# MERCURY CONTROL WITH THE ADVANCED HYBRID™

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## ABSTRACT

This paper was prepared with the support of U.S. Department of Energy, under Award No. DE-FC26-01NT41184 and specifically addresses Technical Topical Area 4 – Testing Novel and Less Mature Control Technologies on Actual Flue Gas at the Pilot Scale. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the DOE. The project team includes the Energy & Environmental Research Center (EERC) as the main contractor; W.L. Gore & Associates, Inc., as a technical and financial partner; and the Big Stone Power Plant operated by Otter Tail Power Company, which will host the field testing portion of the research.

Since 1995, DOE has supported development of a new concept in particulate control, called the advanced hybrid particulate collector (AHPC). The AHPC is licensed to W.L. Gore & Associates, Inc., and is being marketed as the Advanced Hybrid™. The Advanced Hybrid™ combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The Advanced Hybrid™ provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emission with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. The Advanced Hybrid™ appears to have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor.

The objective of the three-task project is to demonstrate 90% total mercury control in the Advanced Hybrid™ at a lower cost than current mercury control estimates. The approach includes bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, pilot-scale testing on a coal-fired combustion system with both a pulse-jet baghouse and an Advanced Hybrid™ to prove or disprove the research hypotheses, and field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

This project, if successful, will demonstrate at the pilot-scale level a technology that would provide a cost-effective technique to accomplish control of mercury emissions and, at the same time, greatly enhance fine particulate collection efficiency. The technology can be used to retrofit systems currently employing inefficient ESP technology as well as for new construction, thereby providing a solution to a large segment of the U.S. utility industry as well as other industries requiring mercury control.

## INTRODUCTION

Since 1995, the U.S. Department of Energy (DOE) has supported development at the Energy & Environmental Research Center (EERC) of a new concept in particulate control, called the advanced hybrid particulate collector (AHPC). The AHPC is licensed to W.L. Gore & Associates, Inc., and is being marketed as the Advanced Hybrid™. The Advanced Hybrid™ combines the best features of electrostatic precipitators (ESPs) and baghouses in a unique configuration, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The Advanced Hybrid™ provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emission with conventional ESPs, and it solves the problem of reentrainment and re-collection of dust in conventional baghouses. In Phase II of the DOE-funded Advanced Hybrid™ project, a 2.5-MW-scale Advanced Hybrid™ was designed, constructed, installed, and tested at the Big Stone Power Plant. For Phase III, further testing of an improved version of the 2.5-MW-scale Advanced Hybrid™ at the Big Stone Power Plant was conducted to facilitate commercialization of the Advanced Hybrid™ technology.[1–8] Another paper on the status of Advanced Hybrid™ commercialization is being presented at this conference.

The Advanced Hybrid™ appears to also have unique advantages for mercury control over baghouses or ESPs as an excellent gas–solid contactor. Following completion of the Phase III work, the DOE National Energy Technology Laboratory (NETL) funded a mercury control project under a separate DOE Program Solicitation Technical Topic Area 4 – Testing Novel and Less Mature Control Technologies on Actual Flue Gas at the Pilot Scale. The project team includes the EERC as the main contractor; W.L. Gore & Associates, Inc., as a technical and financial partner; and the Big Stone Power Plant operated by Otter Tail Power Company, which is hosting the field testing portion of the research.

The objective of this project is to demonstrate 90% total mercury control with commercially available sorbents in the Advanced Hybrid™ at a lower cost than current mercury control estimates. The approach includes three levels of testing: 1) bench-scale batch testing that ties the new work to previous results and links results with larger-scale pilot testing with real flue gas on a coal-fired combustion system, 2) pilot-scale testing on a previously proven combustion system with both a pulse-jet baghouse and an Advanced Hybrid™ to prove or disprove the research hypotheses, and 3) field demonstration pilot-scale testing at a utility power plant to prove scaleup and demonstrate longer-term mercury control.

## TEST PLAN FOR THE 2.5-MW ADVANCED HYBRID™ AT THE BIG STONE POWER PLANT

Testing with the 2.5-MW Advanced Hybrid™ at Big Stone Power Plant was not scheduled to begin until 2002 after completing the first pilot-scale tests. However, the project team decided to conduct a field test the first week of November 2001 prior to the pilot-scale tests at the EERC, to obtain some initial mercury control data.

The field test at Big Stone was completed the week of November 5–10, 2001, with baseline testing on the first day, followed by carbon injection in both Advanced Hybrid™ and pulse-jet operational modes for the remainder of the week. The starting carbon addition rate was set at 24 kg of carbon sorbent/million $m^3$ of flue gas (1.5 lb of carbon sorbent/million acf), with the plan that it could be increased if necessary to achieve good mercury control. However, over 90% mercury control was seen at this carbon addition rate so no testing was completed at higher carbon concentrations.

A total of four Ontario Hydro mercury measurement samples were taken for each day, including both at the inlet and outlet of the Advanced Hybrid™. Two mercury continuous emission monitors (CEMs) provided additional information on the inlet and outlet mercury concentrations during the last three days of testing.

The first day was a baseline test in Advanced Hybrid™ mode with no carbon injection where the Advanced Hybrid™ was held at a constant air-to-cloth (A/C) ratio of 3.0 m/min (10 ft/min), the bags were cleaned on a constant timed 20-min interval, and the ash hopper was emptied once per hour.

For the second day, conditions were identical except for carbon addition at a rate of 24 kg of carbon sorbent/million $m^3$ (1.5 lb of carbon sorbent/million acf). The DARCO FGD carbon used was obtained from Norit Americas and is commercially available. The carbon addition was controlled with a K-Tron powder feeder and was injected pneumatically at a single point into the center of the 0.610 m (24-in.)-diameter inlet duct.

For the third day, the Advanced Hybrid™ was operated with carbon injection as a pulse-jet baghouse at an A/C ratio of 1.5 m/min (5 ft/min), or one half the flow rate of the previous two days. To keep the same carbon-to-flue gas ratio of 24 kg of carbon sorbent/million $m^3$ (1.5 lb of carbon sorbent/million acf), the carbon feed rate was set to half the previous level.

