DOE/NETL's Phase II Mercury Control Technology Field Testing Program

Preliminary Economic Analysis of Activated Carbon Injection

Prepared for

U.S. Department of Energy
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Innovations for Existing Plants Program

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I. EXECUTIVE SUMMARY

On May 18, 2005, the U.S. Environmental Protection Agency (EPA) issued a final regulation for the control of mercury emissions from coal-fired power plants.[1] The Clean Air Mercury Rule (CAMR) establishes a nationwide cap-and-trade program that will be implemented in two phases and applies to both existing and new plants. Based on 1999 estimates, U.S. coal-fired power plants emit approximately 48 tons of mercury per year.[2] As a result, CAMR requires an overall average reduction in mercury emissions of approximately 69% to meet the Phase II emissions cap. Meanwhile, several states have adopted, or are considering legislation that will impose more stringent regulations on mercury emissions from coal-fired boilers than those included in CAMR.

Recognizing the potential for mercury regulation, the U.S. Department of Energy's National Energy Technology Laboratory (DOE/NETL) initiated comprehensive mercury research under the DOE Office of Fossil Energy's Innovations for Existing Plants (IEP) program in the early 1990s to ensure that effective pollution control strategies are available for the existing fleet of coal-fired utility boilers.[3] Currently, the program is focused on slip-stream and full-scale field testing of mercury control technologies. The near-term goal is to develop mercury control technologies that can achieve 50-70% mercury capture at costs 25-50% less than baseline estimates of $50,000-$70,000 per pound of mercury removed ($/lb Hg removed). These technologies would be available for commercial demonstration by 2007 for all coal ranks. The longer-term goal is to develop advanced mercury control technologies to achieve 90% or greater capture that would be available for commercial demonstration by 2010.

In September 2003, DOE/NETL selected eight projects to test and evaluate mercury control technologies under a Phase II, Round 1 (Phase II-1) field testing solicitation. The Phase II-1 projects shown in Table 5 were initiated in 2004 and are scheduled to be completed in early-to-mid 2006. An additional six projects – representing seven technologies - were subsequently awarded in October 2004 under a Phase II, Round 2 (Phase II-2) solicitation that are scheduled for completion in 2007 (Table 6). The Phase II projects focus on longer-term (~ 1 month at optimized conditions), large-scale field testing on plants burning primarily low-rank coals or blends (with some units burning bituminous coal) and equipped with a variety of air pollution control devices (APCD). Most of the fourteen projects fall under two general categories of mercury control – sorbent injection or oxidation enhancements. Sorbent injection generically describes the injection of powdered activated carbon (PAC) or other non-carbon sorbents into the flue gas for mercury control, while mercury oxidation enhancements are intended to improve the mercury capture efficiency of conventional ACI or downstream APCD by converting elemental mercury to a more reactive oxidized state.

This report provides "study-level" cost estimates[a] for four of the fourteen Phase II field testing projects investigating mercury control via activated carbon injection (ACI) and was carried out to provide DOE/NETL a gauge in measuring its success in achieving the target of reducing baseline mercury control costs by 25-50%. The four projects include an evaluation of conventional ACI, brominated (or chemically-treated) ACI, and conventional ACI coupled with the introduction of a sorbent enhancement additive (SEA) to the coal prior to combustion. Brominated ACI and SEA coal treatment are intended to compensate for the lack of naturally-occurring halogens in the combustion flue gas of low-rank coals that appears to limit the mercury capture efficiency of conventional ACI. For example, it was observed during Phase I field testing at Pleasant Prairie Unit 2 that the total mercury removal performance curve flattened out at approximately 65% for this subbituminous-fired unit despite the injection of conventional DARCO® Hg at flue gas concentrations as high as 30 lb/MMacf.[4]

The economic analyses were conducted on a plant-specific basis meaning that the economics are dependent on the actual power plant operating conditions and coal properties observed during full-scale field testing at each of the Phase II sites displayed in Table 7.[b] In addition, the analyses were completed in a manner that yields the cost required to achieve low (50%), mid-range (60-70%), and high (90%) levels of mercury control "above and beyond" the plant-specific baseline mercury removal by existing APCD. In other words, *the levels of mercury control discussed in this report are directly attributable to ACI.* To calculate the ACI mercury capture, a data adjustment methodology was developed to account for the level of baseline mercury capture observed during parametric testing and incorporate the average level of mercury removal measured during the long-term continuous ACI trial. A complete discussion of the ACI data adjustment methodology with sample calculations is provided in Appendix C.

This approach is complicated by the variability of baseline mercury capture caused by changes in coal composition and boiler performance that can impact the quantity of unburned carbon present in the fly ash. In addition, field testing has shown that residual PAC remaining in the ductwork from previous injection trials may contribute to an increase in baseline mercury capture over the course of the parametric testing campaign.

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[a] The accuracy of the cost estimates presented here are expected to be nominally +/- 30%, similar to the accuracy of the rough-order-of-magnitude (ROM) costs or "study" level costs acceptable for regulatory development, as described in the ***EPA Air Pollution Control Cost Manual, Sixth Edition***, EPA-452-02-001 January 2002. The uncertainty of these cost estimates can be traced to the nature of DOE/NETL's Phase II field testing program and general assumptions regarding the installation and continuous operation of a full-scale PAC storage and injection system. During Phase II testing, the mercury capture efficiency of candidate PACs is measured using continuous emission monitors (CEM) that are temporarily installed for the relatively short-term field tests conducted at optimal conditions. The vapor-phase mercury measurements taken by CEM have a degree of uncertainty due to the presence of extremely low mercury concentrations in the flue gas, which makes the quality assurance and quality control (QA/QC) practices of field contractors extremely important. In terms of capital costs, this analysis includes estimates for project and process contingencies, while the cost to install and calibrate mercury monitoring equipment is excluded. The cost estimates developed here assume an uncomplicated retrofit and minimal economic impact due to the installation of the ACI system, assuming that the installation occurs during a regularly scheduled plant outage. The economics are also based on the assumption that mercury control via ACI will not cause any balance-of-plant impacts.

[b] The coal analyses and power plant parameters for each of the Phase II sites included in this study are provided in Appendix A of this report.

With that in mind, *a conscious effort was made to identify the baseline mercury capture observed prior to the parametric tests involving the PAC that was ultimately selected for evaluation during the long-term continuous injection trial.*

Mercury control via ACI upstream of the existing particulate control device will result in commingling of the PAC and fly ash that could potentially have an adverse effect on the marketability of the fly ash. Therefore, the 20-year levelized costs for the incremental increase in cost of electricity (COE) expressed in units of mills[c] per kilowatt-hour (mills/kWh) and the incremental cost of mercury control ($/lb Hg removed) are presented in Tables 1 and 2 with byproduct impacts excluded and included, respectively. While the severity of these byproduct impacts cannot be disputed, *the economic impacts related to byproduct management and disposal resulting from mercury control via ACI, included in this economic analysis, are hypothetical and represent a worst-case scenario.*[d]

Primarily, the increase in COE resulting from mercury control via ACI is determined by annual PAC consumption costs that are dependent on the ACI concentration required to achieve a given level of mercury control and the current delivered PAC cost (Table 8). For this analysis, the 20-year levelized incremental increase in COE varies from 0.14 mills/kWh to 3.92 mills/kWh. The lower bound (0.14 mills/kWh) corresponds to 50% mercury removal due to brominated DARCO® Hg-LH injection at Holcomb Station Unit 1 when byproduct impacts are excluded, while the upper bound (3.92 mills/kWh) was calculated for 70% mercury removal due to conventional DARCO® Hg injection in conjunction with SEA coal treatment at Leland Olds Unit 1 with the inclusion of byproduct impacts.

The incremental cost of mercury reduction, i.e. the cost (in $/lb Hg removed) to achieve a specific reduction is impacted largely by the level of baseline mercury capture exhibited by the existing APCD configuration and coal mercury content (lb/TBtu). For example, the incremental cost of mercury control will increase when: (1) baseline mercury capture by existing APCD is high; or (2) the coal mercury content is low, because a smaller quantity of mercury is removed from the flue gas for a given level of control. For this analysis, the 20-year levelized incremental cost of mercury control varies from $3,810/lb Hg removed to $166,000/lb Hg removed. The lower bound ($3,810/lb Hg removed) corresponds to 70% mercury removal due to DARCO® Hg-LH injection at Holcomb Station Unit 1 when byproduct impacts are excluded, while the upper bound ($166,000/lb Hg removed) was calculated for 50% mercury removal due to conventional Super HOK injection at Plant Yates Unit 1 with the inclusion of byproduct impacts.

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[c] One mill is equivalent to 1/10 of a cent.

[d] For units equipped with a cold-side electrostatic precipitator (CS-ESP), the byproduct impacts incurred once the utility installs an ACI system for mercury control assume that the fly ash can no longer be sold for $18/ton; instead, the utility must pay $17/ton for non-hazardous disposal of the fly ash. For units equipped with a spray dryer absorber and fabric filter (SDA/FF) configuration, the byproduct impacts incurred by the utility assume that the SDA byproducts (i.e., SDA ash and solid calcium sulfite) can no longer be given away; instead, the utility must pay $17/ton for non-hazardous disposal of the SDA byproducts once an ACI system is installed. For this analysis, the quantity of calcium sulfite generated was calculated by assuming the SDA/FF configuration is able to capture 90% of the sulfur dioxide present in the flue gas.

The following paragraphs summarize the cost of mercury control via ACI for each of the Phase II field testing units included in this analysis. A complete discussion of the Phase II field testing results is provided in Appendix B of this report.

Holcomb Station Unit 1

The cost of mercury control for this 360 megawatt (MW) subbituminous-fired unit equipped with an SDA/FF configuration is based on the performance of brominated DARCO® Hg-LH during full-scale parametric and long-term field tests. During the long-term continuous injection trial, an average total mercury removal of 93% was achieved with an average DARCO® Hg-LH injection concentration of 1.2 lb/MMacf. The following key points summarize the economics of mercury control for this unit.

- The installed capital cost of the ACI system is approximately $1,310,000 or $3.63 per kilowatt ($/kW) on a unit capacity basis.
- A DARCO® Hg-LH injection concentration of 1.03 lb/MMacf is required to achieve 90% ACI mercury removal resulting in an annual PAC consumption cost of approximately $493,000 using the current delivered price of $0.95/lb.[e]
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.37 mills/kWh and an incremental cost of $6,060/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 1.09 mills/kWh and an incremental cost of $18,000/lb Hg removed.

Meramec Station Unit 2

The cost of mercury control for this 140 MW subbituminous-fired unit equipped with a CS-ESP is based on the performance of DARCO® Hg-LH during full-scale parametric and long-term field tests. During long-term testing, an average DARCO® Hg-LH injection concentration of 3.3 lb/MMacf was required to achieve an average total mercury removal of 93%. The following points summarize the economics for this unit.

- The installed capital cost of the ACI system is approximately $1,280,000 or $9.16/kW on a unit capacity basis.
- A DARCO® Hg-LH injection concentration of 2.40 lb/MMacf is required to achieve 90% ACI mercury removal resulting in an annual PAC consumption cost of approximately $532,000.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.99 mills/kWh and an incremental cost of $17,700/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 2.37 mills/kWh and an incremental cost of $42,500/lb Hg removed.

Plant Yates Unit 1

The cost of mercury control for this 100 MW bituminous-fired unit equipped with a CS-ESP is based on the performance of conventional Super HOK during full-scale parametric and long-term field tests. During long-term testing, Super HOK injection concentrations of 4.5 lb/MMacf, 6.5 lb/MMacf, and 9.5 lb/MMacf were required to achieve average levels of total mercury control of approximately 68%, 75%, and 76%, respectively. The following key points summarize the economics for this unit.

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[e] For this analysis, the delivered PAC prices shown in Table 8 are based on invoices from Phase II field testing and include $0.10/lb for transportation expenses.

- The installed capital cost of the ACI system is approximately $1,270,000 or $12.66/kW on a unit capacity basis.
- A Super HOK injection concentration of 8.98 lb/MMacf is required to achieve 70% ACI mercury removal resulting in an annual PAC consumption cost of approximately $707,000 using the current delivered price of $0.39/lb.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 1.72 mills/kWh and an incremental cost of $69,500/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 3.69 mills/kWh and an incremental cost of $149,000/lb Hg removed.

Leland Olds Unit 1
For this 220 MW North Dakota (ND) lignite-fired unit equipped with a CS-ESP, the cost of mercury control is based on the mercury capture efficiency of conventional DARCO® Hg injection when the coal is treated with an SEA (i.e., an aqueous calcium chloride ($CaCl_2$) solution) prior to combustion. During long-term testing, an average total mercury removal of 63% was achieved with an average DARCO® Hg injection concentration of 3 lb/MMacf coupled with the addition of an aqueous $CaCl_2$ solution to the coal at a constant rate that is equivalent to adding approximately 500 parts per million (ppm) chlorine to the coal. The following points summarize the economics for this unit.

- The installed capital cost of the SEA and ACI systems is approximately $1,390,000 or $6.33/kW on a unit capacity basis.
- The delivered $CaCl_2$ cost of $0.15/lb, which includes $0.10/lb for transportation expenses, yields an annual SEA consumption cost of approximately $388,000.
- With $CaCl_2$ coal treatment, a DARCO® Hg injection concentration of 4.39 lb/MMacf is required to achieve 70% ACI mercury removal resulting in an annual PAC consumption cost of approximately $875,000 using the current delivered price of $0.54/lb.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 1.25 mills/kWh and an incremental cost of $22,200/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 3.92 mills/kWh and an incremental cost of $69,600/lb Hg removed.

Stanton Station Unit 10
The cost of mercury control for this 60 MW ND lignite-fired unit equipped with an SDA/FF configuration is based on the performance of DARCO® Hg-LH during full-scale parametric and long-term field tests. During long-term testing, an average DARCO® Hg-LH injection concentration of 0.7 lb/MMacf was required to achieve an average total mercury removal of 60%. The following points summarize the economics for this unit.

- The installed capital cost of the ACI system is approximately $1,270,000 or $21.10/kW on a unit capacity basis.
- A DARCO® Hg-LH injection concentration of 1.15 lb/MMacf is required to achieve 70% ACI mercury removal resulting in an annual PAC consumption cost of approximately $116,000.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 1.02 mills/kWh and an incremental cost of $17,400/lb Hg removed.

- The inclusion of byproduct impacts results in an increase in COE of 2.77 mills/kWh and an incremental cost of $47,300/lb Hg removed.

St. Clair Station Unit 1

The cost of mercury control for this 145 MW unit that fires an 85% subbituminous/15% bituminous coal blend and is equipped with a CS-ESP is based on the performance of brominated B-PAC™ during full-scale parametric and long-term field tests. During long-term testing, an average total mercury removal of 94% was achieved with an average B-PAC™ injection concentration of 3 lb/MMacf. The following key points summarize the economics of mercury control for this unit.

- The installed capital cost of the ACI system is approximately $1,280,000 or $8.79/kW on a unit capacity basis.
- A B-PAC™ injection concentration of 2.31 lb/MMacf is required to achieve 90% ACI mercury removal resulting in an annual PAC consumption cost of approximately $619,000 using the current delivered price of $0.85/lb.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 1.06 mills/kWh and an incremental cost of $26,200/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 2.05 mills/kWh and an incremental cost of $50,600/lb Hg removed.

The preliminary Phase II field testing results are very encouraging both in terms of the level of mercury removal achieved and the cost of control on a mills/kWh and $/lb Hg removed basis. However, it must be kept in mind that the field tests still represent relatively short-term testing at optimum conditions. While such testing provides a sound basis for evaluating performance and cost, the limited duration of the testing does not allow for a comprehensive assessment of several key operational and balance-of-plant issues associated with ACI in general and the use of chemically-treated PAC and SEA specifically. These include: (1) changes in coal characteristics (e.g., mercury and chlorine content); (2) changes in load; (3) impacts on small collection area ESPs; (4) PAC carryover into downstream APCD; (5) corrosion issues; (6) potential off-gassing of bromine compounds; (7) formation of flue gas halides; and (8) leaching from brominated PAC byproducts.

It should also be noted that the economic analyses represent “snapshots” in time based on the methodology used, assumptions made, and conditions that were specific to the time when DOE/NETL field testing occurred. Consequently, the economics presented in this report are plant and condition specific and attempts to use this document as a tool to predict the performance of the mercury control technologies described in this report at other power plants should be conducted cautiously regardless of similarities in coal-rank and APCD configuration. In addition, the economics originate from relatively small datasets in many cases. As a result, the cost of mercury control could vary significantly with the inclusion of additional ACI performance data from current and future DOE/NETL field testing.

Table 1 -- 20-Year Levelized Cost of Mercury Control without Byproduct Impacts

Coal Rank		Bituminous		85% Subbit/15% Bit blend			Subbituminous			ND Lignite	
Mercury Removal due to ACI, %		**50%**	**70%**	**50%**	**70%**	**90%**	**50%**	**70%**	**90%**	**50%**	**70%**
CS-ESP	Plant Name	**Plant Yates Unit 1** **Super HOK**		**St. Clair Station Unit 1** **B-PAC™**			**Meramec Station Unit 2** **DARCO® Hg-LH**			**Leland Olds Unit 1** **DARCO® Hg & $CaCl_2$**	
	COE Increase, mills/kWh	0.97	1.72	0.36	0.48	1.06	0.37	0.47	0.99	0.83	1.25
	$/lb Hg Removed	$54,600	$69,500	$16,200	$15,200	$26,200	$11,800	$10,800	$17,700	$20,600	$22,200
SDA/FF	Plant Name	N/A		N/A			**Holcomb Station Unit 1** **DARCO® Hg-LH**			**Stanton Station Unit 10** **DARCO® Hg-LH**	
	COE Increase, mills/kWh						0.14	0.18	0.37	0.82	1.02
	$/lb Hg Removed						$4,220	$3,810	$6,060	$19,500	$17,400

Table 2 -- 20-Year Levelized Cost of Mercury Control with Byproduct Impact

Coal Rank		Bituminous		85% Subbit/15% Bit blend			Subbituminous			ND Lignite	
Mercury Removal due to ACI, %		**50%**	**70%**	**50%**	**70%**	**90%**	**50%**	**70%**	**90%**	**50%**	**70%**
CS-ESP	Plant Name	**Plant Yates Unit 1** **Super HOK**		**St. Clair Station Unit 1** **B-PAC™**			**Meramec Station Unit 2** **DARCO® Hg-LH**			**Leland Olds Unit 1** **DARCO® Hg & $CaCl_2$**	
	COE Increase, mills/kWh	2.94	3.69	1.36	1.47	2.05	1.75	1.85	2.37	3.50	3.92
	$/lb Hg Removed	$166,000	$149,000	$60,100	$46,600	$50,600	$56,400	$42,700	$42,500	$86,900	$69,600
SDA/FF	Plant Name	N/A		N/A			**Holcomb Station Unit 1** **DARCO® Hg-LH**			**Stanton Station Unit 10** **DARCO® Hg-LH**	
	COE Increase, mills/kWh						0.86	0.90	1.09	2.57	2.77
	$/lb Hg Removed						$25,700	$19,200	$18,000	$61,300	$47,300

II. INTRODUCTION

On May 18, 2005, EPA issued a final regulation for the control of mercury emissions from coal-fired power plants. CAMR establishes a nationwide cap-and-trade program that will be implemented in two phases and applies to both existing and new plants. The first phase of control begins in 2010 with a 38 ton mercury emissions cap based largely on "co-benefit" reductions achieved through further sulfur dioxide (SO_2) and nitrogen oxides (NOx) emission controls required under EPA's recently issued Clean Air Interstate Rule (CAIR). The second phase of control requires a 15 ton mercury emissions cap beginning in 2018. Based on 1999 estimates, U.S. coal-fired power plants emit approximately 48 tons of mercury per year. As a result, CAMR requires an overall average reduction in mercury emissions of approximately 69% to meet the Phase II emissions cap. Meanwhile, several states have adopted, or are considering legislation that will impose more stringent regulations on mercury emissions from coal-fired boilers than those included in CAMR.

Recognizing the potential for mercury regulation, DOE/NETL initiated comprehensive mercury research under the DOE Office of Fossil Energy's IEP program in the early 1990s to ensure that effective pollution control strategies are available for the existing fleet of coal-fired utility boilers. Working collaboratively with power plant operators, the Electric Power Research Institute (EPRI), academia, state and local agencies, and EPA, the IEP program has greatly advanced our understanding of the formation and capture of mercury from coal-fired power plants. Initial efforts were directed at characterizing power plant mercury emissions and focused on laboratory- and bench-scale control technology development. The current IEP program is focused on slip-stream and full-scale field testing of mercury control technologies, as well as continued bench- and pilot-scale development of novel control concepts. The results of completed full-scale field testing efforts are discussed in more detail in later sections. The near-term program goal is to develop mercury control technologies that can achieve 50-70% mercury capture at costs 25-50% less than baseline estimates of $50,000-$70,000/lb of mercury removed. These technologies would be available for commercial demonstration by 2007 for all coal ranks. The longer-term goal is to develop advanced mercury control technologies to achieve 90% or greater capture that would be available for commercial demonstration by 2010. Under DOE's Clean Coal Demonstration Program, DOE is carrying out the first-of-a-kind commercial demonstration of mercury control technology at We Energies' Presque Isle Power Plant in Marquette, Michigan.[5]

Previous testing has demonstrated that some degree of co-benefit mercury control is achieved by existing APCD installed to control NOx, SO_2, and particulate matter (PM) emissions from coal-fired power plant combustion flue gas. However, the capture of mercury across existing APCD can vary significantly based on coal properties, fly ash properties (including unburned carbon), specific APCD configurations, and other factors, with the level of control ranging from 0% to more than 90%. Mercury is present in the flue gas in varying percentages of three basic chemical forms: particulate-bound mercury, oxidized mercury (primarily mercuric chloride – $HgCl_2$), and elemental mercury (Hg^o). The term *speciation* is used to describe the relative proportion of the three forms of mercury in the flue gas. Mercury speciation has a large affect on co-benefit mercury control by existing APCD. For example, elemental mercury is not readily captured by existing APCD, while particulate-bound mercury is captured by ESP and FF. Oxidized mercury is water-soluble and therefore readily captured in wet flue gas desulfurization (FGD) systems and to a lesser extent in particulate control devices.

In general, plants burning subbituminous and lignite coals demonstrate significantly lower co-benefit mercury capture than similarly equipped bituminous-fired plants. The lower performance observed for these low-rank coals has been linked to higher levels of elemental mercury, associated with the coal's low chlorine content. The reduced co-benefit mercury capture by the SDA/FF configuration on low-rank coals can be attributed to the fact that much of the chlorine present in the flue gas is captured by the SDA, leaving inadequate chlorine levels at the FF to participate in the oxidation and capture of Hg^o.[6] Table 3 presents a summary of average co-benefit mercury capture for the APCD configurations and coal ranks analyzed in this report. The data presented below is based on testing conducted by the EPA in 1999 as part of their mercury Information Collection Request (ICR) campaign.[2]

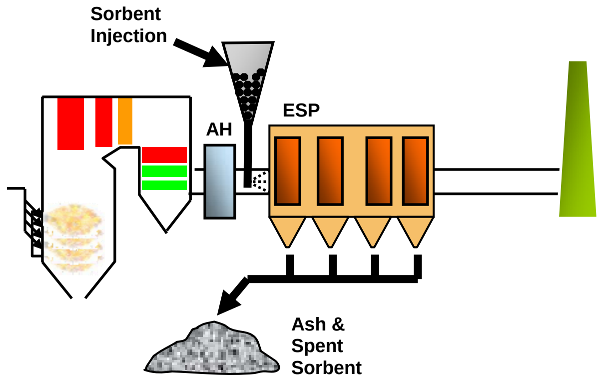
Table 3 -- Average Co-benefit Mercury Capture from EPA ICR Database[f]

APCD Configuration	Average Percentage Mercury Capture			
	Bituminous	**Subbit. / Bit. Blend**	**Subbituminous**	**Lignite**
CS-ESP	36 %	21 %	3 %	- 4 %
SDA/FF	98 %	N/A	24 %	0 %

Although conventional APCD technology can capture some mercury, innovative control technologies will be needed to comply with the CAMR Phase II mercury emission cap. To date, ACI has shown the most promise as a near-term mercury control technology. In a typical configuration, PAC is injected downstream of the plants' air heater and upstream of the existing particulate control device – either an ESP or FF (Figure 1). The PAC adsorbs the mercury from the combustion flue gas and is subsequently captured along with the fly ash in the ESP or FF. Although initial field testing of ACI has been relatively successful, additional research, development and demonstration (RD&D) activities are required before it is considered a commercial technology for the broad range of coals burned by, and various APCDs installed on, today's coal-fired power plants. For example, the effect of continuous long-term ACI on plant operations has yet to be fully determined. In addition, an increase in the fly ash carbon content resulting from ACI may adversely affect the marketability of the fly ash.

[f] The negative value presented for a lignite-fired plant equipped with a CS-ESP is suspected to be a function of mercury measurement limitations.

Figure 1 -- Activated Carbon Injection Technology Schematic



Phase I – Field Testing of Activated Carbon Injection

Through research funded by DOE/NETL, ADA Environmental Solutions (ADA-ES) evaluated the mercury capture efficiency of conventional (i.e., untreated) ACI at four coal-fired electric utility boilers during field testing conducted in 2001-2002. The testing at each plant included parametric tests using several commercially available PACs at various feed rates and operating conditions followed by a one- to two-week, optimized long-term test with a PAC selected from the parametric testing campaign. Testing was carried out sequentially at the four host sites described in Table 4.[4,7,8,9]

Table 4 -- Description of Phase I Field Testing Sites

Utility Company	Plant	Coal Rank	APCD Configuration	Date Test Completed
Alabama Power	E.C. Gaston Unit 3	Bituminous	Hot-side ESP and COHPAC™ FF	April 2001
We Energies	Pleasant Prairie Unit 2	Subbituminous	CS-ESP	November 2001
PG&E	Brayton Point Unit 1	Bituminous	CS-ESP	August 2002
PG&E	Salem Harbor Unit 1	Bituminous	CS-ESP and SNCR	November 2002

DOE/NETL used the Phase I field testing results to complete an economic evaluation of mercury control via ACI in 2003.[10] The economic analysis was based on total mercury removal at representative 500 MW bituminous- and subbituminous-fired units that exhibit baseline mercury removal consistent with the average values observed during the mercury ICR campaign conducted by EPA in 1999 (Table 3). Results from the earlier cost study led to the conclusion that the three most important factors affecting the economics of ACI are: (1) PAC consumption; (2) impact to byproduct management and disposal practices; and (3) capital costs associated with the installation of a compact hybrid particulate collector (COHPAC™) FF for the toxic emission control (TOXECON™) configuration.

The analysis also revealed that conventional ACI upstream of an existing CS-ESP is not a cost-effective option for 90% total mercury removal at bituminous- and subbituminous-fired power plants. In fact, mercury capture reached a maximum asymptote of approximately 65% for the subbituminous-fired unit regardless of the ACI concentration.

Although 90% mercury removal via conventional ACI upstream of the existing CS-ESP was theoretically possible for the representative bituminous-fired power plant, the previous study showed that ACI downstream of the existing ESP and upstream of a retrofitted COHPAC™ FF (i.e., TOXECON™ configuration) was more economical despite the higher capital cost associated with the installation of the COHPAC™ FF. The TOXECON™ configuration also offers the inherent benefit that there would be no additional costs for fly ash disposal or loss of revenue from sale, because fly ash is collected in ESP hoppers upstream of the ACI location.

From an incremental ($/lb of mercury removed) cost perspective, mercury control at subbituminous-fired units appeared to be more cost-effective than at bituminous-fired units. This was caused by the higher incremental mercury removal attributed to ACI at a subbituminous-fired unit due to the assumption of zero co-benefit mercury capture by the existing CS-ESP. A CS-ESP at a bituminous-fired unit was assumed to capture 36% of the mercury exiting the boiler, and therefore less incremental mercury removal was attributed to ACI than for the subbituminous-fired unit.

Phase II – Large-Scale Field Testing of Activated Carbon Injection

In further support of the near-term IEP program goal, DOE/NETL selected eight new projects in September 2003 to test and evaluate mercury control technologies under a Phase II, Round 1 (Phase II-1) field testing solicitation. The Phase II-1 projects shown in Table 5 were initiated in 2004 and are scheduled to be completed in early-to-mid 2006. An additional six projects – representing seven technologies - were subsequently awarded in October 2004 under a Phase II, Round 2 (Phase II-2) solicitation that are scheduled for completion in 2007 (Table 6). Building on promising advances that resulted from the Phase I field testing program, the Phase II projects focus on longer-term (~ 1 month at optimized conditions), large-scale field testing on plants burning primarily low-rank coals or blends (with some units burning bituminous coal) and equipped with a variety of APCD configurations. Most of the fourteen projects fall under two general categories of mercury control – sorbent injection or oxidation enhancements.

Sorbent injection generically describes conventional ACI, brominated (or chemically-treated) ACI, or the injection of non-carbon sorbents into the flue gas for mercury control. Mercury oxidation enhancements are intended to improve the mercury capture efficiency of conventional ACI or downstream APCD by converting elemental mercury to a more reactive oxidized state. For instance, coal or flue gas treatment with SEA is being investigated in conjunction with conventional ACI, while the performance of mercury oxidation catalysts is being evaluated at units equipped with a downstream wet FGD system.

Table 5 -- DOE/NETL's Phase II-1 Field Testing Projects

Project Title	Lead Company	Test Location	Coal Rank	APCD Configuration
Evaluation of Sorbent Injection for Mercury Control	ADA-ES	Sunflower Electric's Holcomb Unit 1	Subbituminous	SDA/FF
		AmerenUE's Meramec Unit 2	Subbituminous	CS-ESP (320 SCA)
		Missouri Basin Power Project's Laramie River Unit 3	Subbituminous	SDA & CS-ESP (599 SCA)
		Detroit Edison's Monroe Unit 4	Subbit. / Bit. Blend	SCR & CS-ESP (258 SCA)
		American Electric Power's Conesville Unit 6	Bituminous	CS-ESP (301 SCA) & Wet FGD
Sorbent Injection for Small ESP Mercury Control	URS Group	Southern Company's Plant Yates Unit 1	Bituminous	CS-ESP (173 SCA) & Wet FGD
		Southern Company's Plant Yates Unit 2	Bituminous	CS-ESP (144 SCA)
Enhancing Carbon Reactivity in Mercury Control in Lignite-Fired Systems	UNDEERC	Basin Electric's Leland Olds Unit 1	ND Lignite	CS-ESP (320 SCA)
		Great River Energy's Stanton Unit 10	ND Lignite	SDA/FF
		Basin Electric's Antelope Valley Unit 1	ND Lignite	SDA/FF
		Great River Energy's Stanton Unit 1	Subbituminous	CS-ESP (470 SCA)
Advanced Utility Mercury Sorbent Field-Testing Program	Sorbent Technologies	Detroit Edison's St. Clair Unit 1	Subbit. / Bit. Blend	CS-ESP (SCA 467)
		Duke Energy's Buck Unit 6	Bituminous	HS-ESP (240 SCA)
Demonstration of Amended Silicates for Mercury Control	Amended Silicates	Cinergy's Miami Fort Unit 6	Bituminous	CS-ESP (353 SCA)
Pilot Testing of Mercury Oxidation Catalysts for Upstream of Wet FGD Systems	URS Group	TXU's Monticello Unit 3	TX Lignite	CS-ESP (452 SCA) & Wet FGD
		Southern Company's Plant Yates Unit 1	Bituminous	CS-ESP (173 SCA) & Wet FGD
Evaluation of MerCAP™ for Power Plant Mercury Control	URS Group	Great River Energy's Stanton Unit 10	ND Lignite	SDA/FF
		Southern Company's Plant Yates Unit 1	Bituminous	CS-ESP (173 SCA) & Wet FGD
Mercury Oxidation Upstream of an ESP and Wet FGD	UNDEERC	Minnkota Power's Milton R. Young Unit 2	ND Lignite	CS-ESP (375 SCA) & Wet FGD
		TXU's Monticello Unit 3	TX Lignite	CS-ESP (452 SCA) & Wet FGD

Table 6 -- DOE/NETL's Phase II-2 Field Testing Projects

Project Title	Lead Company	Test Location	Coal Rank	APCD Configuration
Field Testing of Activated Carbon Injection Options for Mercury Control	UNDEERC	TXU's Big Brown Unit 2	TX Lignite / Subbit. Blend	CS-ESP (162 SCA) & COHPAC® FF
Field Demonstration of Enhanced Sorbent Injection for Mercury Control	ALSTOM Power	PacifiCorp's Dave Johnston Unit 3	Subbituminous	CS-ESP (600 SCA)
		Basin Electric's Leland Olds Unit 1	ND Lignite	CS-ESP (320 SCA)
		Reliant Energy's Portland Unit 1	Bituminous	CS-ESP (284 SCA)
Low Cost Options for Moderate Levels of Mercury Control	ADA-ES	Entergy's Independence Unit 1	Subbituminous	CS-ESP (542 SCA)
		MidAmerican's Louisa Unit 1	Subbituminous	HS-ESP (459 SCA)
		MidAmerican's Council Bluffs Unit 2	Subbituminous	HS-ESP (224 SCA)
		AEP's Gavin Station	Bituminous	CS-ESP (430 SCA) & Wet FGD
Brominated Sorbents for Small Cold-Side ESPs, Hot-Side ESPs, and Fly Ash use in Concrete	Sorbent Technologies	Progress Energy's Lee Unit 1	Bituminous	CS-ESP (300 SCA)
		Midwestern Generation's Crawford Unit 7	Subbituminous	CS-ESP (112 SCA)
		Midwestern Generation's Will County Unit 3	Subbituminous	HS-ESP (173 SCA)
Field Testing of a Wet FGD Additive for Enhanced Mercury Control	URS Group	TXU's Monticello Unit 3	TX Lignite	CS-ESP (452 SCA) & Wet FGD
		Southern Company's Plant Yates Unit 1	Bituminous	CS-ESP (173 SCA) & Wet FGD
Demonstration of Integrated Approach to Mercury Control	GE-EERC	Progress Energy's Lee Unit 3	Bituminous	CS-ESP (300 SCA)

The following is a brief summary of the four Phase II-1 projects included in this economic analysis, while a complete description of these projects can be found in Appendix B of this report.

