National Energy Technology Laboratory

DOE/NETL-2011/1450

TOXECON™ RETROFIT FOR MERCURY AND MULTI-POLLUTANT CONTROL ON THREE 90-MW COAL-FIRED BOILERS

A DOE Assessment

October 2010

U.S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory

DISCLAIMER

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EXECUTIVE SUMMARY

Starting in the mid 1980s, Congress created and funded a series of programs intended to demonstrate the market readiness of new coal-based technologies. These are the Clean Coal Technology (CCT) programs managed by the Department of Energy (DOE) at the National Energy Technology Laboratory (NETL). The first program, the Clean Coal Technology Demonstration Program (CCTDP), comprised five solicitations spanning the period from February 1986, when the first Program Opportunity Notice was issued, to February 2007, when the last Final Report was accepted. In 2001, a second program was introduced called the Power Plant Improvement Initiative (PPII) consisting of a single solicitation. The current program is the Clean Coal Power Initiative (CCPI). To date, three rounds of CCPI program solicitations have been completed. These demonstrations are conducted on a commercial scale to assess the commercial readiness of the technologies and to provide technical and financial information for future applications.

The primary objective of Round 1 of the CCPI (CCPI-1) was to demonstrate technologies that reduce emissions and improve efficiency and maintainability while extending the asset life of coal-based generation, thus bolstering the long-term viability of the United States' abundant coal resources. One of the projects selected in CCPI-1 was "TOXECON™ Retrofit for Mercury and Multi-Pollutant Control on Three 90-Mw Coal-Fired Boilers" that was proposed by We Energies. The project was awarded in April 2004 and was completed in September 2009. The host site was their Presque Isle Power Plant (PIPP) in Marquette, Michigan. Other team members included Cummins & Barnard, ADA Environmental Solutions (ADA-ES), Wheelabrator Air Pollution Control, Inc., and the Electric Power Research Institute (EPRI). ADA-ES provided program management support, design, and specifications for mercury control and monitoring equipment; Cummins & Barnard provided architect and engineering services and construction management; Wheelabrator Air Pollution Control, Inc. provided baghouse design and installation support; and EPRI, the developer and patent holder of TOXECON™, was a technical advisor to the project. Overall project management was

provided by We Energies with oversight by the DOE National Energy Technology Laboratory (NETL).

The project consisted of installing and operating the TOXECON™ technology. This technology involves injecting a mercury sorbent downstream of an existing particulate matter (PM) collector and collecting the spent sorbent, along with any fly ash that passes through the primary PM collector, in a new baghouse. The TOXECON™ technology is intended primarily for units currently equipped with a hot side electrostatic precipitator (HESP) but may be applied to units with a cold side electrostatic precipitator (ESP). Powdered activated carbon was the mercury sorbent used in this demonstration. Two types were primarily used—DARCO® Hg and DARCO® Hg-LH—the latter being an activated carbon that is impregnated with bromine. Some short-term testing was also done with alternate carbon-based sorbents.

The goals of the project were to:

- Demonstrate, over the long-term (three years), 90 percent removal of mercury from power plant flue gas using activated carbon injection.
- Demonstrate a reliable mercury continuous emission monitor system (CEMS) suitable for use in flue gas created by coal-fired power plants.
- Advance commercialization of the technology through successful operation and integration with the power plant.
- Evaluate trona (a naturally occurring sodium bicarbonate mineral) injection to reduce nitrogen oxides (NO_X) and capture 70 percent of sulfur dioxide (SO_2) emissions via the new bag house.
- Demonstrate recovery of mercury from the spent sorbent.
- Reduce particulate matter (PM) emissions via the new bag house.
- Allow the continued reuse and sale of fly ash captured by the existing HESPs.

Construction was completed in early 2006 and start-up and parametric testing began immediately. Long-term testing started in late 2006 and continued through September 2009. One serious problem was encountered in early 2006. The powdered activated

carbon (PAC)/fly ash in the baghouse hoppers would sometimes overheat, catching fire on several occasions. A combination of laboratory work and adjusting operational procedures enabled the project team to understand and solve the problem.

Trona injection did achieve 70 percent SO_2 removal, but interfered with mercury capture. (Note that the goal was merely to evaluate trona injection for this purpose.) The goal of 90 percent mercury capture was achieved during 30 out of 34 months. During those months that it was not achieved, either alternate sorbents were being tested or problems (such as lamp replacement) occurred with the CEMS at the baghouse, disabling mercury measurement. During these periods, the TOXECON™ system continued to operate; however, removal rates could not be verified.

A reliable mercury CEMS for use in a power plant environment was also demonstrated. Since no such CEMS was available at the onset of this project, ADA-ES teamed with Thermo Electron Corporation (Thermo) (now Thermo Fisher) to develop such a system. Before the end of the project, Thermo was able to offer the CEMS commercially.

Although the results (no discernable impact on NO_X) of the trona tests did not quite meet the project objectives, all other goals were clearly achieved and the project is considered a solid success.

I. INTRODUCTION

The Clean Coal Technology Demonstration Program (CCTDP) and the two subsequent programs—the Power Plant Improvement Initiative (PPII) and the Clean Coal Power Initiative (CCPI)—are government and industry co-funded programs. The goal of these programs is to demonstrate a new generation of innovative coal-utilization technologies in a series of projects carried out across the country. These demonstrations are conducted on a commercial scale to prove the technical feasibility of the technologies and to provide performance and financial information for future applications.

The technologies demonstrated in these programs are intended to furnish the marketplace with a portfolio of advanced, more efficient coal-based technologies that meet increasingly strict environmental standards. These technologies will help mitigate the economic and environmental barriers that limit the full utilization of coal. The primary objective of Round 1 of the CCPI (CCPI-1) was to reduce emissions and improve efficiency and maintainability while extending the asset life of coal-based generation, thus bolstering the long-term viability of the United States' abundant coal resources.

The solicitation and project selections for CCPI-1 were completed in January 2003 with the naming of eight projects selected for negotiation. At the completion of this demonstration, only one project was still in the operation phase and operation was completed in April 2010. Of the six projects that entered the negotiation phase, three were completed. The U.S. Department of Energy's (DOE) funding commitments for these three projects represented approximately 45 percent ($47 million) of the total estimated costs ($104 million), while Participant commitments totaled approximately $57 million.

One of the projects selected for negotiation was "TOXECON™ Retrofit for Mercury and Multi-Pollutant Control on Three 90-MW Coal-Fired Boilers". The project was proposed by We Energies and was to be carried out at their Presque Isle Power Plant (PIPP) located in Marquette, Michigan. Other team members included Cummins & Barnard, ADA Environmental Solutions (ADA-ES), Wheelabrator Air Pollution Control, Inc., and the Electric Power Research Institute (EPRI). ADA-ES provided program management support, design, and specifications for mercury control and monitoring equipment; Cummins & Barnard provided architect and engineering services and construction management; Wheelabrator Air Pollution Control, Inc., provided baghouse design and installation support; and EPRI, the developer of TOXECON™, was a technical advisor to the project. Overall project management was provided by We Energies with oversight by the DOE National Energy Technology Laboratory (NETL).

The Cooperative Agreement was awarded on April 1, 2004, and the design phase was completed in November 2004. Construction was completed in January 2006. Startup and operation commenced immediately and continued to the completion of the project. The demonstration phase of the project was completed on September 30, 2009. The final report was accepted by DOE in January 2010.

This project was intended to demonstrate EPRI's patented TOXECON™ air pollution control process. The primary goal of the project was to design, install, evaluate, and demonstrate a technology that would capture 90 percent of mercury emissions, using activated carbon injection, from the three PIPP 90-MW units that burn Powder River Basin (PRB) coal.

This report is an assessment of the project that was conducted by We Energies through September 30, 2009.

II. PROJECT PROCESS DESCRIPTION

A. Project Site

The project took place at We Energies' Presque Isle Power Plant (PIPP) located in Marquette, Michigan. At the start of the project, PIPP had a total of nine units in operation and the demonstration was performed on Units 7, 8, and 9. Units 1-4 have subsequently been retired. Units 7, 8, and 9 are 90 MW (nominal) boilers, each equipped with a hot-side ESP (HESP) as the primary particulate matter (PM) control device. The exhausts from the three ESPs were ducted into individual flues contained in a common stack.

PIPP Units 7 and 8 were placed in service in 1978, and Unit 9 was placed in service in 1979 by the Upper Peninsula Power Company to meet the needs of the Cleveland-Cliffs Iron Company (now Cliffs Natural Resources, Inc.). Wisconsin Electric purchased the plant in 1988. The boilers are Riley Turbo units rated for a maximum continuous capacity of 615,000 lb/hr steam flow at 1625 psig and 1005 ^{o}F superheater outlet

conditions. Each unit is serviced by two 10' x 13' Riley Ball Tube Mills and Directional Flame Burners. The precipitators were designed and built by Joy-Western and were designed as HESPs with an operating range of 565–745 ºF. The ESPs were designed to collect fly ash from a pulverized coal boiler with a gross rating of 93 MW. The design collection efficiency is 99.20 percent.

