

## **DRAFT**

# **Technology for Controlling Mercury Emissions from Coal-Fired Power Plants in Illinois**

The mercury emissions from a coal-fired power plant are the result of the mercury content in the coal that is burned and the extent that processes in the boiler prevent the mercury from being released with the exhaust gases of the power plant. Mercury can be removed from the coal prior to combustion of the coal. This may be achieved by coal cleaning or by some other treatment of the coal. Or, mercury can be removed from the boiler flue gases by air pollution control (APC) equipment. Sometimes the APC equipment that removes the mercury is equipment that is installed primarily to remove other pollutants, such as particle matter (PM) or acid gases in a flue gas desulfurization system (FGD). These are called co-benefit mercury removal. Mercury may also be removed by pollution control systems that are specifically designed to remove mercury from the flue gases.

Mercury emissions control technology is a rapidly developing field. New developments continually improve capabilities to reduce mercury emissions from coal-fired power plants. The following sections address a current understanding of how mercury emissions from Illinois coal-fired power plants may be controlled.

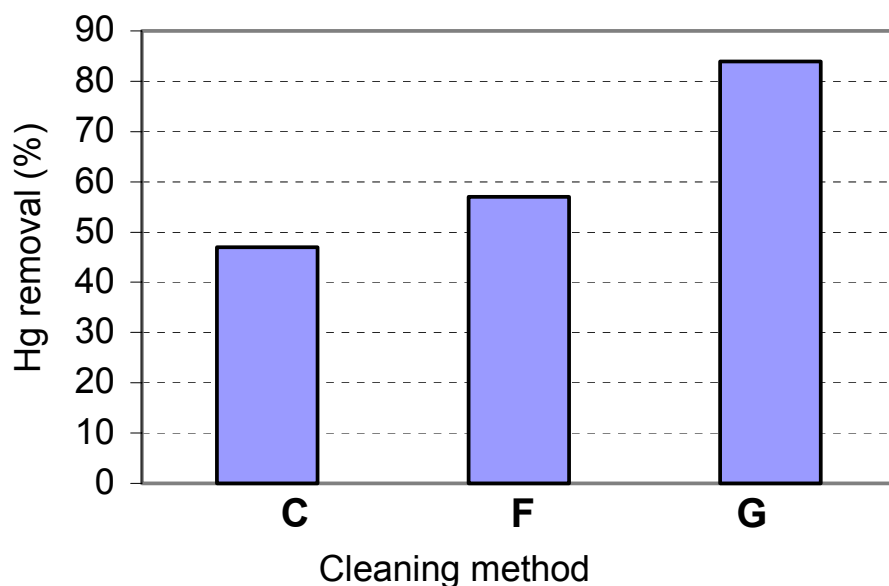
## **Mercury Removal from Coal**

Run of mine (ROM) bituminous coal is frequently cleaned for the following purposes:

- Removal of impurities to improve the heating value of the coal
- Reduction of transportation costs for coal to the power plant and ash from the power plant
- Maintenance of ash content in coal supply within contract requirements
- Removal of sulfur, mainly as pyrites, lowering SO<sub>2</sub> emissions when the coal is burned.

However, cleaning ROM coal will provide the added benefit of removing mercury from the coal. This is because mercury in the coal is preferentially associated with pyrites and

other non-combustible materials that are removed in coal washing. In conventional cleaning methods the coal is crushed and separated into course, medium and fine fractions. Each of these size fractions is cleaned by different methods that may include jigs or heavy media baths (course), cyclones and concentrating tables (intermediate), or disposal or froth floatation (fines). Conventional cleaning methods can remove on average 47% of the coal mercury in ROM Illinois bituminous coal, as shown in Figure 1. Research shows that advanced cleaning techniques, such as advanced floatation or gravity separation can remove higher amounts of mercury from Illinois bituminous coal, as high as 84%. However, more advanced cleaning methods increase the amount of waste material, the amount of energy expended and the amount of coal that must be mined to produce a given amount of product coal. Therefore, there are economic and environmental trade-offs beyond mercury removal that must be considered.



**Figure 1.** Mercury removal efficiency of coal cleaning methods on Illinois coal. Coal cleaned by:

- conventional cleaning (C);
- advanced floatation (F); and
- advanced gravity separation (G).<sup>1</sup>

### The Fate of Mercury During Coal Combustion

Mercury that is present in trace amounts in the coal is released from the coal during combustion. At furnace conditions, the released mercury is present in a gaseous state in the elemental form that is denoted as  $\text{Hg}^0$ . As the combustion exhaust gases cool in the boiler, chemistry shifts to favor an oxidized, or ionic, form of mercury, denoted as  $\text{Hg}^{2+}$ . The temperature window where this transformation occurs varies based upon flue gas

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conditions, and may vary from about about 620 °F to 1250 °F.<sup>2</sup> The most common form of  $\text{Hg}^{2+}$  is  $\text{HgCl}_2$ . As the flue gas cools, some of the mercury may also form particulate or be adsorbed onto solid particles in the combustion gases. This particulate form of Hg is denoted  $\text{Hg}_p$ . At conditions after the last heat exchanger, normally around 300 °F, one would expect all of the mercury to be in the form of  $\text{Hg}_p$  or  $\text{Hg}^{2+}$  if the chemical reactions went to completion. However, in practice, the form of the mercury is normally such that some significant portion (from a few percent to over 90%) of the mercury actually remains in the elemental form ( $\text{Hg}^0$ ). Therefore, the transformation of elemental mercury to oxidized mercury is kinetically limited – that is to say that the chemical reactions associated with mercury oxidation slow down and stop before they can reach completion.

The speciation of mercury – as  $\text{Hg}^0$ ,  $\text{Hg}^{2+}$ , or  $\text{Hg}_p$  – is important because it impacts the capture of mercury by boiler air pollution control (APC) equipment.  $\text{Hg}^0$  is not removed by pollution control equipment without first converting it to another form of mercury – either  $\text{Hg}^{2+}$  or  $\text{Hg}_p$ .  $\text{Hg}_p$  is effectively removed by particulate matter (PM) control devices such as electrostatic precipitators (ESPs) and fabric filters (FFs) and  $\text{Hg}^{2+}$  is water soluble and is efficiently removed by flue gas desulfurization (FGD) equipment. The oxidation of  $\text{Hg}^0$  to  $\text{Hg}^{2+}$  may occur in gas-phase reactions or in heterogeneous, or catalytically-assisted, reactions. The gas-phase oxidation is believed to be influenced by several parameters – temperature and concentration of certain species such as chlorine. The heterogeneous reactions occur mostly on fly ash surfaces or boiler surfaces. If the fly ash contains high amounts of unburned carbon the catalytic effect is greater. In addition, carbon in the fly ash acts as a sorbent. Chlorination of carbon by HCl is a likely first step toward catalytic oxidation of  $\text{Hg}^0$  to  $\text{HgCl}_2$  on the surface of fly ash, and chemisorption of the Hg onto the fly ash carbon can occur this way. Through this mechanism  $\text{Hg}^0$  can be transformed into  $\text{Hg}_p$ , which can be captured by downstream PM control devices. Hence, fly ash characteristics – especially carbon - as well as coal chlorine content play an important role in mercury speciation and capture. Other species –  $\text{SO}_2$  and  $\text{H}_2\text{O}$  – have also been shown to affect mercury speciation, tending to suppress  $\text{Hg}^0$  oxidation to  $\text{Hg}^{2+}$  somewhat as concentration of  $\text{SO}_2$  or  $\text{H}_2\text{O}$  is increased. But, the

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effects of SO<sub>2</sub> and H<sub>2</sub>O are not as significant as the effects of temperature, carbon and chlorine.<sup>2</sup>

Two types of coals are burned at power plants in the state of Illinois – bituminous and subbituminous. Bituminous coals burned in Illinois are usually native Illinois basin coals. Subbituminous coals are usually imported from the western states and are attractive for their low sulfur content. Bituminous coals tend to have higher chlorine contents and also tend to produce higher levels of unburned carbon (UBC) in the fly ash than subbituminous coals. Because of the importance of chlorine and carbon in oxidation of Hg<sup>0</sup>, bituminous coals are more likely to produce low proportion of Hg as Hg<sup>0</sup> while subbituminous and lignite coals produce more Hg as Hg<sup>0</sup>. Since the Hg<sup>0</sup> is not easily captured by existing pollution controls, the plants that burn subbituminous coals would be expected to have higher mercury emissions for the same air pollution control configuration.

### **Mercury Removal by Co-Benefit from PM, NO<sub>x</sub> and SO<sub>2</sub> Controls**

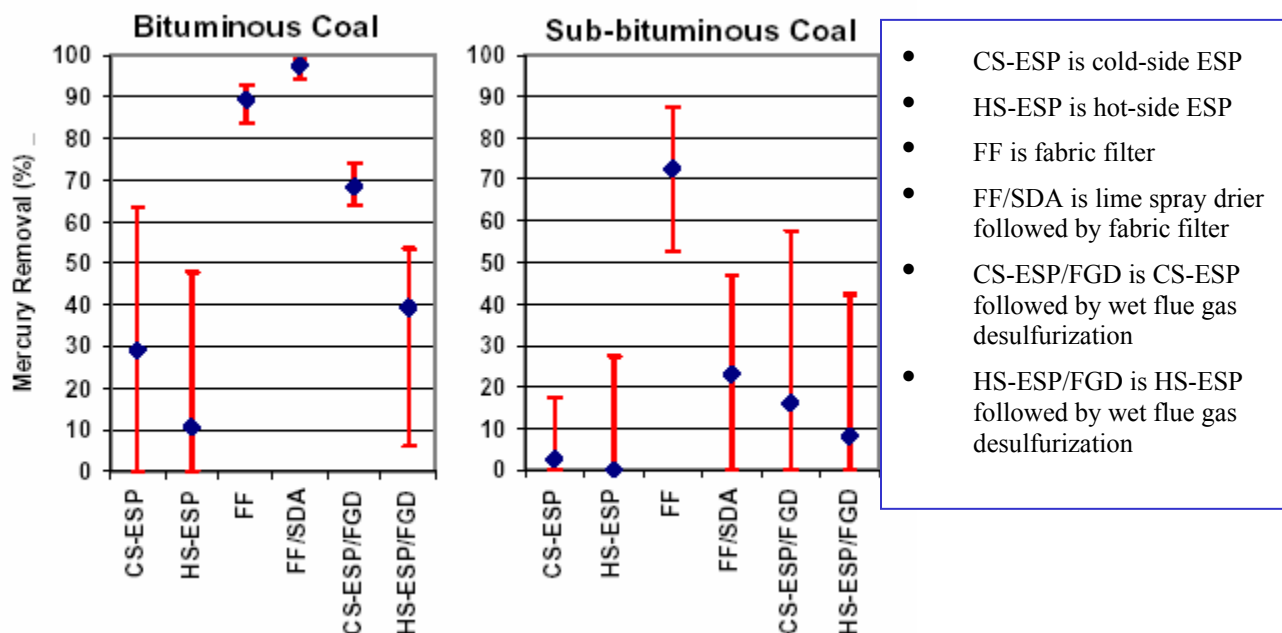
Mercury may be captured by co-benefit of particle matter (PM) controls or SO<sub>2</sub> controls. NO<sub>x</sub> controls can enhance the capture that is achieved in PM and SO<sub>2</sub> controls. Results of measurements of co-benefit mercury removal rates taken in response to the US EPA's Information Collection Request (ICR) are shown in Figure 2 for bituminous and subbituminous coals with various air pollution control (APC) configurations. Figure 2 shows the average removal rates as well as the range that was measured for each APC configuration. There are some important trends in this figure.

