REINHOLD ENVIRONMENTAL Ltd.

2013 NOx-Combustion Round Table
& Expo Presentations

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Advancing Cleaner Energy

Mercury Control from Coal to Stack

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Disclaimer

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

Workshop Roadmap

SCR

SO_2 to SO_3 conversion

Hg Oxidation

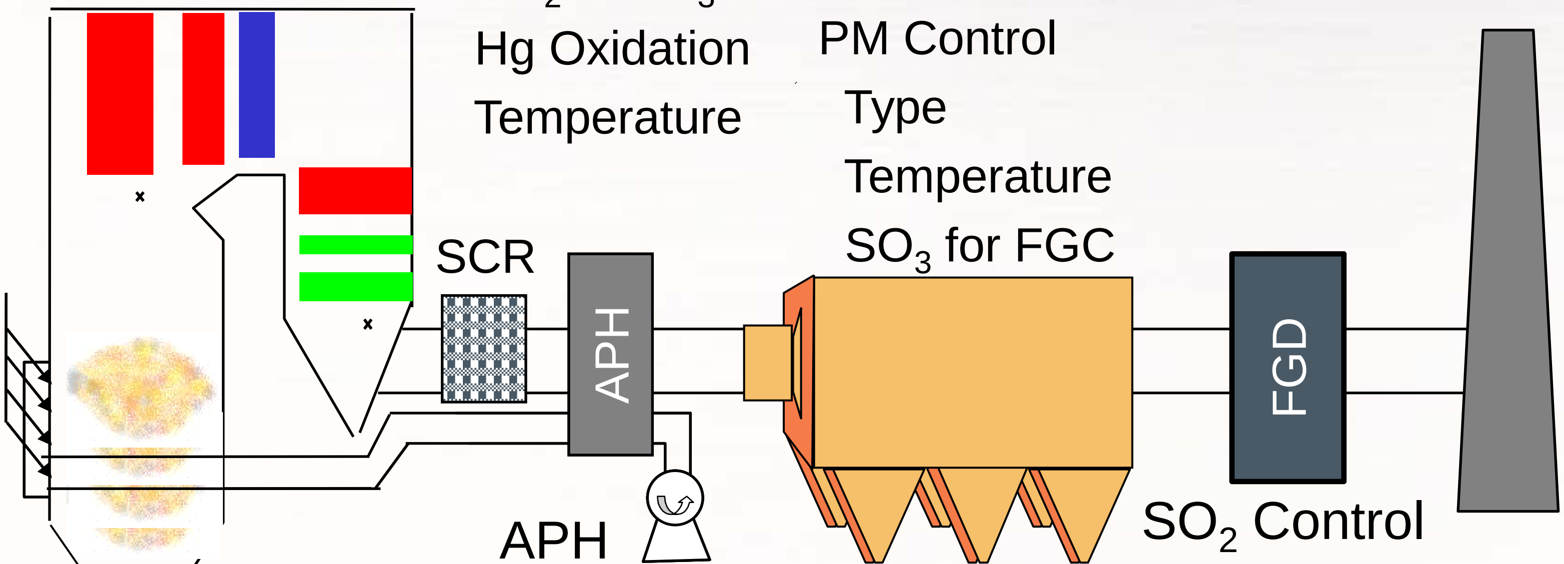
Temperature

PM Control

Type

Temperature

SO_3 for FGC



Boiler Type

Combustion efficiency (LOI)

Coal

APH

Type

Temperature

SO_2 Control

Type

Hg re-emissions

Water management

- Mercury
- Halogens (native or added)
- Sulfur
- Ash, calcium, etc.

→

- LOI
- Ash
- SO_2 and SO_3
- Halogens

→

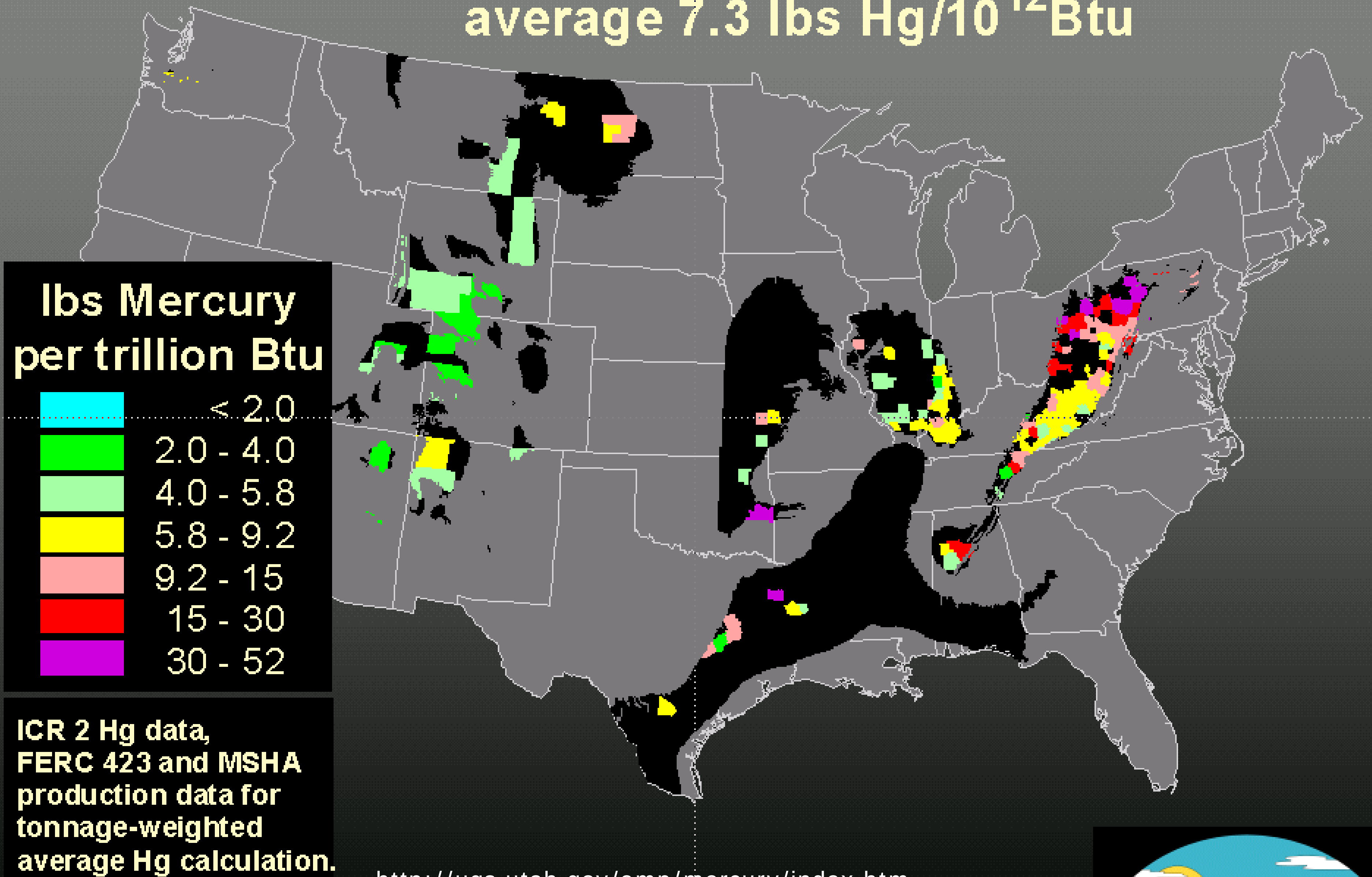
- LOI
- Halogens
- SO_3
- Ash
- Oxidized Hg

→

- Halogens
- Oxidized Hg

Produced Coal Mercury

average 7.3 lbs Hg/10^{12}Btu



http://ugs.utah.gov/emp/mercury/index.htm

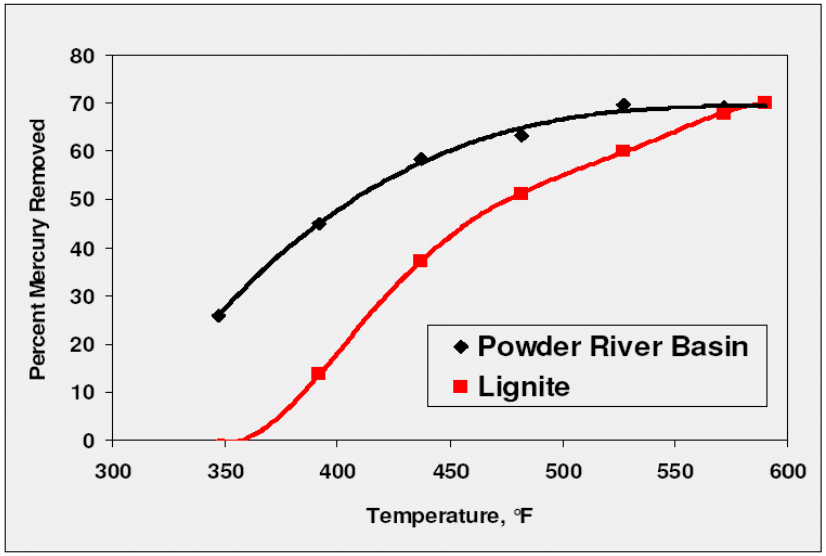
UTAH GEOLOGICAL SURVEY

Can Mercury Be Removed from Coal?

- Bituminous coals:
  - On a limited basis, mercury content follows trends in sulfur or ash – *no general relationship*
  - Coal washing may reduce mercury from some coal sources – limited application

Can Mercury Be Removed from Coal?

- Subbituminous coals:
  - Mercury organically bound in coal
  - Mild heating (e.g., K-Fuel process, WRI process) removes some mercury
  - Cost?



Source: Bland et al., 2005

Native Mercury Removal (Average %)

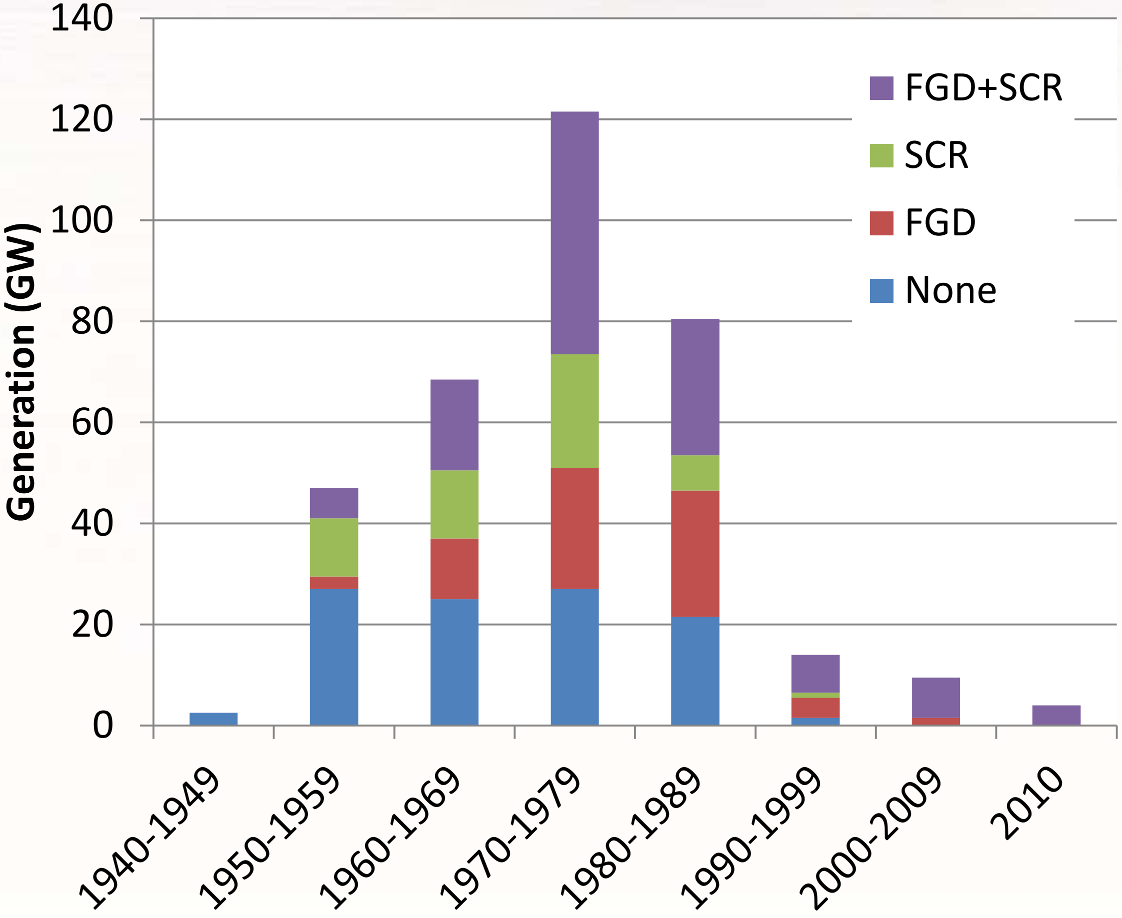
	Bituminous	Subbit.	Lignite
CSESP	**41**	**17**	**-2**
+ WFGD	**73**	**21**	**45**
HS ESP	**22**		
+ WFGD	**44**		
FF	**87**		
+ WFGD	**78**		
SDA + FF	**95**	**31**	**29**
SDA + ESP	**50**	**50**	
WPS	**14**	**-2**	**30**
Projected for MATS	***80-90^{+}***	***80-90^{+}***	***60-90^{+}***

SCRs can increase Hg removal, especially for scrubbed units

Analysis of 1999 EPA ICR data

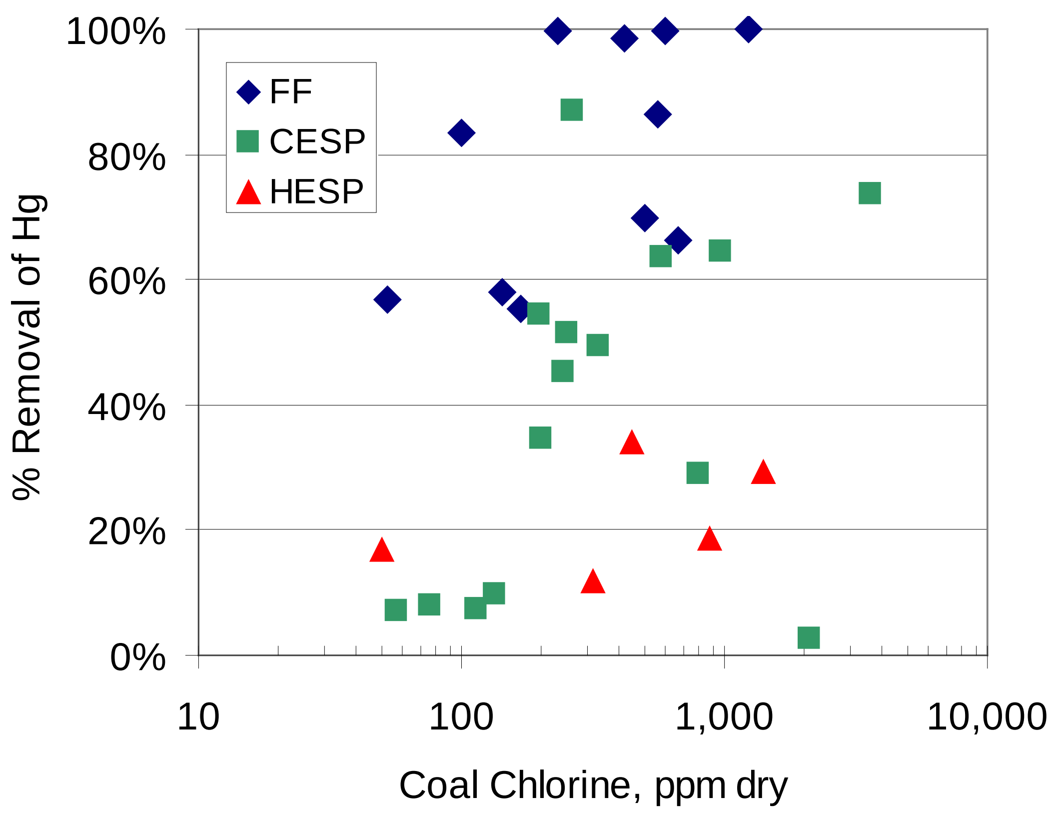
US Coal-Fired Generation Fleet Current Configurations

- More than 1100 units in operation
  - ~ 317 GW
- ~ 66% have SO_2 or NOx controls
- Unscrubbed units
  - ~ 50 GW bituminous
  - ~ 60 GW subbituminous



*http://www.eia.gov

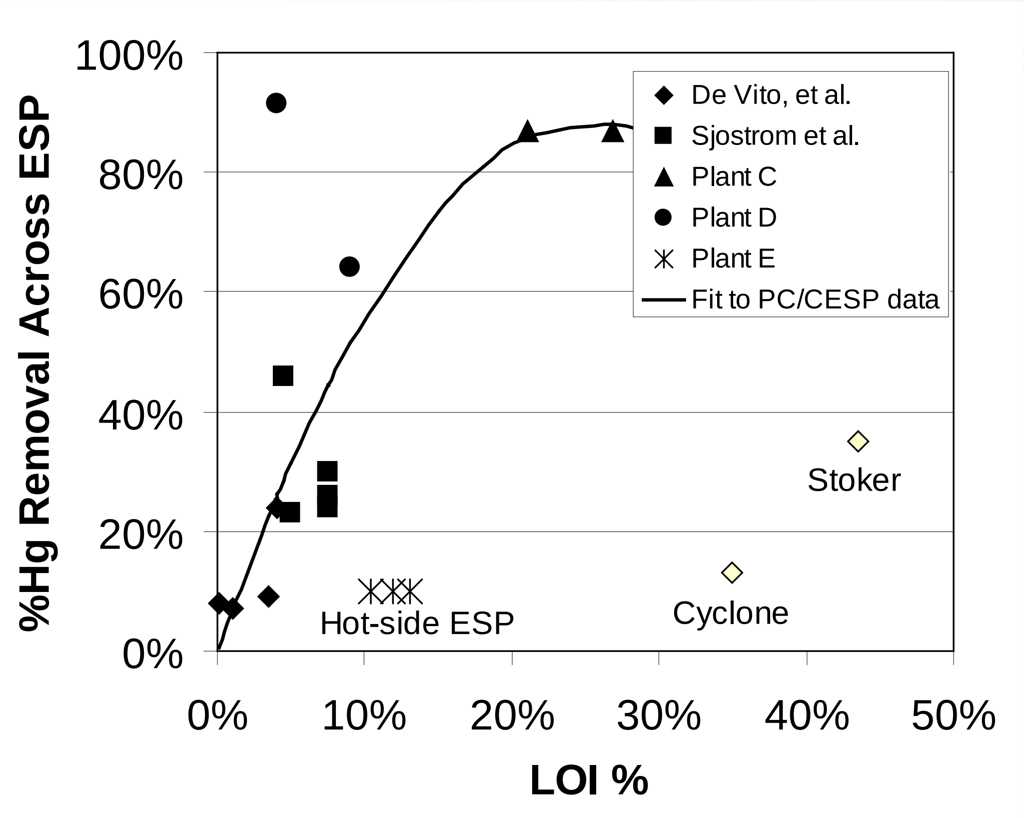
Hg Removal in ESPs and Fabric Filters



- High level of Hg removal possible in FFs
- ESPs have lower removal
- Hot-side ESPs lowest removal of Hg

From 1999 ICR data

Effect of LOI: ESPs

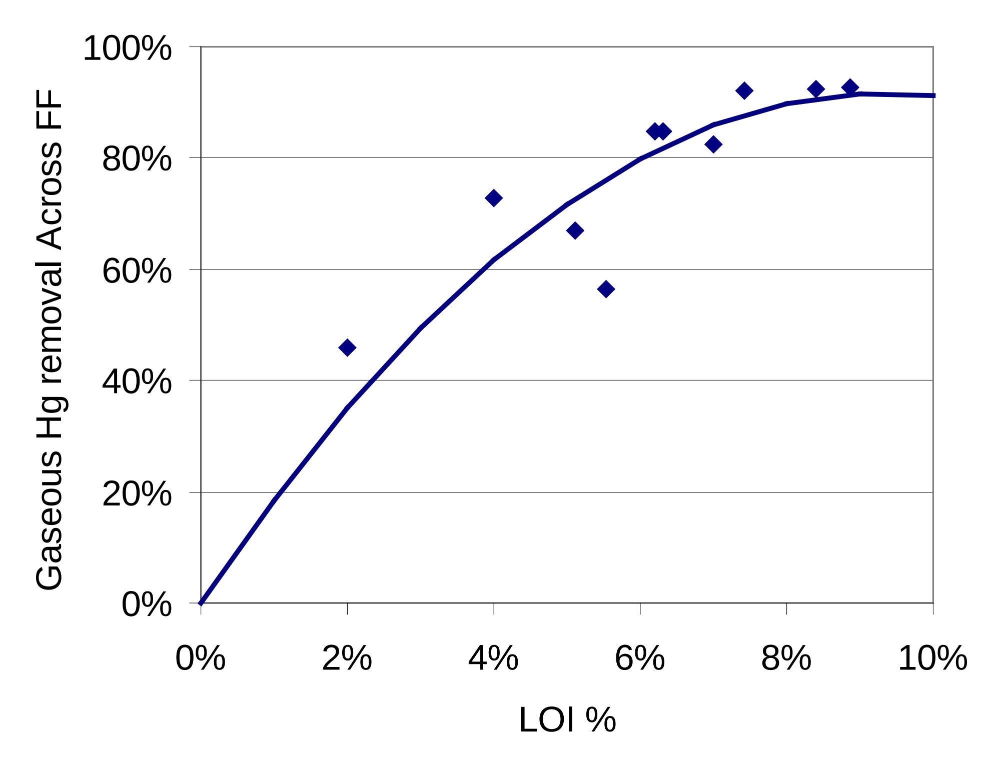


- Carbon from unburned carbon
- Limited coal types in dataset, but surprisingly good correlation with carbon in ash

