REINHOLD ENVIRONMENTAL Ltd.

2014 APC Round Table & Expo Presentation

July 14-15, 2014, in Louisville, KY / Hosted by LG&E/KU

SOUTHERN RESEARCH INSTITUTE

Mercury Basics

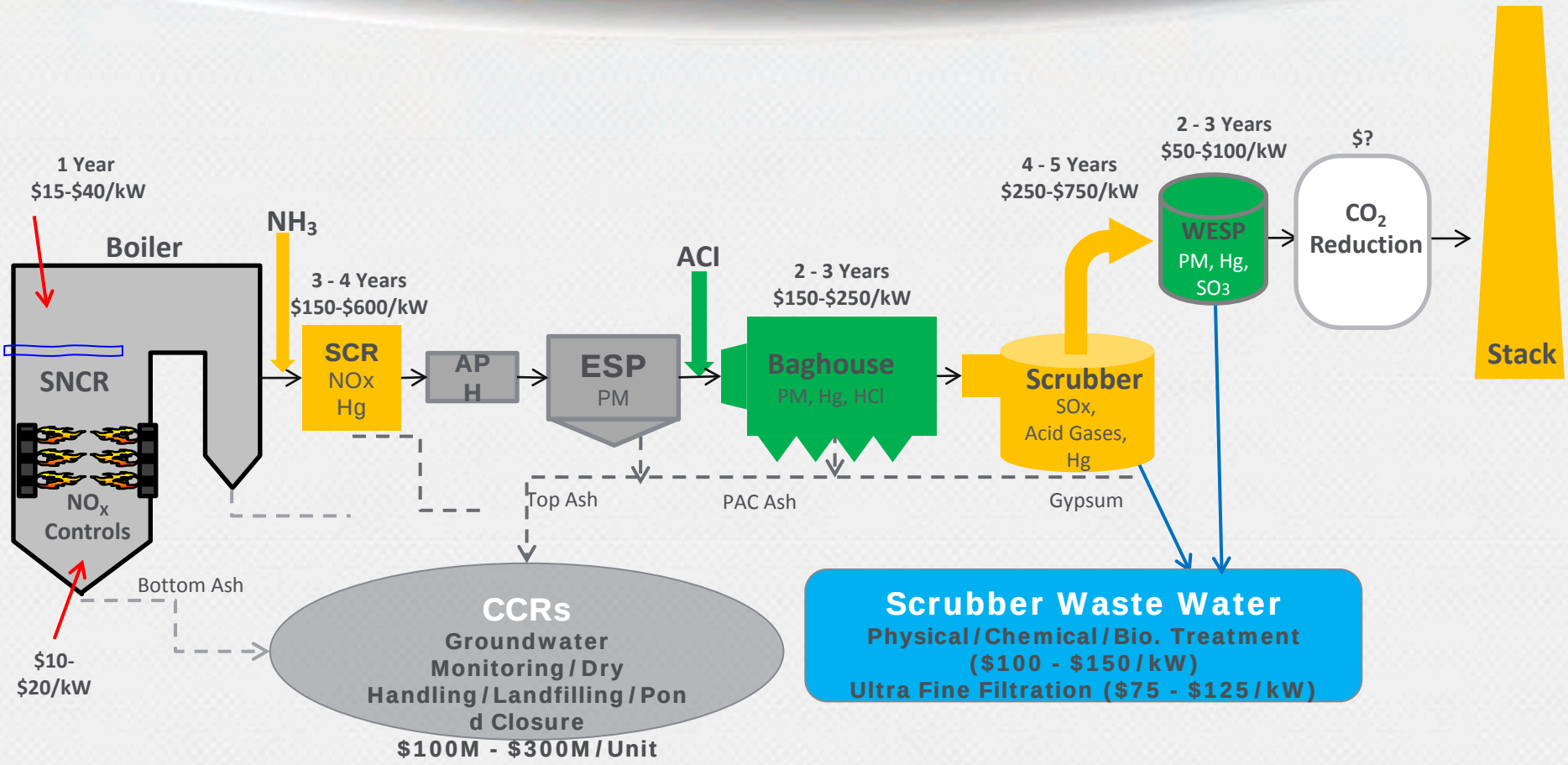
Mark S. Berry, PhD, PE

Reinhold APC Conference

Louisville, KY

July 12th, 2014

A “Controlled” Future

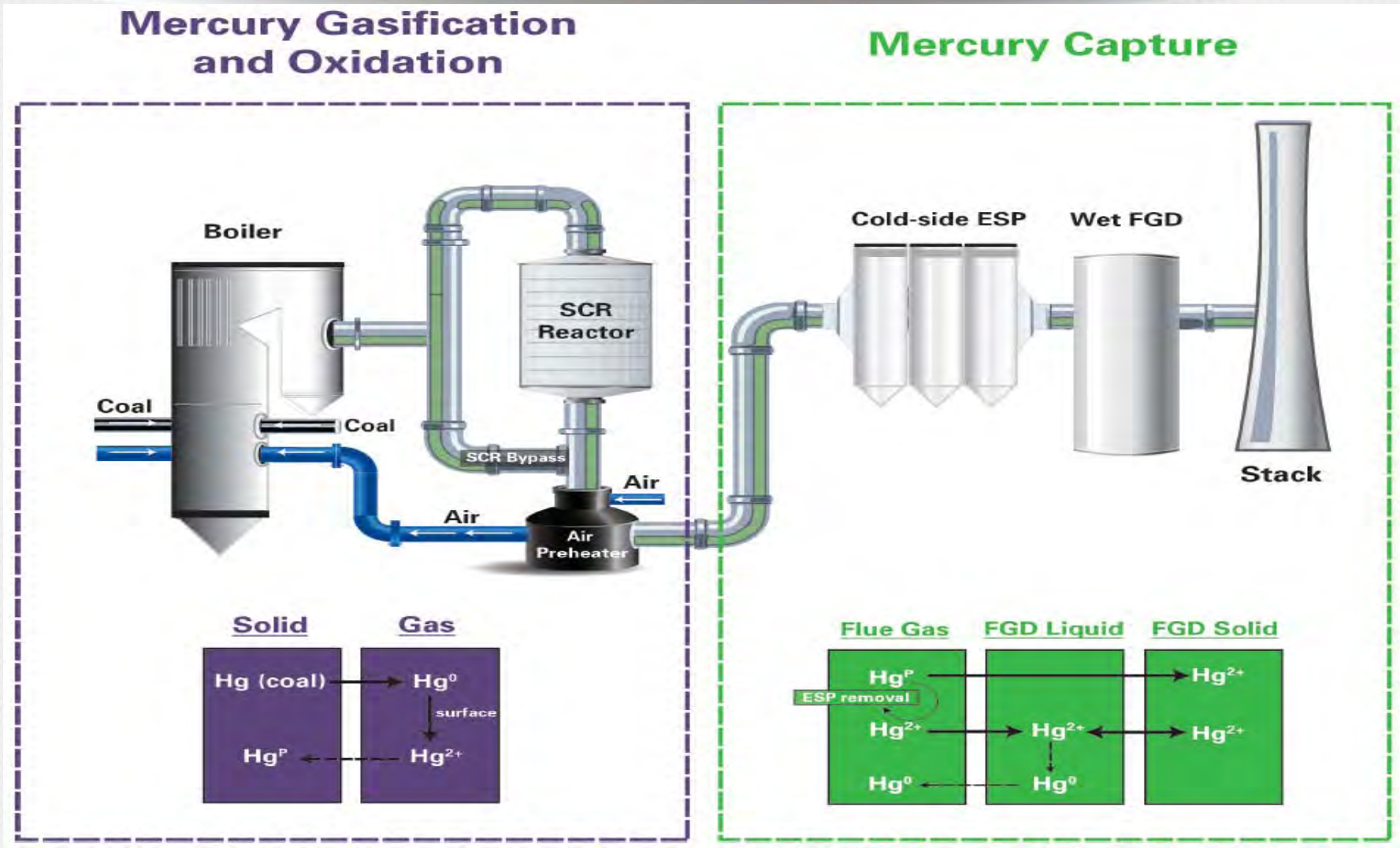


Mercury & Air Toxics (MATS) Limits

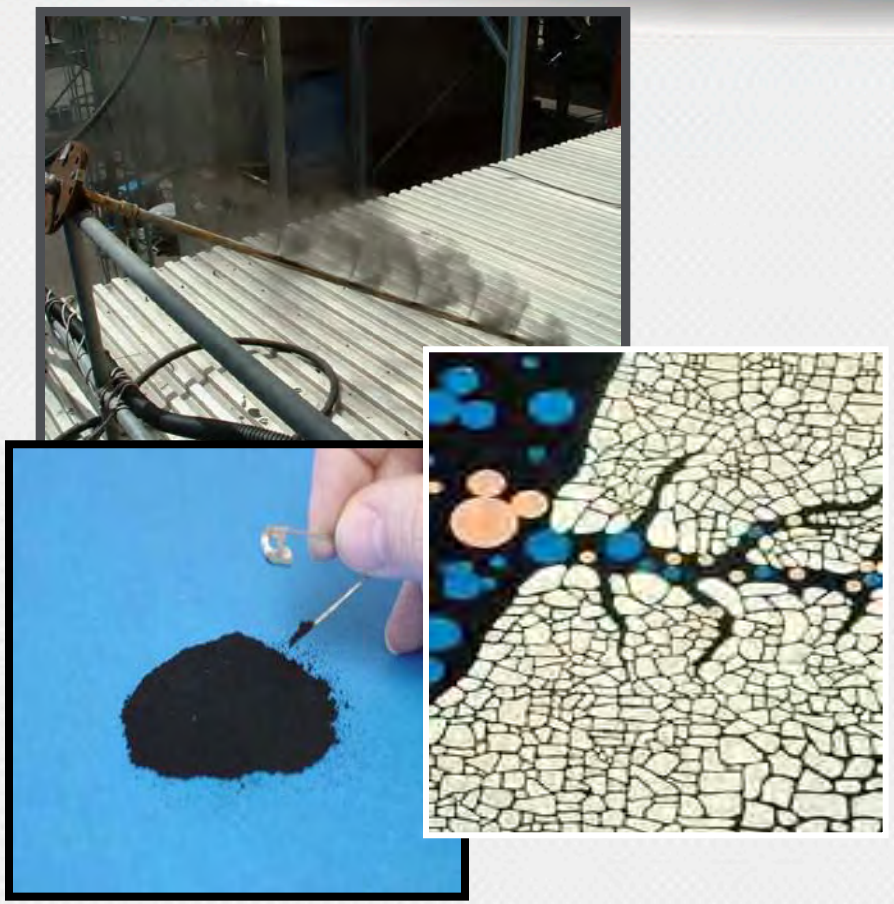
Emission Standards for Existing Coal-Fired Power Plants

Pollutant	Input Base Limit	Output Based Limit
Mercury	**1.2 lb x 10^{12} (TBtu)**	**0.013 lb / GWhr**
Filterable PM	0.03 lb x 10^6 Btu (MMBtu)	0.30 lb / MWhr
HCl / SO_2	0.002 x 10^6 Btu or 0.2 x 10^6 Btu (MMBtu)	0.02 lb / MWhr or 1.5 lb / MWhr

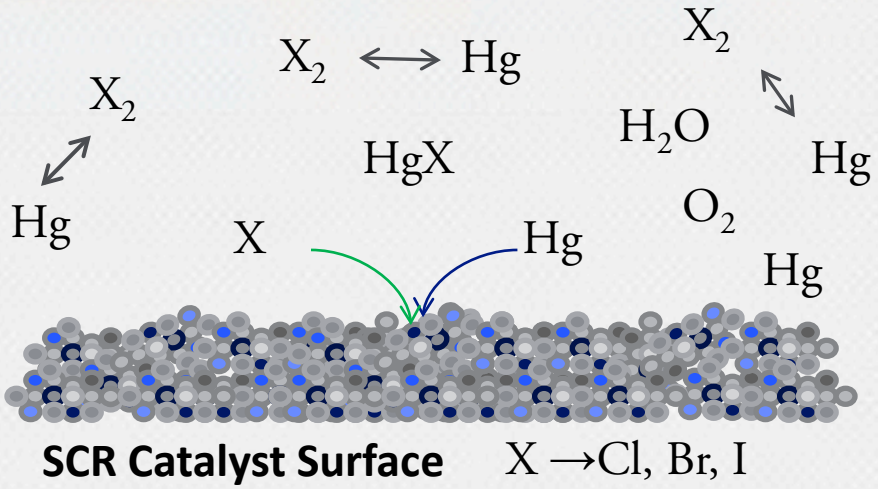
Mercury Basics

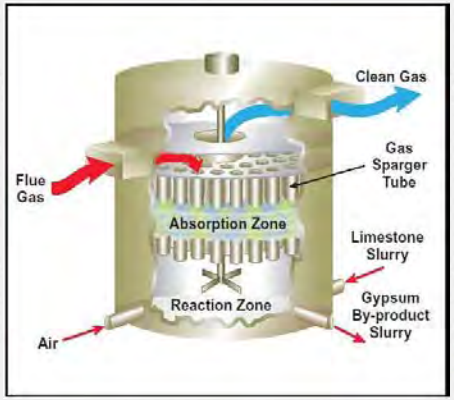


Mercury Specific Technologies



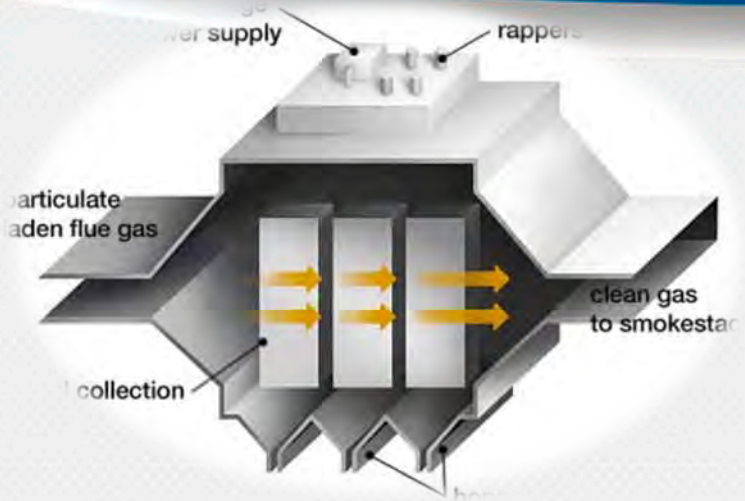
Adsorption Approaches
(Solid)





