

**Aqueous Phase Mercury Removal: Strategies for a Secure Future Water Supply**  
Critical National Need Idea White Paper

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**Note:**

As stated in NIST white paper guidelines, this white paper is neither a Request for Proposals (RFP) nor should it be viewed as a request for pre-proposals. Rather, it is a way to include ideas from the public to identify problems of national interest that justify government support and can be addressed by technological innovations that are not currently being sufficiently supported to meet the challenge.

**Key words:**

Hg; MeHg; Mercury Contaminated Water; Mercury speciation; Mercury analysis; Methylmercury; Clean water act; Mercury research strategy; Aqueous phase mercury; Flue gas desulfurization; Wet scrubbers; Electric utilities; Bioaccumulation; Chlor-alkali; Coal-fired power; Ash pond return water; Waste incineration; Energy security; Job Creation; Ultraviolet; Photochemical; Adsorption; Silica; Titania; Sorbents; Great Lakes Initiative; Aquatic pollution; Volatilization; Catalysis; Health; IQ

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## OPENING STATEMENT

More and more we hear news of the adverse affects of 'trace' level contaminants with warnings from various government agencies now reaching up to a background noise level for mercury, for example. We are asked to make dietary decisions based on growing levels of contamination by federal agencies and even the World Health Organization. Our efforts to ensure healthy lives for all and reduce our dependency on foreign energy sources give us conflicting agendas. Most of the general population has some knowledge of the 'mad hatter' effects of mercury and many understand some of the background noise messages related to the excessive consumption of large fish species. Although all agree it is bad, the full impact of the continuing and growing 'trace' level mercury contamination in our cities, rivers, lakes and oceans is not clearly understood. However, it is known that the continued increase in mercury in our environment will adversely affect our children's ability to compete in a flat world.

Our efforts to reduce dependence on foreign energy sources will clearly prolong and possibly increase the use of coal consequently increasing the environmental burden of mercury (Hg). Although few like to discuss the projected rising ocean temperatures, this too will significantly increase Hg in our diet. Unless cost effective mechanisms are developed and implemented to sequester Hg at its sources and to remove it from mining waste, streams, and lakes, we can only expect more of our newborns to be limited in their capacity to help our society solve problems. The promotion of a national electronic medical record system in the United States makes it feasible to scientifically study, analyze and map many of the confounding factors related to Hg contamination. This white paper attempts to draw attention to the growing Hg contamination of our waters in the USA and the need for effective documentation and, more importantly, actions. Given the current economics of power generation, the growing burden of Hg on our society can be only limited by economical technologies to effectively remove Hg at their sources and from our environment.

A predominant emitter of Hg in both gaseous and liquid forms is the coal-fired power industry, which is presently making decisions or has already committed to a strategy for Hg removal from flue gas. However, a parallel effort for aqueous phase mercury (aqueous Hg) is lacking and perhaps more pressing. In response to the limitations of existing pollution control technologies, research at the University of Florida (UF) have been developing technologies capable of reducing aqueous Hg concentrations down to less than 0.5 parts per trillion (below detection using EPA Method 1631), but more diversified research is required. If suggested water quality standards of 1.3 ppt *or potentially lower* from the Great Lakes Initiative to be enforced in 2010, or the alternative 12 ppt are extended throughout the Nation, Hg emissions from a variety of sources would need to be greatly reduced from the current standards which are dictated by current National Pollution Discharge Elimination System (NPDES) permits and can range from 2 parts per billion to above 50 ppb, for example.

## HEALTH

**"Quiet baby syndrome"** was a phrase coined in the early 1970's when mothers in Iraq would praise their babies for never crying; soon thereafter it became a warning sign for methylmercury induced brain damage in children. An estimated 10,000 Iraqis died and 100,000 were severely and permanently brain damaged from ingesting grain that had been dressed with methylmercury (MeHg), which was the most cost-effective fungicide at the time (Bakir 1973). Many farmers dumped contaminated grain along roadsides, in irrigation canals and in rivers leading to high concentrations of contaminated fish and migratory birds. Subsequently, the consumption of these fish resulted in sensory and motor impairment in exposed adults, and mental retardation, seizures, and cerebral palsy in fetuses exposed to MeHg during gestation (Gilbertson 2004, TED 1997). We now know that Hg is environmentally persistent and bioaccumulates and is transported atmospherically on a local, regional, and global scale (EPA 2008). Despite this warning and other 'isolated' tragedies, little technology interventions are in place to effectively reduce or eliminate this growing unjust tax on our children's development.

**Hg in the United States.** The largest sources of population exposure are coal-fired utility plants, municipal/medical waste incinerators, and commercial/industrial boilers—estimated to be responsible for 158 tons of environmental release per year (EPA 1997). An additional approximately 255 tons of Hg are produced by the recovery of Hg as a by-product from mining other metals, primarily gold, and through recycling from Hg-containing industrial process wastes, mining or industrial site remediation wastes, scrap consumer products, and decommissioned Hg cells at chlor-alkali plants (EPA 2007). Once Hg is in water and sediments, MeHg (CH<sub>3</sub>Hg<sup>+</sup>) is produced as the result of naturally occurring microbial biomethylation. Increased global temperatures would increase Hg methylation since methylation is temperature-dependent. Increased temperature increases fish metabolism and MeHg ingestion. An estimated 4.4% increase in MeHg concentrations would result from a 1.0°C increase (Booth 2005). MeHg is a potent neurotoxin and is one of the most toxic forms of Hg that biomagnifies. MeHg crosses the blood-brain and placental barriers without hindrance to reach its principal target tissue, the brain (Clarkson 1993). Unfortunately, there is no real treatment for MeHg poisoning.