The combustion process is controlled by an Emerson Distributed Control System (EDS) with a Smart–Combustion Optimization software package to optimize NO_X and Loss on Ignition (LOI). PIPP burns Powder River Basin (PRB) subbituminous coal in Units 7–9. The PRB coal is supplied by several mines in Wyoming and Montana. Table 1 provides an analysis of this fuel. Sulfur emissions are kept within regulation by burning low-sulfur coal.

Table 1. Analysis of Subbituminous Coal Used at PIPP (from Ref. 1).

Characteristic	**Typical Value (as received)**
Higher Heating Value	9,052 Btu/lb
Analysis	**Percent by weight**
Moisture	25.85
Carbon	52.49
Hydrogen	3.65
Nitrogen	0.75
Sulfur	0.28
Ash	4.64
Oxygen	12.33
Chlorine	0.01

Analysis of the coal sampled at PIPP in 2001 showed a mercury concentration of 0.046 parts per million by weight (ppmw).

Typical flow rates and gas components in the flue gas exiting the HESPs of Units 7, 8, and 9 are shown in Table 2.

Table 2. Flue Gas Composition Downstream of Existing ESPs at PIPP (from Ref. 1).

Characteristic	Flue 7	Flue 8	Flue 9
Gas Volumetric Flow Rate, acfm	377,719	375,014	335,439
Average Gas Temperature, ºF	364.6	344.8	366.6
Flue Gas Moisture, volume %	12.1	13.3	12.7
Average CO_2, volume %, dry basis	12.8	13.0	13.0
Average O_2, volume %, dry basis	6.2	6.0	6.0
Filterable PM, lb/hr	15.3	9.99	20.35
NO_X, lb/hr	407.8	410.5	406.8
SO_2, lb/hr	461.9	464.7	474.7
Mercury, ppm dry (Average Units 7–9)	0.062	0.062	0.062

B. Project Goals

The primary goal of this project was to reduce mercury emissions from the three 90-MW units at PIPP. This demonstration involved the use of a novel, multi-pollutant control system to reduce emissions of mercury and other air pollutants while minimizing waste from the new control technology. The specific objectives of this project were to:

- Demonstrate the operation of the TOXECON™ multi-pollutant control system to achieve 90 percent mercury removal from flue gas through activated carbon injection (ACI).
- Design and demonstrate a reliable, accurate, mercury CEMS suitable for use in the power plant environment.
- Advance commercialization of the technology by successfully integrating the TOXECON™ system into PIPP's control system and optimizing TOXECON™ operation for mercury and multi-pollutant control.
- Evaluate the potential for 70 percent SO_2 control and trim control of NO_X through sodium-based or other novel sorbent injection.
- Recover 90 percent of the mercury captured in the sorbent.
- Reduce PM emissions through use of the TOXECON™ baghouse.
- Preserve 100 percent of fly ash collected in the existing electrostatic precipitator for reuse and sale.

C. Project Description

We Energies and the project team designed, installed, operated, and evaluated an integrated emissions control system for mercury and particulate matter that treated the flue gases produced by three 90-MW subbituminous coal-fired units. This was the first commercial full-scale demonstration of the TOXECON™ process. The demonstration used ACI for mercury removal. The two primary activated carbons used during the demonstration were DARCO® Hg and DARCO® Hg-LH, the latter being an activated carbon that is impregnated with bromine.

TOXECON™ is an EPRI-patented process (U.S. Patent 5505766) for removing pollutants from combustion flue gas by injecting sorbent between an existing particulate collector and a new fabric filter (baghouse) installed downstream of the sorbent injection point for control of toxic species (primarily mercury). At PIPP, the existing collectors are HESPs. This configuration allows for separate treatment or disposal of the ash collected in the HESPs (99 percent or greater) and the ash/sorbent collected by the TOXECON™ baghouse. Since PIPP's flyash is sold, it was important that it not be mixed with the high carbon material collected in the baghouse.

This project advanced the ancillary processes that are significant to mercury control, such as mercury measurement technology and waste minimization. Secondary priorities included SO_2 and NO_X control, enhanced PM control, mercury recovery from the sorbent, and investigation of beneficial uses for high-carbon flyash.

The project was selected in early 2003 and a Cooperative Agreement was awarded in April 2004. Design work was completed in November 2004 and construction was completed in January 2006. Operation and testing commenced immediately upon completion of construction and was completed in September 2009. The operation phase included optimization of sorbent injection to consistently achieve 90% capture by TOXECON™ operation; a carbon ash management demonstration; testing of trona injection for SO_2/NO_X control; and testing methods for recovering mercury from spent sorbent.

In general, the demonstration went well, encountering only one significant problem related to the primary objective—90 percent mercury removal. Although the objective was readily achieved throughout the demonstration, during the first year of operation there were recurring problems with the material in the baghouse hoppers spontaneously overheating. Adjustments to operations and testing the baghouse material to determine the conditions that lead to overheating effectively mitigated the problem. Detailed results are presented in Section III.

D. Technology Description

The overall concept of the TOXECON™ process is relatively simple. A sorbent is used to capture toxic pollutants in the flue gas produced by the coal-fired boiler of a power plant. The sorbent is injected downstream of an existing fly ash removal system and the spent sorbent is removed by a conventional baghouse. Fly ash removal on Units 7, 8, and 9 at PIPP is accomplished by HESPs. The fact that the bulk of the fly ash is removed by the existing collector has two advantages. One is that the bulk of the fly ash will remain unchanged by the new technology, and thus retain the marketability it had prior to the TOXECON™ retrofit. The second advantage is that the low particulate loading allows a somewhat higher air-to-cloth (A/C) ratio in the baghouse, which reduces the size and cost of the baghouse.

The TOXECON™ process, as installed at PIPP, is presented in Figure 1 below.

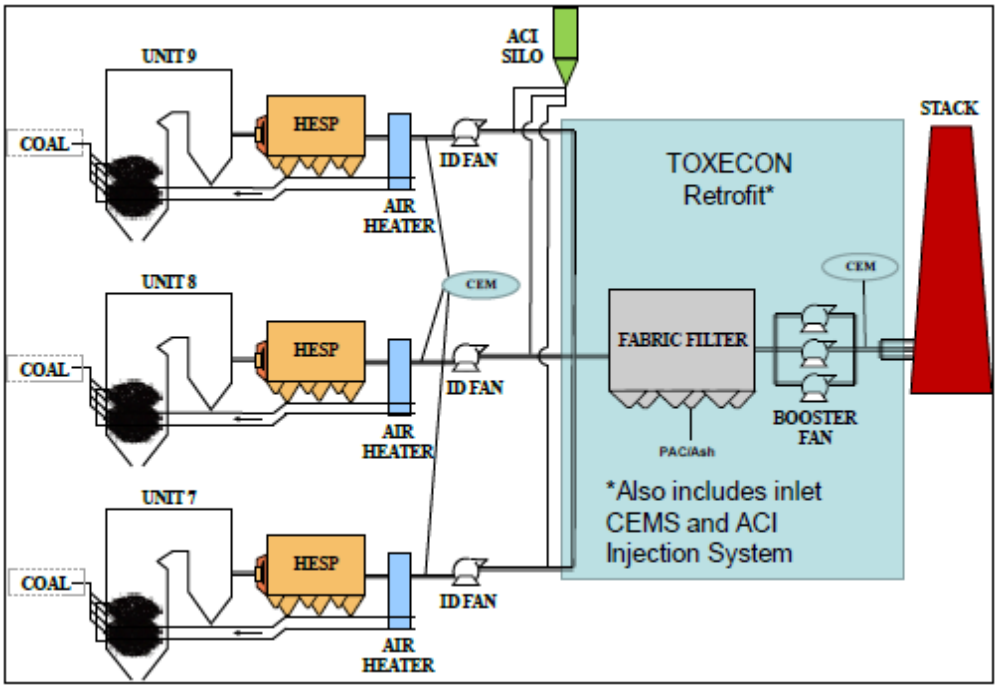

Figure 1. PIPP TOXECON™ Configuration (from Ref 1).

Prior to the installation of the demonstration equipment, each unit was entirely separate. The flue gas leaving each boiler passed through a HESP, an air heater, and an induced draft (ID) fan. The flue gas was then ducted to one of three dedicated flues situated within the common stack. For the demonstration, the flue gas from all three units needed to be combined and directed to the new baghouse.