Source: Senior and Johnson, 2005

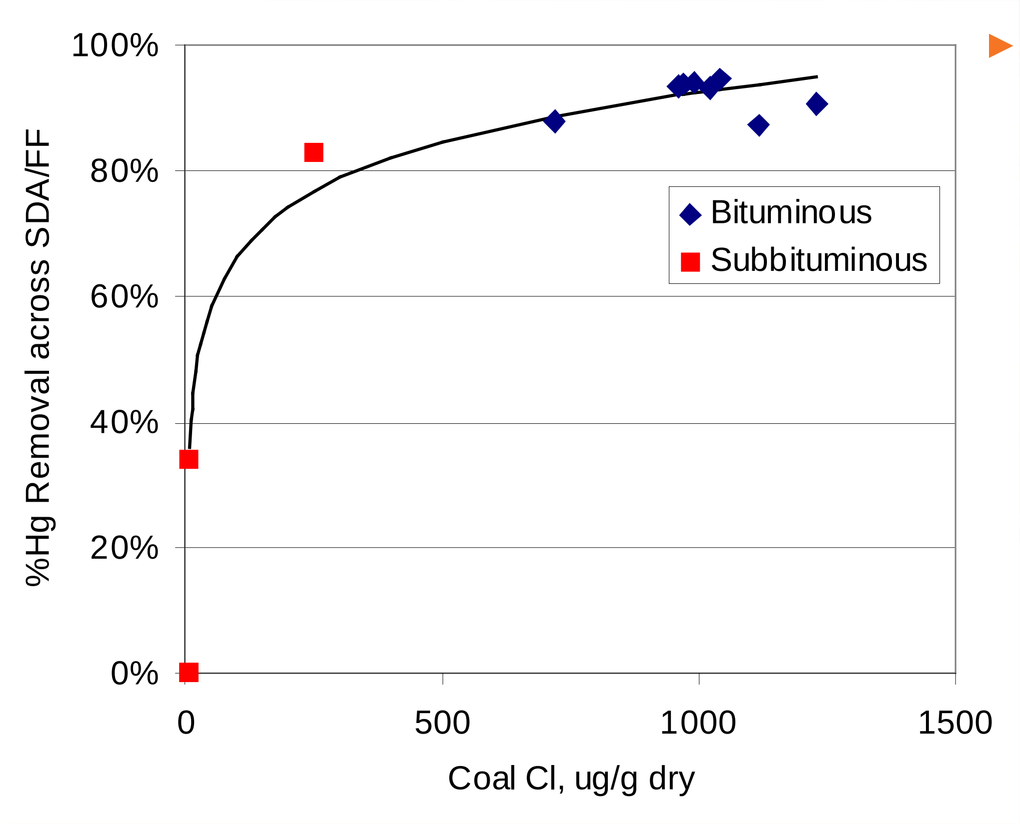
Data from plants burning bituminous coal

Effect of LOI: Fabric Filter



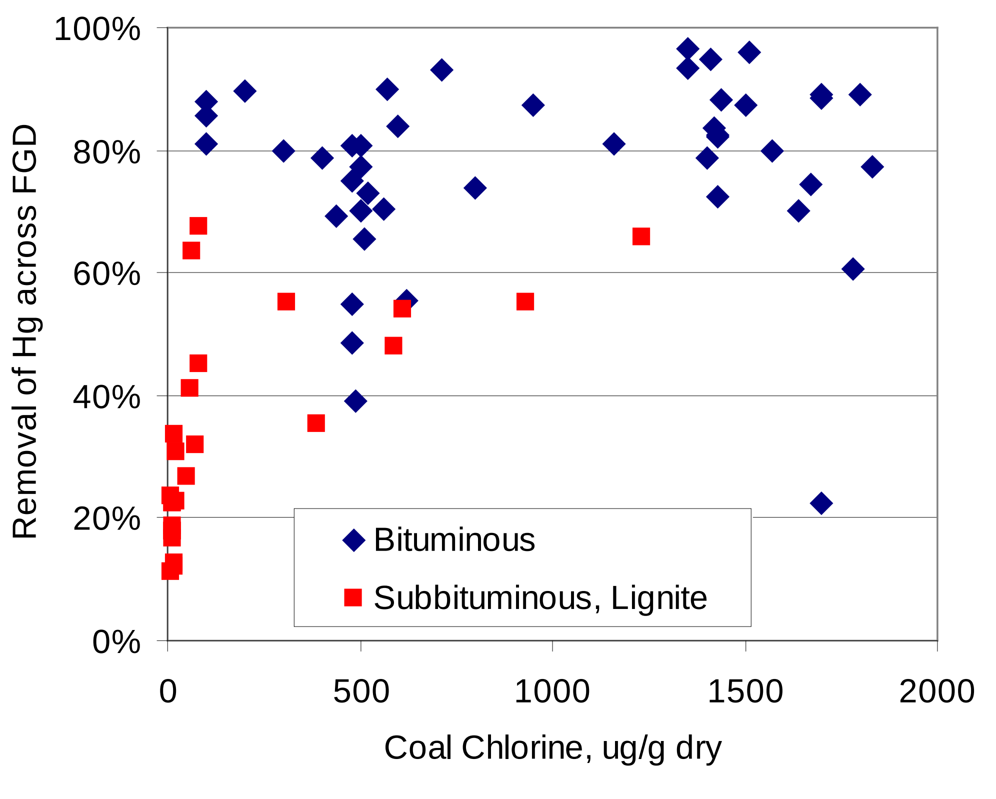
- 170 MW tangential boiler with OFA, GG
- Burning low-sulfur bituminous coal
- LOI in fly ash varied by changing combustion conditions
- FF temperature, 265°F

Mercury Removal in Dry Scrubbers



- Spray dryer/fabric filters effective for high chlorine (>500 µg/g), but not for lower chlorine coals

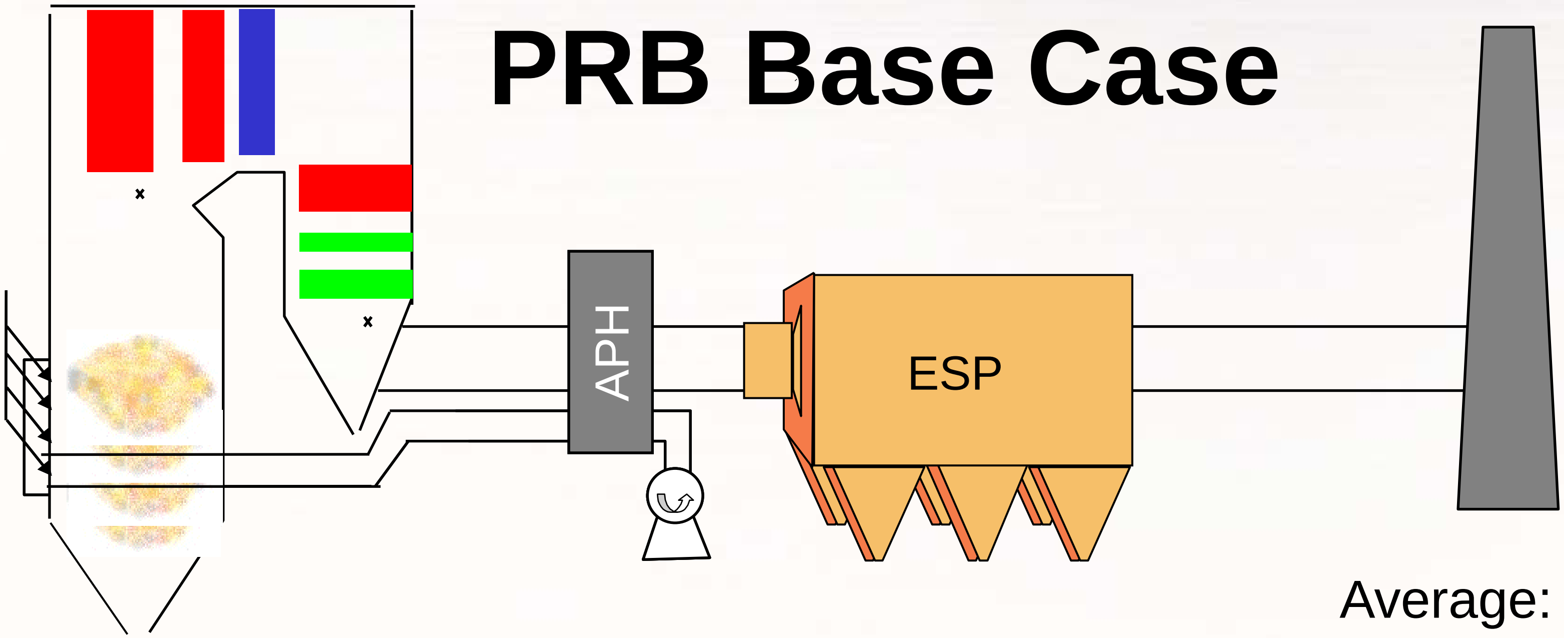
Mercury Removal in Wet Scrubbers



- Speciation at inlet to FGD critical to high removal across scrubber
- Strategies for increasing Hg^{+2} at FGD inlet to be discussed later

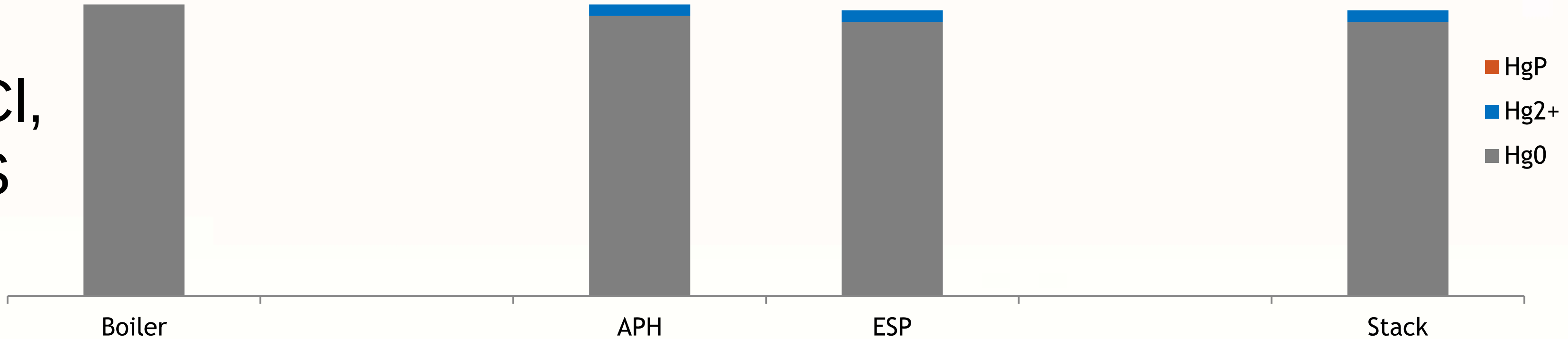
Mercury Control: Case Studies

PRB Base Case



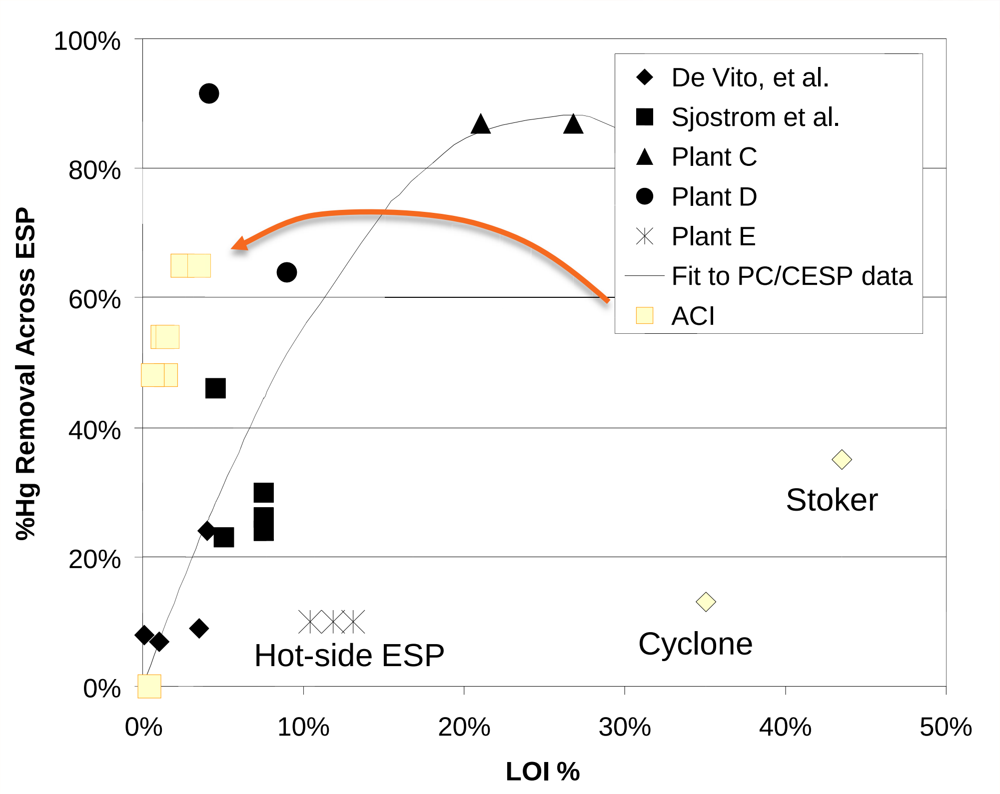
Average: 17%*

Low Cl,
Low S



**Analysis of 1999 EPA ICR data*

Effect of Carbon: ESPs

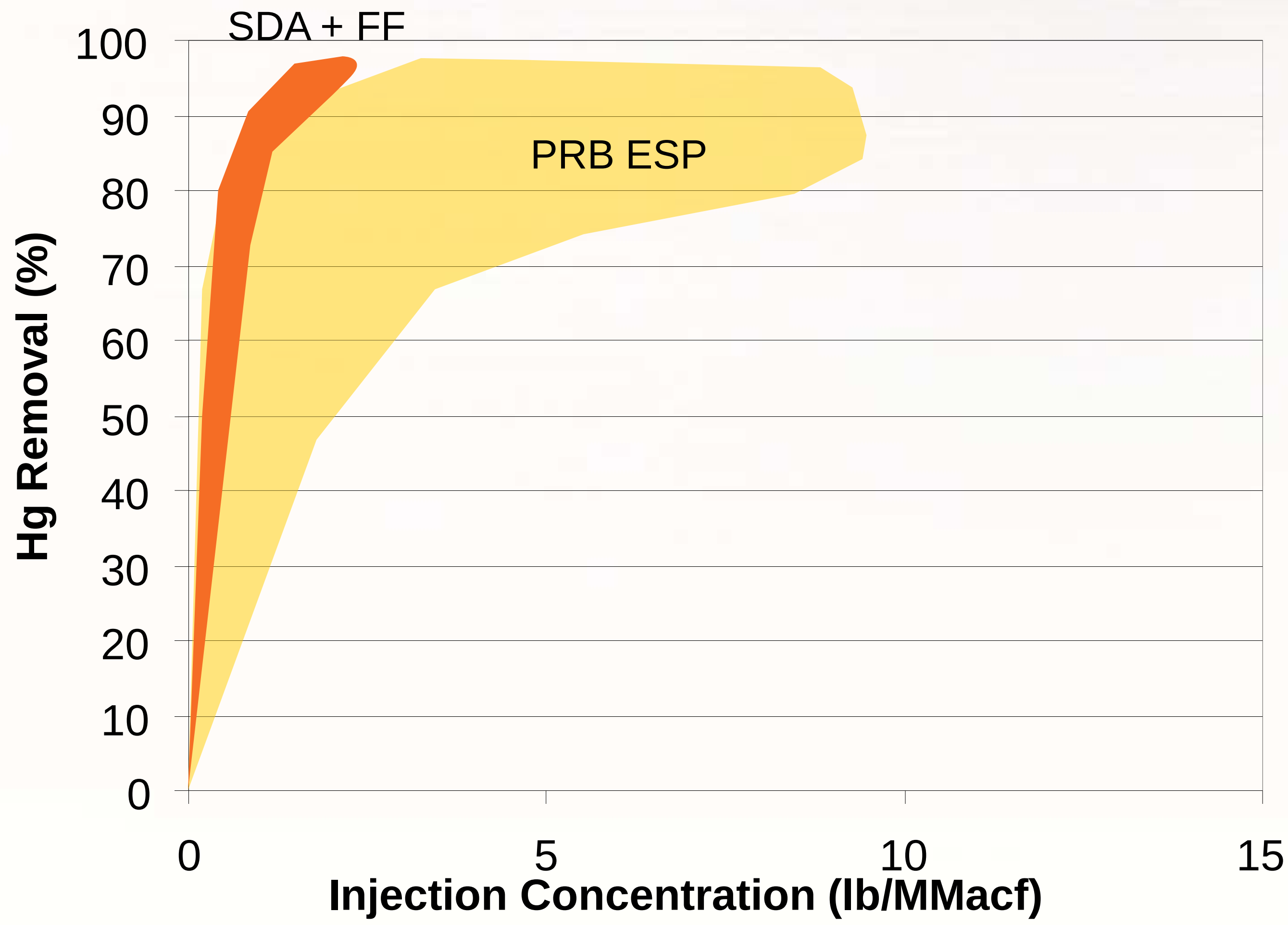


- **Activated carbon** has higher capacity and reactivity than fly ash carbon (per gram)

Source: Senior and Johnson, 2005

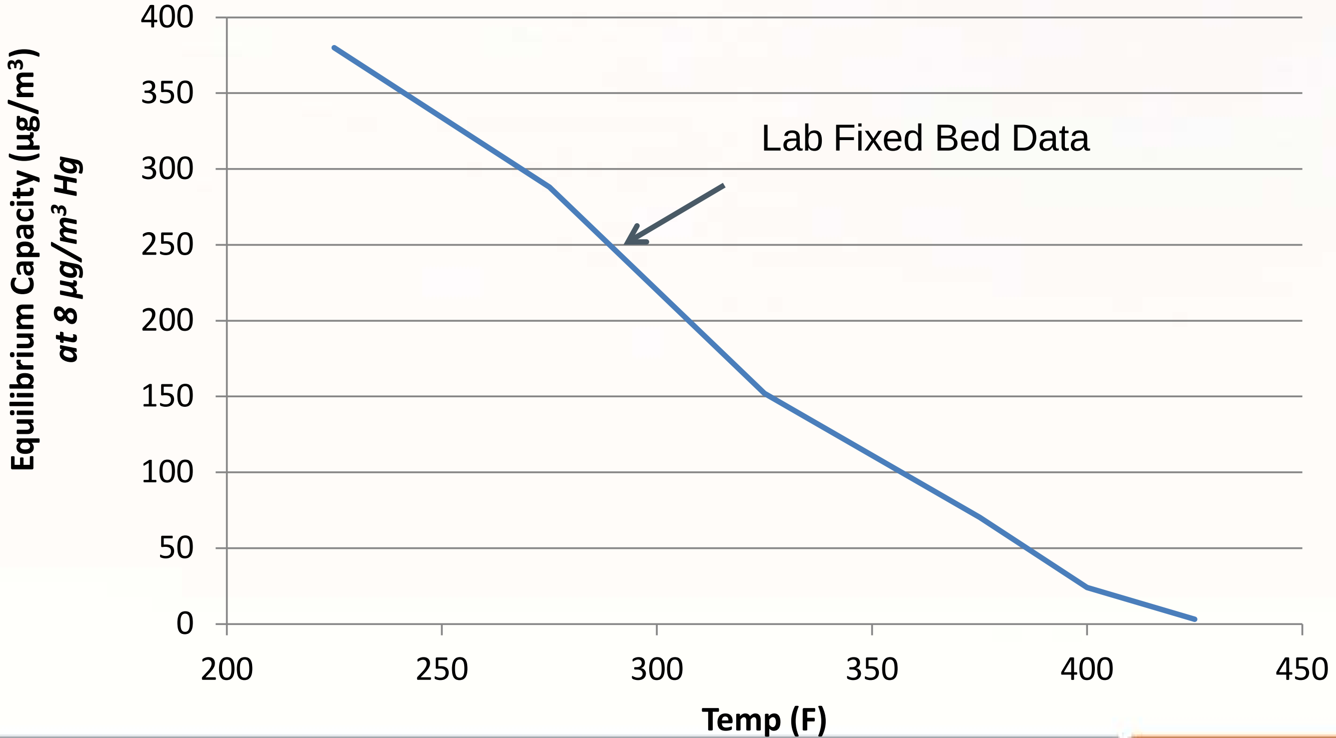
Data from plants burning bituminous coal

