White Paper for NIST TIP Program

Critical National Need Idea Title:

Effective Mercury Removal Technologies for Coal-fired Power Plants

Key Words: mercury removal, energy, coal, power generation, acid gas, environmental protection

To:

Technology Innovation Program
Mail Stop 4701
National Institute of Standards and Technology
100 Bureau Drive
Gaithersburg, MD 20899-4701

Att. **Critical National Needs Ideas**

From:

Sean Lu, PhD
W.L. Gore & Associates, Inc.
100 Upper Chesapeake Blvd
Elkton, MD 21921
Phone: 1-410-506-4816
Fax: 1-410-506-4999
Email: seanlu@wlgore.com
October 28, 2008

1. Summary

Mercury released from coal-fired power plants and other industrial sectors pose great danger to human beings, especially to young kids. Hundreds of thousands infants are born with neurological problems caused by mercury each year in US. Current mercury abatement technology, the activated carbon injection (ACI), is not only ineffective/costly but also secondary-pollution-generating. Lack of an effective/low-cost technology makes government regulation on mercury difficult. Although quite a few innovative technologies are being proposed and developed by various companies and institutes, proper government funding are needed to speed up the development.

2. Maps to The Administration Guidance

Coal is an abundant energy source in United States; about 50% of the electricity in the United States is generated by coal. However, coal-fired power plants release large amount of pollutants such as sulfur oxides (SO_x), nitrogen oxides (NO_x), and mercury (Hg). Although abatement technologies are mature and available for sulfur oxides and nitrogen oxides, there is no proven technology today that can effectively remove Hg from flue gas [1].

The detrimental effects of mercury pollution to human beings, especially to unborn infants and young kids, were well understood. Various government regulations and professional organizations showed the urgency to regulate/remove mercury release from coal-fired power plants [2-4].

In December 20, 2000, the Environmental Protection Agency (EPA) issued a "regulatory determination" under the Clean Air Act that regulation of mercury is "appropriate and necessary" for coal- and oil-fired power plants. On December 15, 2003, EPA issued proposed mercury rules, which primarily focus on mercury removal from coal-based power plants [2]. However, due to lack of an effective mercury removal technology (it's author's opinion), EPA issued its final Clean Air Mercury Rule (CAMR) for coal-based power plants on March 15, 2005, which kind of postponed the deep mercury cuts until to 2018, instead of 2007. This CAMR rule was overturned by the U.S. Court of Appeals for the District of Columbia Circuit in February 8, 2008; the Court vacated the CAMR and sent it back to EPA for reconsideration [2]. Meantime, more than

20 states started to propose their own mercury removal regulations which are more rigorous than CAMR [2].

In 2002, National Academy of Science published a study, "Reducing Mercury Pollution from Electric Power Plants", in the journal of *"Issues in Science and Technology"*, detailed the healthy effects of mercury on human beings, especially on infants and young kids, and urged EPA and Congress to pass laws to regulate mercury from power plants [3].

In 2004, the National Science and Technology Council, Committee on the Environment and Natural Resources, sent a report to the White House, "Methylmercury in the Gulf Of Mexico: State of Knowledge and Research Needs", detailed the harm of mercury from coal-fired power plants to the ecosystem in the Gulf of Mexico and the risk to the human habitats, and proposed the research priorities to abate the mercury pollutions [4].

A rigorous mercury regulation has been highly expected by government and societal identities; however, lack of an efficient and cost-effective mercury control technology makes federal government hesitate to issue such a regulation.

3. Justifies Government Attention

Approximately 60,000 children may be born in the United States each year with neurological problems due to mercury exposure in the womb, according to a year 2000 report by the National Research Council [3]. Even after birth, young children who ingest mercury, from either breast milk or contaminated foods, remain especially susceptible to the pollutant's neurotoxic effects, because their brains are still in a period of rapid development.

One of the biggest anthropogenic mercury sources entering the environment is the coal-fired power generation. About 48 tons mercury released from power plants each year. During past 10 years, federal government agencies such as EPA and Department of Energy (DOE) have funded large sum of money to develop technologies for mercury removal [5]. The most promising technology emerged from these efforts is the activated carbon injection (ACI), in which activated carbon power is injected into flue gas duct and mercury is adsorbed onto the carbon power. The carbon power is then removed by a bag

house or by an electric static precipitator (ESP). However, this technology suffers from the following problems:

1. *It is ineffective.* The efficiency of mercury removal varies from coal to coal; it is ineffective for Eastern bituminous coal that contains high sulfur. Bituminous coal accounts for large percentage of coal mining in US.
2. *It generates secondary-pollution.* By injecting carbon into flue gas duct, the fly-ash becomes unusable for cement production, and has to be land filled. This problem can be avoided by adding another bag house; however, it would be very expensive, about $20 million extra investment for a typical 500MW plant.
3. *It is expensive.* By DOE estimation, the average cost, using carbon injection, is $45,000 per lb of mercury removal [6], which translates to $6.75 million per year extra-cost for a typical 500MW plant.