- In every case, the average mercury removal rate for bituminous coal was greater than the average removal rate of subbituminous coal for the same APC configuration.
- Mercury removal for a FF was significantly higher than for a cold-side ESP (CS-ESP) or hot-side ESP (HS-ESP) for both bituminous and subbituminous coals.

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- Removal for a bituminous coal fired boiler with Spray Drier Absorber and FF (SDA/FF) was very high (over 95%), while for subbituminous coals removal with SDA/FF was actually less than for a FF alone.
- In several cases there was a high level of variability in capture efficiency.

**Figure 1.** Mercury removal rates measured for bituminous and subbituminous coals.



The tendency for mercury to be captured more efficiently from boilers firing bituminous coal is likely a result of the higher chlorine contents that these coals tend to have and the higher unburned carbon in the fly ash of these coals. Both factors will contribute to lower proportions of Hg as  $\text{Hg}^0$  and greater proportions of Hg as  $\text{Hg}^{2+}$  or  $\text{Hg}_p$ , both of which are easier to capture than  $\text{Hg}^0$ . The carbon in fly ash also acts as a sorbent material to capture the mercury.

The improved mercury capture by FF over ESP's can be explained by the intimate contact the gas has with fly ash (and unburned carbon, or UBC) as it passes through the fabric filter. This will contribute to greater catalytic oxidation and subsequent adsorption of the mercury. Bituminous coals, generally having higher UBC contents in the fly ash, would be expected to produce higher removal rates in combination with a FF than subbituminous coals with an FF, and this is the case.

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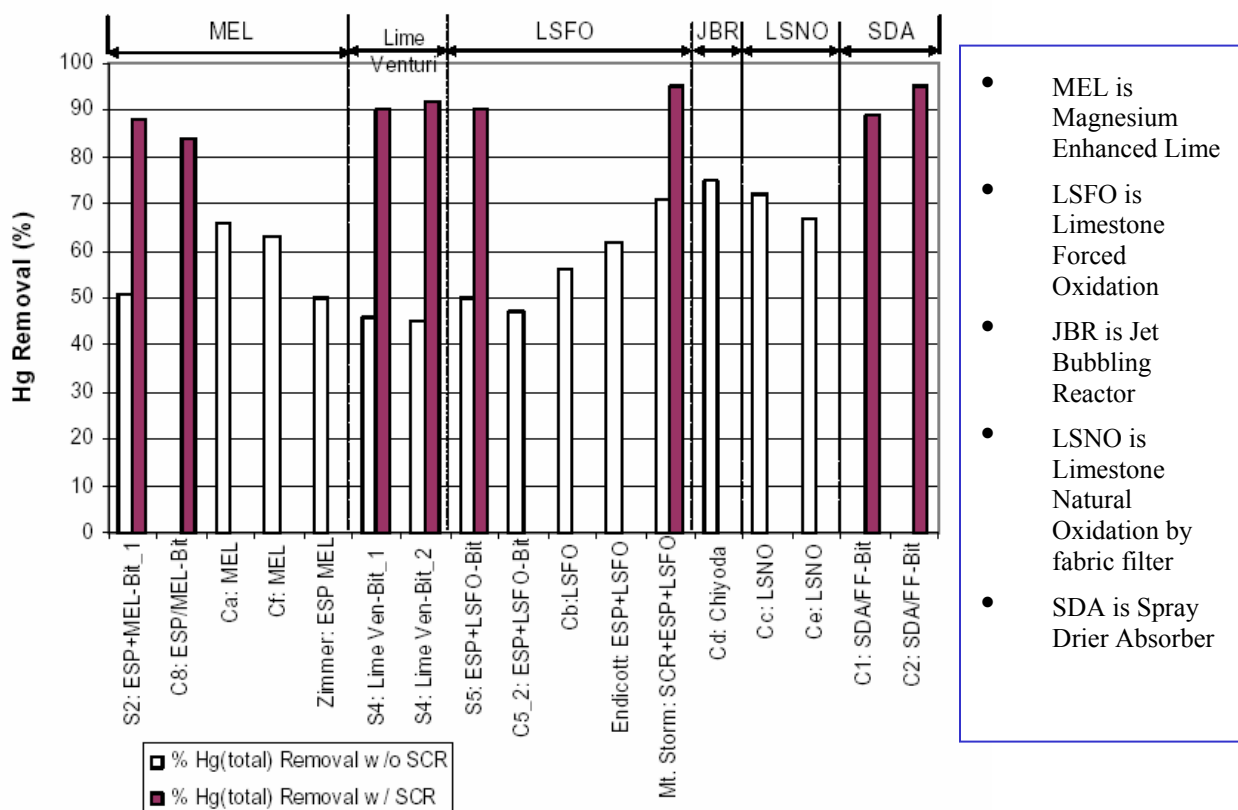
The poor removal of mercury by SDA/FF on subbituminous coals can be explained by the capture of much of the HCl by the SDA, leaving inadequate HCl at the FF to participate in the oxidation of  $\text{Hg}^0$  to particulate that can be captured on the FF. While not used in Illinois power plants, lignite coals exhibit similar behavior due to their low halogen content. For bituminous coals which usually have a higher percentage of Hg as  $\text{Hg}^{2+}$ , this HCl stripping effect is not important and SDA/FFs have very high mercury removal efficiencies.

The high variability of mercury capture for several situations indicates that for these cases there are other important factors besides coal type and APC configuration. For example, the bituminous coal with CS-ESP data covers a range of coal chlorine, fly ash carbon (and content), ESP inlet temperature and coal sulfur levels – all of which can impact mercury capture efficiency. So, even within any classification of coal or control technology, there may be a significant amount of variability.

Since the ICR data was originally collected, several test programs have examined other configurations not covered in the ICR data. One configuration is Selective Catalytic Reduction (SCR) equipment for  $\text{NO}_x$  removal followed by flue gas desulfurization (FGD). Mercury is very effectively captured from the flue gas of boilers that fire bituminous coals and are equipped with both SCR and FGD. The catalyst of the SCR system helps to oxidize the elemental mercury in the flue gas. The oxidized mercury is then very efficiently captured by the FGD system. As shown in the Figure 3, effective capture in the range of about 90% appears to occur for all forms of FGD when SCR is used in combination with FGD. Without the SCR, mercury removal by the FGD is in the range of about 50% to 70% (roughly consistent with the ICR data).

For subbituminous coals the beneficial effect of SCR on mercury capture by FGD does not appear to be as great. This is believed to be due to the lower halogen concentrations in the flue gas of subbituminous coals than bituminous coals, which tends to favor elemental over oxidized mercury.

**Figure 3.** Mercury Removal by wet FGD technology with and without SCR (ORD Report)



#### *Methods to Optimize Co-benefit Controls*

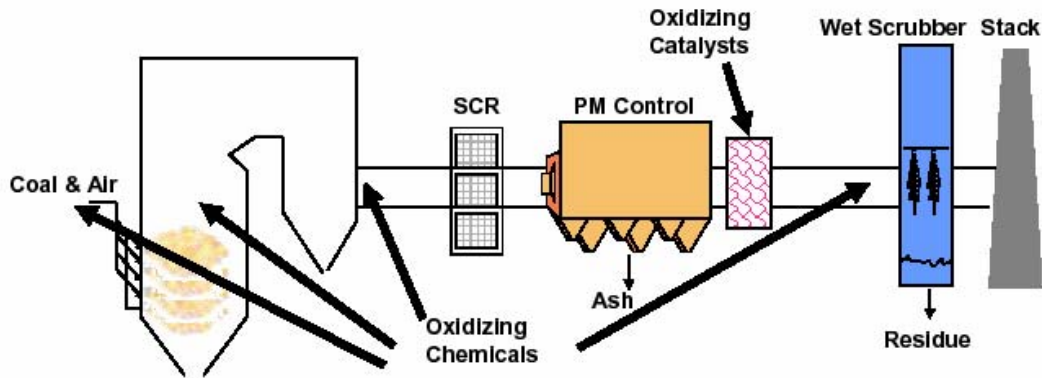
Methods to improve the mercury capture efficiency of PM and SO<sub>2</sub> controls are being developed and have proven to be effective in many cases. Most approaches focus on methods to increase the proportion of Hg as Hg<sup>2+</sup> or Hg<sub>p</sub>, which tends to be much more easily captured. Others are focused on modifying some other aspect of flue gas chemistry. Most of these techniques are summarized here.

- Combustion Staging** – Combustion Staging is known as a method for NO<sub>x</sub> control. However, it has also been shown to help improve capture of mercury in the ESP. This is at least in part due to increased carbon in the fly ash that often results from combustion staging. The increased carbon loading tends to promote formation of Hg<sup>2+</sup> and also acts as a sorbent to capture the mercury. Another effect is suppression of oxidation of SO<sub>2</sub> to SO<sub>3</sub>. SO<sub>3</sub> has been shown to suppress mercury removal by sorbent. This is possibly because it may compete with mercury for oxidation and adsorption sites. In most cases it is not necessary to

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- make hardware changes to affect the fuel staging. This is often achievable by making adjustments to existing hardware to reduce excess air. The extent that combustion staging will improve co-benefit mercury emissions will vary from one unit to another and for any unit would be determined in a test program.
- *Coal Blending* –For subbituminous coals, which tend to have low halogen content and also tend to produce low carbon content in the fly ash, improved mercury capture by existing equipment can result through blending with bituminous coal. For example at Holcomb Station in Kansas, a 360 MW, PRB-fired boiler equipped with SDA/FF for SO<sub>2</sub> and PM control, mercury capture across the fabric filter was increased from zero to nearly 80% by blending about 15% western bituminous coal with the PRB coal.<sup>3</sup> Of course, in any particular situation, coal blending may not be the best choice because there could be impacts on the combustion system. Coal blending can also improve performance of mercury-specific technologies as well, such as sorbent injection.
  - *Fuel and Flue Gas Additives* – Both subbituminous and lignite coals behave similarly with respect to mercury capture due to low halogen contents in these coals. Fuel and flue gas additives have been developed for the purpose of increasing the halogen content of the flue gas or to otherwise promote formation of Hg<sup>2+</sup> over Hg<sup>0</sup>. From a mercury control perspective, these additives can make facilities firing subbituminous or lignite coals behave more like a facility that fires bituminous coals. At Laskin 2 (firing PRB) and at Stanton 10 (firing ND lignite), chlorine salts were added to the fuel to assess the impact of increasing fuel chlorine in this way has on mercury oxidation and capture. Laskin 2 is equipped with a Particle Scrubber (PS) and Stanton 10 with a SDA/FF. In both cases, mercury oxidation increased, although for some salts the mercury capture did not increase.<sup>4</sup> Additives might also be injected directly into the flue gas or into the air pollution control equipment, as shown in Figure 4. Long-term effects, such as corrosion, plugging, impacts on combustion equipment could not be assessed during the short-term parametric tests. Therefore, the use of coal additives offer some promise at improving mercury capture; however, they may have other impacts that need to be evaluated.



