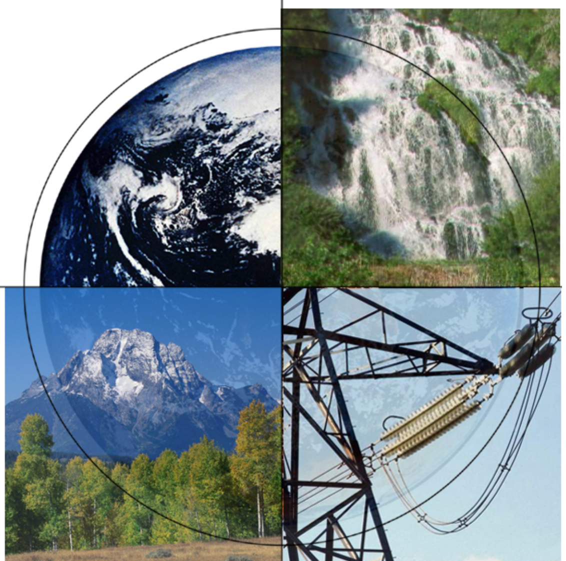
NOx & Mercury Control Technology DOE's R&D Program



2005 EIA Midterm Energy Outlook and Modeling Conference

Washington, DC
April 12, 2005

Bruce Lani, Project Manager
National Energy Technology Laboratory

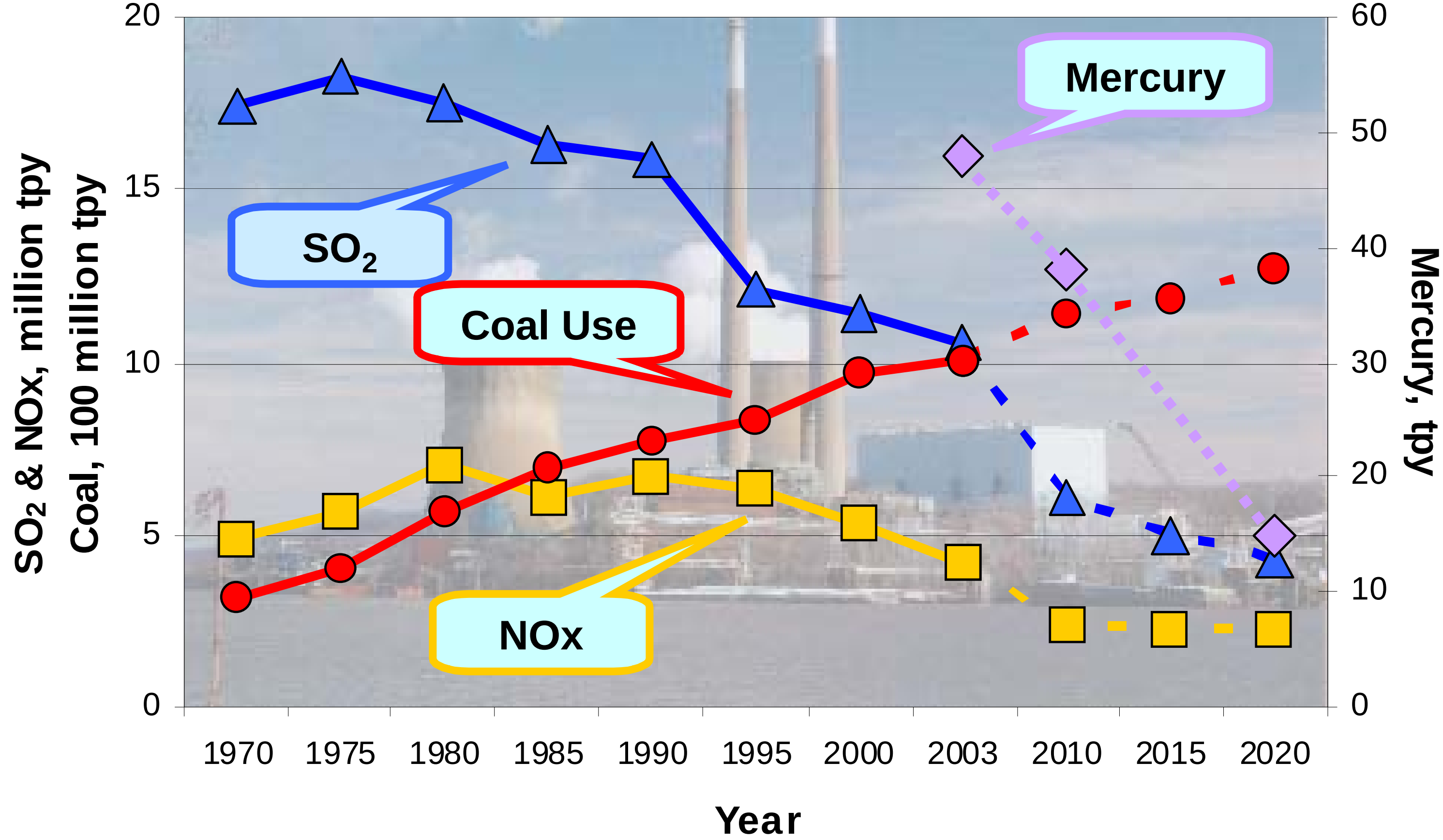
New Regulatory Drivers for Coal-Fired Power Plant Emissions

- **Clean Air Interstate Rule (CAIR)**
  - Announced March 10, 2005
  - Implementation via two phase Eastern regional cap & trade program
  - Phase I (2009/2010)
    - 1.5 million ton NOx cap in 2009 (53% reduction)
    - 3.6 million ton SO_2 cap in 2010 (45% reduction)
  - Phase II (2015)
    - 1.3 million ton NOx cap (61% reduction)
    - 2.5 million ton SO_2 cap (73% reduction)

- **Clean Air Mercury Rule (CAMR)**
  - Announced March 15, 2005
  - Implementation via two phase nation-wide cap & trade program
  - Phase I (2010)
    - 38 ton mercury cap (21% reduction)
  - Phase II (2018)
    - 15 ton mercury cap (69% reduction)

Note: Percentage reductions from 2003 baseline emission levels.