The demonstration technology was installed at the outlet of the existing ID fans. The flue gas leaving the ID fans passes through a section of ductwork where the sorbent injection points are located. A separate injection point is provided for each boiler outlet duct for both the mercury sorbent and the sorbent intended to remove SO_2. After the sorbent is injected, the flue gas streams are combined into a common duct. The combined flue gas stream containing the sorbent(s) is routed to the common baghouse where the sorbent and remaining fly ash particles are separated from the flue gas. The clean flue gas exiting the bag house is then separated into three streams before the pressure is increased by three new but separate booster fans. The streams are then recombined prior to flowing to the three individual flues within the stack. The spent sorbents are periodically removed from

hoppers below the bags within the baghouse and conveyed to a silo for temporary storage prior to being transported to an existing landfill for disposal.

PAC Injection

The powdered activated carbon (PAC) injection system consists of two general components: the PAC storage and feeding system and the duct injection system. Norit Americas supplied the PAC system hardware, as well as the two principal sorbents used during the demonstration. ADA-ES supplied the engineering design for the PAC system.

The PAC storage and feeding system consists of a bulk storage silo with pneumatic truck unloading capability, three PAC feeder trains (each consisting of a feed hopper and variable speed feeder), an eductor, a transport air blower, and is supplied with the controls necessary to operate the system.

The duct injection system consists of the transport piping from the feeding system and the injection lances, which are mounted in each inlet duct prior to the ducts being combined ahead of the baghouse. The PAC system was designed to inject sorbent sufficient to achieve a concentration of 3 pounds per million actual cubic feet (lbs/MMacf) of flue gas per boiler. This projected injection rate was based on data obtained from full- and bench-scale testing offsite. The system at PIPP was sized larger to allow for testing of alternative carbon-based sorbents as well as for recycled spent sorbent. The overall process is depicted in Figure 2.

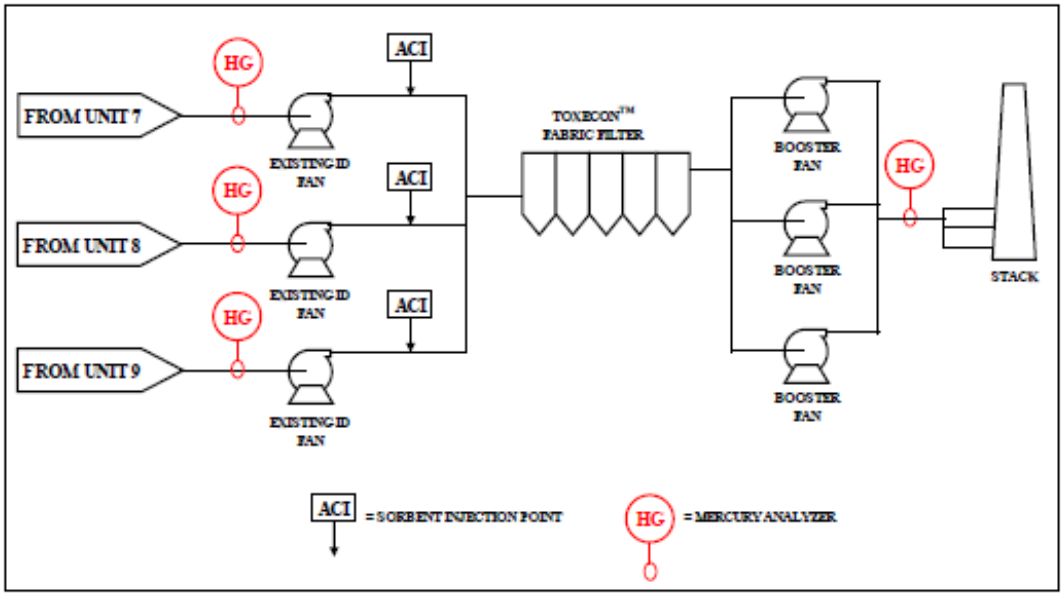

Figure 2. PAC Injection Process Flow Diagram (from Ref. 1).

The TOXECON™ system was designed to use only PAC. The design flue gas flow rate is 1,200,000 acfm at 350 ºF. The PAC injection system uses a single lance in the discharge duct of each ID fan prior to the combination of the three streams before the combined stream enters the TOXECON™ baghouse. With three feeder trains, each boiler has a dedicated injection train, transport line, and injection nozzle. The injection rate is controlled based on several variables, including boiler load/flue gas flow and desired mercury removal. Two Continuous Emission Monitors (CEMs) are used, one measuring mercury concentration prior to ACI and one in the common booster fan discharge duct.

The overall system design included the capability to inject a recycled mercury laden PAC/ash mix collected from the baghouse hoppers. During the demonstration program, it was determined that the mercury laden PAC was at equilibrium with the mercury in the flue gas and sorbent re-injection was not tested.

SO_2/NO_X Sorbent Injection

In order to test SO_2 and NO_X removal, trona was injected into the ducts upstream of the baghouse. No permanent sorbent injection system was installed for the trona injection

tests. Instead, the injection equipment for this test program was contained on two trailers. This equipment consisted of a bulk transport trailer holding approximately 40 tons of trona and a separate trailer housing the blowers and controls. This system injected "as received" sorbent; no onsite processing of the material was attempted. Feed rate for the trona varied from 2,200 lb/hr up to 5,900 lb/hr at full load to cover a wide range of stoichiometric ratios.

The trona was fed to three injection lances which were located downstream of each ID fan discharge, but upstream of the point where the ducts combine. Each lance discharged sorbent into the center of its duct, where turbulent flow provided gas/sorbent mixing. The lances were located below the existing PAC injection lances, downstream of the NO_X analyzer probe used for boiler feedback.

Baghouse

The baghouse is a pulse jet baghouse that is cleaned on-line and is typical for the power industry. It requires a relatively small footprint, which was advantageous for the congested PIPP site. The A/C ratio is 5.5 ft/min. The net (one compartment out of service) and net-net (two compartments out of service) A/C ratios are 6.1 and 6.8 ft/min, respectively.

To allow for changes in mercury content of coal, the installed excess injection capacity allowed for adequate removal considering that the system could inject up to 600 lb/hr (8.3 lb/MMacf). The excess capacity also allowed testing of additional sorbents such as recycled PAC injection material and sodium sorbents.

The volumetric flow of 1,200,000 acfm of flue gas was calculated using heat balance software and compared to test data that were taken for air heater performance and stack emissions tests. The specified operating temperature was 350 °F, which was determined to be an achievable flue gas temperature based on historical operational flue gas

temperatures. In practice, the temperature ranged from 325 to 375 °F, with cooler temperatures occurring during the winter and warmer temperatures during the summer. The higher temperature is near the operating limit for the bags and the lower temperature is better for mercury removal. The fabric filter bag material was a polyphenylene sulfide (PPS) material chosen based on the flue gas temperature, flue gas analysis, and PAC properties.

The mercury concentration in the ducts exiting the HESPs at Presque Isle was measured in 2005 using both the Thermo Electron (now Thermo Fisher) CEM and the Sorbent Trap Method (STM) and was found to be around 6 µg/dNm^3 or about 2.6 x 10^{-6} grains per dry standard cubic foot. This was the mercury concentration typically entering the baghouse along with 1 percent of the total ash.

The particulate loading design was based on the assumed maximum collection rate of 200 lb/hr of fly ash and the maximum injection rate of PAC (450 lb/hr max), which included not only the initial PAC collection, but any recycled material that might be collected in later tests. The total maximum design baghouse loading for fly ash/PAC was 650 lb/hr. Particulate tests were performed at the stack at Presque Isle in June 2005. Table 3 shows the particulate loading for the PIPP baghouse while Table 4 shows the design specifications.

Table 3. Typical Particulate Loading at PIPP(from Ref. 1).

Location	Particulate Loading (gr/acf)	Carbon Injection (gr/acf)
PIPP Flue #7	0.0047	-
PIPP Flue #8	0.0031	-
PIPP Flue #9	0.0071	-
PIPP Estimated Inlet (Total 7–9)	0.0050	0.021

Table 4. Baghouse Design Specifications (from Ref. 1).

Item	Specification
Total Compartments	10
Bags per Compartment	648
Total Bags in Baghouse	6480
Air-to-Cloth Ratio	5.5–6.0
Design Gas Volume	1,200,000 acfm
Cleaning Method	On-line

Ash Handling System

The ash handling system is a dilute-phase pneumatic conveying system. This type of system has been used in conveying both fly ash and PAC. The particulate generation rate was based on the collection rate of fly ash (200 lb/hr max) and the maximum injection rate of sorbent (450 lb/hr max). The total maximum design baghouse loading for fly ash/PAC was 650 lb/hr. The design conveying rate of the ash handling system was based on four times the total particulate loading rate of 650 lb/hr to allow for operational flexibility. This converts to 1.3 tons/hr.