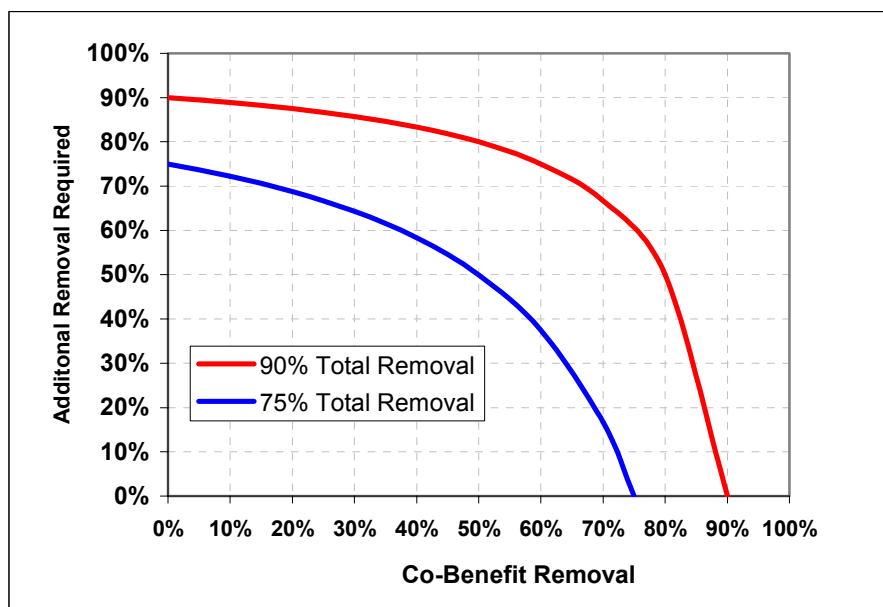
**Figure 4.** Locations for addition of oxidizing chemicals or oxidizing catalysts

- Flue Gas Catalysts* – In the same manner that SCR catalyst improves mercury oxidation, other catalysts might be added upstream of the wet FGD to promote oxidation of  $\text{Hg}^0$  to  $\text{Hg}^{2+}$  which is easily captured in the FGD. Although there has been some testing of catalysts for this purpose, catalyst lifetime remains a concern.
- Wet FGD Additives* – Wet FGD systems are usually very effective at removing  $\text{Hg}^{2+}$ . However, under some wet FGD conditions a very small portion of the  $\text{Hg}^{2+}$  will be chemically reduced to  $\text{Hg}^0$  and the  $\text{Hg}^0$  will then be reemitted.<sup>5</sup> This will reduce the overall Hg removal effectiveness of the FGD somewhat. In some of these cases, especially for limestone forced oxidation (LSFO) scrubbing systems, the chemical reduction of  $\text{Hg}^{2+}$  to  $\text{Hg}^0$  and subsequent reemission have been abated with the help of sulfide-donating liquid reagent. Experience has shown that  $\text{Hg}^{2+}$  reduction and reemission may be more difficult to avoid in magnesium-enhanced lime scrubbers (MEL) than LSFO scrubbers due to the much higher sulfite concentration in these systems<sup>6</sup>. Development continues in this area to improve the effectiveness of these chemicals at improving mercury control efficiency of wet FGD systems.

### Mercury Specific Controls

The previous section addressed the important factors impacting mercury capture by co-benefit of NO<sub>x</sub>, PM or SO<sub>2</sub> control technologies. As discussed, boilers that fire subbituminous coal – which there currently are many of in Illinois – are not likely to achieve high levels of mercury removal from co-benefits alone. Some of the bituminous coal fired boilers may not achieve adequately low mercury emissions by co-benefits alone. Therefore, these plants may need additional controls to achieve the levels of mercury removal that are being required in the proposed rule. The level of additional removal needed by mercury-specific controls are shown in Figure 5 for 90% total removal and 75% total removal. As shown in Figure 5, the additional removal required of mercury specific technology can be substantially reduced by high levels of co-benefit removal.

**Figure 5.** Additional mercury removal required of mercury-specific control technology to achieve 90% and 75% total removal as a function of the co-benefit mercury removal.



In this section, removal of mercury by injection of Powdered Activated Carbon (PAC) and other dry, injected sorbents will be described. Mercury removal by Sorbent Injection (SI) is a control technology that has been used in other industries for mercury

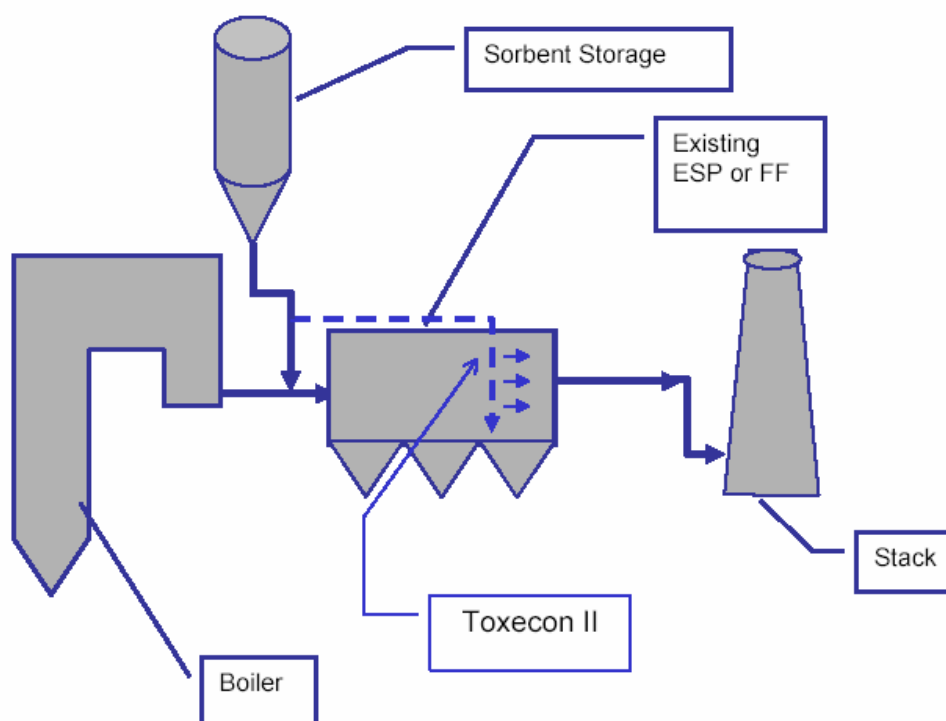
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control and has been tested at numerous coal-fired utility units in the United States. After co-benefit from other controls, SI technology is the mercury control technology that is most likely to be deployed at coal-fired power plants.

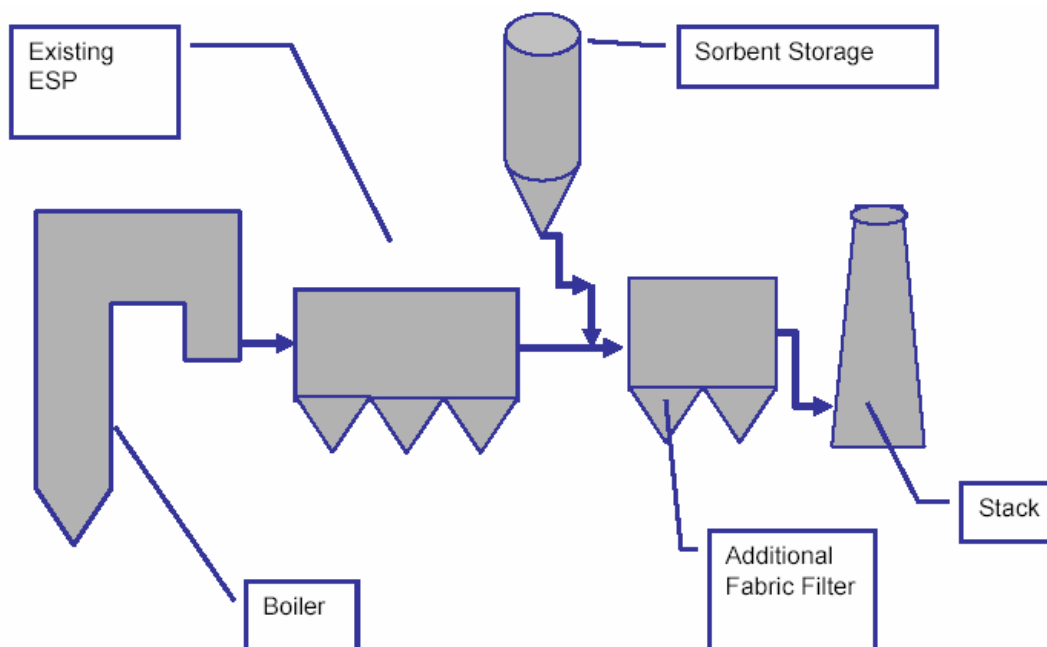
SI technology is a well-established method to control mercury from Municipal Waste Combustors (MWCs) in the United States and Europe. The most widely used sorbent is PAC. However, other sorbents or reactive chemicals have been used. Whether on a MWC or on a coal-fired power plant, the equipment for a sorbent injection system consists of a storage silo, metering valve, pneumatic conveying system and a series of pipes that direct the sorbent that is blown into the plant ductwork. The sorbent is always injected upstream of a PM collection device – typically either an electrostatic precipitator or fabric filter as in Figure 6. The dry particles are dispersed in the flue gas stream and are captured by the downstream PM collection device. When an ESP collects the sorbent, the mercury capture must occur as the sorbent and mercury interact “in-flight”. For a fabric filter, there is “in-flight” interaction, but most interaction between the sorbent and mercury occurs as the gas passes through the fabric filter.

For coal-fired applications, where it may be desirable to keep the sorbent separate from the captured fly ash (such as when the fly ash is sold for use in cement), the sorbent may be injected between fields of the ESP. This is called a TOXECON II arrangement. The bulk of the fly ash is collected in the ESP upstream of the sorbent injection point and is separated from the sorbent and remaining fly ash that is collected in the ESP downstream of the injection point as shown in the TOXECON II arrangement of Figure 6. In other cases it may be preferable to install a new fabric filter downstream of the existing ESP. In this case the configuration is a TOXECON arrangement as shown in Figure 7. This configuration has the benefits of providing segregation of fly ash from sorbent and higher mercury removal efficiencies at lower sorbent injection rates. However, the disadvantage is that the equipment is more expensive than in the case of Figure 6.

**Figure 6.** Arrangement for a typical sorbent injection system, normal arrangement in solid and TOXECON II in dashed



**Figure 7.** Sorbent injection in a TOXECON arrangement



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The sorbent injection hardware does not take up much space and is relatively easy to retrofit onto an existing plant. Figure 8 shows a photo of the equipment used at one coal-fired utility plant. The size of the storage silo is relatively small compared to existing APC equipment. Except in the case of TOXECON, it is not necessary to make any major alterations to ductwork or existing equipment when installing a sorbent injection system.



