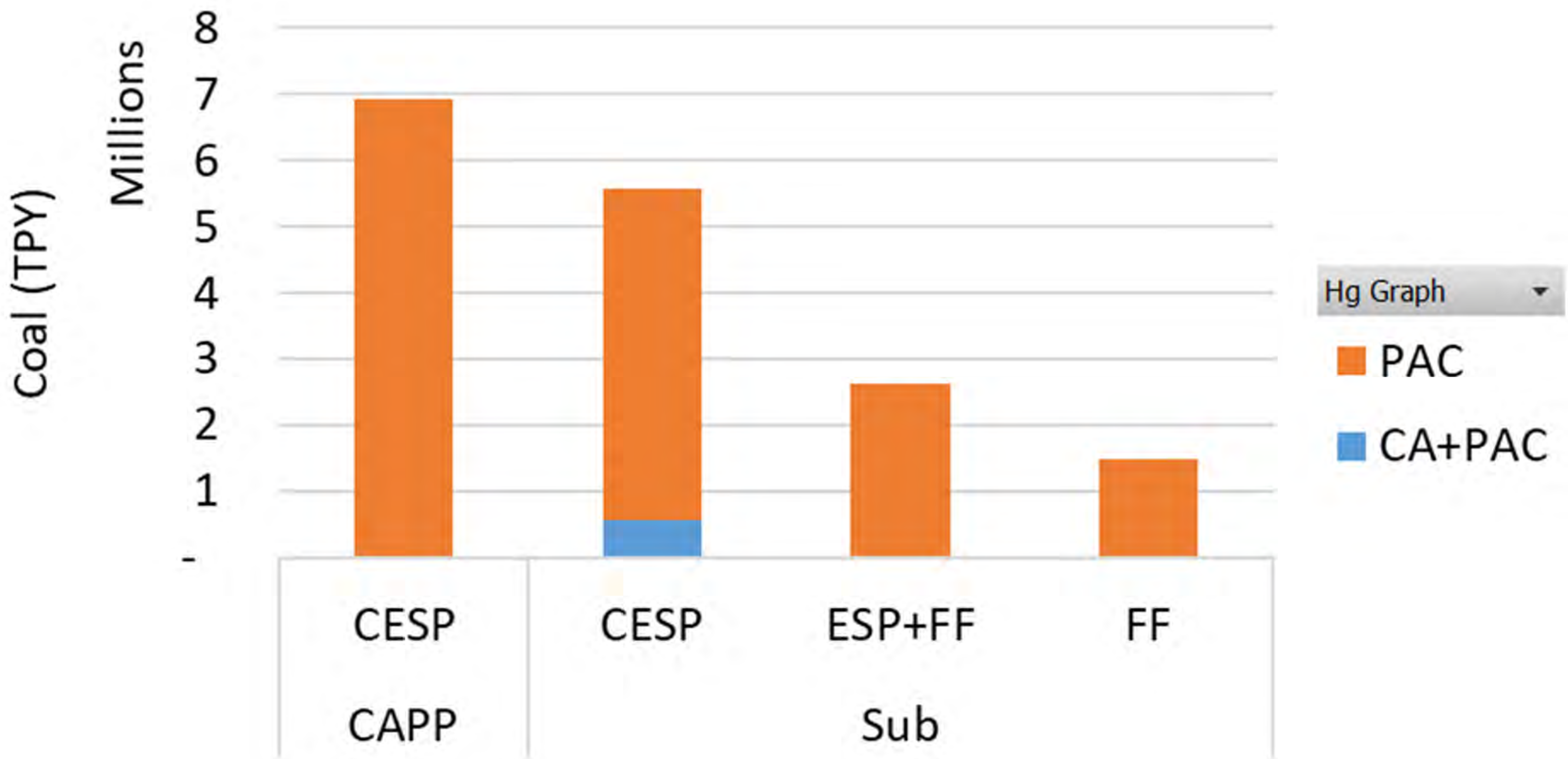
Gen 5 Product Performance in Recent Field Test