The fourth day was a repeat of Day 2 where the unit was again operated in Advanced Hybrid™ mode with carbon injection at 24 kg of carbon sorbent/million $m^3$ (1.5 lb of carbon sorbent/million acf).

For the fifth day of testing the unit was operated with carbon injection in both Advanced Hybrid™ and pulse-jet modes, but with both at an A/C ratio of 1.5 m/min (5 ft/min). This

test was completed to allow for a valid comparison between the Advanced Hybrid™ and pulse-jet modes without changing the residence time or temperature.

For all of the tests with carbon, the sorbent was injected only during the day, and after completing the mercury sampling, the carbon was shut off overnight to allow the unit to return to baseline conditions prior to starting carbon injection the next day.

## COAL ANALYSIS

During the test, the Big Stone plant was burning Codero Rojo complex subbituminous coal from the Powder River Basin. The mercury analysis for five coal samples is shown in Table 1 to have a mean value of 0.126 μg/g. Ultimate and proximate analysis for the coal is shown in Table 2.

**Table 1. Coal mercury analysis.**

| Sample | Hg Concentration, dry coal basis, μg/g |
|---|---|
| Day 1 | 0.127 |
| Day 2 | 0.122 |
| Day 3 | 0.105 |
| Day 4 | 0.149 |
| Day 5 | 0.125 |
| Mean | 0.126 |

**Table 2. Coal analysis for the Big Stone power plant.**

| Proximate Analysis | % As Sampled | % Moisture Free |
|---|---|---|
| Moisture Content | 29.3 | NA |
| Volatile Matter | 33.92 | 47.96 |
| Fixed Carbon | 31.57 | 44.67 |
| Ash | 5.21 | 7.37 |
| Ultimate Analysis | | |
| Hydrogen | 6.48 | 4.57 |
| Carbon | 49.46 | 69.93 |
| Nitrogen | 0.77 | 1.09 |
| Sulfur | 0.38 | 0.54 |
| Oxygen | 37.69 | 16.50 |
| Ash | 5.21 | 7.37 |
| Heating Value, Btu/lb | 8607 | 12,174 |

From the ultimate analysis, a theoretical combustion calculation was completed to determine the theoretical mercury concentration in the inlet flue gas, 15.1 μg/Nm$^3$ of dry flue gas at 3.0% $O_2$.

## CARBON INJECTION

The DARCO FGD activated carbon is a commercially available sorbent produced by Norit Americas. DARCO FGD powdered activated carbon is a lignite coal-based activated carbon manufactured specifically for the removal of heavy metals and other contaminants typically found in incinerator flue gas emission streams. It has a surface area of 600 $m^2/g$ and has been proven in numerous full-scale operating facilities to be highly effective for the removal of gaseous mercury, dioxins (PCDD) and furans (PCDF). 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.

DARCO FGD is a fine-flowing powdered carbon with minimal caking tendencies, which makes it ideal for automatic dosing systems with dry or wet injection. It is manufactured with a very high ignition temperature to permit safe operation at the elevated temperatures inherent in incinerator flue gas streams. This is a carbon that has been previously investigated by the EERC and other researchers for mercury control from coal-fired boilers.

The carbon was fed with a K-Tron dual-screw feeder at a rate of 24 kg of carbon sorbent/million $m^3$ (1.5 lb of carbon sorbent/million acf), which corresponds to 0.29 kg/hr (0.65 lb/hr) at an A/C ratio of 3.0 m/min (10 ft/min) and 0.15 kg/hr (0.325 lb/hr) at an A/C ratio of 1.5 m/min (5 ft/min). The carbon feeder was located in the enclosed area of the Advanced Hybrid™ below the hopper (Figures 1 and 2). From the screw feeder, the carbon was introduced into an Air-Vac eductor that was driven by compressed air. From the outlet of the eductor, the carbon was then transported approximately 6.1 m (20 ft) through 0.019-m (0.75-in.) stainless steel tubing to the elbow location of the inlet piping (Figure 3).


Fig. 1. Overview of carbon injection system.


Fig. 2. Air-Vac eductor of carbon injection system.


Fig. 3. Carbon-injecting location.

Approximately 0.9 m (3 ft) of straight tubing extended inside the duct so that the carbon was injected directly upstream at a single point in the center of the 0.610-m (24-in.)-diameter inlet pipe.

The feeder was calibrated prior to the start of carbon injection and again at the end of each day. In addition, the weight of carbon added during a day was divided by the time of injection to provide an average feed rate. According to the calibration data and weight-of-added-carbon data, the feeder appeared to provide a very steady and consistent feed rate within a few percent of the target rate. The carbon feed and injection system worked very well, and there were no problems with inconsistent feeding or plugging of the feeder or injection system.

## FLUE GAS COMPOSITION

Flue gas composition was measured each day both at the Advanced Hybrid™ inlet and outlet by using a portable Ecom gas analyzer which provided the concentrations of $O_2$, $CO_2$, CO, NO, $NO_2$, and $SO_2$ in the flue gas on a dry basis. The results for the 5-day sampling normalized to 3% $O_2$ are listed in Table 3. Actual $O_2$ concentrations were in the range from 5.0% to 5.5%. Three $SO_3$ samples (by using selective condensation method) and three HCl samples (using U.S. Environmental Protection Agency [EPA] Method 26) were collected at the Advanced Hybrid™ inlet during the 5-day test, as shown in Table 4.