The ash system includes the hoppers in the baghouse, transport lines from the bottom of each hopper leading to a filter/separator located on the penthouse of the ash storage silo, the ash storage silo itself, and finally, trucks to transport the ash to a landfill for disposal. A mechanical exhauster downstream of the filter/separator created the vacuum in the transport lines.

A wet unloading system was selected for the storage silo to condition the ash/PAC mixture leaving the storage silo with water to bind the dust to allow transportation by open-bed trucks. As described later, there was a problem with dusting when the wet unloading system was initially used. A dry unloading system was also installed on the ash silo to allow the ash/PAC mixture to be recovered dry for use in testing re-injection

(recycling) of the mixture into the flue gas stream, or for testing methods of recovering the mercury from the used PAC.

ID Fans

Because of the additional pressure drop associated with the installation of the TOXECON™ baghouse and associated ductwork, new ID booster fans were required. Three booster fans were installed to allow a single fan to be designated for each of the three boiler units, thereby maintaining the established practice at the plant of individual components for the three units. Three fans (rather than two) had a smaller impact on the plant's electrical systems and allowed greater turndown. In addition, three fans would ensure compliance with National Fire Protection Association boiler purge flow requirements.

CEMS

Throughout the demonstration project, ADA-ES worked with Thermo Electron (now Thermo Fisher) Corporation to develop a mercury CEM for use on this project to measure mercury concentrations at the inlet and outlet of the TOXECON™ fabric filter. ADA-ES's role was to validate different components by operating them in parallel with ADA-ES's semi-CEM (EMC unit). The Thermo instrument had four key components: sample extraction probe, sample converter, mercury analyzer, and calibration module.

The extraction probe used an inertial filter to obtain a particulate-free vapor-phase sample without passing the gas through a fly ash filter cake. The dilution ratio was determined based on flue gas conditions and operator preference. All of the extraction probe internal surfaces exposed to sample gas had a glass coating to prevent unwanted chemical reactions with the mercury.

III. REVIEW OF TECHNICAL AND ENVIRONMENTAL PERFORMANCE

A. Technical Performance

Construction was completed and operation commenced in January 2006. It is typical for new plants, even those based on mature technology, to require some minor adjustments to equipment and operating procedures. There was only one significant issue associated with the start-up and operation of the TOXECON™ unit—baghouse hopper fires.

After several weeks of parametric testing, burning embers were found in one of the baghouse hoppers while operators were working to unplug and evacuate it. This compartment was isolated and the baghouse remained in service. All of the compartments were then checked and embers were found in all of the hoppers. The compartments were isolated, PAC injection was discontinued, and the baghouse was put into bypass mode. The hot PAC/ash in each hopper was cooled and removed.

Overheating of the PAC/ash mixture had not been seen at any power plant using PAC injection or the TOXECON™ process up to that point in the demonstration, although Alstom described the dangers of autoignition based on their long-term experiences with PAC injection in their European operations involving waste combustors. A yearlong TOXECON™ test, at a smaller scale, was performed at another plant with no incidence of overheating in the hoppers. The most notable difference between the two systems was the use of hopper heaters at Presque Isle, while none were used at the other facility. Hopper heaters are required in more northern climates to reduce problems with flue gas water condensation reacting with subbituminous fly ash within fly ash hoppers.

Over the next several weeks, frequent checks of the material in the hoppers revealed hot embers in all of the hoppers at one time or another, but not at all times and not always in all hoppers. Inspection of the bags indicated that a number of them had failed due to apparent overheating. As a result, the project team undertook an extensive investigation

of the problem. The investigation included analysis of the combustion properties of PAC and PAC/ash mixtures, thermocouple installation on the hoppers, balance-of-plant set point changes, and laboratory testing for autoignition characteristics of PAC and PAC/ash mixtures.

A comparison was made of the inlet and outlet baghouse temperatures to determine if there was any indication of overheating. No overheating was noted nor was there any indication of pressure drop abnormalities.

A substantial number of tests on both the PAC and PAC ash mixtures were carried out by ADA-ES, We Energies, and outside laboratories. A few of the more informative tests are summarized below. A detailed description can be found in Reference 1.

PAC samples from the storage silo were sent for thermogravimetric analyses (TGA). This analysis was used to determine the temperature of combustion in air. The PAC began losing significant weight at about 750 °F and had a temperature of ignition of 852 °F. PAC/ash samples were also subjected to similar tests and there was no indication that the mixture behaved unexpectedly.

We Energies also performed a series of tests using an open cup flash point determination apparatus. The apparatus consisted of a heavy cup on a hot plate with an open flame above to ignite any volatiles released as the material in the cup was heated. There was no release of combustible volatile compounds at temperatures up to 500 ºF. After several hours of cooling, the sample was removed and hot embers were found near the bottom of the cup. The surface showed no evidence of combustion. This would indicate that PAC can ignite on contact with a hot surface under low-oxygen conditions and maintain combustion. Tests on PAC/ash mixtures gave similar results.

Approximately six months after burning embers were first noted, burning embers were found again, this time in Hopper 6. The wall temperature peaked at 403°F on the south wall in Compartment 6. After Compartment 6 overheated, the hopper heaters were set at 175°F as the low point and 200 °F as high point, down 50°F from 250°F. There were no incidents of hopper overheating after the incident. Lowering the heater temperatures and more frequent removal of material from the baghouse hoppers effectively solved this problem.

Other than damage to the bags caused by overheating, the operation of the baghouse was satisfactory with only a few problems being encountered. One of these involved optimizing the baghouse operation to maintain the proper filter cake thickness on the bags to facilitate PM as well as mercury capture. The filter cake is needed to maintain high PM removal. In order to maintain optimum baghouse operation, the timing of bag cleaning is normally based on the pressure drop across the baghouse. Too frequent cleaning can result in more PM emissions and shorter bag life. Given the very low particulate loading to the baghouse, only infrequent cleaning is required. However, it was also noted during early tests that, if PAC was left on the bags, some Hg desorption could occur. Baghouse cleaning frequency was optimized during a series of tests.

Excessive dusting also occurred during the use of the wet ash/PAC unloading system, especially when starting the pin mixer. Eventually, a larger pin mixer had to be installed because earlier modifications still did now allow for a dust-free unloading process. A partial enclosure was built around the base of the silo to eliminate the wind tunnel effect and prevent airborne dusting. The combination of the new pin mixer and enclosure eliminated the dusting and equipment issues seen during the demonstration. Additional modifications were made to improve flow of the PAC/ash mixture: a new rotary valve was added to replace the original butterfly valve, and, although fluidization at the silo discharge is normally not required, the original fluidization valves were replaced by (3) large air cannons. The balance of the equipment operated with only minor, readily remedied problems.

As stated earlier, a second goal of the project was the development and demonstration of a CEMS to continuously measure mercury in the flue gas. Prior to this project, only semi-continuous monitors had been available for use in harsh power plant environments. The mercury analyzers commercially available were designed for ambient and laboratory mercury measurements, not for a power plant environment where they needed to operate in an automated fashion while continuously producing reliable data. Difficulties in measuring mercury in the extremely low concentrations found in flue gas include extracting the sample from the duct, removing particulate matter, transporting the sample to the analyzer, eliminating sampling artifacts, and conditioning the sample.

In the early 1990s, DOE NETL provided funding to develop mercury analyzers for coal combustion flue gas. The efforts identified the difficulties associated with mercury measurement and identified techniques to overcome these challenges. Upon project initiation in 2004, there was no mercury Continuous Emissions Monitoring System (CEMS) available that had passed the EPA certification tests or that could be operated in a power plant environment without full-time support from experienced technical staff.

One member of the project team, ADA-ES, had designed and built several prototype mercury analyzers that had been used in field evaluations conducted since the start of the CCPI project. The collection and analysis of mercury with this technology was difficult at power plants that burned high-sulfur bituminous coal because the flue gas fouled some components, thus reducing its effectiveness. Several technologies from other companies were considered to replace the ADA-ES mercury analyzer but many of them used the same type of system. Reliable data could be obtained with the semi-continuous emission monitor (SCEM) when it is maintained and manned by experienced personnel. Mercury CEMS are a key component for the mercury process control required for this project and for effective use of the TOXECON™ technology. Thus, the development and demonstration of new CEMS that reduced maintenance requirements and automated analyzer operation was required. The system had to be capable of long-term operation

and reliability, and the mercury CEMS had to meet specifications similar to existing plant CEMS for other emissions, such as SO_2 and NO_X.