Activated Carbon Injection (ACI) PRB Coal Results



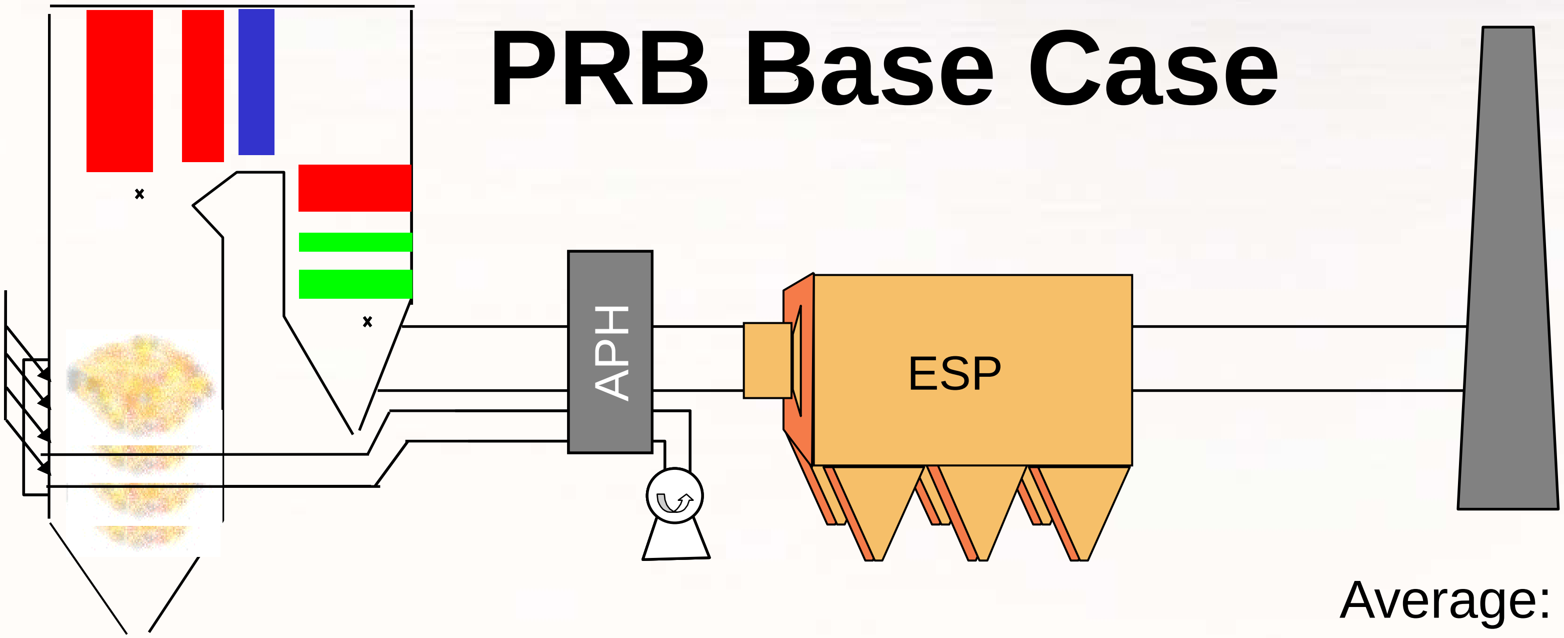
Impact of Temperature on PAC

- The capacity of carbon for mercury decreases significantly within the range of typical APH outlet temperatures
- The impact of changes in capacity are more pronounced on fabric filters than on ESPs



Mercury Control: Case Studies

PRB Base Case



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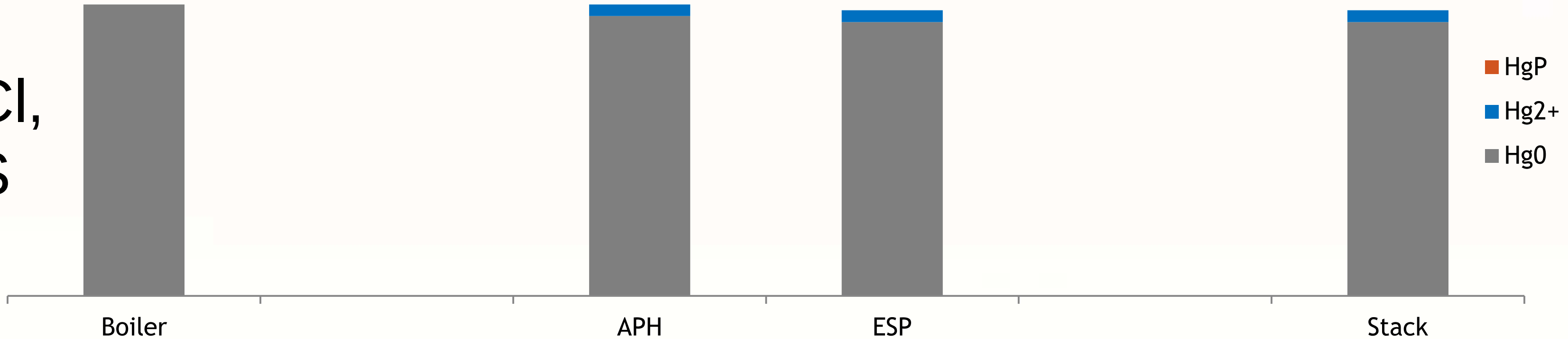
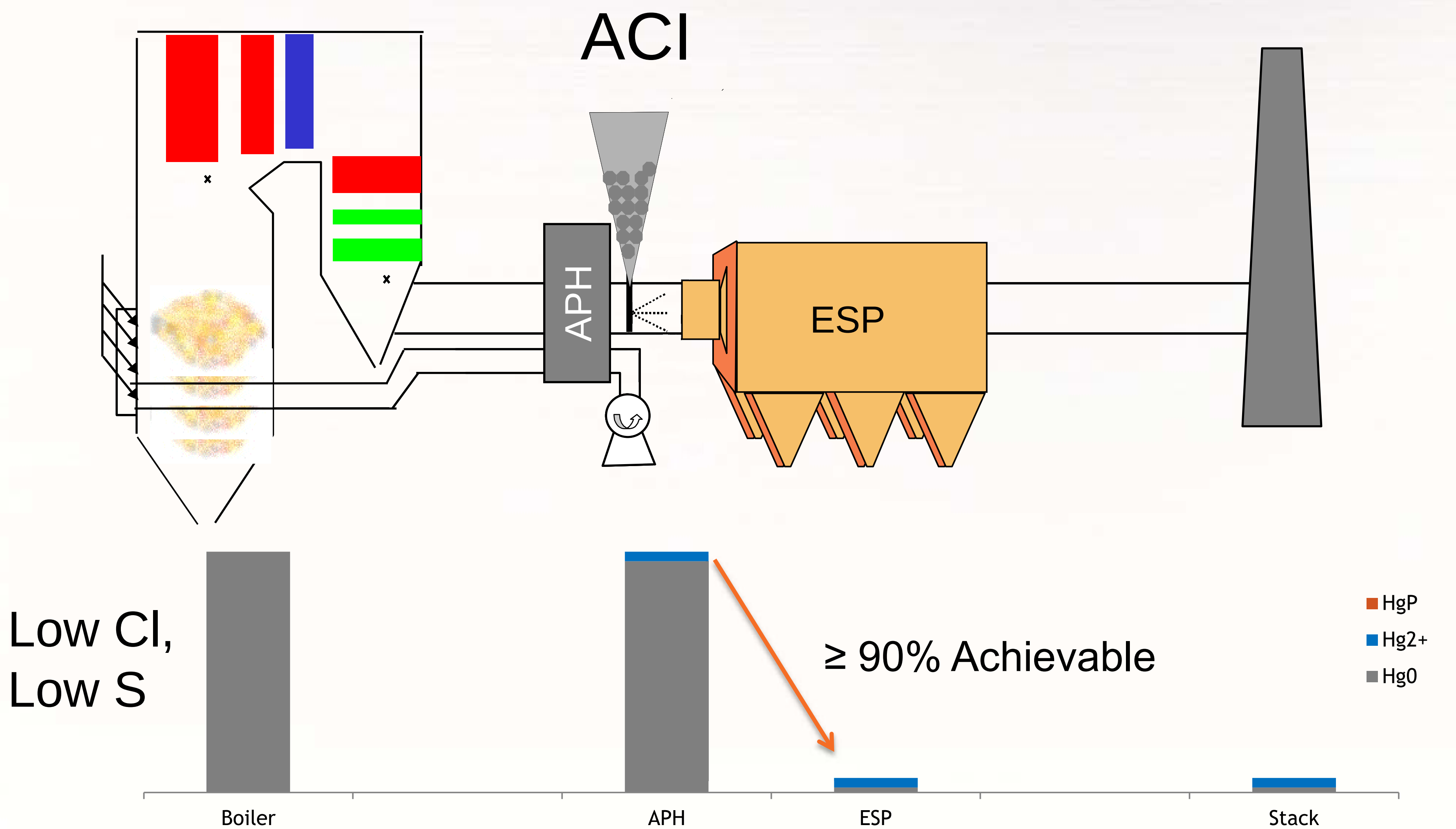
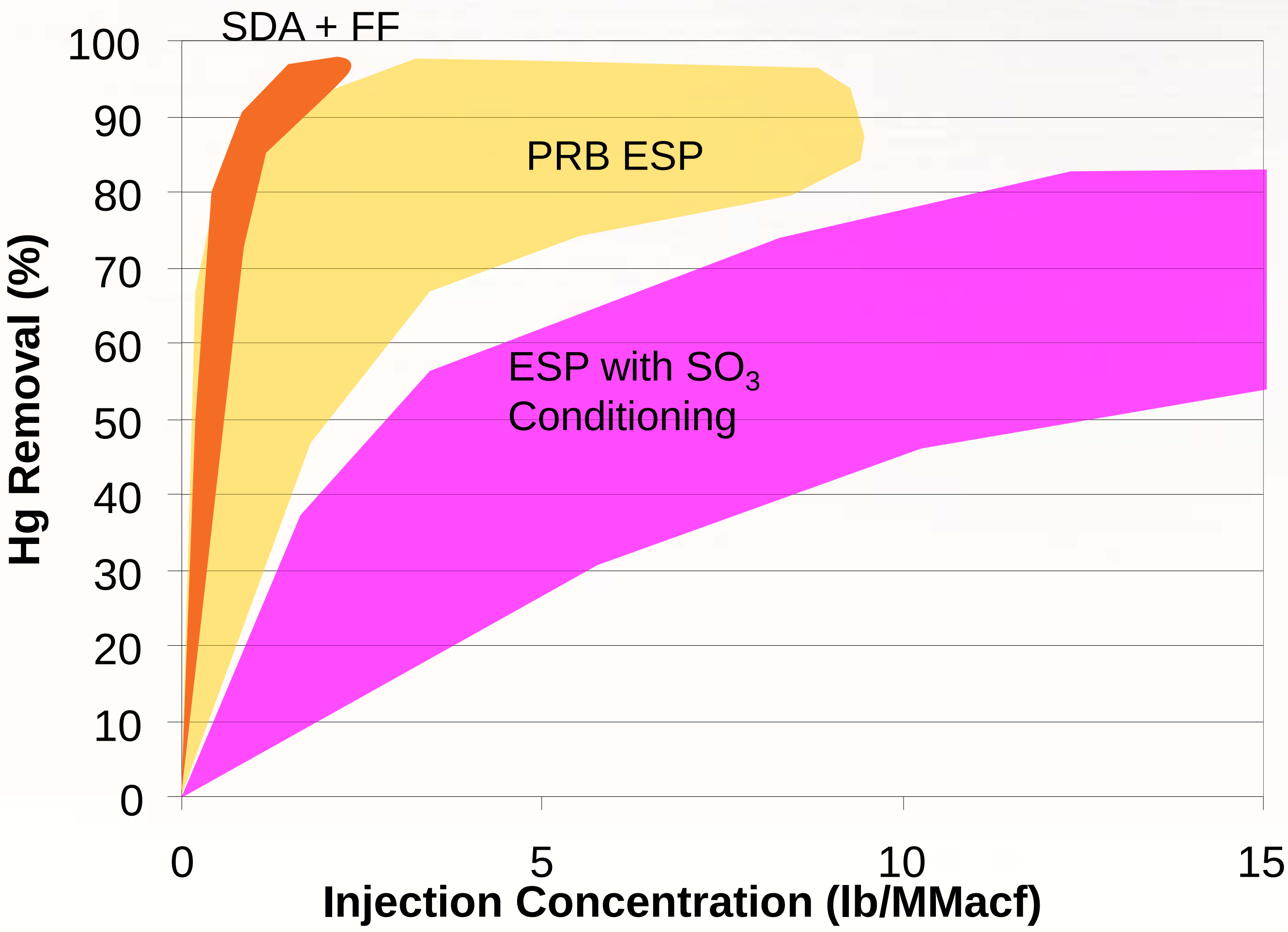


Analysis of 1999 EPA ICR data

Mercury Control: Case Studies

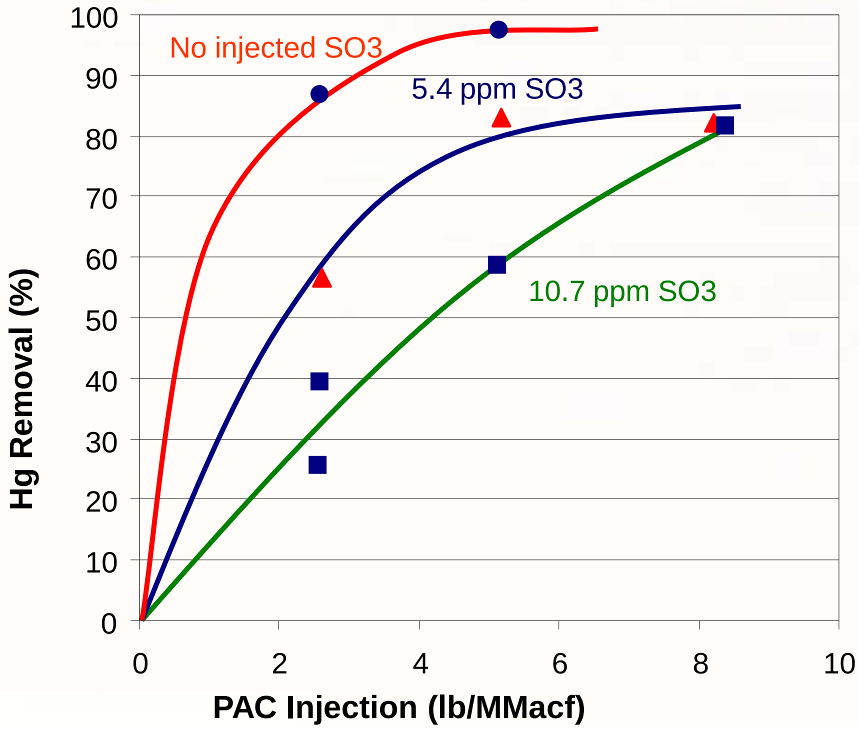


Activated Carbon Injection (ACI) PRB Coal Results

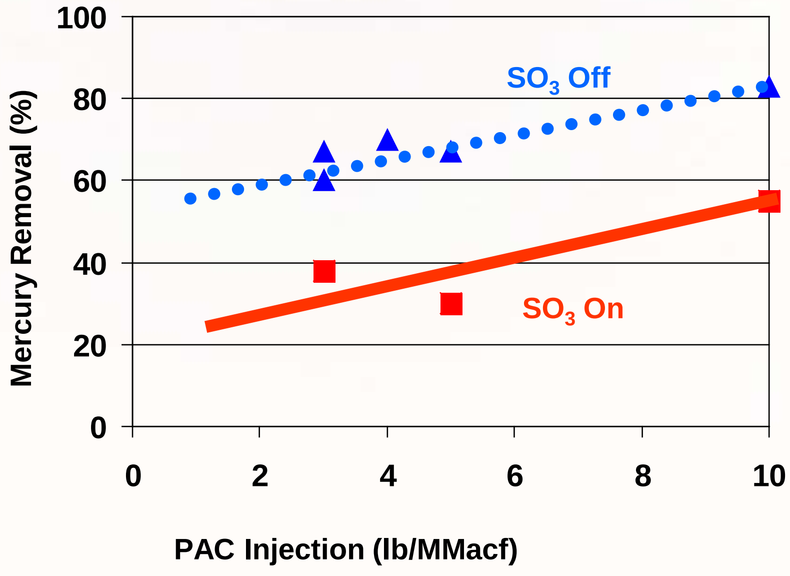


SO_3 Injection and PAC Effectiveness

- Many units firing low sulfur coal use SO_3-based flue gas conditioning
- Any SO_3 in gas phase affects Hg capture

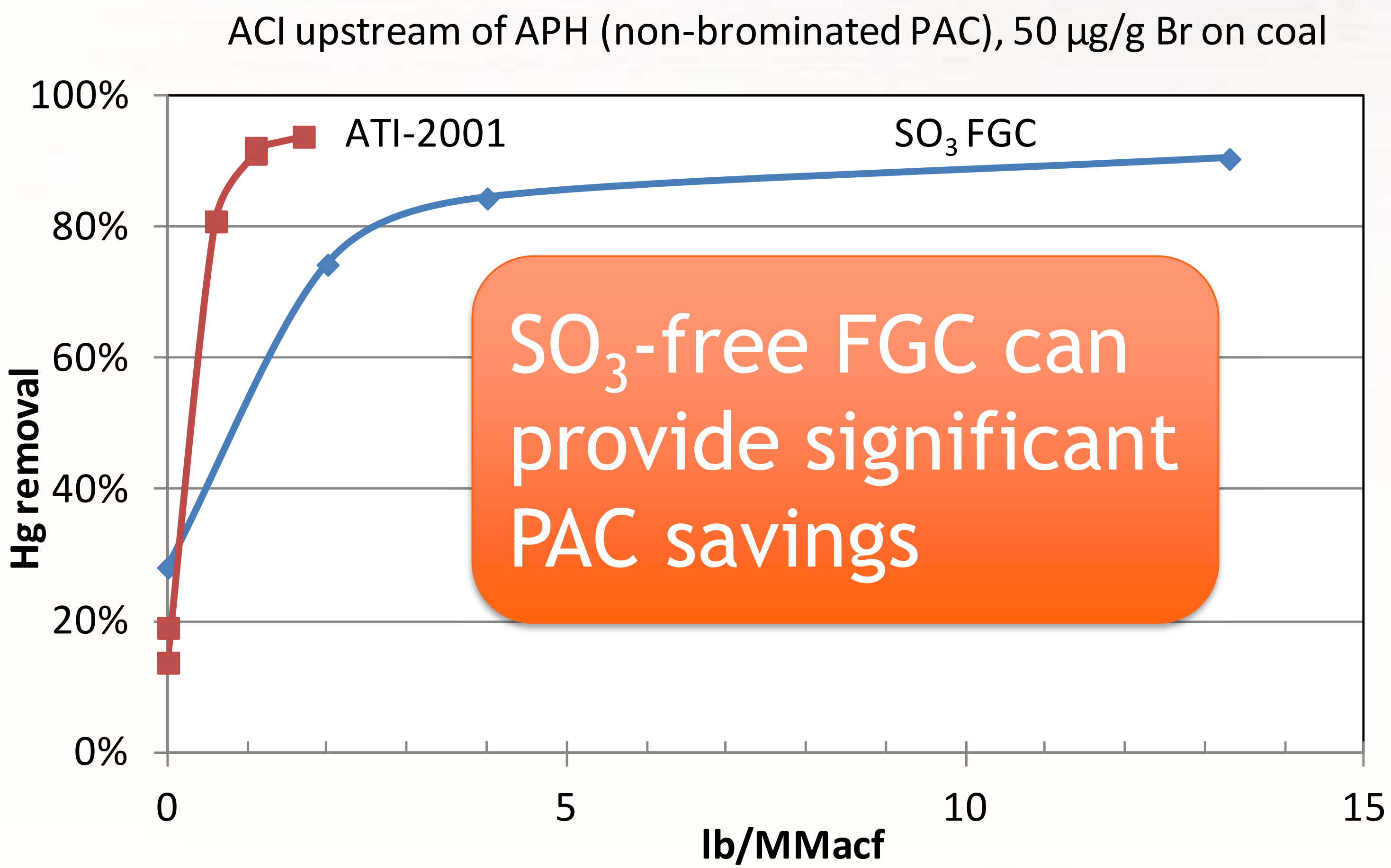


Ameren Labadie Data: DOE DE-FC26-03NT41986 and EPRI
PRB, ESP



Mississippi Power Plant Daniel
Low sulfur bituminous coal

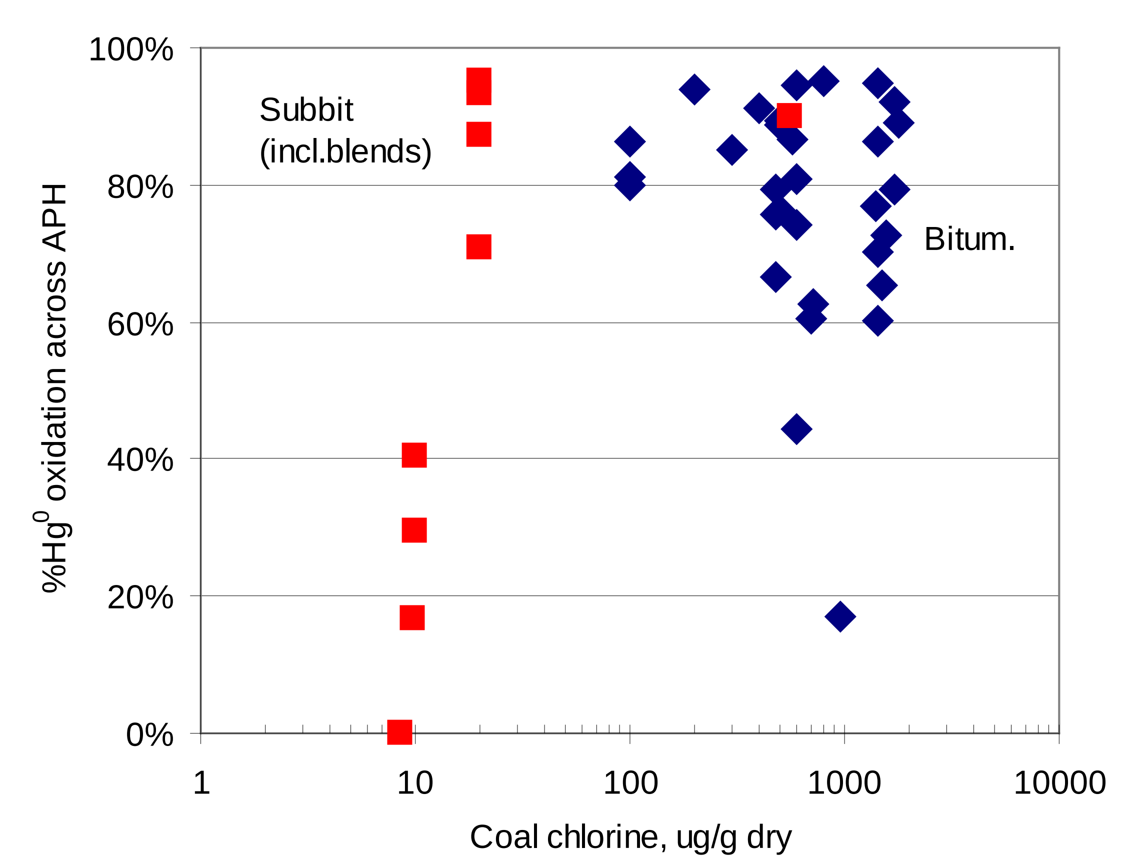
PAC Performance with FGC



Increase Native Capture: Halogen Addition

- Adding halogens (Cl or Br) increases oxidized Hg:
  - Increase effectiveness of some kinds of activated carbon for Hg capture
  - Increase capture of Hg in SO_2 scrubber
- Potential balance-of-plant impacts:
  - Possible increased corrosion in flue gas
  - Halogens build up in wet scrubber liquor
    - Average Cl removals for wet FGDs (2010 ICR): 81% for subbituminous, 97% for bituminous
    - Removal of Br at Plant Miller wet FGD: 94-96% (Dombrowski et al., 2008)

