MICHIGAN'S

MERCURY ELECTRIC UTILITY WORKGROUP

FINAL REPORT

ON MERCURY EMISSIONS FROM COAL-FIRED POWER PLANTS

JUNE 20, 2005

Acknowledgments

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Executive Summary

The Michigan Mercury Electric Utility Workgroup (Workgroup) was formed in response to a request by Governor Jennifer Granholm to provide a report to the Director of the Michigan Department of Environmental Quality (MDEQ). The Workgroup was charged with evaluating opportunities and developing recommendations for an emission reduction strategy for coal-fired electric generating units (EGUs) that achieve timely and measurable reductions in mercury emissions. In order to determine the feasibility and estimated cost of reducing mercury emissions and develop reduction recommendations, a number of technical and policy issues were examined. The Workgroup developed this report as a combined and coordinated effort, and it reflects information collected from numerous sources and participants.

Mercury is a persistent, bioaccumulative neurotoxin. Studies indicate an increased risk to a developing fetus upon exposure to methylmercury via maternal fish consumption. Mercury released from anthropogenic (man-made) and natural sources can be deposited in the environment, a portion of which is converted to methylmercury in aquatic systems before finding its way into fish. Coal-fired EGUs are currently the largest single source of anthropogenic mercury emissions in Michigan and the United States (U.S.).

Mercury emissions for Michigan EGUs were estimated by the U.S. Environmental Protection Agency's (EPA's) 1999 Information Collection Request (ICR) and using the Toxics Release Inventory (TRI) data for the years 2001 and 2002. It is estimated for this time period that Michigan EGUs emitted collectively 2,500 to 3,100 pounds per year (lbs/yr) of mercury. Due to the nature of mercury emissions, mercury from Michigan EGUs can be deposited locally, regionally, and globally. Efforts to measure and model mercury deposition are on-going.

Options for controlling mercury from EGUs include capitalizing on co-benefits using equipment that is designed to control other pollutants (e.g., selective catalytic reduction [SCR] for nitrogen oxides [NO_X] and dry and wet sulfur dioxide [SO_2] scrubbers, fabric filters for particulate) and mercury-specific controls such as activated carbon injection (ACI). Development of controls and optimization of existing controls for mercury removal is an on-going process.

On March 15, 2005, EPA signed the Clean Air Mercury Rule (CAMR). CAMR was promulgated under Section 111 of the Clean Air Act (CAA) and set New Source Performance Standards (NSPS) for new sources and established a federal cap-and-trade program for all existing and future coal-fired EGUs. Several states have developed their own mercury rules. All states, including those that have developed their own rules, at a minimum must comply with the caps imposed by CAMR and the NSPS for new sources, but it is their option to participate in the national cap-and-trade program.

The cost of controls and how to finance that cost in Michigan's competitive electricity generation market is a key concern. The estimated costs for EGUs to install controls is dependent on site specific factors, EGU size, fuel type, and the level of targeted mercury reduction. Financing controls and a method of cost recovery is an issue to be resolved.

The final recommendations included in this report identify reduction strategies, taking into consideration the existing power plant fleet; current and developing mercury emission control technologies; current and future regulatory requirements; the cost to the consumer and to the industry; and considers environmental, economic, and public health impacts.

1. Introduction

Governor Jennifer Granholm's 2002 platform supported the phase-out and elimination of mercury (Hg) emissions from coal-fired power plants, along with tougher controls on SO_2, NO_X, and carbon dioxide (CO_2), and implementing

> "*an approach, such as a cap and trading policy, that sets firm limits and timetables, while giving utilities the ability to incorporate pollution control into long-term investments and to capitalize on market incentives to reduce emissions cost-effectively*."

To act on this commitment, the MDEQ established the Michigan Mercury Electric Utility Workgroup consisting of MDEQ and Michigan Public Service Commission (MPSC) staff, representatives from utilities potentially impacted by the workgroup recommendations, and representatives from environmental, scientific, and public policy groups. The full workgroup charge is as follows:

> "*The workgroup shall evaluate opportunities for significant emission reductions and phase-out of mercury emissions from coal-fired power plants in Michigan. This workgroup shall also develop recommendations for an emission reduction strategy in Michigan that achieves timely and measurable reductions. The workgroup will strive for recommendations based on workgroup consensus. The recommendations will be submitted to the MDEQ Director."*[1]

The final recommendations included in this report identify reduction strategies for Michigan, taking into consideration the existing power plant fleet, current and developing mercury emission control technologies, current and future regulatory requirements, the cost to the consumer and to the industry, and considers environmental, economic, and public health impacts.

NOTE: **Appendix C** lists all the acronyms and their definitions utilized within this report.

[1] From an MDEQ document distributed at the first Michigan Mercury Electric Utility Workgroup meeting on August 5, 2003.

2. Background on Mercury

This section presents a broad background on mercury to promote understanding of the need for mercury reductions to protect public health and the environment. The background section covers the following: 1) a description of mercury, its sources including Michigan's statewide mercury inventory, and current and historic uses of mercury; 2) a description of mercury impacts; 3) an overview of historic mercury regulation in Michigan as well as ongoing monitoring, regulatory, and legislative; and 4) reduction activities.

2.1 Mercury - What is it?

Mercury (symbol Hg) is a heavy, silvery-white metal sometimes called quicksilver. It is the only metal that is liquid at ordinary temperatures and is naturally found in rocks and other environmental media. While it has been historically released to the environment by natural events like volcanic eruptions and weathering of minerals, human and industrial activities, including those that use mercury directly or burn mercury bearing fossil fuels like coal, have increased the amount of mercury in the environment.

At room temperature or above, mercury turns into a colorless, odorless vapor which can be toxic if inhaled. Once this element enters aquatic ecosystems, it can be methylated by microorganisms into a toxic organic form, methylmercury. Methylmercury is highly bioaccumulative and persistent in fish and animal tissue and is the mercury compound of greatest concern because of its greater potential for exposure to the general population.

Mercury can combine with other elements, such as chlorine, sulfur, or oxygen, to form inorganic mercury compounds or "salts," which are usually white powders or crystals. Mercury can also combine with carbon to make organic mercury compounds. In addition, mercury can adsorb to solids and be present in particulate matter (PM).

2.2 Sources of Mercury

Mercury is released into the environment from a variety of sources, both natural and anthropogenic (man-made). Natural sources, primarily in the form of elemental mercury, include forest fires, degassing from soils, and evaporation from the ocean.

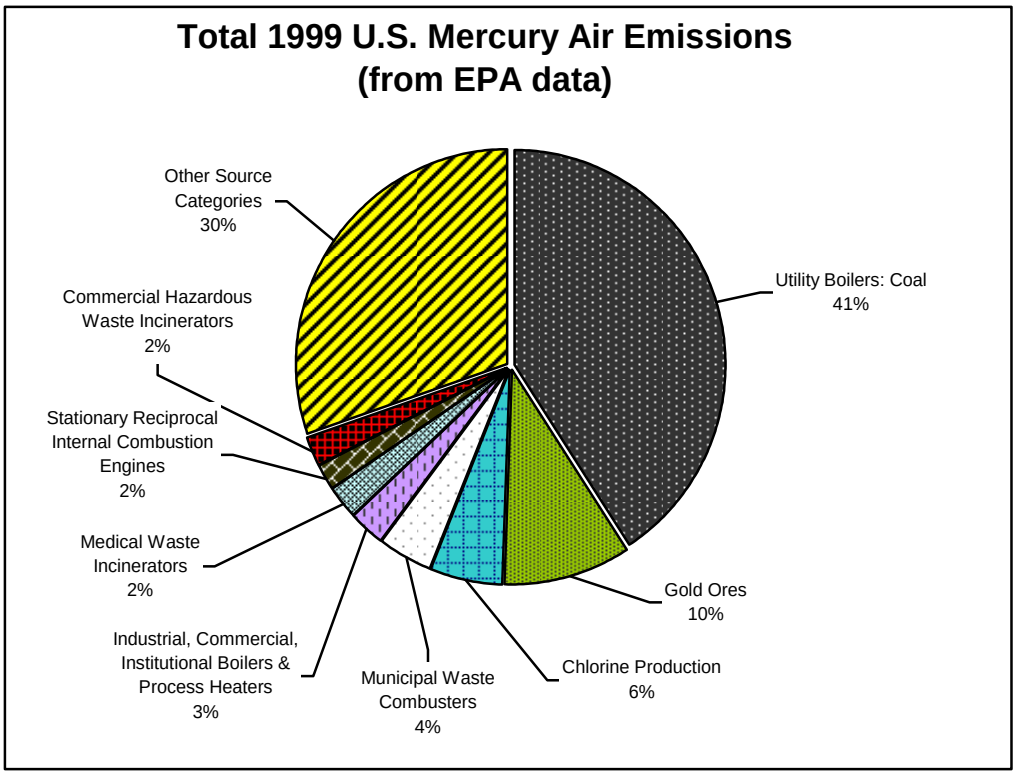
Anthropogenic emissions of mercury include the burning of fossil fuels such as coal and other extracted, treated, or recycled mineral materials. Mercury can also enter lakes and rivers when there is a direct discharge of mercury-laden industrial or municipal waste into the water. Mercury has historically been used in many products and industrial processes, although it has been phased out considerably (see **Section 2.3** for uses).

While it is difficult to determine the proportion of anthropogenic and natural mercury sources contributing to current environmental levels, research on sediment cores and

modeling have indicated that human activity has increased mercury levels in the environment by three- to five-fold or more. Current studies indicate a combination of current anthropogenic and previously released anthropogenic emissions account for approximately two-thirds of the total global mercury emissions.[2]

The EPA states in their 1997 Mercury Study Report to Congress that for the 1994 to 1995 study period, the total global mercury emissions from both natural and anthropogenic sources was about 5,500 tons, with approximately two-thirds of this total attributable to anthropogenic sources. Based on 1999 EPA emissions data, anthropogenic sources in the U.S. contributes 118 tons or about 3% to the global pool. **Figure 1** is derived from EPA data and shows the sources of anthropogenic mercury in the U.S.

Figure 1: Anthropogenic Mercury Sources in the U.S.



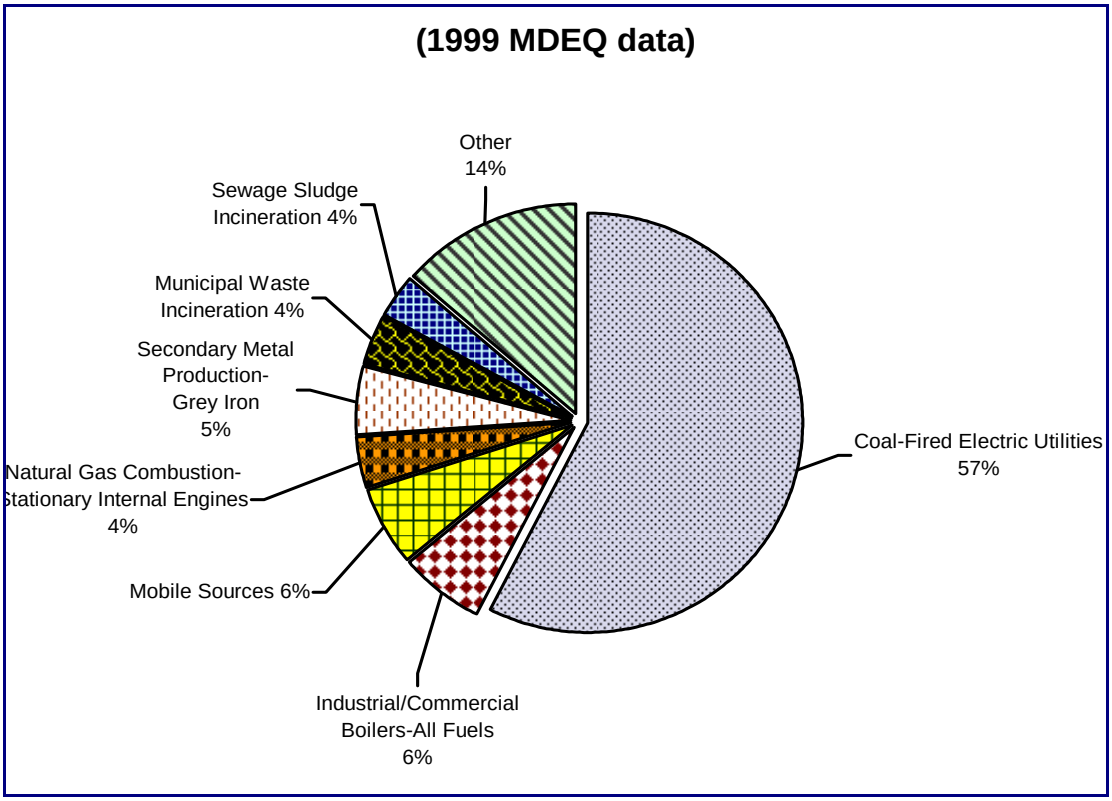
Statewide Mercury Inventory

Based on the 1999 emission inventory data (listed in the following **Table 1**)[3], the largest unregulated source of anthropogenic mercury emissions in Michigan is coal-fired electric utilities, emitting approximately 57% of all Michigan emissions (see **Figure 2**). The next largest source categories, in descending order, include the following:

[2] See reviews in Pirrone et al., 1996; Jackson, 1997; Fitzgerald et al., 1998; Lamborg, et al., 2002.
[3] It should be noted that the **Table 1** emission inventory is the best estimate at the time of this report.

- industrial/commercial boilers - all fuels (6.3%)
- mobile sources (5.9%)
- secondary metal production - grey iron, excluding electric arc furnaces (EAFs) (5.2%)
- natural gas combustion from stationary internal combustion engines (3.9%)
- municipal waste incineration (3.8%)
- sewage sludge incineration (3.5%)
- and other sources account for the remainder.

Figure 2: Michigan Estimate of Mercury Air Emissions



While coal combustion is the largest source of anthropogenic mercury emissions nationally and in Michigan, many types of mercury use can result either in direct or indirect mercury releases to water and air. Significant mercury use reductions have already been achieved, for example between 43 to 47% mercury use reduction has been estimated for the years 1990 through 1999 (EPA, 2004c). Continued efforts to reduce the use of mercury in products and processes are ongoing, such uses that continue include mercury-containing switches in such products as thermostats, sump pumps and bilge pumps, mercury-containing relays, fluorescent lights, and chlorine production (also see **Section 2.3.2**).

Table 1: Estimate of Anthropogenic Mercury Air Emissions in Michigan and Summary of Applicable Regulations

EMISSION SOURCE	MERCURY (LBS/YR) IN 1999 OR YR NOTED (# OF FACILITIES IF KNOWN)	% OF MI TOTAL	APPLICABLE REGULATIONS
Fuel Combustion			
COAL COMBUSTION			
Electric Utilities	2591 (21)	56.7%	3/15/05, EPA issued CAMR which will cap emissions at 38 tons by 2010 and 15 tons by 2018. Emissions may be traded on the open market.
Industrial/Commercial	134 (5)	2.9%	Industrial and commercial boiler MACT promulgated 9/04. Mercury emissions limit is 3 x 10^{-6}6 lb/MMBtu for new sources and 9 x 10^{-6}6 lbs/MMBtu for existing sources. MACT will only apply to existing large units (>10 million Btu/hr) and will apply to both large and small new sources.**
Residential	6	<1%	No MACT required.
OIL COMBUSTION			
Electric Utilities	61 (16)	1.3%	3/15/05, EPA reversed 12/15/00 finding that it was appropriate and necessary to regulate hazardous air emissions from utilities using a MACT.
Residential	88	1.9%	No MACT required.
Industrial/Commercial Boilers	89 (38)	2.0%	**No mercury limits in the MACT for these units.**
Residential Boilers	3	< 1%	
WOOD COMBUSTION			
Electric Utilities	4 (4)	< 1%	No MACT required.
Industrial/Commercial	5 (16)	< 1%	**No mercury limits in the MACT for these units.**
Residential	NA		No MACT required.
NATURAL GAS COMBUSTION			
Electric Utilities	6 (14)	< 1%	No MACT required.
Industrial/Commercial boilers	59 (263)	1.3%	**No mercury limits in the MACT for these units.**
Stationary Internal Combustion Engines	179 (67)	3.9%	
Residential	91	2.0%	
PETROLEUM REFINING			
Fuel Combustion Total	**3,316**		

Table 1: Estimate of Anthropogenic Mercury Air Emissions In Michigan and Summary of Applicable Regulations

EMISSION SOURCE	MERCURY (LBS/YR) IN 1999 OR YR NOTED (# OF FACILITIES IF KNOWN)	% OF MI TOTAL	APPLICABLE REGULATIONS
Incineration			
Sewage	162 (9)	3.5%	EPA delisted sewage sludge incinerators from MACT source list 2/12/00.** NESHAP still requires mercury limits.
Hospital Waste	~6 to 10 lbs/yr on 2001 stack test; only 1 operating in 2002.	< 1%	Michigan adopted stricter standards for mercury. First year mercury limit is 3.0 µg/dscm or 85% reduction, not to exceed 200 µg/dscm; by third year dropping to 50 µg/dscm.
Municipal Waste	176 lbs/yr-1999 stack test for 3, speciation factors applied to PM emissions (1); 4 operating in 2002	3.9%	Michigan adopted federal standards which include mercury. Mercury standard requires either 85% reduction or facility must meet 80 µg/dscm emission limits.
Hazardous Waste Incineration	Emissions data NA. Only 2 out of 3 operating in 2002.		Michigan's facilities have a stricter limit for mercury than the MACT.
Incineration Totals	**348**		
Industrial Sources			
Lime Manufacturing	NA		MACT promulgated 1/04. No mercury limit, although PM controls will likely result in some reduction.
Cement Manufacturing	67 (3); only 1 operating in 2002	1.5%	MACT promulgated 6/99; amended 4/02 and 12/02. Does not currently contain limits for mercury, but EPA was court-ordered in 12/00 to add mercury limits. EPA expects to propose revisions to the MACT rule in 7/05.
Light bulb Recyclers	Emission data NA; 6 operating in 2002		
Coke Producers	Emissions data NA; only 1 operating in 1999.		
Copper Smelting(1)	0		
EAFs in primary metal production (Steel Manufacturing)	94; includes only 1 facility that self reported, no data on others	2.1%	1996 EPA removed EAFs from MACT list of source categories as no sources qualified as a major source.** Recent monitoring results indicate relatively high emissions of mercury have been found from these sources. Will be addressed under area source program.
Taconite Ore Processing	NA (2)		MACT promulgated 10/03. While the MACT does not contain emission limits for mercury, EPA agreed in 1/05 to develop regulations limiting mercury as settlement to a lawsuit filed in 12/03.
Brick Manufacturing	1 (1)	< 1%	MACT promulgated 5/03. PM as surrogate emission limit for HAP metals (including mercury in particulate form).
Natural Gas Production	2 (4)	< 1%	MACT promulgated 6/99. No mercury emission limit.
Secondary Metal Production (Grey Iron), excluding EAFs	237 (9)	5.2%	Iron and Steel Foundry MACT signed 8/03. No mercury emission limits. Work practice standards address mercury removal
EAFs in Secondary Metal Production (Grey Iron)	30 (3)	< 1%	Will be addressed under the area source program.

Table 1: Estimate of Anthropogenic Mercury Air Emissions In Michigan and Summary of Applicable Regulations

EMISSION SOURCE	MERCURY (LBS/YR) IN 1999 OR YR NOTED (# OF FACILITIES IF KNOWN)	% OF MI TOTAL	APPLICABLE REGULATIONS
Industrial Sources (Continued)			
EAFs in Secondary Metal Production (Steel Foundries)	10	< 1%	Iron and Steel Foundry MACT signed 8/03. No mercury emission limits. Work practice standards address mercury removal
Bench Scale Reagents (Research)	65	1.4%	
Thermometer Manufacturing	3	< 1%	
Industrial Source Totals	**509**		
Area Sources			
Cremation	10 (41)	< 1%	MACT covered under Section 129, 11/15/05 promulgation deadline for other solid waste incineration.
Lamp Manufacturing/Breakage	69	1.5%	
Dental Amalgam	53	1.2%	
Area Source Totals	**132**		
Mobile Sources(2)			
On Road	262	5.7%	
Non-road	6	< 1%	
Mobile Source Totals	**268**		
TOTAL MERCURY AIR EMISSIONS	**4,573**	**100%**	

* MACT Floor: The average emission limit achieved by the best performing 12% of the existing sources.

** Major source category: Any source that emits 10 tons per year or more of any HAP, or 25 tons per year or more of any combination of HAPs.

(1) Source currently not operating. This facility indefinitely ceased operations of its smelter in February 1995.

(2) While mobile source estimates represent the best available in 1999, studies are currently being conducted by University of Michigan Air Quality Laboratory researchers to estimate mobile source emissions more accurately.

Acronym definitions: HAPs (hazardous air pollutants); NA (not available); µg/dscm (micrograms per dry standard cubic meter); PM (particulate matter); lbs/yr (pounds per year); > (greater than); MACT (maximum achievable control technology); Btu/hr (British thermal units per hour)

Note: The 1999 point source mercury data was developed by the Air Quality Division (AQD), and was submitted to the EPA to form part of the EPA's 1999 National Emissions Inventory (NEI). The 1999 area source data was developed by both the AQD and the EPA. The EPA developed emissions estimates for area sources which the AQD did not have data for (such as dental amalgams). The area source data was then added to the 1999 NEI. The 1999 on-road and non-road mobile data was developed by the EPA, and incorporated into the 1999 NEI.

2.3 Historic and Current Uses of Mercury

2.3.1 Historic Uses

The toxicity and use of mercury has been known for centuries. The Romans sentenced their prisoners to work in cinnabar ore mines during the early Roman Empire. The prisoners consequently died by the thousands from exposure to mercury vapors (D'Itri P. and D'Itri F., 1977). In the 1800s, mercury was also used in the manufacturing of felt hats, in which the colloquial term "mad as a hatter" was coined to describe the physical symptoms of inorganic mercury poisoning in workers from this mercury use (Michigan Mercury Pollution Prevention [M2P2] Task Force, 1996). Some historic examples of mercury usage include:

- water-based latex paints manufactured before 1991 (to prevent mildew after paint has been applied and as a preservative for paint in storage);
- tilt and pressure switches in such products as "silent" light wall switches, chest freezer lights, automobile hood and trunk lights, children's shoe lights and steam iron safety shut-off;
- U.S. manufactured fireworks and explosives;
- U.S. pesticide registrations canceled by 1995 (old stocks may still exist).

2.3.2 Current Uses

Mercury has been used in thousands of industrial, agricultural, medical, and household applications due to its unique properties.

Mercury is a mined commodity and is also produced as a by-product of gold and bauxite mining. Mercury is a rather poor conductor of heat compared with other metals but, it is a fair conductor of electricity, is the only heavy metal that exists as a liquid at room temperature, and easily alloys with many metals such as gold, silver, and tin. Because mercury has uniform volume expansion with increasing temperature over the entire temperature range of its liquid state, uses of mercury and mercury compounds are considerable. Some examples of current mercury usage include:

- thermometers and sphygmomanometers
- thermostats, barometers, and manometers
- relays and various switches (float switches in septic tanks, sump pumps, and bilge pumps)
- fluorescent and high intensity discharge lamps
- dental amalgams
- preservative in vaccines

Despite its desirable properties for use in many products and processes, mercury's toxicity and persistence in the environment has prompted an approximately ten-fold usage reduction in the U.S. since 1970. (See **Section 2.7.5** on current mercury product legislation in Michigan.)

Mercury is also used culturally. According to the 2002 Task Force on Ritualistic Uses of Mercury Report there are many urban areas in the U.S. where religious supply stores known as botanicas sell a variety of herbal remedies and religious items containing mercury.

Appendix D contains a "Mercury Use Tree"[4] that provides a very detailed listing of mercury sources and product usage. Information on mercury-containing products is available on the MDEQ's website at: http://www.michigan.gov/deqmercuryp2. Additional information is also available in the Mercury Products Study (Gilkeson, 2002).

2.4 Fate of Mercury in the Environment

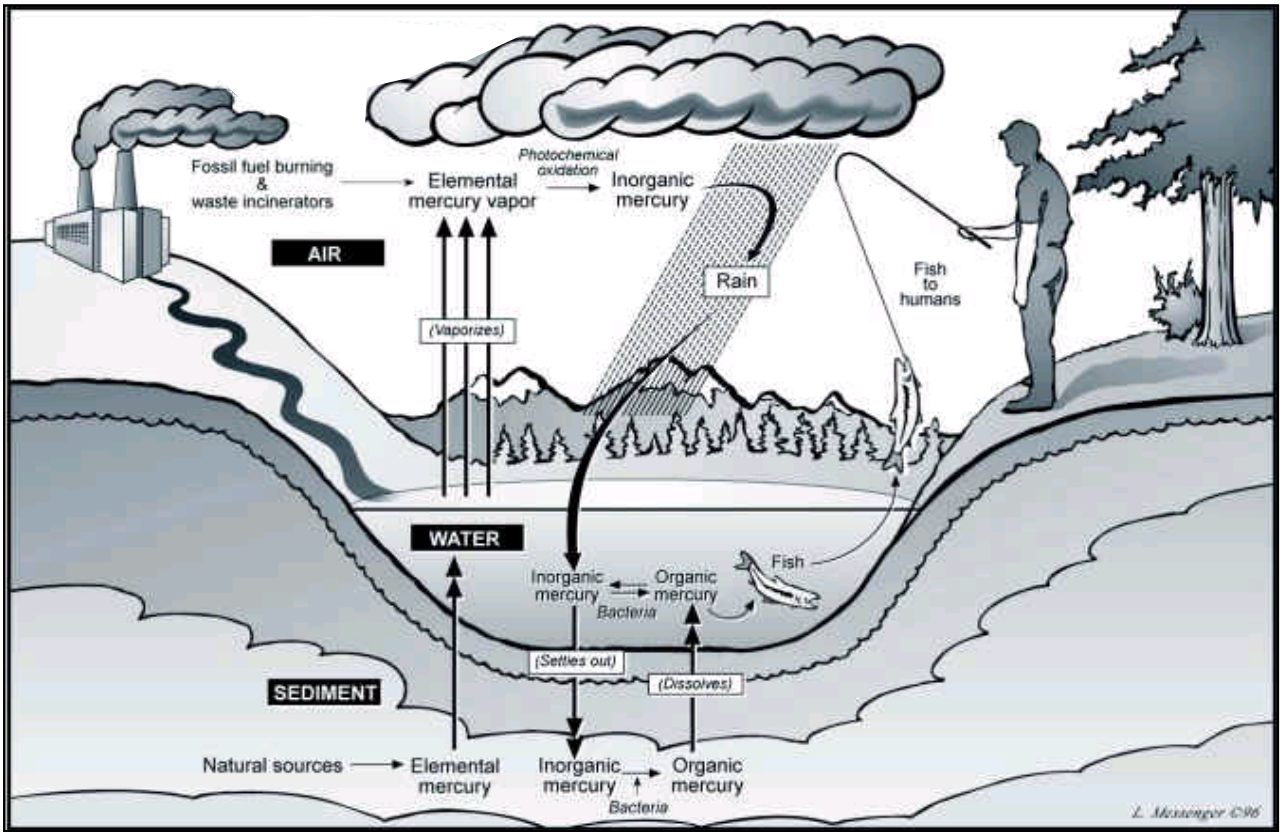
The mercury cycle is quite complex. Mercury is released into the atmosphere from anthropogenic emissions as either a gas or attached to particles and is transferred to the earth's surface via wet or dry deposition or gas transfer. Mercury is emitted to the atmosphere in three basic forms: elemental mercury: (Hg^0); reactive gaseous mercury or RGM (RGM is also known as Hg(II) and oxidized gaseous mercury); and particulate mercury [Hg(p)]. (NOTE: These three abbreviations for mercury [Hg^0, RGM, and Hg(p)] will be utilized throughout the remainder of this document.) Natural emissions are mainly in Hg^0 form. Hg^0 may reside in the atmosphere for up to one year, allowing global circulation systems to transport Hg^0 releases from the source to anywhere on earth before transformation and deposition take place.[5] **Figure 3** shows the mercury cycle.

Mercury is continuously mobilized, deposited, and re-mobilized in the environment. The only means to permanently capture mercury from the biosphere include deep-sea sediments, well-controlled landfills or amalgamation processes. For example, to isolate mercury from the biosphere, Sweden has recommended that mercury waste be stabilized and stored in a permanent deep bedrock repository (Swedish EPA, 2001).

The majority of mercury in surface soil is in the form of oxidized mercury compounds, such as mercuric sulfide. However, a small fraction is methylmercury and Hg^0. Mercury complexes deposited in soils can be transformed back into gaseous mercury by light and humic substances and re-enter the atmosphere. Mercury can also be taken up by plants, both via root uptake in soils and through absorption of elemental or inorganic mercury through the air.

[4] The "Mercury Use Tree" was created April 4, 1998 by the Superior Work Group.
[5] Additional information is available at http://www1.umn.edu/eoh/hazards/hazardssite/mercury/mercfate.html.

Figure 3: Mercury Cycle



As part of a whole-ecosystem mercury cycling study, mercury was measured in the foliage of deciduous trees in Pellston, Michigan over the course of the growing season (Rea et al., 2002). This study found that total foliar mercury accumulation was substantially less than vapor phase Hg^0 deposition as estimated by a different study (Lindberg et al., 1992). It was determined that Hg(p) and RGM dry deposition were rapidly washed off foliar surfaces, and therefore foliar accumulation of mercury most likely represents vapor phase Hg^0 assimilation (Rea et al., 2001). Recently, independently performed controlled pot and chamber studies with aspen trees determined that all foliar accumulation of mercury was due to vapor uptake, regardless of soil mercury concentration (Ericksen et al,. 2003), supporting the Rea 2001 study conclusions. In addition, monitoring of mercury has been done through the use of mosses and lichens, including near industrial facilities (Lodenius, 1994).[6]

In addition to direct deposition, mercury can also reach water from soil run-off, although the amount partitioning to run-off is expected to be small since mercury binds to soil. Mercury in run-off is probably bound to suspended sediments. Once in water, mercury can either enter and biomagnify in the food chain, settle into sediment, or volatilize back into the atmosphere (see previous **Figure 3**). Entrance into the food chain begins with bacteria in water which can take mercury in its inorganic form and metabolize it to methylmercury. All inorganic forms of mercury that are not bound to sediment are potentially available for methylation by microorganisms. A number of factors effect the

[6] Though plants uptake mercury from the environment, there is no clear evidence that mercury in plants is a significant source of human exposure.

potential for methylation of mercury in aquatic systems, but key variables are the potential of hydrogen ([pH] – a measurement of a solution), the oxidizing state (i.e., redox conditions), the levels of sulfur, and the presence of sulfate-reducing bacteria (Ullrich et al., 2001).

Methylmercury-containing bacteria may be consumed by the next level in the food chain, or the bacteria may excrete methylmercury into the water where it can adsorb to plankton and be consumed by the next level in the food chain and so on. Even small environmental concentrations of mercury in water can readily accumulate to potentially harmful concentrations in fish and fish-eating animals, including humans.

The concentration of methylmercury in predatory fish such as largemouth bass or walleye can be 1 to 10 million times higher than the surrounding surface water as a result of biomagnification (Ullrich et al., 2001). In general, fish higher in the food chain such as walleye, pike, shark and swordfish have higher mercury concentrations than fish lower on the food chain like perch. The ratios of methylmercury in fish can vary depending on fish age, size and species as well as watershed characteristics. Because of biomagnification, both state and federal fish consumption advisories have been issued (discussed further in **Section 2.5.3**)

2.5 Mercury Impacts on Environment, Health, Culture, and Recreation

2.5.1 Forms of Mercury, Exposure Pathways, and Public Health Concerns

The chemical and physical properties of mercury, as well as its toxicity, vary by individual compound. Hg^0 is a silver, odorless, heavy liquid with high surface tension. In its liquid form, Hg^0 is not particularly toxic when ingested since it is poorly absorbed by the gastrointestinal (GI) tract. However, at room temperature, Hg^0 can produce toxic vapors which can be inhaled and damage the heart, brain, kidneys and lungs (Hazardous Substance Data Base [HSDB] 1994[7]; and Agency for Toxic Substance and Disease Registry [ATSDR], 1999).

Alkyl mercury compounds used or encountered in industry include volatile liquids such as dimethyl and diethyl mercury (Gilkeson, 2002) which are highly neurotoxic from both acute and chronic exposure (HSDB, 1994). Mercury compounds also include many complex salts, which are usually solids. Inorganic mercury salts are corrosive and have toxic effects on the kidney. Methylmercuric chloride can trigger autoimmune toxicity and has been classified as a possible human carcinogen by the International Agency for Research on Cancer (IARC, 1993[8]).

Although mercury is toxic in many of its forms, it is the ingestion of methylmercury via fish consumption that poses the greatest risk of exposure to the general public

[7] HSDB online access 12/04.
[8] IARC last updated 8/22/1997.

and, therefore, has the greatest potential for adverse environmental and human health effects.

The first report of widespread environmental methylmercury poisoning in recent history was in 1956 in Minamata, Japan. Approximately 2,200 people were officially recognized as having Minamata Disease as a result of being exposed to extreme levels of methylmercury. Approximately 1,000 people have died and up to 12,000 people are suspected of suffering from Minamata Disease with chronic and mild symptoms (Harada, 1994 and 1995).

Then in 1971, an unknown number of people in Iraq were exposed to methylmercury-treated seed grain that was used in home-baked bread. Both poisoning episodes resulted in severe central nervous system (CNS) toxicity in adults and infants born to exposed mothers. At least 459 deaths and 6,530 hospital admissions occurred due to methylmercury ingestion. Reported CNS effects included cerebral palsy, mental retardation, weakness, paresthesia (numbness), seizures, tremors, and sensory, auditory, and visual disturbances (HSDB, 1994; and EPA, 2001c). These epidemics demonstrated that neurotoxicity is the health effect of greatest concern and that the developing fetus is the most susceptible subgroup for methylmercury exposure and neurotoxicity.

In contrast to these acute poisoning episodes, neurotoxic effects from relatively low-level exposure to methylmercury in the diet are more subtle, but nonetheless significant. Reported effects include deficits in memory, language, learning, and intelligence. Dietary methylmercury is almost completely absorbed into the blood and distributed to all tissues including the brain. It also readily passes through the placenta to the fetus and fetal brain (EPA, 1997c; Mahaffey, 2000; Castoldi et al., 2001; Mahaffey et al., 2004b).

There have been exceptions where higher mercury exposures in fish-consuming populations have occurred. Examples include the consumption of both marine fish and Great Lake fish (Knobeloch et al., 1995; Hightower and Moore, 2003; Gerstenberger et al.,1997; and Peterson et al., 1994).[9]

The relationship between methylmercury exposure and neurodevelopment has received considerable attention in the scientific literature. For the sake of brevity in this report, the focus was on the largest and most recent epidemiological studies that were the basis for EPA's RfD. EPA's 2001 updated RfD assessment for methylmercury reads:

> "*The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) over a lifetime (70 years) that is likely to be without an appreciable risk of deleterious effects" (Integrated Risk Information System* [IRIS], 2001).

[9] Additional information also found in the Archives of Environmental Health, 49(11):53-58 and Humphrey and Budd, 1996 as cited in EPA Mercury Study Report to Congress, V.8 pp6-14 – 6-16.

EPA based their RfD on the Seychelles and Faroes Islands studies, two long-term, population-based studies of predominantly fish-eating populations examining the effects of fetal exposure to methylmercury and neurodevelopment in children. The initial data published from these studies has given conflicting results.

The Seychelles Islands study found no association between adverse effects (neurodeficits) and prenatal or postnatal exposure to methylmercury from consumption of ocean fish. In addition they reported an improvement in some neurological scores with increasing mercury exposure. They attributed this puzzling finding to the nutritional benefits of eating a fish-rich diet (Myers et al., 1995 and 2003). The evaluation of this cohort was completed in 1999 when the cohort was approximately 107 months old.

The Faroes Islands study did find an association between fish consumption and neurodeficits. This population is exposed to methylmercury through both pilot whale meat and ocean fish. It has been argued that polychlorinated biphenyls (PCB) contamination could be a confounding factor in this study (Grandjean et al., 1998). However, additional analyses indicate that adverse effects of methylmercury and PCBs are independent of one another (Budtz-Jorgensen et al, 1999). Follow-up research on the cohort at 14 years of age indicates methylmercury-associated decreases in measures of physiological tests (related to hearing and cardiovascular health) were observed (Murata et al., 2004; Grandjean et al., 2004). The 2001 EPA RfD justification noted that an additional, smaller epidemiological study (the New Zealand study) also found methylmercury-related developmental neurotoxicity, and provides supporting evidence for the results of the Faroes Islands study.

In addition to studies focusing on neurotoxic effects from pre-natal and post-natal exposure, other studies are focusing on the contribution of methylmercury in the diet to cardiovascular disease (Guallar et al., 2002; Salonen et al., 1995 and 2000) and decreased neurocognitive function in adults (Yokoo et al., 2003). Adverse effects in adults have received less attention than adverse effects in children since children are known to be more susceptible to exposures, particularly in utero. In addition, the relevance and magnitude of cardiovascular effects in adults is a topic of considerable debate. Research in this area is ongoing. Other studies focus on the potential interaction of PCBs and mercury and their combined effect on neurodevelopment (Stewart, 2003; Yang, 1999).

Rather than choose a single measure as the critical endpoint for the RfD, EPA based its RfD on several measures of effect from the integrative analysis of the Faroes, Seychelles, and New Zealand studies. The derived value of 0.1 microgram/kilogram per day (µg/kg/day) is based on the lower bound of a 95% confidence interval on the dose which produces a 5% effect level (in addition to a background level of 5%). The RfD includes an uncertainty factor of 10 to account for the variability in the maternal to fetal dose ratio and the uncertainty of the individual sensitivity to the delivered dose. The RfD is believed to be a dose that is protective of the population, including sensitive subgroups, but is not a fine line

separating effect levels from no-effect levels. The uncertainty factor of 10 covers a range of doses at which the 5% effect will occur.

The Centers for Disease Control (CDC) estimates that approximately 6% of women of childbearing age have mercury blood levels at or exceeding EPA's RfD of 0.1 µg/kg/day (Morbidity and Mortality Weekly Report [MMWR], 2004). An earlier assessment by EPA indicated that approximately 1% of women have methylmercury exposures three to four times the RfD, based on month-long projections of fish/shellfish consumption. Children in the age group of 3 to 6 have higher intakes of methylmercury than do adults relative to body weight. Approximately 25% of children exceed the RfD, and 5% of children have methylmercury exposures from fish/shellfish two to three times the RfD (i.e., 0.29 µg/kg body weight/day) (EPA, 1997f[10]). A New Jersey exposure assessment estimates that 20% of women of reproductive age exceed the RfD, suggesting that coastal populations may be more at risk than the national average suggests (Stern et al., 1996; cited in Stein et al., 2002).

It has been estimated that over 300,000 infants born annually in the U.S. are exposed to levels of methylmercury above the EPA RfD (based on 7.8% of adult women 16 to 49 years of age whose total blood mercury levels are at or above 5.8 micrograms per liter (µg/L), assuming a 1:1 cord blood to maternal blood ratio (Mahaffey, 2004b). This estimate may be adjusted substantially higher if based on an adjusted exposure estimation method. If the cord blood to maternal blood ratio is assumed to be 1.7:1 (based on the reported range of variability between 0.8 to 4.36 µg/L), then fetal exposures above the RfD are associated with maternal blood levels of total mercury at or above 3.5 ug/L (Mahaffey, 2004a). This would increase the estimate of infants exposed above the RfD upwards of 600,000 (based on 15.7% of adult women age 16 to 49 with blood levels at or greater than 3.5 µg/L).[11] It must be stressed that the RfD is not a "bright line" delineating safe and harmful exposures and therefore these estimates represent central tendencies rather than point estimates. A National Academy of Sciences (NAS) report came up with a different estimate of infants "at risk" (above the RfD) based on fish consumption rates rather than on blood levels of mercury. NAS evaluated a subgroup of women constituting the highest 5% of fish consumers (100 grams or 0.22 pounds of fish per day). They estimated that for this high-exposure subgroup, approximately 60,000 infants are born annually in the U.S. exposed in utero to methylmercury at levels which place them at risk for neurodevelopmental disabilities (National Research Council, 2000).

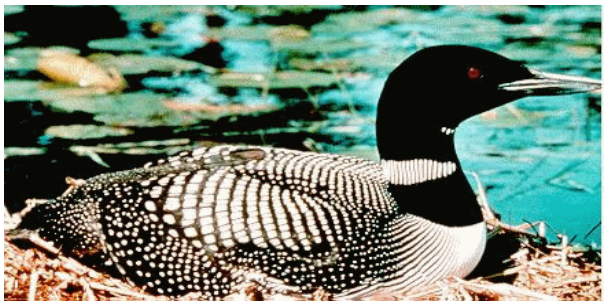
[10] See the Executive Summary of the Mercury Report to Congress.

[11] In comments submitted to EPA by EPRI on the "Proposed Emissions Standards of Performance for Electric Steam Generating Units: Mercury Emissions," EPRI stated that "The estimate that more than 600,000 U.S. children have an exposure to methylmercury at or above the EPA RfD of 0.1 ug/kg/day is not supportable. It is based on the 1.7:1 ratio of cord blood to maternal blood mercury that has already been accounted for by EPA in the derivation of the RfD uncertainty factor." (EPRI letter to EPA, June 16, 2004).

2.5.2 Environmental Impacts

Methylmercury accumulation in the food chain can affect both people and wildlife that are exposed to methylmercury by eating mercury-contaminated fish. While extreme mercury exposure can be deadly, lower level chronic exposures through fish consumption can still cause harm, in particular on the nervous and reproductive systems. Existing EPA water quality criteria indicates that wildlife may be more sensitive than humans to methylmercury exposure (EPA, 1995).

A number of factors can influence the accumulation of methylmercury in the food web, including total mercury loadings to the system, net methylation rates, water chemistry (e.g., levels of sulfur, pH, organic matter), and structure of the food web. Piscivorous (fish-eating) birds and mammals are more highly exposed to mercury than any other known component of aquatic ecosystems. Adverse effects of mercury on fish, birds, and mammals may include death, reduced reproductive success, impaired growth and development, and behavioral abnormalities (Wolfe et al., 1998). Predatory animals primarily associated with aquatic food chains accumulate more mercury than those associated with terrestrial food chains. Thus, piscivores and other carnivores that prey on piscivores generally have the highest exposure to mercury. In a study of furbearing mammals in Wisconsin, the species with the highest tissue levels of mercury were otter and mink, which are top mammalian predators on aquatic food chains (Sheffy and St. Amant, 1982). A study of a small Upper Peninsula lake in Michigan found that mercury levels in smallmouth bass were above a hazard index for mink, and were within a factor of two of the hazard index for bald eagles (Henry et al., 1998). Top avian predators of aquatic-based food chains include raptors, such as the osprey and bald eagle.



Other fish-eating birds at risk include common loons. Because the loon is a long-lived, upper-level trophic predator and an obligate piscivore that spends its breeding season on freshwater lakes, it is susceptible to the bioaccumulation of methylmercury. A recent study involved sampling from eight states in North America with the most heavily sampled sites being in Maine and New Hampshire. The results reported that up to 30% of the loon eggs (number of samples = 24) sampled at several Michigan sites contained mercury at levels presenting at least “moderate risk” to the development of the chicks (Evers et al., 2003).[12] Smaller birds feeding at lower levels in aquatic food chains also may be exposed to substantial amounts of mercury due to their high food consumption rate per body weight, relative to larger birds (Rimmer et al., 2005).[13]

[12] Egg-mercury concentrations ranged from 0.07 to 4.42 micrograms per gram (µg/g) wet weight (ww) or 0.19 to 19.40 µg/g dry weight (dw). Moderate risk (lowest-observed-adverse-effect level [LOAEL]) was defined as 0.60 to 1.30 µg/g (ww) or 2.82 to 6.10 µg/g (dw). The Michigan range for eggs collected between 1997 and 2001 was reported as 0.18 to-1.45 (ww) with a mean of 0.54 +/- 0.30 µg/g.

[13] For additional data on wildlife exposure and effects from methylmercury exposure see Wolfe et al., 1998; Chan et al., 2003; and Evers et al., 2005.

Additionally, the Wisconsin Department of Natural Resources (WDNR), in partnership with other groups, is evaluating the risks that environmental mercury poses to loons in northern Wisconsin. As part of their evaluation (Kenow et al. 2003), collected loon eggs from lakes in northern Wisconsin and then exposed the hatched chicks for 105 days to fish dosed with methylmercury. The mass of the chicks at hatch did not differ significantly among lake sources, although chicks from low pH lakes tended to be about 3.5% smaller than chicks from neutral pH lakes. No overt signs of mercury toxicosis were found in the study. The study also did not find any effects on chick survival, growth, or food intake at dietary mercury levels expected in prey of loons in North America. According to (Kenow and Meyer 2005), a follow-up study found that the immune system and spinal cord myelineation of chicks were affected at a dietary concentration of 0.4 mg mercury/kg food (wet weight). Studies have shown that loon chicks raised on acidic lakes in northern Wisconsin, Nova Scotia, Ontario, and New England consume prey items with this concentration of methylmercury (Kenow and Meyer, 2005).

In addition to effects on wildlife, mercury may cause effects directly on some fish. For example, recent laboratory studies reported that methylmercury decreased the reproductive success of fathead minnows, including decreased reproduction of adult fathead minnows (Hammerschmidt et al., 2002; Drevnick and Sandheinrich, 2003).

2.5.3 Recreational and Cultural Impacts

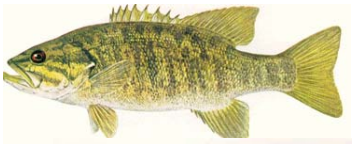
In addition to posing threats to human and wildlife health, mercury contamination of the environment can also impact recreational activity and, in turn, have significant economic impacts for Michigan as well as the Great Lakes' commercial fisheries.

Sport fishing is a popular activity, both nationwide and in Michigan. The most recent U.S. Fish and Wildlife Service review of the issue indicated that over 1.3 million anglers fished in Michigan in 2001. The American Sportfishing Association (ASA) estimated that the overall economic impact of sport fishing in Michigan (including vehicle purchases, prorated based on fishing activity) in 2001 was nearly $2.2 billion (ASA, 2002). Some research has indicated that the presence of fish consumption advisories does affect individual's choices about where they fish. For example, a study in Chesapeake Bay found that 36% of the anglers polled would change their fishing location as a result of a fish consumption advisory (Jakus et al., 2002). Therefore, any substantial loss of Michigan's sport fishing activity due to fish advisories could adversely impact Michigan's economy.

Most of Michigan's 11,000 inland lakes, 2,199 miles of Great Lakes coastline, and 521 miles of river have fish consumption advisories because of contamination from mercury. However, the Michigan Department of Community Health (MDCH) fish advisory provides information for the safe consumption of fish from Michigan

waters. As a result, Michigan anglers and their families can not safely eat all of the fish they catch.

Mercury fish consumption advisories have existed for several decades. This is a widespread problem throughout the north central U.S. and Canada.[14] Since 1988, the MDCH has issued a statewide advisory for all inland lakes in Michigan due to mercury (see also **Section 2.6.2.2**). No one should eat more than one meal a week of these kinds and sizes of fish from any of Michigan's inland lakes (examples shown are of a rock bass, smallmouth bass, and a northern pike):



- Rock bass, perch, or crappie over 9 inches in length
- Any size largemouth bass, smallmouth bass, walleye, northern pike, or muskie.

Women of childbearing age and children under age 15 should not eat more than one meal per month of these fish. Approximately 280 Michigan inland bodies of water have been sampled and the MDCH advisory provides a summary of mercury in fish from these inland lakes.[15]

According to the EPA, there are currently 45 states that have issued mercury advisories in 2003 (EPA, 2004a). On March 19, 2004, the EPA and the U.S. Food and Drug Administration (FDA) issued a joint consumer advisory about mercury in fish and shellfish.[16] This is the first time FDA and EPA have combined their advice into a single uniform advisory.

While the purpose of fish consumption advisories is to protect the public health, these advisories do not fully achieve that purpose. Surveys of anglers have revealed that even with wide-spread publication of advisories, many anglers are not fully aware of the dangers of eating mercury contaminated fish. It is estimated that as many as 69% of anglers consume their catch, despite fish advisories (Jakus, McGuinness, and Krupnick, 2002). Additionally, the exposure pathways, risk factors, and cultural impacts unique to Native American populations are not typically factored into risk analysis and permit considerations of non-Native governments. Although EPA's regulatory impact assessment (RIA) analysis for the federal utility mercury rule attempted to estimate the benefits of the CAMR to this heightened exposure subset of the population, focusing on consumption of freshwater fish.

[14] Information about the relationship between fish advisories and human exposure to mercury is discussed in EPA's Report "America's Children and the Environment: Measures of Contaminants, Body Burdens, and Illnesses, Second Edition") [EPA 240-R-03-001]

[15] Michigan's complete advisory is located at http://www.michigan.gov/documents/2005Fishing-Guide_119644_7.pdf.

[16] Information on the EPA/FDA joint venture is available at http://epa.gov/waterscience/fish/advisory.html. Additional information on fish advisories is available at www.epa.gov/waterscience/fish or http://www.epa.gov/ost/fish.

The Great Lakes Basin is home to Native American communities (Potawatomi/ Bodwewaadamii, Odawa/Ottawa, and Ojibwa/Chippewa Bands who collectively refer to themselves as the Anishinaabek) who have resided in the Great Lakes region, as independent sovereign nations, for hundreds of years prior to the formation of the State of Michigan. Native American communities and reservations, both historically and today, are located on or near the Great Lakes in order to retain their cultural identity and to provide Tribal members access to fisheries and other natural resources. Despite assimilation and modernization, most Native American communities continue to struggle to hold onto their culture by retaining a close connection, both physically and spiritually, with the resources of the Great Lakes Basin. Given their unique culture and lifestyle, native populations have a greater potential for mercury exposure, but such contamination also impacts the integrity of ceremonial and cultural practices which depend upon "pure" air, water, plants, and all animal life. Many Native Americans within Michigan and the Great Lakes Region continue to depend upon fishery resources for subsistence and Native American communities tend to consume substantially more fish, both in amount and frequency, than the general population.

