

# **Full-Scale Evaluation of TOXECON II™ on a Lignite-Fired Boiler**

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## **ABSTRACT**

Activated carbon injection (ACI) has been successfully demonstrated to remove mercury from coal-fired power plant flue gas and reduce stack emissions. In conventional ACI, activated carbon can render the fly ash unsuitable for reuse as a cement admixture, which can result in lost revenues and increased waste disposal costs. A potential solution is EPRI's TOXECON II™, in which the carbon is injected between ESP collecting fields. The majority of the fly ash is collected in the inlet ESP fields upstream of carbon injection while collecting carbon with adsorbed mercury in the downstream ESP fields.

In November 2003, ADA-ES, Inc., conducted a full-scale evaluation of TOXECON II™ at Coal Creek Station through a program funded by Great River Energy and EPRI. This paper presents the results of this evaluation, including the effectiveness of activated carbon injected within the ESP for mercury control and the impacts on ESP performance and particulate emissions.

## INTRODUCTION

### **Background: Mercury Removal Across ESP on Units Burning Low-Rank Coals**

More than 50% of plants burning low-rank fuels use a cold-side electrostatic precipitator (CS-ESP) as the primary particulate collector (Sjostrom et al., 2003a). Results from the ICR effort and subsequent DOE NETL testing suggest that the native mercury removal for plants burning lignite or subbituminous coals with CS-ESPs is poor. The maximum removal by an ESP measured during the ICR effort was 28% on a plant burning a subbituminous coal and 7% on a plant burning lignite coal. Higher removal may be expected at plants with high LOI carbon in the ash.

Activated carbon injection (ACI) into the flue gas represents one of the simplest and most mature approaches to achieve enhanced control of mercury emissions from coal-fired boilers. The gas-phase mercury in the flue gas contacts the sorbent and attaches to its surface. The sorbent with the mercury attached is then collected by the existing particle control device, either a CS-ESP or fabric filter.

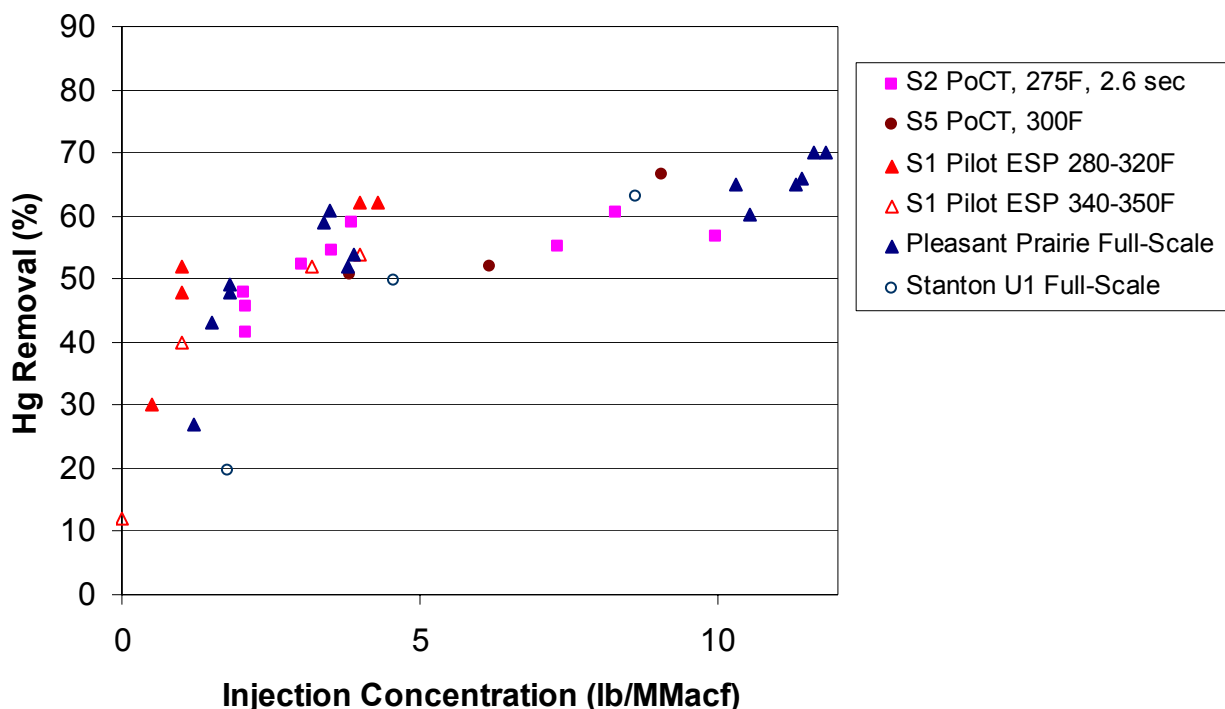
A full-scale evaluation of ACI upstream of the CS-ESP for mercury control was conducted at GRE's Stanton Station Unit 1 (Sjostrom, et al., 2003b). Stanton fires a North Dakota lignite coal. Native mercury removal measured was similar to other units included in the ICR selection. By injecting activated carbon upstream of the CS-ESP, the overall mercury removal increased but was limited to <70%. Earlier full-scale results from We Energies Pleasant Prairie Power Plant (P4) under a DOE program with EPRI co-sponsorship also suggest similar limited mercury removal using ACI injection upstream of an ESP on plants burning Western subbituminous coals. Results from these two sites and other EPRI slipstream evaluations at several subbituminous sites suggest that the average mercury removal achievable by injecting standard activated carbon is limited to <60% for units burning these low-rank fuels.