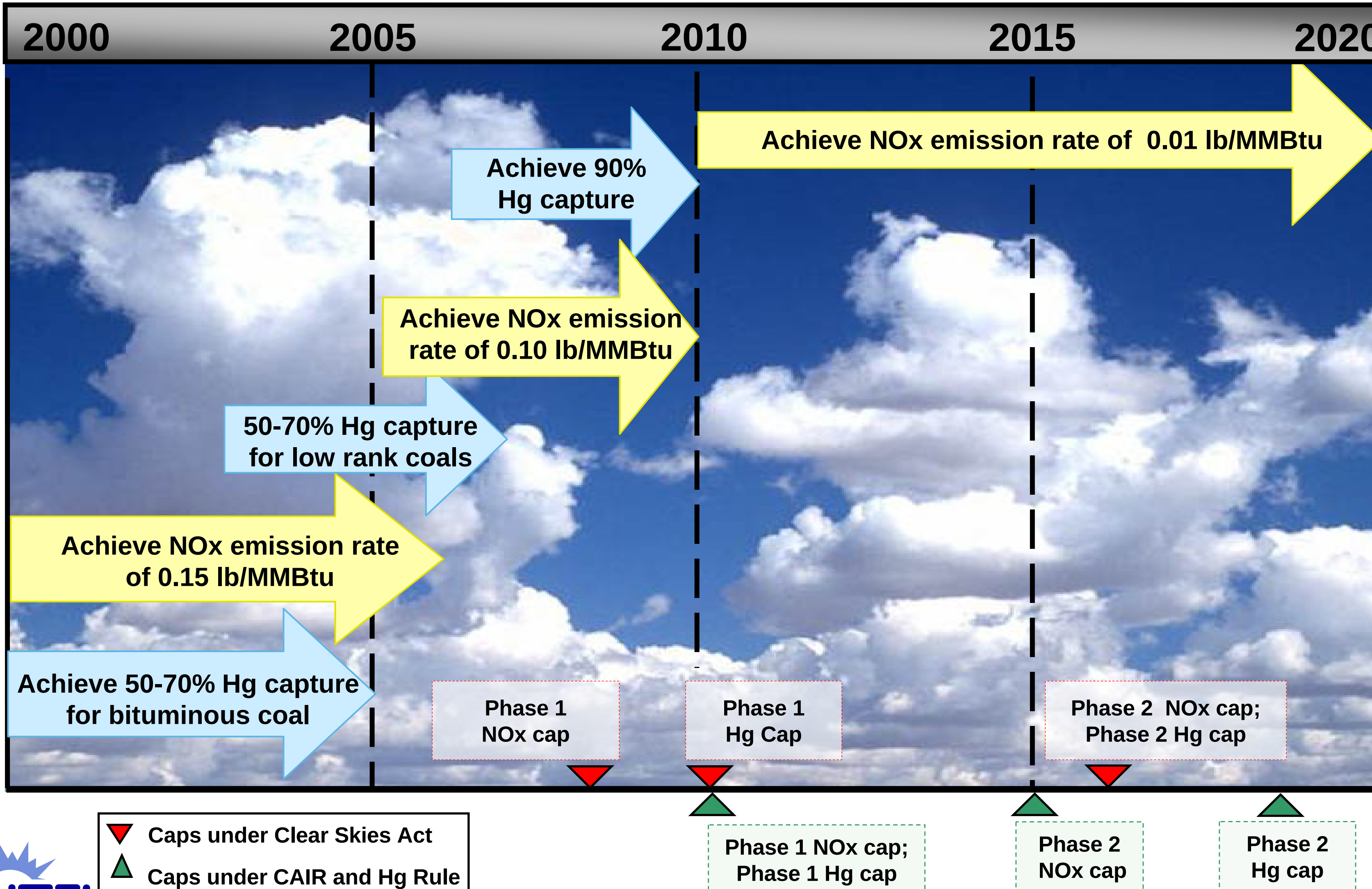
Trends and Projections



National electric power sector coal use and emissions per EIA & EPA databases.