Oxidation of Hg Across APHs

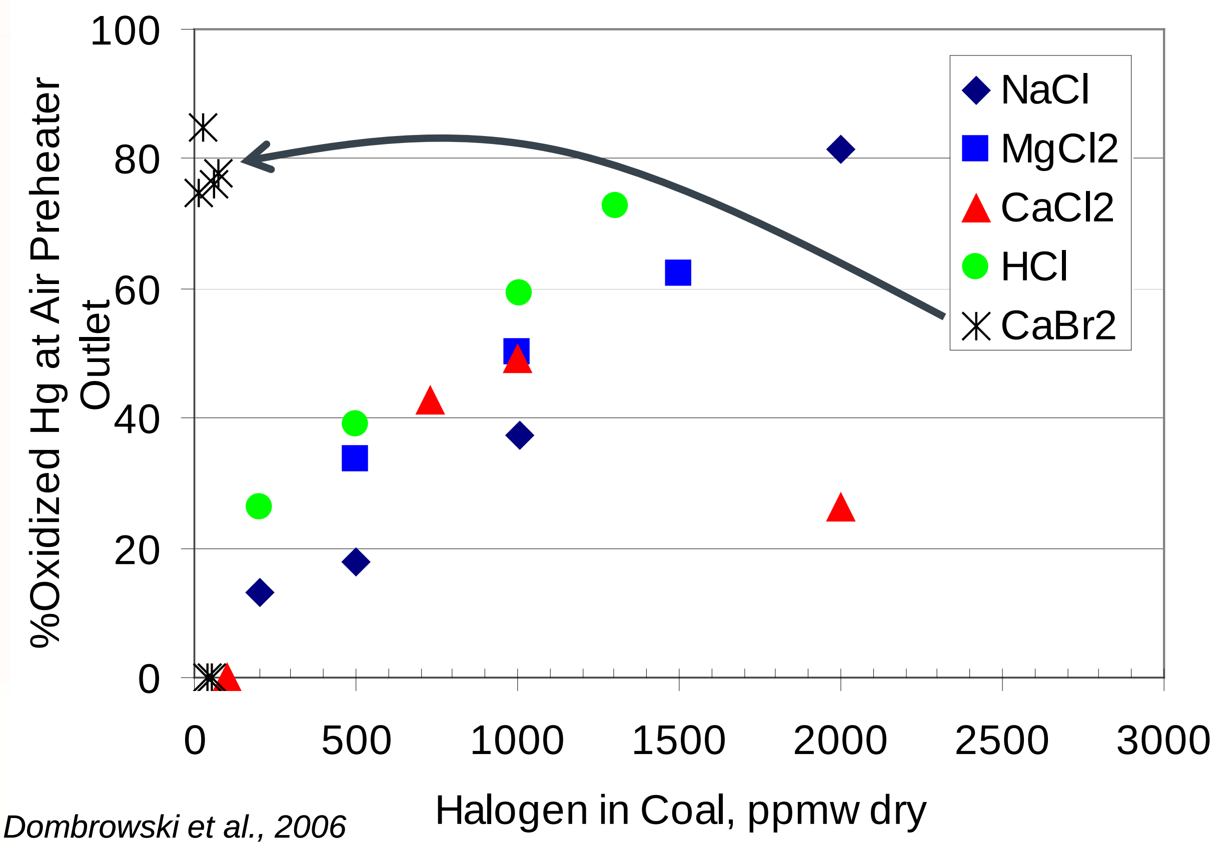


- Significant oxidation across Air Preheater:
  - APH exit temperature
  - Chlorine
  - SO_2/SO_3
  - LOI

Full-scale Hg speciation measurements

Addition of Halide Salts to PRB Boilers

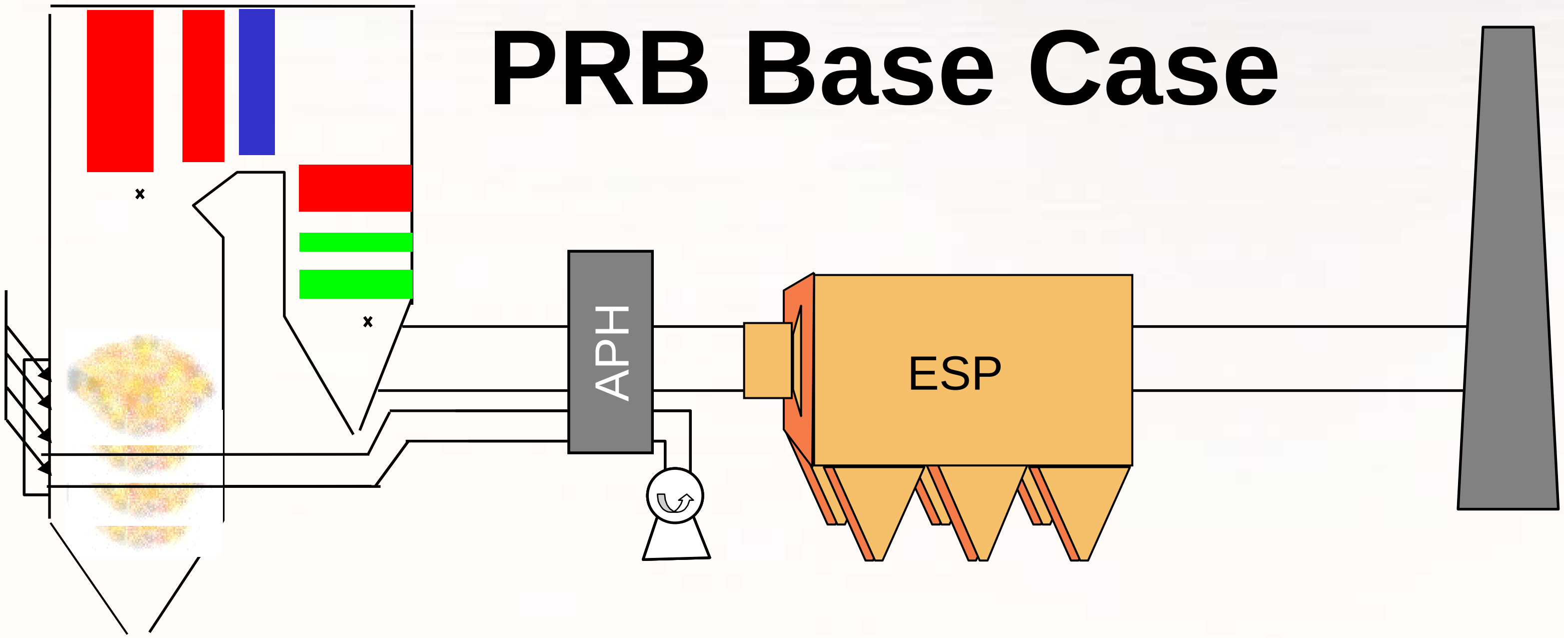
- Adding halogens increases oxidized Hg, which can increase capture of Hg in scrubber
  - SCRs often increase oxidation effectiveness of halogens



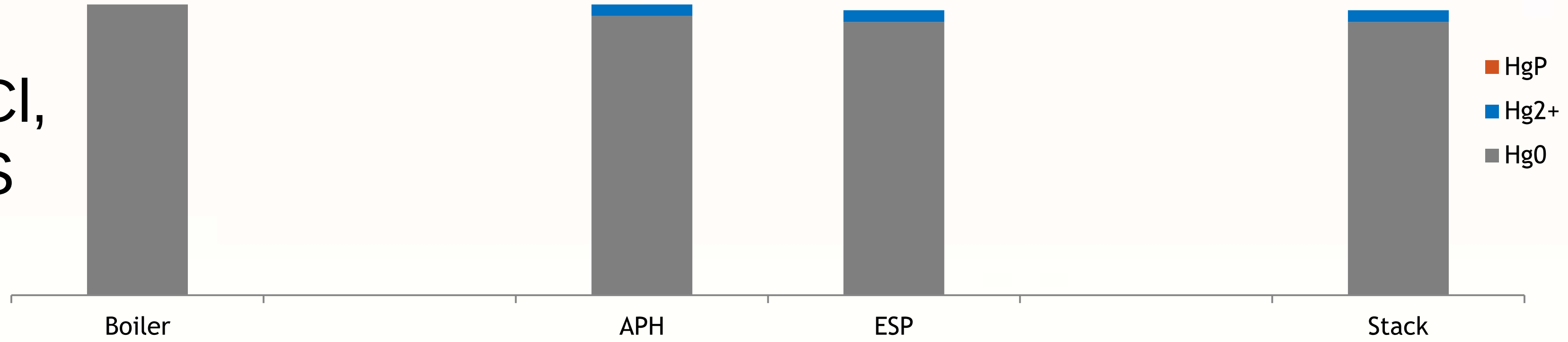
Source: Dombrowski et al., 2006

Mercury Control: Case Studies

PRB Base Case



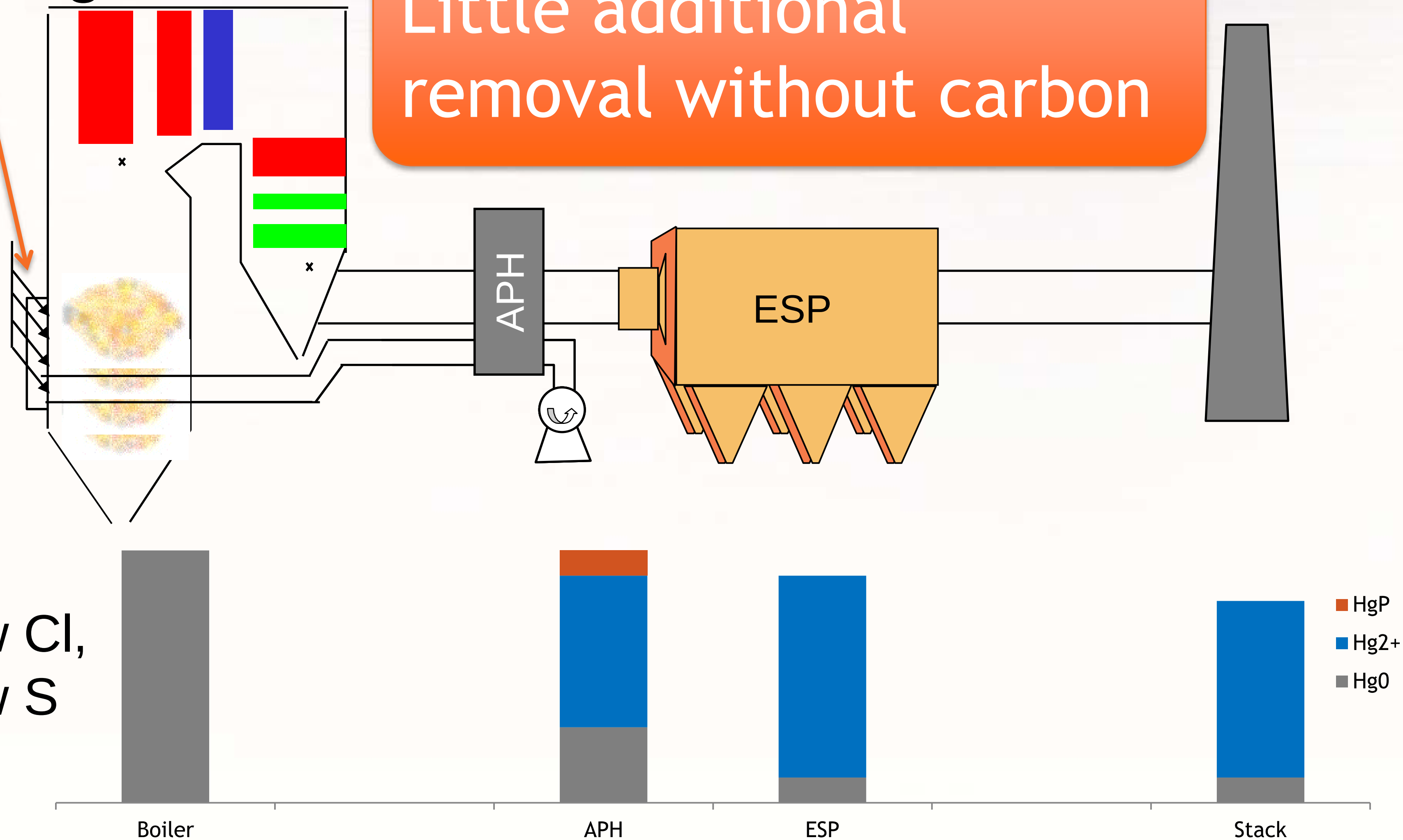
Low Cl,
Low S



Mercury Control: Case Studies

Halogen

Little additional removal without carbon

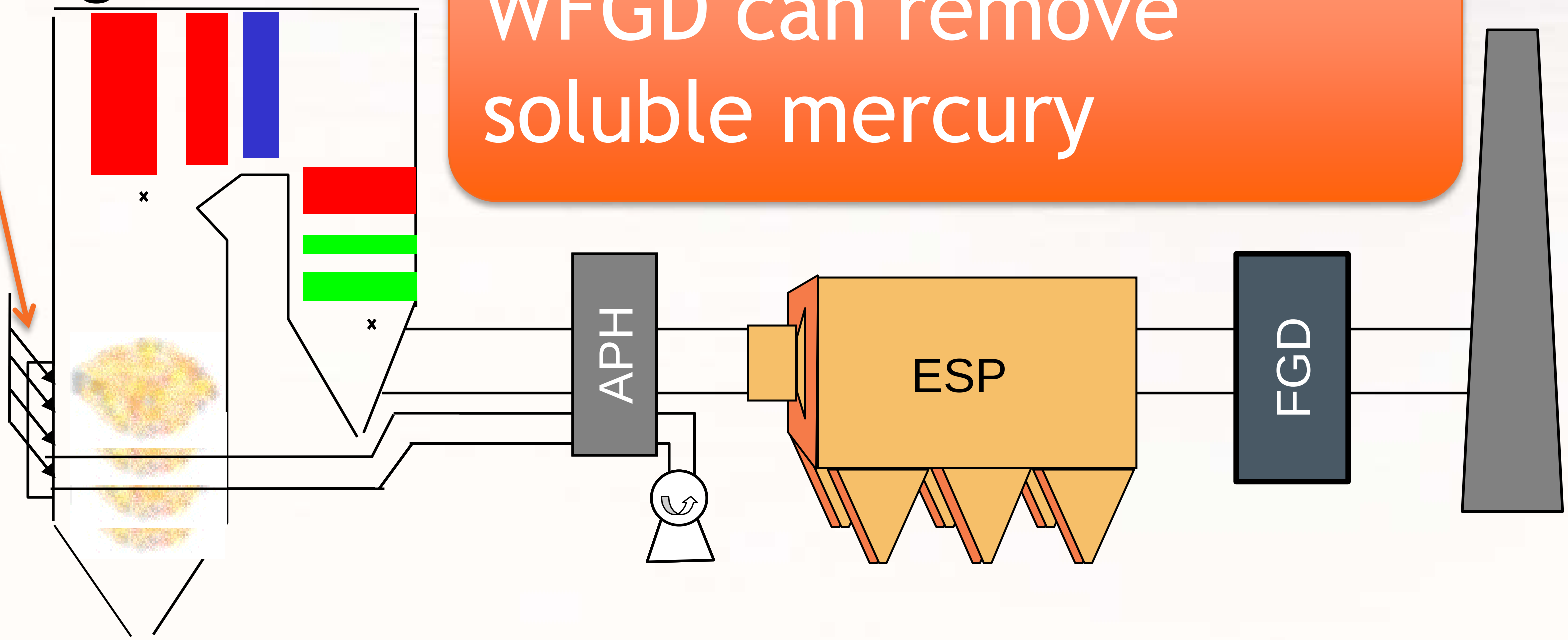


Low Cl,
Low S

Mercury Control: Case Studies

Halogen

WFGD can remove soluble mercury



Low Cl,
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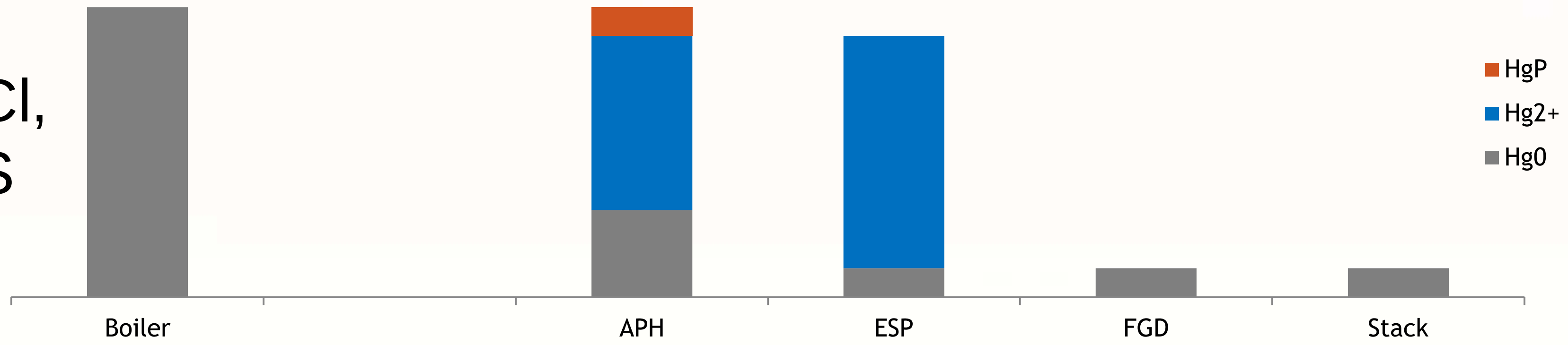
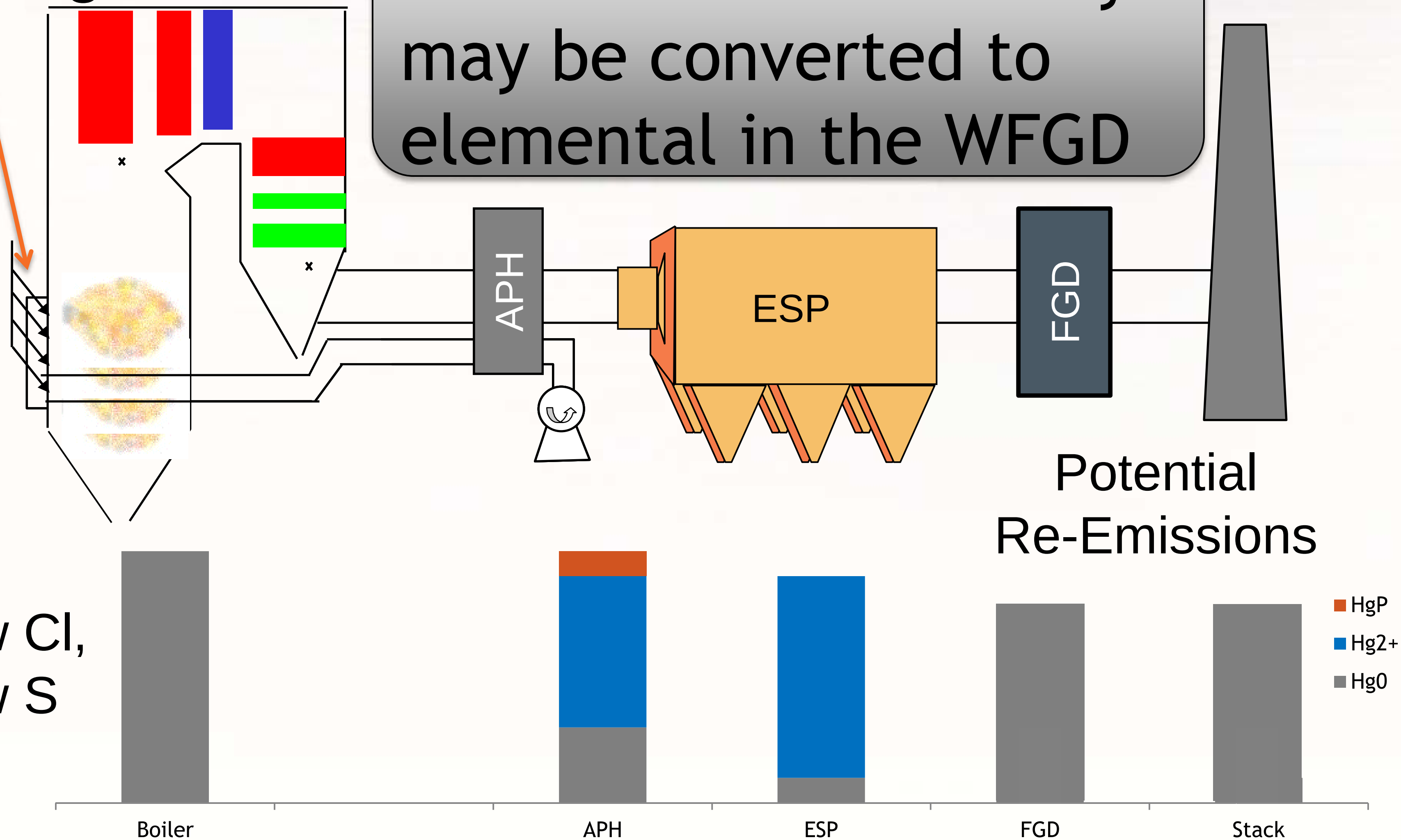