**Figure 8.** Sorbent Injection equipment compared to other air pollution control equipment.<sup>7</sup>

Although the equipment used for injecting sorbent into the flue gases of coal-fired power plants is essentially the same as that used at waste incinerators, significant differences in gas conditions exist between these two applications. In the case of MWCs, the concentrations of mercury and chlorides are typically much higher and the concentration of SO<sub>2</sub> is often lower. Gas temperatures at the sorbent injection point are often lower as well. For these reasons, gas conditions for high mercury capture efficiency using PAC are better in MWCs. Therefore, the air pollution control industry has developed new sorbent materials that are optimized for application in coal-fired power plant flue gas and generally perform better than the PAC sorbents that are used in MWC combustors and for other industrial applications. In recent years, the most widely tested of these are halogenated PACs offered by Sorbent Technologies and Norit.

### *Early Field Testing Experience with Sorbent Injection*

Experience controlling mercury emissions from coal-fired boilers has been gained through laboratory and pilot testing programs that have led to numerous field test

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programs conducted to test sorbent injection systems on the flue gas of coal-fired electric power plants.

Figure 9 shows the results of some early full-scale field tests. Mercury removal resulting from the PAC injection (this is the percent removal of mercury remaining after co-benefit removal) is plotted against the injection concentration of the sorbent measured in pounds of sorbent per million actual cubic feet of flue gas. These parametric tests showed the following:

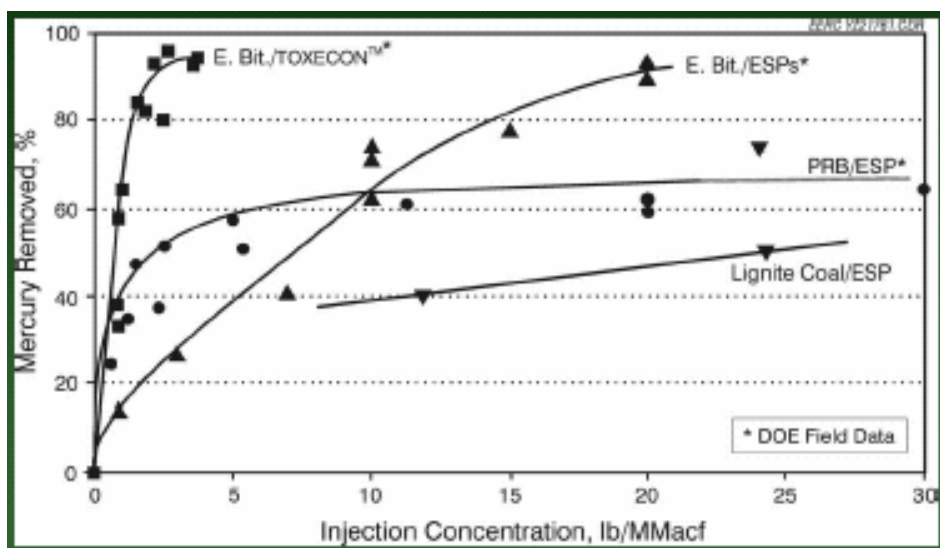
- Based upon experience at Southern Company's Plant Gaston, high levels (over 90%) removal are achievable over short periods on bituminous coals with untreated PAC when a fabric filter was used to capture the PAC in a TOXECON arrangement.
- Based upon pilot testing at Public Service of Colorado's Comanche Station, high levels (over 90%) removal are achievable over short periods on bituminous coals with untreated PAC when a fabric filter was used to capture the PAC and there is not an upstream spray drier absorber.
- Based upon experience at New England Power's Brayton Point Power Plant high levels of mercury removal (90%) are achievable over short periods on boilers firing low sulfur bituminous coals with untreated PAC though in-flight capture, but at very high PAC injection rates.
- Based upon experience at WE Energies Pleasant Prairie Power Plant high levels of mercury removal (90%) are not achievable over short periods on boilers firing subbituminous coal with untreated PAC though in-flight capture.

This early experience raised serious questions regarding the ability to achieve high mercury removal rates on units firing subbituminous coals using untreated PAC – where coal chlorine content is often very low (often under 50 ppm). Testing at other units firing low-rank coals (subbituminous or lignite) which tend to have low halogen content showed similar behavior when untreated PAC was used as the sorbent. Although lignite coals are not used in Illinois, methods used to solve the problem of low halogen content with lignite coals are applicable to subbituminous coals as well.

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Since these early tests were short-term parametric tests, they also left questions regarding the long-term performance of these technologies that were to be addressed in future testing.

**Figure 9.** Early parametric field testing results for mercury control by untreated PAC injection.



### Results of Additional Field testing

Since the first field test programs of PAC performed in 2001<sup>8</sup> the focus of additional testing has been on unanswered questions from the initial tests, new sorbents, and on other applications not addressed in the initial tests. Table 1 lists several of these test programs. These tests have shown that low-rank coals (lignite and subbituminous) have similar challenges with regard to mercury removal by sorbent injection. As a result, lessons learned in lignite test programs have been shown to be useful for subbituminous applications, and vice-versa.

Chemically treated sorbents manufactured by Norit and Sorbent Technologies have been developed to overcome the shortcomings of untreated PAC in low-rank coal applications. Field tests have been performed at numerous plants with halogenated sorbents to compare

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their performance for mercury removal to that achieved with untreated PAC in the early tests for both bituminous and western fuels. Field test programs have also focused on long-term performance over periods extending to several weeks to as long as over a year.

**Table 1.** Sorbent Injection Field Demonstrations <sup>7, 10, 21</sup>

Station	Coal	Equipment	Notes
Gaston (1month)	Low-S Bit	FF	complete
Pleasant Prairie	PRB	CS-ESP	complete
Brayton Point	Low-S Bit	C-ESP	complete
Abbott	High-S Bit	C-ESP/FGD	complete
Salem Harbor	Low-S SA Bit	C-ESP	complete
Stanton 10	ND Lignite	SDA/FF	complete
Laskin	PRB	Wet P Scrbr	complete
Coal Creek	ND Lignite	C-ESP	complete
Gaston (1 year)	Low-S Bit	FF	complete
Holcomb	PRB	SDA/FF	complete
Stanton 10	ND Lignite	SDA/FF	complete
Yates 1	Low-S Bit	C-ESP	complete
Yates 2	Low-S Bit	ESP/FGD	complete
Leland Olds	ND Lignite	C-ESP	complete
Meramec	PRB	C-ESP	complete
Brayton Point	Low-S Bit	C-ESP	complete
6 Commercial Tests	Low-S Bit	ESP	In progress or planned
Laramie River	PRB	SDA/ESP	In progress or planned
Conesville	High-S Bit	ESP/FGD	In progress or planned
DTE Monroe	PRB/Bit	ESP	complete
Antelope Valley	ND Lignite	SDA/FF	In progress or planned
Stanton 1	ND Lignite	C-ESP	In progress or planned
Council Bluffs 2	PRB	H-ESP	In progress or planned
Louisa	PRB	H-ESP	In progress or planned



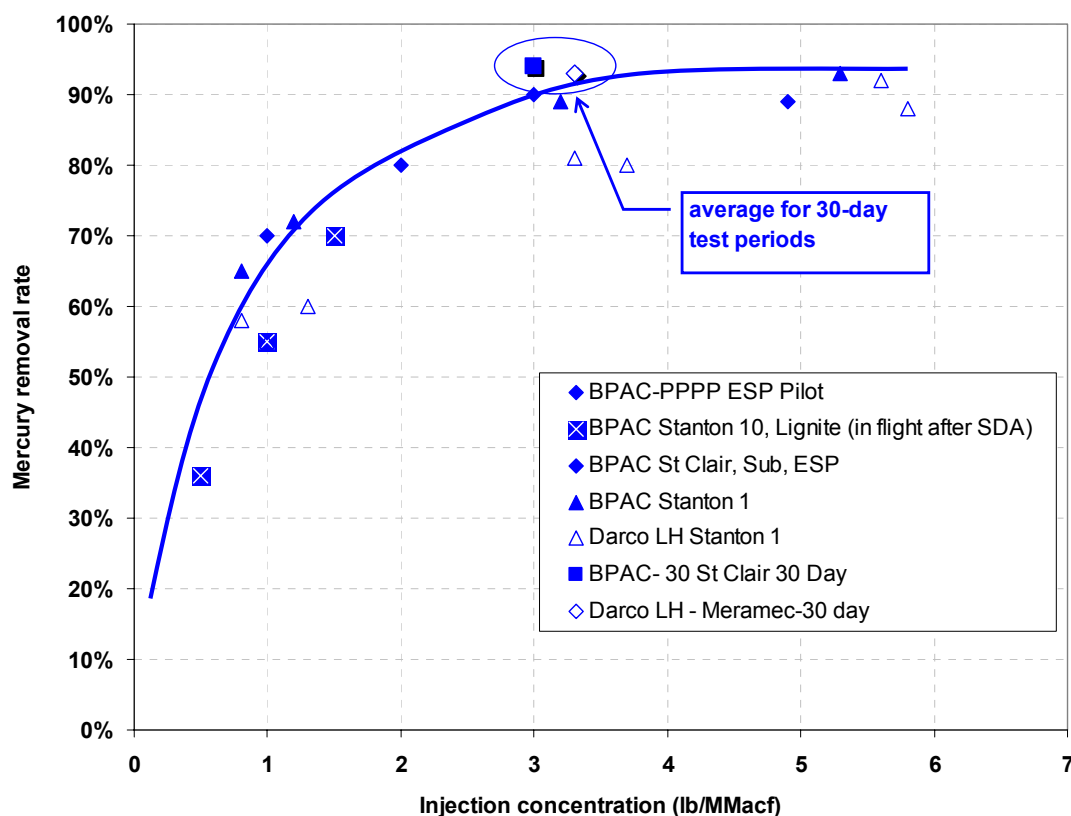
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Independence	PRB	C-ESP	In progress or planned
Gavin	High-S Bit	C-ESP FGD	In progress or planned
Presque Isle HS-ESP	PRB	ESP TOXECON	In progress
Allen Duke	Bitum. Low-S	CS ESP	complete
Lausche Ohio U	Bitum. High-S	CS-ESP	complete
Merrimack PSNH	Bitum. High SO <sub>3</sub>	HS ESP	complete
Cliffside Duke	Bitum. Low-S	HS ESP	complete
Buck Duke	Bitum. Low-S	HS ESP	complete
St. Clair Detroit Ed.	Subbitum.Blend	CS-ESP	complete
St. Clair Detroit Ed.	Subbituminous	CS-ESP	complete
Stanton 1 GRE	Subbituminous	CS-ESP	complete
Stanton 10	Lignite	SD/FF	complete
Stanton 10	Lignite	CS-ESP	complete
Miami Fort	Bitum, Med S	CS-ESP	In progress