Absorption Approaches
(Liquid)

Reactor & Reactant



Compliments of Cabot

Compliments of Novinda

Compliments of Neundorfer

Adsorption: Background

Typical properties:

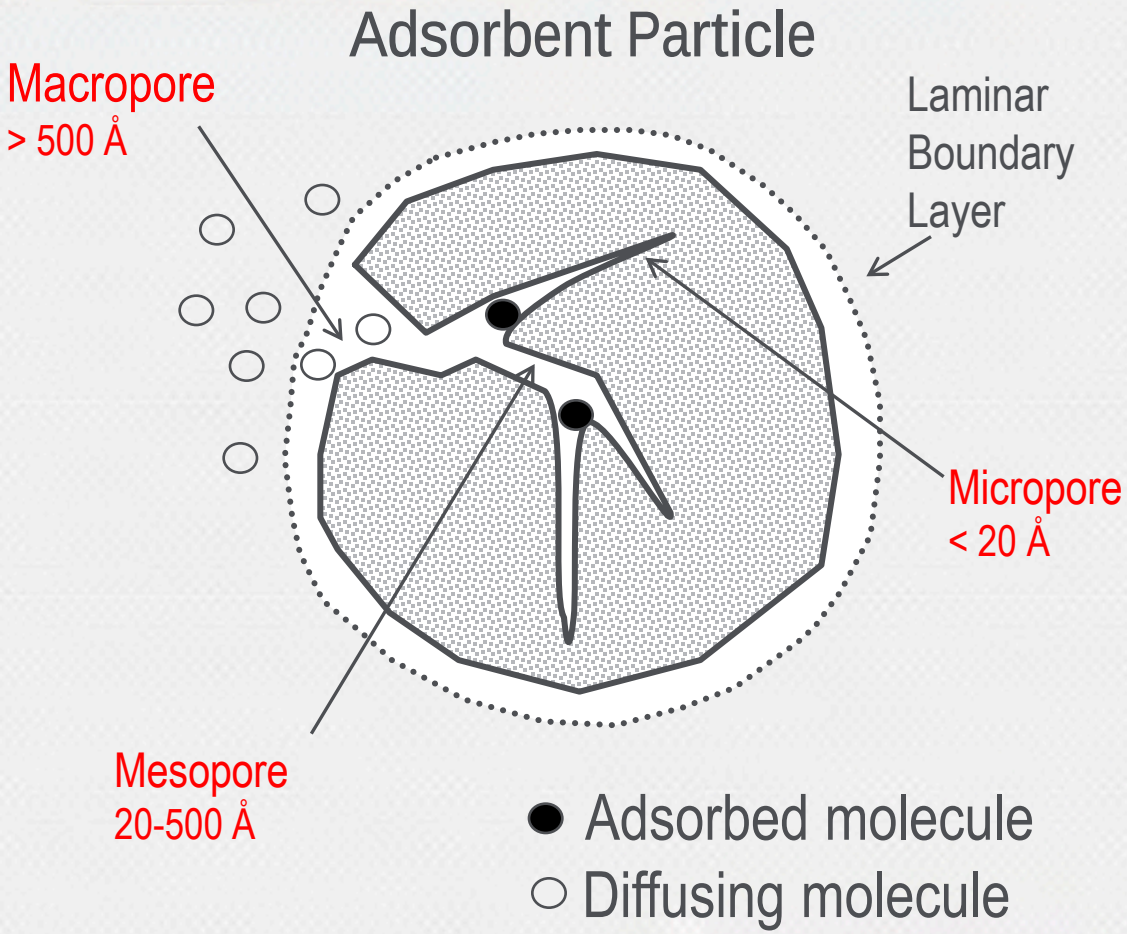
- 5 µm to 1.2 cm
- 300 to 1,200 m^2/g
- 30 to 85 vol%

Steps:

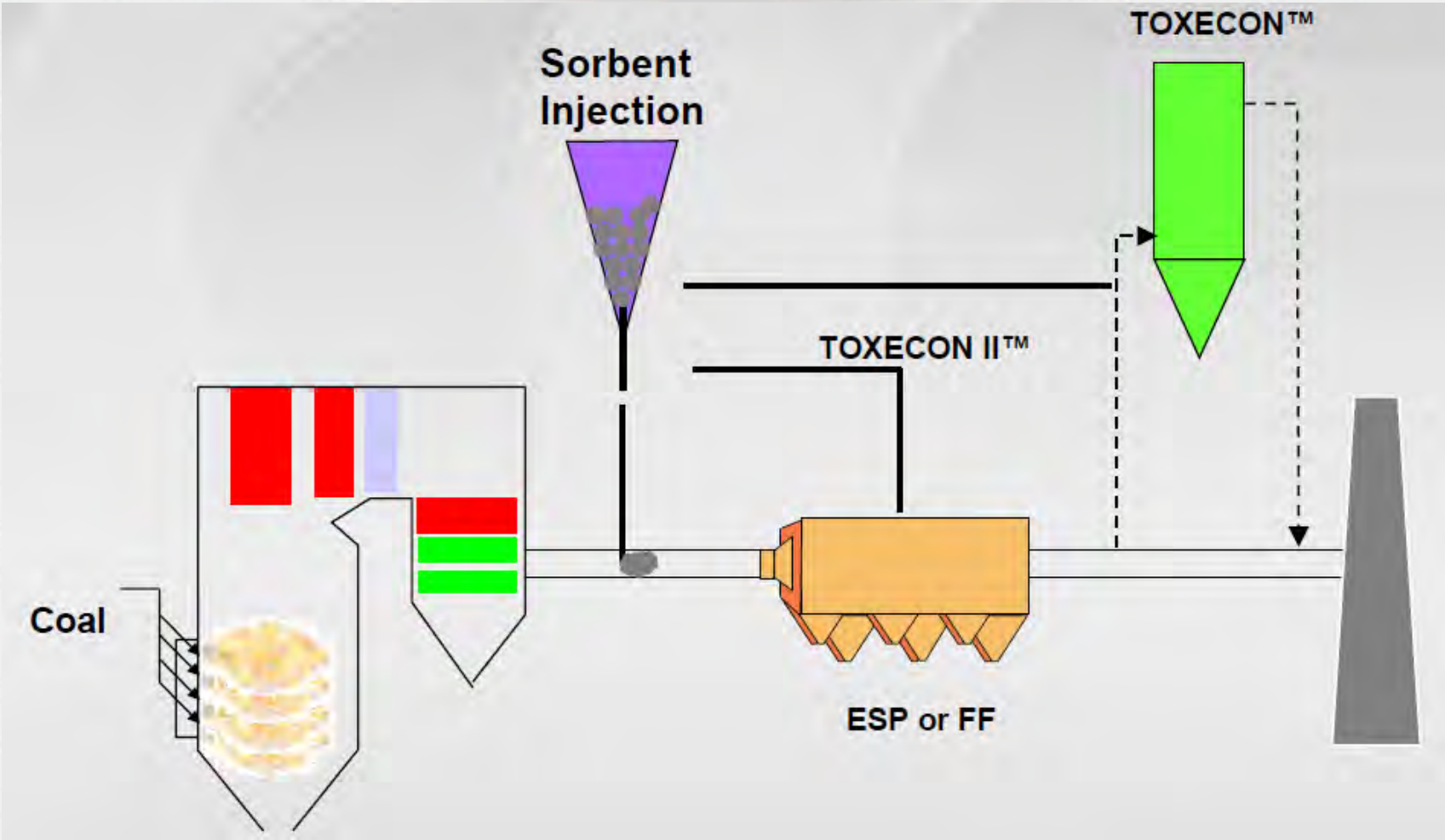
1. External diffusion
2. Internal Diffusion
3. Adsorption (physical or chemical)

Applications:

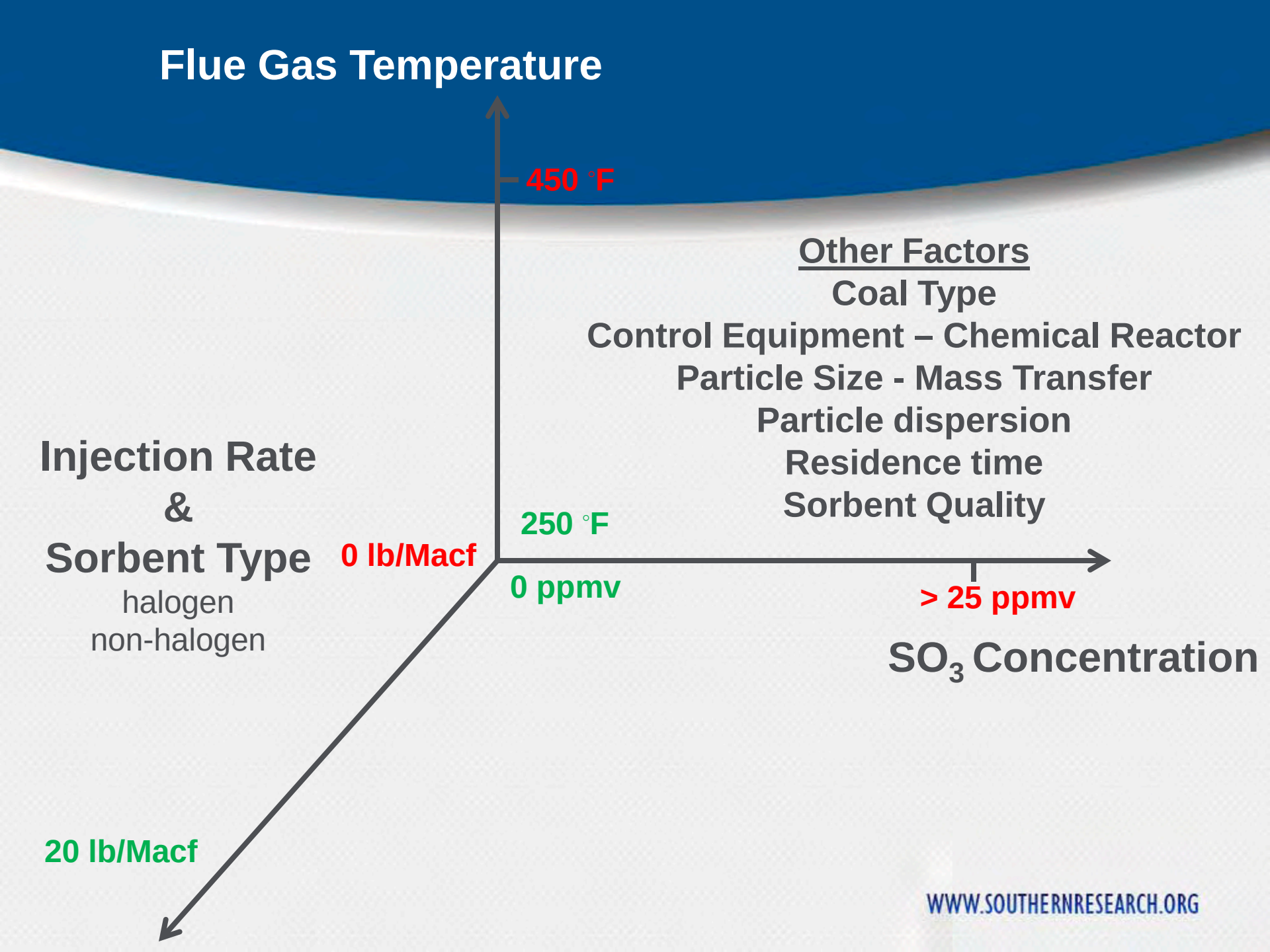
- water treatment
- Air pollution control