Mercury Control: Case Studies

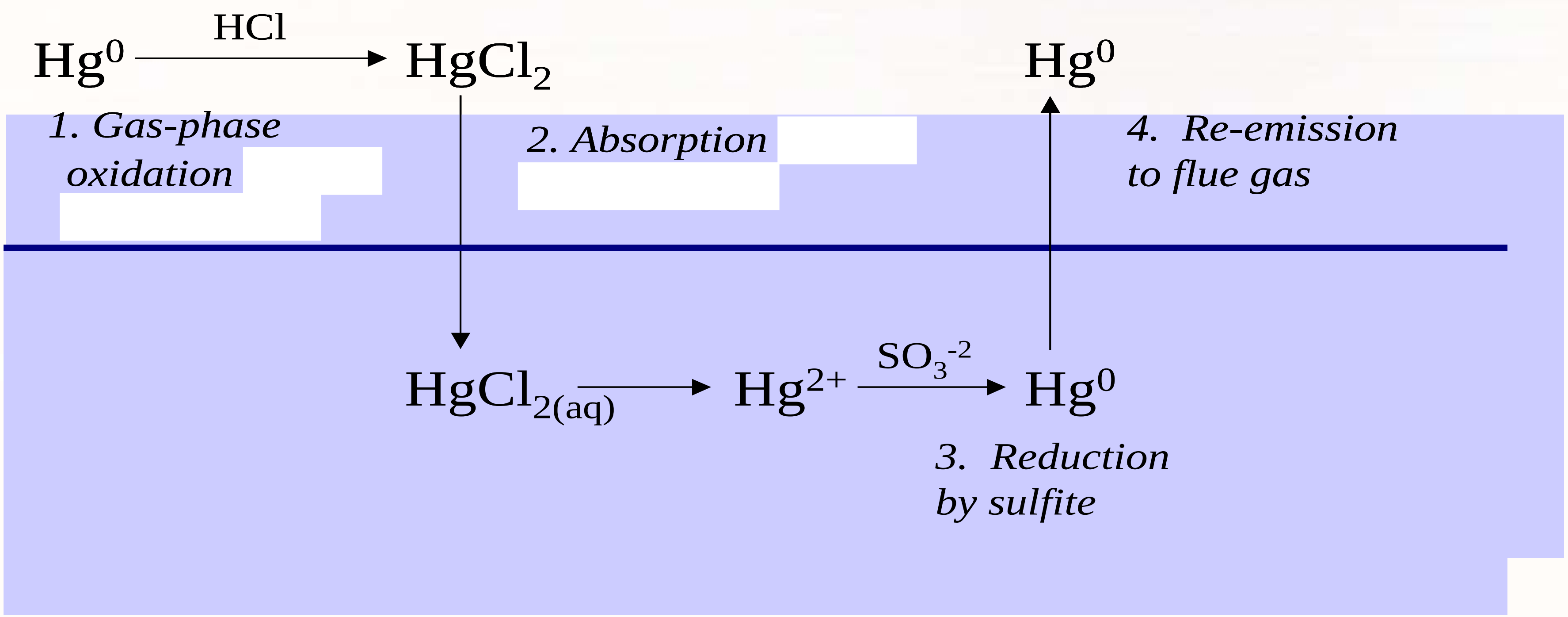
Halogen

Some oxidized mercury may be converted to elemental in the WFGD



Low Cl,
Low S

Re-Emission Mechanism



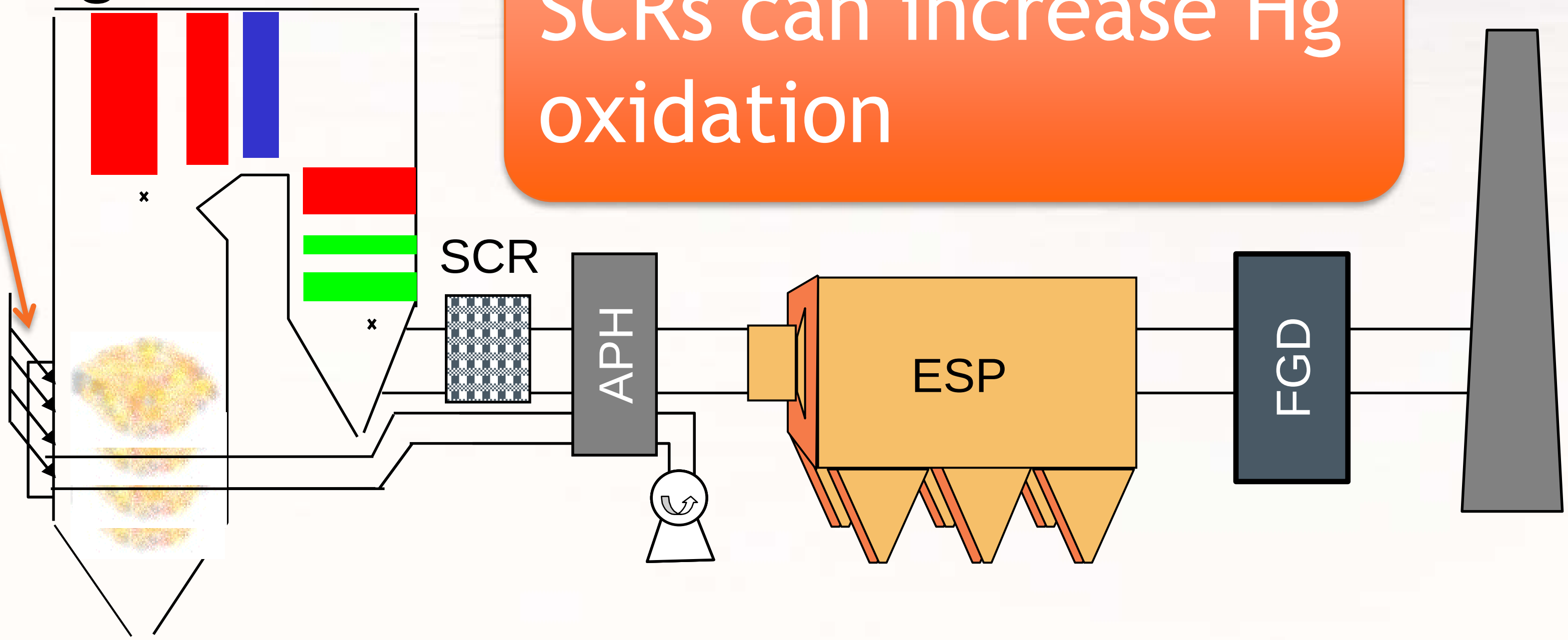
Mercury Control in Wet Scrubbers

- Some oxidized mercury may be converted to elemental mercury in wet scrubbers
  - Low solubility elemental mercury will "re-emit"
- Halogens build up in wet scrubber liquor
  - Some build-up may reduce re-emissions of mercury
  - High concentrations can cause corrosion issues
- Some scrubber additives are marketed to limit re-emissions
  - Scrubber chemistry is critical for success and can be difficult to control to the level required

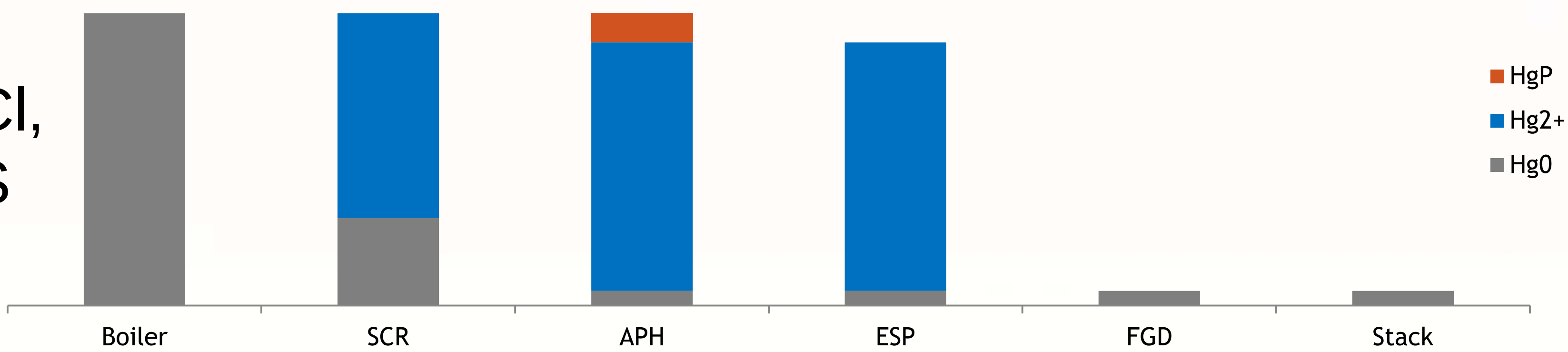
Mercury Control: Case Studies

Halogen

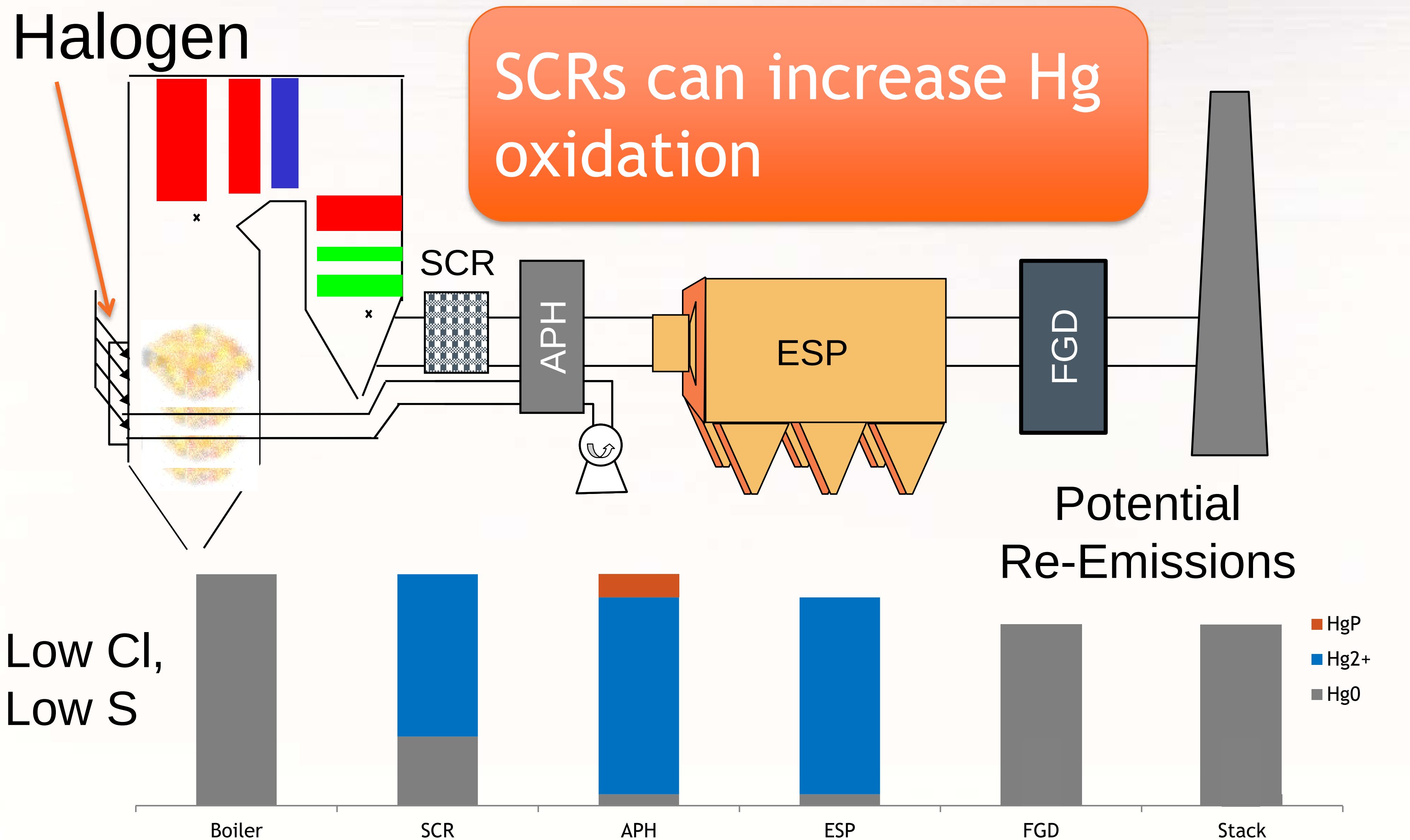
SCRs can increase Hg oxidation



Low Cl,
Low S

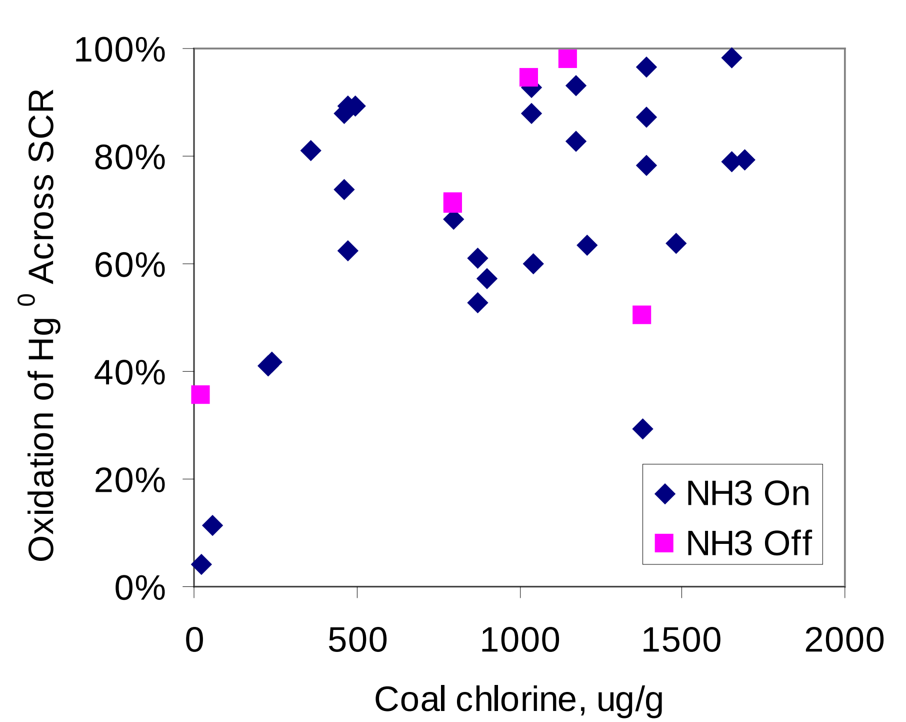


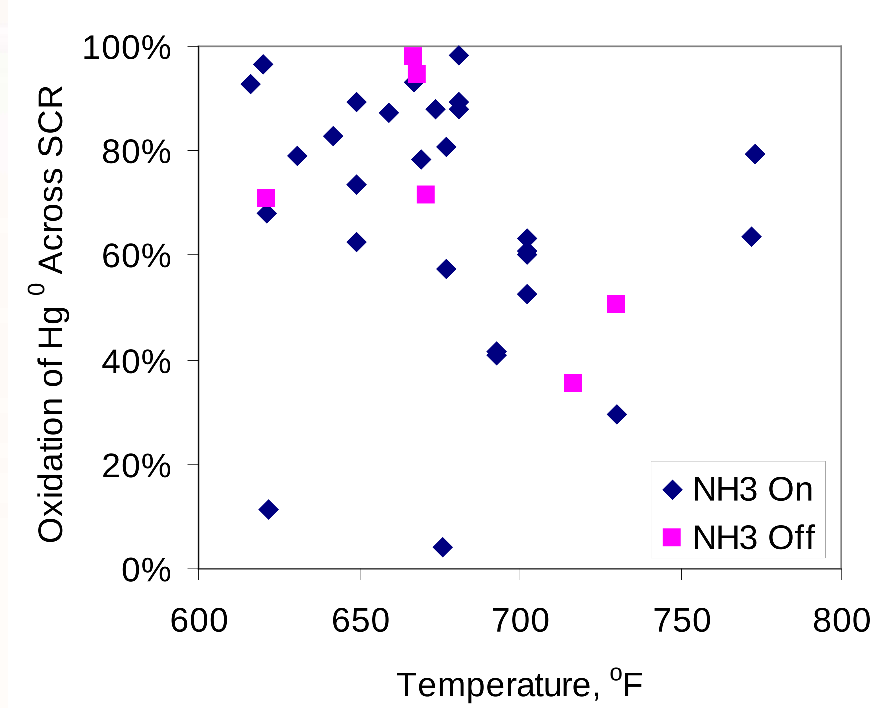
Mercury Control: Case Studies



Factors Affecting Hg Oxidation Across SCRs

Large variation in observed oxidation

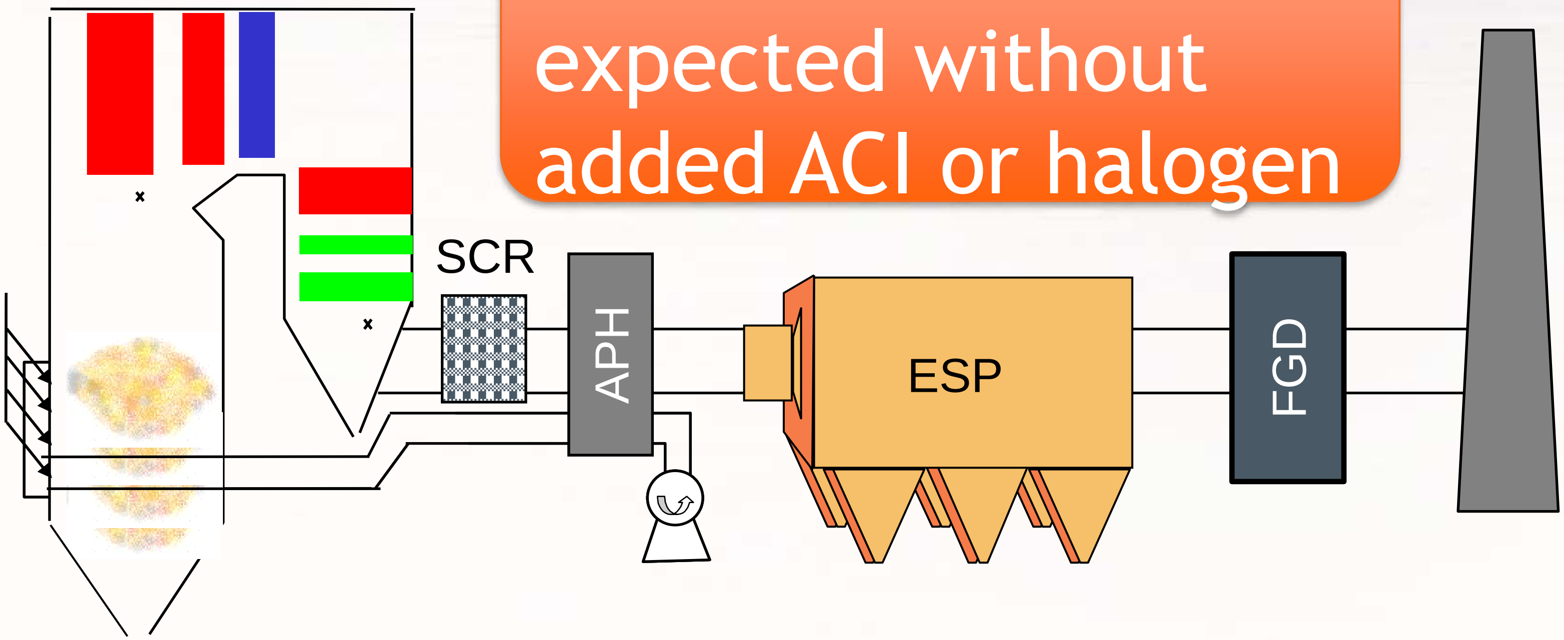




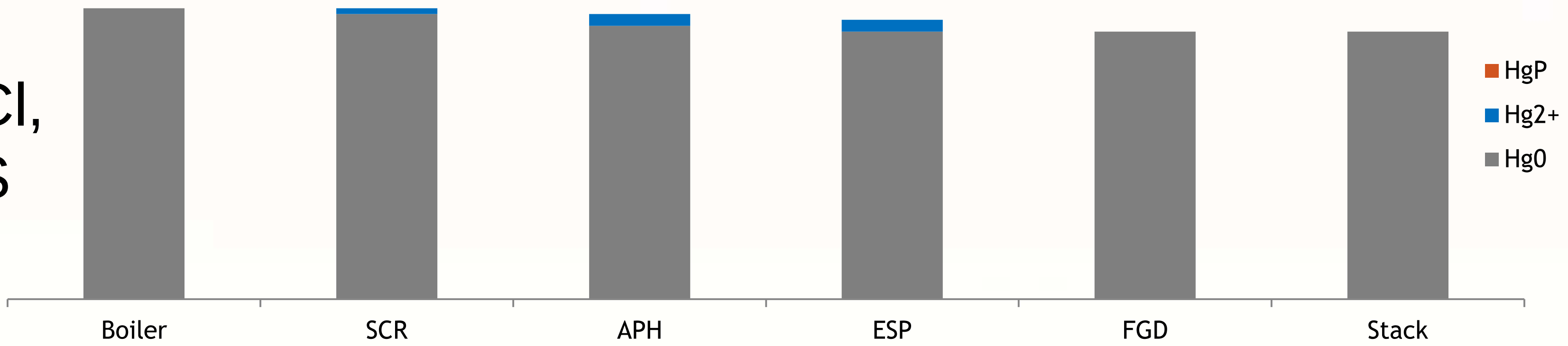
- Effect of Cl:
  - Low oxidation with PRB (low chlorine coal)
- Effect of T:
  - Lower oxidation at higher temperatures