Results from the DOE evaluation at Pleasant Prairie (P4) (Starns et al., 2002) and EPRI slipstream tests at Pleasant Prairie and other subbituminous sites (P4, S1, S5) are summarized in Figure 1. The summary plot also includes data collected from the evaluation conducted at GRE's Stanton Station Unit 1. The data shown on the graph are identified as slipstream (10 acfm PoCT), pilot (160 acfm), or full-scale in the legend.

Coal Creek Station currently sells fly ash collected in their ESP for concrete use. An important lesson learned from the Pleasant Prairie ACI tests is that fly ash, which is usually a high-quality marketable ash, was rendered unusable for concrete applications as screened by the foam index test, when mixed with activated carbon. However, the byproduct did meet the criteria under TCLP and SGLP testing as a non-hazardous waste for disposal. Loss of ash sales is a concern for a significant portion of the industry. Approximately 33% of all fly ash produced from utility coal combustion is used for a variety of commercial applications such as concrete mixture, structural fills, waste stabilization, etc. The plants that are able to sell their fly ash are able to generate a multi-million dollar income from fly ash sales. An alternative to selling ash is land filling, which can become quite expensive. Loss of fly ash sales is a significant financial driver

when determining the feasibility of ACI for mercury control. Therefore, options that separate the bulk of the fly ash from the activated carbon are of interest. In practice, a majority of the fly ash is collected in the front fields of an ESP. Injecting sorbents after most of the ash is collected can protect this valuable byproduct for use as a cement admixture.

**Figure 1.** Summary of ACI Test Results: Low-Rank Fuels.

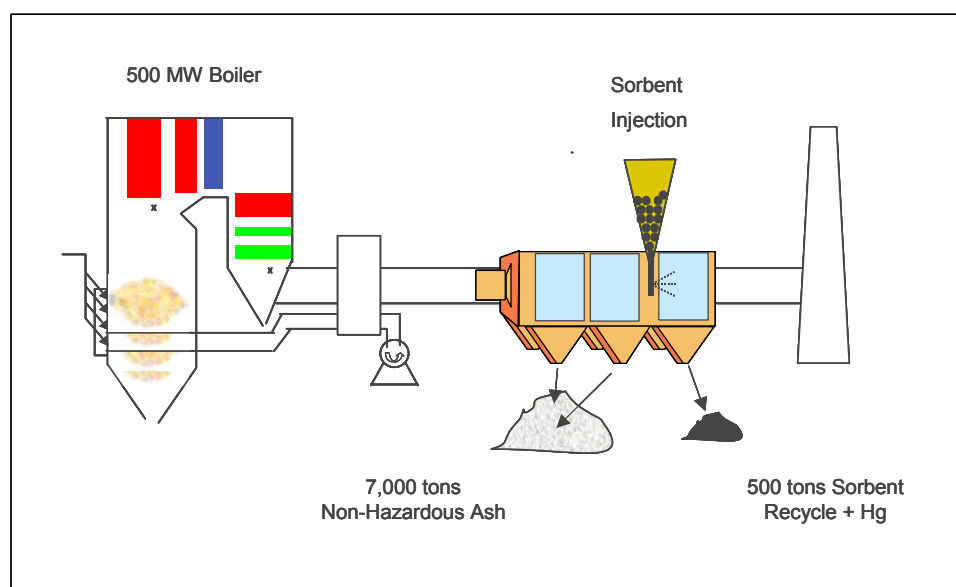


### Description of TOXECON II™

Significant strides have been made in recent years relative to ACI technology for control of mercury. Most of the testing performed to date involves injecting sorbent into flue gas upstream of a particulate control device. Under most conditions, if the carbon achieves good contact with the gaseous mercury for a sufficient amount of time, it will adsorb the mercury. The resulting mercury-laden carbon is then collected by the downstream particulate control equipment. This technology has been tested in two primary configurations: injection ahead of (1) the existing primary particulate collector (baghouse or ESP) (Durham et al., 2003), or (2) a baghouse added downstream of an existing ESP (called TOXECON™; an EPRI-patented technology) (Bustard et al., 2003). The TOXECON™ configuration offers an advantage over injecting carbon ahead of a single particulate control device because it prevents contaminating fly ash with carbon. Because the ESP is located upstream of the carbon injection location with TOXECON™, the ESP will have removed most of the fly ash from the flue gas before the flue gas is treated for mercury removal. This reduces the volume of activated carbon-contaminated fly ash to <5% of the total fly ash volume.