### *In-Flight Mercury Removal*

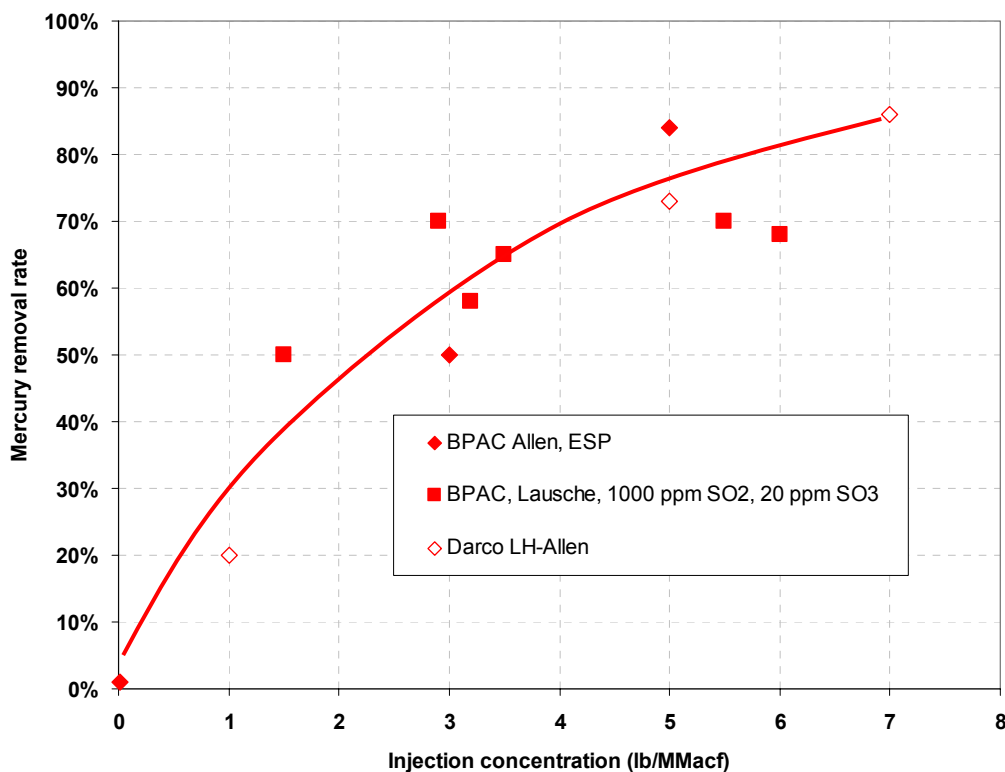
Figure 10 shows the in-flight mercury capture performance of halogenated PAC (B-PAC from Sorbent Technologies and Darco Hg LH from Norit) at full-scale tests (and one pilot-scale test at the Pleasant Prairie power plant). Percent total mercury removal attributed to sorbent injection is plotted against the injection concentration of sorbent in pounds per million actual cubic feet of flue gas (lb/MMacf). Included in this data are results of two 30-day tests at St. Clair station and at Meramec Station. These two 30-day tests showed that over 90% mercury removal was achievable at sorbent injection rates near 3 lb/MMacf. These 30-day tests follow the trend of the parametric test data and even lie somewhat better than the trend of the parametric test data. The pilot test data from the Pleasant Prairie power plant (denoted PPPP ESP Pilot) is included because previous full-scale testing at Pleasant Prairie showed that only 60%-70% removal was possible with untreated PAC at injection rates as high as 12 lb/MMacf. These pilot results at Pleasant Prairie with halogenated PAC are completely consistent with the trend shown at other plants with halogenated PAC where 90% removal is achieved at around 3 lb/MMacf.

**Figure 10.** In-Flight Mercury Removal Results of Full Scale Field Tests of Halogenated PAC Sorbent Injection on Low-Rank Coals.<sup>7, 9, 10</sup>



Although halogenated PAC sorbents were developed primarily to overcome the shortcomings of untreated PAC on boilers firing western coal, they have also been field tested on boilers firing bituminous coal with various sulfur levels. Untreated PAC is not effective when there is high coal sulfur content or particularly when there is a high  $\text{SO}_3$  content in the flue gas. Figure 11 shows the results of parametric testing at Lausche and Allen plant. Allen plant is a low-sulfur coal application and Lausche Plant has a higher sulfur coal (although not as high a sulfur level as in most bituminous coals fired in Illinois). As shown, 90% removal is approached at injection rates of 7 lb/MMacf. Unfortunately, there is currently no test data on units with sulfur levels as high as those of Illinois coals. But, future testing is planned for higher sulfur applications (AEP's Gavin plant in Ohio) that are more representative of those in Illinois.

**Figure 11.** In-Flight Mercury Removal Results of Full Scale Field Tests of Halogenated PAC Sorbent Injection on Bituminous Coals <sup>7, 10</sup>



In-flight removal by sorbent injection has proven to be difficult for units equipped with hot-side ESPs. At these high temperatures (typically over 600 F) the sorbent is not as effective. Nevertheless, testing of novel sorbents on units with hot-side ESPs has shown some promising results. At Duke Power's Cliffside and Buck Stations, which fire bituminous coals, 50%-70% mercury removal was achieved in short-term tests using a specially formulated halogenated PAC. Additional testing of advanced sorbents is planned for 2006 on PRB units as well. <sup>7, 10</sup>

#### *TOXECON and Fabric Filters*

Except on western coals downstream of a Spray Drier Absorber, PAC (untreated or halogenated) in TOXECON arrangements or fabric filter arrangements is generally accepted to be capable of over 90% removal because the sorbent is in very intimate contact with the gas stream as it passes through the filter cake of the fabric filter.

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Numerous full-scale and pilot tests, some extending over one year in duration, have confirmed these results. Issues regarding TOXECON relate largely to cost and to design issues relating to the fabric filter. Cost will be addressed in the next section.

The long-term field tests at Southern Company's Gaston Station addressed some of the TOXECON fabric filter design issues as they relate to fabric filter sizing and the fabrics that are best suited for this type of installation. It is important to note that the fabric filter at Gaston station was originally designed to capture only the small amount of fly ash that escapes the hot-side ESP, not the additional sorbent material that is introduced for capturing mercury. Therefore, when introducing sorbent the cleaning frequency of the fabric filter at Gaston increased to the point where damage might have occurred to the cloth filter bags over an extended time. For this reason the long-term test could not be performed at 90% mercury removal, but did achieve an average removal of 85% over the long-term test. As shown in Table 2, short-term tests at a simulated air-to-cloth ratio of 6.0 resulted in mercury removal as high as 97% while maintaining cleaning frequency below the limit of 1.5 pulses/bag/hour and using untreated PAC.<sup>11</sup>

**Table 2.** Short-term test results at Gaston under simulated air-to-cloth ratio of 6.0.<sup>11</sup>

Injection Rate (lb/h)	Injection Concentration (lbs/MMacf)	Inlet Hg Concentration (µg/Nm <sup>3</sup> )	Outlet Hg Concentration (µg/Nm <sup>3</sup> )	RE (%)	Cleaning Frequency (pulses/bag/hour)
20	0.9	20.6	3.2	84.2	0.6
45	2.0	22.2	1.0	94.6	0.8
70	3.3	21.4	0.61	97.1	1.4

The following was a conclusion of the one-year test program of TOXECON at Southern Company's Plant Gaston.<sup>12</sup>

- "TOXECON units designed at lower air-to-cloth ratios than COHPAC units are capable of high, 90%, mercury removal. For TOXECON baghouses, it is recommended that the maximum design gross air-to-cloth ratio be 6.0 ft/min."

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### Costs of Sorbent Injection Systems

#### *Capital Costs*

The sorbent injection systems themselves – sorbent storage equipment, metering valves, pneumatic conveying system, injection piping, controls and associated installation and startup costs - cost in the range of \$2/KW (somewhat higher for small units and somewhat lower for very large units), or about \$1 million for a 500 MW plant. This is based upon estimates from technology suppliers, the US EPA, and the US DOE.<sup>10, 13, 14</sup> By comparison an SCR system at a typical cost of \$100/KW might cost around \$50 million for the same 500 MW plant.

However, if a TOXECON system is necessary the capital costs will be much higher than a simple sorbent injection system, typically in the range of about \$40-\$60/KW due to the need to install a fabric filter system.<sup>13</sup> However, it is possible for the cost of a TOXECON system to be much higher in unusual circumstances. For example, at the DOE TOXECON demonstration program at WE Energies' Presque Isle power plant in Marquette, MI, the project entailed installing a single fabric filter on three small (~90 MW each) units. A long, complex, duct arrangement (see Figure 12) to and from the fabric filter was required due to inadequate space near the stack – where the fabric filter would have ideally been located with shorter, simpler, duct runs. For that reason the project capital cost was roughly double what would have been expected. In fact the cost estimate of the TOXECON system for the Presque Isle plant shows that the costs of structural steel and the mechanical and structure installation were more than the supply and erection of the key component – the fabric filter.<sup>15</sup> So, depending upon the situation, the retrofit cost of a TOXECON might be higher than what is expected for most plants.

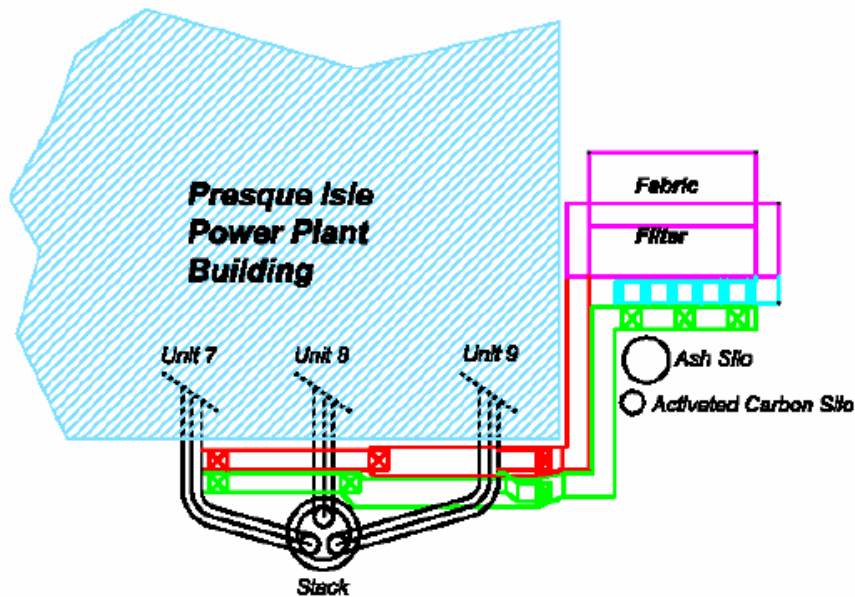
#### *Operating Costs*

For simple sorbent injection systems the largest operating cost is sorbent. There are costs associated with the power to run the pneumatic conveying system and the controls. But, these are usually small compared to the sorbent cost. There are maintenance costs. But, as the sorbent injection system is relatively simple, these are modest as well.