- ADA-ES is evaluating the use of conventional and brominated (or chemically-treated) ACI as well as the addition of SEA for mercury control.[11,12] To date, field testing has been completed at the Holcomb, Meramec, Laramie River, and Monroe Stations. However, this report only includes cost estimates for the Holcomb and Meramec Stations as shown in Table 7. Field testing began in March 2006 at American Electric Power's (AEP) Conesville Station Unit 6.

- URS Group, Inc. (URS) is investigating the mercury capture efficiency of conventional ACI for units equipped with small specific collection area (SCA) CS-ESP.[13,14,15] Although parametric testing was conducted on Plant Yates Units 1 and 2, the 30-day long-term conventional ACI trial was completed on Unit 1.

This decision was made after parametric tests revealed that the ammonia and sulfur trioxide (NH_3/SO_3) dual flue gas conditioning system on Unit 2 had no measurable effect on the reduction in total vapor-phase mercury. However, the impact of SO_3 injection on mercury capture may have been masked by the high sulfur content of the eastern bituminous coal. Consequently, this report only contains cost estimates for Plant Yates Unit 1 as shown in Table 7. The effects of long-term ACI on the operation and performance of Unit 1's CS-ESP (173 SCA) and Jet Bubbling Reactor (JBR) wet FGD scrubber are discussed in Appendix B of this report.

- The University of North Dakota Energy & Environmental Research Center (UNDEERC) is testing two approaches designed to increase mercury capture for plants burning low-rank ND lignite coal.[16,17,18,19] Two mercury control techniques are being evaluated: (1) addition of SEA to the coal in conjunction with conventional ACI; and (2) brominated ACI. Evaluation of the first mercury control strategy has been completed at Leland Olds Station Unit 1 and Antelope Valley Station Unit 1, which is equipped with an SDA/FF. Field testing to investigate the mercury capture efficiency of brominated ACI has been completed at Stanton Station Unit 10 and Stanton Station Unit 1, which recently switched to 100% subbituminous coal and is equipped with a CS-ESP. However, this report only includes cost estimates for Leland Olds Unit 1 and Stanton Station Unit 10 as shown in Table 7.

- Sorbent Technologies Corporation is currently evaluating the mercury capture efficiency of two brominated PACs (B-PAC™ and H-PAC™) during full-scale field tests.[20] Injection of B-PAC™ took place at Detroit Edison's St. Clair Station Unit 1 that is equipped with a CS-ESP and fires a coal blend consisting of 85% subbituminous and 15% eastern bituminous. H-PAC™ was evaluated at Duke Energy's bituminous-fired Buck Plant that is equipped with a HS-ESP. H-PAC™ was developed by Sorbent Technologies to address mercury control at units equipped with a HS-ESP. However, this report only includes cost estimates for St. Clair Station Unit 1 as shown in Table 7.

Table 7 -- Description of Phase II-1 Test Sites Included in this Cost Study

Utility Company	Plant	Coal Rank	APCD Configuration	Date Test Completed
Sunflower Electric	Holcomb Station Unit 1	Subbituminous	SDA/FF	August 2004
AmerenUE	Meramec Station Unit 2	Subbituminous	CS-ESP	November 2004
Southern Company	Plant Yates Unit 1	Bituminous	CS-ESP and wet FGD	December 2004
Basin Electric	Leland Olds Unit 1	ND Lignite	CS-ESP	May 2004
Great River Energy	Stanton Station Unit 10	ND Lignite	SDA/FF	July 2004
Detroit Edison	St. Clair Station Unit 1	Subbit. / Bit. Blend	CS-ESP	October 2004

Short-term parametric tests conducted at each of the Phase II field testing sites are intended to: (1) gain a better understanding of the plant-specific factors that influence mercury capture; (2) determine the best PAC for long-term testing; and (3) establish the optimal operating conditions for the long-term continuous injection test. Therefore, a series of performance curves that graphically display the relationship between ACI concentration and mercury removal are generated during parametric testing. The parametric performance curves displayed in Figure 2 serve as the foundation for the six economic analyses included in this report. The selection of these particular curves was dictated by the long-term continuous injection trial performed at each site. For example, the performance of DARCO® Hg-LH during parametric tests at Stanton Station Unit 10 is shown below, because DARCO® Hg-LH was selected for evaluation during the 30-day long-term test at this unit.

Figure 2 -- ACI Performance Data from Phase II Field Tests

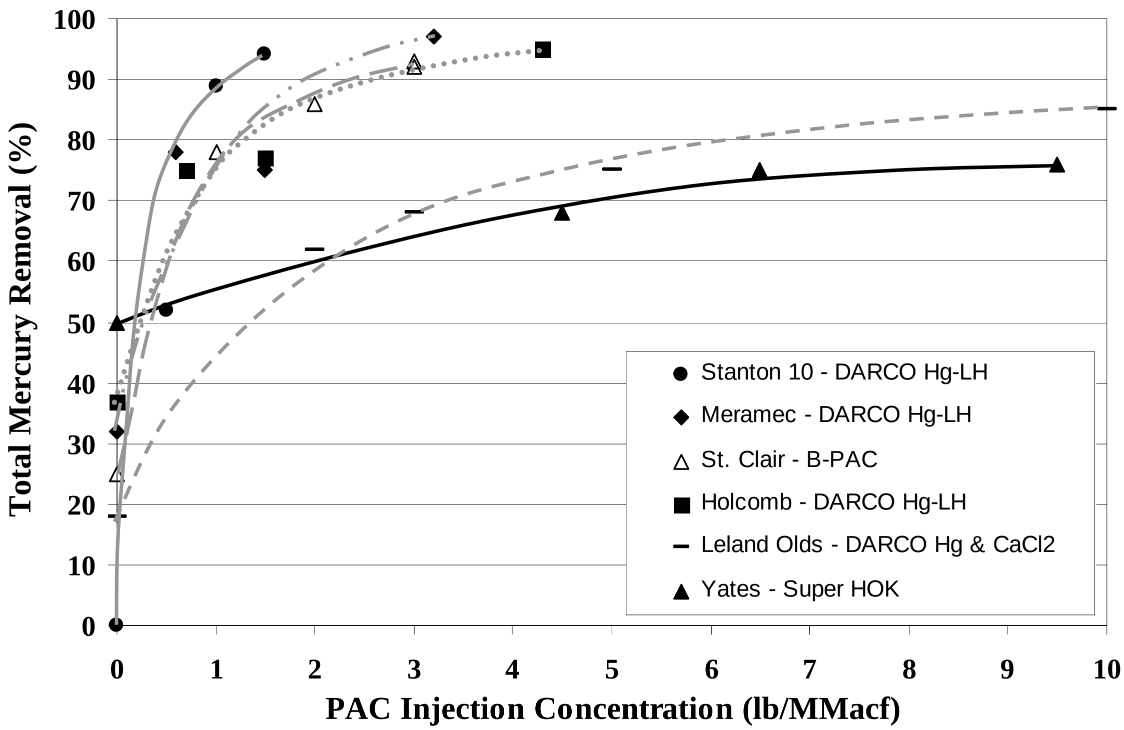


Figure 2 displays the improved mercury capture efficiency of brominated DARCO® Hg-LH and B-PAC™ despite injection downstream of boilers firing low-rank coals. Conversely, the performance of conventional Super HOK exhibits limitations similar to those observed during Phase I testing at Pleasant Prairie Unit 2. However, the addition of an SEA to the coal, which increases the concentration of chloride ions in the flue gas, has shown the ability to improve the mercury capture efficiency of DARCO® Hg. Note the variability in baseline mercury capture, which ranges from 0% to 50% for the Phase II field testing units included in this economic analysis.

III. ECONOMIC FRAMEWORK

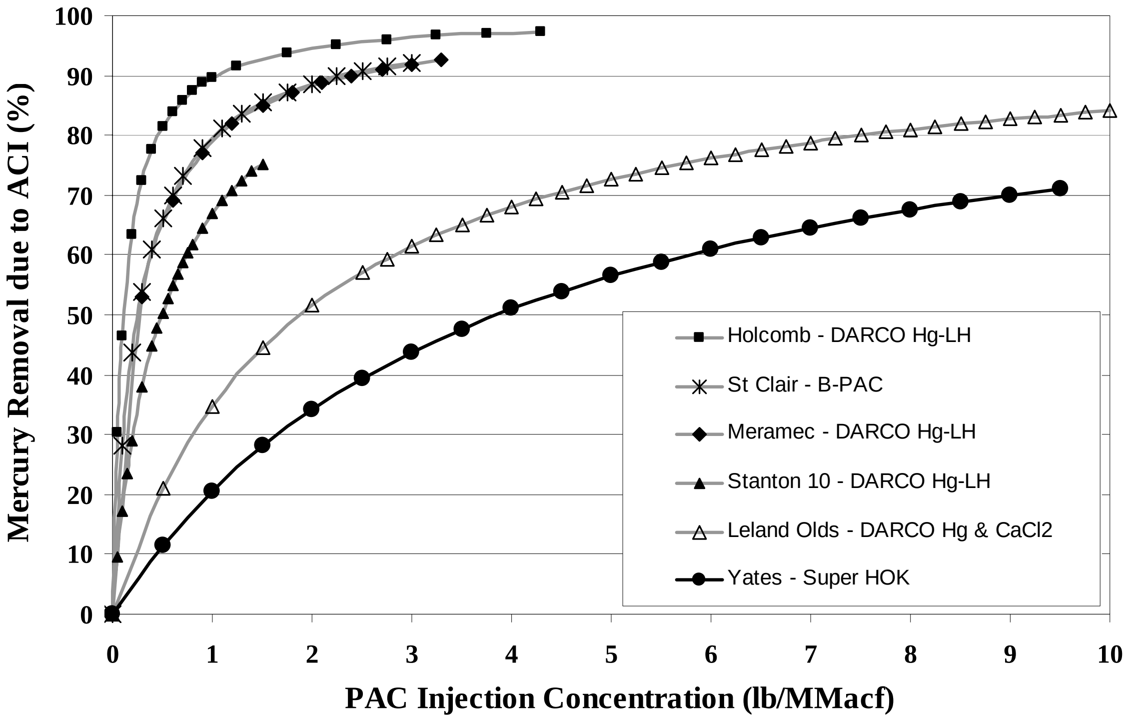
This report provides "study-level" cost estimates for mercury control via ACI based on preliminary results obtained from DOE/NETL's Phase II field testing of advanced mercury control technologies. The study was carried out to provide DOE/NETL a gauge in measuring its success in achieving the target of reducing baseline mercury control costs by 25-50%. The economic analyses were conducted on a plant-specific basis meaning that the economics are dependent on the actual power plant operating conditions and coal properties observed during full-scale testing at each of the Phase II sites displayed in Table 7. In particular, the cost estimates provided in this report are highly dependent on the: (1) ACI concentration required to achieve a given level of mercury control during both parametric and long-term testing; (2) delivered PAC cost; (3) coal mercury content (lb/TBtu); and (4) level of baseline mercury removal by existing APCD observed prior to the parametric tests involving the PAC that was ultimately selected for evaluation during long-term testing. Note the Phase II long-term tests are conducted under optimal conditions established during the parametric testing campaign.

The economic analyses were conducted in a manner that yields the cost required to achieve low (50%), mid-range (60-70%), and high (90%) levels of mercury control "above and beyond" the plant-specific baseline mercury removal by existing APCDs. In other words, the levels of mercury control discussed in this report are directly attributable to ACI. This approach is complicated by the variability of baseline mercury capture caused by changes in coal composition and boiler performance that can impact the quantity of unburned carbon present in the fly ash. In addition, field testing has shown that residual PAC remaining in the ductwork from previous injection trials may contribute to an increase in baseline mercury capture over the course of the parametric testing campaign. With that in mind, a conscious effort was made to identify the baseline mercury capture observed prior to the parametric tests involving the PAC that was selected for evaluation during long-term testing.

To determine the percentage of total mercury capture that is attributable to ACI, the parametric performance curves displayed in Figure 2 as well as the average mercury removal observed during the long-term continuous injection test were adjusted. The data adjustment methodology is intended to account for the baseline mercury removal observed prior to parametric testing. The baseline adjusted parametric performance curves were then scaled to conform to the average mercury removal observed during the long-term test. The latter adjustment was performed, because the results obtained from long-term testing are thought to be more representative of the mercury removal efficiency of ACI than the short-term parametric results. The resultant ACI datasets were used to develop the final adjusted algorithms that express the percent mercury removal attributable to ACI as a function of PAC injection concentration. These algorithms are represented by the non-linear regression curves displayed in Figure 3. A complete discussion of the data adjustment methodology with sample calculations is included in Appendix C of this report.

The importance of developing accurate non-linear algorithms cannot be overstated. The algorithms are used to calculate the quantity of PAC required to achieve a given level of mercury control. In some instances, the costs associated with PAC consumption account for approximately 75% of the total cost of mercury control. Therefore, the algorithms represent a critical element of the cost estimates for mercury control via ACI presented in this report.

Figure 3 -- Adjusted Phase II Non-Linear Regression Curves



The adjusted regression curves shown in Figure 3 display the entire range of ACI concentrations evaluated during the parametric testing campaign conducted at each of the Phase II field testing units. For this analysis, the non-linear algorithms were not used to extrapolate the regression curves beyond the maximum tested ACI concentration. As a result, cost estimates for 90% mercury removal due to ACI were only developed for the Holcomb, Meramec, and St. Clair Stations.

Capital Costs

As part of the DOE/NETL Phase II field testing program, ADA-ES recently completed economic evaluations of mercury control via ACI based on the results obtained during full-scale field testing at the Holcomb and Meramec Stations.[11,12] These estimates were used to approximate the capital costs required to retrofit similar ACI systems at the other Phase II field testing sites included in this economic analysis.[g] The capital cost estimates include both direct and indirect cost components. The total direct cost (TDC) for the ACI system is calculated as the sum of the following cost components: (1) uninstalled equipment cost; (2) materials and labor associated with site integration; (3) applicable taxes; and (4) installation costs that can vary significantly depending on plant-specific retrofit issues. In addition, an estimated cost of $100,000 is included for the installation

[g] A detailed description of these capital cost estimates is provided in Appendix D of this report.

of an SEA storage and injection system used to add an aqueous $CaCl_2$ solution to the coal during field testing at Leland Olds Unit 1.

The indirect costs were estimated as percentages of the TDC using the EPRI Technical Assessment Guide (TAG™) methodology. For instance, 10% of the TDC was set aside for general facility fees as well as engineering fees. The project contingency was calculated as 15% of the TDC, while 5% was used for the process contingency since the technology is relatively simple. The total capital requirement (TCR) for the PAC storage and injection system is calculated with the inclusion of indirect costs and contingencies. However, the capital cost required to install and calibrate a mercury monitoring system was excluded from this economic analysis since utilities will incur these costs regardless of their mercury control strategy. The TCR for each of the Phase II field testing sites included in this economic analysis is presented in Tables 9-11. Upon inspection of these tables, the reader should note that the overall TCR is independent of the desired level of mercury control and only slightly dependent on unit capacity.

The TCR is also commonly expressed as a function of unit capacity ($/kW). For this analysis, the TCR values expressed as a function of unit capacity range from $3.63/kW for the 360 MW Holcomb Station Unit 1 to $21.10/kW for the 60 MW Stanton Station Unit 10. Note that no adjustments were made for interest during construction since it is assumed that the ACI system can be installed in a few months.

Annual Operating and Maintenance (O&M) Costs

Annual O&M costs were calculated using an assumed capacity factor of 80%. These annual expenditures consist of several components, including: (1) PAC consumption; (2) PAC disposal; (3) SEA consumption is included for Leland Olds Unit 1; (4) other costs[h]; and (5) the cost of byproduct management and non-hazardous disposal. An average incremental operating labor requirement of four hours per day was estimated to cover the incremental labor required to operate and monitor the PAC storage and injection system. The annual maintenance costs are based on 5% of the uninstalled equipment cost. The contribution of each component as well as the total first-year annual O&M cost is presented in Tables 9-11.

Primarily, the annual O&M costs are dominated by PAC consumption costs. Table 8 offers a brief description of the PACs evaluated during the Phase II field tests included in this economic analysis. The delivered prices ($/lb) provided in Table 8 are valid as of August 2005 and include $0.10/lb for transportation expenses. However, recent experience has revealed that brominated PAC costs are in a state of flux and prices may depend on the quantity of PAC being purchased due to economies of scale. An estimated delivered cost of $0.15/lb was used for the aqueous $CaCl_2$ solution added to the coal during testing at Leland Olds Unit 1. This price also includes a $0.10/lb charge for transportation expenses.

[h] Other related O&M costs include electric power, O&M labor, and spare parts. The assumptions used to quantify these "other" annual O&M costs are included in Appendix A of this report.

Table 8 -- Description of Powdered Activated Carbons[21,22]

PAC	Manufacturer	Description	Delivered Price ($/lb)
DARCO® Hg (aka DARCO FGD)	NORIT Americas	Conventional PAC; Lignite-derived	0.54
DARCO® Hg-LH (aka DARCO FGD-E3)	NORIT Americas	Brominated PAC; Lignite-derived	0.95
Super HOK	RWE Rhinebraun	Conventional German PAC; Lignite-derived	0.39
B-PAC™	Sorbent Technologies	Brominated PAC; Lignite-derived	0.85

The costs associated with the management and non-hazardous disposal of the captured PAC are included as part of the annual O&M in all cases because these costs would be incurred regardless of existing fly ash management and disposal practices. For this analysis, the PAC disposal costs were calculated using an estimated value of $17/ton.

PAC injection upstream of an existing ESP may adversely impact the ability to market fly ash for beneficial use applications. Because an important market for fly ash is the manufacture of concrete, any additional carbon content may render it unsuitable for sale. For instance, DOE/NETL Phase I field testing at Pleasant Prairie rendered the ash unsuitable for use in concrete during the entire test period. ACI concentrations used for this analysis result in an increase in carbon-in-ash concentration ranging from approximately 0.05 wt% carbon to 2.84 wt% carbon.[i] Along with the potential loss of revenue from the sale of the ash, the affected unit would need to pay for disposal of fly ash that would have otherwise been sold. For this analysis, the total byproduct impacts are based on an estimated value of $35/ton, which includes $18/ton for lost revenue from fly ash sales and $17/ton for non-hazardous fly ash disposal.

However, the byproduct impacts associated with ACI may not be as severe for units equipped with the SDA/FF configuration (e.g., Holcomb Station Unit 1 and Stanton Station Unit 10) since the majority of recycled SDA byproducts are used for low-value mining applications.[j] Therefore, the SDA byproduct (i.e., SDA ash and solid calcium sulfite) impacts only account for the added cost of $17/ton for non-hazardous SDA byproduct disposal (i.e., no lost revenue from sales). For this analysis, the quantity of calcium sulfite generated was calculated using the coal sulfur content (see Appendix A), assuming the SDA/FF configuration is able to capture 90% of the sulfur dioxide present in the flue gas.

Incremental Cost of Mercury Control

Levelized costs for the incremental increase in cost of electricity (COE) expressed in units of mills per kilowatt-hour (mills/kWh) and the incremental cost of mercury control ($/lb Hg removed) are presented in Tables 9-11 with and without the inclusion of added

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[i] The increase in carbon-in-ash concentration is calculated using the following equation:
wt% carbon = [ACI (lb/hr) / (ACI (lb/hr) + Fly ash generation (lb/hr))] x 100%. A complete discussion pertaining to the implications of ACI on fly ash sales is included in the Discussion section of this report.

[j] American Coal Ash Association, 2004 coal combustion product (CCP) production and use survey, URL http://www.acaa-usa.org/PDF/2004_CCP_Survey(9-9-05).pdf

costs associated with byproduct management and non-hazardous disposal. These levelized costs were calculated on a current dollar basis using a standard 3% escalation rate and a 20-year book life. Additional economic assumptions are documented in Appendix A of this report.

The incremental cost of mercury reduction, i.e. the cost (in $/lb Hg removed) to achieve a specific reduction can vary significantly with various assumptions including the plant-specific baseline mercury capture by existing APCD, the coal mercury content (lb/TBtu), and the ash content of the coal (when byproduct impacts are considered). For example, the incremental cost of mercury control will increase when: (1) baseline mercury capture by existing APCD is high; or (2) the coal mercury content is low, because a smaller quantity of mercury is removed from the flue gas for a given level of control. For the economic analyses presented in this report, the incremental cost of mercury control for each of the Phase II field testing sites was calculated using the quantity of mercury removed due to ACI. This was accomplished by: (1) converting the coal mercury content to a flue gas mercury flow rate (lb/hr); (2) reducing the flue gas mercury flow rate by a percentage consistent with that unit's baseline mercury removal to calculate the quantity of mercury removed under baseline conditions; and (3) taking a percentage of the mercury remaining in the system to determine the quantity of mercury removed that is directly attributable to ACI for a given level of control (e.g., 0.7 for 70% mercury control).

Analysis presented in the earlier DOE/NETL economic study[10] demonstrated how, for a given level of control (and therefore given levelized cost), a single parameter such as coal mercury content can result in a broad range of incremental costs of mercury removal.[k] Therefore, the incremental cost of mercury control is inextricably linked to the specific assumptions used in the development of the particular cost estimate, and any comparison of that estimate to other scenarios should be conducted cautiously, with a clear understanding of the context of the specific application. The usefulness of the incremental cost of mercury reduction is most suited for determining the economic impact to a well-defined existing unit considering several control options, or for estimates of "*average*" unit impacts in national-scale energy models such as the National Energy Modeling System (NEMS) or the Integrated Planning Model (IPM).

[k] For 70% total mercury removal via conventional ACI at a representative 500 MW bituminous-fired unit, with coal properties and existing baseline mercury capture based on averages derived from EPA's ICR data, the incremental cost of mercury control ranges from approximately $25,000/lb Hg removed (15 lb/TBtu) to $125,000/lb Hg removed (3 lb/TBtu) when byproduct impacts are excluded.

Table 9 -- Cost Estimate for 50% Mercury Removal (2005$)

50% Mercury Removal due to ACI						
Plant	**Holcomb Station Unit 1**	**Meramec Station Unit 2**	**Plant Yates Unit 1**	**Leland Olds Unit 1**	**Stanton Station Unit 10**	**St. Clair Station Unit 1**
Capacity, MW	360	140	100	220	60	145
Fuel	PRB	PRB	Bituminous	ND Lignite	ND Lignite	PRB / Bit. Blend
Coal Hg Content, lb/TBtu	10.36	7.83	5.92	8.66	8.32	5.66
Unit APCD	SDA/FF	CS-ESP	CS-ESP	CS-ESP	SDA/FF	CS-ESP
PAC / SEA	DARCO® Hg-LH	DARCO® Hg-LH	Super HOK	DARCO® Hg w/ $CaCl_2$	DARCO® Hg-LH	B-PAC™
ACI Rate, lb/MMacf	0.11	0.27	3.85	1.88	0.49	0.26
TCR, $1,000	$1,310	$1,280	$1,270	$1,390	$1,270	$1,280
TCR, $/kW	$3.63	$9.16	$12.66	$6.33	$21.10	$8.79
First-Year Annual O&M with 80% Capacity Factor						
PAC Consumption, $/yr	$54,800	$59,200	$303,000	$374,000	$49,500	$68,800
PAC Disposal, $/yr	$490	$529	$6,600	$5,890	$443	$688
SEA Consumption, $/yr	N/A	N/A	N/A	$388,000	N/A	N/A
Other, $/yr	$105,000	$104,000	$107,000	$107,000	$104,000	$104,000
Total, $/yr	$160,000	$164,000	$417,000	$875,000	$154,000	$174,000
Byproduct Impacts, $1,000/yr	$1,430	$1,060	$1,080	$3,240	$579	$792
COE Increase, 20-Year Levelized Cost (2005 Current$), mills/kWh						
w/o byproduct impacts	0.14	0.37	0.97	0.83	0.82	0.36
with byproduct impacts	0.86	1.75	2.94	3.50	2.57	1.36
Incremental Cost of Control, 20-Year Levelized Cost (2005 Current$), $/lb Hg Removed						
w/o byproduct impacts	$4,220	$11,800	$54,600	$20,600	$19,500	$16,200
with byproduct impacts	$25,700	$56,400	$166,000	$86,900	$61,300	$60,100

Table 10 -- Cost Estimate for 70% Mercury Removal (2005$)

70% Mercury Removal due to ACI						
Plant	**Holcomb Station Unit 1**	**Meramec Station Unit 2**	**Plant Yates Unit 1**	**Leland Olds Unit 1**	**Stanton Station Unit 10**	**St. Clair Station Unit 1**
Capacity, MW	360	140	100	220	60	145
Fuel	PRB	PRB	Bituminous	ND Lignite	ND Lignite	PRB / Bit. Blend
Coal Hg Content, lb/TBtu	10.36	7.83	5.92	8.66	8.32	5.66
Unit APCD	SDA/FF	CS-ESP	CS-ESP	CS-ESP	SDA/FF	CS-ESP
PAC / SEA	DARCO® Hg-LH	DARCO® Hg-LH	Super HOK	DARCO® Hg w/ $CaCl_2$	DARCO® Hg-LH	B-PAC™
ACI Rate, lb/MMacf	0.27	0.62	8.98	4.39	1.15	0.60
TCR, $1,000	$1,310	$1,280	$1,270	$1,390	$1,270	$1,280
TCR, $/kW	$3.63	$9.16	$12.66	$6.33	$21.10	$8.79
First-Year Annual O&M with 80% Capacity Factor						
PAC Consumption, $/yr	$128,000	$138,000	$707,000	$875,000	$116,000	$160,000
PAC Disposal, $/yr	$1,140	$1,230	$15,400	$13,800	$1,040	$1,610
SEA Consumption, $/yr	N/A	N/A	N/A	$388,000	N/A	N/A
Other, $/yr	$105,000	$105,000	$111,000	$111,000	$104,000	$105,000
Total, $/yr	$234,000	$244,000	$833,000	$1,390,000	$221,000	$267,000
Byproduct Impacts, $1,000/yr	$1,430	$1,060	$1,080	$3,240	$579	$792
COE Increase, 20-Year Levelized Cost (2005 Current$), mills/kWh						
w/o byproduct impacts	0.18	0.47	1.72	1.25	1.02	0.48
with byproduct impacts	0.90	1.85	3.69	3.92	2.77	1.47
Incremental Cost of Control, 20-Year Levelized Cost (2005 Current$), $/lb Hg Removed						
w/o byproduct impacts	$3,810	$10,800	$69,500	$22,200	$17,400	$15,200
with byproduct impacts	$19,200	$42,700	$149,000	$69,600	$47,300	$46,600

Table 11 -- Cost Estimate for 90% Mercury Removal (2005$)[1]

90% Mercury Removal due to ACI			
Plant	**Holcomb Station Unit 1**	**Meramec Station Unit 2**	**St. Clair Station Unit 1**
Capacity, MW	360	140	145
Fuel	PRB	PRB	PRB / Bit. Blend
Coal Hg Content, lb/TBtu	10.36	7.83	5.66
Unit APCD	SDA/FF	CS-ESP	CS-ESP
PAC / SEA	DARCO® Hg-LH	DARCO® Hg-LH	B-PAC™
ACI Rate, lb/MMacf	1.03	2.40	2.31
TCR, $	$1,310,000	$1,280,000	$1,280,000
TCR, $/kW	$3.63	$9.16	$8.79
First-Year Annual O&M with 80% Capacity Factor			
PAC Consumption, $/yr	$493,000	$532,000	$619,000
PAC Disposal, $/yr	$4,420	$4,760	$6,190
Other, $/yr	$107,000	$106,000	$107,000
Total, $/yr	$605,000	$643,000	$732,000
Byproduct Impacts, $/yr	$1,430,000	$1,060,000	$792,000
COE Increase, 20-Year Levelized Cost (2005 Current$), mills/kWh			
w/o byproduct impacts	0.37	0.99	1.06
with byproduct impacts	1.09	2.37	2.05
Incremental Cost of Control, 20-Year Levelized Cost (2005 Current$), $/lb Hg Removed			
w/o byproduct impacts	$6,060	$17,700	$26,200
with byproduct impacts	$18,000	$42,500	$50,600

[1] For this analysis, the ACI concentration required to achieve a given level of mercury control was calculated using an adjusted non-linear algorithm that accounts for baseline mercury capture and incorporates the average long-term test results (see Appendix C). If the calculated ACI concentration fell within the range of ACI concentrations evaluated during the parametric testing campaign, then an economic analysis was performed for that level of mercury control. As a result, the cost of 90% mercury control due to ACI was not calculated for Leland Olds Unit 1, Plant Yates Unit 1, and Stanton Station Unit 10. This concept is also graphically illustrated in Figure 3.

IV. DISCUSSION

The plant specific economic analyses presented in this document were derived from the results of full-scale ACI field tests completed to date under DOE/NETL's Phase II mercury control program. As shown in Table 9, the majority of Phase II field tests concluded thus far focus on mercury control at units firing low-rank coal. The Phase II mercury control program was influenced significantly by the results obtained during Phase I field tests. For instance, Phase I field testing at the subbituminous-fired Pleasant Prairie Unit 2 revealed that total mercury removal was limited to approximately 65% despite the injection of conventional DARCO® Hg at flue gas concentrations as high as 30 lb/MMacf. As a result, several of the projects included in the Phase II mercury control program investigate the effect of adding halogens (i.e., bromine and chlorine) to the chlorine-deficient flue gas emitted from boilers burning low-rank coals. It is believed that the excess halogens will promote the oxidation of elemental mercury and improve the mercury capture efficiency of the injected PAC as well as downstream APCD.

The superior performance and cost-effectiveness of these enhanced mercury control technologies is displayed in Tables 10 and 11. For example, brominated PAC injection concentrations ranging from 1.03 lb/MMacf to 2.40 lb/MMacf are required to achieve 90% ACI mercury removal resulting in a COE increase ranging from 0.37 mills/kWh to 1.06 mills/kWh when byproduct impacts are excluded. At Leland Olds Unit 1, 70% ACI mercury removal was achieved with a conventional DARCO® Hg injection concentration of 4.39 lb/MMacf when the ND lignite coal was treated with an aqueous $CaCl_2$ solution prior to combustion.