Sorbent	Sorbent Rate to Achieve 0.8 lb/TBTU Hg Emissions	Relative Injection Requirement
Competitor Non-Halogen A	>150 lb/hr	>176%
Competitor Non-Halogen B	100 – 110 lb/hr	118%
Competitor Halogen C	>120 lb/hr	>141%
ACS Gen 5 Advanced Non-Halogen FastPAC NH	85 lb/hr	100%

BHP Black Hills Power · City Utilities Connecting Our Community · CLECO · DUKE ENERGY · MidAmerican ENERGY · nrg · Southern Company

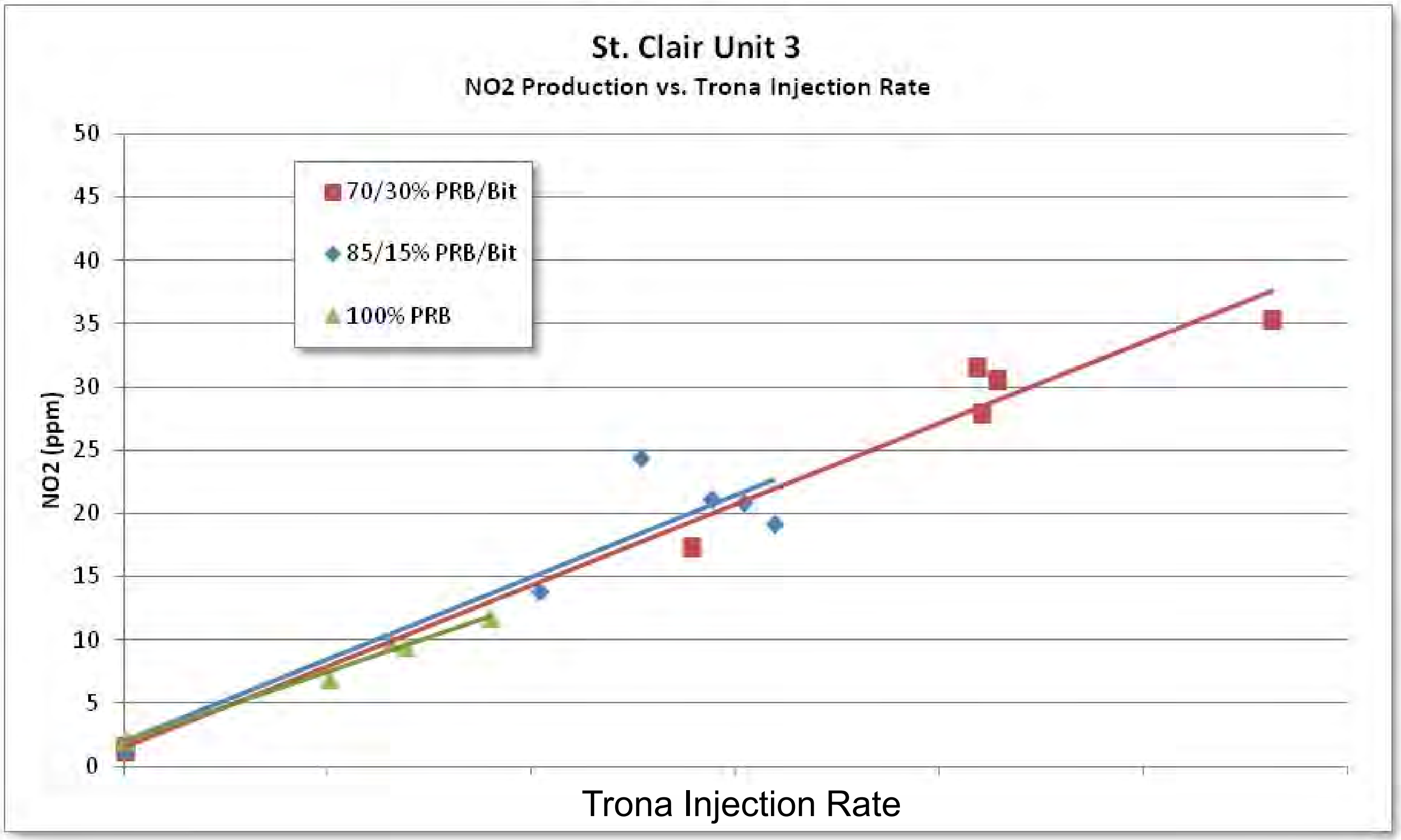
Expertise. Reliability. Compliance.

