REINHOLD ENVIRONMENTAL Ltd.

2011 NOx-Combustion Round Table & Expo Presentation

February 7-8, 2011, in Birmingham, AL / Hosted by Southern Company

Optimizing Plant Operations for Mercury Control

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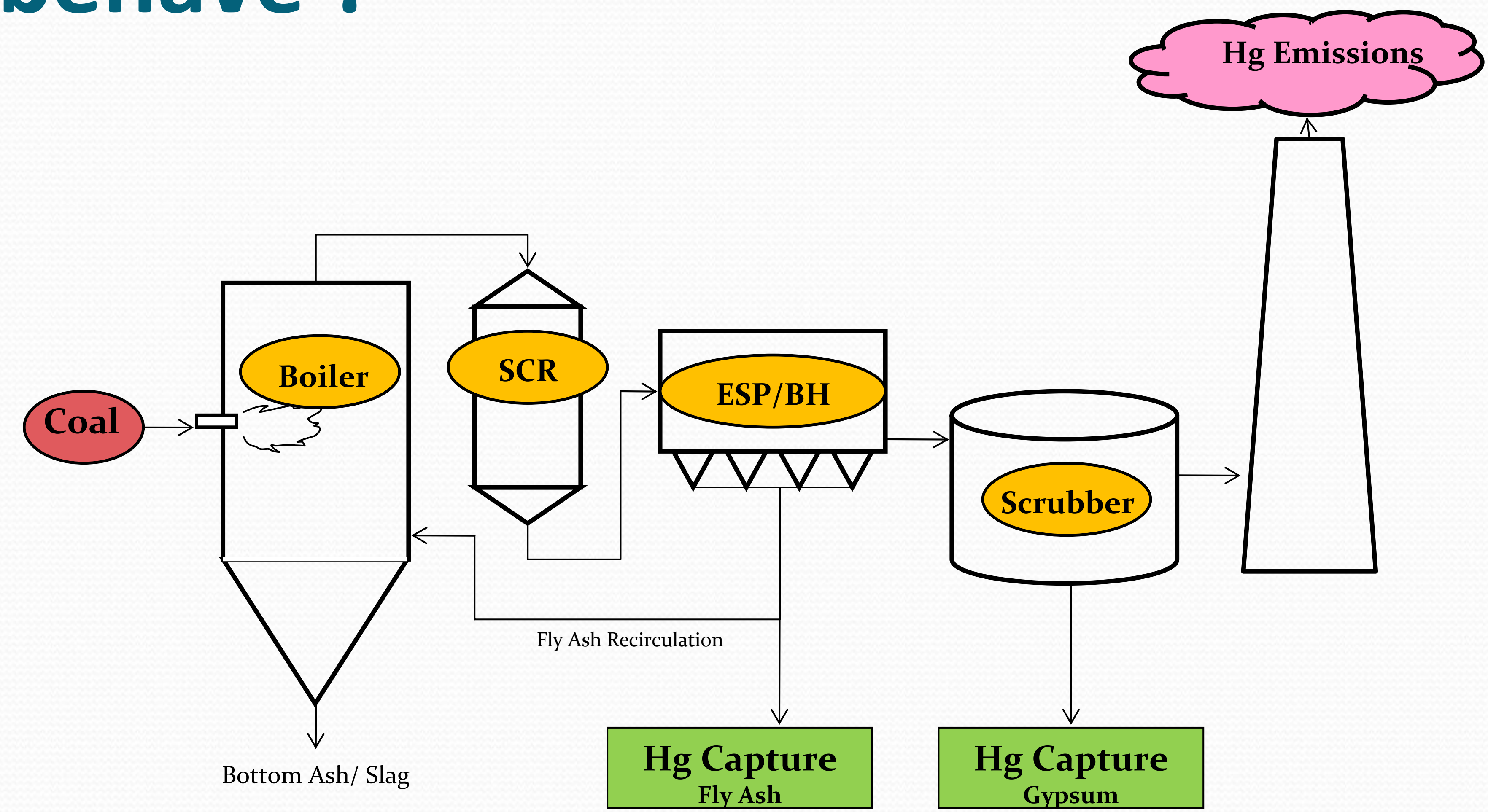
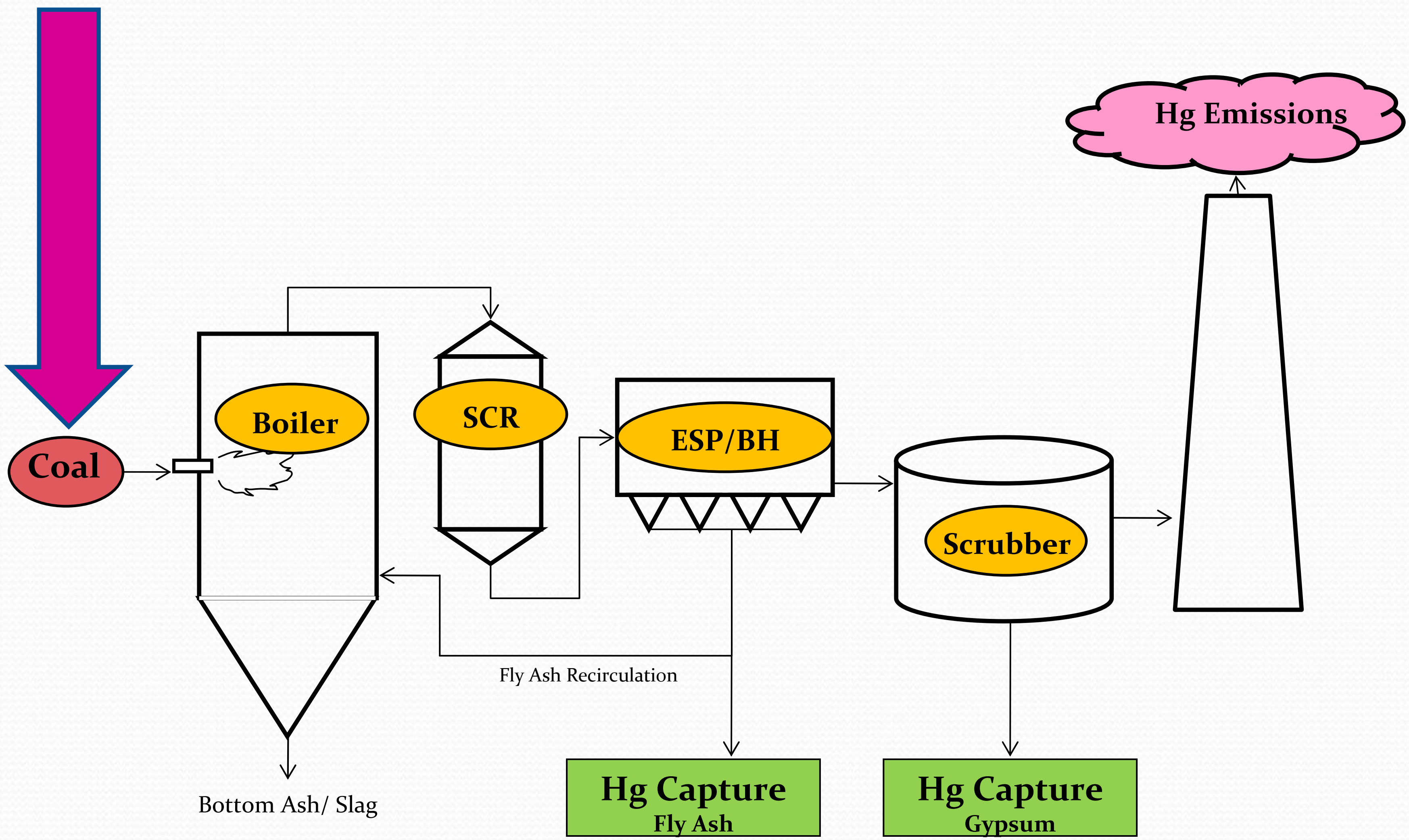
Research and Consulting Engineers

How does each piece of the plant behave ?



Fuel Effects on Mercury Behavior



Fuel Effects

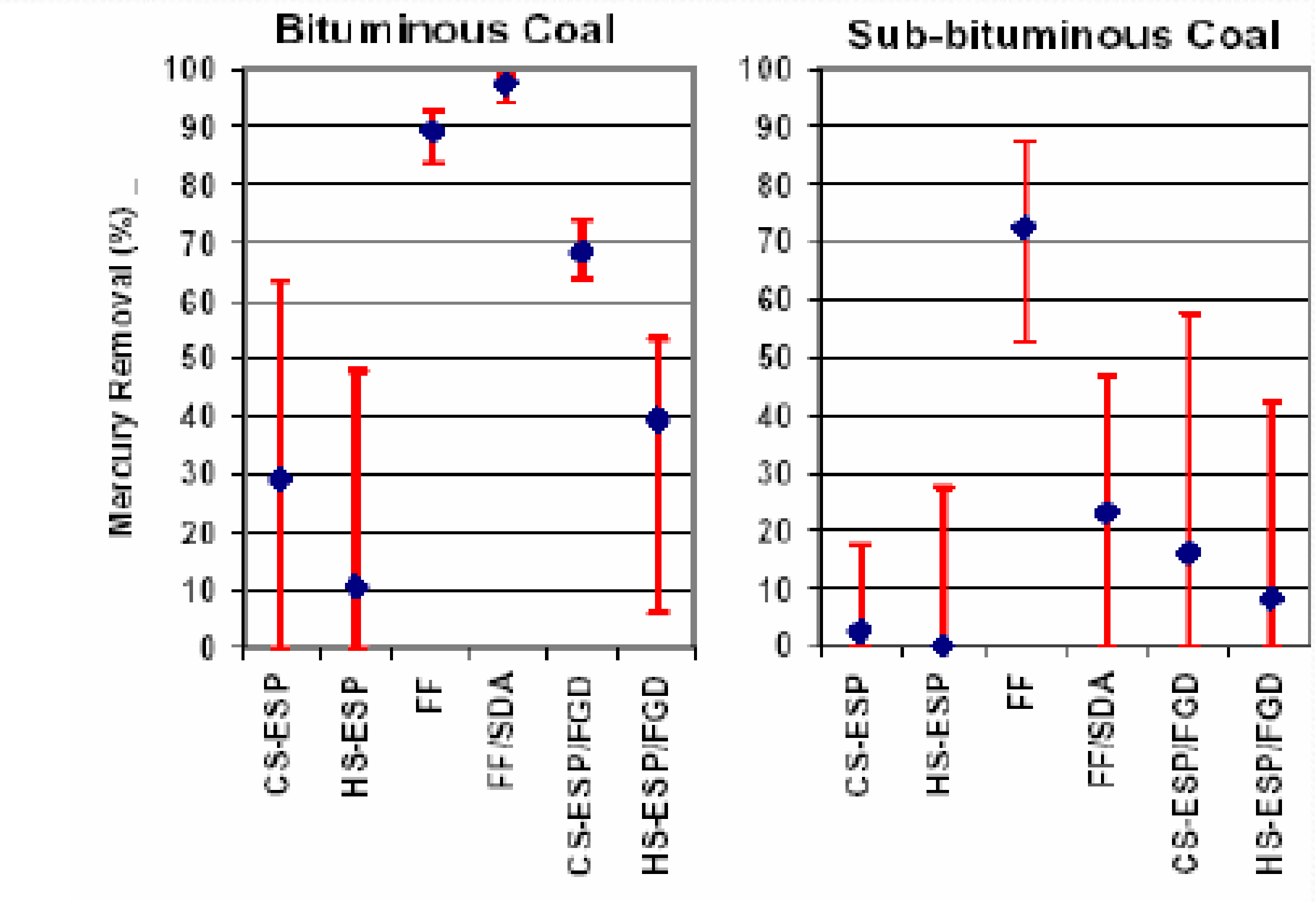
#1 Factor Governing Mercury Behavior

- Initial coal mercury content
- Effects on flue gas
- Effects on ash loading and ash chemistry
- Effects on the APC devices (device selection and operation)

Fuel Related Concerns and Opportunities

- A system will be optimized as a function of fuel characteristics, as they change, the level of optimization will change accordingly
- Facilities firing EB fuels may look very different from those firing PRB in terms of mercury control
- Day-to-day fluctuations in fuel will cause fluctuations in mercury removal
- COAL SELECTION as a method of mercury control ?
- COAL CLEANING as a method of mercury control ?

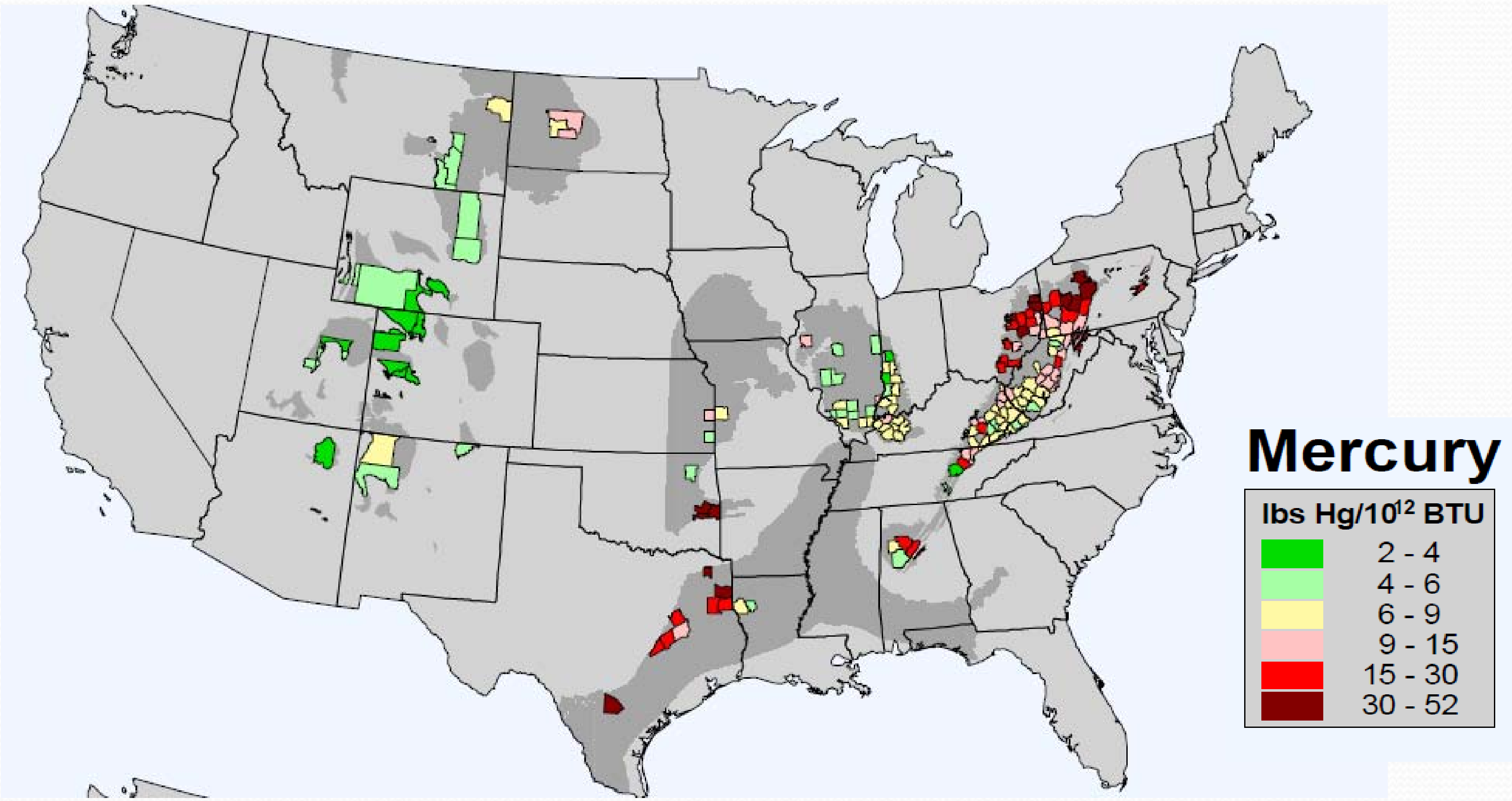
Major Differences in General Fuel Type



Example PRB vs. Bituminous Data

Post-combustion Control Strategy	Post-combustion Emission Control Device Configuration	Average Mercury Capture by Control Configuration		
		Coal Burned in Pulverized-coal-fired Boiler Unit		
		Bituminous Coal	Subbituminous Coal	Lignite
PM Control Only	CS-ESP	36 %	3%	0 %
	HS-ESP	9 %	6 %	not tested
	FF	90 %	72 %	not tested
	PS	not tested	9 %	not tested
PM Control and Spray Dryer Adsorber	SDA+CS-ESP	not tested	35 %	not tested
	SDA+FF	98 %	24 %	0 %
	SDA+FF+SCR	98 %	not tested	not tested
PM Control and Wet FGD System[a]	PS+FGD	12 %	0 %	33%
	CS-ESP+FGD	75 %	29 %	44 %
	HS-ESP+FGD	49 %	29 %	not tested
	FF+FGD	98 %	not tested	not tested