ADA-ES began discussions with Thermo Electron Corporation (Thermo), a company that appeared to offer the best option for directly measuring mercury using atomic fluorescence. Thermo was willing to dedicate a large amount of resources toward the development and manufacture of a reliable mercury CEMS. ADA-ES teamed with Thermo to perform a field evaluation of its components. Early on, the team was able to successfully overcome initial difficulties and produced a mercury CEMS. Tests were conducted at several locations to confirm that it could operate when testing flue gas from different coals that also had different sulfur (potential to interfere with Hg measurements) and mercury levels. After some development, the mercury CEMS was tested to determine whether it could meet newly developed EPA certification criteria. The certification tests, QA/QC tests, and their criteria are outlined in Tables 5 and 6.

Table 5. Mercury CEMS Certification Tests (from Ref. 1).

Performance Test	Test Specifications	Criteria	CAMR Reference
Seven-Day Calibration Error Test	Two-point calibration check (zero and upscale) consecutive days.	< 5.0% of span (or ≤ 1.0 µg/m³ if span is 10 µg/m³)	Part 75, Appendix A, Section 6.3
Linearity Check	Challenge monitor three times with each reference mid, high).	< 10% (or < 1.0 µg/m³) of reference gas value	Part 75, Appendix A, Section 6.2
Cycle Time Test	Zero and upscale.	< 15 minutes to 95%	Part 75, Appendix A, Section 6.4
System Integrity Check*	Three-point converter efficiency test.	< 5.0% of span	Part 75, Appendix A, Section 6.2
Relative Accuracy Test Audit (RATA) and Bias Test	One set of 12 test runs.	< 20% difference (or < 1.0 µg/m³ for low emitters).	Part 75, Appendix A, Section 6.5

Table 6. CAMR 40 Part 75.21 Mercury CEMS On-Going QA/QC Tests (from Ref. 1).

Performance Test	Test Specifications	Criteria	CAMR Reference
Daily Calibration Error Test	Two-point calibration check (zero and upscale).	< 5.0% of span (or ≤ 1.0 µg/m³ if span is 10 µg/m³)	Part 75, Appendix B, Section 2.1.1
Weekly System Integrity Check*	Single-point converter efficiency test.	< 5.0% of span	Part 75, Appendix B, Section 2.6
Quarterly Linearity Check	Challenge monitor three times with each reference gas (low, mid, high).	< 10% (or < 1.0 µg/m³) of reference gas value	Part 75, Appendix B, Section 2.2.1
Relative Accuracy Test Audit (RATA) and Bias Test	One set of 12 test runs.	< 20% difference (or < 1.0 µg/m³ for low emitters)	Part 75, Appendix B, Section 2.3.1

Requirements also specified by the Clean Air Mercury Rule (CAMR) were used as a general guideline for the minimum level of testing considered acceptable for the mercury CEMS used for the duration of the project. In February 2005, Midwest Research Institute (MRI) completed a field evaluation of the Thermo mercury CEMS for the U.S. Environmental Protection Agency (EPA) Office of Air Quality Planning and Standards. The CEMS successfully passed these tests.

After the successful completion of the Long-Term EPA Field Evaluation, Thermo publically introduced their mercury CEMS for coal-fired power plants at EPRI's User Group Meeting and Exhibit on May 3, 2005. A press release announced that purchase orders for the system could now be placed and that delivery of orders was expected to take place in November 2005.

There were several other tests done during the project. Tests using the TOXECON™ process included alternate sorbent testing, testing of high LOI ash from PIPP Units 5 and 6, and trona injection for SO_2 and NO_X removal. Baseline testing was completed prior to trona injection to establish the pollutant concentrations leaving the air preheater and to

determine if there was any native SO_2 or NO_X capture across the TOXECON™ fabric filter without sorbent injection. As expected, the tests showed no measureable SO_2 and NO_X removal across the baghouse prior to trona injection. The trona injection equipment was set up and the first shipment arrived the following day. There were concerns that the trona might set up in the ash silo wet unloader, so an anti-setup agent was obtained. Four hours of sorbent injection at 2,200 lb/hr was performed in order to test the wet unloader and the effectiveness of the anti-setup chemical. At the end of the four hours, the ash silo was unloaded with the chemical in the water feed to the pin mixer. There were no problems with setting up of the reacted trona/ash/PAC in the wet unloader or in the ash. When the silo unloading was inadvertently performed without the anti-setup agent, no problems were observed. Subsequent tests also showed no set up problems.

Although the original plan was to vary the sorbent injection rate from 2,200 lb/hr up to 5,400 lb/hr, injection rates up to 5,960 lb/hr were used to achieve the desired level of SO_2 removal. In order to simultaneously maintain 90 percent Hg removal, PAC injection rates had to be increased by a factor of approximately three while obtaining an SO_2 removal rate of 70 percent. PAC is normally injected at a rate of approximately 1.0 – 2.0 lb/MMacf if DARCO-Hg is being injected.

Other work included tests to demonstrate that 90 percent of the mercury could be removed from the sorbent, to develop a process to use the recovered sorbent in fertilizer, and to demonstrate the use of the PAC/ash mixture in concrete.

Effective removal of the adsorbed Hg was demonstrated by two different techniques, both of which were tested at a small scale and involved heating the PAC to desorb the Hg. One used the “air slide” technology patented by We Energies. The technology exposes the Hg-laden sorbent to heated, flowing air until it reaches a temperature of at least 700 ^{o}F. The second technology used microwave energy to selectively heat the PAC particles. Both tests also demonstrated effective capture of the mercury driven off the sorbent. In addition, a process was developed to produce a nitrogen-rich fertilizer from

the recovered PAC/fly ash. Cost estimates for the process indicate that the product would have a substantial cost advantage over conventional nitrogen fertilizer.

ADA-ES developed a new approach to using PAC-containing ash for structural concrete. This method utilized the combination of a specific batch design (developed by ADA-ES) that was modified with an air entraining additive (AEA) specifically developed for this application. The technology was tested on concrete mixtures with ash containing <1 percent to as much as 30 percent LOI from PAC. A successful field demonstration using 30 percent LOI ash to make a large concrete pad at PIPP was completed in June 2009. Leaching tests for mercury and other trace metals on concrete samples from this field demonstration were well below the Toxicity Characteristic Leaching Procedure (TCLP) reporting criteria. ADA-ES also demonstrated the use of high carbon byproduct to produce a conductive concrete.

B. Environmental Performance

Mercury Removal

The early phase of the TOXECON™ demonstration program, which commenced in January 2006, dealt primarily with equipment startup, defining baseline removal levels, and sorbent injection parametric testing. This period also included laboratory and operational testing to develop a solution to the problem of overheating in the baghouse ash hoppers.

The results of parametric testing proved that the TOXECON™ system was capable of achieving mercury removal levels of 90 percent using PAC injection at rates between 1.5 and 2.0 lb/MMacf for the DARCO® Hg-LH PAC and between 2.0 and 2.5 lb/MMacf for DARCO® Hg. The parametric testing also showed that removal rates for both PACs deteriorated as flue gas temperatures increased.

Long-term mercury removal testing began in November 2006, after the completion of the parametric tests. During the first full month of testing (December 2006) mercury removal averaged 93.6 percent ± 7.8 percent. An early indication that the system could meet the mercury removal goal was that the system achieved 48 consecutive days in which mercury removal was at least 90 percent. Both sorbents were used during these tests. Over the 34 month, long-term test period, the goal of 90 percent average monthly mercury removal was met. Those months in which the goal was not met were periods in which alternative sorbents were tested or when the mercury CEMs malfunctioned or maintenance was required. For example, one alternative sorbent (high LOI fly ash from PIPP Units 5 and 6) removed less than 20 percent of the mercury.

Figures 3 through 5 summarize the results of the long-term tests. Average mercury removal data is shown for all months during the demonstration period. Steady state removal represents "normal operation" at a power plant and excludes periods when special testing occurred. It also includes periods when boilers were out of service, but not when the baghouse was out of service. If there were viable outlet CEM data but no inlet CEM data, then an inlet default value of 6 $\mu g/m^3$ was used to determine the removal value for that period. The second line still excludes special testing, but includes baghouse outages and other equipment issues that impacted mercury removal.

