Mercury Control Technologies for Electric Utilities Burning Lignite Coals





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Project Review Meeting

February 25, 2003

Review Meeting Agenda – 2/25/03

• Welcome/Introduction	8:30	A.M.
• **Project Overview/Background**	**8:45**	**A.M.**
• Phase I – Bench-Scale Test Results	9:00	A.M.
• Break	10:00	A.M.
• Phase I – Pilot-Scale Testing	10:30	A.M.
• Project Schedule	11:30	A.M.
• Open Discussion	11:45	A.M.
• Lunch	12:00	P.M.
• Phase II – Plans and Discussion	1:00	P.M.
• Break	2:30	P.M.
• Review of ND Mercury-Monitoring Project Results	2:45	P.M.
• Adjourn	4:00	P.M.

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Mercury Control Technologies for Electric Utilities Burning Lignite Coals

Introduction/Overview

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Multiclient Project Sponsors/Participants

Canada

- Saskatchewan Power
- Environment Canada
- Ontario Ministry of the Environment
- Luscar Ltd.

United States

- Basin Electric Power Cooperative
- Minnkota Power Cooperative, Inc.
- Otter Tail Power Company
- EPRI
  - Great River Energy
  - Xcel Energy
  - Minnesota Power, Inc.
- North Dakota Industrial Commission
- U.S. Department of Energy

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Project Goals

Develop, Test, and Demonstrate Sorbent-Based Technologies for Utilities Burning Lignite Coal

- Increase the scientific understanding of mercury – flue gas interactions leading to more effective design of sorbents
- Test a range of sorbent-based technology options
- Determine and demonstrate optimum conditions and sorbents for Hg capture in pilot facility
- Field test sorbent-based technology to prove and quantify effectiveness, performance, and cost

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Project Approach

Phase I Bench-/Pilot-Scale Testing

- Lignite flue gas characterizations
- Bench-scale sorbent screening tests
- Pilot-scale control technology screening tests
- By-product analyses

Phase II Full-Scale Testing/Demonstration

- Field Demonstration
  - Select sorbent and technology option
  - Prepare site and install technology hardware
  - Evaluate sorbent effectiveness and impacts
  - Evaluate impact of design and process variables
  - By-product analyses
  - Quantify effectiveness and cost

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Mercury Control Technologies for Electric Utilities Burning Lignite Coals Bench-Scale Testing

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University of North Dakota
Grand Forks, North Dakota

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Overview

- Bench-scale testing
- Screening criteria
- Coal characteristics for char preparation
- Char preparation methods and yield
- Sorbent breakthrough testing
- Results
- Conclusions

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Bench-Scale Testing

Bench-scale screening:

- Evaluate a number of different sorbents, sorbent enhancements/modifications, gas species interactions, oxidation potential, sorbent size, temperature, etc.
- Fixed-bed and entrained-flow using simulated gas similar to that produced from burning lignite coal
- Perform initial screening of sorbents to evaluate capture effectiveness, oxidation potential, and capacity
- Provide relative ranking to determine most promising sorbent for pilot- and full-scale testing based on capacity and cost

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Screening Criteria

- Reactivity – comparison to baseline Norit FGD
- Capacity – bench-scale breakthrough curves
- Physical properties – particle size, surface area, functionality
- Cost – relative to FGD carbon (50 cents/lb)

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Sorbents for Testing

- Carbon-based sorbent selection – six sorbents
  - Baseline – Norit FGD
  - Luscar – coal, char, fines (?)
  - Minnkota – high-sodium Center lignite
  - Basin/Otter Tail – high-sodium Beulah Zap lignite
  - Calcium silicate

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Sorbent Comparison

Activated carbons were prepared from the following coals and chars:

- Luscar coal
- Luscar coal char
- Center coal
- Beulah Zap coal

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Proximate Analysis

	Luscar Coal		Luscar Coal Char		Beulah Zap		Center Coal		Norit FGD Activated Carbon	
	AR, %*	MF, %**	AR, %	MF, %	AR, %	MF, %	AR, %	MF, %	AR, %	MF, %
Moisture	32.5		7.8		28.3		23.3		3.10	
Volatile Matter	27.76	41.12	22.35	24.25	31.62	44.09	33.04	43.1	13.85	14.29
Fixed Carbon	26.48	48.83	54.84	71.03	30.77	49.34	34.74	51.23	51.21	52.85
% Ash	13.26	19.64	15.01	16.29	9.3	12.97	8.92	11.63	31.84	32.86

*As-received **Moisture-free



Ultimate Analysis

Sample	Luscar Coal		Luscar Coal Char		Beulah Zap		Center Coal		Norit FGD Activated Carbon	
	MF, %*	AR, %**	MF, %	AR, %	MF, %	AR, %	MF, %	AR, %	MF, %	AR, %
Hydrogen	4.21	6.45	2.69	3.35	4.06	6.05	3.94	5.61	0.30	0.63
Carbon	64.91	43.82	66.08	60.9	62.66	44.94	59.91	45.93	62.83	60.89
Nitrogen	1.22	0.82	1.21	1.12	1.16	0.83	1.09	0.84	0.22	0.21
Sulfur	0.9	0.61	0.87	0.8	0.84	0.6	1.29	0.99	1.06	1.03
Oxygen (ind.)	9.21	35.03	12.86	18.82	18.31	38.27	22.14	37.72	2.73	5.39
% Ash	19.64	13.26	16.29	15.01	12.97	9.3	11.63	8.92	32.86	31.84

*Moisture-free **As-received

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Bulk Ash Composition

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3
Sample	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)
Luscar Coal	38.3	15.2	6.0	0.6	0.2	15.5	3.5	8.7	1.4	10.6
Luscar Coal Char	32.9	17.3	6.4	0.6	0.2	16.4	3.8	9.9	0.6	12.0
Antelope/Beulah Zap	36.6	13.6	8.1	0.5	0.2	18.1	5.8	5.8	1.1	10.3
Center Coal	43.8	14.3	7.6	0.5	0.1	11.6	4.5	4.3	2.0	11.2
Norit FGD	38.5	15.6	10.6	1.3	0.0	18.1	4.7	0.7	0.6	10.0

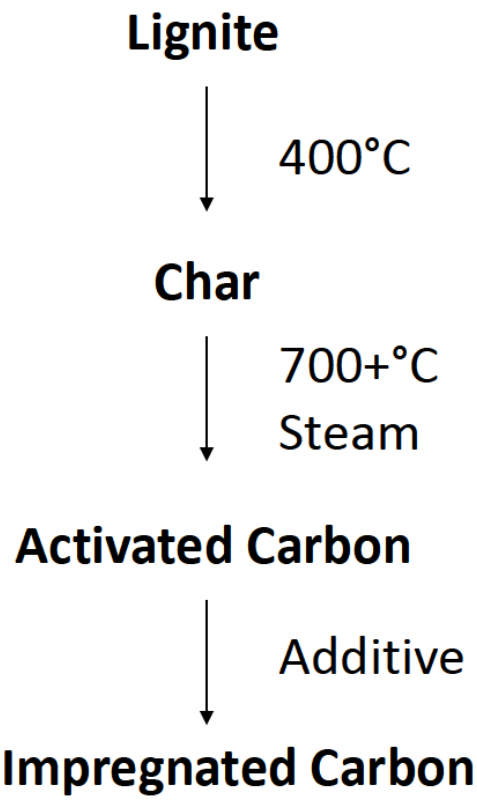
Chlorine Analysis

Dried Basis

	Chlorine
Sample	µg/g
Luscar Coal	18.0
Antelope/Beulah Zap	12.6
Center Coal	14.3

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Activated Carbon Production



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Char Formation

- The coals were air-dried and ground, and the particles (-8 +20 mesh) were collected.
- For carbonization, 150 g of the granular coal (-8 +20 mesh) were placed in a quartz tube reactor, and heated to 400°C in a gentle flow of nitrogen.
- The reactor was held at this temperature until tarry material ceased to evolve.
- The char was stored under nitrogen for further use.

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Activated Carbon Production

For steam activation:

- The char was placed in a vertical quartz tube reactor and heated to either 750° or 800°C in a gentle flow of nitrogen.
- The char was then heated at either 750° or 800°C in a gentle flow of steam and nitrogen introduced from the bottom of the reactor for 30 minutes.
- The reactor was cooled to room temperature in flowing nitrogen.
- The activated carbon was removed from the reactor, weighed, and stored under nitrogen for further use.

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Carbon Yields

	Activation Conditions	Ratio of Char to Coal	Ratio of Carbon to Coal	Ratio of Carbon to Char
Luscar Coal	Carbonized @400°C, steam activation @750°C/30 min	0.481	0.367	0.764
Luscar Coal	Carbonized @400°C, steam activation @800°C/30 min	0.493	0.356	0.722
Luscar Char	Steam activation @750°C/30 min	NA	NA	0.647
Luscar Char	Steam activation @800°C/30 min	NA	NA	0.576
Beulah Coal	Carbonized @400°C, steam activation @750°C/30 min	0.510	0.370	0.726
Center Coal	Carbonized @400°C, steam activation @750°C/30 min	0.496	0.360	0.725
Center Coal	Carbonized @400°C, steam activation @800°C/30 min	0.521	0.346	0.665

Surface Areas

Surface area of the activated carbons was determined by iodine numbers:

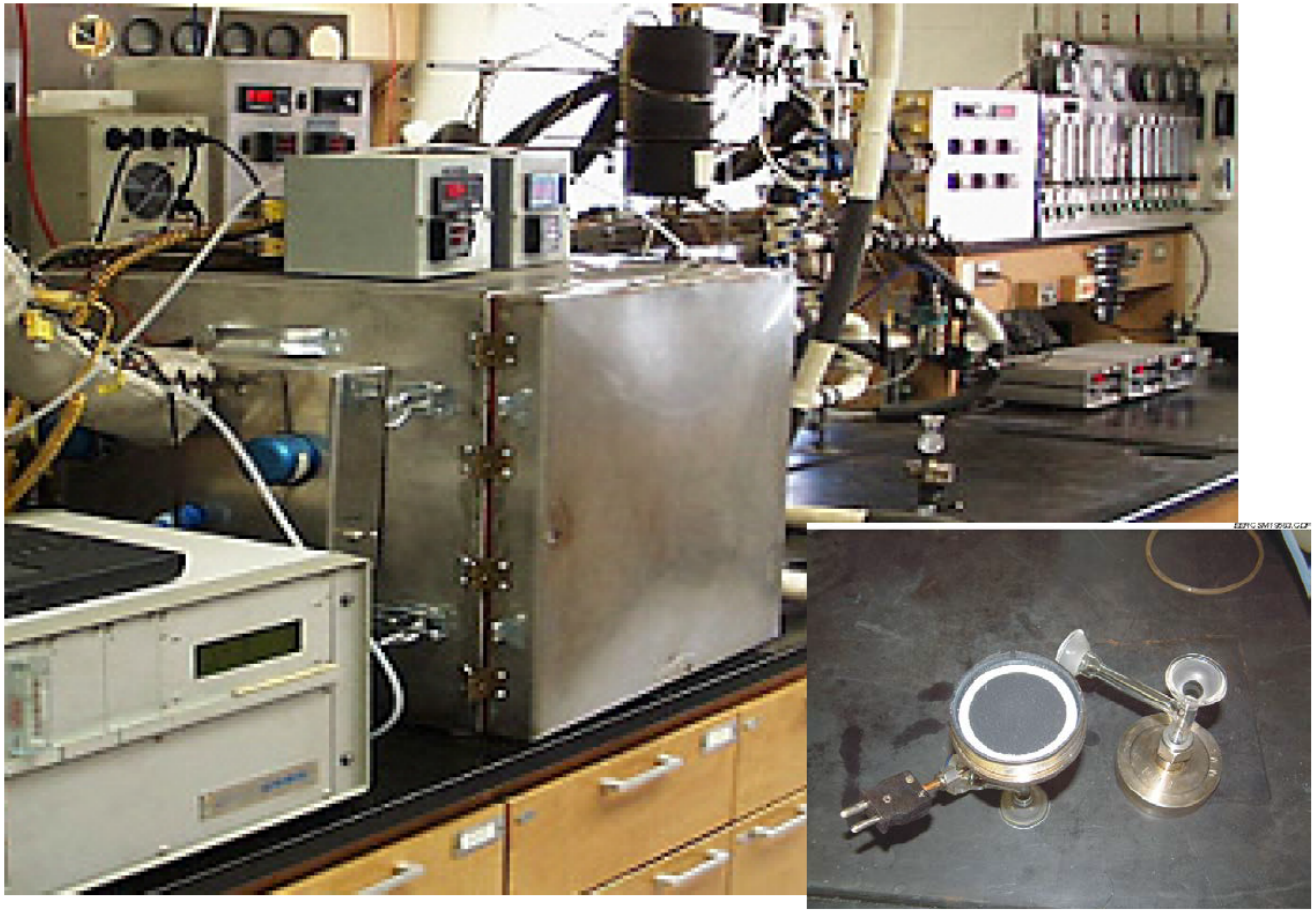
- Carbons were ground to pass through 200-mesh sieve.
- Iodine numbers for the carbons were determined by ASTM procedure.

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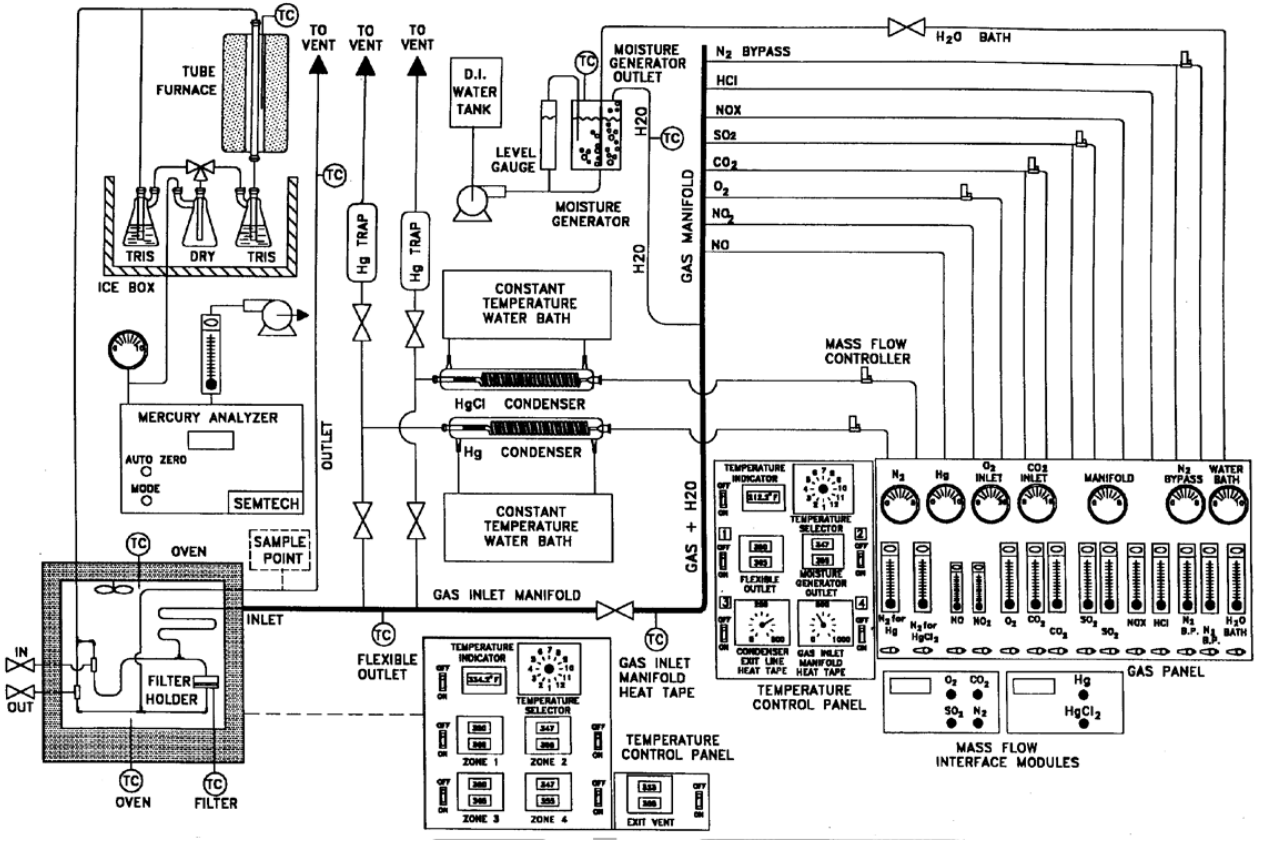
Surface Areas

	Activation Conditions	Iodine No.
Luscar Coal	Carbonized @400°C, steam activation @750°C/30 min	424.3
Luscar Coal	Carbonized @400°C, steam activation @800°C/30 min	398.1
Luscar Char	Steam activation @750°C/30 min	439.6
Luscar Char	Steam activation @800°C/30 min	427.4
Beulah Coal	Carbonized @400°C, steam activation @750°C/30 min	331.5
Center Coal	Carbonized @400°C, steam activation @750°C/30 min	352.8
Center Coal	Carbonized @400°C, steam activation @800°C/30 min	321.5
Norit FGD	Unknown	524.8

EERC Mercury Bench-Scale System



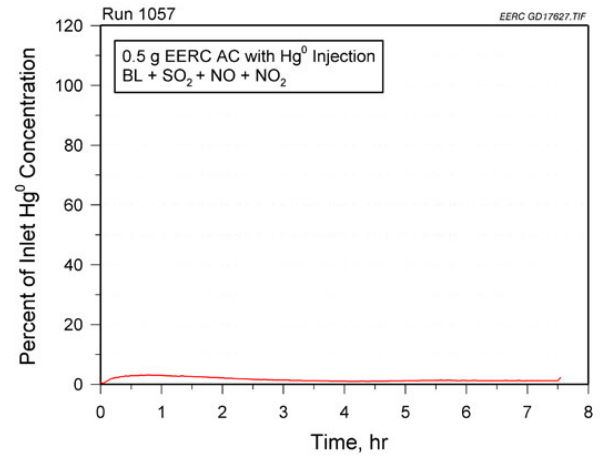
Schematic of the Mercury Lab Setup

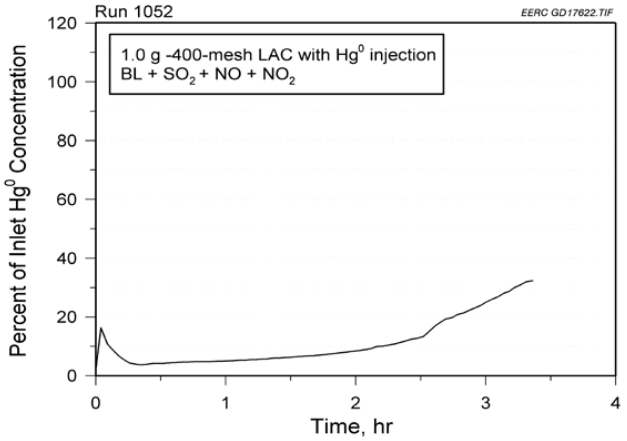


Breakthrough Curves for Norit FGD and High-Na North Dakota Lignite AC

Simulated Flue Gas – Baseline

- Hg^0 – 15 µg/m^3
- O_2 – 6%
- CO_2 – 12%
- H_2O – 8%
- N_2 – Balance
- HCl – 50 ppm
- SO_2 – 1500 ppm
- NO – 400 ppm
- NO_2 – 20 ppm

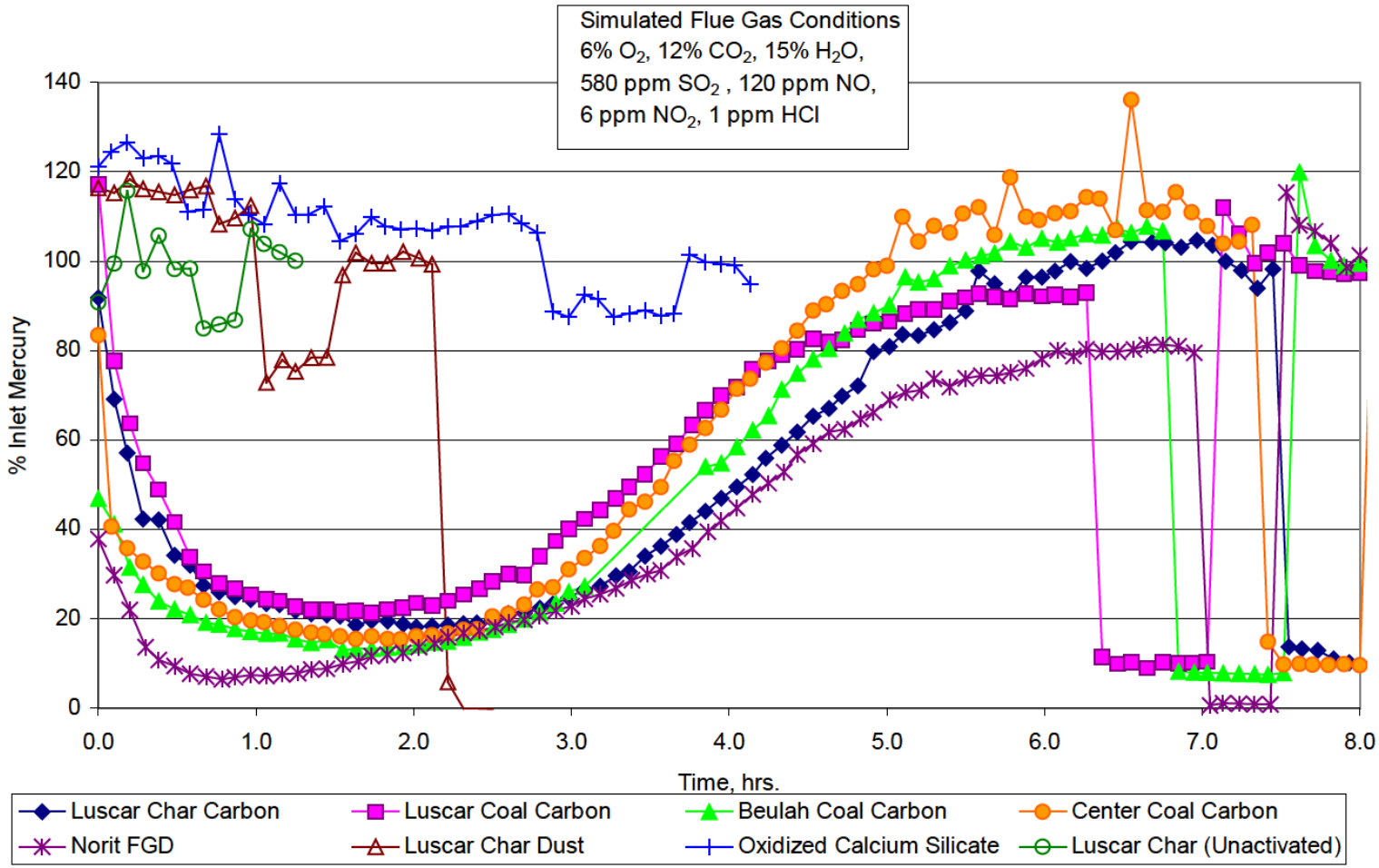




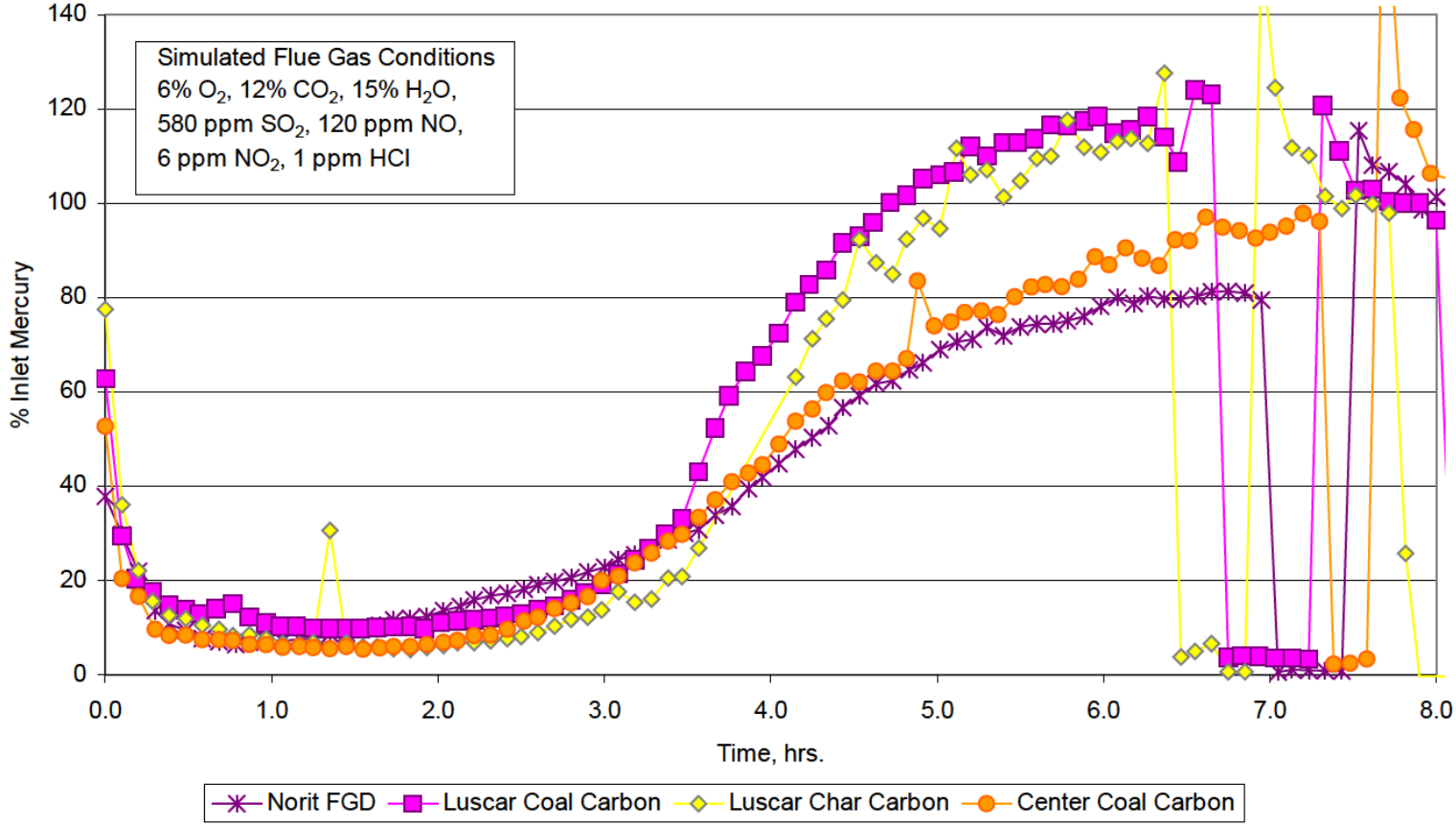
Simulated Flue Gas Composition of Mercury Bench-Scale Tests (nominal conditions)