**MeHg is a developmental neurotoxin at extremely low doses.** Almost a decade ago the National population data from the 1999-2000 National Health and Nutrition Examination Survey found that 15.7% of American women of childbearing age had total maternal blood Hg concentrations greater than or equal to 5.8 µg/L (ppb) (Mahaffey 2004). In the same year, cord blood Hg levels greater than 3.5 µg/L were shown to impair neurodevelopment after in-utero exposure. Recent studies suggest the cord blood Hg concentration may be 30% - 70% higher than the maternal blood Hg concentration (Budtz-Jorgensen 2004, Stern 2003). Furthermore, there is no evidence to date validating the existence of a threshold blood mercury concentration below which adverse effects on cognition are not seen according to the National Academy of Sciences in a report on the toxicological effects of MeHg (NRC 2000). Is it acceptable that one out of six of our newborn children continue to be exposed to excessive levels of Hg?

**Impact of MeHg Exposure on IQ.** Hg is well established as a neurotoxin that can be problematic at extremely low concentrations. Chronic, low-dose prenatal MeHg exposure from maternal consumption of fish has been associated with more subtle end points of neurotoxicity in children, including poor performance on neurobehavioral tests, particularly on tests of attention, fine-motor function, language, visual-spatial abilities (e.g., drawing), and verbal memory (Kjellstrom 1986; 1989, Grandjean 1995; 1999, NRC 2000, Murata 2004). While all who consume fish are at risk, women who are or may become pregnant, breastfeeding mothers, and young children will be most affected by MeHg exposure. An estimated 300,000 to 640,000 children born each year have cord blood Hg levels > 5.8 ppb, a level associated with loss of intelligent quotient (IQ) (Jorgensen 2004, Crump 1998). Several studies estimate that loss in IQ associated with adverse impacts on neurodevelopmental tests averaged 0.93 IQ points per 1 ppb increase in cord blood Hg concentration. This decrement in IQ appears to be permanent and irreversible, and it adversely affects a significant portion of the annual birth cohort's economic productivity over a lifetime. Iodine promotion in China during the last decades has resulted in an estimated increase of one billion IQ points (WHO 2006), which leads to the question how many IQ points an Hg-free environment would generate in the USA and the true cost of MeHg toxicity to our children's developing brains, their health, and thus their future productivity. Our national loss of IQ leads to greater loss of economic productivity, increased need for special education and health care and other costs. Scientists have recently linked Hg as a cause of autism and ADHD in children (Bernard 2001; 2002, Vojdani 2003, Cheuk 2006). While estimates of the dollar values of these costs widely vary, the estimates range from hundreds of millions to billions of dollars per year. Without much more action and regulation, too many individual American families and the American public suffer unnecessarily. The opportunity cost is clearly significant.

**Aqueous Hg is least studied subject in Hg pollution.** In order to protect the environment and human and wildlife health, technologies that can effectively and economically remove Hg from gases and liquids are needed. Although promising technologies for gas-phase Hg removal are becoming more apparent, they still do not meet long-term performance criteria (Feeley 2003). Far fewer viable technologies exist for removing trace levels of aqueous Hg from industrial process waters. While some Hg contamination is present in all environmental media, aquatic systems

experience the greatest exposures because of bioaccumulation (EPA 2009). (Bioaccumulation refers to the net uptake of a contaminant from all possible pathways. It includes the accumulation that occurs through the mining waste contamination of our streams and lakes where it reaches excessive levels and is then further concentrated in the fish, wildlife and humans who drink the water.)

## MERCURY CONTAMINATION IN WATER

Hg is a naturally occurring metal found in coal, waste, and other materials. When these materials burn, Hg is released into the air. In 2000, an estimated 4,400 to 7,500 tons of Hg were emitted globally (UNEP 2002). Anthropogenic sources constitute an estimated 75% of that total (Feeley 2003). In the U.S., the primary sources of anthropogenic releases stem from power production, which utilizes fossil fuels. Other significant sources include waste incineration, and processing of metals and ores. Hg has been contaminating water bodies associated with historic gold mining in the United States for the past 150 years (USGS 1999a).

Hg in water bodies can be attributed to either atmospheric deposition or the direct discharge of Hg-laden wastewater. Sources of Hg pollution have been thoroughly documented. Briefly, Hg-laden wastewater may be generated by sources such as dental offices, hospitals, laboratories, and a variety of industries, including coal-fired power plants employing wet scrubbers and chlor-alkali facilities employing Hg-cell processes.

In 2006, 42 states and Puerto Rico reported at least one water body as impaired due to Hg with a listing of more than 9,000 specific water bodies as impaired due to Hg, either solely or in combination with other pollutants. In addition, with the implementation of the new MeHg fish tissue criterion by the EPA, monitoring of previously unmonitored water bodies, and use of more sensitive analytical methods, it is expected that the number of water bodies found to be impaired due to Hg will significantly increase (EPA 2009).

**Electric Utility Industry.** All forms of coal contain trace amounts of Hg in varying forms and concentrations. Thus, in the United States, coal-fired power plants emit about 48 tons of Hg and are the largest point source of emissions. Air pollution control devices currently remove between 50-90% of Hg from the flue gas effluent by various means. One such strategy is the installation of flue gas desulfurization (FGD) systems (i.e., wet scrubbers), which has the co-benefit of capturing Hg while reducing gaseous sulfur dioxide (SO<sub>2</sub>) emissions to comply with the Clean Air Act. Currently about 15 to 25% of existing U.S. coal-fired power plants have FGD systems installed, which corresponds to 39% of the current U.S. coal-fired power plant capacity (i.e., 130,000 MW of the 330,000 MW total U.S. capacity is scrubbed). New coal-fired power plants will be required to install FGD systems for SO<sub>2</sub> removal. It is well understood that the co-benefit of Hg removal is achieved by the wet scrubbers capturing oxidized Hg, which therefore is providing a technology development for overall Hg reduction. However, this strategy ignores the fate of the aqueous Hg in the wastewater streams. As the scrubber water re-circulates through the wet FGD process, the concentration of aqueous Hg will further continue to increase. These increased levels could promote the re-emission of Hg to the atmosphere (i.e., released through the stack exhaust) and decrease the driving gradient for capture of the air-phase oxidized Hg (i.e., the concentration of aqueous Hg exceeds the air-phase Hg, and therefore, the air-phase Hg is not captured). Additionally, accumulation of aqueous Hg in the wet scrubber water will negatively impact coal utilization by products through accumulation in the gypsum by-product. By ignoring aqueous Hg, we will likely find many of our streams, lakes and communities in a difficult situation, which will be detrimental to our children's health.