In addition to the impacts on Native American culture, a number of studies have indicated higher fish consumption rates among people of color. An earlier study of licensed Michigan anglers found higher fish consumption rates among Latino, African-American, and Native American anglers than white anglers (West et al., 1992; cited in Beehler et al., 2003).

2.5.4 Quantifying Costs of Mercury Impacts

Ongoing elevated exposures to methylmercury through fish consumption can also affect Michigan's economy through direct effects on human health. There have been recent efforts to quantify and assign monetary value to monetize the human health benefits that would be expected to result from reduced mercury emissions from coal-fired power plants. All three benefit analyses summarized herein utilized different methodologies and assumptions to attempt to place a monetary value on anticipated health benefits of mercury reductions. Different health endpoints, different exposed populations, and different dose-response assumptions are just a few of the key differences between them. These initiatives result in a wide range of estimated benefit values.

1) **EPA:** In the EPA's final CAMR released March 15, 2005, the benefits of reduced mercury emissions from the utility sector were estimated based on monetized "improvements in IQ decrements" for a subset of the U.S. population exposed *in utero* which included the freshwater angler population (women of childbearing age) in the eastern half of the U.S. EPA also analyzed a smaller subset of the population who consume greater amounts of fish than the general population, which included subsistence fishers, certain Native Americans, and Asian Americans.

EPA reasoned that since the largest change in power plant deposition associated with the final Clean Air Interstate Rule (CAIR) and CAMR programs would occur in the eastern-half of the U.S., the unquantified benefits for the western-half of the U.S. would be expected to be quite small (EPA, 2005b; Section 10-1). EPA stated that the focus of their analysis was limited to freshwater fish consumption exposure due to limitations in the modeling of how changes in mercury deposition will affect fish tissue concentrations from other consumption pathways (namely ocean fish consumption) (EPA 2005b; Section 10-1). EPA's analysis further indicated that only freshwater fish are significantly impacted by U.S. power plants. EPA did recognize, however, that ocean fish consumption is the predominant pathway for methylmercury exposure in the U.S. (approximately 90%) (EPA, 2005b; Section 10-144). EPA stated that

> *"exclusion of these commercial pathways means that this benefit analysis, while covering an important source of exposure to domestic mercury emissions excludes a large and potentially important group of individuals."*

EPA's benefit estimates represent the monetary values of expected IQ improvements assessed in terms of future foregone earnings recovered after reductions are achieved via the final CAMR. This considered, EPA assessed exposure reductions for each of the regulatory options utilizing various control scenarios, timelines, and lag times between reductions and subsequent benefits. EPA's core analysis used a primary dose-response curve that implies that each 1 part per million (ppm) increase in mercury in hair results in a 0.13 IQ decrement. The monetized value of avoided IQ decrements was estimated to be between $0.8 and $3.0 million annually at a 3% discount rate (1999 dollars), under CAMR Option 1 assuming no threshold (RIA, Table 11-7). Combined benefits of CAIR and CAMR resulted in a range of estimated benefits between $10.4 to $46.8 million annually (1999 dollars) (EPA, 2005b; Table 10-1c). The benefits associated with each of the emission reduction scenarios were estimated as the difference (reduction) in the total value of IQ losses, going from the relevant baseline scenario to conditions with emissions reductions in place (EPA, 2005b; 10-11).

EPA recognized that full scale IQ might not be the cognitive endpoint that is most sensitive to prenatal mercury exposure (EPA, 2005b; 9-9). They state that their benefits assessment has several known uncertainties and biases and that these biases are both in the upward and downward direction but that, taken together

> …… *"the Agency believes that the benefits presented in this section likely underestimate the total benefits of reducing mercury emissions from power plants due to the potential health effects and potentially exposed populations that are not quantified in this analysis."*

In addition to quantifying benefits based on IQ improvements, EPA acknowledged that other health and ecosystem benefits (other neurological

effects besides IQ, cardiovascular, genotoxic, immunotoxic, and ecological) may also result from reductions. However, they did not feel confident in quantifying these potential benefits. These benefits were addressed qualitatively and listed in Table 10-45 in EPA's RIA (EPA, 2005b). Furthermore, EPA performed an illustrative analysis to monetize co-benefits of avoided premature adult mortality expected to result from reductions in emissions of $PM_{2.5}$ (fine particulate matter with a diameter of $\leq$ 2.5 microns) if ACI with the addition of a polishing baghouse is used (such as TOXECON™). Potential benefits resulting from Option 1 ranged from $1.5 to $44 million depending upon the availability of advanced sorbents technology. Similarly, potential benefits under Option 2 ranged from $1.5 to $130 million, again depending upon the status of advanced sorbent technology. The explanation and rationale for EPA's approach is described in Johnson (2005), as well as EPA's 2005b RIA.

2) **Harvard/NESCAUM:** In a separate analysis, researchers from the Harvard Center for Risk Analysis, on contract with the Northeast States for Coordinated Air Use Management (NESCAUM), assessed the health benefits of reducing mercury from U.S. coal-fired power plants based on targeted emission amounts similar to those EPA had proposed in their draft maximum achievable control technology (MACT) standard (i.e. preliminary reduction to 26 tons of mercury emissions annually, and final reduction to 15 tons after 2018). The researchers relied on regional deposition modeling results from EPA's analysis of the Clear Skies Initiative as the basis for expected changes in fish tissue mercury levels. Modeling was based on five freshwater regions (Northeast, Mid-Atlantic, Southeast, Midwest, and West) and three saltwater regions (Atlantic Coastal, Gulf of Mexico, and All Other Waters). Estimated expected decreases in freshwater regions and the Atlantic Coastal and Gulf of Mexico regions ranged from 1% to 10%. Estimated expected decreases to the "All Other Waters" region was assumed to be proportional to the change in total global emissions which equates to less than 1%.

The health effects considered in this analysis were "cognitive abilities" (including IQ), and also cardiovascular effects which were not quantitatively monetized by EPA (EPA, 2005b). Human exposure pathways considered included commercially and non-commercially harvested fish based on FDA and EPA consumption rates. The exposed population for calculating IQ benefits consisted of U.S. women of childbearing age with estimated exposure levels above the RfD (roughly 9% of U.S. females). The exposed population for calculating cardiovascular benefits was the U.S. population of men and women over the age of 39 (based on 2000 Census data). A slope estimate of the dose-response relationship was estimated to be 0.6 IQ points lost per 1 ppm increase in hair mercury concentration which was stated as a central tendency estimate based on existing literature. They utilized a cost-of-illness approach to derive a value of $16,500 (year 2000 dollars) for each IQ decrement. Their results indicated average national benefits due to IQ increases alone in the annual birth cohort ranged between $75 and $194 million (after the MACT Phase I 26 ton cap) and between $119 and

$288 million (after the MACT Phase II 15 ton cap), depending on whether or not a neurotoxicity threshold is assumed (all dollar values are year 2000). The researchers assumed that "…*increases in a child's intelligence quotient (IQ) that result from decreases in intrauterine methylmercury exposures capture some of the neurodevelopmental delays reported in positive epidemiological studies*." They indicated that these values were likely a conservative estimate of the total value individuals place on IQ changes, because such changes may have value that is independent of their impact on lifetime earnings.

According to the Harvard/NESCAUM study, the potential cardiovascular effects of methylmercury exposure are less well understood and therefore any monetized values representing cardiovascular benefits are accompanied with a great deal of uncertainty. It is noted that this uncertainty was the EPA (EPA, 2005b) rationale for focusing their quantitative analysis on IQ benefits, which are better established including an available model for monetizing benefits. The Harvard/NESCAUM study derived two estimates based on epidemiological studies of methylmercury exposure in males who consumed non-fatty freshwater fish. The endpoints evaluated in these studies were increased risk of non-fatal myocardial infarction and premature mortality from myocardial infarction. Using a cost-of-illness approach (2000 value year), the estimated value of myocardial infarction was $50,000 per individual. Using a willingness-to-pay approach for the same value year, the estimated value of premature fatality was $6,000,000 per individual. Total benefits of $4.9 billion annually due to reduced cardiovascular disease were estimated, assuming benefits are extended to the entire adult population. The authors strongly cautioned against the use of these predicted benefits until further study and review was available to support the relationship between increased cardiovascular risk and methylmercury exposure.

3) **Trasande et al.:** In another available study, Trasande et al. (2005) estimated the national, annual cost associated with methylmercury exposure due to lost productivity during the lifetimes of children who were exposed *in utero* resulting in neurological effects (IQ loss). The rationale for this approach was that loss of intelligence causes diminished economic productivity that persists over the entire lifetime of affected children. Their cost estimates included direct costs of health care, costs of rehabilitation, and lost productivity. They also estimated the fraction of that loss which is attributable to mercury emissions from U.S. power plants. The exposed population is the estimated number of children born each year with cord blood mercury levels greater than the level associated with the RfD, which is protective of effects on IQ. That information was obtained from national blood mercury prevalence data from the CDC. The resulting at-risk subgroup was estimated as between 316,588 and 637,233 exposed children, which includes children exposed through any maternal consumption pathway including consumption of freshwater and ocean fish. The estimated cost of loss in productivity due to the reduction in intelligence was estimated to be between $2.2 and $43.8 billion, depending on fetal effect level assumptions. Based on these estimates, $1.3 billion (range: $0.1 to $6.5 billion) annually was attributable to emissions from U.S. coal-fired power

plants according to the researchers. This study did not discuss or include quantification or monetization of potential cardiovascular effects of methylmercury exposure (Trasande et al., 2005).

Table 2 summarizes the key assumptions and value estimates made in each of the three benefits analyses presented above.

Table 2: Comparison of Benefits Analyses for Neurological Effects in the U.S.

ASSUMPTIONS/ ESTIMATES	EPA	HARVARD/NESCAUM	TRASANDE
Benefit Estimates (annually)	In 1999 dollars: Zero Out of EGU Emissions (relative to 2001 baseline) **$8.9 to $37.0 million** 2020 Base Case with CAIR (relative to 2001 baseline) **$9.6 to $43.8 million** CAMR Option 1 (relative to 2020 base case with CAIR) **$0.8 to 3.0 million** Combined Benefits of CAIR and CAMR **$10.4 to $46.8 million**	In 2000 dollars: **$75 to $194 million** (after 26 ton cap in 2010) **$119 to 288 million** (after 15 ton cap in 2018)	In 2000 dollars: **$2.2 to $43.8 billion** (due to worldwide anthropogenic sources) **$0.4 to $15.8 million** (due to U.S. anthropogenic sources **$0.1 to $6.5 billion** (due to U.S. coal-fired power plants)
U.S. Utilities' Contribution to Modeled Exposure Scenario	For the U.S. freshwater fish consumers, 1%* of the mercury exposure is attributable to U.S. power plants.	Expected decreases in U.S. utilities' contribution to mercury exposure after MACT reductions would be 1% to 10% for freshwater, Atlantic Coastal, and Gulf of Mexico regions and less than 1% for All Other Waters (U.S. contribution to global pool)	U.S. power plants contribute 41% of U.S. anthropogenic emissions, which contribute 18 to 36% of worldwide anthropogenic emissions
Exposure Assumptions	Freshwater fish consumption (non-commercial)	Freshwater and ocean fish consumption (commercial and non-commercial)	Children born to women with blood mercury levels indicating exposure above the RfD.
Exposed Population	Freshwater angler population in the Eastern half of U.S. in the 77th to 100th consumption percentiles (approx. 420,000 to 580,000 persons)	Annual birth cohort (assuming no threshold) and approximately 9% of annual birth cohort (assuming threshold at RfD)(2000 Census).	Estimated number of children born each year with *in utero* mercury exposures above the RfD (between 316,588 and 637,233 children)
IQ Decrement	0.13 IQ points lost per 1ppm mercury in hair	0.6 IQ points lost per 1ppm mercury in hair	1.5 (base case) and 0.85 to 2.4 (outer bounds) IQ points lost per doubling of blood mercury
IQ Value	$8,800 per IQ improvement per capita	$16,500 per IQ decrement per capita	Loss of 1 IQ point = decrease in lifetime earnings: Boys $1,032,002 Girls $ 763,468

Table 2: Comparison of Benefits Analyses for Neurological Effects in the U.S.

ASSUMPTIONS/ ESTIMATES	EPA	HARVARD/NESCAUM	TRASANDE
Cost Approach	Monetized "improvements in IQ decrements" in terms of future foregone earnings recovered after reductions under CAMR/CAIR are achieved	Cost of illness approach as dollars saved (in terms of future foregone earnings) after reductions under proposed MACT rule are achieved	Cost of illness approach as lifetime lost productivity (in terms of lost productivity and direct costs of health care and rehabilitation) from exposure to mercury above the RfD

* 1% is the product of combining the 8% contribution of U.S. utilities to U.S. deposition (and fresh water fish levels); from page 8 to 14 of CAMR RIA and the 13% contribution of wild fresh water fish to the U.S. fish diet; from page 4 to 46 of CAMR RIA.

** Trasande et al. attributed 33% of the total cost of IQ deficits to U.S. power plants. This equates to $1.3 billion out of a total cost of $3.9 billion.

2.6 Overview of Mercury in Michigan

2.6.1 Historical Perspective

Mercury has been recognized as an environmental pollutant of concern for decades in Michigan. In 1970, mercury contamination was found in Lake St. Clair and the St. Clair River fish as a result of six tons of mercury being discharged into the waters annually from the Dow Chemical chlor-alkali complex in Sarnia, Canada. This resulted in a Governor's Executive Order that made it illegal to fish in Michigan waters of Lake St. Clair; along with a policy by the Michigan Water Resources Commission stating that there would be no direct discharges of mercury to the waters of the state. Consequently, the most significant direct water discharges of mercury were eliminated in Michigan by 1972; and the severely contaminated fish mercury levels in Lake St. Clair and the St. Clair River decreased to low levels in most species by the late 1980s. However, fish advisories for 12 fish species in Lake St. Clair still exist as a result of elevated mercury levels.

These substantial releases of mercury into Michigan's environment also resulted in a state report enlisting the assistance Michigan State University (MSU) to find solutions to the mercury contamination problem (D'ltri, 1971). Several recommendations were made in this report as first steps toward mercury reduction in Michigan. They included such initiatives as:

- establishing a statewide inventory for mercury uses and discharges,
- a ban on the use and sale of alkyl mercury containing compounds,
- a requirement for proper labeling and disposal of packages and products containing mercury,
- encouragement of the use of mercury-free alternatives to fungicides and pesticides, and
- requiring all large users of fossil fuels, except individual homeowners in Michigan, to determine the amounts of mercury present in the coal or crude oil

before it is burned or converted into another product. The mercury content of ash should also be required to be determined.

Efforts to implement the above recommendations, at that time, were viewed as too resource-intensive and lacked political support (M2P2 Task Force, 1996). Eventually, some of the recommendations were adopted.

During the 1980s, mercury emissions emerged as a controversial issue related to the air permitting for municipal waste combustors. Atmospheric modeling estimated that the point of maximum impact would result in deposition to a water body that already had fish tissue concentrations that exceeded the MDCH's fish consumption advisory limit. At the time, the Governor announced that there should be a state-wide strategy that should be developed for mercury. To follow this charge, in 1991 a Michigan mercury workgroup was convened which included participants from the MDEQ, the MDCH, and the Michigan Department of Agriculture. This state mercury workgroup drafted and released a report on the state-of-knowledge on mercury in 1992 titled, "Mercury in Michigan's Environment: Causes and Extent of the Problem."

In 1992, the Michigan Environmental Science Board (MESB) was convened to investigate the risk posed to Michigan citizens by excessive levels of mercury; to determine the sources of mercury and the pathways by which mercury enters the environment; and to propose and evaluate options for controlling or eliminating harmful emissions of mercury to the environment. The MESB utilized the state report as background information and collected additional data. They released their report in April 1993 titled, "Mercury in Michigan's Environment: Environmental and Human Health Concerns" (A Science Report to Governor John Engler). Key points included:

- There is a potentially small margin of safety between background (i.e., natural) levels of mercury exposure and concentrations that can cause harm in humans. These factors add uncertainty to conclusions about the current health risk and preclude predictions regarding future health risks. Mercury must be taken seriously as a potential threat to public health and the environment.
- Michigan has the ability to reduce its contribution to atmospheric mercury within the Great Lakes region. Given this, and in light of the potential human health threat which can result from local as well as regionally derived mercury in the environment, Michigan should take necessary steps to reduce controllable mercury emissions within its borders.

The MESB report also contained recommendations on what further studies were needed to implement the above charges including additional information on the abundance, transport, and fate of mercury in the Michigan environment; current levels and trends of mercury exposure of Michigan citizens; and mercury emission rates from Michigan facilities.

In regards to mercury emissions from coal-fired utilities, the MESB recommended that in order to reduce mercury emissions, better information regarding the

amounts and forms of mercury from coal-fired utilities are required in order to determine the most appropriate and effective control options.

As a result of this recommendation, MPSC's chairman sent out a letter on June 2, 1993, to 11 coal-fired utilities requesting the following information:

1) a summary of monitoring of mercury emissions that is currently being performed and results over the last twelve months;
2) an estimate of the costs of extending monitoring to any other coal plants; and
3) a summary of current activity with respect to washing coal and any suggestions regarding appropriate criteria.

This information was to be used for compiling the state-wide action plan to implement the MESB recommendations, as requested by the Governor. In the responses received, some facilities had estimated their mercury emissions based on mercury content in coal.

In December 1993, a Michigan Mercury Action Plan (MMAP) was developed by the MDEQ, MDCH, and MPSC to address the numerous recommendations made by the MESB. The action items relating to mercury emissions from coal-fired utilities included the following recommendation:

> "*…to review data provided by the utilities in response to former MPSC Chairman Steve Fetter's June 2, 1993 request on mercury emissions data. Identify mercury reductions which could be implemented through demand side management efforts*."

The two largest utilities (Detroit Edison [DTE Energy] and Consumers Energy) then began submitting emission estimates every six months to the MPSC, based on the mercury concentration analyzed in coal. The data submitted to date includes the following summary (shown in **Table 3**):

Table 3: Mercury Emissions from Michigan's Largest Utilities
(pounds/year)

YEAR	DTE ENERGY	CONSUMERS ENERGY	TOTAL
1994	1,468	665	2,133
1995	1,750	927	2,677
1996	1,850	901	2,751
1997	1,782	817	2, 599
1998	1,632	998	2,630
1999	1,694	1,031	2,725
2000	1,540	873	2,413
2001	1,585	875	2,460
2002	1,515	883	2,398
2003	1,416	872	2,288

All of the above estimates assume that 30% of the mercury is controlled by current air pollution control devices. Consumers Energy and DTE Energy generate approximately 86% of Michigan's energy. Utilities' TRI data is now publicly available.

The MMAP also recommended the formation of the M2P2 Task Force, which was convened in 1994, and in their 1996 report, they made more than 70 recommendations. This M2P2 report was the impetus behind numerous highly successful mercury pollution prevention (P2) efforts in various sectors including dental, healthcare, schools, dairy farms, the automobile sector, and the electric and gas (utility) sectors (regarding mercury product collection).[17] An interesting note is the M2P2 Task Force Report was the first nationally to recognize the auto industry's usage of 10 tons of mercury in the form of 13 million mercury switches used annual in automobile production.

The M2P2 Task Force had several key subgroups, one was specific to coal-fired electric utilities. The specific utility subgroup developed recommendations for the utility sector. These recommendations included:

- The M2P2 Task Force, the MDEQ and the MPSC should encourage EPA to finalize the mercury and utility studies and ensure that significant resources are allocated to determine the scientific basis to promulgate national standards for mercury emissions from electric utility boilers.
- The MPSC and the MDEQ, working in cooperation with Michigan utilities, should support additional research efforts to evaluate the full environmental costs and impacts of mercury emissions and subsequent deposition from electric power generation.
- Michigan utilities should continue to support projects on evaluating renewable energy sources, including wind and solar energy.
- The M2P2 Task Force calls upon electric utilities to factor in the costs and benefits of mercury emissions control into all Environmental Impact Statements required under federal and state law.
- The M2P2 Task Force calls upon Michigan utilities to develop a plan with timetables and goals that are measurable, in quantitative or other terms, as well as means to achieve the goals, to further reduce mercury usage or emissions from the generation of electricity and/or other sources. This plan should be submitted to the MDEQ and the MPSC and progress in achieving mercury reductions should be reported on an annual basis.

Both Consumers Energy and DTE Energy responded by conducting outreach within their respective facilities and collected Hg^0 from obsolete equipment or bulk mercury that was being stored. For the years 1996 to 2003, Consumers Energy collected and recycled 1,488 pounds of elemental stock mercury and mercury from mercury-containing equipment or approximately 60% of the original 1996 inventory of 2,464 pounds of mercury from their facilities. Between the years 1997 and 2000, DTE Energy collected 2,745 pounds of mercury from their facilities to follow through on their M2P2 Task Force commitment. Additionally, on their own initiative the Lansing Board of Water and Light (LBWL) eliminated more than 450 pounds of mercury from their facilities between the years 2000 and 2005.

[17] For a copy of the report and a summary of the various mercury P2 efforts implemented in Michigan visit MDEQ's website at: http://www.michigan.gov/deqmercuryp2.

2.6.2 Summary of Statewide Mercury Monitoring Efforts

The MDEQ has made progress and continues to implement activities focused on identifying and reducing the release of anthropogenic sources of mercury to the environment. Primary methods for accomplishing these efforts include: controls through permits and enforcement; legislation prohibiting the sale or use of certain mercury products; research and monitoring of mercury data; and aggressive efforts to encourage voluntary reductions in the use of mercury-containing products and devices (through P2) along with education and outreach activities. For example, numerous mercury-containing items continue to be collected at several "clean sweep" centers in the state. Over 500 pounds of Hg^0 was collected at clean sweep centers in both 2003 and 2004.[18]

2.6.2.1 Air Monitoring Projects

Tri-State Mercury Monitoring Project

The Great Lakes' states of Michigan, Minnesota, and Wisconsin face similar challenges regarding mercury contamination of the environment. In an effort to identify and quantify under-appreciated sources of mercury to the atmosphere, the three Great Lakes' states jointly applied for and received grant funding from the EPA in 2000.

The MDEQ was responsible for administering the funds which included the design and building of a mobile mercury laboratory, housed in a climate-controlled trailer, complete with a generator, two Tekran 2537A mercury vapor analyzers, meteorological monitoring equipment, data loggers, and a computer for data compilation and analysis. The mobile laboratory has been and will continue to be shared among the three states for data collection.

The EPA funding also allowed for the purchase and sharing of two Lumex RA 915+ mercury vapor analyzers for the identification of mercury sources. The Lumex is at least an order of magnitude less sensitive than the Tekran devices, but is much more portable and quicker to yield data. In general, the Tekran was found to be useful for precise and accurate quantification of subtle differences in mercury concentration outdoors or in clean indoor environments. In contrast, the Lumex devices were useful for identifying relatively large mercury sources, spills, and indoor contamination.

[18] More information is available on the MDEQ's website at: http://www.michigan.gov/deqmercuryp2.

The three states continue to use the equipment to quantify mercury releases from manufacturing facilities (thermometers, chlor-alkali), mercury recyclers (fluorescent bulbs and other materials), scrap metal yards and shredders, solid waste processing facilities, medical waste autoclaves, land-applied wastes (sewage sludge, wood ash, coal ash), and taconite tailing basins. In addition, Michigan, Minnesota, and Wisconsin have all assisted local health departments in providing use of the Lumex instruments to facilitate quantification of mercury concentrations in homes or businesses where mercury was spilled. The final grant report titled, "Identification of Atmospheric mercury Sources in the Great Lakes States Through an Ambient Monitoring Program" was finalized in November 2003.[19]

Mercury Monitoring Workshop

Additionally, as part of the EPA-funded Tri-State Mercury Monitoring Grant, the Air Quality Division (AQD) co-sponsored the Mercury Monitoring Workshop with EPA titled, Great Lakes Regional Workshop Proceedings - Measuring Atmospheric Mercury: Goals, Methods and Results in East Lansing, Michigan on March 26 to 27, 2003.[20]

Michigan Atmospheric Mercury Monitoring Network

In the fall of 2001, another mercury project was started. The AQD, partnering with the University of Michigan (U of M), was awarded a grant from the Michigan Great Lakes Protection Fund (GLPF) to develop a mercury monitoring network. Sites were established in three urban areas (Grand Rapids, Flint, and Detroit) because Michigan lacks long-term mercury data from urban areas. This study also continued the long-term event-based mercury deposition recorded at three rural sites in Michigan (Dexter, Pellston, and Eagle Harbor) (also see **Section 3.3.2**). The first and second year's annual reports were submitted to the GLPF. Preliminary data has already demonstrated the influence of local sources emitting mercury and the importance of speciated mercury monitoring to assess anthropogenic source contributions to wet (e.g., rain) deposition of mercury. The AQD and U of M have received additional funding to extend this project through the Spring of 2005. This project will continue monitoring at the various sites established in the first year of the mercury study to allow trend analysis. A final report will be completed December 2006.

Comprehensive Ambient and Atmospheric Deposition Network Strategy

While several persistent, bioaccumulative toxic (PBT) air monitoring and atmospheric deposition studies have been conducted in the past several

[19] The report is available on the MDEQ's AQD website at http://www.deq.state.mi.us/documents/deq-aqd-toxics-Hgfinalreport.pdf.

[20] The workshop proceedings and power point presentations are available at http://www.deq.state.mi.us/documents/deq-aqd-toxics-HgWorkshop.doc.

years, they were for a limited time frame and for a limited set of pollutants. These somewhat fragmented studies demonstrate the need for implementation of a comprehensive, continuous atmospheric deposition network within the state and region. In 2002, the AQD drafted a comprehensive ambient and atmospheric deposition network strategy that outlines AQD's long-term goals for air toxics monitoring, including PBTs.[21] This report, The Development of an Air Toxics Monitoring Strategy for Michigan, was finalized in 2002; implementation now depends on securing an adequate funding source.

2.6.2.2 Wildlife and Fish Monitoring

Michigan Wildlife Contaminant Monitoring Project

The MDEQ initiated monitoring of mercury and other contaminants in bald eagles (*Haliaeetus leucocephalus*) within the Great Lakes region in 1999. The bald eagle is considered an ideal biosentinel species because it is a top-level predator that feeds primarily on fish and waterbirds, it often returns to the same nesting territory year after year, and its large size allows sufficiently large samples to be collected for contaminant analysis. **Table 4** summarizes the results of the first two years of sampling from 1999 to 2000 (Roe, 2001) and for comparison purposes, the concentrations of mercury in bald eagle nestlings within the Great Lakes region measured during 1985 to 1989 (Bowerman et al., 1994). **Table 4** shows the geographic mean mercury concentrations in breast feathers of nestling bald eagles from four sub-populations in Michigan and one sub-population in Minnesota (Voyageurs National Park) for the time periods 1985 to 1989 and 1999 to 2000.

Table 4: Mercury Concentrations In Nestling Bald Eagle Breast Feathers
(milligrams per kilogram [mg/kg])

LOCATION	1985 to 1989		1999 to 2000	
	n	Mean	n	Mean
Interior Lower Peninsula, MI	28	8.8	62	8.13
Interior Upper Peninsula, MI	44	8.1	55	8.40
Lake Superior	19	8.7	33	8.17
Lake Michigan and Huron	10	8.0	57	6.82
Voyageurs National Park, MN	8	20	19	8.84

n = Number of Samples.

In summary, mercury was detected in all nestling breast feathers collected during the two time periods. The mean concentrations of mercury in

[21] The strategy is available at http://www.deq.state.mi.us/documents/deq-aqd-toxics-peerRVstrategy.pdf and includes information on the MDN.

nestling breast feathers for five bald eagle sub-populations within the Great Lakes region ranged from 8.0 to 20 mg/kg (1985 to 1989) and 6.82 to 8.84 mg/kg (1999 to 2000). No relationship was found between the concentrations of mercury in nestling breast feathers and productivity or nest success for either time period. This finding suggests that mercury is not affecting bald eagle reproduction in the Great Lakes region.

To assess temporal trends, mercury concentrations measured in bald eagle nestlings in 1999 to 2000 were compared with concentrations measured in 1985 to 1989. No significant differences were found between the mercury concentrations in bald eagle nestlings from Michigan between these two time periods. However, a significant decrease was found in the concentrations of mercury in nestlings from Voyageurs National Park, Minnesota from 1985 to 1989 to 1999 to 2000.

To assess spatial trends, comparisons were made among mercury concentrations measured in sub-populations of bald eagle nestlings during the same time period. The mercury concentrations measured in 1985 to 1989 in bald eagle nestlings from the Voyageurs National Park were significantly higher than mercury concentrations measured in nestlings from all of the Michigan sub-populations during this same time period. No significant differences were found among mercury concentrations in bald eagle sub-populations measured in 1999 to 2000.[22]

Michigan Fish Contaminant Monitoring Program

The MDEQ monitors mercury in fish fillets to assess the need for sport fishing consumption advisories or commercial fishing regulations, and in whole fish to assess temporal changes and ecological risk. Methylmercury can accumulate in fish tissue to levels of concern for humans and other fish-eating animals. Also, changes in fish tissue levels can be used to measure the impact of mercury control programs over time.

The MDEQ has analyzed mercury concentrations in about 13,000 edible portion fish tissue samples collected from approximately 550 locations since 1980. Currently, the MDEQ collects approximately 600 edible portion samples from 40 locations per year. The MDCH uses these edible portion data to issue sport fishing consumption advisories in the Michigan Fishing Guide. The MDCH uses two "trigger levels" to issue advisories: waters and species with sample concentrations between 0.5 mg/kg and 1.5 mg/kg are covered by a "restrict consumption" advisory, while waters and species with sample

[22] For additional information, see Bowerman et al., 1994; and Roe, 2001.

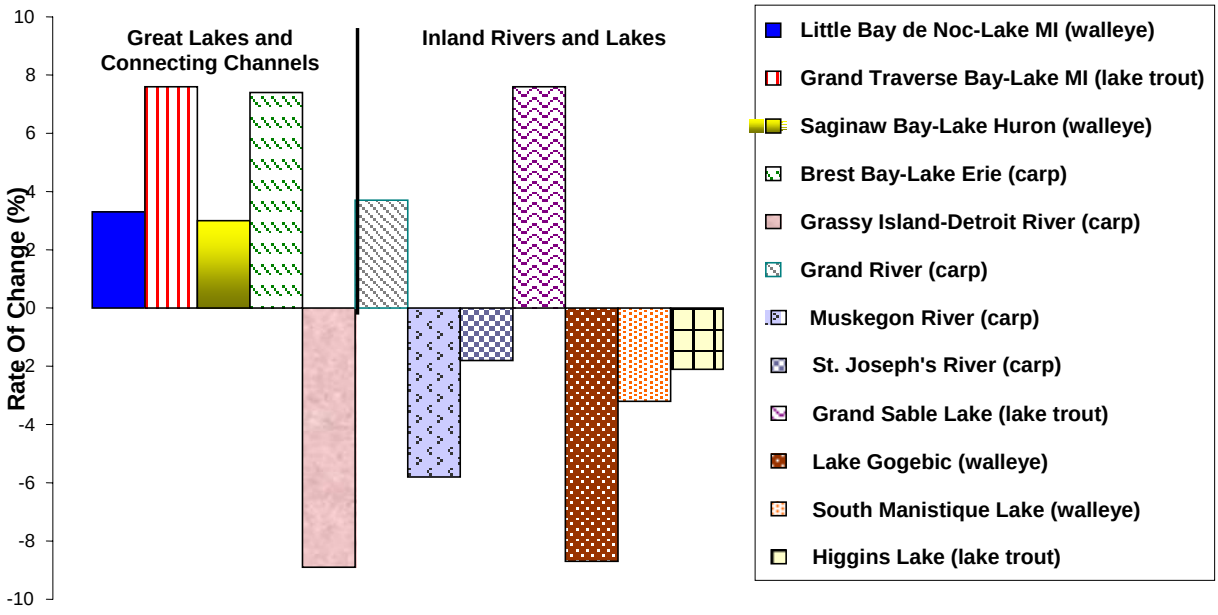
concentrations over 1.5 mg/kg are covered by "no consumption" advisories. The MDCH's "restrict consumption" advisory is defined as no more than one meal per week for the general population and no more than one meal per month for nursing mothers, pregnant women, women who intend to have children, and children under the age of 15. Between 1985 and 2003, approximately 69% of the 279 lakes sampled by MDEQ have at least one fish at or exceeding the 0.5 ppm advisory limit and 10% of the lakes have at least one sample at or exceeding the 1.5 ppm limit. The MDCH updates the Michigan Fish Advisory[23] annually and communicates advice via their website at http://www.michigan.gov/mdch.

In addition to the edible portion monitoring, the MDEQ has conducted a fixed station, whole-fish contaminant trend monitoring program since 1990. Sampling at the program sites is conducted every two to four years. Where trends have been detected, mercury concentrations are usually increasing in fish from the Great Lakes or connecting channels stations and decreasing in fish from inland lakes and rivers. Multiple species were collected at most of the nine fixed stations in the Great Lakes or connecting channels. Mercury concentrations increased in at least one species from three stations (median increase of 5.8% per year), decreased in one species from one location (decrease of 8.9% per year), and remained unchanged in the remaining data sets.

Minimum detectable trends were calculated in cases where a significant trend was not detected. The minimum detectable trend is the smallest possible trend that could have been detected with the available data for each species and station. The median minimum detectable trend for Great Lakes or connecting channel stations was +/-2.8% per year indicating that any undetected changes were likely small. Also, one species was collected at 13 inland lakes or Great Lakes tributaries. Mercury concentrations decreased in fish from seven locations (median decrease of 4.7% per year), increased in fish from two locations (median decrease of 5.8% per year), and remained unchanged in fish from four locations (see **Figure 4**).

[23] The 2005 Fish Advisory is available at http://www.michigan.gov/documents/2005Fishing-Guide_119644_7.pdf.

Figure 4: Annual Rates of Change in Mercury Concentrations Measured in Whole Fish Collected from 1990 to 2003 (from Fixed Station Trend Monitoring Sites)



*** only waterbodies and species with statistically significant trends are shown**

2.6.2.3 Sediment and Water Projects

<u>Michigan Inland Lake Sediment Trend Monitoring Project</u>

Most toxic chemicals entering lakes are or become adsorbed to particles such as organic matter, clays, or iron oxides. The ultimate fate of these particle-bound chemicals is to become deposited on the lake bottom. As this deposition happens over time, sediments in lakes become a chemical "tape-recorder" of the temporal trend of toxic chemicals in the environment. Contaminated sediments can directly impact bottom-dwelling organisms, and represent a continuing source of toxic substances in aquatic environments that may impact wildlife and humans through food or water consumption. Thus, the chemistry of lake sediments is an integral part of Michigan's overall environmental quality monitoring efforts.

In 1999, the MDEQ established an Inland Lake Sediment Trend Monitoring Project in partnership with MSU. This project was designed to provide data to evaluate the effectiveness of air and water quality legislation and the National Pollutant Discharge Elimination System (NPDES) permitting program in reducing contaminant levels in the sediments of the waters of the state.

From the summer of 1999 to 2004, sediment cores were collected from 27 inland lakes in Michigan. **Table 5** lists the inland lakes sampled and year sampled. Lakes were chosen to reflect the diversity of land uses in the

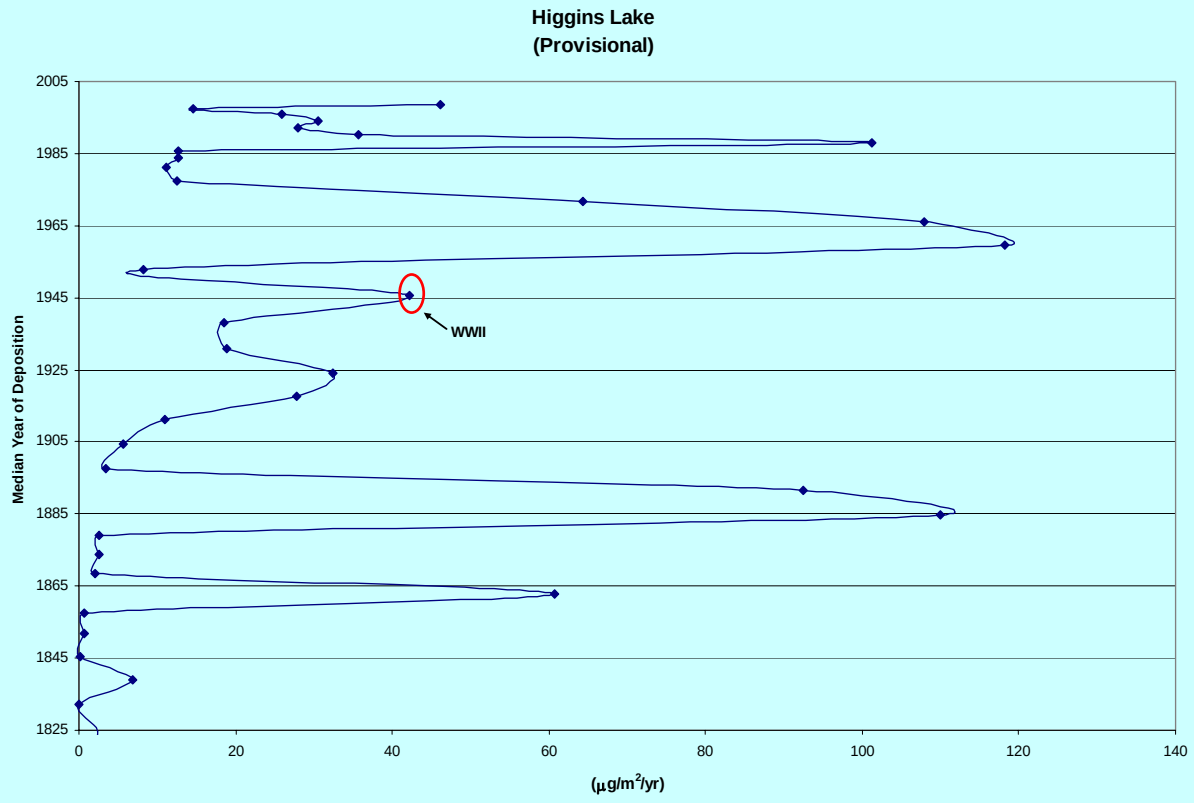
state; selection was also based on position along north-south and east-west transects and proximity to state borders. This latter criterion was an important factor in addressing the likelihood of long-range atmospheric transport of contaminants to the state.

Table 5: Lakes Sampled Since 1999 for the Michigan Inland Lakes Sediment Trend Monitoring Project

1999	2000	2001	2002	2003	2004
Cass Lake	Crystal Lake (Montcalm Co.)	Crystal Lake (Benzie Co.)	Houghton Lake	Muskegon Lake	Lake George
Elk Lake	Littlefield Lake	Mullett Lake	Imp Lake	Birch Lake	Otter Lake
Gratiot Lake		Lake Cadillac	N. Manistique Lake	Sand Lake	Crystal Lake (Mecosta Co.)
Higgins Lake		Paw Paw Lake	Torch Lake	Avalon Lake	Hacker Lack
Gull Lake		Whitmore Lake	Witch Lake	Stupac Lake	Round Lake (Dickinson Co.)

Initial results indicated that the method used to analyze for mercury in the sediment needed to be refined. This resulted in a delay in the reporting of the data and the development of a refined and improved analytical method. Preliminary results from this monitoring effort show that spatial trends of decadal-interval inland lake sediment mercury accumulation rates do not clearly indicate a regional or global source signal. Common among many lakes are episodic mercury accumulation events, which occur over short time periods (years) with regularity. As shown in the following **Figure 5**, some of the events can be attributed to historical increases in U.S. mercury consumption (e.g., World War II); while others are a possible indication of watershed-scale sources of mercury loadings. Many lakes also exhibit an undefined source of mercury to the lake. This is just a sample of the currently available data.

Figure 5: Mercury Accumulation Preliminary Results



The preliminary results in **Figure 5** show background (i.e., pre-industrial revolution) mercury concentrations ranging from 0.015 to 0.1 mg/kg (similar to background levels found in the Great Lakes), and peak mercury concentrations ranging from 0.16 to 1.1 mg/kg (Marvin et al., 2004). For comparison purposes, sediments with mercury concentrations at or exceeding 2 mg/kg are considered to have a very high probability of causing severe effects on bottom-dwelling organisms; sediment clean-up efforts often have a goal of 1.0 mg/kg of mercury in the sediment. Final results from this sediment monitoring effort are expected August 2005.

A study of sediment cores collected 1986 to 1990 from 66 inland lakes in Michigan indicated an average historical background concentration of 0.05 mg/kg (Evans et al., 1991). This study supports the background levels suggested by preliminary results from the Inland Lake Sediment Trend Monitoring Project described above. Surficial sediment levels in lakes without known point source discharges ranged from 0.05 to 0.157 mg/kg, and surficial sediment levels in lakes with known point source discharges ranged from 0.055 to 8.3 mg/kg (Evans et al., 1991). This study concluded that increased atmospheric deposition was likely the cause of observed elevated levels except for Deer Lake, where a direct point source discharge was clearly the cause. Deer Lake was the only site in this study that had

cores whose concentrations exceeded 2 mg/kg (Michigan Department of Natural Resources, 1992).

Michigan Water Chemistry Monitoring Project

The MDEQ initiated its Water Chemistry Monitoring Project (WCMP) in June 1998. The goals of the WCMP are to assess the current status and condition of individual waters of the state and determine whether standards are being met; measure temporal and spatial trends in the quality of Michigan's surface waters; provide data to support the MDEQ water quality programs and evaluate their effectiveness; and detect new and emerging water quality problems.

The current study design of the WCMP calls for annual contaminant monitoring at approximately 49 locations statewide including streams tributary to the Great Lakes, the Great Lakes connecting waters, Saginaw Bay, and Grand Traverse Bay. Depending upon the monitoring station, as few as 4 or as many as 12 mercury samples are collected in a given year.

Mercury samples are collected and handled using the ultra-clean techniques outlined in EPA Method 1669, "Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels." Samples are analyzed for total mercury using EPA Method 1631, which has a method detection level of 0.2 nanograms per liter (ng/L).

All total mercury results currently available from the WCMP (June 1998 through November 2002) are summarized in **Table 6.** Exceedance is determined by comparison with Michigan's Water Quality Standard (WQS) of 1.3 ng/L total mercury (See **Section 2.7.3**).

Table 6: Mercury Concentrations in Surface Water, 1998 – 2002 (ng/L)

Location	Mean	Median	Range	Number of Exceedances/n	Percent of Exceedances
Waters Tributary to Lake Michigan	3.74	2.40	ND – 55	276 / 378	73%
Waters Tributary to Lake Huron	1.61	0.71	ND – 14	114 / 300	38%
Waters Tributary to Lake Erie	4.14	2.30	ND - 107	204 / 303	67%
Waters Tributary to Lake Superior	3.85	3.00	0.3 - 10	28 / 35	80%

n = Number of samples.

As shown in **Table 6**, the majority of samples collected statewide for total mercury between 1998 and 2002 exceeded the Michigan WQS of 1.3 ng/L. Temporal trend analyses are not yet possible in this early stage of the project.

2.7 Current Regulatory Programs In Michigan

Michigan utilizes its base regulatory programs to reduce mercury releases to the environment in media such as air, water, and waste. The following sections list these programs that are used to regulate hazardous waste, air point sources, water discharges, and water body nonattainment (Total Maximum Daily Loads).

2.7.1 Universal Waste Rule

The MDEQ adopted the Universal Waste Rule in Michigan in 1996.[24] Thermostats, batteries, banned pesticides, electric lamps, mercury–containing thermostats, switches, thermometers, and any waste device that contains mercury as the hazardous waste constituent, is classified as universal waste. This classification provides several advantages for waste handling such as reduced record keeping and storage requirements as compared to hazardous waste requirements.

2.7.2 Air Rules

Michigan utilizes its base regulatory programs to reduce mercury released from point sources through the air permitting process.[25] Any new or modified source of mercury emissions must go through a Best Available Control Technology for Toxics review. Each source is required to demonstrate the maximum degree of mercury emission reduction reasonably achievable taking into account energy, environmental, economic impacts, and other costs. Sources of mercury emissions must also go through a health-based screening review that uses modeling of source emissions to predict the ambient impact of a toxic chemical. Predicted ambient impacts can be no greater than health-based screening levels. Typically, these screening levels only consider exposure from direct inhalation. Because the primary concern for mercury is from indirect exposure pathways (i.e., consumption of fish), the health-based inhalation screening level of 0.3 micrograms per cubic meter ($\mu g/m^3$) (with a 24-hour averaging time) was withdrawn and emissions of mercury are evaluated on a case-by-case basis. Therefore, mercury emission limits for new and modified sources are primarily set on a case-by-case basis.[26]

The MDEQ has developed stricter standards for medical waste incinerators because documented mercury stack test data has demonstrated that with the application of mercury controls and a mercury waste management plan, facilities can easily meet an emission limit much lower than the federal standard. The AQD has also included mercury education outreach and collection of mercury-containing wastes as part of a permit requirement for a municipal waste

[24] A fact sheet is available electronically at: http://www.deq.state.mi.us/documents/deq-wmd-universl.pdf
[25] AQD guidance on permitting is available at http://www.deq.state.mi.us/documents/deq-ess-caap-airpermittechmanual-Tab16.PDF.
[26] More on Michigan's Air Toxic Regulations is available at http://www.deq.state.mi.us/documents/deq-ess-caap-airpermittechmanual-Tab06.PDF.

combustor. Michigan auto shredders, as part of their permit conditions, must remove mercury switches prior to vehicle shredding.

2.7.3 Mercury Water Discharge Permitting Strategy

The Mercury Permitting Strategy (Strategy), developed by the MDEQ's Water Division in February 2000, established a multiple discharger variance for mercury and outlined an approach for implementing Method 1631 in existing NPDES permits without causing widespread noncompliance with NPDES permit limits for mercury. This Strategy included a level currently achievable (LCA) of 30 ng/l, based primarily on effluent data from the state of Maine, and a pollutant minimization plan requirement to continue efforts to meet the WQS of 1.3 ng/l for mercury. The LCA was established consistent with R 323.1103(6), which requires that the permit establish a water quality-based effluent level that represents a level achievable by the permittee. A pollutant minimization plan is also required by R 323.1103(6) and requires the permittee to identify and eliminate sources of mercury in the discharge. A permittee is considered to be in compliance with the mercury limit if they do not exceed the LCA and are implementing the pollutant minimization plan. The Strategy provided permittees a period of time to switch from Method 245.1 to Method 1631, allowing for the development of laboratory capabilities and the collection of additional mercury data.

The MDEQ is updating its approach to implementing Method 1631 in NPDES permits for Fiscal Years 2005 to 2009. The goal of the 2004 Revised Mercury Permitting Strategy[27] is to move NPDES permitted discharges towards meeting the mercury WQS of 1.3 ng/l. Current effluent data continue to indicate that most point source discharges do not meet the mercury WQS. Recent mercury data collected using Method 1631 under the February 2000 Strategy documents that mercury concentrations in most NPDES permitted discharges are significantly less than the 30 ng/l LCA. Therefore, the revised Strategy lowers the LCA to 10 ng/l. The revised Strategy will further the goal of attaining the mercury WQS through a reduced LCA and continued implementation of pollutant minimization plans.

There are at least 45 individual NPDES permits that contain mercury limits and/or low-level monitoring requirements. Low-level mercury analyses continue to indicate that the level of mercury in many point source discharges can be expected to routinely exceed the WQS of 1.3 ng/l. Data obtained from compliance monitoring for point source discharges indicate that 42 out of 45 facilities with mercury limits or monitoring requirements have arithmetic mean mercury concentrations below 10 ng/l, with 35 facilities less than 5 ng/l.

2.7.4 Total Maximum Daily Loads

When sufficient water chemistry monitoring data are available indicating that a given water body is not meeting the Michigan WQS of 1.3 ng/L for mercury, or when samples of fish tissue from a water body are determined to exceed

[27] The 2004 Revised Mercury Permitting Strategy is available at http://www.deq.state.mi.us/documents/deq-wd-mercury-permittingstrategy2004.pdf.

0.35 mg/kg for mercury, the water body is considered in nonattainment for mercury and is listed in the Clean Water Act Section 303(d) list. The concentration of 0.35 mg methylmercury/kg fish is being used by Michigan to determine whether the standard for mercury in surface waters is being met. This value is not being used for fish consumption advisories. The MDEQ derived this value using the same methodology that EPA used to derive their value of 0.3 mg methylmercury/kg fish. The two values are not identical because the MDEQ value is based on the exposure scenario for the Great Lakes states, whereas the EPA value is based on the exposure scenario for the entire U.S.

The 303(d) list identifies all nonattaining water bodies and the contaminant(s) for which these water bodies are nonattaining, and it identifies the date by which total maximum daily loads (TMDLs) must be developed for these water bodies. The 303(d) list provides Michigan's supporting documentation required by 40 Code of Federal Regulation (CFR), Section 130.7(b)(6), and rationale in fulfilling Section 303(d) requirements, and is submitted to the EPA in even-numbered years.

A TMDL is a tool for implementing Michigan's WQS. The objective of a TMDL is to allocate allowable contaminant loads among different pollutant sources so that the appropriate control actions can be taken and the Michigan WQS achieved. The TMDL determines the allowable contaminant loads and provides the basis for establishing or modifying controls on pollutant sources. After TMDL development is complete, TMDL implementation begins.

The most recent 303(d) list was submitted by the MDEQ to the EPA in April 2004.[28] This list identifies 135 lakes and 478 river miles in nonattainment for mercury within Michigan. A total of 171 mercury TMDLs are scheduled for 2011. The next 303(d) list is scheduled for completion in 2006 year.

2.7.5 Mercury Legislation

There are two specific statutes that address the reduction of mercury sources in Michigan.