Plants Reporting DSI for SO_2 Control



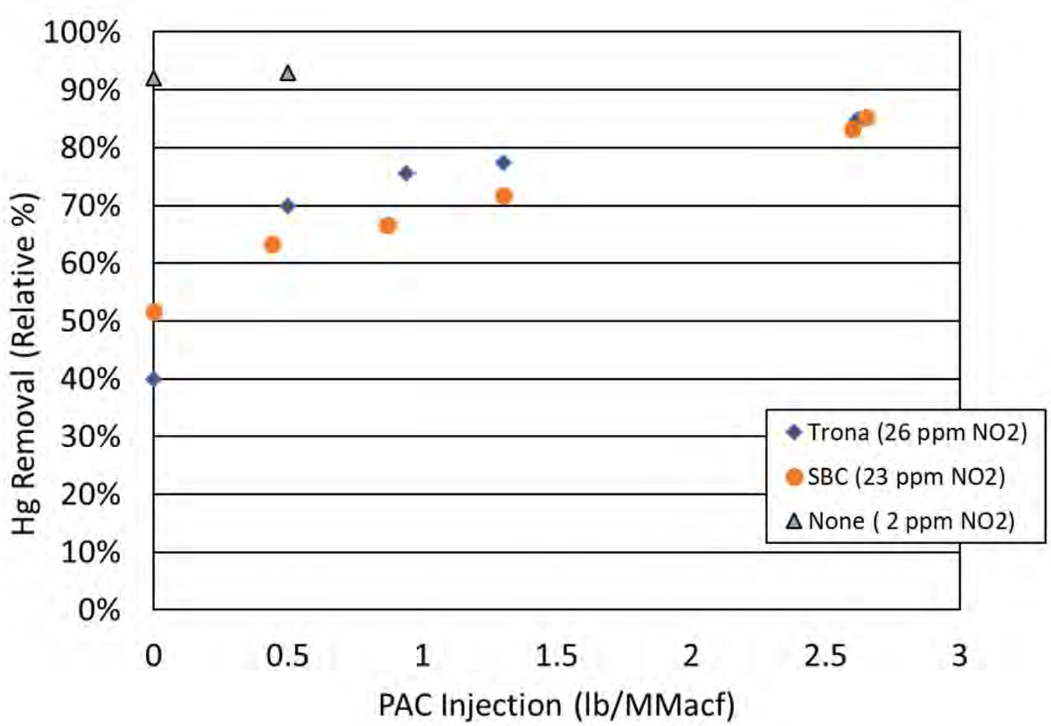
Potential DSI Challenges: NO_2 Production with DSI

- Sodium-based DSI can increase flue gas NO_2
- Trona or SBC injection increased stack NO_2 to as much as 35 ppmv