Innovations for Existing Plants Program

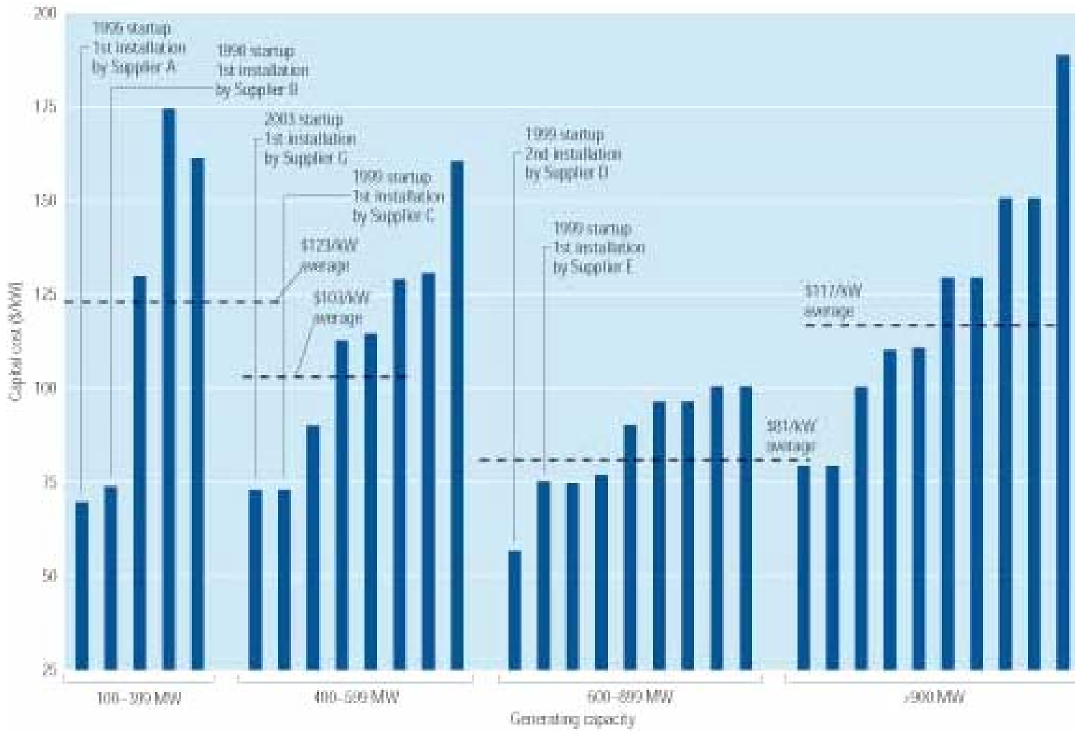
Mercury & NOx Goals



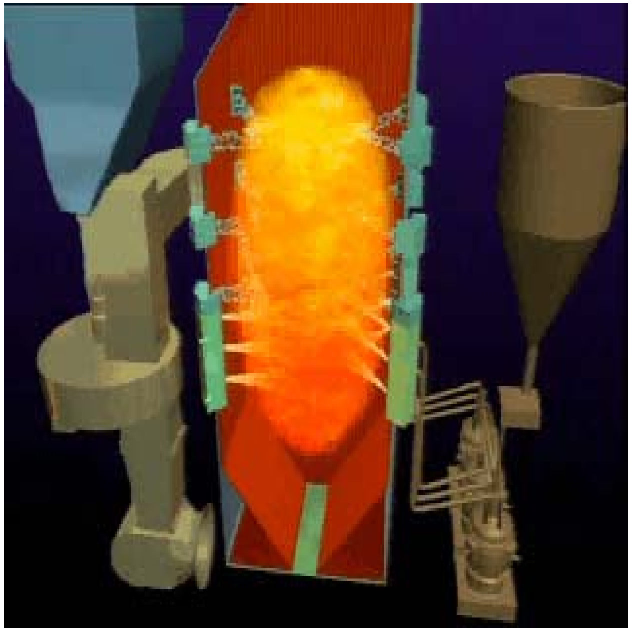
Current NOx Performance Standard - SCR

- **Advantages**
  - 90% reduction
  - Adaptive to most boilers

- **Disadvantages**
  - Expensive
  - NH_3 storage and slip
  - Parasitic load
  - SO_3 generation

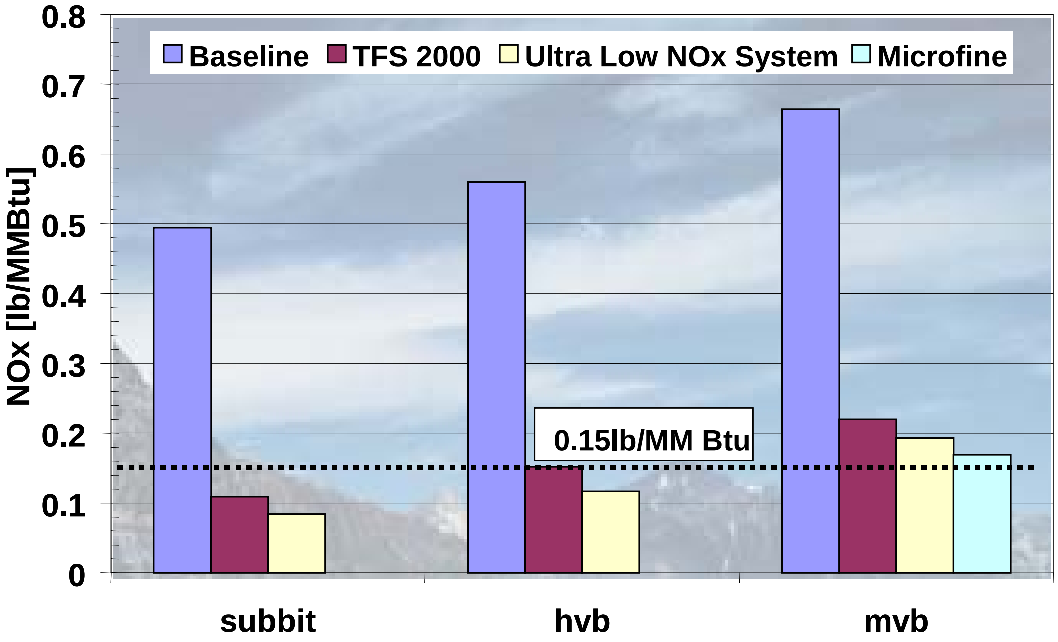


Alstom – Tangential Fired Technology

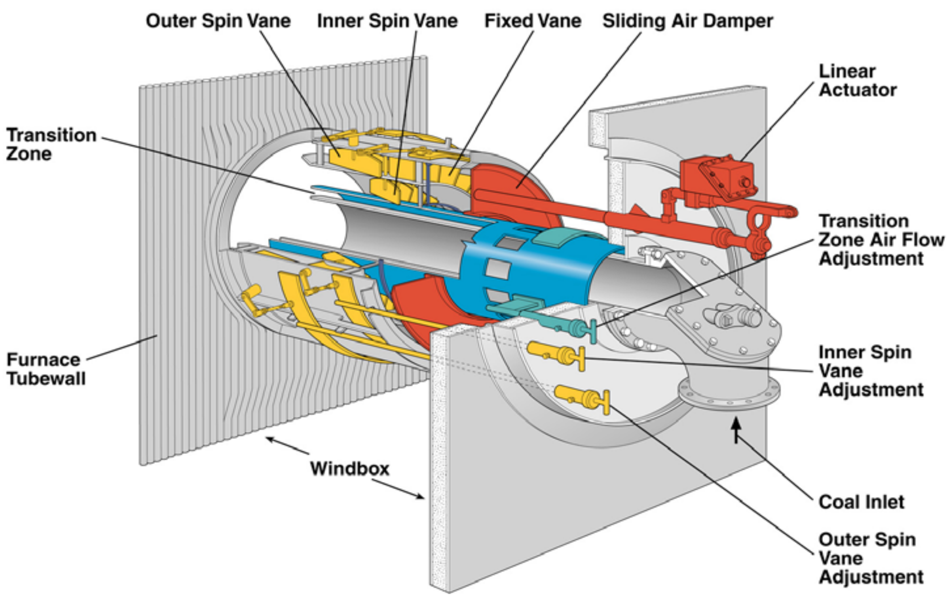


- Basis is commercially proven TFS 2000™ T-fired technology
- Enhanced and optimized fuel and air distribution

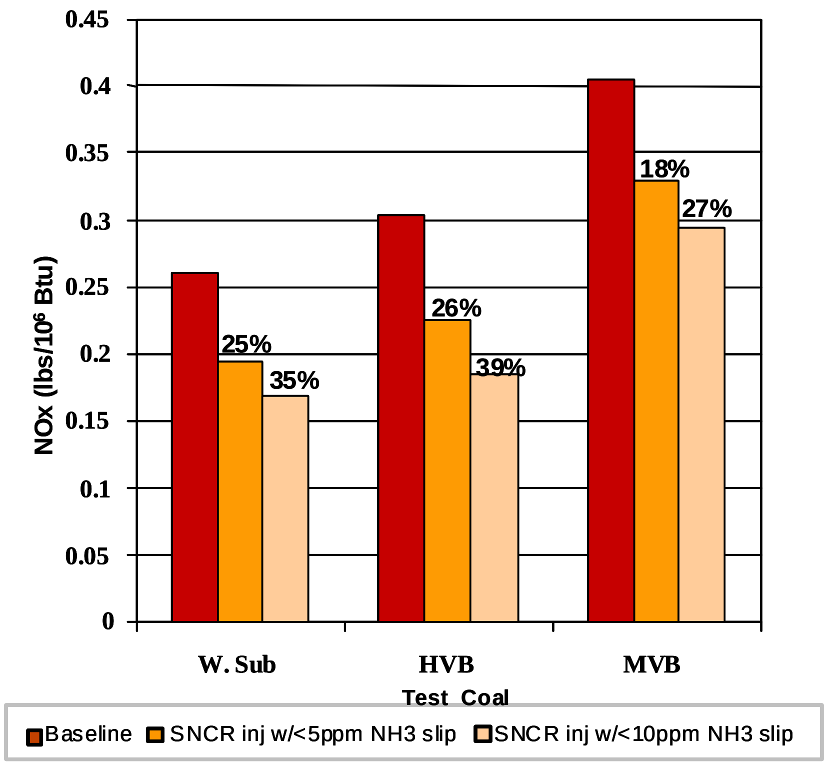
- <0.15 lb/MMBtu can be achieved with subbit and hvb coals