Although it is a highly effective configuration for removing mercury from flue gas, retrofitting existing plants with a baghouse can be expensive. An attractive alternative solution is EPRI's TOXECON II™ technology, in which the same effect can be achieved without a baghouse but instead uses the existing multi-field ESP alone (see Figure 2). In this configuration, carbon is injected within the ESP into downstream collecting fields. The majority of the fly ash is collected in the inlet ESP fields while carbon is injected in one or more downstream ESP fields. With this approach, most of the fly ash in the flue gas will have been collected in the first several fields (in general, 70%–90% of the ash in flue gas is collected in each field), and beneficial use of this ash is preserved since it will contain no carbon. The remaining fields of the ESP will then serve to collect the injected carbon.

**Figure 2.** TOXECON II™ Concept.



This technology is based on the fact that up to 90% removal of mercury can be achieved with a residence time of only one-half second as demonstrated on earlier ADA-ES programs funded by NETL (Martin et al., 2003). In an ESP, the gas velocity is 4–6 feet per second, so a one-half second residence time requires 2–3 feet of space. This amount of space is often available between sections of an ESP. Any ESP with multiple fields can potentially use this approach.

## FULL-SCALE EVALUATION OF TOXECON II™

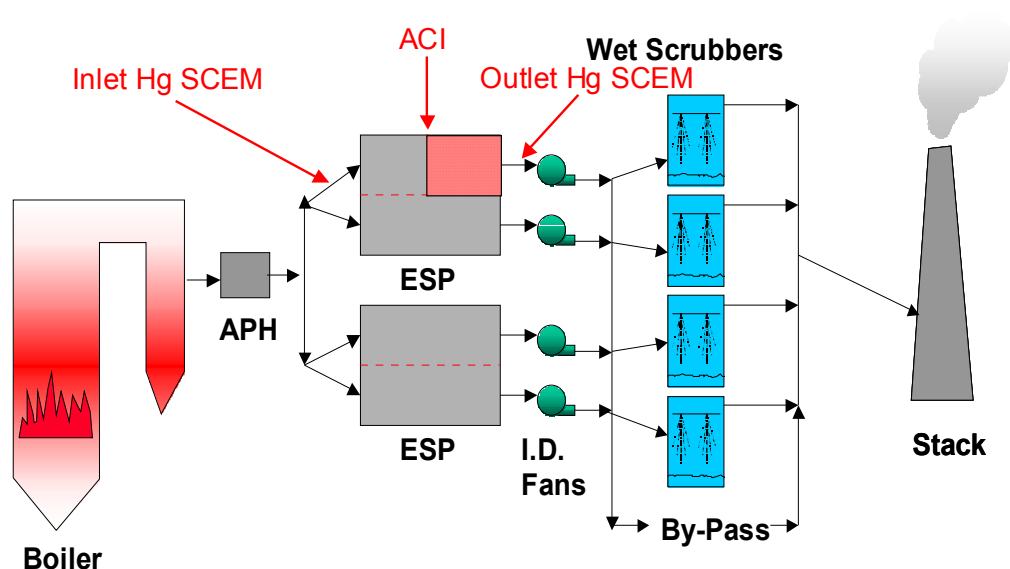
In November 2003, ADA-ES conducted the first full-scale evaluation of TOXECON II™ at Coal Creek Station through a program funded by Great River Energy and EPRI. GRE's Coal Creek Station (CCS) is located in Underwood, North Dakota. Mercury control testing at CCS was conducted on Unit 1. The boiler on the 546-MWg Unit 1 is a Combustion Engineering tangential-fired design that burns a North Dakota lignite coal.

The particulate control device for Unit 1 at CCS is an ESP manufactured by Wheelabrator-Frye Inc. The specific collecting area (SCA) calculated for the ESP is 599 ft<sup>2</sup>/1,000 cfm. The collecting system, comprised of six electrical fields, consists of numerous 18-gauge steel sheets

approximately 46 feet in length. Each electrical field is approximately 12.5 feet in length in the direction of gas flow. Inlet flue gas temperatures to the ESP range from 330 to 360°F, while the discharge temperatures from the ID fans range from 320 to 350°F depending on boiler load, air heater performance, and ambient temperatures.

The activated carbon was injected inside the ESP in between the third and fourth collecting fields. Vapor-phase mercury measurements were made at the inlet and outlet of the ESP. Figure 3 illustrates the flue gas path for Unit 1 and the testing locations. Coal Creek Station also utilizes a wet flue gas desulfurization system (WFGD) for SO<sub>2</sub> control.