Mercury Control: Case Studies

Poor removal expected without added ACI or halogen



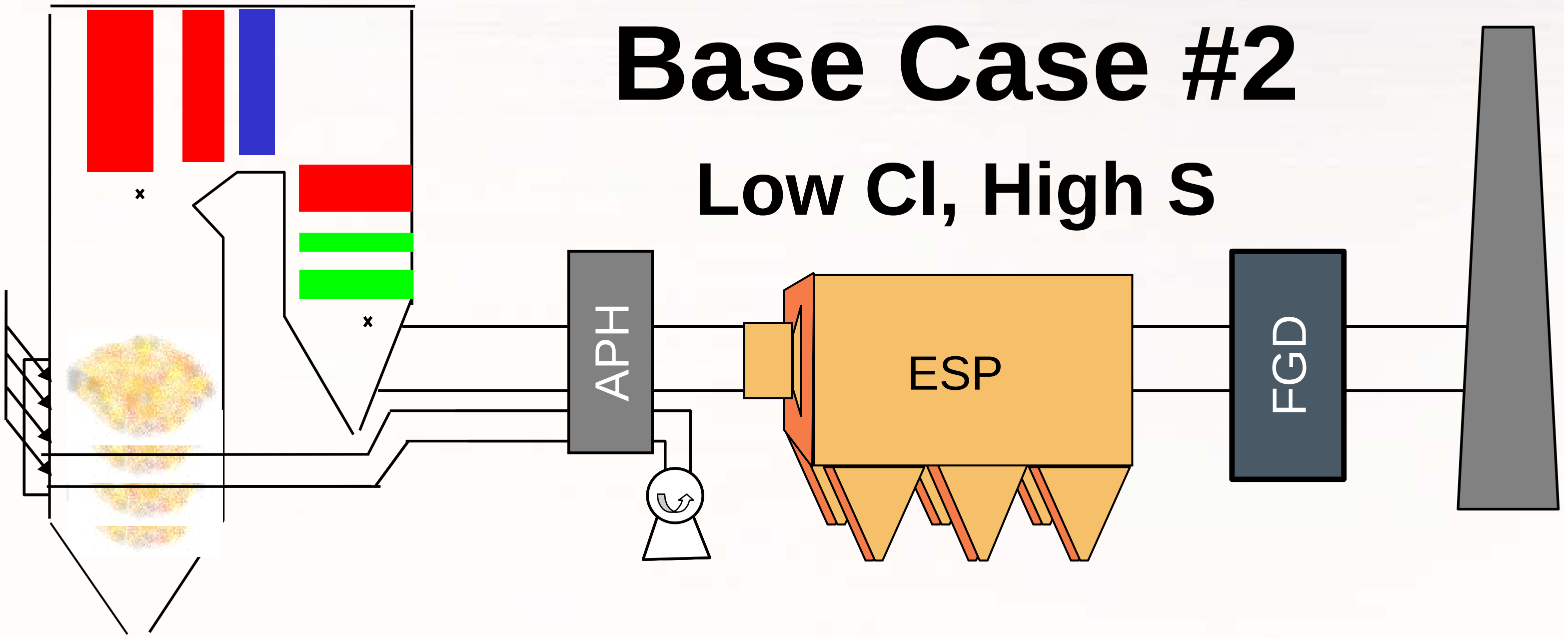
Low Cl, Low S



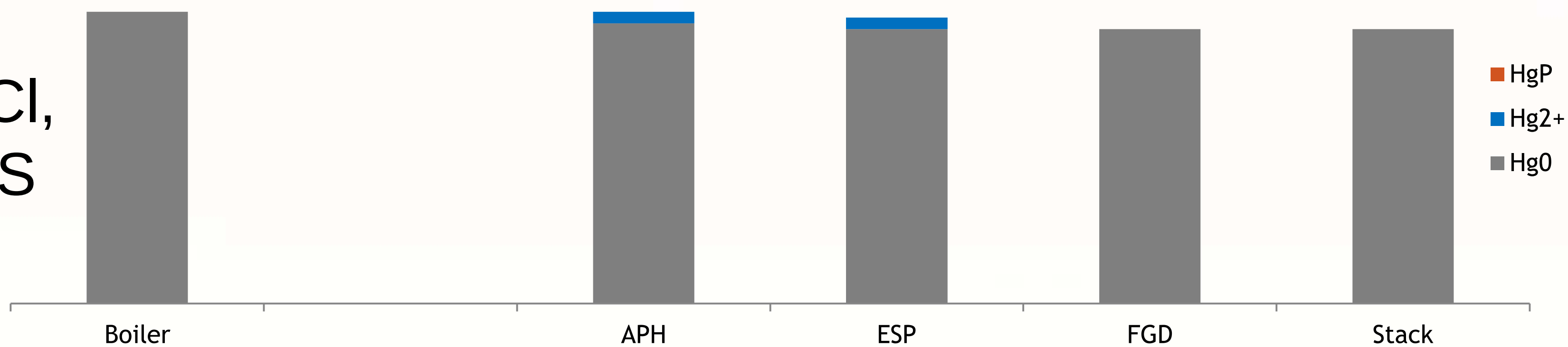
Mercury Control: Case Studies

Base Case #2

Low Cl, High S

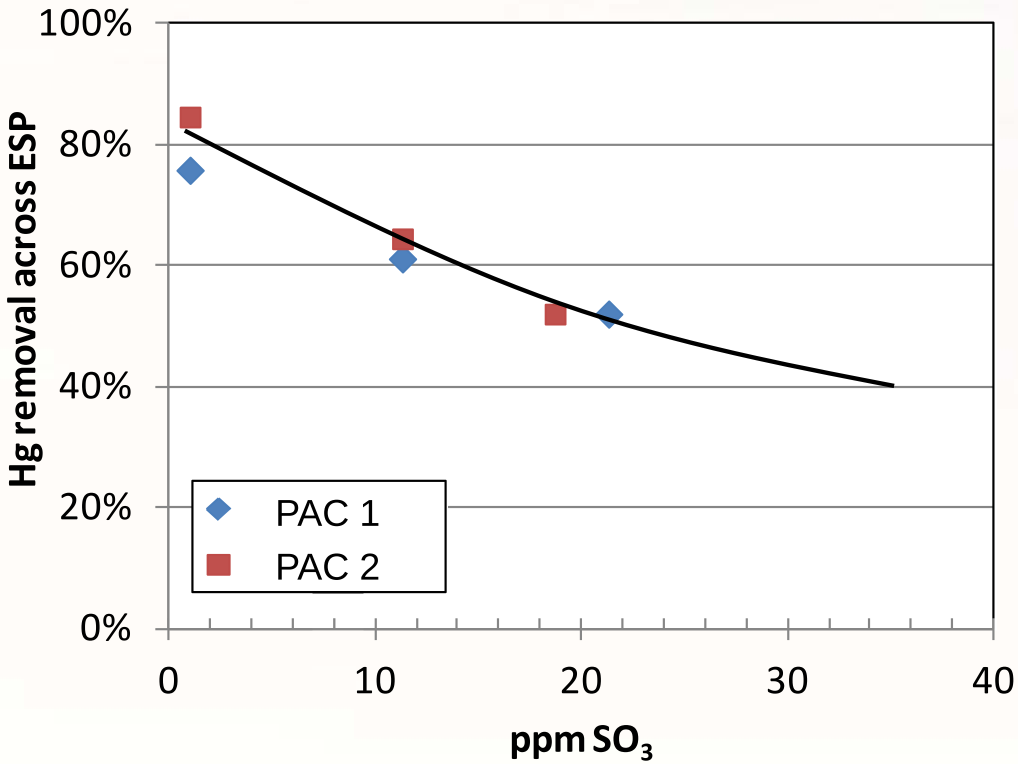


Low Cl,
High S



SO_3 and ACI Performance

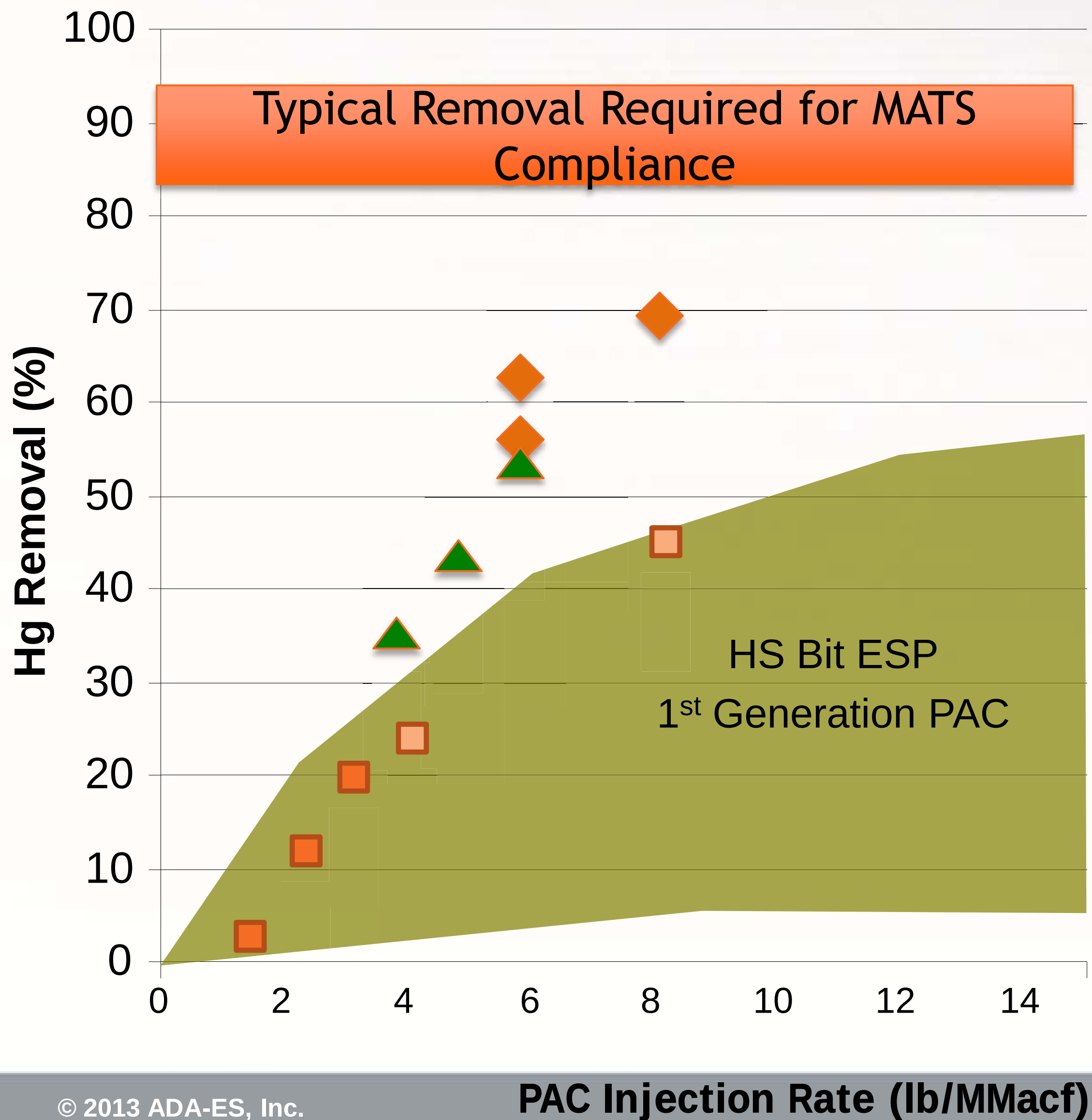
MRC Results: 10 lb/MMacf, injection upstream of APH
APH Inlet: 627 F; APH outlet: 300 F (assume 1 ppm baseline SO_3)



Any SO_3 in gas phase appears to affect Hg capture

- SO_3 higher in bituminous flue gas, especially after SCR

PAC and High Sulfur Coal



High Sulfur (2.8 wt%) Bituminous Coal

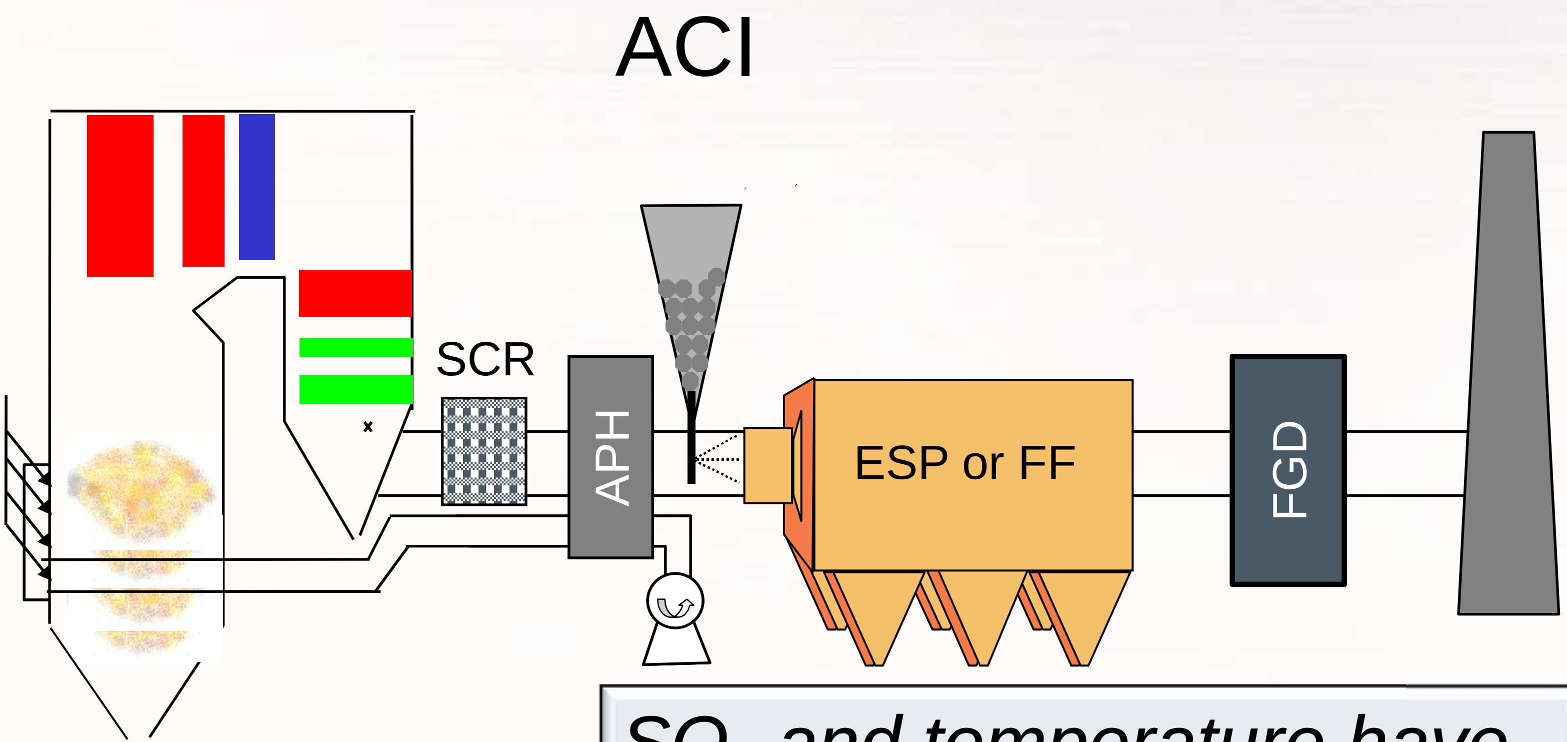
Cold Side ESP

FastPAC™ Premium

FastPAC™ Premium S

FastPAC™ Premium S + Hydrated Lime

Challenges for Hg Removal

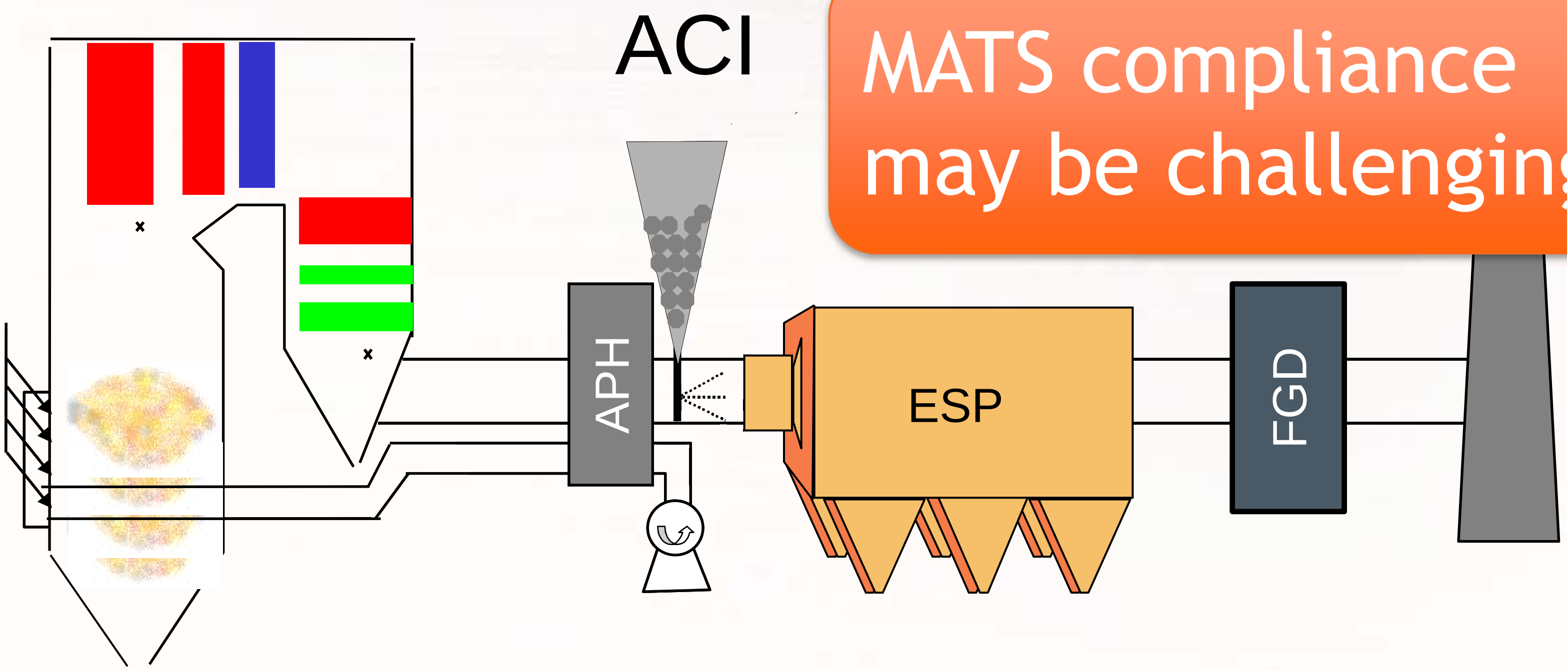


- Temperature
- SO_3
- Halogens
- Oxidized Hg

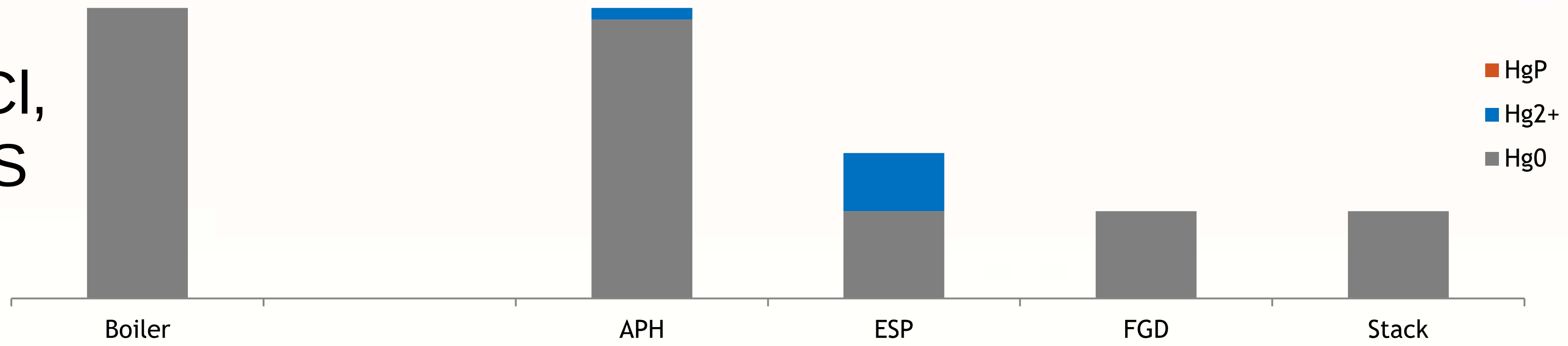
SO_3 and temperature have compounding negative impact on performance of activated carbon