Existing Air Pollution Control Devices (APCD) in operation that have kept toxins from escaping into the air have left the solid wastes from coal plants, which is mostly ash, more poisonous. Every year, domestic power plants produce more than 125 million tons of coal combustion waste. Most of the waste is disposed of as slurry in aboveground ponds with retaining walls or dry in landfills. The EPA is uncovering sites throughout the Nation where groundwater was contaminated by heavy metals including Hg from coal ash dumps. The EPA has determined that these "surface impoundment" ponds (also known as "wet dumps") are the most likely storage sites to leak pollution into groundwater

and surface water, even without a catastrophic failure such as the one before Christmas of 2008 at the Tennessee Valley Authority's Kingston Steam Plant coal ash retention pond, which burst and covered the nearby area with more than a billion gallons of toxic-laden sludge.

Coal spills have cast a spotlight on what is a very serious national problem - - the existence of under-regulated toxic pollution coal dump sites near coal-fired power plants that pose a serious threat to drinking water supplies, rivers and streams. The EPA has developed improved tests that show more toxins leaching from the ash into groundwater than previously thought. At this time, there is no treatment technology that eliminates serious environmental risks associated with disposal of this coal industry waste (Lenly 2004). To date, there have been no parallel efforts to control aqueous Hg pollution.

**An alarming trend** is the prevalence of dangerously high Hg blood levels in coastal and island regions due to a higher consumption of fish and shellfish (USEPA 2007); moreover, 50% of the Nations population lives within 50 miles of the coast (NOAA 2008). As a part of the Clean Water Action Plan under the Mercury Research Strategy developed by the U.S. Environmental Protection Agency (EPA 1998a) a national survey of Hg levels in fish and shellfish was conducted over the years 1998 –2000. Figure 1 shows the results from that study.

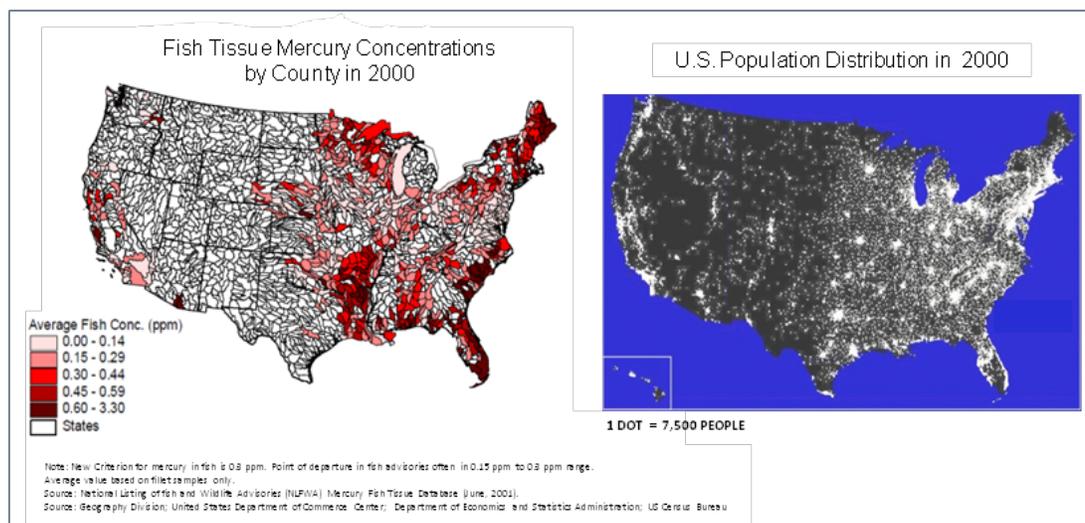


Figure 1. Distribution of fish tissue concentrations and human population in the United States in 2000.

## FINDING SOLUTIONS

In light of the developments that have been made evident in the previous sections, it is clear that solutions to the Hg problem are imperative. What should our Government do in the face of the conflicting national priority for energy independence and a moral mandate to promote a healthy population? Given the current economic conditions, some may argue that now is not the time to make coal users pay for mercury control and removal technologies. However, a survey of available research funding grants revealed that there are currently none available. In either case, we must find a way to economically remove and sequester mercury from coal burning and mining activities and equally important to remove mercury from our contaminated water bodies. While there are some studies and attempts, the science for such an effort is not clear nor is the cost understood.

Due to the paucity of information on aqueous Hg removal, fundamental research is needed. Peer reviews and published literature by experts from various disciplines attest to the conclusion that aqueous Hg physiochemical removal reactions and mechanisms are not clearly understood, nor have they been explored. A thorough understanding of the

underlying scientific principles would be advantageous to developing processes for Hg removal from industrial wastewaters which could likely be used on waters with a broad range of chemical compositions.

An opportunity for a path forward is made possible by the current administration's commitment to reducing Hg emissions both nationally and Worldwide. While the Economic Stimulus Package is a high risk, high return investment that has for the time being increased our National debt by a 1.3 trillion USA dollars, this White Paper aims to provide focus and attention on the resources needed to generate transformational technologies that can reduce the release of Hg into our drinking and natural waters, ultimately providing a service to the Nation that is long overdue.