Using Solids to Remove Mercury



Compliments of ADA.ES


Flue Gas Temperature
450 °F
Other Factors
Coal Type
Control Equipment – Chemical Reactor
Particle Size - Mass Transfer
Particle dispersion
Residence time
Sorbent Quality
Injection Rate
&
Sorbent Type
halogen
non-halogen
250 °F
0 lb/Macf
0 ppmv
> 25 ppmv
SO3 Concentration
20 lb/Macf
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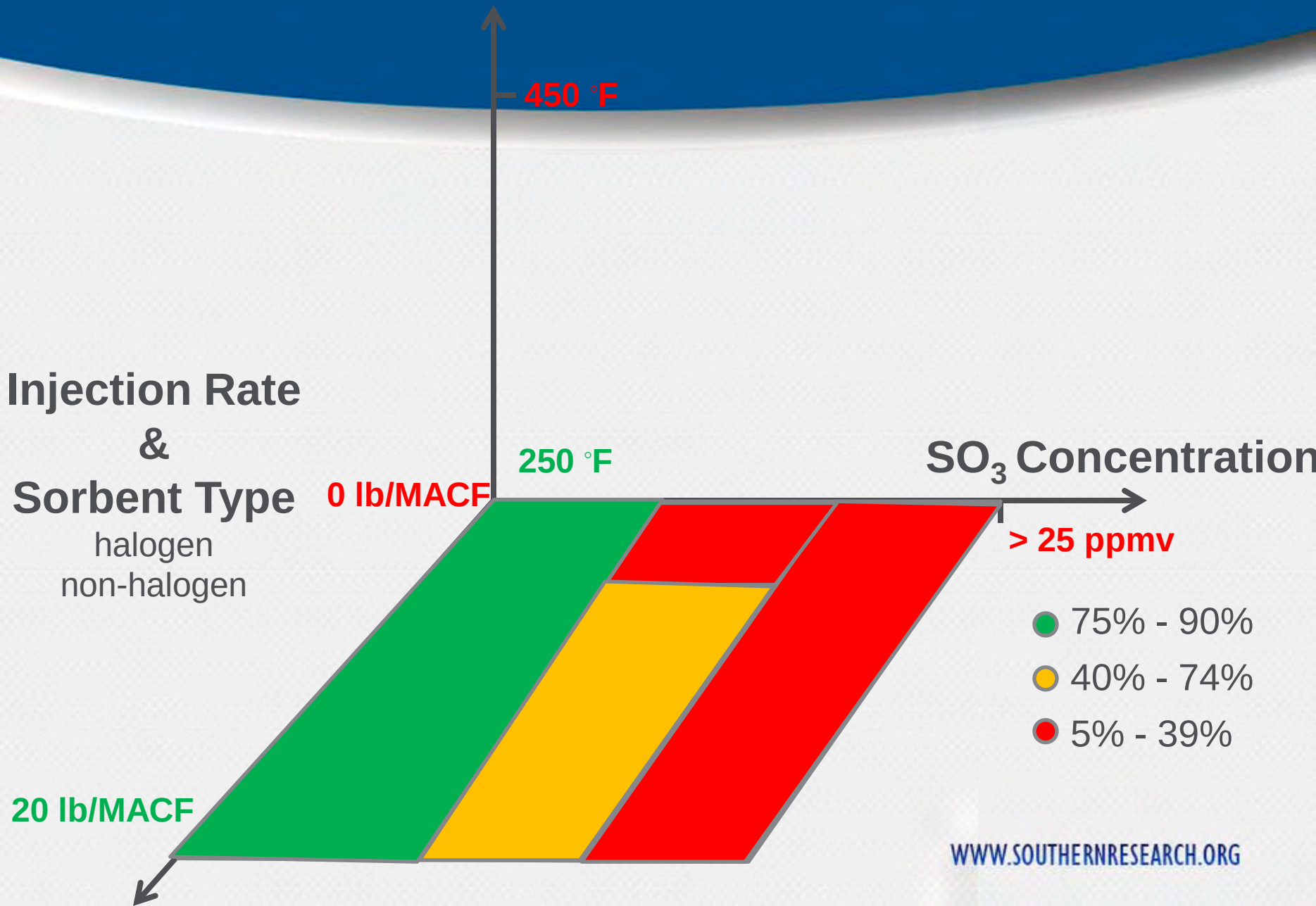
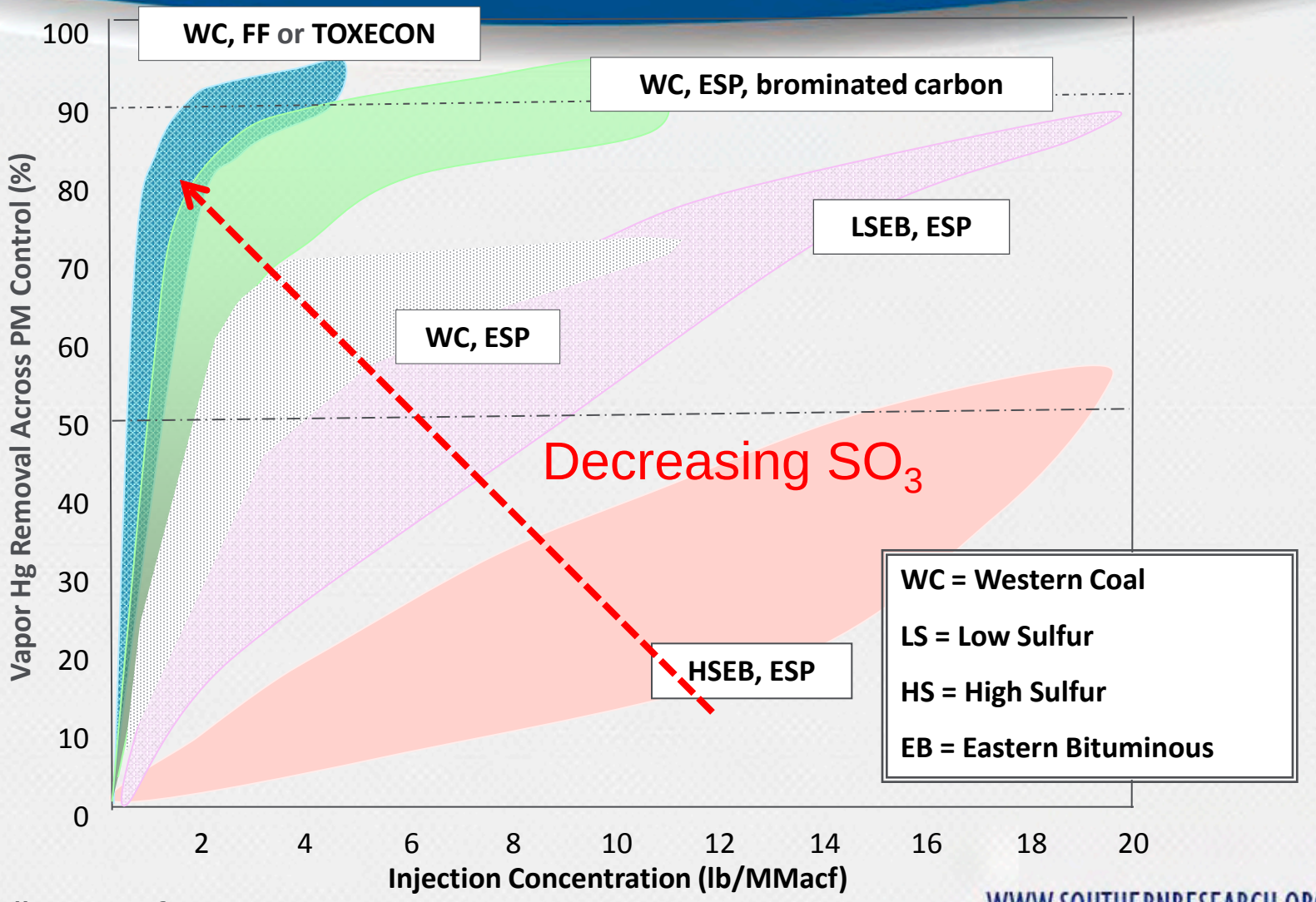
Flue Gas Temperature



Activated Carbon Removal Trends



Compliments of EPRI

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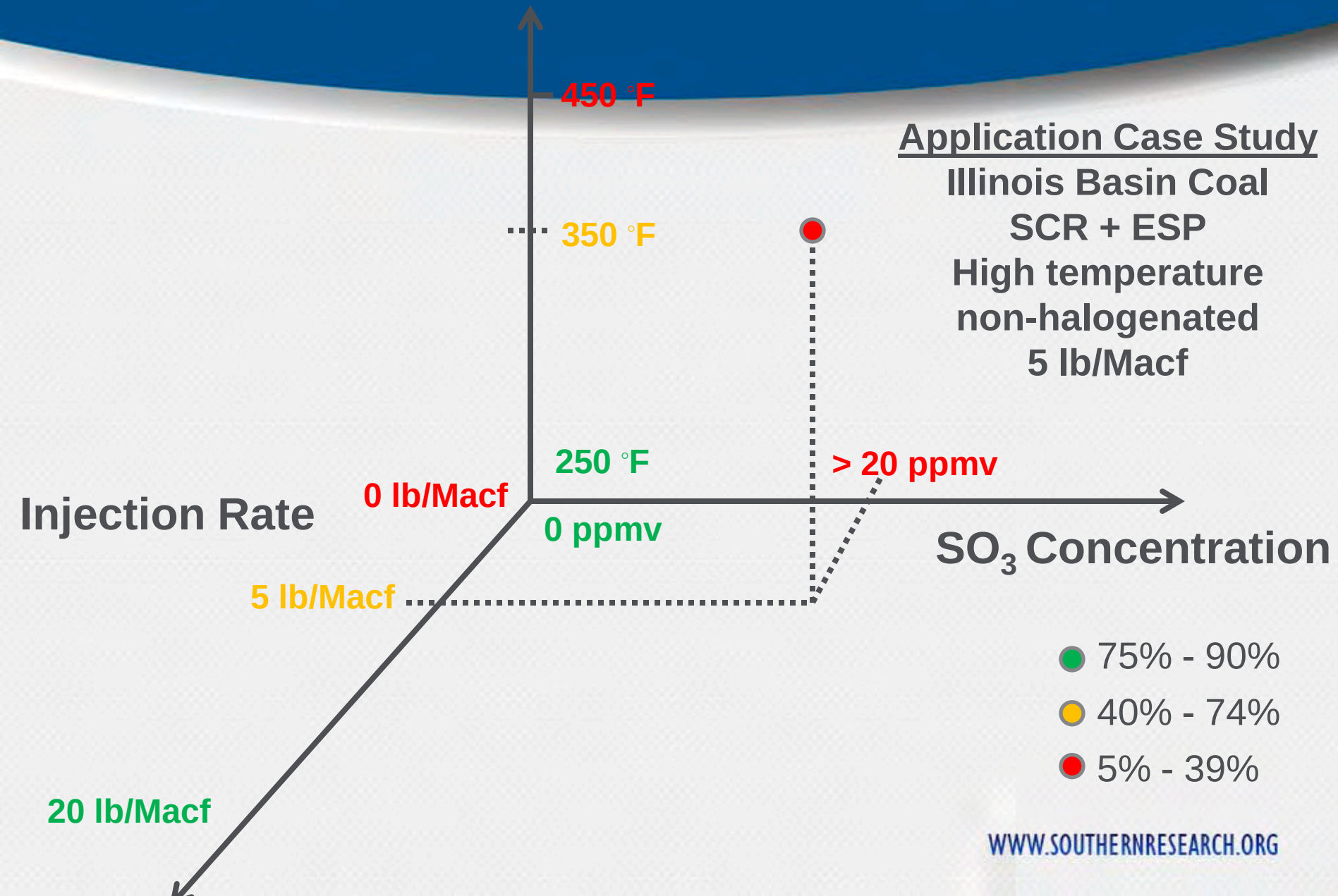
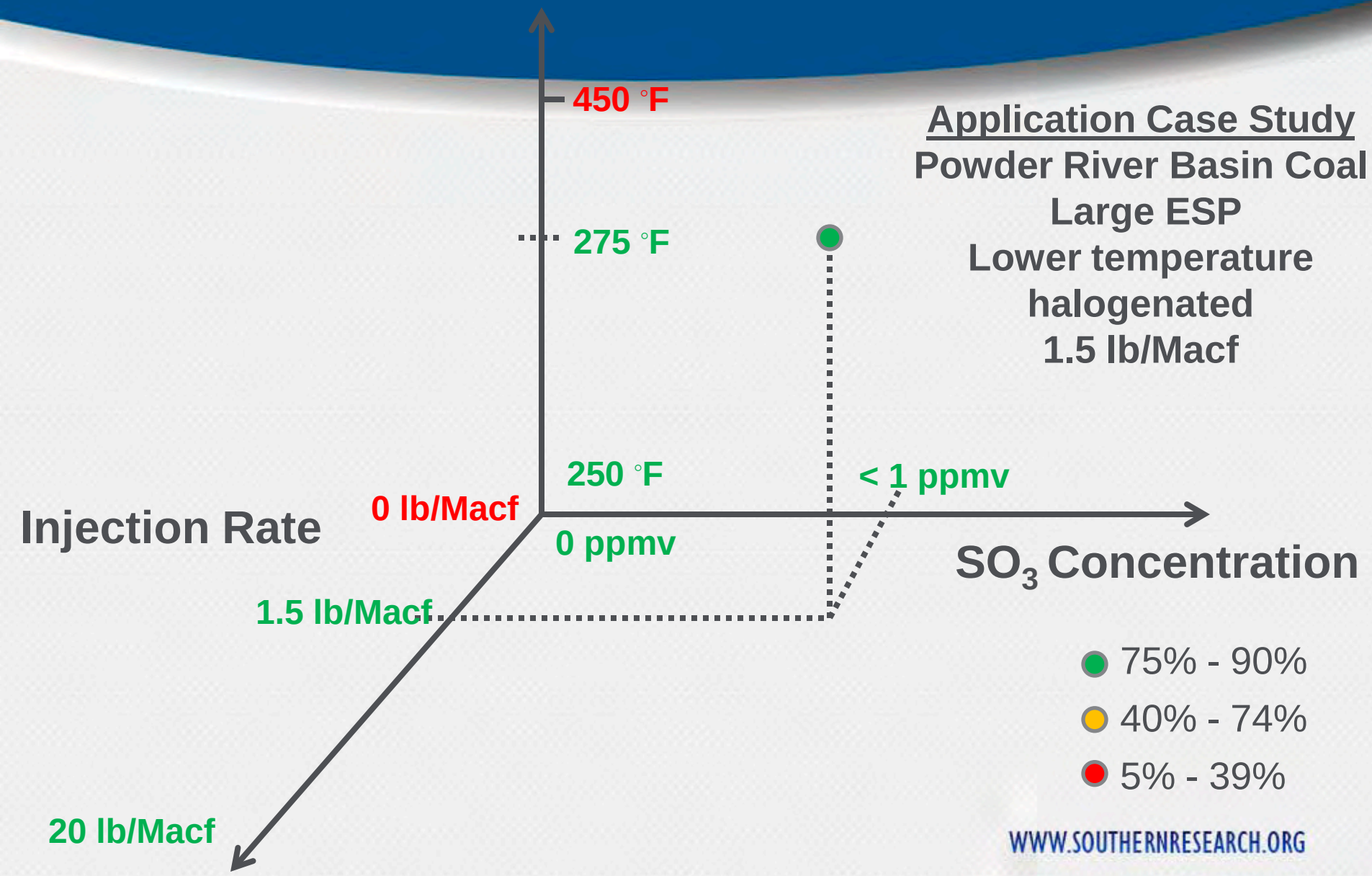
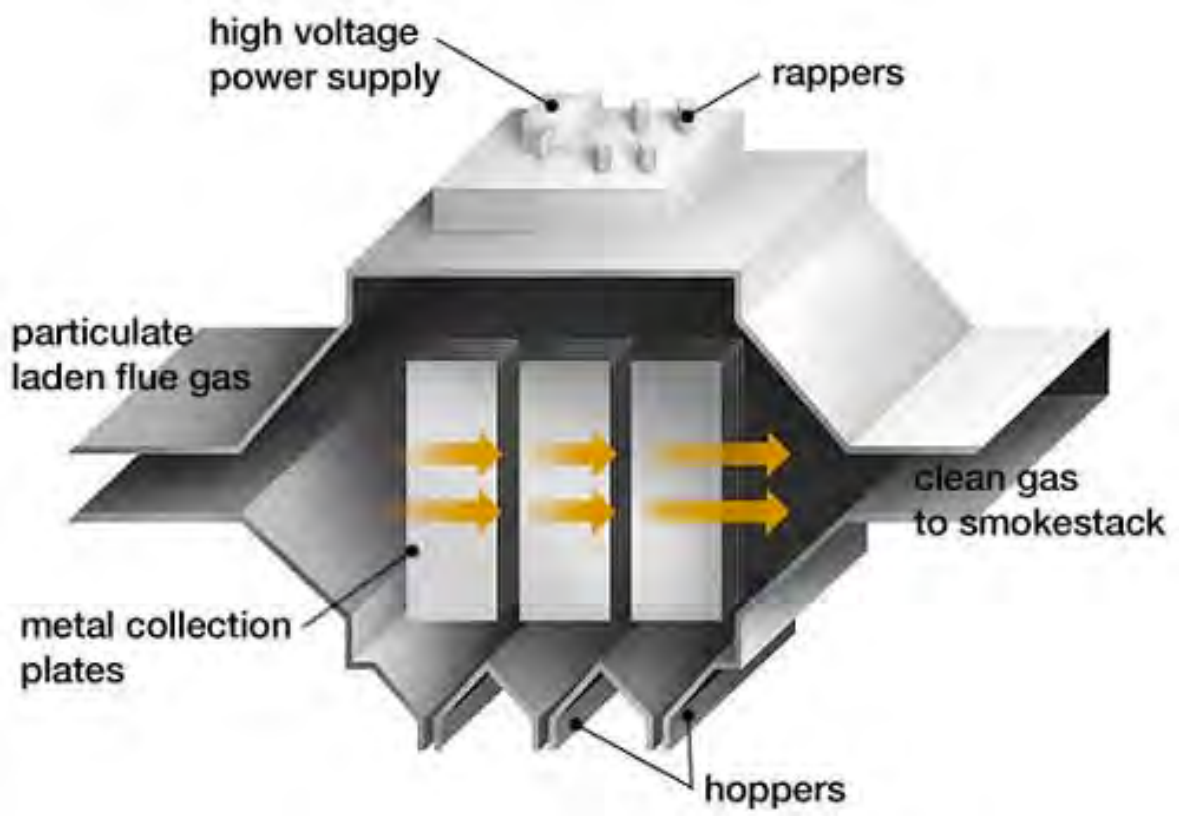
Flue Gas Temperature