**Figure 3.** Flue Gas Path—Coal Creek Station Unit 1.



## Equipment Description

### *Mercury Measurement*

Two semi-continuous mercury analyzers were used during this program to provide near real-time feedback during baseline and sorbent injection testing. Continuous mercury concentration measurements are considered critical components of a field mercury control program where mercury levels fluctuate with boiler operation (temperature, load, etc.) and decisions must be made concerning parameters such as sorbent feed rate.

The mercury analyzer consists of a cold vapor atomic absorption spectrometer (CVAAS) coupled with a gold amalgamation system (Au-CVAAS). The system is calibrated using vapor-phase elemental mercury. The analyzer determines total mercury concentrations by reducing all of the oxidized mercury to the elemental form upstream of the gold, or only elemental mercury concentrations by removing the oxidized mercury while allowing elemental mercury to pass through without being altered.

### ***Particulate Measurements***

During the evaluation, particulate emissions from the outlet of the ESP were measured using two different methods; a portable duct opacity probe and EPA Method 17 measurements.

The duct opacity monitor, manufactured by Lear Siegler, provides continuous, low maintenance, precision measurement of the optical density and opacity of smoke and dust emissions. This instrument outputs a 4–20 mA signal representing optical density and opacity. The current signal was measured and logged every 30 seconds using a data logger.

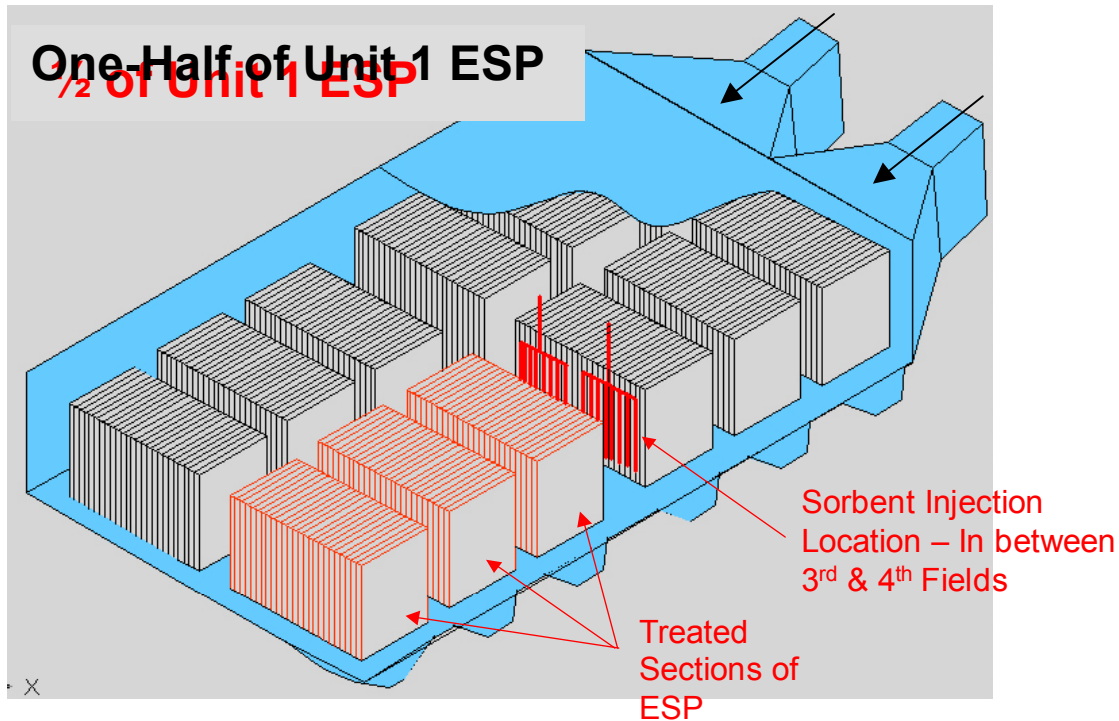
The outlet particulate emissions were also measured using the US-EPA Method 17 during two days of testing (six runs). This testing method was used to determine the concentration of particulate matter at the outlet of the ESP during normal operating conditions (baseline), and during the activated carbon injection tests. Three sampling runs were conducted during each test condition.

### ***Sorbent (Activated Carbon) Feeder and Sorbent Injection Grid***

The activated carbon injection (ACI) system used at CCS consisted of two Porta-PAC dosing systems and two carbon injection grids. The Porta-PACs, supplied by NORIT Americas, pneumatically convey a predetermined and adjustable amount of powdered activated carbon (PAC) from bulk bags into the flue gas stream via a sorbent injection grid. The units PAC is metered using a volumetric feeder into a pneumatic eductor, where the air supplied from the regenerative blower provides the motive force needed to transport the carbon to the final injection locations. Each feeder can deliver from 20 to 350 lbs/hr of activated carbon. Both feeders were located inside the penthouse of the ESP.