The following paragraphs summarize the cost of mercury control via ACI for each of the Phase II field testing units included in this analysis. The economics were developed on a plant specific basis using the process parameters and coal characteristics presented in Appendix A, while the levels of mercury control presented in this document are directly attributable to ACI (i.e., exclude baseline removal). A complete discussion of the Phase II field testing results is provided in Appendix B of this report.

Holcomb Station Unit 1

The economics of mercury control developed for this 360 MW subbituminous-fired unit equipped with an SDA/FF configuration are based on the performance of brominated DARCO® Hg-LH during full-scale field tests. During the long-term continuous injection trial, an average DARCO® Hg-LH injection concentration of 1.2 lb/MMacf was required to achieve an average total mercury removal of 93%.[m] Using the adjusted ACI performance algorithm, a DARCO® Hg-LH injection concentration of 1.03 lb/MMacf is required to achieve 90% ACI mercury removal resulting in an annual PAC consumption cost of approximately $493,000 using the current delivered price of $0.95/lb for DARCO® Hg-LH. When byproduct impacts are excluded, the 20-year levelized incremental cost of 90% ACI mercury control is approximately $6,060/lb Hg removed

[m] The standard operation at this unit is to recycle approximately 75% of the FF effluent back into the SDA. Therefore, during the long-term continuous injection trial a portion of the injected DARCO® Hg-LH was recycled back into the SDA, which may have contributed to the high level of mercury control observed at this unit. Not all units equipped with the SDA/FF configuration utilize recycle.

and the increase in COE is 0.37 mills/kWh. The annual byproduct impacts of approximately $1,430,000 assume that following the installation of an ACI system, the SDA byproducts can no longer be given away for low-value mining applications and would be subject to non-hazardous disposal at $17/ton.

Meramec Station Unit 2

For this 140 MW subbituminous-fired unit equipped with a CS-ESP, the economics of mercury control are based on the performance of DARCO® Hg-LH during full-scale field tests. An average DARCO® Hg-LH injection concentration of 3.3 lb/MMacf was required to achieve an average total mercury removal of 93% during the long-term continuous injection trial. Using the adjusted ACI performance algorithm, a DARCO® Hg-LH injection concentration of 2.40 lb/MMacf is required to achieve 90% ACI mercury removal resulting in an annual PAC consumption cost of approximately $532,000. When byproduct impacts are excluded, the 20-year levelized incremental cost of 90% ACI mercury control is approximately $17,700/lb Hg removed and the increase in COE is 0.99 mills/kWh. The annual byproduct impacts of approximately $1,060,000 assume that following the installation of an ACI system, the utility would lose revenues of $18/ton from fly ash sales and incur a non-hazardous fly ash disposal fee of $17/ton.

Plant Yates Unit 1

The economics of mercury control developed for this 100 MW bituminous-fired unit equipped with a CS-ESP are based on the performance of conventional Super HOK during full-scale field tests. During long-term testing, Super HOK injection concentrations of 4.5 lb/MMacf, 6.5 lb/MMacf, and 9.5 lb/MMacf were required to achieve average levels of total mercury control of approximately 68%, 75%, and 76%, respectively. Using the adjusted ACI performance algorithm, a Super HOK injection concentration of 8.98 lb/MMacf is required to achieve 70% ACI mercury removal resulting in an annual PAC consumption cost of approximately $707,000 using the current delivered price of $0.39/lb for Super HOK. When byproduct impacts are excluded, the 20-year levelized incremental cost of 70% ACI mercury control is approximately $69,500/lb Hg removed and the increase in COE is 1.72 mills/kWh. The annual byproduct impacts of approximately $1,080,000 assume that following the installation of an ACI system, the utility would lose revenues of $18/ton from fly ash sales and incur a non-hazardous fly ash disposal fee of $17/ton.

Leland Olds Unit 1

For this 220 MW ND lignite-fired unit equipped with a CS-ESP, the cost of mercury control is based on the mercury capture efficiency of conventional DARCO® Hg injection when the coal is treated with an SEA (i.e., an aqueous $CaCl_2$ solution) prior to combustion. During long-term testing, an average total mercury removal of 63% was achieved with an average DARCO® Hg injection concentration of 3 lb/MMacf coupled with the addition of an aqueous $CaCl_2$ solution to the coal at a constant rate that is equivalent to adding approximately 500 ppm chlorine to the coal. Mercury control via the co-injection of an aqueous $CaCl_2$ solution onto the coal and DARCO® Hg upstream of the existing CS-ESP requires the installation of distinct storage and injection systems for the SEA and PAC. For this analysis, an installed cost of $100,000 was estimated for the SEA storage and injection system. Using the adjusted ACI performance algorithm, 70% ACI mercury removal is achieved with a DARCO® Hg injection concentration of 4.39

lb/MMacf in conjunction with SEA coal treatment. The delivered $CaCl_2$ cost of $0.15/lb yields an annual SEA consumption cost of approximately $388,000, while the annual PAC consumption cost is approximately $875,000 for 70% ACI mercury removal using the current delivered price of $0.54/lb for DARCO® Hg. When byproduct impacts are excluded, the 20-year levelized incremental cost of 70% ACI mercury control is approximately $22,200/lb Hg removed and the increase in COE is 1.25 mills/kWh. The annual byproduct impacts of approximately $3,240,000 assume that following the installation of an ACI system, the utility would lose revenues of $18/ton from fly ash sales and incur a non-hazardous fly ash disposal fee of $17/ton.

Stanton Station Unit 10

The economics of mercury control for this 60 MW ND lignite-fired unit equipped with an SDA/FF configuration are based on the performance of brominated DARCO® Hg-LH during full-scale field tests. During the parametric testing campaign, 94% total mercury removal was achieved with a DARCO® Hg-LH injection concentration of 1.5 lb/MMacf. However, incorporation of the long-term data where an average DARCO® Hg-LH injection concentration of 0.7 lb/MMacf was required to achieve an average total mercury removal of 60% had a significant impact on the economics of mercury control for this unit. In fact, the adjusted ACI performance algorithm used to complete this economic analysis yields a maximum mercury removal of approximately 75% for a DARCO® Hg-LH injection concentration of 1.5 lb/MMacf. Using the adjusted ACI performance algorithm, a DARCO® Hg-LH injection concentration of 1.15 lb/MMacf is required to achieve 70% ACI mercury removal resulting in an annual PAC consumption cost of approximately $116,000. When byproduct impacts are excluded, the 20-year levelized incremental cost of 70% ACI mercury control is approximately $17,400/lb Hg removed and the increase in COE is 1.02 mills/kWh. The annual byproduct impacts of approximately $579,000 assume that following the installation of an ACI system, the SDA byproducts can no longer be given away for low-value mining applications and would be subject to non-hazardous disposal at $17/ton.

St. Clair Station Unit 1

The economics of mercury control developed for this 145 MW unit that fires an 85% subbituminous/15% bituminous coal blend and is equipped with a CS-ESP are based on the performance of brominated B-PAC™ during full-scale field tests. During the long-term continuous injection trial, an average B-PAC™ injection concentration of 3 lb/MMacf was required to achieve an average total mercury removal of 94%. Using the adjusted ACI performance algorithm, a B-PAC™ injection concentration of 2.31 lb/MMacf is required to achieve 90% ACI mercury removal resulting in an annual PAC consumption cost of approximately $619,000 using the current delivered price of $0.85/lb for B-PAC™. When byproduct impacts are excluded, the 20-year levelized incremental cost of 90% ACI mercury control is approximately $26,200/lb Hg removed and the increase in COE is 1.06 mills/kWh. The annual byproduct impacts of approximately $792,000 assume that following the installation of an ACI system, the utility would lose revenues of $18/ton from fly ash sales and incur a non-hazardous fly ash disposal fee of $17/ton.

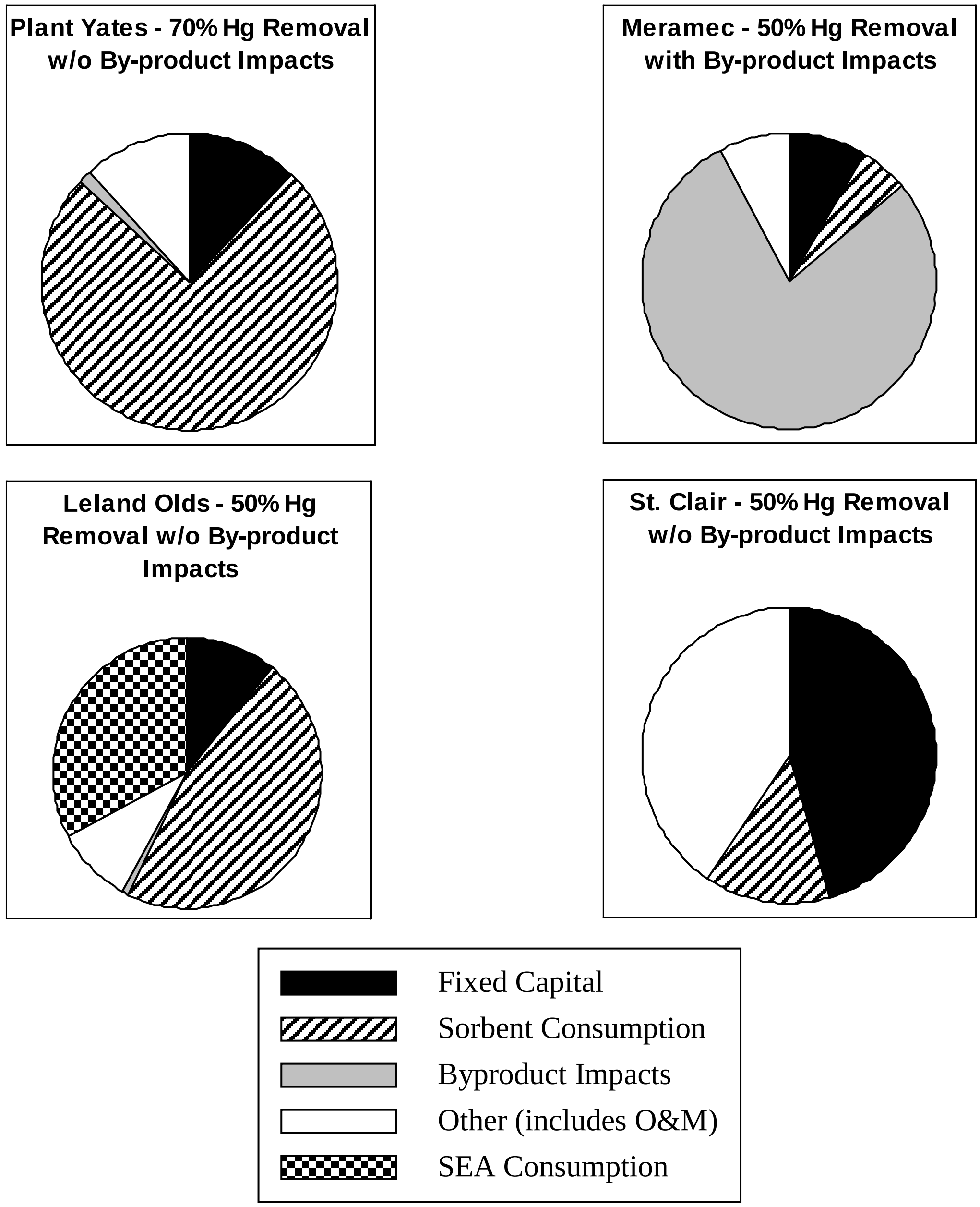
Key Factors Affecting the Economics of Mercury Control

The economics of mercury control via ACI can be strongly influenced by a number of key factors. The three most significant cost components are:

- PAC consumption;
- Impacts to byproduct management and disposal; and
- Fixed capital costs for the installation of a PAC storage and injection system.

Figure 4 provides a graphical illustration of the relative significance of the major cost components to the total 20-year levelized cost of mercury control. It is clear from the examples that for each scenario, a different cost component dominates the total levelized cost of mercury control. At Plant Yates Unit 1, a Super HOK injection concentration of 8.98 lb/MMacf is required to achieve 70% ACI mercury removal. For this example, the levelized PAC consumption cost accounts for approximately 75% of the total 20-year levelized cost of mercury control when byproduct impacts are excluded. For Leland Olds Unit 1, a DARCO® Hg injection concentration of 1.88 lb/MMacf is required to achieve 50% ACI mercury removal when an aqueous $CaCl_2$ solution is added to the coal. In this case, the levelized PAC and $CaCl_2$ consumption costs account for approximately 76% of the total 20-year levelized cost of mercury control when byproduct impacts are excluded. At Meramec Station Unit 2, a DARCO® Hg-LH injection concentration of 0.27 lb/MMacf is required to achieve 50% ACI mercury removal. For this example, the levelized byproduct impacts resulting from ACI accounts for approximately 80% of the total 20-year levelized cost of mercury control. In general, the capital costs associated with the installation of an ACI system represent a relatively minor component of the total cost of mercury control. However, capital expenditures can play a more significant role in situations involving low ACI concentrations. For example, a B-PAC™ injection concentration of only 0.26 lb/MMacf is required to achieve 50% ACI mercury removal at St. Clair Unit 1 according to the adjusted ACI performance curve shown in Figure 3. In this case, the levelized fixed capital cost and other O&M costs account for a much larger (40% and 36%, respectively) portion of the total 20-year levelized cost of mercury control when byproduct impacts are excluded.

Figure 4 -- Relative Significance of Major Cost Components to 20-Year Levelized Costs



Sorbent Consumption

The consumption of activated carbon is directly related to the desired level of mercury control. The methodology used for estimating ACI requirements is based entirely on PAC mass-per-volumetric-flue-gas-flow-rate (lb/MMacf) for a desired level of mercury reduction. Therefore, for a given level of performance (e.g., 70% ACI mercury removal) at an individual unit, annualized capital and O&M costs would be independent of the mass of mercury captured. In other words, the analyses presented in this report were conducted under the assumption that the ACI concentration is independent of the flue gas mercury concentration, because the ACI system behavior mimics 1st order kinetics (i.e., a constant reduction process).

The 20-year levelized incremental increase in COE is directly related to the PAC injection concentration, and inherently the desired level of mercury control. For example, the incremental increase in COE for a particular unit will be lowest for 50% ACI mercury removal (Table 9) and highest for 90% ACI mercury removal (Table 11). Therefore, the increase in COE for each unit will be impacted primarily by the ACI concentration required to achieve a given level of mercury control and the chemical characteristics of the PAC (i.e., conventional or brominated) due to price variability. In fact, the Phase II economic results presented in this report show that brominated PAC consumption costs remain the most significant component of the increase in COE when byproduct impacts are excluded. However, the total cost for a given level of mercury control has been reduced significantly by the introduction of brominated PACs that offer greater mercury reactivity at lower injection concentrations.

A sensitivity analysis was conducted to establish a relationship between delivered PAC cost and the 20-year levelized costs of mercury control. Figures 5 and 6 display the impact of varying conventional PAC cost on the 20-year levelized increase in COE (mills/kWh) and the incremental cost of mercury control ($/lb Hg removed), respectively. The conventional PAC cost varies from $0.10/lb to $1.30/lb and the oval symbols shown on each graphic indicate the delivered costs for Super HOK and DARCO® Hg used to complete this economic analysis (Table 8). Note the economic data presented in the following figures represents 70% mercury removal due to conventional ACI when byproduct impacts are excluded.

Figures 5 and 6 illustrate the linear relationship that exists between the 20-year levelized costs of mercury control and conventional PAC cost. The degree of sensitivity exhibited by the 20-year levelized increase in COE is directly proportional to the required conventional ACI concentration. For instance, the Plant Yates Unit 1 data displays a higher degree of sensitivity to changes in PAC cost due to a required Super HOK injection concentration of 8.98 lb/MMacf. Conversely, a DARCO® Hg injection concentration of 4.39 lb/MMacf was required to achieve 70% ACI mercury removal at Leland Olds Unit 1 when the coal was treated with an aqueous $CaCl_2$ solution prior to combustion. As a result, the 20-year levelized increase in COE calculated for Leland Olds Unit 1 exhibits a lower degree of sensitivity to changes in conventional PAC cost.

The degree of sensitivity to changes in conventional PAC cost exhibited by the 20-year levelized incremental cost of mercury control is influenced by the level of baseline mercury capture across existing APCD, the coal mercury content, and the required ACI concentration. In general, the incremental cost of mercury control will be higher for units firing coal with low mercury content and for those that exhibit a higher level of baseline mercury capture, because a smaller quantity of mercury will be removed for a given level of mercury control. For example, the Plant Yates Unit 1 data shown in Figure 6 displays a higher degree of sensitivity to changes in conventional PAC cost due to a high baseline mercury capture of 50% across the CS-ESP, low coal mercury content of 5.92 lb/TBtu, and a required Super HOK injection concentration of 8.98 lb/MMacf. Meanwhile, the incremental cost of 70% ACI mercury removal for Leland Olds Unit 1 exhibits a lower degree of sensitivity to changes in conventional PAC cost due to a lower baseline mercury capture of 18% across the CS-ESP, higher coal mercury content of 8.66 lb/TBtu, and a required DARCO® Hg injection concentration of 4.39 lb/MMacf when the coal is treated with an aqueous $CaCl_2$ solution prior to combustion.

Figure 5 -- Effect on the 20-Year Levelized COE Increase due to 70% ACI Mercury Control without Byproduct Impacts by Varying Conventional PAC Cost

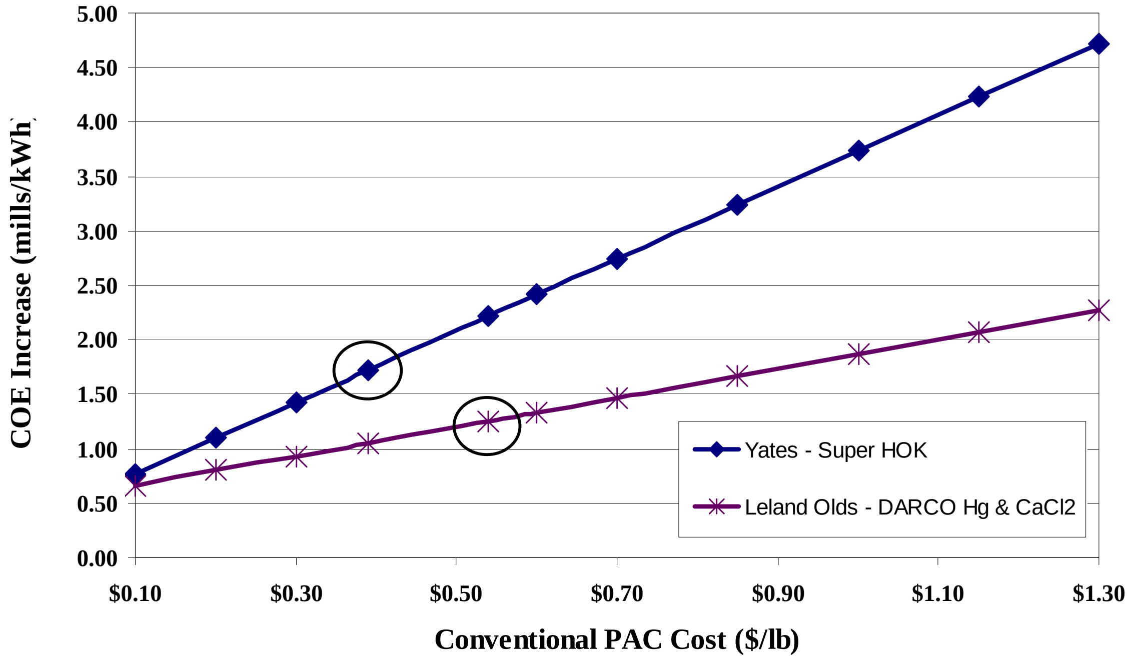
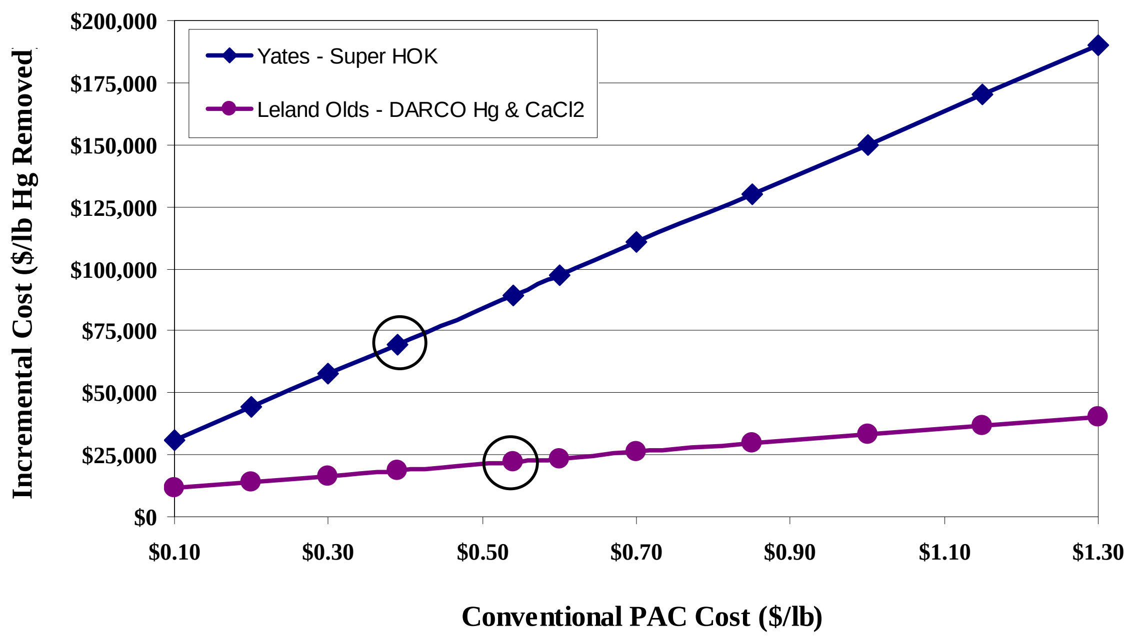


Figure 6 -- Effect on the 20-Year Levelized Incremental Cost of 70% ACI Mercury Control without Byproduct Impacts by Varying Conventional PAC Cost



The effect of varying brominated PAC cost on the 20-year levelized increase in COE and the incremental cost of mercury control is displayed in Figures 7 and 8, respectively. The brominated PAC cost ranges from $0.40/lb to $2.00/lb and the oval symbols shown on each graphic indicate the delivered costs for B-PAC™ and DARCO® Hg-LH used to complete this economic analysis (Table 8). Note the economic data presented in the following figures represents 70% mercury removal due to brominated ACI when byproduct impacts are excluded.

Figures 7 and 8 illustrate the linear relationship that exists between the 20-year levelized costs of mercury control and brominated PAC cost. As shown in Figure 7, the increase in COE for Stanton Station Unit 10 displays the highest degree of sensitivity to changes in brominated PAC cost due to a required DARCO® Hg-LH injection concentration of 1.15 lb/MMacf. Conversely, a DARCO® Hg-LH injection concentration of 0.27 lb/MMacf is required to achieve 70% ACI mercury removal at Holcomb Station Unit 1 resulting in the lowest degree of sensitivity to variations in brominated PAC cost. At St. Clair Station Unit 1, a B-PAC™ injection concentration of 0.60 lb/MMacf is required to achieve 70% ACI mercury removal, while a DARCO® Hg-LH injection concentration of 0.62 lb/MMacf is required to achieve the same level of mercury control at Meramec Station Unit 2. However, the increase in COE remains slightly higher for St. Clair Station Unit 1 due to a higher annual B-PAC™ consumption cost resulting from the higher flue gas flow rate of approximately 751,000 actual cubic feet per minute (acfm). The full-load flue gas flow rate for each of the coal-fired units included in this economic analysis is provided in Appendix A.

Figure 7 -- Effect on the 20-Year Levelized COE Increase for 70% ACI Mercury Control without Byproduct Impacts by Varying Brominated PAC Cost

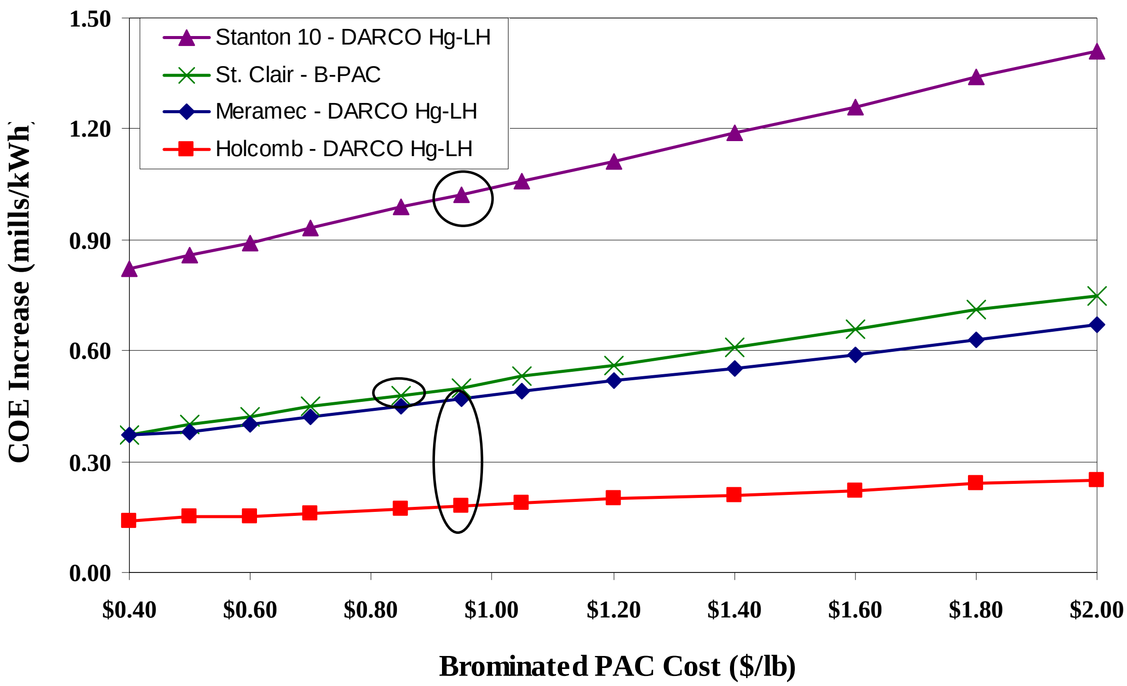
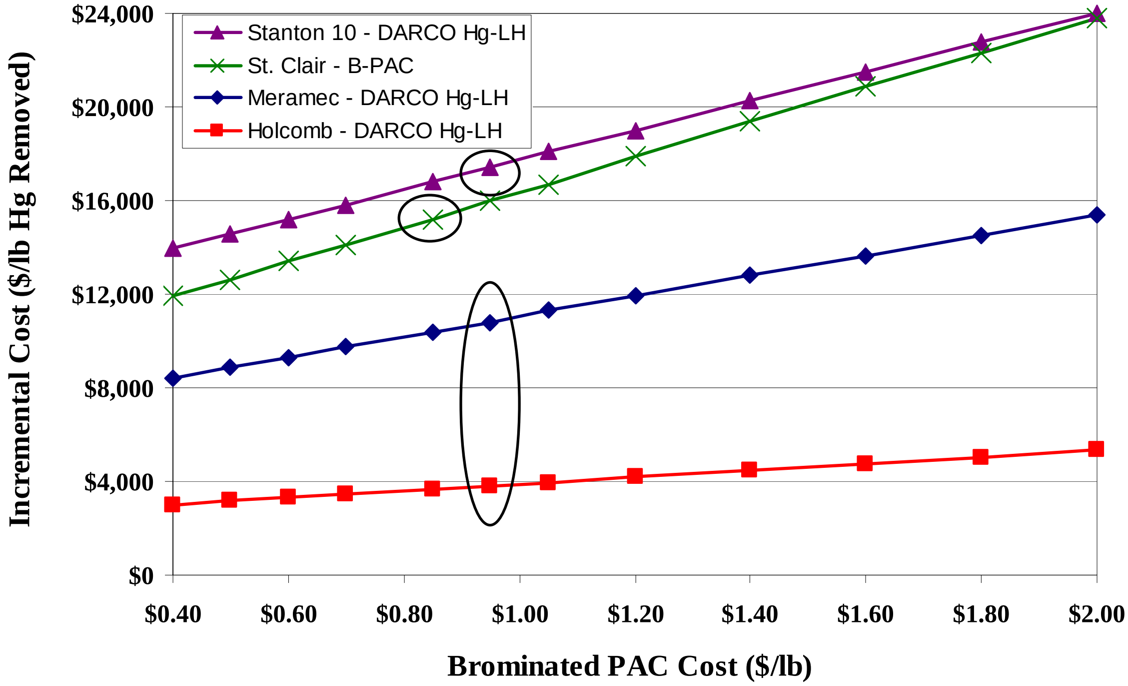


Figure 8 -- Effect on the 20-Year Levelized Incremental Cost of 70% ACI Mercury Control without Byproduct Impacts by Varying Brominated PAC Cost



The degree of sensitivity exhibited by the 20-year levelized incremental cost of mercury control to variations in brominated PAC cost is influenced by the level of baseline mercury capture across existing APCD, the coal mercury content, and the required ACI concentration. The St. Clair Station Unit 1 data presented in Figure 8 exhibits the highest degree of sensitivity to changes in brominated PAC cost due to a baseline mercury capture of 25% across the CS-ESP, coal mercury content of 5.66 lb/TBtu, and to a lesser extent a required B-PAC™ injection concentration of 0.60 lb/MMacf. The Stanton Station Unit 10 data also displays a high degree of sensitivity to variations in brominated PAC cost due to a required DARCO® Hg-LH injection concentration of 1.15 lb/MMacf, while the 0% baseline mercury capture across the SDA/FF configuration and the relatively high coal mercury content of 8.32 lb/TBtu serve as competing factors that drive the incremental cost of mercury control downward. Once again, the Holcomb Station Unit 1 data exhibits the lowest degree of sensitivity to changes in brominated PAC cost due to a required DARCO® Hg-LH injection concentration of 0.27 lb/MMacf and a high coal mercury content of 10.36 lb/TBtu, while the 37% baseline mercury capture across the SDA/FF serves as a competing factor.

To summarize, the annual operating costs associated with the consumption of conventional and brominated PAC dominate the economics of mercury control when byproduct impacts are excluded. Despite the higher cost of brominated PACs, the economics of mercury control are more sensitive to changes in conventional PAC cost due to the higher injection concentrations required to achieve a given level of mercury control.

Impacts to Byproduct Management and Disposal

Coal-fired boilers create large amounts of solid byproducts, a result of the ash and sulfur associated with coal. Particulate control devices such as ESP and FF are installed with the sole purpose of capturing the fly ash and particulate matter entrained in the flue gas. The captured fly ash is either disposed in landfills or utilized in a variety of beneficial applications. Table 12 provides 2004 American Coal Ash Association (ACAA) statistics on generation and reuse of national utility fly ash and SDA ash.

Table 12 -- 2004 Fly Ash and SDA Ash Generation and Utilization Statistics

Overall Utility Coal Combustion Byproduct Statistics		
	Fly Ash	**SDA Ash**[n]
Total Generation, tons/yr	70,800,000	1,829,830
Total Utilization, tons/yr	28,068,970	177,480
% of Generation that is Utilized	39.65%	9.70%

The ACI systems discussed in this report are designed to inject PAC upstream of a particulate control device to enable simultaneous capture of the spent PAC and fly ash. This mercury control strategy will result in commingling of the PAC and fly ash that could potentially have an adverse effect on the marketability of the fly ash. For instance, one of the highest-value reuse applications for fly ash is use as a substitute for Portland cement. The utilization of fly ash in concrete production is particularly sensitive to carbon content as well as the surface area of the carbon present in the fly ash.

Inherently, mercury control via ACI will increase the carbon content of the fly ash with the degree of carbon contamination dependent upon the ACI concentration required to achieve a given level of mercury control. In addition, PAC has a high surface area ranging from 900 – 1,100 square meters per gram (m^2/g) that is ideal for mercury capture, but also promotes the adsorption of surfactants known as air entraining admixtures (AEA) that are added to the concrete slurries to stabilize an optimum amount of air in the concrete product, thus improving its workability and durability to freeze-thaw cycles.[23,24] The adsorption of AEA by the injected PAC will lead to an increased Foam Index (FI) value, which refers to the quantity of AEA required to saturate the fly ash and cement mixture, resulting in an inferior concrete product. Furthermore, the association of fly ash with mercury capture may influence marketability simply due to a perceived connection with the hazards of mercury.