Flue Gas for the Coal Creek Station: Temperature: 275° – 295°F	
Hg	10–11 µg/Nm^3
O_2	6% at the ESP
CO_2	12%
NO_x	125 ppm*
H_2O	15%
SO_2	580 ppm
HCl	1–2 ppm
*Assume 5% NO_2 = 6.25 ppm	

Bench-Scale, Fixed-Bed Tests – May 2002 (carbons activated at 750°C)



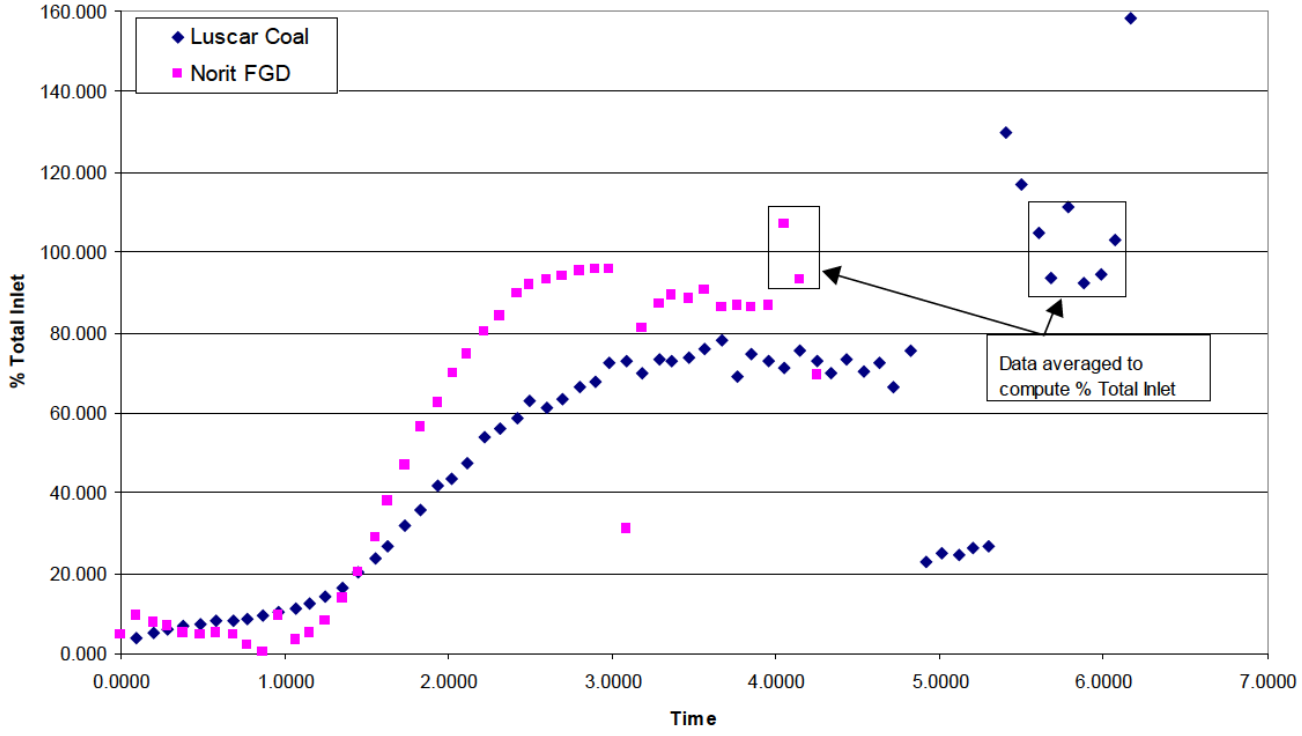
Bench-Scale, Fixed-Bed Tests – May 2002 (carbons activated at 800°C)



Breakthrough Curves – FGD and Luscar Carbon (baseline conditions)

Simulated Flue Gas Conditions:
6% O_2, 12% CO_2, 8% H_2O,
1600 ppm SO_2, 400 ppm NO,
20 ppm NO_2, 50 ppm HCl

Luscar Coal Activated to 800°C Compared with LAC (baseline gases)

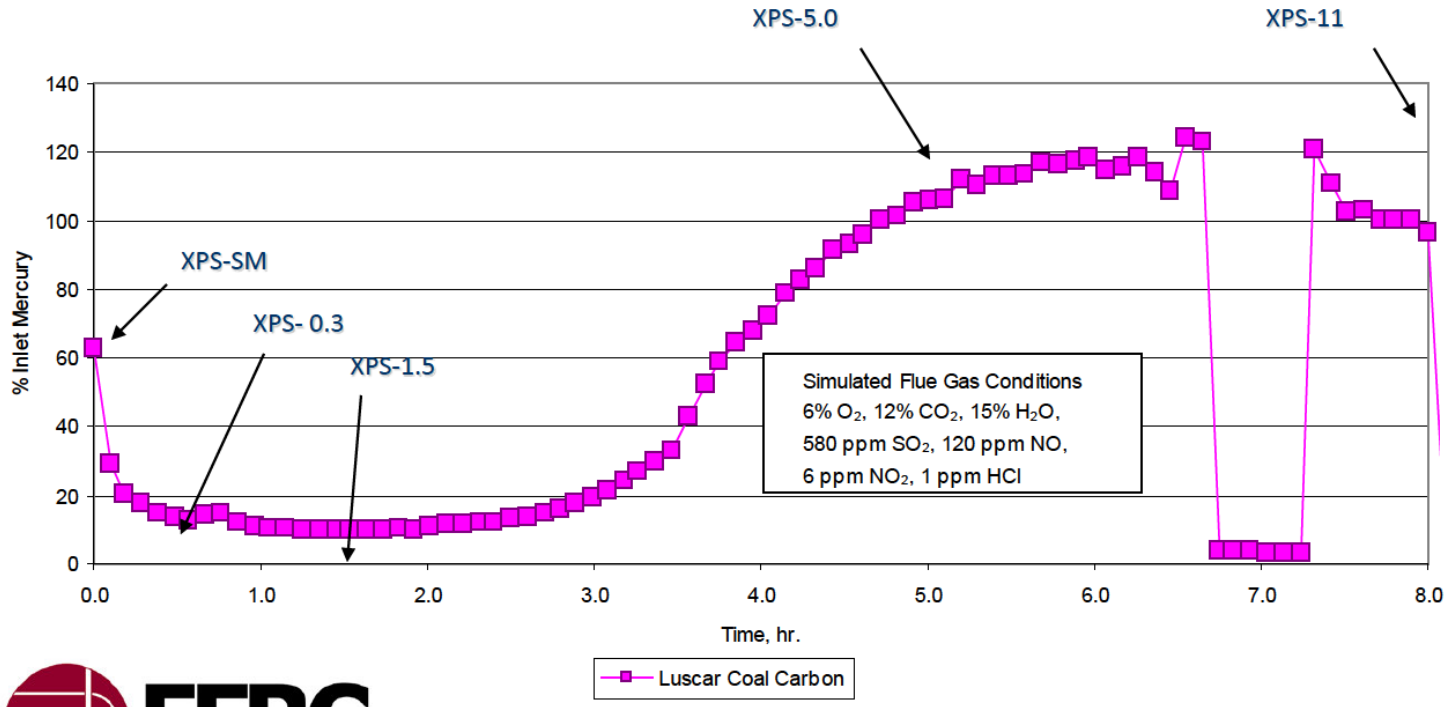


X-Ray Photoelectron Spectroscopy (XPS)

- XPS is also known as electron spectroscopy for chemical analysis (ESCA).
- XPS analysis involves irradiating a sample with a mono-energetic x-ray beam that causes photoelectrons to be emitted from the sample.
- An energy analyzer is used to determine the binding energy of the emitted photoelectrons.
- From the binding energy and intensity of a photoelectron peak, the elemental identity, chemical state, and quantity of an element can be determined.

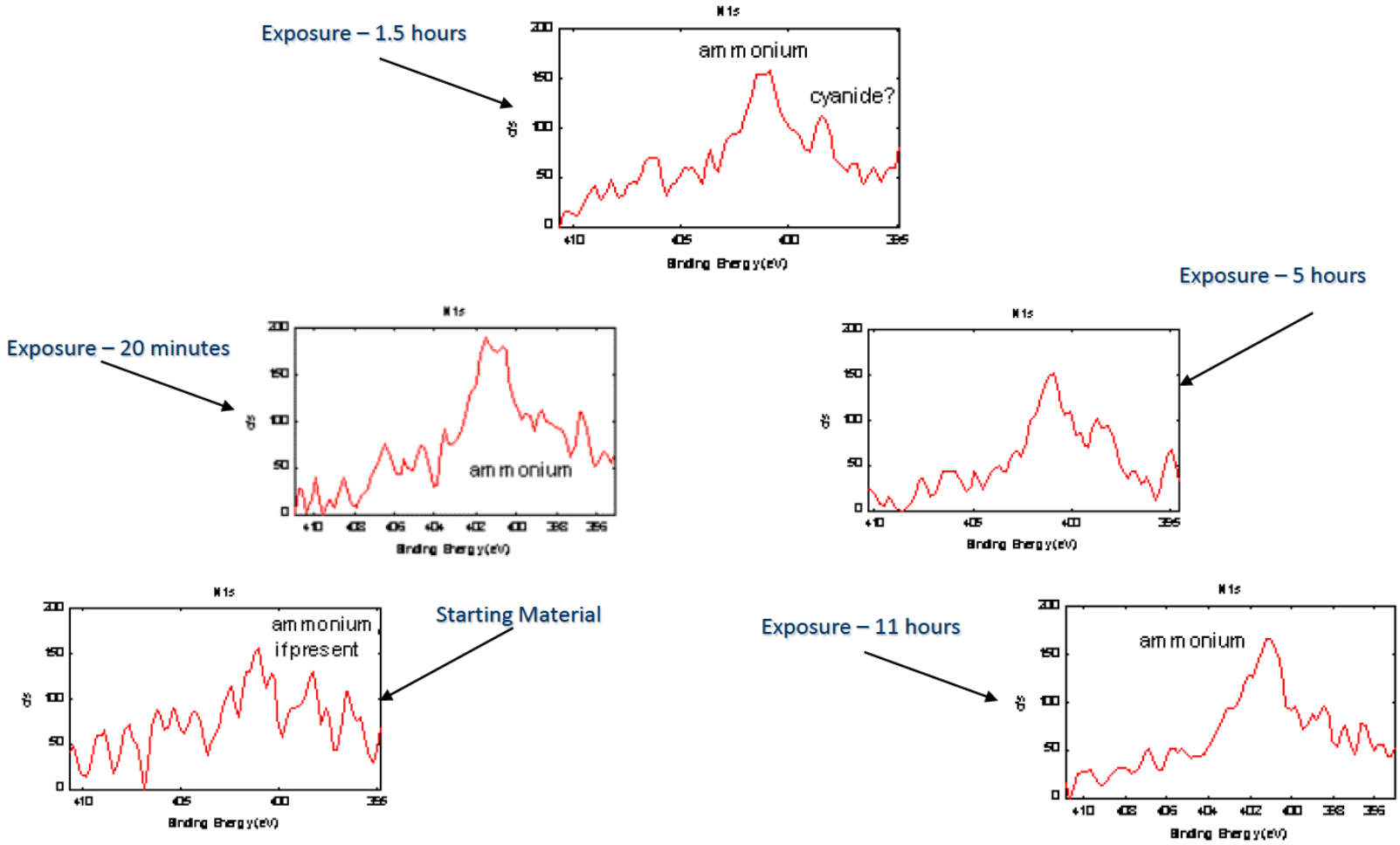
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Samples Selected for XPS Analysis



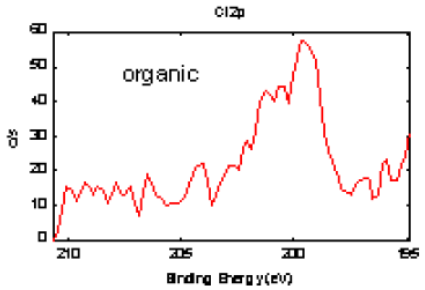
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XPS Spectra – Nitrogen Species

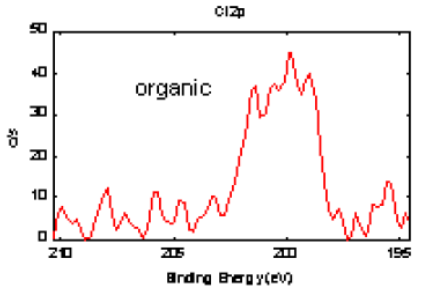


XPS Spectra – Cl Species

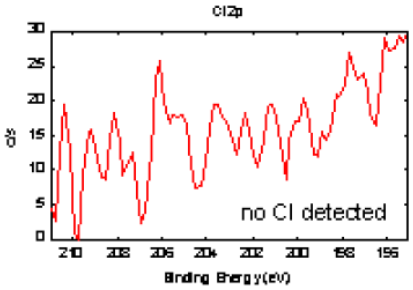
Exposure – 1.5 hours



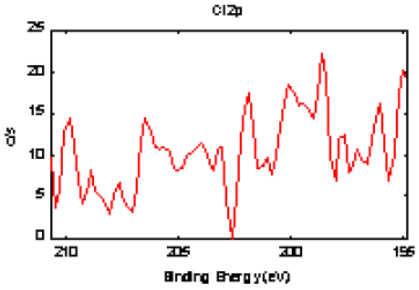
Exposure – 5 hours



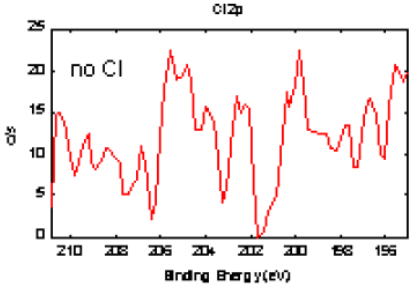
Exposure – 20 minutes



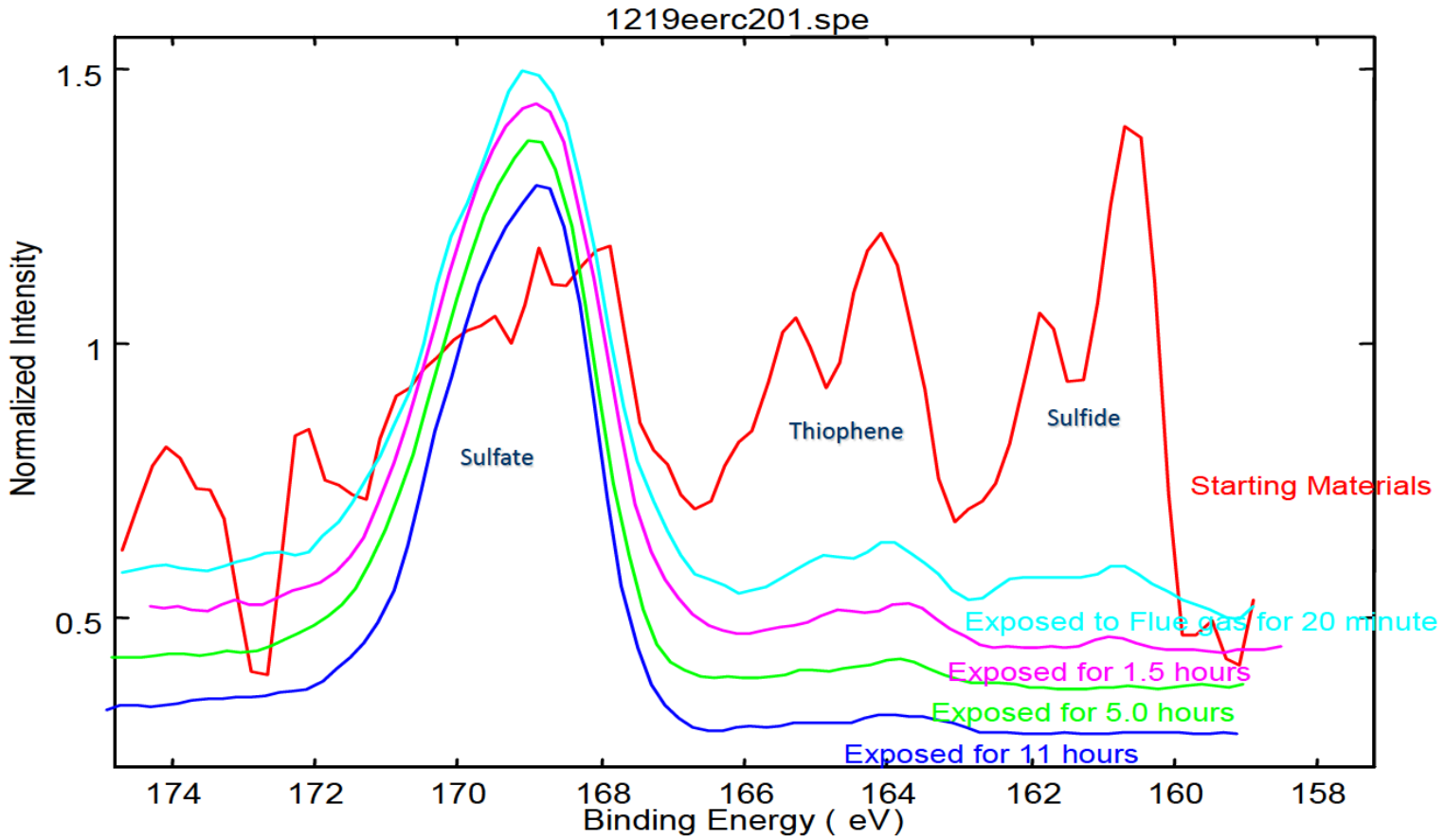
Starting Material



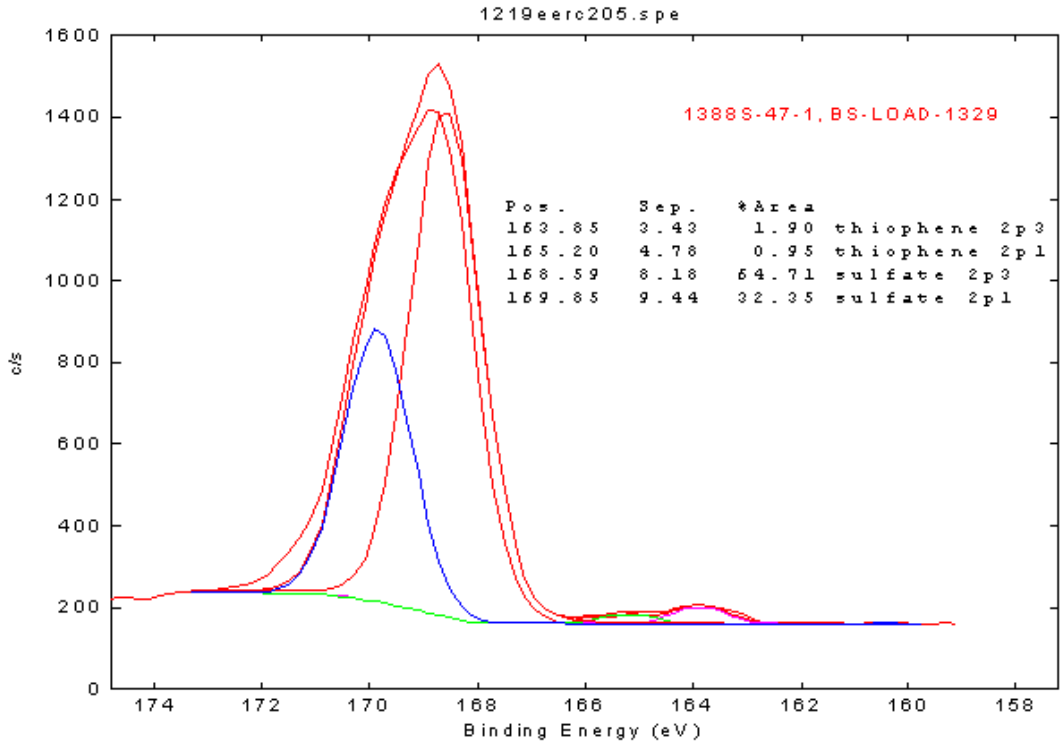
Exposure – 11 hours



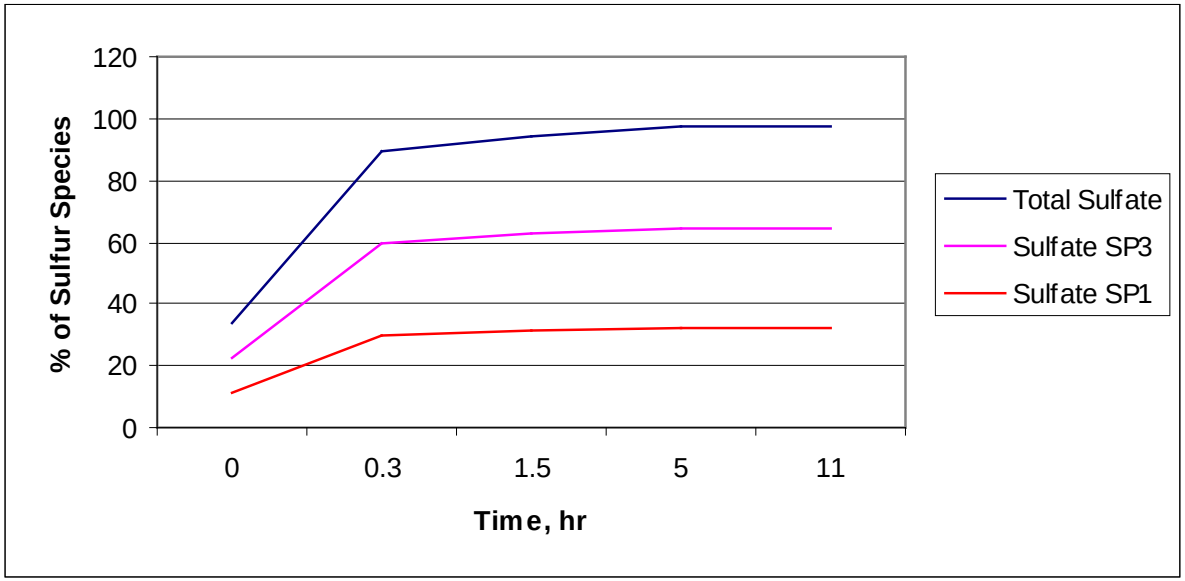
XPS Spectra – Sulfur Species



XPS – Detail of Sulfur Peak

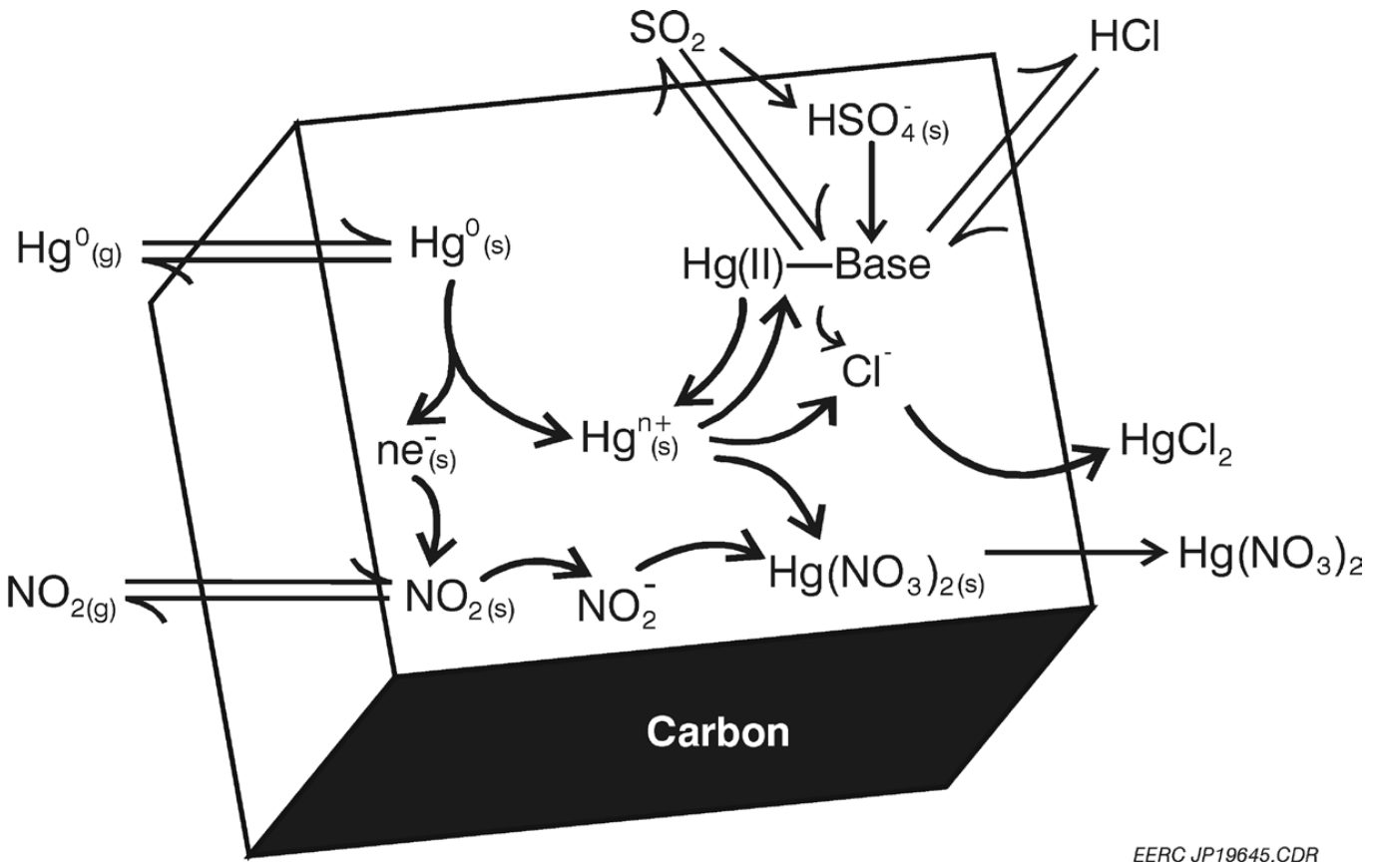


XPS – Surface Sulfate Levels



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Mechanistic Model of Sorbent–Mercury Interactions



Conclusions on Bonding Site

- All mercury on the sorbent and effluent gas is oxidized.
- Flue gas components have an effect on mercury capture.
- XANES analysis (past study) showed most sulfur as sulfate and most mercury as a chloride and/or carbon bonded.
- XPS analysis showed most sulfur as sulfate, thiophene, and sulfide.