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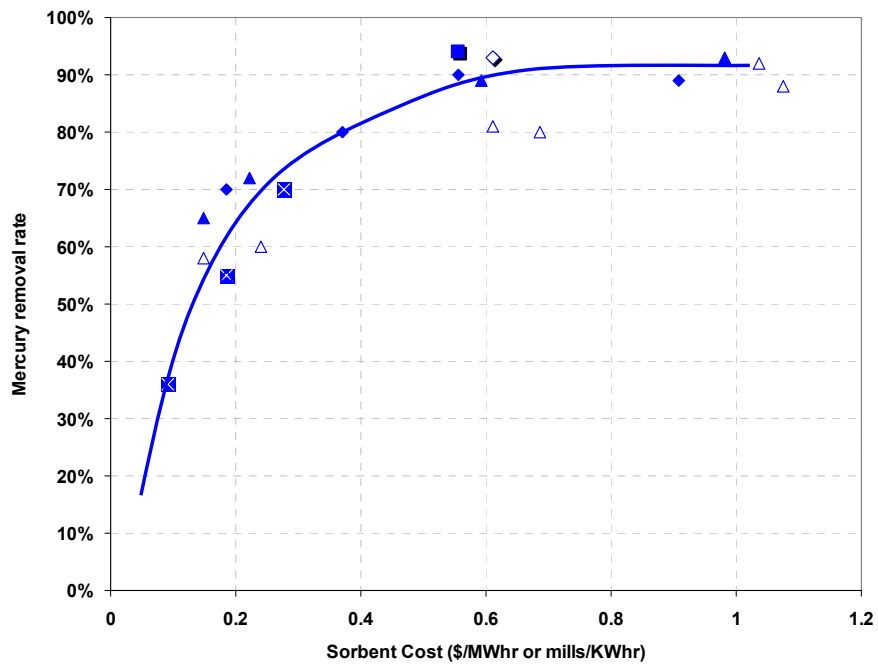
For a TOXECON system, sorbent cost is likely to be lower since the sorbent is more efficiently utilized. However, the pressure drop across the fabric filter and the maintenance cost for the fabric filter result in higher operating and maintenance costs.

**Figure 12.** Configuration of the TOXECON system at the Presque Isle Plant in Marquette, MI.<sup>15</sup>

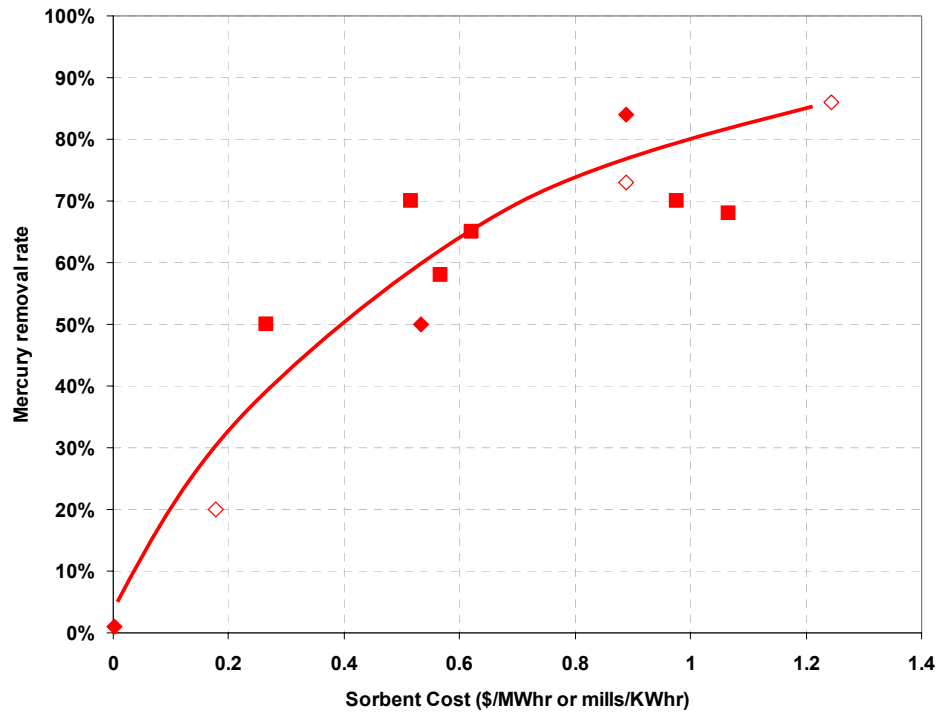


Halogenated PAC sorbent currently costs in the range of \$0.75 to \$0.85/lb, depending upon source and shipping, etc. Untreated PAC sorbent costs in the range of \$0.50/lb. Using a cost of \$0.80/lb of sorbent, the treatment rates of Figures 10 and 11, a gas flowrate of about 3,700 ACFM/MW for bituminous coal and 3,860 ACFM/MW for subbituminous coal, and heat rate of 10,500 BTU/KWhr, the control cost for sorbent (in \$/MWhr or mills/KWhr) is shown in Figures 12 and 13 for subbituminous and bituminous coal fired boilers respectively. The contribution of capital cost to generation cost for a simple sorbent injection system (\$2/KW) at a capacity factor of 80% and capital recovery factor of 14% is only about \$0.04/MWhr – almost negligible compared to the effect of sorbent cost.

**Figure 12.** Estimated Cost Impact to Generation of Sorbent for Mercury Removal on a subbituminous coal-fired boiler using halogenated PAC



**Figure 13.** Estimated Cost Impact to Generation of Sorbent for Mercury Removal on a bituminous coal-fired boiler using halogenated PAC



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For a TOXECON system the sorbent cost will be significantly less but the capital cost will be much more significant. At a capital cost of \$50/KW and 80% capacity factor and 14% capital recovery the impact to generation cost is about \$1/MWhr. At a cost of parasitic power (mostly from increased fan load) of \$30/MWhr, and pressure drop of 8 inches of water column, parasitic power cost is estimated at \$0.17/MWhr and other O&M (excluding sorbent, such as bag replacement and equipment maintenance) is expected to total about the same amount. Hence, before sorbent costs the total cost impact is about \$1.34/MWhr (or 1.34 mills/KWhr).<sup>13</sup>

Assuming an injection concentration of untreated PAC at 2 lb/MMacf for 90% removal with a cost of \$0.50/lb and a gas flowrate of 3,860 ACFM/MW, the cost impact of sorbent is \$0.23/MWhr (or 0.23 mills/KWhr).

For a TOXECON arrangement the most costly part and the part with the most cost uncertainty is the capital cost. Therefore, TOXECON is not likely to be selected by a utility for mercury control if a simple sorbent injection system will provide adequate removal unless there are other reasons to install the fabric filter. However, at this point in time TOXECON is the only approach that has demonstrated a capability to achieve 90% removal on units equipped with hot-side ESPs.

### **Balance of Plant Issues**

Because of the newness of mercury control technology for coal-fired boilers, there are issues of concern to the utility industry that are explored below.

#### *Impact on other equipment*

Sorbent injection has the potential to impact downstream equipment, especially the PM control devices such as the ESP or the FF. For an ESP, additional material has the potential to influence the capture efficiency of the ESP.



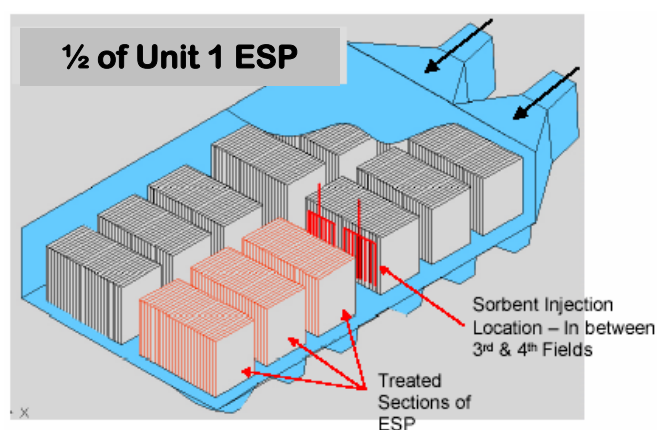
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There have been dozens of test programs where sorbent was injected upstream of an ESP. Of these, only at Southern Company's Plant Yates<sup>16, 17</sup> and Great River Energies' Coal Creek<sup>18</sup> plant have any adverse impacts been observed. At Southern Company's Plant Yates which fires eastern bituminous coal the ESPs are very small (Specific Collection Area = 173 ft<sup>2</sup>/1000ACFM for Unit 1 and 144 ft<sup>2</sup>/1000ACFM for unit 2). During testing these units experienced an increase in arc rate and a slight increase in particulate matter out. At the Coal Creek plant, which fires North Dakota Lignite, a TOXECON II system was installed on an ESP with an SCA of 599 ft<sup>2</sup>/1000 ACFM. The sorbent was injected between fields 3 and 4 as shown in Figure 14. Untreated PAC sorbent was used in this field test and therefore sorbent injection rates were quite high (up to 12 lb/MMACF). Particulate emissions from the ESP increased during periods of carbon injection from an average of 0.027 gr/dscf to an average of 0.054 gr/dscf.

The tests at Yates and Coal Creek that showed some impact on the ESP were performed with untreated rather than halogenated PAC. Halogenated PAC would have significantly reduced the sorbent injection rate at any given removal level and would likely have reduced, if not eliminated, the adverse impacts to these plants. Other than these two tests there have been no tests where ESP performance was reported to be adversely impacted.

To date there have been no reported impacts on equipment corrosion or erosion, plugging or any other adverse effect on downstream equipment.

**Figure 14.** TOXECON II Arrangement at Coal Creek Plant<sup>18</sup>



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### *Environmental impact of sorbent disposal*

There have been numerous tests of both untreated and halogenated PAC sorbents to determine if toxic materials leach from these sorbents. Leaching studies have been conducted on the spent sorbent on most of the tests conducted to date. All have shown that any leached material is well below US EPA guidelines with most below the detectable limit of 0.01 µg/liter. Therefore, the mercury appears to be tightly bound to the sorbent and there is no reason to believe that fly ash that is otherwise non-hazardous may be reclassified as a hazardous material as a result of sorbent injection .

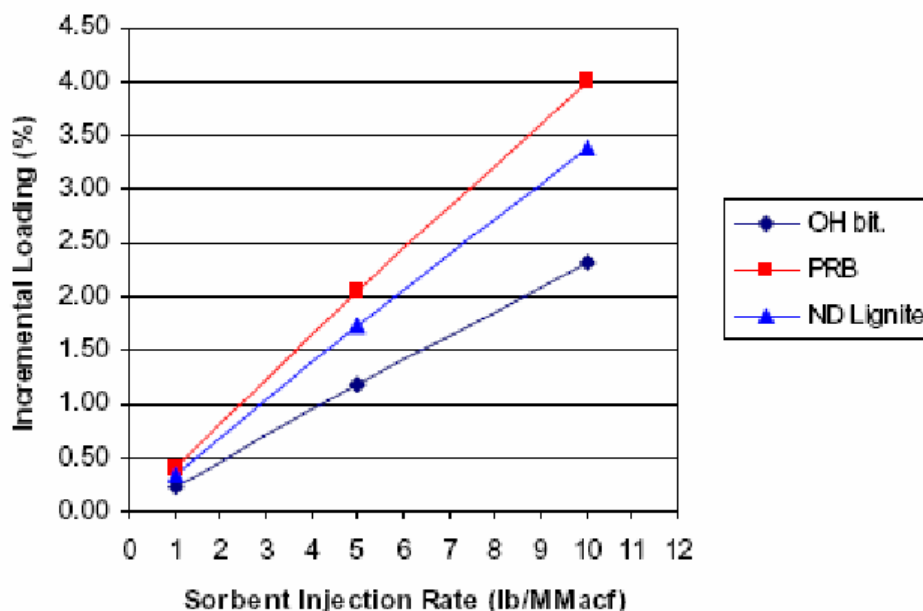
### *Impact on coal combustion product utilization*

Fly ash is an inexpensive replacement for portland cement used in concrete, while it actually improves strength, segregation, and ease of pumping of the concrete. Fly ash is also used as an ingredient in brick, block, paving, and structural fills. However, concrete is the most valuable use. About 20% of the fly ash from US coal fired power plants is sold to the cement industry. The value of the fly ash as a concrete additive is determined by its mineral constituents, the impurities present (such as unburned carbon from the coal), and other properties. The ASTM has maximum allowable standards for accepting coal fly ash with carbon in it for purposes. However, this normally is not the limiting criteria. Carbon (especially activated carbon) absorbs an Air Entrainment Admixture (AEA) that is added to cement to control cement strength.