Two carbon injection grids were placed inside one-half of one of the two Unit 1 ESPs between the third and fourth collecting fields. Each Porta-PAC dosing system delivered the PAC to one of the injection grids. The carbon injection grids were designed such that a relatively equal amount of PAC discharged through each nozzle along the length of the lances. This arrangement, which treated one-fourth of the Unit 1 flue gas, is shown in Figure 4 with the gas flow exiting the ESP in the lower left corner of the sketch. Refer to Figure 3 for an overall sketch of Unit 1. The combined injection grids covered approximately a 50'x 46' cross section inside the ESP.

**Figure 4.** Sketch of One-Half of Unit 1 ESP.



## Sorbent Descriptions

DARCO FGD, a Texas lignite coal-based activated carbon manufactured specifically for the removal of heavy metals and other contaminants typically found in incinerator flue gas emission streams, was included in the test matrix for Coal Creek. Its open pore structure and fine particle size permit rapid adsorption, which is critical for high performance in flue gas streams where contact times are short. Average particle size for DARCO FGD is  $19 \mu\text{m}_{\text{D}50}$  and it has a bulk density of 25–30 lbs/ft<sup>3</sup>. DARCO FGD has been tested during several lab-scale, pilot-scale, and full-scale demonstrations and is considered the benchmark sorbent for EPRI and DOE demonstrations.

The project team also evaluated the performance of CB 200xF, an iodine-impregnated carbon manufactured by Calgon/Barnebey Sutcliffe. Manufactured from coconut shells, this specialty-impregnated activated carbon was specifically designed to capture vapor-phase mercury from various mediums (e.g., liquid streams, incinerator flue gas). Data provided by Barnebey Sutcliffe showed an average bulk density of  $\sim 36 \text{ lbs/ft}^3$ , with an average particle size of  $35 \mu\text{m}_{\text{D}50}$ . Post-test analysis showed that the average particle size for the CB 200xF was  $87 \mu\text{m}$ . Table 1 shows the physical characteristics of the two sorbents that were used during the evaluation at CCS.

**Table 1.** Description of Sorbent Materials Tested at Coal Creek Station.

Name	Description	Bulk Density (lbs/ft <sup>3</sup> )	Particle Size Distribution*		
			D <sub>90</sub> (μm)	D <sub>50</sub> (μm)	D <sub>10</sub> (μm)
DARCO FGD	Texas Lignite – AC	20–30	44	19	<3
CB 200xF	Coconut Shell – AC	36	n/a	87	n/a

\* Percent of particles less than size in microns

## Test Description

Six days of testing were conducted on Coal Creek Station’s Unit 1. The first two days of tests were used to measure vapor-phase mercury concentrations at the inlet and outlet of the ESP (baseline). The remaining four days of testing were used to evaluate the effectiveness of sorbent injection inside the ESP for mercury control (parametric).

During the baseline testing series, there was no activated carbon injection inside the ESP. The unit was held steady at normal full load operating conditions, from nominally 7:00 a.m. to 7:00 p.m. In addition to the vapor-phase mercury measurements, outlet particulate emissions from the ESP were measured using a portable opacity monitor and US-EPA M-17.

Upon completion of the baseline testing series, the project team conducted activated carbon injection tests inside the ESP at various injection concentrations to develop a relationship between vapor-phase mercury capture and ACI. During the first three days of parametric testing the mercury removal performance of the benchmark sorbent, DARCO FGD, was characterized at five injection concentrations. During each day of testing, FGD was injected inside the ESP until the outlet mercury concentration approached a relatively constant value. The data collected was analyzed and compared to data from other full-scale demonstrations including Stanton Unit 1 (ND lignite coal) and Pleasant Prairie Power Plant (PRB coal).

During the final day of parametric testing, the project team injected an impregnated activated carbon into the ESP at three injection concentrations. The Porta-PAC dosing systems were calibrated prior to these parametric tests to ensure accurate feedrates, considering each sorbent had different physical characteristics.

In addition to the vapor-phase mercury measurements and outlet particulate emissions from the ESP, other operating parameters and solid samples were collected. The coal and fly ash samples were used to gather information about coal characteristics that may affect mercury capture, and to measure the mercury concentration in the coal and fly ash. Plant operating parameters were monitored each testing day (e.g., ESP operating conditions, stack opacity, Unit 1 Boiler load). The particulate measurements made at the outlet were used to help determine the impacts of ACI on ESP performance and other balance of plant issues.

## SUMMARY AND DISCUSSION OF RESULTS

### Baseline Results

The baseline testing series was conducted November 15–16, 2003. During this period, there was no activated carbon injection. Vapor-phase mercury concentrations were made at the inlet and outlet of the ESP.