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Conclusions on Bonding Site (continued)

- There is competition for active sites by Cl and S species.
- Mercury sorption on the surface depends upon sulfide-to-sulfate conversion, buildup of Cl, followed by desorption.
- Mercury on the sorbent is not Hg^0, sulfate, or nitrate (past work – XANES).

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Conclusions on Bonding Site (continued)

- Bonding site for mercury – base site may be a carbon-edge structure that has Lewis-base characteristics.
  - Base can donate electrons to Hg^{2+}, HCl, H_2SO_4, and SO_2.
  - Acid gases poison the Hg sites – prolonged exposure.

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Conclusions from Bench-Scale Testing of Potential Mercury Sorbents

- Unactivated Luscar char and oxidized calcium silicate were ineffective in capturing or heterogeneously oxidizing mercury.
- Lignite-based activated (750°C) carbons required a 30- to 45-minute conditioning period in the simulated lignite flue gas before they exhibited good mercury sorption capacities and Hg^0 oxidation potentials (>90% Hg^{2+}).

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Conclusions from Bench-Scale Testing of Potential Mercury Sorbents (continued)

- Lignite-based activated (800°C) carbons required a shorter, 15-minute conditioning period in the simulated lignite flue gas and captured gaseous mercury more effectively with greater Hg^0 oxidation (>95% Hg^{2+}) than those activated at 750°C.
- Activated (750°C) Luscar char and DARCO FGD did not experience significant early mercury breakthrough in the acid gas-rich baseline flue gas.

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Conclusions from Bench-Scale Testing of Potential Mercury Sorbents (continued)

- Mercury capacities of the activated (800°C) Luscar char ranged from 164 to 202 µg/g in the presence of the simulated lignite combustion flue gas.
- Activated (800°C) Luscar char and DARCO FGD most effectively captured mercury in the simulated coal combustion flue gases.

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Sorbents for Pilot-Scale Testing

- Norit FGD
- Luscar char activated carbon

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Directions

- Working with Luscar to develop sorbent – optimization

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Pilot-Scale (PTC) Testing





Pilot-Scale Test Parameters

- Coal
  - Poplar River (C1)
  - Freedom (C2)
- Sorbent type
  - Luscar char derived (S1)
  - Norit FGD (S2)
- Sorbent loading
  - 0 to 25 lb/million acf
- Sorbent size
  - Fine ~ 5 µm
  - As-received, 10–20 µm
- Temperature
  - 300° and 400°F
- Hardware configuration
  - ESP only
  - ESP followed by fabric filter
  - Fabric filter only
  - Advanced Hybrid™ Filter (AH™)

Performed over 60 tests

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Pilot-Scale Test Matrix

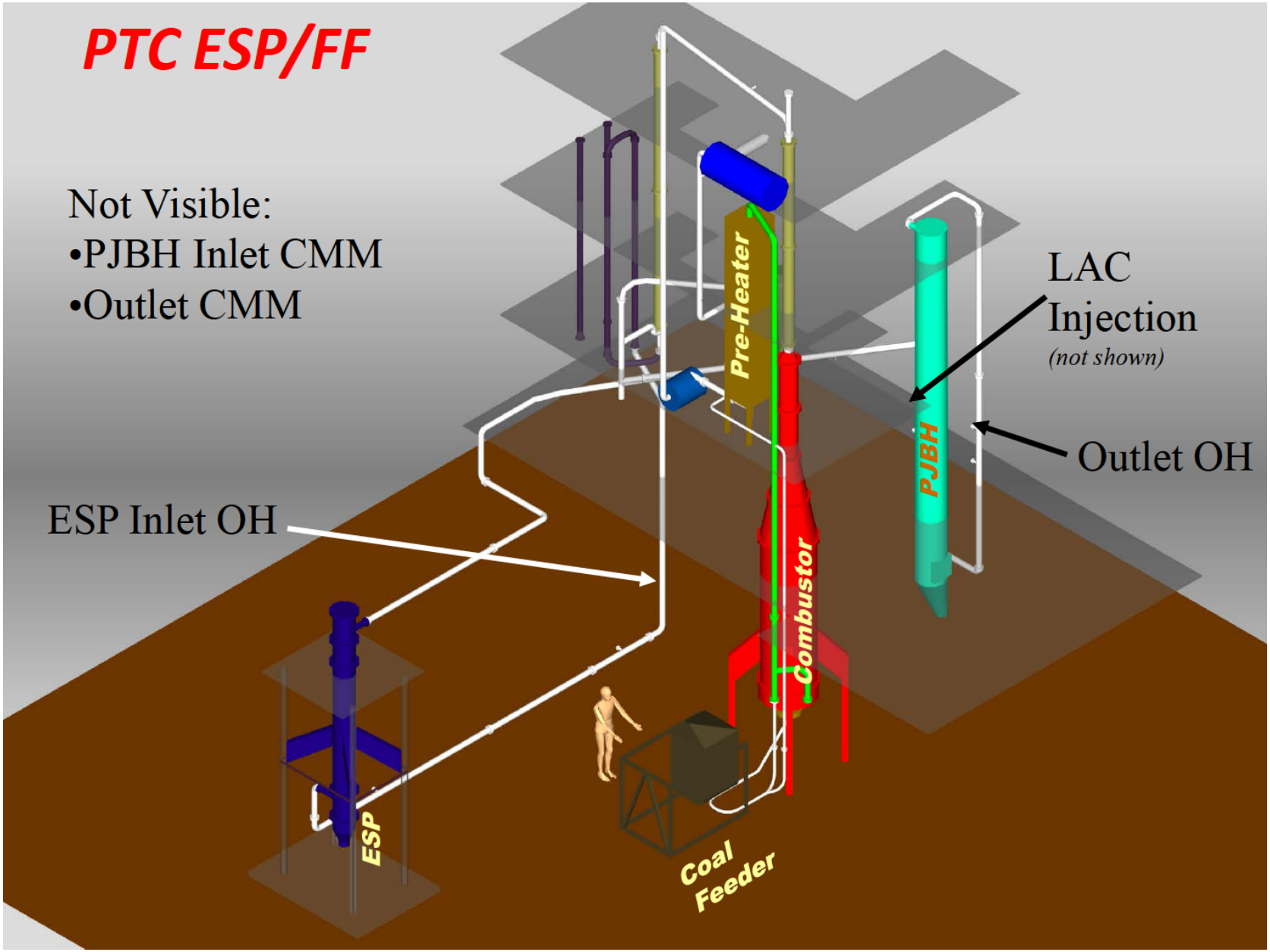
Coal	Control Device	Sorbent	Test No.	Injection Rate, g/hr	Temperature, °F
Poplar River	ESP	NA[a]	1, 4, 10, 28	NA	300
	ESP–FF		13, 17, 19, 24, 26, 49		
	Advanced Hybrid™ Filter		31		
	ESP	S1[b]	5, 6, 9, 12, 29	40–150	300
		S1 fine	8, 11, 30	25–75	
	ESP–FF	S1	14, 25, 27	10–50	300
			21	10–60	400
		S1 fine	16	25	300
			20	10–40	400
	FF	S1	35	10–60	300
	Advanced Hybrid™ Filter	S1	32	20–120	
	ESP	S2[c]	2, 3	75–150	300
	ESP–FF	S2	18, 50–53	20–60	300
			23	10–60	400
		S2 fine	22	10–60	400
Freedom	ESP	NA	40	NA	300
	ESP–FF		36, 38		
	Advanced Hybrid™ Filter		43		
	ESP	S1	42	50–150	300
		S1 fine	41	25–115	
	ESP–FF	S1	37	10–40	300
	Advanced Hybrid™ Filter	S1	44	10–40	300
	ESP–FF	S2	39	10–40	300

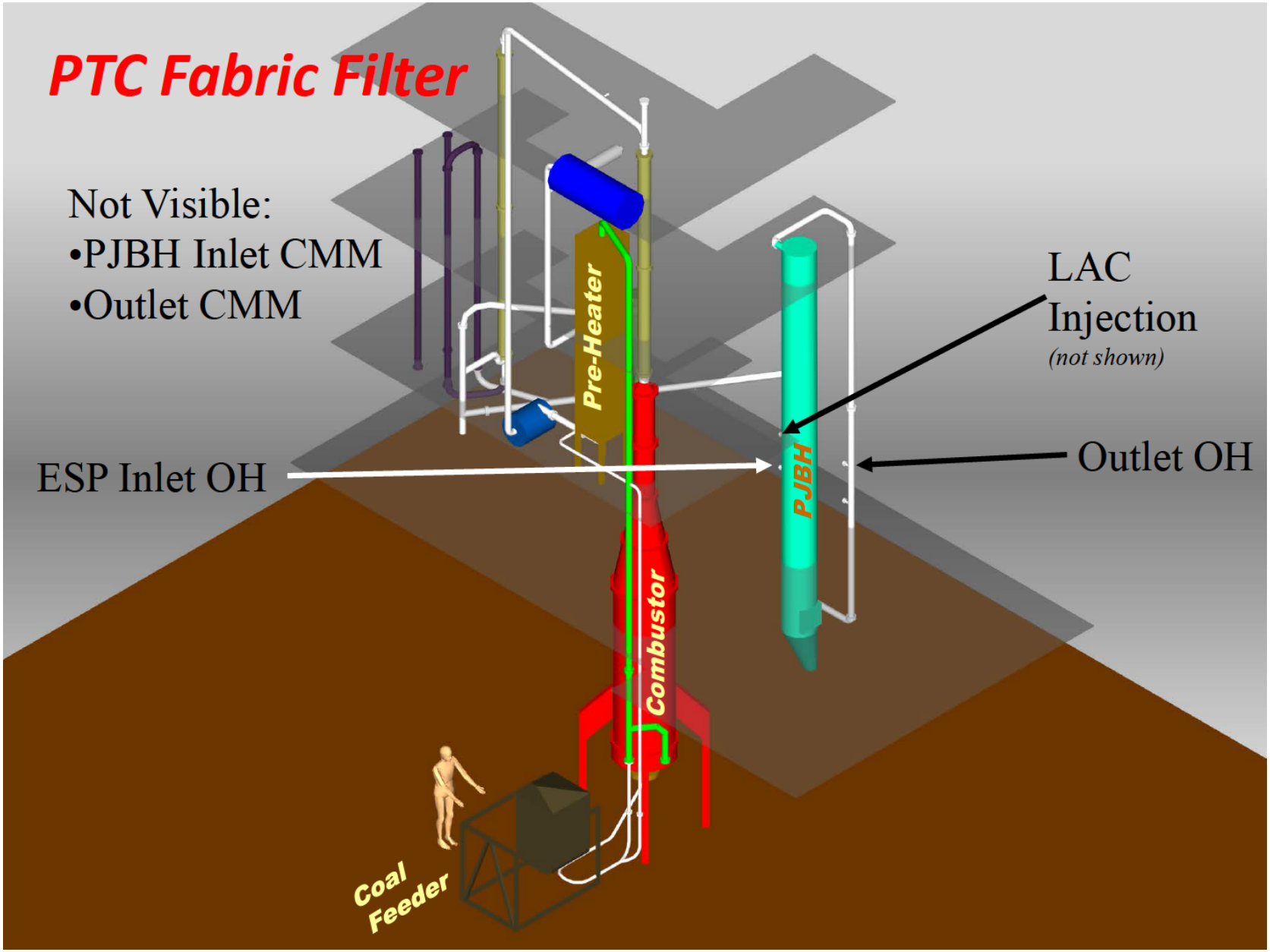
[a] NA = Not applicable.
[b] S1 = Lignite-Based Steam Activated (800°C, 1472°F) Luscar Char.
[c] S2 = DARCO FGD.

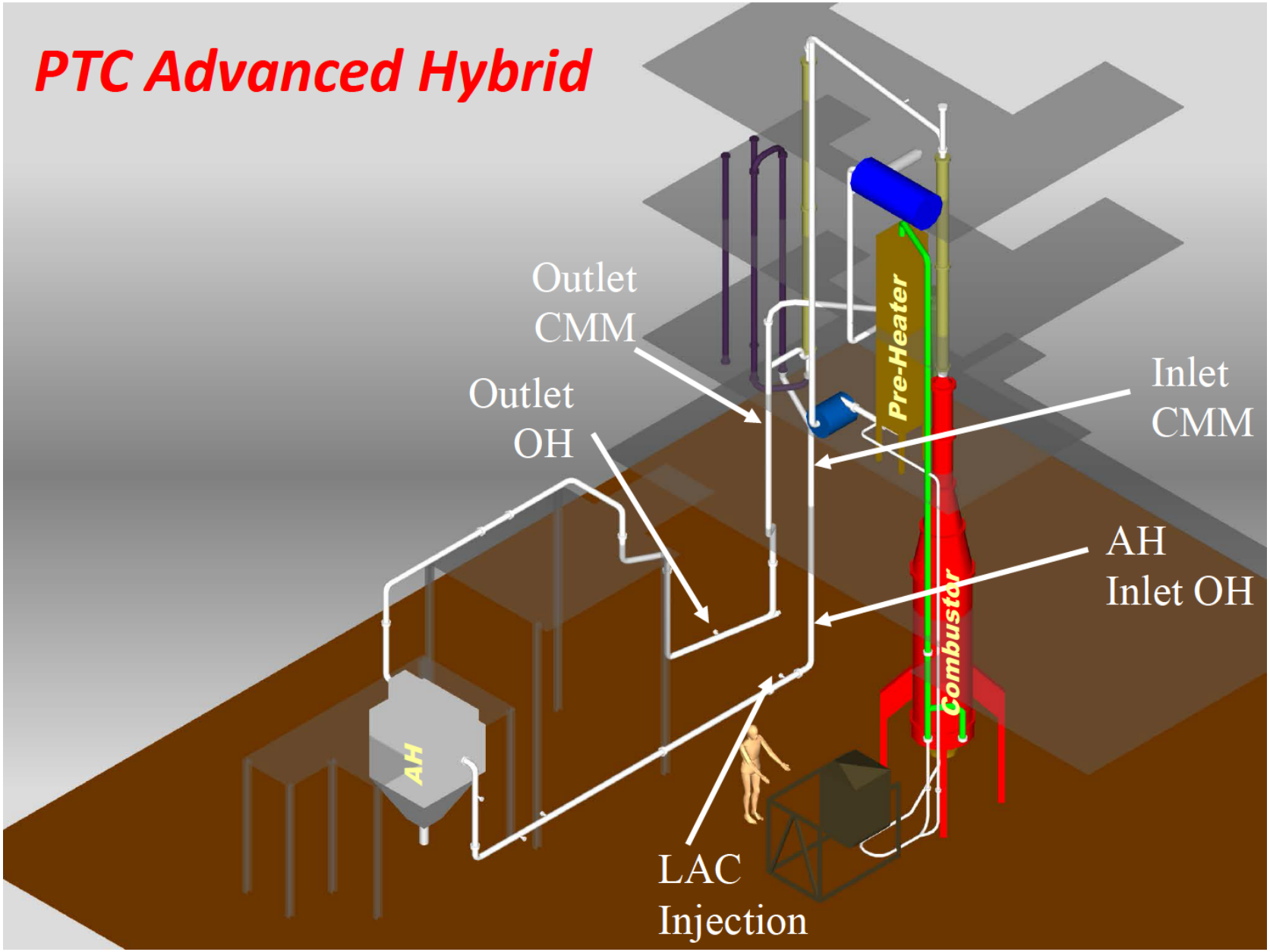
PTC ESP Only



Pre-Heater
Outlet CMM
Inlet CMM
Inlet OH
Outlet OH
Combustor
LAC
Injection
ESP
Coal
Feeder


PTC ESP/FF
Not Visible:
•PJBH Inlet CMM
•Outlet CMM
LAC
Injection
(not shown)
Outlet OH
ESP Inlet OH
Pre-Heater
Combustor
PJBH
ESP
Coal
Feeder


PTC Fabric Filter
Not Visible:
•PJBH Inlet CMM
•Outlet CMM
Pre-Heater
LAC
Injection
(not shown)
ESP Inlet OH
Outlet OH
PJBH
Combustor
Coal
Feeder


PTC Advanced Hybrid
Outlet
CMM
Outlet
OH
Pre-Heater
Inlet
CMM
AH
Inlet OH
Combustor
AH
LAC
Injection

Characteristics of Test Coals Moisture-Free Basis

	Poplar River Coal							Freedom Coal		
	Moist. Free	Moist. Free	Moist. Free	Moist. Free	Moist. Free	Moist. Free	Average	Moist. Free	Moist. Free	Average
Proximate Analysis, %	6/7/2002	T1	T4	T12	T20	7/8/2002		6/7/2002	7/19/2002	
Moisture	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Volatile Matter	45.08	45.81	46.43	45.74	46.95	45.93	45.99	44.48	46.47	45.48
Fixed Carbon	34.49	33.30	32.57	33.32	33.74	34.94	33.73	41.69	42.92	42.31
Ash	20.43	20.89	21.00	20.94	19.31	19.13	20.28	13.83	10.61	12.22
Ultimate Analysis, %										
Hydrogen	3.61	3.37	3.35	0.00	3.46	3.60	3.48	3.83	4.01	3.92
Cabon	53.22	52.06	52.47	0.00	52.62	53.63	52.80	59.74	61.08	60.41
Nitrogen	0.85	0.81	0.80	0.00	0.80	0.80	0.81	1.01	1.02	1.02
Sulfur	0.70	0.95	1.00	0.85	0.96	0.90	0.90	0.79	0.92	0.86
Oxygen (IND)	21.19	21.92	21.38	0.00	22.85	21.94	21.86	20.80	22.36	21.58
Ash	20.43	20.89	21.00	20.94	19.31	19.13	20.28	13.83	10.61	12.22
Heating Value (Btu/lb)										
Btu	8428	8493	8507	8673	8843	8732	8613	9702	10276	9989
Mercury ppm (dry)	0.117	0.171	0.165	0.160			0.153	0.062	0.093	0.077
Chlorine ppm (dry)	11		24		23	18	19	18	21	20

Sorbents Tested in Pilot-Scale System

Sorbent	Mass Mean Diameter
Luscar Derived Carbon	19.5
Luscar (fine)	5.52
Norit FGD	18.1
Norit (fine)	6.63

EERC

Sorbent Characteristics

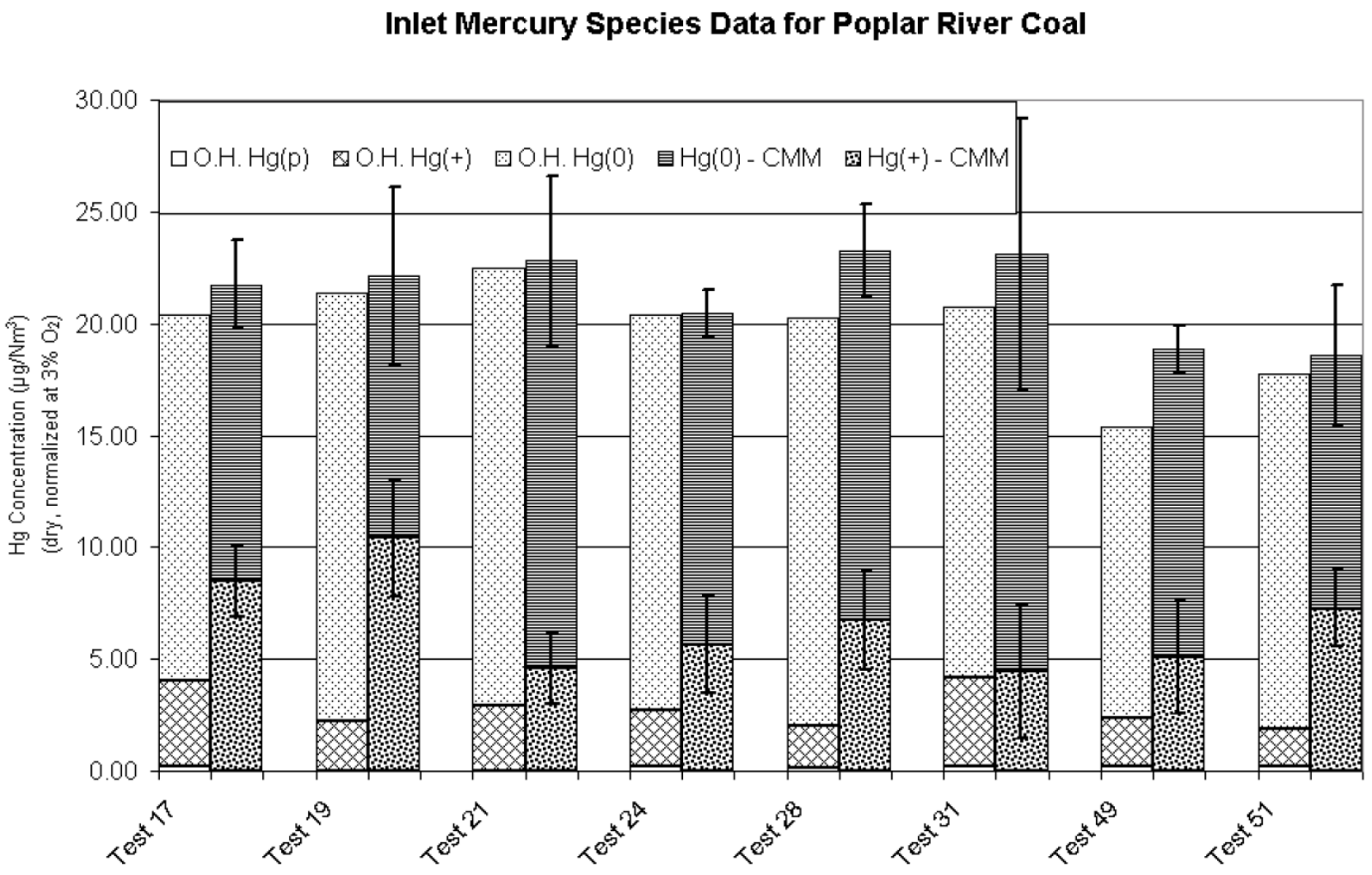
	Activation Conditions	Iodine No.
Luscar Coal	Carbonized @400°C, steam activation @T1°C/30 min	424.3
Luscar Coal	Carbonized @400°C, steam activation @T2°C/30 min	398.1
Luscar Char	**Steam activation @T1°C/30 min**	**439.6**
Luscar Char	**Steam activation @T2°C/30 min**	**427.4**
Beulah Coal	Carbonized @400°C, steam activation @T1°C/30 min	331.5
Center Coal	Carbonized @400°C, steam activation @T1°C/30 min	352.8
Center Coal	Carbonized @400°C, steam activation @T2°C/30 min	321.5
Norit FGD	**Unknown**	**524.8**

Pilot-Scale Test Results

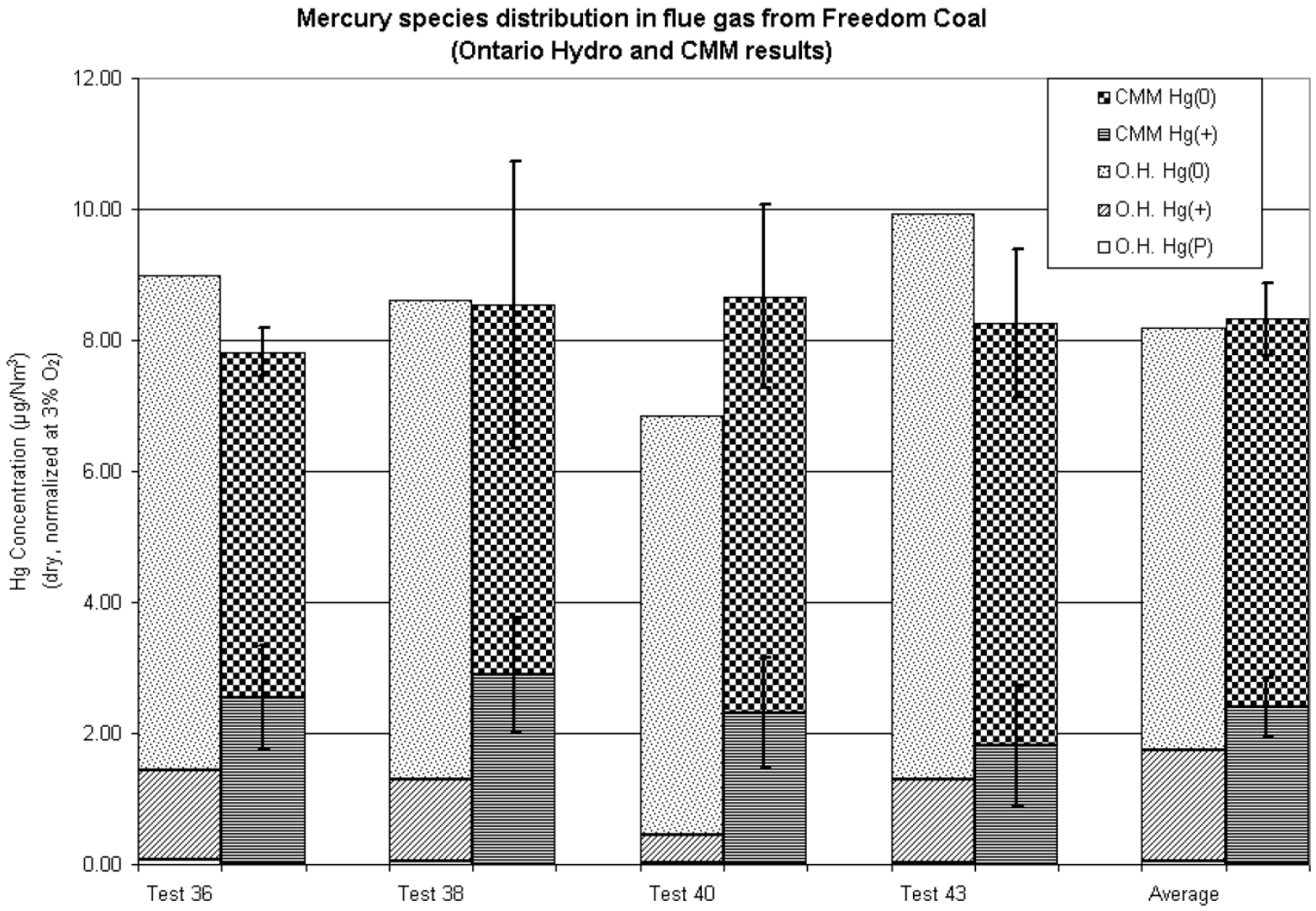
Results Presented Are Final Pending Consortium Review