B&W – Wall Fired Technology

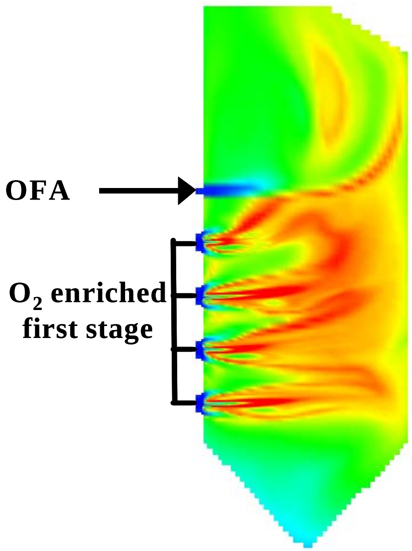


- Basis is **DRB-4Z plug-in ULNB without OFA**
- Evaluate SNCR to determine its effectiveness at low NOx levels



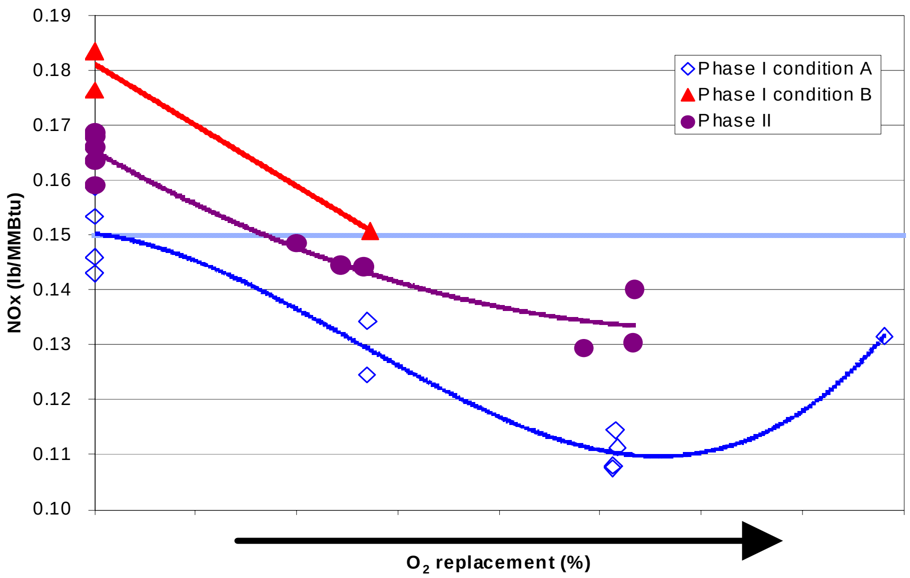
- Higher than expected furnace temperatures suggest utilization of SNCR water-cooled lance in front of superheater tubes and OFA
- Utilization of OFA and SNCR lance reduced W. Sub to 0.09 and 0.07 lb/MMBtu, respectively

Praxair – Oxygen Enhanced Combustion

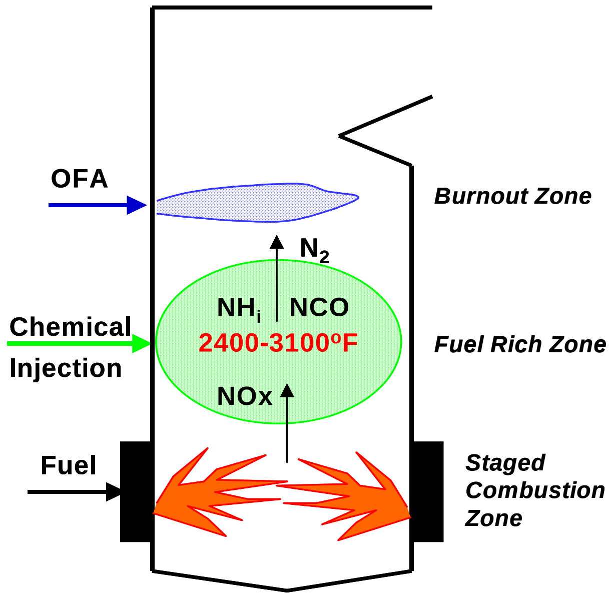


- Retrofit to existing burners
- Improve staged combustion performance by increasing flame temperature to accelerate NOx reduction reactions
- Reduce LOI/UBC
- Increase boiler efficiency

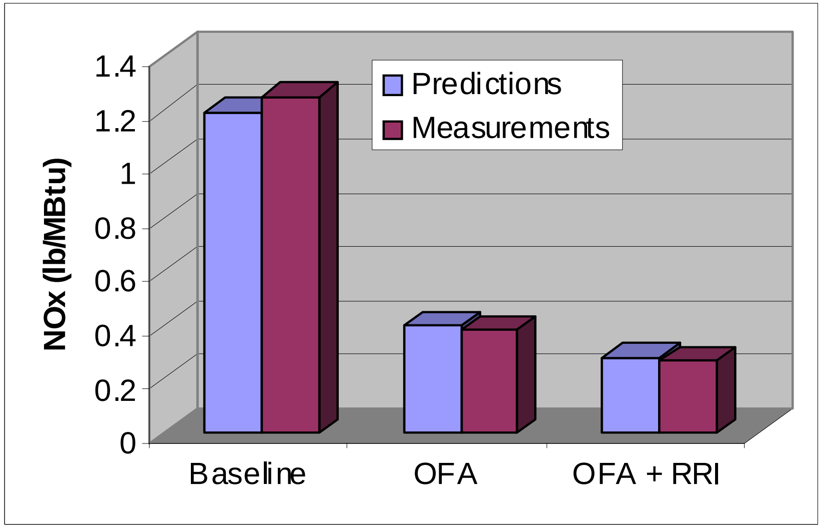
- Parametric studies achieved NOx emissions of 0.11 lb/MMBtu
- Even when initial NOx concentrations are low, O_2 further reduces NOx