Public Act 376 of 2000 requires Michigan schools to phase out mercury use in the classroom and in the health (nurse's) office. This law applies to liquid (free flowing) Hg^0, as well as, mercury-containing instruments such as thermometers, barometers, manometers, and sphygmomanometers (blood pressure gauges). Schools had until 2004 to complete this process. The step-by-step Mercury Elimination Guidelines For Michigan Schools[29] was prepared and distributed to schools to assist them in completing this process.

[28] The 2004 Water Quality and Pollution Control in Michigan: 2004 Sections 303(d) and 305(b) Integrated Report is available at http://www.deq.state.mi.us/documents/deq-wd-swqas-2004integratedreport.pdf.

[29] The Mercury Elimination Guidelines for Michigan Schools is available at http://www.deq.state.mi.us/documents/deq-ead-p2-mercury-mercinschools.pdf.

Additionally, Public Act 578 of 2002 added Part 172 to the Natural Resources and Environmental Protection Act, bans the sale of mercury-containing thermometers as of January 1, 2003. Two exceptions apply; the first is if the thermometer is required by state or federal statute, regulation or administrative rule and the second is for pharmaceutical research purposes.

2.8 Reductions Expected or Achieved

Air Emissions

The MDEQ's AQD has been compiling mercury emissions inventories for a number of years, however, due to significant differences in inventory methods and approaches, it is not possible to directly compare these AQD inventories. In addition, in 1996 a significant change occurred in the reporting of annual emissions. To streamline emission reporting, an AQD policy change revised the requirements for the type of sources that were required to submit an annual emissions report. The AQD's Operational Memorandum No. 13 (effective date November 25, 1996) outlines this revision.[30] One result of this policy change decreased the number of sources reporting from approximately 14,000 in 1994 to approximately 1,900 sources in the 1999 emissions inventory, thereby eliminating numerous sources that were in the original 1994 mercury emissions inventory. This impacted the future compilation of mercury emissions inventories from those eliminated sources. However, reductions can still be estimated for specific source categories. Two such specific sources are the medical waste and municipal waste incineration source categories that have had significant reductions in mercury emissions over the past several years. These reductions were due to state and federal regulations, as well as mercury reduction and P2 efforts.

The majority of the point source categories that comprise more than 1% of the total air emissions will be or are subject to a federal MACT standard (see **Table 1** in **Section 2.2**). The amount of mercury reductions expected from implementation of these standards is uncertain, but could be significant for some source categories. Those source categories that represent more than 1% of the inventory that will not be subject to a MACT standard include natural gas combustion from stationary internal combustion engines and sewage sludge incineration. Reductions in mercury emissions from sewage sludge incineration could occur if the mercury loading to the wastewater treatment facilities is decreased.

EPA promulgated the Iron and Steel Foundries MACT on April 22, 2004. This MACT includes work practice standards requiring foundries to either not use automobile scrap or to remove the mercury-containing switches prior to processing in EAFs.[31] In addition, EPA is considering the development of an area source MACT for "minimills," the sector consisting of the greater proportion of EAF use in steel making. In the meantime, reductions in mercury emissions could occur if existing mercury switches were removed from vehicles prior to their use in steel making.

[30] AQD Operational Memorandum #13 is available at http://www.deq.state.mi.us/documents/deq-aqd-opmemo13.pdf.

[31] The Iron and Steel Foundries NESHAP is available at http://www.epa.gov/ttn/atw/ifoundry/ifoundrypg.html.

Area sources of mercury greater than 1% of the inventory that will not be subject to any regulation include residential fuel combustion (all fuel sources), bench scale reagents, lamp manufacturing/breakage, and emissions from the use of dental amalgams. Additionally, while federal regulations have been promulgated to address air toxics from mobile sources, these regulations are not expected to reduce mercury emissions.

Source categories that represent 1% or more of the emission inventory and that may provide further mercury reductions through additional P2 efforts include municipal waste incineration, sewage sludge incineration, EAFs, and some area source categories. Further study is needed in this area to better target P2 efforts for these source categories as well as other potential sources (P2 efforts are further described below).

If no federal or state regulation exists on sources, AQD staff develops specific emission limits and special permit conditions to reduce the emissions from that particular source. Such sources have included automobile shredders, EAFs, sewage sludge incinerators, and fluorescent light recyclers. AQD staff also conducts risk assessments, including multi-pathway risk assessments, where appropriate, for certain atmospheric sources of mercury that may adversely impact the environment through deposition and subsequent accumulation in the aquatic food chain.

Pollution Prevention (P2)

The goal of the Mercury P2 Initiative is to reduce anthropogenic releases of mercury to Michigan's environment. This program promotes the elimination of non-essential uses of mercury by encouraging the use of mercury-free substitutes. In doing so, this practice eliminates potential public health threats and resulting environmental hazards that stem from spills and/or improper disposal of mercury. The MDEQ's Environmental Science and Services Division (ESSD) has the lead on mercury P2 efforts and will continue implementing mercury P2 programs with a focus on the automobile and health care sectors.[32]

The use of mercury switches in automobiles for convenience lighting and ABS braking systems has been a primary area of environmental concern for some time. Although automakers subsequently eliminated the use of mercury switches in the 2003 model year, thousands of vehicles are retired annually that contain mercury. The challenge therefore for the next ten to fifteen years, is to safely remove mercury switches before vehicle bodies are crushed, shredded, or smelted during the process of making new steel.

In 2004, Michigan became the first state in the country to enter into a cooperative agreement with automobile manufacturers to offer a statewide collection program for the recovery of mercury automotive switches from end of life vehicles. This voluntary program known as the Michigan Mercury 'Switch Sweep' (M2S2) Program, was rolled out August 1, 2004.[33] Participants (dismantlers, recyclers, salvage yards and others)

[32] For additional P2 information visit the MDEQ's website at: www.michigan.gov/deqmercuryp2.
[33] Information on the M2S2 Program is available at http://www.deq.state.mi.us/documents/deq-ess-p2-mercury-switchsweepmou.pdf

entering into the program are provided with instructions, program logistics, training, storage buckets, and/or mailers. After the dismantler removes the mercury switches, the Alliance of Automobile Manufacturers and/or their designated project manager will arrange for transport to one of the existing Michigan Groundwater Stewardship 'Clean Sweep' Programs or another 'team approved' collection point for recycling or disposal.

The purpose of the new M2S2 Program is to ensure that mercury switches are safely removed from vehicles and that no mercury is released to the environment. The goal is to inspect, and when present, remove mercury switches from at least 80% of the total number of motor vehicles processed in Michigan each year. This agreement remains in effect until September 30, 2006.

For the last 13 years, the ESSD has provided mercury P2 technical assistance to Michigan's health care community. As a result of these collaborative efforts, Michigan hospitals rank high in comparison to the rest of the country when it comes to eliminating the use of mercury and reducing generation of hospital waste. In 2004, three out of four recipients for Hospitals for a Healthy Environment (H2E) National Awards for Environmental Leadership were presented to Michigan hospitals. Michigan has approximately 50 H2E Partners out of a total 700 nationwide. H2E and EPA's Region 5 recently used the Michigan model to assist other states like Wisconsin and Illinois in developing their own state programs. ESSD will continue their P2 technical assistance efforts to Michigan's health care community to further reduce the use of mercury-containing products.

3. Mercury Emissions in Michigan

Section 3 describes Michigan's current power plant fleet, fuel types burned, emission controls, estimated mercury emissions from the fleet, and continue with a discussion on mercury deposition in Michigan.

3.1 Inventory from Michigan Coal-Fired Utilities

There are currently 21 coal-fired electric utility power plants operating in Michigan (see **Figure 6**).[34] **Table 7** provides a listing of the 65 coal-fired EGUs that are operating within these power plants (NOTE: power plants listed in italics did not participate in the Michigan Mercury Electric Utility Workgroup.) **Table 7** is organized to show the ownership, number of operating units, average age, generating capacity, and megawatt hours (MWh) generated in the year 2000. These units are owned and operated by a combination of:

- Investor Owned Utilities: i.e., DTE Energy, Consumers Energy, and We Energies;
- Municipal Owned Utilities: including the Cities of Grand Haven, Holland, Lansing, Marquette, Wyandotte, and Michigan South Central Power Agency (MSCPA);
- Independent Power Producer: TES Filer City
- Campus Based Cogeneration Plant: MSU

Table 7 also documents the operating units which use sub-bituminous coal, bituminous coal, and blends of the two coal types as primary fuels. **Figure 6** shows what types of coal are used within each of the Michigan plants.

For 2000, there was a total of 12,543 megawatts (MW) of coal-fired installed capacity in Michigan and a total electric power generation of just under 68 Million MWh. Michigan, like many other states, relies heavily on an aging fleet of coal-fired power plants.

[34] NOTE: This report is just looking at units greater than 25 MW.

Figure 6: Coal-Fired Electric Utility Plants in Michigan

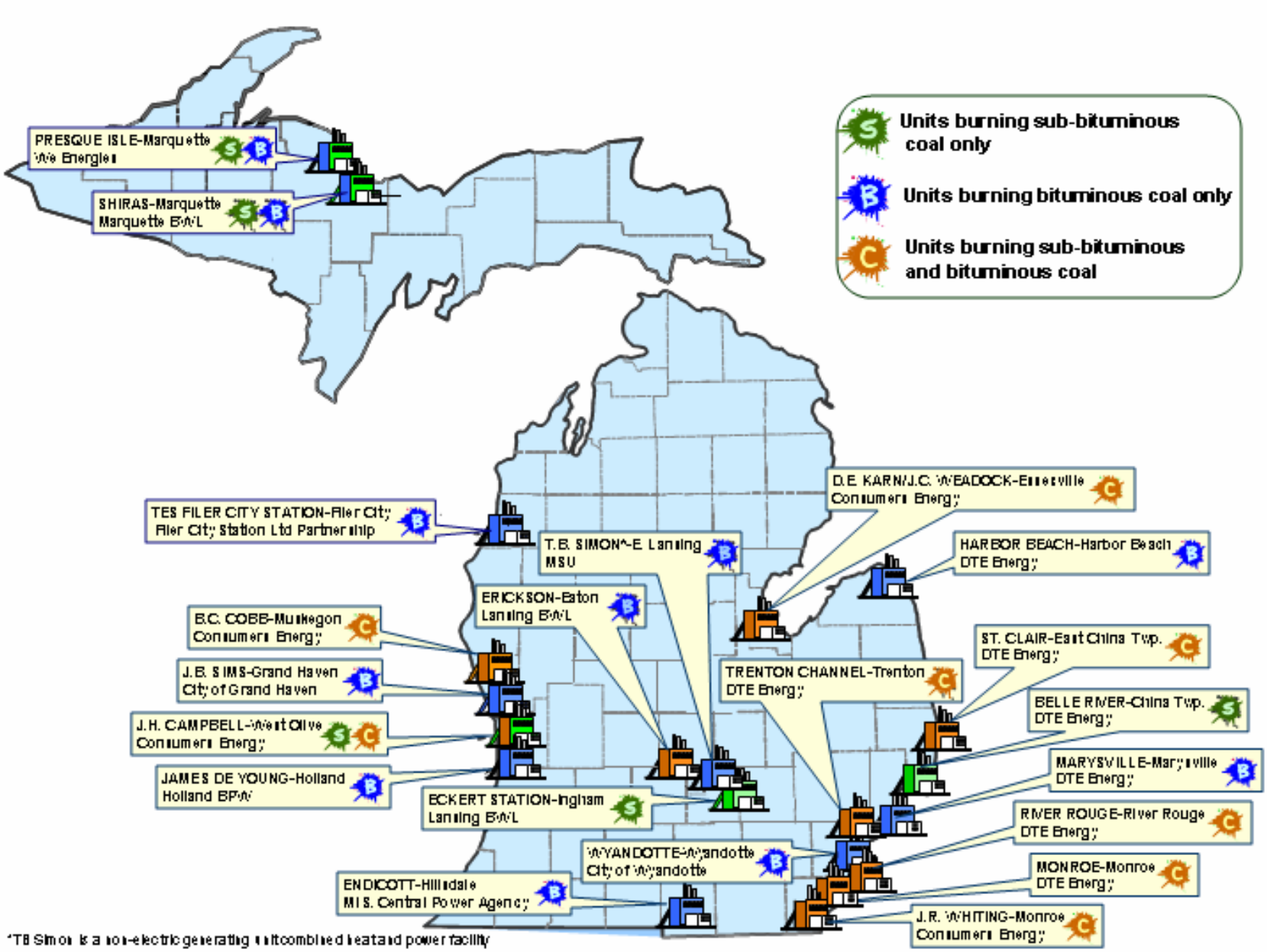


Table 7: Coal-Fired Power Plants in MI, Boiler Number and Age, Generator Capacity, and Net Generation

PLANT NAME	OWNER	BOILER UNITS[1]	AVERAGE BOILER/ GENERATOR AGE (YRS)	TOTAL NET GENERATOR CAPACITY (MW)	2000 NET GENERATION (MWh)[2]
Coal-Fired Boiler Units Burning Sub-Bituminous Coal Only					
Belle River	DTE Energy	1, 2	20	1,395	9,280,608
J. H. Campbell	Consumers Energy Co.	1	42	265	1,690,412
Presque Isle	We Energies	7, 8, 9	26	270	1,645,772
Shiras	*Marquette Board of Light and Power*	*3*	*21*	*44*	*232,888*
Eckert Station	Lansing BWL	1, 2, 3, 4, 5, 6	42	375	1,678,978
Coal-Fired Boiler Units Burning Bituminous Coal Only					
Endicott	*MI South Central Power Agency*	*1*	*22*	*55*	*153,610*
Erickson[3]	Lansing BWL	1	31	155	872,715
Harbor Beach	DTE Energy	1	36	121	284,677
J.B. Sims	City of Grand Haven, MI	3	21	65	380,585
Marysville	DTE Energy	6, 7, 8, 9, 10, 11, 12	64	200	129,893
Presque Isle	We Energies	1, 2, 3, 4, 5, 6	36	330	1,753,451
TES Filer City Station	TES Filer City Station Ltd. Partnership	1, 2	14	63	495,332
James De Young	Holland BPW	3, 4, 5	43	61	340,651
T. B. Simon	Michigan State University	1, 2, 3, 4	30	61	224,744
Wyandotte	*City of Wyandotte*	*7, 8*	*18.5*	*57.5*	*251,846*
Shiras	*Marquette Board of Light and Power*	*1, 2*	*36*	*34*	*28,314*
Coal-Fired Boiler Units Burning Both Sub-Bituminous And Bituminous Coals					
B. C. Cobb	Consumers Energy Co.	4, 5	48	313	2,182,702
Dan E. Karn	Consumers Energy Co.	1, 2	44	530	3,580,567
J. C. Weadock	Consumers Energy Co.	7, 8	48	313	2,196,344
J. H. Campbell	Consumers Energy Co.	2, 3	31	1,256	6,613,666
J. R. Whiting	Consumers Energy Co.	1, 2, 3	51	325	2,004,412
Monroe	DTE Energy	1, 2, 3, 4	31	3,280	18,353,799
River Rouge	DTE Energy	2, 3	47	651	2,817,446
St. Clair	DTE Energy	1, 2, 3, 4, 6, 7	47	1,547	7,344,317
Trenton Channel	DTE Energy	7, 8, 9	48	776	3,725,939

[1] James De Young burns a blend of 60% western bituminous and 40% central App. bituminous. James De Young Unit 3 (11 MW) and Unit 4 (22 MW) are in the Industrial MACT as are Shiras Units 1 and 2. T.B. Simon is a non-EGU combined heat and power facility. Presque Isle Units 1, 2, 3, 4, 5, and 6 burn western bituminous coal only. Wyandotte and TES Filer City burn a percentage of tire-derived fuel.

[2] Generation for Endicott plant represents 1998 value; generation for Shiras plant represents an average of 1996 to 1998 E-GRID data (E-GRID 2000 value for each was zero, fact is both plants are still operating).

[3] All Erickson units were switched to sub-bituminous coal in April of 2004.

Data sources: Owner information is principal owner from EPA ICR database; boiler numbers are from EPA ICR; generator age are averaged from EPA E-GRID2000 (Version 2.0) database; total net generator capacity is from E-GRID 2000 database; some information was acquired through personal communication with the utilities..

3.2 Review/Comparison of Emissions from Michigan Coal-Fired Utilities by Type of Emission Unit and Control

Table 8 shows the breakdown of emissions control systems used at the 65 coal-fired units in Michigan and the control methodology applied for SO_2, NO_X, and PM (NOTE: Power plants listed in italics did not participate in the Michigan Mercury Electric Utility Workgroup.) The calculated emissions of mercury (per EPA recommended guidelines) are from the listed units for calendar years 1999 (per EPA ICR), and 2001 and 2002 (per the TRI). Mercury emissions from 1999 to 2002 appear to be decreasing. Due to differences in the data bases, mercury emission estimating techniques, and the generation for the different years, this trend may not be accurate.

Table 8 also shows that PM emission control systems are the primary control systems used on coal-fired generating units in Michigan. The majority of these units utilize electrostatic precipitators (ESP) for collection of particulate (either cold-side or hot-side ESP [CS-ESP or HS-ESP, respectively]). However, the following units utilize fabric filter (FF) baghouses:

- MSU - T.B. Simon Units 1, 2 and 4
- TES - Filer City Units 1 and 2
- Marquette - Shiras Units 1, 2 and 3
- Wyandotte Unit 8
- We Energies - Presque Isle Units 1-4

Control of SO_2 emissions from coal-fired units is accomplished primarily by the use of low-sulfur coals. The following four plants in Michigan use SO_2 scrubbers:

- Grand Haven Sims Unit 3 - Wet flue gas desulfurization (FGD)
- Marquette Shiras Unit 3 - Dry Scrubber
- Michigan South Central Endicott Unit 1 - Wet FGD
- TES Filer City Units 1 and 2 - Dry FGD

The MSU - T.B. Simon Unit 4 is a circulating fluidized bed boiler (CFB) that achieves SO_2 and NO_X reduction/control without add-on emission controls.

Of the low-sulfur coal fuels that are burned, the large majority are classified as western sub-bituminous fuel mined in the Powder River basin (PRB) area of Wyoming. As shown in **Table 8**, a significant number of units use a blend of PRB and eastern bituminous coal, some of which is low-sulfur fuel. The following units burn PRB exclusively:

- DTE Energy Belle River Units 1 and 2
- Consumers Energy Campbell Unit 1
- We Energies Presque Isle Units 7-9
- Lansing Eckert Units 1-6
- Marquette Shiras Unit 3

NOTE: the following acronyms are used in **Table 8**:

CFB: circulating fluidized bed boiler
CS-ESP: cold-side electrostatic precipitators
FF: fabric filter
FGD: flue gas desulfurization
HS-ESP: hot-side electrostatic precipitators
LNB: low-NO_X burners
MSFB: multi-solid fuel fluidized bed boiler
n.s.: not subject.
OFA: Overfire air
SCR: selective catalytic reduction
SNCR: selective non-catalytic reduction
SO_X: oxides of sulfur

Table 8: Coal-Fired Power Plants in MI With Existing and Planned SO_X, NO_X, and PM Controls With Mercury Emissions

PLANT NAME	SO_X Controls[1]	NO_X Controls[1]	PM Controls[1]	REQUIRED CONTROLS[1]			MERCURY EMISSIONS (lbs)		
				SO_X	NO_X	PM	1999[2]	2001[3]	2002[3]
Coal-fired boilers burning sub-bituminous coal only									
Belle River	Low-sulfur coal	LNB	CS-ESP	-	LNB w/ OFA	-	242.8	310	311
J. H. Campbell – Unit 1	Low-sulfur coal	LNB	CS-ESP	-	-	-	103.9	included below	included below
Presque Isle – Units 7, 8, 9	Low-sulfur coal	LNB	HS-ESP	-	New LNB, Advanced Combustion controls	-	76.1	90.5	71.4
Shiras – Unit 3	*Dry scrubber*	*OFA*	*FF*	-	-	-	*20.2*	*4.2*	*18*
Eckert Station	Low-sulfur coal	LNB	CS-ESP	-	LNB	-	155.8	107	102.3
Coal-fired boilers burning bituminous coal only									
Endicott	*Wet FGD*	*OFA*	*CS-ESP*	-	-	-	*6.4*	*13*	*13*
Erickson	Low-sulfur coal	LNB	CS-ESP	-	-	-	50.7	25	27.7
Harbor Beach	Low-sulfur coal	None	CS-ESP	-	-	-	9	8.4	8.7
J.B. Sims	Wet FGD	LNB	CS-ESP	-	LNB w/ OFA	-	6	22	16
Marysville	Low-sulfur coal	None	CS-ESP	-	-	-	4.4	4.7	No operation
Presque Isle – Units 1, 2, 3, 4, 5, 6	Low-sulfur coal (co-fire petroleum coke)	LNB, Advanced Combustion Controls (units 3, 4, 5, 6)	CS-ESP (units 5, 6), FF (units 1, 2, 3, 4)	-	-	-	47.4	21.1	18.5
TES Filer City Station	Dry scrubber	OFA	FF	-	-	-	2.3	5.3	5.4
James De Young	Low-sulfur coal	LNB (unit 5 only)	CS-ESP	-	-	-	6.8	7.8	7.1
T. B. Simon	Low-sulfur coal, CFB	LNB, OFA, SNCR, CFB	Baghouse, HS-ESP	-	Units 1-4	-	n.s.	n.s.	n.s.
Wyandotte	Low-sulfur coal *(unit 7)* *Limestone injection, MSFB (unit 8)*	*LNB (unit 7)*	*ESP (unit 7), baghouse (unit 8)*	-	-	-	*n.s.*	*12.4*	*11.2*
Shiras – Units 1, 2	*Sulfur content limit*	*None*	*FF*	-	-	-	*Included above*	*Included above*	*Included above*
Coal-fired boilers burning both sub-bituminous and bituminous coals									
B. C. Cobb	Low-sulfur coal	LNB	CS-ESP	-	-	-	120.7	79.2	84.7
Dan E. Karn	Low-sulfur coal	LNB	CS-ESP	-	SCR	-	214	130.6	137.3
J. C. Weadock	Low-sulfur coal	N/A	CS-ESP	-	-	-	122	73.6	77.7
J. H. Campbell – Units 2, 3	Low-sulfur coal	LNB	CS-ESP	-	SCR	-	406.3	363.1	317.6
J. R. Whiting	Low-sulfur coal	LNB	CS-ESP	-	-	-	127.4	78.3	70.8
Monroe	Low-sulfur coal	LNB	CS-ESP	-	SCR	-	810.4	754.6	620
River Rouge	Low-sulfur coal	LNB w/ OFA	CS-ESP	-	-	-	139.5	100.4	120
St. Clair	Low-sulfur coal	LNB w/ OFA	CS-ESP	-	LNB w/ OFA	-	246	220	250
Trenton Channel	Low-sulfur coal	None	CS-ESP	-	-	-	198.1	194.1	200
Total:							**3116.2**	**2625.2**	**2488.4**

[1] For plants with multiple boilers/generators, controls indicated cover majority of boilers/generators. Required controls refer to controls that are planned to meet implemented standards (in particular the NO_X State Implementation Plan [SIP] Call). Low-sulfur coal is <1% sulfur content in the fuel.
[2] For the Presque Isle plant, the emissions for EPA 1999 ICR are based on emissions from the U.S. Electric Power Research Institute (EPRI) 2000.
[3] 2001 and 2002 TRI data is for air emissions only. Data sources: Sulfur, NO_X, and PM controls from EPA ICR database or communications with utilities.

3.3 Mercury Emissions and Deposition

Once released to the atmosphere, regardless of the source, mercury can be transported on local, regional, and global scales. The concern over mercury in the atmosphere stems from its eventual deposition at the earth's surface and subsequent conversion to methylated mercury. This section addresses issues relevant to mercury emissions and deposition in Michigan, with a brief overview of important factors influencing deposition, discussions on watershed transport and methylation of mercury, and atmospheric deposition monitoring and modeling that has been conducted in the state.

3.3.1 Factors Influencing Atmospheric Deposition of Mercury

Mercury is generally thought to exist in the atmosphere in three states – Hg^0, RGM, and Hg(p) (in either oxidation state). The behavior of all three species in the atmosphere is unique and dependent on their physical and chemical properties.

Greater than 95% of the mercury in the atmosphere is in the elemental form (Lin and Pehkonen, 1999; Slemr et al., 1985). Hg^0 has a high vapor pressure, is relatively insoluble in water at 4.9×10^{-5} gram per liter (g/L) (Schroeder and Munthe, 1998), and has a low deposition velocity on the order of 0.05 to 0.1 centimeter per second (cm/s). As a result, Hg^0 has a long atmospheric half life (weeks to months) and therefore can be transported on a global scale. However, recent laboratory research has indicated that Hg^0 can be oxidized (by hydroxyl radical) more readily than previously assumed, and researchers indicate that this increased rate could mean a lower average residence time of Hg^0 in the atmosphere (i.e., 124 days instead of one year) (Pal and Ariya, 2004).

RGM has a lower vapor pressure, is water soluble at 66 g/L, as mercuric chloride (Schroeder and Munthe, 1998), and is estimated to have a deposition velocity on the order of 1 to 5 cm/s (EPA, 1998; Lindberg and Stratton, 1998). Hg(p) is usually a small fraction of RGM, with the possible exception of urban areas and in the vicinity of some emission sources (Keeler et al., 1995). Hg(p) has a deposition velocity which is particle size dependent and ranges from 0.1 to 1 cm/s (Landis and Keeler, 2002).

Because the deposition of mercury is very dependent on its atmospheric form, knowledge of the reactions which interconvert the various mercury forms is critical to understand and to model mercury deposition. Knowledge of the reactions which transform mercury, and their rates, is also important in assessing the sources of mercury that affect deposition to various ecosystems. Atmospheric chemical transformations and gas-particle interactions can significantly alter the gaseous form (e.g., Hg^0 or RGM) of the mercury as well as the physical state [gas vs. Hg(p)].

While the predominance of atmospheric mercury is in the Hg^0 state, it is the Hg(p), as well as RGM, which are highly water soluble as noted above (Fitzgerald et al.,

1991; Schroeder and Munthe, 1998). It is this water solubility that makes the RGM species the critical components in understanding mercury removal processes and deposition rates from the atmosphere (Lindberg et al., 1992; Landis et al., 2004). The fact that the gaseous forms of mercury interact in a complex way with PM suggests that gas-to-particle partitioning of mercury also controls the mercury deposition from the atmosphere. A large fraction (as much as 95%) of the mercury emitted by various source types was in a water soluble form as RGM (Prestbo and Bloom, 1995; Dvonch et al., 1999; Lindberg and Stratton, 1998).

While much progress has been made in identifying and quantifying mercury emission sources, few field-based studies have attempted to identify the mechanisms and processes critical to enable predictive modeling of mercury transport, transformation, and deposition. These include the characterization of speciated mercury in emissions, ambient air, and ultimately in deposition.

Mercury deposition has been monitored at several sites in Michigan on an event basis for more than a decade (see **Section 3.3.2**). The Michigan Network includes monitoring total mercury concentrations and deposition on a daily-event basis using automated wet-only collectors designed for trace element collection. In addition to mercury, a suite of other trace elements and major ions are monitored concurrently to allow analysis of the sources and patterns of the mercury wet deposition.

Mercury deposition in the U.S. and Canada has been monitored for nearly a decade through the Mercury Deposition Network (MDN), a sub-network of the National Atmospheric Deposition Program (NADP)/National Trends Network. The network involves monitoring mercury concentrations and total mercury deposition through integrated, weekly, wet-only sampling. The data can be used to examine spatial and temporal trends in mercury deposition (MDN, 2004). A discussion of the MDN data can be found in the "Scoping Study for Mercury Deposition in the Upper Midwest," (Seigneur et al., June 2003).[35]

3.3.2 Mercury Emission Deposition Patterns and Deposition in Watersheds

It was not until the early 1990's that reliable measurements of atmospheric mercury deposition were measured in the state of Michigan. With the advent of clean techniques and the growing realization that atmospheric transport and deposition was an important link in the cycling of mercury in the environment, research to characterize the spatial and seasonal trends in mercury deposition was performed in the state. The Lake Michigan Urban Air Toxics Study was one of the first multi-site studies conducted in the Great Lakes to quantify the concentration of mercury and other air toxics in the southern Lake Michigan basin. Ambient mercury measurements performed in Chicago aboard the research vessel Laurentian stationed offshore in Lake Michigan and South Haven, Michigan, revealed that total gaseous and particulate mercury levels in Chicago's

[35] This study is available at http://www.ladco.org/toxics/reports/Mercury%20Scoping%20Study.pdf

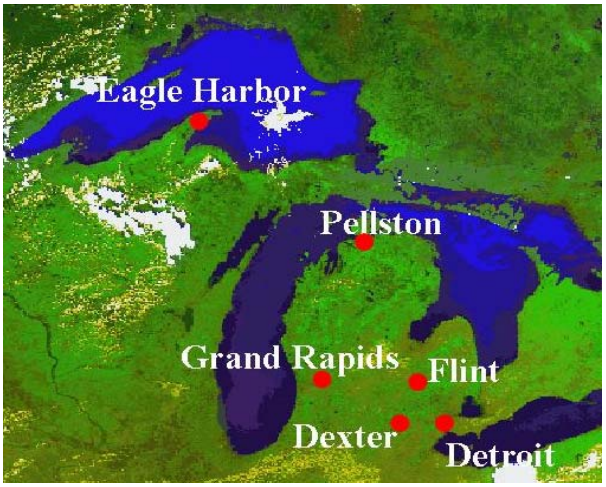
urban center were 5 to 15 times higher than at Michigan's rural site. These ambient measurements clearly showed the importance of over-water transport of air toxics from Chicago into Michigan and strongly suggested the need for further research into the wet and dry deposition of the mercury forms.

Starting in March 1992, event precipitation samples were collected for two years at three Michigan sites including South Haven, Pellston, and Dexter (Hoyer et al., 1995; Keeler and Hoyer, 1997). These sites were chosen to investigate spatial gradients and seasonal patterns in the concentration of mercury in precipitation. Daily event sampling was performed to allow one to investigate both the meteorological and source influences at each site. A spatial gradient in the wet deposition of mercury from the southern part to the northern part of the Lower Peninsula was observed, with South Haven receiving 1.6 and 2.3 times more mercury deposition than Pellston in the two respective years of sampling. While the spatial differences in mercury wet deposition are clearly a function of the different amounts of precipitation received, the difference in mercury concentration between the sites also contributes substantially to the regional gradient in wet deposition. The mercury concentration in event precipitation varied by season with mercury concentrations two times greater during spring and summer months than during winter. The majority of the mercury deposition measured at the sites in spring and summer was associated with transport from the southwest (e.g., Chicago and Indiana area). However, at both Pellston and Dexter, transport from the northwest contributed significant fraction (22%) of the mercury wet deposition. This finding is consistent with back trajectory models demonstrating that point sources of mercury in Michigan contribute to the mercury deposition measured at Dexter and sources in the Upper Peninsula of Michigan, as well as Canada contributing to mercury deposition measured at Pellston (Keeler and Hoyer, 1997).

The relative impact of the Chicago/Gary urban area on the ambient levels and deposition of mercury in the Lake Michigan basin was investigated as part of the Lake Michigan Mass Balance Study (LMMBS) and the Atmospheric Exchange Over Lakes and Oceans Study (AEOLOS). As part of the LMMBS, event wet-only precipitation, total particulate, and vapor phase samples were collected for mercury and trace element determinations from five sites around Lake Michigan from July 1994 through October 1995. In addition, as part of the AEOLOS, intensive over-water measurements were conducted aboard the EPA research vessel Lake Guardian during the summer of 1994 and the winter of 1995. Atmospheric mercury concentrations were found to be significantly higher on average in the Chicago/Gary urban area than surrounding sites: mercury in precipitation was a factor of two and Hg(p) was a factor of seven higher. Over-water measurements found elevated mercury concentrations 19 kilometers (km) off shore of Chicago/Gary suggesting an enhanced near field atmospheric deposition to Lake Michigan. A meteorological transport analysis also determined that local sources in the Chicago/Gary urban area significantly impacted all of the LMMBS sites indicating a broad impact to the entire Lake Michigan basin (Landis et al., 2002). These results supported the previous study performed in Michigan (Keeler and Hoyer, 1997), which report that the highest mercury concentration

and deposition events occurred with transport from the southwest to the South Haven, Michigan site. The relative mercury deposition contribution from urban areas such as Chicago was not the only significant finding of the LMMBS. For example, the report found that each year, Lake Michigan receives a total of approximately 1,403 kg (3,093 lbs) of mercury, of which approximately 84% enters the lake through direct atmospheric deposition.

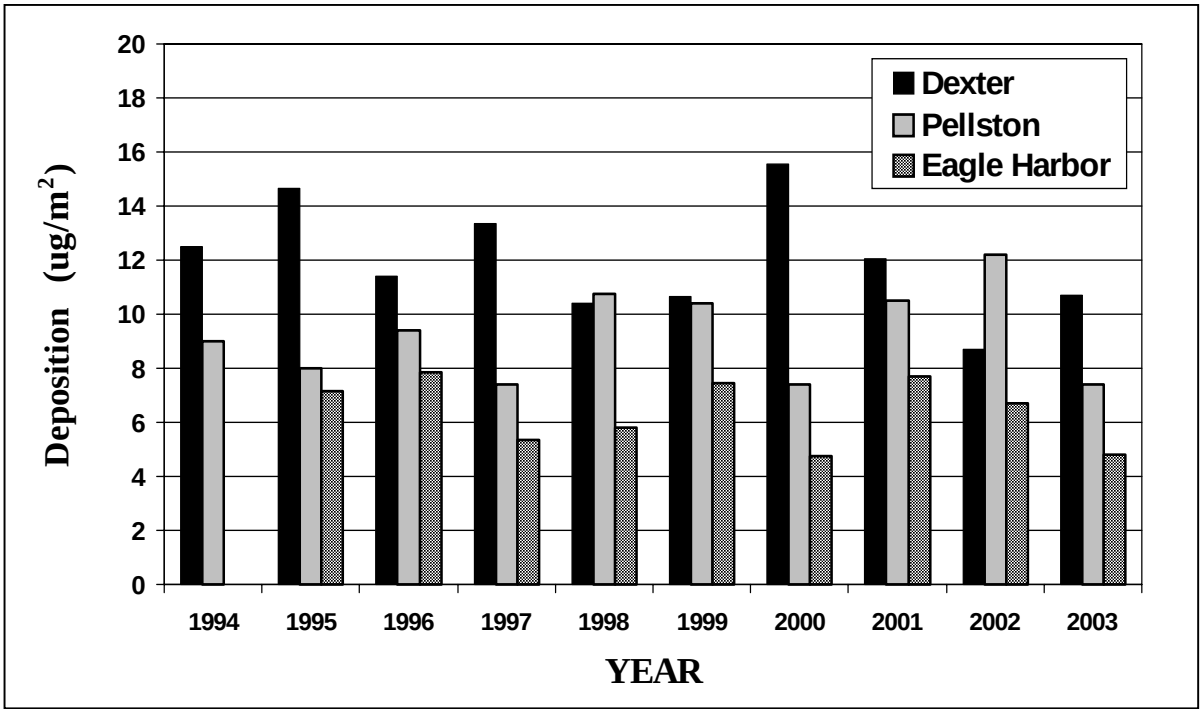
Figure 7: Site Locations for the Michigan Mercury Monitoring Network



Since the completion of the LMMBS, mercury sampling in Michigan has continued at several sites across the state as shown in **Figure 7**. Event precipitation sampling at Pellston, Dexter, and Eagle Harbor, a site on the shore of Lake Superior on the Keweenaw Peninsula, have continued to the present. The annual mercury deposition measured in event precipitation samples over time are shown in **Figure 8**.

Recognizing that long-term precipitation records are essential for establishing trends and understanding the impacts of changes in mercury emissions, the U of M Air Quality Laboratory collected a decade of event precipitation data samples at three sites in Michigan (Dexter, Pellston, and Eagle Harbor, shown in **Figure 7**). **Figure 8** displays the annual mercury wet deposition measured at these sites for the period 1994 to 2003. Over the 10-year deposition record, a clear decreasing gradient from south to north was observed. While the year-to-year variability in the deposition was on average 18% at each site, the 10-year total wet deposition sum at Dexter was 1.6 times the deposition collected at Pellston and 2.1 times that measured at the Eagle Harbor site. With the exception of the 2002 mercury deposition for Pellston (the maximum annual deposition over the 10 year record) the south to north decreasing gradient in deposition was observed each year. Furthermore, there was not an obvious trend in the deposition rates at the three sites over the decade of measurements. While there have been recent attempts to control mercury emissions within the region and nationally over the past decade, this data illustrates the consistent long-term impact that anthropogenic sources in the southern part of the Great Lakes region have had on mercury deposition across the Great Lakes Basin. Year-to-year variability in the precipitation amount received at a site together with meteorological transport differences from year to year largely control the deposition from site to site over time.

Figure 8: Annual Mercury Deposition Totals from Event Precipitation Samples Collected at Three Michigan Sites from 1994 to 2003



Wet vs. Dry Deposition

There is currently a dearth of measurements of the dry deposition of mercury anywhere in the world. This is largely due to the difficulty in performing these measurements and the cost of obtaining a long-term data base for this purpose. Measurements of ambient mercury concentrations have been performed that suggest strong gradients in the levels of Hg(p) as well as for RGM. These gradients would imply similar gradients in the dry deposition fields, but to date only limited data has been obtained for testing this assertion.

A 1996 Detroit study was funded by the Detroit Waste Water Treatment Plant in 1996 to ascertain in part, the atmospheric contributions of mercury in urban runoff (Gildemeister, 2001). This study collected dry deposition data at several sites in Detroit using surrogate surfaces, and revealed large spatial gradients in Hg(p) deposition. The dry deposition of mercury was found to be comparable to the wet deposition measured concurrently over the seven month study (10.2 µg/m^2 versus 14.8 µg/m^2, respectively). It is anticipated that the total dry deposition flux due to both Hg(p) and RGM would have been greater than the wet deposition flux, based upon the flux measurements performed in Chicago which suggested that about 52% of the dry deposition was due to Hg(p) (Landis and Keeler, 2002). While it was evident that urban sources were impacting mercury deposition to downwind lakes and ecosystems, studies performed to date were limited by the lack of RGM measurements. The RGM data is essential for estimating the dry deposition of mercury and for identifying the source or sources of the mercury deposited to the surface.

Currently, the network of mercury monitoring sites operational in Michigan is funded by the Michigan GLPF and EPA's Great Lakes Atmospheric Deposition program. Event precipitation samples are collected at all six Michigan sites (see **Figure 7**). Speciated ambient mercury measurements are performed simultaneously at the Dexter and Detroit sites using automated Tekran instrumentation. The concentrations of RGM in Detroit are highly variable but significantly higher than those observed at Dexter. The concentrations of all forms of mercury are higher at Dexter when air mass transport is from the east out of the Detroit corridor. The levels of RGM and Hg(p) are significantly lower at Dexter than those measured in Detroit at the same time. Thus, a fairly significant gradient in the ambient levels of mercury responsible for the dry deposition is suggested.

3.3.3 Watershed Transport of Mercury

Mercury forms that are emitted to the air from point and area sources can eventually deposit on aquatic systems. The transport and fate of mercury deposited in aquatic systems is another very complex issue that has received considerable attention in North America and other regions. For example, in the upper Midwest, detailed studies of mercury cycling within lakes was the subject of a multi-year research program in the 1990's that was largely funded by EPRI and its' many utility members. The project focused on seepage lakes, which are defined as small lakes that receive most of their water from the atmosphere via rain and snow. These lakes are especially common in Wisconsin, the Upper Peninsula of Michigan, as well as in the Northeastern region of the U.S. The entire project was managed by the WDNR. Numerous other studies of watershed transport of mercury have also been conducted in the Upper Midwest, with funding sources that include the WDNR, Lake Superior Basin Trust, EPA Region 5, EPA Science to Achieve Results program, the National Science Foundation, U.S. Department of Agriculture, and the Michigan GLPF.

The Wisconsin seepage lake research (Harris et al., 1996) provided a fundamental understanding of how mercury is processed by lakes in Northern Wisconsin, which are considered to be very susceptible to atmospheric inputs. Most significantly, it provided an understanding as to why some lakes had fish with high mercury levels while others less than a mile away, had fish with low mercury levels. The general reason for the apparently very different realities resides in the diversity of water chemistry and hydrologic conditions that exist in these seepage lakes. Mercury levels in fish are also related to land features, where lakes that have significant wetland development adjacent to them also tend to have higher mercury levels in fish (due to generally favorable conditions for methylmercury production). Finally, lakes that exhibit intense thermal or dissolved oxygen stratification, support low levels of plankton, or have pH levels less than 7.0 also tend to have fish that are higher in mercury (Harris et al., 1996; Watras et al., 1996; Chen and Folt, 2005). This is due to the fact that the microorganisms

that convert inorganic mercury[36] into methylmercury that is then taken up by the food chain in these lakes, can only live in lake areas (e.g., bottom sediments or surrounding wetland sediments) that are devoid of oxygen. While seepage lakes are important, they are not the only water bodies where methylation of mercury occurs.

With respect to the role that lake pH plays in methylmercury production, based on work that was conducted in the Wisconsin lakes, the following insight was gained. When the pH of a lake is above 7.0, the chemical reactions involving oxidized mercury that occur in the water column, tend to favor the reduction of oxidized mercury to the much more biologically inert Hg^0 form (Watras et al., 1996; Kelley et al., 2003). Researchers noted that Hg^0 was not oxidized in the water column, but was instead re-emitted to the atmosphere. By contrast, in more acidic lakes with pH less than 7.0, the reduction was less prominent as more oxidized mercury participated in the methylation reactions mediated by the subject microorganisms.

At the same time, numerous studies have documented that all lakes (including even higher pH [or higher alkalinity] lakes) can accumulate mercury in their sediments from air deposition - that is, not all the mercury input to water bodies is reduced to Hg^0 and evaded to the atmosphere for transport elsewhere. Several papers have reviewed sediment chronologies of mercury deposition showing generally increased deposition rates later in the 20th Century (e.g., Jackson, 1997; and Fitzgerald, 1998), and these patterns persist even in lakes with relatively higher alkalinity (e.g., Engstrom and Swain, 1997; Kamman and Engstrom, 2002). Another study also noted that the more acidic lakes tended to support lower biological productivity in the form of plankton (Watras et al., 1996). In addition, more recent work supports the premise that lakes exhibiting lower productivity also have fish that exhibit higher mercury burdens (Chen and Folt, 2005).

These findings have considerable ramifications for the Great Lakes as well. For example, Lake Michigan, similar to most of the other Great Lakes except Lake Erie, has a pH that averages about 8.0, and is also fully oxygenated from its surface to the bottom. Therefore, the required chemical environment for methylating microorganisms apparently does not exist in the lake proper. However, it should be pointed out that research (primarily in the laboratory) has indicated that abiotic methylation of mercury can occur through various routes (e.g., Morel et al., 1998; Ullrich et al., 2001). The end results from this understanding: oxidized mercury or Hg^0 that is deposited on the surface of the Great Lakes would likely not enter the reaction pathway that would lead to the production of methylmercury in the lakes; although, tributaries and surrounding wetlands would support methylation activities.

In a paper published in 2002, the fate of mercury being deposited on the surface of Lake Michigan was measured (Vette et al., 2002). They found that the amounts

[36] Inorganic mercury refers to compounds that do not include carbon and include salts, such as mercuric chloride and mercuric sulfate and other compounds (e.g., mercuric oxide, mercuric hydroxide, and mercuric sulfide).

of RGM plus Hg(p) dry deposited to the lake surface was approximately equal to the amount of total mercury deposited via precipitation to the lake (47% versus 54%). Furthermore, 37% of mercury that was deposited to the lake was re-emitted in the form of Hg^0 from the water column. Vette et al. (2002) also found strong gradients in the deposition of mercury with the highest values over Lake Michigan closest to the Chicago/Gary urban industrial areas.

As mentioned previously, the lakes also receive mercury from their many tributaries. Some of this mercury has already been converted to methylmercury by forests and wetlands within the tributary drainage basins before entering the lakes (Hurley et al., 1995; Hurley et al., 1998). Therefore, while the open waters of the Great Lakes do not, in general, exhibit optimal conditions for methylating microorganisms, bioaccumulation of mercury in the Great Lakes' food webs has been documented (e.g., results from the LMMBS[37]).

Because of the factors discussed above, mercury levels in Great Lakes predator fish tend to be lower than what has been found in typical upper Midwest inland lakes (Mason and Sullivan, 1997). At the same time, the MDCH has issued a fish advisory for Lake Michigan walleye due to both PCB and mercury contamination (MDCH, 2004).

Recent ongoing research has identified atmospherically deposited mercury as more bioavailable for conversion to methylmercury. Such studies include the METAALICUS, which stands for "Mercury Experiment to Assess Atmospheric Loadings in Canada and the United States."[38] METAALICUS is a whole-ecosystem experiment in which mercury loading to a small Canadian headwater lake (pH = 6.5; maximum depth - 21 ft.; area - 21 acres) and its watershed is being altered experimentally. This study represents the first whole-ecosystem experiment involving the addition of stable mercury isotopes. It should provide valuable insight as to how long it may take for mercury levels in aquatic systems to decline following reductions in mercury deposition to these systems.

In addition to the issues discussed above, with respect to seepage lakes and Lake Michigan, numerous other factors affect watershed transport of mercury including the extent of plant coverage (agricultural, forested, grasslands, etc.), litter fall (deposition of leaf and other debris with associated mercury to soils), transformations in soils, and surface and groundwater transport to lakes and other water bodies (see review in Grigal, 2002).

3.4 Modeling Atmospheric Mercury Deposition

Atmospheric transport and deposition models are also used to estimate the contributions of mercury emissions from various sources to local and regional

[37] Results from the LMMBS is available at http://www.epa.gov/glnpo/lmmb/results/hg_phyto.html#hg_lakestnave

[38] METAALICUS is available on the Canadian website at http://www.biology.ualberta.ca/metaalicus/metaalicus.htm).

deposition. These models rely on good emission inventory data, adequate understanding of atmospheric transformations of mercury, and ambient monitoring data or comprehensive measurement studies against which to compare model predictions (see discussion in Seigneur et al., 2004). Recent efforts to model mercury transport and deposition in North America (including in the Great Lakes region) have included approaches using Eulerian models (e.g., Seigneur et al., 2003); Lagrangian models (e.g., EPA, 1997e; Cohen et al., 2004); and a hybrid deposition approach (Landis and Keeler, 2002), some results of which are summarized in the following sections.

3.4.1 Results of Utility-Sponsored Mercury Deposition Modeling Studies

A modeling study funded by the Wisconsin Utilities was conducted by Atmospheric and Environmental Research, Inc. (AER) (Vijayaraghavan et al., 2002). The results of the Wisconsin Case Study (AER modeling) were presented to the Michigan Mercury Utility Workgroup at its November 2003 meeting. The modeling approach provided simulations of wet and dry deposition that were subsequently compared to MDN data as well as to estimates generated by other researchers. The simulations provided reasonable estimates of current deposition occurring in the upper Midwest, outside of the urban areas. The results of the Wisconsin Utility Case Study indicated that on an annual basis, coal-fired utility boilers in Wisconsin contribute approximately 1% to 4% of the mercury being deposited via precipitation near Wisconsin's MDN stations.

Approximately 84% of the coal burned by Wisconsin utilities is unblended PRB (sub-bituminous coal) while utilities in Michigan primarily burn blends of bituminous and sub-bituminous coal (see **Table 7**). Approximately 68% of the coal burned in Michigan is sub-bituminous (Federal Energy Regulatory Commission [FERC] coal usage data for 2002). This difference in coal combustion between the two states suggests that the mercury speciation profiles for Michigan power plants may be somewhat different than what was the case in Wisconsin. As a result of this and other considerations, the Michigan utilities contracted with AER to conduct a similar modeling exercise in Michigan to understand if the difference in fuel combustion significantly impacted model outputs. The results of the Michigan utility sponsored modeling are provided in **Appendix E**, which contains AER's report, "Modeling Deposition of Atmospheric Mercury in Michigan and The Great Lakes Region."

This AER report describes TEAM, a 3-D Eulerian multiscale model system used for continental, regional, and global modeling, that simulates the transport, chemical and physical transformations, and wet and dry deposition of the mercury species. Since model outputs can be sensitive to background concentration assumptions, as well as initial and boundary conditions, some details from the AER report are provided here.

The background emissions of Hg^0 include natural emissions from active volcanoes and releases from rocks with high amounts of mercury-containing minerals, as well as re-emissions of deposited mercury. AER assumed that 50%

of deposited mercury is re-emitted (see detailed discussion on re-emissions in Seigneur et al., 2004).

The results of the global model simulation (Seigneur et al., 2001, 2004) were used to provide the boundary conditions for the TEAM application to North America. It is important to note that the use of boundary conditions from a global model is different from previous modeling studies where boundary conditions were assumed by the modelers. It has been demonstrated that model results can be sensitive to boundary conditions, and consequently, the use of a global model (after satisfactory performance evaluation) to get the boundary conditions may be the better approach (Pai et al., 1999; Seigneur et al., 2004; Vijayaraghavan et al., 2004).

The boundary conditions included concentrations of Hg^0, RGM, and Hg(p) as a function of location, height, and season (boundary conditions vary according to the season). The values simulated for January, April, July, and October were used to represent winter, spring, summer, and fall conditions, respectively.

Above the boundary layer, AER allowed RGM and Hg(p) concentrations to decrease rapidly with height to a value of 0.1% of the model's top boundary layer. This decrease accounts for the effective scavenging of RGM and Hg(p) by clouds. The vertical variation of Hg^0 was more gradual to account for the fact that Hg^0 is a relatively long-lived species and has a longer residence time in the atmosphere.