Map of Mercury Content in Coal



COAL SELECTION: Example of Variability in Indiana Coal

Coal bed	County	Full channel in mg/kg	Full channel in lb/10^{12} Btu	Float in mg/kg	Float in lb/10^{12} Btu
Danville	location 1 - Knox	0.03	2.6	0.02	1.6
Danville	location 2 - Knox	0.02	1.7	nd	nd
Danville	location 1 - Sullivan	0.05	4.3	0.04	3.1
Danville	location 2 - Sullivan	0.07	6.3	0.04	3.1
Hymera	Gibson	0.06	5.5	0.05	4.2
Hymera	Sullivan	0.25	23.0	0.18	14.1
Springfield	Gibson	0.06	5.1	0.05	3.9
Springfield	Warrick	0.13	11.5	0.06	4.7
Minshall	Parke	0.13	11.4	0.10	7.7
Buffaloville	Daviess	0.10	8.9	nd	nd
Upper Block	Clay	0.09	6.4	nd	nd
Upper Block	Daviess	0.07	6.2	nd	nd
Upper Block	Greene	0.23	18.2	nd	nd
Upper Block	Parke	0.31	24.8	0.15	10.8
Lower Block	Clay	0.21	17.8	0.02	1.4
Lower Block	Daviess	0.04	3.2	nd	nd
Lower Block	location 1 - Greene	0.04	3.3	0.04	3.0
Lower Block	location 2 - Greene	0.10	7.4	nd	nd
Lower Block	location 3 - Greene	0.12	9.0	nd	nd
Lower Block	Spencer	0.11	9.2	0.06	4.5
Unnamed Mansfield	Greene	0.11	9.2	0.09	7.0
Unnamed Mansfield	Clay	0.16	12.8	0.09	6.3
Mariah Hill	Spencer	0.05	4.1	0.04	2.9
Average		**0.11**	**9.2**	**0.07**	**5.2**
St. deviation		0.08	6.4	0.05	3.5

Coal Cleaning to Reduce Mercury Input

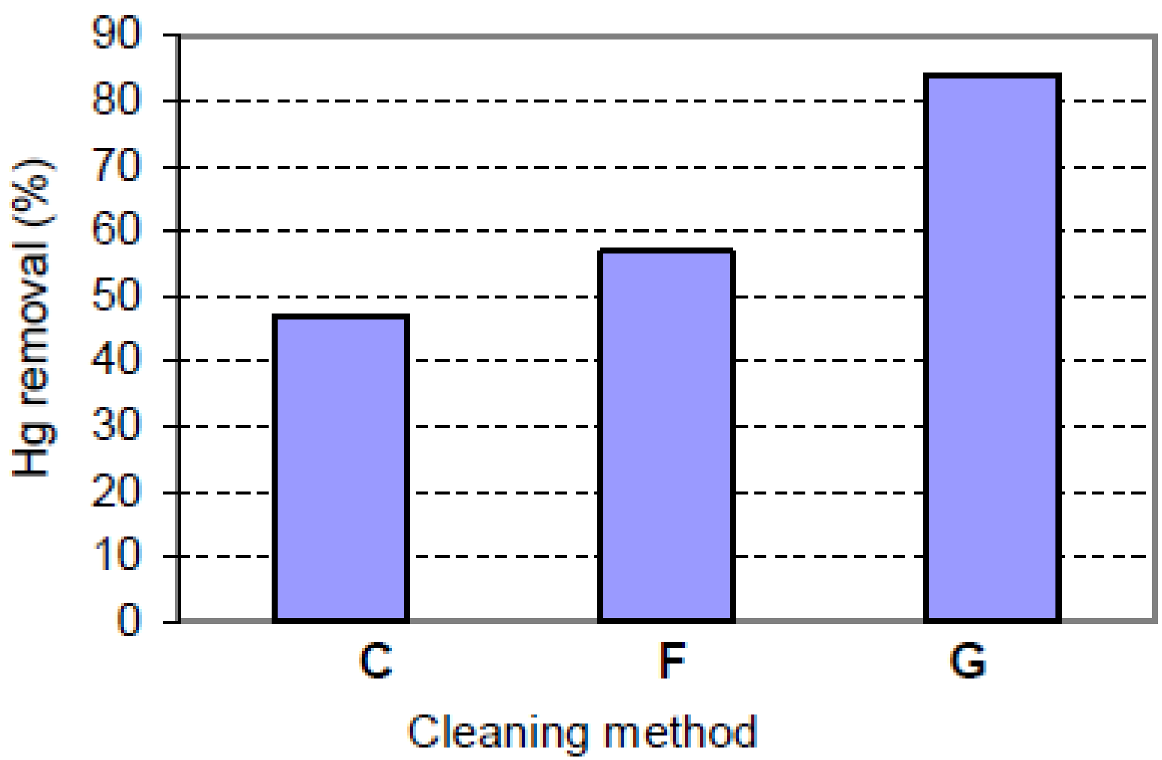
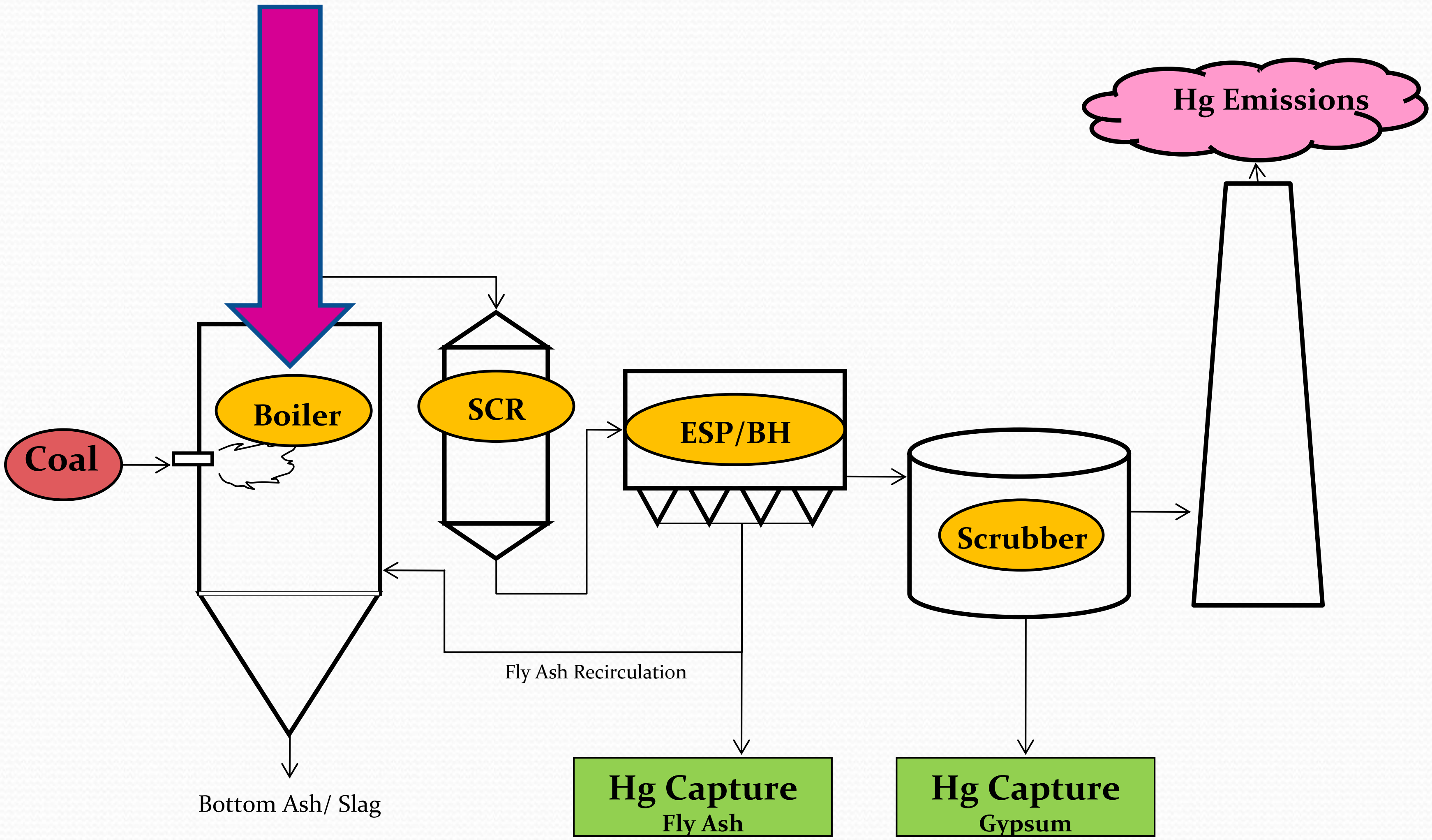


Figure 1. Mercury removal efficiency of coal cleaning methods on Illinois coal Coal cleaned by:

- conventional cleaning (C);
- advanced flotation (F); and
- advanced gravity separation (G).[1]

Technology for Controlling Mercury Emissions from Coal-Fired Power Plants in Illinois

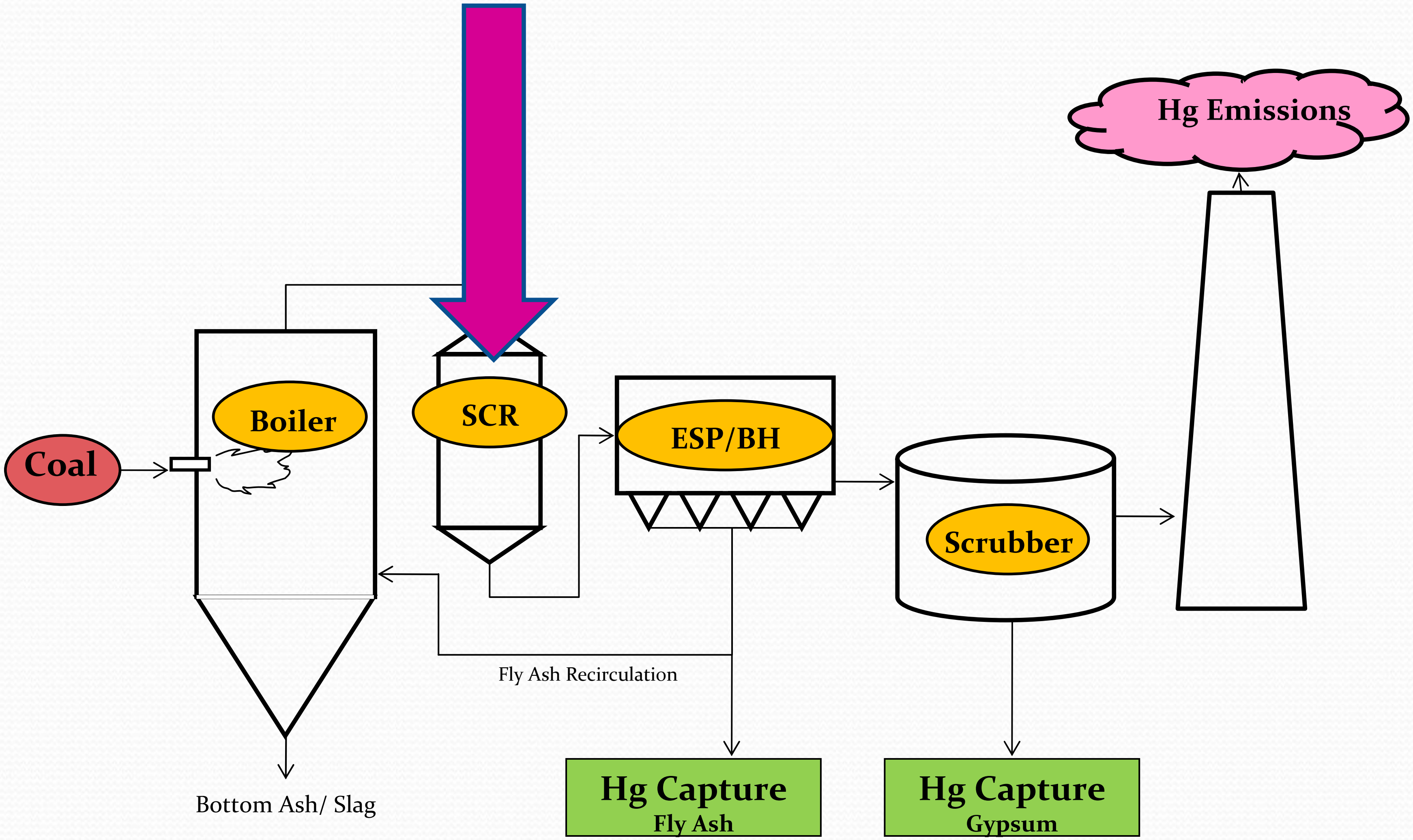
Boiler Effects on Mercury Behavior



Boiler Effects

- Time-temperature profile affects homogeneous mercury oxidation in the boiler.
- Boiler operation affects O2, NOx, and SO3, all of which affect downstream mercury oxidation and capture.
- Boiler operation affects fly ash characteristics, especially unburned carbon which can have significant impact on mercury capture