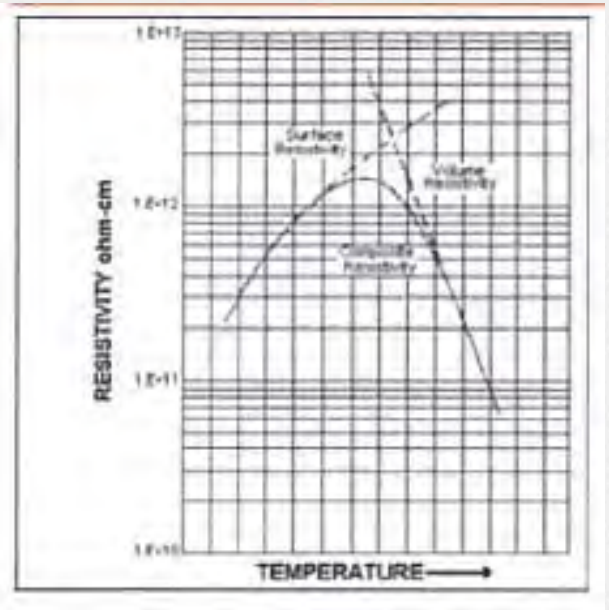


Flue Gas Temperature



Electrostatic Precipitation





Other Important Parameters

- Insulators
- Rapping Frequency
- Hopper Evacuation
- ESP Flow

Electrostatic Precipitation

MERCURY

1.2 lb / TBtu

Increase ACI Rate
Reduce SO_3 Concentration
- DSI
- Eliminate SO_3 FGC

Decrease particle size

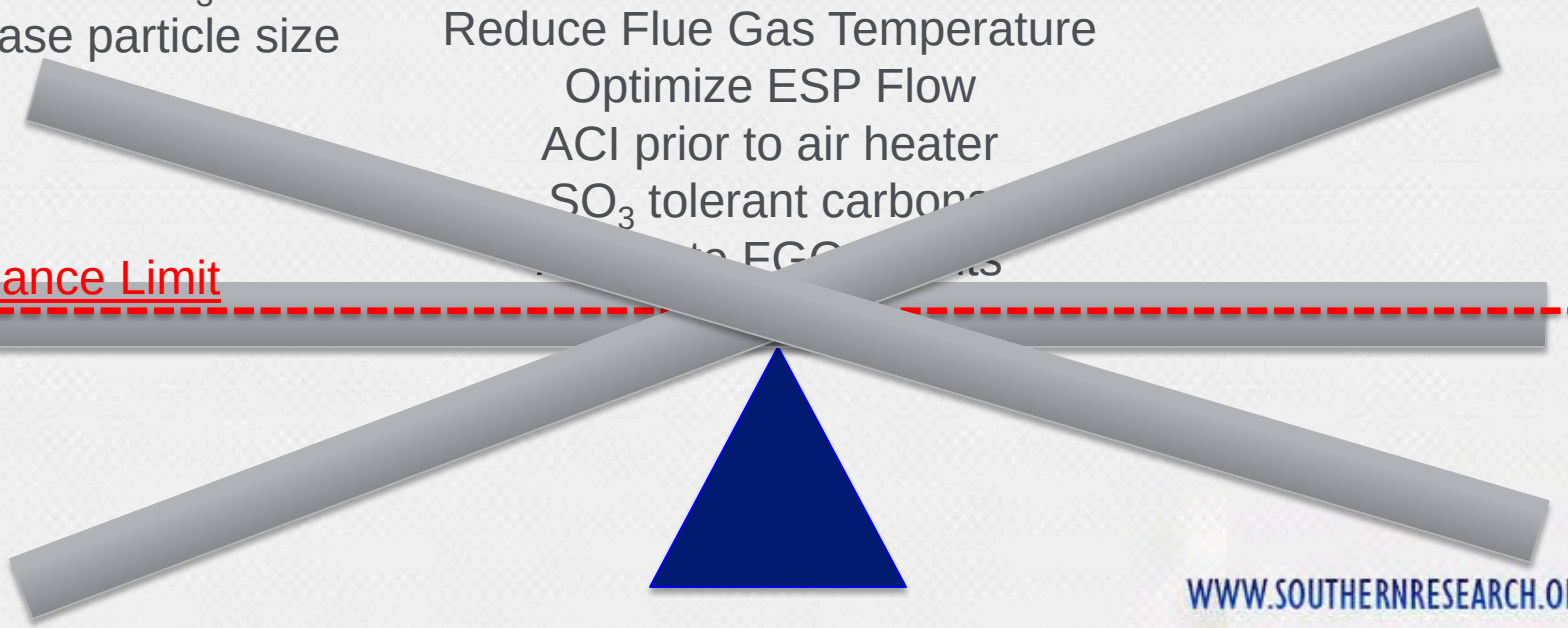
PARTICULATE MATTER

0.03 lb / MMBtu

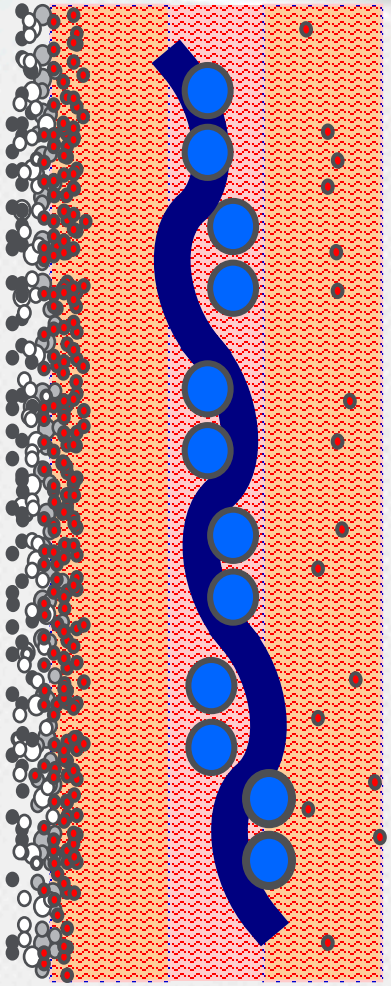
Optimize PM Resistivity

Increase ESP Size
Reduce Flue Gas Temperature
Optimize ESP Flow
ACI prior to air heater
SO_3 tolerant carbon

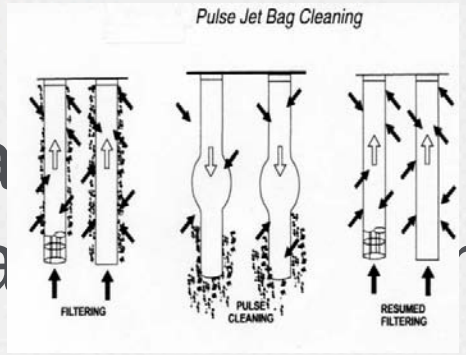
Compliance Limit



Baghouse Technology



Bag



Bag Cleaning

MW	# of Bags	# of comp	Total Collection area (ft^2)	Football Field eq.
500	12,288	12	419,758	7.3
750	26,112	24	891,986	15.5

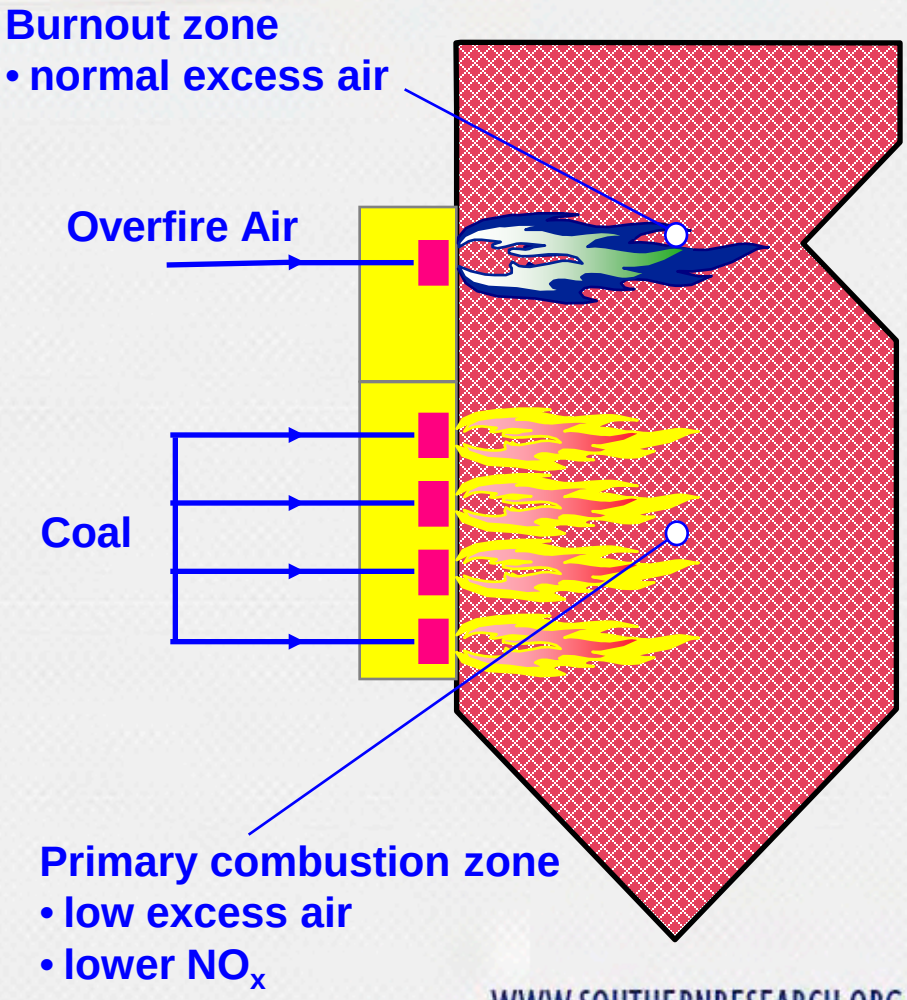
Baghouse Removal Efficiency

Compounds	Chemical Abbreviation	Typical concentration	Typical Removal (%)	Typical Effluent Concentration
Sulfur Dioxide** (ppmv)	SO_2	150 - 3500	0 - 25%	150 – 2625
Sulfur Trioxide** (ppmv)	SO_3	0 - 25	25 - 95%	0 – 17
Hydrochloric Acid** (ppmv)	HCl	10 - 500	99.9%	0 - 0.5
Oxidized Hg** (lb/TBtu)	Hg^{2+}	4	20 - 90%	0.4 – 3.6
Elemental Hg** (lb/TBtu)	Hg^{O}	4	0 - 90%	0.4 – 4
Filterable PM (lb/MMBTU)	PM	0.05	99.9%	0.005
Heavy Metals (ppbv)	As, Mg, Mn	N/A	95%	N/A