**Table 3. Summary of the flue gas compositions during the 5-day sampling (dry basis normalized to 3% $O_2$).**

| | | $CO_2$, % | CO, ppm | NO, ppm | $NO_2$, ppm | $SO_2$, ppm |
|---|---|---|---|---|---|---|
| Day 1 | In | 15.9 | 1.2 | 619 | 4.9 | 201 |
| | Out | 16.0 | 1.1 | 615 | 3.4 | 269 |
| Day 2 | In | 16.0 | – | 609 | 2.2 | 282 |
| | Out | 16.0 | 11 | 597 | 2.2 | 278 |
| Day 3 | In | 16.0 | 2.3 | 659 | 2.3 | 288 |
| | Out | 16.0 | 1.1 | 589 | 3.4 | 284 |
| Day 4 | In | – | – | 621 | 2.3 | 296 |
| | Out | – | 4.6 | 572 | 1.1 | 343 |
| Day 5 | In | 16.0 | 2.3 | 612 | 2.3 | 256 |
| | Out | 16.0 | 1.2 | 607 | 3.5 | 233 |

**Table 4. HCl and $SO_3$ analysis in the flue gas, ppm dry at 3% $O_2$.**

| Gas | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| HCl | 9.1 | 10.1 | 9.9 |
| $SO_3$ | 0.4 | 0.6 | 0.6 |

## ONTARIO HYDRO MERCURY MEASUREMENT RESULTS

Ontario Hydro sampling trains were set up at the Advanced Hybrid™ inlet and outlet to measure mercury species concentrations in the flue gas. Figure 4 shows the inlet sampling location which was 6.1 m (20 ft) upstream of the carbon injection location. A heated Teflon line was used between the probe and impinger train. The target sampling time was 2 hours. The outlet sampling location was just before the flue gas entered the fan, as shown in Figure 5. Since the Ontario Hydro method uses isokinetic sampling to measure mercury concentration in fly ash particles, it also provides information on dust loading in the flue gas. As shown in Figure 4, the inlet sampling location was around 1.5 m (5 ft) downstream of an elbow where flue gas had a 90 degree change of flow direction, which may result in a nonuniform fly ash distribution in the duct cross section. Some of the larger-sized fly ash particles may concentrate in the lower part of the dust because of their greater inertia, causing a lower dust-loading measurement than the real value in the system. A biased dust-loading measurement may result in slight underestimations of both particle collection efficiency and total mercury capture efficiency.

The Advanced Hybrid™ unit was operated at an A/C ratio of 3.0 m/min (10 ft/min) without carbon injection on the Day 1 test. Two pairs of simultaneous inlet and outlet Ontario Hydro samples were collected.

The Ontario Hydro sampling method provides mercury species information in flue gas as elemental mercury vapor, oxidized mercury, and mercury associated with particulate matter. All the results are presented in the form of $\mu g/Nm^3$ based on the cold-vapor atomic

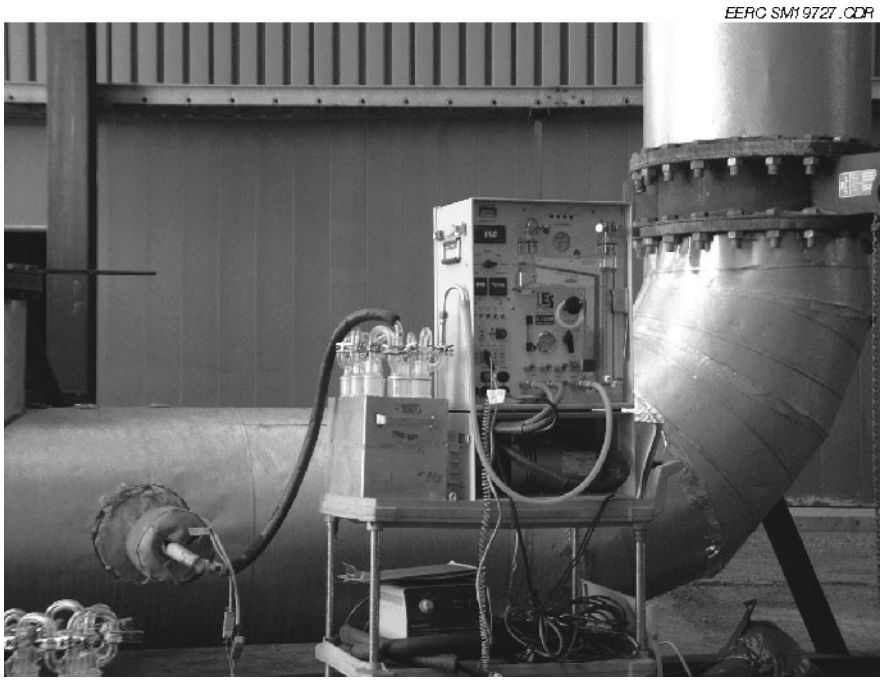


Fig. 4. Ontario Hydro sampling train at the Advanced Hybrid™ inlet.

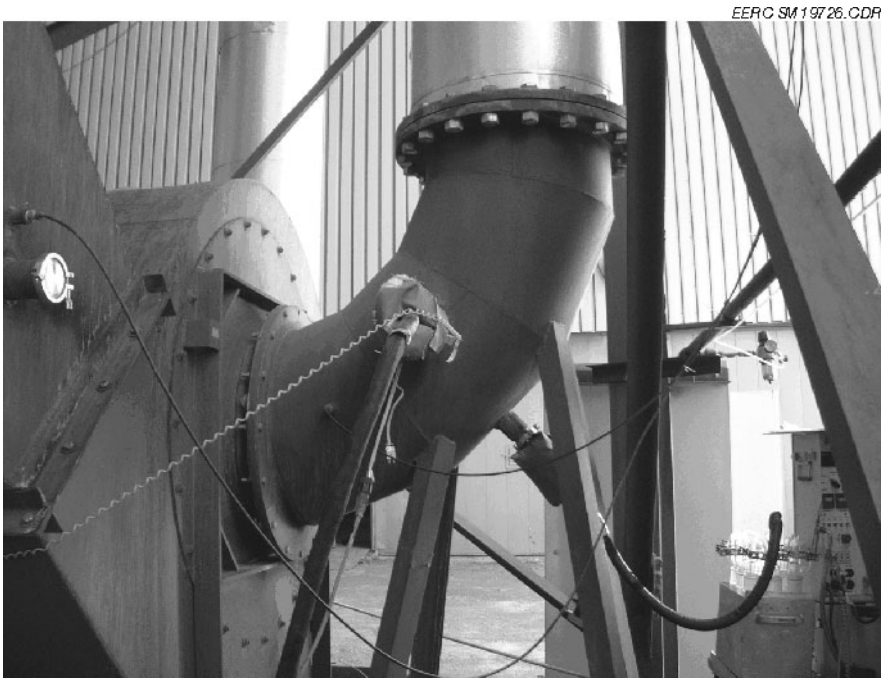


Fig. 5. Ontario Hydro sampling at the Advanced Hybrid™ outlet.

absorption (CVAA) analysis results of the impinger solutions, sampling flue gas volume, and dust loading. All of the measured mercury concentrations in the flue gas were corrected to a moisture-free 3% $O_2$ level to allow a valid comparison at varying $O_2$ levels.