The AER report used EPA's mercury emission inventory for non-utility sources located in Michigan while power plant emissions were obtained from the 1999 EPA ICR database. The estimates of total mercury emissions and mercury speciation for these power plants were taken from EPRI's analysis of the 1999 ICR database. AER used the inputs summarized above in this model to simulate mercury deposition in Michigan for the year 1998 (the most recent year for which wind field and precipitation patterns for North America was available) and to determine the amount of deposition that is attributable to Michigan power plants. The model predicted that approximately 4.0 metric tons of mercury was deposited annually within the state's boundary. For the Northeast region of the U.S., observed concentrations of wet and dry deposition, in general, agreed within a factor of two with model predictions. There was a relatively strong relationship between predicted and observed wet mercury deposition for the MDN sites outside of Michigan with a coefficient of determination (r^2) of 0.55 (a perfect fit between predicted and measured deposition would result in an r^2 of 1.0).

When the wet deposition model results for 1998 are compared with annual mercury deposition estimates based on the U of M Air Quality Laboratory's measurements taken at Dexter, Pellston, and Eagle Harbor stations in 1998, the results are within 14% for the Pellston and Eagle Harbor stations. However, the model did overestimate deposition at the Dexter site by a factor of two. Additionally, since wet deposition fluxes are highly influenced by precipitation fields, AER used daily precipitation fields from the National Center for

Atmospheric Research and refined them using annual precipitation data from the NADP/MDN database.

For dry deposition, the calculations used in the model to estimate dry deposition (which are outlined in Seigneur et al., 2004) can not be validated due to a lack of available dry mercury deposition measurements in Michigan.

Annual RGM emissions from Michigan power plants were estimated to be 0.6 tons and total mercury emissions were 1.1 tons. (These estimates are lower than estimated emissions for Michigan plants derived from the 1999 ICR data by EPA [i.e., 1.36 metric tons].)

The modeling report also discussed an observation, which was made at power plants located in Wisconsin and Georgia, that a portion of the RGM in some power plant plumes, may be reduced to Hg^0 during plume transport. Currently, the evidence indicates that reduction prevails in power plant plumes and oxidation prevails in urban plumes (Karamchandani et al., 1998). However, this aspect of mercury modeling exhibits considerable uncertainty. It should be noted that there are a limited amount of field-based data demonstrating these reduction/oxidation pathways. As many studies on the transformation of mercury in the environment have demonstrated, oxidation/reduction reactions are reversible, depending on the various parameters in the environment.

To examine the impact of uncertainty regarding the fate of utility emitted RGM, AER evaluated a scenario that assumed RGM reduction to Hg^0 was applicable to all coal-fired power plants in Michigan. For this scenario, the report concluded that power plants were responsible for only 0.05 tons of the approximately 4.0 tons of mercury deposition to the state. However, if this transformation was not included in the model runs, power plants became responsible for 0.1 tons (200 pounds) of mercury deposition. The statewide deposition attributable to Michigan power plants in northern Michigan was less than 2%, and less than 5% to deposition fluxes in central and southern Michigan. This estimated percentage was specific to deposition to Michigan's state borders and did not include the regional deposition impact. Additionally, AER states that, "Isolated areas near Detroit, southeastern Michigan and on the eastern shore of Lake Michigan that comprise less than 3% of the state's land mass and are near major emission sources show simulated contributions to mercury deposition fluxes that are between 10 to 24%." There are other uncertainties associated with atmospheric mercury transport and fate modeling including:

- There is a lack of speciated stack test data for all coal-fired electric utilities in the state, as well as other point and areas sources in and outside of the state. A number of uncertainties in mercury emissions remain, in particular for non-utility sources.[39]
- Regional 3-D Eulerian models are not designed to simulate localized impacts of point sources at the grid cell level, and consequently, the local impact (or a

[39] See for example Murray and Holmes, 2004.

potential hot spot) is likely to be overestimated by the regional model. In addition, even regional predictions are sometimes not internally consistent. For example, in Seigneur et al., (2004), strong plumes of atmospheric Hg^0 are evident in downwind regions of major source areas in Europe and East Asia, but not for U.S. sources.

- Challenges exist in integrating meteorological processes with physio-chemical processes in models (e.g., off-line approaches, where meteorological data is fed in periodically versus on-line approaches, where the two are integrated) (Dastoor and Larocque, 2004).
- The potential for strong influence of assumed boundary conditions exists because of the large volume of air mass transported over continents. Assumed boundary conditions that are too high or low by even relatively small amounts can significantly alter the outcome of models. For example, a crude calculation shows that assuming a baseline concentration of 1.6 nanograms per cubic meter (ng/m^3) in the lowest 10 km of the atmosphere over the continental U.S. leads to a baseline mercury mass over the country at any one time that is about 8.5 metric tons higher than is the case assuming a concentration of 1.5 ng/m^3. While this issue may be more relevant to modeling efforts where boundary conditions are assumed rather than calculated as intermediate output (as in the Seigneur et al., 2004 approach), in either case accurate input concentration data for regional models are important.

Further recommended studies to evaluate model performance are demonstrated by the following issues:

- The inability to show ambient and the wet plus dry deposition fields on a shorter time frame (i.e., daily) to validate speciated concentrations. Some global/regional mercury modeling has included comparisons of atmospheric concentrations on shorter time frames to measured data (see for example Dastoor and Larocque, 2004).
- The limited amount of field-based data on the mechanisms and processes critical to enable predictive modeling of mercury transport, transformation, and deposition. For example, there have been very few attempts at direct estimates of mercury dry deposition, and values for surrogates (such as nitric acid) vary by nearly two orders of magnitude (see Seigneur et al., 2004).
- The lack of Michigan specific speciated data for validating the dry deposition component of the model.

3.4.2 Additional Studies Examining Local and Regional Mercury Deposition

Though not necessarily specific to Michigan nor to utility emissions, a number of other studies have examined the issue of local and regional deposition of mercury and potential impacts on watershed and fish tissue levels, through both measurement and modeling approaches, as summarized below:

- Using a modified HYSPLIT model with 1996 emissions for a domain including mainly the U.S. and Canada, researchers estimated that approximately 48% of the mercury depositing on Lake Michigan came from sources within 100 km of

the lake. Modeling for the other lakes indicated a greater importance of sources lying from 200 to 700 km from the lakes. In addition, the researchers found that coal combustion in the U.S. "was found to be the most significant source category contributing mercury through atmospheric deposition to the Great Lakes" (Cohen et al., 2004). It should be noted, however, the authors also state that no contributions beyond the North American continent were considered in this analysis. North America contributes approximately 200 of the estimated 6400 metric tons of mercury emitted annually to the global atmosphere (Seigneur et al., 2004).

- In modeling of deposition to New York State, considering global anthropogenic and natural mercury sources, U.S. sources accounted for 56% to 63% of total deposition at a Catskill Mountains receptor site, with slightly lower values (42% and 55%) for the local deposition scenarios at the Adirondacks and Finger Lakes receptor site (Seigneur et al., 2003).
- Use of the REMSAD model by EPA and a modeling domain extending just outside the continental U.S. predicted that a significant portion of deposition at a number of Great Lakes sites could be ascribed to in-state sources (Atkinson, 2003). For example, AER's modeling work for the Michigan utilities (AER's Appendix D, page 4-2, Figure 4-1) suggests that local emission sources may increase total mercury deposition in Southeast Michigan to 50 to 100 $\mu g/m^2/yr$, considerably higher than projected deposition in surrounding areas.
- There have been very few studies measuring deposition systematically near power plants (and other mercury sources). A study measuring deposition near a coal-fired power plant and an adjacent municipal waste incinerator in Maryland found deposition, on a short-term basis (24 to 48 hours), up to four times higher downwind of the two plants than upwind (Prestbo, 2004). The work's primary purpose was to determine if a deposition gradient from local sources could be measured. More research is certainly needed in this area before any conclusions can be drawn.
- Modeling as part of the pilot mercury TMDL conducted in the Florida Everglades found a nearly 1:1 relationship between mercury deposition and levels in largemouth bass. In addition, data showed that consistent with significant reductions in incinerator emissions starting in the early 1990s, mercury levels in largemouth bass and egrets declined substantially, up to 80% (Florida Department of Environmental Protection [DEP], 2003). It should also be noted that 80% to 90% of the mercury present in flue gas produced by incinerators is assumed to be RGM and Hg(p) based upon the speciation profiles measured at the two largest incinerators in South Florida operating in 1995 (Dvonch et al., 1999).

In general, most models do not adequately account for the reactions leading to the local and regional formation of RGM. All models do suggest, however, that emissions within the U.S. are important sources for regions of high mercury deposition. Given the rapid deposition of RGM, and the potential for mercury to be oxidized in the atmosphere, emissions of mercury can contribute to local and regional deposition. Thus, mercury emissions are a global, regional, and local problem.

4. Regulations - Federal and Other States/Regional

In the 1990 Clean Air Act Amendments (CAAA), Congress put forth Section 112 that expressly addresses a list of 188 hazardous air pollutants (HAPs). The EPA is required to list categories and subcategories of "major sources" and "area sources" of the listed HAPs. EPA is further required to periodically review the lists of HAPs, major sources, and area sources. The CAAA outlines processes by which EPA may add new HAPs, major sources, and area sources to the lists. The CAAA also has a process to delete HAPs, major sources, and area sources from the lists. Once a major or area source category is listed, Section 112 requires the EPA to promulgate national standards to restrict emissions to the levels of MACT standards.

In CAAA Section 112(n)(1)(A), Congress addressed utility units separately and distinctly from major and area sources. Congress directed EPA to:

- Conduct a study that analyzed hazards to public health resulting from emissions of HAPs from utility units that would reasonably be anticipated to occur following imposition of the other requirements of the CAA (see EPA's Utility Report to Congress);
- Report to it the results of such a study by November 1993 (EPA' report was completed in 1998);
- Develop and describe, in the report, alternative control strategies for emissions which may warrant regulation under this section; and
- Determine whether, based on the results of the study, regulation of utility units under CAAA Section 112 was appropriate and necessary.

Additionally, CAAA Section 112(n)(1)(B) stipulates that EPA shall:

- Conduct a study of mercury emissions from electric utility steam generating units, municipal waste combustion units, and other sources (see EPA's Mercury Study Report to Congress issued in December 1997);
- Consider the rate and mass of such emissions, the health and environmental effects of such emissions, technologies which are available to control such emissions, and the costs of such technologies;
- Report the results to Congress by November 1994 (EPA did not complete until December 1997).

Neither of these reports was completed in the required timeframe established by Congress and they did not include any regulatory determinations. Environmental groups sued to require EPA to collect further information on mercury emissions and control technologies, issue a regulatory determination, and propose regulations. In November 1998, EPA signed a settlement establishing a deadline for the Agency to determine, by December 2000, whether the regulation of HAPs from power plants under Section 112 was "appropriate and necessary." The settlement was further amended to set a deadline of December 15, 2003 for issuing proposed MACT rules. The final rule deadline was extended by the court until March 15, 2005.

There were four major studies conducted on mercury between 1997 and 2000 upon which the EPA's regulatory determination was based:

1. **EPA's Mercury Study Report to Congress issued in December 1997** (EPA, 1997a)[40]

   This Report to Congress fulfills the requirements of Section 112(n)(1)(B) of the CAAA and provides an assessment of the magnitude of U.S. mercury emissions by source, the health and environmental implications of those emissions, and the availability and cost of control technologies.

   The Mercury Study Report to Congress found that epidemics of mercury poisoning following high-dose exposures to methylmercury in Japan and Iraq demonstrated that neurotoxicity is the health effect of greatest concern when methylmercury exposure occurs to the developing fetus. The Japanese event was the result of the direct discharge of methylmercury contaminated sludge, into Minamata Bay. Once present in the bay, the methylmercury accumulated in the tissue of shellfish and fish that were subsequently consumed by wildlife and humans. Average fish consumption was reported to be in excess of 300 g/day, compared to an average U.S. consumption of 8 to 10 g/day. At the height of the epidemic, mercury concentrations in the fish were between 10 and 30 ppm wet weight. Average concentrations in U.S. fresh water fish are roughly 0.3 ppm. The Iraqi epidemic followed the consumption of seed grain that had been treated with a fungicide containing methylmercury.

   In addition, the EPA Mercury Study Report had the following findings:

   - Fish consumption dominates the pathway for human and wildlife exposure to methylmercury.
   - The study concluded that methylmercury is a developmental toxicant in humans.
   - At the RfD (oral reference dose) or below, exposures are considered unlikely to cause harm. The RfD is a dose of methylmercury that is protective of the developing fetal nervous system. It is anticipated to be protective of brain development in the young child.
   - There is a plausible link between anthropogenic releases of mercury from industrial and combustion sources in the U.S. and methylmercury in fish.
   - It is not possible to quantify how much of the methylmercury in fish consumed by the U.S. population is contributed by U.S. emissions relative to other sources of mercury, such as natural sources and re-emissions from the global pool.
   - Given the current scientific understanding at the time of the study, because of the limited scientific understanding of the environmental fate and transport of mercury, it could not be assumed that a change in total mercury emissions will be linearly related to any resulting change in methylmercury in fish, nor over what time period these changes would occur. This is an area of ongoing study.

[40] The EPA 1997 study is available at http://www.epa.gov/ttn/atw/112nmerc/mercury.html.

- Coal-fired utility boilers are the largest domestic source category for total mercury emissions.
- For the year 1994, coal-fired utilities emitted approximately 51 tons of mercury to the atmosphere in the U.S. (32% of the anthropogenic total). This total was estimated to be 13% to 26% of the total (natural plus anthropogenic) airborne emissions of mercury in the U.S. based on EPA estimates using the RELMAP model.
- Based on the information presented in the report, the U.S. emissions represent 0.55 grams of mercury per person per year. This compares to 0.90 grams of mercury per person per year in the United Kingdom, 0.75 grams per person per year in the western area of Germany, and 0.88 grams per person per year in Poland. The European average is about 1.2 grams of mercury per person per year.

2. **EPA's Utility Hazardous Air Pollutant Report to Congress (Utility RTC) issued in March 1998** (EPA, 1998,)[41]

In the Utility RTC, EPA examined 67 of the 188 HAPs listed in Section 112. These 67 HAPs represent the pollutants EPA believed could potentially be emitted from utility units. The Utility RTC found the following:

- Mercury from coal-fired utilities is the HAP of greatest potential public health concern and merits additional research and monitoring.
- Based on the extant data and knowledge of developing studies, human populations exposed to sufficiently high levels of methylmercury either in utero or post partum will have increased incidence of neurotoxic effects.
- Dioxins and arsenic were HAPs of potential concern from coal-fired power plants, with further evaluations and research needed.
- Nickel is a HAP of potential concern from oil-fired power plants.
- EPA identified several control options that should reduce HAPs emissions from utility units.

In addition, the Utility RTC reiterated the following findings of the EPA's Mercury Report to Congress:

- Consumption of fish is the dominant pathway of exposure to methylmercury for fish-consuming humans.
- Coal-fired utilities were estimated in 1994 to be emitting approximately 51 tons of mercury to the atmosphere in the U.S. There is a plausible link between mercury emissions from anthropogenic combustion and industrial sources, and methylmercury in fish.
- That it is not possible to quantify how much of the methylmercury in fish is contributed by current U.S. emissions relative to other sources of mercury, such as natural sources and re-emissions from the global pool.

[41] The Utility RTC is available at http://www.epa.gov/ttn/atw/combust/utiltox/eurtc1.pdf.

3. EPA's 1999 Mercury Information Collection Request (ICR)[42]

As part of the effort to assist EPA in making its regulatory determination whether it is appropriate and necessary to regulate emissions of HAPs by electric utility steam generating units, as required by Section 112(n)(1)(A) of the CAAA, the EPA conducted an ICR. The purpose of the ICR was to determine the amount and variability of mercury in coal used in 1999, as well as targeted measurement of mercury emissions from specific facilities including two Michigan facilities (DTE Energy's St. Clair plant[43] and We Energies Presque Isle[44]). Following are some of the ICR results:

- During 1999, 1,143 coal-fired units conducted chemical analyses of the coal shipments received. The coal was tested for mercury, chlorine, ash, sulfur, Btu, and moisture content. EPA received a total of 40,527 analyses.
- Also during 1999, 86 stack tests for speciated mercury emissions were conducted. Of these, 73 took place under the authority of Section 114, seven were part of a U.S. Department of Energy (DOE) test program, and six were voluntary. Measurements were taken before and after the last control device on the tested unit.
- Based on the results of the ICR, EPA estimated that in 1999 the utility industry emitted 48 tons or 41% of all industrial sources of mercury emissions.
- The data collected through this ICR served as a focal point for discussion by the Utility MACT Working Group, formed by EPA in 2001. It also served to shape the subcategories and their corresponding MACT controls that went into the proposed mercury rule published on January 30, 2004.

4. NAS's Toxicological Effects of Methylmercury issued in July 2000 (NAS, 2000)[45]

At the direction of Congress, EPA funded the NAS to perform an independent evaluation of the available data related to the health impacts of methylmercury and provided recommendations for EPA's RfD. The RfD is the amount of a specific chemical which, when ingested daily over a lifetime is anticipated to be without adverse health effects to humans, including sensitive subpopulations (see **Section 2.5.1**). The NAS conducted an 18-month study of the available data on the health effects of methylmercury and provided EPA with a report of its findings in July 2000. The key findings from the NAS study are:

- Mercury is widespread and persistent in the environment. Its use in many products and its emission from combustion processes have resulted in well-

[42] EPA's Mercury ICR is available at http://www.epa.gov/ttn/atw/combust/utiltox/utoxpg.html#ICR).
[43] A final report on the stack testing conducted at DTE Energy's St. Clair plant is available on the EPA website at: http://www.epa.gov/ttn/atw/combust/utiltox/mercury/stclair4r.pdf.
[44] We Energies Presque Isle plant's report on their conducted stack testing is available at http://www.epa.gov/ttn/atw/combust/utiltox/mercury/presq59r.pdf. In addition, the Presque Isle Plant also conducted additional voluntary flue gas measurements for insight on the behavior of mercury in flue gases utilizing different particulate control devices. This report is available at: http://www.epa.gov/ttn/atw/combust/utiltox/mercury/pre146r.pdf
[45] The 2000 NAS information is available at http://www.nap.edu/books/0309071402/html/.

documented instances of population poisonings, high-level exposures of occupational groups, and worldwide chronic, low-level environmental exposures.

- Consumption of contaminated fish is the major source of human exposure to methylmercury in the U.S.
- Methylmercury is highly toxic. Exposure to methylmercury can result in adverse effects in several organ systems throughout the life span of humans and animals. There is extensive data on the effects of methylmercury on the development of the brain (neurodevelopmental effects) in humans and animals.
- The committee found that neurodevelopmental problems are the most appropriate basis for setting an exposure limit. Strong scientific evidence exists from human and animal studies to link certain levels of methylmercury exposure and neurological problems, including poor performance on tests that measure attention and motor function. The report notes that evidence also indicates that the cardiovascular and immune systems could be affected by methylmercury. Information on whether methylmercury causes cancer in humans is still inconclusive.
- Fetuses are particularly vulnerable to methylmercury because of their rapid brain development, and some may currently be receiving exposures at levels that cause observable adverse neurological effects.
- Long-range transport modeling indicated that approximately 30% (15 tons per year) of utility mercury emissions deposit in the U.S.
- EPA's RfD is a scientifically justifiable level for the protection of public health (see **Section 2.5.1**).

4.1 Regulatory Determination

On December 20, 2000, EPA determined that it was both appropriate and necessary to regulate coal and oil-fired utility units under Section 112 of the CAA, and subsequently added these units to the list of major source categories under Section 112(c) (EPA, 2000).[46]

The EPA premised its December 2000 "appropriate and necessary" finding primarily on the results of the Utility RTC. EPA also found that:

- Data gathered since the Utility RTC, corroborated the previous nationwide mercury emissions estimate and confirmed that utility units were the largest remaining unregulated anthropogenic source of mercury emissions to the atmosphere in the U.S.
- There is a plausible link between methylmercury concentrations in fish and mercury emissions from coal-fired utility units.
- It was appropriate to regulate HAP emissions from coal and oil-fired utility units under Section 112 of the CAA because they had identified several control options that should reduce these emissions.
- It was necessary to regulate HAP emissions from coal and oil-fired utility units because the implementation of other requirements under the CAAA will not

[46] EPA-452/R-97-003, 79825, December 20, 2000, available at http://www.epa.gov/ttn/atw/combust/utiltox/utilfind.pdf.

adequately address the serious public health and environmental hazards arising from such emissions.

EPA's appropriateness finding in December 2000 focused on the significant health hazards associated with mercury in the environment and the availability of control options which EPA anticipates will effectively reduce HAP emissions from EGUs. The EPA determination that regulation of HAP emissions from coal-fired and oil-fired units, under Section 112(c) of the CAA, triggers regulation under Section 112(d) requiring that all HAPs emitted by major sources in listed industrial categories be regulated using a MACT standard.

Under the MACT standard, at minimum, new sources must achieve the same emissions rate as is achieved by the best controlled similar source in the industry (42 U.S.C. 7412 [2000]). Existing sources emission rates must be set at a level based on the average of the best performing 12% of existing similar sources. This is known as "the regulatory floor." EPA may regulate industrial sources more stringently than the floor, considering technical feasibility, cost, and environmental benefits.[47]

4.2 The Clean Air Act Advisory Committee (CAAAC) Utility MACT Working Group

As part of the regulatory development process, EPA indicated a willingness to include various stakeholder groups in the effort to structure a regulation while achieving maximum input. It was decide that the most effective means of ensuring inclusion would be through the formation of a working group under the existing Permits, New Source Review and Toxics Subcommittee of the CAAAC, established under the Federal Advisory Committee Act (FACA).

The Utility MACT Working Group was formed with an original constituency of six representatives of state/local/tribal agencies, eight representatives of environmental organizations, and sixteen representatives of affected sources, fuel producers, suppliers, and labor groups. The overall goal was to provide EPA with input regarding federal air emissions regulations for coal-fired and oil-fired electric utility steam generating units that will maximize the benefits of a rule, in flexible framework, at a reasonable cost of compliance within the constraints of the CAA.

The Working Group was formed for an initial period of one year, with the first meeting on August 1, 2001. A total of 13 meetings were held through October of 2002. A summary presentation of the Working Group's process and recommendations was made at the October 30, 2002 meeting.[48] Excerpts from the presentation follow.

[47] In 2001, prior to completion of the EPA MACT floor determination, EPA staff made a presentation that current technologies could allow coal-fired power plants to achieve an overall average of 89% reductions in mercury emissions under a MACT standard. Under such a standard, existing domestic coal-fired power plant mercury emissions could be reduced from 48 tons per year in 1999 to roughly 5.5 tons per year after control. (EPA, December 4, 2001, supplementary presentation for Edison Electric Institute on mercury, p. 6, available at http://cta.policy.net/epamercury.pdf).

[48] A summary of each meeting, plus all relevant documents presented and discussed at each meeting, can be found at: http://www.epa.gov/ttn/atw/combust/utiltox/utoxpg.html#CAAAC.

The initial goal was to develop consensus of opinion on identified issues. It was quickly determined that there was a significant divergence of opinions within the participants. Given that, the goal was refocused to identify the issues, thoroughly discuss those issues, and clearly identify the various stakeholder positions.

4.2.1 Subcategories for Mercury

The group discussed whether and how to subcategorize the source category "oil and coal-fired electric utility steam generating units." The consensus was that oil and coal-fired boilers should be separate subcategories. No other consensus was reached on this issue.

4.2.2 MACT Floor Levels for Mercury

The group discussed the mercury MACT floor level, considering the ICR data and the variability in measurements, in sampling, and in the operation of the best performing plants. Consensus was reached with respect to the new source floor, which would be based on the best performing similar source. No other consensus emerged on this issue.

4.2.3 Beyond the MACT Floor Levels for Mercury

Under the MACT provisions of the CAA, EPA may impose MACT standards that are more stringent than the MACT floor. In doing so, the Agency must consider the cost of achieving such an emission reduction, any non-air quality health and environmental impacts, the ability to reasonably achieve that standard, and energy requirements. There was little agreement with in the Working Group on the need for beyond the floor controls for mercury.

4.2.4 Non-Mercury HAPs

The group addressed the question of whether or not EPA must set standards for HAPs other than mercury. There was a prevailing opinion that existing sources should have standards or limits based on subcategorization. Categories suggested focused on the type of combustion process and the rank of coal being used as fuel. No consensus was on this issue for existing units.

4.2.5 Compliance Time

The group discussed the applicability of statutory provisions allowing extensions from the presumptive 3-year compliance time. The consensus opinion recognized that this regulation may require extensive retrofits. The CAA provides additional time to install controls under some circumstances, which may be triggered in this instance.

4.2.6 How to Address Variability in the ICR Data and Its Application to the Rule

The stack test data and the performance of the various existing control technologies in use produced a data set with a high degree of variability. Issues addressed included:

- The representativeness of the stack tests,
- The worst case performance,
- The averaging time,
- The control technology parameters,
- The appropriate format for the standard, based on this data set (30-day average, annual average),
- The correlation of mercury and other parameters., and
- Statistical approaches for resolving the variability issues.

EPA was left to sort out the multiple approaches that could be used to address this issue. More analyses were warranted. EPA continued to seek advice and recommendations from the participants, after the Working Group process concluded.

The option of regulation under Section 111 of the CAA was not presented to the workgroup. **Table 9** shows a comparison of recommended mercury reductions by workgroup members including environmental stakeholders, state air pollution officials, major utilities, the Clean Energy Group, and western utilities.

Table 9: Comparison of Stakeholder Mercury Emission Rate Reduction Recommendations

COAL TYPE	STAKEHOLDER RECOMMENDATIONS (in lbs/TBtu)				
	Environmental	State	Major Utilities	Clean Energy Group	Western Utilities
Bituminous	0.2	0.6	2.2	1.2	2.4
Sub-bituminous (wet FGD)	0.2	0.6	4.2	1.2	5.8
Lignite	0.2		6.5	9.1	11.2

4.3 Federal Regulation: EPA Clean Air Mercury Rule

EPA CAMR was proposed on December 15, 2003, signed on March 15, 2005, and published in the Federal Register on May 18, 2005. EPA is reported to have received more than 600,000 public comments, more than any previous EPA proposed rule. The CAMR uses the NSPS under Section 111 of the CAA to set emissions limits for new sources and establishes a cap-and-trade program for all existing and future coal-fired EGU sources. **Table 10** lists the mercury NSPS for new sources.

Table 10: Final Mercury NSPS for New Sources

COAL TYPE	EMISSIONS LIMITS	
	lbs./MWh	lbs./TBTU*
Bituminous	21×10^{-6}	2.0
Sub-bituminous – wet FGD	42×10^{-6}	4.0
Sub-bituminous – dry FGD	78×10^{-6}	7.4
Lignite	145×10^{-6}	13.6
Coal refuse	1.2×10^{-6}	0.1
IGCC	21×10^{-6}	1.9

*Converted from lbs./MWh: lbs./MWh x (1 MWh/1000 kWh) x (1 kWh/3413 BTU) x (10^{12} BTU/TBTU) x efficiency = lbs./TBTU [Efficiencies obtained from data in EPA draft MACT standard on emissions limits, roughly 0.32 (i.e. 32%) for each coal type].

The cap-and-trade regulation would set a cap of 38 tons and yield approximately a 20% reduction by 2010 and impose a 15 ton cap yielding a reduction of nearly 70% by 2018. This approach sets a hard cap and any new sources coming on line would have to fit within this cap. Should a source exceed its emissions cap, its exceedance must be offset by purchased or banked allowances. Exceedances of the national cap must be offset by banked allowances resulting from over control of mercury emissions. Under a cap-and-trade system, the sources, states and EPA track emissions on a continuing basis, in order to assure that sufficient credits will be available for the end of the year accounting. The CAMR requires states to develop regulation and a state implementation plan (SIP) for existing coal-fired EGUs. These plans must be submitted to EPA by October 2006. With the promulgation of CAMR, the U.S. becomes the first nation to regulate coal-fired EGUs for Mercury (source – CAMR).[49]

CAMR includes a cap-and-trade program with a banking provision. EPA acknowledges that the banking provision could allow total emissions to exceed the second phase cap well beyond 2018. In fact, in two different model scenarios, EPA estimates total national utility mercury emissions in 2020 with implementation of CAIR and CAMR at approximately 25 tons or 21 tons.[50]

EPA revised its regulatory finding that was issued in December 2000 pursuant to Section 112, removing coal and oil-fired electric utility steam generating units from the CAA Section 112(c) source category list. This means that coal-fired electric utility steam generating units are a “delisted source category” from Section 112(c) and are no longer subject to a MACT regulation. At the time of this report, a coalition of thirteen states’ Attorneys General had filed a lawsuit challenging the rule on the grounds that the rule improperly exempts power plants from regulation under Section 112 of the CAA.

[49] The CAMR rule was published in the Federal Register May 18, 2005 and is available at:: http://www.epa.gov/fedrgstr/EPA-AIR/2005/May/Day-18/a8447.pdf.

[50] See EPA, 2005b, Regulatory Impact Analysis of CAMR, March 2005, pp. 8-2 – 8-4.

4.3.1 Cap-and-Trade

Market-based mechanisms for reducing pollution include a variety of economic or market-oriented incentives and disincentives, such as tax credits, emissions fees, or tradable emissions limitations (emissions trading for short) or cap-and-trade. Cap-and-trade sets a limit (or cap) on total amount of pollution that can be emitted from all regulated sources, and allows sources to buy or sell emissions allowances from other sources. [51]

Cap-and-trade was first implemented in the U.S. to control SO_2 emissions under Title IV of the CAA, or the Acid Rain Program. This program has helped reduce national SO_2 emissions from power plants by 32% from 1990 levels and is regarded as a success. The overall SO_2 budget was met and for this program, total emissions decreased. Similarly, a cap-and-trade program is being used to implement the NO_X SIP Call. As with the Acid Raid Program, the objective is to reduce long range transport for what is considered to be a regional issue. To date, this effort is mirroring the success of the Acid Rain Program in achieving the overall emission reduction target. Operating within the prescribed caps, a given source's emissions may rise or fall from year to year as long as the overall regional or national cap is maintained.

According to a study by Abt Associates, Inc., SO_2 emissions in 16 states increased from 1990 levels, and progress in decreasing SO_2 at individual power plants also was uneven over this period. Of the nearly 600 sulfur-emitting plants operating in both 1990 and 2001, 42% (252 plants) increased their sulfur emissions by 2001, including Michigan's J.H. Campbell power plant, which increased SO_2 emissions by 6% (Abt., 2002).[52]

EPA has acknowledged local increases in SO_2 emissions during the Acid Rain Program and is identifying ways to address this problem. At the May 4, 2004, Emissions Marketing Association Spring Meeting, a PowerPoint presentation was given titled, The Acid Rain Program Experience: Should We Be Concerned about SO_2 Emissions Hotspots? (Kinner et al., 2004).[53]

EPA's CAMR is the first time that a cap-and-trade program has been proposed or promulgated for a HAP. This continues to raise concerns over possible increases in localized emissions and/or deposition. Consequently, the fact that some facilities have been found to increase emissions under a national cap-and-trade program, and concerns about the impacts of toxic hot spots (localized concentrations of mercury near large emitters) resulting from increases in local deposition, are generating significant comment and scrutiny. In the Preamble to the Revision of the December 2000 Regulatory Finding, EPA addresses these concerns, outlining why it does not believe the CAMR will lead to the creation of a

[51] More information is available on the EPA's website at: http://www.epa.gov/airmarkets/trading/basics/index.html.
[52] The Abt Associates, Inc. study is available at http://64.78.32.98/pubs/PMHealthImpact2001.pdf.
[53] The presentation is available at available at http://www.epa.gov/airmarkets/articles/arpexperience.ppt)

utility hot spot. In addition, EPA defines 'utility hot spot' and the criteria for establishing whether or not a utility hot spot has been created.

4.4 Other States Regulations

Several states have initiated actions on state-specific mercury rules. These actions were taken in anticipation of delays in implementing a federal mercury rule (possibly as a result of the aforementioned lawsuits) and/or belief that a federal rule would not go far enough to protect human health and the environment. **Table 11** is a summary of those actions, as of the date of this report. NOTE: Due to the CAMR, rule making will need to be done by all states.

Table 11: Summary of Other States Regulatory Activities on Mercury Emissions

STATE	GOAL	REGULATORY ACTIVITIES	2003 COAL-FIRED GENERATION CAPACITY (MW)[1] (% Total Generation Capacity)
Connecticut	Legislation adopted in 6/2003, requires power plants to achieve 90% reduction in current emissions or meet emissions limit of 0.6 lbs/trillion Btu by 2008.	Utility importing Venezuelan coal to meet state recommended mercury emission limits.	400 (5.13%)
Illinois	The Illinois EPA completed a report to the House and Senate Environmental and Energy Committees in September of 2004 on "Fossil Fuel-Fired Power Plants.	Illinois EPA recommended to Governor that there be no state action, only federal action.	17,021 (34%)
Indiana	Formed a workgroup to evaluate mercury emissions.	No regulatory activities yet.	20,723 (80.1%)
Massachusetts	By 1/1/08 must use CEMS. Phase I: 7.15lb/tetra watt-hour (TWH) or 85% reduction by 1/1/08 with offsite credits allowed till 1/1/10. Phase II: 2.5 lb/TWH or 95% reduction by 10/1/12 with only facility bubble (no inter-facility trading).	Regulations adopted 5/26/04, effective 6/4/04. The final rule is available at http://www.mass.gov/dep/bwp/daqc/daqcpubs.htm#regs. .	1,690 (11.8%)
Michigan	Formed a workgroup to evaluate mercury emissions.	Regulations will be developed following the release of this report.	12,490 (42%)
Minnesota	1999 legislation established goal of 70% reduction from all emission sources by 2005 based on 1990 levels. The same legislation also established a voluntary reduction program.	No regulations. The state pledged not to pursue regulatory reductions as long as voluntary reductions from coal utilities continued. While 70% reduction goal will be met by 2005, voluntary reductions from coal utilities will account for less than 1% of reductions. The planned voluntary conversion of two coal-fired plants to natural gas and enhanced emissions controls on a third will result in a 15% reduction of utility sector emissions from current levels by 2009.	5,630 (49.4%)

Table 11: Summary of Other States Regulatory Activities on Mercury Emissions

STATE	GOAL	REGULATORY ACTIVITIES	2003 COAL-FIRED GENERATION CAPACITY (MW)[1] (% Total Generation Capacity)
North Carolina	Multi-emission regulations call for a study on mercury and development of standards for coal-fired units by 9/2005.	Action pending; rulemaking on hold pending federal action. Agency action not likely before studies and reports are completed in 2005. Also, expect Clean Smokestacks regulation to provide co-benefits.	12,494 (45.2%)
New Hampshire	Legislation enacted 5/2002 requires state Department of Environmental Services to recommend a cap on mercury emissions by 3/2004.	Action pending; agency to propose rules within 60 days of federal EPA MACT rule, no later than 12/31/04, to be effective 1/1/07.	609 (13.8%)
New Jersey	Seeking 90% reduction from coal-fired utilities by 2007 if control mercury only and 50% reduction if use multi-pollutant option with final compliance by 2012. Scrap metal smelters and municipal solid waste incinerators also required to reduce emissions.	Proposed rules on 1/5/04. Proposed rules available at http://www.state.nj.us/dep/ipoca/toxic_nj.htm.	1,710 (10.1%)
Oregon	Voluntary reduction program	Action pending. Mercury reduction strategy was released in December 2002. The report included a goal (not necessarily regulatory) of reducing mercury releases by 75% from 2001 levels by 2011.	601 (5.4%)
Virginia	Would require each facility to reduce mercury 90% by 1/1/08.	HB 1472 Introduced 1/23/04. Multi-emissions bill modeled after North Carolina Clean Smokestacks Legislation. Formed a mercury advisory committee in April 2004.	5,397 (25.4%)
Wisconsin	Cap-and-trade. 40% reduction by 2010; 75% by 2015; 80% by 2018..	Modified rule adopted 7/14/04. Rule development website is http://www.dnr.state.wi.us/org/aw/air/reg/mercury/ruledev.htm. NOTE: State action will be superseded by the federal action	7,118 (52%)

Acronyms: CEMS: continuous emission monitoring system; MW: megawatt; TWH: tetra watt per hour

[1]These values include nameplate capacity for Electric Generators, Electric Utilities and Independent Power Producers. Excluded from the categories were Combined heat and power for Electric, Commercial, and Industrial Powers. Website address for reference: http://www.eia.doe.gov/cneaf/electricity/epa/existing_capacity_state.xls

4.5 Regional Actions

4.5.1 The Great Lakes Binational Toxics Strategy

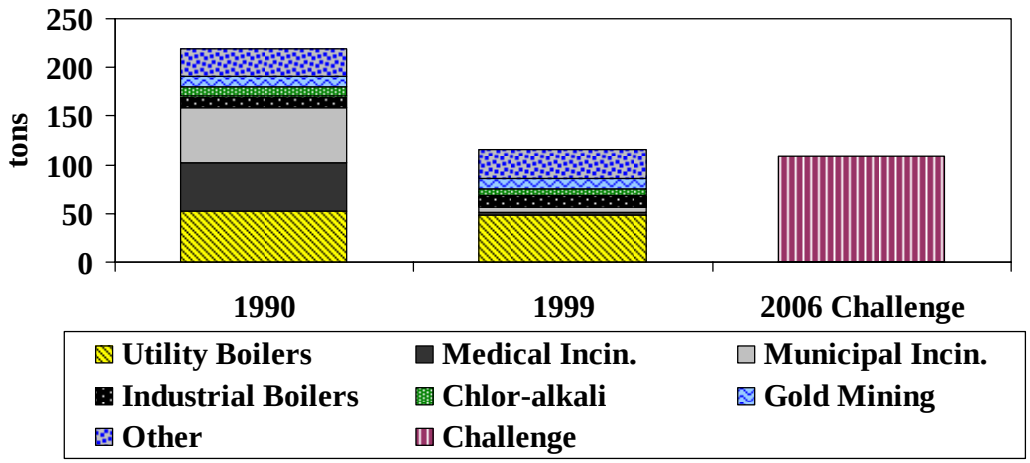
In keeping with the objectives of the Revised Great Lakes Water Quality Agreement of 1978, as amended by the Protocol signed on November 18, 1987 to restore and protect the Great Lakes, the Great Lakes Binational Toxics Strategy (GLBTS) is intended to develop a collaborative process toward the goal of virtual elimination of persistent toxic substances from the Great Lakes Basin. The parties include Environment Canada, the EPA, the Great Lakes' states, the Province of Ontario, and Native American Tribes and First Nations, working in cooperation with public and private partners.

The goal of virtual elimination is to be achieved through a variety of programs and actions, with the primary emphasis on P2. It is a long-term objective, with the GLBTS providing a framework to achieve specific actions, beginning in 1997. PBTs comprise a list of Level 1 substances representing the primary focus of the GLBTS. Mercury is a Level 1 substance.

The U.S. challenge is to see a 50% reduction nationally in the deliberate use of mercury, and a 50% reduction in the release of mercury from sources attributed to human activity. The best available data indicates that significant progress is being made in reducing releases, with a reduction of more than 43% to 47% between 1990 and 1999 (see **Figure 9)**. The prospects are good for meeting the 50% reduction challenge by 2006. For mercury use, the best available data indicate that the challenge has already been achieved (EPA, 2004c)[54] (See **Figure 10**). The release challenge applies to the aggregate of releases to the air nationwide, and of releases to the water within the Great Lakes Basin. These targets are considered interim and will be revised if warranted.

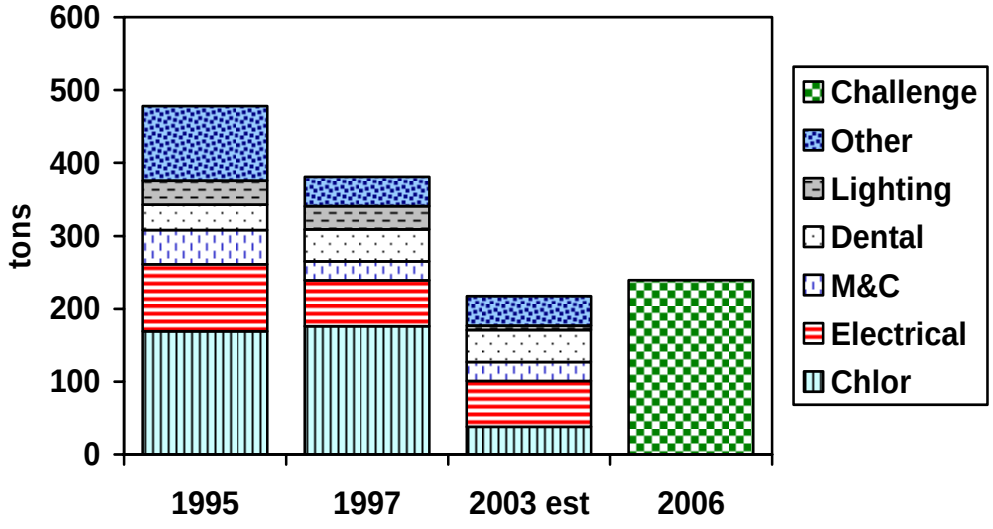
[54] Additional information is available at http://www.epa.gov/glnpo/bns/documents.html#annual%20Progress.

Figure 9: U.S. Mercury Emissions - 2006 Challenge, 1990 Baseline



Source: USEPA, Office of Air Quality Planning and Standards

Figure 10: U.S. Mercury Use



Source: U.S. Geological Survey, *Minerals Yearbook, 1996, 1997*. Chlorine Institute Annual Report to EPA, 2004; National Electrical Manufacturer's Association, direct communication, 2004.

The Canadian challenge is to seek a 90% reduction in the release of mercury, or where warranted, the use of mercury, from polluting sources attributed to human activity in the Great Lakes Basin. This is also an interim target, subject to revision if warranted.

The GLBTS acknowledges that the primary remaining source of mercury emissions in the Great Lakes ecosystem is atmospheric deposition. In the U.S., standards for municipal and medical waste combustors have been finalized. Implementation of controls on electric utility boilers is being developed. Controls on other point sources, such as chlor-alkali facilities, are also being developed and implemented. Analogous programs are being implemented in Canada. In the International Joint Commission's (IJC)[55] 12th Biennial Report on Great Lakes Water Quality, (2004)[56] the IJC urged the governments of both nations to step up protection and restoration efforts.

4.5.2 Mercury Action Plan, New England Governors/Eastern Canadian Premiers

The New England Governors and Eastern Canadian Premiers (NEG/ECP), comprised of six states and five provinces, adopted a Mercury Action Plan in 1998. The Plan documents a long-term goal of virtual elimination of anthropogenic emissions of mercury and a 50% reduction in regional emissions by 2003. In the Plan, the NEG/ECP also agreed to implement regional strategies to promote the maximum economically and technically feasible reductions in mercury emissions from electric generating facilities and other boilers in the region. In 2000, the NEG/ECP workgroup recommended a reduction in mercury emissions from coal-fired utilities by 20% to 50% by 2005 and 60% to 90% reduction by 2010. This recommendation has not been adopted by the Governors and Premiers. In the August 2002 Report To The Governors And Eastern Canadian Premiers On The Mercury Project, the issue of reducing mercury emissions from coal-fired utilities was still being reviewed with respect to the economic practicality, and with a multi-pollutant approach in mind (EPA, 2002c).[57]

This regional approach would allow states and provinces to address mercury contamination and deposition in their region while paying heed to interstate and international competition between electric utilities. This approach could complement, but not replace, state-level efforts in the Great Lakes region. Regional work to protect Great Lakes resources is well established and forums for this work, such as the Commission of Great Lakes Governors and Canadian premiers, are already in place.

4.6 Future Regulations and Co-Benefits

It is recognized that mercury emissions are reduced as controls for other pollutants are implemented. This concept is typically referred to as a "co-benefit." EPA is in the process of implementing and proposing several regulatory initiatives for other pollutants which are expected to produce co-benefits resulting in mercury reductions.

[55] The IJC was established through the 1909 Boundary Waters Treaty between the U.S. and Canada.
[56] The IJC 12th Biennial Report is available at http://www.ijc.org/php/publications/html/12br/english/report/index.html.
[57] The New England Governors and Eastern Canadian Premiers report is available at http://www.negc.org/documents/850088019.pdf.

Virtually all coal-fired power plants in Michigan have some measures in place to control or reduce particulate, SO_2, and NO_X emissions. Most of these existing air pollution controls also reduce mercury emissions. The amounts of reductions are dependent upon several factors, including coal type, configuration of controls, operating conditions, and unit type. A detailed discussion of the levels of mercury controls derived from co-benefits is contained in **Section 5**.

4.6.1 The NO_X State Implementation Plan (SIP) Call

The NO_X SIP Call is a federal rule aimed at forcing the reduction of NO_X emissions from utilities and large industrial sources in 19 eastern states to eliminate significant contribution of transported ozone.

The final rule requires the 19 eastern states and the District of Columbia to submit SIPs that reduce NO_X emissions from affected sources. Each state has been given a budget or cap for NO_X emissions from these sources. The implementation date for this rule was May 31, 2004.

To comply with the NO_X cap assigned to Michigan, several control options are being implemented. One category of controls is referred to as combustion controls. This includes measures like low-NO_X burners, computerized controls of the combustion process, over-fired air, and the combustion of PRB coal.

Post-combustion controls are being accomplished by the addition of SCR units to select boilers, typically newer larger units. SCRs also produce a co-benefit reduction for mercury. How much of a co-benefit is dependent upon coal type, coal blend, and other controls added on to the unit. A more detailed discussion is contained in **Section 5**.

4.6.2 The Clean Air Interstate Rule (CAIR)

On March 15, 2005, the EPA Administrator signed the CAIR to address the long-range transport of emissions that contribute to nonattainment of the new National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ and ozone. In this rule, 28 states, including Michigan, and the District of Columbia were found to contribute significantly to the nonattainment of one or both these new NAAQS. EPA proposes to reduce emissions of selected precursors to these two pollutants. The precursors chosen are SO_2 and NO_X. SO_2 is a precursor to the formation of $PM_{2.5}$, and NO_X is a precursor to both $PM_{2.5}$ and ozone.

CAIR targets emissions of SO_2 and NO_X from EGUs. In a manner similar to the NO_X SIP Call and the Acid Rain Program and utilizes a cap-and-trade system for both pollutants. Each state is assigned an emissions budget for each. The program would be implemented in two phases, with the first phase by 2010, and the second phase by 2015.

CAIR is projected to provide significant co-benefits for mercury. In order to meet the budget targets for NO_X emissions, SCRs installed for the NO_X SIP Call would be required to operate year-round, as opposed to just the ozone season (typically from May through September each year as ozone is a warm weather pollutant that is associated with hot, sticky summer days with light winds). Additional SCRs would be installed in CAIR states not included in the NO_X SIP Call. In order to meet the SO_2 budgets, it is expected that numerous wet or dry scrubbers will be installed. Scrubbers can be highly effective in capturing RGM in the flue gas. The effectiveness depends upon boiler type, coal type, coal blend, and other controls. A more detailed discussion of effectiveness is contained in **Section 5**.

In Phase 1 of the CAMR, almost all the reductions assumed by the cap-and-trade plan will come from co-benefits of the CAIR. Phase 2 of the CAMR would see the addition of mercury-specific controls which are currently being tested and/or developed for application on the commercial scale at utility boilers.

4.6.3 Legislative Multi-Pollutant Proposals

Over the last three years several legislative proposals have been put forth. Each of these would modify the CAA as it applies to EGUs. Each offers to replace the traditional pollutant-by-pollutant regulatory approach with a comprehensive process that would reduce emissions of SO_2, NO_X, and mercury, and in some proposals CO_2. The three leading proposals are the Bush Administration's Clear Skies Act, the Jeffords Bill, and the Carper Bill. The Clear Skies Act addresses SO_2, NO_X, and mercury. The Jeffords Bill and Carper Bill both address those same three pollutants plus CO_2.

It is important to note that one version of the Clear Skies proposal (S. 131) would entail developing a cap-and-trade system for SO_2, NO_X, and mercury, but also eliminate or suspend several CAA programs that currently affect emissions of these pollutants, including New Source Review, Prevention of Significant Deterioration, and the NO_X SIP call, under the rationalization that these programs would be redundant under Clear Skies legislation (McCarthy, 2005). This bill has yet to be voted out of committee.

5. Mercury Controls at Coal-Fired Utilities

Control of mercury air pollution sources has been investigated over the past two decades. Mercury-specific controls have been installed in the municipal and medical waste incineration industries in order to comply with federal regulations promulgated in the 1990s requiring stringent mercury control. Various mercury-specific and multi-pollutant control technologies have been investigated for application on coal-fired utility boilers, and a number of limited and full-scale pilot tests have been carried out over the past decade. This section presents information on key aspects of mercury control approaches to coal-fired electric utility emissions, including the effect of firing conditions (including coal and boiler type) on mercury emissions, configuration of existing coal-fired fleet in Michigan, development status of controls and options for reducing mercury at Michigan utilities, and costs associated with the most promising control options.

A number of publicly and privately funded research programs are exploring approaches to reducing mercury emissions from coal-fired utilities. For example, the DOE's National Energy Technology Laboratory (NETL) currently manages the largest funded research program in developing an understanding of fossil combustion-based mercury emissions, including their measurement, characterization, and the development of cost-effective control technologies for the U.S. coal-fired utilities.[58] Additional information on tests of a wide range of utility mercury control technologies is collected on-line by the Institute for Clean Air Companies, which represents companies that make and install the pollution control equipment used in many of the DOE and privately funded tests.[59]

5.1 Variation of Mercury Emissions Due to Fuel Type and Firing Characteristics at Michigan Facilities

Emissions from Michigan utility power plants are affected primarily by the type of coal burned, the type of coal-fired boiler used to combust the fuel, and the existing flue gas cleanup systems used to control pollutants. Each of these three elements is discussed in this section.

5.1.1 Effect of Coal Properties on Mercury Reduction

Forms of Mercury in Coal Combustion

Mercury in coal combustion flue gas exists in three basic forms: Hg^0, RGM, and Hg(p). Naturally present mercury in coal vaporizes due to the intense heat in the boiler. A portion of the vaporized mercury is oxidized by chlorine to form RGM. A variable amount binds to particulates in the flue gas and factors that affect variability are discussed later in this section.