**Mercury Removal Technology.** There are several alternative methods for Hg removal from water, including precipitation, adsorption, volatilization and bioremediation, none of which have been commercialized for Hg removal to the 1-10 ppt range anticipated to be required in the near future. Precipitation typically reduces Hg concentrations to less than 2 ppb and requires chemical addition, continuous monitoring and large footprints for settling (EPA 2007). Precipitation processes have been used for chlor-alkali wastewaters and coal-fired power plant scrubber water (Chlorine Institute 2003; Siemens 2007), but have not resulted in Hg reduction to below 10 ppt. Adsorption with granular activated carbon is a commonly used method for Hg removal from water. Generally, carbons are impregnated with sulfur to reach higher capacities for Hg. Mersorb LW, produced by Nucon International Inc. (Columbus, Ohio), has been tested for aqueous Hg removal but encountered several operational setbacks, increasing cost of treatment and not achieving the low standards that are desired. The Forager Sponge (Dynaphore, Inc., Richmond, VA), which is an open-celled cellulose sponge incorporating an amine-containing chelating polymer, applied to Hg removal achieved 0.2 ppb (i.e., 200 ppt) of Hg from initial concentrations of 8.6 ppb during bench scale testing with synthetic water, again missing the 10 ppt mark. Additionally, the Sponge has high affinity for other species, with Hg being close to the bottom of the list and therefore it is likely to exhibit worse removal performance in the presence of competitive ions (EPA 1997). Another adsorbent, a thiolbased resin, Self-Assembled Monolayers on Mesoporous Supports (SAMMS), was developed at the Pacific Northwest National Laboratory (PNNL) and commercialized by Steward Environmental Solutions, LLC (Chattanooga, TN). According to Steward's web site (<http://sammsadsorbents.com>), in a recent lab study using SAMMS, Hg reduction from a starting concentration of 4.5 ppt to 0.7 ppt was realized. The economic feasibility of applying Thiol-SAMMS (\$68/lb according to PNNL (2006)) for voluminous wastes is in question.

Since selectively removing very small quantities of Hg is extremely challenging, conversion of aqueous Hg to elemental Hg followed by air stripping as a removal strategy was investigated to treat groundwater from the Department of Energy Savannah River Site (Looney 2003). With up to 25:1 molar ratios of Sn:Hg, 138 ppt Hg solutions were reduced by 94%. However, this method added an undesired Sn contaminant to the solution, required subsequent gas-phase elemental Hg removal, and was only applicable to easily reducible species of Hg.

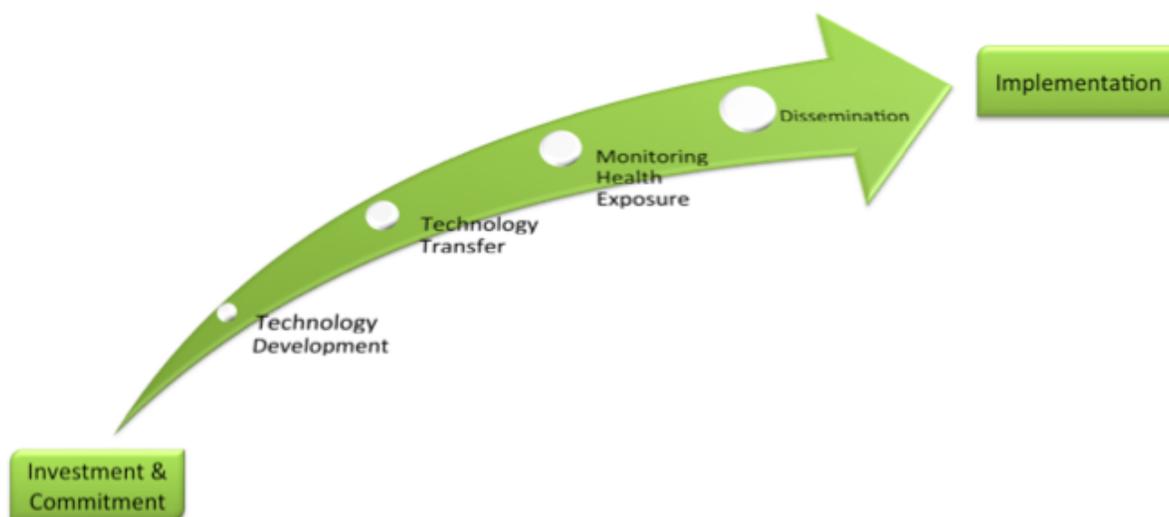
Unlike the technologies above, which rely on chemicals to achieve the desired levels of Hg removal, biological Hg removal technologies rely on microbes to convert soluble Hg to elemental or to an insoluble form that facilitates removal (e.g., HgS) (Watlington 2005). Biological treatment was investigated by GE with a method called ZENON ABMet (GE 2007). The ABMet process consists of bioreactors containing granular activated carbon beds for microbial growth. Sulfate-reducing bacteria will convert sulfates from water to sulfide, which can then complex with Hg (GE 2007). It is unknown if the technology can remove Hg to below 10 ppt. Another attempt at biological remediation is the use of genetically engineered plants for Hg removal. Researchers at Clemson University have evaluated a pilot-scale wetland treatment system for simulated coal-fired power plant scrubber water treatment. Removal rates for Hg were between 64 and 97% except for a sample in which the Hg concentration was already below 100 ppt, which was their target.

Although the above-described technologies are unable to consistently achieve Hg concentrations below 10 ppt, there are viable technologies under development that have accomplished excellent Hg removal from a variety of wastewaters, including groundbreaking technology solutions that have achieved concentrations as low as below 0.5 ppt.