Results from Testing at DTE St. Clair Unit 3, W. Rogers, EUEC 2013

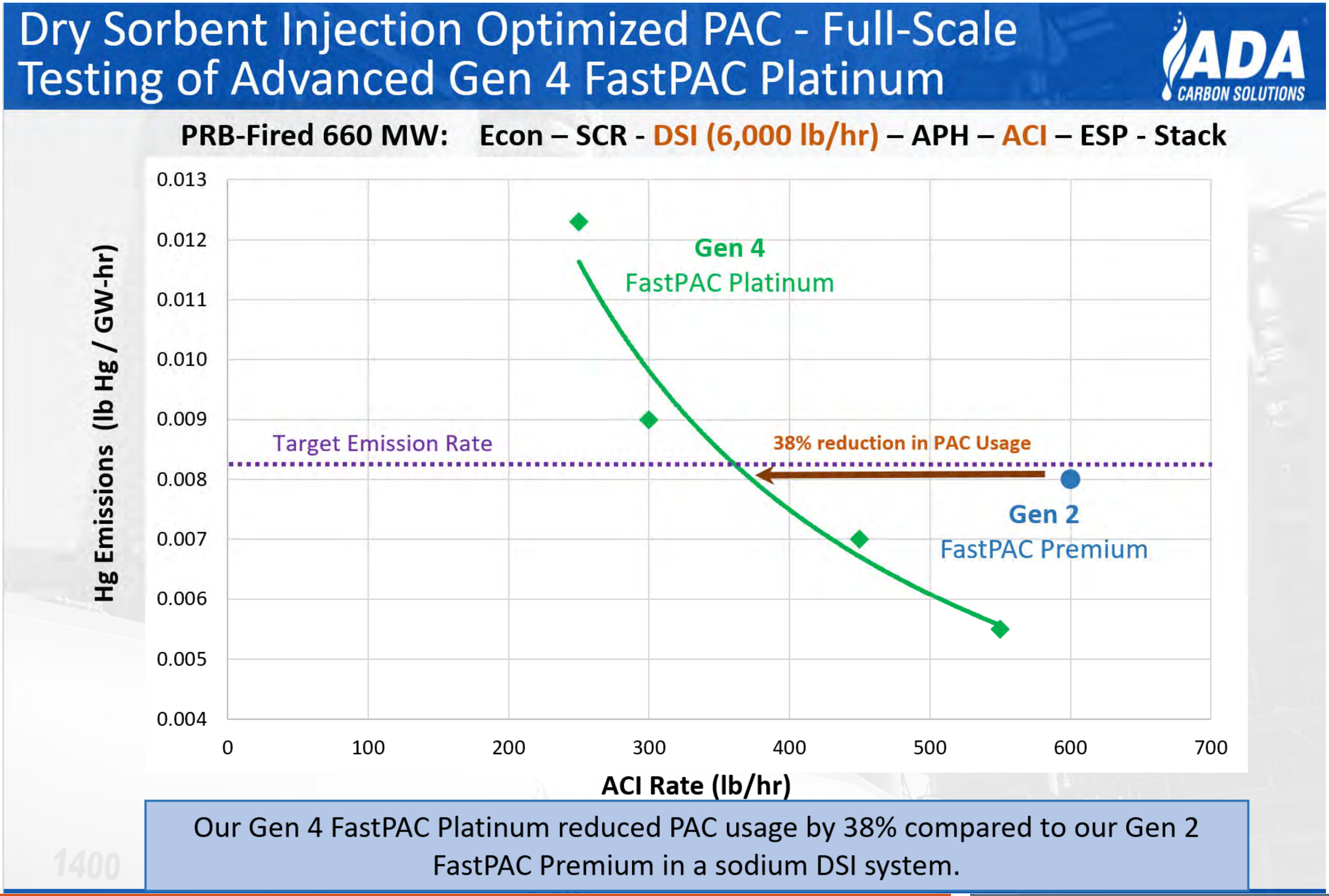
Can DSI impact mercury control?



- NO_2 in flue gas can impact PAC effectiveness for Hg control*
- ~ 19% of subbituminous units use alkaline sorbents (DSI) for acid gas control
- We estimate ~ 50|50 split between lime and sodium sorbents for subbituminous units