Reaction Engineering International RRI - Cyclone Technology



- **Significant NOx reductions achievable with air staging for cyclone boilers**
  - Increased NOx reduction with fuel rich zone and increased residence time
- **Amine reagents accelerate the rate of NOx reduction**
  - NOx reduction in fuel rich zones
  - NOx formation in fuel lean zones



- **AmerenUE's Sioux Unit 1 - 500 MW**
- **Achieved 0.38 lb/MMBtu OFA**
- **Additional 30% NOx reduction with RRI at <1 ppm NH_3 slip**

Cost and Performance Assumptions for Advanced NOx Combustion Control Technologies

Technology	ULNB	ULNB	RRI	OEC	SCR
Boiler/Burner Type	**Tangential**	**Wall**	**Cyclone**	**Wall**	**All**
Controlled NOx rate, lb/MMBtu (Bituminous)[1]	**0.20**	**0.30**	**0.38**	**0.15**	**0.05 or 90%**
Controlled NOx rate, lb/MMBtu (Low Rank)[c]	**0.14**	**0.15**	**0.27**	**0.15**	**0.05 or 90%**
Capital Cost, $/kW[2]	**24**	**28**	**20**	**32**	**119**
Fixed O&M Cost, $/kW-yr	**0.26**	**0.43**	**0.30**	**1.42**	**0.64**
Variable O&M Cost, mill/kWh	**0.03**	**0.08**	**1.00**	**0.21**	**0.66**

Note: All costs in 2005$

How good is the methodology?

If new technologies not available –

Methodology projects 93 GW for SCR control versus 102 GW by IPM for compliance with Clear Skies Act

Advanced NOx Combustion Control vs. SCR for Compliance with the Clear Skies Act (preliminary)

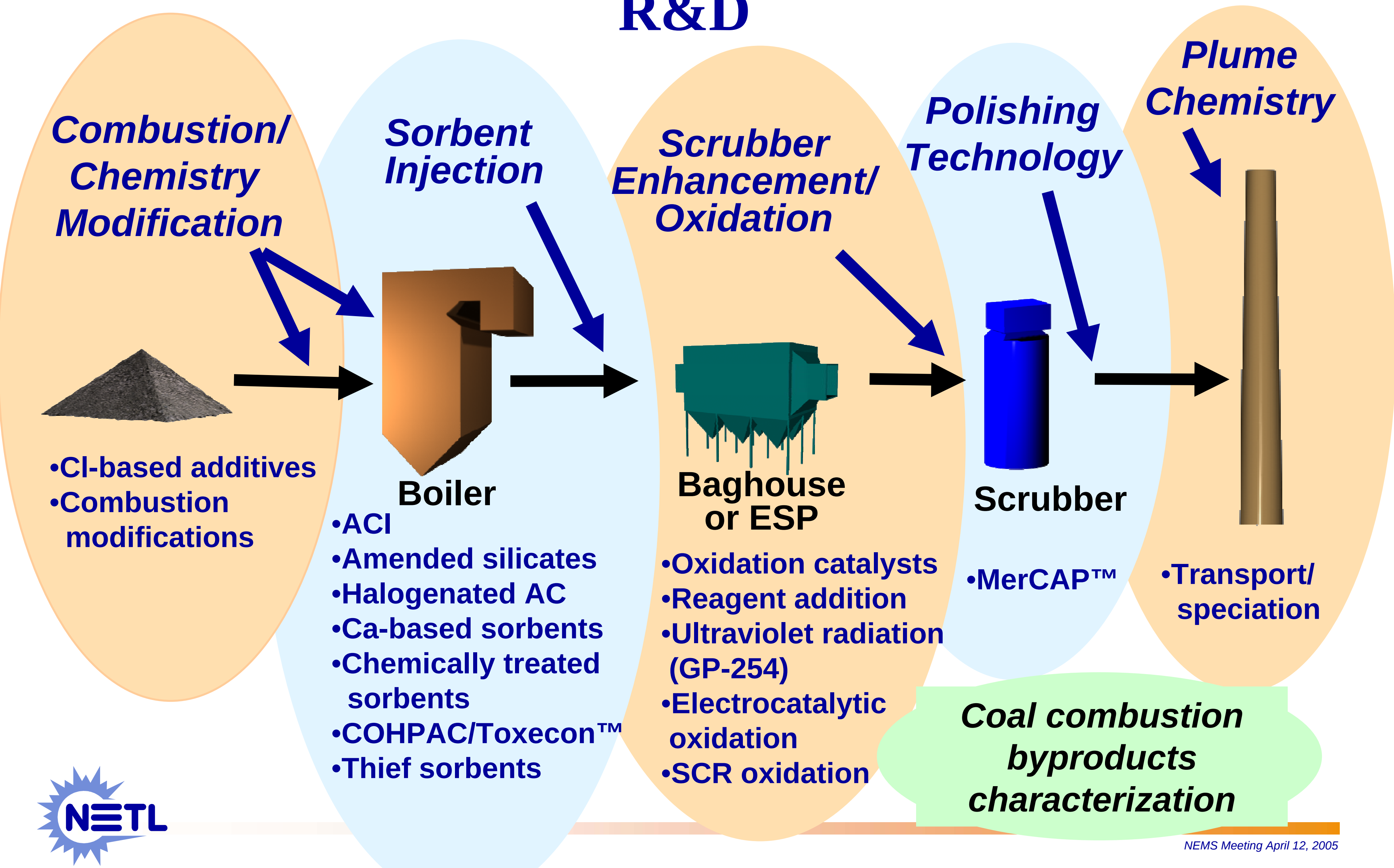
	NETL Analysis			EPA IPM	Difference
	ULNB	SCR	Total	SCR	
Control Retrofit, GW	151	27	178	102	-75 (SCR)
No. Units	531	104	635	281	-177 (SCR)
NOx Reduction, x1000 tons	993	395	1,388	1,385	3
Capital Cost, Billion$	3.7	3.1	6.8	10.7	-4.0
O&M Cost, Million$/yr	118	147	265	533	-268
Levelized Annual Cost, Million$/yr	573	539	1,112	1,840	-729
Average Cost, $/ton NOx	577	1,363	801	1,329	-528