Dr. David Mazyck and his research team at the University of Florida (UF) have developed a novel adsorbent material, Silica-Titania Composites (STC), which has been commercialized for Hg removal from air in the chlor-alkali industry, and is currently being developed for Hg removal from water. In studies carried out by Sol-gel Solutions, LLC (Gainesville, FL), which licensed the STC technology from UF, it was determined that the STC can effectively remove Hg from ash pond return water from a coal fired power plant to 1.1 and 1.2 ppt (i.e., using two formulations of the STC). In addition, in studies with chlor-alkali secondary treatment water, concentrations as low as below 0.5 ppt were obtained using an advanced oxidation strategy termed Ultraviolet Activated Chelation (UVAC). The cost of the STC material is expected to be below \$20/lb, and the STC have the potential of being used numerous times.

## PATH FORWARD

Clearly, additional Government involvement, both Nationwide and globally, is needed to reduce aqueous Hg emissions and protect human and wildlife health. An investment in technology development and commercialization is crucial, as is monitoring health exposure as a means of ensuring successful implementation.



The timely transfer of scientific knowledge to government, research organizations, academia, industry, and the general public is needed to secure a safe water supply for present and future human development in the United States and Worldwide. Regulations in North America have heightened interest in solving Hg control issues, and stakeholders have become even more eager to obtain research that addresses characterization, measurement, and control of Hg emissions based on scientifically sound principals (NETL 2003). The general research community and the public are becoming more aware of trace metal issues and need the most current research in this area. In order to most effectively respond to our National commitment, the following strategy provides the guidance needed for the most desirable mode of operation for the solutions proposed:

The research venues described herein will be conducted through collaborations between Federal and private organizations. Scientists, engineers, and health and policy specialists will see opportunities to collaborate in one or more of the research areas described below:

### 1. DEVELOPMENT OF REMOVAL TECHNOLOGIES FOR MERCURY CONTAMINATED WATERS

Aqueous Hg removal is particularly challenging because the background matrix of the waters requiring treatment are typically present in much higher concentrations (e.g., mg/L or ppm) than Hg (ug/L or even ng/L). This challenge has the potential to be met based on the progression of accomplished research. However, **available funding to support**

*these activities has been low compared to the billions of dollars made available for the development of Hg control technologies for the air-phase.*

A vast number of industries require technologies that remove Hg to trace concentrations. For example, the variety of waters associated with chlor-alkali manufacturers, scrubber water from the wet FGD process, effluents from publically owned treatment works (POTWs), other industrial waters and drinking water will each have different characteristics, thus requiring robust technologies that are selective to mercury. Based on achievements of previous Hg research and the direction of water treatment technologies, significant landmarks toward advanced Hg removal can be reached with committed investments in the following areas:

a. Additives to Prevent Reemission of Hg in Wet Scrubbers

Since elemental Hg is insoluble in water, Hg has to be in oxidized form in order to be captured in wet scrubbers. It has recently been found that Hg can become reduced in the wet FGD process via redox reactions or by microorganisms, which causes reemission of elemental Hg into the flue gas. Therefore, research is needed to develop “additives” that prevent Hg reduction and hence reemission. This can include powerful oxidizers or coagulants, for example.

b. Chemicals to Assist in Hg Removal

Chemical precipitation is often used for the removal of metals from, for example, potential drinking water and acid mine drainage. Moreover, chemical precipitation using sodium sulfide is used in the chlor-alkali industry to lower the discharge concentration of mercury from above 50 ppb (ug/L) to about 1-2 ppb. Chemicals that can further enhance removal to ppt levels are needed. Alternatively, technologies such as Sol-gel Solutions, LLC’s UVAC described above are needed as a “polishing step” to further lower Hg concentrations achieved via precipitation. As stated above, the UVAC technology has achieved Hg concentrations below the 0.5 ppt detection limit of EPA Method 1631.

c. Sorbents for Hg Capture

The University of Florida, Sol-gel Solutions, LLC, and others has been developing sorbents for Hg capture from the gas and liquid phase. Using UF-derived technology, Sol-gel Solutions has commercialized an air-phase Hg capture technology for the chlor-alkali industry whereby more than 95% of the Hg is captured. The technology is regenerated in-situ. It is currently under development for aqueous Hg capture, and has achieved concentrations as low as 1.1 and 1.2 ppt in ash pond water from a US coal-fired power plant. There is a lack of other sorbents that can consistently and economically achieve ppt level Hg concentrations.

d. Catalytic Surfaces for Hg Removal

Hg removal from water is challenging because it can be present in three redox states (0, +1, and +2 valence). Moreover, the oxidized forms can be hydrated with water or the Hg could be complexed with chlorine or other anions in solution. With regards to catalytic surfaces to transform and bind Hg, if one can control the redox state of Hg (e.g., convert “all” of the Hg present in a liquid sample to a desired state), then developing a removal technology becomes quite realistic.

## 2. TECHNOLOGY TRANSFER

Treatment technologies that achieve less than 12 ppt and even more challenging to less than 1.3 ppt mercury from a variety of industrial wastewaters, are mostly unheard of and out of reach to industries. Moving technology from development to commercialization is key to realizing solutions. Based on proposed regulation, technology solutions should be made available as soon as 2013. A major impediment to development stage solutions entering the market is

the reluctance of the coal-fired power industry, and many others, to accept technologies that have not been proven outside of the laboratory. Inputs to accomplish the technology transfer from the bench scale to commercialization would include pilot- and full-scale studies (NETL 2003). Investment into these larger scale studies could instill confidence in investors.

The US can show guidance and leadership in Hg research and technology implementation. Through this position, the nation would encourage cooperative efforts for developing countries such as China and India who have surpassed 90% of Asia's coal consumption. Global cooperation for Hg control is imperative to protecting human and ecosystem health in the US since over 60% of the Hg deposited is from external sources and food products exposed to Hg are globally cycled.