With this in mind, the 20-year levelized costs of mercury control provided in Tables 9-11 are presented with and without the inclusion of byproduct impacts. While the severity of these byproduct impacts cannot be disputed, *the economic impacts related to byproduct management and disposal resulting from mercury control via ACI, included in this economic analysis, are hypothetical and represent a worst-case scenario*. For units equipped with a CS-ESP, it is assumed that the utility is able to sell all fly ash collected in the ESP hoppers for $18/ton prior to ACI. The valuation used for fly ash sales in this analysis is based on estimates provided by ACAA, weighted by fly ash use distribution. However, the revenue from fly ash sales can vary significantly by regional demand and end-use. The byproduct impacts incurred once the utility installs an ACI system for

[n] As submitted based on 60% coal burn.

mercury control assume that the fly ash can no longer be sold; instead, the utility must pay $17/ton for non-hazardous fly ash disposal. The byproduct disposal cost used for this analysis was estimated using data provided by ACAA. It is recognized that disposal costs can vary significantly based on a number of factors, including regional demand, disposal method, and bulk transportation method (e.g., piped or trucked, etc.).

Prior to the installation of an ACI system, it is assumed that units equipped with an SDA/FF configuration are able to simply give their byproducts away since the majority of SDA byproducts (i.e., SDA ash and solid calcium sulfite) are used for low-value applications such as mining applications and flowable fill. After installing an ACI system, the SDA byproduct impacts assume that the material can no longer be given away; instead, the utility must pay $17/ton for non-hazardous SDA byproduct disposal (i.e., no lost revenue from sales). For this analysis, the quantity of calcium sulfite generated was calculated using the coal sulfur content (see Appendix A), assuming the SDA/FF configuration is able to capture 90% of the sulfur dioxide present in the flue gas.

The cost of byproduct management and disposal is dependent on the quantity of byproducts (i.e., fly ash, SDA ash, calcium sulfite, etc.) generated by the coal-fired unit. Factors that affect byproduct generation include: (1) unit capacity; (2) coal ash content; (3) coal sulfur content; (4) net plant heat rate; and (5) the higher heating value (HHV) of the coal. For this analysis, the annual byproduct impacts range from approximately $579,000 for the 60 MW Stanton Station Unit 10 to $3,240,000 for the 220 MW Leland Olds Unit 1. While both of these units burn ND lignite coal, the disparity in unit capacity and the assumption of no lost revenue from the reuse of SDA byproducts leads to a wide range in byproduct impacts.

Furthermore, the spent PAC may not fall under the existing Bevill Exemption because it may not fit the description of a listed waste. If so, the captured PAC and fly ash would likely be managed and disposed of under regulations required by the Resource Conservation and Recovery Act (RCRA). In fact, mercury control via ACI may trigger required compliance with RCRA Subtitle C hazardous byproduct regulations since the captured PAC would inherently possess an increased mercury concentration. RCRA Subtitle C regulations are substantially more stringent than Subtitle D non-hazardous byproduct regulations and would result in higher byproduct disposal costs. However, for this analysis, the captured PAC is assumed a non-hazardous byproduct under the Beville Exemption and management and disposal costs are equivalent to that of fly ash.

Other Issues Affecting the Economics of Mercury Control

Additional factors can influence the cost of mercury control, including, but not limited to, economic factors (labor rate, taxes and contingencies, economic life of capital equipment, etc.), process disruptions (unexpected or excessive outages, etc.), proximity to a reliable PAC manufacturer, and modifications to existing equipment. The estimates developed here assume an uncomplicated retrofit and minimal economic impact due to the installation of the ACI system, assuming that the installation occurs during a regularly scheduled plant outage. The estimates are also based on the assumption that mercury control via ACI will not cause any balance-of-plant impacts (e.g., the existing ESP or SDA/FF performance will not be negatively affected by the additional particulate loading). A discussion of the balance-of-plant issues observed during the Phase II long-term continuous injection trials included in this economic analysis is provided in Appendix B of this report.

For this analysis, the 20-year levelized costs for increase in COE and the incremental cost of mercury control are reported on a current dollar basis. The current dollar cost estimates represent the dollar value of goods or services in terms of prices current at the time the goods or services are purchased. In other words, the 20-year levelized costs developed during this economic analysis include the effects of inflation.

The coal mercury content and the baseline mercury capture by existing APCD are also known to influence the economics of mercury control via ACI. In particular, these site-specific parameters have a significant impact on the 20-year levelized incremental cost of mercury control ($/lb Hg removed). In general, the incremental cost of mercury control will be lower for units firing coal with high mercury content, because a larger quantity of mercury must be removed by the injected PAC to achieve a given level of control. For example, a DARCO® Hg-LH injection concentration of 0.62 lb/MMacf is required to achieve 70% mercury removal due to ACI at Meramec Station Unit 2, which fires a subbituminous coal with a mercury content of 7.83 lb/TBtu. Meanwhile, a B-PAC™ injection concentration of 0.60 lb/MMacf is required to achieve the same level of mercury control at St. Clair Station Unit 1, which burns an 85% subbituminous/15% bituminous coal blend with a mercury content of 5.66 lb/TBtu. As expected, the 20-year levelized increase in COE is nearly identical for these two units (Table 10). However, the 20-year levelized incremental cost of 70% mercury control is $15,200/lb Hg removed for St. Clair Station Unit 1 as compared to only $10,800/lb Hg removed for Meramec Station Unit 2 when byproduct impacts are excluded. Therefore, the higher mercury content of the subbituminous coal burned at Meramec Station Unit 2 yields a lower incremental cost of mercury control even though the brominated ACI concentrations are comparable.

Determining the appropriate level of baseline mercury capture across the existing APCD configuration proved to be a major challenge during this economic analysis. As part of the DOE/NETL Phase II mercury field testing program, the level of baseline mercury capture is measured several times during the baseline testing campaign and these measurements provide a good indication of the unit's typical mercury emissions in the absence of ACI. Additional baseline tests are performed prior to the injection of all candidate PACs evaluated during the parametric testing campaign. However, field testing has shown that residual PAC remaining in the ductwork from previous injection trials may contribute to an increase in baseline mercury capture over the course of the parametric testing campaign. With that in mind, a conscious effort was made to identify the baseline mercury capture observed prior to the parametric tests involving the PAC that was ultimately selected for evaluation during the long-term continuous injection trial.

A sensitivity analysis was conducted to address the variability of baseline mercury capture across the existing APCD configuration. This analysis investigated the impact of baseline mercury capture variability on the 20-year levelized incremental cost of mercury control when byproduct impacts are excluded. To complete this analysis, the level of baseline mercury capture by existing APCD was altered, while the levels of total mercury control observed during full-scale parametric tests were held constant. The resulting hypothetical parametric datasets were then subjected to the data adjustment methodology described in Appendix C to calculate the 20-year levelized incremental mercury control cost estimates presented in Figures 9 and 10. In addition, the flue gas mercury flow rate (lb/hr), derived from the coal mercury content, was reduced by a percentage consistent with the level of baseline mercury control being investigated at the time. This final adjustment ensures that the injected PAC is given credit for removing the appropriate quantity of mercury from the flue gas.

In general, the sensitivity curves displayed in Figures 9 and 10 show the 20-year levelized incremental cost of mercury control rising with increasing levels of baseline mercury capture. This relationship is expected, because the injected PAC is required to remove a smaller quantity of mercury to achieve a given level of mercury control as the baseline mercury capture by existing APCD increases. The economic data presented in Figure 9 corresponds to 70% mercury removal due to conventional ACI, while the oval symbols highlight the baseline mercury capture values of 50% and 18% that were used to complete the economic analyses for Plant Yates Unit 1 and Leland Olds Unit 1, respectively.

The Plant Yates Unit 1 data exhibits a higher degree of sensitivity to changes in the level of baseline mercury capture across the existing CS-ESP due to a low coal mercury content of 5.92 lb/TBtu and a required Super HOK injection concentration of 8.98 lb/MMacf. Meanwhile, the incremental cost of 70% mercury control for Leland Olds Unit 1 displays a lower degree of sensitivity to changes in the level of baseline mercury capture due to a higher coal mercury content of 8.66 lb/TBtu and a required DARCO® Hg injection concentration of only 4.39 lb/MMacf when the coal is treated with an aqueous $CaCl_2$ solution prior to combustion.

Figure 9 -- Effect on the 20-Year Levelized Incremental Cost of 70% ACI Mercury Control without Byproduct Impacts by Varying the Level of Baseline Mercury Capture

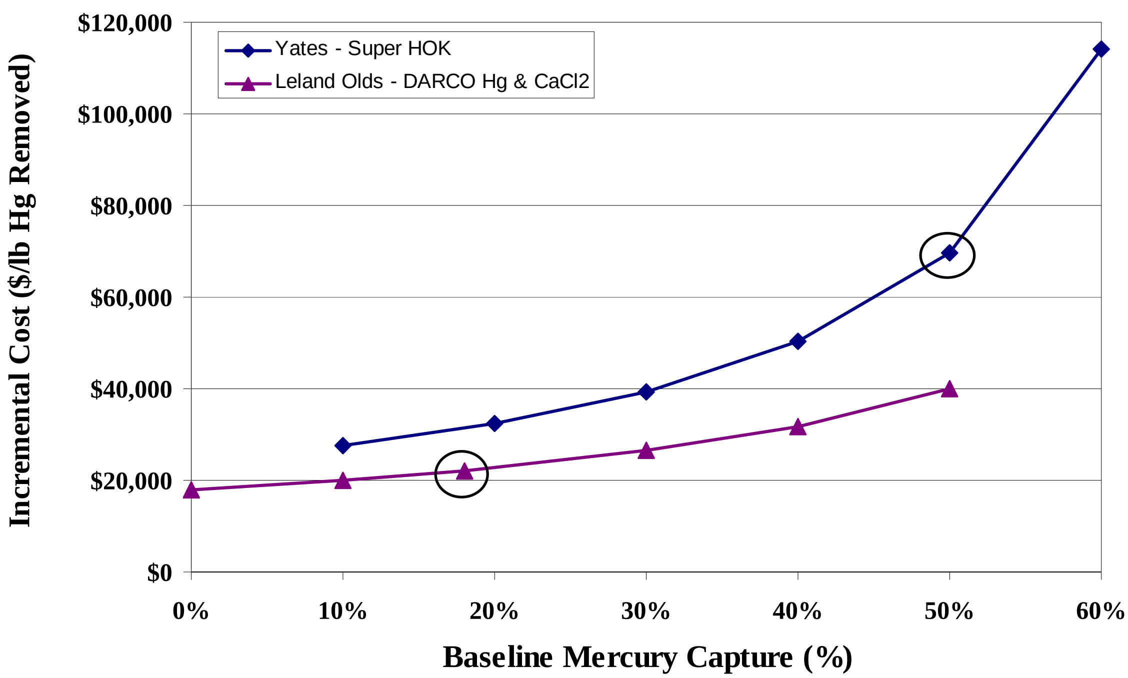
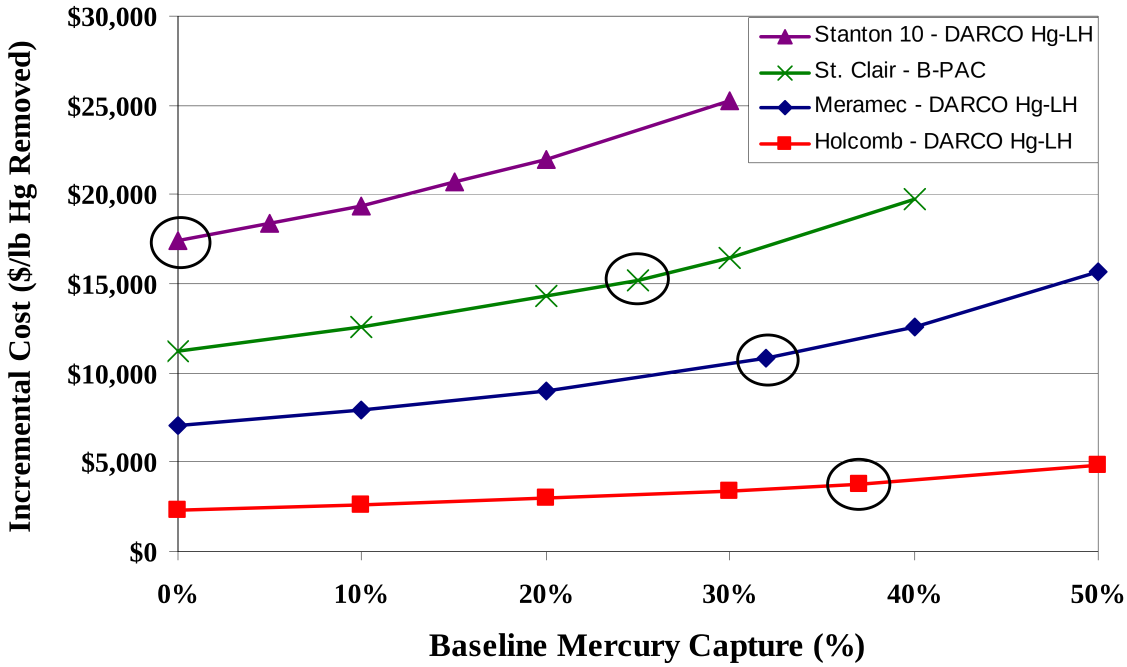


Figure 10 -- Effect on the 20-Year Levelized Incremental Cost of 70% ACI Mercury Control without Byproduct Impacts by Varying the Level of Baseline Mercury Capture



The economic data presented in Figure 10 corresponds to 70% mercury removal due to brominated ACI, while the oval symbols highlight the baseline mercury capture values of 0%, 25%, 32%, and 37% that were used to complete the economic analyses for Stanton Station Unit 10, St. Clair Station Unit 1, Meramec Station Unit 2, and Holcomb Station Unit 1, respectively. For each level of baseline mercury capture investigated in this analysis, the incremental cost of mercury control at Stanton Station Unit 10 is highest due to a required DARCO® Hg-LH injection concentration of 1.15 lb/MMacf. The shape of the sensitivity curves displayed for St. Clair Station Unit 1 and Meramec Station Unit 2 are very similar; however, the incremental cost of mercury control is higher for St. Clair Station Unit 1 due to lower coal mercury content of 5.66 lb/TBtu. The incremental of mercury control for Holcomb Station Unit 1 is lowest and exhibits the smallest degree of sensitivity to changes in the level of baseline mercury capture due to high coal mercury content of 10.36 lb/TBtu and a required DARCO® Hg-LH injection concentration of 0.27 lb/MMacf.

V. SUMMARY

This report provides "study-level" cost estimates for mercury control via ACI based on preliminary results obtained from DOE/NETL's Phase II field testing of advanced mercury control technologies. The Phase II projects included in this study focus on longer-term (~1 month), full-scale field tests that evaluate the mercury capture efficiency of conventional ACI, brominated ACI, and conventional ACI coupled with SEA coal treatment for a broad range of coal-ranks and APCD configurations. These enhanced mercury control strategies (i.e., brominated ACI and SEA coal treatment) are intended to compensate for the lack of naturally-occurring halogens in the combustion flue gas of low-rank coals that appears to limit the mercury capture efficiency of conventional ACI based on the results obtained during the Phase I field testing program.

The economic analyses were conducted on a plant specific basis meaning that the economics are dependent on the actual power plant operating conditions and coal properties observed during full-scale testing at each of the Phase II sites displayed in Table 7. In addition, the analyses were completed in a manner that yields the cost required to achieve low (50%), mid-range (60-70%), and high (90%) levels of mercury control "above and beyond" the plant-specific baseline mercury removal by existing APCD. In other words, *the levels of mercury control discussed in this report are directly attributable to ACI.* To calculate the ACI mercury capture, a data adjustment methodology was developed to account for the level of baseline mercury capture observed during parametric testing and incorporate the average level of mercury removal measured during the long-term continuous ACI trial. A complete discussion of the ACI data adjustment methodology with sample calculations is provided in Appendix C.

This approach is complicated by the variability of baseline mercury capture caused by changes in coal composition and boiler performance that can impact the quantity of unburned carbon present in the fly ash. Field testing has also shown that residual PAC remaining in the ductwork from previous injection trials may contribute to an increase in baseline mercury capture over the course of the parametric testing campaign. With that in mind, *a conscious effort was made to identify the baseline mercury capture observed prior to the parametric tests involving the PAC that was selected for evaluation during the long-term continuous injection trial.*

The cost estimates for mercury control via ACI presented in this report are dependent on a number of factors including, but not limited to:

- ACI concentration required for a given level of mercury control;
- Delivered PAC cost;
- Coal mercury content;
- Level of baseline mercury capture by existing APCD observed prior to the parametric tests;
- Economic assumptions including economic life of capital equipment; and
- Impact to byproduct management and disposal practices (including assumption that byproducts are exempt from hazardous waste disposal requirements).

The following paragraphs summarize the cost of mercury control for each of the Phase II field testing units included in this analysis. A complete discussion of the Phase II field testing results is provided in Appendix B of this report.

Holcomb Station Unit 1

The cost of mercury control for this 360 MW subbituminous-fired unit equipped with an SDA/FF configuration is based on the performance of brominated DARCO® Hg-LH during full-scale field tests. During the long-term continuous injection trial, an average total mercury removal of 93% was achieved with an average DARCO® Hg-LH injection concentration of 1.2 lb/MMacf. The following key points summarize the economics of mercury control for this unit.

- The installed capital cost of the ACI system is approximately $1,310,000 or $3.63/kW on a unit capacity basis.
- The annual byproduct impacts of approximately $1,430,000 assume that following the installation of an ACI system, the SDA byproducts can no longer be given away for low-value mining applications; instead, the material would be subject to non-hazardous disposal at $17/ton.
- A DARCO® Hg-LH injection concentration of 0.11 lb/MMacf is required to achieve 50% ACI mercury removal resulting in an annual PAC consumption cost of approximately $54,800 using the current delivered price of $0.95/lb for DARCO® Hg-LH.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.14 mills/kWh and an incremental cost of $4,220/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 0.86 mills/kWh and an incremental cost of $25,700/lb Hg removed.
- A DARCO® Hg-LH injection concentration of 0.27 lb/MMacf is required to achieve 70% ACI mercury removal resulting in an annual PAC consumption cost of approximately $128,000.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.18 mills/kWh and an incremental cost of $3,810/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 0.90 mills/kWh and an incremental cost of $19,200/lb Hg removed.
- A DARCO® Hg-LH injection concentration of 1.03 lb/MMacf is required to achieve 90% ACI mercury removal resulting in an annual PAC consumption cost of approximately $493,000.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.37 mills/kWh and an incremental cost of $6,060/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 1.09 mills/kWh and an incremental cost of $18,000/lb Hg removed.

Meramec Station Unit 2

The cost of mercury control for this 140 MW subbituminous-fired unit equipped with a CS-ESP is based on the performance of DARCO® Hg-LH during full-scale field tests. During long-term testing, an average DARCO® Hg-LH injection concentration of 3.3 lb/MMacf was required to achieve an average total mercury removal of 93%. The following points summarize the economics of mercury control for this unit.

- The installed capital cost of the ACI system is approximately $1,280,000 or $9.16/kW on a unit capacity basis.
- The annual byproduct impacts of approximately $1,060,000 assume that following the installation of an ACI system, the utility would lose revenues of $18/ton from fly ash sales and incur a non-hazardous disposal fee of $17/ton.
- A DARCO® Hg-LH injection concentration of 0.27 lb/MMacf is required to achieve 50% ACI mercury removal resulting in an annual PAC consumption cost of approximately $59,200.

    - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.37 mills/kWh and an incremental cost of $11,800/lb Hg removed.
    - The inclusion of byproduct impacts results in an increase in COE of 1.75 mills/kWh and an incremental cost of $56,400/lb Hg removed.
- A DARCO® Hg-LH injection concentration of 0.62 lb/MMacf is required to achieve 70% ACI mercury removal resulting in an annual PAC consumption cost of approximately $138,000.
    - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.47 mills/kWh and an incremental cost of $10,800/lb Hg removed.
    - The inclusion of byproduct impacts results in an increase in COE of 1.85 mills/kWh and an incremental cost of $42,700/lb Hg removed.
- A DARCO® Hg-LH injection concentration of 2.40 lb/MMacf is required to achieve 90% ACI mercury removal resulting in an annual PAC consumption cost of approximately $532,000.
    - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.99 mills/kWh and an incremental cost of $17,700/lb Hg removed.
    - The inclusion of byproduct impacts results in an increase in COE of 2.37 mills/kWh and an incremental cost of $42,500/lb Hg removed.

Plant Yates Unit 1

The cost of mercury control for this 100 MW bituminous-fired unit equipped with a CS-ESP is based on the performance of conventional Super HOK during full-scale field tests. During long-term testing, Super HOK injection concentrations of 4.5 lb/MMacf, 6.5 lb/MMacf, and 9.5 lb/MMacf were required to achieve average levels of total mercury control of approximately 68%, 75%, and 76%, respectively. The following points summarize the economics for this unit.

- The installed capital cost of the ACI system is approximately $1,270,000 or $12.66/kW on a unit capacity basis.
- The annual byproduct impacts of approximately $1,080,000 assume that following the installation of an ACI system, the utility would lose revenues of $18/ton from fly ash sales and incur a non-hazardous disposal fee of $17/ton.
- A Super HOK injection concentration of 3.85 lb/MMacf is required to achieve 50% ACI mercury removal resulting in an annual PAC consumption cost of approximately $303,000 using the current delivered price of $0.39/lb for Super HOK.
    - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.97 mills/kWh and an incremental cost of $54,600/lb Hg removed.
    - The inclusion of byproduct impacts results in an increase in COE of 2.94 mills/kWh and an incremental cost of $166,000/lb Hg removed.
- A Super HOK injection concentration of 8.98 lb/MMacf is required to achieve 70% ACI mercury removal resulting in an annual PAC consumption cost of approximately $707,000.
    - When byproduct impacts are excluded, this level of control yields an increase in COE of 1.72 mills/kWh and an incremental cost of $69,500/lb Hg removed.
    - The inclusion of byproduct impacts results in an increase in COE of 3.69 mills/kWh and an incremental cost of $149,000/lb Hg removed.

Leland Olds Unit 1

For this 220 MW ND lignite-fired unit equipped with a CS-ESP, the cost of mercury control is based on the mercury capture efficiency of conventional DARCO® Hg injection when the coal is treated with an aqueous $CaCl_2$ solution prior to combustion. During long-term testing, an average total mercury removal of 63% was achieved with an average DARCO® Hg injection concentration of 3 lb/MMacf coupled with the addition of an aqueous $CaCl_2$ solution to the coal at a constant rate that is equivalent to adding approximately 500 ppm chlorine to the coal. Mercury control via the co-injection of an aqueous $CaCl_2$ solution onto the coal and DARCO® Hg upstream of the existing CS-ESP requires the installation of distinct storage and injection systems for the SEA and PAC. For this analysis, an installed cost of $100,000 was estimated for the SEA storage and injection system. In addition, the delivered $CaCl_2$ cost of $0.15/lb yields an annual SEA consumption cost of approximately $388,000. The following points summarize the economics for this unit.

- The installed capital cost of the SEA and ACI systems is approximately $1,390,000 or $6.33/kW on a unit capacity basis.
- The annual byproduct impacts of approximately $3,240,000 assume that following the installation of an ACI system, the utility would lose revenues of $18/ton from fly ash sales and incur a non-hazardous disposal fee of $17/ton.
- With $CaCl_2$ coal treatment, a DARCO® Hg injection concentration of 1.88 lb/MMacf is required to achieve 50% ACI mercury removal resulting in an annual PAC consumption cost of approximately $374,000 using the current delivered price of $0.54/lb for DARCO® Hg.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.83 mills/kWh and an incremental cost of $20,600/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 3.50 mills/kWh and an incremental cost of $86,900/lb Hg removed.
- With $CaCl_2$ coal treatment, a DARCO® Hg injection concentration of 4.39 lb/MMacf is required to achieve 70% ACI mercury removal resulting in an annual PAC consumption cost of approximately $875,000.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 1.25 mills/kWh and an incremental cost of $22,200/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 3.92 mills/kWh and an incremental cost of $69,600/lb Hg removed.

Stanton Station Unit 10

The cost of mercury control for this 60 MW ND lignite-fired unit equipped with an SDA/FF configuration is based on the performance of DARCO® Hg-LH during full-scale field tests. During the parametric testing campaign, 94% total mercury removal was achieved with a DARCO® Hg-LH injection concentration of 1.5 lb/MMacf. However, incorporation of the long-term data where an average DARCO® Hg-LH injection concentration of 0.7 lb/MMacf was required to achieve an average total mercury removal of 60% had a significant impact on the economics of mercury control for this unit. In fact, the adjusted ACI performance algorithm used to complete this economic analysis yields a maximum mercury removal of approximately 75% for a DARCO® Hg-LH injection concentration of 1.5 lb/MMacf. The following key points summarize the economics of mercury control for this unit.

- The installed capital cost of the ACI system is approximately $1,270,000 or $21.10/kW on a unit capacity basis.
- The annual byproduct impacts of approximately $579,000 assume that following the installation of an ACI system, the SDA byproducts can no longer be given away for low-value mining applications; instead, the material would be subject to non-hazardous disposal at $17/ton.
- A DARCO® Hg-LH injection concentration of 0.49 lb/MMacf is required to achieve 50% ACI mercury removal resulting in an annual PAC consumption cost of approximately $49,500.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.82 mills/kWh and an incremental cost of $19,500/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 2.57 mills/kWh and an incremental cost of $61,300/lb Hg removed.
- A DARCO® Hg-LH injection concentration of 1.15 lb/MMacf is required to achieve 70% ACI mercury removal resulting in an annual PAC consumption cost of approximately $116,000.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 1.02 mills/kWh and an incremental cost of $17,400/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 2.77 mills/kWh and an incremental cost of $47,300/lb Hg removed.

St. Clair Station Unit 1

The cost of mercury control for this 145 MW unit that fires an 85% subbituminous/15% bituminous coal blend and is equipped with a CS-ESP is based on the performance of B-PAC™ during full-scale field tests. During the long-term continuous injection trial, an average total mercury removal of 94% was achieved with an average B-PAC™ injection concentration of 3 lb/MMacf. The following key points summarize the economics of mercury control for this unit.

- The installed capital cost of the ACI system is approximately $1,280,000 or $8.79/kW on a unit capacity basis.
- The annual byproduct impacts of approximately $792,000 assume that following the installation of an ACI system, the utility would lose revenues of $18/ton from fly ash sales and incur a non-hazardous disposal fee of $17/ton.
- A B-PAC™ injection concentration of 0.26 lb/MMacf is required to achieve 50% ACI mercury removal resulting in an annual PAC consumption cost of approximately $68,800 using the current delivered price of $0.85/lb for B-PAC™.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.36 mills/kWh and an incremental cost of $16,200/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 1.36 mills/kWh and an incremental cost of $60,100/lb Hg removed.
- A B-PAC™ injection concentration of 0.60 lb/MMacf is required to achieve 70% ACI mercury removal resulting in an annual PAC consumption cost of approximately $160,000.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 0.48 mills/kWh and an incremental cost of $15,200/lb Hg removed.

- The inclusion of byproduct impacts results in an increase in COE of 1.47 mills/kWh and an incremental cost of $46,600/lb Hg removed.

- A B-PAC™ injection concentration of 2.31 lb/MMacf is required to achieve 90% ACI mercury removal resulting in an annual PAC consumption cost of approximately $619,000.
  - When byproduct impacts are excluded, this level of control yields an increase in COE of 1.06 mills/kWh and an incremental cost of $26,200/lb Hg removed.
  - The inclusion of byproduct impacts results in an increase in COE of 2.05 mills/kWh and an incremental cost of $50,600/lb Hg removed.

The preliminary Phase II field testing results are very encouraging both in terms of the level of mercury removal achieved and the cost of control on a mills/kWh and $/lb Hg removed basis. However, it must be kept in mind that the field tests still represent relatively short-term testing at optimum conditions. While such testing provides a sound basis for evaluating performance and cost, the limited duration of the testing does not allow for a comprehensive assessment of several key operational and balance-of-plant issues associated with ACI in general and the use of chemically-treated PAC and SEA specifically. These include: (1) changes in coal characteristics (e.g., mercury and chlorine content); (2) changes in load; (3) impacts on small collection area ESPs; (4) PAC carryover into downstream APCD; (5) corrosion issues; (6) potential off-gassing of bromine compounds; (7) formation of flue gas halides; and (8) leaching from brominated PAC byproducts.

It should also be noted that the economic analyses represent “snapshots” in time based on the methodology used, assumptions made, and conditions that were specific to the time when DOE/NETL field testing occurred. Consequently, the economics presented in this report are plant and condition specific and attempts to use this document as a tool to predict the performance of the mercury control technologies described in this report at other power plants should be conducted cautiously regardless of similarities in coal-rank and APCD configuration. In addition, the economics originate from relatively small datasets in many cases. As a result, the cost of mercury control could vary significantly with the inclusion of additional ACI performance data from current and future DOE/NETL field testing.

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APPENDIX A

Power Plant and Coal Data

Economic Assumptions

Power Plant Data	**Holcomb Unit 1**	**Meramec Unit 2**	**Yates Unit 1**	**Leland Olds Unit 1**	**Stanton Unit 10**	**St. Clair Unit 1**
Coal-Rank	PRB	PRB	Bituminous	ND Lignite	ND Lignite	85% PRB / 15% Bituminous
Unit Capacity, MW	360	140	100	220	60	145
Net Plant Heat Rate, Btu/kWh	10,272	11,642	11,992	11,344	10,076	10,625
Capacity Factor, %	80	80	80	80	80	80
Flue Gas Temperature, ^oF	290	310	310	340	300	290
Flue Gas Flow Rate, ACFM	1,194,444	555,556	480,000	878,049	251,789	751,000
Ash exiting the boiler, %	80	80	80	80	80	80
Coal Mercury Content, lb/Trillion Btu	10.36	7.83	5.92	8.66	8.32	5.66
Mercury in Flue Gas, lb/hr	0.0383	0.0128	0.0071	0.0216	0.0050	0.0087
Coal Properties						
Coal Ultimate Analysis (ASTM, as rec'd), wt%						
Moisture	26.14	26.93	6.14	36.44	34.45	22.83
Carbon	51.89	52.32	71.55	35.38	40.48	41.19
Hydrogen	6.44	5.69	4.58	6.56	2.6	N/A
Nitrogen	0.75	0.79	1.39	0.7	0.52	N/A
Sulfur	0.41	0.55	0.93	0.66	0.71	0.6
Ash	5.36	5.93	11.67	8.49	10.07	5.09
Oxygen	35.15	26.14	5.34	48.21	11.17	N/A
HHV, Btu/lb	8,897	8,905	12,661	6,420	6,613	9,717
Capital Costs						
Indirects						
General Facilities	10%	10%	10%	10%	10%	10%
Engineering Fees	10%	10%	10%	10%	10%	10%
Project Contingency	15%	15%	15%	15%	15%	15%
Process Contingency	5%	5%	5%	5%	5%	5%
Variable O&M and Costs						
Activated Carbon Disposal Costs	$17/ton	$17/ton	$17/ton	$17/ton	$17/ton	$17/ton
Fly ash Disposal Costs	$17/ton	$17/ton	$17/ton	$17/ton	$17/ton	$17/ton
Revenue From Fly Ash Sales	N/A	$18/ton	$18/ton	$18/ton	N/A	$18/ton
Power Cost	$0.05/kW	$0.05/kW	$0.05/kW	$0.05/kW	$0.05/kW	$0.05/kW
Operating Labor	$45/hr	$45/hr	$45/hr	$45/hr	$45/hr	$45/hr
PAC Injection Maintenance Costs	5% of equipment cost	5% of equipment cost	5% of equipment cost	5% of equipment cost	5% of equipment cost	5% of equipment cost
PAC Injection Periodic Replacement Items	$10,000 Flat Rate	$10,000 Flat Rate	$10,000 Flat Rate	$10,000 Flat Rate	$10,000 Flat Rate	$10,000 Flat Rate

Economic Factors						
Cost Basis - Year Dollars	Current 2005	Current 2005	Current 2005	Current 2005	Current 2005	Current 2005
Construction Years	0.5	0.5	0.5	0.5	0.5	0.5
Annual Inflation	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Discount Rate (MAR)	9.2%	9.2%	9.2%	9.2%	9.2%	9.2%
AFUDC Rate	10.8%	10.8%	10.8%	10.8%	10.8%	10.8%
First Year Fixed Charge Rate, Current$	22.3%	22.3%	22.3%	22.3%	22.3%	22.3%
First Year Fixed Charge Rate, Const$	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%
Lev Fixed Charge Rate, Current$ (FCR)	16.9%	16.9%	16.9%	16.9%	16.9%	16.9%
Lev Fixed Charge Rate, Const$ (FCR)	11.7%	11.7%	11.7%	11.7%	11.7%	11.7%
Service Life, years	20	20	20	20	20	20
Escalation Rates :						
Consumables (O & M)	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Fuel	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Power	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%

APPENDIX B

Preliminary Phase II ACI Field Test Results

Phase II – Preliminary ACI Field Test Results

In September 2003, DOE/NETL selected eight new projects to test and evaluate mercury control technologies under a Phase II, Round 1 (Phase II-1) field testing solicitation. The Phase II-1 projects were initiated in 2004 and are scheduled to be completed in early-to-mid 2006. An additional six projects – representing seven technologies - were subsequently awarded in October 2004 under a Phase II, Round 2 (Phase II-2) solicitation that is scheduled for completion in 2007. Building on promising advances that resulted from the Phase I field testing program, the Phase II projects focus on longer-term (~ 1 month at optimized conditions), large-scale field testing on plants burning primarily low-rank coals or blends (with some units burning bituminous coal) and equipped with a variety of APCD configurations. Most of the fourteen projects fall under two general categories of mercury control – sorbent injection or oxidation enhancements.