SCR Effects on Mercury Behavior



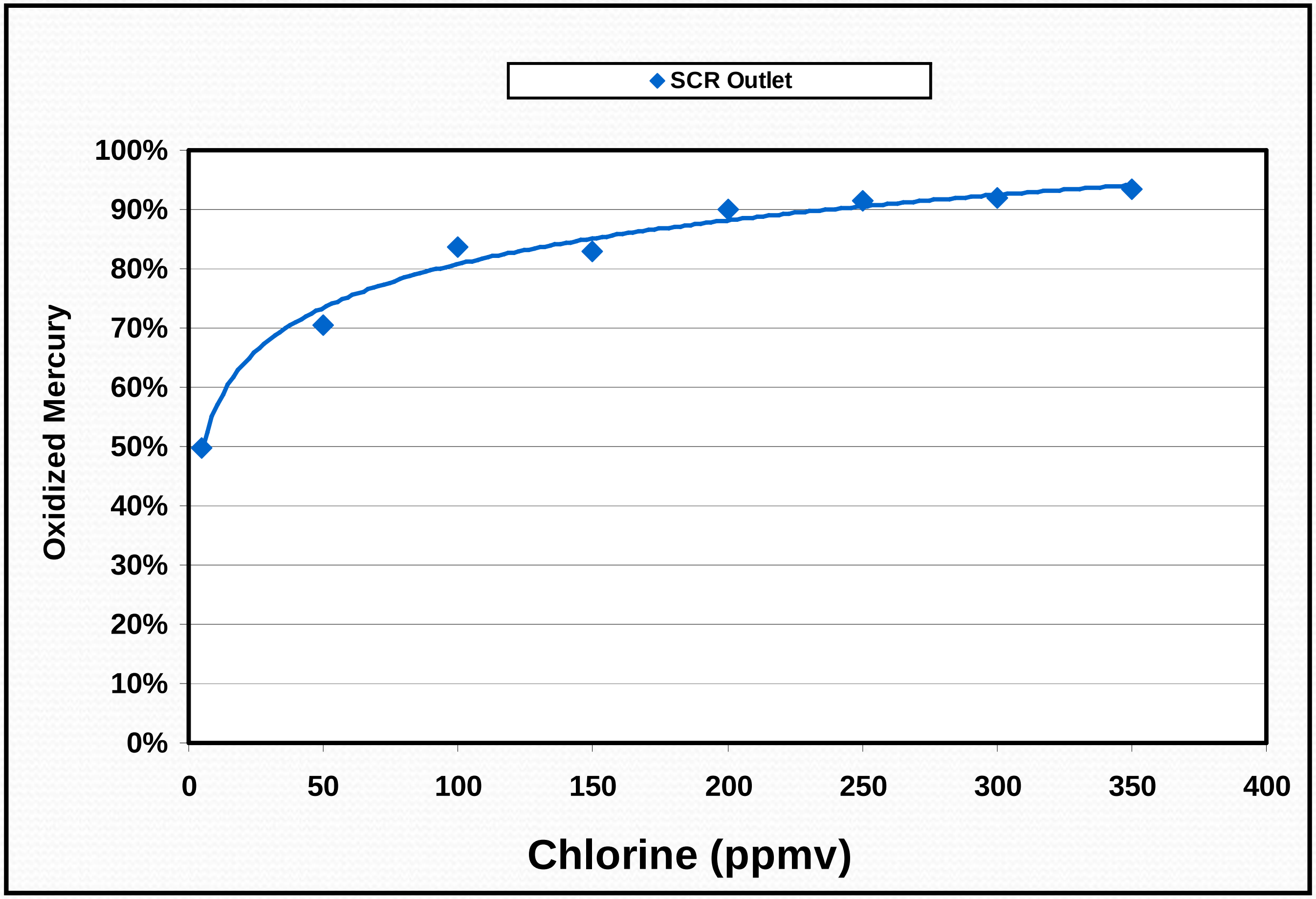
SCR Effects

- SCR oxidizes mercury but doesn't capture it.
- Many factors affect SCR mercury oxidation.
- Optimizing mercury oxidation is only part of the puzzle.
- Optimization of mercury oxidation across the SCR does not necessarily optimize mercury capture !

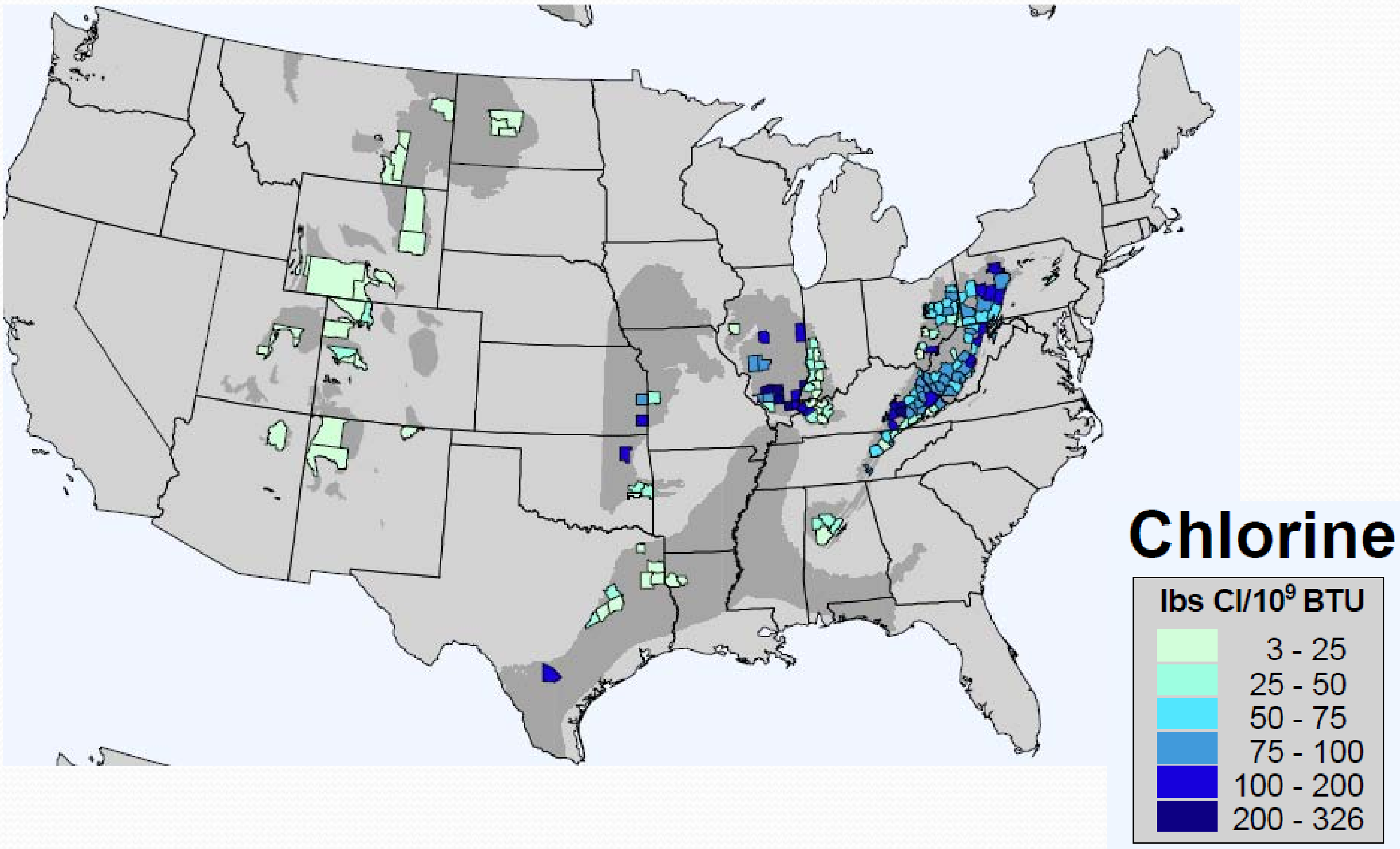
Parameters Affecting SCR Hg Oxidation

- Catalyst Design
- Catalyst Volume
- Catalyst Age
- Flow Rate/ Space Velocity
- Temperature
- NH_3/NO_x Ratio and Profiles
- Ammonia Slip
- Flue Gas Chemistry (especially halogens)

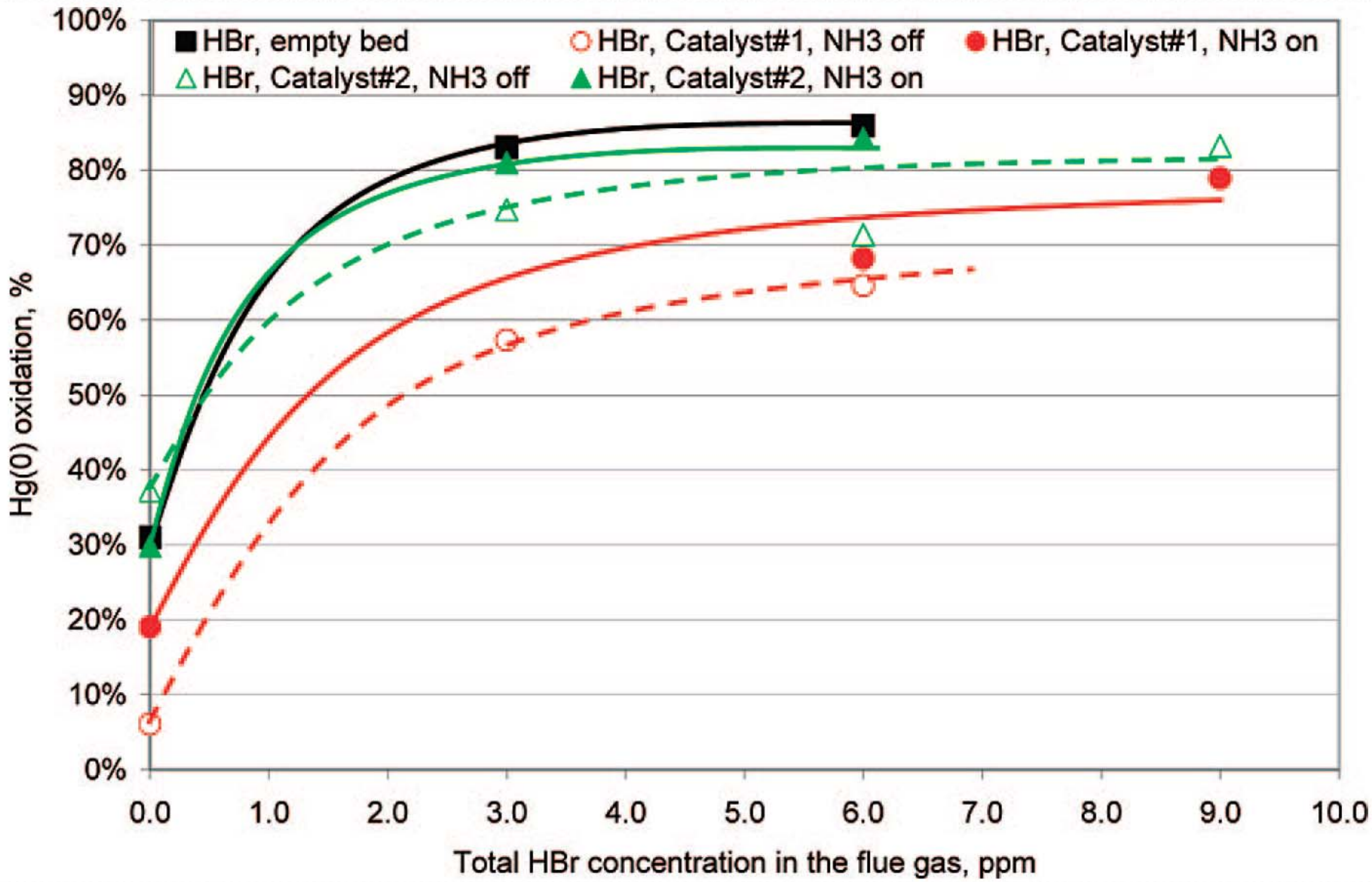
Example Effect of Chlorine on SCR Hg Oxidation



Map of Chlorine in Coal



Example Effect of Bromine on SCR Hg Oxidation



Environ. Sci. Technol.

Impacts of Halogen Additions on Mercury Oxidation, in A Slipstream Selective Catalyst Reduction (SCR), Reactor When Burning Sub-Bituminous Coal

YAN CAO,*,† ZHENGYANG GAO,*,‡ JIASHUN ZHU,† QUANHAI WANG,† YAJI HUANG,† CHENGCHUNG CHIU,†,§ BRUCE PARKER,* PAUL CHU,⊥ AND WEI-PING PAN*,†

Institute for Combustion Science and Environmental Technology (ICSET), Western Kentucky University (WKU), Bowling Green, Kentucky 42101, North China Electric Power University, BaoDing 071003, HeBei, P.R. China, Mingchi University of Technology, Taipei, Taiwan, Electric Energy, Inc. (EEI), Joppa, Illinois 62953, and Electric Power Research Institute (EPRI), Palo Alto, California 94304