Mercury Control: Case Studies

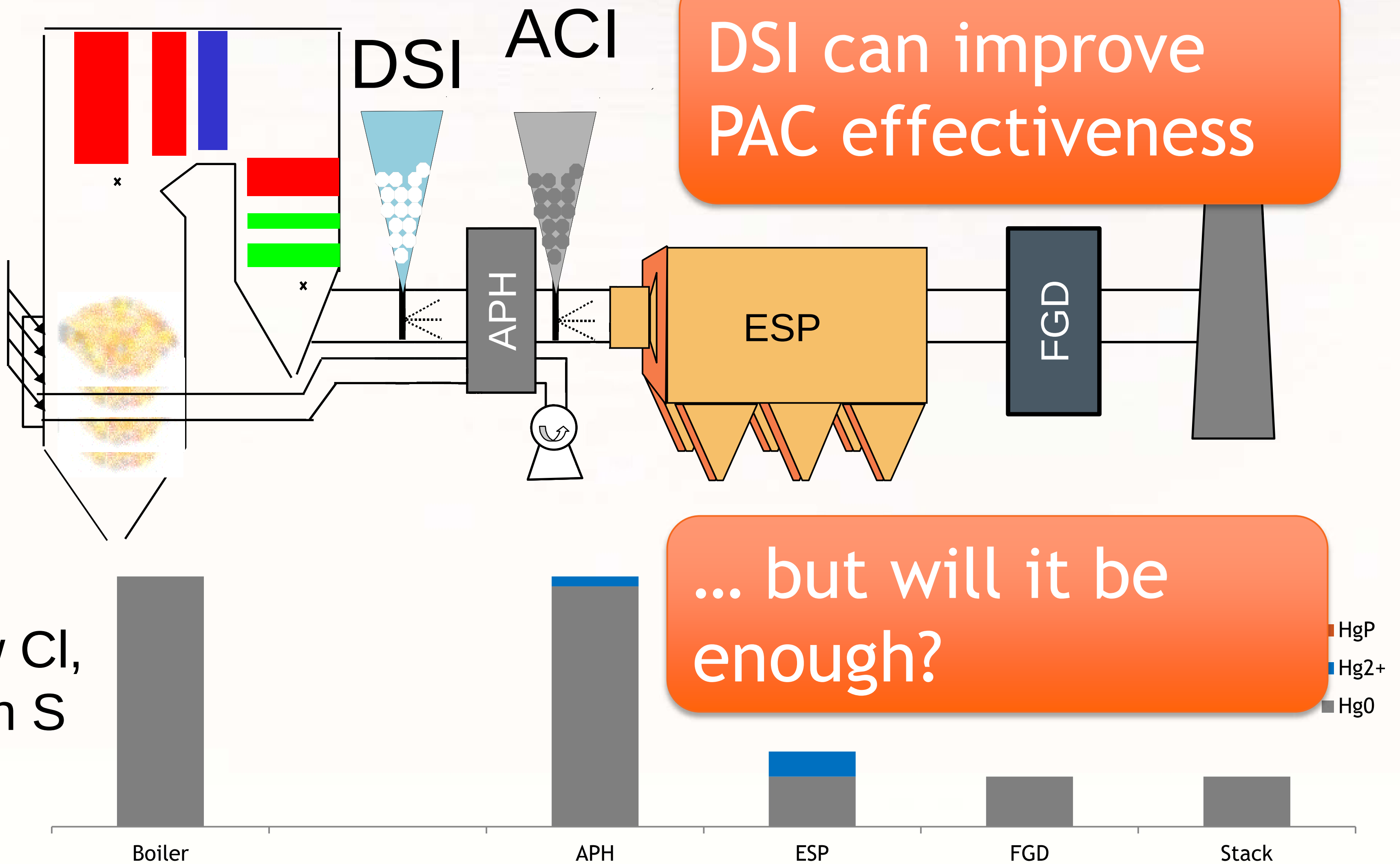
MATS compliance may be challenging



Low Cl, High S



Mercury Control: Case Studies



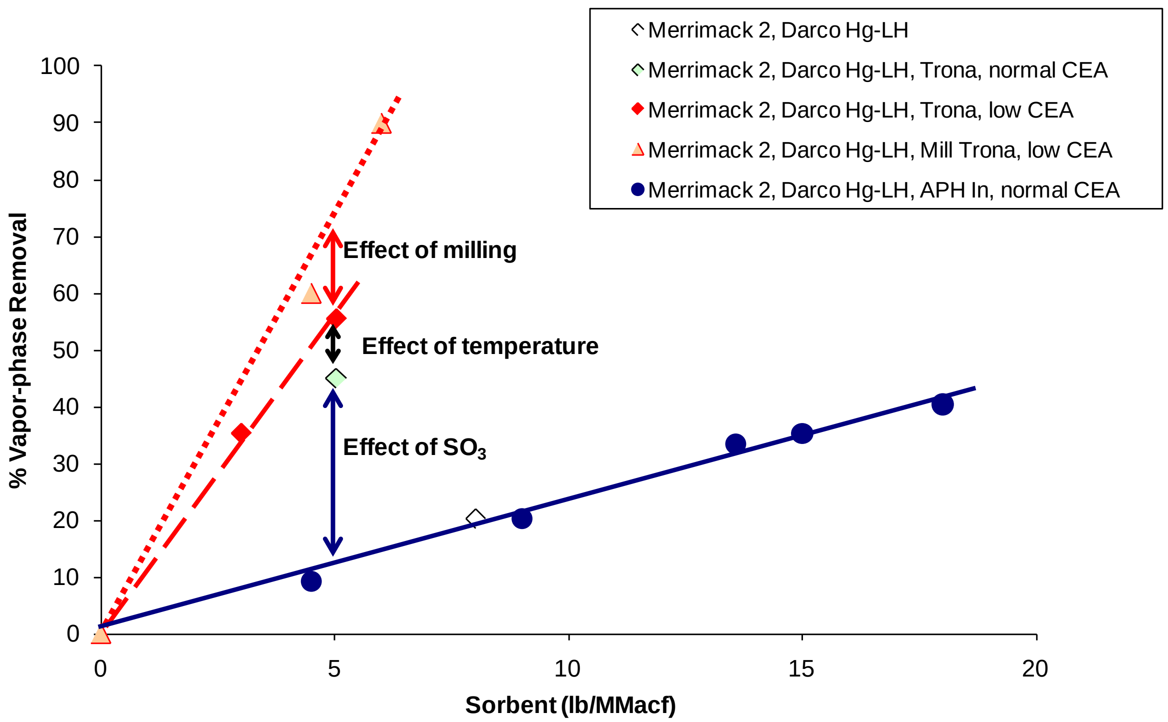
DSI can improve PAC effectiveness

… but will it be enough?

Low Cl, High S

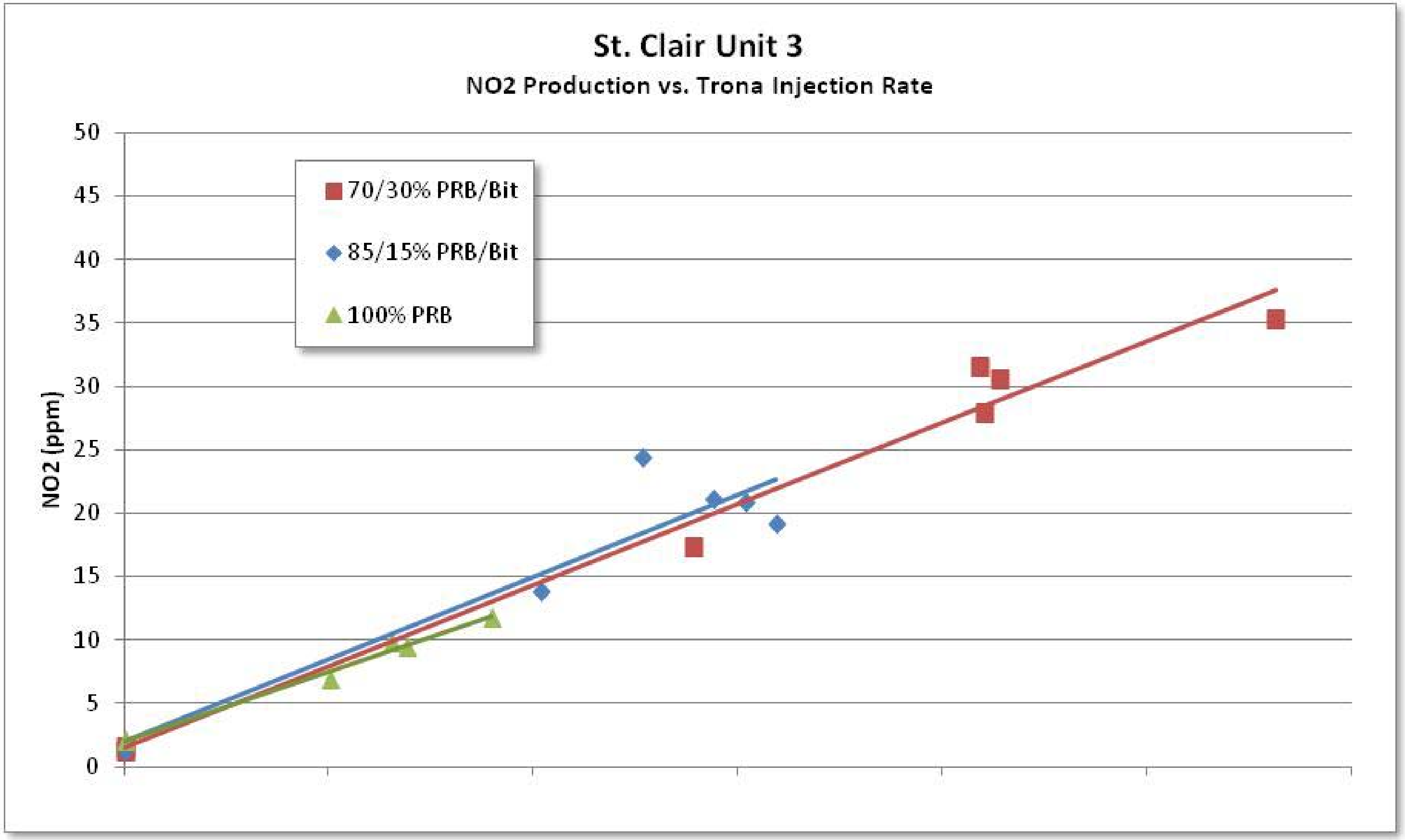
Application of AC to Bituminous Coal-Fired Plants

- Plants with ESP and high SO_3 (i.e., high-sulfur coals or low-sulfur coals with an SCR/FGD) struggle to achieve high levels of removal
  - High temperatures and high SO_3 concentrations in the flue gas downstream of the APH strongly affect sorbent performance
  - Other factors, possibly important, including coal chlorine content and sorbent mixing in the flue gas duct



More Challenges: NO_2 Production with Trona Injection

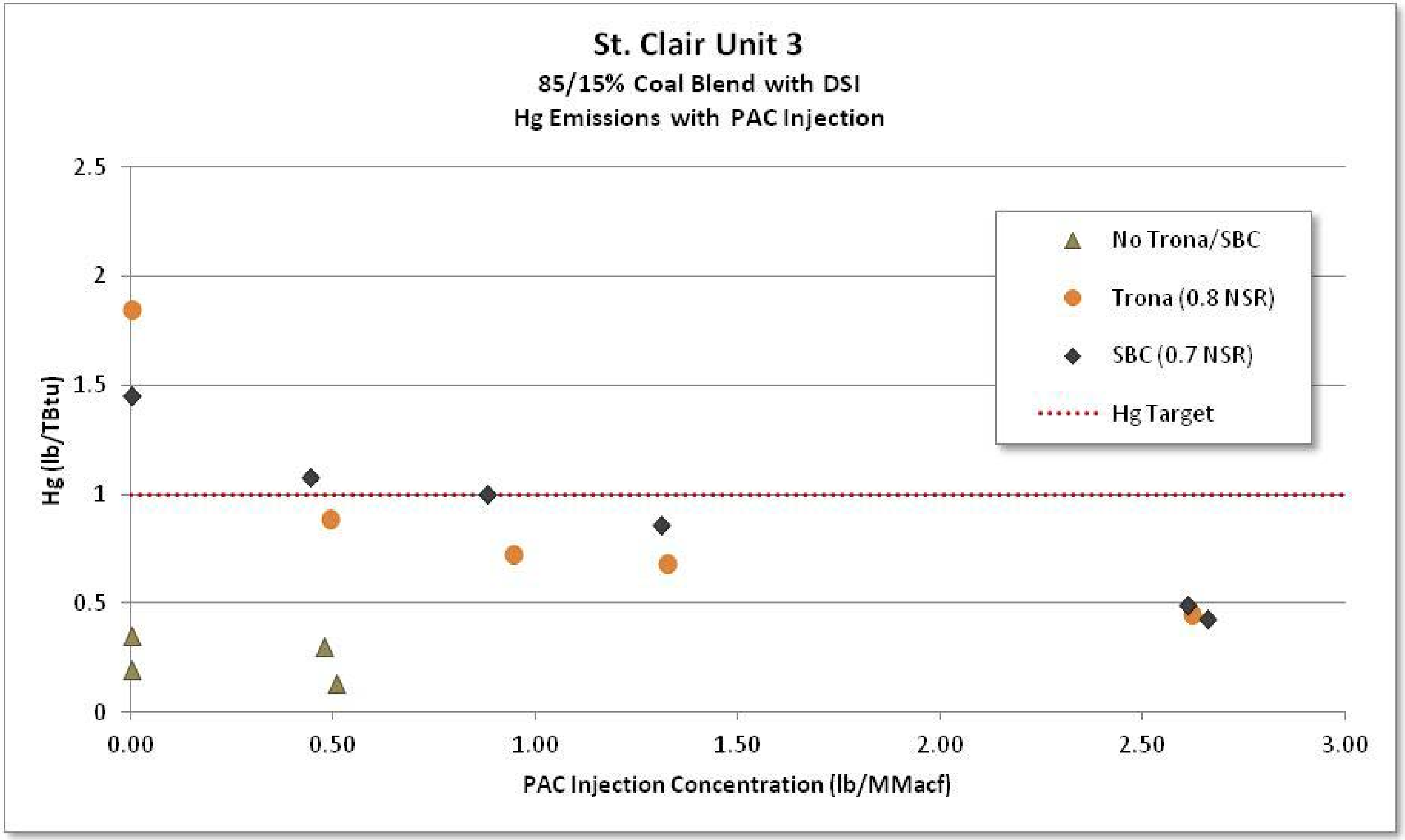
- Sodium-based DSI can increase flue gas NO_2



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

Impacts of NO_2 on PAC

- NO_2 will interfere with Hg removal by PAC

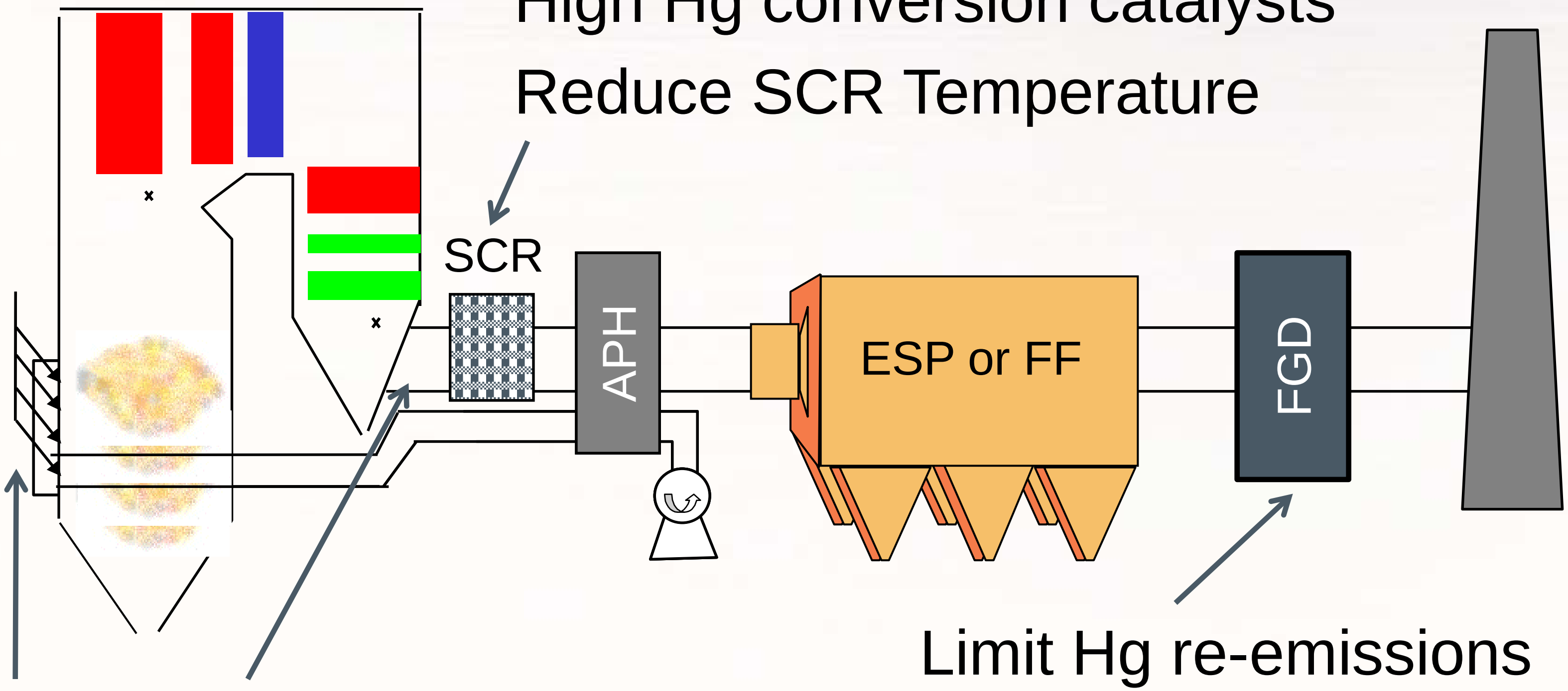


Results from Testing at DTE St. Clair Unit 3, W. Rogers, EUEC 2013

Improving Mercury Control in Wet Scrubbers

High Hg conversion catalysts

Reduce SCR Temperature



Limit Hg re-emissions

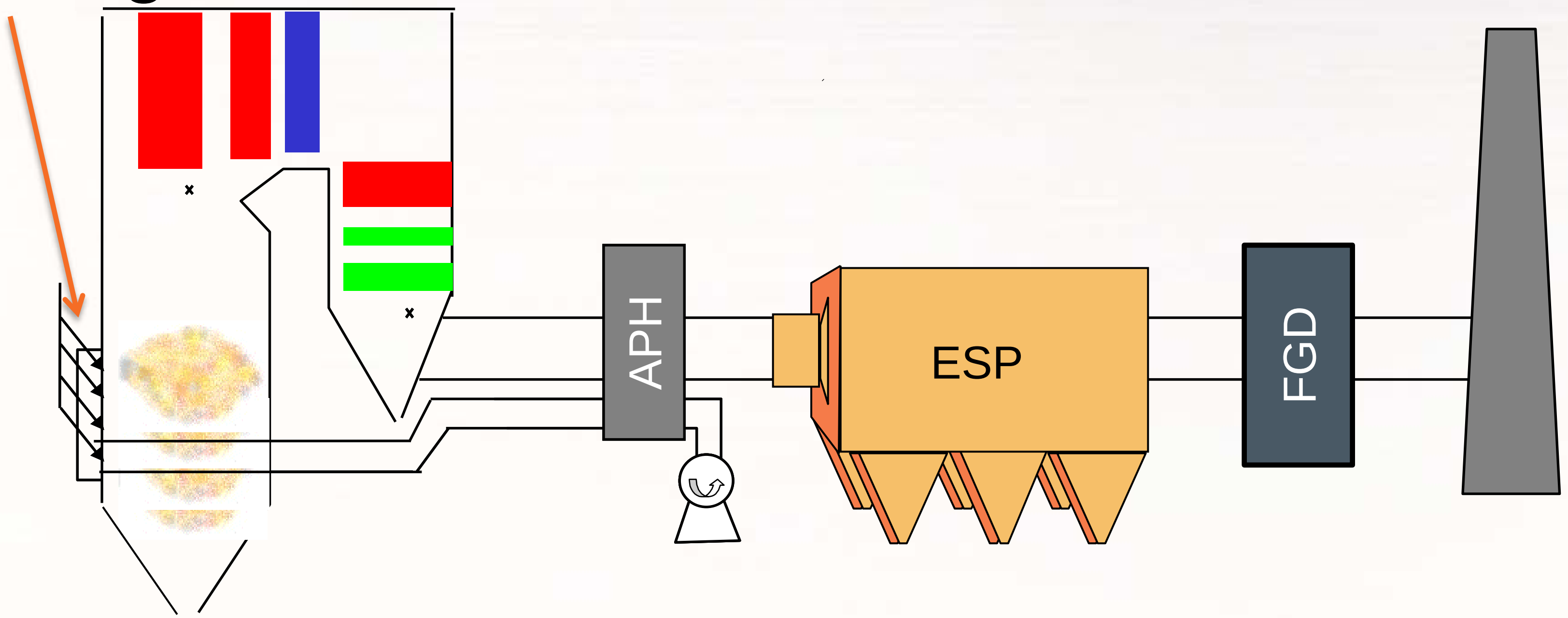
- Halogens
- Carbon
- Other Additives ???
- Novel structures??