Sorbent injection generically describes conventional ACI, brominated (or chemically-treated) ACI as well as the injection of non-carbon sorbents into the flue gas for mercury control. Phase II field testing also includes an evaluation of PACs designed for HS-ESP applications. Mercury oxidation enhancements are intended to improve the mercury capture efficiency of conventional ACI or downstream APCDs by converting elemental mercury to a more reactive oxidized state. For instance, coal or flue gas treatment with SEA is being investigated in conjunction with conventional ACI, while the performance of mercury oxidation catalysts is being evaluated at units equipped with a downstream wet FGD system. The figure below provides a brief description of the DOE/NETL Phase II test sites.

Coal Rank	Cold-side ESP (low SCA)	Cold-side ESP (medium or high SCA)	Hot-side ESP	TOXECON	ESP/FGD	SDA/FF or SDA/ESP
Bituminous	Miami Fort 6 Yates 1&2	Lee 1 Lee 3 Portland	Cliffside Buck	Gavin	Yates 1 Yates 1 Conesville	
Subbituminous	Crawford	Meramec Dave Johnston Stanton 1	Council Bluffs Louisa Will County	Independence		Holcomb Laramie River[b]
Lignite (North Dakota)		Leland Olds 1 Leland Olds 1			Milton Young	Antelope Valley 1 Stanton 10 Stanton 10
Lignite (Texas)						
PRB / Bit Blend		St. Clair Monroe				
TX Lignite / PRB Blend				Big Brown	Monticello Monticello Monticello	

Sorbent Injection

Oxidation Additive

Chemically-treated sorbent

Sorbent Injection & Oxidation Additive

Oxidation Catalyst

Other – MERCAP, FGD Additive, Combustion

Holcomb Station Unit 1

Full-scale field testing was conducted at the subbituminous-fired unit equipped with a SDA/FF configuration as part of the Phase II-1 project entitled *Evaluation of Sorbent Injection for Mercury Control*. Several mercury control technologies were investigated at Holcomb, including: (1) coal blending; (2) conventional ACI; (3) coal and flue gas treatment with halogenated chemical additives; and (4) brominated/chemically-treated ACI. However, the economics presented in this report are based on mercury control via the injection of brominated DARCO® Hg-LH since this PAC was evaluated during the 30-day long-term test. Field testing was completed in August 2004. Some particulars of the test site are provided in the following graphic.

Sunflower Electric's Holcomb Station

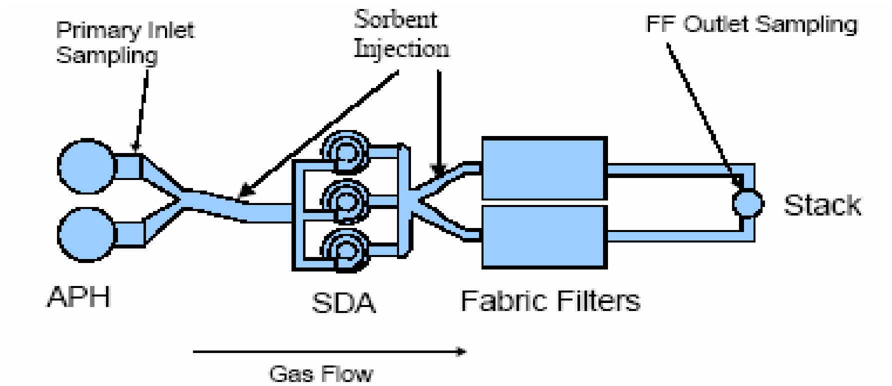
- 360 MW opposed-fired boiler
- Particulate Control
  - Fabric Filter
- Sulfur Control
  - Spray Dryer Absorber
- PRB Subbituminous Coal
  - 8,897 Btu/lb
  - 0.41% S
  - 0.078 ppm Hg
  - 5.83 ppm Cl
- SDA Inlet Temperature: 290°F

The tests were conducted in three phases (baseline, parametric, and long-term testing). Baseline mercury capture was only 13% across the SDA/FF while burning 100% PRB coal. A portion of the parametric tests was devoted to mercury control via coal blending. Blending 15% western bituminous coal with the PRB increased mercury capture to almost 80%. The mercury concentration of the western bituminous coal was similar to the PRB, but the chlorine concentration was higher (106 µg/g vs. 8 µg/g).

Three PACs were evaluated during parametric testing: (1) NORIT's DARCO® Hg – a conventional PAC; (2) Calgon 208CP - a highly activated, but untreated PAC; and (3) NORIT's brominated DARCO® Hg-LH. Total mercury removal was limited to approximately 50% with the injection of DARCO® Hg and 208CP at a flue gas injection concentration of 1.0 lb/MMacf. A proprietary chemical additive, ALSTOM Power's

KNX, increased mercury removal from 50% to 86% when used with DARCO® Hg at 1.0 lb/MMacf. The KNX additive decreased the elemental mercury fraction at the air preheater outlet from 70-90% to 20-30%. However, there was no improvement in mercury capture using the KNX without ACI. Meanwhile, DARCO® Hg-LH was able to achieve approximately 75% mercury removal at an injection concentration of 0.7 lb/MMacf.

The results described above suggest that the presence of excess halogens has a significant impact on the mercury capture efficiency of ACI. The importance of halogens was also characterized by injecting PAC downstream of the SDA as shown in the following sketch.[o] With a DARCO® Hg injection concentration of 5.7 lb/MMacf, 90% mercury removal was observed with injection upstream of the SDA while mercury capture was less than 35% when ACI occurred downstream of the SDA.[p] The results indicate that adsorption of halogens by DARCO® Hg is a critical component of mercury control via conventional ACI. Conversely, the ACI location had no impact on the performance of DARCO® Hg-LH.

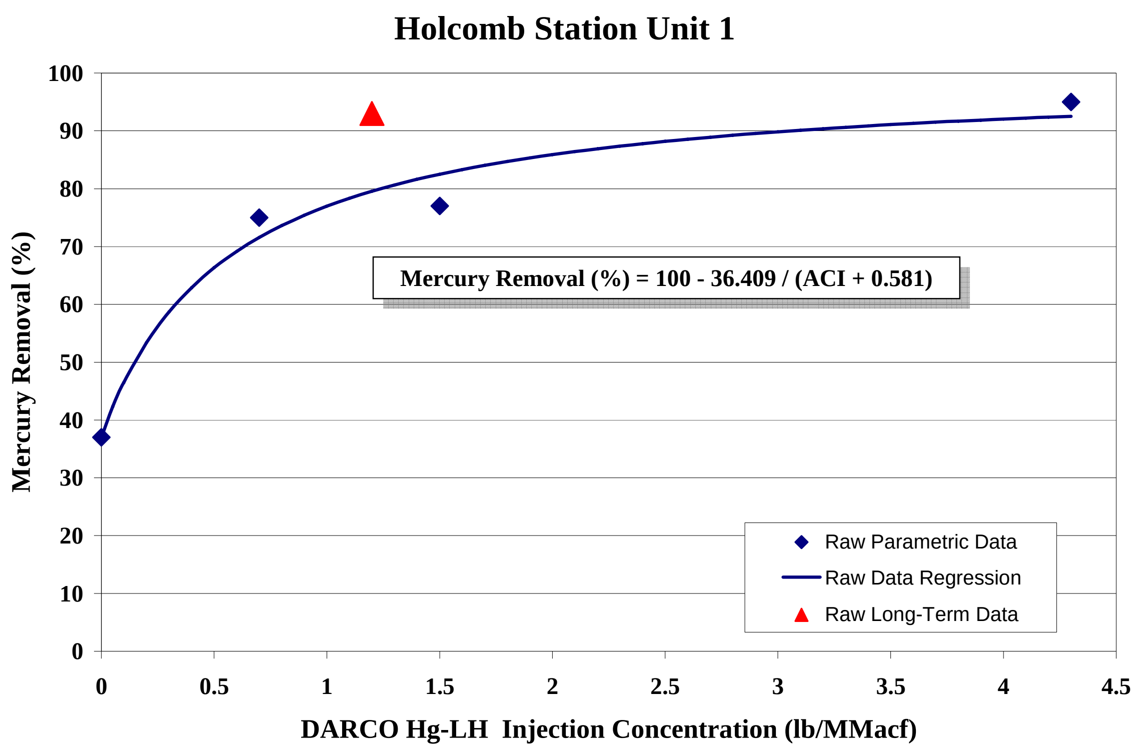


The mercury capture efficiency of DARCO® Hg-LH is shown in the following figure. The performance data shown below was observed with the unit firing 100% PRB coal. The high baseline mercury removal of approximately 37% observed during parametric testing was likely caused by PAC remaining in the system from previous parametric tests. The diamond symbols represent the limited and potentially unreliable parametric dataset. In fact, tests conducted at two DARCO® Hg-LH injection concentrations (1.5 and 4.3 lb/MMacf) were concluded after less than 130 minutes whereas the typical parametric test lasted 6-8 hours to ensure the system had reached equilibrium. However, the complete dataset was used to develop the least squares curve-fit of the parametric performance data as a function of DARCO® Hg-LH injection concentration that is also shown in the following figure.

[o] Results from EPA M26A tests conducted during the baseline test period indicate that HCl and HF were fairly low at the inlet to the SDA (0.5 and 1.5 ppm respectively) and 41% of the HCl and 75% of the HF was removed in the SDA.

[p] The injection concentration in pounds per *actual* cubic foot, which was calculated at the SDA inlet temperature for comparison purposes, is approximately 17% higher at the SDA outlet location due to the reduced gas volume at the lower temperatures (175ºF downstream of the SDA as compared to 290ºF upstream of the SDA).

DARCO® Hg-LH was injected upstream of the SDA for 30 days from July 7 through August 6, 2004. For the first five days of testing, the injection concentration was increased until 90% mercury removal was achieved. From Day 6 through 30, the DARCO® Hg-LH injection concentration was set for nominally 1.2 lb/MMacf, resulting in an average mercury removal of 93%. The average long-term performance of DARCO® Hg-LH is represented by the red triangle shown below.



The following non-linear regression equation was used to empirically fit the data. Note that ACI represents the DARCO® Hg-LH injection concentration in lb/MMacf. Details of the regression results are provided in Appendix E of this report.

Mercury Removal (%) = 100 – a / (ACI + b)

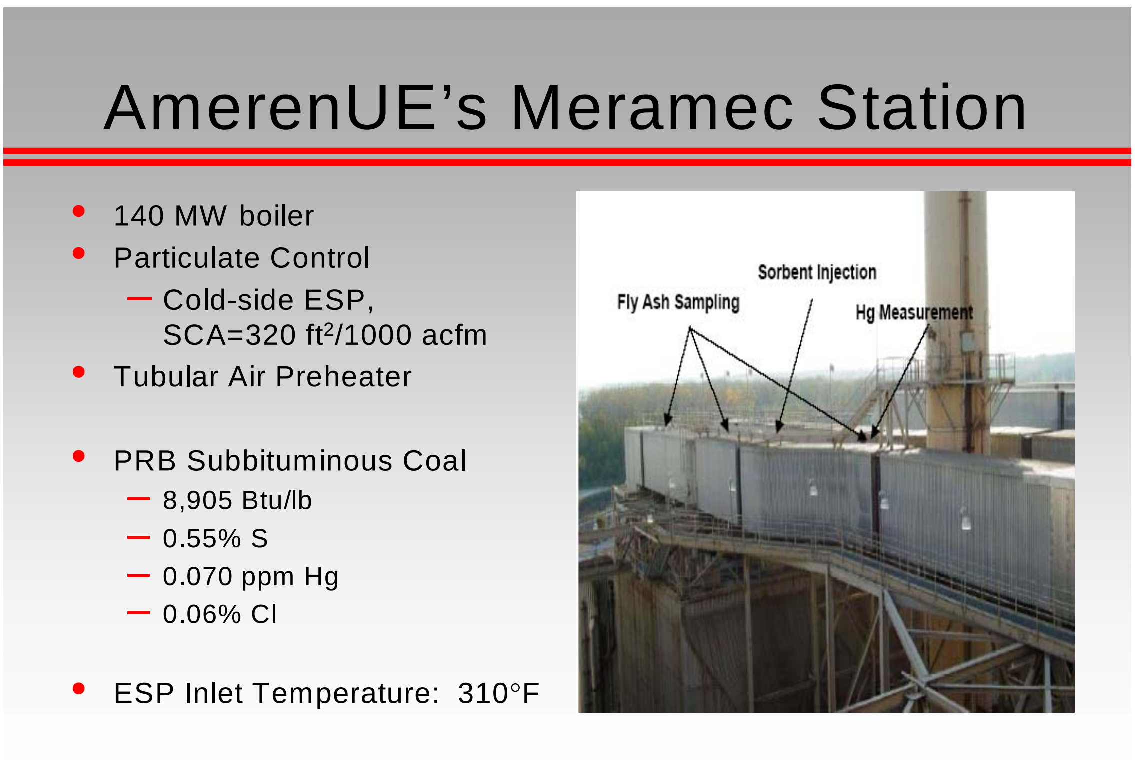
Where a = 36.409
b = 0.581

During the 30-day long-term test, no adverse balance-of-plant impacts were noted and excess levels of bromine in the flue gas were not observed. In addition, neither the pressure drop across the FF nor the stack opacity was affected by the presence of DARCO® Hg-LH. Although a 30-day test is too short for a full evaluation of the impacts of ACI on FF bag life, the results will indicate if a catastrophic failure is inevitable. A bag was removed from the baghouse, analyzed for strength, and visually inspected. The results indicated that no loss of strength was apparent and no unusual visual features were noted.

The high mercury removal efficiency observed at Holcomb Unit 1 during full-scale field testing may be a product of somewhat unique operating conditions. The standard operation at this unit is to recycle approximately 75% of the material collected in the FF back into the SDA. Therefore, during continuous ACI some injected PAC will also be recycled into the SDA and may improve the overall mercury removal. Not all units equipped with the SDA/FF configuration utilize recycle.

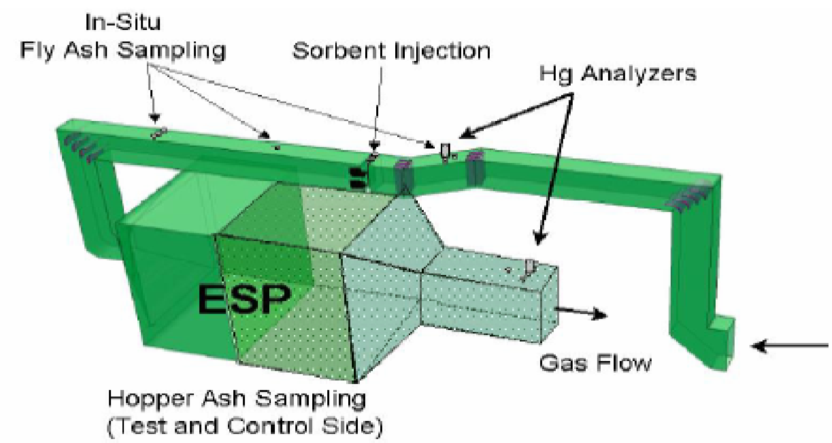
Meramec Station Unit 2

Full-scale field testing was conducted at the subbituminous-fired unit equipped with a CS-ESP as part of the Phase II-1 project entitled *Evaluation of Sorbent Injection for Mercury Control*. Several mercury control technologies were investigated at Meramec, including: (1) conventional ACI; (2) coal or flue gas treatment with halogenated chemical additives; and (3) brominated (or chemically-treated) ACI. However, the economics are based on mercury control via DARCO® Hg-LH injection since this PAC was evaluated during the 35-day long-term test. Field testing was completed in November 2004. Some particulars of the test site are provided in the following graphic.



Baseline mercury capture across the CS-ESP ranged from 15-18% while burning 100% PRB coal. During the parametric tests with DARCO® Hg-LH, Unit 2 experienced an outage in mill B resulting in higher variability in the vapor-phase mercury concentration at the ESP inlet likely caused by rapid changes in the quantity of unburned carbon as measured by the loss-on-ignition (LOI) test method. The LOI carbon variability may have contributed to higher levels of particulate-bound mercury at the CS-ESP inlet and consequently higher than normal baseline mercury removal of approximately 32% across the CS-ESP. In addition, Unit 2 operated at a reduced load of approximately 115 MW due to the mill outage.

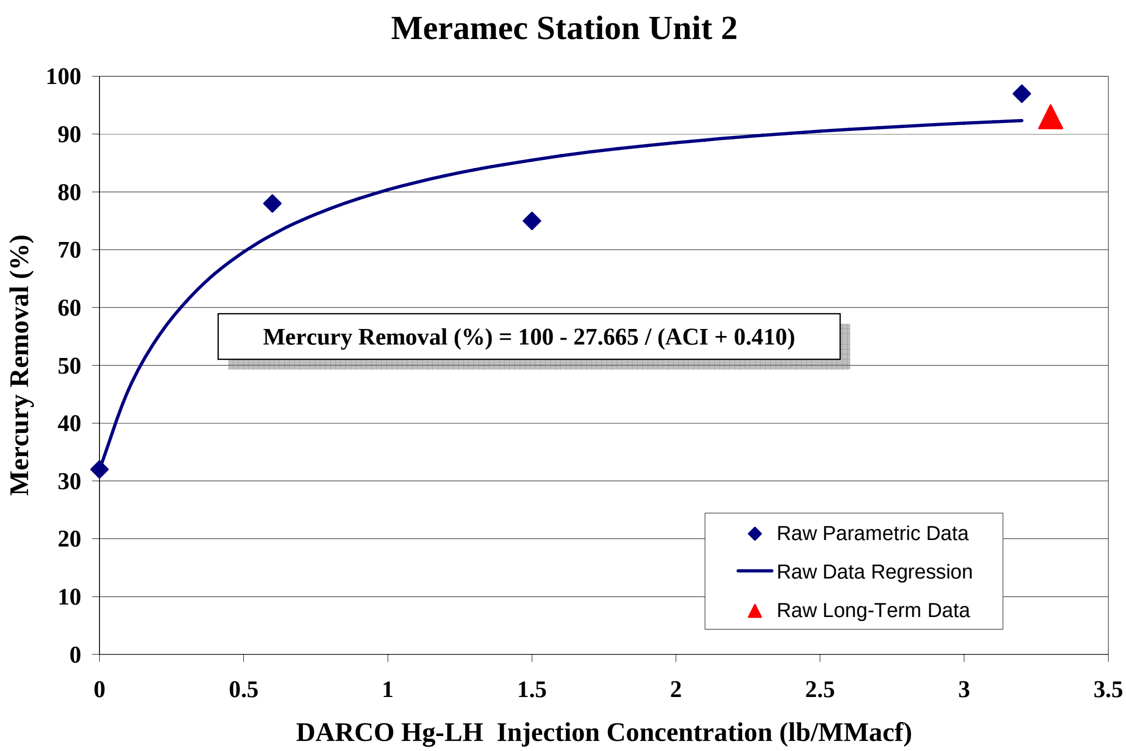
Two methods for mercury control were evaluated during parametric testing – ACI (using either DARCO® Hg or DARCO® Hg-LH) and ALSTOM Power's KNX coal additive (with and without conventional DARCO® Hg injection). With a DARCO® Hg injection concentration of 5 lb/MMacf, total mercury removals of 88% and 74% were achieved with and without the addition of halogenated KNX coal additive, respectively. With the KNX coal additive alone, mercury removal ranged from 57-64% compared to 22-34% under baseline conditions during the same time period. An illustration of the PAC injection and mercury sampling locations is provided below.



The following figure displays the mercury capture efficiency of DARCO® Hg-LH. The diamond symbols represent the raw parametric data. For example, 97% mercury removal was observed at a DARCO® Hg-LH injection concentration of 3.2 lb/MMacf. However, as explained above, the baseline mercury removal was elevated during parametric tests due to a mill outage. Residual PAC from previous tests may have also been a contributing factor to the high co-benefit mercury capture. Also shown on the figure is a least squares fit of mercury control performance as a function of DARCO® Hg-LH injection concentration.

During the long-term continuous injection trial, DARCO® Hg-LH was injected upstream of the CS-ESP from October 14 through November 17, 2004. For the first five days of testing, an average injection concentration of 1 lb/MMacf was required to achieve 60-70% mercury removal. The DARCO® Hg-LH injection concentration was set for nominally 3.3 lb/MMacf resulting in an average mercury removal of 93% for the remainder of the long-term test. The average long-term performance of DARCO® Hg-LH is represented by the red triangle shown below.

Approximately 30% of the total mercury entering the CS-ESP was particulate bound during the 35-day continuous injection period at Meramec Station Unit 2. The combustion characteristics present during the long-term test resulted in higher than expected LOI carbon in the ash. The high levels of LOI carbon coupled with the high surface area present in Meramec's tubular air pre-heater (APH) and the long duct run between the APH and CS-ESP likely contributed to a higher fraction of particulate-phase mercury than typically observed for units firing PRB coal with lower LOI and regenerative APHs, and may have contributed to the high overall mercury removal observed at this site.



The following non-linear regression equation was used to empirically fit the data. Note that ACI represents the DARCO® Hg-LH injection concentration in lb/MMacf. Details of the regression results are provided in Appendix E of this report.

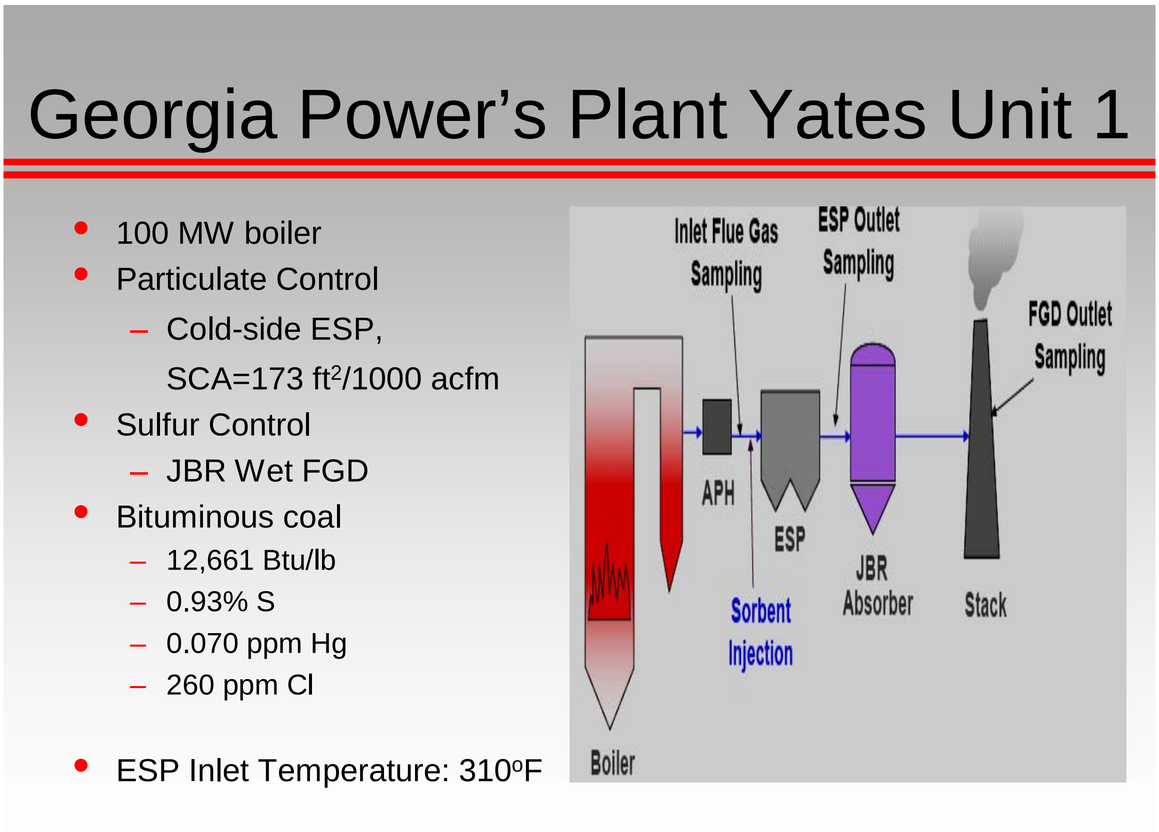
Mercury Removal (%) = 100 – a / (ACI + b)

Where a = 27.665
b = 0.410

As at Holcomb, no adverse balance-of-plant impacts were observed during the long-term test and no excess levels of bromine were measured in the flue gas. In particular, the Synthetic Groundwater Leaching Procedure (SGLP) results revealed that 67% of the bromine in the control-side ash samples leached within 18 hours and 80% within 30 days. For the test-side ash samples where DARCO® Hg-LH injection occurred, the baseline bromine content was higher, but only 31% of the bromine leached within 18 hours and 55% within 30 days. Furthermore, Method 1311, Toxicity Characteristic Leaching Procedure (TCLP) results showed mercury levels below the detection limit in the leachate solution. In addition, there was no measurable increase in stack opacity, SO2, or NOx emissions and ACI did not impact the performance of the ESP during the long-term test.

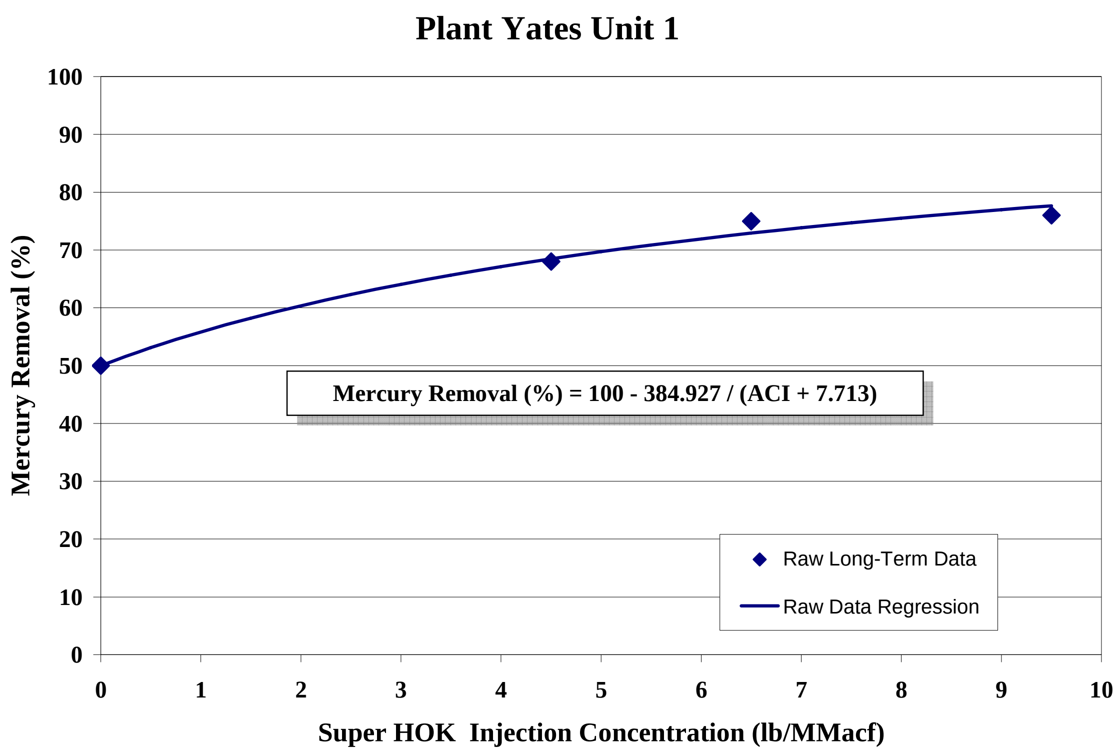
Plant Yates Unit 1

Full-scale field testing was conducted at the bituminous-fired unit equipped with a CS-ESP as part of the Phase II-1 project entitled *Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas*. The objectives of this project were to: (1) demonstrate the ability of various PACs to remove mercury from full-scale units configured with small specific collection area (SCA) ESPs; (2) document the impacts of ACI on small-SCA ESP and wet FGD scrubber operations; and (3) evaluate the effect of ACI on combustion byproduct properties. Based on parametric test results, Super HOK - a conventional PAC developed in Germany, was selected for evaluation during the 30-day long-term test conducted on Unit 1. Testing was completed in December 2004. Some particulars of the test site are provided in the following graphic.



During baseline tests, average mercury removal was approximately 35%. However, the baseline mercury capture was approximately 50% across the CS-ESP (80% across the CS-ESP and wet FGD) during parametric testing. Parametric tests lasting approximately two hours each were conducted on Unit 1 at various feed rates using two conventional PACs (NORIT's DARCO® Hg and RWE Rhinebraun's Super HOK) as well as Ningxia Huahui's iodine-impregnated NH Carbon. Performance was similar for the three PACs with maximum mercury removal of approximately 60% across the ESP using an ACI concentration of 6 lb/MMacf. Additional parametric tests performed on Unit 2 revealed that the dual NH_3/SO_3 flue gas conditioning system had no impact on the mercury removal efficiency of DARCO® Hg. However, the impact of SO_3 injection on mercury capture may have been masked by the high sulfur content of the eastern bituminous coal.

As mentioned above, the mercury capture efficiency of Super HOK was evaluated during the 30-day long-term test that took place in November through December 2004. In contrast to other long-term tests, the ACI concentration varied from 0-16 lb/MMacf in order to evaluate the effect on ESP outlet particulate emissions. For the most part, the Super HOK injection concentration fluctuated between 4 and 10 lb/MMacf with mercury removal ranging from 50-91% across the CS-ESP.[q] The average mercury capture observed during the long-term test as well as a least squares fit of mercury control performance as a function of Super HOK injection concentration are displayed in the following figure.



The following non-linear regression equation was used to empirically fit the data. Note that ACI represents the Super HOK injection concentration in lb/MMacf. Details of the regression results are provided in Appendix E of this report.

Mercury Removal (%) = 100 – a / (ACI + b)

Where a = 384.927
b = 7.713

At the conclusion of the long-term continuous injection trial, a second round of parametric testing was conducted in January 2005.[25] These short-term tests evaluated a Coarse HOK sorbent, DARCO® Hg-LH, a 50:50 mixture of DARCO® Hg and Miller

[q] During long-term testing, Super HOK injection concentrations of 4.5 lb/MMacf (~12 days), 6.5 lb/MMacf (~4 days), and 9.5 lb/MMacf (~4 days) were required to achieve average mercury removals of approximately 68%, 75%, and 76%, respectively.