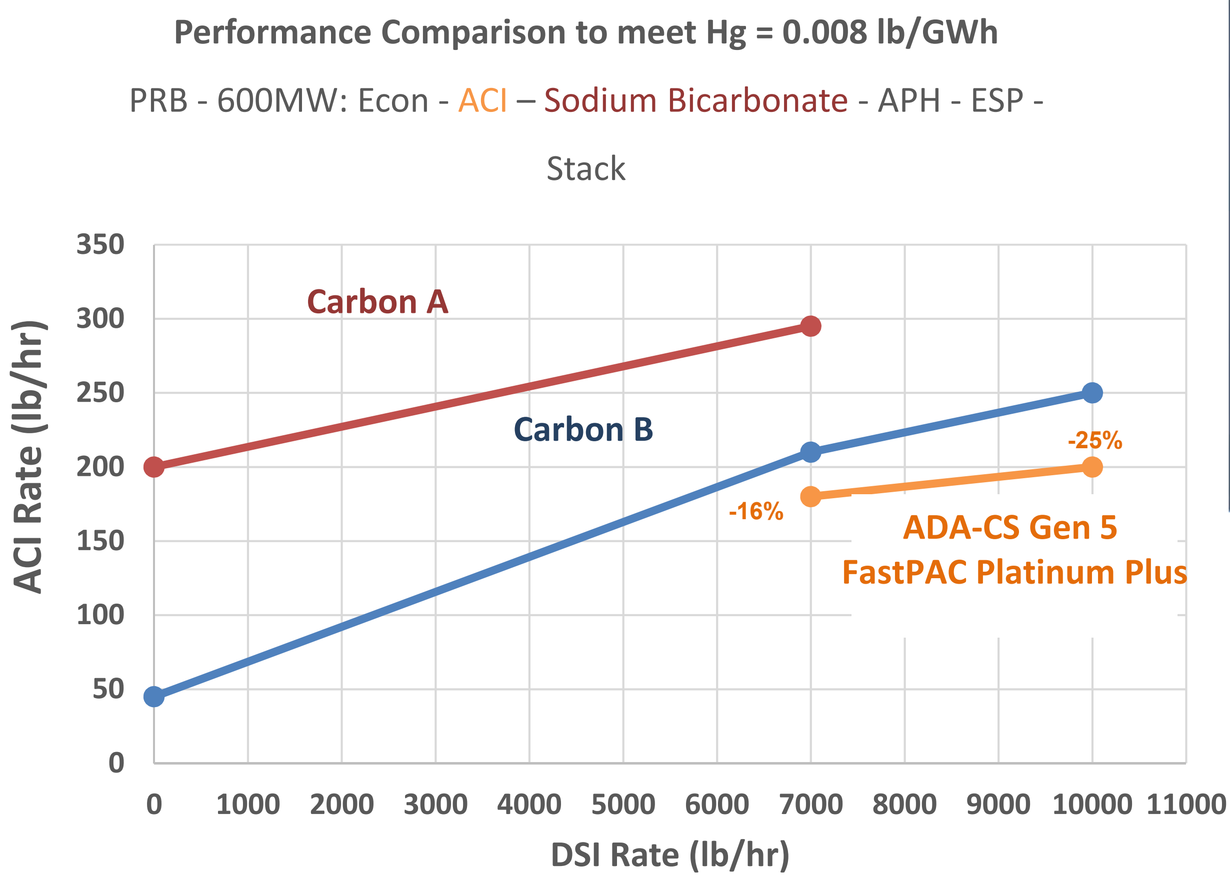
*Rogers, 2013: *Is There a Place for DSI at Detroit Edison?*