EERC

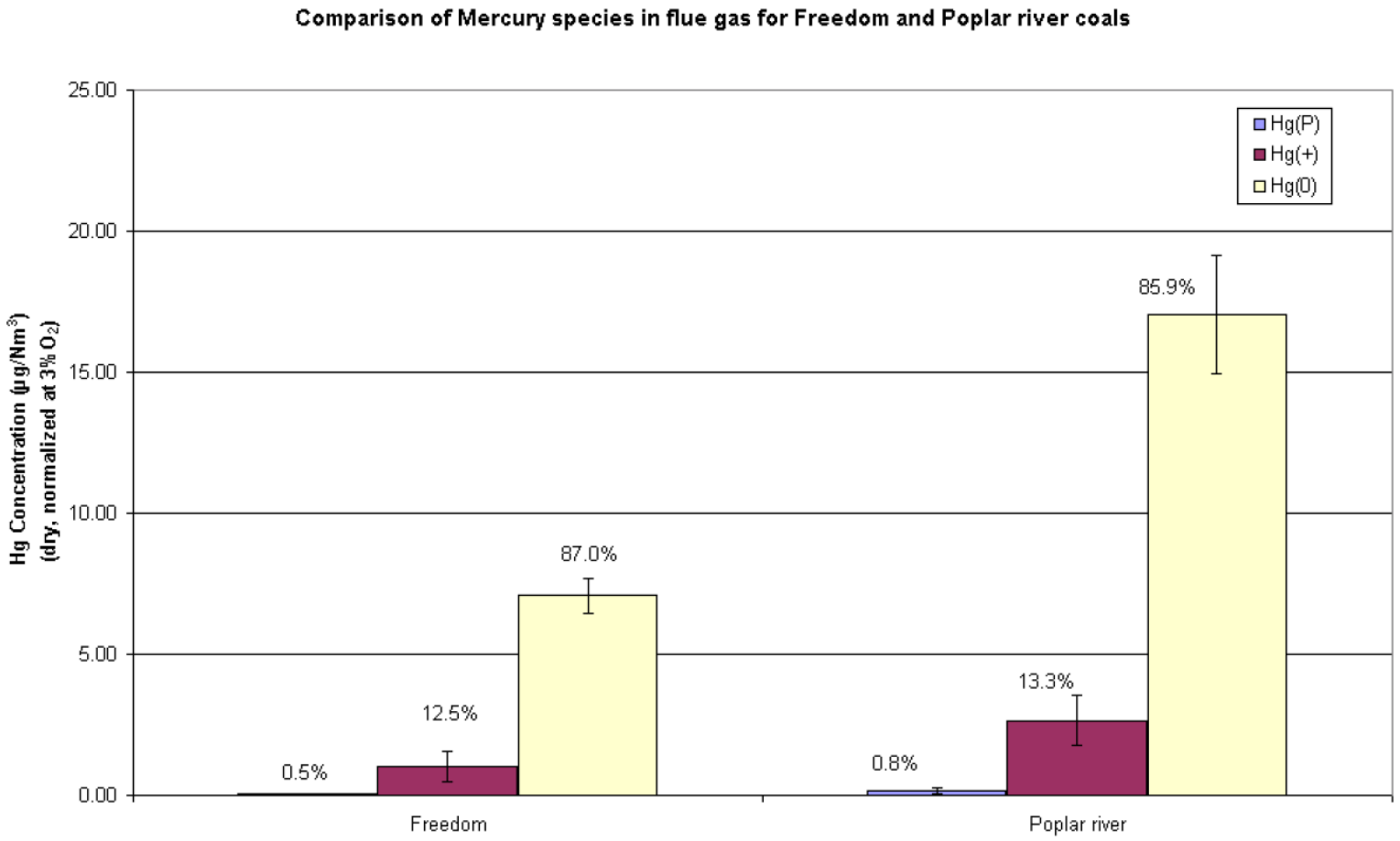
Inlet Speciated Mercury Poplar River (C1)