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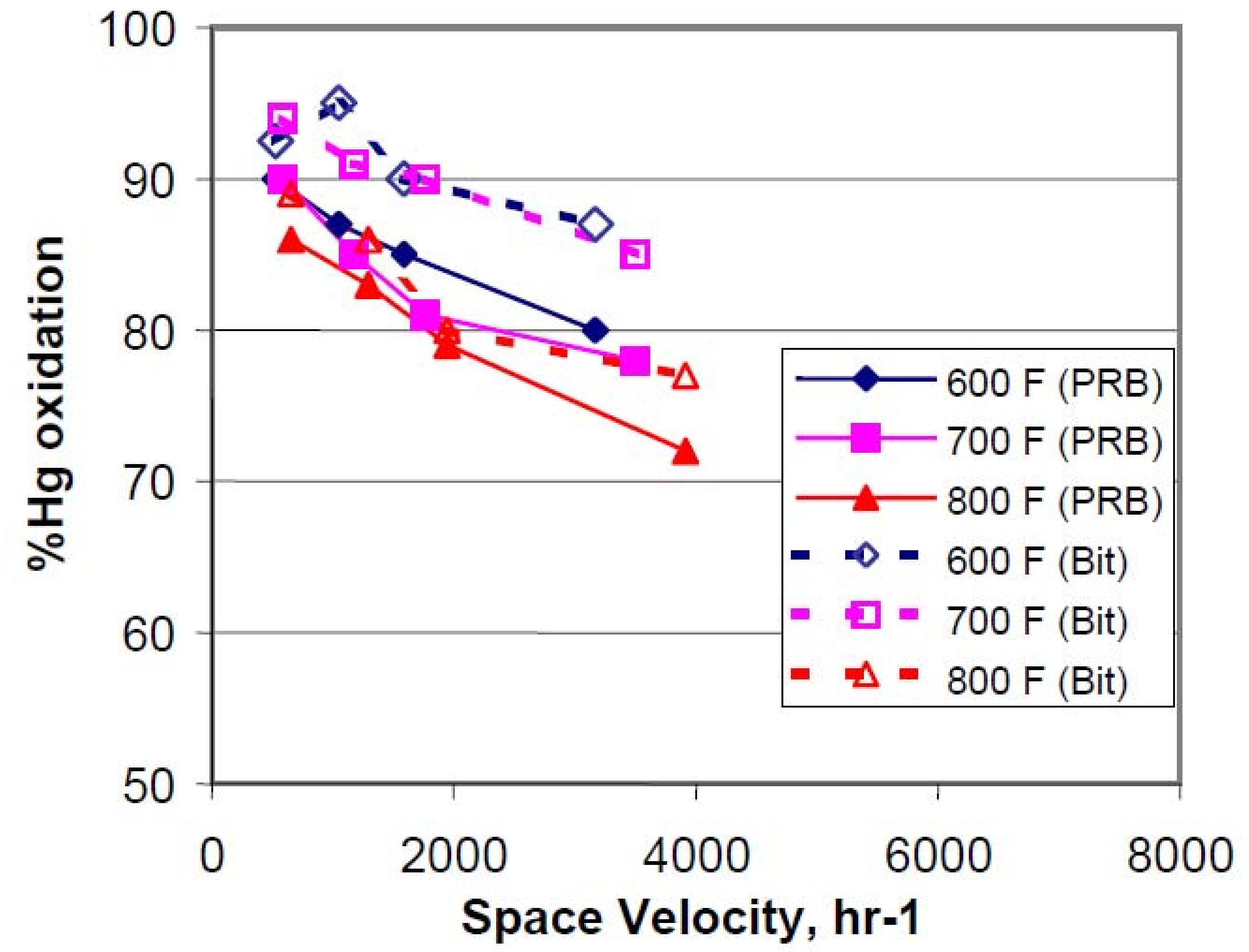
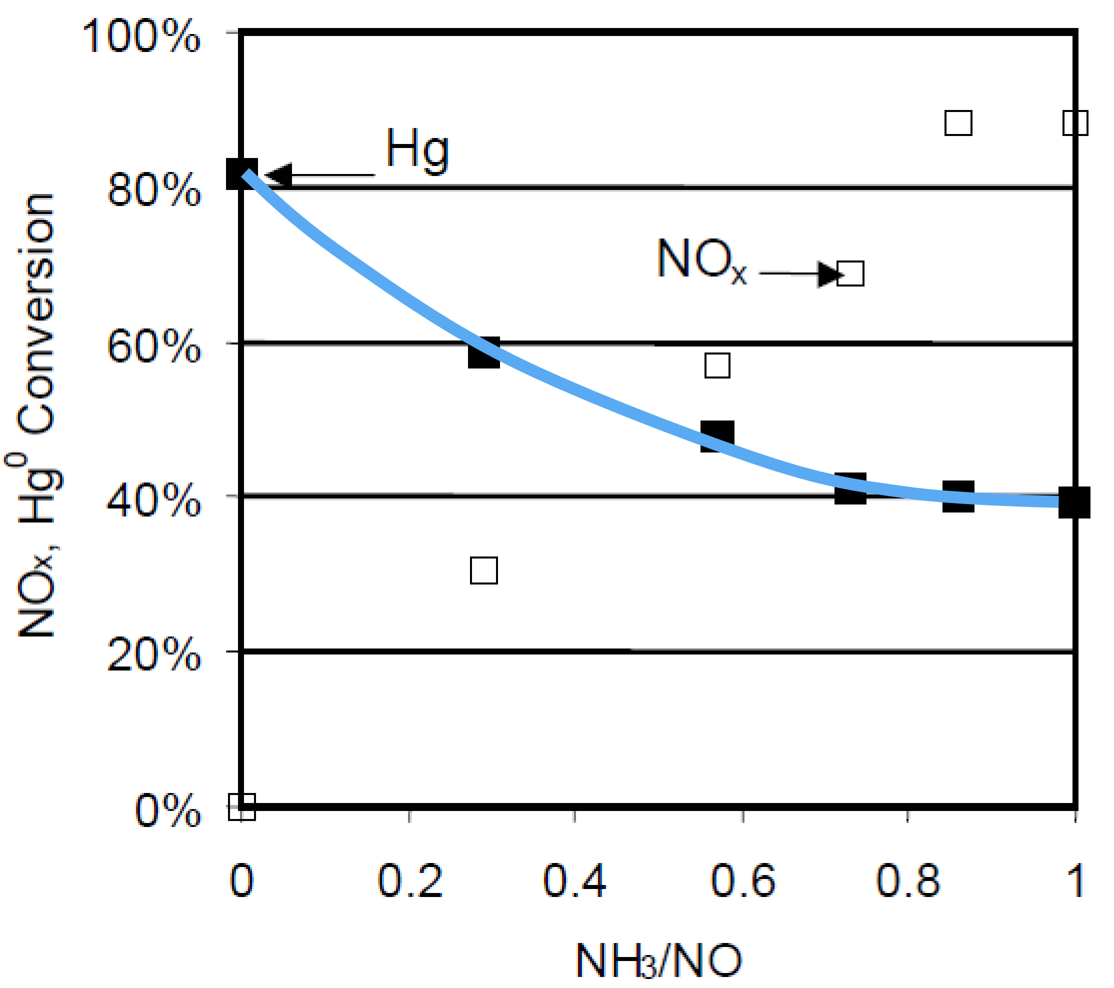
Example Effect of Space Velocity



Example Effect of Ammonia



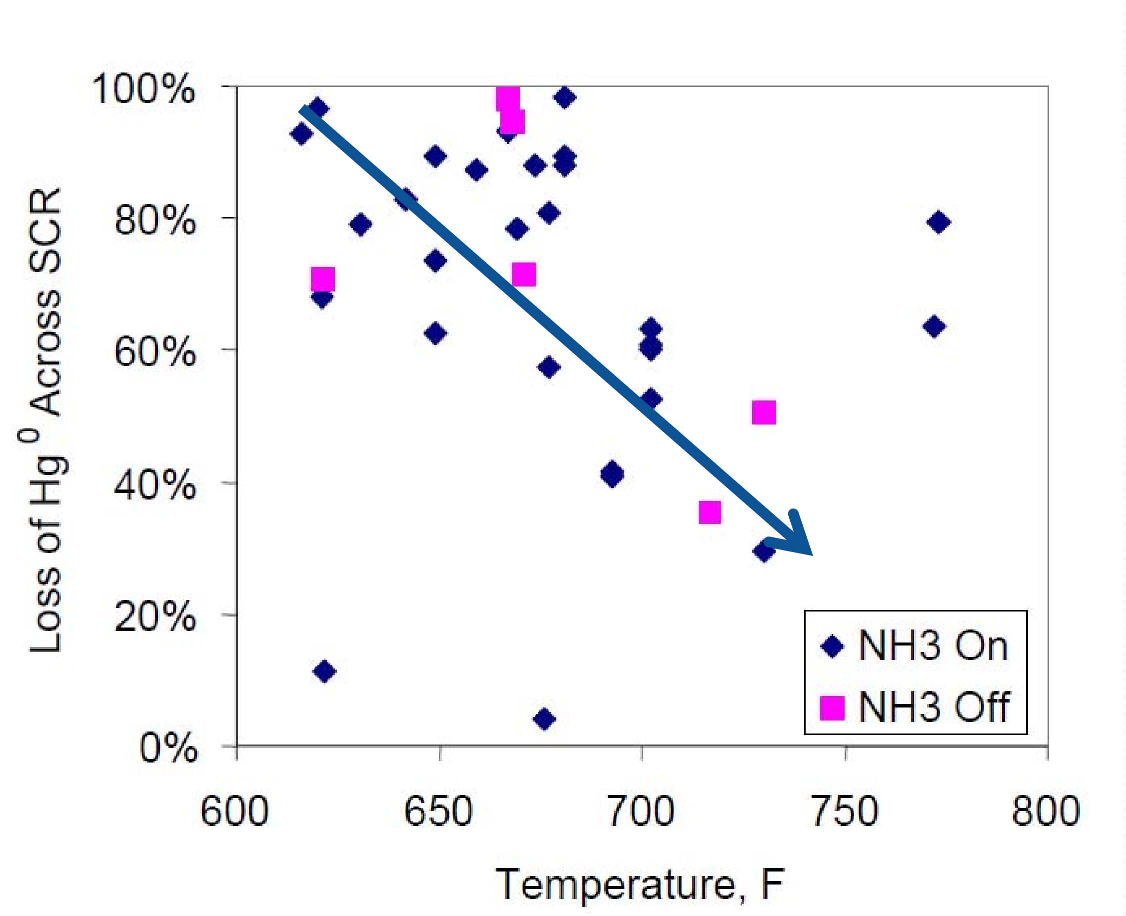
Mercury Oxidation across SCRs in Coal-Fired Power Plants

Connie Senior
Reaction Engineering International

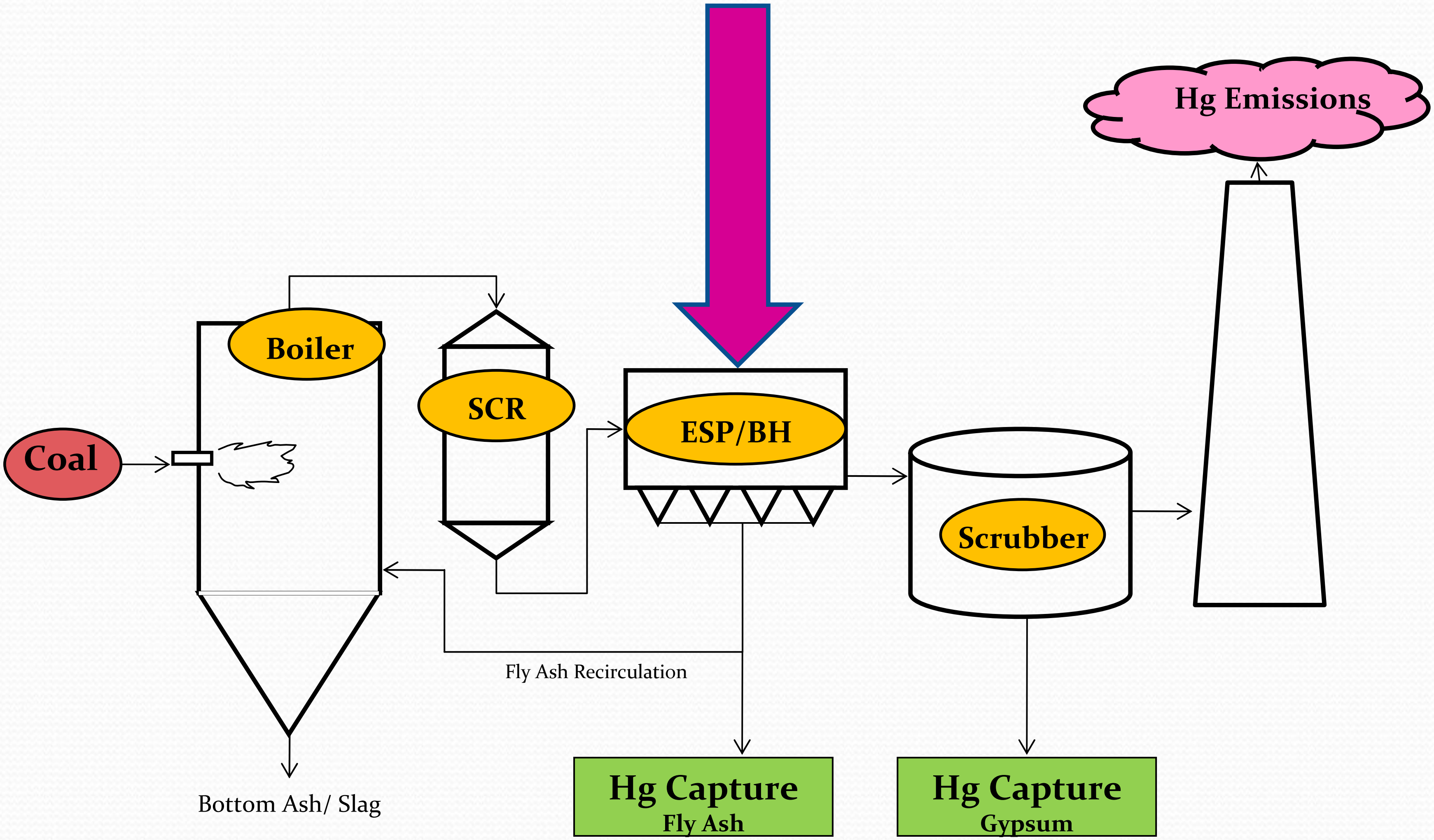
Mercury Control Technology R&D Program Review
Pittsburgh, PA
July 12014, 2005

Example Effect of Temperature

(Full-Scale Data)



Effect of Particulate Controls on Mercury Oxidation and Capture



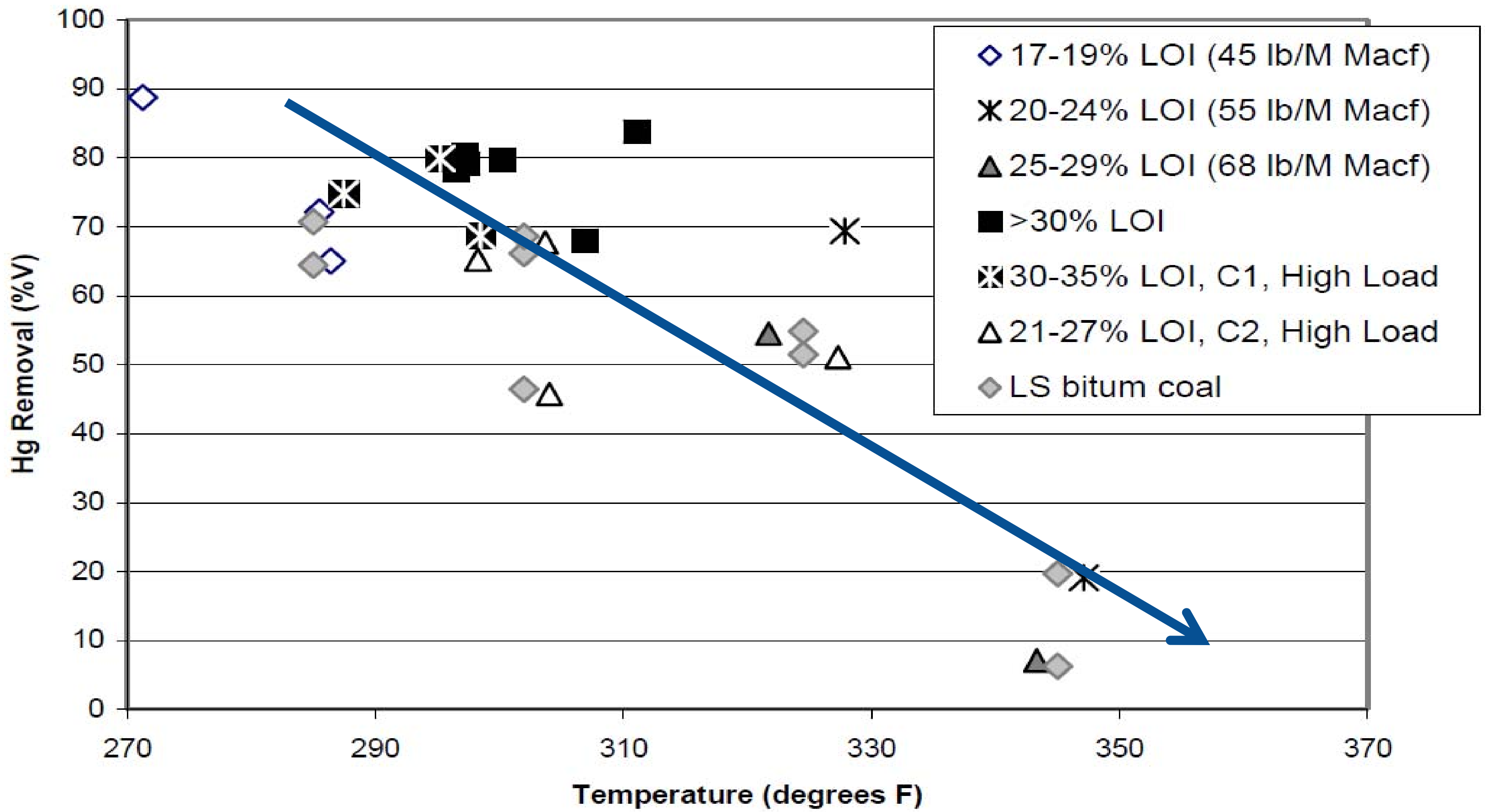
ESP/Baghouse Basics

- ESPs and Baghouses remove mercury via fly ash removal
- Mercury oxidation may occur in conjunction with mercury capture
- Many factors affect mercury behavior