Various companies and institutes are rushing to develop new technologies to remove mercury from flue gases. One area which looks promising is the fixed-carbon-bed technology. It is well known that fixed-carbon-bed achieves much better mercury removal than carbon injection. However, fixed-carbon-bed has the following problems: 1) requires frequent carbon regeneration, and 2) causes high pressure drops. Many institutes are proposing and researching technologies that can eliminate these two problems [7-9]. For example, Corning is developing a carbon honeycomb structure to reduce the pressure drop [7]. The Electrical Power Research Institute (EPRI) is teaming up with power companies to develop a semi-fixed-carbon-bed system which makes regeneration processes simple and easy [8].

W.L. Gore and Associates, Inc., this paper's author, is developing a game-changer technology, which completely eliminates the carbon regeneration requirement; furthermore, Gore's technology can simultaneously removes sulfur oxides and fine particles [9]. This technology will be discussed more in Section 5.

Although lab tests and small scale field demonstrations showed promising results of the above-mentioned technologies, medium to large scale field demonstrations are needed to fully validate a new technology. For a power plant operation, medium to large scale demonstrations are very expensive, usually in millions or multi-million dollars for a demonstration. The financial burden and lack of a firm government regulation on

mercury control, makes individual companies and institutes hesitate to perform such medium to large scale field studies.

Therefore, it is imperative that government agencies provide proper financial support to ensure such promising technologies can be fully developed and commercialized in timely manner. It is also imperative that government should issue firm regulations on mercury removal as soon as possible to make sure that there is market for the emerging mercury removal technologies.

4. Essentials for TIP Funding

As indicated by many experts, activated carbon injection (ACI) for mercury control might be a short-term solution for power plants; it is, however, not a preferred-efficient/cost-effective solution. Better technologies are needed to effectively address the mercury pollution problems the nation and the world are facing today.

Government agencies, such as EPA and DOE had funded large sum of money to develop mercury control technologies during past ten years. However, in recent years, these agencies shifted their attentions to carbon dioxide (CO2) removal and spent very little money on mercury research.

As many companies/institutes are developing better technologies for mercury control, government financial support is needed to help these companies/institutes to speed up the development, and mitigate their financial risk for doing such development work. As other agency's money is less available, NIST's TIP program may play an important role to foster this important national capability.

Developing efficient/cost-effective mercury control technologies will not only affect power generation industry in United States, it will also affect other pollution generating industries. For example, other industries release about the same amount of mercury into sky each year as power industry does [2]. The overall world mercury releasing are 5 to 8 times more than US each year. It is well known that elemental mercury can travel many thousand miles in air before settling in land, which makes mercury pollution a global problem. An efficient/low-cost mercury control technology makes global mercury control possible.

5. Innovative Mercury Removal Technologies

As mentioned above, many companies and institutes are rushing to develop better technologies to remove mercury from flue gases. One of the most promising technologies is based on the fixed-carbon-bed approach, and the emphasis of the new technologies is to solve the intrinsic problems associated with fixed-bed approaches [7-9], that is, the requirement of frequent regeneration and large pressure drop.

Recently, W.L. Gore and Associates, Inc., the author of this paper, are developing a game-changer technology using ***activated-carbon-fluoropolymer composite material*** [9].

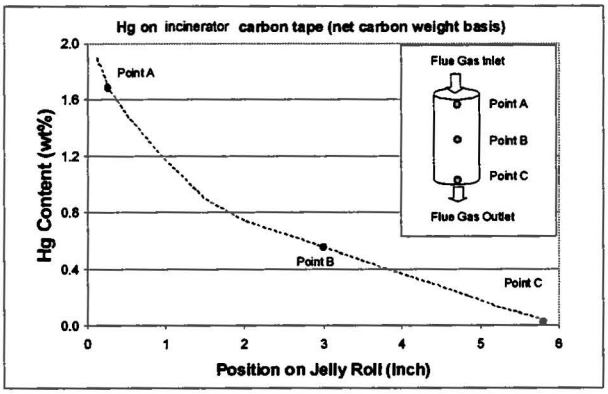
Activated carbons have been studied extensively for industrial flue gas purification applications, e.g., to remove SOx (SO2 & SO3) and mercury (Hg) from flue gases. Activated carbon can effectively adsorb and convert SOx into sulfuric acid on its surfaces, as well as adsorb Hg elements on its small pores. However, due to the requirement of regeneration (after saturation by sulfuric acid), fixed-carbon-bed applications for mercury removal is not a viable approach, as is.