Inlet Speciated Mercury Freedom Coal

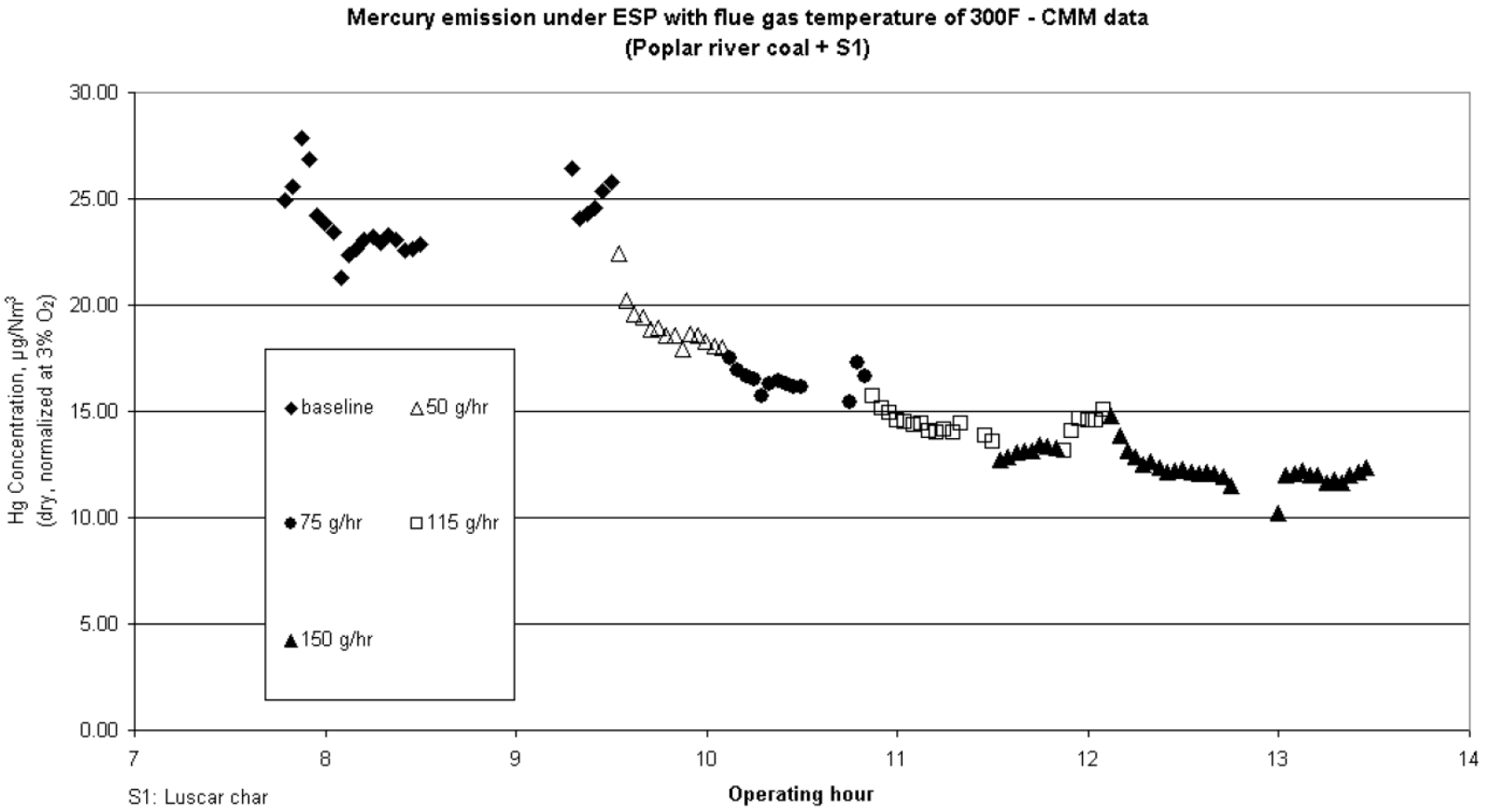


Inlet Speciated Mercury

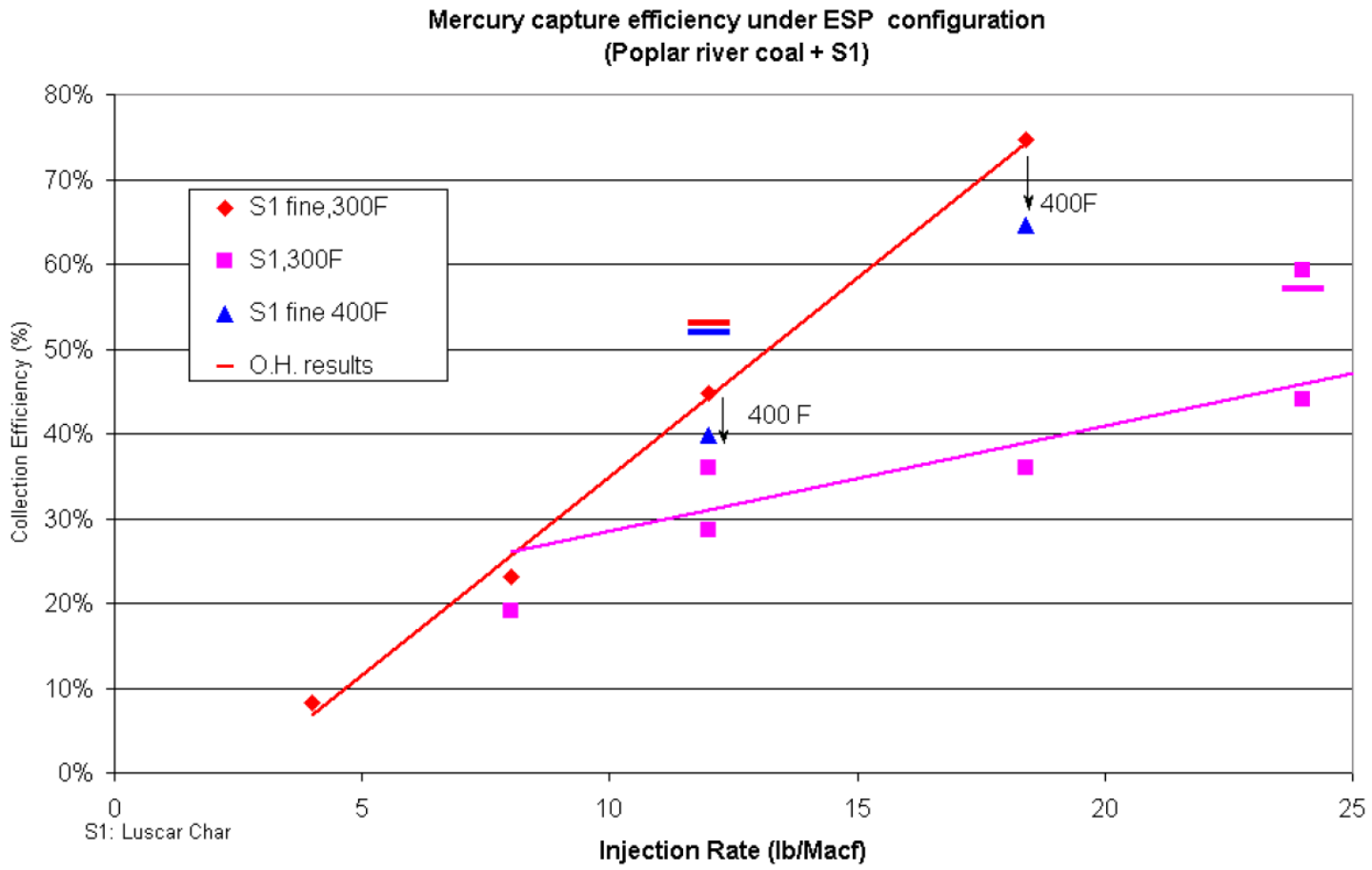


Mercury Control Technology Results

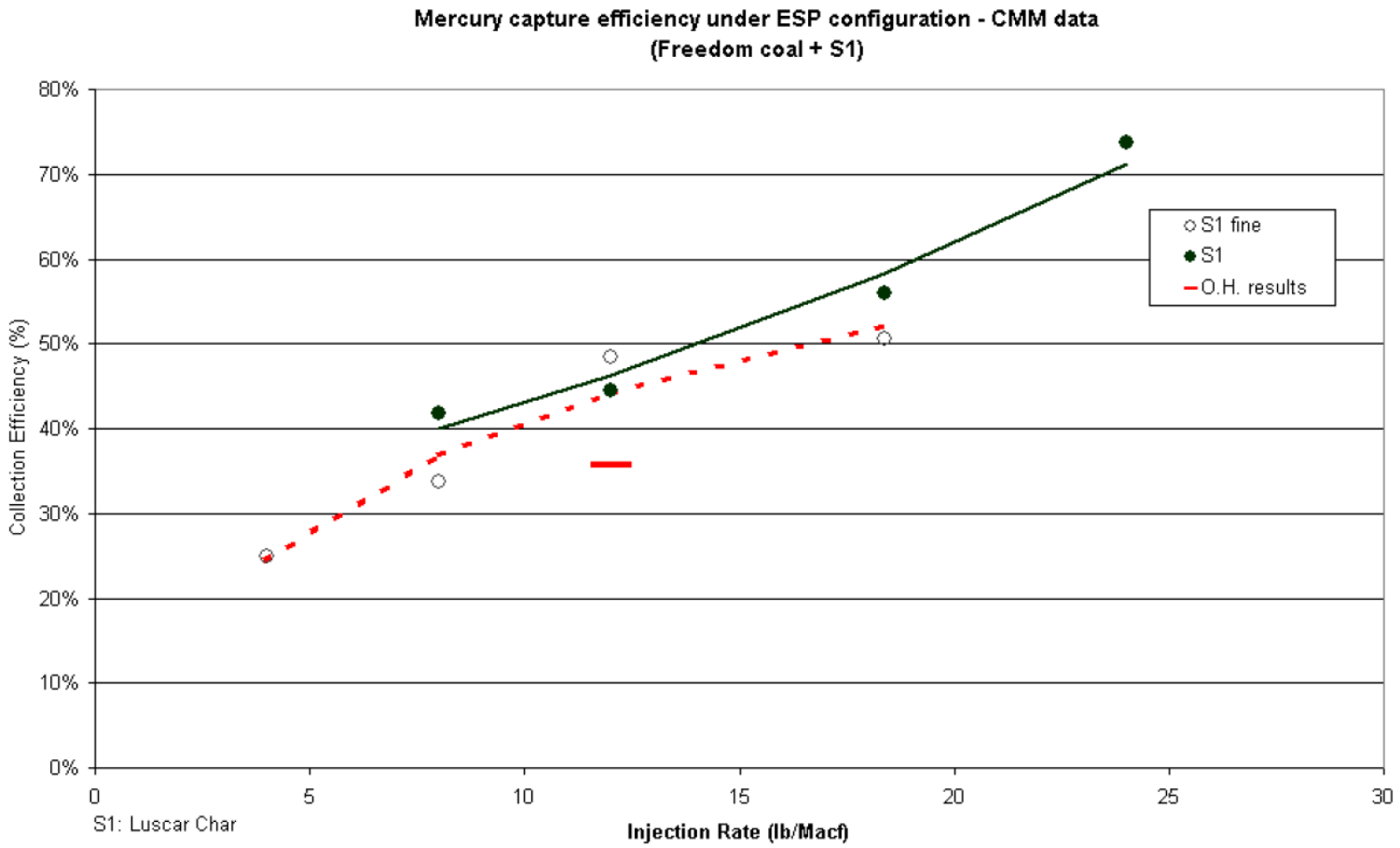
ESP Only – Mercury Emissions



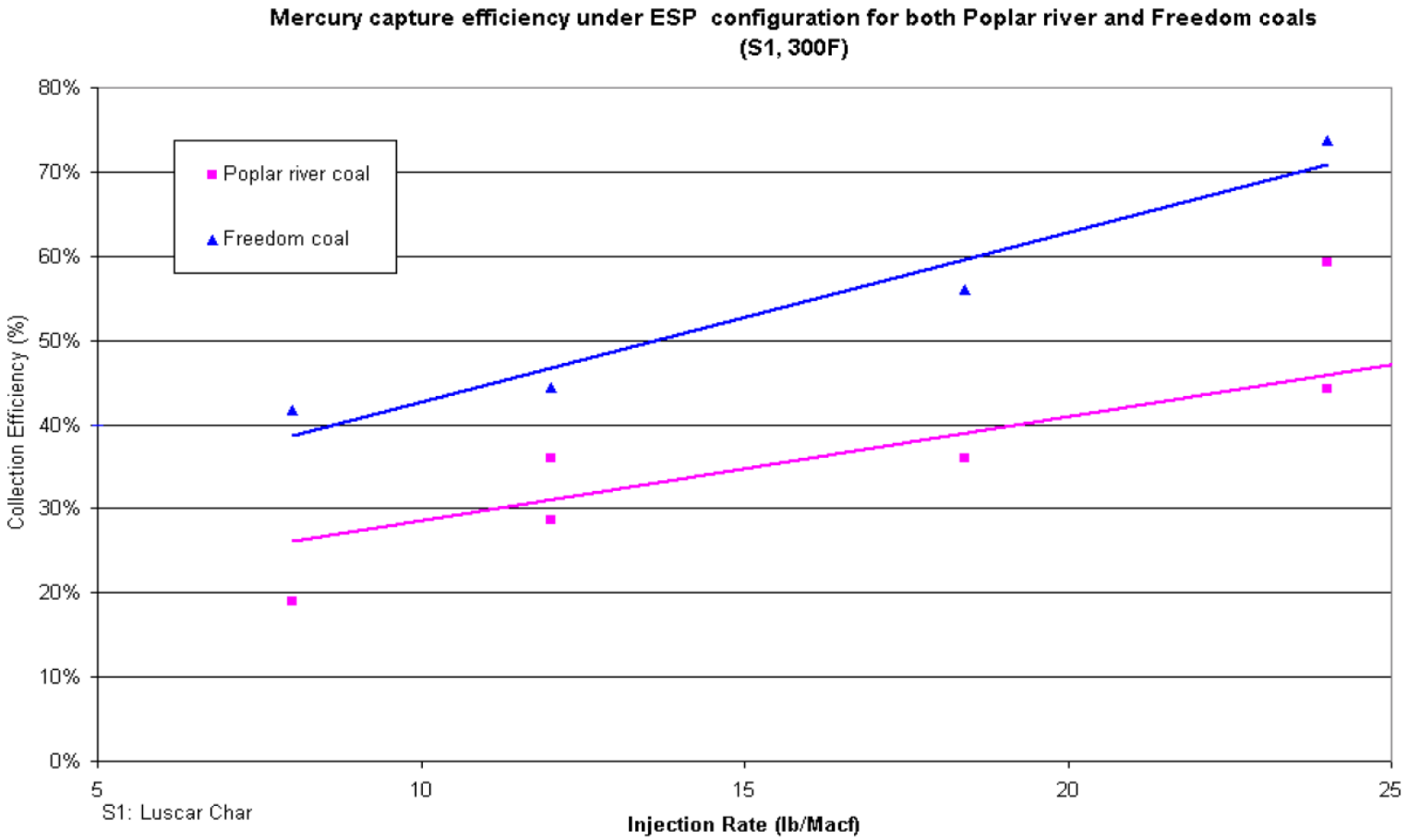
ESP Only – Mercury Removal Efficiency



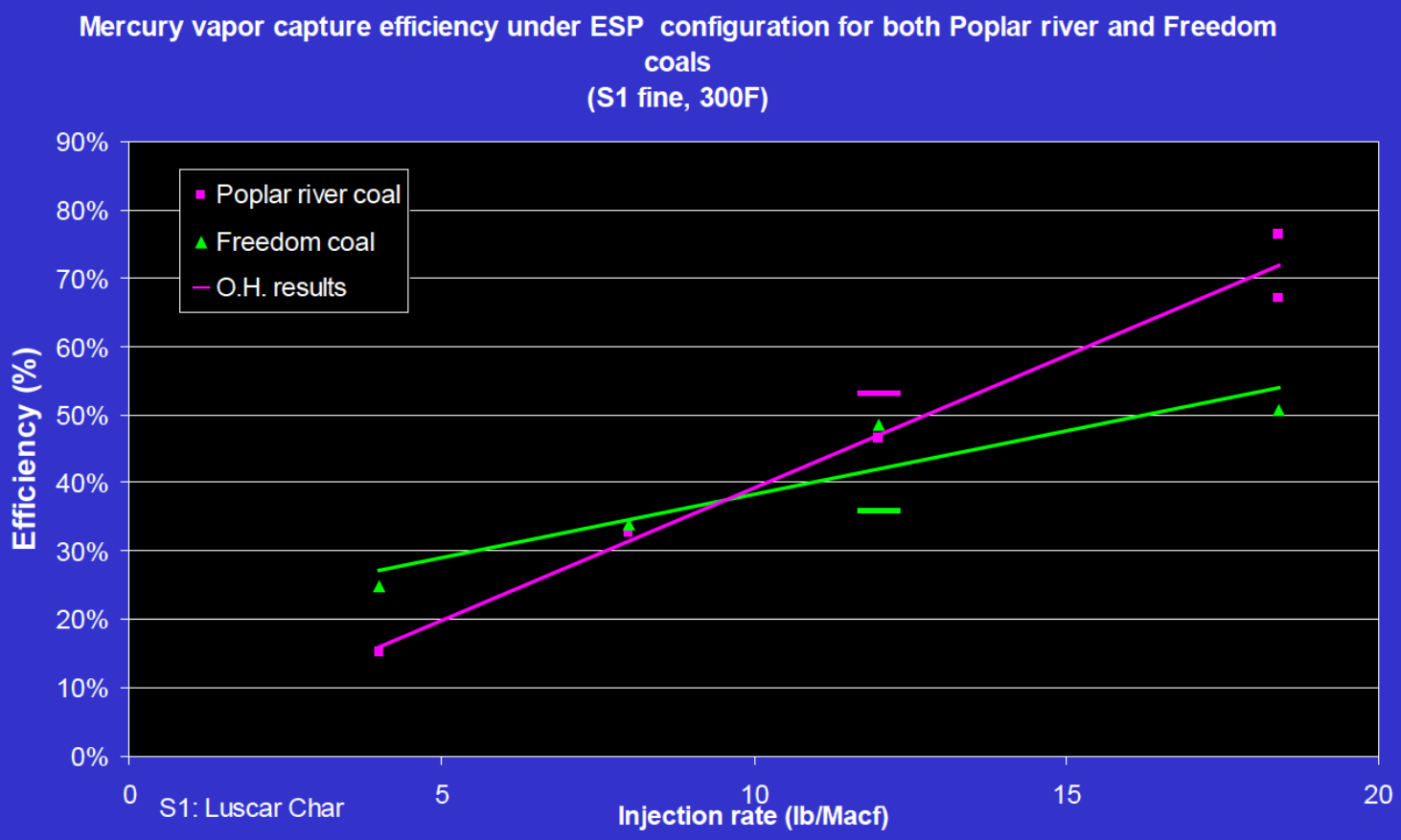
ESP Only – Mercury Removal Efficiency



ESP Only – Mercury Removal Efficiency

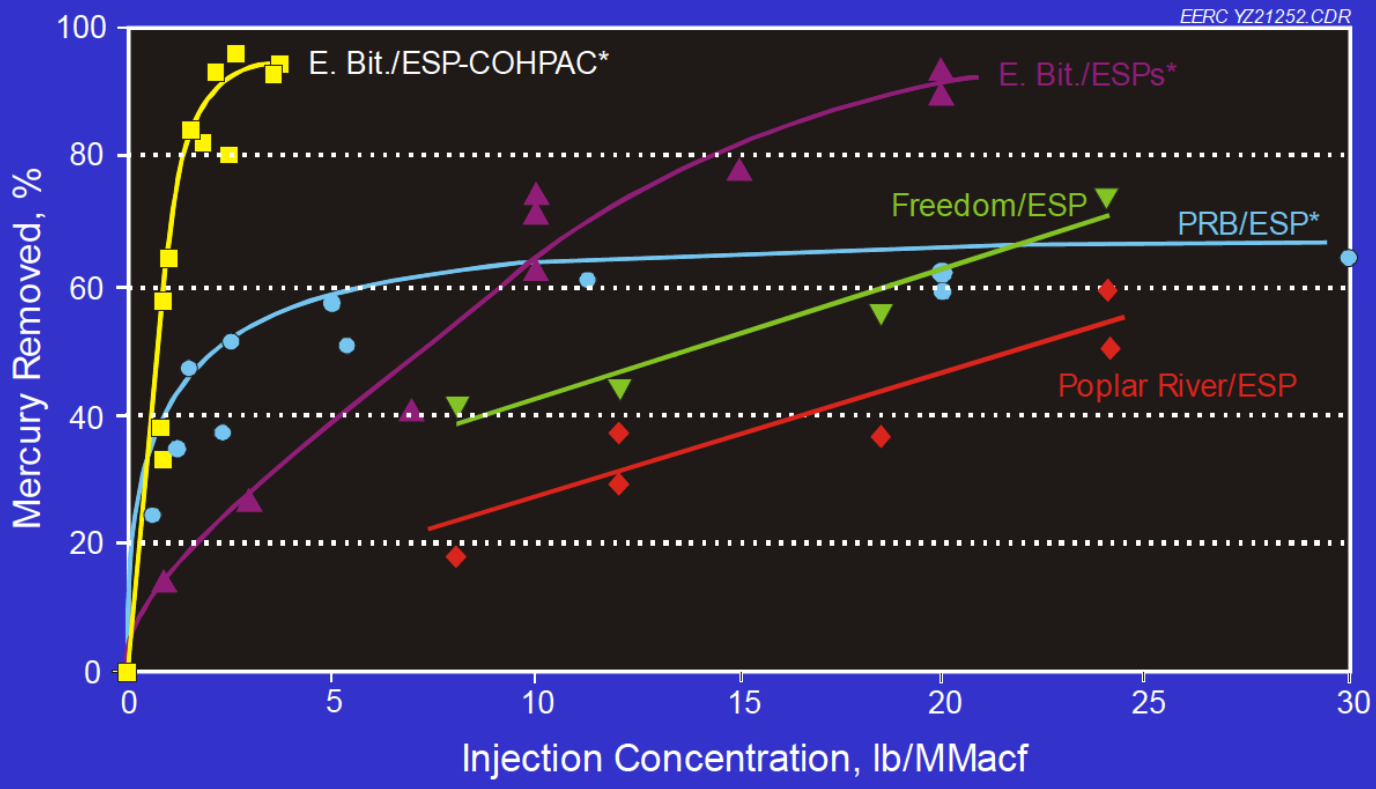


ESP Only – Mercury Removal Efficiency C1, C2, S1 fine, 300°F



Mercury Removal Trends with ACI

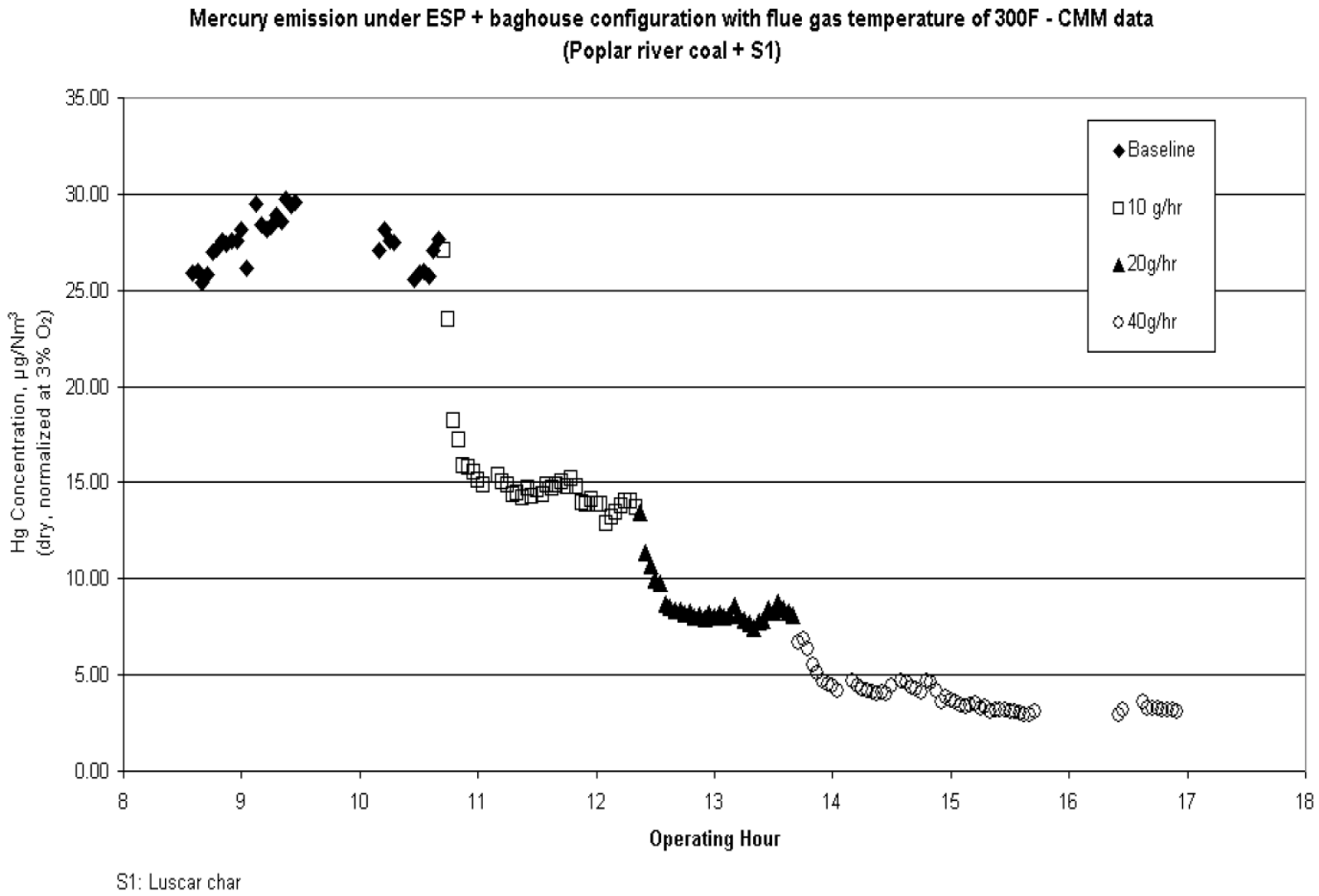
Compared to EERC Pilot-Scale ESP Only Results



EERC

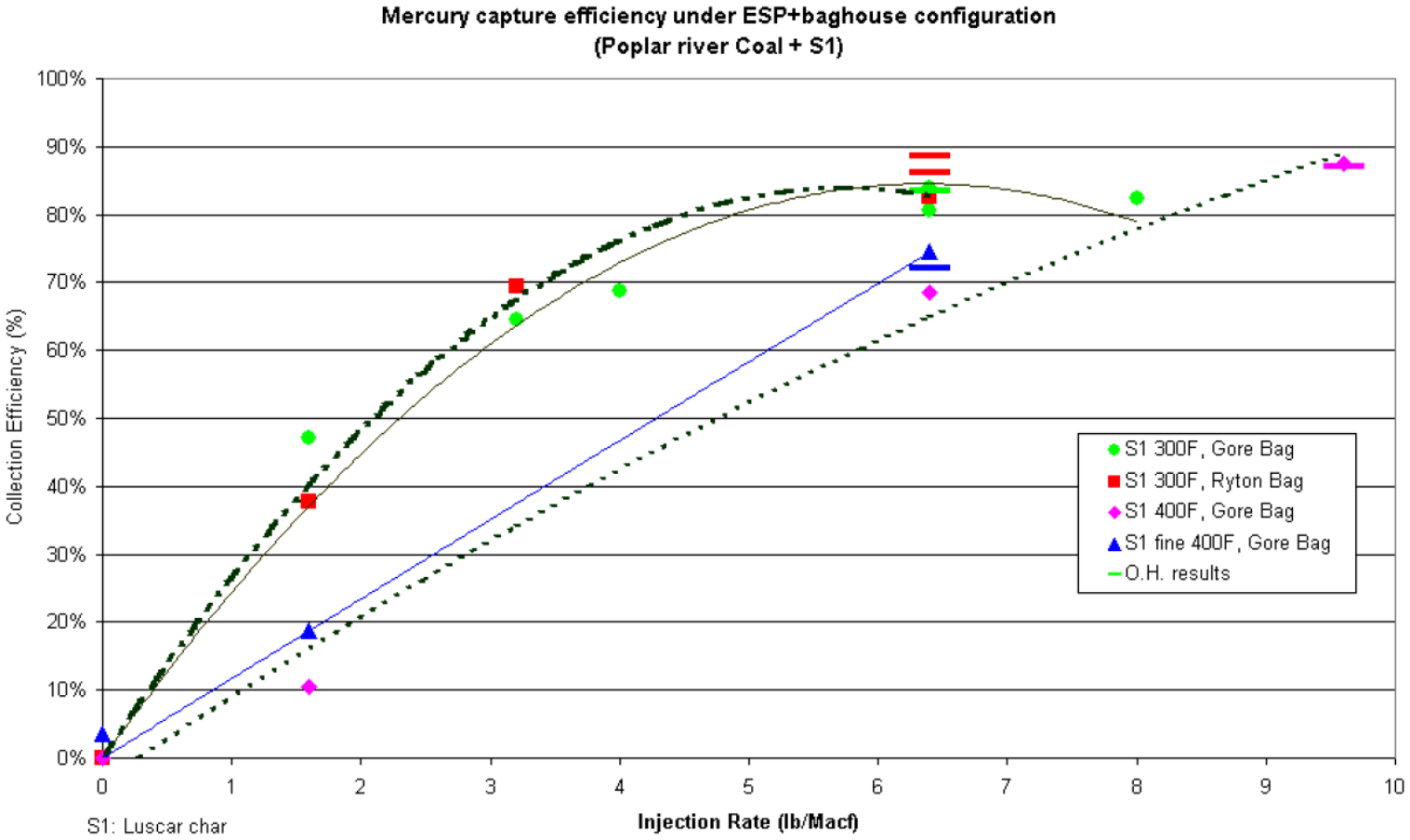
Data Courtesy of NETL

ESP/FF – Mercury Emissions

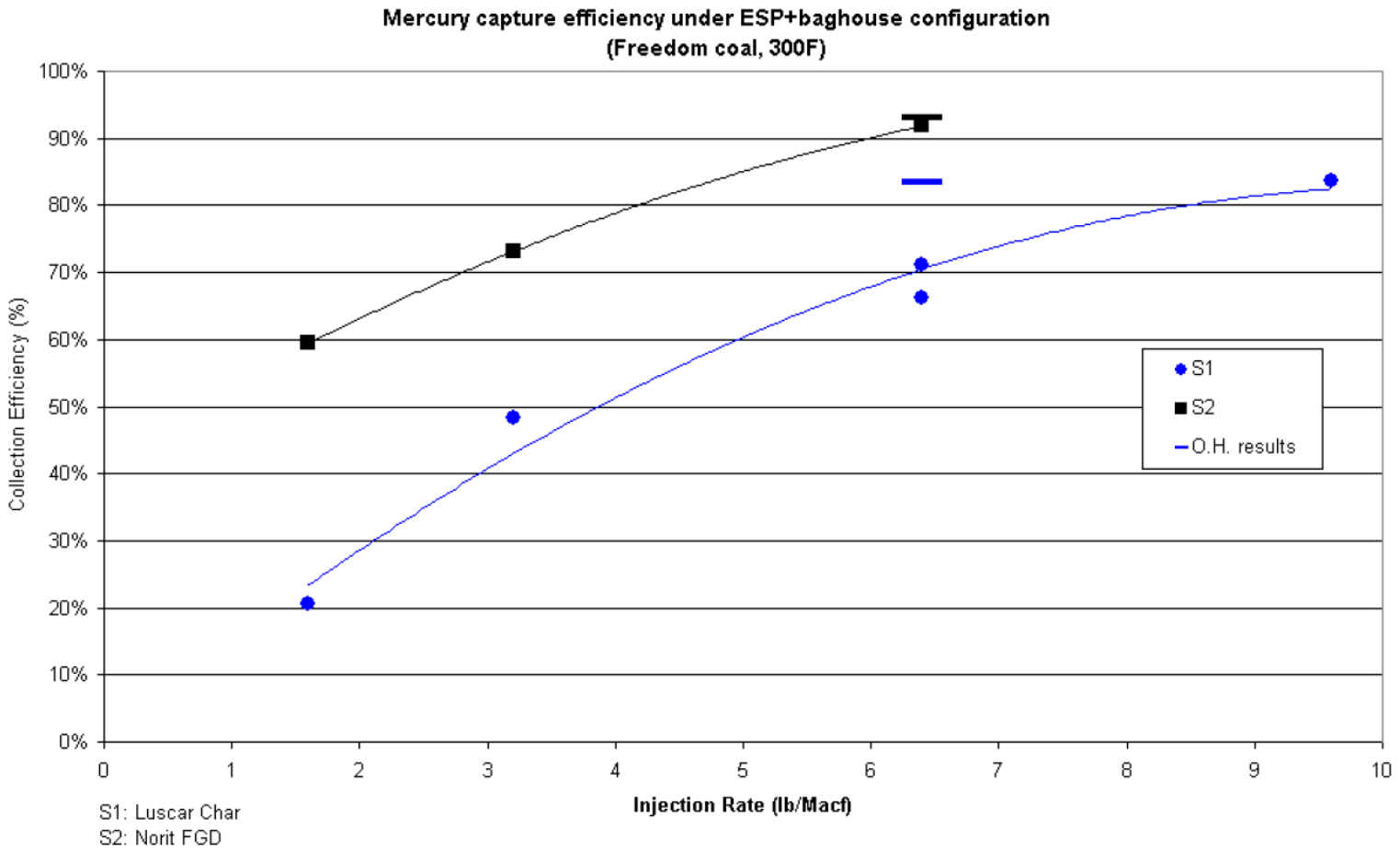


S1: Luscar char

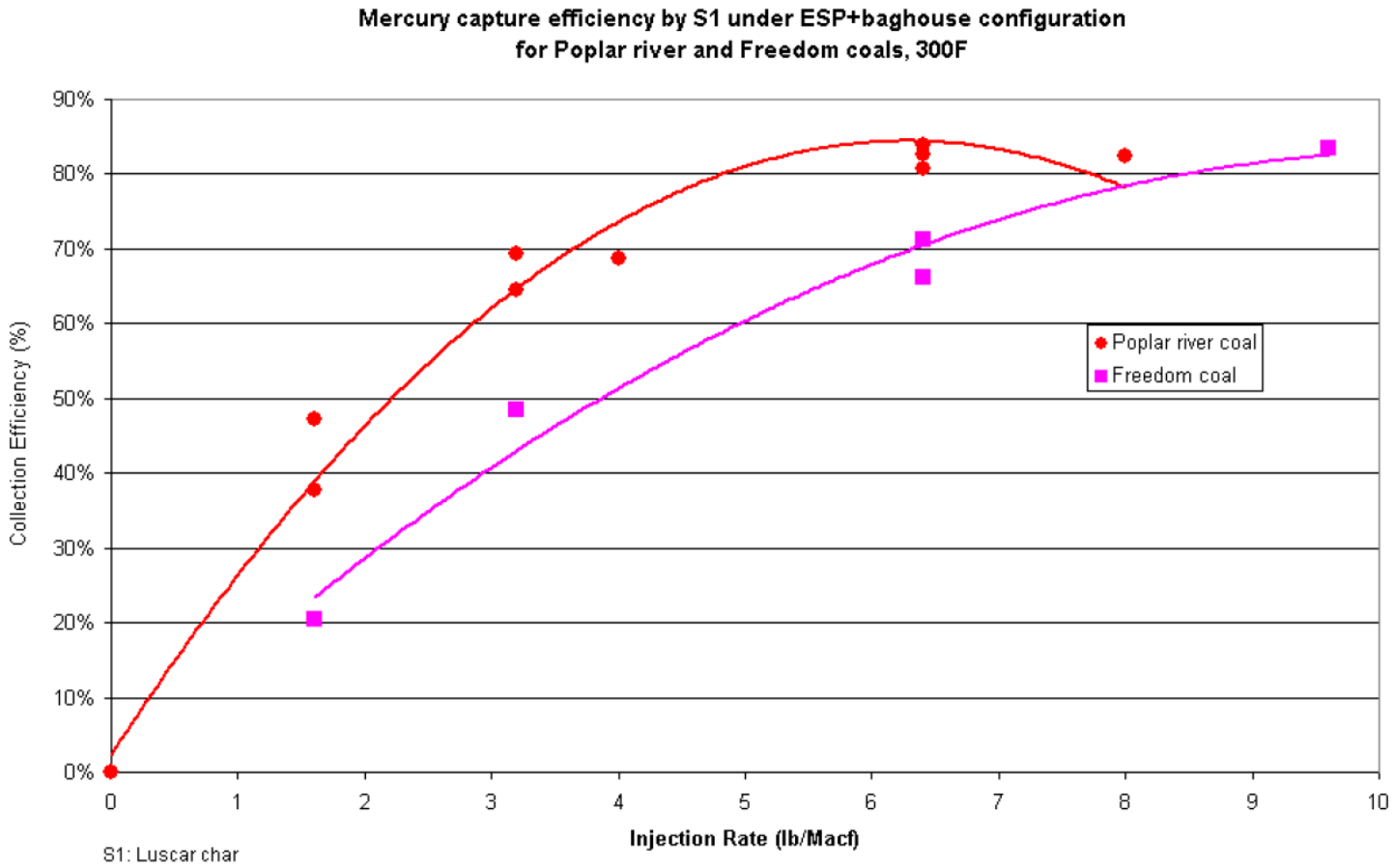
ESP/FF – Mercury Removal Efficiency



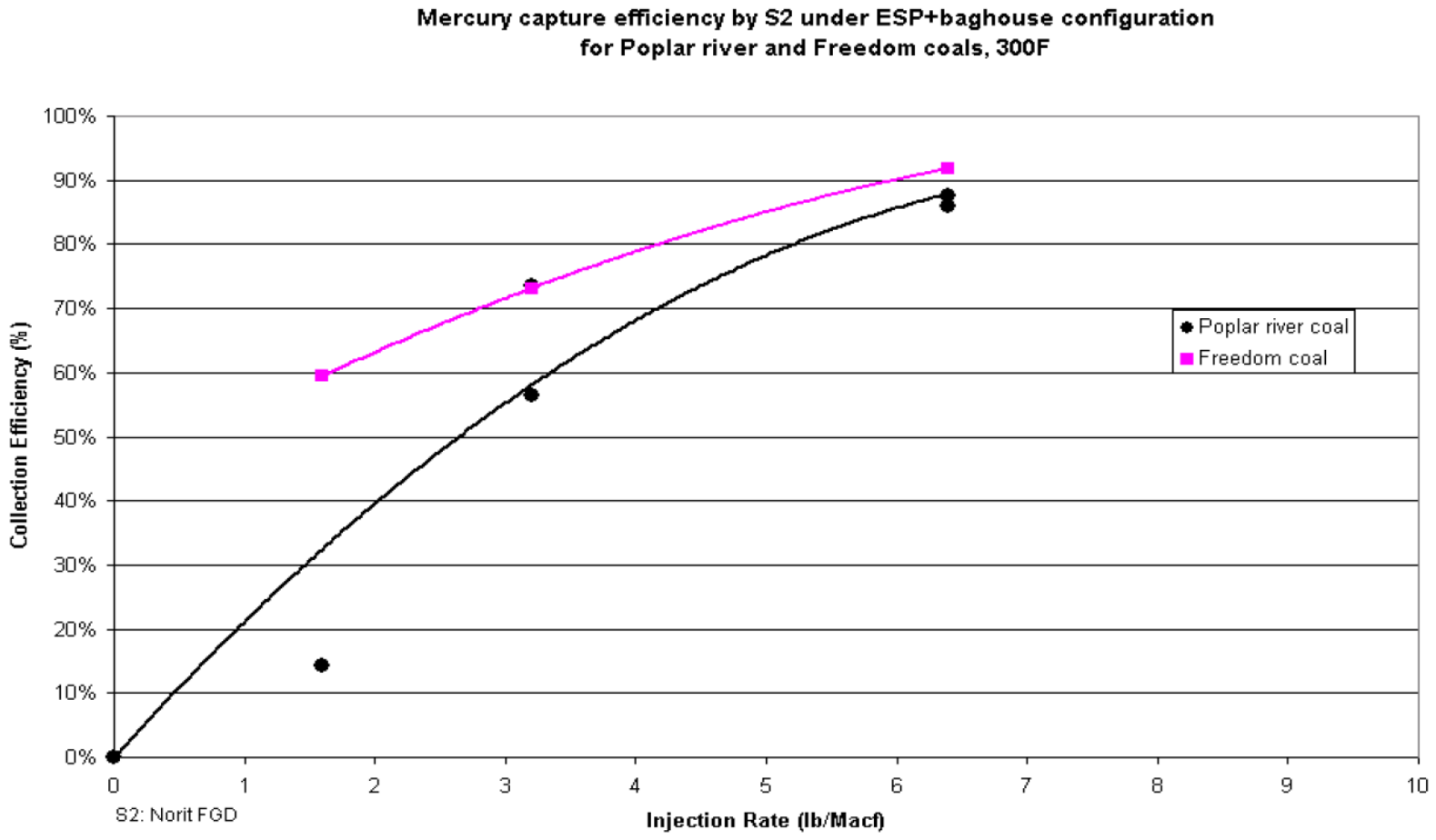
ESP/FF – Mercury Removal Efficiency



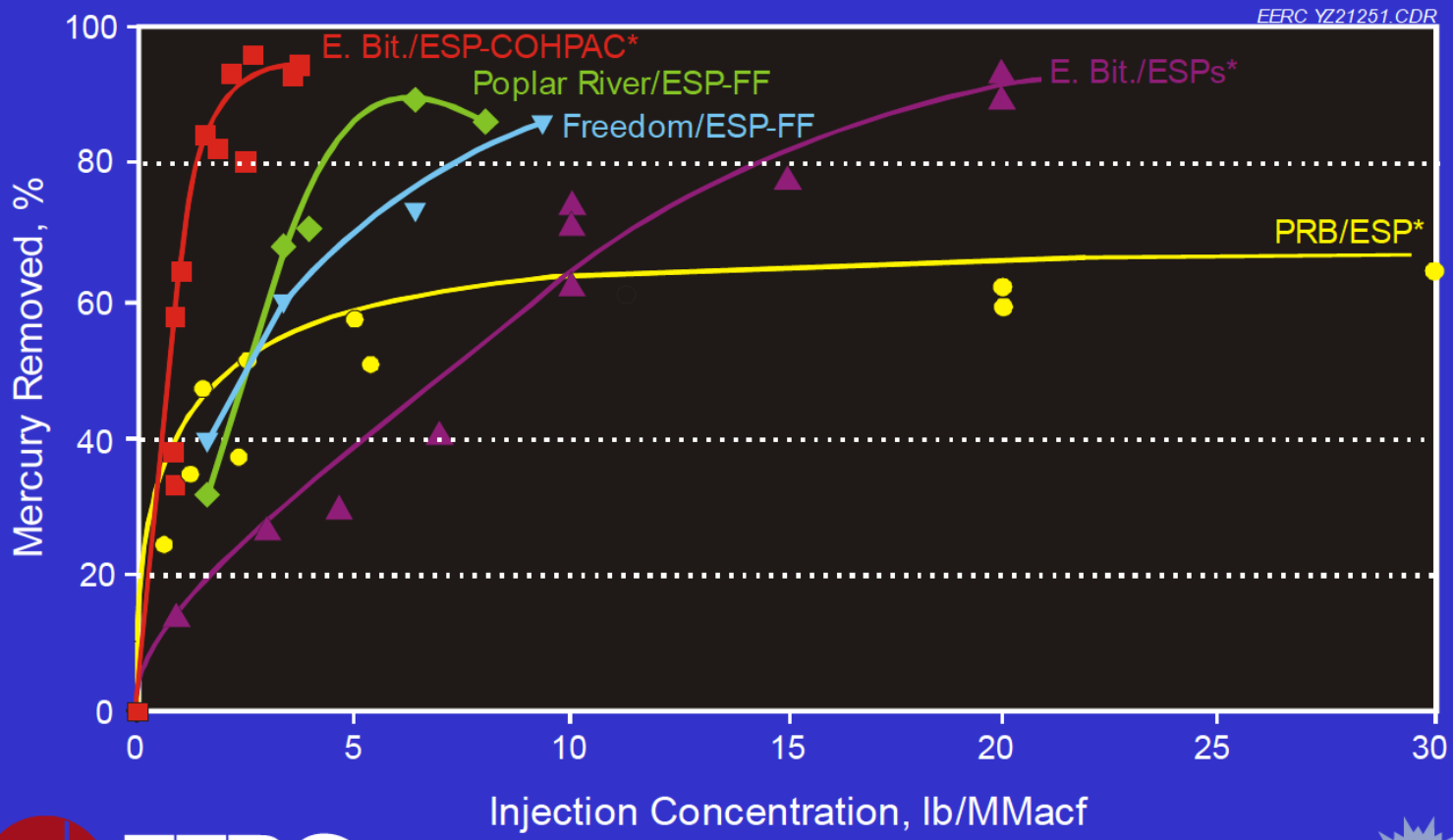
ESP/FF – Mercury Removal Efficiency



ESP/FF – Mercury Removal Efficiency



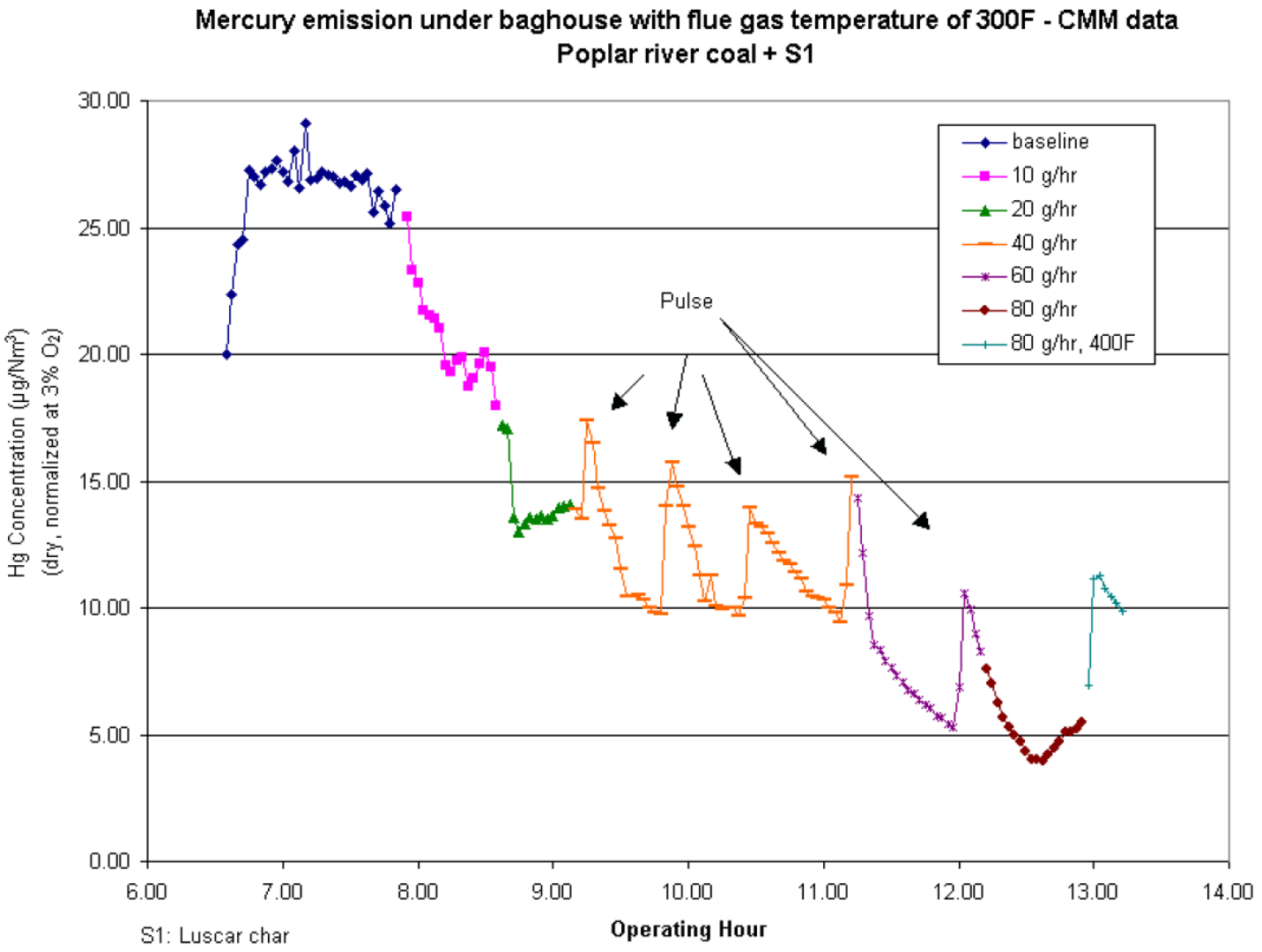
Mercury Removal Trends with ACI
Compared to EERC Pilot-Scale ESP/FF Results