All mercury concentrations presented herein are corrected to 3% O<sub>2</sub>. During the baseline tests, total inlet vapor-phase mercury concentrations ranged from 15 to 20 µg/dNm<sup>3</sup>, while the outlet ranged from 13 to 18 µg/dNm<sup>3</sup>. The native mercury removal efficiency across the ESP ranged from 5 to 20%, with an average vapor-phase mercury capture of 7.1%.

Speciation measurements were also made during testing. Table 2 shows the average results of the Hg SCEM measurements made at the inlet and outlet of the ESP during the baseline testing series.

**Table 2.** Average Hg SCEM Measurements—Baseline Testing Series.

Mercury Species	ESP Inlet	ESP Outlet	Removal Efficiency (%)
Hg <sup>++</sup> (Oxidized) (µg/dNm <sup>3</sup> )	3.4	4.7	-38.2
Hg <sup>0</sup> (Elemental) (µg/dNm <sup>3</sup> )	12.0	9.6	20.0
Total Vapor-Phase Hg (µg/dNm <sup>3</sup> )	15.4	14.3	7.1

### Parametric Results

Parametric testing showed mercury removal as a function of injection concentration and sorbent type. The impact of activated carbon injection on ESP performance was closely monitored.

The first three days of parametric tests used the benchmark DARCO FGD as the sorbent, and tested several injection rates from 1 to 15 lbs/MMacf. During these tests, vapor-phase mercury concentrations were measured at the inlet and outlet of the ESP. Prior to the injection of DARCO FGD, each Porta-PAC dosing system was calibrated to ensure accurate feedrates.

During the final day of parametric testing, the performance of an impregnated activated carbon was characterized at injection concentrations of 1, 3, and 10 lbs/MMacf. ESP inlet temperatures, as measured at the Hg SCEM extraction probe, were approximately 360°F, while temperatures at the ESP outlet measured 350°F. Sorbent injection rates were held steady until the outlet mercury concentration was stable.

The majority of the mercury control response was immediate upon starting injection. It was estimated that the activated carbon particles had approximately a one-second residence time in

between the third and fourth collecting fields, before the carbon particles entered the fourth collecting field. Once carbon injection was ceased, it took several hours before the outlet mercury concentrations returned to their baseline levels. This would indicate that the residual carbon particles inside the ESP had the capability to remove vapor-phase mercury for several hours.

One of the surprising trends seen during the parametric tests was the higher than expected mercury capture at the lower injection concentrations. On November 19, the DARCO FGD carbon was injected at 1 and 3 lbs/MMacf with an average mercury removal efficiency of 46 and 58% respectively. These points can be seen in Figure 5, which shows the results of the carbon injection tests during the parametric testing series.