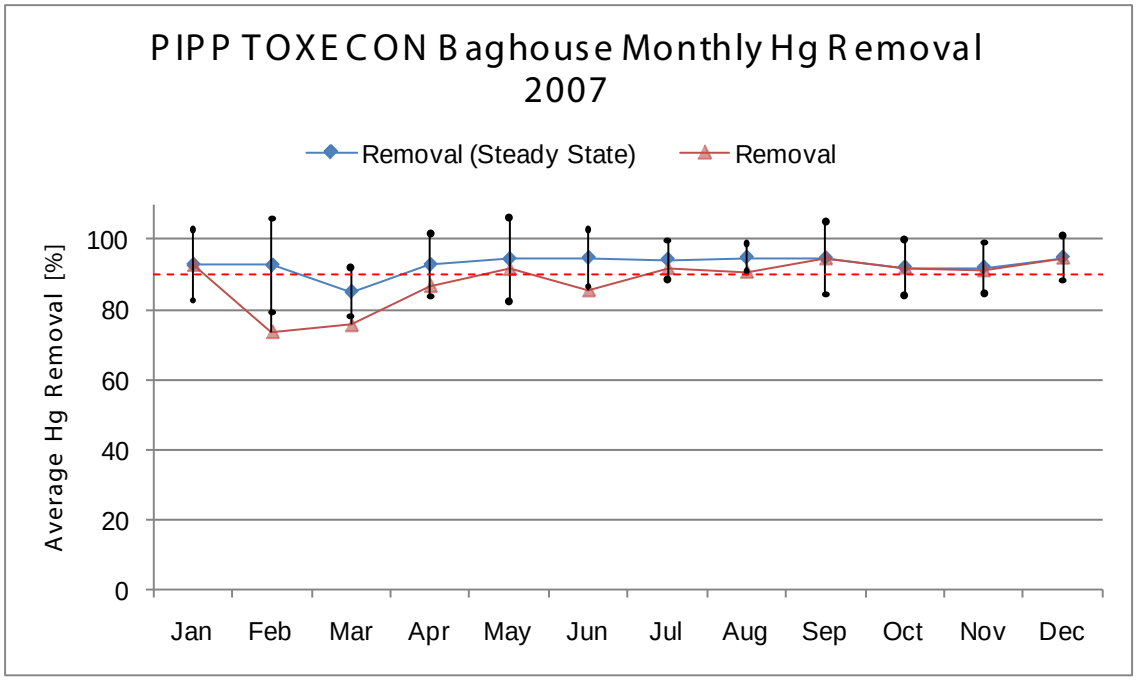

Figure 3. Average Mercury Removal 2007(from Ref. 1).

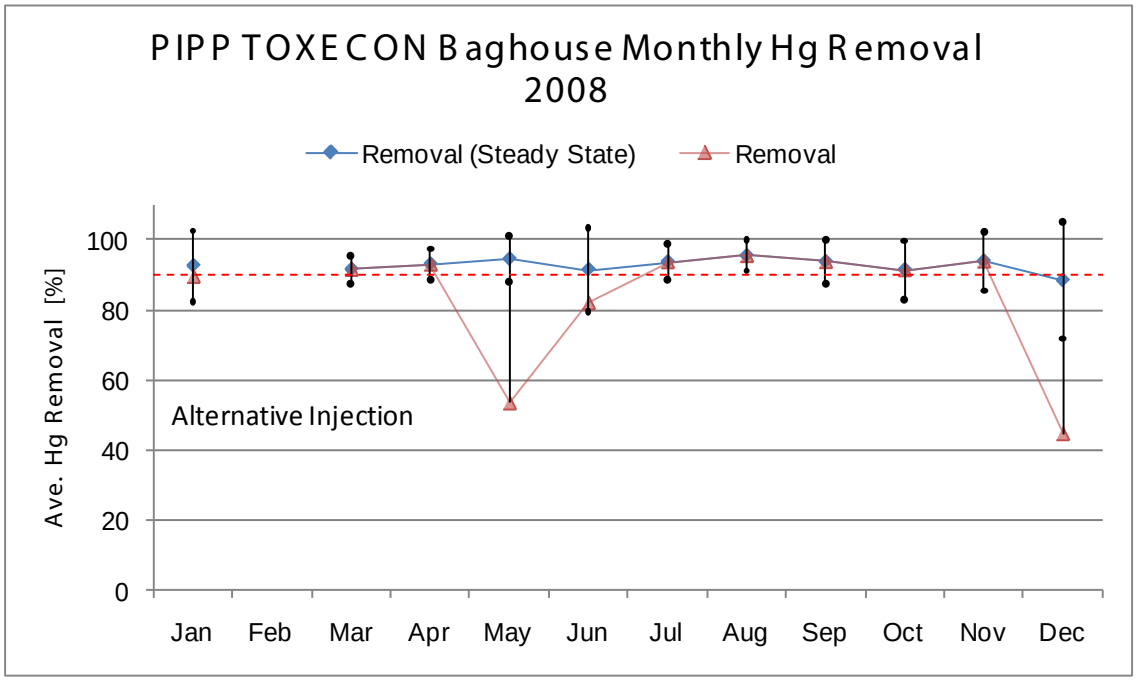

Figure 4. Average Mercury Removal 2008(from Ref. 1).

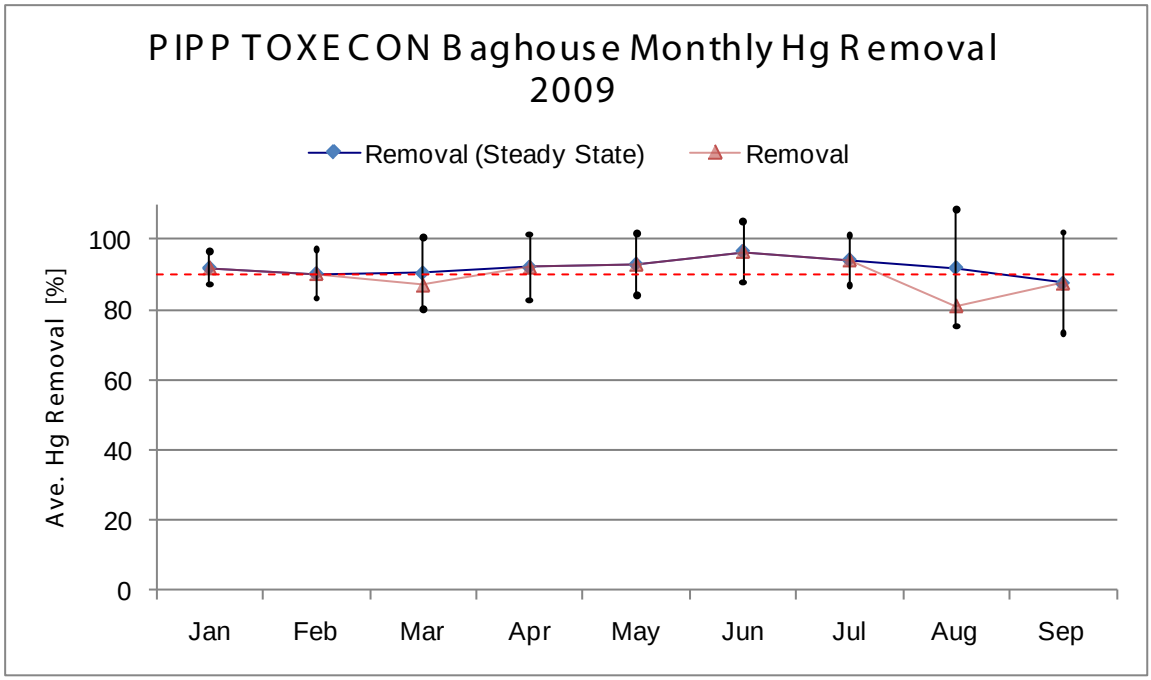

Figure 5. Average Mercury Removal 2009 (from Ref. 1).

Inspection of the above charts confirms that the mercury removal goal was met as stated above. The error bars represent two standard deviations. As such, the data clearly demonstrate that while this technology achieves an **average** removal rate of 90 percent under injection rates defined in the previous section, removal typically varied significantly over the course of a given month. This suggests that the compliance regulations should consider an appropriate averaging period for mercury removal reporting.

Trona Injection

The trona injection tests lasted approximately two weeks. Within the injection range tested, lower injection rates did not achieve the desired result of 70 percent SO_2 removal, while higher injection rates did. PAC had to be increased by a factor of three to simultaneously achieve the 90 percent Hg removal goal at the trona injection rate needed to achieve 70 percent SO_2 removal. A normal stoichiometric ratio (NSR) of 1.02 was required to achieve 70 percent SO_2 removal. The NSR is a measure of the number of moles of sorbent injected compared to the number of moles required to absorb all of the target pollutant if the reaction between the target pollutant and the sorbent is complete.

Thus, the NSR of 1.02 indicates that there was more than enough sorbent injected to remove all of the SO_2; however, only 70 percent was absorbed.

No NO_X removal was detected during the trona injection tests. Typically, a very small amount of NO is converted to NO_2 in near-field plumes from coal-fired boilers. NO_2 normally imparts a brown color in plumes but at PIPP, the quantity produced was insufficient to be visible when PAC was being injected, although opacity did increase by 0.75 percent. When PAC was not being injected, opacity increased by 3 percent and a visible brown color plume was formed. The results of the SO_2 removal tests are presented below in Table 7.