The dust-loading measurement results at the inlet and outlet of the Advanced Hybrid™ system (obtained from Ontario Hydro method) indicated particle collection efficiency ranged from 99.972% to 100%, which represents the level of accuracy that can be achieved by this method with a 2-hr sample. Earlier tests on the Big Stone Advanced Hybrid™ where the outlet was sampled for over 15 hours indicated collection efficiencies well over 99.99%. Independent measurements with real-time particle analyzers have also proven the collection efficiency to be far better than 99.99%.

A summary of mercury analysis results from the Ontario Hydro method is listed in Table 5. The total mercury concentration in the flue gas (present as total mercury concentration at the Advanced Hybrid™ inlet) ranged from 10.6 to 13.2 μg/Nm$^3$, which is slightly lower than the theoretical value of 15.1 μg/Nm$^3$ obtained from the coal combustion calculation based on the coal analysis. A possible reason is the underestimated inlet dust loading. However, considering the complexity of mercury analysis, the measured mercury results are close to the theoretical value.

The Day 1 baseline mercury species distributions are plotted as a function of sampling location in Figure 6. At the Advanced Hybrid™ inlet, the mercury associated with particulate

**Table 5. Summary of Ontario Hydro mercury results, dry flue gas at 3.0% $O_2$ (μg/Nm$^3$).**

| | | $Hg^0$ | $Hg^+$ | Hg(p) | Hg(total) |
|---|---|---|---|---|---|
| Day 1 | Inlet | 0.87 | 5.2 | 7.12 | 13.19 |
| | | 0.87 | 6.55 | 5.91 | 13.33 |
| | Outlet | 1.0 | 4.72 | 0 | 5.72 |
| | | 1.23 | 6.46 | 0 | 7.69 |
| Day 2 | Inlet | 1.04 | 3.04 | 6.49 | 10.57 |
| | Outlet | 0.75 | 0 | 0 | 0.75 |
| | | 0.87 | 0.55 | 0 | 1.42 |
| | | 0.74 | 0.06 | 0 | 0.80 |
| Day 3 | Inlet | 1.13 | 5.99 | 4.32 | 11.44 |
| | Outlet | 0.11 | 0.27 | 0 | 0.38 |
| | | 0.14 | 0.46 | 0 | 0.6 |
| | | 0.14 | 0.05 | 0 | 0.19 |
| Day 4 | Inlet | 0.41 | 2.64 | 10.2 | 13.25 |
| | Outlet | 0.21 | 1.07 | 0 | 1.28 |
| | | 0.13 | 0.75 | 0 | 0.88 |
| | | 0.13 | 0.96 | 0 | 1.09 |
| Day 5 | Inlet | 0.62 | 5.5 | 5.86 | 11.98 |
| | Outlet | 0.13 | 0.61 | 0 | 0.74 |
| Day 5 | Inlet | 0.42 | 3.88 | 7.83 | 12.13 |
| | Outlet | 0.09 | 0.54 | 0 | 0.63 |

Day 1 – No carbon injection, Advanced Hybrid™, 3.0 m/min (10 ft/min).
Day 2 – Carbon: 0.65 lb/hr, Advanced Hybrid™, 3.0 m/min (10 ft/min).
Day 3 – Carbon: 0.33 lb/hr, pulse jet, 1.5 m/min (5 ft/min).
Day 4 – Carbon: 0.65 lb/hr, Advanced Hybrid™, 3.0 m/min (10 ft/min).
Day 5 – Carbon: 0.33 lb/hr, Advanced Hybrid™, 1.5 m/min (5 ft/min).
Day 5 – Carbon: 0.33 lb/hr, pulse jet, 1.5 m/min (5 ft/min).

was 5.91–7.12 μg/Nm$^3$ and the oxidized mercury was 5.2–6.55 μg/Nm$^3$, while the elemental mercury vapor was at a surprisingly low level of 0.87 μg/Nm$^3$. All the mercury associated with the fly ash particles was completely removed from the flue gas because of the extremely high particle collection efficiency (>99.99% based on dust loading measured at the Advanced Hybrid™ inlet and outlet). However, gas-phase mercury, including elemental and oxidized, penetrated the Advanced Hybrid™ with virtually no capture, resulting in an elemental mercury concentration of 1–1.23 μg/Nm$^3$ and an oxidized mercury concentration of 4.72–6.46 μg/Nm$^3$ at the outlet, almost the same level as that of the inlet. A nearly 100% collection efficiency of mercury associated with fly ash was achieved because of the excellent capture efficiency of particulate by the Advanced Hybrid™ unit.