Figure 15 shows the estimated carbon contribution to fly ash at a range of injection rates. At these injection rates, which are well below those of Figures 10 or 11, the carbon content remains well below the ASTM limit (6%ASTM C-618).

If the fly ash that was otherwise sold for cement purposes is no longer marketable for cement purposes, the cost impact to generation will vary depending upon.

- The amount of fly ash that is being generated at the power plant (depends on coal ash content, heating value and unit heat rate, etc.)
- The marketable value of the ash as a cement material
- The marketable value of the ash for lower quality applications
- The cost to dispose of the ash, if necessary

**Figure 15.** Estimated carbon content in fly ash for different coals and injection rates<sup>10</sup>

Depending upon these factors, the effect could potentially be quite significant – up to about 1 mill/KW hr. Therefore, there is a great deal of effort being expended to address this potential concern.

To address the problem with the effects on the cement AEA additive, there are several possible solutions.

- One is separation of the carbonaceous portion of the fly ash from the mineral portion. However, this leaves a carbonaceous waste stream that is typically added back to the boiler for combustion. This requires equipment for separation and material handling.
- Another promising technique being examined by EPRI and US DOE is ozone passivation.<sup>19</sup> Passivating the fly ash will neutralize the sorbent properties that impact the AEA additive.
- High carbon fly ash may actually be used in the cement kiln, as has been done at Illinois Cement Company, located in LaSalle, Illinois using a high-carbon fly ash from Coffeen Power Station. Using high carbon fly ash, the cement plant

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achieved fuel savings of approximately 3.9%, the production increased by approximately 9.7%, and several key processing parameters were improved.<sup>20</sup>

- Sorbent Technologies has an approach for making their sorbent “cement friendly”. This sorbent material has been successfully demonstrated to remove mercury effectively (similar effectiveness as their brominated PAC) and to produce a low “foam index” – a measure of the effect on the AEA additive – that leaves fly ash marketable for cement purposes.
- Finally, Engelhard is developing a mineral-based sorbent that will not have any impact on the fly ash. In fact, they are also able to take fly ash, chemically treat it, and use it as the sorbent material. This is a new technology and the first full-scale 30-day test of a mineral sorbent is currently in progress at the Cinergy Miami Fort Plant in Ohio.<sup>21</sup>

### *Environmental Impacts of Brominated Sorbents*

Bromine is an ozone depleting agent and can also contribute to the formation of toxic materials in combustion systems. Studies have shown that the Bromine remains adhered to the carbon and is not emitted to the atmosphere.

With regard to toxic emissions, testing was performed by US EPA at two units, one with a CS-ESP and the other with a HS-ESP, to determine if polychlorinated dibenzo-*p*-dioxin (PCDD) and polychlorinated dibenzofuran (PCDF) or polybrominated dibenzo-*p*-dioxin (PBrDD) and polybrominated dibenzofuran (PBrDF) are formed when brominated PAC is injected. Tests showed that they do not appear to be formed and if any may be formed they are well below the limits established by US EPA for these materials.<sup>22</sup>

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### **Issues Relating to Commercial Availability and Impact to the Utility Sector**

There are a number of issues that are raised regarding the potential impact to utility plant reliability and whether these technologies are commercially available.

#### *Time and Materials to Engineer, Procure Install Sorbent Injection Systems*

Sorbent injection systems can generally be fully installed and commissioned within about six months from a utility placing an order. This includes engineering, procurement, installation and start up. Because the equipment required is not very specialized (silo, feeder valve, blower, piping, and controls), the equipment is readily purchased from a number of suppliers. Interface with the boiler system involves installation of penetrations for injection piping. These can normally be installed over an outage of a few days. Therefore, there should be no impact to the operation of the plant for a simple sorbent injection system.

In the event a fabric filter system is installed as part of the mercury control system, engineering, procurement and installation will take longer (likely over a year) and will require more extensive outages. The Presque Isle program is planned to be just under two years from start of design to completion of start up (March 2004 to January 2006).<sup>15</sup> Considering the complexity of the installation, most systems would likely take less time.

Installation of mercury control equipment can be performed during a planned outage of the unit boiler. When air pollution control equipment such as a fabric filter is added, outages are only necessary when existing ductwork is altered. This way the equipment can be erected with the boiler on line and outage time is minimized. In some cases, especially if a bypass is available, the outage can be taken early in the project and any later outage, if needed, can be of a very brief duration. So, even if a TOXECON system is installed on a boiler, it is expected to have little or no impact to unit availability.

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### *Guarantees*

Guarantees are a subject that is raised by industry when “Commercial Availability” is discussed. According to the Institute of Clean Air Companies, pollution control equipment suppliers are currently offering mercury control technologies with commercial guarantees on performance.<sup>23</sup>

While the specifics of the guarantees in any contract are negotiated between supplier and buyer, these guarantees typically include a guarantee on the pollutant removal performance of the technology (under specified process conditions), the usage rates of consumables (such as sorbent feed rate and power) and remedies to address any shortcomings in performance. The following is part of the guarantee wording taken from a portion of a proposal from Sorbent Technologies.<sup>10</sup> As shown, the guarantee language stipulates a required performance at a particular sorbent feed rate under specified conditions.

#### **PERFORMANCE GUARANTEES**

Sorbent Technologies will guarantee the more restrictive of ninety (90) percent removal or to a level of  $20 \times 10^{-6}$  lb of Hg/MWH of total mercury in the flue gas using brominated B-PAC™ powdered activated carbon at a rate not to exceed 230 lbs/hr based on the design flow rate of about 1,535,000 ACFM for each boiler. The removal rate is from the air preheater outlet to the stack. The mercury removal guarantee is valid only when the units are firing the coals described in the Customer Specification, when the air heater outlet flue gas temperatures are maintained at below 370°F, when the fabric filters are operating properly, and when the relative SO<sub>3</sub> mass flow rates at the air preheater are no greater than that specified. If no certified continuous mercury emissions analyzers are available, compliance shall be determined by others using certified CEMs or another method as determined by the March 15 utility mercury regulation. This guarantee shall be met according to page D-4 of Schedule D.

Normally, the liability to the vendor to remedy a performance shortfall as specified in the performance guarantees is limited to an amount that is related to the cost of the project. These guarantees are currently offered by suppliers of mercury control technology, although the specifics of their guarantees may differ because they are negotiated with the buyer.

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Consequential damages are associated with a power plant's lost profits that may result from the lost revenues and increased costs that may result from an unplanned outage or a reduction in plant output. Because these consequential damages have the potential to be many times greater than the cost of the pollution control equipment, consequential damages are rarely included in a contract. This is very similar to the fact that the electric company will not reimburse a business for lost profits during a power shortage. In order to accept such a potentially unlimited liability for the small profit of selling electricity, the electric company would have to make the electricity very expensive. The same holds true for pollution control equipment. And, therefore, consequential damages are rarely, if ever, included in a contract. In some cases liquidated damages may be agreed to. However, these are normally a fixed amount associated with time out of service up to a total amount of limited liability.

### *Supply of sorbent*

Activated carbon sorbents are available from a number of suppliers, including Norit, Calgon, HOK and several other companies. Halogenated (particularly brominated ) activated carbon sorbents are available from Norit and from Sorbent Technologies. The halogenated sorbents are manufactured from an untreated carbon that is treated with bromine. Treatment of the sorbent is a relatively simple process that can be scaled up quickly. These companies have committed to increasing the supply of halogenated sorbents to meet the market needs. The availability of activated carbon is high at this time. There is currently an oversupply of carbon in the US that is compounded by oversupply worldwide because there was a period of overbuilding of capacity in the 1990's. If demand did grow to the point where supply had to be increased, it would take 2-3 years to add a plant.<sup>24</sup> Therefore, there is plenty of capacity of PAC for Illinois power plants and if demand throughout the US increases to where more capacity is needed, it can be built in time to meet demand.

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### *Long-Term Experience*

Sorbent injection systems have been in operation on hundreds of MWCs for several years. So, experience with the equipment is well established. Outstanding questions therefore are associated with the ability of the sorbent to provide reliable mercury removal on a day-to-day basis.

Unlike SCR systems, where long-term catalyst activity is a serious concern or FGD systems where reliability of equipment in highly corrosive environments is a concern, sorbent injection systems use a material that is continually injected and has shown no tendency to corrode or degrade equipment (moreover there is no reason to think it might induce corrosion). So, many of the long term issues that existed for other technologies don't exist to a great extent with sorbent injection.

Impacts to downstream fabric filters have been examined, especially for TOXECON arrangements. As a result of these studies, design parameters for TOXECON fabric filter systems have been developed to address these concerns.

In the configuration where halogenated sorbent is injected upstream of a cold-side ESP on a boiler firing subbituminous coal there have been several tests, some several weeks in length, with very consistent results – not only at the unit over the test period but also consistent when comparing different units. As a result, the confidence that the sorbent will perform as expected over the range of normal operation for these units is high.

For less conventional applications, such as TOXECON II, this is an application where there is far less data and there is reason to have concern about the limitations of the ESP. Several test programs are underway to examine this.



## **Other Emerging Control Technologies**

This Technology Support Document focused primarily on technologies that are available in the near term and are most likely to be deployed by Illinois power plants. But, there are technologies that are emerging quickly and could address some of the concerns with existing available controls.

### *Improved Sorbents and Sorbent-Related Technology:*

Work is underway to develop improved mercury sorbents that overcome some of the shortcomings of existing PAC and halogenated PAC sorbents. These include:

- PAC-based sorbents designed for high temperature applications that may make high removal rates possible from boilers with hot-side ESPs without the need for a TOXECON system.
- PAC-based sorbents designed for high sulfur coal applications that can provide high removal efficiencies at low treatment rates.
- Mineral-based sorbents that utilize either treated clays or treated coal fly ash to capture mercury. This sorbent is being developed by Engelhard Corporation and also Amended Silicates Corporation and is being tested at the full scale. The advantages of mineral-based sorbents potentially are: 1) lower sorbent costs since fly ash is “free” to a power plant; 2) no adverse impact to fly ash marketability; and 3) potentially higher temperature applications.
- Chemical additives for the fuel or ductwork that improve sorbent utilization.
- Passivation technology mitigates the effect activated carbon has on the AEA additive for cement. Fly ash with a small amount of activated carbon can be treated and then used as a high value cement additive.