Table 7. Trona Injection Results (from Ref. 1).

Date	Trona Injection Rate (lb/hr)	Average NSR*	SO_2 Inlet (lb/MMBtu)	SO_2 Removal (%)
8/1/07	2223	0.37	0.50–0.66	46.6
8/2/07	2223	0.41	0.48–0.63	47.6
8/3/07	4446	0.81	0.48–0.59	65.4
8/4/07	4446	0.79	0.50–0.58	65.5
8/5/07	5432	0.97	0.49–0.57	69.8
8/6/07	5926	-	-	-
8/7/07	5926	1.02	0.52–0.60	70.7
8/8/07	5926	1.02	0.52–0.66	68.5
8/9/07	5926	1.03	0.49–0.62	72.1
8/10/07	5926	1.02	0.51–0.64	74.1

* Normalized Stoichiometric Ratio

The PAC-ash mixture and reacted trona are all suitable for landfill disposal. There are no liquid effluents that require treatment.

One of the stated goals of the project was to reduce PM emissions from the plant. Measurements were taken at the inlet and outlet of the baghouse to determine how

effective the baghouse was at removing PM emissions. The results are presented in Table 8.

Table 8. Flue Gas Particulate Matter (from Ref. 1).

	Year	Method	TOXECON™ Inlet (lb/hr)	TOXECON™ Outlet (lb/hr)	Baghouse Efficiency %
Filterable PM	2006	Range	84.9–141.2	0. 6–4.2	
		Average	110.1	1.7	98
	2007	Range	70.1–162.0	16. 7–20.0	
		Average	114.0	17.8	84
	2008	Range	259.9–608.9	11.9–27.4	
		Average	413.8	17.0	96
	2008	Inlet PM using Baghouse Fly Ash LOI%	137.5	17.0	88

In analyzing the data in the above table, it should be noted that the inlet values were measured downstream of the sorbent injection point. The one exception was in 2006 when PAC was not being injected. During this period, 98 percent removal was achieved. While this is somewhat less than normal baghouse capability, it must be remembered the bulk of the PM had already been removed by the HESPs and that the PM entering the baghouse likely consisted of mostly very small particles. The reasons for the higher inlet loadings in 2008 are not known.

Another stated goal of the project was that the fly ash collected in the HESPs would continue to be marketable. Installation of the demonstration technology had no impact on the quantity, quality, and marketability of fly ash collected by the HESPs.

IV. DISCUSSION OF RESULTS

One of the two major goals of the project was to demonstrate that the TOXECON™ technology could reliably remove at least 90 percent of the mercury from the flue gas of a coal burning power plant using PAC. This goal was achieved. During 34 months of long-term testing, average mercury removal rates of 90 percent or better were achieved during 30 months. During one of the four months that 90 percent was not achieved, alternative sorbents were being tested. During the other three months that failed to meet the criteria, operational issues with the outlet CEM occurred and thus mercury removal could not be confirmed with actual measurements. The TOXECON™ process operated effectively and reliably when there were no issues with plant equipment or operations.

The second major goal was the demonstration of a reliable, accurate, mercury CEMS suitable for use in the harsh environment of a power plant flue gas stream. Prior to this project, the only mercury analyzers that were available were useful only under laboratory conditions and were not suitable for power plant use. Since no such CEM existed at the start of this project, one needed to be developed. ADA-ES collaborated with Thermo Electron Corporation to produce reliable CEMS suitable for use in a power plant. These were installed at the inlet and outlet of the baghouse, were monitored remotely, and provided mercury removal data during the project. This CEMS demonstrated the ability to measure mercury in concentrations as low as 0.1 $\mu g/m^3$. An improved version offered commercially is identified as the “iSeries” which features flexible communications, increased serviceability, and an easier-to-use interface.

During the development of the CEMS, a significant number of problems with the various components needed to be overcome. These problems were resolved as they occurred resulting in a reliable, commercial, mercury CEMS. Without such a device, mercury control would be difficult. Sorbent would need to be injected at higher rates and could

only be adjusted periodically as manual measurements were taken. In addition, there would be an economic penalty since the older monitors required a highly trained staff to operate and maintain them.

Another goal of the project was to evaluate to the ability of the TOXECON™ process to remove 70 percent of the SO_2 and 30 percent of the NO_X from the flue gas when combined with a sodium-based sorbent. SO_2/NO_X removal was tested using a temporary, trailer-mounted system for trona injection. The target SO_2 removal rate was achieved, albeit at high sorbent injection rates. However, trona injection interfered with mercury removal to the extent that it was estimated that PAC injection rates would have to be tripled to achieve 90 percent removal if trona is being injected. There was no discernable impact on NO_X other than some small amount of conversion to NO_2. Furthermore, the conversion to NO_2 caused opacity at the stack to increase by 3 percent. The project thus provided information that trona injection does not dovetail well with PAC injection, at least at plants similar to PIPP.

One additional benefit of the TOXECON™ process is a reduction in particulate matter (PM) emissions. With full load conditions and all three units directed to the baghouse, the inlet particulate flow was 117 lb/hr prior to PAC injection and outlet flow was 17 lb/hr, which represents an 85 percent reduction beyond that which was captured in the HESP. While 85 percent capture is below normal performance when a baghouse is the primary collection device, it must be noted that the inlet loading was very low to start with and that the HESP selectively captured mostly the larger, easy-to-capture PM, leaving the more difficult fine particles for the baghouse. The 85 percent collection rate is also misleading since the inlet dust load was actually higher due to PAC injection. Thus, the inlet loading and capture efficiency were actually higher than the measurements suggest.

Two thermal desorption methods were successful in removing mercury from the TOXECON™ PAC/ash material. The first method utilized the “air slide” technology

patented by We Energies and licensed to an engineering firm. Sorbent and/or fly ash with affixed mercury compounds is exposed to heated flowing air until the sorbent reaches a temperature of at least 700^{o}F. The desorbed Hg can then be removed from the gas stream. A design for a process to use the carbon to manufacture a nitrogen-based fertilizer was also developed.

The second technology used microwave energy to selectively heat the PAC particles, thereby saving on energy costs. This technology was demonstrated under this project by UP Steel. Demonstrating the ability to remove the Hg from the sorbent opens possibilities for reusing spent PAC.

In addition to the other accomplishments of the project team, ADA-ES developed a new approach to using PAC-containing ash for manufacturing structural concrete. This method utilized the combination of a specific batch design with a foam-based AEA that was modified specifically for this application. This combined technology was tested on concrete mixtures with ash containing <1 percent to as much as 30 percent LOI from PAC. A successful field demonstration using 30 percent LOI ash to make a large concrete pad at the Presque Isle plant was completed in June 2009. Leaching tests on concrete samples showed that all samples were well below the TCLP reporting criteria. All samples showed that only a very small amount of bromide was leachable.

One of the additional goals listed by the We Energies was the continued use of the fly ash that was captured in the HESPs. This goal was readily achieved since the HESPs are located upstream of the air heater and the project equipment was installed downstream of the air heater.

The final goal of the project was the successful integration of the TOXECON™ baghouse and associated equipment into plant operations. Failure to achieve this goal would have resulted in the overall failure of the project, but this goal was achieved with only minor

problems. In addition, the equipment and operation of the system were upgraded and optimized during the demonstration project, leading to the project's success.

V. MARKET ANALYSIS

A. Potential Market

The Environmental Protection Agency (EPA) and the U.S. Congress are currently considering the degree to which mercury emissions from coal-fired power plants in the United States should be reduced. It is generally accepted that a high degree of control will be required. Organizations developing control technologies are generally aiming for the capability to remove 90 percent of the mercury. Because both the demonstration at PIPP and another CCPI project have demonstrated the ability to control to the 90 percent level, technology capability need not be a consideration when the final regulation becomes effective. However, existing site complexities may greatly impact retrofit costs.

TOXECON™ is a technology that can be integrated into the electricity generating unit's existing air pollution control system to enhance mercury control. TOXECON™ is a process that is installed downstream of an existing PM control device. While TOXECON™ can be installed wherever a primary particulate control device exists, TOXECON™ is currently the main option in cases where the primary particulate control device is unable to capture high levels of inorganic mercury. For those units equipped with a HESP, TOXECON™ appears to be the prime control option when high levels of control are required.

There are over 335 GW of coal-fired generating capacity in the United States; however, only 18 GW remains configured with HESPs. According to We Energies, TOXECON™ may be applied to power plants burning bituminous coals (81 GW) and western subbituminous coals (68 GW) that are equipped with cold-side electrostatic precipitators. Thus, the total potential market for the demonstration technology appears to be

approximately half of the existing coal fired generating fleet. We Energies indicate that the ability to inject trona for acid gas control is advantageous for the TOXECON™ technology.