At flue gas temperatures, both Hg^0 and RGM exist in the vapor phase. A fraction of this vapor phase mercury can adsorb onto porous solids (fly ash, powdered

[58] More information is available on the DOE/NETL's website at http://www.netl.doe.gov/coal/E&WR/mercury/index.html.

[59] Information on mercury control technologies collected by the Institute for Clean Air Companies is available at http://www.icac.com/controlhg/hgcontrols.html.

activated carbon [PAC], calcium-based sorbents) and subsequently be removed in ESPs and FFs. Hg(p) is already attached to solids and is readily captured in ESPs and FFs. RGM is weakly to strongly soluble in water and is generally captured in wet FGD. Hg^0 has a low solubility in water and is not captured in FGD systems.

Types of Coal

Coals burned in utility power plants are classified using a hierarch ranking system based on the degree of metamorphism (basically, the geological age of the coal and the conditions under which the coal formed). Coals are divided into four major categories called "ranks." Listed from highest rank to lowest rank, they are as follows (NOTE: Anthracite coal and lignite coal are not burned in Michigan.):

1. Anthracite coal
2. Bituminous coal
3. Sub-bituminous coal
4. Lignite coal

The coal ranks vary in heating values with anthracite coal having the highest heating values and lignite coal the lowest heating values. The mercury concentrations in the coal also vary according to rank as shown in **Table 12**.

Table 12: Ranges in Coal Mercury Content by Type (based on 1999 ICR data) *

COAL TYPE	MERCURY CONCENTRATION RANGE (ppm)
Bituminous	0.01 – 0.45
Sub-bituminous	0.02 – 0.36
Lignite	0.02 – 0.42

*(Berkenpas et al., 2001)

Table 12 also shows the wide range in coal mercury levels measured through the ICR effort. Although the ranges were large, median coal mercury levels (on an energy level basis – i.e., pounds of mercury per TBtu) were lignite > bituminous > sub-bituminous. However, coal mercury concentration alone does not determine the amount of mercury emitted from boilers. Other properties in the coal (discussed later in this section) and coal preparation prior to firing in a boiler can affect the emission of mercury (Kilgroe et al., 2002). Furthermore, coal rank is a continuous variable. Classifications such as "lignite," "sub-bituminous," and "bituminous" grade into each other and, in a few cases, can be subject to dispute.

Fly Ash Amount and Carbon Content

Mercury removal on fly ash alone (without sorbent injection) can vary widely, with control effectiveness (from mercury in coal) ranging from 0% to 90% (Pavlish et al., 2003). Some of the factors influencing the effectiveness of fly ash in adsorbing mercury include temperature, catalytic effects of ash constituents, and unburned carbon in the ash (see **Section 5.1.2**). Sub-bituminous coals on average produce less fly ash than bituminous coals; when considering fly ash

amount alone, this would indicate a greater likelihood of fly ash mercury control potential for bituminous coals. Lignite is typically equal to or greater than bituminous. However, a more important parameter appears to be ash carbon content. Mercury removal across an ESP or FF increases with the increase in the carbon content of fly ash. This is probably due to the carbon providing sites for mercury adsorption that acts similarly to a carbon injection system. In general, sub-bituminous and lignite coals have lower fly ash carbon content than bituminous coals. While the presence of a high unburned carbon content is a positive from the aspect of potential mercury removal, unburned carbon in ash is a negative with regard to boiler operating efficiency and minimizing the amount of coal to be burned to generate a kilowatt of electricity.

Chlorine Content

The chlorine content of coal is important for two reasons. It oxidizes Hg^0 to RGM in the boiler. RGM can then be easily removed in a wet FGD system (or controlled to some extent with a FF). Chlorine also generates hydrogen chloride (HCl) gas in the flue gas stream. HCl aids in the adsorption process of mercury onto fly ash, loss-on-ignition carbon, and other solid particles/sorbents. In general, eastern bituminous coal has higher chloride level than western sub-bituminous coal and lignite coal, and partially contributes to a higher degree of mercury capture in existing particulate control devices for bituminous coals.

5.1.2 Coal Combustion Technologies

All three of the following combustion technologies are used by Michigan power plants. The predominant combustion technology used in the state is pulverized coal combustion. Stoker-fired boilers and circulating fluid bed boilers are used for only a small percentage of the electricity generated.

Pulverized Coal (PC)-Fired Boilers

PC-fired units are the most widely used combustion technology by utilities today. PC boilers offer good combustion efficiency and can be designed and constructed for large scale applications of up to 1,300 MW. Using this combustion technology, coal is ground to a fine talcum powder-like consistency and is carried in suspension with pre-heated combustion air to boiler wall mounted burners where it is ignited. The combustion efficiency achieved with this process results in a lower potential of in-process mercury capture due to the lesser presence of unburned carbon in the ash.

Stoker-fired Boilers

This combustion technology burns coal in lump form on a traveling grate. This form of coal combustion was generally used in the early 20th century and was primarily used on smaller, industrial scale units. It does have some use in older utility power plants. Using this technology, lump coal (1½ inch and smaller) is broadcast on to a chain grate and combustion air is fed from under the grate. The grate moves slowly from rear wall to front wall of the furnace and the fuel is burned out with remaining ash being dropped into an ash collection pit off the front of the stoker. This technology is less efficient in terms of combustion efficiency

and is limited in size by the sizing of the grate. Stoker-fired units are generally limited to electrical generation sizes of 50 MW or less. In process, mercury capture in this older and less efficient technology is influenced by the relatively higher unburned carbon content in ash when compared to modern PC units. The unburned carbon can be a positive influence in in-process mercury capture.

Circulating Fluidized Bed (CFB) Boilers

CFB boilers are a more recent development in combustion technology. Their development was driven by increasingly stringent requirements for SO_2 and NO_X emissions. The intent of a CFB boiler design is to capture SO_2 in the combustion process and not post-combustion with backend cleanup equipment as is done with PC units. Likewise, a CFB unit produces less NO_X since the combustion temperatures in a fluid bed are less than in a PC unit. In a CFB, fine to moderately graded coal (usually < ¼ inch, but in some cases up to ¾ inch) is introduced into the furnace along with a sorbent bed material (usually limestone if sulfur capture is required). The entire mass of fuel and bed material is kept in suspension by combustion air and is circulated through the furnace and through cyclone collectors which classifies the heavier combustible and bed material back through the furnace in a circulating pattern, and routes the lighter fly ash material with the flue gas through to the exit of the unit. Sulfur capture is accomplished with the sorbent and leaves the unit with the heavier bottom ash or spent bed material.

CFB units have found application in burning a wide variety of coals, including ranging from low rank to higher rank coals as well as anthracite waste coals. CFB units are somewhat less efficient than PC units with common boiler efficiencies in the low to mid 80% range, while PC unit boiler efficiency is normally in the range of 86% to 88%. Currently, the largest available size for this type of combustion unit is limited to the range of approximately 250 MW for a single boiler, single turbine unit. Although difficult to quantify, the potential for in-process mercury capture with this type of combustion technology is somewhat enhanced by the amount of residence time that the fuel spends in the process and the presence of a sorbent material to allow mercury to be adsorbed. The use of CFB boilers has been common in industrial scale units of 10 to 100 MW capacity. The Council of Industrial Boiler Operators has documented data on the co-benefits of mercury reduction with this type of combustion technology.

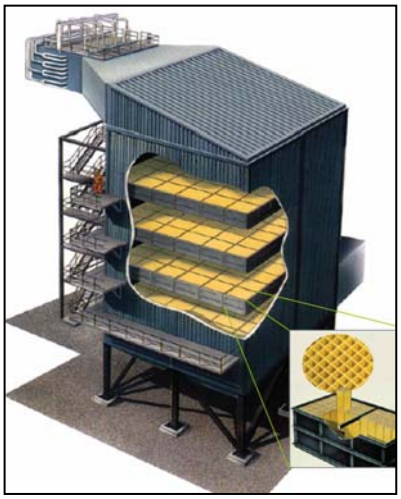
5.1.3 Flue Gas Cleaning Technologies

Flue gas cleaning technologies that have some applicability for mercury removal and are utilized by Michigan power plants include the following:

a. SCR or SNCR for NO_X reduction.
b. ESP and FF for particulate reduction (PM_{10} - particulate matter with a diameter of 10 microns or less).
c. Dry FGD systems using Spray Dryer Absorbers (SDA) for SO_X (oxides of sulfur) reduction.
d. Wet FGD systems for SO_X reduction.

The following brief discussion of these technologies draws largely on EPA's interim report (Kilgroe et al., 2002).

Selective Catalytic Reduction (SCR) Systems

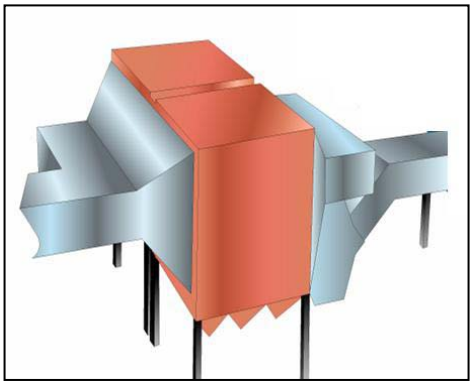


A SCR system uses a catalyst impregnated bed to reduce NO_X emissions. The catalyst in the SCR reactor can also oxidize a small percentage of Hg^0 to RGM, enabling the RGM to be captured in a downstream wet scrubber. Research to date on existing SCR systems has shown that oxidation does not occur to any appreciable extent with sub-bituminous coals but occurs to a large extent with most bituminous coals and blends that have about 30% or more bituminous coal. The rate of mercury oxidation depends on the type of SCR catalyst, flue gas flow rate, flue gas temperature, and the reactive catalyst site (remaining catalyst life cycle). Ammonia, injected in a SCR system, somewhat inhibits the mercury oxidation process. Overall, SCRs absent a downstream scrubber have variable impact on mercury removal depending on the specific installation and fuel type used.

Selective Non-Catalytic Reduction (SNCR) Systems

A SNCR system is a post-combustion NO_X reduction method that reduces NO_X through a controlled injection of a urea solution into the combustion gas path of fossil-fired and waste-fired boilers, furnaces, incinerators, or heaters. The resulting chemical reaction transforms NO_X, urea, and oxygen into molecular nitrogen, CO_2, and water. The NO_X reducing reaction is temperature sensitive: by-product emissions become significant at lower than optimum temperatures and NO_X reduction decreases at higher than optimum temperatures. It is not known if SNCR has any effect on mercury emissions.

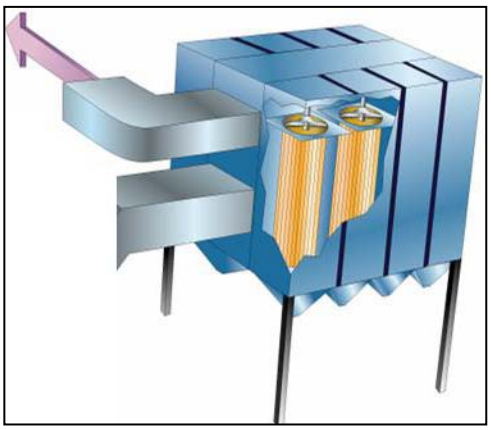
Electrostatic precipitators (ESPs)



ESPs are high-efficiency particulate control devices that have been used to control PM emissions for over 80 years. ESPs operate by imparting an electrical charge to flue gas particles and then attracting the particles to oppositely charged metal plates. The collected particles are periodically discharged from the plates and collected in hoppers. The effectiveness of particulate capture depends mainly on the electrical resistivity of the particles. In general, fly ash produced from higher sulfur coals is efficiently captured by an ESP, while lower sulfur coals produce a higher resistivity ash that is harder to capture. However, alteration of boiler firing temperature or fly ash conditioning upstream of the ESP can optimize

resistivity for particle collection. Particulates in the region of 0.3 micrometers (µm) are typically more difficult to control than larger particles. The ESPs installed are either HS-ESP or CS-ESP depending on whether the ESP is located upstream or downstream of the air heater. ESPs have the potential to remove most particulate and variable amounts of RGM (more in cases of higher unburned carbon levels in ash), but in general very little potential to remove Hg^0.

Fabric Filters (FFs)



FFs are high-efficiency particulate control devices that utilize a packing of fibers to intercept particles in the gas stream. Most FFs have one of two designs based on the cleaning method – either reverse-air or pulse-jet, with flue gas moving through the filter bags differently in each case. An advantage of FFs over ESPs for particulate control is relatively consistent control effectiveness across various fuel ash characteristics or particulate load (Lavely and Ferguson, 1996). FFs are generally more effective than ESPs at controlling smaller particles (< 0.3 um) and have greater potential to remove mercury than ESPs. Not only will Hg(p) be removed but RGM and potentially Hg^0 can be removed by sorbing onto the filter cake on the FFs. Overall, greater mercury removal rates are expected from the use of FFs.

Flue Gas Desulfurization (FGD) Systems

Dry FGD systems use dry or wet spray to absorb SO_2 gas and form dry particles that are collected in a particulate control device. For purposes of this report, wet-dry scrubbers (also known as SDAs) are considered together with dry scrubbers. Dry FGD systems include SDAs and CFB absorbers, the latter of which is integrated with the combustion technology. A calcium-based slurry/sorbent is injected into the reaction vessel where the flue gas reacts with the drying slurry droplets.

Wet FGD systems use a liquid absorbent to absorb SO_2 gas. The liquid is typically an aqueous solution containing an alkaline chemical that reacts with the SO_2 to form insoluble salts that are then removed from the scrubber effluent. Most wet FGD systems for SO_2 control use either limestone or lime as the alkaline source. Parameters that effect SO_2 removal efficiency include liquid-gas ratio, pH of the scrubbing medium, and ratio of calcium sorbent to SO_2.

Mercury capture in FGD systems is species dependent. FGD systems in general have the potential to remove Hg(p) and RGM to relatively high extents. Ranges of mercury removal efficiencies is shown in **Table 13**. RGM is generally water soluble and can absorb in the aqueous solution of a wet FGD system. Because Hg^0 has low water solubility, it's removal would only occur to the extent that it is adsorbed on either fly ash or added slurry/sorbent, which would typically be relatively limited. For bituminous coals, higher capture of all three species would

typically be expected in dry FGD units that are followed by fabric filters. Also, testing has shown potential for re-emission if the chemistry of the wet FGD favors the conversion of RGM to Hg^0.

5.1.4 Fuels Used, Current Emissions Controls and Combustion Technologies at Michigan's Utility Power Plants

Table 7 in **Section 3** provides a listing of the existing coal-fired power plants currently being operated by Michigan Investor Owned Utilities, Municipal Public Power Companies, Independent Power Producers, and the coal-fired Campus Based Cogeneration Plant. As **Table 8** in **Section 3** shows, Michigan coal-fired generators use both sub-bituminous and bituminous coals, either as a single fuel or a blend of the two fuels in their generating units. The two largest investor-owned utilities, DTE Energy and Consumers Energy, burn a substantial amount of sub-bituminous coal in their units.

The combustion technologies of choice for most of the utility coal-fired units in Michigan are PC-fired units. All of the coal-fired units currently being operated by DTE Energy and Consumers Energy are PC units, as are most of the municipal owned units and MSU's units.[60] The exceptions are:

- T.B. Simon Unit 4 at MSU, which is a CFB Unit
- Wyandotte Unit 8, which is a MSFB Unit
- TES Filer City Units 1 and 2, which are Stoker-Fired Units
- Marquette Shiras Units 1 and 2 which are Stoker-Fired Units

Emissions control devices at Michigan utilities are referenced in **Table 8** (in **Section 3**) and are primarily designed for the control of particulates. The particulate control device most commonly used (both in Michigan and nationally) is the ESP. FFs are used at the following units:

- Marquette Shiras Units 1, 2, and 3
- MSU's T. B. Simon Units 1, 2, and 4
- We Energy Presque Isle Units 1-4
- TES Filer City Station Units 1 and 2
- Wyandotte Unit 8

SO_2 scrubbers (either wet or dry) are used at:

- Michigan South Central Endicott Station (wet)
- Grand Haven Sims Unit 3 (wet)
- Marquette Shiras Unit 3 (wet/dry)
- TES Filer City (dry)

[60] NOTE: Based on EPA definitions of electric utility units, the MSU units, Shiras Units 1 and 2, and James De Young Units 3 and 4 are industrial boilers.

For all other units, control of SO_2 emissions is maintained by the use of low-sulfur fuels to comply with state and federal requirements.

Control of NO_X emission is maintained by several methods at Michigan utility units. Low NO_X combustion technology has been installed on the majority of the PC-fired utility units. In addition, the largest generating units owned by DTE Energy and Consumers Energy have been or are in the process of being retro-fitted with SCR systems for increased control of NO_X emissions. The units scheduled for SCR retro-fits are: DTE Energy's Monroe Plant Units 1, 2 and 4; and Consumers Energy's Karn Units 1 and 2 and Campbell Units 2 and 3. SCR retrofit of Monroe Unit 3 is tentative. MSU has retro-fitted selective non-catalytic reduction systems on T.B. Simon Units 1 to 3, whereas Unit 4, which is a CFB unit, was originally installed with this system.

In general, the strongest influences on the existing ability of Michigan coal-fired utility units to capture the mercury present in the coal fuel are the type of coal being burned and the existing emissions control equipment in place for capture for conventional controls alone. The use of sub-bituminous fuels, while effective in limiting SO_2 emissions due to their inherent low-sulfur content, presents a more difficult problem in mercury capture. While difficult to quantify and variable from unit to unit, this fact combined with the predominant use of ESPs as the particulate collection device of choice, results in low to moderate existing mercury capture effectiveness within the majority of existing EGUs. EGUs currently utilizing FFs as the particulate control device and/or scrubbers for sulfur control are expected to provide a higher level of mercury removal on a percentage basis. The potential benefits and risks of coal to coal fuel switching as a mercury control measure is further discussed in **Section 5.5.2**.

5.2 Relationship of Multi-Pollutant Controls and Mercury Reduction

Although flue gas cleaning technologies to date have been employed to remove other air pollutants, a percentage of mercury is also removed as a co-benefit. The amount of mercury removed can range from no removal to over 90% depending on mercury speciation (the chemical and physical form of mercury in the flue gas stream), the cleaning technology employed, and the temperature at which the cleaning technology is operated.

Table 13 shows the potential for mercury reduction as a co-benefit based on the type of combustion technology used, the type of coal burned, and the air quality control system technology used.[61] This table indicates average reductions observed on a limited test basis. As stated above, most of the largest EGUs in Michigan use a combination of PC-combustion technology, bituminous, sub-bituminous, or blended fuels, and CS-ESPs.

[61] All the listed units burn either 100% bituminous, or 100% sub-bituminous coals.

Table 13: Potential Mercury Reduction as a Co-Benefit

BOILER TYPE	COAL BURNED	AIR QUALITY CONTROL SYSTEM TECHNOLOGY UTILIZED			
		NO_X	SO_2	PM	Average % Total of Mercury Removed
PC	Bituminous	-	-	CS-ESP	36
PC	Sub-bituminous	-	-	CS-ESP	9
PC	Bituminous	-	-	HS-ESP	14
PC	Sub-bituminous	-	-	HS-ESP	7
PC	Bituminous	-	-	FF	90
PC	Sub-bituminous	-	-	FF	72
PC	Bituminous	-	Dry FGD	CS-ESP	Not Tested
PC	Sub-bituminous	-	Dry FGD	CS-ESP	43
PC	Bituminous	-	Dry FGD	FF	98
PC	Sub-bituminous	-	Dry FGD	FF	25
PC	Bituminous	SCR	Dry FGD	FF	98
PC	Sub-bituminous	SCR	Dry FGD	FF	Not Tested
PC	Bituminous	-	Wet FGD	CS-ESP	81
PC	Sub-bituminous	-	Wet FGD	CS-ESP	29
PC	Bituminous	-	Wet FGD	HS-ESP	46
PC	Sub-bituminous	-	Wet FGD	HS-ESP	20
PC	Bituminous	-	Wet FGD	FF	98
PC	Sub-bituminous	-	Wet FGD	FF	Not Tested
CFB	Bituminous	SNCR	-	FF	94
CFB	Sub-bituminous	SCR	-	FF	57

Source: Staudt and Jozewicz (2003). CFB data from Kilgroe et al., 2002.

No significant testing was done prior to 2003 of units that burned blends of bituminous/sub-bituminous coal. However, utilities have subsequently tested those types units and those preliminary test results indicate units that burn appreciable amounts of bituminous coal (greater than 30%) have a large percentage of Hg^0 present in the flue gas converted to RGM. It is expected that a large portion of this converted mercury will be captured by downstream control devices for units burning blended fuels.

5.3 Development Status of Controls and Options

A number of technologies can be used to remove mercury from utility coal-fired power plant flue gas. These technologies fall into two broad categories: existing control technologies intended for control of other pollutants, which can be optimized for control of mercury; and mercury-specific control technologies. These technologies vary in terms of the mercury control they can achieve, the kinds of coal type and power plant configuration to which they are best suited, and the extent to which they have been deployed on power plants to date. The following sections review the technological options for mercury control, including through the use of existing pollution control devices for other pollutants, mercury-specific technologies, and emerging multi-pollutant technologies.

5.3.1 Optimization of Current Control Configurations

While not designed for the control of mercury, each of the following control devices (ESPs, FFs, and both wet and dry SO_2 scrubbers) provide for some incidental removal of mercury. A major factor in determining mercury control effectiveness is speciation in the flue gas. RGM and Hg(p) are more readily controlled by existing pollution control devices than Hg^0. In general, on a mass basis (measured as ppm in the coal), western sub-bituminous coals have a lower mercury content than bituminous coals. Even though a coal may have a lesser mercury concentration as compared to other coal types, there is not a direct correlation between the mercury content in the coal and what is emitted from the stack. Other variables which need to be considered when trying to establish this relationship include the chlorine content of the flue gas, the carbon content of the ash, the quantity of the mercury contained in the coal that is speciated into Hg^0, RGM, and Hg(p), and the type(s) or controls that are utilized for PM control.

In general, because of higher chlorine and lower calcium levels, eastern bituminous coals tend to produce more RGM than sub-bituminous coals (Kilgroe et al., 2002). The following sections describe the extent to which existing pollution control devices remove the three different forms of mercury (Hg(p), RGM, and Hg^0).

Electrostatic Precipitators

Recent EPRI, EPA, and DOE-funded research has shown that ESPs remove virtually all of the Hg(p) from flue gases. Depending on the chemistry and character of the fly ash and flue gas, some of the RGM and a smaller percentage of Hg^0 will be absorbed onto fly ash and removed by the ESP as the flue gases cool after leaving the boiler. Because of greater Hg^0 produced, western coals (sub-bituminous, bituminous, and lignite-type coals) tend to lead to smaller overall percent removal rates by ESPs. In contrast, plants equipped with ESPs, which burn eastern bituminous coals, tend to capture more mercury than similarly equipped plants which burn western coals. Based on the ICR database, EPA found average mercury removal rates for a CS-ESP were 9**%** for sub-bituminous coal-fired boilers and 36% for bituminous coal-fired boilers. By contrast, the removal percentages for HS-ESPs were 14% and 7%, respectively (Staudt and Jozewicz, 2003).

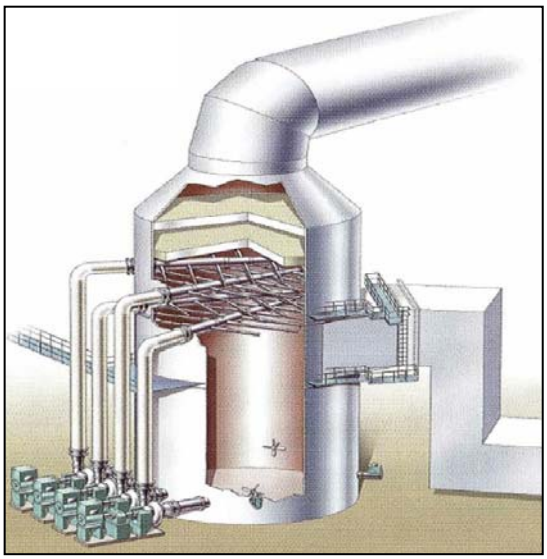
Fabric Filters

FFs have the potential for increased mercury capture compared to ESPs, because the mercury can be adsorbed by entrained fly ash as well as directly by the filter cake on a FF. FFs remove virtually all of the Hg(p) and are generally more, but not completely effective in removing RGM and Hg^0 from flue gas. Based on tests at five units through the ICR (an additional unit's results were thought to be compromised due to testing problems), average mercury control effectiveness of 90% and 72%, respectively, were tested for units burning bituminous and sub-bituminous coals (Staudt and Jozewicz, 2003).

FF technology evolved and gained widespread utilization in the power plant industry about a decade ago. Today, most new power plants utilize FFs or FFs in tandem with ESPs. In this latter hybrid set up, flue gas can first be passed through a smaller ESP to remove the majority of fine particulate, and then through a small, higher air-to-cloth ratio bag filter to more efficiently remove the residual particulates. However, virtually all of Michigan's coal-fired power plants were built before the FF technology was perfected and use is currently limited to thirteen Michigan units.

While new plants can employ FF technology alone or in combination with ESPs at reasonable costs, it can be costly for existing units to be retrofitted with FFs. The pressure drop across a FF is substantially higher than the pressure drop across an ESP. For newly built plants, boilers, ductwork systems, and fans are designed for a total system pressure drop, which is set by the various components in the system. When a new component is added to the system and the total system pressure drop increases, there is the potential for collateral impacts on the structural elements of the boiler, air heaters, and ductwork which can result in extensive structural modifications. Likewise, the units induced draft fans must be modified, supplemented by booster fans, or replaced all together to provide for adequate pressure capability. These modifications result in a substantial capital investment which is collateral to simply adding a FF as a new piece of equipment, driving up the total installed cost of the FF installation. An example of this effect is the total installed cost of the FF and ACI project being installed at the We Energies Presque Isle Plant, which is further discussed in **Section 5.6**.

Wet SO_2 Scrubbers



Wet SO_2 scrubbers remove many gases/compounds that are soluble in water; consequently, scrubbers can remove RGM but not Hg^0 since the elemental form is virtually insoluble in water. Due to increased production of RGM from bituminous coals, SO_2 scrubbers will, in general, be more effective in removing mercury from units burning these coals. Absent scrubbers, units that burn eastern coal have higher SO_2 emission rates and generally higher mercury emissions rates as well. Consequently, scrubbers are more likely to be installed on such units for SO_2 control. Those scrubbers will more cost effectively remove the higher concentrations of mercury associated with eastern coals. In addition, units burning bituminous coals and having FFs in combination with SO_2 controls can have removal efficiencies in excess of 90%.

There will be some scrubber retrofits in Michigan within the next decade and these can be expected to reduce RGM emissions.

Dry SO_2 Scrubbers

SO_2 emissions can also be controlled by injecting reagents into the flue gas and collecting the reacted sulfur residuals in an ESP or FF. As part of the ICR Part III data collection activities, several power plants equipped with dry scrubbers were tested. According to EPA, the efficacy of this control configuration to capture mercury is quite variable. The variability is a function of both coal rank and the particulate control device used. For example, for a bituminous coal-fired boiler equipped with a FF, 98% of the mercury was captured, while for sub-bituminous coal-fired boiler equipped with an ESP, mercury control (across the control device) was down to 43%. Mercury control effectiveness of dry scrubbers for units burning sub-bituminous coals was consistently lower, whether the units were equipped with CS-ESP/SDA. (The low removal rates for the three plants tested [Craig and Rawhide (Colorado), and NSP Sherburne (Minnesota) may have been due to the low coal chlorine levels, which would have contributed to very high fractions of Hg^0 in the flue gas [EPA, 2001b].)

5.3.2 Mercury-Specific Controls

Technologies designed specifically or in part for mercury control are at various stages of development. These range from technologies used extensively in other industries and already in pilot implementation on power plants, to more minor modifications of existing technologies, or to truly novel experimental technologies.

It should be noted that the application mercury controls introduces increased mercury concentrations into other waste streams from the control devices which must be properly managed (also see **Section 6.9**).

Technologies Available Now or in Near Future

ESP Modification/SO_2 Scrubbers: Low temperature catalysts that can be installed within an ESP or in the duct downstream of an ESP or FF, are being evaluated as a means to convert Hg^0 to RGM and thereby allow existing or planned wet SO_2 scrubbers to collect elemental as well as oxidized forms of gaseous mercury. Low temperature catalysts appear to be a more cost-effective technology being developed for retrofit applications in the near term. This option is limited to plants that have or are going to install SO_2 removal equipment. Cost information is not yet publicly available on some of the proprietary catalysts being tested.

In addition, proprietary reagents are being tested for use in existing scrubbers to help retain captured RGM in a scrubber's sludge. During the ICR measurement program, as well as during subsequent measurement work conducted by EPRI and DOE, researchers observed that some of the captured RGM was re-emitted as Hg^0. While the actual nature of these apparent reduction reactions remains undefined, it is believed that the reactions involve sulfur species. Cost information is not yet publicly available for these proprietary chemicals nor for the chemical storage tanks and injection equipment they would require.

Sorbent Injection: One of the most promising technologies for add-on mercury control at coal-fired power plants is sorbent injection. This involves injections of a sorbent material (typically in powdered form) in the flue gas upstream of a particulate collection device. Activated carbon has gained the most attention; in powdered form the sorbent provides the necessary surface needed for adsorption of mercury species. Any sorbent will be more effective when injected upstream of a FF because of the additional opportunity for mercury removal as the flue gas passes through the filter cake. Coal fly ash itself, depending upon its carbon and other mineral content, may also act as an effective adsorbent if FF technology is employed. Lime (in the event the plant utilizes dry scrubbing) and the impurities associated with the lime may also potentially absorb some RGM.

There are generally two types of ACI, standard ACI and chemically treated ACI. Chemically treated ACI generally has halogens added to the carbon which have a similar oxidizing effect to chlorine in the flue gas and are believed to be more effective in removing mercury from low chlorine sub-bituminous coals. Further discussion on chemically treated ACI is contained in **Section 5.7.3**.

One proprietary version of sorbent injection involves the TOXECON™ technology developed by the EPRI. The process involves injection of PAC into a pulse-jet FF installed downstream of the existing particulate collection device. A demonstration of this approach (currently just through the engineering phase) is now in progress at the We Energies Presque Isle Power Plant.[62]

We Energies Presque Isle Power Plant

Table 14 summarizes recent full scale field tests that have been performed at coal-fired power plants utilizing powdered ACI for mercury control. In addition, another 18 full-scale tests of sorbent injection are ongoing or scheduled for 2004 to 2005 (Durham, Michael D., 2004 workshop).

Mercury reduction is given as upper limits, where the reduction percentage has started to level off with additional carbon injection. Mercury reduction on the low end will vary based on the coal type (for native mercury reduction – i.e., without sorbent injection), the add-on technology, and the type and amount of sorbent injected. For units without fabric filters, the combination of standard carbon and bituminous coal has been shown to require approximately 20 lbs/MMacf (pounds of carbon per million actual cubic feet of flue gas) to reach 90%, while minimal increase in reduction (beyond about 70%) was seen for standard carbon and sub-bituminous coal beyond about 5 lbs/MMacf. In contrast, brominated carbons have been shown to be more effective at controlling elemental mercury emissions. Some testing has shown control levels of 90% or greater, while other tests

[62] Information is available at http://www.netl.doe.gov/coalpower/environment.

indicate control levels of approximately 70%. These and other test results are summarized in a recent EPA publication (EPA, 2005a).

Table 14: Mercury Control Efficiencies with Powdered ACI in Full-Scale Tests at Coal-Fired Power Plants

POWER PLANT (STATE)	COAL TYPE	EXISTING CONTROLS	ADD-ON TECHNOLOGY	MERCURY REDUCTION	REFERENCE
Alabama Power – Gaston Unit 3 (AL)	bituminous	HS-ESP	ACI and COHPAC* FF	Up to 90%	Bustard et al., 2002
Southern Co. – Yates Units 1,2 (GA)	bituminous	CS-ESP	ACI	Up to ~75%	Richardson et al., 2004
PG&E –NEG Brayton Point Unit 1 (MA)	bituminous	two CS-ESPs	ACI	Up to 90%	Durham et al., 2003a
WEPCO – Pleasant Prairie Unit 2 (WI)	Sub-bituminous	CS-ESP	ACI	70% (long-term)	Durham et al., 2003b
Sunflower Electric's Holcomb Station	Sub-bituminous	SDA, FF	ACI – several sorbent types	Up to 90%+	Sjostrom et al., 2004
DTE Energy - St. Clair Power Plant (MI)	85/15 sub-bituminous/ bituminous	CS-ESP	Brominated ACI	Over 90%	Nelson et al., 2004
Leland Olds Station Unit 1 (ND)**	lignite	Two parallel CS-ESPs	ACI	63% (average for month-long test)	Thompson et al., 2004
Great River Energy– Stanton Unit 10 (ND)	lignite	SDA, FF	Untreated ACI; Iodine-impregnated ACI	Up to 81% Up to 96%	Sjostrom, et al., 2002

*COHPAC is Combined Hybrid Particulate Collector (patented type of fabric filter).
**NOTE: Leland Olds test - target mercury removal rate was only 55%, carbon injection rate was adopted accordingly.

Another important consideration in ACI with only ESP particulate control is the ESP size. Coal-fired boilers have variably sized precipitators. The Specific Collection Area (SCA) describes the relative size of a precipitator, and is used to estimate the collection efficiency. The SCA is calculated as the total collector plate area divided by the gas volume flow rate (and thus has units of time/length). Before SO_2 control requirements were added in the CAAA of 1977, many Michigan plants burned higher sulfur coal that produced fly ash which was more easily captured by an ESP. Power plants built before this time typically had smaller precipitators with SCAs of 200 or less. The ease with which power plant ash is captured by a precipitator is a function of the chemical makeup of the ash and the SO_2 content of the flue gas. Eastern high-sulfur coal produces flue gas with higher SO_2 concentrations and ash with lower resistivity. After 1980, Michigan mandated lower SO_2 emissions and power plants in Michigan generally found that switching to lower sulfur coal, rather than installing scrubbers, was more economical to meet the lower SO_2 mandate. However, with the combustion of lower sulfur coal, many plants have found that their existing precipitators are functioning much closer to a particulate compliance limit. This is important when considering whether the particulate loading to an ESP or the resistivity of the fly ash can be further increased. ACI may change the resistivity of ash and increase particulate loading to the existing ESP, both potentially making PM control more difficult. Units that have an ESP with less than 300 SCA, particularly units that

burn sub-bituminous coals or blends containing sub-bituminous coals, may not perform properly from a particulate removal perspective if activated carbon is injected. **Table 15** shows where ESPs are utilized and the SCA of the unit is provided. Regarding the performance of ACI into small ESPs, the DOE mercury control research program includes a two-year project in this area due to be completed in September 2005.[63]

Table 15: Specific Collection Area of Existing ESPs
(square foot per 1000 actual cubic ft per minute [acfm])

PLANT NAME	OWNER	BOILER UNIT	SCA OF THE ESP
B.C. Cobb	Consumers Energy Co.	4 5	176 176
Belle River	DTE Energy	1 2	669 669
Dan E. Karn	Consumers Energy Co.	1 2	348 346
Eckert Station	Lansing BWL	1 2 3 4 5 6	341 341 341 313 313 313
Endicott	MI South Central Power Agency	1	517
Erickson	Lansing BWL	1	304
Harbor Beach	DTE Energy	1	171
J. B. Sims	City of Grand Haven, MI	3	536
J.C. Weadock	Consumers Energy Co.	7 8	180 180
J.H. Campbell	Consumers Energy Co.	1 2 3	385 643 640
J.R. Whiting	Consumers Energy Co.	1 2 3	323 323 323
James De Young	Holland BPW	5	457
Marysville	DTE Energy	9 11	238 199
Monroe	DTE Energy	1 2 3 4	191.5 191.5 285 285
Presque Isle	We Energies	5 6 7 8 9	220 241 262 255 300
River Rouge	DTE Energy	2 3	880 915

[63] This program and more information are available on the DOE website at http://www.netl.doe.gov/coal.

Table 15: Specific Collection Area of Existing ESPs
(square foot per 1000 actual cubic ft per minute [acfm])

PLANT NAME	OWNER	BOILER UNIT	SCA OF THE ESP
St. Clair	DTE Energy	1 2 3 4 6 7	715 715 715 715 730 177
Trenton Channel	DTE Energy	7 8 9	207 207 177

There is a great deal of variability associated with both the routine removal accomplished by an ESP and the incremental removal effected by carbon injection. Consequently, individual tests routinely report the composite removal since the routine mercury removal of any given ESP is too variable to predict on any given day. Test designs need to take into account the potential variability in mercury control effectiveness, both within and between plants.

Two additional recent reports from the DOE NETL and the EPA Office of Research and Development summarize recent test results on mercury control technologies at coal-fired power plants (Feeley et al., 2003; EPA 2005a).

Technologies That May be Available in the More Distant Future

A number of novel technologies being researched as means of reducing mercury or mercury and other pollutant emissions from coal-fired power plants include gold-plated absorbing tubes, electric corona arcs (to convert Hg^0 to RGM), oxidant injection in flue gases, and catalytic oxidation. Technologies to be tested at Michigan coal-fired power plants in the next several years are discussed in **Section 5.7**.

Control Technologies and Small Emitters

Field testing of sorbent-based mercury removal technologies is on going on smaller and larger coal-fired units. Cost-effective compliance options and mercury control technologies for utility units that emit less than 25 lbs/yr of mercury is still under review. On this issue the EPA, in deciding which utility units to control for mercury emissions under the proposed mercury reduction rules, expressed a "concern about Utility Units with low mercury emissions rates." The recently promulgated EPA CAMR acknowledges the potential for mercury reduction requirements to adversely and disproportionately impact small entities and small EGUs. The rule states that "EPA recommends States address small entities through the [mercury allowance] allocation process" noting that

> "*[p]otentially adverse impacts of CAMR on State and municipality-owned entities could be limited by the fact that the cap-and-trade program is designed such that States determine how mercury allowances are to be allocated across units. A state that wishes to mitigate the impact of the*

rule on state or municipality-owned entities might choose to allocate mercury allowances in a manner that is favorable to these entities."

Current DOE/EPRI/EPA efforts to test the availability and effectiveness of mercury control technologies for coal-fired utility units involves smaller units and larger sized units.[64]

There has been a relatively small number of slipstream or full-scale tests to date on mercury control at smaller units (< 80 MW); some smaller units evaluated include the Endicott Station in Michigan, as well as Abbott No. 5 (IL), Cliffside No. 2 (NC), Stanton No. 10 (ND) and Valley No. 3 (WI). Due to lack of economies of scale, control costs could be higher for smaller plants. While mercury-specific control requirements could be waived for smaller units (i.e., below a certain emission or capacity threshold), because of the potential for more substantial emissions from multiple units at a single plant, this determination may need to be made on a case-by-case basis for feasibility and cost.

Table 16 indicates the status of mercury control technologies from coal-fired power plants.

Table 16: Commercial Status of Various Control Approaches for Reducing Mercury Emissions from Coal-Fired Power Plants (both mercury-specific and multi-pollutant)

MERCURY CONTROL APPROACH	DEVELOPER	COMMERCIAL STATUS	REF.
Technologies That Would be Targeted Mainly at Mercury Control			
Conventional coal cleaning	Various	Available	1
Installation of conventional controls (e.g. fabric filter)	Various	Available	2
Optimization of conventional controls (e.g. ESP modification)	CR Clean Air Technologies, Babcock & Wilcox, McDermott Technology, other	Available or near commercial depending on individual technology	1,3
Compact Hybrid Particulate Collector (COHPAC)	EPRI	Available	4
ACI	ADA-ED, NORIT, EPRI, others	Available	1, 5, 6
Amended sorbents (e.g. BPAC)/Other sorbent injection	Sorbent Technologies Inc., others	Available or near commercial depending on individual technology	1, 7, 8
TOXECON™ [a]	EPRI	Available	4 to 7
Advanced Hybrid filter technology	W.L. Gore & Associates, Inc.	Not available.	8, 9

[64] From the Combined Power Plant Air Pollutant Control Mega Symposium, August 30 - September 2, 2004, Washington, D.C. Also see http://www.netl.doe.gov/goal.

Table 16: Commercial Status of Various Control Approaches for Reducing Mercury Emissions from Coal-Fired Power Plants (both mercury-specific and multi-pollutant)

MERCURY CONTROL APPROACH	DEVELOPER	COMMERCIAL STATUS	REF.
Multi-pollutant Technologies			
Advanced dry flue gas desulfurization	Lurgi Lentjes, F.L. Smidth Airtech, RJM Beaumont, WULFF	Available	10
Electro-catalytic oxidation (ECO)	Powerspan	Currently in field demonstration testing	10 to 12
Pahlman process	EnviroScrub Technologies	Slip stream tests conducted at numerous plants; advanced developmental	8, 13
Airborne Process	Airborne Pollution Controls, Inc., & Wilcox, others	Advanced developmental	14
Plasma-Enhanced ESP (PEESP)	MSE Technology, CR Clean Air Technologies	Developmental	3
Low Temperature Oxidation (LoTOx)	BOC Group	Advanced developmental	8
Mercury Control Adsorption Process (MerCap)	EPRI	Developmental	8
RJM-Beaumont	RJM Corporation[b]	Developmental	15
Felt Filter Bags	W.L. Gore & Associates	Developmental	8
K-Fuel™	KFx Inc.	Currently in field demonstration testing	8, 16

[a.] TOXECON™ configuration involves use of ACI upstream of an added FF – the latter alone is the COHPAC configuration.

[b] Company acquired by Combustion Components Associates, Inc. in 2004.

References:

1. Pavlish et al., 2003; 2. Power Engineering, 2004; 3. Reynolds, 2004; 4. EPRI, 2005; 5. ICAC, 2005; 6. Durham et al., 2003; 7. McCoy et al., 2004; 8. Canadian Electricity Association, 2004; 9. Miller et al., 2003; 10. Staudt and Jozewicz, 2003; 11. Alix and Boyle, 2004; 12. Duncan, 2004; 13. Hammil, 2004; 14. Johnson et al., 2004; 15. Goss and Sedman, 2004; 16. KFx, 2004.

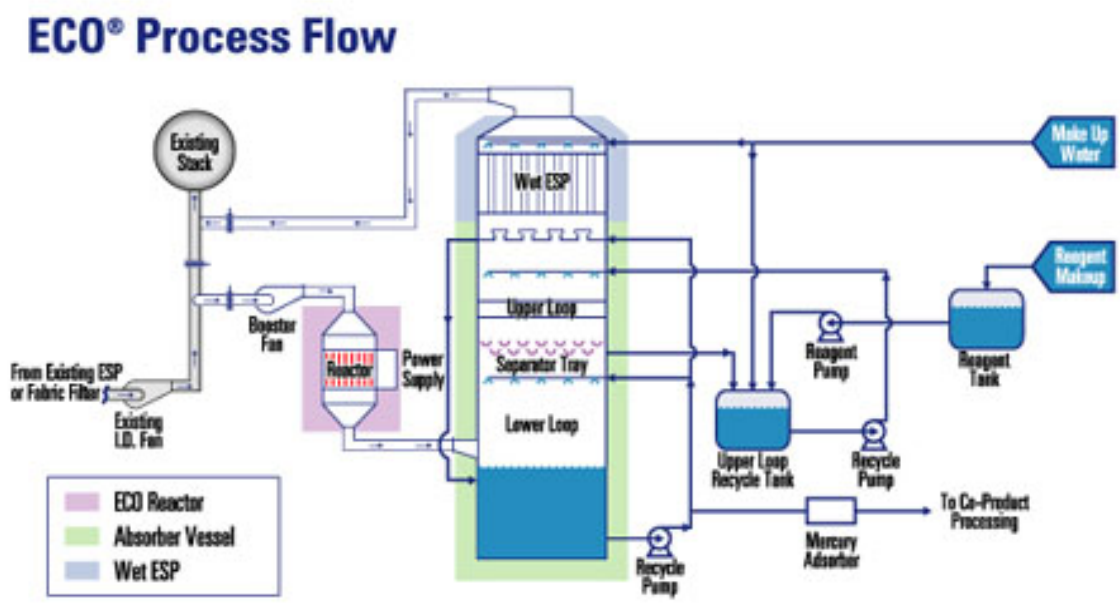
5.3.3 New Multi-Pollutant Controls

Several new air pollution control systems are currently under development and testing. These new systems will integrate established and emerging technologies into a single system that will be capable of removing multiple pollutants (SO_2, NO_X, $PM_{2.5}$, and mercury) for future coal-fired plant applications. In addition to the environmental benefits of reducing multiple pollutants, there could be potential economic benefits as well, if the multi-pollutant approaches can achieve equivalent or greater reductions at costs less than the those of combined costs for SO_2 and NO_X control (e.g., typically $250 to $300/kW for a combined SCR and wet scrubber installation). True one-component multi-pollutant control technologies include the following.

Electro-Catalytic Oxidation System (ECO)

The ECO system is a four stage pollution control process developed by PowerSpan (see **Figure 11**) that is designed to remove SO_X, NO_X, and mercury from high sulfur coal. The key component is a reactor in which NO_X and mercury is oxidized into collectable species by ozone oxidation. The oxidized species are then scrubbed by ammonia and the cleaner gas flows to a wet ESP for aerosol removal. The scrubbed product is further treated by chemicals to produce a commercially saleable ammonium sulfate nitrate fertilizer co-product. The system reduces operating costs and also avoids landfill disposal.

Figure 11: The ECO System



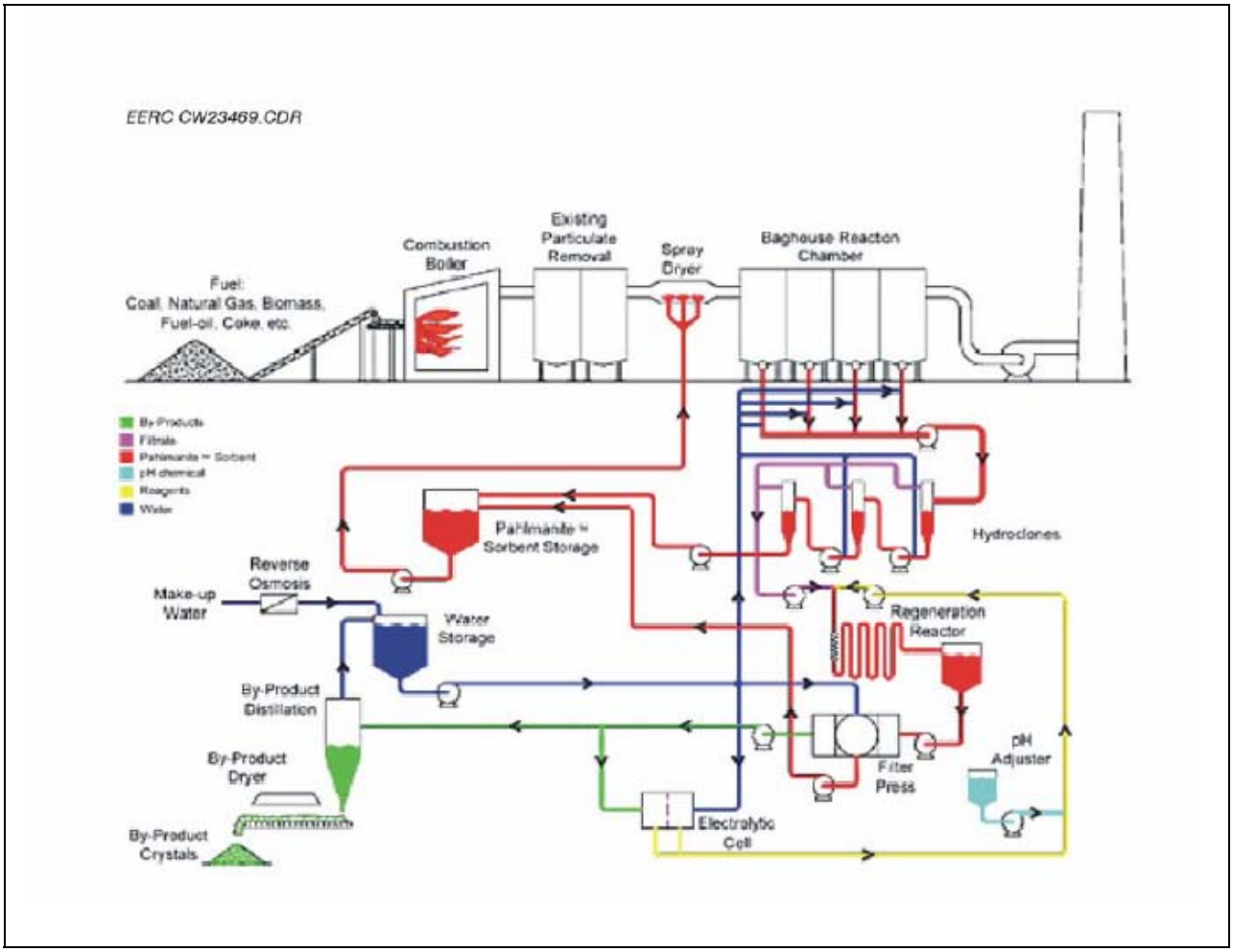
The ECO system is currently in field demonstration testing. It has shown to provide 98% reduction of SO_2 emissions, 90% of NO_X emissions, 80% to 90% of mercury emissions, and 95% of $PM_{2.5}$ emissions.

The ECO system has been undergoing pilot testing in a 1 to 2 MW slipstream unit at First Energy's R.E. Burger Plant since February 2002. A 50 MW ECO commercial demonstration unit was under construction at the same plant and was scheduled to be operational in early 2004.

Pahlman Process

EnviroScrub Technologies Corporation has developed the Pahlman Process of multi-pollutant control (see **Figure 12**). This process is claimed to provide removal efficiencies of over 99% for NO_X, 99% for SO_2, and 60% to 70% for vapor phase mercury (Hg^0 and RGM). Hg(p) is removed in the upstream ESP/FF. The Pahlman process by-products (waste) are sodium sulfate, ammonium nitrate, and potassium sulfate. All of these are marketable products.