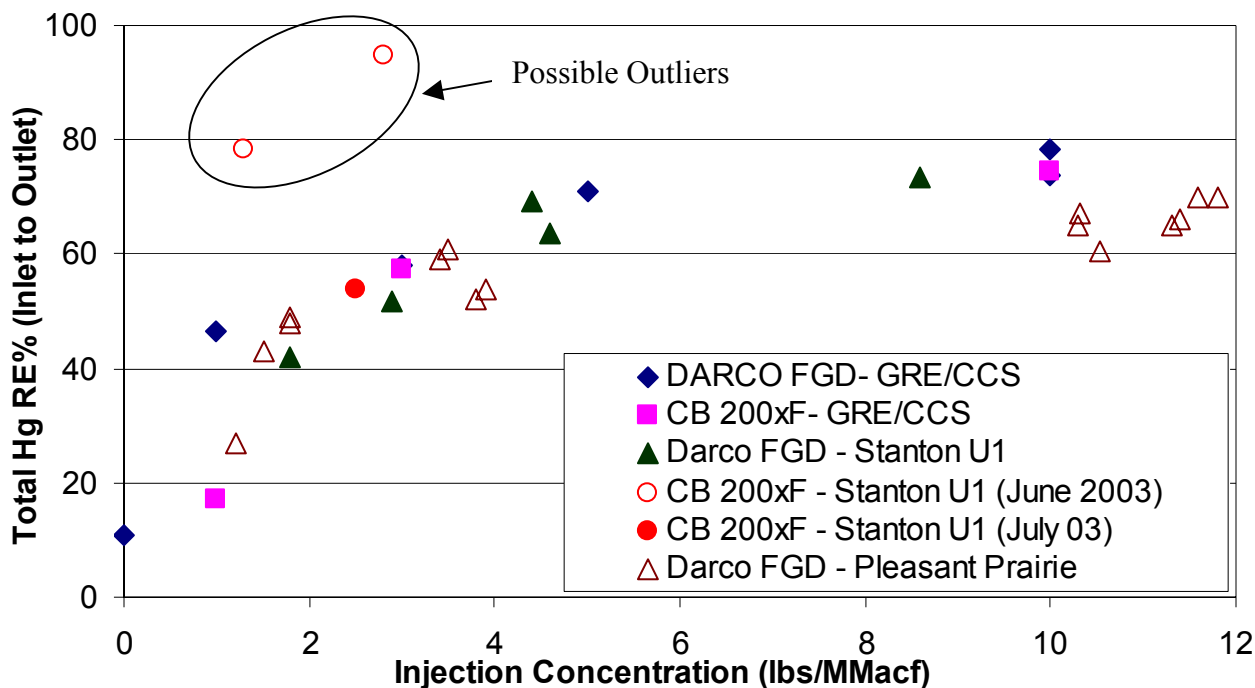
One of the interesting observations made during the parametric test series is that the impregnated carbon did not show an increase in mercury capture compared to the DARCO FGD sorbent. A possible explanation for the lack of increased performance with the impregnated carbon at Coal Creek could be attributed to flue gas temperature. Typical SDA outlet temperatures at Stanton Unit 10 are <225°F, while the flue gas temperatures at Coal Creek Unit 1 were in the range of 350 to 360°F. The vapor pressure of elemental iodine increases exponentially with temperature. Sublimation for elemental iodine begins around 212°F. At approximately 360°F, the vapor pressure for elemental iodine is approximately 1 atm (760 mm Hg). At the hotter flue gas temperatures, most of the iodine volatilizes and off-gases from the sorbent particle. During EPRI/GRE testing at Stanton Station Unit 1 in 2003, gas-phase iodine measurements were made while injecting iodine treated sorbents from three different vendors. Flue gas temperatures at the ESP inlet for Stanton Unit 1 were in the range of 330 to 340°F. During periods of no carbon injection, baseline iodine levels in the flue gas were <6.6 ppb<sub>v</sub>. While injecting the impregnated carbon from Calgon/Barnebey Sutcliffe CB 200xF, the flue gas iodine concentrations increased to approximately 350 ppb<sub>v</sub> (Sjostrom, et al., 2003b).

Another possible explanation for the lack of increased performance with the treated sorbent might be related to the sorbent's particle size. Data provided by Barnebey Sutcliffe showed an average particle size of the treated sorbent was 35 μm. However, post-test analysis showed that the average particle size for the CB 200xF was 87 μm. Both sorbents tested were injected at the same feedrates on a mass basis. Fifteen particles with a diameter of 35 μm have the same mass as one particle with a diameter of 87 μm. In addition, the surface area available for reaction on fifteen small particles will be 2.5 times higher than the single larger particle. When comparing the FGD (particle size = 18 μm) to the larger CB 200xF, the differences are even more pronounced (ratio of number of particles = 113:1, ratio of surface area = 4.9:1, not accounting for differences in sorbent density). Higher particle density and surface area should increase mercury capture. Therefore, it is likely that the lower than expected mercury removal effectiveness of the CB 200xF was influenced by the large particle size.

Combining the data sets from Stanton Station Unit 1 ACI testing in 2003 and the ACI evaluation at Coal Creek, the mercury removal trends fall on top of each other. For the most part, during the parametric testing series, maximum mercury removal efficiencies were in the range of 70 to 80%. Figure 5 shows the ACI results from Stanton Unit 1 and Coal Creek Unit 1. There are two data points from the Stanton data set on the graph, which suggest that mercury removal

efficiency can be greater than 80% with the injection of an impregnated sorbent. However, this performance was not repeatable in tests conducted with the same sorbent at a later date. Additional testing is scheduled at Stanton Unit 1 in 2005 to help determine the performance limits of ACI for mercury control for an ESP at temperatures <350°F.

**Figure 5.** ACI Results for Great River Energy’s Stanton Station Unit 1 and Coal Creek Station Unit 1 Compared to Pleasant Prairie.



### Byproduct Characterization

Grab samples of coal and fly ash were collected during the evaluation at Coal Creek. Given the short duration of testing, the samples collected may not be representative of testing conditions and may be subject to biased results. Additional testing is needed, with longer sorbent injection periods, to collect representative samples. Results from the coal analyses show an average mercury content of 0.117 µg/g.

Two fly ash samples were sent to the laboratory for analysis. One sample was collected during the baseline period and the other was collected during the parametric testing. Fly ash samples from the fourth collecting field in the testing lane show increased chlorine concentrations from 5 µg/g to 51 µg/g. The carbon content, as measured by a loss-on-ignition (LOI) test, also increased from 0.14% to 3.79%.