(PRB) ash, and DARCO® Hg for reference. A Coarse HOK injection concentration of 16.2 lb/MMacf was required to achieve 77% total mercury removal across the CS-ESP. A DARCO® Hg-Miller ash injection concentration of 10.4 lb/MMacf (equivalent to 5.2 lb/MMacf of DARCO® Hg) was required to achieve 74% total mercury removal across the CS-ESP. For comparison, a DARCO® Hg injection concentration of 5.2 lb/MMacf yielded a total mercury removal of 69% across the CS-ESP. Mercury removal across the CS-ESP appeared to plateau at 82% with a brominated DARCO® Hg-LH injection concentration of 10.4 lb/MMacf. During DARCO® Hg-LH injection, a significant increase in the level of hydrogen bromide (HBr) in the flue gas was observed. Under baseline conditions, Method 26 measurements showed an HBr flue gas concentration of 0.18 ppmv. The HBr flue gas concentration increased to 0.86 ppmv and 1.20 ppmv during the injection of DARCO® Hg-LH at feed rates of 143 lb/hr and 200 lb/hr, respectively. Since DARCO® Hg-LH is brominated; this suggests that a portion of the bromine associated with the carbon desorbed during injection. Furthermore, these data imply that the amount of bromine desorbed into the flue gas is related to the DARCO® Hg-LH injection concentration.

Plant Yates was selected for long-term testing, in part, to gain a better understanding of the effect of ACI on small-SCA ESP and wet FGD operation. Erratic ESP arcing behavior was observed during baseline and short-term ACI parametric tests conducted in Spring 2004. Subsequent inspection of the ESP internals revealed the presence of damaged (i.e., carbon "baked" onto the surface) and broken stand-off insulators that may have caused, or at least contributed to the irregular and potentially detrimental ESP performance observed during these tests. However, it is unclear when the ESP damage occurred, or if the damage was a direct result of the ACI trials. In October 2004, the damaged insulators were either repaired or replaced during a scheduled maintenance outage. This allowed plant operators to monitor the ESP electrical behavior for approximately one month prior to the long-term continuous ACI trial, and compare the baseline ESP performance to that observed during ACI. Analysis of the ESP electrical behavior focused on the first (A) field, because arcing was most severe in the initial electrical field.

In an effort to determine the effect of load and ACI concentration on the arcing rate in field A, raw ESP data was collected from 10/13/04 (immediately following the maintenance outage) until 2/1/05 (approximately 1.5 months after the long-term Super HOK injection test was completed) and reduced to hourly averages. During the long-term injection test, Yates Unit 1 operated at low load (50-60 MW) and high load (95-107 MW) while the Super HOK injection concentration varied from 0-16 lb/MMacf as mentioned above. The following observations were made after sorting the ESP data based upon load and ACI concentration.

- *The arcing rate in field A was higher during ACI.* At low load, the average arc rate was 0.5 arcs per minute (apm) prior to, 4-5 apm during, and 1.2 apm following the long-term injection trial.
- *The arcing rate in field A was higher during high load versus low load.* With a Super HOK injection concentration of 4-5 ln/MMacf, the average arc rate was 4 apm at low load and 17 apm while operating at high load conditions.

- *At low load, the arcing rate in field A appeared to be independent of the Super HOK injection concentration.* Average arc rates of 4.6 apm and 5.2 apm were observed at ACI concentrations of 4 lb/MMacf and greater than 7 lb/MMacf, respectively.
- *At high load, the arcing rate in field A may increase with ACI concentration.* The average arc rate was 17 apm at a Super HOK injection concentration of 4-5 lb/MMacf, while the average arc rate was approximately 29 apm with an ACI concentration greater than 7 lb/MMacf.
- *The long-term injection test caused no visible physical damage to the ESP.* However, it remains unclear what effect the increased arcing rate will have on ESP performance over longer time periods.

The impact of continuous Super HOK injection on the ESP outlet particulate matter concentration was quantified by taking single-point EPA Method 17 transverses. Approximately 70% of the data fell within or below the range of ESP outlet particulate matter concentrations measured during baseline testing. For the 30% of data that exceeded the measured baseline concentrations, there did not appear to be any correlation between the ACI concentration and the ESP outlet particulate matter concentration. However, the presence of carbon on the Method 17 filters confirmed the breakthrough of carbon from the small-SCA ESP.

Samples of the wet scrubber slurry were also taken periodically. The slurry samples were an unusually dark color (suggesting PAC carryover from the ESP) during a two-week period when the ACI concentration ranged from 4-6 lb/MMacf. Prior to and subsequent to this time period, the scrubber slurry did not show any visual evidence of carbon contamination even though the ACI concentration exceeded 10 lb/MMacf at times.

Leland Olds Unit 1

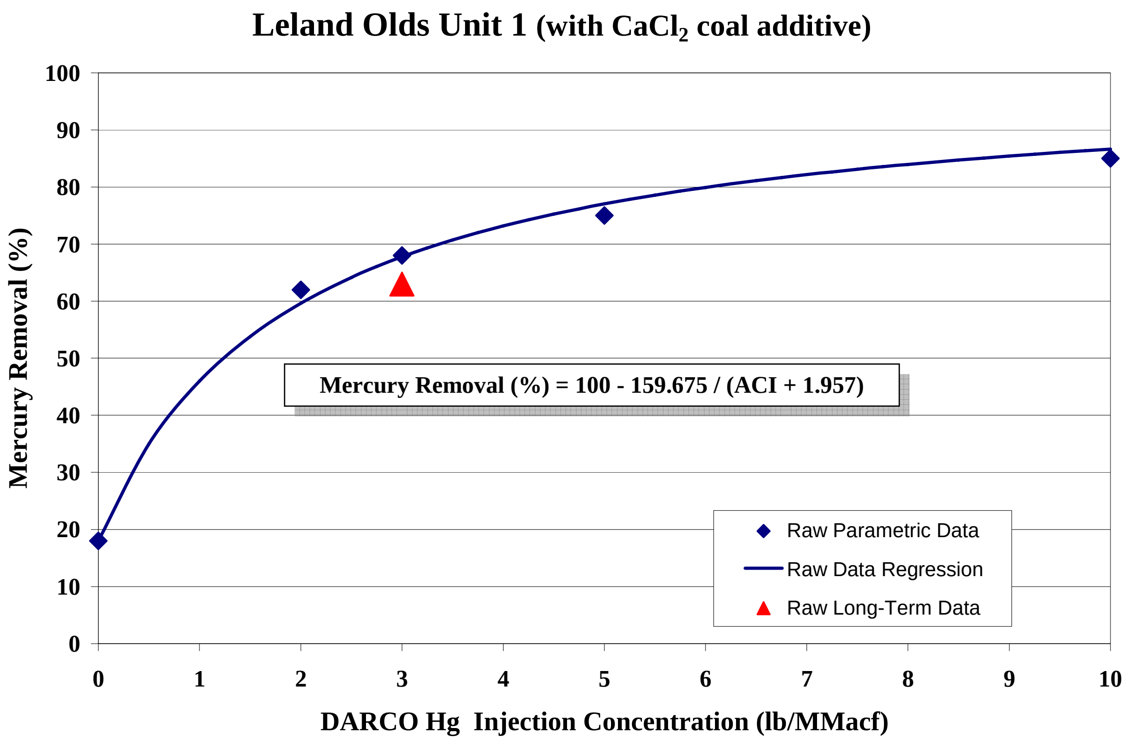
Full-scale field testing was conducted at the ND lignite-fired unit equipped with a CS-ESP as part of the Phase II-1 project entitled *Enhancing Carbon Reactivity for Mercury Control in Lignite-Fired Systems*. The primary objective of this project was to evaluate the improved mercury capture efficiency of conventional ACI when the low-rank coal is treated with an SEA prior to combustion. This technology is intended to serve as an alternative mercury control strategy for units that produce halogen-deficient flue gas from the combustion of low-rank coals. The economics presented in this report are based on the mercury capture observed with the addition of an SEA (i.e., aqueous $CaCl_2$ solution) to the coal in conjunction with DARCO® Hg injection during parametric and long-term testing with the unit firing 100% ND lignite. Testing was completed in May 2004. Some particulars of the test site are provided in the following graphic.

Basin Electric's Leland Olds Unit 1

- 220 MW Wall-fired boiler
- Particulate Control
  - Cold-side ESP, SCA=320 ft^2/1000 acfm
- North Dakota Lignite Coal
  - 6,420 Btu/lb
  - 0.66% S
  - 0.056 ppm Hg
  - 10.9 ppm Cl
- ESP Inlet Temperature: 340°F

Approximately 56% of the total mercury entering the ESP was elemental resulting in a baseline mercury removal of 18% across the CS-ESP while firing 100% ND lignite coal. During parametric testing, DARCO® Hg injection concentrations of 3 lb/MMacf and 10 lb/MMacf were required to achieve total mercury removals of approximately 47% and 64%, respectively.

The primary objective of this project was to evaluate the mercury capture efficiency of DARCO® Hg when the ND lignite coal is treated with an aqueous $CaCl_2$ solution prior to combustion. With a constant $CaCl_2$ feed rate that is equivalent to adding approximately 500 ppm chlorine to the coal, total mercury removal of 68% and 85% were observed at DARCO® Hg injection concentrations of 3 lb/MMacf and 10 lb/MMacf, respectively. Based on the parametric results, the 30-day long-term test was conducted with a constant $CaCl_2$ feed rate (equivalent to ~500 ppm in the coal) and a DARCO® Hg injection concentration of 3 lb/MMacf resulting in an average mercury removal of 63% across the CS-ESP. The parametric dataset is represented by the small diamond symbols displayed on the following figure. The red triangle corresponds to the average mercury capture observed during the long-term test. Also shown on the figures is a least squares curve-fit of the parametric data as a function of DARCO® Hg injection concentration.



The following non-linear regression equation was used to empirically fit the data. Note that ACI represents the DARCO® Hg injection concentration in lb/MMacf. Details of the regression results are provided in Appendix E of this report.

Mercury Removal (%) = 100 – a / (ACI + b)

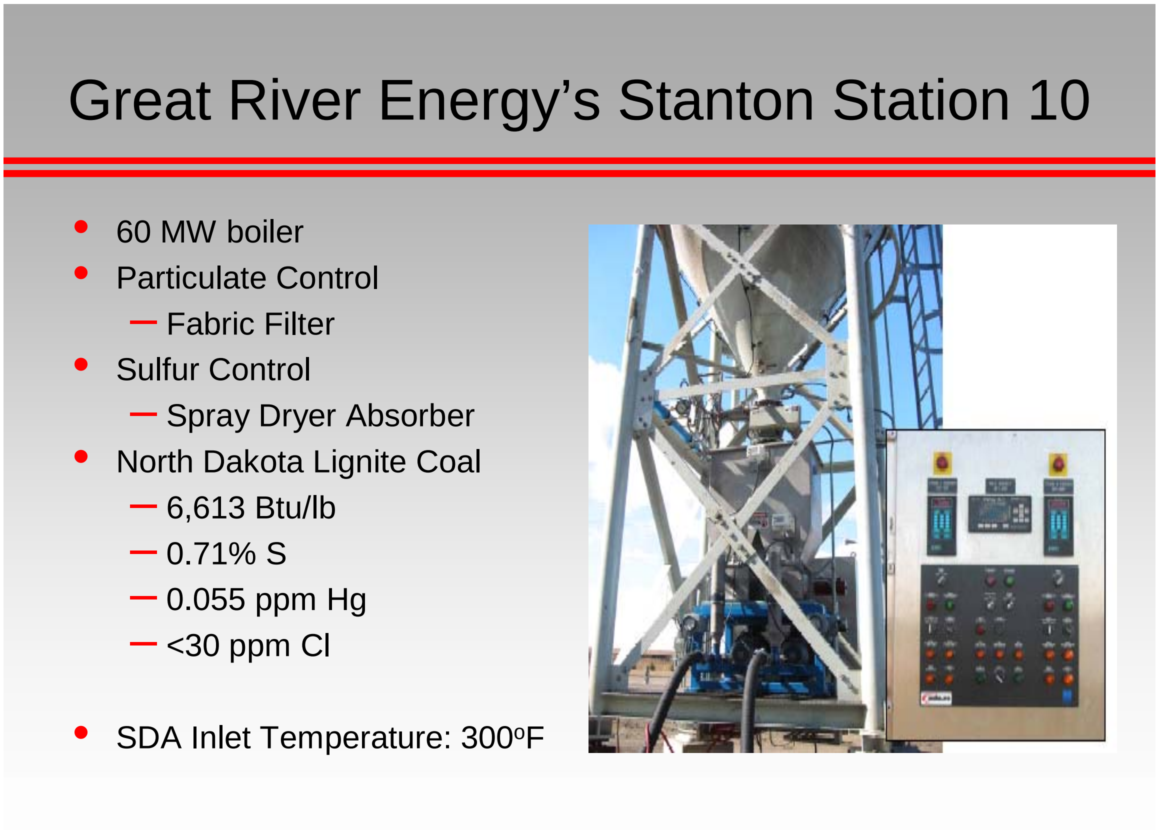
Where a = 159.675
b = 1.957

One week of parametric testing was devoted to coal blending where a blend consisting of 30% PRB coal was evaluated. With a $CaCl_2$ feed rate of 1 lb/MMacf, total mercury removal of approximately 58% and 66% was observed at DARCO® Hg injection concentrations of 3 lb/MMacf and 5 lb/MMacf, respectively. In addition, approximately 78% mercury removal was achieved with a $CaCl_2$ feed rate of 7 lb/MMacf and a DARCO® Hg injection concentration of 3 lb/MMacf. The results obtained from these short-term coal blending trials reveal that the addition of excess halogens to the flue gas is required to achieve high levels of mercury capture when firing low-rank coals.

No adverse balance-of-plant impacts were observed during the long-term test and no excess halogen levels were measured in the flue gas. In particular, there was no measurable increase in stack opacity and ACI did not impact the performance of the ESP during the long-term test.

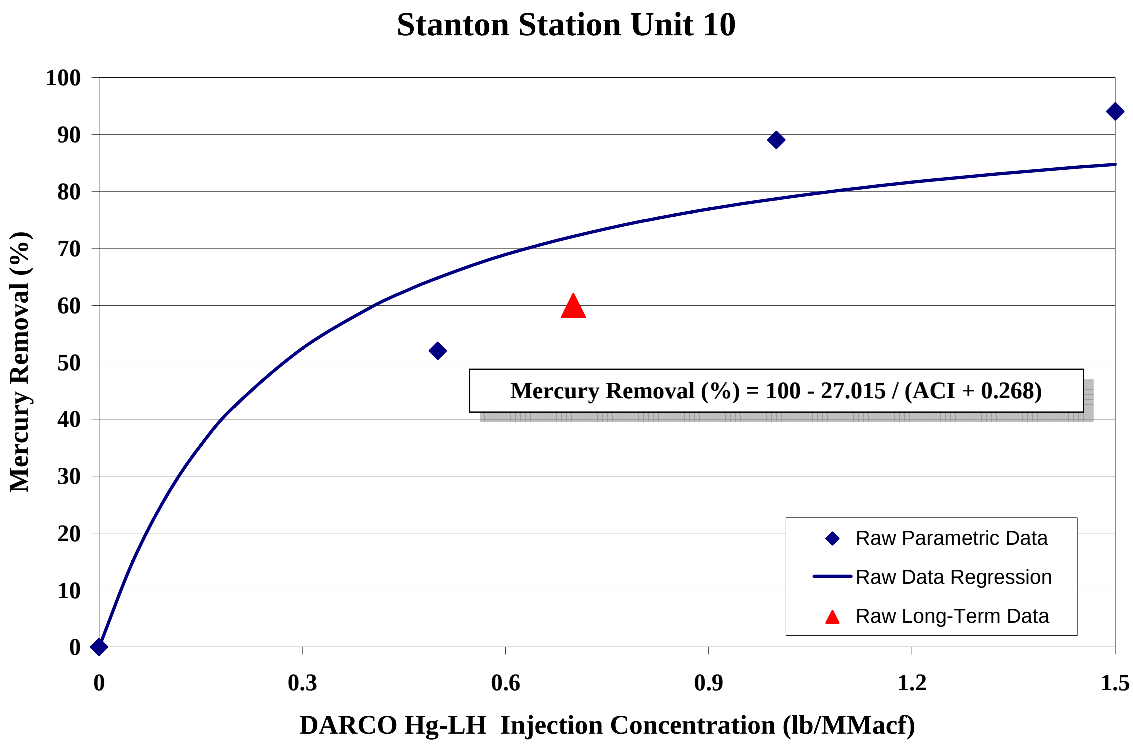
Stanton Station Unit 10

Full-scale field testing was conducted at the ND lignite-fired unit equipped with a SDA/FF configuration as part of the Phase II-1 project entitled *Enhancing Carbon Reactivity for Mercury Control in Lignite-Fired Systems*. Parametric tests were devoted to the evaluation of several PACs. Based on the performance observed during these short-term injection trials, DARCO® Hg-LH was selected for continuous injection during the 30-day long-term test. Testing was completed in July 2004. Some particulars of the test site are provided in the following graphic.



Baseline mercury removal across the SDA/FF configuration was less than 10%. Total vapor-phase mercury concentrations ranged from 7.5-13 µg/dncm at both the SDA inlet and FF outlet with less than 10% oxidized mercury. The following PACs were evaluated during the parametric testing campaign: (1) DARCO® Hg; (2) NORIT's chemically-treated DARCO® E1; (3) DARCO® Hg-LH; (4) B-PAC™; (5) Barnebey Sutcliffe's super-activated 208CP™; and (6) Barnebey Sutcliffe's iodated CB 200xF™. A DARCO® Hg injection concentration of 6 lb/MMacf was required to achieve 75% mercury removal across the SDA/FF configuration. Mercury removal was limited to 63% with an iodated 200xF™ sorbent injection concentration of 1.7 lb/MMacf. DARCO® E1 was able to achieve 89% mercury removal at an injection concentration of 2 lb/MMacf, while total mercury removal was limited to 58% with a super-activated 208CP™ injection concentration of 1.5 lb/MMacf. Meanwhile, DARCO® Hg-LH and B-PAC™ were able to achieve approximately 95% mercury removal at an injection concentration of 1.5 lb/MMacf.

The following figure displays the performance of DARCO® Hg-LH during parametric and long-term tests. Note the baseline mercury removal during the parametric testing campaign was essentially zero. The diamond symbols represent the results obtained during short-term parametric tests. The red triangle represents the average mercury capture efficiency of DARCO® Hg-LH during long-term testing where mercury removal ranging from 45-80% (60% average) was observed at an average injection concentration of 0.7 lb/MMacf. Also shown on the figures is a least squares curve-fit of the parametric data as a function of DARCO® Hg-LH injection concentration.



The following non-linear regression equation was used to empirically fit the data. Note that ACI represents the DARCO® Hg-LH injection concentration in lb/MMacf. Details of the regression results are provided in Appendix E of this report.

$$\text{Mercury Removal (\%)} = 100 - a / (ACI + b)$$

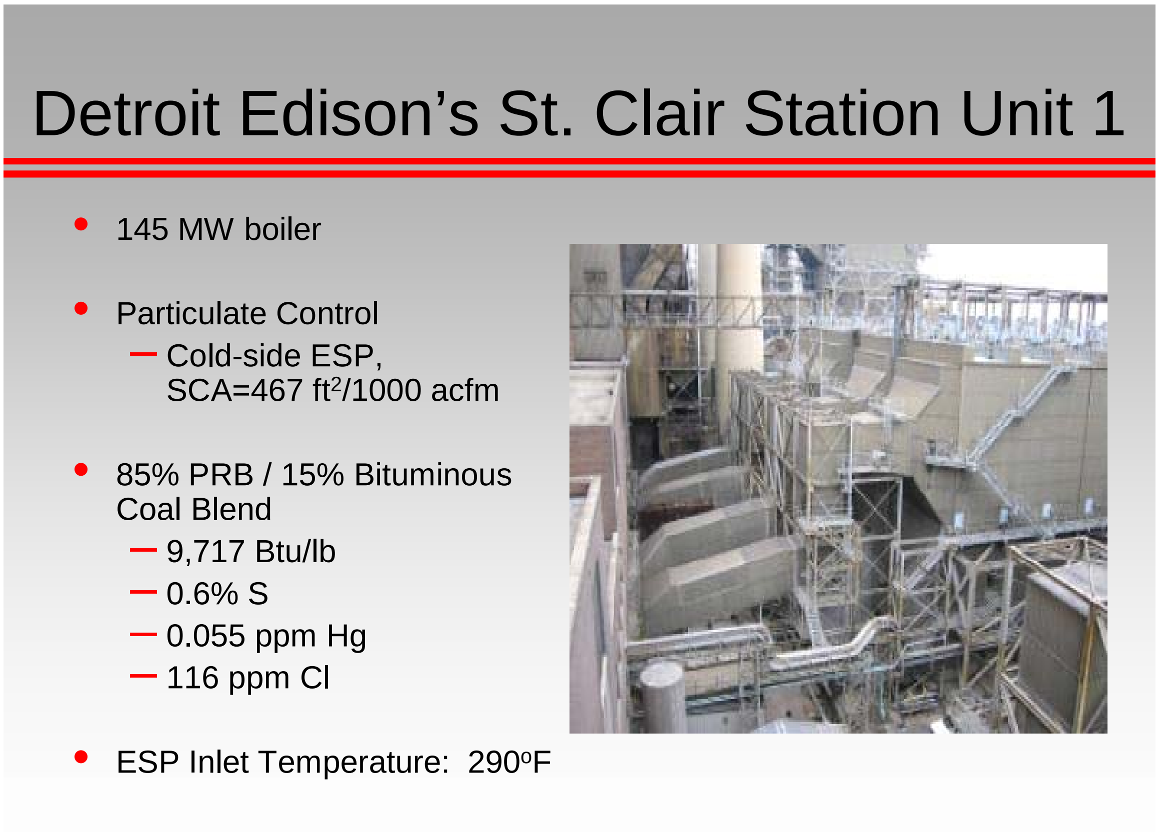
Where $a = 27.015$

$b = 0.268$

Over the course of the long-term test, the cleaning frequency of the FF baghouse increased to every three to four hours, as compared to six to eight hours under baseline conditions. However, the contribution of continuous ACI to the increased cleaning cycle cannot be quantified, because the slurry feed to the SDA, which can affect the baghouse cleaning frequency, was not held constant due to coal sulfur variations. In fact, ACI at a concentration of 1 lb/MMacf is estimated to cause only a 0.2% increase in particulate loading. In addition, a 4–6% increase in opacity was observed for a short time (< 5 minutes) immediately after each baghouse cleaning cycle.

St. Clair Station Unit 1

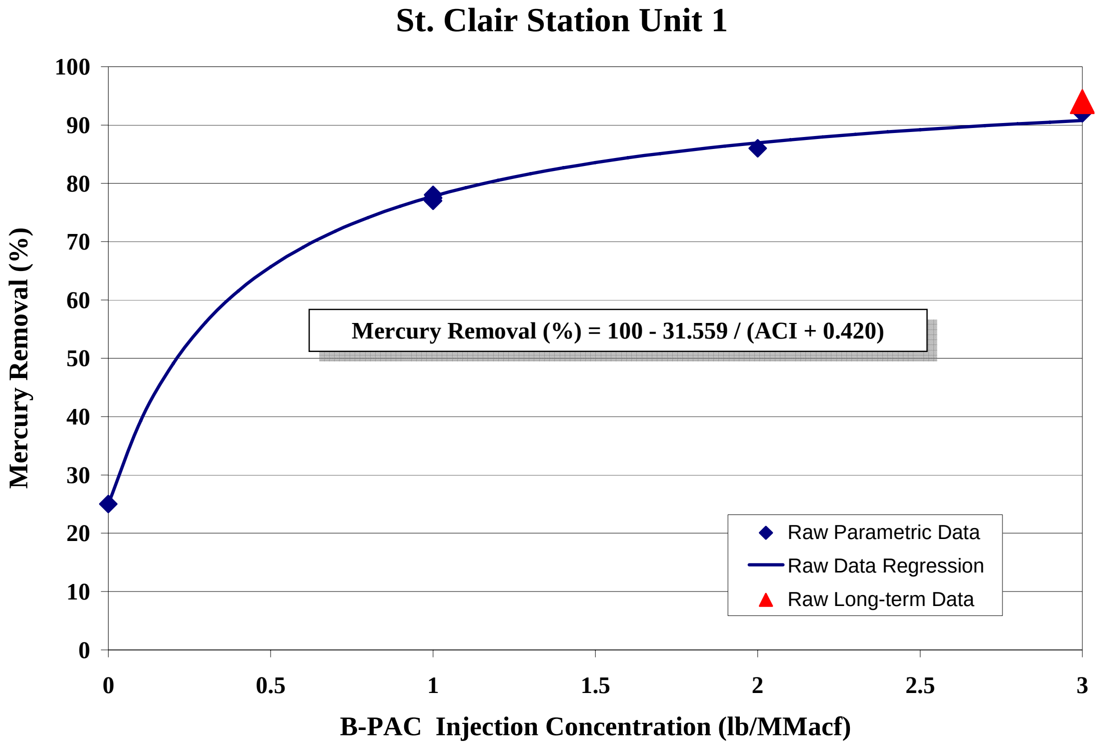
Full-scale field testing was conducted at this site, which typically burns a blend of 85% PRB and 15% eastern bituminous coal and is equipped with a CS-ESP as part of the Phase II-1 project entitled *Advanced Utility Mercury Sorbent Field-Testing Program*. The primary focus of parametric testing as well as the 30-day long-term test was to evaluate the mercury capture efficiency of Sorbent Technologies' brominated B-PAC™. Testing was completed in October 2004. Some particulars of the test site are provided in the following graphic.



Under baseline conditions, approximately 80% of the total mercury entering the CS-ESP was elemental resulting in 0-40% co-benefit mercury removal. However, baseline mercury removal was approximately 25% prior to the parametric testing campaign. Mercury removal was limited to approximately 70% with DARCO® Hg injection concentrations ranging from 6 to 12 lb/MMacf. Meanwhile, B-PAC™ injection concentrations of 1 lb/MMacf and 3 lb/MMacf were required to achieve total mercury removals of approximately 78% and 93%, respectively.

The following figure displays the performance of B-PAC™ during parametric and long-term tests. The diamond symbols represent the results obtained during short-term parametric tests where the baseline mercury removal was approximately 25%. The red triangle represents the results obtained during the 30-day long-term test where an average mercury removal of 94% was observed at an average B-PAC™ injection concentration of

3 lb/MMacf. Also shown on the figure is a least squares curve-fit of the parametric data as a function of B-PAC™ injection concentration.



The following non-linear regression equation was used to empirically fit the data. Note that ACI represents the B-PAC™ injection concentration in lb/MMacf. Details of the regression results are provided in Appendix E of this report.

Mercury Removal (%) = 100 – a / (ACI + b)

Where a = 31.559
b = 0.420

During the long-term continuous injection trial that took place between September 24, 2004 and October 24, 2004, two strategies for potentially reducing the cost of mercury control were investigated. The first test involved switching to a lower-cost version of B-PAC™ that contains less bromine. The low-cost B-PAC™ was injected continuously for approximately 10 hours on October 11, and for about 13 hours on October 23. Total mercury removal on these two days remained constant at approximately 91-92% despite the switch to the lower-cost version of B-PAC™. Another test was conducted where the ACI system was switched on and off every minute for a period of 64 minutes. The intermittent operation of the ACI system effectively reduced the B-PAC™ injection concentration from 3 lb/MMacf to 1.5 lb/MMacf resulting in an average mercury removal of 81%. Conversely, 92% mercury removal was observed before and after this test with a B-PAC™ injection concentration of 3 lb/MMacf.

No adverse balance of plant impacts were observed during continuous B-PAC™ injection at St. Clair. In particular, there was no increase in stack opacity, no brominated PAC-related corrosion issues were identified, the HBr content of the flue gas was minimal, and the performance of the CS-ESP was not impaired.

APPENDIX C

Phase II Data Adjustment Methodology

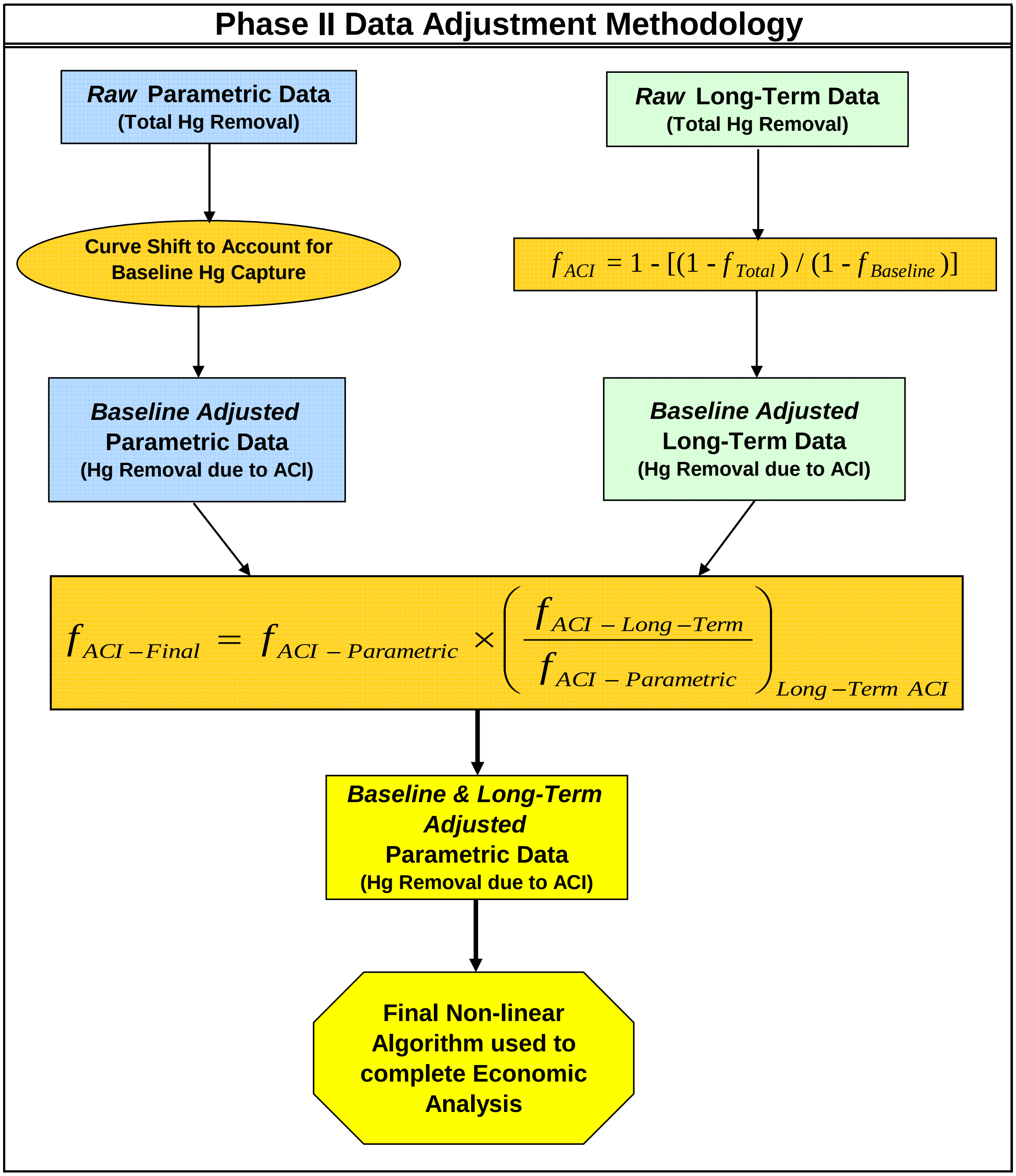
Phase II Data Adjustment Methodology

In order to estimate ACI costs, it is necessary to establish a mathematical relationship (algorithm) between ACI concentration and mercury capture performance for each of the DOE/NETL Phase II field test sites.

To calculate the percent mercury removal that is directly attributable to ACI, a methodology was developed to incorporate the baseline, short-term parametric, and long-term field test data. The methodology is comprised of the following steps:

(1) Develop an ACI concentration versus mercury removal non-linear regression algorithm using the short-term parametric field test data;
(2) Shift the ACI performance curve developed in step 1 to account for the baseline mercury capture observed prior to the short-term parametric tests;
(3) Adjust the average total mercury removal achieved during the long-term field test to account for the baseline removal calculated for the average long-term ACI concentration;
(4) Scale the adjusted algorithm developed in step 2 to include the baseline adjusted long-term field test data point developed in step 3; and
(5) Re-calculate the ACI performance algorithm using the baseline and long-term adjusted parametric test data.