Note: All costs in 2005$

NOx Summary

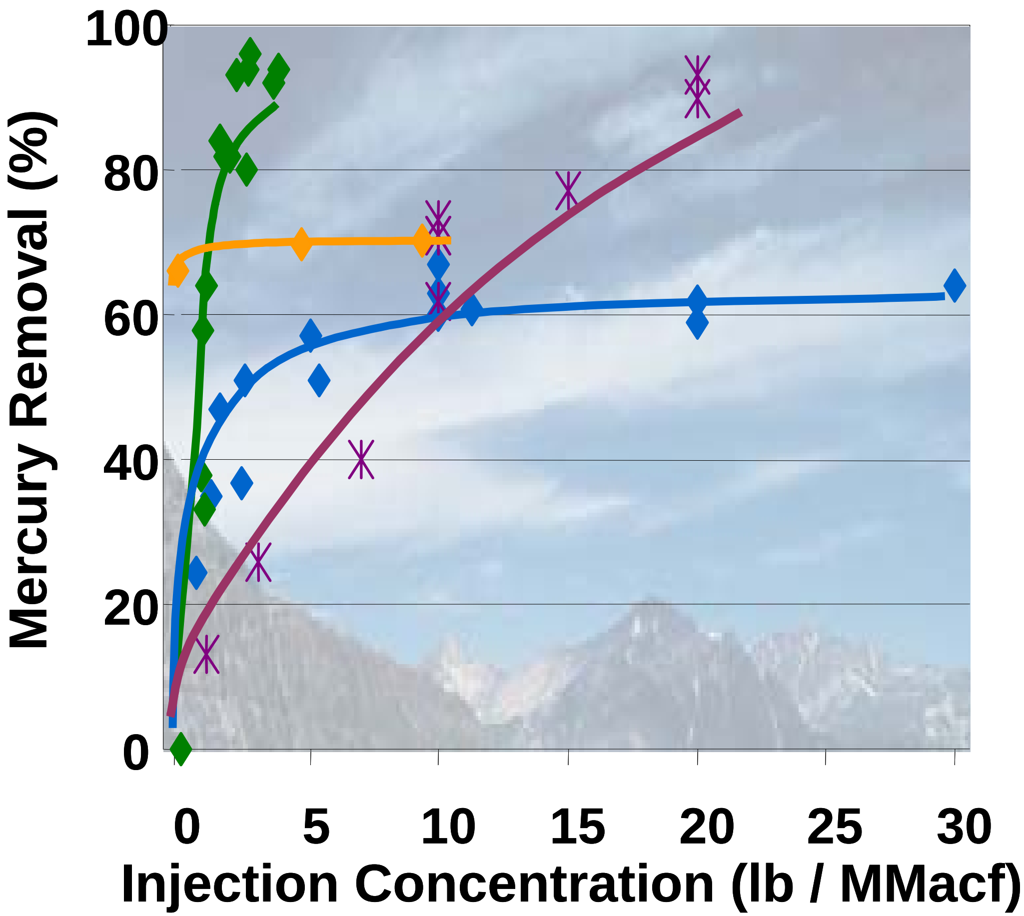
- **NETL's NOx Program technologies can have a substantial market when compared to SCR.**
- **Economics favor large deployment of low NOx combustion controls over strategic SCR installations.**
- **The utility industry can significantly reduce the cost of NOx compliance if technologies are demonstrated successfully at the commercial-scale**
- **New projects are building upon these results to achieve 0.15 lb/MMBtu by 2006 and 0.10 lb/MMBtu by 2010 with eastern bituminous coals**

DOE/NETL Mercury Control Technology R&D



ADA-ES Phase I Field Test Results

Activated Carbon Injection



- ACI with fabric filter can achieve high Hg removal
- Hg removal with ACI in a ESP can be enhanced by lowering the gas temperature
- Capture of Hg from low rank coals can be more difficult
- To achieve high Hg capture in a ESP, large quantities of AC may be required

Mercury Control Using ACI
Preliminary Bituminous Cost Estimate

	Activated Carbon Injection System for 500 MW Bituminous Coal-Fired Plant*		
Mercury Removal,%	50%	70%	90% w/ COHPAC
Sorbent Feed Rate, lb/MMacf	2.2	8.5	2.4
Capital Cost, $/kW	1.8	2.5	56
Levelized Cost	Without lost ash sales penalty		
Mills/kWh	0.36	1.21	2.14
$/lb mercury removed**	31,900	43,900	48,800
	With lost ash sales penalty***		
Mills/kWh	2.78	3.63	2.14
$/lb mercury removed**	245,000	131,700	48,800

*Plant equipped with cold-side ESP

**Incremental cost excluding co-benefit ESP mercury capture (36%)

***Penalty includes lost sales revenue ($18/ton) and ash disposal cost ($17/ton).

Mercury Control Using ACI
Preliminary Subbituminous Cost Estimate

	Activated Carbon Injection System for 500 MW Subbituminous Coal-Fired Plant*		
Mercury Removal,%	50%	60%	90% w/ COHPAC
Sorbent Feed Rate, lb/MMacf	3.3	12.0	3.0
Capital Cost, $/kW	1.8	3.0	57
Levelized Cost	Without lost ash sales penalty		
Mills/kWh	0.58	1.96	2.36
$/lb mercury removed	$17,500	$49,300	$39,600
	With lost ash sales penalty**		
Mills/kWh	1.82	3.20	2.36
$/lb mercury removed	$55,000	$80,500	$39,600

*Plant equipped with cold-side ESP

**Penalty includes lost sales revenue ($18/ton) and ash disposal cost ($17/ton).

NETL

B&W Phase I Field Test Results

Enhanced Mercury Control in Wet FGD

Wet FGD Mercury Removal,%

MSCP's Endicott Plant

Mercury Species	Baseline	Reagent*
Total	~ 60%	76%
Oxidized	~ 90%	93%
Elemental	~ (40%)	20%

Cinergy's Zimmer Plant

Mercury Species	Baseline	Reagent*
Total	~ 45%	51%
Oxidized	~ 90%	87%
Elemental	~ (20%)	(41%)

*Reagent feed results during two-week verification testing.