Figure 12: The Pahlman Process



EnviroScrub estimates a Pahlman installation would cost about 30% to 50% less to construct, operate, and maintain over a 20-year life cycle than the combined cost of the alternative combination of a wet scrubber, SCR, and ACI injection for

SO_2, NO_X, and mercury control. The Pahlman process provides power plants the flexibility of selecting whatever coal is economic.

EnviroScrub offers mobile onsite demonstration of their technology. The mobile unit is built on a 48' semi-trailer and it can be transported virtually anywhere in the U.S. or Canada. The unit is able to scrub emission flows ranging from 500 to 2,000 cubic foot per minute. Nooter/Eriksen has been licensed to design, supply, and install the Pahlman Process in North America.

Airborne Process

Airborne Pollution Control Inc. has partnered with Babcock & Wilcox, U.S. Filter, and the LG&E Energy Corporation to conduct the first ever field testing of its proprietary multi-pollutant control process. This technology will remove NO_X, SO_2, mercury, and other heavy metals. Claimed reductions for SO_2, NO_X, and mercury are 99%+, 95%+, and 95%+, respectively.

The scrubbing agent used to remove the pollutants is sodium bicarbonate. Although this is an expensive reagent, the product of the sodium bicarbonate SO_X reaction (sodium sulfate) is recycled back into sodium bicarbonate and a sulfate-based fertilizer co-product is produced.

5.3.4 New Semi Multi-Pollutant Control Technologies

This section describes a few of several technologies being developed that are combined with existing technologies to provide multi-pollutant controls.

Plasma-Enhanced Electrostatic Precipitators (PEESP)

The PEESP technology was developed by MSE Technology Applications and Croll-Reynolds Clean Air Technologies. PEESP combines existing ESP technology with low energy plasma technology.

An injector electrode-type corona discharge to standard air pollution control equipment is the basis of the PEESP. Conventional wet ESPs are quite effective at reducing particulate emissions, but are not effective at removing gaseous pollutants, such as Hg^0, NO_X, and SO_X. However, by modifying the central electrode to inject a reagent gas through the corona discharge, a standard wet ESP (coaxial cylinders design) can be effective at removing Hg^0 and potentially, other trace contaminants.

The PEESP extends the collection capabilities of a dry ESP/FGD scrubber or a FGD/Wet ESP system to include mercury removal as a collateral. However, such a technology would have limited applications for units burning sub-bituminous coals/blends, due to the production of cementatious ash.

RJM – Beaumont

The RJM-Beaumont process is offered by RJM Innovative Energy Solutions. Combined with its RJM-LT™ (layered technology) NO_X reduction system, the company claims to remove 99%+ of SO_2, 90%+ of NO_X, and 90%+ of mercury.

The RJM-LT™ system is installed upstream of the RJM-Beaumont system and removes NO_X from the flue gas stream. The flue gas then enters the RJM-Beaumont CFB reactor. Lime slurry is injected into the reactor and SO_2 is removed. A FF/ESP is installed downstream of the reactor to collect ash and dry slurry particles.

5.3.5 Other Measures to Reduce Mercury Emissions

Coal Cleaning/ Precombustion Processing

Mercury in coal is generally present either as cinnabar (mercury sulfide) or is bound up in the organic matrix of the coal. However, despite increasing research on the modes of occurrence of mercury in coal, a number of questions remain (Toole-O'Neil et al., 1999; Tewalt et al., 2001). In float-sink experiments, earlier studies found significant occurrence of mercury in the heavier fractions consistent with an inorganic association (in particular pyrite, or iron sulfide) (Toole-O'Neil et al., 1999). Studies on two bituminous coals (Pittsburgh No. 8 and Illinois No. 6) indicated primarily pyretic mercury association, although over 20% of the mercury in the Illinois coal was associated with the organic matrix (Luttrell et al., 2000). Another study of an Illinois coal and PRB coal found appreciable mercury association (44% and 57%, respectively) with the organic-rich float fraction (Galbreath et al., 2000).

The effectiveness of coal cleaning in removing mercury is dependent upon which mineral form of mercury is present and the type of cleaning. Coal cleaning can be done through physically cleaning (washing) or it can be aided by chemical processes. Advanced coal cleaning techniques involving heat treatment have also been explored.

All of the coal cleaning that is done at the commercial level in the U.S. relies upon physical cleaning or washing that separate out the denser ash and pyretic materials from the coal particles. Pyrites are removed from the coal to reduce both the sulfur and ash content of the fuel. Some of the mercury in coal occurs as cinnabar and is bound up with the pyrite material. Consequently removal of the pyrite in general reduces the portion of the mercury that occurs as cinnabar. Most eastern bituminous coals are washed. The exceptions are bituminous coal that contains no pyrites or pyrites in such finely divided minerals that they cannot be removed by standard washing techniques, coals that are burned in locales that allow high sulfur emissions, or coals that are burned in units that remove sulfur (e.g., fluidized bed combustion units or PC units with scrubbers). Michigan has long had stricter sulfur emissions than most eastern states and almost all of the eastern bituminous coal that is burned in the state is washed to meet these more stringent sulfur limits.

Chemical processes rely on chemical treatment or bioreactors to remove ash, sulfur, or mercury from coal. In some cases, heat is used in addition. Some chemical processes can remove the mercury that is part of the carbon matrix in coal. The mercury that is part of the carbon matrix cannot be removed by coal washing because it is not associated with pyrites, cinnabar, or other minerals that have a greater specific gravity. Although data is limited, most of the mercury and sulfur in western sub-bituminous coal from the PRB is associated with the carbon matrix, and this fraction is not removed by coal washing; consequently this coal is not typically washed.

K-fuel™ is a new chemical process that is being developed to clean coal relying upon heat to drive off moisture, as well as nitrogenous, sulfurous, and mercuric compounds, following a physical separation step (KFx, 2003). Unfortunately the end result, while purporting to remove 70% of the mercury on the basis pounds of mercury per Btu of coal, contains enough dust that it can neither be transported in conventional coal cars nor stored without fear of spontaneous combustion. A temporary experiment has been suggested to blend 50% unprocessed coal with K-fuel™ to eliminate such problems, but this reduces the overall mercury reduction to 35% expressed on the basis of pounds of mercury per Btu of coal and increases handling costs. Additionally, the actual reduction expressed in terms of pounds of mercury per MWh will be further reduced because conventional coal processing at power plants already reduces the moisture content of the coal to some extent through milling and other processes. Consequently, comparing the mercury content of 50/50 K-fuel™/raw coal blend with the mercury content of sub-bituminous coal as it is fired into the boiler, would provide a better metric and would show less than a 35% net reduction. This and other factors have held back the viability to date of K-fuel™.

However, research continues into thermal precombustion treatments for reduction of mercury in coal. For example, in bench scale tests involving thermal treatment of lignite and PRB coal, Guffey and Bland (2004) reported mercury removal percentages of up to 70%. In addition, they noted that the results were achieved at temperatures that avoided pyrolysis of the coals (which would lead to lower heating value of the coals), in contrast to some experiments on bituminous coals. In other research, bench scale tests involving hydrothermal treatment of bituminous coals gave average mercury removals of 60%.[65]

Precombustion methods to reduce emissions of mercury, other HAPs, and criteria pollutants resulting from coal combustion continue to be researched and hold promise for the future.[66]

Non Equipment Related Control Measures, Fuel Switching

Switching from one fuel to another is a means of reducing mercury emissions. Examples include switching from higher mercury coal to a lower mercury coal,

[65] See review in Pavlish et al, 2003.

[66] See for example Timpe et al., 2001; Matsuoka et al., 2002; Dronen et al., 2004; Iwashita et al., 2004, as well as projects summarized on the DOE/NETL website.

and switching from coal to natural gas. Converting from one coal to another requires changes to the configuration of an existing plant, given that units are designed to burn a specific type of coal. Switching coals typically necessitates changes in the coal handling system, burners, and burner configurations within the boiler. At the same time, a number of Michigan power plants now burn blended (in this case bituminous and sub-bituminous) coals and one plant, BWL's Erickson, has switched from bituminous to sub-bituminous in April of 2004 because the advantages out-weighed the disadvantages. There has been some preliminary testing of coal blend to determine the impact that blending has on mercury speciation. The preliminary data indicates that a blend of 15% bituminous coal and 85% sub-bituminous coal did not appreciably affect the speciation of mercury in the flue gas. It appears that a blend of at least 30% bituminous coal may be needed to cause the flue gas to have properties similar to a unit fired by only bituminous coal. A potential downside of coal switching/blending is the possibility of such changes resulting in reductions in efficiencies of the affected unit or those changes that would be incompatible with the design of the boiler itself but the economics may and have made it favorable to switch coals.

Greater reductions in emissions, via fuel switching, would be achieved by switching from coal to natural gas. In addition to significant reductions in mercury emissions, conversion to natural gas leads to substantial reductions in SO_2, NO_X, and particulate emissions. This type of fuel switch is technically feasible; however, the primary drawbacks result from the increased costs of natural gas as a fuel, the supply of natural gas, the lack of an adequate infrastructure to deliver the natural gas to many existing plant locations, and a certain reduction in efficiency and capacity. Gas burns differently than coal and generates the hottest flame in a different portion of the boiler, consequently, a boiler designed to recover heat from coal will be less efficient in recovering heat from gas. The implications of fuel switching as a mercury control measure are discussed in more detail relevant to the situation in Michigan in **Section 5.5.2**.

Efficiency Improvements at Existing Stations

Various initiatives are underway to increase the amount of electricity generated from existing boilers. These initiatives would reduce coal consumption and indirectly reduce mercury emissions. For instance, turbine upgrades at existing plants can increase a unit's efficiency by approximately 4% resulting in a comparable reduction in the amount of coal, SO_X, NO_X, particulate, and mercury emitted.

Next Generation of More Efficient, Lower Emitting Power Plants

New PC-fired power plants are expected to have overall efficiencies in the 36% to 40% range for the 2005 to 2010 time period. The DOE and the Proposed Energy Policy Act of 2003, strived for improvements in the 40% to 45% range for the 2011 to 2012 time frame. These goals compare to the existing fleet of plants in Michigan that have efficiencies ranging from 30% to 35%. Using a 40% efficient unit to replace an older 30% efficient unit would result in a 25% decrease in the amount of coal needed to generate a MWh. Efficiencies of 36% to 40% can be

achieved with the ultra supercritical steam cycles on PC units employing the very latest turbine designs. Once-through cooling (i.e., the use of colder lake water to provide cooling water to the steam turbine condenser, rather than using a closed loop cooling tower) also aids in making plants more efficient. A separate environmental issue is the additional harm to aquatic life (e.g., fish entrainment) that occurs with once-through cooling water.

Integrated Gasification Combined-Cycle (IGCC) technology offers an additional option for reducing emissions of mercury (and other pollutants). These plants involve the gasification (rather than combustion) of coal, and the subsequent driving of combustion and steam turbines. Though the basic coal gasification technology was first developed over 200 years ago, most application of the technology to date worldwide has been in industrial settings rather than electricity generation. There are currently two operating IGCC plants in the U.S. – the Tampa Electric Polk Power Station in Florida and the Wabash River Repowering Project in Indiana. The technology may ultimately deliver efficiencies in the 50% to 60% range, and capture of most pollutants is easier than in combustion technologies. However, their high capital costs and the risks involved with innovative electricity generation technologies have slowed investment in IGCC by power producers. (The Wisconsin Public Service Commission [PSC] recently turned down a request to construct an IGCC unit citing its high cost.) At the same time, the DOE's Clean Coal Technology Program is demonstrating IGCC technologies, and recent innovations have improved both the performance and economics of IGCC units (Stiegel and Maxwell, 2001). IGCC units hold substantial promise for the distant future and supercritical PC units with the most advanced turbines hold the best promise for the immediate future.

Finally, in addition to new plants using coal more efficiently, new plant designs emit fewer pollutants per pound of coal.

5.4 Balance of Plant Impacts Associated with Mercury Controls

Any additional control technologies added to a given plant to control mercury emissions can potentially impact other aspects of the plant's operation, including additional energy requirements for the new equipment and impacts (including additional wear) on existing pollution control systems.

In the case of energy requirements, the use of ACI would require a relatively small amount of additional power to run the injection system. (In a broader assessment of energy costs to use ACI, the energy costs of producing the ACI – which would most likely involve coal for producers in many areas of the Midwest – would need to be taken into account.) If ACIs were used in conjunction with an add-on FF, the latter would have additional energy requirements, both for the fan to move gas through the filter and for cleaning periods. Engineering calculations done for the We Energies Presque Isle units to be retrofitted with ACI and pulse-jet FFs indicate the additional electricity demand for FF operation will be approximately 1% of gross power generation.

The use of additional mercury-specific control measures could also lead to impacts on existing pollution control devices. For example, ACI would lead to additional particulate loadings to either an ESP or FF; any increased cleaning frequency (e.g., rapping of dry ESP plates or reverse-air or pulse-jet operations on FFs) may impact the lifetime of these devices. The workgroup is not aware of any efforts to date to assess the long-term impacts of ACI on the durability of other pollution control devices; the limited shorter term tests to date do not show significant impacts on other equipment, including on overall ESP operation and the effectiveness at reducing particulate emissions (see for example Bustard et al., 2002; Durham et al., 2003). However, some research has shown the potential of ACI to contribute to arcing between ESP plates. For example, in tests at Georgia Power's Yates plant, arching was observed during ACI, although in a sporadic manner. Longer-term tests on this potential problem are underway (EPA, 2005a).[67]

Potential impacts of enhanced FGD might include changing character of scrubber slurries with any added material. In addition, there have been no long-term tests on the impact of chemical additives on the operation of FGD units. Shorter term tests of one technology involving addition of a proprietary ingredient to wet FGD slurries has shown no negative impacts on either scrubber performance or the quality of gypsum made from the scrubber sludge (Nolan et al., 2002).

5.5 Control and Process Change Options and Feasibility for Michigan Coal-Fired Utilities

There are several different approaches by which Michigan coal-fired utilities could reduce mercury emissions including through process change and/or control options, or addressing overall energy demand. As noted previously, key factors that influence mercury emissions from coal-fired power plants include coal rank and levels of other constituents (in particular chlorine), boiler combustion conditions, flue gas composition and temperature, fly ash properties, and post-combustion pollutant controls for other pollutants (Kilgroe et al., 2002). This section looks at the specific configuration of Michigan's plants and at what mercury control options exist to achieve significant mercury control on this portfolio of plants.

Coal rank and controls for other pollutants are particularly important in determining mercury emissions. Although levels can vary substantially, sub-bituminous coals on average have slightly lower mercury levels (on a dry weight basis) than bituminous coals. Because of the lower energy content of sub-bituminous coals, larger amounts have to be combusted in order to produce the same amount of energy. In addition, when sub-bituminous coals are burned, they produce a higher fraction of Hg^0 which is less readily controlled by existing conventional pollution control devices (Kilgroe et al., 2002). **Table 7** (in **Section 3**) indicates that Michigan utilities as a whole burn a mix of bituminous and sub-bituminous coals; plants representing approximately 72% of Michigan generation capacity burned both coal types in 1999.

[67] Information available at http://www.netl.doe.gov/coal/e&wr/mercury/control_index.html.

As discussed in previous sections, the majority of coal-fired power plants in Michigan burn low-sulfur coal to reduce SO_2 emissions; four plants representing less than 2% of generation capacity in 1999 have scrubbers installed for SO_2 control. In addition, the large majority of units employ CS-ESPs for particulate control, with approximately 95% of capacity having CS-ESPs installed. Several units (including Marquette Shiras, TES Filer City Station, MSU T.B. Simon Units 1, 2, and 4, and We Energies Presque Isle Units 1-4) have a FF in place. These control configurations have implications for control options to reduce mercury emissions.

Michigan utilities could achieve mercury reductions both by addition of control technology for other pollutants and/or by addition of mercury-specific controls. Mercury reduction could also be achieved through fuel switching, coal gasification, efficiency improvements, and demand-side management (as discussed further in **Section 6.8**). The approach taken would to some extent be determined by the reduction target and timeframes, and several approaches could be pursued simultaneously. A more detailed look at the options for the state's electric generating plants is described in the following.

5.5.1 Addition of Controls for Mercury

Michigan utilities could achieve significant mercury control through either the addition of control technologies for other pollutants (e.g., with FGD/SCR combination on bituminous or blended coal units, or with a FF), or through addition of mercury-specific control technologies. A general breakdown of coal-fired electricity generation by fuel type and PM control configuration is indicated in **Table 17**. As shown in the table, the majority of Michigan coal-fired electricity generation involves the burning of both bituminous and sub-bituminous coals with CS-ESPs as the PM control approach. This has significant implications for best approaches to achieving mercury removal.

Table 17: Coal-Fired Electric Utility Generation in Michigan, 1999[1]

COAL RANK	PARTICULATE CONTROL	GENERATION CAPACITY (MW)	PERCENT OF TOTAL CAPACITY
Sub-bituminous	CS-ESP	2,035	16.2
	Other	314	2.5
Bituminous	CS-ESP	864	6.9
	Other	339	2.7
Bituminous and sub-bituminous	CS-ESP	8991	71.7
	Other	0	0
TOTAL		**12543**	**100.0**

[1] Source: Summarizing plant-level data in **Table 7**; original data from EPA ICR database.

<u>Use of Other Pollution Control Devices for Mercury Control</u>

As noted previously, pollution control devices for other pollutants (e.g., SO_2, NO_X, and PM) incidentally capture mercury to varying degrees. For existing controls, as noted above, only a small fraction of Michigan utility capacity currently has

devices in place that are most effective at incidentally controlling mercury emissions – namely wet scrubbers (mainly for SO_2, which can control significant fractions of RGM, especially applicable to bituminous coals producing greater amounts of this mercury form), and FFs (for particulates, which can incidentally control all three forms of mercury to varying extents). For plants burning mostly or entirely bituminous coals in particular, significant additional mercury control could be achieved through the addition of scrubbers and/or FF alone (without addition of ACI). However, as a result of existing NO_X SIP calls and compliance plans, as well as anticipated plans to comply with new NO_X and SO_X standards in CAIR, major reductions in mercury emissions are anticipated over the next decade. EPA's CAMR contains two phases. The first phase relies largely, but not entirely, on the co-benefits associated with the control of SO_X and NO_X under the first phase of the CAIR rule. In other words, EPA does not assign a cost of mercury control to units that will be achieving mercury reductions solely as a result of the incidental mercury they achieve through SO_X and NO_X controls with SCRs and scrubbers. The second phase of the CAMR coincides roughly with the second phase of CAIR and some additional co-benefits are achieved here through the installation of a second round of scrubber and SCR installations. EPA's mercury control costs are associated with the mercury specific control technology that is anticipated to be installed to a small extent in the first phase and to a growing extent in the second phase of CAMR. EPA's mercury allocation to Michigan in the second phase of CAMR is only about 20% of the mercury content of the coal. The technology for going beyond the second phase of CAMR is very site specific and uncertain because of our inability to accurately quantify the exact level of performance of future multi-pollutant and mercury specific control technologies.

Based on data compiled through the EPA ICR for five units, existing FFs were controlling from 87% to 93% of mercury for bituminous coals, 62% to 83% for sub-bituminous coals, and 70% for a unit burning blended (bituminous/sub-bituminous) coals (Kilgroe et al., 2002). Thus, assuming average results from tests on five units through the ICR would be applicable to individual units in Michigan, addition of FFs to Michigan units burning bituminous coals exclusively (i.e., about 7% of current generation) could lead to 90% mercury control from these units. The addition of FFs alone to units burning either sub-bituminous coals or a mix of bituminous/sub-bituminous could result in 70% mercury reduction from these units, again based on average ICR test results. The actual control achieved would depend on the fraction of bituminous vs. sub-bituminous coals burned at an individual unit, in addition to other plant-specific characteristics. Thus, though the addition of FFs may not be necessary to meet requirements of the CAIR, installation of this technology on units in Michigan not currently configured with them could lead to appreciable reductions in mercury emissions.

In addition, several Michigan utilities are planning or in the process (or have completed the process) of upgrading several plants with the additions or construction of SCR devices to meet existing NO_X emissions limits. These include:

- three units at the Monroe Plant (two units have already been constructed and are currently operational);
- Units 2 and 3 at the J.H. Campbell Plant (Unit 3 is currently being installed and is scheduled to be operational for the 2007 ozone season); and
- Units 1 and 2 at the D.E. Karn plant where SCRs have already been constructed and are currently in operation.

In addition, three units at the Presque Isle Plant will be installing low-NO_X burners and advanced combustion controls.

Results on other plants to date have been somewhat ambiguous on the impact of SCR on mercury removal from flue gases. In a review of 2001 field tests, Staudt and Jozewicz (2003) reported that two of three tests on boilers firing bituminous coals showed increased mercury oxidation, while tests on two sites (one firing eastern bituminous and the other sub-bituminous coal) showed insignificant increase in oxidation. However, in the cases of insignificant oxidation as a result of the SCR, high levels of RGM (either gaseous or in the particulate phase) already existed in the flue gas at the particulate control device. For the configurations most typical of Michigan coal-fired plants currently (i.e., an ESP and no scrubber), mercury removal was not improved by the SCR (Staudt and Jozewicz, 2003). However, further tests are planned investigating potential to increase mercury removal with SCR.

On the other hand, use of combustion controls to control NO_X (e.g., low NO_X burners or other approaches to fuel staging[68]) has in some cases increased mercury removal (Staudt and Jozewicz, 2003). One effect of staging is to increase the amount of unburned carbon in the fly ash, which can serve to increase mercury sorption and allow for increased capture. A downside of staging is that it tends to reduce combustion efficiency. It is not clear how the ongoing upgrades to meet NO_X requirements will impact mercury emissions from Michigan utilities. Further tests on similar units (or Michigan units themselves) would be necessary to better determine effects of NO_X control measures (both combustion and post-combustion) on mercury emissions.

Flue gas desulfurization controls (or scrubbers) can also lead to mercury control as a co-benefit, as noted previously. Data from the ICR indicated greater control potential for bituminous coals, with average reductions due to the FGD alone ranging from 36% to 76%; reductions for units burning sub-bituminous coals ranged from 10% to 52% (Kilgroe et al., 2002).

Existing federal regulatory programs to reduce SO_X and NO_X emissions in EPA's rule (CAIR published May 15, 2005, 40 CFR Parts 51, 72, and 96) may require SCR and FGD retrofits on many of the major Michigan units to meet ambient ozone and PM standards. These installations can provide the co-benefit of substantially reducing state-wide mercury emissions and are discussed in more

[68] Fuel staging - reducing air available in the primary combustion zone and providing it in a second combustion zone, which reduces the peak flame temperature and oxygen available for NO_X production.

detail in **Table 11**. Optimal approaches for meeting separate mercury reduction targets need to consider the co-benefits associated with these multi-pollutant control programs.

Mercury-Specific Control Options for Michigan Plants

As stated previously, ACI is the most promising control technology considered to date for reducing mercury emissions from coal-fired power plants. Issues that would need to be addressed in adopting the technology on a large scale in Michigan include commercial availability of the technology, longer term availability of carbon sorbent, retrofit potential, balance-of-plant impacts , fate of captured mercury , and captured fly ash salability. The technology has been tested in various settings in the U.S., and has shown success in substantial reductions (i.e., 90% for bituminous coals in some cases) in mercury emissions (e.g., Pavlish, et al., 2003; Staudt and Jozewicz, 2003).

In evaluating the commercial availability of a technology, it will be necessary to evaluate tests and short-term evaluations as well as demonstrations over longer periods of time that look at variability in performance. Also considered in the determination of commercial availability will be the availability of valid performance guarantees. It has been suggested that commercial availability also needs to consider whether or not the new technology would create collateral increases of other pollutants. While it is possible that the new technology may have collateral increases of other air contaminants, it would be necessary to evaluate those increases on a case by case basis, and in some cases it may be necessary to make process changes to mitigate any impacts from those collateral increases. Since the evaluation would be done on a case by case basis and the collateral increase could potentially be corrected or minimized by a process change (such as the type of sorbent used), deeming a control technology is commercially unavailable because of a collateral increase of another pollutant may not be appropriate.

For Michigan power plants, the majority utilize CS-ESPs as the particulate control device, and burn sub-bituminous coals or blends (see **Table 17**). Initially, tests conducted on these types of configurations in other states (i.e., on the Pleasant Prairie Plant in Wisconsin), demonstrate a maximum control efficiency of about 70%, even at high levels of carbon injection (e.g., Durham et al., 2003). Additional testing using a halogenated PAC has shown that a range or 70% to greater than 90% control efficiency is possible with a CS-ESP for particulate control (Nelson et al., 2004).

Potential loss of fly ash sales due to contamination with carbon would be of concern for those plants selling fly ash, if carbon injection were done upstream of an ESP. This problem would be avoided if the injection were downstream of the ESP, with collection on a FF. This would require installation of an ACI system, the FF, and additional fans and ductwork as necessary which would increase costs for control.

In summary, several approaches are available for achieving high levels of mercury control (i.e., > 80%) from Michigan coal-fired power plants. These approaches are summarized for several broad categories in **Table 18**. The table indicates that in some cases, substantial mercury reduction may be achievable through co-benefit of installation of scrubbers and/or SCR units for sulfur and nitrogen control, respectively. Further studies on mercury co-benefits to be expected with installation of additional SCRs and/or combustion changes for NO_X control at certain units are needed to clarify how these measures will effect mercury emissions in the state.

For the majority of the state's capacity that utilizes either sub-bituminous or blended coals and CS-ESPs, testing is showing that a substantial degree of mercury reduction is possible (e.g., 70% to 90% reduction). Eventual mercury reduction targets chosen and required controls for SO_X and NO_X will drive the type of control that power plants choose to use, whether that is a co-benefits option or a specific mercury control option. Currently, there are two DOE-funded research projects in Michigan involving sorbent injection. At the We Energies Presque Isle plant a project is underway using an ACI with a FF; and at the St. Clair plant a project examining advanced sorbent injection upstream of the ESP has been completed.

ACI with add-on FF will also be utilized by Mid-American Energy to meet the mercury emissions limit at its new plant in Council Bluffs, Iowa. In addition, though not presented in **Table 18** below, it is possible that research on emerging multi-pollutant technologies will identify other promising approaches to control both mercury and criteria pollutants (more is discussed in this section).

NOTE: **Table 18** uses the following acronyms:

FGD: flue gas desulfurization (scrubbers)
SCR: selective catalytic reduction
MMacf: million actual cubic feet
PACI: powdered activated carbon injection
PFF: polishing fabric filter.

Table 18: Summary of Potential Mercury Control Approaches for Michigan Coal-Fired Power Plants[1]

COAL RANK	PARTICULATE CONTROL	APPROXIMATE REDUCTION PERCENTAGE FOR CONTROL APPROACH[2]					
		Co-Benefit Approaches			Approaches Targeted at Mercury		
		FGD	SCR[3]	SCR-FGD	FF	PACI	PACI-PFF
Sub-bituminous	CS-ESP	10 – 52	Insig.	-	62 – 83	50 – 90[5]	85 – 98[7]
	Other	1 – 37	-	-	NA	NA	NA
Bituminous	CS-ESP	64 – 68	0 – 88	>90[3]	87 – 93	40 to 90[6]	80 – 90[8]
	Other	36 – 76	46 – 90	-	NA	NA	NA
Bituminous and sub-bituminous	CS-ESP	10 – 52	Insig.	-	70[4]	50 – 90[5]	85 – 98[7]
	Other	1 – 37	-	-	NA	NA	NA

[1] Based on classification of Michigan plants as in **Table 17**.
[2] Unless otherwise noted, control data derived from EPA ICR; data for FGD (wet scrubber data only) and FF is from Kilgroe et al. (2002); data for SCR is from Staudt and Jozewicz (2003).
[3] High values in ranges include reduction percentage across both SCR and FGD/PM control devices. For tests evaluated in Staudt and Jozewicz (2003), SCR added insignificant mercury removal for plants burning sub-bituminous coals and having CS-ESPs. (Renninger et al., 2004).
[4] For blended coal configuration, it is assumed that results derived from boilers burning all sub-bituminous coal apply; data from one plant with this configuration and having a FF was available through the ICR, giving the 70% reduction noted in table.
[5] Based on tests at We Energies Pleasant Prairie plant, for ACI rates of 5 lb./**MMacf** or greater (Durham et al., 2003) and DTE St. Clair plant with halogenated PACI at injection rates of 3 lb./**MMacf** (Nelson et al., 2004).
[6] Based on tests at PG&E NEG Brayton Point plant, for ACI rates of 5 lb./**MMacf** or greater (Durham et al., 2003).
[7] Based on tests at Midwest Generation's Powerton Station; parametric testing of three sorbents for ACI rates of 1.0 lb/MMacf and greater (Ley et al., 2003**).**
[8] Based on tests at Alabama Power Gaston plant, with COHPAC™ FF, and for ACI rates of 1.5 lb/MMacf or greater (Bustard et al., 2002).

5.5.2 Other Means for Achieving Mercury Reduction at Michigan Utilities

In addition to retrofitting existing plants, a number of other mechanisms exist to achieve statewide mercury reductions. The primary approaches are discussed below.

Fuel Switching

As noted previously, one approach to reducing mercury emissions from power generation is to use natural gas rather than coal to generate electricity. However, before reviewing the option of fuel switching a discussion of how power plants are selected to run during a given hour or day is required. Distribution utilities and marketers acquire electricity from the lowest cost sources available to meet load requirements at any given time. The source maybe a unit dispatched from the utility's own fleet, a purchase from another utility's unit (both in or out of state) or a

purchase from an Independent Power Producer. As the load changes from a low load situation to a high load situation, additional power sources are acquired based on the operational cost of each power source. This process creates a situation where in any given time period generating units with lower costs (on a kWh basis) will have more run time and kWh output then higher cost units. Typically units which are capable of supplying low cost energy on a kWh basis have high initial capital costs which are low on a kWh basis when spread over the large amount of kWh generated annually. Units with lower capital costs and higher operating costs are typically used to meet requirements imposed on the system by short-term daily and annual load peaks. These units will have shorter annual run times and have less annual kWh to spread their capital costs over.

Switching the primary fuel used to generate electricity in an existing unit will in most cases substantially change the cost of the electricity produced by that unit. This change in production cost will alter the units' position on the cost curve and effect the annual run time of the unit and its annual kWh production. For example, electricity supplied by lower cost coal and nuclear units as well as economic purchases from other sources is capable of meeting Michigan's electricity demands during a large portion of the year. Higher cost sources which currently consist primarily of natural gas-fired facilities are used to meet daily and annual peak requirements.

There are three major ways of accomplishing fuel switching. The approach which requires the lowest capital investment, is switching fuels at an existing coal-fired power plant. The minimal capital investment associated with this option is evidenced by the $11 million cost DTE Energy incurred in 1999 to convert its 270 MW Connors Creek Power Plant to use natural gas. While the capital cost of such a conversion is low, the increased operating costs, in particular with current natural gas prices, are high. The delivered coal price to major coal-fired power plants within Michigan is approximately $1.50/MBtus (per million Btus). The delivered natural gas price is currently approximately $7.00/MBtu. A typical steam electric power plant boiler requires about 10,000 Btu's of fuel to generate a kWh of electricity, consequently if employed across the state on all coal-fired power plants, typical electrical rates would increase by about $0.055/kWh. A number of oil and smaller coal-fired units in Michigan have been converted to use natural gas as the primary boiler fuel. None of these converted units were planned to run as base load units. These units were reconfigured to run as load following and/or peaking units and the recent increases in natural gas prices has further decreased the economic viability of the converted plants.

A second approach to generating electricity with natural gas is to construct a new single cycle gas turbine to replace the coal-fire units which emit mercury. This approach has a capital cost considerably less than the construction of a new steam electric boiler, but still suffers from prohibitively high operating expenses. Single cycle gas turbines, due to their low efficiency and low capital costs, have been used to supply electric energy during short periods of high demand. Many single cycle gas turbines installed in Michigan over the last five years sit idle on all but the highest demand days, because their fuel cost is still $0.05/kWh greater

than coal-fired power plants The addition of single cycle combustion turbines fired by natural gas that only run during peak periods will have little impact on annual coal usage.

The third approach for generating electricity with natural gas is to construct a combined-cycle plant that extracts the heat from the turbine exhaust in a heat recovery steam boiler. Energy is recovered from both the gas turbine and the steam turbine which increases the overall efficiency to the 55% range as opposed to 35% to 40% efficiencies targeted for new coal plants in the next 5 to 10 years. The constructed capital costs for combined-cycle are less than the capital costs of a conventional coal-fired boiler; however, this is more than made up by the fuel costs. During the recent period where the cost of natural gas on a Btu basis was more favorable to the price of coal, combined-cycle units could compete on a price basis with coal-fired units. Today's higher natural gas price greatly limits the ability of these units to compete with existing coal-fired base load units for annual run time. Combined-cycle units when used as part of a cogeneration system, have additional economies generated by using a portion of the steam in an industrial process. Cogeneration facilities can compete with base-load units on a cost basis and could reduce the use of coal in the annual generation fuel mix. However, the sites where substantial amounts of process steam are required are limited and as of 2002, according to EIA, most electricity generation by natural gas was in the utility sector, rather than in the industrial/commercial cogeneration sectors (EIA, 2004).[69]

While recent gas prices have been high, some conversions have occurred in the utility industry in recent years. For example, Tampa Electric in Florida recently replaced its Gannon coal-fired plant with the state-of-the-art natural gas-fired Bayside Power Station (Edison Electric Institute, 2003), and Xcel Energy in Minnesota announced in 2002 a plan to repower two power plants from coal to combined-cycle natural gas in the Minneapolis/St. Paul area at a total capital cost of over $600 million (Xcel Energy, 2002). (These projects were announced when gas prices had begun to rise, but were lower than current levels). Nationally, most additions to electric utility capacity (i.e., 175 of 187 gigawatts [GW] from 2000 to 2003) were natural gas, although some developers reported plans to delay or cancel plants (EIA, 2004). Based on data available from calendar year 2002 (i.e., after natural gas prices had begun their recent rise, but were projected to stay in the neighborhood of $4/MBtus), EIA projected that while coal-fired plants would be built in increasing numbers as compared to the recent past, over 60% of new capacity additions nationally would be natural gas-fired combined-cycle, combustion turbine, or distributed generation plants (EIA, 2004). However, EIA is now predicting that natural gas prices are projected to be approximately $6 per thousand cubic feet in December 2006 (Henry Hub spot natural gas prices).[70] Although gas-fired generation is predicted to continue to increase nationally (EIA, 2005), that may not be the case in Michigan in the future. Again, decisions to actually construct and use such plants would depend on utility assessments of

[69] Information available at http://tonto.eia.doe.gov/FTPROOT/forecasting/steomonthly/jul05.pdf .
[70] Information available at http://tonto.eia.doe.gov/steo_query/app/ngpage.htm.

fuel price trends and other factors, such as gas supplies and infrastructure issues, including pipeline availability and capacity.

An additional fuel switching option available to utilities is to switch to lower mercury coal. However, this option is of more questionable benefit concerning reducing mercury emissions; for example, increased use of lower mercury western sub-bituminous coal may not appreciably change actual mercury emissions, given the lower heat content of sub-bituminous coals, and the fact that as discussed previously, its combustion tends to produce a greater fraction of Hg^0, which is less readily removed in existing pollution control systems. Broader concerns to be addressed in coal switching are impacts on coal handling systems, fuel preparation and firing systems, and impacts on ash handling (Stallard and Jonas, 1996). In addition, a switch back to Eastern bituminous fuel from PRB would result in a substantial net increase in SO_2 emissions which could put generators in violation of their existing Air Permits or would require further capital investments in SO_2 scrubbing systems.

Currently Available Coal Gasification

While coal gasification technology was first pursued in the 18th Century, it has been of increasing interest recently in the power generation sector in the U.S. Gasification has been pursued aggressively outside the U.S. with 128 plants in place worldwide, in particular in industrial applications (Stiegel and Maxwell, 2001). The approach most intensively pursued (including through industry-government partnerships) has been coal gasification combined with clean and efficient gas and steam turbines; coupled together, the technology is termed IGCC power plants (Stiegel and Maxwell, 2001). While the plants offer significant benefits in reducing emissions of criteria pollutants compared to standard coal-fired units, the impact on mercury emissions is less clear. Data from preliminary tests indicated that most of the mercury in gas turbine exhaust was Hg^0, and overall mercury removal at the two U.S. IGCC power plants averaged only 34% and 41% (Kilgroe et al., 2002). As reported in the Parsons/DOE study of Mercury Removal in IGCC facilities, at Eastman Chemicals' gasification unit in Tennessee, carbon beds have been used and have demonstrated removal efficiencies of 90 to 95%. The report also states that, although not verified, there is commercial experience with a Calgon Carbon system on natural gas that achieves over 99% removal. The report also cautions that the presence of other trace components in syn-gas can significantly compromise the removal capabilities of the activated carbon.[71]

Development of coal gasification for electricity generation in Michigan would likely not be driven by potential mercury benefits alone, but in the context of broader air emissions and business or commercial benefits. Challenges for the technology include the high capital costs, questions about reliability in some cases, and the uncertainties involving innovative technologies that plant owners face.

[71] Cost of Mercury Removal in an IGCC Plant, Parsons Infrastructure and Technology Group, Inc., for DOE, September 2002.

Near Term Efficiency Improvements

Reduction in mercury emissions (and all other pollutants) can be obtained through improvement in generating efficiencies at existing plants (increasing efficiencies and reducing consumption on the demand side are addressed in **Section 6**). Increase in efficiency at a plant means that the same generation could be achieved with less fuel consumption. An important component of overall plant efficiency is boiler efficiency, which in modern power plants can range from just over 80% to just under 90%. The use of high pressure super-critical boiler designs has driven boiler efficiency up, reducing the amount of fuel consumption needed for a MW of electricity. Some progress on plant efficiencies has already been made in the past two decades through modifications at coal-fired power plants. Approaches to improving efficiencies at existing coal plants could take a number of forms, depending on optimization that has already been done at a given plant in the state. Potential upgrades may include identifying means to reduce slagging and fouling of the walls and suspended surfaces of the furnace from molten ash and condensed volatile constituents (Stallard and Jonas, 1996), and optimizing steam flow through the turbine (e.g., through the hybrid variable-pressure – governing control mode) (Armbruster, 1996). These types of turbine upgrades can improve steam turbine cycle efficiency by 4% to 5%.

Mid-Term and Long-Term Efficiency Improvements

The DOE has established goals for further increases in efficiencies from coal-fired power plants. By 2010, DOE plans to help commercialize technology that would achieve 45% to 50% plant efficiencies. By 2020, DOE plans to help commercialize technology that would achieve 50% to 60% plant efficiencies. DOE is pursuing two separate technology tracks.

One technology involves ultra supercritical steam boilers that would use new alloys and generate much higher pressure and temperature steam. This in turn would increase the efficiency of the turbine cycle which converts the steam energy into electrical energy.

The other technology involves advanced gasifier systems for IGCC systems that would have lower costs, higher efficiencies, and higher reliability than the present generation of IGCC plants.

DOE's goal is to not only increase efficiency, but also to decrease both cost and emissions, including mercury emissions. By 2020, DOE hopes to spur the development of technologies that can produce electricity for less than 30 mills/kWh compared to today's base case bus bar cost of 35 mills/kWh. The bus bar cost is the cost of generation as the electricity leaves the power plant and does not include transmission and distribution costs.[72]

[72] More details are available at http://www.netl.doe.gov/coalpower/ccpi/pubs/CCT-Roadmap.pdf.

5.6 Costs Associated with Mercury Controls

As discussed in the previous sections, several approaches and concepts for the control of mercury from coal-fired power stations are under development. The control technology which is the most advanced in development is the use of ACI, either using existing particulate collection systems or with the addition of FF baghouses to collect the carbon and captured mercury downstream of existing particulate control devices. This control technology has also had the most work done relative to the total installed capital cost and the annual operations and maintenance costs involved with the removal of mercury at varying reduction efficiencies and varying coal fuels, such as eastern bituminous and western sub-bituminous fuel. While still under development, ACI is being required on at least one new power plant (Mid-American Energy's new coal plant in Council Bluffs, Iowa). Costs to human health and the environment from mercury pollution are briefly discussed in **Section 2**.

Two recent studies have been issued and serve as references for the costs associated with control of mercury. These studies are:

- EPA, Office of Research and Development, Performance and Cost of Mercury and Multi-Pollutant Emission Control Technology Applications on Electric Utility Boilers.[73]
- DOE, NETL, Innovations for Existing Plants Program, Preliminary Cost Estimate of Activated Carbon Injection for Controlling Mercury Emissions from an Un-Scrubbed 500 MW Coal-Fired Power Plant.[74]

Both of these studies attempt to quantify the installed capital cost of equipment and the annual operations and maintenance cost for a variety of scenarios using ACI in combination with various existing and retrofitted air quality control equipment. Also addressed are the potentials of ancillary impacts on current costs of generation resulting from impacts on by-product recycle or disposal and loss of power for sale due to higher plant parasitic loads from the additional air quality control equipment.

A third point of reference is the DOE's Clean Coal Demonstration Project currently ongoing within Michigan at We Energies' Presque Isle Power Plant in Marquette.[75] This project is intended to use ACI via the TOXECON™ process to demonstrate mercury removal potentials on a full plant scale basis for western sub-bituminous fuel (PRB).

We Energies Presque Isle Power Plant

[73] Authors: James E. Staudt, Wojciech Jozewicz, Published October 2003.
[74] Authors: Jeff Hoffman, Jay Ratafia-Brown, Published November 2003.
[75] Additional information is available at http://www.we-energies.com/environment/mercury_control_pipp.htm or visit the DOE NETL website at http://www.netl.doe.gov

Capital Costs

In the work sponsored by EPA and DOE, both reference the use of the EPA's Coal Utility Environmental Cost (CUECost) model in the development of projected capital costs expected of installed equipment and systems.[76] As stated in the EPA report, capital cost using this model is related to the purchase cost of the FF baghouse for collection of injected carbon and mercury. Using this costing model, costs of $36 to $59/kW are projected. These cost ranges are largely affected by economy of scale with the lower value representing ACI plus FF on a 975 MW unit and the higher value representing the same added controls on a 100 MW unit. However, both studies caution that this level of cost impact does not represent the full project constructed cost and that the total installed cost can vary widely based on site specific conditions. An example is the demonstration project at the Presque Isle plant. This project has been through a detailed cost estimating exercise and is now in the engineering phase. The current total installed project cost is approximately $120/kW for a total of 270 MW of plant capacity.

The Presque Isle plant is relatively typical of the majority of the coal-fired power generating capacity in Michigan where the current installed emissions control equipment consists of CS-ESP for particulate collection. The addition of ACI for mercury control requires that a new injection system, new FF baghouse, and new induced draft fans, along with ash conditioning and ash handling equipment be installed. Should this scale of capital investment be applied to the majority of the installed generating capacity in Michigan, the cost of retro-fitted equipment and systems for the reduction of mercury emissions would be in the range of $1.5 billion. If the lower capital cost projections as referenced in the DOE and EPA studies prove to be more typical ($45 to $50/kW), then the required investment to add ACI and FFs to Michigan's coal-fired plant fleet for a 90% reduction in mercury emissions would be in the range of $575 million to $625 million.

Operating Costs

As pointed out in the DOE and EPA studies, the operating costs related to mercury removal systems using ACI are highly variable and strongly influenced by:

- the unit cost and quantity of the activated carbon to be injected for mercury control,
- the disposal cost of the mercury contaminated particulate collected, and
- the power production loss experienced by an increase in plant parasitic loads to higher pressure drops through the draft system, therefore requiring more ID fan horsepower to move exhaust gases through the draft system.

Predictions made in the DOE report for first year operating and maintenance costs, based on a single 500 MW unit and 90% removal efficiency, are in the range of $3 to $4 million. Using this base and extending to the installed capacity in Michigan, the impact on plant operations and maintenance costs would be approximately $75 to $100 million annually.

[76] CUECost is a spreadsheet-based program for estimating capital and operating costs of air pollution control devices on coal-fired power plants.

Unit Cost of Mercury Removal

Based on the work done in the DOE study and realizing that this study underestimates the total installed cost impact of retro-fit ACI and FF baghouse systems, the current cost estimate for 90% mercury removal ranges from $49,000 to $80,000 per pound of mercury removed (at 90% removal level) for sub-bituminous coals (Ratafias-Brown, 2003). According to DOE, these costs include annualized capital cost, annual operation and maintenance costs, and the impact of solid waste disposal cost. Should the installed capital cost projected for the Presque Isle Plant prove to be more typical, the unit cost of mercury removal for Michigan plants would be in the range of $127,500 per pound removed. However, recent estimates of costs associated with use of brominated ACI without add-on FFs have been in the range of $7,000 to $9,000 per pound of mercury removed on units burning sub-bituminous coals and having only cold-side ESPs for particulate control (Nelson, 2004; Nelson et al., 2004).

As stated in **Section 5.5.1**, many of the largest units in the state (representing 25 to 50% of the state's coal-fired generating capacity) will be retrofitted with SCR and FGD systems to comply with CAIR requirements. The co-benefit of these retrofits will be a 75 to 80% reduction of mercury emissions from retrofitted units. With 20 to 40% of the state's total annual mercury emission removed through co-benefit, further stand alone mercury retrofits at capital and annual costs similar to those discussed above will result in a significant magnification of the per pound cost of mercury removal. On a state-wide emissions basis, the per pound cost will increase to $75,000 to $120,000. For units that have already been retrofitted with SCR and FGD, the per pound cost will magnify to the range of $300,000 per pound; i.e., similar capital and annual costs for further stand alone mercury retrofits divided by a much smaller number of incremental pounds removed. Knowledge of which units would be installing these other controls would be helpful to determine the impact in detail of magnification factors on cost per pound removed during the rule-making process.

Using the Presque Isle numbers for capital and the DOE numbers for operation and maintenance, the impact on the cost of energy would be in the range of 4 mills/kWh (based on current full scale constructed cost experience from the DOE's Clean Coal Mercury Reduction Demonstration Project at the Presque Isle Plant in Marquette). The EPA studies (as shown in **Tables 19** and **20**) project average unit cost numbers in the range of 1.2 to 1.9 mills/kWh for 90% removal with the addition of ACI plus FF. As stated above, this range of costs is significantly impacted by realistic capital costs of added equipment for mercury removal and the annual operation and maintenance costs, which are strongly influenced by solid waste disposal costs, cost of carbon injected, and cost of salable power lost.

Acronyms used in **Tables 19** and **20** include:

ACI: activated carbon injection
Mill/kWh: mill per kilowatt hour
PFF: polishing fabric filters
MWe: megawatts of electricity

Table 19: Estimated Annualized Costs for Controlling Mercury at Three Levels For Large and Small Boilers Burning Bituminous Coals, with CS-ESPs and No SO_2 Controls*

RETROFIT OPTION	MERCURY CONTROL EFFICIENCY	ANNUAL COSTS (MILL/KWH)	
		975 MWe	100 MWe
ACI	90%	2.451	2.639
	80%	1.381	1.497
	70%	0.974	1.057
ACI and PFF	90%	1.233	1.751
	80%	1.171	1.682
	70%	1.144	1.650

*: From Table 17, Staudt, and Jozewicz, 2003.

Table 20: Estimated Costs for Controlling Mercury at Three Levels, for Large and Small Boilers Burning Sub-bituminous Coals, with CS-ESP and No SO_2 Controls*

RETROFIT OPTION	MERCURY CONTROL EFFICIENCY	ANNUAL COSTS (MILL/KWH)	
		975 MWe	100 MWe
ACI	90%	20.924	21.756
	80%	20.924	21.756
	70%	1.907	2.015
ACI and PFF	90%	1.369	1.903
	80%	1.236	1.753
	70%	1.176	1.685

* From Table 22, Staudt, and Jozewicz, 2003.

The tables indicate that for both bituminous and sub-bituminous coals, the marginal cost increase in going from 70% to 90% control is much less for scenarios where a FF is added than in the case of ACI alone (i.e., the first half of each table). The cost differences are particularly striking for sub-bituminous coals, where costs for the smaller plant would be over 11 times higher to reach 90% control (21.756 mills/kWh vs. 1.903 mills/kWh) without a FF than in the case where ACI is done with a FF. This differential reflects the extremely high ACI rates experienced in recent tests involving ACI at plants burning sub-bituminous coals and only having CS-ESPs for particulate control, where additional mercury control beyond 70% was difficult, even with high ACI rates. These cost estimates did not take into account most recent results on brominated-PAC discussed previously and in the next section, where 70% to 90% levels of control were achieved at modest injection rates. For bituminous coal, **Table 19** indicates that 90% control with ACI can be achieved even without FFs at relatively low cost, if the SCA of the precipitator can accommodate the higher ash load and lower ash resistivity caused by ACI injection. Also it should be cautioned that these results are based on very limited amount of actual test data. A two day test also demonstrated that brominated ACI accomplished approximately 90% removal at St. Clair when 100% sub-bituminous coal was burned.

Based on unit costs provided by EPA and recent generation data, controlling mercury at all Michigan coal-fired power plants using ACI with polishing FFs would result in annualized costs which could range from $100 million on the low side (i.e., applying EPA's per unit cost estimates to all existing configurations in Michigan) to $270 million on the upper end (utilizing projected costs from the Presque Isle's Mercury Reduction Demonstration Project, extended to all Michigan facilities), based on an average degree of retro-fit difficulty at each generation site. This range of annualized cost will be required to achieve a 90% reduction in mercury emissions.[77] Based on the existing configurations and 90% reduction target, it was assumed that ACI and a polishing jet FF would be needed in most cases. This led to total annualized control cost estimates for each unit which amounted to about $100 million annually across all coal-fired power plants in Michigan (NWF, 2004). In contrast, the actual experience of the ongoing Presque Isle's Mercury Reduction Demonstration Project indicates a much higher statewide cost impact, in the range of $270 million annually or more, depending on the remaining service life and actual capacity factor of older coal-fired units.