**Table 3.** Results from Fly Ash Analyses.

Date	Description	LOI, %	Chlorine, $\mu\text{g/g}$	Mercury, $\mu\text{g/g}$
11/15/2003	Row 4, ESP (Baseline)	0.14	5	0.0651
11/17/2003	Row 4, ESP (Parametric)	3.79	51	0.0642

## Balance of Plant Impacts

### *Particulate Emissions*

During the ACI evaluation, plant operating parameters (e.g., ESP operating conditions, stack opacity) were closely monitored. Outlet particulate emissions were also measured using a portable opacity monitor, and US-EPA Method 17 particulate tests were conducted.

When the outlet field (sixth row) is experiencing a rapping cycle, the duct opacity increases about 10% during the baseline series (no carbon injection). The rapping frequency for the outlet field is set up to rap every 165 minutes. During the parametric tests (with carbon injection), the amplitude associated with the outlet rapping spikes is increased from 10% to approximately 30%.

The stack opacity for Unit 1 during the evaluation did not show an incremental increase during periods of carbon injection. However, only one-fourth of Unit 1 flue gas stream was tested.

A qualitative indicator that activated carbon was passing through the ESP was the visible presence of carbon floating on top of the scrubber slurry. In addition to visual inspections, two sets of three particulate matter (PM) emissions tests were performed utilizing the US-EPA Method 17. These results also indicate an increase in particulate emissions from the ESP during periods of carbon injection. Tests were conducted at two injection concentrations: 5 and 10 lbs/MMacf. The average baseline emission was 0.027 gr/dscf. During the higher injection concentration tests (10 lb/MMacf), the average outlet emission was 0.054 gr/dscf, which is twice the average baseline PM emission. The M-17 results are snapshots and do not provide a clear picture of the potential causes of increased emissions. Based upon the opacity data, the carbon appeared to collect relatively well in the ESP and some was re-entrained during rapping. It may be possible to reduce the PM emissions resulting from rapping re-entrainment by optimizing the rapping sequence.

ESP electrical data was collected during the evaluation. The ESP electrical data does not have the capability to be logged automatically, but the project team was able to record a snapshot of the data every hour or so while on-site. An initial review of the data from the fourth field (immediately downstream of carbon injection) suggests that the power levels were quite low prior to starting carbon injection. Because the power levels in the fourth field were low prior to injection, it is difficult to assess the effects of carbon injection alone. After the second day of parametric testing (approximately seven hours after carbon injection had stopped), the T/R set located in the fifth field of U1-1W shorted out. This is possibly due to tracking-like symptoms

associated with carbon injection in the ESP. If this was the cause of the short, purge blowers could be added to minimize carbon buildup on the insulators. In order to clearly identify and quantify the impacts to ESP performance, further testing is needed. It is also suggested that the ESP data be collected on a more frequent basis during testing.

## CONCLUSIONS

A full-scale evaluation of mercury control using activated carbon injection inside a cold-side ESP was conducted at Great River Energy's Coal Creek Station Unit 1. This short proof-of-concept test answered many questions about the potential for mercury control at Coal Creek, and also pointed to several areas in which more information is needed.

The overall test conclusions are:

- Activated carbon injection at concentrations  $>2$  lbs/MMacf resulted in a reduction of mercury emissions of  $\geq 50\%$ .
- Activated carbon injection at concentrations  $\geq 5$  lbs/MMacf resulted in a reduction of mercury emissions up to  $\sim 70\%$ .
- Increasing sorbent injection concentration beyond 10 lbs/MMacf did not increase vapor-phase mercury capture.
- Iodated carbon (CB 200xF) from Calgon/Barnebey Sutcliffe showed no increase in mercury capture. This is likely due to duct temperatures near where the vapor pressure for elemental iodine is 1 atm and the iodine volatilizes from the carbon.
- Reduction in outlet mercury emissions occurred immediately upon starting carbon injection.
- Collected ESP electrical data was not sufficient to evaluate the effects of carbon injection on ESP performance. One T/R set tripped several hours following a high injection concentration period. This may have been a result of sorbent material depositing on insulators or other ESP components. Adding purge blowers may minimize sorbent deposition on insulators.
- Particulate emissions from the ESP increased during periods of carbon injection from an average of 0.027 gr/dscf to an average of 0.054 gr/dscf. Based upon opacity data, the carbon appeared to collect relatively well in the ESP and some was re-entrained during rapping. It may be possible to reduce the PM emissions resulting from rapping re-entrainment by optimizing the rapping sequence.

These full-scale tests demonstrated the viability of TOXECON II<sup>TM</sup>. The main advantages of this approach are:

- preservation of the large majority of fly ash sales,
- potential for sorbent recycle, regeneration and reuse,
- enhanced oxidation of elemental mercury to increase capture in a downstream scrubber,
- minimal capital cost, and
- minimizes amount of mercury-bearing byproducts that need processing or disposal.

Further research is required to better document impacts on ESP performance and options for optimization.

## **ACKNOWLEDGMENTS**

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