B. Capital, Operating, and Maintenance Costs

We Energies performed an economic analysis which is included in the final report. All tables included in this section are taken from their Final Report with some minor editing. The costs are all in 2009 dollars and are based on the experience obtained during the nearly 3 years of operation. The technology is viewed as a retrofit technology and this is reflected in the costs. Tables 9 and 10 present the basis for the economic analysis.

Table 9. Economic Analysis Parameters (from Ref. 1).

Item	Units	Value Used
Cost of debt	%	6.06
Cost of equity	%	10.75
Debt/total capital	%	50
Income tax rate	%	40
Debt rate of return	%	3.0
Equity rate of return	%	9.0
Project rate of return	%	12.0
Depreciation rate	%	3.0
Annual capital carrying charge	%	15.0
Inflation rate	%	2.5
Discount rate (with inflation)	%	7.5
Escalation of raw materials above inflation	%	0
Asset life	Years	30
Year for cost presented in this report	-	2009
Capacity factor used in estimates	%	84
Generating capability	MW	270
AFUDC rate	%	8.94
CWIP AFUDC	%	100

Table 10. Summary of Plant Data (from Ref. 1).

TOXECON™ Summary of Plant Data		
Plant Attributes	**Units**	**Value**
Plant capacity	MW	270
Normal full load	MW	255
Power produced, net	10^9 kWh/yr	1.667
Capacity factor	%	74
Coal feed	10^6 tons/yr	1.12
Mercury emissions uncontrolled	lb/hr	0.0170
Mercury emissions uncontrolled	lb/GWH	0.067
Mercury emissions uncontrolled	lb/yr	110

Table 11 presents the total installed costs broken down by major equipment items.

Table 11. Major Equipment Costs (from Ref. 1).

Item No.	Item Name	Total Cost
1	Baghouse	$21,247,342
2	Electrical Equipment	$1,363,020
3	Controls (Including Enclosure)	$644,915
4	Air Compressor/Dryer	$265,546
5	ID Booster Fans	$2,620,329
6	Ash System	$1,362,335
7	PAC System	$787,945
8	Dampers	$1,432,123
9	Expansion Joints	$221,714
10	Ductwork and Structural Steel	$6,801,333
11	Mercury Continuous Emissions Monitors	$1,494,153
TOTAL		**$38,240,755**

When allowance for funds during construction is added, the total capital requirement is increased to $41,700,000. Operating and maintenance costs are given in Table 12 and the costs per pound of mercury captured are given in Table 13. The operation is assumed to achieve an average of 90 percent mercury removal level. Table 13 does not include annualized capital costs of $6.2 million based on a capital recovery factor of 0.15. These costs are based on the installation at PIPP and are expected to be somewhat high due to this being a retrofit and also a first of its kind system.

Table 12. Operating and Maintenance Costs (from Ref. 1).

Fixed O&M Costs	**Units**	**Quantity**	**$/Unit**	**$/Year**
Operating labor	Person hr/yr	450	63.44	28,548
Maintenance labor	Person hr/yr	309	61.61	19,037
Maintenance material	$/yr			262,112
Administration/support labor	Person hr/yr	500	89.35	44,675
			Subtotal Fixed Costs	**354,372**
Variable Operating Costs	**Units**	**Quantity**	**$/Unit**	**$/Year**
Sorbents				
Powdered activated carbon	lb	535,907	1.034	554,231
Utilities				
Electric power	kWh/hr	3000	0.02	452,724
Waste disposal charges				
Dry solids (trucked-landfill)	Tons/yr	500	81.50	41,765
			Subtotal Variable Cost	**1,048,720**
TOTAL O&M COST (FIXED + VARIABLE)				**1,403,092**

Table 13. Cost of Mercury Removal - $/Pound (from Ref. 1).

	$/Pound of Mercury Removed			
Mercury Removal Rate	**80%**	**85%**	**90%**	**95%**
Capital Charge	$71,087	$66,906	$63,189	$59,863
Fixed O&M Cost	$4,031	$3,794	$3,583	$3,395
Variable O&M Cost	$8,783	$8,860	$9,442	$12,264
Total Cost	**$83,902**	**$79,560**	**$76,214**	**$75,522**

VI. CONCLUSIONS

The We Energies' team successfully designed, installed, and operated the TOXECON™ system at We Energies Presque Isle Power Plant. Following completion of start-up and parametric testing, long-term testing commenced in late 2006 and proceeded through September 2009. During startup and initial parametric tests, one serious problem was encountered—overheating of the PAC/fly ash mixtures in the baghouse. This led to fires that damaged a number of the bags. A combination of laboratory work and operational changes solved the problem.

The most critical goals of the project were to demonstrate consistent mercury removal to the 90 percent level and to demonstrate mercury CEMS that could continuously provide accurate, reliable mercury data while installed in the harsh environment of a power plant. The goal of 90 percent mercury removal was achieved during 30 of the 34 months of long-term testing. One of the months during which the mercury removal goal was not achieved was during alternative sorbent testing and the other three months were due to problems with mercury measurements at the system outlet. Although the TOXECON™ system continued to operate normally during the periods when the CEMS was off-line, 90 percent removal could not be verified.

ADA-ES teamed with Thermo Electron Corporation to develop and demonstrate a mercury CEMS. This effort also was successful and Thermo offered a commercial unit for sale well before the end of the project.

The goal of testing trona injection was successfully carried out using temporary equipment. The SO_2 removal goal was achieved albeit at a significant penalty to mercury removal. No reduction in NO_X emissions was discernable. (Note that the goal was only to evaluate trona injection which had shown the best potential for SO_2 removal.)

Removal of 90 percent of the mercury from the spent PAC was demonstrated and the use of high LOI ash in concrete was also demonstrated. One of the other stated goals was the continued use of the fly ash captured by the existing HESP. The demonstration resulted in no changes to the quantity, quality, or marketability of the fly ash. The Final Report states that potential trona injection has an advantage over wet FGD systems in plants equipped with cold side electrostatic precipitators (ESPs) if SO_2 removal requirements are less than 70 percent. While there appears to be a definite cost advantage, trona injection does not appear to be competitive from an SO_2 removal standpoint. Both wet FGD and spray dryers, while more costly, are capable of over 90 percent SO_2 removal.

When all factors are taken into consideration, the project should be considered a solid success. A major problem (hopper fires) was solved early in the project and an effective, economic, mercury capture technology for plants equipped with HESPs was developed and thoroughly tested. The technology is also an option for power plants equipped with cold-side ESPs. In addition, the development of a CEMS suitable for power plants is an important component for the successful deployment of all mercury control technologies.

VII. REFERENCES

1. We Energies, ADA Environmental Solutions, Cummins & Barnard, and the Electric Power Research Institute, "TOXECON™ Retrofit For Mercury and Multi-Pollutant Control on Three 90-Mw Coal-Fired Boilers, Final Report: Project Performance and Economics", December 2009.
2. We Energies, ADA Environmental Solutions, Cummins & Barnard, and the Electric Power Research Institute, "TOXECON™ Retrofit For Mercury and Multi-Pollutant Control on Three 90-Mw Coal-Fired Boilers, Final Public Design Report", December 2009.

These documents can be viewed at:

http://www.netl.doe.gov/technologies/coalpower/cctc/ccpi/bibliography/demonstration/environmental/ccpi_toxecon.html

VIII. ABBREVIATIONS AND ACRONYMS

ACI	activated carbon injection
ADA-ES	ADA Environmental Solutions
AEA	air entraining additive
A/C	air to cloth ratio
CAMR	Clean Air Mercury Rule
CCPI	Clean Coal Power Initiative
CCT	Clean Coal Technology
CCTDP	Clean Coal Technology Demonstration Program
CEMS	continuous emission monitoring system
DOE	U.S. Department of Energy
ESP	electrostatic precipitator
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
gr/acf	grains per actual cubic foot
HESP	hot side electrostatic precipitator
ID	induced draft
(lb/MMBtu)	pounds per million British thermal units
lb/hr	pounds per hour
lbs/MMacf	pounds per million actual cubic feet
LOI	loss on ignition
NETL	National Energy Technology Laboratory
NO_X	nitrogen oxides
NSR	normal stoichiometric ratio
ppmw	parts per million by weight
PPS	polyphenylene sulfide
PRB	Powder River Basin
PIPP	Presque Isle Power Plant
PM	particulate matter
PAC	powdered activated carbon
PPII	Power Plant Improvement Initiative
SCEM	semi-continuous emission monitor
SO_2	sulfur dioxide
TGA	thermogravimetric analyses
Thermo	Thermo Electron Corporation