### 3. HEALTH ASSESSMENT

While EPA's *Mercury Research Strategy* was developed in 2000 to provide information and data that reduce scientific uncertainties limiting the Agency's ability to assess and manage Hg and MeHg risks, long term health studies are necessary to track trends in levels of mercury exposure and health impacts. These correlations will assist government decision making to effectively implement policy and changes for the future.

Health impacts are generally correlated to a particular toxin of interest. However, in a world of man-made chemicals and anthropogenic emissions, humans are exposed to a greater quantity of hazards. The impact of co-contaminants on health and well being is complex and not well understood. While mercury has been established as a neurotoxin, conflicts have arisen based on how co-contaminants (such as selenium and PCBs) impact study results, requiring interdisciplinary work on health, law and engineering.

The promotion of a national electronic medical record system in the United States would make it feasible to scientifically study, analyze, and map many of the confounding factors related to mercury contamination. The promotion of GIS/Health by the Department of Health and Human Services provides additional analytical tools to determine the effectiveness of current Hg removal efforts through the tracking of health and environmental trends.

### 4. SCIENTIFIC ANALYSIS

Hg bioavailability and therefore toxicity, and Hg removal technologies both depend upon speciation. The analytical instrumentation required to differentiate between elemental, ionic, particulate bound and organic mercury is lacking. Indeed, one can differentiate between organic-bound Hg and inorganic-bound Hg, but within the inorganic species, of which there can be more than 20, an analytical technique is missing. The development of accurate analytical methods for speciation would further advancements in modeling and Hg removal technologies.

To implement these programs, progress needs to be made in scientifically sound monitoring devices. Currently, the accuracy and precision of Hg measurements using both the manual wet chemistry Ontario Hydro method and several different mercury continuous emission monitors (CEMs) have demonstrated significant variability (NETL 2003). Thus, there is a need for consistently accurate analytical methods for Hg, both for continuous and periodic measurements in gas- and aqueous-phase applications.

### 5. BROADER IMPACTS

In order to achieve the maximum benefits from any scientific work, dissemination efforts must be taken into consideration. Effective dissemination of best management practices, technology, and policy needs would enhance cooperation and willingness to address the issue of Hg as a global pollutant. The manner in which information is disseminated can have a major impact on action versus inaction. It is important to understand how to communicate important messages to Americans for action to be pursued.

International cooperation, especially in the environmental sector, is difficult to achieve. In the scenario of Hg pollution, detrimental effects are real and can continue to worsen for all parties in the near future. Therefore, despite difficulties associated with global environmental policy, it is recommended that future collaborative action of international governments would be necessary to protect waters and fish populations all over the world.

Technology development significantly impacts long-term economic growth and productivity for an increase of social wealth through creation of jobs for new businesses and expansion of existing business. Since 1993, high technology has brought over one million jobs to the US economy (DOL 1999). Monetary benefits can be realized through bridging technology gaps with solution pioneering followed by the establishment of industry standards. These types of developments will contribute to the sustainable movement and ability for the US to compete in the global economy.

## WHY WE BENEFIT

*Water is recognized, not only as a limited natural resource and a public good but also as a human right. The right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water, and it must be enjoyed without discrimination and equally by women and men. - Sergio Vieira de Mello, 3<sup>rd</sup> United Nations High Commissioner for Human Rights*

The restoration of the water resources should no longer be viewed as an expense, but as an investment; for every dollar spent on bringing technologies online that have proven unsurpassed Hg removal from water as low 1.3 ppt, the United States and the world is likely to see at least another dollar returned on investment. Research conducted in this area of National critical need will provide transformative contributions to our ability to treat water with increasingly complex characteristics as more pollutants, including endocrine disruptive pharmaceuticals, enter our natural and drinking water resources.

Because of increasing global environmental concerns, training, education, and dissemination of information to the general research community that includes stakeholders in government agencies, research and educational institutions, and industry in a timely manner are critical and highly beneficial. Sharing cutting-edge research findings with industry, environmental groups, state agencies, and EPA will be instrumental in establishing scientifically based solutions that are robust and affordable. Information on what technologies are available will be provided to those decision makers who must implement policy, evaluate environmental and health impacts, and determine the most judicious course of action in light of the most recent information.

Several populations depend on fish for their protein. Fish are a good source of omega-3 fatty acids and are a lean protein source, both of which are beneficial to good health. Health studies that have observed an association suggest that the exposure to MeHg might offset the beneficial effects of fish consumption (USEPA 2005a). For the protection of children in America and around the globe, aqueous phase Hg reduction is needed in order to reduce the risks of eating Hg contaminated fish.

There are numerous other contaminant problems associated with both raw coal and its waste byproducts. Far less attention has been placed on selenium. Hg has been shown to magnify toxicity of other trace elements. Like Hg, Selenium (Se) is both highly toxic and naturally occurring trace element that can be released in the waste materials from certain mining, agricultural, petrochemical, and industrial manufacturing operations. The EPA reported that over the past decade (1998-2006) the EPA has documented 8.7 million lbs total on- and off-site disposal or other releases of selenium. One of the primary human activities responsible for mobilizing selenium in the environment is the procurement, processing, and combustion of coal for electric power production. While major advances have been made in reducing the particulate air pollution from power plants, the same technology that improved air quality has exacerbated threats to aquatic life by producing increased volumes of seleniferous fly ash (CATF 2000). Once in the aquatic environment, Se concentrations can rapidly attain levels that are toxic to fish and wildlife because of

bioaccumulation in food chains and resultant dietary exposure (Lemly 2004). This rapid bioaccumulation causes the response curve for selenium poisoning to be very steep; for example, a transition from no effect to complete reproductive failure in fish can occur within a range of only a few mg/L, or parts per million, ppm, aqueous phase Se. However Se is a micronutrient that is essential to humans and all living creatures.