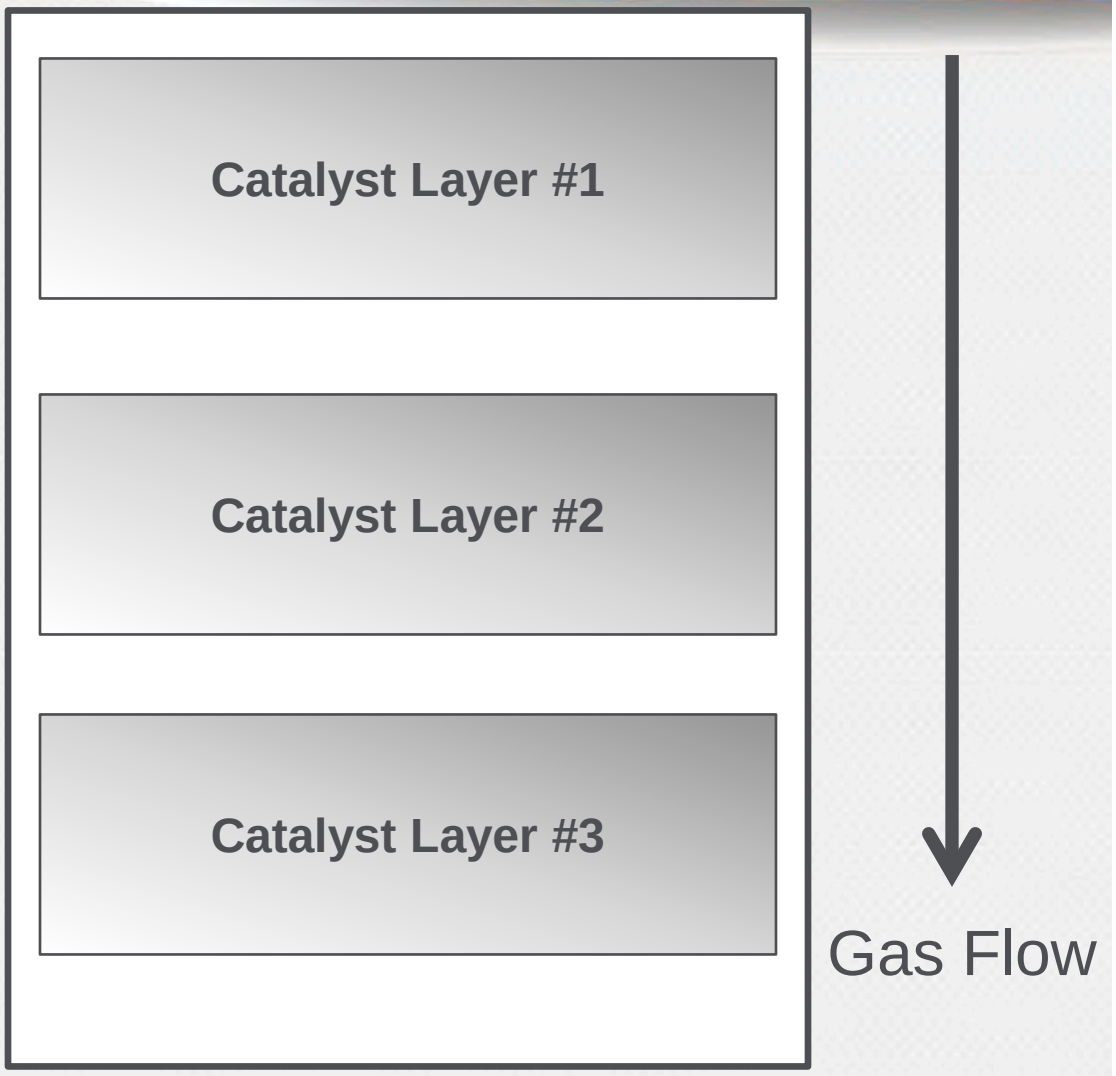
** Removal is due to the addition of sorbent (carbon, trona, lime)
PM Inlet concentration is based on ESP in front of baghouse

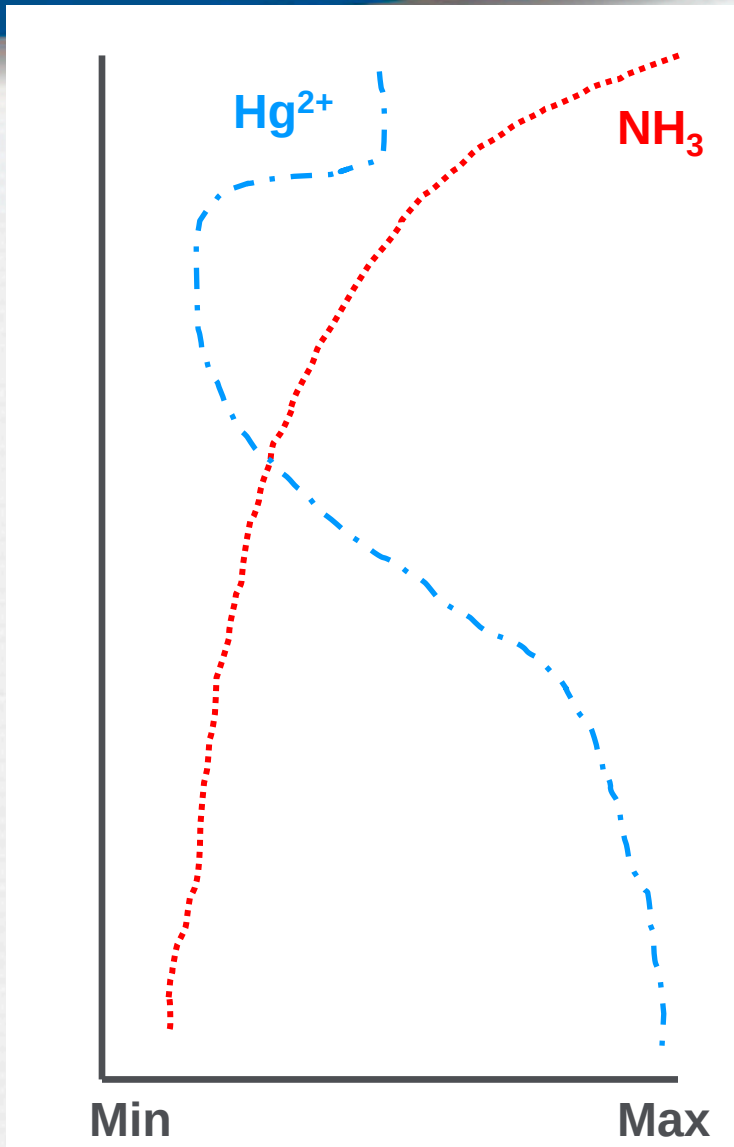
NO_x Formation & Abatement

- NO_x formed during combustion from nitrogen in fuel or air
- Low NO_x burners and air staging provide 60% reduction (1.2 lb/MBtu to ~0.5 lb/MBtu)
- Next level of NO_x reduction more difficult