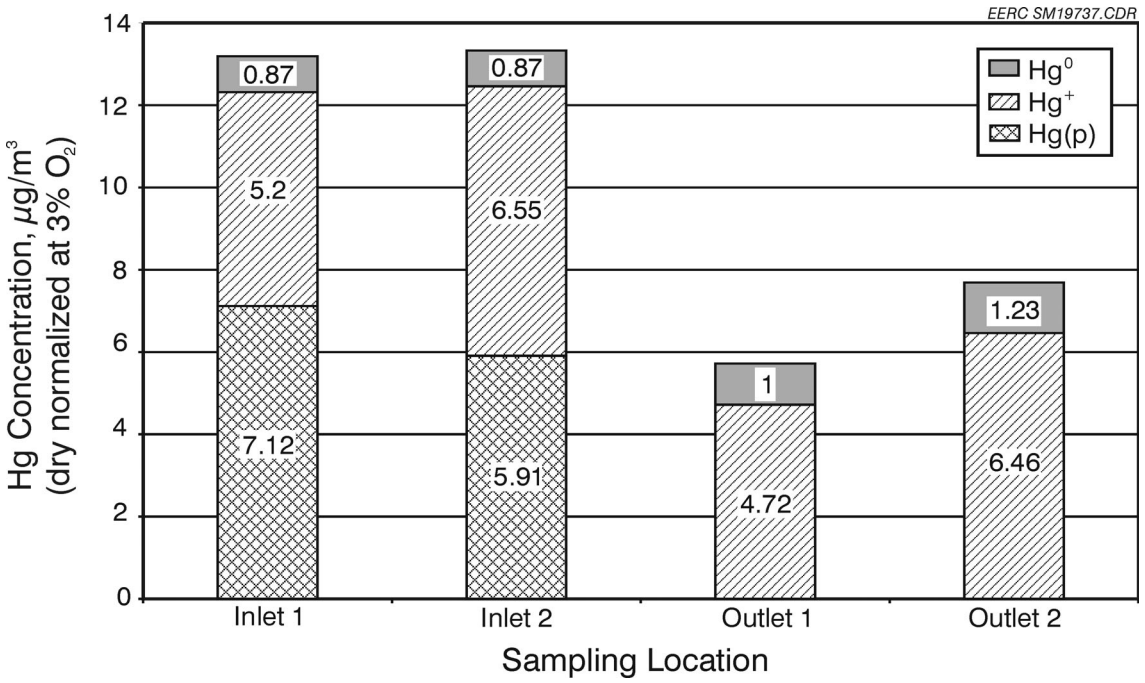


Fig. 6. Day 1 – mercury species concentration in flue gas across the Advanced Hybrid™ (10 ft/min, 20-min bag-cleaning interval [BCI], multibank cleaning, no carbon injection).

The outlet $Hg^0$ and $Hg^+$ concentrations were similar to the inlet values, and the 49.4% overall collection efficiency of mercury by the Advanced Hybrid™ without carbon injection was the result of capturing particulate-bound mercury.

On the Day 2 sampling test, the unit was operated in an Advanced Hybrid™ mode (70 mA, 58 kV, 3.0 m/min [10 ft/min], 20-min BCI), with a carbon injection of 0.29 kg/hr (0.65 lb/hr) (corresponding to 24 kg of carbon/million $m^3$ [1.5 lb carbon/million acf]). Results from one inlet and three outlet Ontario Hydro samples are shown in Figure 7. In the presence of the activated carbon in the flue gas, the outlet mercury emission was reduced to 0 μg/$Nm^3$ of particulate mercury, 0–0.55 μg/$Nm^3$ of oxidized mercury, and 0.74–0.85 μg/$Nm^3$ of elemental mercury vapor. The overall mercury collection of 90.6% compared to 49% without carbon indicates the carbon injection was effective.

On Day 3, the Advanced Hybrid™ unit was then operated in pulse-jet mode (without high-voltage power) with a 20-min BCI. In order to keep the pressure drop across the system at a reasonable level, the A/C ratio was reduced to 1.5 m/min (5 ft/min) and the carbon injection rate was correspondingly reduced to 0.15 kg/hr (0.33 lb/hr) to keep the same carbon-to-flue gas ratio of 24 kg of carbon/million $m^3$ (1.5 lb carbon/million acf). The measured mercury species concentrations (one inlet and three outlet samples) are plotted in Figure 8. The inlet mercury species distribution was similar to the previous two days. The outlet mercury was at a very low level in the presence of carbon injection: 0 μg/$Nm^3$ of particle associated mercury, 0.07–0.46 μg/$Nm^3$ of oxidized mercury, and 0.11–0.14 μg/$Nm^3$ of elemental mercury vapor.

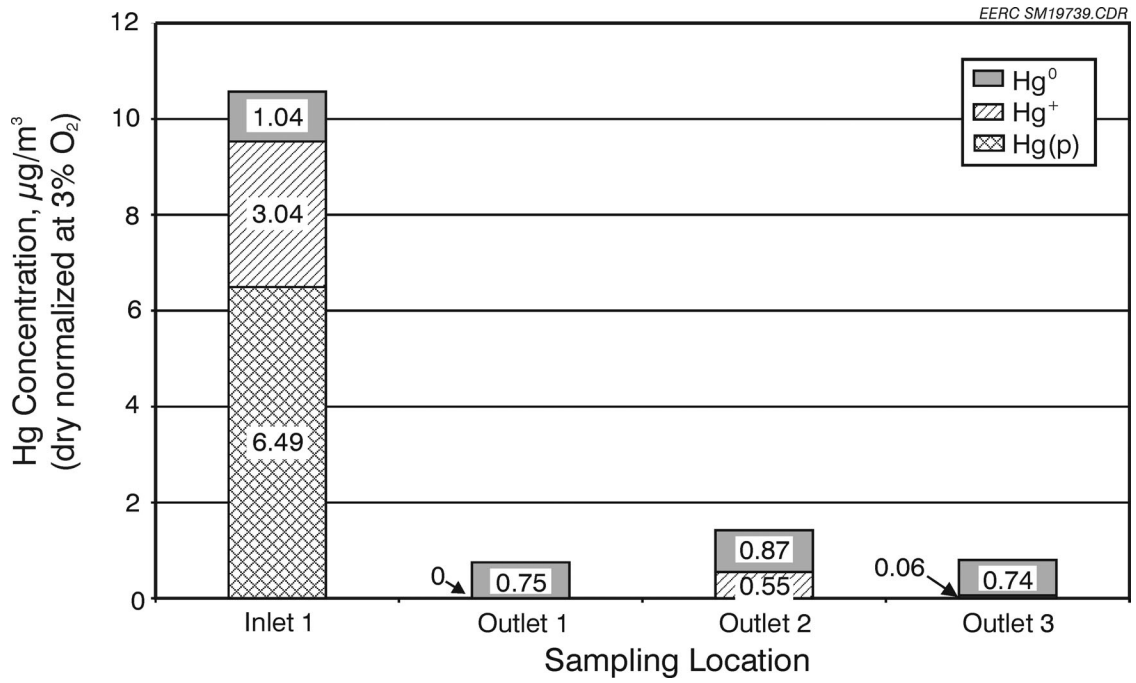


Fig. 7. Day 2 – mercury species concentration in flue gas across the Advanced Hybrid™ unit in Advanced Hybrid™ mode (10 ft/min, 20-minute BCI, multibank cleaning, carbon: 0.65 lb/hr).