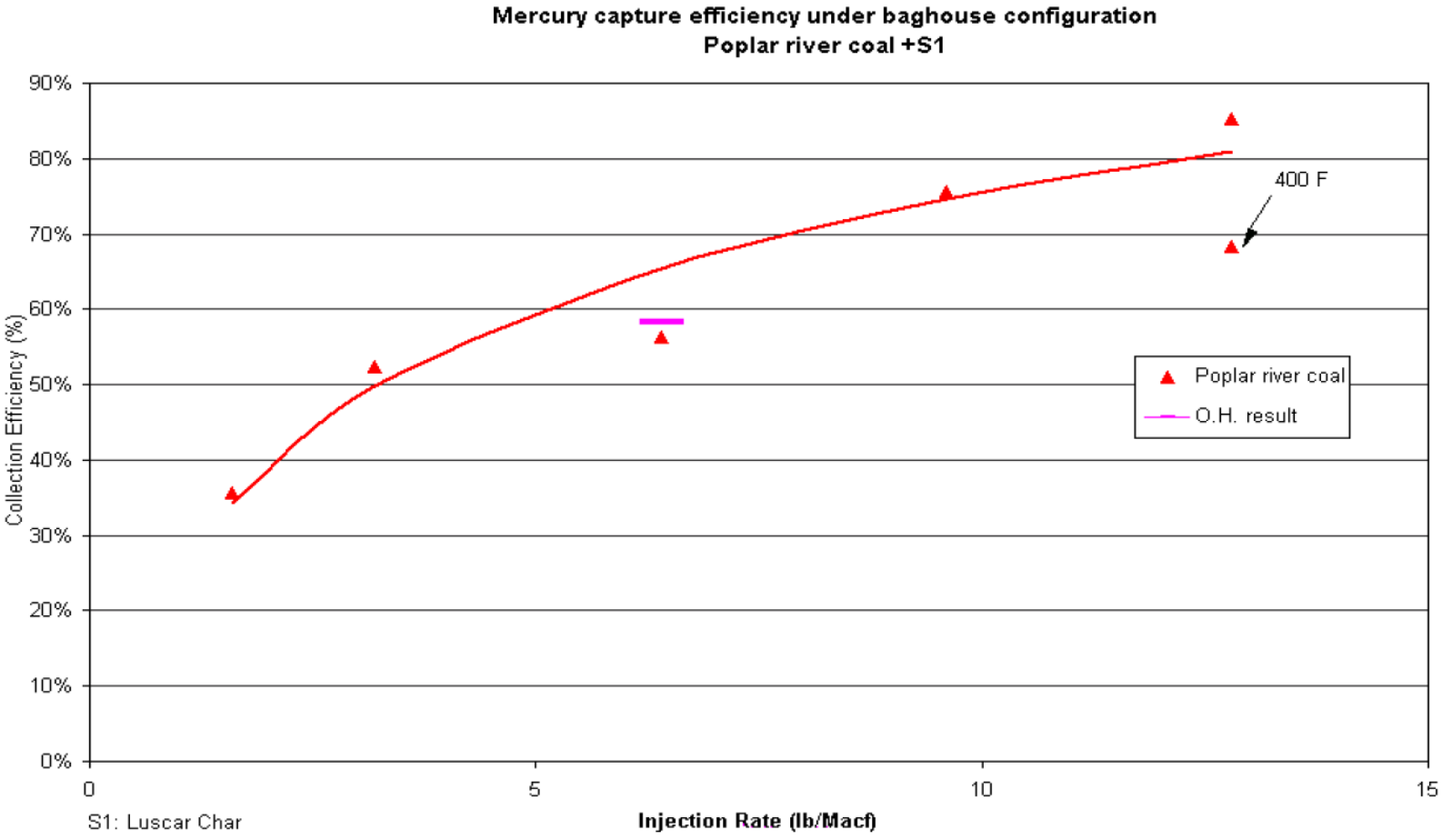
EERC

Data Courtesy of NETL

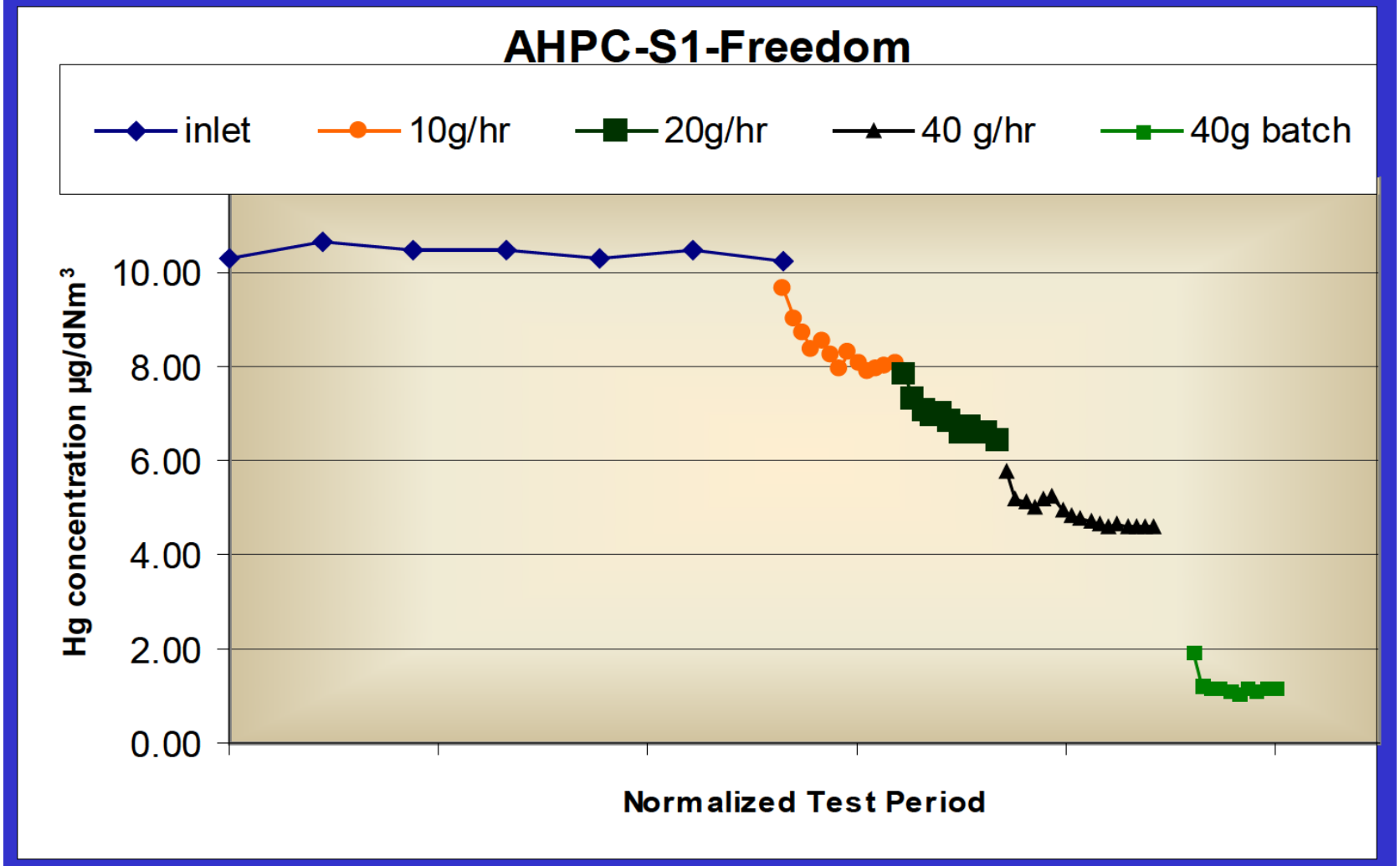
Fabric Filter Only – Mercury Emissions



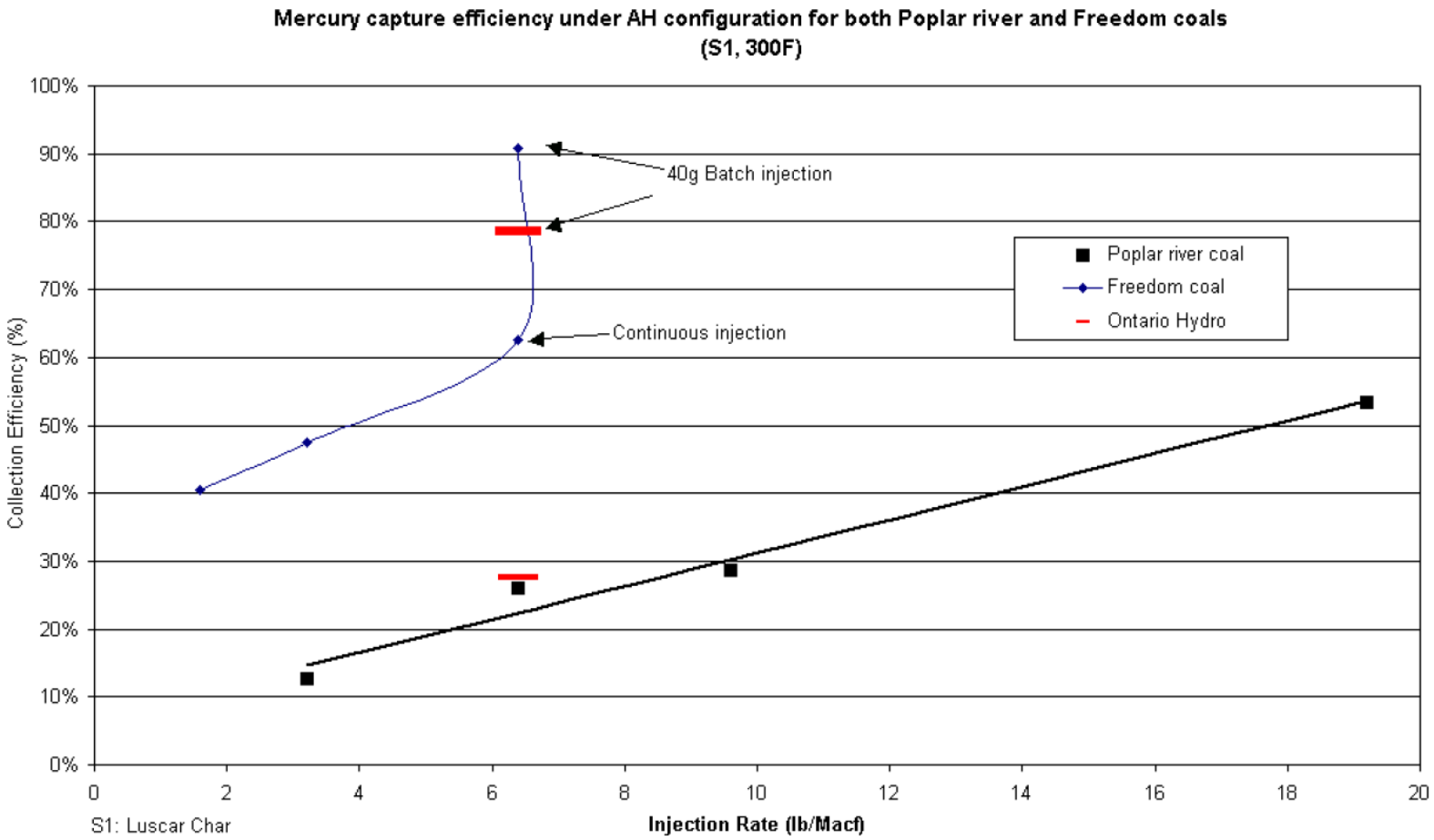
FF Only – Mercury Removal Efficiency



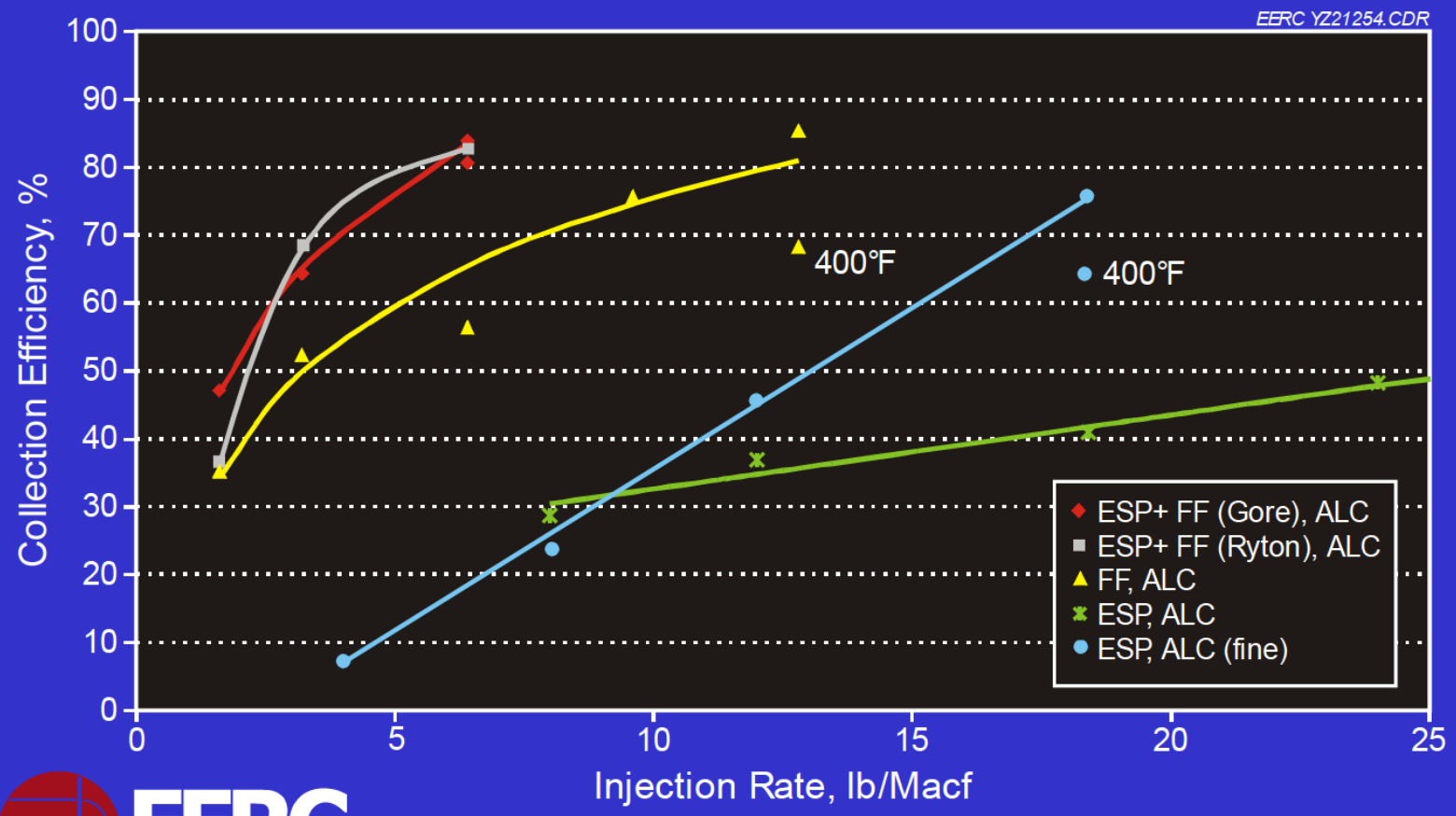
Advanced Hybrid – Mercury Emissions



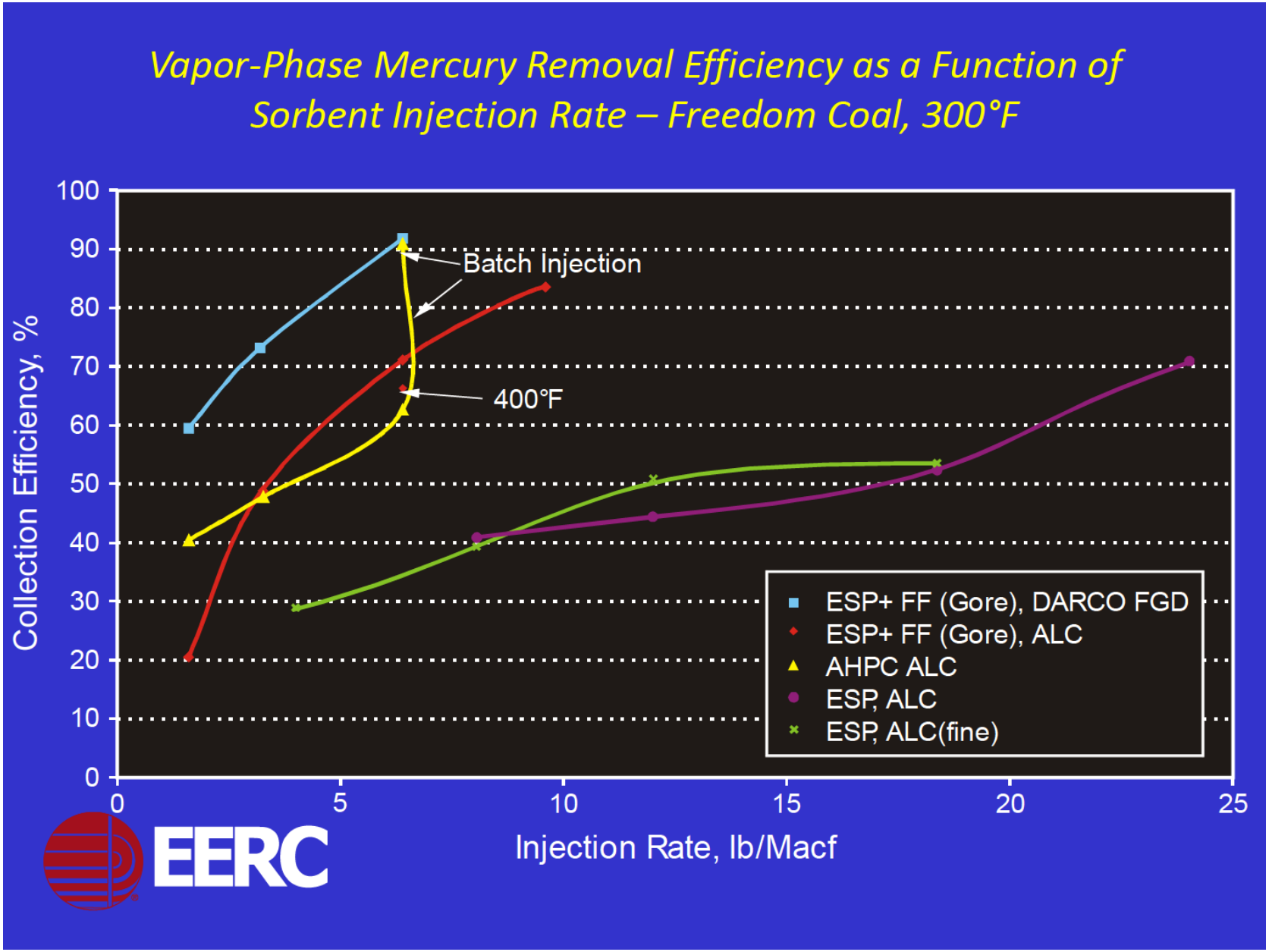
Advanced Hybrid – Mercury Removal Efficiency



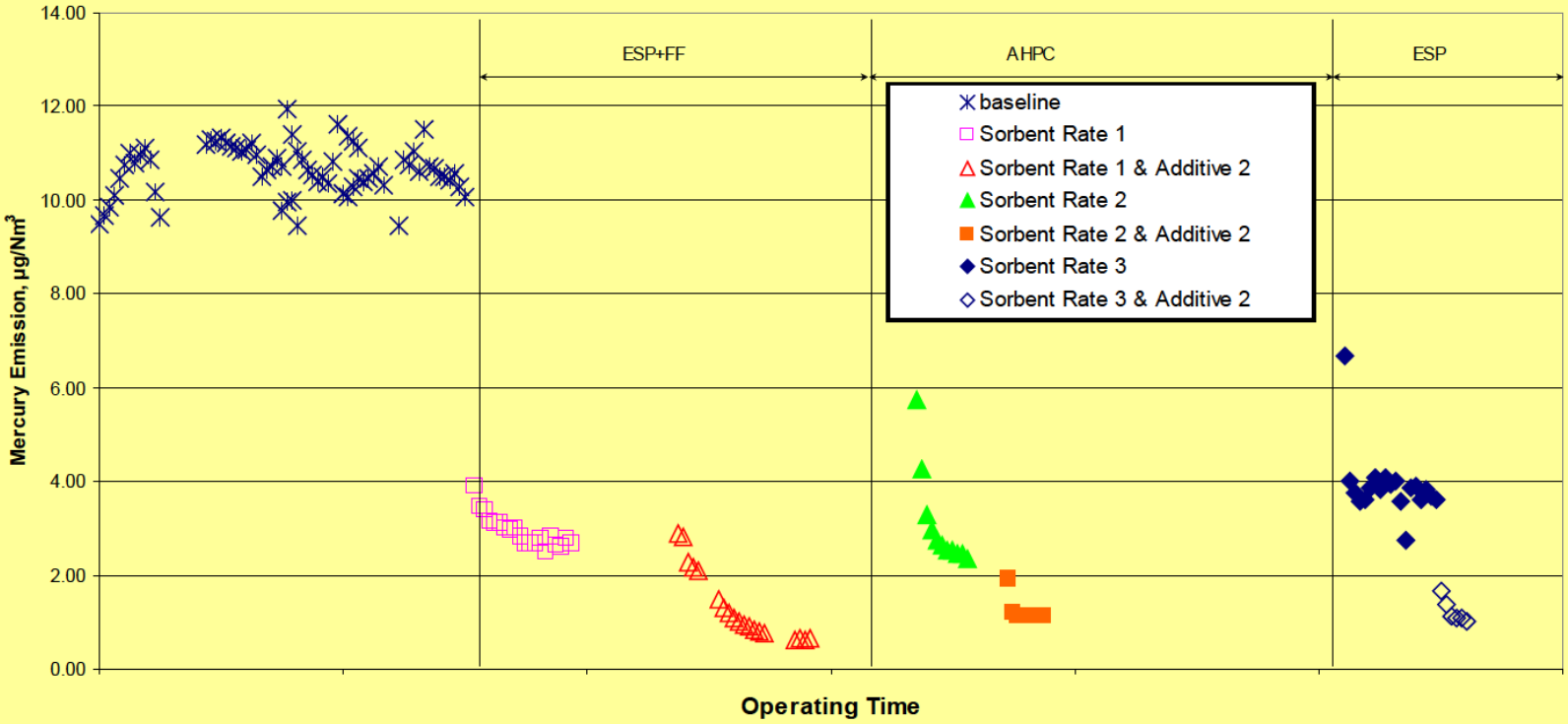
Vapor-Phase Mercury Removal Efficiency as a Function of Sorbent Injection Rate – Poplar River Coal, 300°F