- **Scrubber enhancers show modest improvement in capture effectiveness**

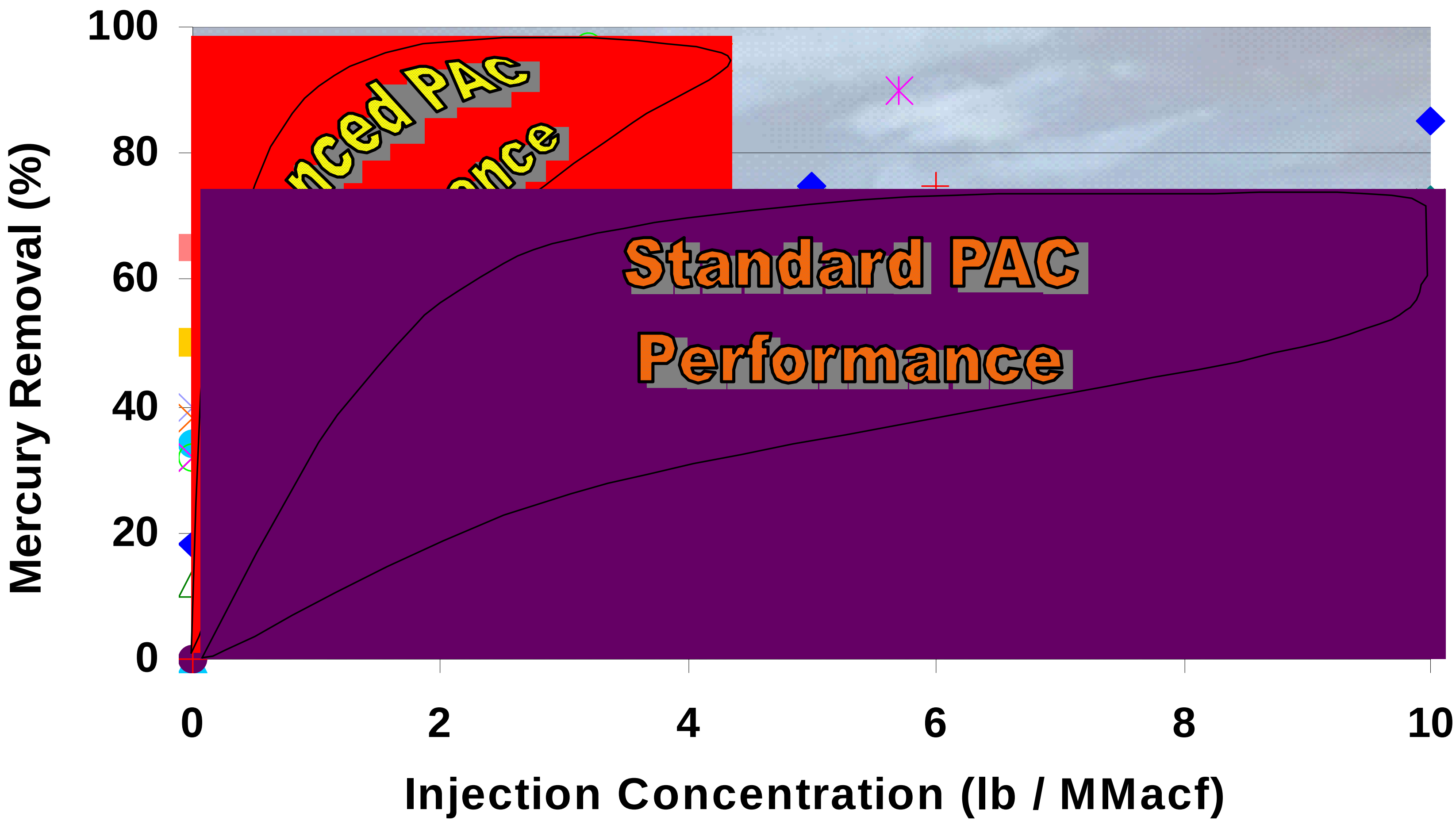
Uncertainties From Phase I Field Tests

- Performance over longer periods of operation
- Effectiveness of chemically modified sorbents
- Effectiveness of SCR and Hg-specific catalysts
- Capture effectiveness with low-rank coals and coal blends
- Sorbent feed rate and costs
- Effectiveness with small SCA ESPs
- Impact on ESP performance and bag life
- FGD Hg reduction/re-emission
- By-product use and disposal
- Need for fabric filter for units equipped with ESP