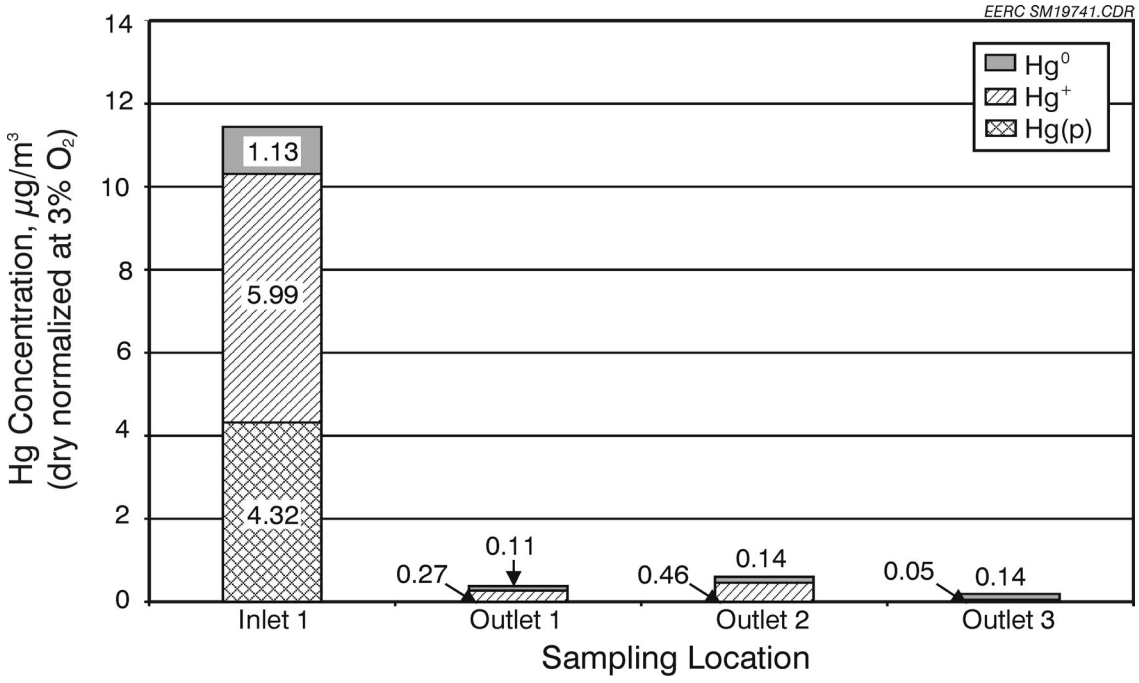


Fig. 8. Day 3 – mercury species concentration in flue gas across the Advanced Hybrid™ unit in pulse-jet mode (5 ft/min, 20-minute BCI, multibank cleaning, carbon: 0.33 lb/hr).

The corresponding overall mercury capture efficiency was 96.6%, which is somewhat better than the 90.6% achieved in the Day 2 sampling test. For Day 3, longer residence time at the reduced A/C ratio of 1.5 m/min (5 ft/min) and a lower temperature may have contributed to the somewhat lower mercury emissions compared to Day 2.

The Day 4 sampling test was a repeat of the Day 2 test (Advanced Hybrid™ mode, 20-min BCI, 3.0 m/min [10 ft/min] of A/C ratio, and 0.29 kg/hr [0.65 lb/hr] carbon injection rate). The mercury concentrations and collection efficiency (shown in Figure 9) are in good agreement with the results obtained in the Day 2 test. The total mercury collection efficiency was 91.8%, almost the same as the 90.6% achieved in the Day 2 test.

For Day 5, the unit was operated with carbon injection in both Advanced Hybrid™ and pulse-jet modes at the same A/C ratio of 1.5 m/min (5 ft/min). The tests provided a better comparison between the two operating modes because the residence time and temperature were constant. The measured mercury concentrations under the two operating modes are plotted in Figure 10. The total inlet mercury concentration was 11.98 μg/Nm$^3$ in Advanced Hybrid™ mode and 12.13 μg/Nm$^3$ in pulse-jet mode, indicating constant inlet conditions. The outlet mercury was also similar for both operating modes. The collection efficiencies are plotted in Figure 11, showing the removal efficiencies for oxidized, elemental, and total mercury were the same for both modes.

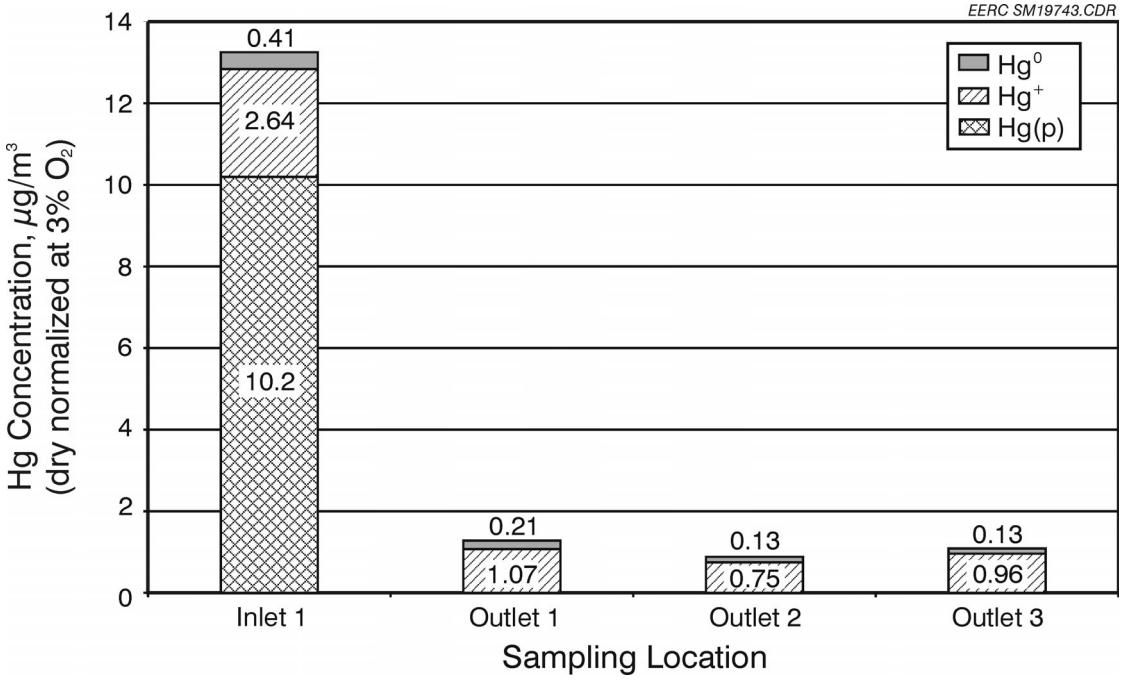


Fig. 9. Day 4 – mercury species concentration in flue gas across the Advanced Hybrid™ unit in Advanced Hybrid™ mode (10 ft/min, 20-minute BCI, multibank cleaning, carbon: 0.65 lb/hr).