Hg Behavior Correlates w/ SCR Operations





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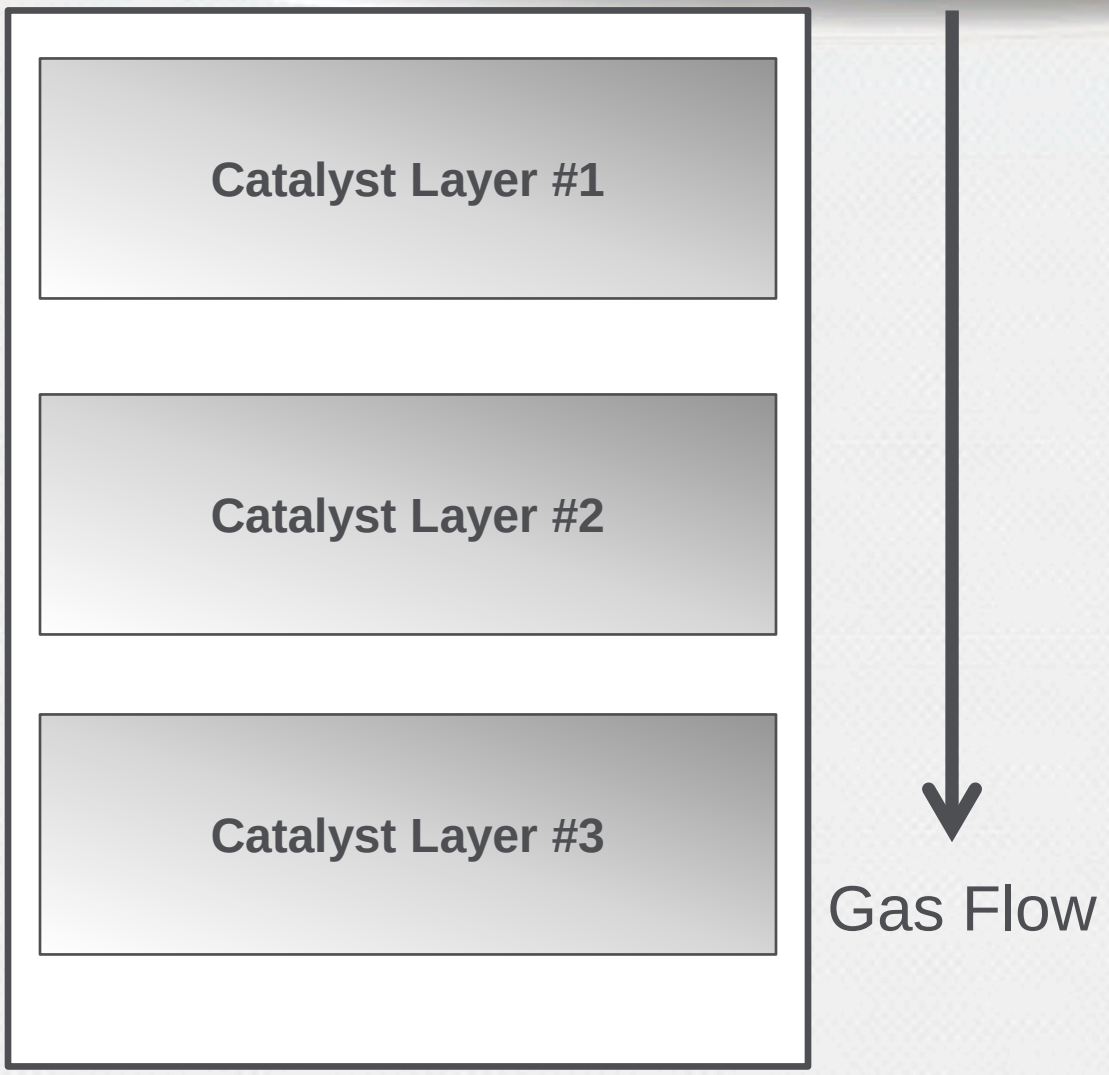
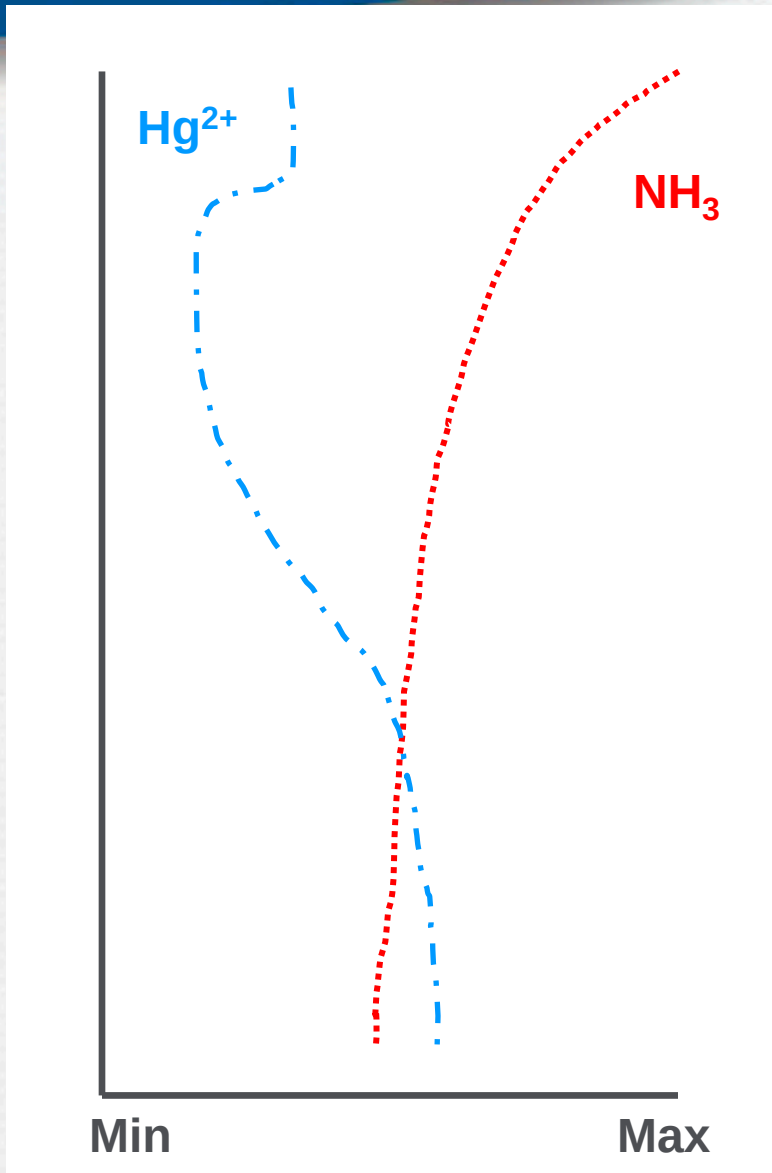
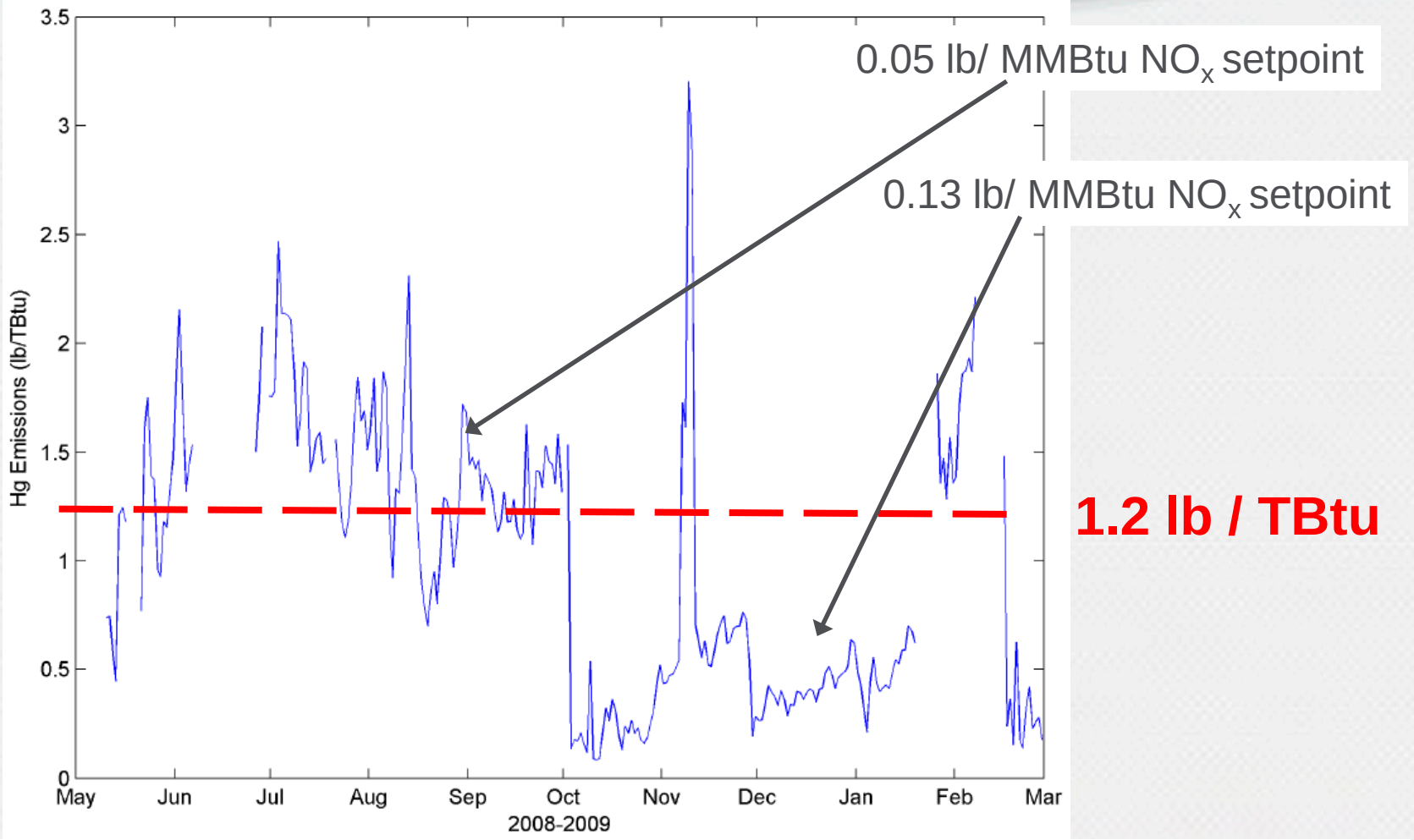


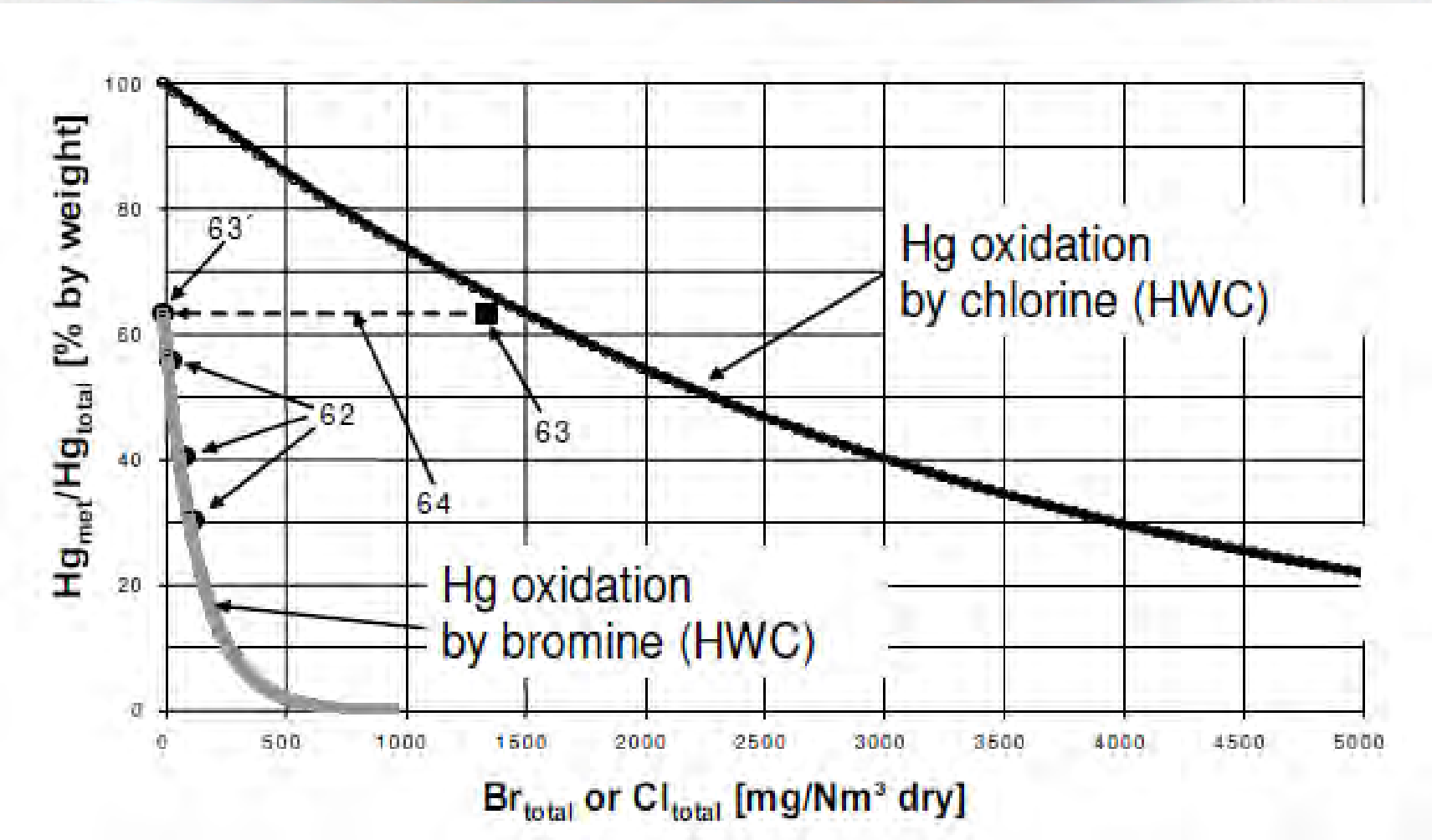


Hg Emissions Correlates w/ SCR Operations



900 MW Eastern bit unit with SCR and wet FGD

Bromine vs. Chlorine



Provided by Bernhard Vosteen

Halogens as Oxidants

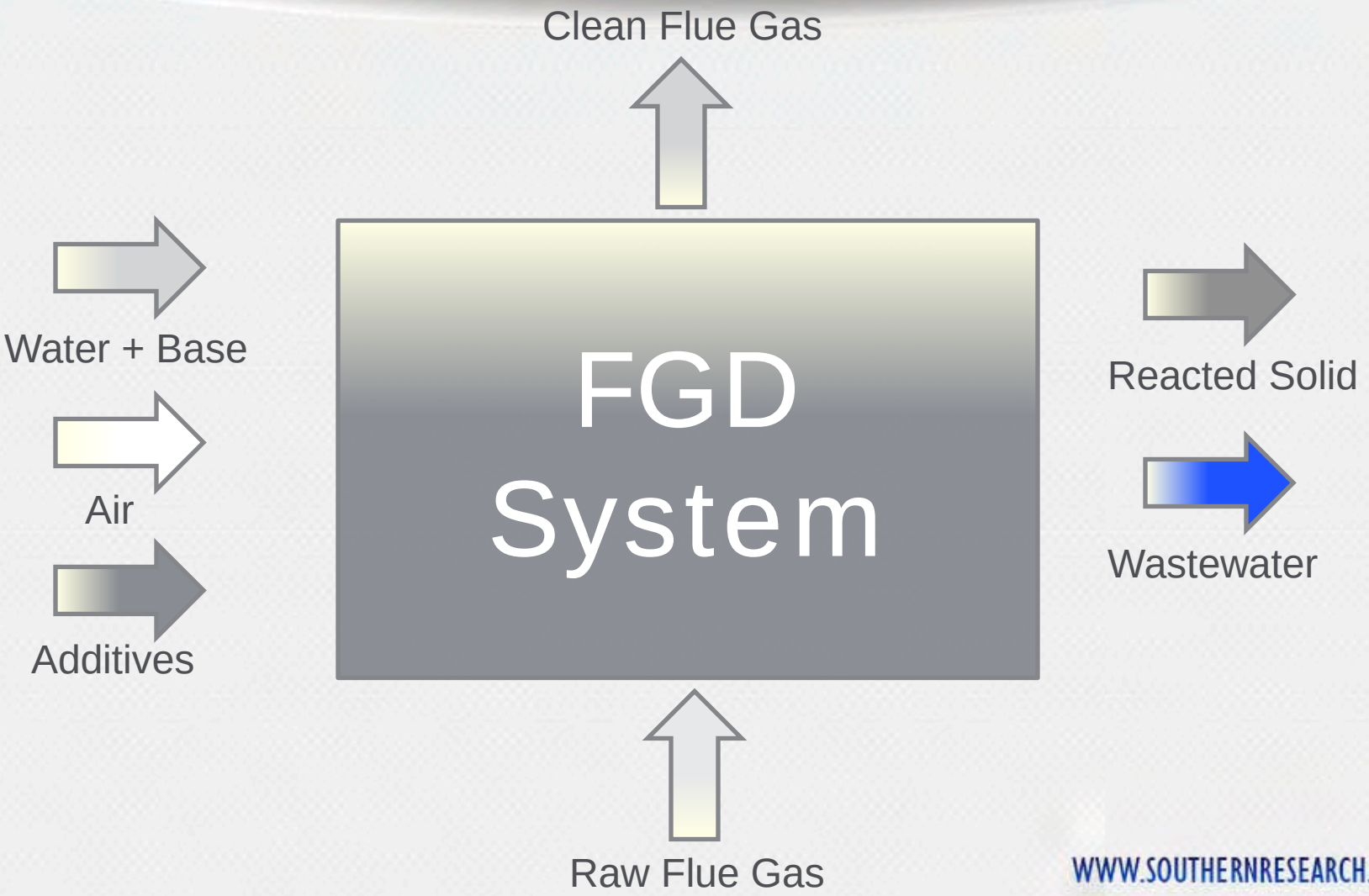
- Common Halogens Added to the Coal
  - Calcium Bromide ($CaBr_2$)
  - Calcium Chloride