Developing Improved PAC for Use with Sodium DSI



Developing Improved PAC for Use with Sodium DSI

DSI Compatible: Plant Testing of Oxidatively Enhanced Gen 5+ PAC with High SBC



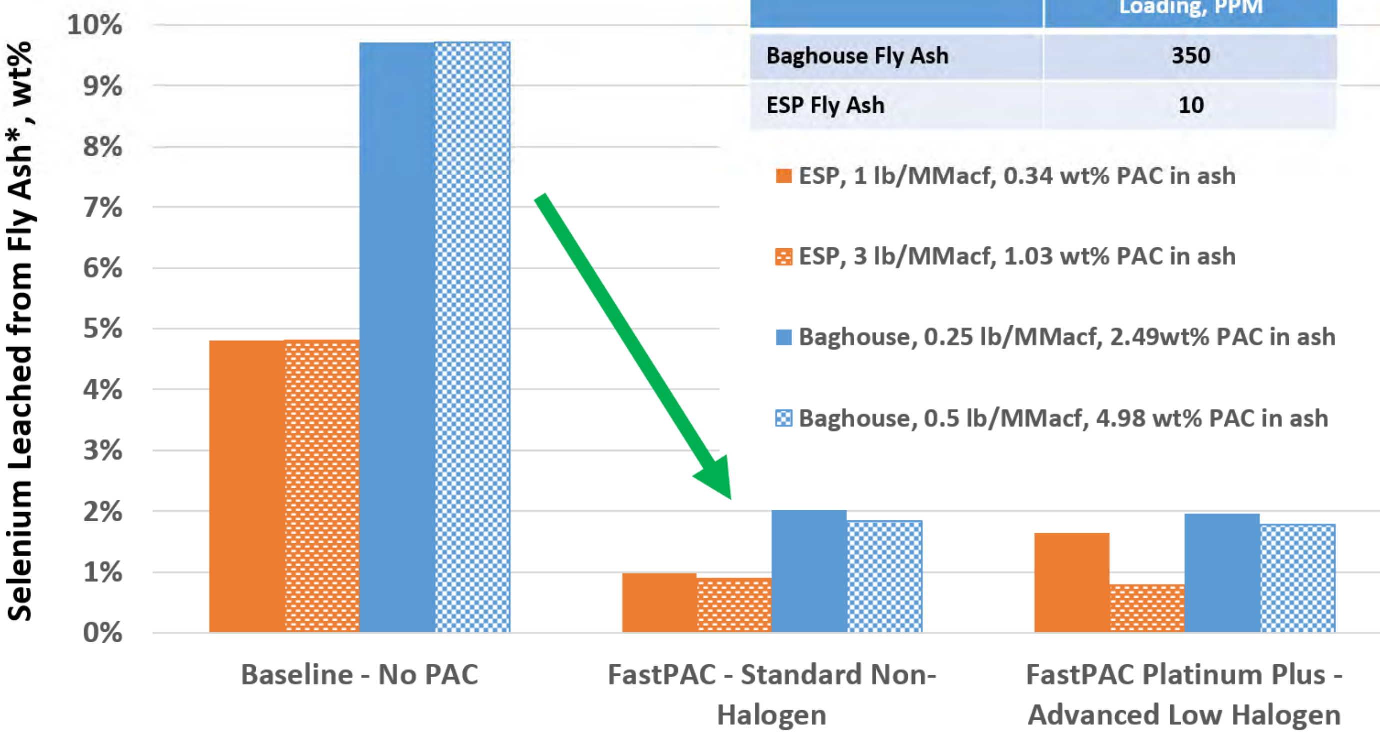
- Gen 5+ FastPAC Platinum Plus applies high oxidation and optimum carbon pore structure to drive DSI compatibility
- Achieved 16% and 25% reduced consumption at 7,000 lb/hr and 10,000 lb/hr SBC, respectively

Additional Benefits of PAC

PAC Sequestration of Selenium in Fly Ash

ADA CARBON SOLUTIONS

	Starting Selenium Loading, PPM
Baghouse Fly Ash	350
ESP Fly Ash	10



*In 25 C deionized water for 24 hours at 10:1 liquid:solid

- Illinois Basin Coal Fly ash without PAC leaches Selenium by 5-10 wt%
- Addition of various PACs has a co-benefit in reducing the leaching of Selenium by up to 5x to sub-2 wt%

Configurations

- What did we find when we surveyed boilers complying with MATS?
- 572 boilers and 243 GW
- General observations about configurations:

☑ Bituminous Units

- 63% (by coal fired) report no Hg-specific controls.
  - Down to 34% if RC is included as Hg control
- Most (76% by coal burned) have SCRs
- Almost all (95% by coal burned) have wet FGDs
- Most (76% by coal burned) have CESPs