Recent findings by the US Geological Survey indicate that exposure to Hg and Se resulted in antagonistic and synergistic effects on the mallard ducks. Ten ppm of Hg in the diet killed adult male ducks, but when 10 ppm selenium was also in the diet, the ducks did not die - a classic case of antagonism. The synergism between Hg and Se was reported when eggs laid by female mallards that had eaten a combination of 10 ppm of Hg plus 10 ppm of Se experienced greater mortality and deformities of embryos than eggs of females fed only Hg or Se (USGS 1999b).

The adverse health effects of Hg are fairly well documented but, for selenium we only know that when combined with Hg, it disrupts bird and fish reproduction (Grandjean 1992, Lemly 2002). We only hope that human reproduction is not so affected. Providing key information that has not been well studied regarding the impact of mercury–selenium toxicity affects is an opportunity to develop strategies and solutions to prevent further damage caused by Hg pollution.

## SUMMARY

With the Obama administration on the world stage, the Nation has demonstrated commitment to international environmental issues, of which Hg contamination has been fore front and center. Our Nation's delegation strongly endorsed negotiations for a new global treaty to control Hg pollution with 140 nations around the world represented in the United National Environmental Program (UNEP) Governing Council. By the year 2013, we must make unprecedented progress in developing, implementing and disseminating new control technologies that reduce aqueous Hg concentrations to 1.3 ppt. China, India and other nations have also agreed to endorse the goal of a mandatory treaty. A cause for critical concern, however, is the absence of a call for technology innovation and analysis on the treatment of Hg contaminated wastewaters. The types of technology research financially supported is of critical importance to securing safe drinking water, food supply, and an environment in which future generations will be better prepared to lead our Nation forward in innovation. Again; the intent of this paper is to call for action with the development of sound efficient and economical methods to reduce our children's vulnerability to Hg. Any such 'American' solution would clearly benefit most of the world.

## REFERENCES

- Bakir, F., Damluji, S. F., Amin-Zaki, L., Murtadha, M., Khalidi, A., Ai-Rawi, N. Y., Tikrit, S., Dhahir, H. I., Clarkson, T. W., Smith, J. C., Doherty, R. A. Methylmercury poisoning in Iraq. *Science*. 1973, 181, 230–241.
- Bernard, S., Enayati, A., Redwood, L., Roger, H., Binstock, T. Autism: a novel form of mercury poisoning. *Medical Hypotheses*. 2001, 56, 462–471.
- Bernard, S., Enayati, A., Roger, H., Binstock, T., Redwood, L. The role of mercury in the pathogenesis of autism. *Molecular Psychiatry*. 2002, 7, S42–S43.
- Booth, S., Zeller, D. Mercury, Food Webs, and Marine Mammals: Implications of Diet and Climate Change for Human Health. *Environmental Health Perspectives*. 2005, 113 (5), 521-526.
- Budtz-Jorgensen, E., Grandjean, P., Jorgensen, P.J., Weihe, P., Keiding, N. Association between mercury concentrations in blood and hair in methylmercury-exposed subjects at different ages. *Environmental Research*. 2004, 95(3), 385-393.
- Clarkson, T.W. Mercury - major issues in environmental-health. *Environmental Health Perspectives* 1993, 100, 31–38.
- Cheuk, D.K.L., Wong, V. Attention-Deficit Hyperactivity Disorder and Blood Mercury Level: A Case-Control Study in Chinese Children. *Neuropediatrics*. 2006, 37, 234 – 240.
- Clean Air Task Force (CATF) Laid to Waste—The Dirty Secret of Combustion Waste from America’s Power Plants. Clean Air Task Force, Boston, MA, 2000.
- Crump, K. S., Kjellstrom, T., Shipp, A. M., Silvers, A., Stewart, A. Influence of prenatal mercury exposure upon scholastic and psychological test performance: Benchmark analysis of a New Zealand cohort. *Risk Analysis*. 1998, 18 (6), 701-713.
- DOL. US.. Department of labor. *Futurework: trends and challenges for work in the 21st century*. 1999.
- Euro Chlor. (1998) *Environment, Mercury process for making chlorine*. Chlorine Online, Information Resource.
- Feeley, III, Thomas. Murphy, James, Hoffmann, Jeffrey, Renninger Scott. *A Review of DOE/NETL’s Mercury Control Technology R&D Program for Coal-Fired Power Plants*. 2003.
- Foulke, J.E., Mercury in Fish: Cause for Concern? *FDA Consumer*, September 1994, Revised May 1995. Accessed February 28, 2009 at URL <http://www.fda.gov/fdac/reprints/mercury.html>
- Gilbertson, M., Carpenter, D. O. D. An ecosystem approach to the health effects of mercury in the Great Lakes basin ecosystem. *Environmental Research* 2004, 95 (3), 240-246.
- Grandjean, P., Weihe, P., White, R. F., Debes, F., Araki, S., Yokoyama, K., Murata, K., Sorensen, N., Dahl, R., Jorgensen, P. J. Cognitive Deficit in 7-Year-Old Children with Prenatal Exposure to Methylmercury. *Neurotoxicology and Teratology* 1997, 19 (6), 417-428.
- Grandjean P, Budtz-Jorgensen E, White RF, Jorgensen P J, Weihe P, Oebes F, et al. Methylmercury exposure biomarkers as indicators of neurotoxicity in children age 7 years. *Am J Epidemiol*, 1999, 150:301-305.
- Grandjean, P., Weihe, P., Jorgensen, P. J., Clarkson, T., Cernichiari, E., Videro, T. Impact of maternal seafood diet on fetal exposure to mercury, selenium, and lead. *Arch. Environ. Health* 1992, 47, 185–195.
- Hylander, L.D., Goodsite, M.E. Environmental costs of mercury pollution. *Science of the Total Env*. 2006. 368, 352-370.
- Horvat, M., Nolde, N., Fajon, V., Jereb, V., Logar, M., Lojen, S., Jacimovic, R., Falnoga, I. et al. Total mercury methylmercury and selenium in mercury polluted areas in the province Guizhou, China. *Sci. Total Environ*. 2003, 304, 231–256.
- Jorgensen EB, Debes F, Weihe P, Grandjean P. Adverse Mercury Effects in 7 Year-Old Children as Expressed as Loss in "IQ." Odense: University of Southern Denmark, 2004. Available: <http://www.chef-project.dk/PDF/iq04louis5.pdf> [accessed 15 May 2004].
- Kjellstrom T, Kennedy P, Wallis S, Mantell C. *Physical and Mental Development of Children with Prenatal Exposure to Mercury from Fish. Stage I: Preliminary Tests at Age 4*. 1986, Report 3080. Solna, Sweden: National Swedish Environmental Protection Board.
- Kjellstrom T, Kennedy P, Wallis S, Stewart A, Friberg L, Lind B, *Physical and Mental Development of Children with Prenatal Exposure to Mercury from Fish. Stage II: Interviews and Psychological Tests at Age 6*. 1989, Report 3642. Solna, Sweden: National Swedish Environmental Protection Board.
- Lemly, A.D., *Selenium Assessment in Aquatic Ecosystems: A Guide for Hazard Evaluation and Water Quality Criteria*. Springer, New York, NY. 2002.
- Lemly, A.D., Aquatic selenium pollution is a global environmental safety issue. *Ecotoxicology and Environmental Safety*. 59. 2003. 44–56.
- Murata, K., Weihe, P., Budtz-Jorgensen, E., Jorgensen, P. J., Grandjean, P. Delayed brainstem auditory evoked potential latencies in 14-year-old children exposed to methylmercury. *Journal of Pediatrics*. 2004, 144(2), 177-183.