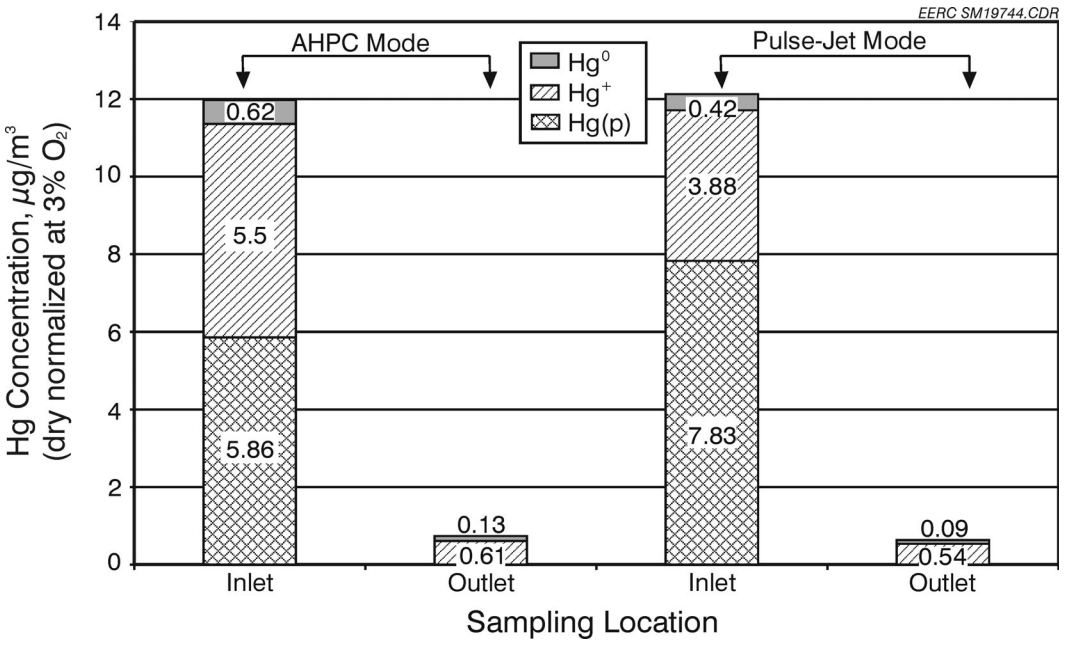


Fig. 10. Day 5 – mercury species concentration in flue gas across the Advanced Hybrid™ unit at Big Stone in both Advanced Hybrid™ and pulse-jet mode.

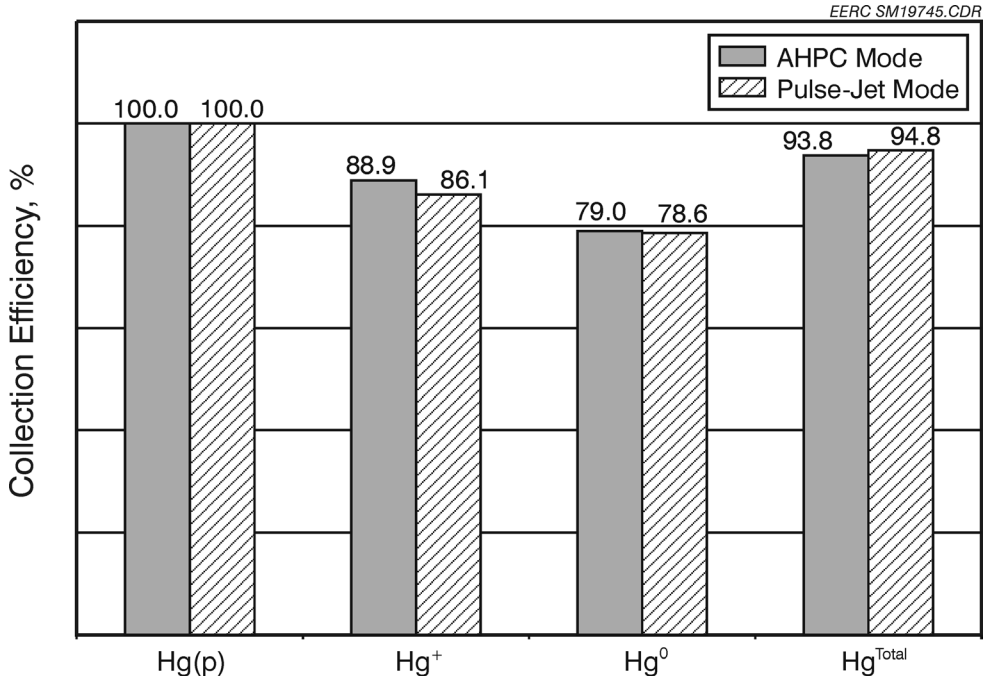


Fig. 11. Day 5 – mercury species collection efficiency under Advanced Hybrid™ and pulse-jet mode.

## MERCURY CEM RESULTS

The total mercury vapor concentration and elemental mercury vapor concentration at the Advanced Hybrid™ inlet and outlet were continuously monitored on Days 3–5 by a PS Analytical Sir Galahad analyzer. Since only measuring mercury vapor, a nonisokinetic sample of flue gas was pulled through a thimble filter to remove the fly ash. The particle-free flue gas was then passed through a conversion unit where the oxidized mercury could be reduced to elemental state. Depending on which side of the pretreatment system the flue gas was passed through, either elemental or total mercury concentration could be obtained.