☑ Subbituminous Units

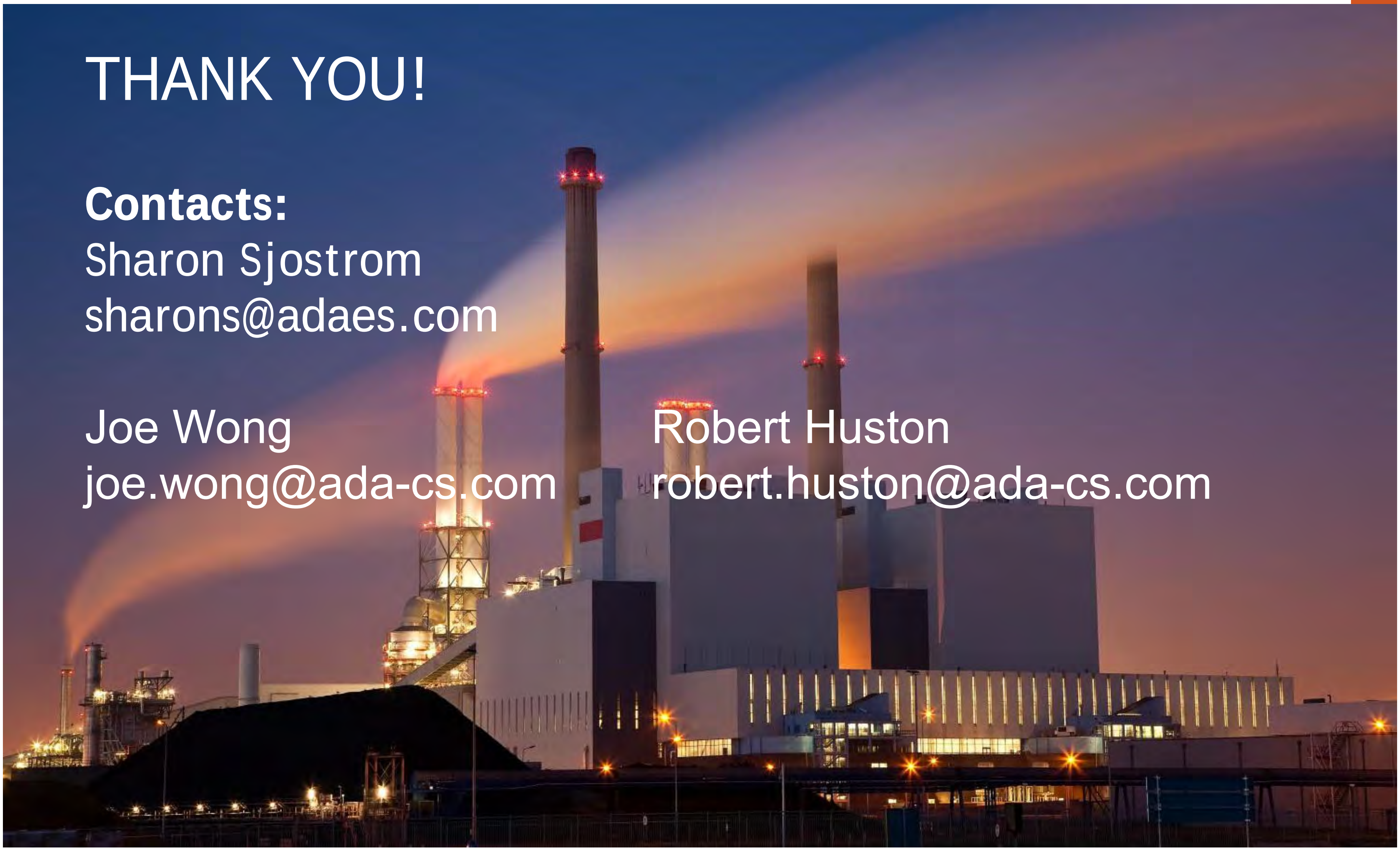
- 95% (by coal fired) have some Hg control (including RC)
- 38% (by coal burned) have an SCR for NOx control
- 76% (by coal burned) are scrubbed (including DSI, DFGD, WFGD)
- 56% (by coal burned) have CESPs

What worked best for bituminous units?

- SCRs decrease the reliance on PAC for mercury compliance for units with CESPs, but not for units with FFs
- SCRs appear to lower emissions for units with CESPs and WFGDs
- DSI appears to mitigate the impact of coal sulfur on mercury emissions for co-benefit units
- A polishing fabric filter results in lower average Hg emissions compared to ESP units
- Most units that report using PAC report using non-brominated PAC
- New sulfur-tolerant PACs are being developed and results are promising

What worked best for subbituminous units?

- Most units rely on halogens to meet mercury compliance
  - Almost all units (96% by coal burned) use PAC, coal additives (including refined coal), or a combination of these
  - Most units using PAC alone (no coal additives) report using halogen-treated PAC
  - 19% of coal treated with halogens use iodine
- Non-Halogen PAC is under development
- An SCR significantly decreases the reliance on PAC for CESP+WFGD units
- An SCR doesn't impact the reported use of PAC for DFGD+FF units
- Sodium-based DSI can impact the effectiveness of PAC
  - New PACs are being developed and results are promising



THANK YOU!

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