- Halogens Added to the Flue Gas
  - Bromine Gas (Br_2)
  - Hydrobromic Acid (HBr)
  - Hydrochloric Acid (HCl)
  - Ammonium Chloride (NH_4Cl)
  - Potassium Iodide (KI)

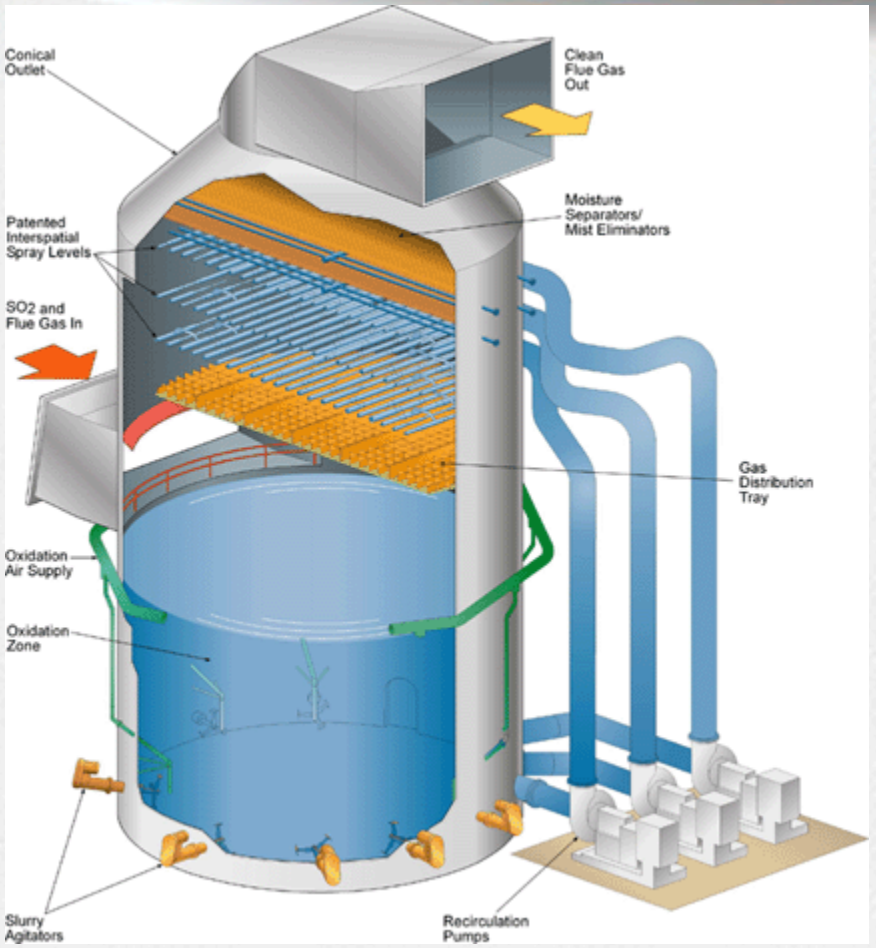
SCR / SNCR Removal / Conversion Efficiency

Compounds	Chemical Abbreviation	Typical concentration	Typical Removal (%)	Typical Effluent Concentration
Sulfur Dioxide (ppmv)	SO_2	150 - 3500	0%	150 – 3500
Sulfur Trioxide** (ppmv)	SO_3	0 - 25	+1 - 5%	0 – 30
Hydrochloric Acid**	HCl	10 - 500	0%	10 - 500
Oxidized Hg** (lb/TBtu)	Hg^{2+}	4	+50 – 90%	6 – 7.6
Elemental Hg** (lb/TBtu)	Hg^{O}	4	-50 – 90%	0.4 – 2
SCR – NO_X (lb/MMBtu)	NO_x	0.5	90%	0.05
SNCR – NO_X (lb/MMBtu)	NO_x	0.5	25%	0.375

SO_2 Scrubbers



SO_2 Wet Scrubbing Process

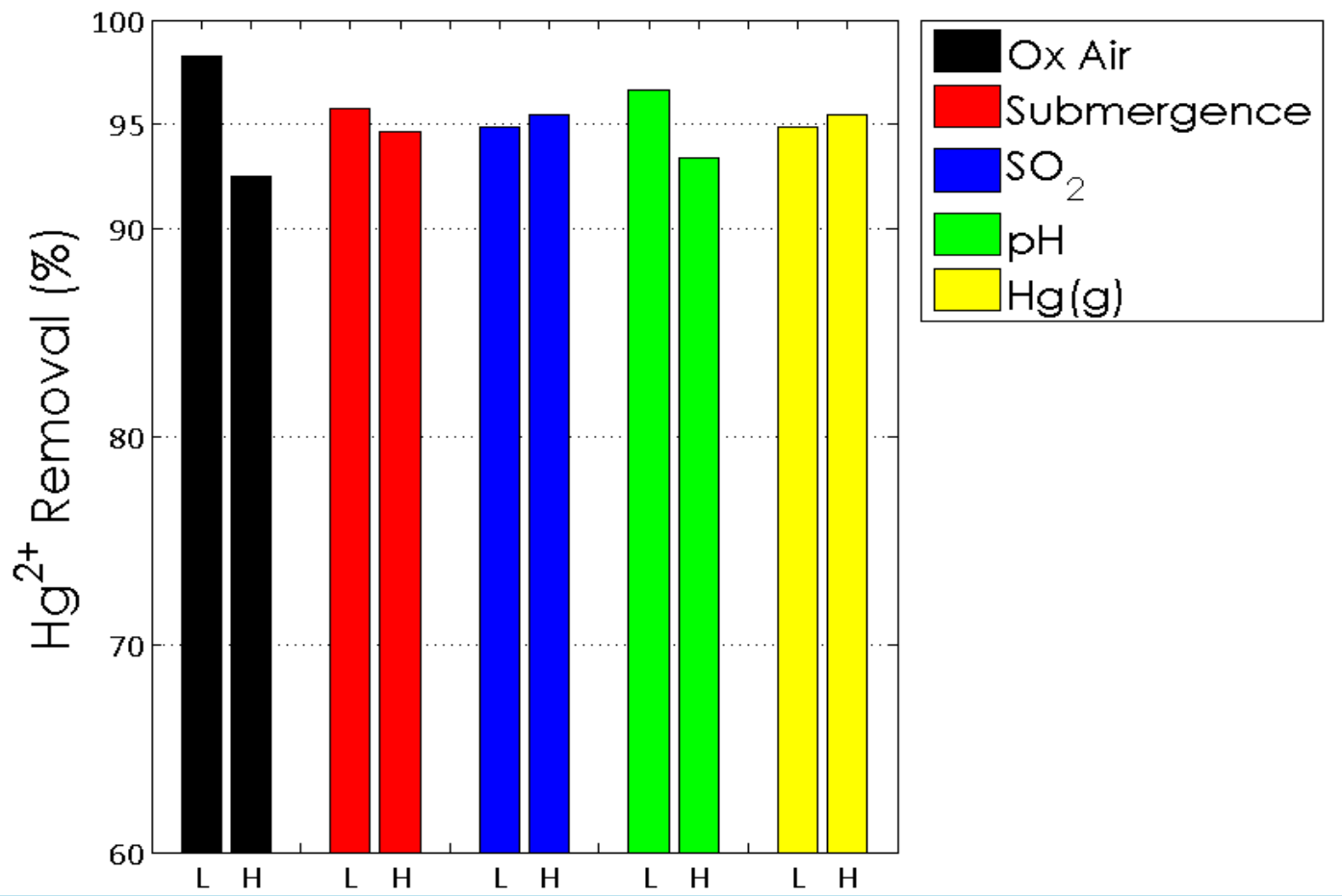


$$CaCO_3 + SO_2 + \tfrac{1}{2} O_2 \rightarrow CaSO_4 + CO_2$$

General Equation

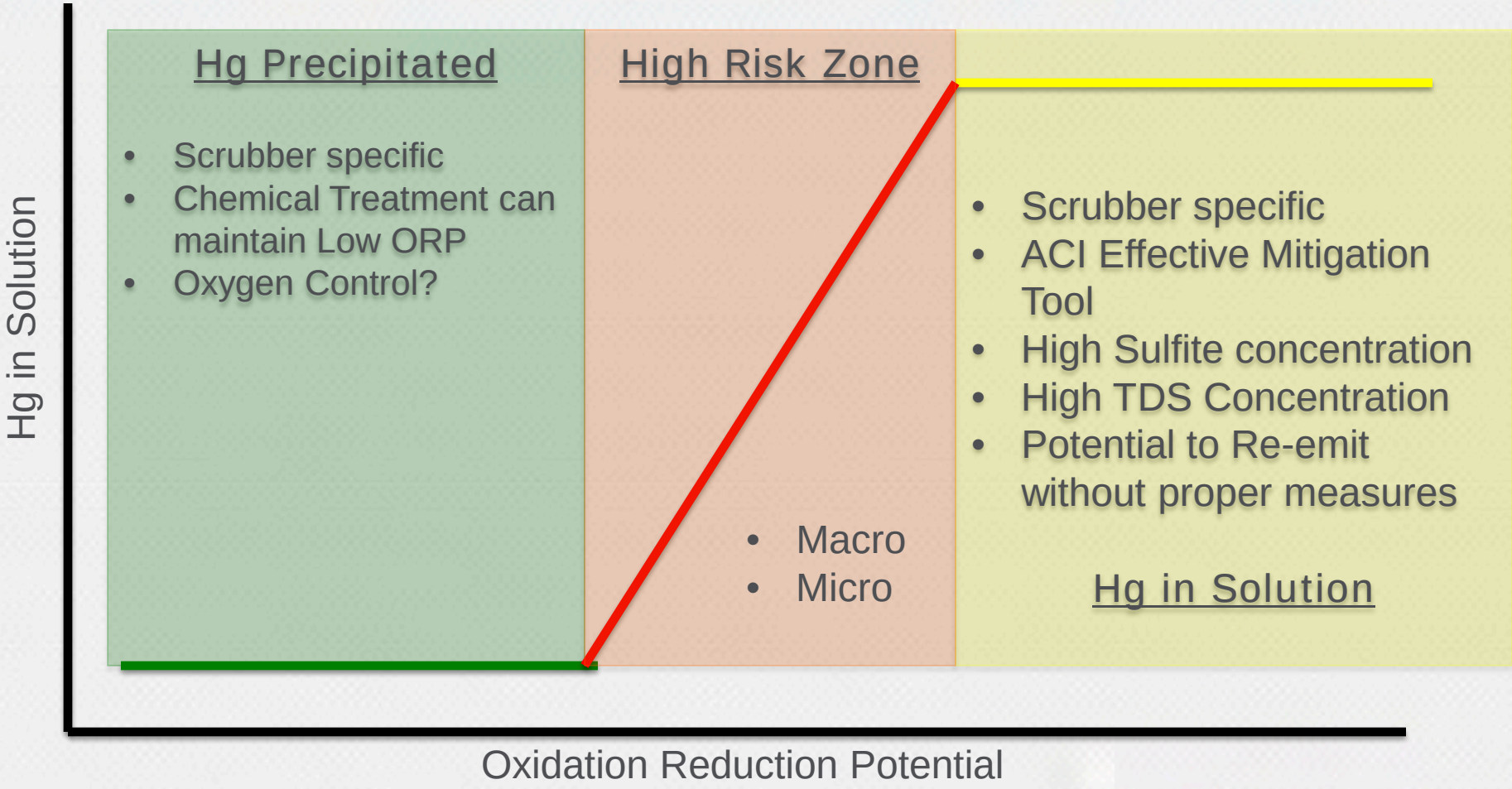
- Use limestone-water slurry (base) to neutralize the SO_2 (acid)
- Intimate contact between flue gas and slurry required
- Sludge or gypsum produced
- Flue gas is cooled and saturated with water

Variables that affect Hg^{2+} capture



Oxidized mercury capture averaged 95% and was independent of fuel S, fuel Hg, liquid submergence, pH, and oxidation air.