Historical experience with other pollution control programs indicates that implementation costs can sometimes be lower than initially anticipated. For example, prior to implementation of the acid rain program, it was estimated that SO_2 control costs would be between $4.7 to $6.6 billion per year and in actuality, by 1997, implementation turned out to be 3 to 4 time lower ($1.5 to $2.1 billion per year) (NESCAUM, 2000). On the other hand, more recent experience with NO_X control costs demonstrated that actual costs were significantly greater than EPA estimated costs (Annual Energy Outlook, 2005). Depending on the type of technology, one would typically expect control costs to decline with time as less capital-intensive technologies, in particular, mature.

The costs of going beyond the second phase of CAMR are very site specific. The largest units are anticipated to have SCRs and scrubbers and mercury removal in the range of 75 to 80%. At these units, any additional reduction would have a high marginal cost (in terms of additional dollars spent to remove each additional pound of mercury) as explained earlier. Other mid-size, base-loaded units, which will not be retrofitted with SCRs and scrubbers, may be anticipated to have 90% mercury removal as a result of add-on mercury specific controls. EPA's trading rules envision mercury specific controls on older, less frequently operated units where the unit control costs are much higher. EPA's control costs are predicated on a base-load operated unit being able to recover costs over a 30-year time period. On an older unit that only operates at one-quarter of the frequency of a base-loaded unit and has longevity of less than 10 years, the unit costs of mercury controls would be about an order of magnitude higher.

Specific, detailed and accurate analyses of the costs for going beyond CAMR in Michigan is difficult to predict, because the marginal costs or each incremental level of control are so dependent upon assumptions regarding existing baseline emissions of

[77] The lower figure was derived by NWF as part of an assessment of five case study states for utility mercury control, involving 2002 configuration information (including on coal rank and pollution control equipment), average generation for 2001 and 2002, and unit control costs from Staudt and Jocewicz (2003).

older units and uncertainties associated with the exact level of control that will actually be achieved from installing controls on larger and mid-size base-loaded units. The marginal unit costs ($ per incremental pound of mercury removed) for going beyond CAMR will, in any event, be much greater than costs associated with achieving the level of control required by CAMR.

An important issue with respect to costs is the policy context – with the federal CAMR finalized, Michigan utilities will have the obligation to meet state-wide mercury caps. As the CAMR was designed and currently stands, Michigan utilities should be able to meet the Phase I budget (2010 to 2017) through additional controls for SO_2 and NO_X (to meet requirements of CAIR), but some units will require mercury-specific controls to meet the Phase II budget (1,028 lbs. starting in 2018). So absent any state action going further than the federal rule, Michigan utilities will have some expenses (in particular after 2010) associated with mercury control. The additional (or marginal) costs to Michigan utilities of conforming with a more stringent state mercury rule would thus be the difference between the cost estimates provided above and what the utilities would have otherwise spent to meet the federal limits.

5.7 Experimental Testing of Mercury Control Systems

Several innovative mercury removal technologies will be tested on Michigan generating units beginning in 2004.

5.7.1 Consumers Energy – J.H. Campbell Plant

Consumers Energy's J.H. Campbell Plant has been selected as a testing site for a promising mercury removal technology, using sodium tetrasulfide injection. This will be the first large-scale test of this technology at a commercial-scale, 275 MW coal-fired electrical generating station.

This technology was first developed in Europe, where it is widely used to reduce the amount of mercury released by incinerators. Campbell Unit 1 will be set up so that a sodium tetrasulfide solution can be injected at multiple points within the ducts upstream of the ESP. A variety of injection rates will be tested. The sodium tetrasulfide reacts with mercury in the flue gas to form particulate mercuric sulfide. This by-product, commonly referred to as "cinnabar," is stable and non-leachable. Cinnabar is frequently mined for commercial mercury production. The cinnabar will be removed by the unit's ESP for anticipated disposal in Consumers Energy's ash fields. All work will be performed with the unit on line. Equipment installation and removal will not require a unit derate or outage.

Testing is scheduled to begin in the 2005. The project participants include Consumers Energy, EPRI, Babcock Power, and the URS Group.

5.7.2 Consumers Energy – B.C. Cobb Plant

Consumer Energy's B.C. Cobb Plant was selected as a testing site for an alternative carbonaceous sorbent and injection system developed by ALSTOM, known as Mer-Cure™. This process employs a sorbent preparation and injection that is intended to enhance performance by changing the physical nature of the sorbent.

Mercury emission testing will be conducted by the University of North Dakota's Energy and Environmental Research Center. The process will be tested over a range of test conditions. For a given test condition, sorbent injection will be performed over an 8 – 12 hour period. A unit recovery period of 12 – 16 hours will take place between tests. Testing will be performed at different feed rates for the sorbents in order to derive a measure of sorbent consumption versus mercury capture.

The testing program was conducted in November 2004. The data are currently being processed, analyzed and quality assured.

5.7.3 DTE Energy - St. Clair Plant

DTE Energy's St. Clair Power Plant is one of the test sites selected by the DOE to test mercury control technologies at coal-fired power plants. This plant uses a blend of sub-bituminous and bituminous coal, providing unique data in the evaluation of sorbent injection capability for mercury removal. There are six units at the plant. Unit 1 was selected for the test as it has a precipitator with a SCA of 700. The significance of the SCA for a precipitator is discussed in **Section 5.3.2.**

The overall project objectives are to determine the mercury removal performance and relative costs of sorbent injection for advanced PAC and other advanced sorbent materials in large-scale field trials. Setup began in the summer of 2004, and testing occurred through October of 2004. Partners in the project include DTE Energy, Sorbent Technologies, Duke Power, Fuel Tech, Western Kentucky University's Combustion Laboratory, PS Analytical, Spectra Gases, and Stock Equipment Company.

The advanced PAC that offered the best performance for this unit was a brominated PAC. Halides in general, have an affinity for mercury and bromine appears to have a greater affinity than either iodine or chlorine. Bromine chemistry has also recently been discovered to play a key role in the natural cycling of mercury (Ariya et al., 2003; Raofie and Ariya, 2003).

The use of brominated PAC on Unit 1 provided higher removal rates (approximately 90% mercury removal) and lower PAC injection rates than standards absorbents when the unit was burning a blend of 85% western sub-bituminous and eastern bituminous coal over a 30-day trial period. These are the first results from full-scale tests indicating high control effectiveness with sorbent injection on a unit burning sub-bituminous coals and having only a CS-ESP for

particulate control (Nelson, 2004; McCoy et al., 2004). Follow up work that is needed includes:

- Longer term testing,
- Testing on units with smaller ESP's (i.e., lower SCAs),
- Conducting similar tests with "concrete friendly" sorbents,
- And, the development of production-quality monitoring capability.

In Table 9 of the EPA/ORD's March 25th Control of Emissions from Coal-Fired Electric Utility Boilers: An update, EPA identified the remaining issues with halogenated PAC to be: "Direct experience with longer-term testing, testing with larger duct sizes, air toxics, ESP impacts, residue impacts, long-term corrosion, (and) sorbent supply."

5.8 Mercury Measurement Methodologies

The test of the effectiveness of any air emissions regulation is the ability to demonstrate compliance. There is a level of confidence in the ability to measure and report the mercury content in coal. The challenge is being able to accurately sample and measure mercury at concentration levels found in the flue gas of a coal-fired power plant. Currently, there are three primary categories for measuring mercury emissions: intermittent stack sampling – which provides a snapshot in time; integrated stack sampling – which provides a predetermined sampling period (e.g., hours or days) where a sample is collected in an adsorbent cartridge/tube; and finally, CEMS which provides real-time measurements.

5.8.1 Stack Sampling

Presently, well-established EPA Methods 29 and 101A have been available for mercury measurement. Methods 29 and 101A do not segregate the mercury sample into its speciated forms. To address the speciated forms of mercury, American Society for Testing and Materials (ASTM) Method D6784-02 commonly know as the Ontario Hydro Method (OHM) was developed and validated. The OHM provides Hg(p), Hg^0, RGM, and total mercury emissions. This test method uses specialized equipment (probe, filter, impingers, and a vacuum pump) to extract flue gas at a specific rate (isokinetic collection). A typical sampling time is two hours with a minimum of three test runs. In the OHM the Hg(p) is trapped on a filter while the Hg^0 and RGM phases are trapped in specific chemical solutions in the impinger glassware. After the sampling event, the filter and impinger contents are recovered in the field and the separate samples are analyzed in a laboratory using specific analytical methods.

This method has been considered to provide the most reliable results, and was used in EPA's ICR in 1999. The method can provide results with a high level of sensitivity, but is labor intensive and requires strict quality assurance/quality control and a highly trained sampling crew. The results, which can require a lengthy turnaround time, provide only a single data point. To attain consistent

results the stack sampling procedure and laboratory analysis require experienced personnel and can be expensive.

5.8.2 Integrated Sampling

EPA has recently proposed non-isokinetic Method 324 (based on the EPRI-developed Quick SEM™) for mercury sample collection. This method uses a constant rate sampling pump and a solid carbon sorbent trap to capture mercury emissions from the flue gas stream. The paired carbon traps are left in the gas stream for several hours, typically 24 hours, removed and sent to a laboratory for analysis. The resulting analysis of the carbon traps provides average of total mercury over the sample period. In cases of low concentrations, this longer sampling period may provide a larger sample for the laboratory to attain a low detection limit. While not providing real-time data as with a CEMS, or a single result as with intermittent stack testing, Method 324 results are a time integrated measurement. Also, Method 324 is lower in cost and simpler than the other methods and was designed to be set-up and maintained by a single technician.

A similar method called Flue Gas Adsorbent Mercury Speciation (FAMS) has been used to selectively capture and quantify the three mercury species: Hg(p), RGM, and Hg^0. This sampling train uses a heated probe containing a quartz-FF, and two specialized solid sorbent traps controlled by a mass flow meter and vacuum pump. The developers (Frontier Geosciences, Inc.) of this procedure consider this a semi-isokinetic method and boast equivalency to the OHM method.

5.8.3 Continuous Emission Monitoring System (CEMS)

The ability to continuously monitor the emissions of a given compound is a powerful tool for demonstrating the compliance with a regulation and also the effectiveness of a control technique. CEMS for SO_2 and NO_X have been at the heart of regulatory initiatives such as the federal Acid Rain and the NO_X Budget programs. Unlike the SO_2 and NO_X CEMS that industry has reliably used for years, mercury CEMS are in developmental stages.

There are several mercury CEMS offered commercially. The analyzers are capable of evaluating total vapor mercury on a near-continuous basis. Most of the commercial monitors use wet chemistry methods to convert RGM to Hg^0 for the analysis to get total mercury. Presently there is a mercury CEMS being field tested that uses a dry converter. Also, EPA has proposed Performance Specification (PS) 12A (PS-12A) to certify a stationary mercury CEMS. PS-12A will challenge the stationary mercury CEMS against either Method 29 or ASTM Method D6784-02 and require a minimum relative accuracy for certification.

As with all CEMS, sample conditioning is a key issue. The gas extracted from the duct/stack must be clear of any interference such as reactive fly ash, $PM_{2.5}$, chorine gas, excess SO_2, or other metals prior to detection by the analyzer. Conditioning of the stack gas is critical if measurement is performed prior to any control technique as the loading of interfering pollutants may be high. After

conditioning of the gas is complete, the mercury is quantified by detection with atomic adsorption or atomic fluorescence techniques. Location of the monitoring equipment is an important consideration since ambient temperature and humidity can affect the extraction, conditioning, and quantification of mercury.

The available instruments require pre-treatment and conditioning systems prior to detection and can be complex to operate and maintain. For long-term use, the current generation of mercury CEMS are primarily research grade instruments that require full-time engineering support and require significant maintenance. It is the opinion of some that a technology breakthrough is needed before mercury CEMS will be suitable for routine operation and compliance certification. As with all research grade CEMS, the selection of a system requires thorough evaluation and is site-specific as with choosing an appropriate control technology. Currently, the closest thing to a true CEM system for mercury is a mobile testing unit that can be used to accumulate data on a 24- to 48-hour test run basis to show variations in mercury removal from normal, day-to-day plant operating conditions, such as load changes and fuel variations. Mobile CEMs are very valuable on a test condition basis, but do not represent permanently installed, long-term CEM systems that have been developed and are in use for NO_X, SO_2, CO, and particulate. .

5.8.4 Current Evaluations

Efforts to test and evaluate mercury CEMS are under way in Michigan and across the nation. For Michigan, an extensive effort is taking place in a project being coordinated by We Energies and DOE as part of the Presque Isle Clean Coal Project.

In the year of 2001, a mercury control program took place at MSCPA, Endicott Station by Babcock & Wilcox and McDermott Technology. A proprietary liquid agent was injected at various rates into the wet scrubber. During the injection, the OHM was performed periodically and mercury CEMS (PS Analytical) were located at the inlet and outlet of the control device.

Recently, DTE and DOE used a PS Analytical CEMS for a mercury reduction project using a carbon-based adsorbent at the DTE St. Clair Power Plant. Again, a mercury CEMS was located prior to and after the sorbent injection. OHM sampling was also conducted at both locations.

More recently, Consumers Energy in a cooperative effort with Alstom/EERC, utilized and evaluated different manual sampling methods (OHM, Method 324 and FAMS) and CEMS (Nippon, Tekran, PS Analytical and Lumex) at the B.CCobb Plant. Mercury sampling and monitoring took place prior to the carbon-based injection location and prior to and after the ESP control device. Additional manual sampling took place even further past the ESP. In early 2005 Consumers Energy will evaluate tetra sodium sulfate as a mercury reducing agent at the J.H. Campbell power plant. Mercury CEMS (EPRI analyzer) will be used to evaluate the reducing agent.

6. Other Issues Associated with Mercury Reduction Programs from Coal-Fired Utilities

Environmental program development needs to consider the ramifications to the industry that is the target of proposed reductions in order to be a complete and thorough process. For the electric industry, the program development must consider the impacts due to interstate energy supply, retail customer choice, and system reliability. Perhaps more importantly, this reduction program development should be considered within the context of a Michigan energy policy. This would create a process that can address the impacts to the state's economy and energy reliability while considering appropriate environmental programs for Michigan. The subsections herein attempt to highlight the significant issues that need to be considered within the context of a mercury reduction program.

6.1 Interstate Energy

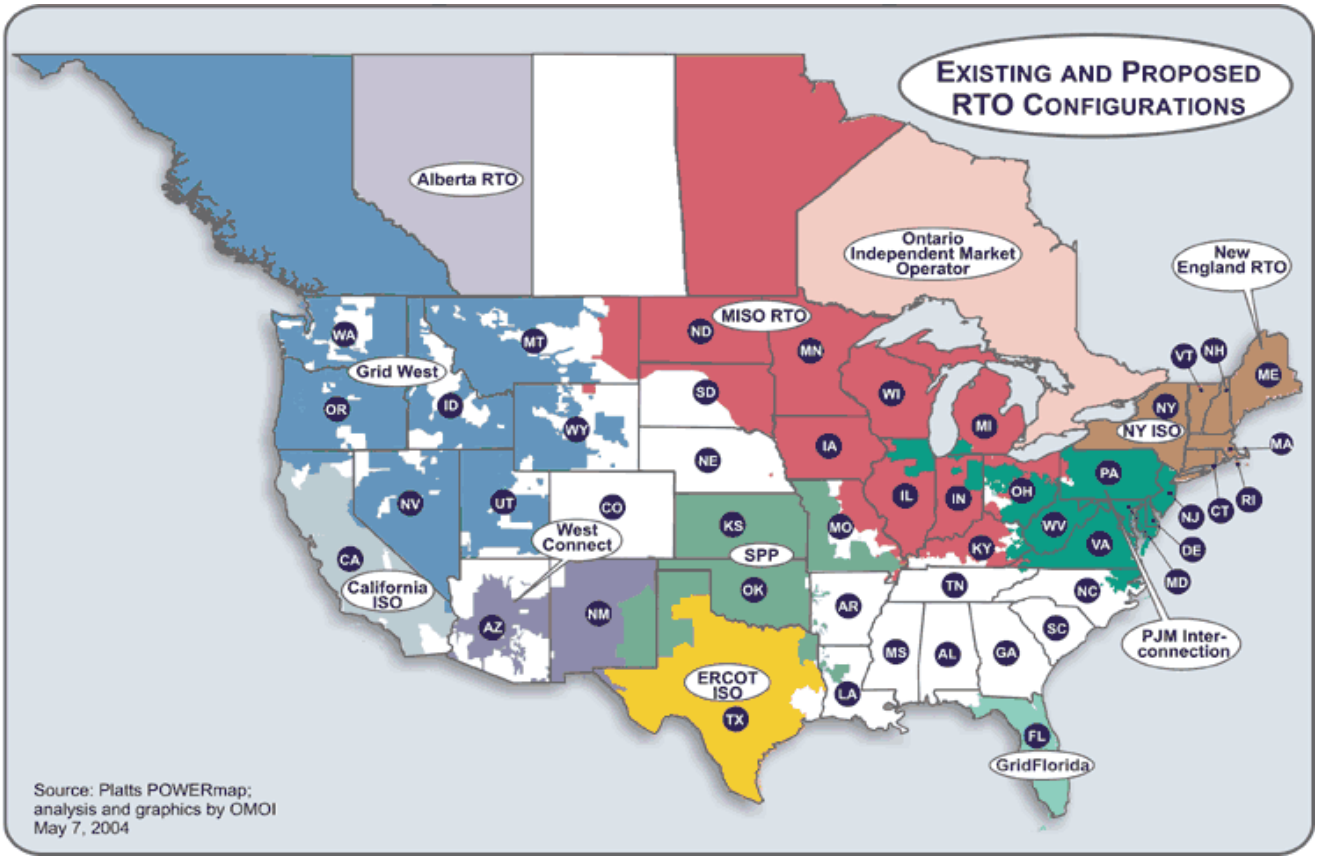
In the mid 1990's, FERC developed rules that forced vertically integrated utilities[78] to separate their transmission functions from their generation and distribution functions. This started with FERC Rule 888. What began afterward was a system that allowed for increased competition among generators and more open access to the nation's transmission grid.

In the year 2000, FERC introduced Order 2000, which required transmission owners to consider placing their assets under the control of a regional transmission owner (RTO). FERC believed that the transmission owners were still operating their systems in a way that gave preferential treatment to their native load customers and to their affiliated generators. By placing control in the hands of an RTO, FERC believed that this would provide an independent body that would operate the system.

One such RTO that has emerged is the Midwest Independent System Operator (MISO). MISO is located in Carmel, Indiana and is the operator of more than 100,000 miles of transmission line in 1.1 million square miles of area from Manitoba to Kentucky. The geographic area served by the MISO includes much of Michigan. A small remaining area in southwest Michigan is served by the PJM which is the RTO that originally served the Pennsylvania, Jersey, and Maryland markets and has since expanded to serve an area from New Jersey to Illinois. All utilities in Michigan that are connected to the transmission system are customers of either MISO or PJM. **Figure 13** shows the MISO and PJM service territories, as well as other proposed RTOs in development.

[78] Vertically integrated utilities have more than one level of processes or functions.

Figure 13: MISO and PJM Service Territories and Other Proposed RTOs

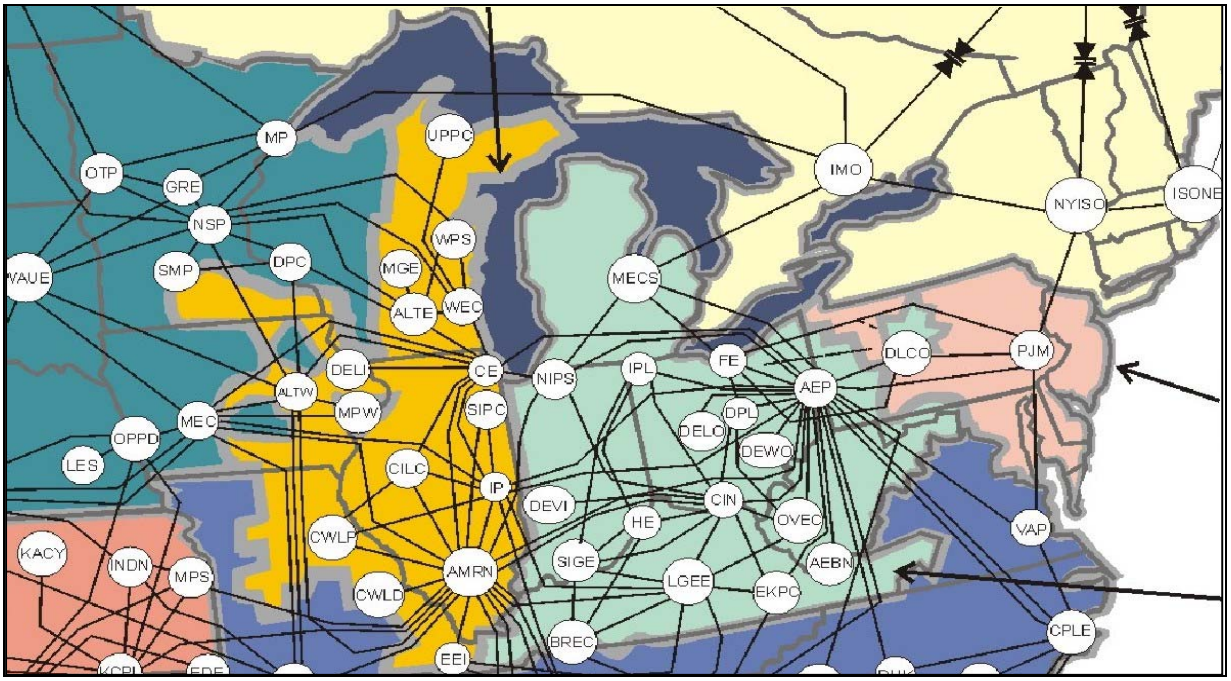


The MISO intends to not only be an operator of the transmission system, but also create an energy market by December 1, 2004 (the implementation date has been extended to April 1, 2005, with testing periods in between), whereas all generators and loads can bid into for the sale or purchase of electricity. This type of energy market is based on a plan proposed by the FERC and labeled Standard Market Design (SMD). For PJM, a similar market is already operating. Both the PJM and MISO markets are designed to match generators with loads until a clearing price is established for the entire region. To the extent that the transmission is not constrained, the lowest cost generators in the Midwest region will be the first to be chosen to operate. Therefore, Michigan's generators will be in competition with other out-of-state generators on a daily basis.

Figure 14 shows the electrical interconnections into Michigan. It is estimated that there is approximately 3000 MW of transfer capability into Michigan's Lower Peninsula, representing an equivalency of about 15% of the peak customer demand in Michigan. According to the June 5, 2001 MPSC Staff Report on Electric Industry Market Power in Michigan's Upper Peninsula, the transfer capability into the Upper Peninsula is 220 MW.[79]

[79] The MPSC staff report is available at http://www.cis.state.mi.us/mpsc/electric/restruct/reports/upreport.pdf.

Figure 14: Electrical Interconnections into Michigan



While the Midwest has embraced the FERC's SMD model labeled the Midwest Market Initiative, other regions of the country like the southern states oppose competitive models based on SMD. They believe it would take jurisdiction away from states that now manage their electricity and transfer it to a federal entity. These southern states also believe that a market based on SMD principles would send the relatively inexpensive power within their region to other high price areas of the country. Additionally, they believe that any SMD type proposal would force ratepayers in southern states to cover the costs of upgrading transmission in order for lower cost power to be shipped out of the region.

6.2 Customer Choice

Public Acts 141 and 142 of 2000, the Customer Choice and Electricity Reliability Act, were passed by the Legislature and signed on June 3, 2000 by former Michigan Governor John Engler.[80] Under the law, the MPSC was required to issue an order establishing the rates, terms, and conditions of service that allow all retail customers of a regulated electric utility or provider to choose an alternative electric supplier. The electric distribution systems remain under a regulated monopoly utility structure, but transmission systems are either owned or operated independent of the utility.

With Consumers Energy and DTE Energy providing service to almost 90% of Michigan's electric customers, the 2000 legislation also required the MPSC to establish residential rates for DTE Energy and Consumers Energy customers that would result in a 5% reduction from electric retail rates in effect on May 1, 2000. These reduced rates

[80] Additional information on the Customer Choice and Electricity Reliability Act is available at http://www.cis.state.mi.us/mpsc/electric/restruct/pa141.htm.

were frozen until December 31, 2003, and they are capped through 2005. Rates for large commercial and industrial consumers were capped through 2003. Small business consumer's rates were capped through 2004.

Since the new law took effect in June 2000, the MPSC has issued many orders to implement its various provisions. Open access was provided to all customers of Michigan investor-owned utilities, beginning January 1, 2002. Customers of Michigan's member-owned cooperative electric distribution companies that have a maximum demand of 1 MW or more and co-op customers with a peak load of 200 kW and above are now also eligible to participate (co-op customer' choice became effective January 1, 2005).

For municipal electric utilities, their local governing boards have until January 1, 2008 to decide if retail choice will be allowed for customers that are served outside of the city/village limits. If the municipality chooses to not allow retail choice in these areas, other electric utilities could petition the MPSC to grant them a Certificate of Convenience and Necessity that would allow that utility to provide distribution service to an existing customer of a municipal utility, thereby allowing the municipal customer to switch their electric distribution provider.

In February 2004, the MPSC issued their annual "Status of Electric Competition in Michigan" which is required under PA 141.[81] The 2003 report notes that over 13,000 Michigan customers (2,728 MW) are participating in Michigan's Retail Open Access. This represents 7% of the commercial class sales for Consumers Energy and 20% of the commercial class sales for DTE Energy, as well as 16% of the industrial sales for each of the utilities.

The MPSC released their 2004 annual "Status of Electric Competition in Michigan" report, in January 2005.[82] In this new report the MPSC notes that in 2004, there was continued growth in the number of customers and suppliers participating in both the Consumers Energy and DTE Energy service territories.[83] By the end of 2004, the total load of electric choice service in Michigan was 3,304 MW for a total of 18,714 customers. For Consumers Energy's service territory, about 10% of commercial sales and 22% of industrial sales were through electric choice service, with a total of 1,473 customers. In DTE Energy's service territory, electric choice sales represented about 32% of commercial and 23% of industrial sales for a total of 17,241 customers.[84]

On April 1, 2005, the MISO control area began operation under a "Local Marginal Price" (LMP) market-based system. Under this system, generation within the MISO control

[81] The February 1, 2004 report, *Status of Electric Competition in Michigan*, is available at http://www.cis.state.mi.us/mpsc/electric/restruct/reports/compreport2003.pdf.

[82] The January 31, 2005 report is available at http://www.michigan.gov/documents/elec-comp05_115196_7.pdf.

[83] Open access is available in all other service territories of Michigan's other investor-owned and member-owned (cooperative) electric utilities regulated by the MPSC, but no customers have yet enrolled for choice service.

[84] To view these reports and other reports as they are posted, visit the MPSC website at: http://www.cis.state.mi.us/mpsc/electric/restruct/reports/compreport2003.pdf .

area will be dispatched on the basis of a price bid into the market system by the generation owner. Regulated utility systems within the MISO control area, while continuing to receive traditional cost recovery for their generating units dedicated to service of their native load customers, will have options regarding how they bid their generation units into the market, schedule their generation to run at hourly levels, and become price takers in the market pool or schedule their unit to serve native load on their system and stay out of the market pool. The revenue associated with the sale of electricity by generation owners and the cost of electricity to load serving entities will be balanced out in a financial clearing process operated by MISO. These revenues and expenses incurred by regulated utilities will then be processed through the regulatory process at the MPSC. The impact of the market process on the ability of a traditional utility to recover its costs related to emissions reduction activity is uncertain at this time.

6.3 Historical Cost Recovery

Historically, the costs associated with the generation of electricity, capital items and non-capital items such as operation, maintenance, and fuel, were recovered in a regulated environment. The rates were set by the MPSC through a complex hearing process that employed formulaic approaches to determine the appropriate total amount of charges, and an equally complex cost allocation scheme to assign costs to individual classes of customers. This recovery mechanism practically guaranteed recovery of all expenditures legitimately related to electric power generation, including environmental equipment through regulated tariffs that all customers of the vertically integrated utility were required to pay. Under this system of cost recovery, generation facility owners would apply to the MPSC for recovery of costs associated with mercury emissions abatement and these expenses would be placed into customer rates with all other costs[85].

6.4 Capital Recovery in a Competitive Market - Concerns

Regulated Facilities

The ability of an owner of a MPSC regulated generation facility to recover mercury reduction investments has now been modified with the adoption of PA 141. Should the MPSC not permit full stranded cost recovery, choice customers would avoid, or bypass, paying for investments related to mercury reduction equipment on regulated facilities located within Michigan.

Thus, as mercury and other environmental control equipment is brought on-line in Michigan, all costs associated with the utilization of that equipment to date has been borne only by those customers choosing to remain generation customers of their current regulated utility. Should such policy continue, customers who live in Michigan, but procure their generation from unregulated alternative suppliers with generation sources located outside of Michigan, would realize a benefit without sharing in the cost to produce the benefit.

[85] Since the enactment of PA 141, recovery of costs for environmental equipment can no longer be guaranteed as customers can now purchase their electric generation from non-regulated alternative electric suppliers.

Should Michigan implement mercury rules that exceed those adopted by other states in the Midwest region, an "unlevel playing field" leading to unintended financial and environmental consequences could be created.

The following is an example using Consumers Energy.[86] Based on the cost of a service study that supports their current rate structure, each $500 million of plant investment results in about $90 million of annual fixed costs, which would require a 2 mill per kWh charge to all customers. Residential customers are responsible for about 28% of this $90 million, or about $25 million.

Let us assume a $625 million investment[87], which relates to ACI with FFs installed on the 12,500 MW of Michigan coal-fired generation. This investment would be estimated to result in a $112 million of annual capital costs recovery as well as an additional $100 million of operation and maintenance expenses to the customer. This would be expected to have the following impacts:

- Residential customers would cover about 28%, or $59 million, of the additional investment and operating costs.
- A rate increase to residential customers of approximately 2.05 mills per kWh, or about 2.5% of the average delivered rate.
- A residence that uses 750 kWh per month would see its bill increase by approximately $1.54 per month.
- Traditionally, non-residential customers would absorb the remaining 72% of the additional investment costs, or about $153 million annually.

The above example illustrates how increased utility investment and operating costs could ultimately lead to higher utility rates. If customers that purchase generation from an alternative electric supplier were allowed to bypass these costs, it could provide additional incentive for the remaining full-service customers to participate in choice and procure generation from an out-of-state generator.[88] This in turn may leave the utility with a declining customer base, weighted more heavily of residential customers, from which the utility must recover its full annual costs related to the installation of mercury reduction equipment. The extent of such a potential outcome can't be described completely as it is unknown to what extent a disparity will exist.

Should Michigan elect to implement mercury reductions that are more aggressive than the Federal CAMR, both costs and economic benefits can be expected to occur. A complete cost – benefit analysis, weighing the cost of controls, increased electric rates, impacts to the individual, to impacts industry, impacts to commerce, jobs lost,

[86] This example is specific to Consumers Energy. Other utilities rate structures will vary.
[87] The $625 million investment was an estimate provided by NWF that uses $50 KW for installed costs (from Section 5) and extrapolates O and M costs based on an estimated $4 million in annual O and M costs on a 500 MW plant (also referenced in Section 5). By comparison, We Energies Presque Isle plant located in Marquette has estimated installation costs of $120 KW.
[88] Regulations are under discussion in surrounding states.

construction jobs gained, ancillary industrial jobs gained, is beyond the capabilities of this workgroup and scope of this report.

In addition to disproportionate rising electric rates for non-choice customers, the implementation of a more stringent mercury rule in Michigan, which would lower mercury emissions that emanate from Michigan sources, could have the effect of increasing mercury emissions in the Midwest region as a whole, as well as increasing mercury deposition in Michigan. This could happen as additional customers procure electricity from lower cost but higher mercury emitting plants located out-of-state. Based on the likely geographic location of these alternative generation sources, through transport, emissions from these plants could get deposited in Michigan or the Great Lakes.

Thus, under the competitive model now being used by the electric utility industry in Michigan and the Midwest, alternatives to traditional methods of cost recovery to prohibit customer bypass of environmental related charges must be explored. Establishment of such a surcharge will need legislative action.

Non-regulated Facilities

A substantial portion of Michigan's newer electric generation facilities are owned and operated by non-regulated entities.[89] Almost all of these facilities are fueled by natural gas. These entities differ from the existing investor-owned, municipally owned, and rural electric cooperatives in Michigan, in that they neither have a legal obligation to serve customers within a designated service area, nor are they required to sell their generation under local board or MPSC cost-based regulated rates. These entities supply electricity to either the competitive market or regulated distribution companies, both in Michigan and outside of the state. They recover costs associated with capital and operational expenses from the sale of their product. Costs associated with mercury emission abatement for these plants would have to be recovered through the sale of electricity in the competitive market.

Municipal Utilities

The small plants owned and operated by municipal utilities systems are essential to electric reliability and energy supply diversity, and critical to the communities they serve. These facilities increase electric reliability and help avoid wholesale electric market price spikes. They provide reactive power to the transmission grid, and serve "load pocket" areas in which there are limited available options for securing power.

The capital costs for emissions control at small-sized utility units is disproportionately high due to inefficiencies in mercury removal, space constraints for control technology retrofits, and the fact that municipal utilities have fewer rate base customers upon which to spread these costs. In addition, smaller utility units contribute a relatively

[89] Non "rate" regulated would be a better term, as these power generation facilities fall under various forms of regulation.

small amount of mercury in the context of the industry-wide contribution of mercury emissions.[90]

A Michigan-specific mercury rule should take into account the particular challenges of installing high cost technology on small units, as it could imperil the viability of these facilities. In such a case, the negative impact to the local communities and the energy markets could be significant.

6.5 Capital and Recovery for Environmental Upgrades

As noted in **Section 6.4**, while Michigan considers new standards for reducing mercury emissions from Michigan utilities, it becomes important to consider how investment by Michigan utilities in controls to meet the new mercury standards will impact statewide electric rates. Additionally, in light of the new competitive electricity market, equal consideration must also be given to the impact that higher electric rates will have on the ability of Michigan utilities to recover their investment. Before implementing new mercury reductions standards, Michigan needs to explore alternative financing methods in order to minimize costs for Michigan customers, while also assuring that Michigan utilities can recover for their investment in new mercury reduction equipment.

Wisconsin, for example, has passed a bill titled "Financing of Environmental Improvements to Energy Utility Facilities" (2003 Wisconsin PA 152).[91] This bill allows for a special financing mechanism, referred to as "environmental trust financing," to finance certain environmental improvements to existing utility generating facilities. The Act allows for the creation of bonds issued under the authority of the Wisconsin PSC, to be repaid through revenues derived from fees applied to the customer's bills. Since this fee is placed directly on the customer bill, the utility is not placed at a competitive disadvantage to other state's generators. A variation of this type of legislation could entail establishing a state utility clean air fund. This fund would be paid by the rate payers and a utility installing mercury controls could apply for reimbursement for the controls from the fund. The customers receiving the environmental benefits are guaranteeing to repay the investment in the control equipment.

[90] In EPA's final CAMR (Standards of Performance for New and Existing Stationary Sources: Electric Utility Steam-Generating Units, OAR-2002-0056), the Agency stated that the smallest coal-fired units are responsible only for a negligible amount of mercury emissions, explaining that "The 1999 ICR data indicated that the 396 smallest emitting coal-fired units account for less than 5 percent of total Hg emissions. EPA also indicated in the proposal that there is reason to believe that the 15 ton Phase II cap can be achieved in a cost-effective manner, even if the lowest emitting 396 units are excluded from the coverage under this cap" (CAMR at 104-106). The EPA decided in the final CAMR to not completely exempt these units, because the Agency's focus is on protecting small entities from disproportionate impacts and "[o]f the 396 units with estimated Hg emissions under 25 lb. in 1999, most (about 95 percent) are not owned by small entities…" *Id.* This EPA acknowledgement reinforces the need for regulatory relief for small, low-emitting utility units owned and operated by small entities.

[91] 2003 Wisconsin PA 152 is available at http://www.legis.state.wi.us/2003/data/acts/03Act152.pdf.

6.6 Reliability

The installation of mercury emissions reduction equipment may impact the reliability and availability of coal-fired units on the Michigan system. Units will experience some level of unavailability during the construction/installation phase and will also experience an increased forced outage rate due to the reliability factor associated with the added equipment. There will also be increased annual planned outage periods associated with maintenance of the additional equipment both during and after the installation process in the following three ways:

1) The units in question will be unavailable for service during part of the time period required to install the equipment necessary to reduce mercury emissions which will likely vary from unit to unit.
2) The time period required to install the equipment will vary from unit to unit.
3) The unavailability of the units during the construction period will result in reduced system capability and reduced system reliability.

The installation of any additional device on a power plant associated with the operation of the plant reduces the reliability of that plant by the reliability of the installed component. The equipment required to remove mercury emissions from power plant flue gas will have a failure rate associated with its operation. Operation of new control equipment such as mercury controls will require a shakedown period, and initial reliability of the equipment may be in question. This should not be assumed to mean that problems associated with new control equipment will necessarily equate to down time for the EGU. This can be accommodated in a rulemaking process.

All equipment associated with the operation of a power plant must be maintained at some time during its life and emission related equipment is no exception. The term used to describe the time period associated with planned maintenance activity is the planned outage rate. During the time period when the unit must be shut down for maintenance of the mercury emissions reduction equipment, the unit will not be available to generate electricity. Proper planning during these outages will insure that this will not reduce the level of system reliability. Coordination of these outages between generators will be necessary to allow adequate resource availability to meet customer demand.

6.7 Supply Alternatives to Fossil Fuels

Michigan could realize the important benefits of substituting renewable power for some of its coal-based electricity production. Fossil fuel combustion releases a number of pollutants including ozone precursors, particulates, and toxics such as mercury. Therefore, reducing the amount of coal burned in Michigan would lower pollution levels, improving public health. Generating more electricity from instate renewable sources including wind, solar, biomass, and hydropower would also yield less reliance on imported fuels. Another benefit could be a greater opportunity for domestic economic development by keeping more investment dollars in Michigan's economy.

All forms of renewable energy ultimately derive from the sun. Solar energy can be directly harvested using photovoltaic materials, or indirectly as radiative heat. In addition, the sun powers atmospheric circulation and weather systems (wind), growth of organic material (biomass), and hydrologic cycling (hydropower). In the near term, wind and biomass comprise most of Michigan's viable renewable energy, although technologies for harvesting all forms can be developed and produced here. Section 10r(6) of PA 141[92] directs the MPSC to establish a Michigan Renewable Energy Program[93] (MREP) to educate consumers on the availability and value of renewable energy, and to promote its development in Michigan. MPSC staff submitted its first required annual report, *Michigan Renewable Energy Program: Annual Report to the Michigan Public Service Commission*, to the legislature in November 2003.[94]

According to the 2003 MREP report, the American Wind Energy Association (AWEA) has ranked Michigan fourteenth in terms of wind power potential with 7,460 MW (MPSC, 2003).[95] Due to a variety of factors that influence wind generation development, there is a disagreement that this preliminary figure represents an unrealistic upper bound in terms of what could actually be installed, owing to factors such as local opposition to many wind power projects, and insufficient transmission capacity to remote sites. Nevertheless, there is opportunity for significant growth, particularly as only 2.4 MW of nameplate capacity have been developed in Michigan so far (0.6 MW in Traverse City, 1.8 MW in Mackinaw City). For example, Traverse City Light and Power has a 600 kW wind generator that provides power for approximately 200 households. The National Renewable Energy Laboratory (NREL) has estimated that Michigan has a potential for development of 16,560 MW.

More reliable information on wind distribution throughout Michigan is forthcoming. TrueWind Solutions, LLC, in a collaborative effort with the Michigan Department of Labor and Economic Growth's (DLEG's) Energy Office, NREL, and the DOE, has developed comprehensive wind energy resource maps using satellite data.[96] These maps are estimates of wind resources and are based primarily upon computer modeling. They are intended to be suggestive of areas within Michigan that may be suitable for wind generators.[97] This new information will greatly inform the prospects for wind development in Michigan.

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[92] The complete PA 141 is available at http://www.legislature.mi.gov/documents/1999-2000/publicact/pdf/2000-PA-0141.pdf

[93] Electronic case filings on the Michigan Renewable Energy Program (Case No. U-12915) are available at http://efile.mpsc.cis.state.mi.us/cgi-bin/efile/viewcase.pl?casenum=12915.

[94] The 2003 MPSC annual report is available at http://www.michigan.gov/documents/mrep_annual_03_78447_7.pdf;

[95] The AWEA report *An Inventory of State Incentives for the U.S.: A State by State Survey,* is available at http://www.awea.org/policy/documents/inventory.PDF

[96] More information on DLEG's Energy Office website is available at http://www.michigan.gov/cis/0,1607,7-154-25676---,00.html

[97] Values represented for any geographic location may differ from actual conditions at the same location. Although the maps are believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement before purchase or installation of any wind power systems.

The Environmental Law and Policy Center (ELPC) recently estimated that with proper policy vehicles (including the state's adoption of a renewable portfolio standard and renewable energy investment fund), the state could add over 3,900 MW of new capacity of generation from renewables (primarily wind and biomass) by 2020 (ELPC, 2001).[98] ELPC's study estimated that through improvements in energy efficiency, their proposed energy development would lead to net savings in the cost of energy in the state by 2020. A 2001 assessment comparing high efficiency wind turbines using Class 4 wind resources to coal generation indicated that the costs of producing electricity were slightly lower for wind (i.e., approximately 3 to 4 cents/kWh for wind vs. 3.5 to 4 cents/kWh for coal) (Jacobson et al., 2001). While there may be a limited supply of Class 4 wind in Michigan, communities may choose to invest even in Class 3 winds when comparing the overall benefits of using a renewable energy source relative to coal or other fossil fuels.

There is understandable concern that wind power is not dispatchable, meaning that it cannot be produced on demand. However, if enough wind turbines are spread widely throughout a service territory, then the aggregate can provide significant capacity on a predictable basis, even though the amount might be only a fraction of total generator nameplate ratings. Studies have shown that resulting impacts on utility operating costs are small at wind penetrations up to 5% and moderate up to 20%. Finally, RTOs including the MISO are investigating revisions to grid operating rules and tariffs to better accommodate wind energy variability (MPSC, 2003).

Beyond wind, biomass has potential for generating some additional renewable power in Michigan. Instate biomass resources include agricultural crops, forest products, and wastes from food processing, livestock and poultry. Interestingly, anaerobic methane digesters that convert organic materials into biogas offer the additional benefit of relieving some environmental impacts from waste-intensive activities, such as concentrated animal feeding operations and municipal wastewater treatment. There are available data on Michigan's existing biomass capacity.[99] For example, six generating units (Cadillac, Genesee, Grayling, Hillman, Lincoln, McBain) totaling 160 MW of installed capacity that burn wood wastes exclusively. Comprehensive information about total potential biomass capacity remains incomplete because measurements have not been conducted for many subsectors (e.g., manure, wood waste, crop waste). The DLEG's Energy Office and MREP are currently engaged in this research and results are expected within a year.

Another potential alternative to coal-based power generation is nuclear energy. Nuclear power continues to be used for power generation in much of the world. In the U.S. where there has been no new plants started since 1979, 20% of power nationally is generated by nuclear power. Certainly, any discussion of energy generation from nuclear power is a sensitive one; however it is a demonstrated generation technology on a large scale.

[98] The ELPC study is available at http://www.repowermidwest.org/michigan.php.
[99] For more information, see the Michigan Biomass Energy Program website at http://www.michigan.gov/biomass/.

6.8 Energy Efficiency

Another strategy to reduce mercury emissions and save money is investment in energy efficiency. In 2002, Michigan users spent $7.4 billion on 118 million MWh of electricity.[100] Utilities burned 33.4 million short tons of coal, a product that must be completely imported, to produce 57% of this energy.[101] According to the Energy Star 2002 Annual Report, all sectors could use an array of technologies and practices available right now to reduce energy expenses by 20 to 30%.[102] Clearly, the potential benefits to society from efficiency are enormous. Strategies for implementation include equipment replacement and retrofit, new construction, and building renovation. Systems range from lighting, insulation, and appliances to industrial pumps and motors.

Beyond direct cost savings from avoided electricity, total economic gains from efficiency include indirect state investment and multiplier effects, and unpriced yet real improvements in public health and the environment due to pollution reductions. Moreover, lower aggregate demand for electricity tends to lower the market-clearing prices for power, especially during times of highest electricity demand. For the comparatively low cost of 2 to 3 cents/kWh, energy efficiency improves the electric system's ability to supply aggregate energy demand at all times because it reduces the base load as well as the peak power demand. This delivers the added benefit of reduced stress at various points on the power grid, enabling it to better withstand sudden disturbances such as the blackout suffered by Michigan in August 2003.

In addition to being cost effective, energy-efficient technologies and practices can be installed quickly and are not subject to time-intensive siting and permitting processes required for the construction of new power plants. Numerous case studies demonstrate the long and proven track record of successful efficiency projects. Perhaps the one significant barrier to expanding these projects is the lack of financing options that fully recognize the life cycle cost-benefits of energy efficiency.

6.9 Utility By-Products

Coal-burning power plants, which supply more than half of U.S. electricity, also generate coal combustion by-products. The reuse of coal combustion process by-products is not a new concept. The Romans used product similar to coal ash, volcanic ash, to construct the Coliseum, aqueducts, and other structures that remain today. Coal ash has been commercially used in concrete in both Europe and the U.S. for more than 60 years. As an example, between 1948 and 1953 over 120,000 metric tons of fly ash was used in the construction of Hungry Horse Dam in Montana. As a local example, DTE Energy ash was used in the construction of the Mackinac Bridge.

Table 21 was generated from the EIA form 767 for the year 2001 that identifies coal combustion and FGD by-products that were recycled/reused. For each ton of material

[100] 2002 Summary Statistics are available at http://www.eia.doe.gov/cneaf/electricity/st_profiles/michigan.pdf.
[101] To view the EIA data table, go to http://www.eia.doe.gov/cneaf/coal/page/acr/table26.html.
[102] Energy Star 2002 report is located at http://www.energystar.gov/ia/partners/cpdann02.pdf.

reused, not only is there a large financial swing from an expense to a revenue stream, but there are secondary impacts on the environment. Using ash as an example, although a variety of re-uses exist or are in development (see **Table 22**), the majority of recycled ash is used in the manufacture of cement or concrete. For each ton of ash replacing a ton of cement in the manufacture of concrete, over a barrel of oil is saved, there is a reduction in greenhouse gases such as CO_2, and landfill space is saved (U.S. Geological Survey [USGS], 2002).[103] These secondary environmental benefits can be significant. The amount of space require to dispose of one ton of coal ash is equivalent to that required for the solid waste produced by an average American in a 455-day period.

Table 21: 2001 Coal Combustion and FGD By-Products Recycled/Reused

EIA767 DATA	ASH TONS RECYCLED	ASH RECYCLED REVENUE $	FGD SLUDGE TONS RECYCLED	SLUDGE RECYCLED REVENUE $
U.S.	23,399,100	$19,231,900	6,535,000	$26,107,500
Michigan	599,800	$2,006,000	0	$0

Table 22: Saleable By-Products

MATERIAL	COMMON AND DEVELOPING RE-USES
Ash	Admixture in the concrete Feedstock in production of cement and asphalt Flowable fill Sludge and waste stabilization Reuse in energy production Reclamation and neutralization of waste coal abandoned mine sites Combine with sludge from industrial lagoons and waste from hog farms Highway roadbeds Structural fill in embankments or under buildings (e.g., malls) Inert clinker for roads (when stabilized with cement) High quality grit blasting media Cast brick and block Low density aggregate Roofing tiles Glass products Fertilizer Extruded high strength bricks Extruded wall panels Light-weight aggregate Filler materials Extruded masonry blocks with two-way joints Coloring aggregates for asphalt Manufacture of magnesium Highway sound barrier walls and privacy walls
FGD	Gypsum Agricultural soil stabilizer Inert fill

[103] The USGS Fact Sheet 076-01 is available at http://pubs.usgs.gov/fs/fs076-01/fs076-01.html.

Anytime by-products are used in lieu of another natural material, like soil, sand, or gypsum, a portion of the fossil energy required to mine, transport, place, or process is reduced. For example, using coal ash instead of natural soil in the construction of highway fills or embankments eliminates the need to remove soil from undisturbed areas, saving energy. As another example, the use of FGD synthetic gypsum provides material to manufacture wallboard, avoiding the energy intensive mining and processing activities when natural gypsum is used. If mercury control technology negatively impacts the reuse of by-products (e.g., if activated carbon is injected upstream of an ESP), it would eliminate many of the environmental benefits mentioned above.

An additional concern is the fate of mercury captured via pollution control devices. There has been some concern that ACI for mercury control could make ACI-contaminated fly ash a hazardous waste, or at a minimum that mercury could potentially be leached from the fly ash. Research to date using standard test procedures has shown relatively limited leaching of mercury from fly ash and FGD materials; however, researchers note that additional tests on release rates, leachability, and potential impacts of mercury from a wider variety of fly ash, sludges, and other materials are needed (Pavlish et al., 2003).

In addition, from the financial perspective of utilities in Michigan (assuming the waste can go to a typical type 2 or 3 landfill), based on 2001 EIA767 data, the $2.0 million in revenue would turn into a $11.98 million expense, a swing of $13.98 million. With recent conversions to PRB coal for NO_X compliance, the tons of ash recycled in 2002 and 2003 were likely much higher and reflect a bigger financial swing.

6.10 Environmental Challenges to Economic Opportunity

Faced with environmental challenges such as mercury emissions to our atmosphere in Michigan, this must be faced and also opportunities identified in that challenge. As the Workgroup went through the process, it became apparent that the reduction of mercury from coal combustion is an evolving science and an improving one. Other factors that were brought out include the challenge to newer and cleaner energy production in Michigan in the future. These two are intertwined and related.

Air pollution control equipment was a greater part of the Michigan economy in the past than it is today. As time passed and the industry consolidated, less and less of this equipment was manufactured in Michigan. Faced with air emission control challenges such as mercury and give the large percentage of generating capacity that is from coal-fired combustion, there is an opportunity to encourage air pollution control technology to increase in Michigan. This will require a partnership among the State, the energy industry, and the institutions of higher learning. From this partnership all of these groups as well as the citizens of Michigan can benefit.