Factors Affecting ESP/BH Mercury Capture

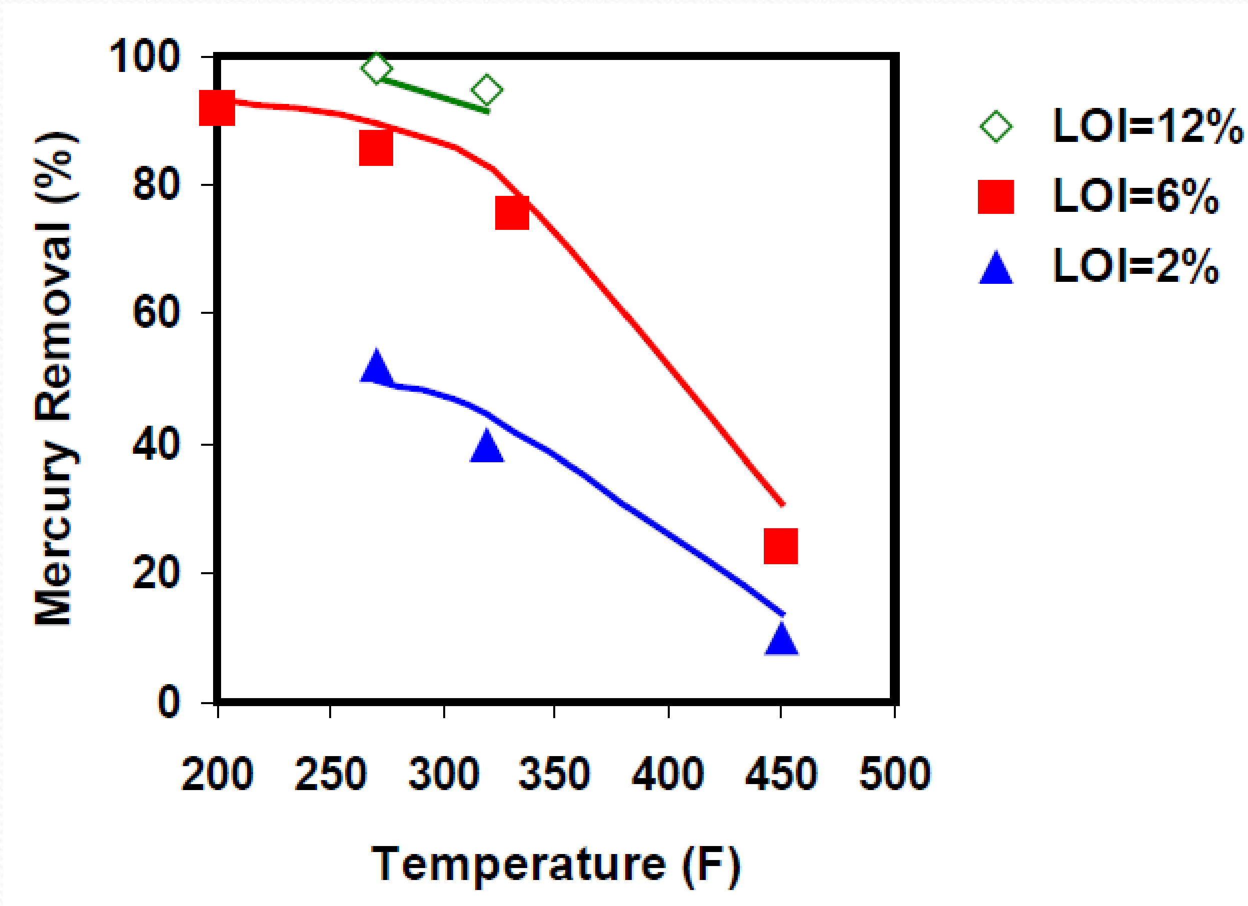
- Overall collection efficiency
- Collection efficiency as a function of particulate size
- Device design
- Flue gas chemistry (SO_3, ammonia, halogens, etc.)
- Flow rate
- Temperature
- General operations (rapping, pulse rate, etc.)

Example Effect of Temperature on ESP Mercury Capture



[6] *DOE National Energy Technology Laboratory Mercury Field Evaluation - PG&E NEG Salem Harbor Station – Unit 1*, Project No. 00-7002-76-10, Field Evaluation Summary Report, January 2003.

Example Effect of LOI and Temperature on ESP Mercury Capture

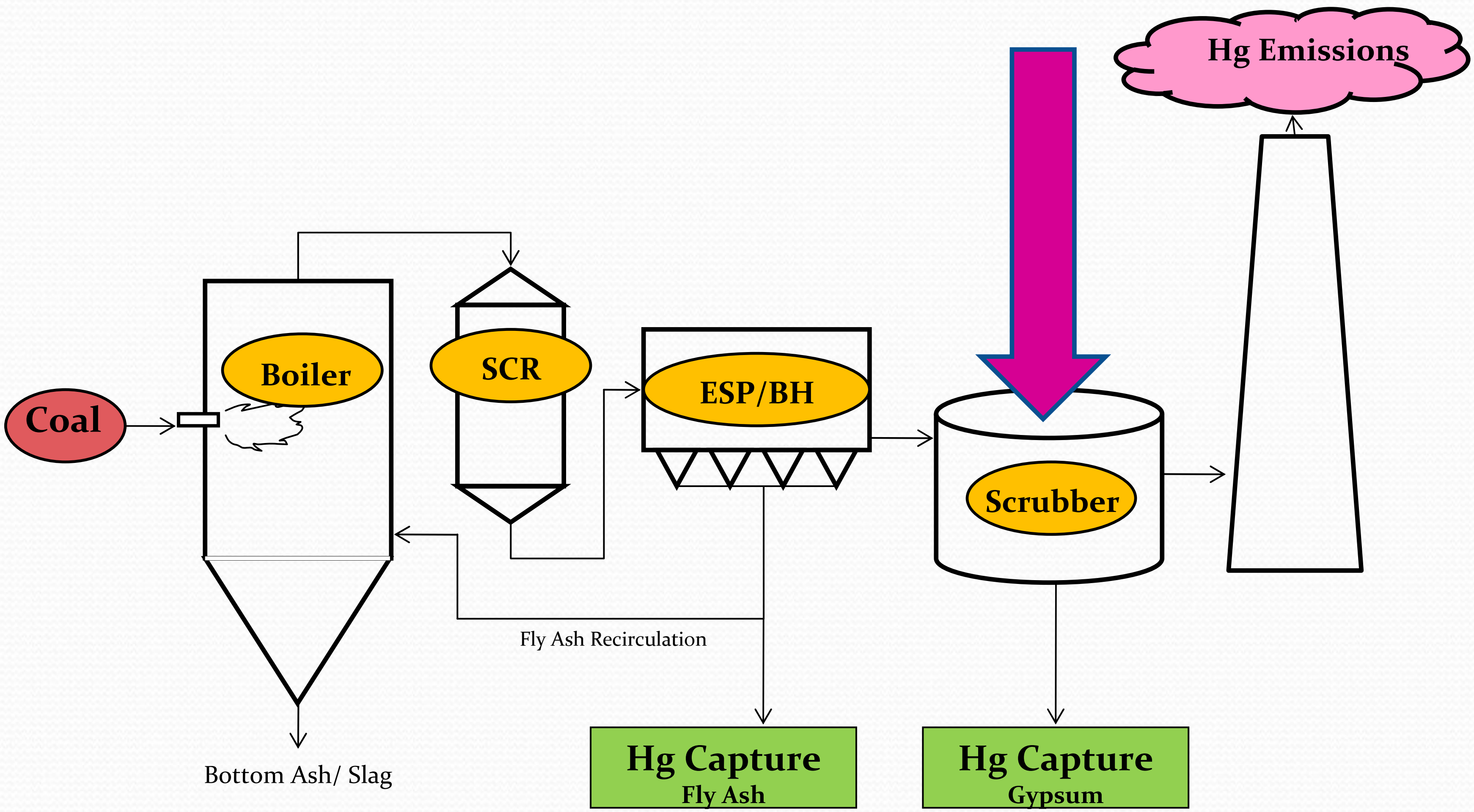


Enhancement of the "naturally occurring" mercury capture by fly ash

World of Ash Conference
Lexington, Kentucky
April 13, 2005

imagination at work

Scrubber Effects on Mercury Behavior



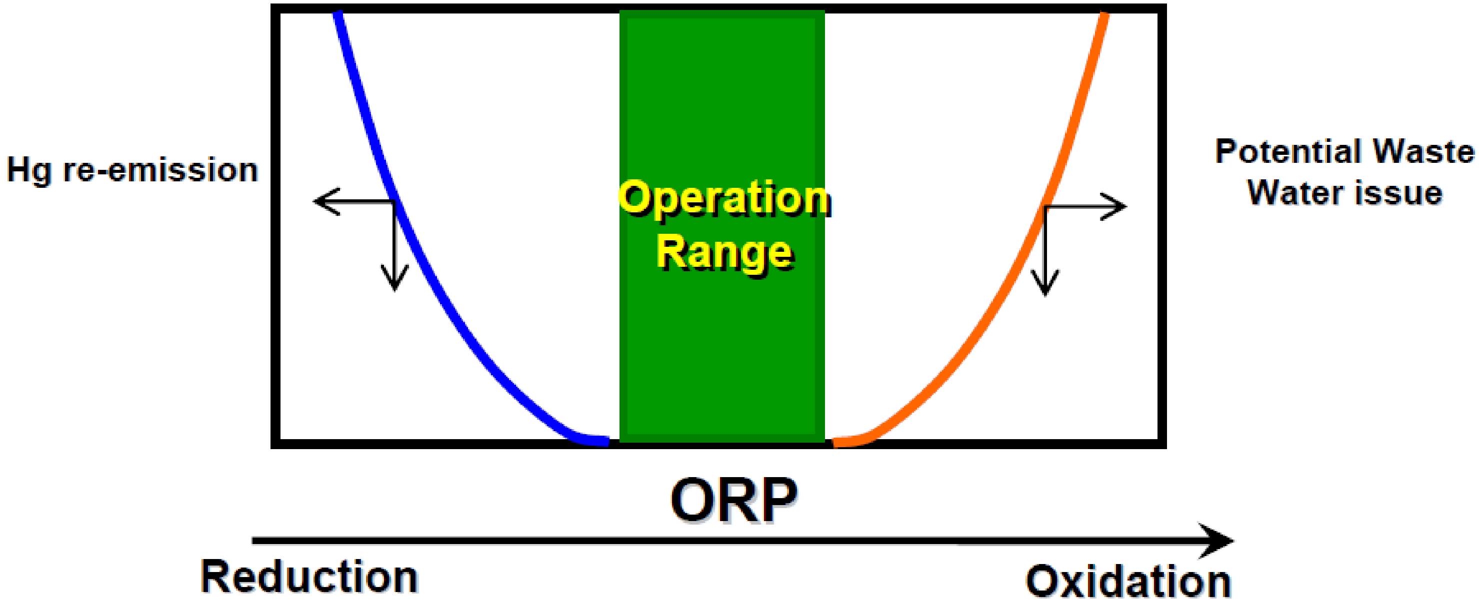
Scrubber Basics

- Wet scrubbers generally remove most oxidized mercury
- Re-emissions are possible
- Complex chemistry within the scrubber
- Mercury is ultimately sequestered in the solids (hopefully)
- Options available for additives to improve mercury capture and limit re-emissions

Factors Affecting Wet Scrubber Capture

- Scrubber type and specific design
- Mercury Speciation
- Oxidation-Reduction potential
- Temperature
- Ionic strength
- Initial reactant concentrations
- pH
- Chloride (both in flue gas and within the scrubber
- Thiosulfate, and other complexing agents

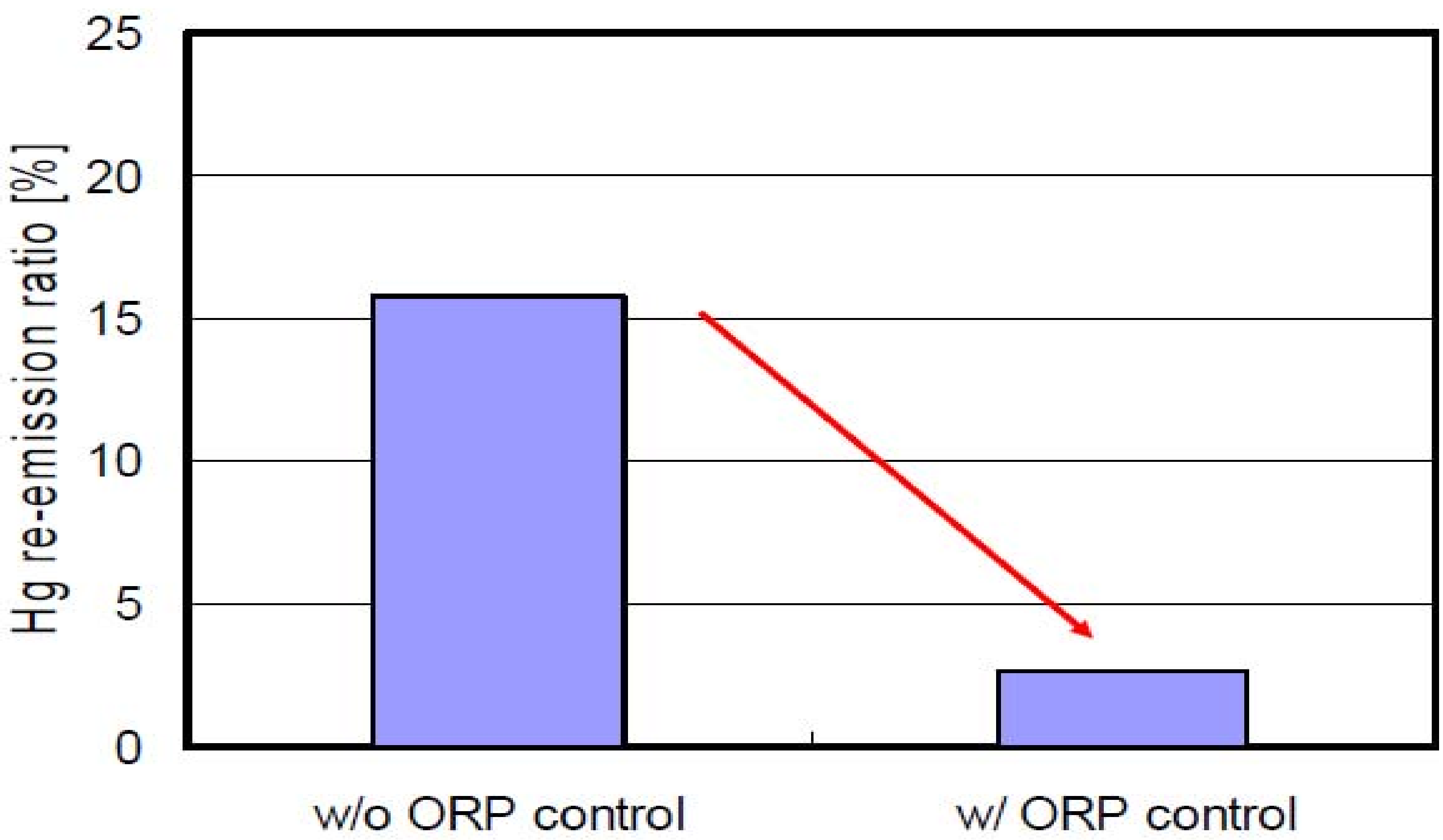
Example General Effect of Oxidation-Reduction Potential