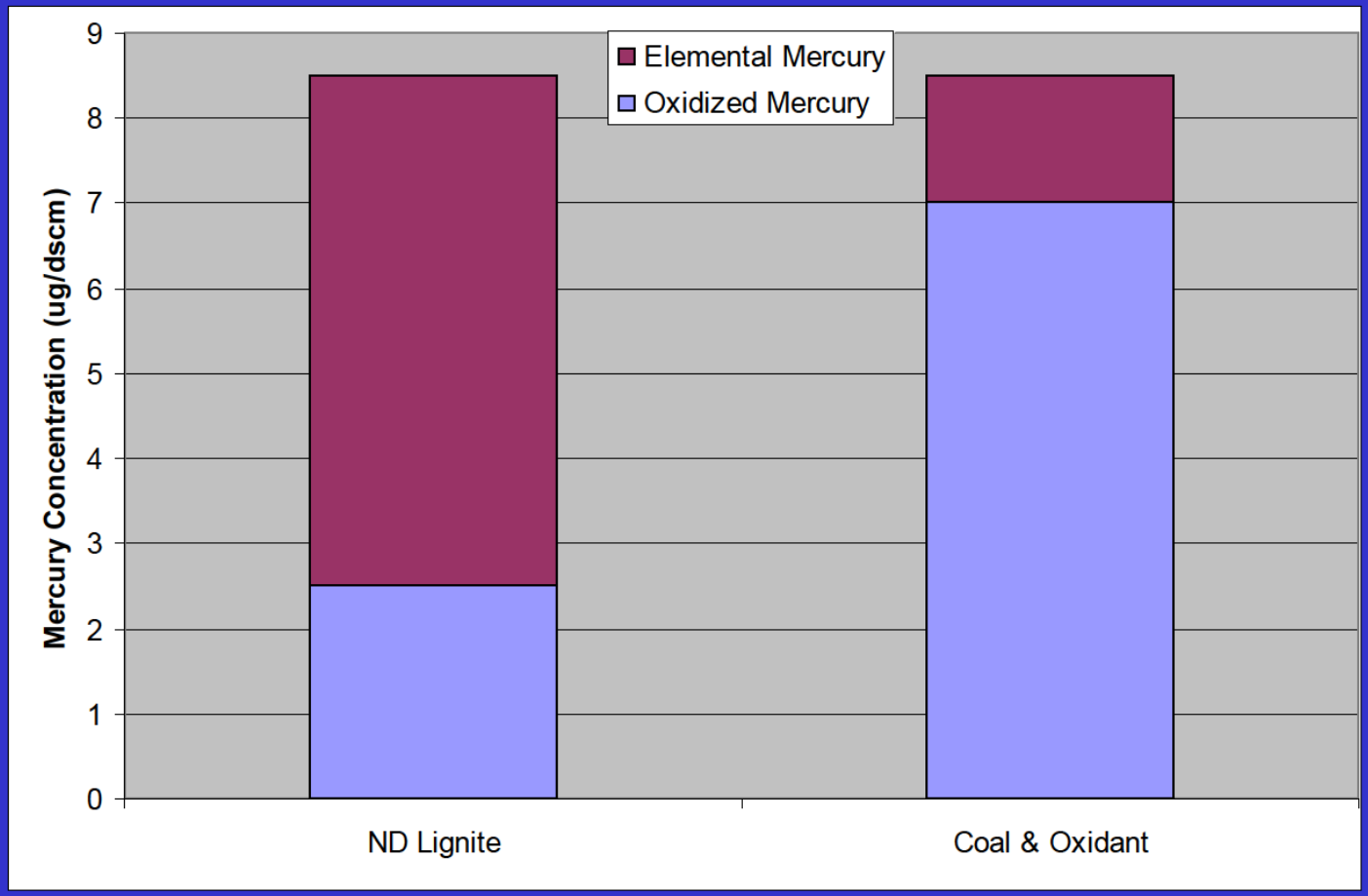
EERC


Vapor-Phase Mercury Removal Efficiency as a Function of Sorbent Injection Rate – Freedom Coal, 300°F
Collection Efficiency, %
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
Injection Rate, lb/Macf
Batch Injection
400°F
ESP+ FF (Gore), DARCO FGD
ESP+ FF (Gore), ALC
AHPC ALC
ESP, ALC
ESP, ALC(fine)
EERC

The Effect of Additives on Mercury Emissions under Different Control Configurations – Freedom Coal



The Effect of Oxidant Addition on Mercury Speciation – Freedom Coal



Leachability and Mass Balance Results

Leachability Measurements

- 18-hour, 30-day and 60-day test results show all samples at or below detection limits (0.01 μg/L).
- Data for other projects show leachability and volatility are typically minimal; separate large program under way at EERC

Mass Balance Results

- Mercury balances around the particulate control system were generally good.
- Average for the project is 94% recovery of the inlet mercury.

EERC

Conclusions from Pilot-Scale Testing of Activated Carbon Injection

- Speciation results were very similar for the Poplar River and Freedom coal flue gases at approximately:
  - Hg^0 = 85%
  - Hg^{2+} = 15%
  - Hg(p) <1%
- At periods of incomplete combustion of Poplar River and Freedom coals during initial tuning of the system, subsequent production of unburned carbon in the resulting fly ashes promoted the formation of Hg^{2+} and/or Hg(p).
- The activated carbons were able to oxidize a portion of the Hg^0 that remained uncaptured.

EERC

Conclusions from Pilot-Scale Testing of Activated Carbon Injection (continued)

- Increasing activated (800°C) Luscar char and DARCO FGD injection rates and decreasing gas temperatures in the four control devices significantly improved mercury removal from the lignite combustion flue gases.
- In general, mercury was slightly more reactive toward the activated carbons for the Freedom flue gas relative to the Poplar River flue gas.
- Typically, the DARCO FGD and activated Luscar char provided very similar results, with a few exceptions.

EERC

Conclusions from Pilot-Scale Testing of Activated Carbon Injection (continued)

- A reduction in activated (800°C) Luscar char and DARCO FGD particle size provided mixed results.
- Differences in fabric filter material (Ryton versus Gore) did not significantly affect mercury capture.
- The fabric filter and AH™ provide better flue gas-to-sorbent contact and thus showed better mercury removal relative to the ESP.
- The relative mercury removal efficiencies for the control device technologies were ESP–fabric filter>fabric filter>ESP.
- The ranking of the AH varied with operating strategy.

EERC

Conclusions from Pilot-Scale Testing of Activated Carbon Injection (continued)

- Sorbent enhancements showed the potential to significantly enhance mercury removal for both coals.
- Mercury in Poplar River and Freedom coal fly ashes remained insoluble after 18-hour, 30-day, and 60-day exposures to deionized water.
- Activated carbon injection combined with COHPAC and ESP devices installed on full-scale boilers generally provided better mercury removal efficiency at a given injection rate relative to activated carbon injection followed by the pilot-scale ESP.

EERC

Conclusions from Pilot-Scale Testing of Activated Carbon Injection (continued)

- Activated carbon injection with the pilot-scale ESP–fabric filter provided mercury removal efficiencies intermediate relative to those obtained on full-scale units burning eastern bituminous coals and equipped with COHPAC and ESP control devices, but much better relative to a PRB subbituminous burning plant equipped with an ESP.
- The cost of reducing mercury from plants burning lignite coal is expected to be higher compared to plants burning bituminous coals.

EERC

Critical Considerations for Phase II Effort

- Provide significant reductions in activated carbon requirements (and related operating costs) through the use of sorbent enhancement additives.
- Test activated carbon pretreatment method for lignite applications as an alternative to enhancement additives.
- Develop activated carbon regeneration to further reduce operating costs associated with sorbent purchases.
- Provide a second alternative for ESP only systems
  - To be discussed by J. Pavlish

EERC

Review Meeting Agenda – 2/25/03

• Welcome/Introduction	8:30	A.M.
• Project Overview/Background	8:45	A.M.
• Phase I – Bench-Scale Test Results	9:00	A.M.
• Break	10:00	A.M.
• Phase I – Pilot-Scale Testing	10:30	A.M.
• **Project Schedule**	**11:30**	**A.M.**
• **Open Discussion**	**11:45**	**A.M.**
• Lunch	12:00	P.M.
• Phase II – Plans and Discussion	1:00	P.M.
• Break	2:30	P.M.
• Review of ND Mercury-Monitoring Project Results	2:45	P.M.
• Adjourn	4:00	P.M.

EERC

Draft Report

MERCURY CONTROL TECHNOLOGIES FOR ELECTRIC UTILITIES BURNING LIGNITE COAL

Draft Final Report

(for the period of February 1, 2002 – March 31, 2003)

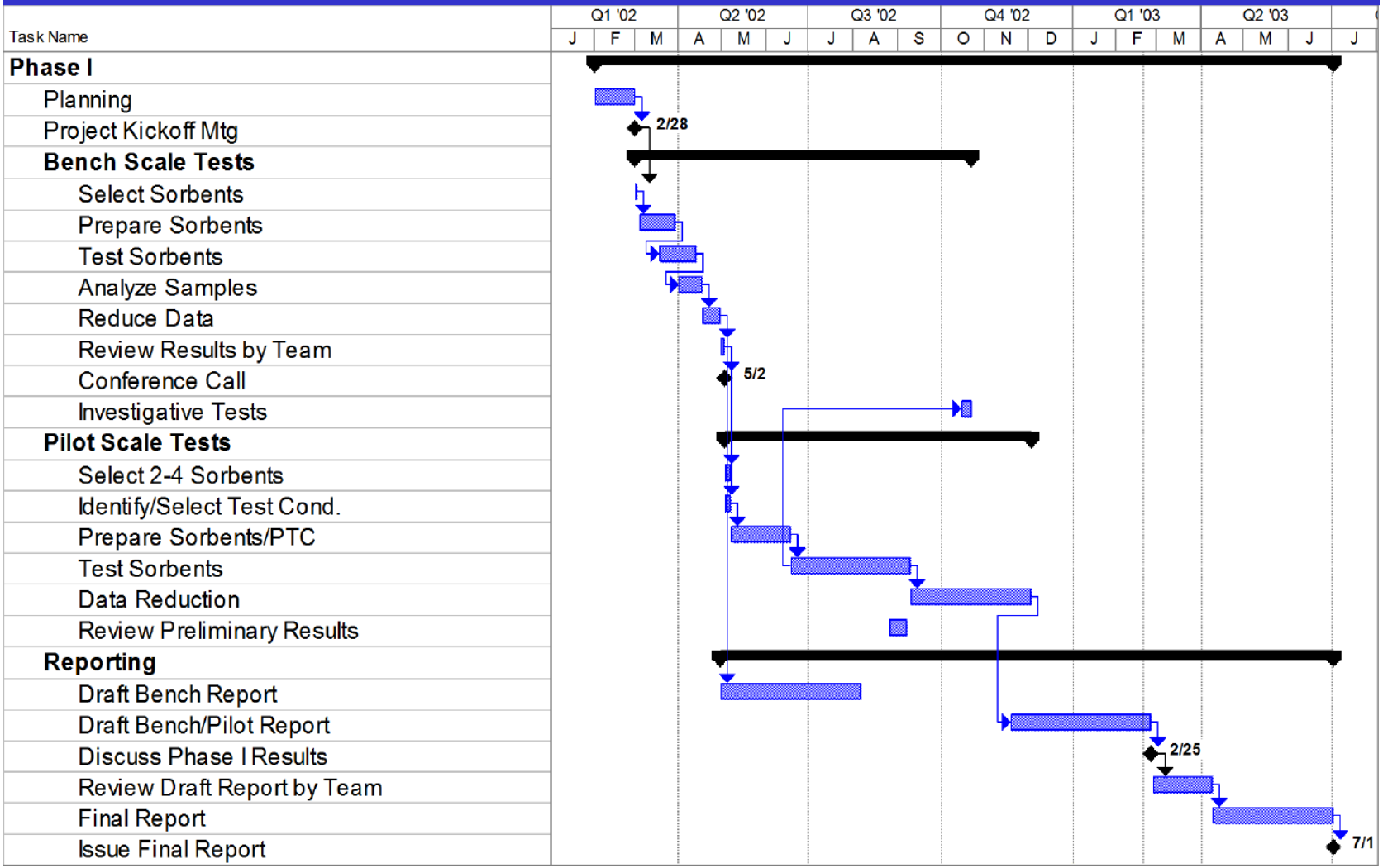
Prepared by:

John H. Pavlish
Michael J. Holmes
Steven A. Benson
Charlene R. Crocker
Ed S. Olson
Kevin C. Galbreath
Ye Zhuang
Brandon Pavlish

Energy & Environmental Research Center
University of North Dakota
Box 9018
Grand Forks, North Dakota 58202-9018

March 2003

Phase I Schedule



Review Meeting Agenda – 2/25/03

• Welcome/Introduction	8:30	A.M.
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Phase II Plans

Phase II, Field Testing/Demonstration

Proposed Site – Poplar River Power Station (SaskPower)

- Two units, Unit 1 = 298 MW and Unit 2 = 294 MW, commissioned in 1981 and 1983
- ESPs for particulate control





Poplar River Power Station

- South-central Saskatchewan
- 10 km SE of Coronach

Phase II
Poplar River Power Station

Poplar Station

Plant/ Unit	MW	Cap Fact	Boiler Type	NO_x Cont.	PM Cont.	Boiler Input,	Gas Temp.	Hg in Coal,
						MBtu/h	F	lbs/yr
Poplar River 1	300	0.85	CE T-Fired	CCOFA	Cold ESP	4,200	302	360
Poplar River 2	300	0.78	B&W Op. Wall	LNB	Cold ESP	4,200	302	360

Poplar Station Coal, dry basis

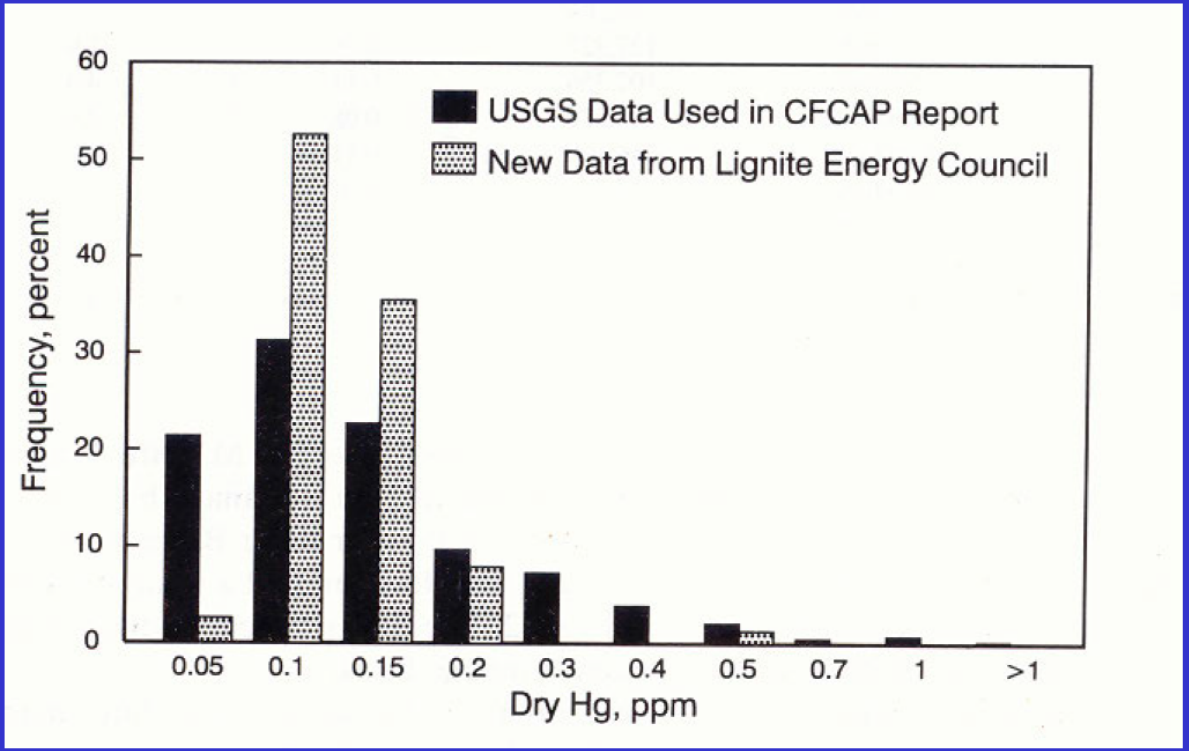
HHV	Moisture	Ash	Sulfur	Chlorine	Mercury	Coal Burned
Btu/lb	%	%	%	ppm	ppm	tpy (dry)
9000	38	20	0.90	22	0.15	3,300,000

Comparative Coal Analyses

Analysis Parameters	Poplar River	Center	Falkirk	Texas Lig.
Moisture	38	36	32	26
Ash (dry)	20	23	18	22
Sulfur (dry)	0.9	1.2	1.1	1.0
Btu/lb (dry)	9000	9500	9900	8800
Chlorine, ppm (dry)	22	14	20	
Mercury, ppm (dry)	0.15	0.11 0.08–0.15	0.10 0.05–0.14	0.29

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Mercury Variability in ND Lignite



Katrinak, K.A. et al., Fuel Processing Technology, 1994.

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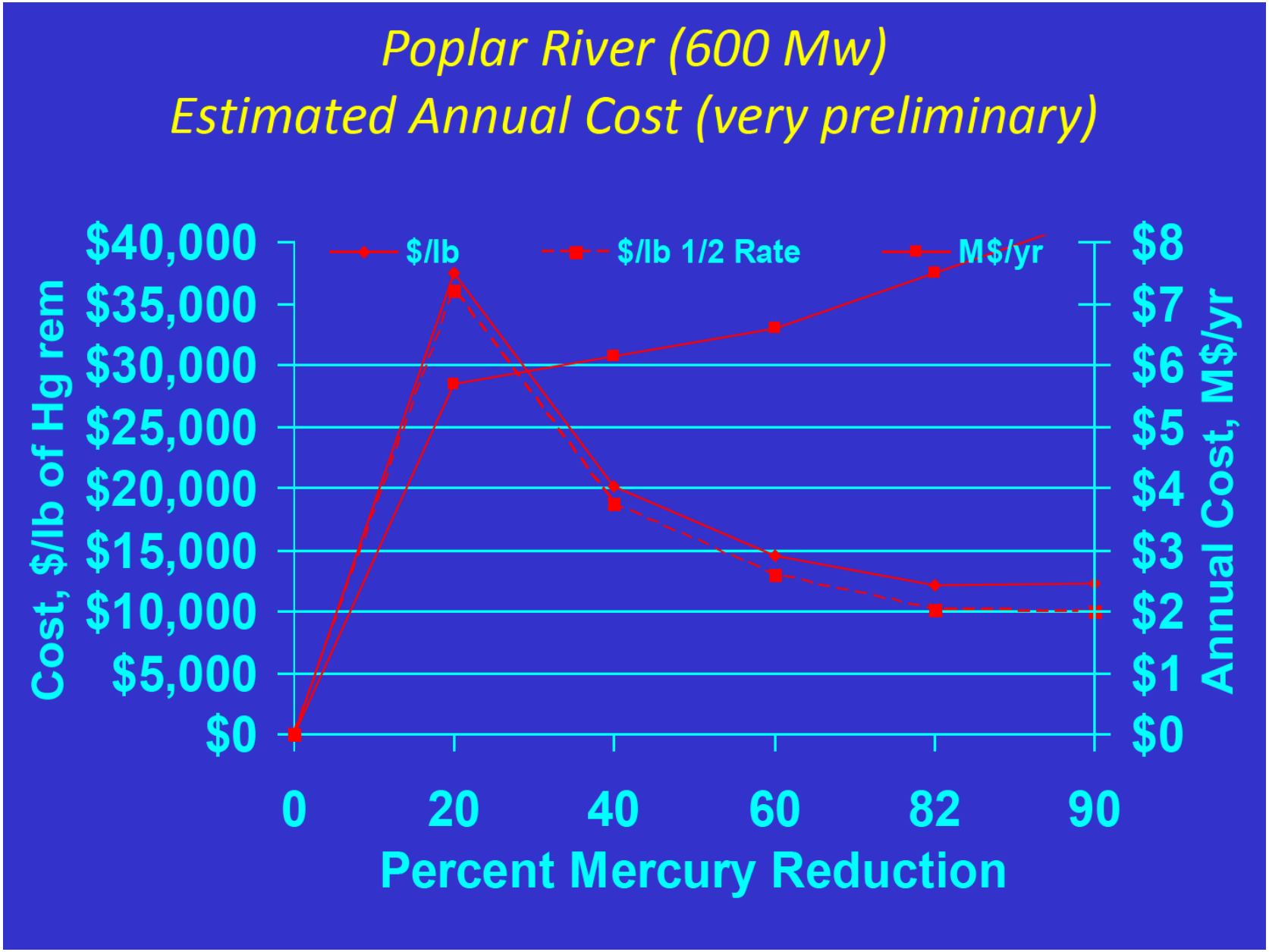
Comparative Ash Analyses

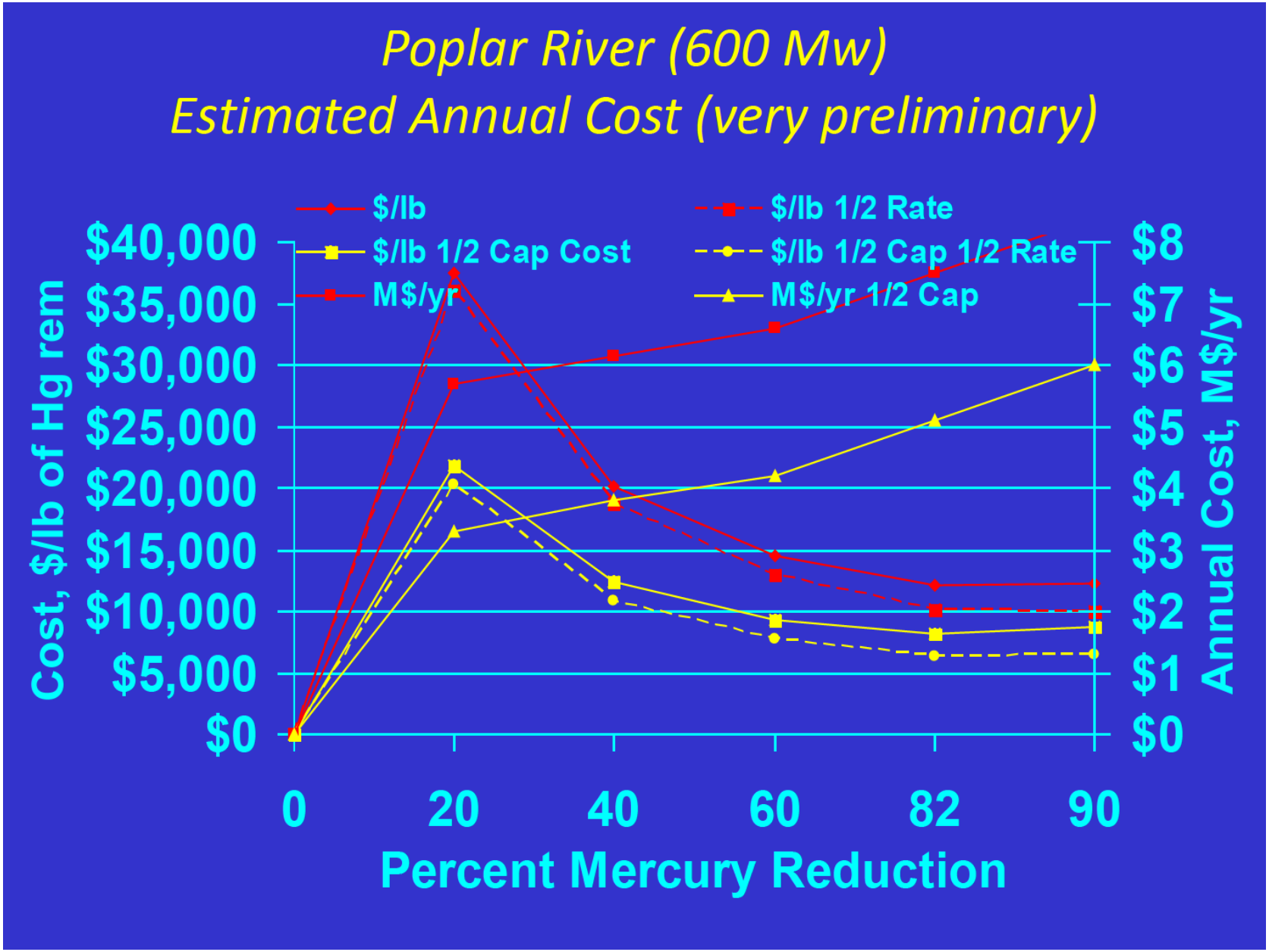
SO_3-Free Basis

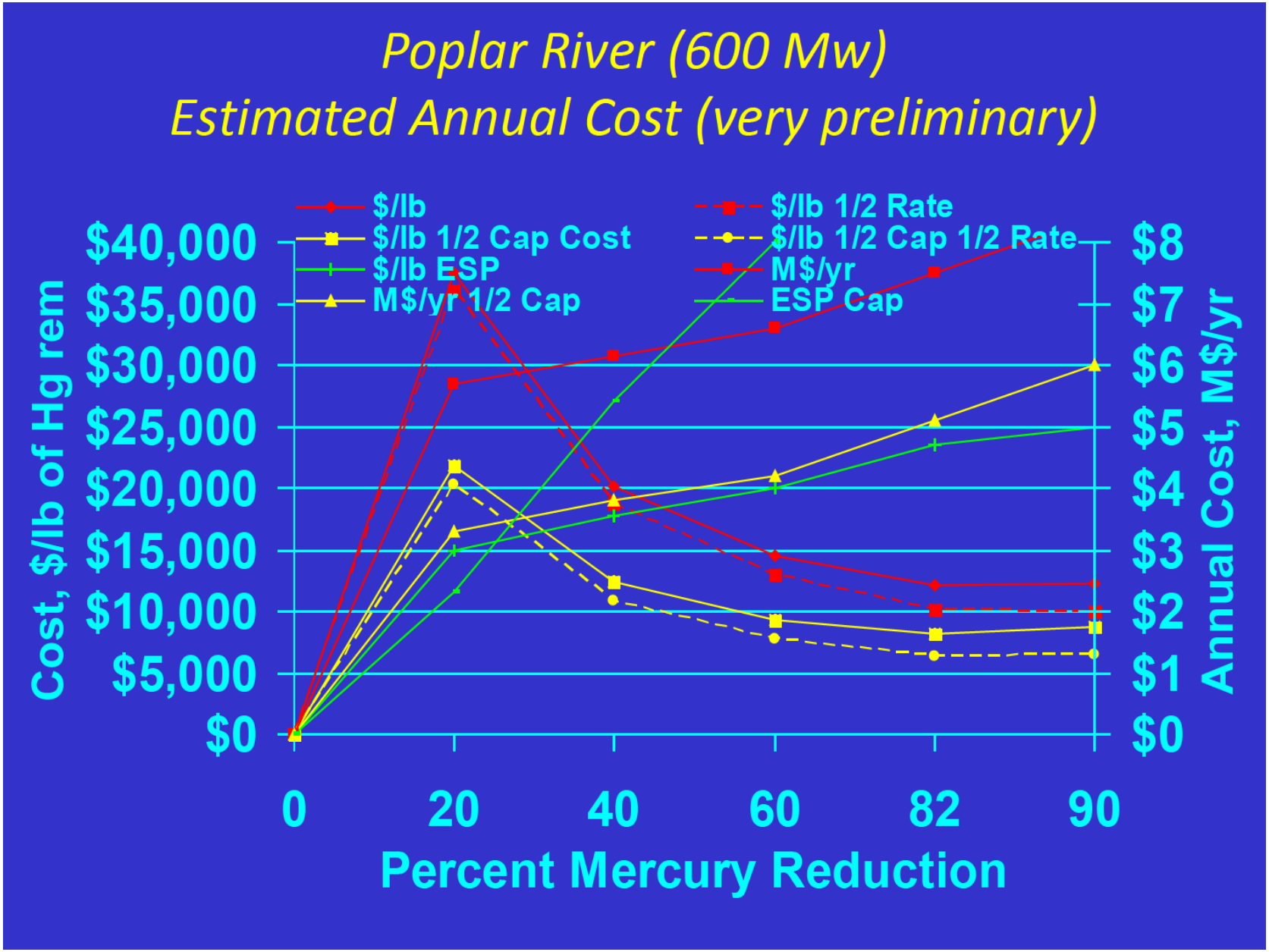
Elemental Oxide	Poplar River	Center	Falkirk	Texas Lig.
SiO_2	44.1	48.2	47.1	48.8
Al_2O_3	27.7	17.1	15.7	18.1
Fe_2O_3	7.6	8.5	5.3	8.6
TiO_2	0.66	0.6	0.6	1.5
P_2O_5	0.04	0.1	0.2	0.6
CaO	16.6	9.6	18.1	17.5
MgO	5.3	5.1	10.4	3.9
Na_2O	0.1	2.1	0.8	0.8
K_2O	0.7	2.2	0.5	0.7
SO_3	0.0	0.0	0.0	0.0