Potential to Re-Emit Mercury



Performance Improvement Techniques

Mercury Research Center
Pilot wet FGD

Courtesy of Particulate Control Technologies

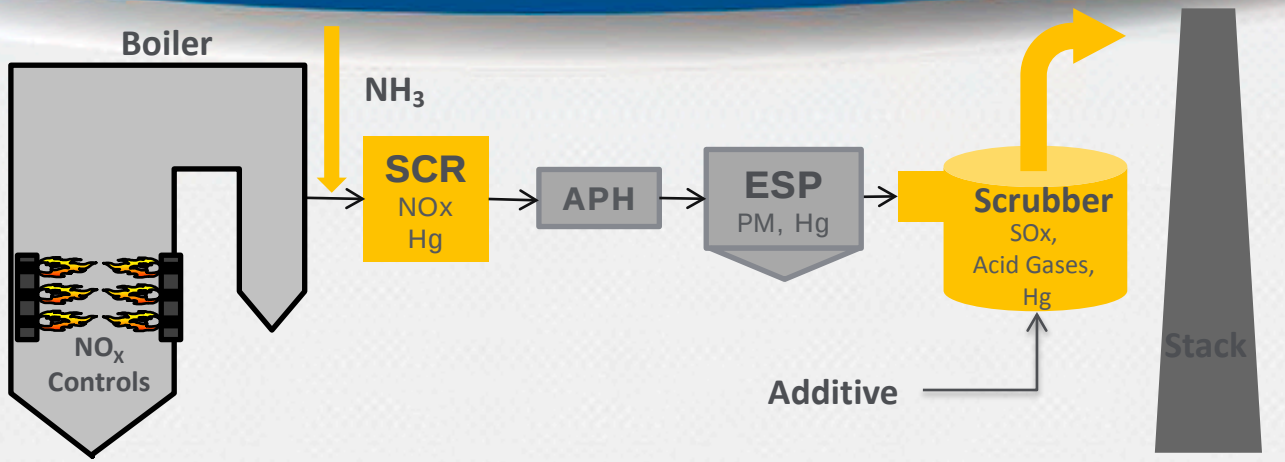
- Increase Hg Oxidation
  - Purchase Hg Oxidation Catalyst
  - Replace catalyst more frequently
  - Increase halogen content artificially
  - Decrease NH_3 concentration
  - Decrease flue gas temperature
- Manage wet FGD operations
  - Minimize Hg re-emissions
    - Use of chemical additives
    - Better Understand ORP of your scrubber

FGD Removal Efficiency

Compounds	Chemical Abbreviation	Typical concentration	Typical Removal (%)	Typical Effluent Concentration
Sulfur Dioxide (ppmv)	SO_2	150 – 3500 150 -1000	95 - 98% 90 – 95%	8 – 175 15 - 50
Sulfur Trioxide (ppmv)	SO_3	0 - 25	0 - 25% 90 -99%	0 – 17 0 – 2.5
Hydrochloric Acid**	HCl	10 - 500	99.9%	0 - 0.5
Oxidized Hg** (lb/TBtu)	Hg^{2+}	7.6	95%	0.4
Elemental Hg** (lb/TBtu)	Hg^{O}	0.4	0 to -200%	0.4 – 1.2
PM (lb/MMBtu)	PM	0.05 5	-50% to 80% 95 - 99%	0.01 - 0.075 0.05

** Assumes SCR is Installed for deNOx and Hg Oxidation

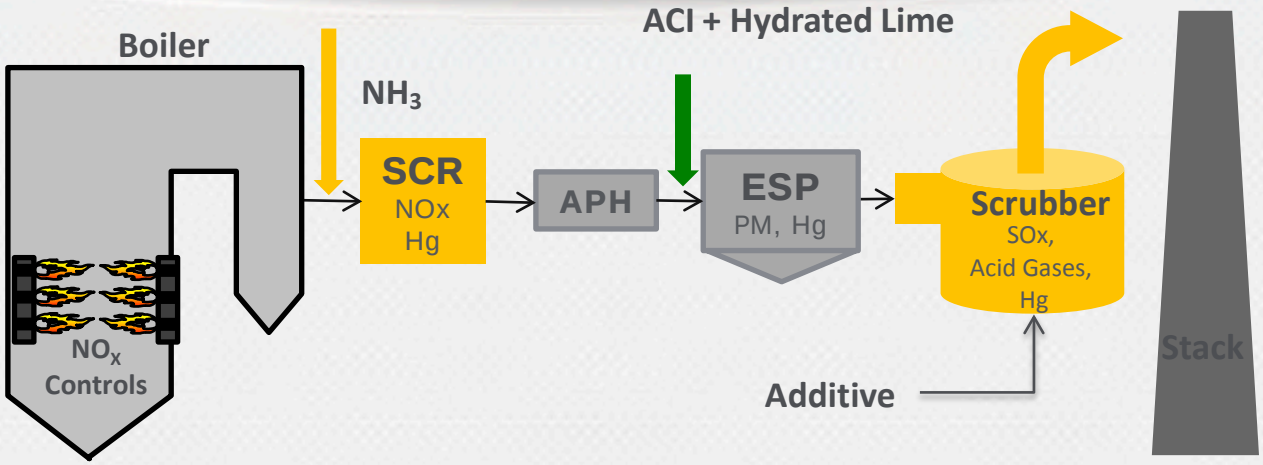
Example – "What Happens to Mercury"



	Boiler	Boiler Exit	SCR	ESP	FGD	Removal
Hg^0	10					
Hg^{2+}	0					
Hg^T	10					
Removal						

ILB Coal with 2000 ppm Cl

Example – "What Happens to Mercury"



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Hg^0	10					
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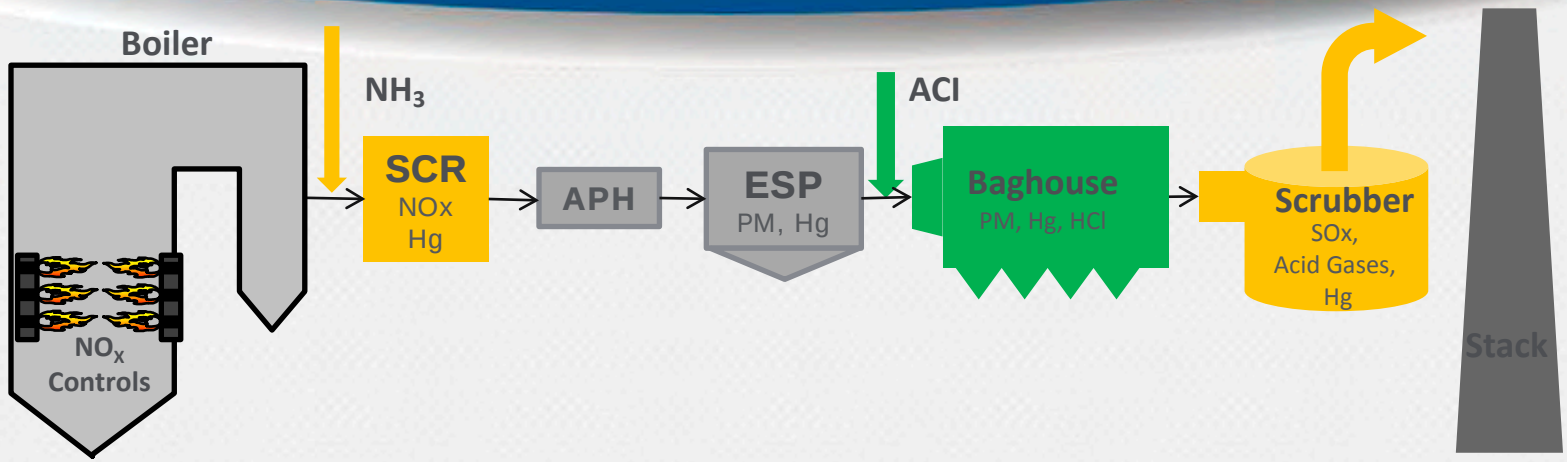
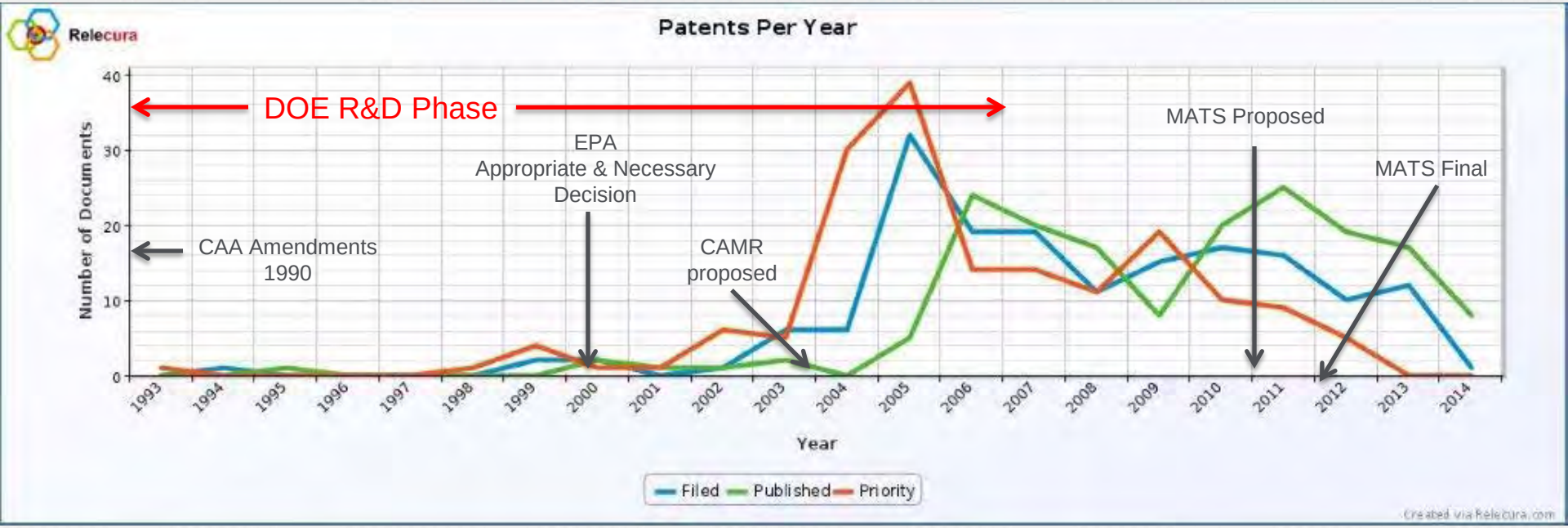


	Boiler	Boiler Exit	SCR	ESP	TOXECON	FGD	Removal
Hg^0	10						
Hg^{2+}	0						
Hg^T	10						
Removal							

PRB Coal with $CaBr_2$ Addition & Halogenated Carbon Inj.

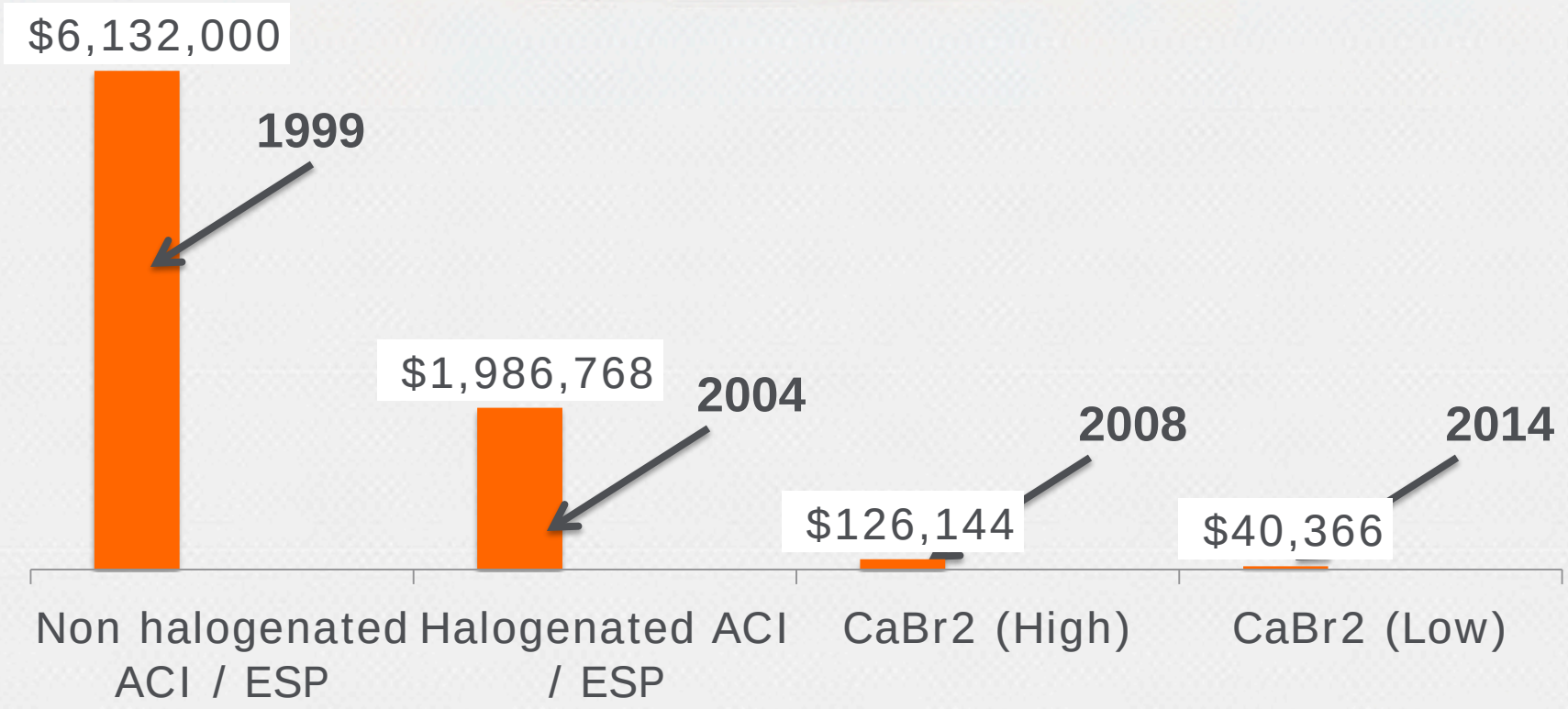
Mercury Patented Technology Technology Development

Patent Search Keywords: Mercury; Power Plants; Flyash, Control



- Number of filed patent closely resembles EPA Regulatory Timeline

“Diminishing Cost”
Yearly Additive Cost



700MW Unit, Powder River Basin Coal
SCR, ESP, Wet FGD with 90% Hg removal

Future of Mercury Control

- Technology Development
  - Vendors continue to innovate
  - Value proposition will continue to change
  - Utilities will innovate once operation phase commences
  - Removal efficiencies will increase asymptotically
- Other
  - Electricity will be impacted by MATS compliance ~ magnitude uncertain

QUESTIONS