- *Poor oxidation / Gypsum*
- *Unstable SO2 removal*
- *High Hg re-emission*
- *Good for Waste Water*
- *Less power consumption*

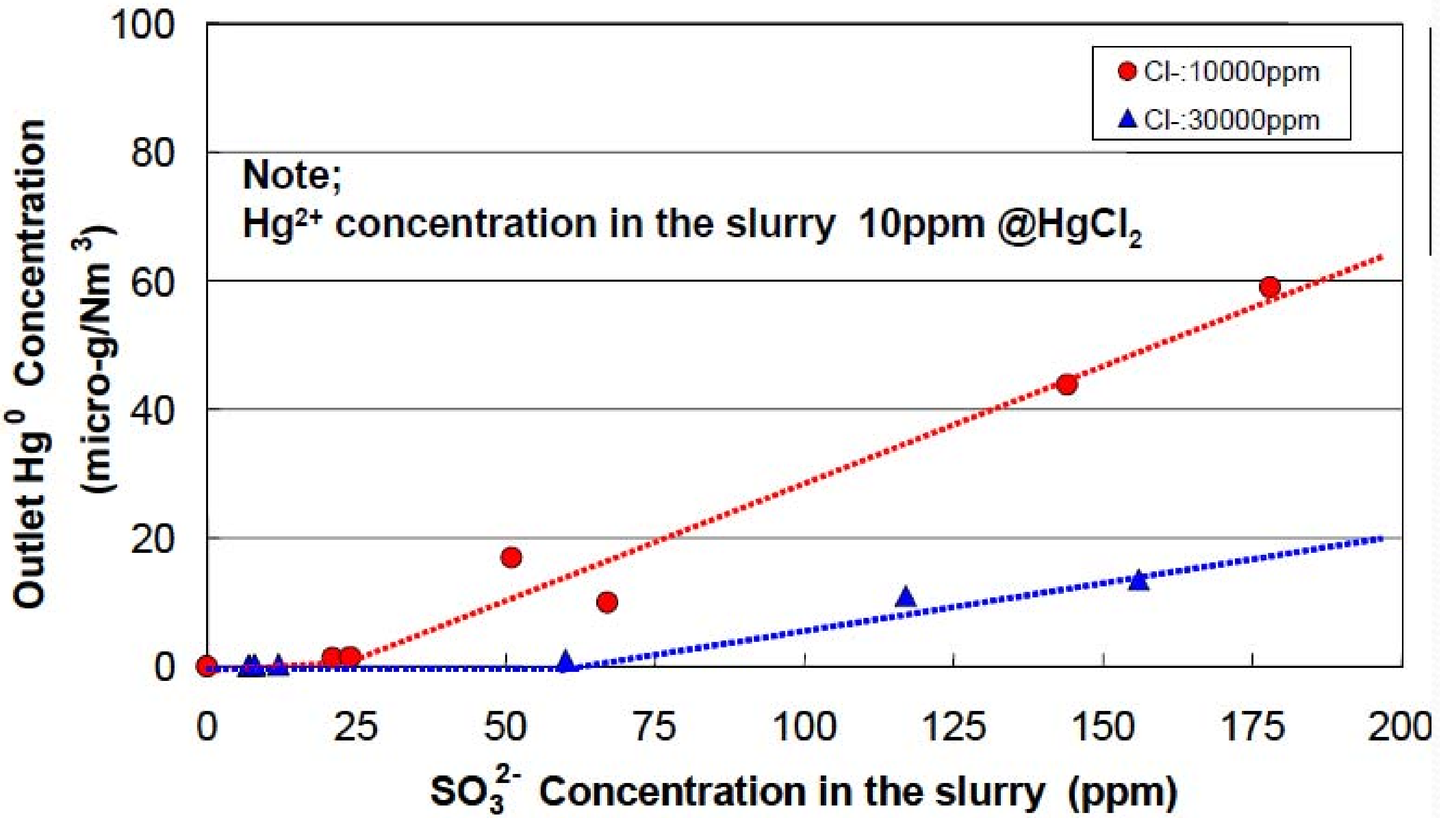
- *Good oxidation / Gypsum*
- *Stable SO2 removal*
- *Less Hg re-emission*
- *FGD WW (COD, Se(VI))*
- *More power consumption*

Example of Improved Capture with ORP Control

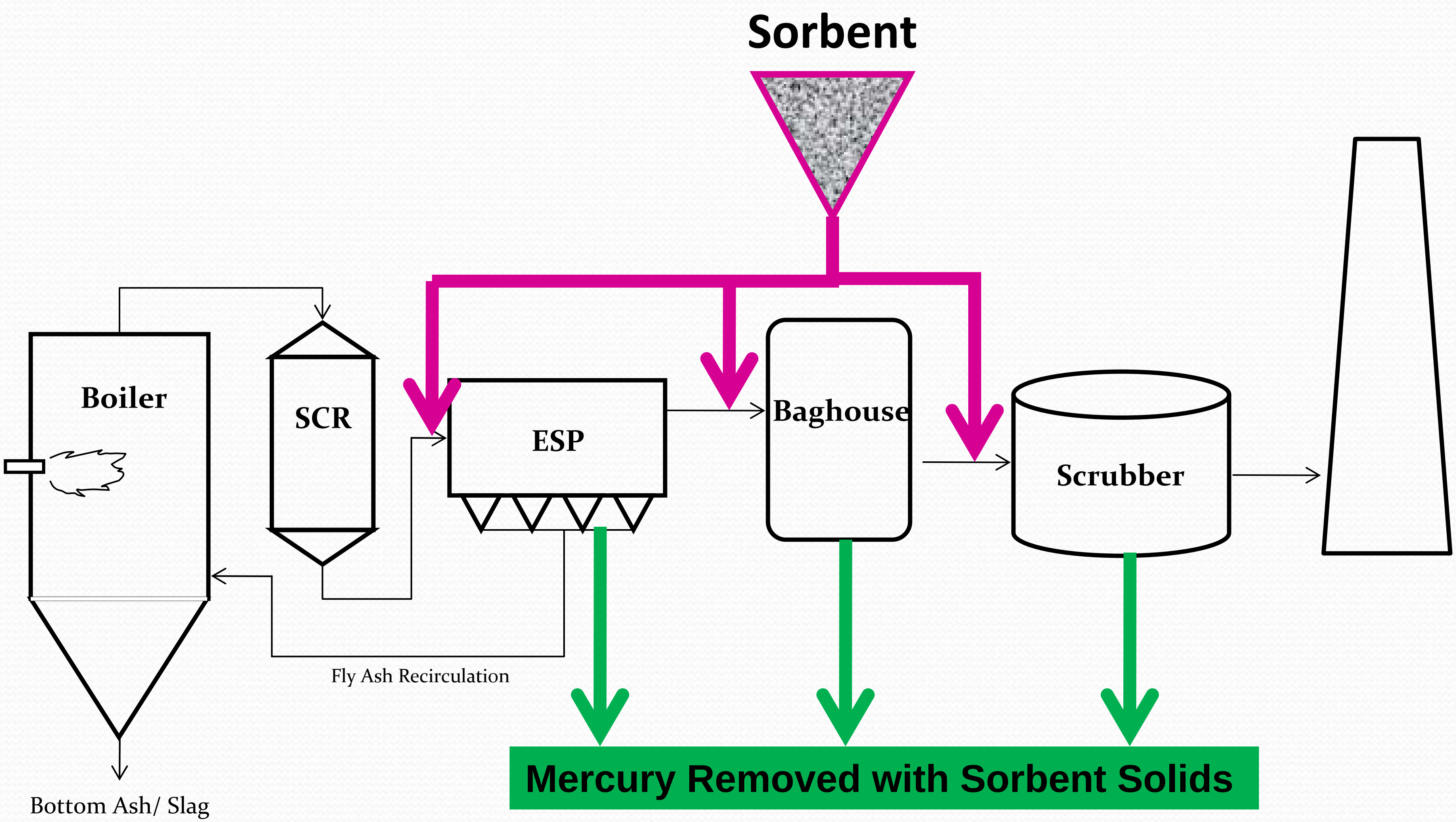


Takeo Shinoda
Manager, Environmental System Div
Mitsubishi Heavy Industries America, Inc.

Example Effect of Sulfites and Chlorides on Hg^0 Capture



Dedicated Mercury Control: Is sorbent injection the easy answer ?

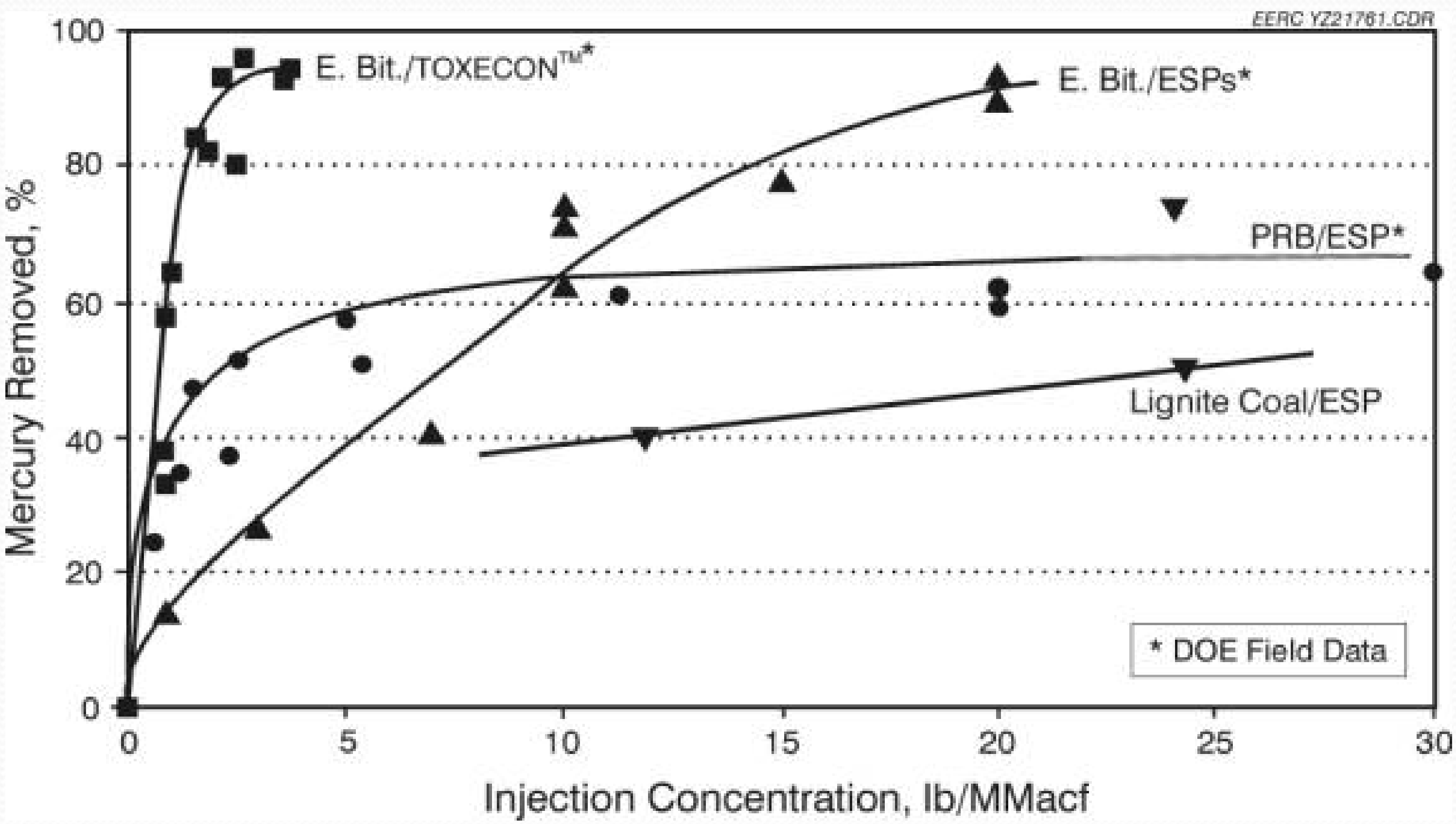


Factors Affecting Sorbent Injection

- Coal type
- Halogens (chlorine and bromine)
- SO2, SO3
- Temperature
- Mercury Speciation
- <u>Sorbent System Design</u>