NETL's Mercury Field Testing

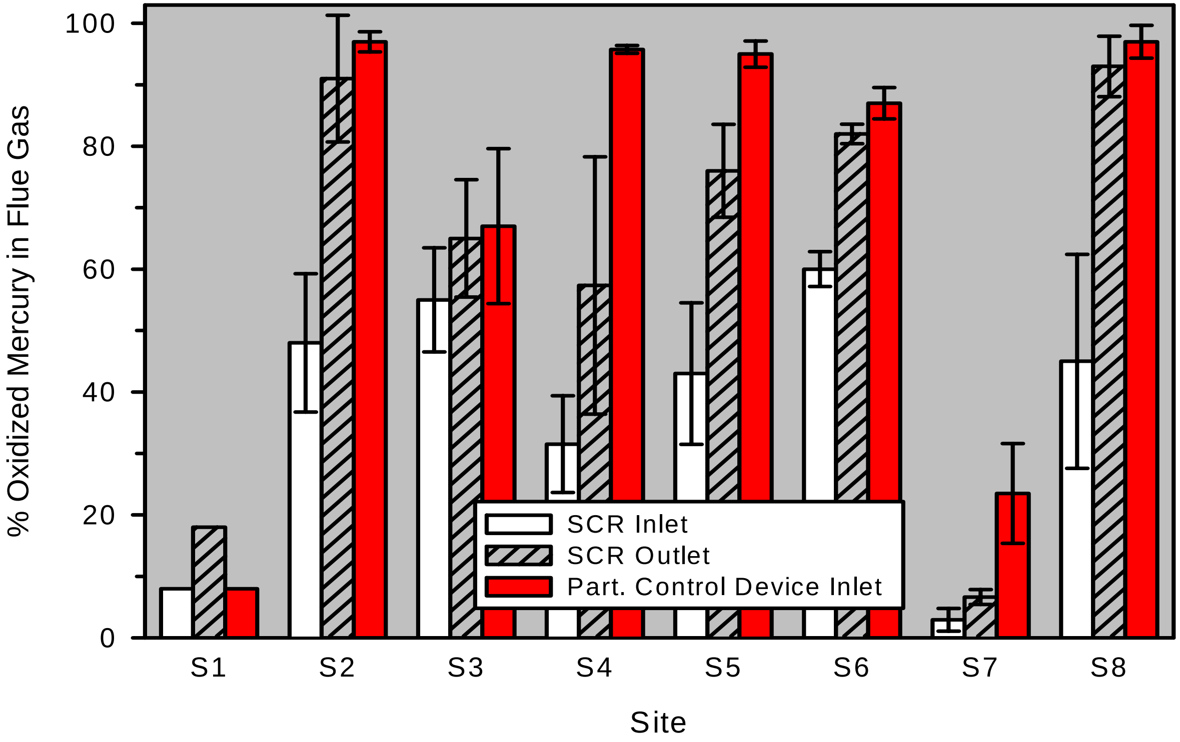
Phase I and II Field Testing Results

Comparison of Standard & Enhanced PAC



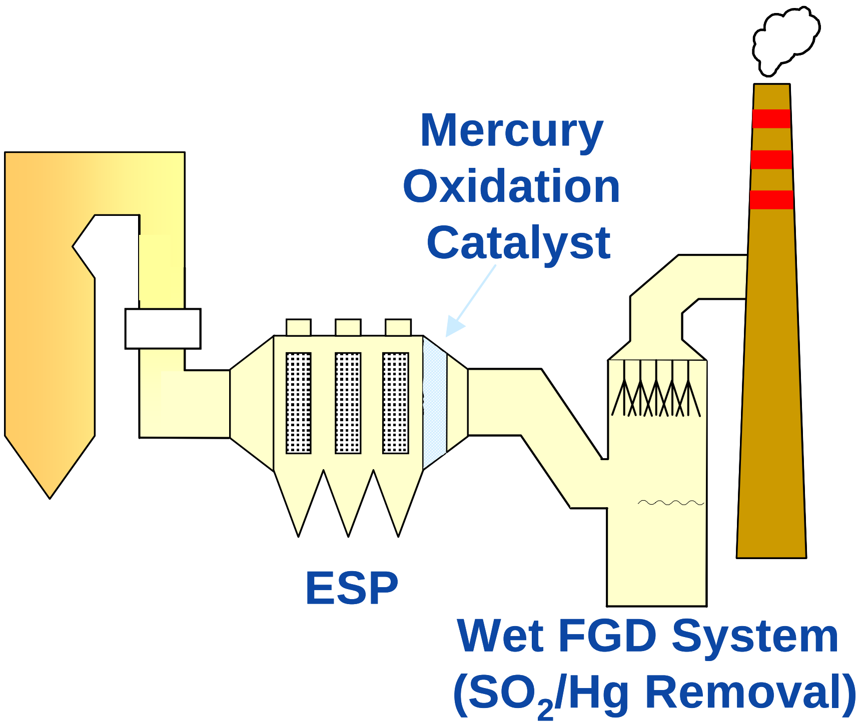
Co-Benefits From SCR and FGD

- **A large fraction of oxidized Hg is achieved with bituminous coals, but it varies**
- **Minimal Hg is oxidized with low rank coals (S1 & S7)**
- **Typically, FGD systems capture most of the oxidized Hg**
- **As SCR catalysts age, the impact on Hg oxidation is unknown**



Mercury Oxidation Catalysts

- Evaluate honeycomb catalyst for oxidizing mercury
- Removal in downstream wet lime or limestone FGD
- Catalysts deactivate but can be regenerated
- Mercury captures of +75% have been demonstrated on lignite and subbituminous coals.
- Preliminary costs show savings of 20% (w/o ash sales) and 55% (w/ ash sales) vs. ACI



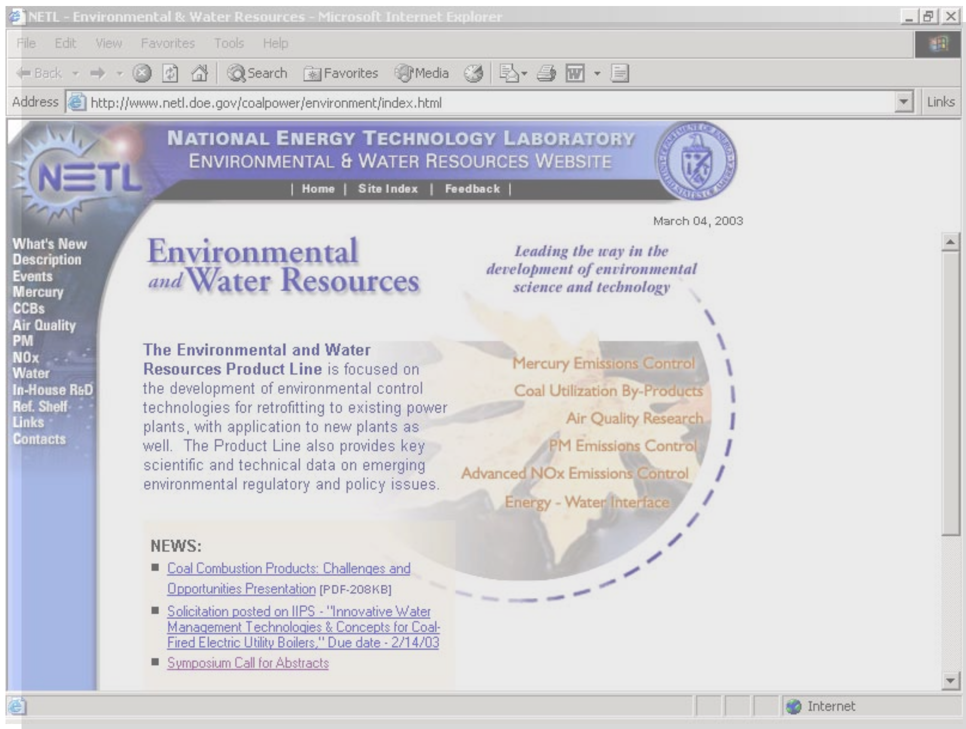
Additional Mercury Control Options

- Sorbents which do not impact fly ash sales
- High carbon ash as a sorbent
- Reduction of flue gas temperature to increase Hg capture on fly ash
- Fixed-structure gold plates/screens for polishing removal after ESP, FF, or FGD
- Chemical oxidation additives to the boiler to increase Hg capture in fly ash, sorbents or FGD
- Injection of sorbent in middle of ESP in order to generate an uncontaminated fly ash product in addition to the ash/spent sorbent collection
- Chemical additive to FGD to prevent re-emission of captured Hg

Mercury Summary

- Many of the most promising mercury control technologies are currently undergoing field testing on commercial coal-fired boilers as part of DOE/NETL's Innovations for Existing Plants Program
- Chemically enhanced sorbents have demonstrated higher removals at lower injection rates than standard activated carbons.
- The co-benefit of mercury capture from a boiler equipped with SCR/FGD and burning bituminous coal can be substantial, but there is variability from plant to plant.
- Oxidation technologies (coupled with sorbents or scrubbers) are leading approaches for coal-fired power plant mercury control
- Further RD&D, especially long-term demonstrations, are needed to fully address technical and performance uncertainties
- Program would not be possible without contributions from technology developers, utilities, universities, EPRI, EPA, and DOE.

DOE/NETL Environmental and Water Resources (Innovations for Existing Plants Program)



To find out more about DOE-NETL's Hg R&D activities visit us at:

http://www.netl.doe.gov/coal/E&WR/index.html