It is important to note that the algorithm adjustment used in step 2 assumes that during ACI the effective baseline mercury capture gradually decreases and approaches zero as the ACI concentration increases. This approach is supported by the results of thermal desorption tests conducted at Holcomb Station, which led to the conclusion that during ACI, *there is no "native" mercury capture by the fly ash*; instead, the gaseous mercury is captured by the more reactive activated carbon rather than the fly ash.



Variables	Definition
f_{ACI}	Fractional Hg removal due to ACI
f_{Total}	Fractional total Hg removal
$f_{Baseline}$	Fractional Hg removal by existing APCDs
$f_{ACI\text{ - }Final}$	Fractional Hg removal due to ACI that accounts for baseline Hg capture and incorporates the average long-term ACI performance
$f_{ACI\text{ - }Parametric}$	Fractional Hg removal due to ACI during short-term parametric tests
$f_{ACI\text{ - }Long\text{-}Term}$	Fractional Hg removal due to ACI during long-term testing
$Long\text{-}Term\ \ ACI$	Average ACI concentration during long-term test

To facilitate a better understanding of the methodology described above, the following section demonstrates how the adjustments were made to the baseline, parametric, and average long-term data collected during Phase II field testing at Holcomb Station Unit 1.

Data Adjustment for Holcomb Station Unit 1

The economic analysis of mercury control is based on the performance of DARCO® Hg-LH during parametric and long-term testing. The results obtained from these full-scale field tests are shown in the following table.

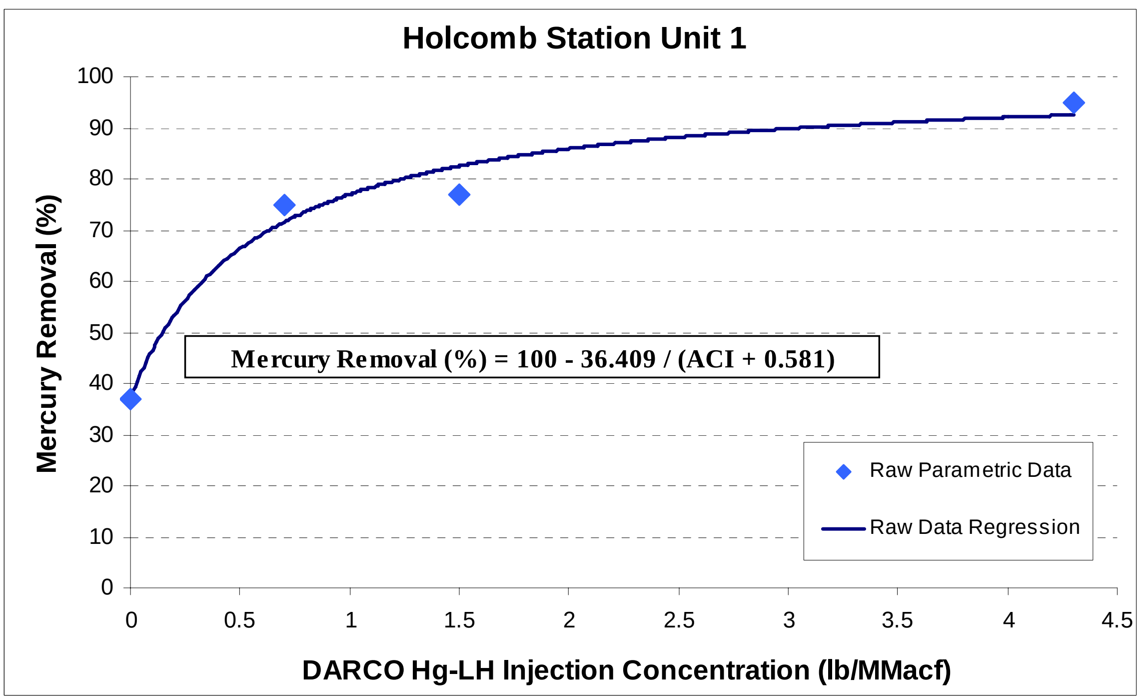
Raw Parametric Data		Average Long-Term Data	
DARCO® Hg-LH, lb/MMacf	Mercury Removal, %	DARCO® Hg-LH, lb/MMacf	Mercury Removal, %
0	37	1.2	93
0.7	75		
1.5	77		
4.3	95		

Step 1

The raw parametric data was used to develop the non-linear algorithm shown below in Figure C-1. Details of the regression results are provided in Appendix E of this report.

$$\%\,Hg\,\mathrm{Re}\,moval = 100 - \frac{36.409}{ACI + 0.581}$$

Figure C-1 – Parametric ACI Performance Data and Algorithm – Unadjusted



Step 2
The unadjusted parametric performance curve from step 1 was extrapolated to determine the X-axis intercept of the algorithm, which corresponds to a theoretical DARCO® Hg-LH injection concentration of -0.22 lb/MMacf. According to the unadjusted parametric performance curve, a DARCO® Hg-LH injection concentration of 0.22 lb/MMacf would be required to achieve the baseline mercury removal of 37% observed prior to the parametric testing campaign. Therefore, the unadjusted curve was shifted to the right by 0.22 lb/MMacf. The resultant adjusted parametric regression curve displays the level of mercury control that is directly attributable to ACI as a function of DARCO® Hg-LH injection concentration.

This parametric data adjustment assumes that during ACI the effective baseline mercury capture gradually decreases and approaches zero as the ACI concentration increases. To quantify this declining baseline phenomenon, the levels of mercury control predicted by the unadjusted (total mercury removal) and adjusted (mercury capture due to ACI) parametric regression curves were compared to develop a relationship expressing the predicted level of baseline mercury capture as a function of DARCO® Hg-LH injection concentration. The following calculation was repeated over the entire range of ACI concentrations investigated during the parametric testing campaign.

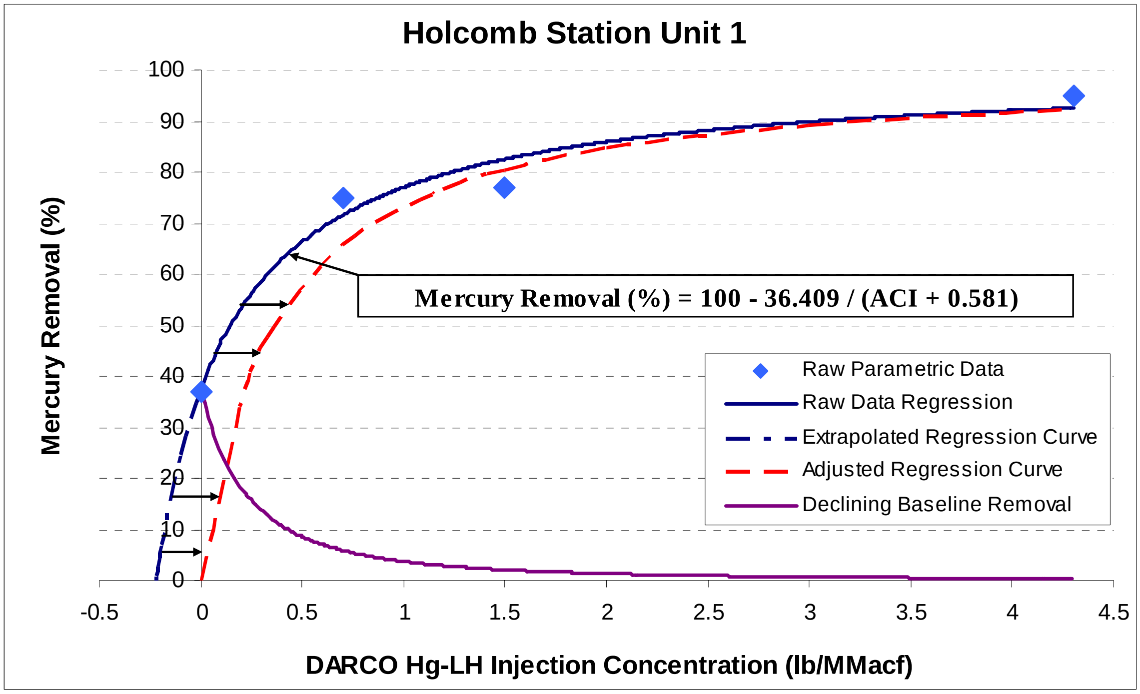
Baseline Hg Removal, % = Total Hg Removal, % – Hg Capture due to ACI, %

Table C-1 provides the non-linear regression results for several DARCO® Hg-LH injection concentrations, the adjusted DARCO® Hg-LH injection concentrations, and the baseline mercury removal calculated for each of the adjusted ACI concentrations. The adjustment made to the parametric performance curve as well as the declining baseline curve are graphically illustrated in Figure C-2.

Table C-1 –Parametric Performance Data - Adjustment for Baseline Removal

Raw Data Regression		Adjustment	Baseline Mercury Removal, %
[DARCO® Hg-LH], lb/MMacf	Mercury Removal, %	[DARCO® Hg-LH], lb/MMacf	
-0.22	0	**0**	37.33
0	37.33	0.22	17.21
0.48	65.68	**0.70**	5.89
0.70	71.58	0.92	4.17
0.98	**76.68**	**1.20**	**2.88**
1.20	79.56	1.42	2.25
1.28	80.44	**1.50**	2.07
1.50	82.50	1.72	1.67
4.08	92.19	**4.30**	0.35
4.30	92.54	4.52	N/A

Figure C-2 – Parametric Data Adjustment and Declining Baseline Mercury Capture



Step 3

During long-term testing at Holcomb, an average total mercury removal of 93% was observed at an average DARCO® Hg-LH injection concentration of 1.2 lb/MMacf. To determine the level of mercury control that is attributable to ACI, the level of baseline mercury capture at an ACI concentration of 1.2 lb/MMacf was calculated as 2.88% by taking the difference between total mercury removal (79.56%) and ACI mercury removal (76.68%) from the unadjusted and adjusted parametric regression curves, respectively. Using 2.88% as the baseline removal, the average level of long-term mercury control that is attributable to ACI was determined using the following equation, where *f* represents fractional mercury removal.

$$f_{ACI} = 1 - \left(\frac{1 - f_{Total}}{1 - f_{Baseline}} \right) = 1 - \left(\frac{1 - 0.93}{1 - 0.0288} \right) = 0.9279 \Rightarrow 92.79\%$$

Step 4

The baseline adjusted parametric regression curve was scaled to include the average level of long-term mercury control that is attributable to ACI as calculated in step 3. This was accomplished by applying the following equation over the entire range of DARCO® Hg-LH injection concentrations investigated during parametric testing.

$$f_{Final} = f_{ACI-Parametric} \times \left(\frac{f_{ACI-Long-Term}}{f_{ACI-Parametric}} \right)_{Long-Term\ ACI}$$

The following sample calculation applies to an ACI concentration of 1.5 lb/MMacf. Note that the adjusted parametric regression curve yields 76.68% mercury removal due to ACI for an injection concentration of 1.2 lb/MMacf.

$$f_{Final} = 80.44\% \times \frac{92.79\%}{76.68\%} = 97.34\%$$

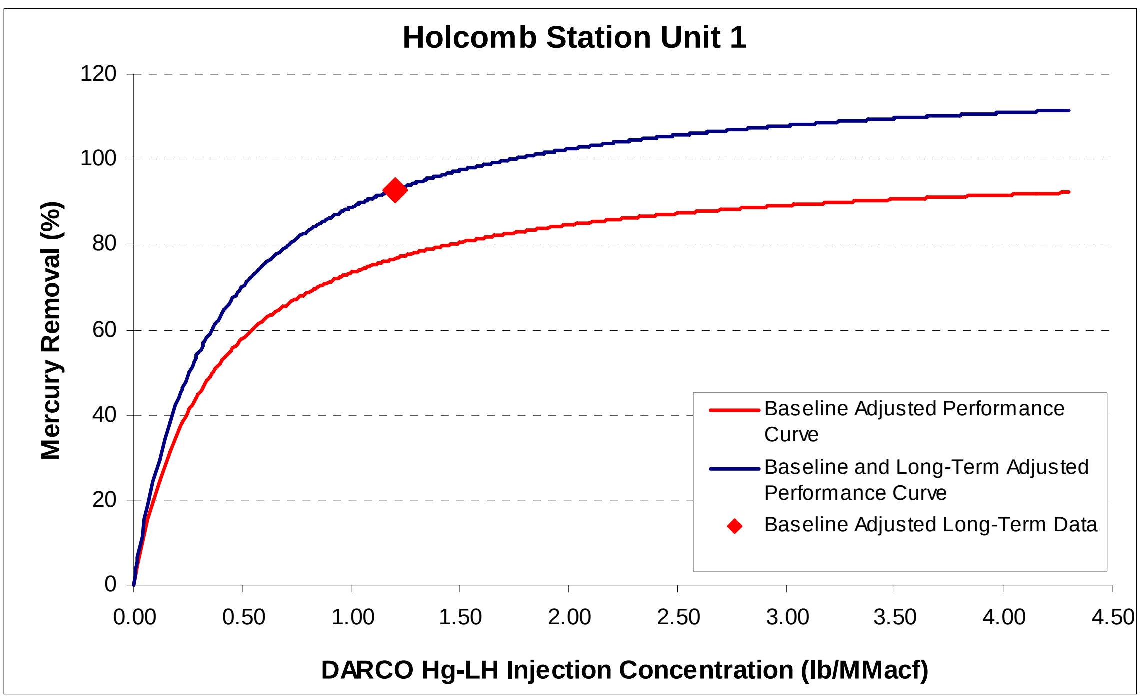
The baseline adjusted parametric data calculated in step 2 as well as the baseline adjusted parametric data that incorporates the average level of long-term mercury control due to the injection of DARCO® Hg-LH are presented in Table C-2.

Table C-2 –Parametric Performance Data - Adjustment for Long-Term Data

	Parametric Performance Data – Adjusted for Baseline	Parametric Performance Data – Adjusted for Baseline and Long-Term Data
[DARCO® Hg-LH], lb/MMacf	Mercury Removal due to ACI, %	Mercury Removal due to ACI, %
0.0	0.00	0.00
0.7	65.68	79.49
1.2	76.68	92.79
1.5	80.44	97.34
4.3	92.19	111.57

Figure C-3 displays the baseline adjusted parametric performance curve, the baseline adjusted parametric performance curve that incorporates the average level of long-term mercury control due to the injection of DARCO® Hg-LH as well as the adjusted long-term data calculated in step 3.

Figure C-3 – Adjusted Parametric Performance Curves and Long-Term Data



Step 5

The baseline and long-term adjusted parametric performance data from step 4 was then used to develop the final adjusted non-linear algorithm shown below. The form of this equation ensures that the level of mercury control due to ACI approaches, but never exceeds 100%. Details of the regression results are provided in Appendix E of this report.

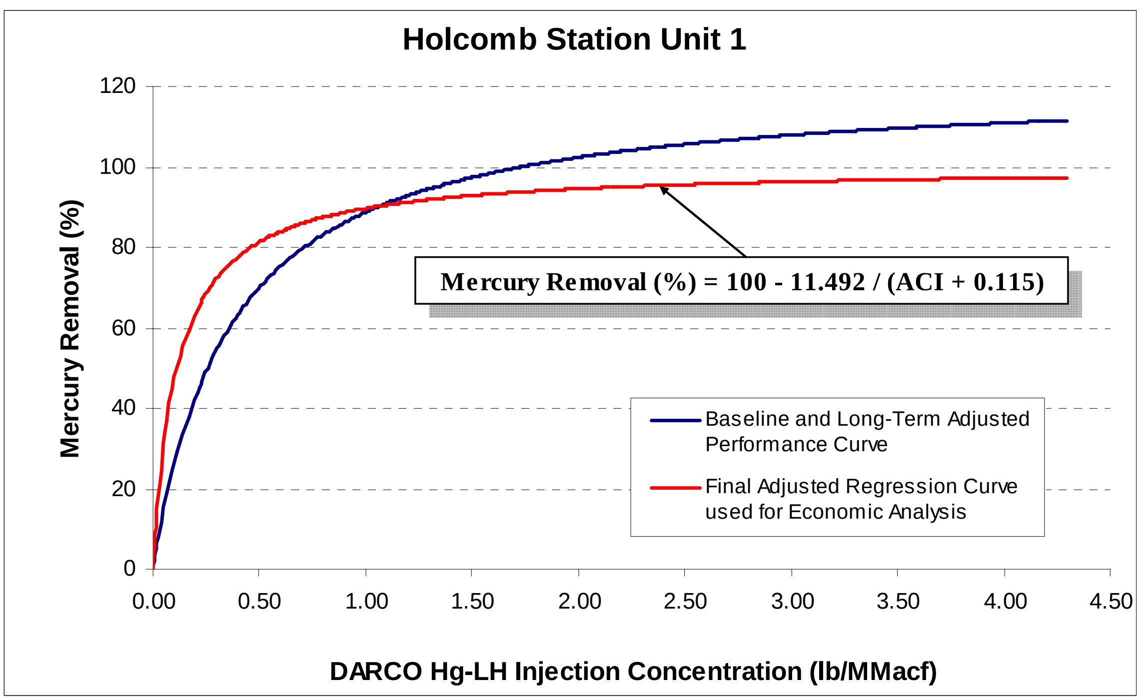
$$\%\,Hg\ removal\ due\ to\ ACI = 100 - \frac{11.492}{ACI + 0.115}$$

Table C-3 presents a comparison of the baseline and long-term adjusted parametric performance data to the results of the final adjusted algorithm that was used for the economic analysis. Figure C-4 presents that same data plotted graphically.

Table C-3 – Parametric Performance Data –
Adjustment to Limit Maximum Mercury Removal to less than 100%

	Parametric Performance Data – Adjusted for Baseline and Long-Term Data	Final Adjusted Algorithm
[DARCO® Hg-LH], lb/MMacf	Mercury Removal due to ACI, %	Mercury Removal due to ACI, %
0.0	0.00	0.07
0.7	79.49	85.85
1.2	92.79	91.24
1.5	97.34	92.87
4.3	111.57	97.40

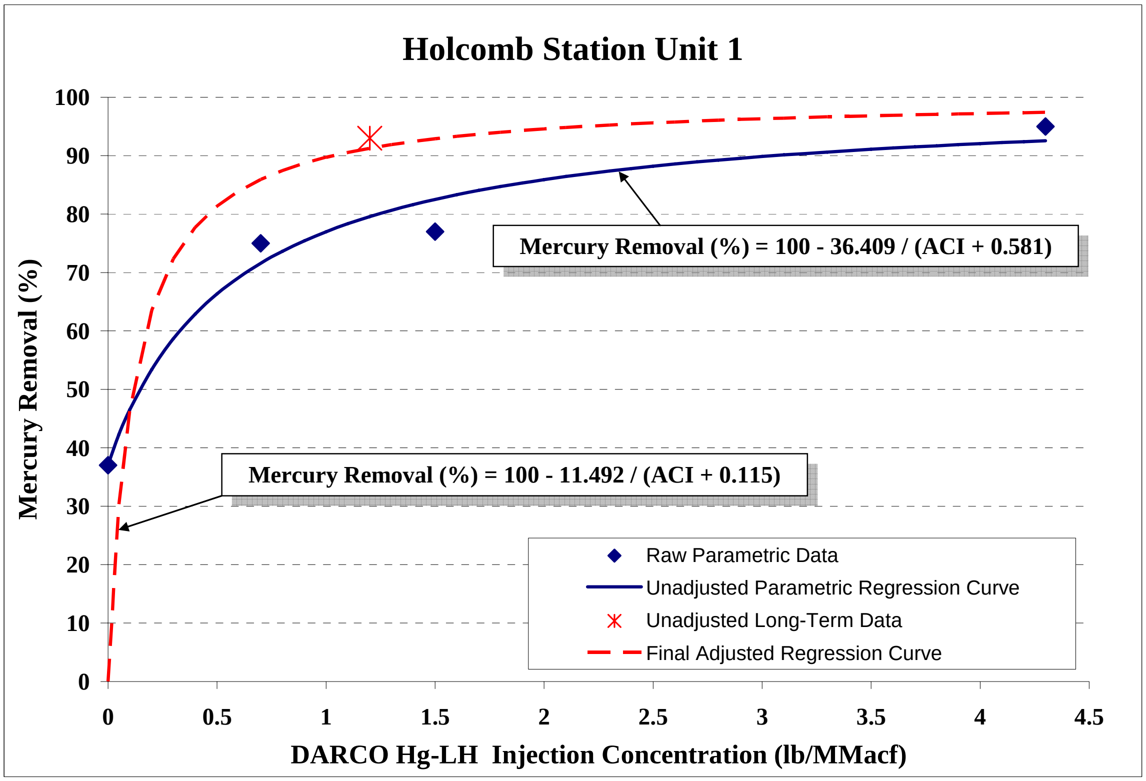
Figure C-4 – Parametric Performance Data
- Adjustment to Limit Maximum Mercury Removal to less than 100%



Summary of Data Adjustment for Holcomb Station Unit 1

Figure C-5 illustrates the final adjusted (dashed curve) and unadjusted (solid curve) mercury removal performance of DARCO® Hg-LH at Holcomb. The diamond symbols represent the raw parametric data and the asterisk represents the average total mercury capture observed during the long-term continuous injection trial.

Figure C-5 – Summary of Unadjusted and Adjusted ACI Performance Data

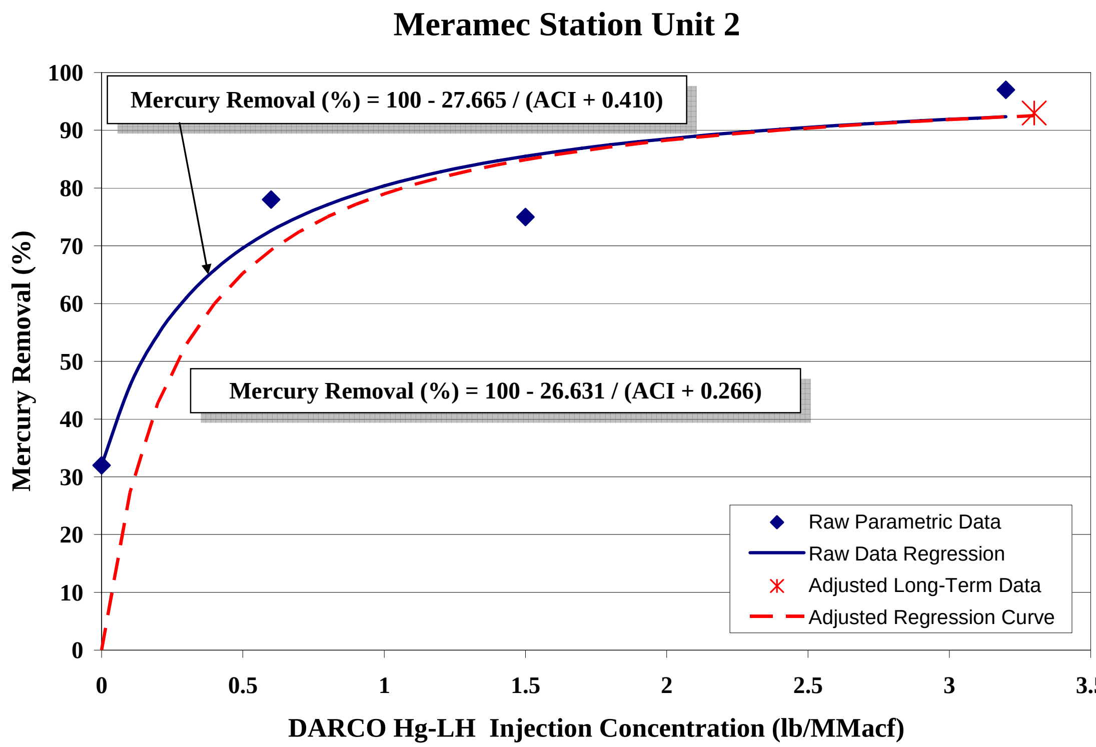


Meramec Station Unit 2

The entire data adjustment methodology was also applied to the parametric and average long-term performance data obtained during full-scale field testing at Meramec Station. Once again, the economics of mercury control are based on the performance of DARCO® Hg-LH. Injection upstream of the existing CS-ESP resulted in an average total mercury removal of 93% with an average DARCO® Hg-LH injection concentration of 3.3 lb/MMacf during the long-term continuous injection trial. The average level of long-term mercury control that is attributable to the injection of DARCO® Hg-LH was calculated to be 92.98% using a predicted baseline mercury capture of 0.27% for an injection concentration of 3.3 lb/MMacf. The final adjusted algorithm, derived from a statistical regression, is shown below. Details of the regression results are provided in Appendix E of this report.

$$\%\,Hg\,\mathrm{Re}moval\;due\,to\;ACI = 100 - \frac{26.631}{ACI + 0.266}$$

The figure below displays the final adjusted regression curve (dashed curve) as well as the unadjusted parametric regression curve (solid curve) for Meramec Station Unit 2. The asterisk represents the average total mercury capture observed during the long-term continuous injection trial with DARCO® Hg-LH.

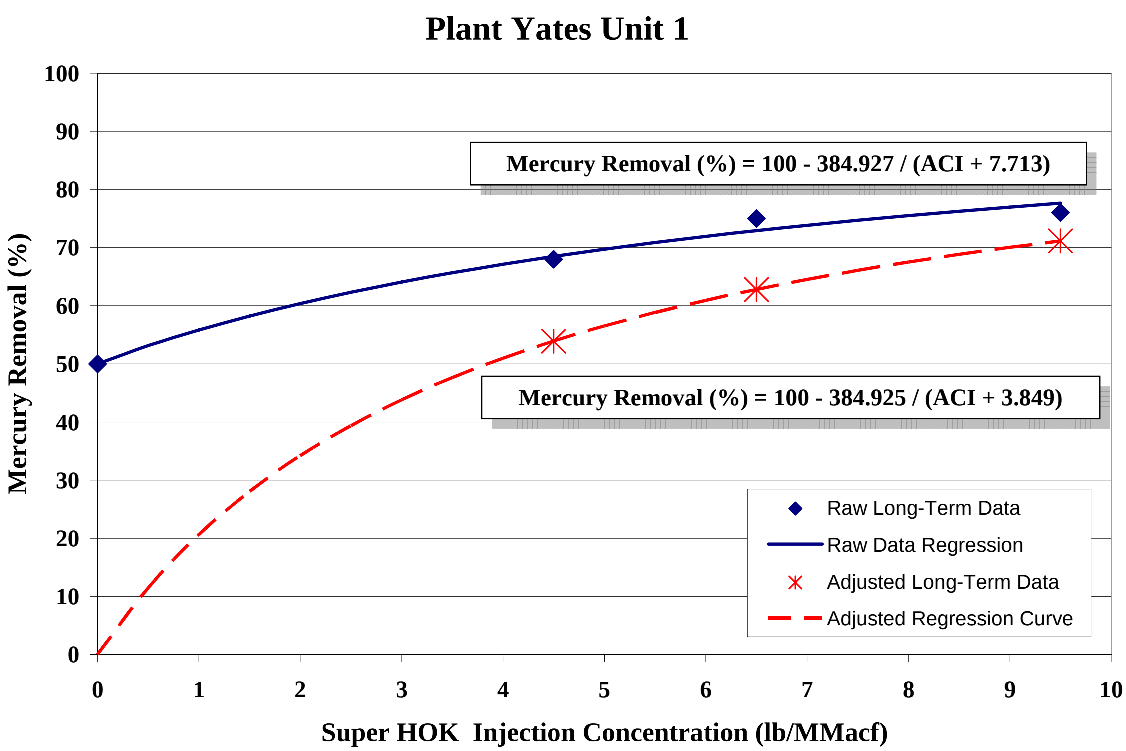


Plant Yates Unit 1

The economic analysis for Plant Yates is based on the performance of Super HOK during the long-term continuous injection trial since three distinct ACI concentrations were investigated over the 30-day period. Therefore, the average long-term data was simply adjusted to account for the baseline mercury removal of approximately 50% observed prior to the long-term test. The final adjusted algorithm, derived from a statistical regression, is shown below. Details of the regression results are provided in Appendix E of this report.

$$\% \, Hg \, \mathrm{Re}moval \, due \, to \, ACI = 100 - \frac{384.925}{ACI + 3.849}$$

The figure below displays the final adjusted regression curve (dashed curve) as well as the unadjusted raw regression curve (solid curve) for Plant Yates Unit 1. The asterisks represent the average long-term mercury capture that is directly attributable to the injection of Super HOK.



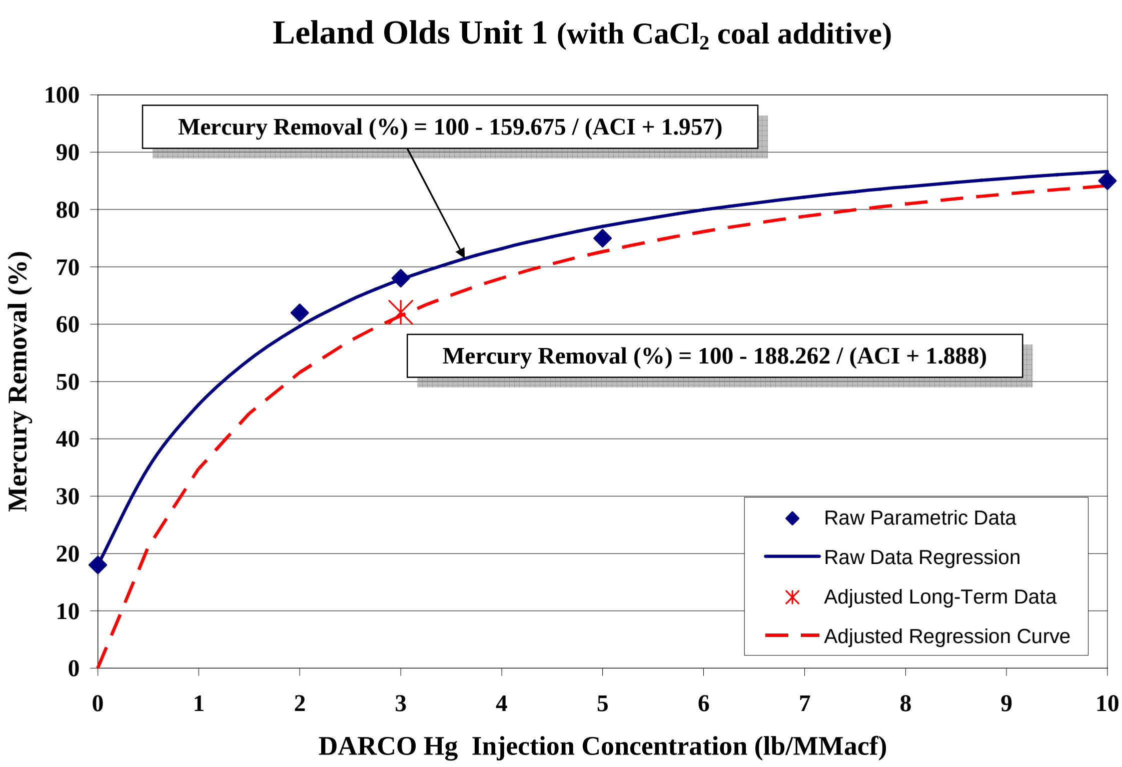
Leland Olds Unit 1

The economic analysis is intended to show the mercury capture efficiency of DARCO® Hg when the low-rank coal is treated with an aqueous $CaCl_2$ solution at a constant rate that is equivalent to adding approximately 500 ppm chlorine to the coal prior to combustion. To complete this analysis, the entire data adjustment methodology shown for Holcomb Station was completed. During long-term testing, an average DARCO® Hg injection concentration of 3 lb/MMacf coupled with $CaCl_2$ coal treatment was required to achieve 63% total mercury removal. The average level of long-term mercury control that is attributable to the mercury-specific control technologies was calculated to be 62.07% using a predicted baseline mercury capture of 2.45% for an injection concentration of 3 lb/MMacf.