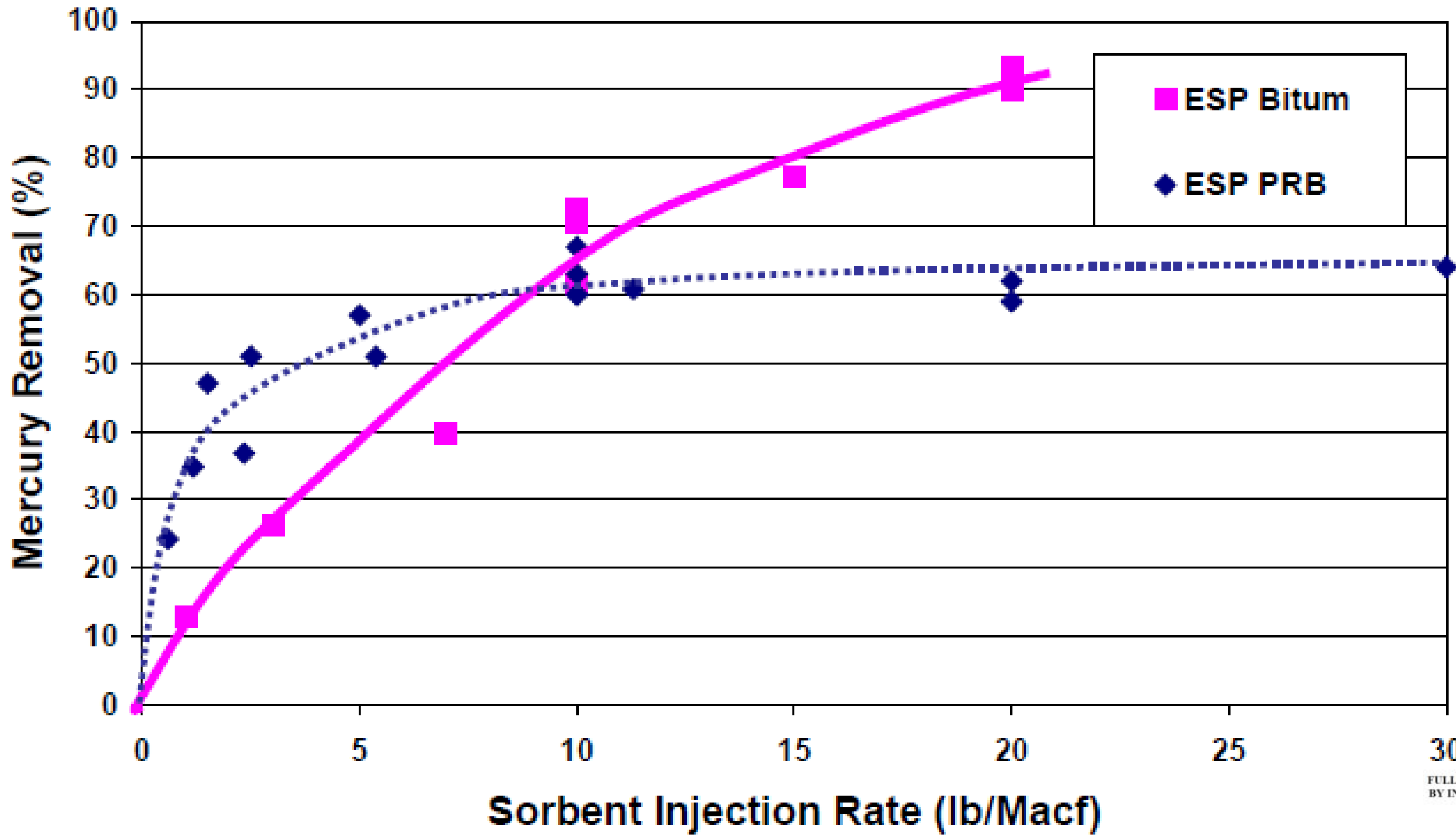
  type of sorbent
  injection location
  distribution of sorbent
  gas/solid contacting
  residence time
  sorbent collection efficiency

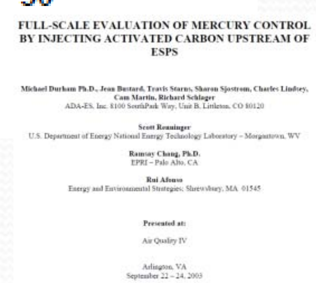
Example Effectiveness of ACI as a Function of Coal Type and Location



Committee on Environment and Public Works
United States Senate
Subcommittee on Clean Air, Climate Change, and Nuclear Safety
Testimony of Dr. Steven A. Benson
June 5, 2003

Example Effectiveness of ACI as a Function of Coal Type





FULL-SCALE EVALUATION OF MERCURY CONTROL BY INJECTING ACTIVATED CARBON UPSTREAM OF ESPS

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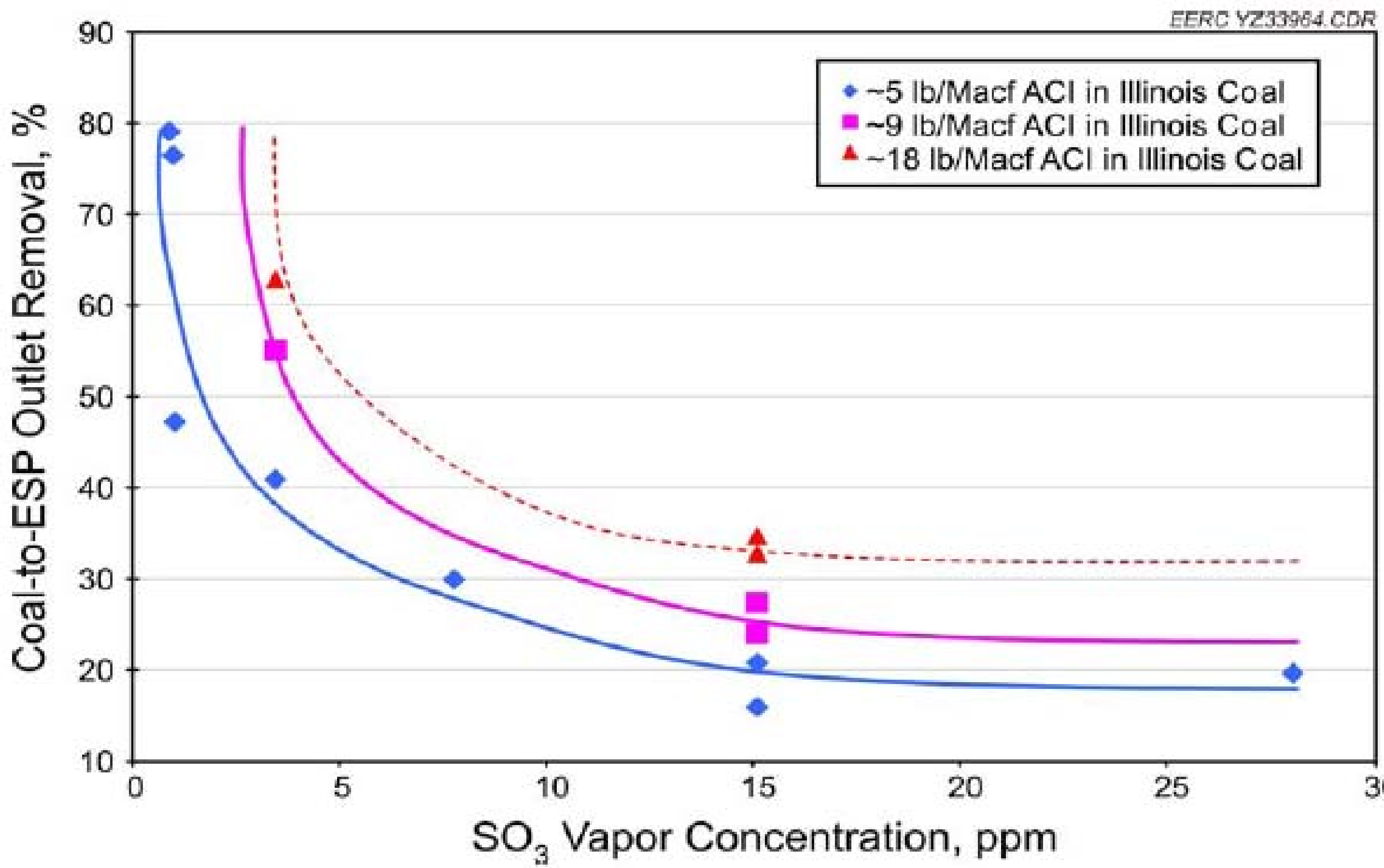
Energy and Environmental Strategies: Shrewsbury, MA 01545

Presented at:

Air Quality IV

Arlington, VA
September 22 – 24, 2003

Example Effect of SO_3 on ACI Capture



JV TASK 124 – UNDERSTANDING MULTI-INTERACTIONS OF SO_3, MERCURY, SELENIUM, AND ARSENIC IN ILLINOIS COAL FLUE GAS

Final Report

(for the period April 1, 2008, through March 31, 2009)

Prepared for:

AAD Document Control

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National Energy Technology Laboratory
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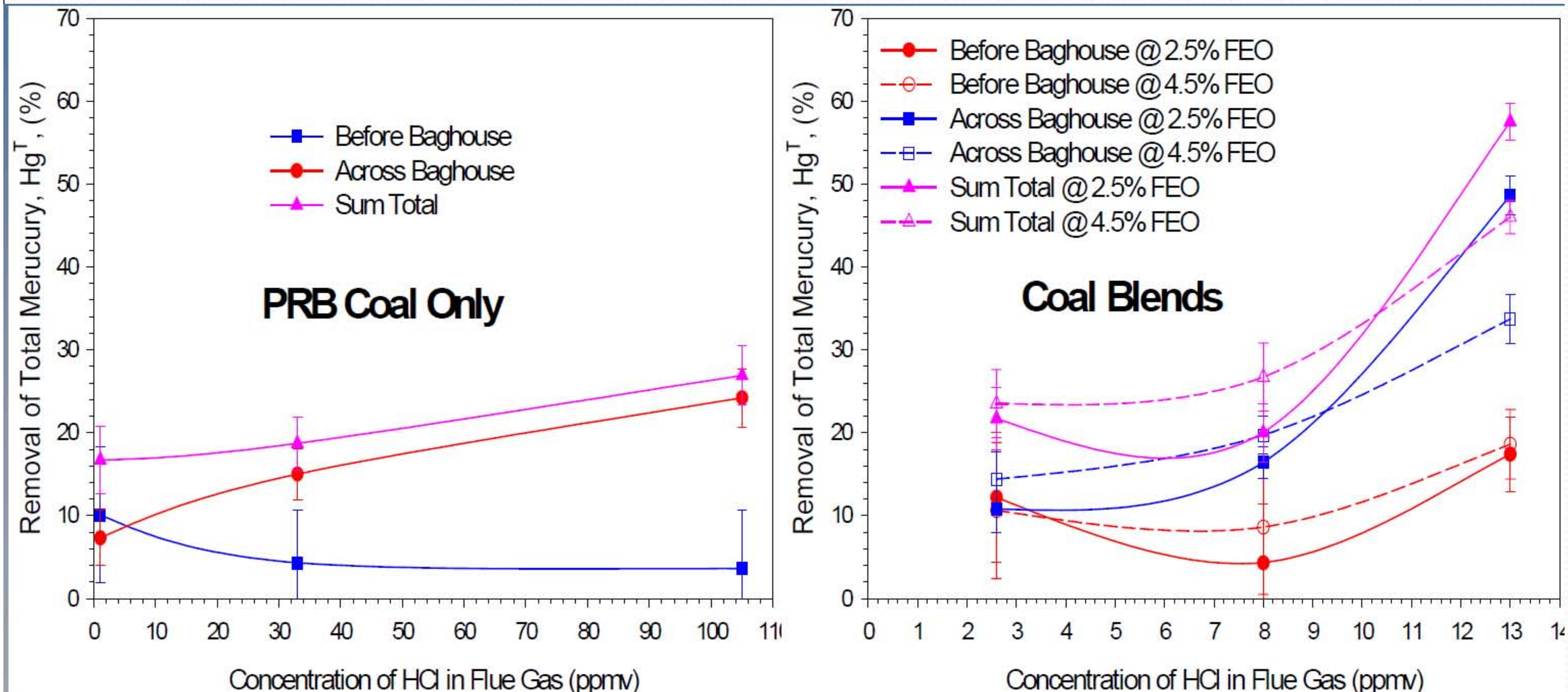
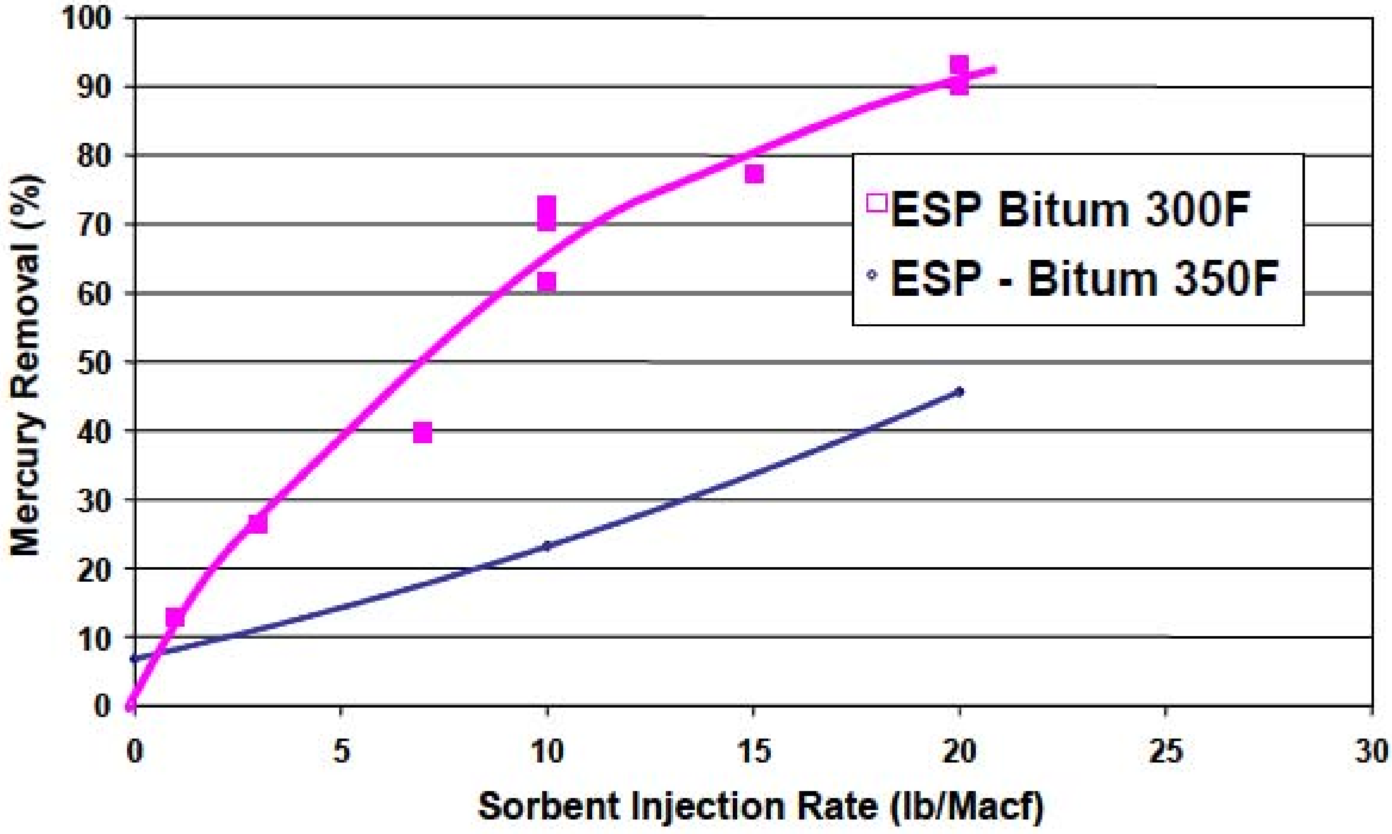
Pittsburgh, PA 15236-0940

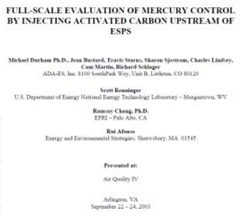
Cooperative Agreement: DE-FC26-98FT40321
Project Manager: Jenny Tennant