Increase halogen content

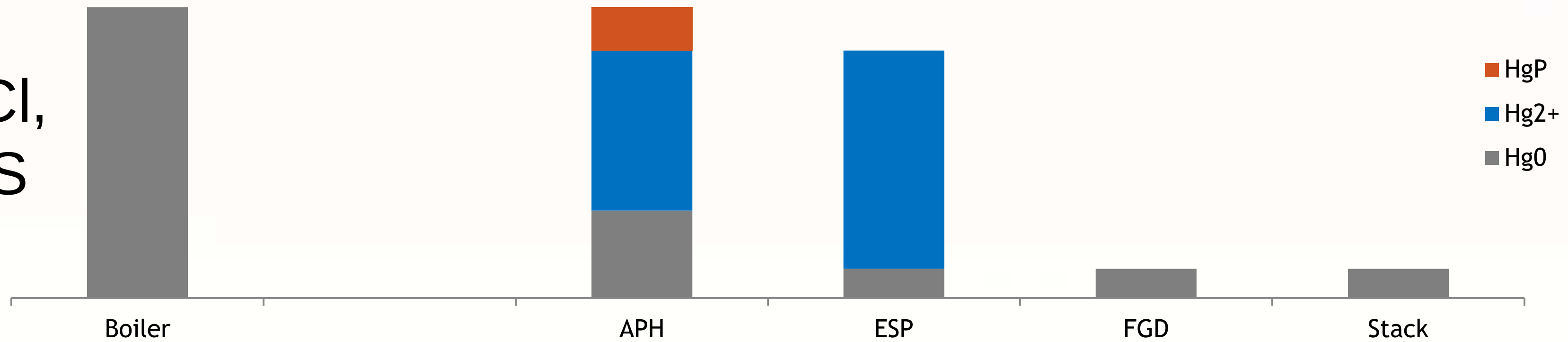
if coal levels are low

Mercury Control: Case Studies

Halogen



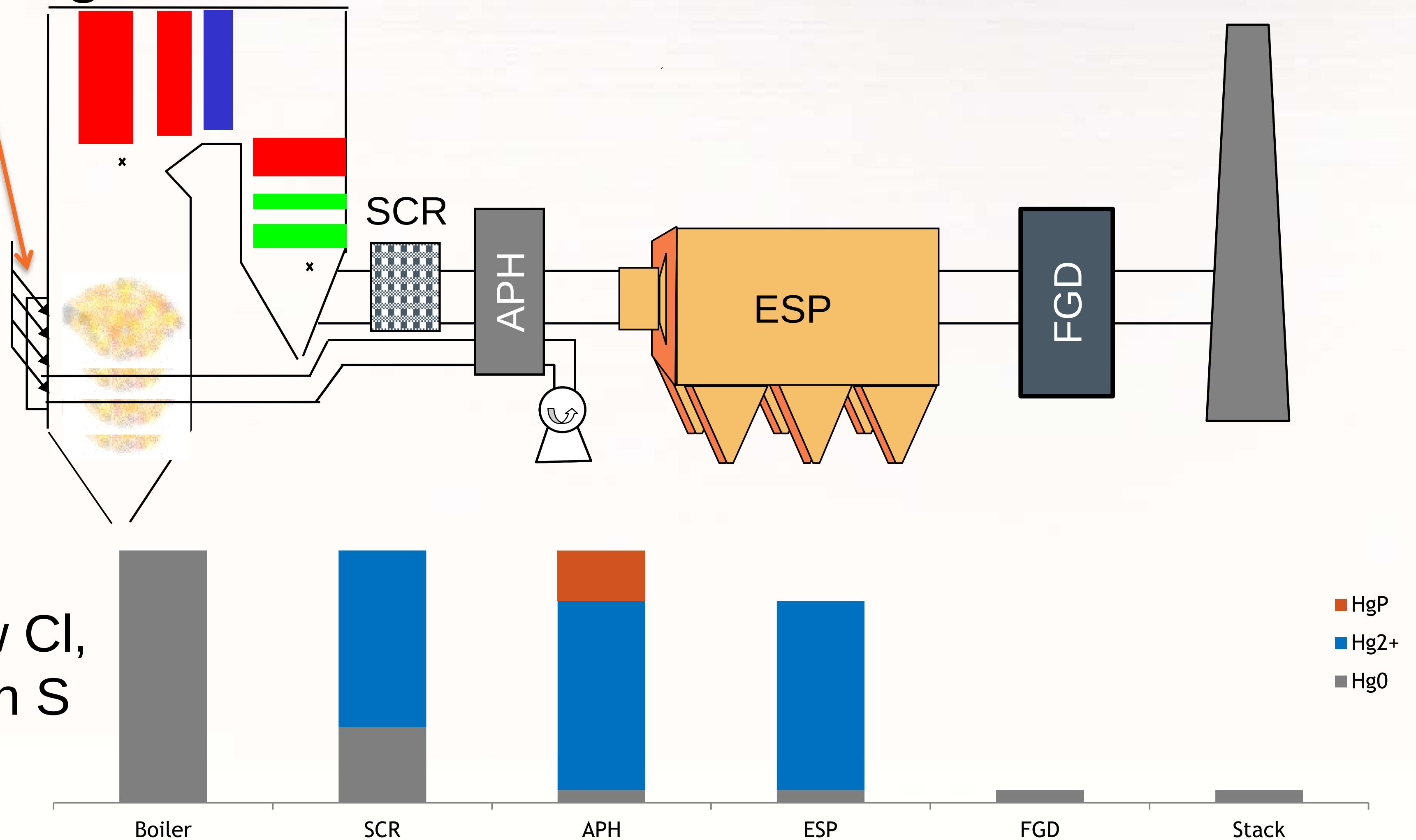
Low Cl,
High S



Mercury Control: Case Studies

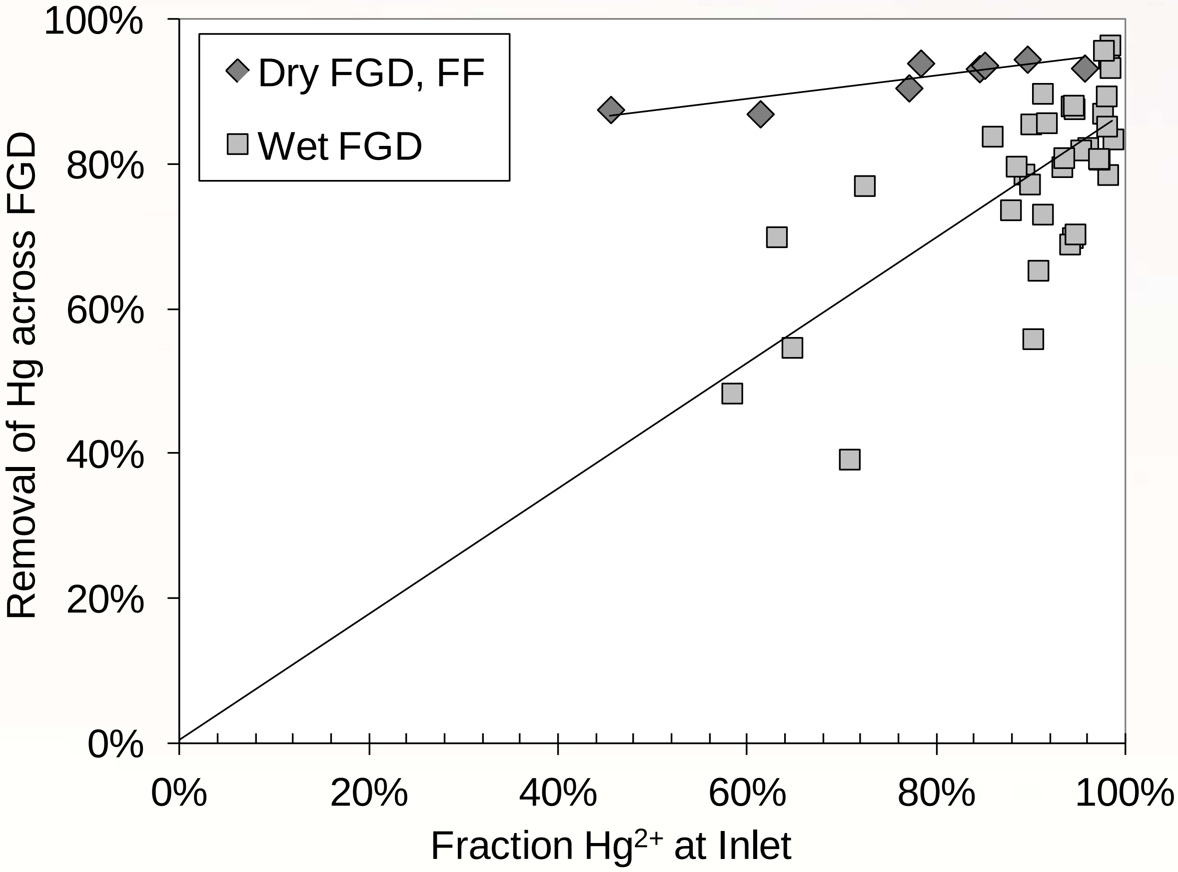
Halogen

Low Cl,
High S

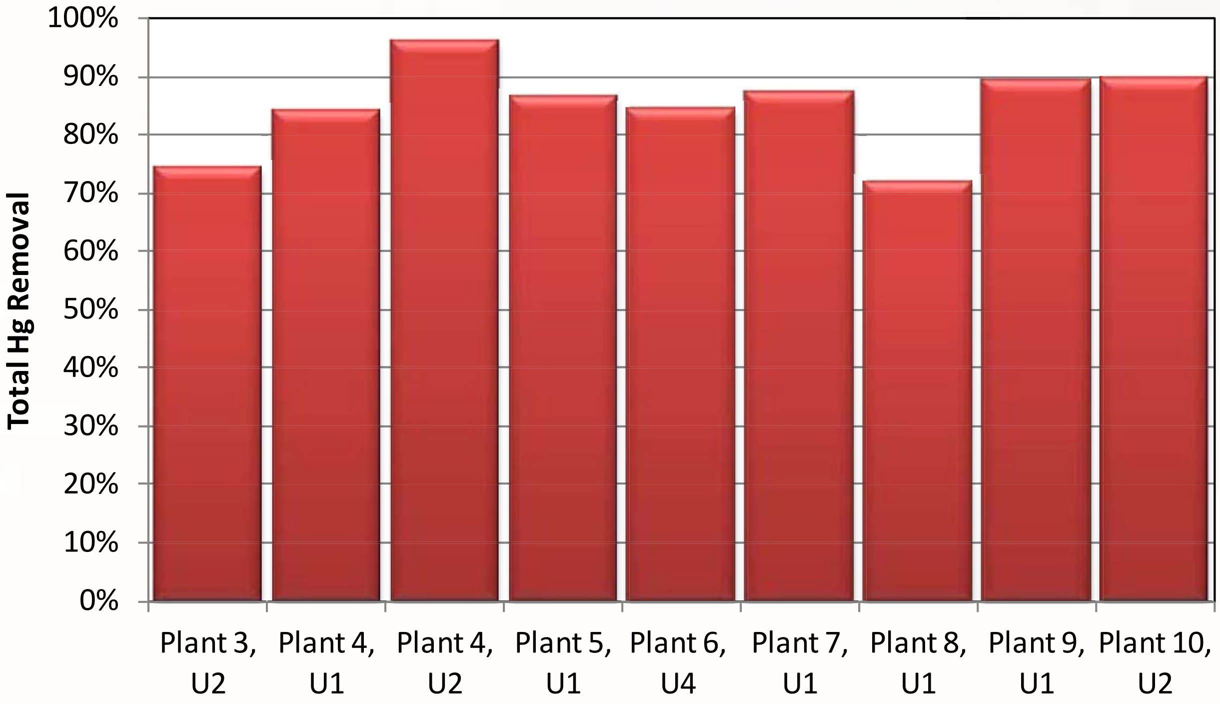


Benefits of Oxidized Mercury

Many scrubbed plants can take advantage of native capture…if there's enough oxidized Hg (Hg^{2+})



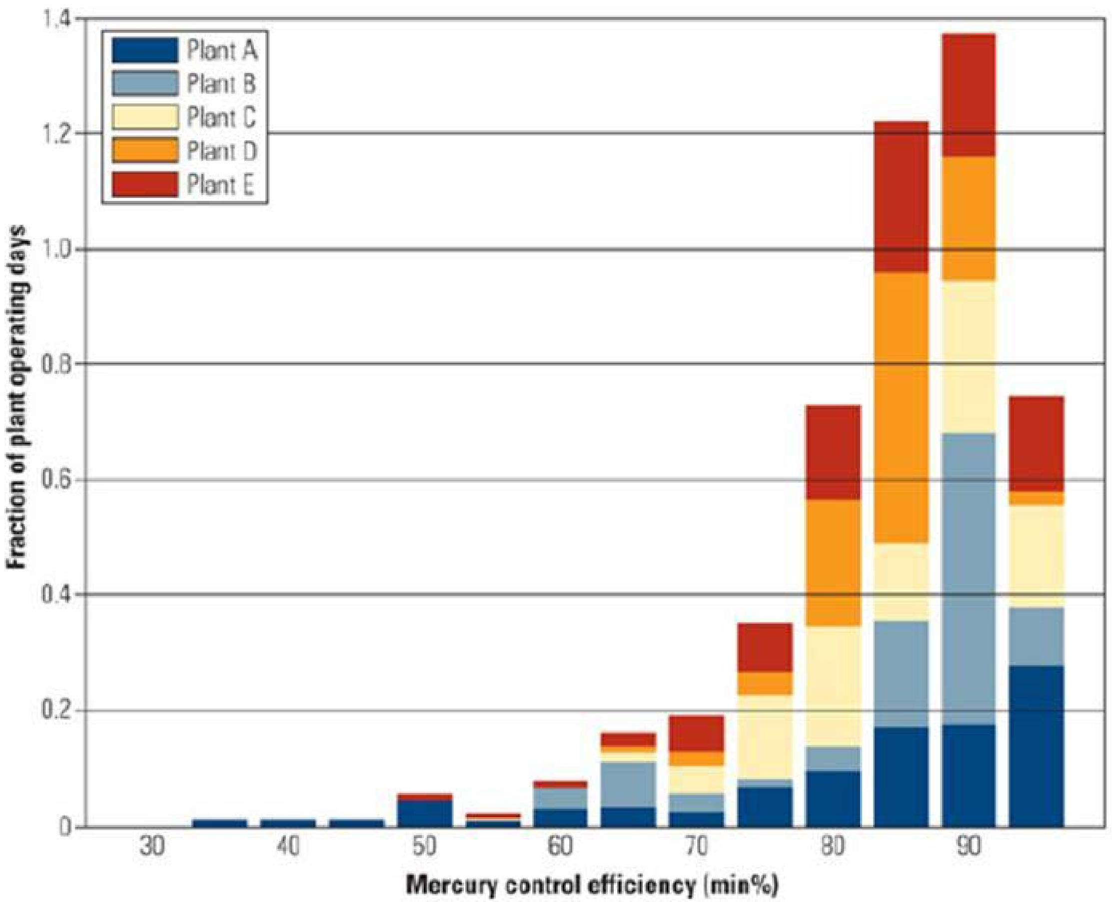
Removing Oxidized Mercury in WFGDs



- …but >90% removal not always achieved

Source: Bituminous-fired plants from Consol sampling program

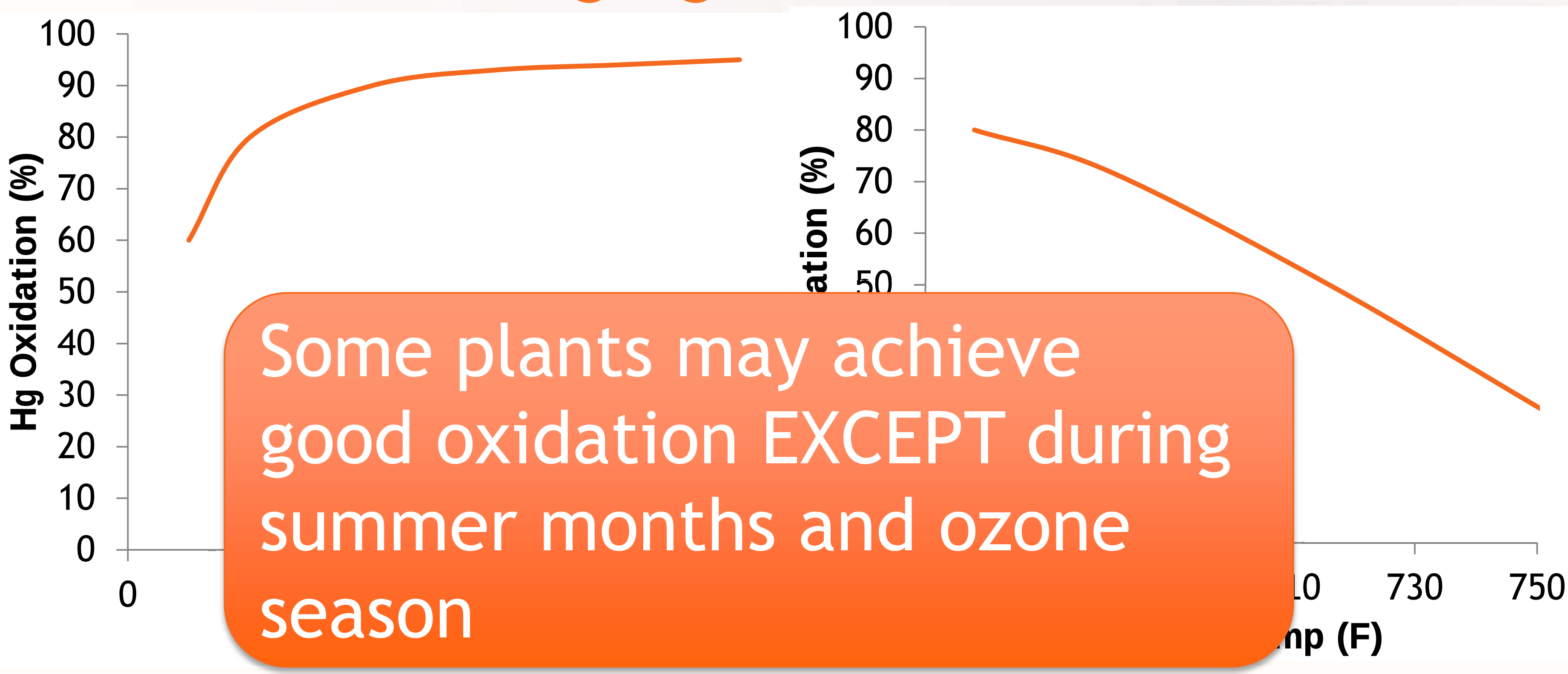
Removing Oxidized Mercury in WFGDs



- Southern Company Plants with SCR, ESP, WFGD
- More than 40 months of WFGD operations
- Mercury control greater than 90% was achieved 47% of the time
- Important factors include SCR temperature, age, coal halogen

Corey A. Tyree, Southern Company, 2010

Factors Affecting Hg Oxidation Across SCRs



Some plants may achieve good oxidation EXCEPT during summer months and ozone season

- Higher temperature → Lower oxidation
- Higher ammonia → Lower oxidation

Shintaro Honjo, Mitsubishi Heavy Industries America, Mega Symposium 2012

Review of Hg Mechanisms

Component	Factors	Impact
Fuel	Chlorine content, sulfur content, rank	Speciation of Hg in flue gas at Econ. exit
Furnace Combustion	LOI, fuel halogens, fuel sulfur	Speciation of Hg in flue gas at Econ. exit
SCR	Catalyst type and age, FG temperature, halogen in gas	Oxidation of elemental Hg
Air Preheater	FG temp, AH type, quench rate, exit temp	Oxidation of elemental Hg, formation of Hg_p
ESP/Fabric Filter	FG temp, halogen in flue gas, fly-ash composition, LOI	Removal of Hg_p (ESP), oxidation of elemental Hg (FF)
Dry Scrubber	Halogen in flue gas, downstream PCD	Removal of Hg_p and gaseous Hg
Wet FGD	Inlet Hg speciation, scrubber design	Removal of oxidized Hg, re-emission of Hg^0

Coal to Stack: Integrated Approaches for Multi-Pollutant Compliance

Example: Fuel (low mercury, low sulfur, low chlorine)

- DSI as required to meet HCl limits and/or control SO_3 to maximize ACI effectiveness
- Utilize coal additives to manage ACI usage and Hg removal effectiveness
- Manage SCR operation and catalyst choice to increase fraction of oxidized mercury and resulting removal in WFGD
- Use scrubber additives or manage scrubber operation as needed to limit re-emissions

Coal to Stack: Integrated Approaches for Multi-Pollutant Compliance

Example: Fuel (high mercury, high sulfur, high chlorine)

- Manage SCR operation and catalyst choice to control NOx and increase fraction of oxidized mercury and resulting removal in WFGD
- Use scrubber to control SO_2 and HCl, scrubber additives and/or manage scrubber operation as needed to limit re-emissions
- DSI as required to control SO_3 to maximize ACI effectiveness when required (e.g. summer operation)

Hg Control Technology Summary

Technology	Application	Commercial Readiness	Key Potential Risks
High Hg Oxidation SCR	Scrubbed units with SCRs, all coals	In development	Limited duration tests to-date
Halogen-Based Coal Additives	Low-halogen fuels	Used for compliance	Corrosion, increased halogen emissions, leaching
Halogen Flue-Gas Additives	Low-halogen fuels	Full-scale demos	Corrosion, increased halogen emissions, leaching
Scrubber Re-emission Additives	WFGDs with Hg re-emissions	Some types sold commercially	Scrubber chemistry is critical for success
Polymer Resin Monolith	Some WFGDs	In development	Not demonstrated at scale

Hg Control Technology Summary

Technology	Application	Commercial Readiness	Key Potential Risks
Non-SO_3 FGC	Units using SO_3 for FGC	Used for compliance	Limited commercial experience
ACI	Primary or trim Hg control	Used for compliance	SO_3 and temperature impacts. Loss of ash sales
DSI	Units with high SO_3	In commercial use	Ash sales (sodium), APH dP (sodium), ESP performance

Compliance Strategies for Mercury

- 80 to >90% control at the stack to meet proposed MATS emission limits required for most units
- MATS limits achievable with ACI or ACI + coal additives on most subbituminous units if SO_3 flue gas conditioning (FGC) is eliminated
- For units with SCR/FGD:
  - Low conversion $SO_2 \rightarrow SO_3$ SCR catalyst and minimize NH_3 slip
  - Provide sufficient halogens to oxidize the Hg
  - Minimize re-emission of Hg^0 from wet FGD
  - Use ACI as needed for trim
- MATS limits may be challenging on units with higher sulfur coals. Year round compliance may require SO_3 mitigation and careful WFGD re-emissions management

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Questions?