The final adjusted algorithm, derived from a statistical regression, is shown below. For this analysis, the adjusted algorithm actually yields the level of mercury control that is attributable to the co-injection of an aqueous $CaCl_2$ solution onto the coal and DARCO® Hg into the flue gas upstream of the existing CS-ESP. Details of the regression results are provided in Appendix E of this report.

$$\% \, Hg \, \mathrm{Re}\, moval \; due \, to \; ACI = 100 - \frac{188.262}{ACI + 1.888}$$

The figure below displays the final adjusted regression curve (dashed curve) as well as the unadjusted parametric regression curve (solid curve) for Leland Olds Unit 1. The asterisk represents the average long-term mercury capture that is directly attributable to the co-injection of an aqueous $CaCl_2$ solution and DARCO® Hg.

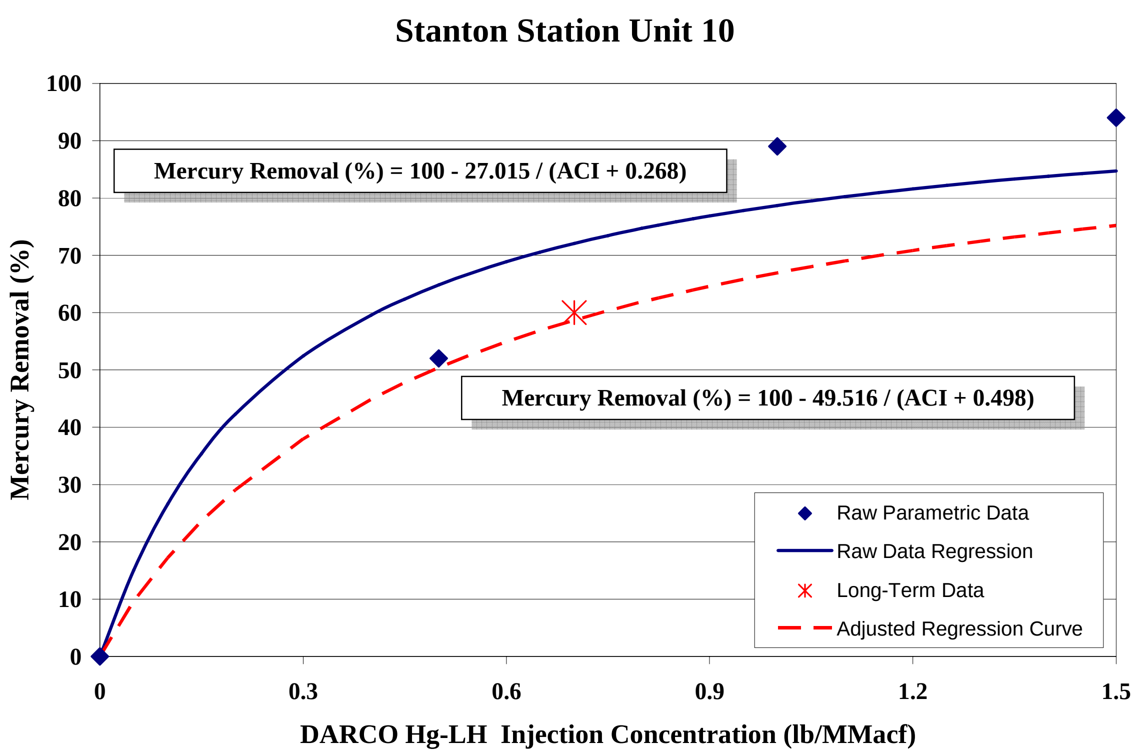


Stanton Station Unit 10

During full-scale field testing, baseline mercury capture across the SDA/FF configuration was 0% throughout the parametric testing campaign. Therefore, the raw parametric regression curve was simply scaled to include the average long-term results where 60% mercury capture was observed at an average DARCO® Hg-LH injection concentration of 0.7 lb/MMacf. The final adjusted algorithm, derived from a statistical regression, is shown below. Details of the regression results are provided in Appendix E of this report.

$$\%\,Hg\,\mathrm{Re}\,moval\;due\;to\;ACI = 100 - \frac{49.516}{ACI + 0.498}$$

The figure below displays the final adjusted regression curve (dashed curve) as well as the unadjusted parametric regression curve (solid curve) for Stanton Station Unit 10. The asterisk represents the average total mercury capture observed during the long-term continuous injection trial with DARCO® Hg-LH.

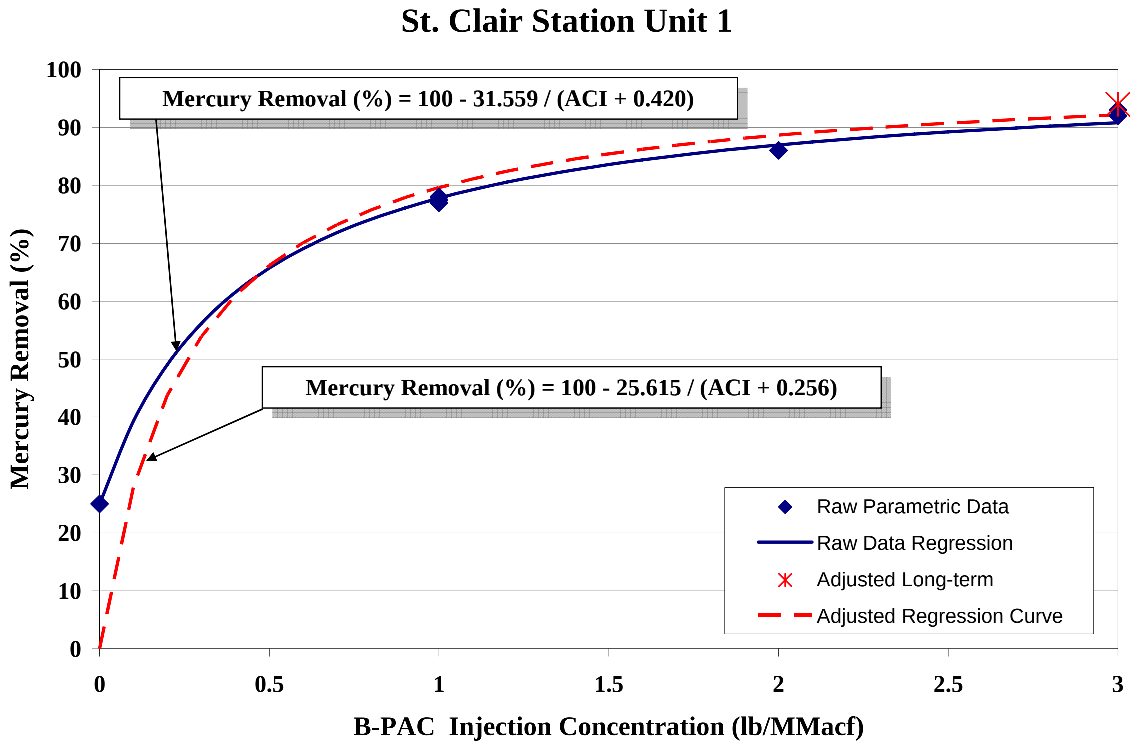


St. Clair Station Unit 1

The entire data adjustment methodology was also applied to the parametric and average long-term performance data obtained during full-scale field testing at St. Clair Station. The economics of mercury control for this unit are based on the performance of B-PAC™. Injection upstream of the existing CS-ESP resulted in an average total mercury removal of 94% with an average B-PAC™ injection concentration of 3 lb/MMacf during the long-term continuous injection trial. The average level of long-term mercury control that is attributable to the injection of B-PAC™ was calculated to be 93.98% using a predicted baseline mercury capture of 0.28% for an injection concentration of 3 lb/MMacf. The final adjusted algorithm, derived from a statistical regression, is shown below. Details of the regression results are provided in Appendix E of this report.

$$\% \, Hg \, Removal \, due \, to \, ACI = 100 - \frac{25.615}{ACI + 0.256}$$

The figure below displays the final adjusted regression curve (dashed curve) as well as the unadjusted parametric regression curve (solid curve) for St. Clair Station Unit 1. The asterisk represents the average total mercury capture observed during the long-term continuous injection trial with B-PAC™.



APPENDIX D

Capital Cost Estimates

Activated Carbon Storage and Injection System

As part of the DOE/NETL Phase II field testing program, ADA-ES recently completed economic evaluations of mercury control via ACI based on the results obtained during full-scale testing at the Holcomb and Meramec Stations.[11,12] With input obtained from NORIT Americas, which has built and installed dozens of similar systems at waste-to-energy and incineration plants, ADA-ES provided estimates for the total capital cost required to install a full-scale PAC storage and injection system. These estimates were used to approximate the capital costs required to retrofit similar ACI systems at the other Phase II field testing sites included in this economic analysis.

The total direct cost (TDC) for the ACI system is calculated as the sum of the following cost components:

(1) *Uninstalled equipment cost* (e.g., bulk storage silo, pneumatic conveying systems, foundations, distribution manifold, injection lances, etc.);
(2) Materials and labor associated with *site integration* (e.g., electrical supply upgrades, process control integration, instrument air, adequate lighting, etc.);
(3) *Sales tax* of 6%; and
(4) *Installation costs* that can vary significantly depending on plant-specific retrofit issues.

The indirect costs were estimated as percentages of the TDC using the EPRI TAG™ methodology. For instance, 10% of the TDC was set aside for general facility fees as well as engineering fees. The project contingency was calculated as 15% of the TDC, while 5% was used for the process contingency since the technology is relatively simple. The total capital requirement (TCR) for the ACI system is calculated with the inclusion of indirect costs and contingencies. However, the capital cost required to install and calibrate a mercury monitoring system were excluded from this economic analysis. The TCR is commonly expressed as a function of unit capacity ($/kW). Note that no adjustments were made for interest during construction since the ACI system can be installed in a few months.

Table D-1 provides a detailed breakdown of the individual cost components used to calculate the TCR for the ACI systems. Upon inspection of this table, the reader should note that the overall TCR for each of the Phase field testing units included in this economic analysis is only slightly dependent on unit capacity. However, the TCR values expressed as a function of unit capacity range from $3.63/kW for the 360 MW Holcomb Station Unit 1 to $21.10/kW for the 60 MW Stanton Station Unit 10.

The relative significance of the fixed capital and annual O&M costs to the 20-year levelized incremental increase in COE when byproduct impacts are excluded is shown in Table D-2. The levelized costs shown below correspond to the highest level of mercury control achieved by the final adjusted non-linear algorithms discussed in Appendix C. In general, the increase in COE is dominated by annual O&M costs that are driven by PAC consumption expenditures. The inclusion of byproduct impacts would have no effect on the fixed capital cost, but the annual O&M costs would rise leading to a larger increase in the 20-year levelized incremental cost of COE.

Table D-1 – Itemized Capital Cost Estimates for ACI Technology

Unit	Holcomb Unit 1	Meramec Unit 2	Yates Unit 1	Leland Olds Unit 1	Stanton Unit 10	St. Clair Unit 1
ACI Equipment	$711,000	$696,000	$691,000	$706,000	$691,000	$696,000
Installed SEA Equipment	N/A	N/A	N/A	$100,000	N/A	N/A
Site Integration	$51,900	$50,800	$50,400	$51,500	$50,400	$50,800
Installation	$124,000	$124,000	$118,000	$120,000	$118,000	$119,000
Taxes	$45,800	$44,800	$44,500	$45,500	$44,500	$44,800
Indirects / Contingencies	$373,000	$366,000	$362,000	$370,000	$362,000	$364,000
TCR, $	$1,306,000	$1,282,000	$1,266,000	$1,393,000	$1,266,000	$1,275,000
TCR, $/kW	$3.63	$9.16	$12.66	$6.33	$21.10	$8.79

Table D-2 - 20-Year Levelized Incremental Increase in COE (mills/kWh) - $Current

Unit	Holcomb Unit 1	Meramec Unit 2	Yates Unit 1	Leland Olds Unit 1	Stanton Unit 10	St. Clair Unit 1
ACI Hg Removal (%)	90%	90%	70%	70%	70%	90%
Fixed Cost, mills/kWh	0.06	0.15	0.21	0.11	0.35	0.15
O&M Cost, mills/kWh	0.31	0.84	1.51	1.14	0.67	0.91
Total Cost, mills/kWh	0.37	0.99	1.72	1.25	1.02	1.06

APPENDIX E

Non-Linear Regression Analysis

Holcomb Station Unit 1
Raw Parametric Data - Nonlinear Regression Analysis

Iteration History [b]

Iteration Number	Residual Sum of Squares	Parameter A	Parameter B
1.0	3589.351	4.400	.400
1.1	1445.021	34.747	1.276
2.0	1445.021	34.747	1.276
2.1	70593.264	22.580	-.801
2.2	145.851	37.098	.700
3.0	145.851	37.098	.700
3.1	54.243	36.141	.555
4.0	54.243	36.141	.555
4.1	48.180	36.329	.578
5.0	48.180	36.329	.578
5.1	48.167	36.404	.581
6.0	48.167	36.404	.581
6.1	48.167	36.408	.581
7.0	48.167	36.408	.581
7.1	48.167	36.409	.581

Derivatives are calculated numerically.

b. Run stopped after 15 model evaluations and 7 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
A	36.409	8.654	-.826	73.643
B	.581	.154	-.080	1.242

Correlations of Parameter Estimates

	A	B
A	1.000	.957
B	.957	1.000

ANOVA [a]

Source	Sum of Squares	df	Mean Squares
Regression	21899.833	2	10949.917
Residual	48.167	2	24.083
Uncorrected Total	21948.000	4	
Corrected Total	1784.000	3	

Dependent variable: VAR00003

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .973.

Holcomb Station Unit 1

Adjusted Parametric & Long-Term Data - Nonlinear Regression Analysis

Iteration History [b]

Iteration Number	Residual Sum of Squares	Parameter A	Parameter B
1.0	1309.364	40.000	.400
1.1	705.360	1.907	.017
2.0	705.360	1.907	.017
2.1	445.698	5.178	.047
3.0	445.698	5.178	.047
3.1	302.055	8.260	.079
4.0	302.055	8.260	.079
4.1	265.367	11.543	.114
5.0	265.367	11.543	.114
5.1	264.046	11.496	.115
6.0	264.046	11.496	.115
6.1	264.046	11.492	.115
7.0	264.046	11.492	.115
7.1	264.046	11.492	.115

Derivatives are calculated numerically.

b. Run stopped after 14 model evaluations and 7 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
A	11.492	6.681	-9.769	32.752
B	.115	.068	-.101	.331

Correlations of Parameter Estimates

	A	B
A	1.000	.987
B	.987	1.000

ANOVA[a]

Source	Sum of Squares	df	Mean Squares
Regression	36587.601	2	18293.801
Residual	264.046	3	88.015
Uncorrected Total	36851.647	5	
Corrected Total	7790.332	4	

Dependent variable: VAR00002

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .966.

Meramec Station Unit 2

Raw Parametric Data - Nonlinear Regression Analysis

Iteration History[b]

Iteration Number	Residual Sum of Squares	Parameter A	Parameter B
1.0	1429.372	40.000	.400
1.1	161.905	27.617	.406
2.0	161.905	27.617	.406
2.1	161.663	27.648	.409
3.0	161.663	27.648	.409
3.1	161.663	27.663	.410
4.0	161.663	27.663	.410
4.1	161.663	27.665	.410

Derivatives are calculated numerically.

b. Run stopped after 8 model evaluations and 4 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
A	27.665	11.990	-23.925	79.254
B	.410	.194	-.423	1.242

Correlations of Parameter Estimates

	A	B
A	1.000	.961
B	.961	1.000

ANOVA[a]

Source	Sum of Squares	df	Mean Squares
Regression	21980.337	2	10990.169
Residual	161.663	2	80.831
Uncorrected Total	22142.000	4	
Corrected Total	2261.000	3	

Dependent variable: VAR00002

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .928.

Meramec Station Unit 2
Adjusted Parametric & Long-Term Data - Nonlinear Regression Analysis

Iteration History[b]

Iteration Number	Residual Sum of Squares	Parameter	
		A	B
1.0	133.304	40.000	.400
1.1	2.928	24.980	.250
2.0	2.928	24.980	.250
2.1	.281	26.610	.266
3.0	.281	26.610	.266
3.1	.281	26.631	.266
4.0	.281	26.631	.266
4.1	.281	26.631	.266
5.0	.281	26.631	.266
5.1	.281	26.631	.266

Derivatives are calculated numerically.

b. Run stopped after 10 model evaluations and 5 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
A	26.631	.388	24.959	28.302
B	.266	.004	.249	.284

Correlations of Parameter Estimates

	A	B
A	1.000	.970
B	.970	1.000

ANOVA[a]

Source	Sum of Squares	df	Mean Squares
Regression	20646.840	2	10323.420
Residual	.281	2	.140
Uncorrected Total	20647.120	4	
Corrected Total	5385.359	3	

Dependent variable: VAR00002

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = 1.000.

Plant Yates Unit 1
Raw Data - Nonlinear Regression Analysis

Iteration History[b]

Iteration Number	Residual Sum of Squares	Parameter A	Parameter B
1.0	3636.724	4.400	.400
1.1	2507.508	184.347	15.341
2.0	2507.508	184.347	15.341
2.1	6939.842	200.959	-31.330
2.2	282.914	277.918	7.246
3.0	282.914	277.918	7.246
3.1	8.242	383.971	7.827
4.0	8.242	383.971	7.827
4.1	7.260	384.937	7.711
5.0	7.260	384.937	7.711
5.1	7.260	384.927	7.713
6.0	7.260	384.927	7.713
6.1	7.260	384.927	7.713

Derivatives are calculated numerically.

b. Run stopped after 13 model evaluations and 6 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
A	384.927	39.166	216.410	553.445
B	7.713	.952	3.615	11.811

Correlations of Parameter Estimates

	A	B
A	1.000	.962
B	.962	1.000

ANOVA[a]

Source	Sum of Squares	df	Mean Squares
Regression	18517.740	2	9258.870
Residual	7.260	2	3.630
Uncorrected Total	18525.000	4	
Corrected Total	434.750	3	

Dependent variable: VAR00003

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .983.

Plant Yates Unit 1
Adjusted Data - Nonlinear Regression Analysis

Iteration History [b]

Iteration Number	Residual Sum of Squares	Parameter A	Parameter B
1.0	3116.517	40.000	.400
1.1	235.942	256.402	2.564
2.0	235.942	256.402	2.564
2.1	3.250	367.896	3.679
3.0	3.250	367.896	3.679
3.1	.001	384.634	3.846
4.0	.001	384.634	3.846
4.1	.000	384.925	3.849
5.0	.000	384.925	3.849
5.1	.000	384.925	3.849
6.0	.000	384.925	3.849
6.1	.000	384.925	3.849

Derivatives are calculated numerically.

b. Run stopped after 12 model evaluations and 6 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008, and the relative reduction between successive parameter estimates is at most PCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
A	384.925	.003	384.913	384.938
B	3.849	.000	3.849	3.849

Correlations of Parameter Estimates

	A	B
A	1.000	.947
B	.947	1.000

ANOVA[a]

Source	Sum of Squares	df	Mean Squares
Regression	11727.819	2	5863.909
Residual	.000	2	.000
Uncorrected Total	11727.819	4	
Corrected Total	3049.965	3	

Dependent variable: VAR00002

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = 1.000.

Leland Olds 1
Raw Parametric Data - Nonlinear Regression Analysis

Iteration History[b]

Iteration Number	Residual Sum of Squares	Parameter A	Parameter B
1.0	8089.289	4.400	.400
1.1	6028.176	115.114	7.886
2.0	6028.176	115.114	7.886
2.1	14185.382	142.217	-18.491
2.2	85.574	164.554	2.247
3.0	85.574	164.554	2.247
3.1	14.503	159.051	1.918
4.0	14.503	159.051	1.918
4.1	12.652	159.570	1.955
5.0	12.652	159.570	1.955
5.1	12.651	159.670	1.957
6.0	12.651	159.670	1.957
6.1	12.651	159.675	1.957
7.0	12.651	159.675	1.957
7.1	12.651	159.675	1.957

Derivatives are calculated numerically.

b. Run stopped after 15 model evaluations and 7 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
A	159.675	9.851	128.326	191.024
B	1.957	.142	1.505	2.408

Correlations of Parameter Estimates

	A	B
A	1.000	.943
B	.943	1.000

ANOVA[a]

Source	Sum of Squares	df	Mean Squares
Regression	21629.349	2	10814.675
Residual	12.651	3	4.217
Uncorrected Total	21642.000	5	
Corrected Total	2669.200	4	

Dependent variable: VAR00003

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .995.

Leland Olds 1

Adjusted Parametric & Long-Term Data - Nonlinear Regression Analysis

Iteration History[b]

Iteration Number	Residual Sum of Squares	Parameter A	Parameter B
1.0	2239.509	40.000	.400
1.1	154.143	138.654	1.387
2.0	154.143	138.654	1.387
2.1	8.941	182.556	1.828
3.0	8.941	182.556	1.828
3.1	7.381	188.105	1.886
4.0	7.381	188.105	1.886
4.1	7.380	188.259	1.888
5.0	7.380	188.259	1.888
5.1	7.380	188.262	1.888
6.0	7.380	188.262	1.888
6.1	7.380	188.262	1.888

Derivatives are calculated numerically.

b. Run stopped after 12 model evaluations and 6 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
A	188.262	7.305	165.013	211.511
B	1.888	.086	1.615	2.160

Correlations of Parameter Estimates

	A	B
A	1.000	.943
B	.943	1.000

ANOVA[a]

Source	Sum of Squares	df	Mean Squares
Regression	18550.599	2	9275.299
Residual	7.380	3	2.460
Uncorrected Total	18557.979	5	
Corrected Total	4087.500	4	

Dependent variable: VAR00002

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .998.

Stanton Station Unit 10
Raw Parametric Data - Nonlinear Regression Analysis

Iteration History [b]

Iteration Number	Residual Sum of Squares	Parameter A	Parameter B
1.0	9854.876	4.400	.400
1.1	57859.289	23.663	-1.140
1.2	4373.061	6.864	.150
2.0	4373.061	6.864	.150
2.1	1352.967	9.064	.108
3.0	1352.967	9.064	.108
3.1	756.593	13.008	.132
4.0	756.593	13.008	.132
4.1	443.448	19.927	.198
5.0	443.448	19.927	.198
5.1	357.536	27.147	.270
6.0	357.536	27.147	.270
6.1	357.413	26.992	.268
7.0	357.413	26.992	.268
7.1	357.412	27.018	.268
8.0	357.412	27.018	.268
8.1	357.412	27.014	.268
9.0	357.412	27.014	.268
9.1	357.412	27.015	.268

Derivatives are calculated numerically.

b. Run stopped after 19 model evaluations and 9 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
A	27.015	11.648	-23.102	77.132
B	.268	.125	-.269	.805

Correlations of Parameter Estimates

	A	B
A	1.000	.959
B	.959	1.000

ANOVA [a]

Source	Sum of Squares	df	Mean Squares
Regression	19103.588	2	9551.794
Residual	357.412	2	178.706
Uncorrected Total	19461.000	4	
Corrected Total	5654.750	3	

Dependent variable: VAR00003

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .937.

Stanton Station Unit 10
Adjusted Parametric & Long-Term Data - Nonlinear Regression Analysis

Iteration History[b]

Iteration Number	Residual Sum of Squares	Parameter	
		A	B
1.0	122.194	40.000	.400
1.1	39.850	48.495	.487
2.0	39.850	48.495	.487
2.1	39.073	49.473	.498
3.0	39.073	49.473	.498
3.1	39.071	49.515	.498
4.0	39.071	49.515	.498
4.1	39.071	49.516	.498
5.0	39.071	49.516	.498
5.1	39.071	49.516	.498

Derivatives are calculated numerically.

b. Run stopped after 10 model evaluations and 5 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
A	49.516	4.148	36.314	62.718
B	.498	.050	.339	.658

Correlations of Parameter Estimates

	A	B
A	1.000	.939
B	.939	1.000

ANOVA[a]

Source	Sum of Squares	df	Mean Squares
Regression	15732.895	2	7866.447
Residual	39.071	3	13.024
Uncorrected Total	15771.966	5	
Corrected Total	3276.365	4	

Dependent variable: VAR00002

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .988.

St. Clair Station Unit 1
Raw Parametric Data - Nonlinear Regression Analysis

Iteration History[b]

Iteration Number	Residual Sum of Squares	Parameter	
		A	B
1.0	5820.850	4.400	.400
1.1	291.969	31.549	.538
2.0	291.969	31.549	.538
2.1	60.707	30.843	.375
3.0	60.707	30.843	.375
3.1	8.694	31.480	.415
4.0	8.694	31.480	.415
4.1	8.209	31.560	.420
5.0	8.209	31.560	.420
5.1	8.209	31.559	.420
6.0	8.209	31.559	.420
6.1	8.209	31.559	.420

Derivatives are calculated numerically.

b. Run stopped after 12 model evaluations and 6 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
A	31.559	1.070	28.941	34.177
B	.420	.017	.380	.461

Correlations of Parameter Estimates

	A	B
A	1.000	.922
B	.922	1.000

ANOVA[a]

Source	Sum of Squares	df	Mean Squares
Regression	49151.291	2	24575.646
Residual	8.209	6	1.368
Uncorrected Total	49159.500	8	
Corrected Total	3255.000	7	

Dependent variable: VAR00003

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .997.

St. Clair Station Unit 1
Adjusted Parametric & Long-Term Data - Nonlinear Regression Analysis

Iteration History[b]

Iteration Number	Residual Sum of Squares	Parameter A	Parameter B
1.0	337.787	40.000	.400
1.1	14.431	24.013	.240
2.0	14.431	24.013	.240
2.1	9.369	25.607	.256
3.0	9.369	25.607	.256
3.1	9.369	25.615	.256
4.0	9.369	25.615	.256
4.1	9.369	25.615	.256

Derivatives are calculated numerically.

b. Run stopped after 8 model evaluations and 4 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
A	25.615	.904	23.402	27.828
B	.256	.010	.232	.280

Correlations of Parameter Estimates

	A	B
A	1.000	.946
B	.946	1.000

ANOVA[a]

Source	Sum of Squares	df	Mean Squares
Regression	50687.156	2	25343.578
Residual	9.369	6	1.562
Uncorrected Total	50696.525	8	
Corrected Total	6622.611	7	

Dependent variable: VAR00002

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .999.

References

[1] See http://www.epa.gov/ttn/atw/utility/utiltoxpg.html

[2] Kilgroe, J.; Sedman, C.; Srivastava, R.; Ryan, J.; Lee, C.; Thorneloe, S. *Control of Mercury Emissions from Coal-Fired Electric Utility Boilers: Interim Report Including Errata Dated 3-21-02*; EPA-600/R-01-109; U.S. Environmental Protection Agency, April 2002.

[3] Feeley, T.J.; Murphy, J.T.; Hoffmann, J.W.; Granite, E.J.; and Renninger, S.A. DOE/NETL's Mercury Control Technology Research Program for Coal-Fired Power Plants; *EM* 2003, *October*, 16-23.

[4] *Field Test Program to Develop Comprehensive Design, Operating, and Cost Data for Mercury Control Systems;* Final Site Report for Pleasant Prairie Power Plant Unit 2 to the U.S. Department of Energy under Cooperative Agreement No. DE-FC26-00NT41005; ADA-ES, Inc., May 2003.
See http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

[5] Johnson, Dick. *TOXECON™ Retrofit for Mercury and Multi-Pollutant Control.* Proceedings of DOE/NETL's Mercury Control Technology R&D Program Review, Pittsburgh, PA, July 12-14, 2005.
See http://www.netl.doe.gov/publications/proceedings/05/Mercury/HgConf05.html

[6] *Control of Mercury Emissions from Coal Fired Electric utility Boilers: An Update*; U.S. Environmental Protection Agency, February 18, 2005.

[7] *Field Test Program to Develop Comprehensive Design, Operating, and Cost Data for Mercury Control Systems;* Final Site Report for E.C. Gaston Unit 3 to the U.S. Department of Energy under Cooperative Agreement No. DE-FC26-00NT41005; ADA-ES, Inc., May 2003. See http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

[8] *Field Test Program to Develop Comprehensive Design, Operating, and Cost Data for Mercury Control Systems;* Final Site Report for PG&E NEG Salem Harbor Station Unit 1 to the U.S. Department of Energy under Cooperative Agreement No. DE-FC26-00NT41005; ADA-ES, Inc., October 2004.
See http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

[9] *Field Test Program to Develop Comprehensive Design, Operating, and Cost Data for Mercury Control Systems;* Final Site Report for Brayton Point Generating Station Unit 1 to the U.S. Department of Energy under Cooperative Agreement No. DE-FC26-00NT41005; ADA-ES, Inc., March 17, 2005.
See http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

[10] Hoffmann, J., Ratafia-Brown, J. *Preliminary Cost Estimate of Activated Carbon Injection for Controlling Mercury Emissions from an Un-Scrubbed 500 MW Coal-Fired Power Plant.* Prepared for DOE/NETL's IEP Program, November 2003.

[11] *Evaluation of Sorbent Injection for Mercury Control;* Topical Report for Sunflower Electric's Holcomb Station Unit 1 to the U.S. Department of Energy under Cooperative Agreement No. DE-FC26-03NT41986; ADA-ES, Inc., June 28, 2005.
See http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

[12] *Evaluation of Sorbent Injection for Mercury Control;* Topical Report for AmerenUE's Meramec Station Unit 2 to the U.S. Department of Energy under Cooperative Agreement No. DE-FC26-03NT41986; ADA-ES, Inc., September 23, 2005.
See http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

[13] Dombrowski, K. et al. *Sorbent Injection for Mercury Control Upstream of Small-SCA ESPs.* Proceedings of the A&WMA/EPA/DOE/EPRI Combined Power Plant Air Pollutant Control Mega Symposium, Washington, DC, August 30-September 2, 2004.

[14] *Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas;* Quarterly Technical Report to the U.S. Department of Energy under Cooperative Agreement No. DE-FC26-03NT41987; URS Group, Inc., January 2005.
See http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

[15] Dombrowski, K. et al. *Full-Scale Evaluation of Activated Carbon Injection.* Proceedings of the Air Quality V Conference, Arlington, VA, September 19-21, 2005.

[16] Machalek, T. et al. *Full-Scale Activated Carbon Injection for Mercury Control in Flue Gas Derived from North Dakota Lignite.* Proceedings of the A&WMA/EPA/DOE/EPRI Combined Power Plant Air Pollutant Control Mega Symposium, Washington, DC, August 30-September 2, 2004.

[17] Thompson, J. et al. *Enhancing Carbon Reactivity for Mercury Control: Field Test Results from Leland Olds.* Proceedings of the A&WMA/EPA/DOE/EPRI Combined Power Plant Air Pollutant Control Mega Symposium, Washington, DC, August 30-September 2, 2004.

[18] *Enhancing Carbon Reactivity in Mercury Control in Lignite-Fired Systems.* Quarterly Technical Report to the U.S. Department of Energy under Cooperative Agreement No. DE-FC26-03NT41989; Energy & Environmental Research Center, University of North Dakota, February 2005.
See http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

[19] Dombrowski, K. et al. *Full-Scale Activated Carbon Injection for Mercury Control in Flue Gas Derived from North Dakota Lignite and PRB Coal.* Presented at the Air Quality V Conference, Arlington, VA, September 19-21, 2005.

[20] *Advanced Utility Mercury-Sorbent Field Testing Program.* Semi-Annual Technical Progress Report to the U.S. Department of Energy under Cooperative Agreement No. DE-FC26-03NT41990; Sorbent Technologies Corporation, April 2005.
See http://www.netl.doe.gov/technologies/coalpower/ewr/index.html

[21] URS Group, Inc. *Summary of Parametric Results at Yates #1*. Received via email from NETL Project Manager Dawn Deel, March 24, 2005.

[22] Email correspondence with NETL Project Manager Lynn Brickett, August 22, 2005.

[23] *Brominated Sorbents for Small Cold-Side ESPs, Hot-Side ESPs and Concrete*. Project Kickoff Meeting to the U.S. Department of Energy under Cooperative Agreement No. DE-FC26-04NT42308; Sorbent Technologies Corporation, November 29, 2005.

[24] Dodson, V.H., *Concrete Admixtures*, Van Nostrand Reinhold, New York, 1990.

[25] *Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas;* Quarterly Technical Report to the U.S. Department of Energy under Cooperative Agreement No. DE-FC26-03NT41987; URS Group, Inc., July 2005.
See http://www.netl.doe.gov/technologies/coalpower/ewr/index.html