### *Advanced Fuel Beneficiation*

KFX offers K-Fuel that thermally treats otherwise unmarketable subbituminous coal to increase the heating value and to reduce the emissions when the fuel is burned. KFX has shown high mercury removal rates of about 70% with KFUEL. Through the use of a

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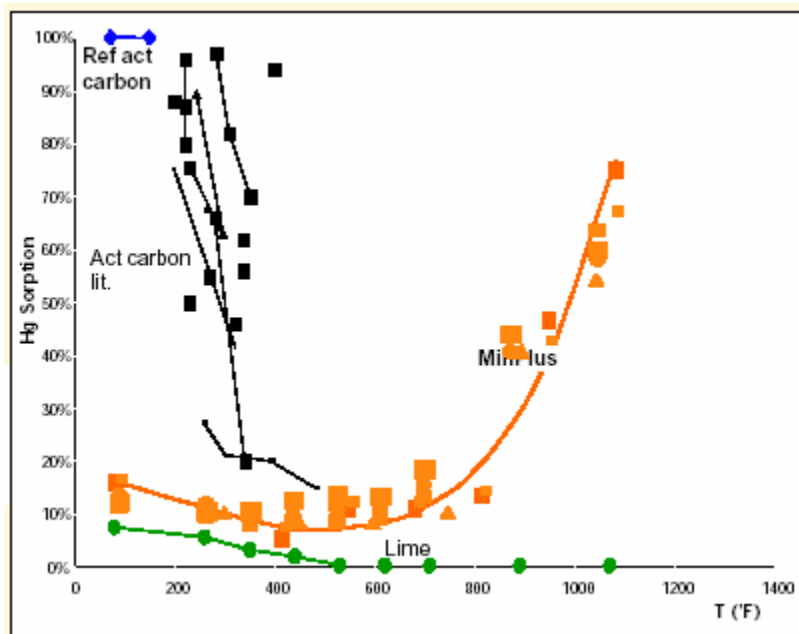
treated coal such as KFUEL, it would be easier to meet the output-based standard in the proposed rule.

### *Multipollutant Controls*

Some of these multipollutant controls are being commercially deployed. The following is an incomplete list.

- Electro-Catalytic Oxidation (ECO) is a multipollutant control technology that is being commercially deployed at First Energy's Bay Shore Plant in Toledo, OH on 215 MW Unit 4. ECO has shown in a commercial scale demonstration that it is capable of high NO<sub>x</sub>, SO<sub>2</sub>, and mercury removal.
- Mobotec's ROFA and ROTAMIX technology uses rotating overfire air (ROFA) to reduce NO<sub>x</sub> and also uses injection of NO<sub>x</sub> reducing reagents, SO<sub>2</sub> sorbents and mercury sorbents for reduction of NO<sub>x</sub>, SO<sub>2</sub> and mercury (ROTAMIX). ROFA and ROTAMIX are commercially deployed for NO<sub>x</sub> and SO<sub>2</sub> control. ROTAMIX is currently commercially deployed at the Vermillion power plant Unit 1 for NO<sub>x</sub> control. Mercury control by ROTAMIX has been tested at the full-scale in field trials. At Richmond Power & Light's Whitewater Valley Unit #2 in Richmond IN, 98% mercury removal was achieved with MinPlus sorbent injected at about 2000 °F or more with injection rates of 10-20 lb/MMacf. Whitewater Valley Unit #2 is bituminous fired with a CS-ESP that operates above 400 °F. Fixed bed laboratory tests shown in Figure 16 suggest that mercury capture is above 1500 °F.<sup>25</sup> Therefore, this appears to be an approach that may be useful for boilers with hot-side ESPs without adding a fabric filter for a TOXECON arrangement.
- Enviroscrub's Pahlman process is a sorbent-based process for combined NO<sub>x</sub>, SO<sub>2</sub>, and mercury removal while using a regenerable sorbent. It is not commercially deployed at this time.

**Figure 16.** Fixed Bed laboratory tests comparing Hg sorption by various sorbents<sup>26</sup>



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### Control Options for Coal-Fired Boilers in Illinois

In this section we will discuss the control options that appear to be available to Illinois coal-fired boilers.

#### *Control Options for Boilers Firing Bituminous Coals*

Air pollution control technologies at plants burning Illinois bituminous coal include:

- SCR+CS-ESP+wet FGD
- SCR+HS-ESP+wet FGD
- CS-ESP+FGD
- HS-ESP+SCR
- CS-ESP
- FBC+SNCR+FF

The units that have SCR and FGD as well as the unit with FBC + FF are likely already achieving relatively high levels of mercury removal and may already comply with 2012 requirements of the proposed rule. If not, these units may be able to come into compliance through optimization or addition of oxidizing chemicals to improve FGD capture efficiency. However, if additional mercury removal is required, sorbent injection can provide this additional removal at a reasonable cost because the incremental removal is likely to be quite low. Although untreated PAC has been shown to have poor effectiveness in removing mercury from the flue gas of high sulfur coal, tests with halogenated PAC SI technology indicate that this should provide the additional removal necessary for compliance.

CWLP's two units that are equipped with only cold-side ESPs are currently expected to be retired. But if they are not retired 90%, mercury removal may be achievable through a combination of co-benefit optimization, coal cleaning, and sorbent injection. 75% mercury removal is very likely to be achievable.

Havana, which has HS-ESP+SCR is under consent decree to install a spray drier absorber and fabric filter, which has been shown to provide a high level of mercury control over 90% on bituminous coal fired boilers. Also under consent decree is the Vermillion plant

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that has agreed to install a fabric filter and mercury control technology. Therefore, that plant should be able to achieve 90% control of mercury.

- For bituminous coal fired boilers equipped with SCR, ESP and FGD, 90% removal is achievable through co-benefit of these controls. 90% removal, or close to it, has been measured at several facilities. Test programs with chemical additives to enhance oxidation have demonstrated an ability to improve mercury capture further. Therefore, additional mercury-specific controls are not likely to be necessary on such units.
- For bituminous coal fired boilers equipped with a cold-side ESP, wet FGD and without an SCR, about 60% removal from co-benefit is expected and the additional removal may be achieved through halogenated PAC injection upstream of the ESP, coal cleaning, or possibly through co-benefit optimization with oxidizing chemicals.
- Mercury capture from a CFB boiler with a fabric filter firing bituminous coal is expected to be high – about 90% or possibly better. The SIPCO CFB may also install a limestone spray tower, which will improve mercury control even further.

### *Control Options for Boilers Firing Subbituminous Coals*

The subbituminous coal fired boilers in the state (including those that burn primarily subbituminous coal and a small amount of bituminous coal) generally have cold-side ESP's, with a small number of units equipped with hot-side ESPs. The units with cold-side ESP's can be effectively controlled with halogenated sorbent. However, the units with hot-side ESPs are a greater challenge because at this point in time TOXECON is the only control technology that has been shown to be effective in providing 90% or better control of mercury emissions on unscrubbed units equipped with hot-side ESPs.

TOXECON, as noted earlier, is more costly than a simple SI system. ROTAMIX using the MinPlus sorbent may also prove to be an option for these units that is less expensive than TOXECON.

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- For subbituminous coal fired boilers equipped cold-side ESP, 90% removal can be achieved with halogenated PAC at treatment rates in the range of 3 lb/MMacf. This has been achieved at several short-term parametric test programs and also for 30-day test periods. The consistency of these results at several test programs on low-rank coal increases the confidence that this method is likely to provide the high level of mercury reductions needed over long term operation.
- For boilers equipped with a hot-side or cold-side ESPs, 90% removal is possible with PAC or halogenated PAC in a TOXECON arrangement at relatively low injection rates – below 2 lb/MMacf.
- For unscrubbed units with hot-side ESPs, TOXECON is the technology that is most certain to be capable of providing 90% mercury removal. ROTAMIX with MinPlus sorbent may be an alternative. Another alternative to TOXECON is addition of a scrubber combined with use of oxidizing chemicals and/or coal blending and an SCR could provide 90% removal. This approach would also provide NO<sub>x</sub> and SO<sub>2</sub> control benefits.

Tables 3a and 3 shows the various fuel and APC equipment configurations and possible methods for achieving 90% mercury removal. With the exception of the units with hot-side ESPs, most units should be able to achieve 90% or better removal through optimization of co-benefits, combination of co-benefits with sorbent injection, or through sorbent injection alone. Therefore, most units are capable of achieving 90% mercury removal with a relatively small capital expenditure.

The units with hot-side ESPs pose a more difficult challenge because the current sorbent technology that is known to be capable of achieving 90% removal from subbituminous units with hot-side ESPs is the TOXECON arrangement. Sorbent technology is improving and there have been some promising results on hot-side ESPs. TOXECON does provide air pollution control benefits beyond mercury control and should be considered for these benefits. However, ROTAMIX with MinPlus sorbent may be a promising alternative to TOXECON and has been shown to achieve over 90% mercury removal on a bituminous coal fired unit at high temperatures. Field testing on

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subbituminous coal has not yet been performed. ROTAMIX may also provide other pollutant control benefits, such as NO<sub>x</sub> and SO<sub>2</sub>. Other approaches available to operators of these units include FGD retrofit with fuel blending, which would have SO<sub>2</sub> as well as mercury control benefits.

**Table 3a.** Summary of Boiler Types and Control Options for Bituminous Coal Fired Boilers

Coal Type	Existing Configuration	Hg Control Technology	Comments
Bituminous	CS-ESP+FGD	Coal Cleaning	90% achievable through these methods, possibly used in combination
		Fuel or flue gas additives	
		Co-benefit Optimization	
	SCR+ESP+FGD	Halogenated PAC	90%+achievable
		Coal Cleaning	
		Co-benefit optimization	
	CS-ESP	Additives	Use in combination with sorbent injection
		Coal Cleaning	
		Co-benefit Optimization	
	HS-ESP+SCR	Halogenated PAC	75% achievable
		Dry FGD + FF	90%+ achievable
	CFB + FF	ROTAMIX with MinPlus	90%+ may be possible (impact to SCR needs to be examined)
			90% may already be achieved without additional controls
	CFB + SDA + FF		90%+ achievable

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**Table 3b.** Summary of Boiler Types and Control Options for Subbituminous Coal Fired Boilers

Coal Type	Existing Configuration	Hg Control Technology	Comments
Subbituminous	CS-ESP	Fuel Blending (increase co-benefit) + Halogenated PAC	90% achievable
		Halogenated PAC	
	CS-ESP+SCR	Fuel Blending or oxidizing chemical + FGD	90% achievable
	HS-ESP	Halogenated PAC	90% not yet achieved
		Fuel Blending <i>and/or</i> oxidizing chemical + FGD	90% may be achievable
		TOXECON	90%+ achievable
		ROTAMIX with MinPlus	90%+ shown on bituminous, performance on subbituminous TBD
	HS-ESP+ SCR	Halogenated PAC	90% not achievable
		Fuel Blending <i>and/or</i> oxidizing chemical + FGD	90% achievable
		ROTAMIX with MinPlus	90%+ may be possible (impact to SCR needs to be examined)
		TOXECON	90%+ achievable



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