Example Effect of HCl on Hg Capture with Sorbents



Example Effect of Temperature on Sorbent Capture





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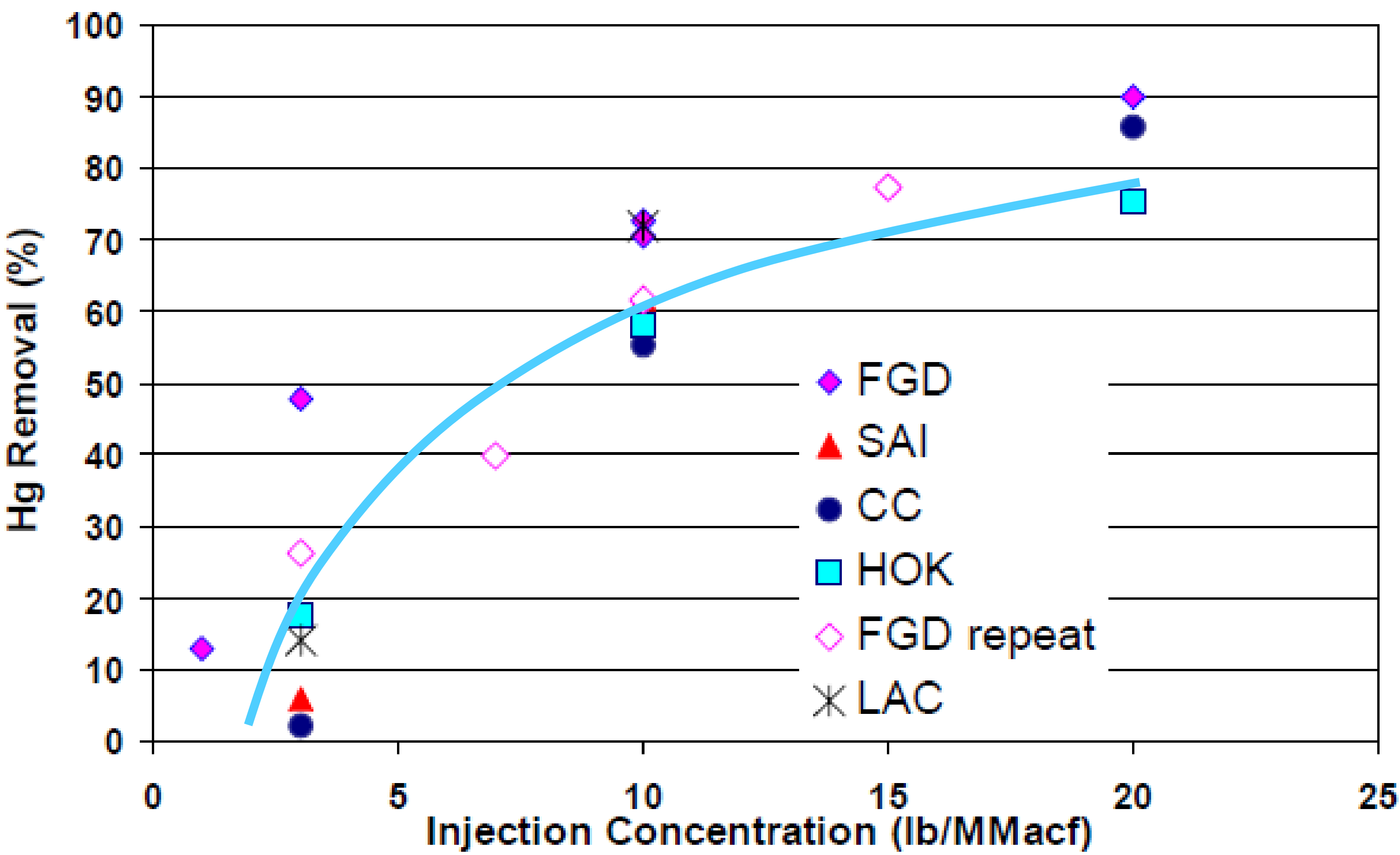
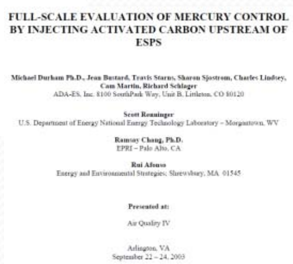
Example Effect of Sorbent Type and Injection Rate on Hg Capture

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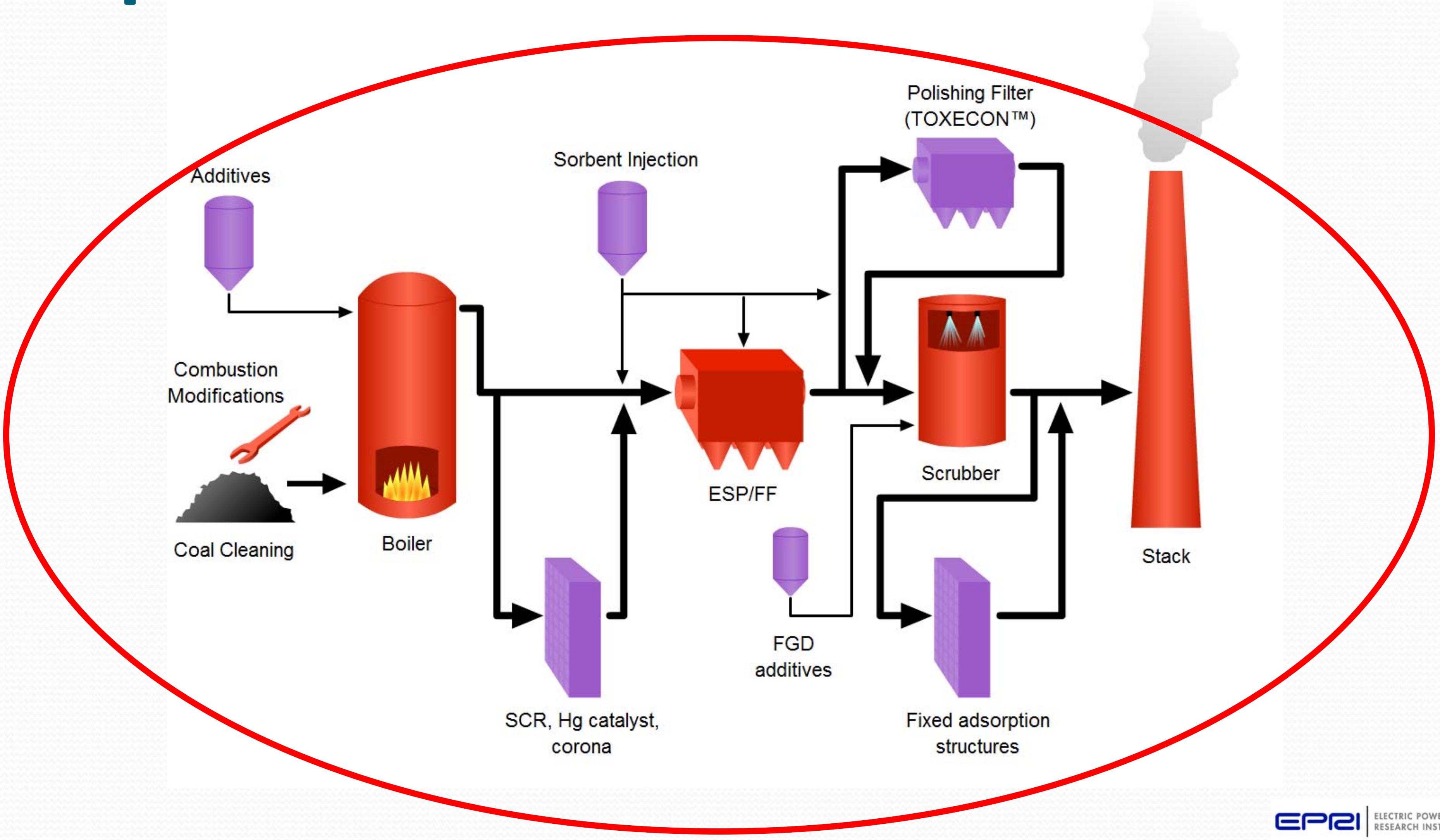
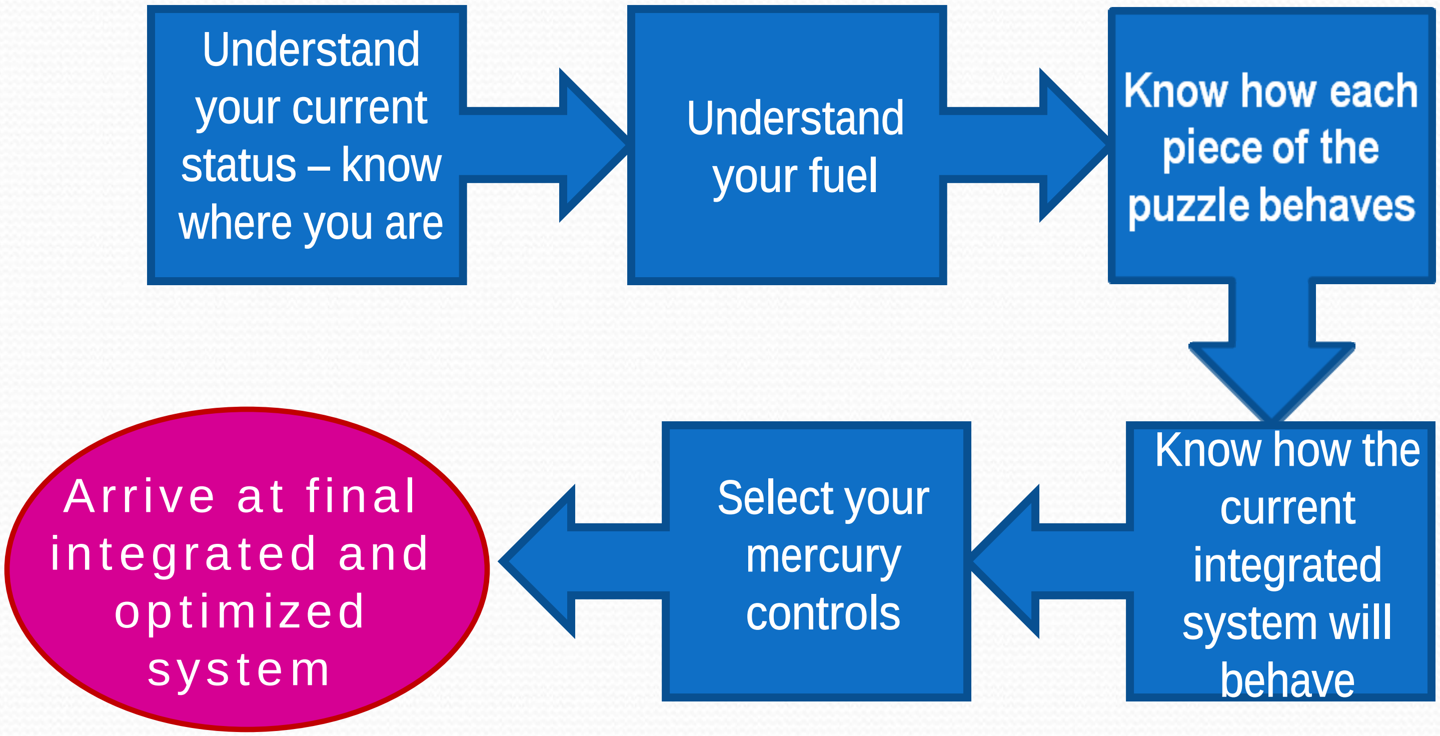
How Do We Integrate, Select, and Optimize for Mercury Control ?



Steps to Optimizing Mercury Control



Steps to Optimizing Mercury Control

#1. Understand Your Current Mercury Emissions Status

- Learn the current mercury behavior of your unit.

  If you don't know the "here", it's difficult to get to the "there".

- Quantify your current inherent variability – this could have a major impact in light of averaging periods.

- Understand how future global system changes will potentially impact mercury *(the here might change !).*

Steps to Optimizing Mercury Control

#2. Understand Your Fuel

- Fuel is the single most important factor in mercury control, both terms of co-benefits and dedicated control options.
- Look at current fuel quality and variability and how it impacts inherent mercury behavior (and variability).
- Understand how fuel will impact dedicated mercury controls, if required.
- Identify problematic fuels or purchasing scenarios.
- Evaluate future fuel purchase trends.

Steps to Optimizing Mercury Control

#3. Understand Each Piece of the Puzzle

- Understand how each piece of major equipment affects the flue gas, how it responds to operating and flue gas changes, and how it will affect mercury.

Steps to Optimizing Mercury Control

#4. Understand the Current Integrated System

- Put the pieces together to understand overall mercury behavior in response to current operations, inherent variability, expected future operations – know the "big picture" in terms of how the unit will behave with respect to various operational and fuel changes. (basically a comprehensive model)

- With the above knowledge, determine what the achievable mercury emissions will be for various future operating scenarios and system changes.

Steps to Optimizing Mercury Control

#5. Select Your Poison

- For the various operating scenarios, determine if augmenting controls are needed (halogen injection, scrubber additives, oxidation catalysts, etc.) or if dedicated controls will be required (sorbent injection, new particulate controls, etc.)

- Based on the above knowledge, select control options that integrate well into the overall system needs in light of physical design, inherent variability, and future fuel and operating scenarios.

Steps to Optimizing Mercury Control

#5. Arrive at final integrated system and optimize

- With all mercury controls in place understand how the integrated system needs to be operated to maintain mercury emission limits, learn the limitations, and learn what operating scenarios will cause exceedances.

EPA Expectations with *Aggressive R&D*

Control Technology	Existing Capacity (MW) in 2003[5]	Projected Hg Removal Capability in 2010 by the Use of ACI[4]		Projected Hg Removal Capability in 2010 by Enhanced Multipollutant Controls[4]		Projected Hg Removal Capability in 2015 by Optimizing Multipollutant Controls[4]	
		Bitum-inous (Bit)	Low-rank coals	Bit. Coals	Low-rank coals	Bit. Coals	Low-rank coals
PM Control Only-CS-ESP	153133	70[6]	70[6]	NA[7]	NA	NA	NA
PM Control Only-CS-ESP + retrofit FF	2591	90	90	NA	NA	NA	NA
PM Control Only-FF	11018	90	90	NA	NA	NA	NA
PM + Dry FGD	8919	NA	NA	90[8]	60-70[8]	90-95[8]	90-95[8]
PM + Wet FGD	48318	NA	NA	90[9]	70-80[9]	90-95[9]	90-95[9]
PM + Wet or Dry FGD + SCR	22586	NA	NA	90	70-80[10]	90-95[10]	90-95[10]

[4] Based on the assumption of aggressive RD&D implementation as outlined elsewhere in this white paper.
[5] Capacity values have been obtained from EMF controls available in "EPA's 2003 Clear Skies Act parsed file for 2010" available at http://www.epa.gov/airmarkets/epa-ipm/results2003.html. The capacity values have been rounded to the nearest whole number.
[6] This control level is based on data from the Pleasant Prairie field tests.
[7] NA = not applicable.
[8] Assumes that additional means to ensure oxidation of Hg^0 or innovative sorbents will be used as needed.
[9] Assumes that means to oxidize Hg^0 will be used as needed. Note that in some cases this may, in part, be accomplished by FF.
[10] Assumes that additional means to ensure oxidation of Hg^0 or innovative sorbents will be used as needed.

CONTROL OF MERCURY EMISSIONS
FROM COAL-FIRED ELECTRIC UTILITY BOILERS
Air Pollution Prevention and Control Division
National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC

CONCLUSION: LOT'S OF WORK !