The elemental and total mercury concentrations monitored at the Advanced Hybrid™ inlet during the Day 3 test are plotted as a function of operating time and shown in Figure 12. The inlet elemental mercury was around 0.39 μg/Nm$^3$, only accounting for 8.4% of the measured total mercury vapor concentration of 4.62 μg/Nm$^3$, which agreed with the Ontario Hydro results. In the presence of activated carbon in flue gas, the total mercury concentration at the outlet was about 0.54 μg/Nm$^3$ (also shown in Figure 12), and the elemental mercury concentration in flue gas was below the CEM detection limit, which was in reasonable agreement with the results from the Ontario Hydro method. They both showed that most of the inlet mercury vapor in the flue gas was in the oxidized state and excellent mercury capture in the presence of the activated carbon. At 16:00, the carbon injection was shut down while the outlet was continually monitored for mercury. As seen in Figure 12, the total outlet mercury concentration gradually increased and reached the same level as that of the inlet.

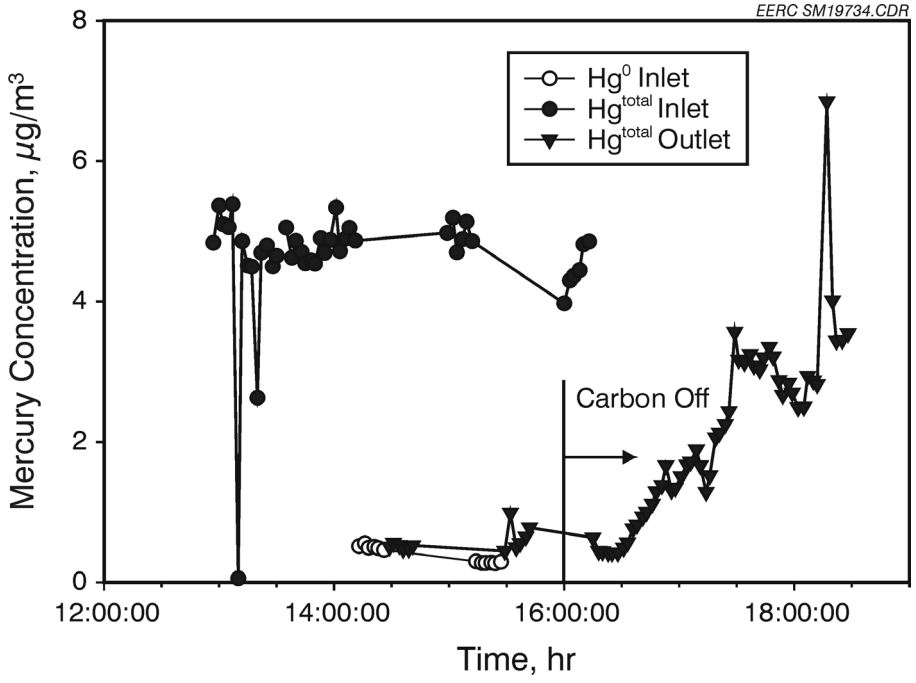


Fig. 12. Hg species measurement by CEM – Day 3.

## CONCLUSIONS AND DISCUSSION

- The average inlet total mercury concentration of 12.3 μg/Nm$^3$ (dry @3% $O_2$) was slightly below the theoretical value of 15 μg/Nm$^3$. One possible reason for the difference is that the inlet sample location was at a point where the inlet dust loading may be somewhat biased low. Since about half of the mercury was particulate bound, a low dust loading measurement would also result in a low total mercury measurement. For example, if the dust loading was 30% low, this would translate to a 15% low bias in the total inlet mercury.

- The average inlet mercury speciation for seven samples was 55.4% particulate bound, 38.1% oxidized, and 6.4% elemental. The high level of particulate-bound mercury and oxidized mercury was somewhat surprising because for western Powder River Basin coals, lower levels of particulate-bound mercury and oxidized mercury are more typical. However, significant capture of mercury by the fly ash has been observed in previous EERC pilot tests as well as a number of coal-fired plants burning western fuels. Possible factors that determine the level of particulate-bound and oxidized mercury include coal type, boiler type, HCl (as well as other flue gases), temperature, and amount of carbon in the fly ash. The current level of understanding of how these factors work together is insufficient to explain the observed mercury speciation for individual plants.

- A carbon injection rate of 1.5 lb/million acf corresponds to a carbon-to-mercury ratio of approximately 2500 for the measured inlet mercury. With this carbon injection rate, from 91% to 97% total mercury collection efficiency was achieved compared to 49% removal for the baseline case. Even though the carbon addition rate was low, the carbon was highly effective at removing mercury. The data show that the carbon was effective at removing both elemental and oxidized mercury.

- Mercury removal with carbon removal in Advanced Hybrid™ mode was 91% and 92% on Days 2 and 4 compared to 97% on Day 4 in pulse-jet mode. At first glance, this would seem to indicate that the pulse-jet configuration is better than the Advanced Hybrid™ for mercury removal. However, in the pulse-jet mode, the residence time in the duct and chamber was twice as long and the temperature was also about 11°C (20°F) lower because of the lower flow rate. Both the longer residence time and lower temperature would be expected to lead to better mercury capture. On Day 5, the unit was operated in both modes at the same flow rate, which resulted in 94% capture in Advanced Hybrid™ mode and 95% capture in pulse-jet mode. From these results, it can be concluded that both modes provided excellent mercury capture, at least for short-term tests, and there was no difference in mercury capture between the two modes. The conditions that produce the best collection efficiency with activated carbon are not well known. Previous pilot and field data indicate that the level of mercury capture with carbon is highly dependent on the coal type, other flue gases present, temperature, contact geometry, and residence time, but no model is available that can employ these factors to predict the level of capture for a specific configuration.

- These short-term tests are highly encouraging because they prove that excellent mercury removal can be achieved with very low addition rates of carbon injected upstream of the Advanced Hybrid™. Further testing is needed to demonstrate that the high level of mercury removal can be maintained over the longer term and that the carbon injection will not have any adverse effect on the longer-term operation of the Advanced Hybrid™. Since the conditions that lead to good mercury capture with carbon are not well known, at this point the results should not be generalized to other coals or plants.

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