Technology Options

Technology Description	Comments and Needs
Sorbent injection upstream of ESP	For older plants, for low-removal scenario, or to buy time to plan multi-pollutant options. • Relatively high injection rates to achieve significant reductions • Using additives in combination with sorbent injection may lower sorbent requirements • Mercury, sorbent, and ash all collected together
Sorbent injection downstream of ESP and upstream of newly installed fabric filter	Likely option for new units or existing units that have particulate issues. • Relatively low-cost retrofit and reduced carbon needs • Mercury and sorbent are collected separate from bulk ash
Sorbent injection downstream of first field ESP and upstream of newly installed Advanced Hybrid™ Filter	Likely option for new units or existing units that have particulate issues. • Relatively low-cost retrofit and presumably low carbon needs • Limited test data for mercury control • Depending on injection location, mercury and sorbent could be collected separate from bulk ash
Mercury oxidation upstream of wet scrubber	For currently scrubbed units and any future scrubber additions. • Use oxidants to shift the elemental-to-oxidized mercury ratio and collect in scrubber • Mercury is collected mainly in scrubber sludge
Sorbent injection or mercury oxidation upstream of dry scrubber fabric filter combination.	Makes use of existing scrubber and fabric filter • Use oxidants to shift the elemental-to-oxidized mercury ratio • Inject sorbent upstream of scrubber or possible use pretreated sorbents • Mercury, sorbent, and ash all collected together


Poplar River (600 Mw)
Estimated Annual Cost (very preliminary)
$/lb
$/lb 1/2 Rate
M$/yr
Cost, $/lb of Hg rem
$40,000
$35,000
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$0
Annual Cost, M$/yr
$8
$7
$6
$5
$4
$3
$2
$1
$0
0
20
40
60
82
90
Percent Mercury Reduction


Poplar River (600 Mw)
Estimated Annual Cost (very preliminary)
$/lb
$/lb 1/2 Cap Cost
M$/yr
$/lb 1/2 Rate
$/lb 1/2 Cap 1/2 Rate
M$/yr 1/2 Cap
Cost, $/lb of Hg rem
$40,000
$35,000
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$0
Annual Cost, M$/yr
$8
$7
$6
$5
$4
$3
$2
$1
$0
0
20
40
60
82
90
Percent Mercury Reduction


Poplar River (600 Mw)
Estimated Annual Cost (very preliminary)
$/lb
$/lb 1/2 Cap Cost
$/lb ESP
M$/yr 1/2 Cap
$/lb 1/2 Rate
$/lb 1/2 Cap 1/2 Rate
M$/yr
ESP Cap
Cost, $/lb of Hg rem
$40,000
$35,000
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$0
Annual Cost, M$/yr
$8
$7
$6
$5
$4
$3
$2
$1
$0
0
20
40
60
82
90
Percent Mercury Reduction

Phase II

Ongoing Activities

- Planning/discussing scope and schedule
- Discussing/selecting control technology
  - Selecting most promising sorbent(s)
  - Identifying technology requirements and design criteria
- Scale of technology, 1–10 MW (note Alstom indicates that this scale should provide data adequate to ensure guarantees)
- Addressing preliminary site consideration and requirements

Goals

- Design, construct, and install slipstream technology
- Perform technology performance tests.
  - [Evaluate sorbent and technology effectiveness as a function of design and process variables (temperature, sorbent type, sorbent characteristics, particulate control system operation, unit operation, etc)]
- Evaluate impact of mercury on ash reuse and/or disposal
- Quantify performance, effectiveness, and cost

Phase II Objectives

- Continue to develop an improved scientific understanding of mercury interactions with flue gas constituents and sorbent-based technologies specifically for lignite-fired systems.
- Design, construct, and install selected technology at appropriate scale at the Poplar River power station located near Coronach, Saskatchewan.
- Further examine the effect of critical design and process parameters on mercury capture by performing parametric testing on the slipstream technology.
- Test the selected technologies ability to capture mercury using various sorbents, injection rates, and short-to-long test periods.
- Monitor mercury emissions over long periods of time to determine technology effectiveness and identify operational problems.
- Quantify the effectiveness, performance, and cost of the selected technology.

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Phase II – Proposed Activities

Task 1 – Design and Install Sorbent-Based Fabric Filter Technology

Task 2 – Test Technology at Poplar River Plant

Task 3 – Evaluate Mercury Impact on Ash

Task 4 – Summarize Technology Performance and Cost

Task 5 – Reporting and Management

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Phase II – Proposed Activities
Task 1

Task 1 – Design and Install Technology

- Assist in design by providing more specific design information and criteria on the selected technology.
- Identify and collect test data from other similar tests conducted outside of this project, if available. Assess applicability of data to this project.
- Identify and gather data on number of existing installations and operating experience.
- Identify availability of technology suppliers and design support/assistance.
- Assist in providing cost estimates of technology and supporting equipment.
- Provide additional bench- and pilot-scale test data targeted at providing specific data needs.
  - [One week of bench-scale testing and one week of pilot-scale testing has been budgeted to provide additional information throughout this project. Specific tests may include sorbent screening tests, additive screening tests, tests to examine specific design parameters (i.e., A/C), tests to examine specific process parameters (i.e., temperature, flue gas condition, etc), or other tests the project sponsors feel are important and related to this project. These 2 weeks of testing would be discussed and decided on by consensus of all project sponsors.]

Phase II – Proposed Activities
Task 2

Task 2 – Test Technology at Poplar River Plant

Test Condition	Test Duration, Days
Shakedown testing	5–10
Week Long Tests	
Sorbent 1, Luscar	2–5
Sorbent 2, NORIT FGD	2–5
Sorbent 3, TBD	2–5
Sorbent 4, TBD	2–5
Month Long Tests including Parametric Tests	
Sorbent 1 or 2 or 3 or 4	20–30
Long Term Tests	
Sorbent 1, Luscar	90–180

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Phase II – Proposed Activities
Task 3

Task 3 – Evaluate Mercury Impact on Ash

- Six samples will be submitted for short- and long- term leachability tests (analysis of all trace elements of relevance including mercury).
- Four samples will be subjected to thermal analysis.
- Four samples will be exposed to a number of different biologically simulated conditions.
- The EERC will also assess the ash for potential reuse application and perform necessary tests to assist in this determination.

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Phase II – Proposed Activities
Tasks 4

Task 4 – Summarize Technology Performance and Cost

- Data generated throughout the test program will be reduced, compiled, interpreted, and summarized.
- Mercury speciation and total concentration will be calculated at each test location for each test and statistically averaged over short- and long-term tests.
- Mercury collection efficiency will be calculated based on coal inlet concentrations as well as on inlet and outlet measurements. Mercury levels and variability in the flue gas will be compared to the mercury content of the coal.
- Data that are logged by plants will be reduced and plotted along with mercury to identify trends and relationships.
- Technology effectiveness relative to mercury control will be calculated for short- and long-term tests.
- The cost of scaling the technology up to large scale will be estimated.
- The cost of mercury control at large scale will be estimated.

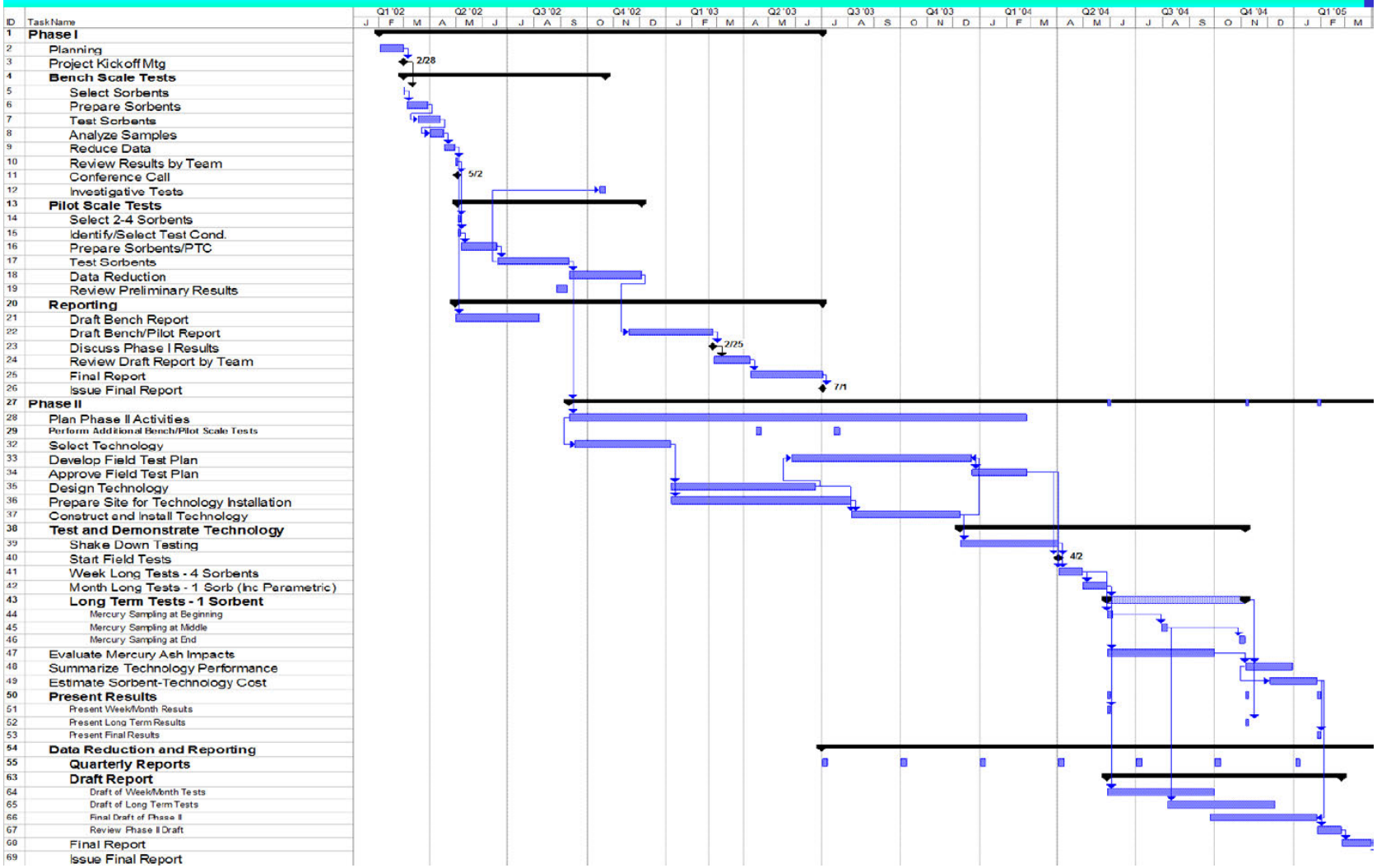
Phase II – Proposed Activities
Tasks 5

Task 5 – Reporting and Management

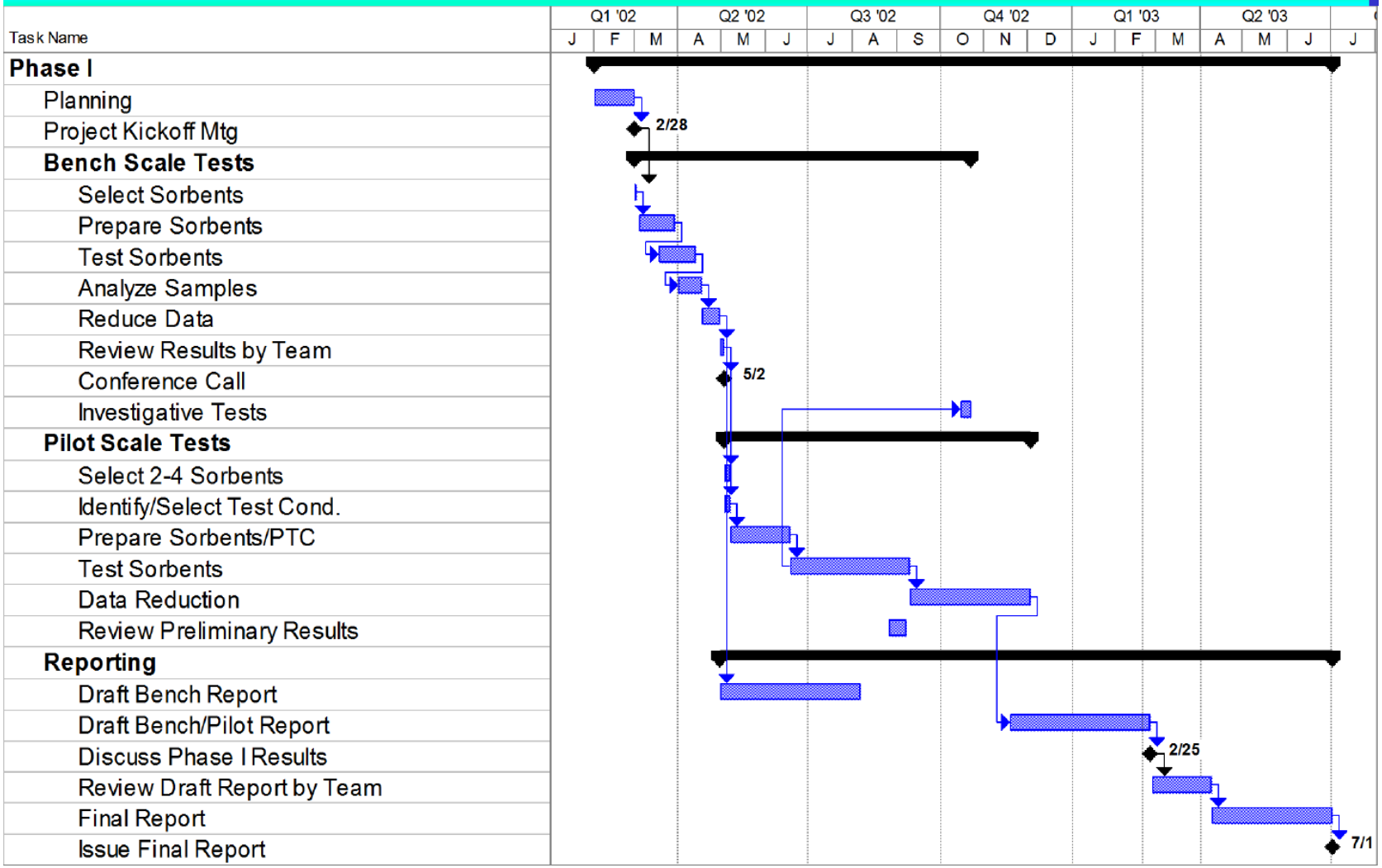
- Quarterly reports
- Draft report of week/monthlong test results
- Draft report of long-term test results
- Draft report of Phase II results
- Final report of Phase II
- Presentation of results throughout project
- Presentation of results at conferences
- Management of overall technology testing program

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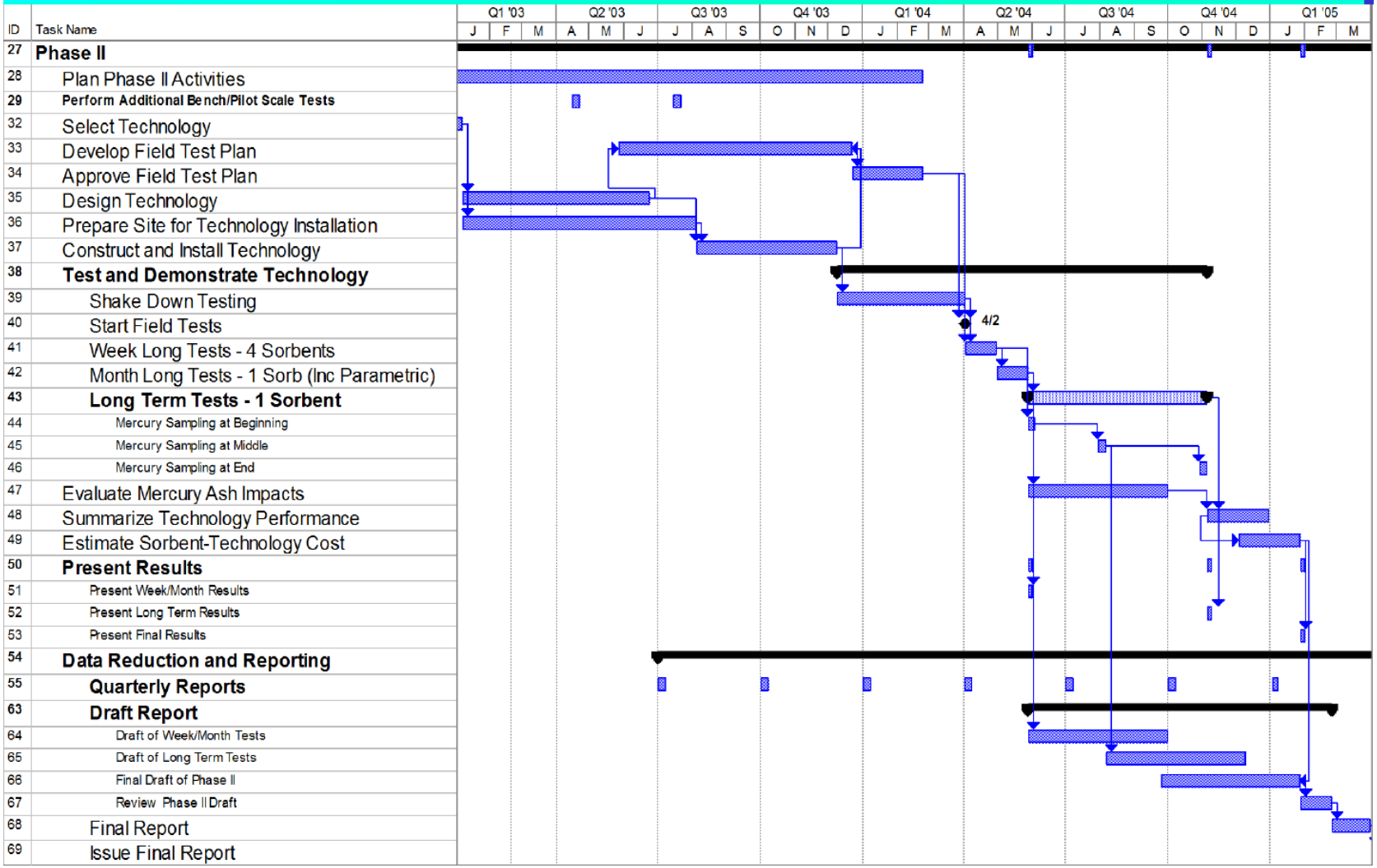
Project Time Line



Project Time Line – Phase I



Project Time Line – Phase II



Funding Scenario

Phase	Phase Description	Cost
1	**Development and Testing of Sorbents at EERC Bench-/Pilot-Scale Facilities**	**$833,000**
2	**Demonstration of Sorbent Technology at Poplar River Power Plant**	**$1,200,000 - $1,500,000***
2	Task 1 – Design and Install Technology	$200,000
2	Task 2 – Test Technology at Poplar River Plant	$600,000 – $800,000 *
2	Task 3 – Evaluate Mercury Impact on Ash	$50,000 - $100,000
2	Task 4 – Summarize Technology Performance and Cost	$150,000 - $200,000
2	Task 5 – Reporting and Management	$150,000 - $200,000

* Assumes SaskPower will fund technology installation and subcontract directly to SRC for OH sampling. Assumes Luscar will provide sorbent.

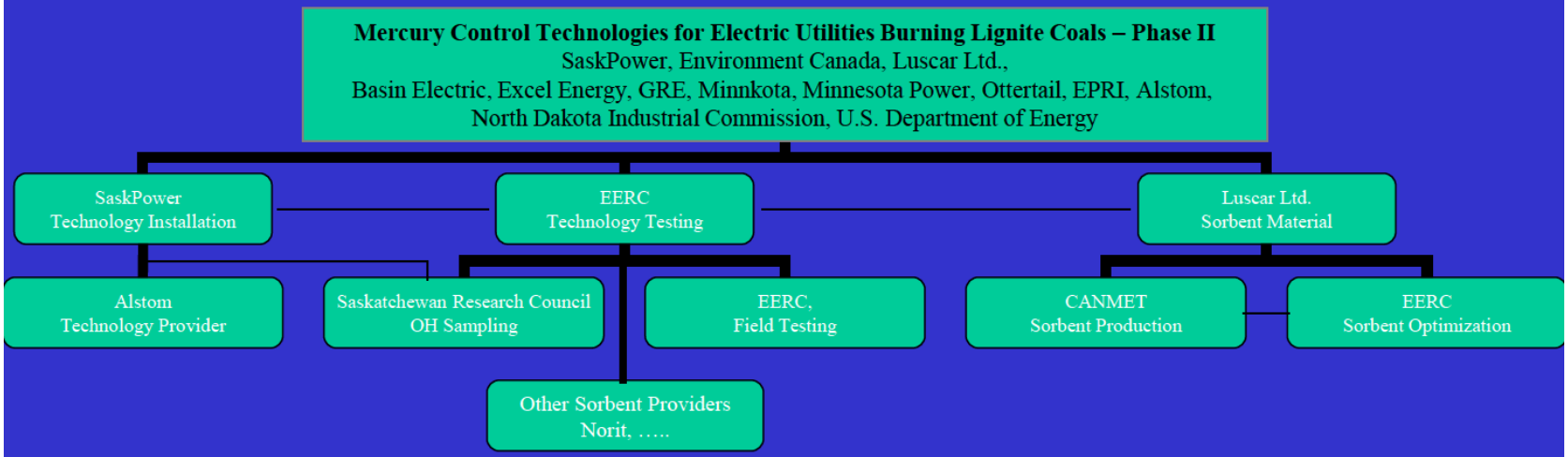
Mercury Control Technologies for Electric Utilities Burning Lignite Coals – Funding Scenario

Funding Source	Phase I	Phase II (2 years)		
	Total	Tech Cost*	Field Tests**	Total
Canada Sources				
SaskPower	$100,000	$1,000,000 - $3,000,000	$300,000	$1,600,000 - $3,600,000
Environment Canada			$300,000	
Luscar Ltd.	$25,000		$100,000 - $200,000	$100,000 - $200,000
US Sources				
ND Utilities				
Basin Electric Power Cooperative	$25,000		$40,000 - $50,000	$40,000 - $50,000
Minnkota Power Cooperative, Inc.	$25,000		$40,000 - $50,000	$40,000 - $50,000
Montana-Dakota Utilities			$40,000 - $50,000	$40,000 - $50,000
Otter Tail Power Company	$25,000		$40,000 - $50,000	$40,000 - $50,000
EPRI Great River Energy Xcel Energy Minnesota Power, Inc.	$50,000		$80,000 - $100,000	$80,000 - $100,000
Alstom		?	?	?
North Dakota Industrial Commission	$150,000		$200,000 - $250,000	$200,000 - $250,000
U.S. DOE - EERC JV Program	$333,000		$400,000 - $500,000	$400,000 - $500,000
Total	$833,000	$1,000,000 - $3,000,000	$1,500,000 - $1,800,000	$2,500,000 - $4,800,000

* Cost associated with technology installation

** Costs would be incurred over two years. SaskPower would subcontract to SRC for Ontario Hydro sampling. Luscar would provide in-kind coast share by agreeing to provide sorbent material for testing.

Project Management Plan
Phase II



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THANK YOU

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Review Meeting Agenda – 2/25/03

• Welcome/Introduction	8:30	A.M.
• Project Overview/Background	8:45	A.M.
• Phase I – Bench-Scale Test Results	9:00	A.M.
• Break	10:00	A.M.
• Phase I – Pilot-Scale Testing	10:30	A.M.
• Project Schedule	11:30	A.M.
• Open Discussion	11:45	A.M.
• Lunch	12:00	P.M.
• Phase II – Plans and Discussion	1:00	P.M.
• Break	2:30	P.M.
• **Review of ND Mercury-Monitoring Project Results**	**2:45**	**P.M.**
• Adjourn	4:00	P.M.

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