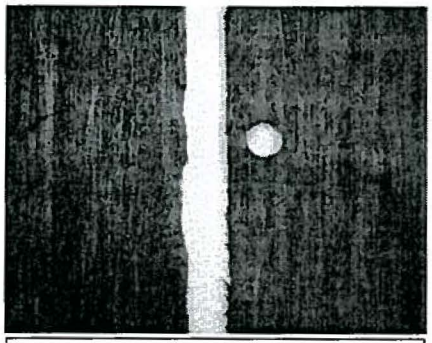
With Gore's activated-carbon-fluoropolymer composite, due to the *porous structure* & the *hydrophobic nature* of the material, it has self-regeneration capability, which was never discovered before [9]. The composite material expels the formed aqueous sulfuric acid automatically to its outer surfaces due to its capillary forces; and the expelled liquids coalesce and dribble down by the gravity, therefore, **a regeneration process is not required**. With this capability, the activated-carbon-fluoropolymer composite material will be able to continuously remove Hg from flue gas for long term without any regeneration processes. Furthermore, the composite material also removes SOx and final particles (PM2.5) from flue gases.

The activated-carbon-fluoropolymer composite material can be made into various forms, including thin tapes, therefore, system can be design to achieve minimum pressure drop, which eliminates another problem associated with fixed-bed approach.

Gore's technology has been tested extensively in labs and small-scale on the field, which showed very promising results. For example, in a 3.5-month field test in a medical waste incinerator, as shown in figure on the right (nest page), the activated-carbon-fluoropolymer composite tape was rolled together with a porous spacer layer and packed

into a cylindrical holder. Flue gas was continuously flow pass the sample for 3.5 months without any regeneration process. The mercury removal capacity of the carbon tape is as high as 1.7% by weight. As comparison, in carbon injection technology (ACI), mercury removal capacity of the injected carbon is in the order of 0.002% by weight, a difference of 3 orders of magnitude. By checking the activated-carbon-fluoropolymer composite tape after 3.5-month field exposure, as shown in picture on the left, there is no visible deterioration or damaging, which showed good durability of the material.





Left: fresh composite tape; Right: after 3.5-month exposure

Small-scale tests on the coal-fired power plants are being perfomed and promising results have been obtained. Gore is going to team up with outside companies and institutes to perform medium to large scale test on power plants.

Due to the advantages, no regeneration, low pressure drop, and multi-pollutant removal, Gore technology offers a much efficient and cost-effective method to control mercury and other flue gas pollutants. The estimated cost would be only 1/3 or less than the current ACI method.

6. Conclusions

Mercury released from coal-fired power plants and other industrial flue gases pose great danger to human beings, especially to young kids. Current mercury control technologies are inefficient and expensive. New technologies are needed so that federal government can enforce tight regulations on mercury control.

Many companies and laboratories are developing new technologies for mercury removal, W.L. Gore and Associates, Inc. is one of them. Gore have developed and patented a carbon-fluoropolymer-composite based technology. The lab tests and small

scale field tests showed that the technology is very promising. With this technology, mercury from power plants and other industrial flue gases, can be removed with less than 30% of current cost, furthermore, this technology also removes other industrial flue gas pollutants, such as sulfur oxides and fine particles.

To commercialize new technologies, medium- to large-scale field demonstrations are needed, which will be very expensive. It is imperative that government agencies, such as NIST, provide proper financial support to ensure such promising technologies can be developed and commercialized in timely manner. It is also imperative that government should issue firm regulations on mercury remove to make sure that there is market for the innovative mercury removal technologies.

References

[1] Ya. E. Yudovich and M.P. Ketris, "Mercury in coal: a review Part 2. Coal use and environmental problems" *International Journal of Coal Geology, Volume 62, Issue 3, 11 May 2005, Pages 135-165*

[2] http://www.epa.gov: Federal Register / Vol. 72, No. 79 / Wednesday, April 25, 2007 / Proposed Rules.

http://www.earthportal.org: Mercury: Appeals court strikes down EPA cap-and-trade regulation, February 8th, 2008

http://www.4cleanair.org: National Association of Clean Air Agencies - State Mercury Programs for Utilities, December 4, 2007

[3] National Academy of Science, "Reducing Mercury Pollution from Electric Power Plants", *Issues in Science and Technology*, Summer 2002

[4] National Science and Technology Council, Committee On The Environment And Natural Resources, "Interagency Working Group On Methylmercury", Washington, D.C. June 9, 2004

[5] G. Offen (EPRI), "Mercury Control for Coal-fired Power Plants – an Update on Technology Options", 2008 Electric Utility Environmental Control Conference, Paper B5.1, Tucson, AZ, Jan. 2008

[6] S. Sjostrom, et al. (DOE & EPRI) "TOXECON II™ and Other Options for Preserving Ash Sales", 2008 MEGA Symposium, Paper #: 172, Baltimore, MD, Aug. 2008

[7] Y. Cao (Corning), "Novel Mercury Control Technology", 2008 Electric Utility Environmental Control Conference, Paper B9.5, Tucson, AZ, Jan. 2008

[8] T. Machalek, R. Chang, et al (URS & EPRI), "Field Investigations of Fixed-Bed Sorbents for Mercury Capture from Coal-fired Flue Gas", 2008 MEGA Symposium, Paper #: 106, Baltimore, MD, Aug. 2008

[9], X. Lu, et al (Gore), "A Flue Gas Purification Process Using a Sorbent Polymer Composite Material", US patent application, Pub. No. US 2005/0019240 A1 2004, Jan. 2005