- Mahaffey, K.R., Clickner, R.P., Bodurow, C.C. Blood organic mercury and dietary mercury intake: National Health and Examination Survey, 1999 and 2000. *Environmental Health Perspectives*. 2004, 112, 562-570.
- National Ocean and Atmospheric Agency (NOAA). Population Trends Along the Coastal United States: 1980-2008 NACWA (2002) Evaluation of the Effectiveness of Publicly Owned Treatment Works (POTW) Mercury Pollution Prevention/Minimization Programs. Accessed January 2007: <http://www.amsacleanwater.org/advocacy/mercgrant/>
- Stern AH, Smith AE. An assessment of the cord blood-maternal blood methylmercury ratio: implications for risk assessment. *Environ Health Perspect*. 2003, 111:1465-1470.
- TED Case Studies Minamata, Japan Disaster, 246, Jan 11, 1997.
- The National Research Council (NRC) Toxicological effects of methylmercury, 2000.
- U.S. EPA, Treatment Technologies for Mercury in Soil, Waste, and Water U.S. Environmental Protection Agency Office of Superfund Remediation and Technology Innovation. Available at <http://clu-in.org/542R07003>. Accessed on March 1, 2009.
- U.S. EPA. Agency Mercury Maps A Quantitative Spatial Link Between Air Deposition and Fish Tissue Peer Reviewed Final Report. 2001. EPA-823-R-01-009.
- U.S. EPA, Mercury Study Report to Congress, The Panel on Health Risks and Toxicological Effects of Methylmercury: Donna Mergler, Henry A. Anderson, Laurie Hing Man Chan, Kathryn R. Mahaffey, Michael Murray, Mineshi Sakamoto and Alan H. Stern Methylmercury Exposure and Health Effects in Humans: A Worldwide Concern. 1997. EPA-452/R-97-003.
- U.S. EPA, Mercury, elemental (CASRN 7439-97-6), Integrated Risk Information System. Accessible at: <http://www.epa.gov/ncea/iris/subst/0370.htm>. Accessed on February 28, 2009.
- U.S. EPA, Methylmercury (MeHg) (CASRN 22967-92-6), Integrated Risk Information System. Accessible at: <http://www.epa.gov/iris/subst/0073.htm#reforal>. Accessed on February 28, 2009.
- U.S. EPA, EPA's Roadmap for Mercury, EPA-747-R-06-001, July 2006.
- U.S. EPA, Analysis of Mercury-Added Products and Substitutes, July 2008.
- U.S. EPA, Background Paper for Stakeholder Panel to Address Options for Managing U.S. Non-Federal Supplies of Commodity-Grade Mercury, March 14, 2007. Accessible at <http://www.epa.gov/mercury/stocks/backgroundpaper.pdf>. Accessed on February 28, 2009.
- U.S. EPA, Guidance for Implementing the January 2001 Methylmercury Water Quality Criterion Final United States Environmental Protection Agency. Office of Science and Technology. 2009. Available at <http://www.epa.gov/triexplorer/> Accessed on March 6, 2009.
- USGS. United States Geological Survey. Mercury Bioaccumulation in Fish in a Region Affected by Historic Gold Mining: The South. Yuba River, Deer Creek, and Bear River Watersheds, California. Authors Jason T. May, Roger L. Hothem, Charles N. Alpers, and Matthew A. Law U 1999a.
- USGS. Patuxent Wildlife Research Center. Mercury and Selenium Poisoning: when 1+1 = 2. 1999b.
- Vojdani A, Pangborn JB, Vojdani E, Cooper EL. Infections, toxic chemicals and dietary peptides binding to lymphocyte receptors and tissue enzymes are major instigators of autoimmunity in autism. *Int. Journal Immunopathol Pharmacol*. 2003, 16(3):189-199.
- WHO-IPCS. Environmental health criteria 101-Methylmercury, WHO: Geneva,WHO Environmental Health Criteria 101: Methylmercury Environmental Health Criteria 101: Methylmercury.1990.