In 2003, environmental businesses generated $301 billion in total industry sales in the U.S. (Bezdek and Wendling, 2004). Of the environmental businesses in Michigan:

- 29% of the jobs are in manufacturing compared to 17% in manufacturing among all private sector industrial activities,
- 29% of environmental jobs are in professional, scientific, and technical services compared to 5% of all private sector jobs,
- 19% of environmental jobs are in administrative, support, and waste management services, compared to 8% of all private sector jobs,
- 2.2% of environmental jobs are in educational services, compared to 1.9% of all private sector jobs in the state (Bezdek and Wendling, 2004).

Specifically, first, a coordinated testing program for mercury emissions in conjunction with all of the parties above and with pollution control equipment vendors could be crafted in such a way as to offer incentives to the vendors to sell their products in the mid-west and locate their research and development and manufacturing in Michigan.

Second, new energy development technology should be encouraged. NextEnergy is already embarking on supporting development of energy technology. NextEnergy is already involved in development of renewables. NextEnergy could be empowered to seek out new opportunities in the energy development sector including coal gasification. This could be expanded to include research, development, and training opportunities in Michigan. We should not only be the users of new energy technology; we should be developing research centers associated with our world class universities, seeking project development, and developing national educational and training programs for the new technologies. This development will also attract manufacturing and component suppliers to Michigan.

It is recommended that a very focused workgroup be formed to examine and recommend actions that can be taken in the near future to make things happen that will benefit Michigan environmentally and economically with respect to pollution control.

7. Recommendations for Mercury Reductions from Coal-Fired Utilities in Michigan

In 2003, the MDEQ was tasked by Governor Granholm to review past initiatives and progress and develop a Mercury Action Plan. The MDEQ identified this task as one of their 2003 one year action items and the Michigan Mercury Electric Utility Workgroup was established.

The Workgroup's charge is to evaluate opportunities for reduction of mercury emissions from the state's largest remaining source - coal-fired utilities, and recommend a reduction strategy for Michigan. Coal-fired utilities have not previously been subject to any mercury emissions reduction requirements.

7.1 Summary of Findings

7.1.1 Background on Mercury

Mercury is a persistent, bioaccumulative neurotoxin. There are epidemiological as well as experimental studies in humans and animals to indicate an increased risk to the developing fetus upon exposure to methylmercury via maternal fish consumption. In the past, mercury has been widely used in a variety of products and processes due to its unique physical properties. However, evidence of its high toxicity has resulted in considerable reductions and, in some cases, the complete ban of mercury in household and industrial products and applications. The burning of fossil fuel remains a significant source of mercury emissions in the environment and coal-fired utilities represent the largest sector for anthropogenic mercury emissions in Michigan and the U.S.

The history of mercury regulation in Michigan dates back to the early 1970's but has been piecemeal and inconsistent. A comprehensive plan for mercury reduction and regulation in Michigan is lacking. Although controversy exists with regard to the extent to which mercury is deposited locally from nearby sources and with regard to speciation of mercury in the flue gas which influences deposition and bioavailability factors, the need for mercury reductions to protect public and environmental health remains. In 1999, Michigan's statewide mercury inventory estimated that all anthropogenic sources emitted 4,573 lbs of mercury to the air.

7.1.2 Mercury Emissions and Deposition in Michigan

Coal-Fired Power Plants and Mercury Emissions

Section 3 provides a summary of Michigan's coal-fired power generating units. Specifically, the section identifies these generating units; their generating capacities; the type of coal burned in each unit; the existing and currently planned controls for NO_X and SO_X emissions; the particulate controls currently in place at each facility; and the estimated mercury emissions reported to the EPA in an ICR and TRI reporting.

As of 2000, the existing coal-fired units represented approximately 12,500 MW of generating capacity. Nearly 57% of the state's total electricity is generated using coal. With respect to the type of coal currently being burned, the majority (68%) is a low-sulfur, sub-bituminous coal (PRB) from Wyoming. A large portion of the generating units are equipped with ESPs, with only a handful of smaller units, representing less than 400 MW, being equipped with FFs. Some of the larger units are equipped or are in the process of being equipped with SCR equipment for NO_X control. However, only a small number of units representing 227 MW are equipped with FGD for SO_X control. All of the above represent important factors that require consideration when discussing the potential for mercury emission control.

Section 3 also provides estimates for contemporary emissions from coal-fired power plants. For the years 1999, 2001, and 2002, the coal-fired units collectively emitted approximately 3,100, 2,600, and 2,500 pounds or mercury, respectively. Units that fire sub-bituminous coal only emitted approximately 600 lbs; those that burn western and eastern bituminous coal emitted approximately 130 lbs; while those that burned a blend of bituminous and sub-bituminous coals emitted approximately 2,300 lbs in 1999.

Mercury Deposition and Fate

Research has shown that mercury emitted by human activities, including coal-fired power plants, can be transported and deposited locally, regionally, and globally. Where emitted mercury actually deposits cannot be stated with absolute certainty. In part, this is due to the fact that emitted mercury can exist in one of three major chemical forms: Hg^0, RGM, and Hg(p). All three forms can be deposited, however, many complex factors are involved, some of which are incompletely understood. Hg^0 is likely to exist in the atmosphere for up to a year, while the RGM and Hg(p) are more readily deposited. From monitoring, it is known that mercury is being deposited in Michigan and that the amount being deposited varies, with lower amounts deposited in the western portion of the Upper Peninsula and higher amounts in the southeast portion of the Lower Peninsula.

Research has also provided a basic understanding of how deposited mercury interacts with aquatic resources. Of particular interest to resource managers is how mercury is taken up by aquatic food chains and why there exists differences among water body types with respect to the mercury levels present in large predator fish. While many factors are involved, in general, it appears that lakes that have higher acidity levels (pH less than 7.0); lakes that thermally stratify and have regions within them that are devoid of oxygen; and lakes that receive water from nearby wetlands are more likely to have fish with higher levels of mercury than lakes that do not exhibit these characteristics.

Based on very complex chemical transport models, there appears to be patterns in mercury deposition across the U.S., Canada, and other nations. In some areas, the modeled and measured deposition values agree quite closely; in other areas, the two values differ. This suggests that our ability to determine direct linkages

between the many sources of mercury and where the mercury deposits is not yet in hand. However, the models have been useful for estimating the approximate ramifications of proposed mercury controls.

7.1.3 Mercury Regulations

Federal

In the CAAA of 1990, Congress put forth Section 112 that expressly addresses a list of 188 HAPs which includes mercury. In Section 112(n)(1)(A), Congress addressed utility units separately and distinctly from major and area sources. Congress directed EPA to conduct a study of mercury emissions from electric utility steam generating units (and other sources). EPA was to consider the rate and mass of such emissions, the health and environmental effects of such emissions, review control technologies, and report the results to Congress.

There were actually four major studies conducted including the Utility RTC and an ICR. As part of the effort to assist EPA in making its regulatory determination to regulate HAPs emissions from electric utility steam generating units, EPA conducted an ICR. The purpose of the ICR was to determine the amount and variability of mercury in coal used in 1999, as well as targeted measurement of mercury emissions from specific facilities. Based on the results of the ICR, EPA estimated that in 1999 the utility industry emitted 48 tons or 41% of all industrial sources of mercury emissions.

In March 2005, EPA revised its regulatory finding that was issued in December 2000 pursuant to Section 112, removing coal and oil-fired electric utility steam generating units from the CAA Section 112(c) source category list. This means that coal-fired electric utility steam generating units are a “delisted source category” from Section 112(c) and are no longer subject to a MACT regulation.

EPA signed CAMR on March 15, 2005. The CAMR uses the NSPS under Section 111 of the CAA to set emissions limits for new sources and established a cap-and-trade program of all existing and future coal-fired EGU sources. The cap-and-trade regulation would set a cap of 38 tons and yield approximately a 20% reduction by 2010 and impose a 15 ton cap by 2018 yielding a nearly 70% reduction in subsequent years. The CAMR requires states to develop regulation and a SIP for existing coal-fired EGUs.

Other States’ Regulations and Regional Actions

There are nine other states in some stage of regulatory development to control mercury emissions from coal-fired utilities. These states are looking at regulation using a variety of methods including mercury emission limits, percent reduction requirements, or cap-and-trade programs.

In accordance with the revised Great Lakes Water Quality Agreement of 1978, as amended by the Protocol signed on November 18, 1987 to restore and protect the Great Lakes, the GLBTS included a mercury reduction strategy component. The

U.S. challenge is to see a 50% reduction, nationally, in the deliberate use of mercury and a 50% reduction in the release of mercury from sources attributed to human activity (see **Section 4.5.1**).

The NEG/ECP, comprised of six Northeastern states and five provinces, adopted a Mercury Action Plan in 1998. The Plan documents a long-term goal of virtual elimination of anthropogenic emissions of mercury and a 50% reduction in regional emissions by 2003. In 2000, the NEG/ECP workgroup recommended a reduction in mercury emissions from coal-fired utilities by 20% to 50% by 2005 and 60% to 90% reduction by 2010. This recommendation has not yet been formally adopted by the Governors and Premiers.

Other Regulations and Co-Benefits

EPA is in the process of implementing and proposing several regulatory initiatives for other pollutants which are expected to produce co-benefits resulting in mercury reductions.

The NO_X SIP Call is a federal rule aimed at reducing NO_X emissions from utilities and large industrial sources in 19 states to eliminate significant contribution of transported ozone. The NO_X SIP Call has resulted in the installation of post-combustion controls such as SCR units on select boilers, typically newer larger units. SCRs also produce a co-benefit reduction for mercury.

EPA promulgated CAIR to address the long-range transport of emissions that contribute to nonattainment of the new NAAQS for $PM_{2.5}$ and ozone. CAIR reduces emissions of selected precursors (SO_2 and NO_X) to $PM_{2.5}$ and ozone, and utilizes a cap-and-trade system for both pollutants similar to previous programs. This rule is projected to provide significant co-benefits for mercury. Additional SCRs would be installed in states not included in the NO_X SIP Call. It is expected that numerous wet or dry scrubbers will be installed which also provide a mercury co-benefit.

Over the last three years several federal legislative proposals have been put forth. Each of these would modify the CAA as it applies to EGUs. Each offers to replace the traditional pollutant-by-pollutant regulatory approach with a comprehensive process that would reduce emissions of SO_2, NO_X, and mercury, and in some proposals CO_2.

7.1.4 Mercury Controls for Coal-Fired Utilities

Several options for controlling mercury from power plants that are either in current widespread use (e.g., scrubbers or FFs) or are in the early stages of commercialization (e.g., ACI) can be pursued in Michigan. These technologies – either alone or in combination, depending on the type of coal burned and other factors – can achieve substantial reductions in mercury emissions, based on pilot tests on other units. Preliminary estimates indicate that costs for these technologies would be in the neighborhood of 1.2 – 4 mills/kWh, or in the range of costs currently incurred for installation of scrubbers for SO_2 or catalytic reduction

units for NO_X controls. A summary of the various approaches that may achieve mercury reductions (and in many cases other benefits) are given in **Tables 23** and **24**. **Table 24** shows mercury control efficiency using the various pollution controls.

Table 23: Summary of Possible Approaches to Reducing Mercury Emissions at Michigan Utilities

REDUCTION APPROACH	APPROXIMATE MERCURY REDUCTION (%)[1]
Coal cleaning/precombustion treatment	10 – 35[2]
Fuel switching – lower mercury coal	10 – 20
Fuel switching – natural gas	> 95
Efficiency improvements	10 to 25

[1] Reduction percentages rounded from Pavlish et al. (2003), as well as discussions in **Section 5**.
[2] For individual units, it would depend on coal rank burned and extent of cleaning already done. Upper range assumes advanced precombustion treatment for sub-bituminous coals (e.g., K-fuels™ process), and that processed coal would be shipped with an equal amount of unprocessed coal.

Table 24: Pollution Controls and Mercury Control Efficiency

TYPE OF COAL FIRED	COMBUSTION TECHNOLOGY USED	POLLUTION CONTROLS (EXISTING AND POTENTIAL)[1]	REPORTED MERCURY CONTROL EFFICIENCY[2]
Bituminous	PC Boilers Stoker-Fired Boilers CFB/MSFB	FF	Up to 90%
		Wet FGD and HS-ESP	Up to 46%
		Wet FGD and CS-ESP	Up to 68%
		Wet/Dry FGD and FF	Up to 76%
		Dry FGD and FF and SCR	Up to 98%
		CFB and SNCR and FF	Up to 94%
		ACI	40% to 90%
		ACI + PFF	80% to 90%
Sub-bituminous	PC Boilers	FF	62 to 8372%
		Wet FGD and HS-ESP	Up to 20%
		Wet/dry FGD and CS-ESP	10% to 52%
		Dry FGD and FF	Up to 25%
		Dry FGD and FF and SCR	Not Tested
		CFB and SCR and FF	Up to 57%
		ACI	50% to 90%
		ACI + PFF	85% to 98%
Bituminous/ Sub-bituminous Blend	PC Boilers	FF	62% to 90%
		Wet FGD and HS-ESP	1% to 37%
		Wet/dry FGD and CS-ESP	10% to 52%
		Dry FGD and FF	25% to 76%
		Dry FGD and FF and SCR	NA
		CFB and SCR/SNCR and FF	57% to 94%
		ACI	40% to 90%
		ACI + PFF	80% to 98%

[1] Data is mainly for PC boilers unless specifically noted.
[2] Data drawn from Kilgroe et al. (2003), S, Staudt and Jozewicz (2003), and additional studies cited in **Section 5**. Some of these efficiencies are based on one or limited testing, and efficiency is variable.

Because most bituminous coals burned in Michigan are already cleaned, additional conventional coal cleaning would have a relatively minor impact on overall utility mercury emissions in the state. However, newer physical/thermal treatment technologies can potentially lead to 70% precombustion reduction rates for sub-bituminous coals. (Shipping considerations of the powdered coal produced may require shipment with unprocessed coal to minimize loss during transit; the only other option would be if cleaning were done at the site of the power plant). Switching to other coals would likely have a relatively minor impact in Michigan, given issues with lower mercury sub-bituminous coals (i.e., the fact that they are lower in chlorine and tend to produce more Hg^0) and the fact that many Michigan plants already burn substantial amounts of western coals. There could be some reductions for plants burning bituminous coals if lower mercury coals of this rank were identified. Conversion or complete repowering projects with natural gas would lead to substantial reductions in mercury emissions for any existing coal plant. However, natural gas supply infrastructure issues and particularly price trends, are all limiting variables in using natural gas for repowering projects. Plant efficiency improvements (including conversion to supercritical steam cycles on PC units) could lead to up to 25% reductions in emissions of mercury and other pollutants, per unit of electric output. The DOE is pursuing technologies for utilizing coal more efficiently and has identified both mid-term and long-term efficiency and pollutant reduction goals.

There are two control approaches that can lead to more substantial mercury reduction targets via a single approach (as opposed to several of the approaches listed above implemented in concert). With implementation of the CAIR, installation of additional measures to comply with the SO_2 and NO_X reduction requirements would lead to mercury co-benefits; these reductions will be occurring at Michigan power plants as a result of the installation of additional SCRs and wet scrubbers. While the extent of these reductions is still unknown, they could be significant. Additional work is occurring to determine the long-term ability of SCRs to convert Hg^0 to RGM, particularly for blended coals and the ability of downstream wet scrubbers to remove the converted mercury. The extent to which scrubbers and SCR systems will be installed in Michigan will be dependent on CAIR.

For more significant reductions (e.g., 60% or greater) on most individual plants, use of an add-on FF or ACI – or both – would be needed. Use of a FF alone on plants where not already installed could lead to reductions of up to 90% (for bituminous coal-fired plants). Up until recently, it was assumed that ACI alone was not able to achieve higher mercury reductions at plants burning sub-bituminous coals and having an ESP for PM control (and thus a FF would be needed). However, with the latest results of brominated PAC injection at the St. Clair plant, it appears that high control effectiveness at these plants may be possible with ACI alone. For the majority of the state's capacity that involves this type of configuration (i.e., sub-bituminous coals and CS-ESPs), it is now possible that a brominated PAC may be sufficient to meet the most stringent reduction target (i.e., 90% or greater).

For the combination of ACI and a FF, removal rates would vary with several parameters including coal rank and chloride content of the coal. Installation of an ACI/FF system at the Presque Isle plant will provide additional data on the performance of this type of combination on Michigan units burning sub-bituminous coals. The costs for these installations would vary depending on a number of factors, including type of coal burned and existing plant design and layout; estimated costs range from about 1.2 mills/kWh (general EPA findings) to about 4 mills/kWh (based on an engineering study for planned installation at the Presque Isle plant). Emerging control technologies – including multi-pollutant approaches – may mature to the point in the near future where control effectiveness can be optimized and commercialization can begin.

7.1.5 Other Issues with Mercury Reduction Programs

With the introduction of competitive electricity generation markets both on a statewide and regional basis, cost recovery for the installation and operation of environmental equipment to reduce mercury and other harmful emissions from coal-fired power plants becomes an important issue.

As the cost for this environmental equipment is incurred, price responsive customers, usually made up of commercial and industrial customers, may be incentivized to bypass their obligation to contribute to the benefits of cleaner air and water by purchasing their generation from alternative generation sources that are not reducing mercury to the same extent as Michigan's coal-fired utilities. This may leave utilities with a declining customer base weighted more heavily of residential customers to cover the entire costs. As their electricity price rises, residential customers could choose the lower rate supplier, and rates could increase as the customer base decreases.

Thus, Michigan should explore alternative ways of financing the installation and operation of environmental equipment under a competitive electricity generation market. Since all customers receive a benefit (both choice and non-choice customers) all customers should be obligated to contribute to the costs to reduce air pollutants.

One-way to ensure recovery, and keep costs as low as possible for customers, is to enact legislation that would spread the cost of mercury controls. One such way is a law similar to one adopted by the Wisconsin Legislature. The Wisconsin Act allows for the issuance of low-interest bonds to be repaid through a distribution charge on each customers bill. Another way is with a variation of this type of legislation that could entail establishing a state utility clean air fund as discussed in **Section 6.5**. These types of legislation could keep Michigan generators from being placed at a competitive disadvantage vis-à-vis other state's generators, and guarantees that all who benefit from the reductions in mercury emissions will share in the costs to produce that benefit.

Michigan should also be cognizant of potential unintended consequences should the state move to adopt mercury standards more stringent than those in surrounding states and throughout the region. This would happen as customers procure electricity from lower cost but higher mercury emitting plants located outside of Michigan. Through transport, emissions from the out of state plants could get deposited in Michigan or the Great Lakes.

7.2 Considerations and Recommendations for Mercury Reduction

7.2.1 Environmental Benefit

Given the evidence for the potential impact to the general population and widespread contamination of waterways and water bodies globally, reduction of mercury to the environment continues to be an important issue in Michigan. As was discussed in **Sections 1** and **2** of this report, mercury once released from anthropogenic and natural sources can be deposited in the environment, a portion of which is converted in aquatic systems to the potent neurotoxin methylmercury. Methylmercury is widespread in fish sampled in Michigan and elsewhere. The major pathway of mercury to the aquatic environment in Michigan is through atmospheric deposition. In-state, regional, and global sources contribute to deposition of mercury in Michigan.

There is both monitoring and modeling (see **Section 3**) of the amount of deposition of mercury to the aquatic environment in Michigan, and a relatively good understanding of the sources that emit mercury into the atmosphere (see **Sections 1** and **2**). A reduction in emissions will result in less mercury available for subsequent deposition and bioaccumulation.

Consumption of fish with elevated levels of methylmercury has been linked with subtle, but nonetheless significant neurotoxic effects (see **Sections 1** and **2**). The fetus is most susceptible for adverse health effects due to methylmercury exposure. The health benefits of reducing mercury emissions are also discussed in **Sections 1** and **2**.

The Workgroup is charged with developing recommendations for an emission reduction strategy for coal-fired electric generating units (EGUs) that achieve timely and measurable reductions in mercury emissions. In order to determine the feasibility of reducing mercury emissions, there were a number of policy and technical issues examined. The policy and technical issues described below need to be considered in the development of a mercury reduction program and/or regulations.

7.2.2 Policy Considerations - EPA Clean Air Mercury Rule (CAMR)

On March 15, 2005, EPA promulgated the CAMR requiring mercury emission reductions from EGUs (see **Section 4**). On a parallel path EPA also promulgated CAIR which combined with CAMR intends ultimately to reduce national mercury

emissions by nearly 70% and sets a hard cap of 15 tons by 2018. There are several elements in these rules that Michigan must consider.

EPA promulgated CAMR under Section 111 of the CAA. It requires that individual states develop rules for mercury emission reduction from EGUs. Michigan must develop specific rules and submit a SIP to EPA that demonstrates it is meeting or exceeding the reduction requirement in the rule for existing and new facilities.

CAMR provides for a market-based approach to mercury reduction through cap-and-trade of emissions. The cap-and-trade program is nationwide. CAMR does allow flexibility for states to develop their own programs, and allows states to determine how mercury trading allowances will be allocated to EGUs. It is less prescriptive than other federal cap-and-trade programs. For more information on cap-and-trade see **Section 4.3.1**. This and the other aspects of the rule are under review by Michigan, and are being legally challenged by other states.

This is the first time a cap-and-trade program has been used for a hazardous air pollutant. This has raised concerns over possible increases in localized emissions and/or deposition ("hot spot"). In the Preamble to the Revision of the December 2000 Regulatory Finding, EPA defines a "utility hot spot" and the criteria for establishing whether or not a utility hot spot has been created. **Section 4.3.1** discusses this further.

7.2.3 Technical Considerations

Mercury emissions vary by fuel type, unit size, control configurations, and firing characteristics at the EGUs. Mercury is emitted from these units in three forms: elemental, oxidized, and particulate. These factors combined with the consideration of multi-pollutant controls must be evaluated when controlling mercury emissions at a particular EGU.

7.2.3.1 Multi-Pollutant Controls

There are mercury reduction co-benefits from installation of air pollution control equipment such as SCRs for NO_X, wet or dry scrubbers for SO_2, and ESPs and FFs for particulate as discussed in **Section 5**. The range of reduction for mercury is dependent on the control device, efficiency of removal of the primary pollutant, and the type of coal used as fuel. These reductions should be measured and accounted for when calculating present or future mercury reduction values.

There are SCRs installed, or in the process of being installed, on six coal-fired boiler units in Michigan, SO_2 scrubbers on five smaller units, and FFs on eleven smaller units listed in **Table 6** in **Section 3**. For those units that have SCRs installed, or in the process of being installed, the potential exists for co-benefit mercury reductions if SO_2 scrubbers are installed behind the SCRs. One large EGU with an SCR is in the planning process to install an SO_2 scrubber. This installation will likely occur within this

decade. It is likely that most large units in the state will install SO_2 scrubbers within the next decade to comply with CAIR.

7.2.3.2 Mercury Specific Controls

As discussed in **Section 5**, mercury specific add-on controls have in the past and are currently being tested at coal-fired EGUs. Several technologies show very promising results and good removal efficiency. Most of these technologies require sorbent injection and a two-stage particulate control device. Two stages are typically required since most existing EGUs in Michigan control particulate emissions with only a single-stage control device such as an ESP and this may not be adequate to capture mercury or the mercury and sorbent. The addition of a second stage particulate collection device (most likely a FF) differs from the type of collection device used on existing EGUs and sorbent injection can be installed between the two stages. Where secondary collection devices are required, extensive engineering and construction for existing EGUs will be necessary. Add-on technology is available at this time; however, there is less certainty on the cost or level of control for different EGUs, different sized units, and different fuel types. Discussions of control technologies and costs are included in **Section 5**.

7.2.3.3 Technical Feasibility of Reductions

The broader question is not whether mercury controls are feasible, but rather the type of control and the potential mercury control efficiency that would result for each EGU. Some level of control is feasible for most of the coal-fired EGUs in Michigan. **Section 5** summarizes pollution controls and potential mercury control efficiencies that may be achieved by Michigan EGUs.

The potential level of control compared with the range of costs is discussed in **Section 5**. Greater than 80% control of mercury overall for EGUs in Michigan is possible with the use of ACI and in many cases additional particulate control devices. The time required to install mercury reduction devices and the practical aspect of timing all must be considered in a reduction strategy. With the technology that is becoming available, greater than 90% control should be technically feasible. Economic feasibility is discussed below.

7.2.3.4 Mercury Emissions Monitoring

EPA and ASTM stack test methods are being used to measure total and speciated mercury emissions from EGUs. These intermittent sampling methods provide a snapshot of emissions, for a given set of operating conditions, at one set point in time. Also, proposed sampling methods such as Method 324 and its variations offer an integrated sample which provides an average of total or speciated mercury over a specified time period.

There are mercury CEMS that are commercially available, but they can be complex to operate and maintain. Although, they do not yet meet EPA's certification standards, CAMR requires they be installed and operational by 2008. Presently, mercury CEMS are being field tested nationwide with varying results. Selection of mercury CEMS for an EGU is very complex, and facility and operational specific. Long-term operation and maintenance are issues of concern in the development of mercury monitoring. Current use of mercury CEMS has been a valuable tool in control projects to show mercury reduction on a real-time basis. Continuous mercury data with speciation is highly desirable to provide an accurate baseline, as well as to measure the success of any specific control program. However, technological validation is still needed for these monitors to be utilized in a production setting.

CAMR contains two methods for mercury monitoring, one of which is a CEMS. CAMR also acknowledges the potential for disproportionate monitoring costs for smaller EGUs and small mercury emitters. Therefore, EPA has decided to provide a "less rigorous, cost-effective monitoring option for low emitting units."

7.2.4 Other Policy Considerations

7.2.4.1 Interstate Competition

A major portion of the electric transmission grid in the Midwest including the portion of the grid located in Michigan is managed by two RTOs. Except for a small portion of territory in the southwest corner of the state, Michigan's electric grid is currently managed by MISO. On April 1, 2005, MISO begun operation of a dispatch system and an electricity market based on the local marginal price of electricity. Under this market-based system, the EGUs under MISO control will be selected for operation based on the price each EGU bids into the market. Entities serving native load within Michigan will either be required to purchase power directly from this market or from specific resources, including their own generation, using a form of bilateral contracts. Consequently, Michigan based EGUs will be in direct competition with all EGUs in the multi-state MISO region. Currently, however, electric utilities regulated by the MPSC, although required to participate in this new energy market, will continue to recover investment and operational costs under the traditional regulatory system. The impact of the move to a market-based electric system must be taken into consideration when devising a plan to recover substantive costs associated with mercury emission controls. Consideration of a state energy policy discussed later in this section will also impact this issue.

7.2.4.2 Customer Choice

In addition to the MISO energy market, the Customer Choice and Electricity Reliability Act (2000 PA 141), allows Michigan's retail electricity customers through an alternative electric supplier to purchase electric generation from out-of-state plants. Like the MISO energy market, PA 141 places EGUs located within Michigan in direct competition with out-of-state EGUs, whether they are located in the MISO or PJM RTO region (see **Section 6.1** for more detail). While Michigan based EGUs will be forced to compete with out-of-state EGUs for electric customers, not all of these competitor plants would be required to adhere to the same standards for the emissions of mercury that would be required by a more restrictive Michigan standard. This would place the in-state EGUs at a competitive disadvantage vis-à-vis out-of-state EGUs. Furthermore, EPA modeling has indicated that through transport a substantial amount of air pollutants emitted by EGUs located in neighboring states get deposited in Michigan. Should customers choose to procure electricity from lower cost but higher mercury emitting plants, this could have the effect of increasing mercury emissions in the Midwest region as a whole, as well as increasing mercury deposition in Michigan. As noted in the previous section, the impact of the move to a market based electric system, both on the wholesale side of the industry and the retail side, must be taken into consideration when devising a plan to recover substantive costs associated with mercury emissions controls. Therefore, the successful resolution and certainty of cost recovery by EGU owners and associated utilities in Michigan for the installation of mercury control technology is a critical issue.

7.2.4.3 New Generating Units

Michigan's economy depends on a reliable and affordable supply of electricity and existing businesses located in Michigan require a reliable supply of electricity to perform their daily functions. Moreover the retention, expansion, and location of industrial and commercial facilities in Michigan that provide jobs for the citizens of this state would likely be hindered by the absence of reliable and reasonably priced electricity. The source for this electricity is the current inventory of Michigan's base-load EGUs. The average age of base-load EGUs located in Michigan is increasing and the last major base-load addition is 16 years old. The average age of the Consumers' and DTE's base-load EGUs is 46 years. Assuming continued load growth and possible retirement of older Michigan-based EGUs, new capacity additions will likely be required.

Typically, new EGUs in Michigan will be required to meet more strict standards for mercury emissions levels than the current fleet of EGUs which will lead to reduced mercury emissions per KWh. The addition of new EGUs in Michigan may provide lower total Michigan based emission levels as new EGUs replace older higher mercury emitting facilities.

On October 14, 2004, the MPSC issued an order directing its Staff to conduct an investigation into the present and future capabilities of Michigan's electric power system to supply adequate levels of electricity at a reasonable price. The MPSC Staff in response to this directive, organized a Capacity Need Forum consisting of working groups comprised of commission technical Staff, representatives of the electric power industry, and other interested parties to investigate future capacity requirements in Michigan and determine how they could best be served. This investigation will include analysis designed to evaluate the impact of future emissions reductions requirements (including mercury) on available generating capacity,.

7.2.4.4 Energy Policy

Mercury reduction is interlinked with other energy issues and should be considered as part of an overall policy. It is clear that mercury reduction will require capital investment and consideration of new technologies, other forms of energy production, energy efficiency and energy conservation should be part of the equation. While making specific recommendations for issues other than mercury reduction is beyond the scope of this Workgroup, the Workgroup feels it is necessary to recommend development of an energy policy. Workgroups separate from the Michigan Mercury Electric Utility Workgroup have started to address these issues.

7.2.4.5 Cost and Design of Cost Recovery

The imposition of new and more stringent mercury compliance requirements will add significant cost to the existing EGU fleet and to new EGU additions in the future. The magnitude of that cost will be dependent on the final level of targeted mercury reduction and the programmatic approach utilized to achieve it. The range of costs is presented in **Section 5** for the add-on control devices. One issue that needs to be resolved, in a manner that is most affordable to Michigan customers, is the recovery of costs associated with environmental improvements.

As outlined in other sections of this report, the existence of competitive wholesale and retail markets for EGU output in Michigan and the region as a whole allows prospective purchasers of electric supply to seek the most economical source of supply in the region, regardless of the physical location of the supplying EGU facility, given transmission capability.

The current compliance and competitive market paradigm in Michigan presents a challenge concerning the recovery of the incremental Michigan EGU investment necessary to achieve the compliance standard. New costs in Michigan can only be assessed to the Michigan customer base. The larger this base, the more affordable the ultimate cost will be to all users in Michigan. However if consumers of electricity in Michigan can by-pass charges associated with recovery of these incremental costs, recovery

will not be assured. Assured recovery is a necessity in today's paradigm to attracting the capital necessary to fund the add-ons to existing base-load plants and/or to build new environmentally friendly base-load plants to meet the new compliance standard. Thus, a method of cost recovery must be implemented that does not allow retail users of electricity in Michigan to bypass charges related to recovery of compliance costs. Given that all Michigan customers receive a benefit from higher air quality standards in Michigan, all customers should pay for the benefit received.

Furthermore, consideration should be given to minimizing the annual cost to Michigan customers through the utilization of creative financing mechanisms, such as securitization. Securitization allows projects to be financed totally using AAA-rated debt, thus minimizing annual carrying charges on the investments and resulting charges to customers.

7.2.4.6 Other Considerations

Michigan mercury reduction strategies should recognize the potential for disproportionate costs of control for smaller EGUs owned by small entities that may suffer from diseconomies of scale in control technologies.

A MACT standard has been promulgated for industrial boilers that include mercury emission limits for coal-fired industrial units. This category is separate from utility boiler units, and is excluded from mercury reduction considerations in this report.

New sources, meaning new EGUs, will be required to meet the most stringent standard for mercury considering Best Available Control Technology for Toxics (T-BACT), health-screening requirements, and the federal NSPS standard and the trading cap (CAMR).

7.2.4.7 Environmental Challenges to Economic Opportunity

While going beyond federal requirements to control mercury at the state's coal-fired utility units would result in additional costs to consumers, there would also be some economic benefits. These would include boilermaker and other jobs associated with retrofits, ancillary benefits in local economies, and the potential for new jobs if technology vendors or allied industries established production plants in the state or if additional technology developers located in Michigan. Research in 2003 indicated that with 3.4% of the nation's population, Michigan's environmental industry (which was considered to include manufacturing workers, truck drivers, computer analysts and others working in some manner on projects aimed at environmental protection) generated 4.3% of the total industry's national sales. This study also reported nearly $13 billion in sales and nearly 217,000 jobs in the state's environmental industry (Bezdek and Wendling, 2004).

7.2.5 Recommendations

7.2.5.1 General Principles of Agreement

- Michigan's coal-fired power plant fleet will be controlled for mercury emissions.
- Through advancements in technology, planning and incentives, Michigan can achieve greater mercury reductions than those required under CAMR.
- An effective cost recovery mechanism is critical to enhance and speed mercury reductions.
- Incentives for early action on mercury and for reductions beyond minimum (CAMR) requirements should be developed to promote implementation by Michigan utility companies.
- Technology flexibility should be encouraged to keep costs as low as possible and encourage competition among vendors.
- Mechanisms to reduce technological and financial risk should be adopted.
- New generation, taking advantage of new technologies, including advances in plant efficiency and emissions control, as well as advances in alternative energy generation, which allows transformation of base-load generation over time, is key to the long-term continuation of environmental improvements.
- Mercury reduction is interlinked with other energy issues. Developing a state energy policy is important and should be pursued. Such an energy policy would help ensure the most rapid and cost-effective transition to the next generation of energy provision.
- A coordinated on-going impact study should be conducted to evaluate the effectiveness of the mercury control program once it has been implemented with regard to human health and the environment, and to provide guidance for subsequent decision-making.

7.2.5.2 Reduction Strategy

The proposed reduction strategy has two phases. NOTE: Phase Two of the strategy contains some alternative language reflecting differing Workgroup views.[104]

<u>PHASE ONE</u>: Co-benefits and beyond by 2010, and baseline monitoring development.

The first phase will accomplish three objectives. First, it will implement the federal CAIR and CAMR rules, and take advantage of co-benefits from the installation of multi-pollutant controls that produce a secondary mercury reduction benefit. Second, it will establish the baseline for actual mercury

[104] **Appendix B** contains any Workgroup participant's exceptions to the recommendations.

emissions along with a measurement of reductions. Third, it will encourage additional and real reductions in mercury emissions beyond co-benefits by enhancing ongoing testing and installation of mercury control technologies.

The first round of mercury emissions reductions, due to implementation of CAMR and CAIR, will be in place by 2010. The CAMR will impose a hard cap of 2,606 pounds of mercury emissions per year from EGUs, beginning with 2010 and lasting through 2017. (Refer back to **Table 8** for estimated emissions from the EGUs.) Additional co-benefits will continue to be achieved beyond 2010 through the continuing implementation of CAIR. This will also coincide with other reduction rules and SIPs such as the reductions required for the ozone and $PM_{2.5}$ SIPs.

Limited data currently exist regarding the actual mercury emissions of Michigan EGUs, with current inventories relying heavily on EPA's 1999 ICR. In this phase, Michigan EGUs will conduct monitoring to determine source performance with regard to establishing a current baseline. This source monitoring will provide a more accurate accounting of current emissions by Michigan utilities and of the control efficiency of any control equipment or processes in use. Installation of permanent monitoring systems, as required by 2008 under CAMR, will produce a federally certifiable record of mercury emissions, by unit, allowing the tracking of emissions and reductions, as CAIR, CAMR, or any additional changes to EGU equipment or processes are implemented.

A goal of reducing mercury emissions below the federal 2010 cap resulting from co-benefits combined with the early adoption of mercury-specific reductions will be targeted. In order to implement reductions beyond co-benefits, it will be necessary for Michigan EGUs to continue and expand the testing of mercury-specific control technologies. Timely cost recovery will also be essential to the implementation of early reductions.

The current state of the art for mercury-specific control technologies is evolving rapidly and is producing encouraging results for specific short-term tests. In order to put these new technologies into full-scale commercial operation, it is necessary to demonstrate that they can operate long-term, without affecting the balance of plant operation and without producing unintended adverse impacts to the environment. The results derived from these tests and future tests would be needed to implement reductions that go beyond CAMR.

Development of a system to allow Michigan utilities to take advantage of the federal market-based approach specified in the CAMR and taking into consideration localized impacts, will provide incentives and flexibility for reductions in both Phase One and Two. Promulgation of state legislation and/or rules will be necessary per federal requirements.

Compliance Demonstration

The compliance demonstration at a minimum will match the federal requirements. The federal regulation currently specifies that compliance shall be determined using a CEMS or an appropriate long-term method that can collect an uninterrupted, continuous sample of Hg in the flue gases as specified in CAMR. These systems must be fully certified and in operation no later than 2008.

Timing

The implementation date of Phase One is consistent with the implementation of the initial requirements of CAIR and CAMR.

PHASE TWO: Set and achieve a Michigan reduction goal beyond the CAMR

Building on the federal program, two alternatives are proposed for reductions:

Alternate 1	***Alternate 2***
A results-driven reduction goal, derived from the experience gained in Phase One, will be set to achieve the reductions by 2018. Participation in the federal trading program, including full allocation of allowances is integral. If an EGU commits to the reductions by 2015, incentives and/or compliance flexibility provisions would apply.	A results-driven reduction requirement, building on the experience gained in Phase One, will be set to achieve 90 percent reduction in emissions by 2013. Incentives to facilitate meeting the requirement will be provided. Compliance flexibility provisions can be provided for EGUs that do not initially achieve expected reductions.

Cost recovery for reduction goals beyond the federal requirements is essential. It is likely that the process will require a degree of creativity in order to assure that Michigan's utilities and electric rates remain competitive nationally and globally. To this end, the partner organizations in this Workgroup must engage the MPSC, and if necessary, the Legislature to put a timely cost recovery mechanism in place.

A robust system of incentives and mechanisms to provide technology flexibility and to limit financial and technology risk will be important both to meet and to go beyond the CAMR. Incentives which reward early adoption of controls, or reductions beyond the goal, should also be adopted. The more robust the program, the larger the incentive should be for going beyond CAMR. In addition to market-based approaches discussed above, examples of incentives or compliance flexibility mechanisms include:

- exemption of plants scheduled to close within the compliance timeframe from more stringent state requirements,

- extension of time for compliance to allow for achievement of greater than goal-level reductions,
- extension of time for installation of multi-pollutant controls, or
- to address situations where mercury-specific technology is installed and operated in line with an earlier and more stringent goal, but fails to achieve expected goal-level reductions.

The financial incentives discussed in **Section 7.2.5.4** will also be important to facilitating reductions.

The two alternatives target significant reductions in mercury emissions for example through varying levels of add-on controls, repowering with newer low-emissions technologies, fleet replacement, renewable energy, or alternative fuel sources. Each alternative will have very different costs, benefits, and ramifications. For example, depending on the level of reduction, additional EGU closures and increased level of power importation may result.

By putting in place a results-driven and coordinated set of goals and incentives or targets and incentives, Phase Two will allow Michigan to draw on state, federal, industry and public resources and expertise to provide the tools to enable its utilities to optimize mercury reductions at lower cost. By adopting and implementing Phase Two objectives, Michigan will stay on track to implement timely and measurable mercury emission reductions. These recommendations are intended to encourage investment in new, innovative technologies and position Michigan to attract the jobs and businesses necessary to modernize the region's energy infrastructure.

The final federal CAMR rule has now been published. It is under legal challenge. While these challenges are under way, Michigan's utilities continue to plan for eventual mercury reductions. These recommendations are intended to keep the planning process, innovation and implementation of mercury controls moving forward.

Compliance Demonstration

The compliance demonstration at a minimum will match the federal requirements. The federal regulation currently specifies that compliance shall be determined using a CEMS or an appropriate long-term method that can collect an uninterrupted, continuous sample of Hg in the flue gases. These systems must be fully certified and in operation no later than 2008.

7.2.5.3 Impact Study Recommendation.

The impact study is intended to complement Phases One and Two, and is not presented either as an option or as an alternative.

Many reasons are presented for regulating mercury emissions from coal-fired EGUs. The impact study is intended to address the effectiveness of implementing those regulations with regard to human health and the environment, and to provide guidance for subsequent decision-making.

The Workgroup has compiled a list of questions it regards as necessary to be answered once the mercury control program has been implemented. The Workgroup believes that it is incumbent upon all parties, with the leadership from the DEQ and EPA, to pursue the answers. Engagement of the environmental regulatory agencies from neighboring states is likely. The questions are:

- What is the baseline contribution of atmospheric deposition of mercury, by species, to the environment from each EGU and from other source categories?
- How did this baseline change as the result of this control program?
- Are there any baseline mercury hot spots? If so, what is the nature of the source(s)?
- What is the baseline concentration of mercury in Michigan fish?
- How did this baseline change as the result of the implementation of controls?
- What is the background level of mercury coming into Michigan and what are the sources?
- What geographic domain should be considered for the study?
- What is the incremental increase above background deposition values?
- Do any residual hot spots remain after implementation of this program? If so, what is the nature of the source(s)?
- Are any new hot spots created after implementation of this program? If so, what is the nature of the source(s)?
- What is the environmental impact and how to characterize it?
- What is the risk and how to characterize it?
- If it is determined that an unacceptable risk remains after this program is implemented, what additional reductions are required and from which source categories?
- Or, additional questions to be asked/defined by the Workgroup.

While the questions are simple, the process of getting to the answers will be complex. It is recommended that an organization with expertise in these areas be contracted to develop a scoping study to design the study, along with the types of input data that will be necessary to answer

the questions asked. Data handling and quality assurance protocols, to protect the integrity of the project, should be outlined. This should also include a project schedule and an estimate of cost. Studies currently in progress will be evaluated and prioritized for incorporation into this effort.

It is anticipated that this project will involve many organizations, including but not limited to the DEQ, EPA, DOE, other states' environmental agencies, Michigan's utilities, environmental, conservation and public interest stakeholders, outside contractors and consultants, universities, and research institutions.

This project is intended to make a definitive advancement in the state of mercury science. Given the charge to the Workgroup and the recommendations being offered, Michigan should take a leadership role in this scientific effort, to fulfill its commitment to the people of the State. This project is also expected to require significant human and financial resources. The burden of defining the funding mechanisms rests with the key participants.

Justification

The state-of-knowledge for mercury emissions, their fate and their impact upon the environment is also evolving. The purpose of this study is to answer fundamental questions:

- What changes have resulted from the implementation of this program?
- Are any additional steps warranted?
- If so, what steps?

Under the MACT provisions of the CAA, EPA is required to evaluate the residual risk that remains, following the implementation of controls required under 112(d). EPA must evaluate the risk to public health as well as adverse environmental effects that remain, and the technologically and commercially available methods and costs of reducing such risks. The Workgroup believes that EPA continues to bear this burden under the Section 111 approach contained in the final CAMR.

This step recommends a comprehensive investigation to guide future regulatory decision making at the state, regional and national levels. The data requirements will be substantial, as will be the human and financial resources. But the answers will tell whether or not we have made an impact on protecting human health and the environment.

The Workgroup believes that this study will make a definitive advancement in the state of the science and will serve as model for

others to follow as they plan and/or assess future environmental regulatory programs.

7.2.5.4 Financial

Obtaining financing for large-scale capital improvements at existing power plants and for the construction of new lower mercury emitting base-load generation is dependent on the certainty of cost recovery, which is problematic under the current Michigan retail choice program. Therefore, Michigan must explore alternative ways to assure that retail electric customers cannot bypass costs associated with meeting new mercury emission standards. One way to assure recovery is through the use of a distribution charge or wires charge on all customers' bills. This is reasonable since all citizens in Michigan will receive the benefits from lower mercury emissions. In addition, to allow utilities to obtain the lowest cost financing possible, legislation could be enacted to allow securitization.

This method of financing would lower the borrowing costs for utilities to meet new mercury emissions standards, an in turn minimize that component of customer rates related to financing such improvements. Again, however, any financing mechanism will require assurance of recovery. Any alternative financing and cost recovery mechanisms will require action by the MPSC and Legislature.

7.2.5.5 Regional Coordination

The Workgroup believes pursuit of a regional approach to enhanced mercury reductions will level the economic playing field. This approach would mainly focus on the EPA Region 5 states with the possible inclusion of New York and Pennsylvania. This approach should be consistent with the expression of some Region 5 states to explore region-wide mercury reductions within the federal framework.

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APPENDIX B: WORKGROUP PARTICIPANT'S EXCEPTIONS TO THE RECOMMENDATIONS

Some Workgroup participants have expressed concerns or exceptions with the recommendations. Listed below are those participants and their comments.

DISCLAIMER: THE FOLLOWING STATEMENTS HAVE NOT BEEN DISCUSSED BY THE WORKGROUP NOR VERIFIED.

WORKGROUP PARTICIPANT	COMMENT
DTE Energy	Phase Two's Alternative 1 and Alternative 2 each carry different ramifications for the EGUs, the State and the State's economy. This report does not discuss them. Before any policy decision can be properly made, a listing of the pros and cons, including a cost-benefit analysis, must be conducted. The 70% reductions in utility emissions required by the federal program maximize the use of multi-pollutant controls. These controls are the foundation of any program targeting mercury emissions. They simultaneously reduce several pollutants at a lower cost and a greater efficiency than mercury-specific controls. The federal program also allows controls to be focused on the largest plants and the plants that will operate in the future. This approach provides the most cost effective method of controlling mercury. The cost associated with Alternative 2's 90% reduction will require expensive mercury-specific controls on every power plant in the state including those that seldom operate or are about to retire. The 2013 deadline is unrealistic, considering the lead times for planning, engineering and procurement, and the need to protect the integrity of the grid. The Michigan Mercury Electric Utility Workgroup Report provides an estimate of how a 90% control would raise electric rates in the state for residential customers. The example is not extended to industrial and commercial customers. There is no mention of the expected benefit, in the form of a measurable improvement in the mercury levels in fish. The EPA, in issuing its Clean Air Mercury Rule this spring, concluded that utilities contribute little (8%) to mercury levels in rainfall today and will contribute even less (3%) in the future after they comply with the federal rule. Michigan utilities have little impact on mercury levels in freshwater fish and will have even less impact on fresh water fish, once they comply with federal standards, which require, on average, a 70% reduction in mercury emissions. The concern around utility emissions centers on how air emissions from coal-fired power plants might lead to higher levels of mercury in rainfall, lakes, and ultimately freshwater fish, yet there mercury levels in freshwater fish are lower, not higher in the Great Lakes and inland lakes that are in the closest proximity to the largest power plants in Michigan. Most of the 4 tons of mercury that is deposited to the state is from national, global, and natural sources. Michigan utilities only emit about ½ ton of RGM; the form which combines with rainfall and only a fraction of this two-thirds of a ton is deposited in the state. The EPA has concluded that U.S. utilities have no measurable impact on ocean and farm-raised fish, which constitutes 87% of fish consumption by the U.S. population.

WORKGROUP PARTICIPANT	COMMENT
Consumers Energy and We Energies	Section 7.2.5.2 of the Report presents the recommendations of the Workgroup. The bulk of these recommendations portray the large degree of consensus that evolved among the members of the Workgroup. Where consensus could not be reached is shown in Phase 2 of the recommendations, which presents two alternatives for the State. Both alternatives offer the State the opportunity to meet and exceed the requirements of the Federal mercury rule. Consumers Energy believes that these two alternatives each carry different and significant ramifications for the State, the State's electric utilities, and the State's economy. While the report mentions differing ramifications, it does not present an adequate discussion of the pros and cons of the two alternatives. Absent such discussion, Consumers Energy believes that policy makers are not being provided with sufficient information to weigh the cost-benefit of one alternative versus the other. As the State prepares to choose the direction it wishes to take for Michigan and its utilities, Consumers Energy believes that an objective consideration of the pros and cons of each alternative, including a comprehensive cost-benefit analysis, is warranted and should be incorporated as part of the State's rulemaking process.
Environmental Groups	After twenty-two months of work developing this comprehensive, nearly 300-page, report, it is time for the State to move to the next step, which is developing a rule to address mercury emissions from coal-fired power plants. This report documents that mercury is a serious threat to public health and its effects on childhood development are significant, widespread, and preventable. This report documents that Michigan's power plants are its largest source of mercury, and that by reducing airborne mercury emissions, contamination of fish and wildlife can decline significantly and rapidly. This report also documents that control technologies are available to reduce at least 90% of the mercury emitted from Michigan's power plants, and that doing so by 2013 is practical. A standard of this stringency is supportive of public health. Certain specific costs and benefits could not and cannot be considered fully, however, without a concrete draft rule in place. Similarly the report has not fully developed statutory mechanisms which might facilitate faster, cheaper, or more effective mercury reductions. These types of analysis are certainly appropriate, but only within the context of a rulemaking process underway to meet a health-based target. Given the ongoing impact emissions of mercury are having on Michigan waters, and the ability to achieve substantial mercury reductions in a cost-effective manner, it is important that the State move forward as rapidly as possible with the rule-making process to avoid further delays.

APPENDIX C: ACRONYMS AND THEIR DEFINITIONS

ACRONYM	DEFINITION
~	approximately
<	less than
≤	less than or equal to
>	greater than
µg/dscm	micrograms per dry standard cubic meter
µg/g	micrograms per gram
µg/kg/day	micrograms per kilogram per day
µg/L	micrograms per liter
$\mu g/m^2$	micrograms per squared meter
$\mu g/m^3$	micrograms per cubic meter
µm	micrometer
ACFM	actual cubic ft per minute
ACI	activated carbon injection
AEOLOS	Atmospheric Exchange Over Lakes and Oceans Study
AER	Atmospheric and Environmental Research, Inc.
AQD	Air Quality Division
ASA	American Sportfishing Association
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substance & Disease Registry
AWEA	American Wind Energy Association
Btu	British Thermal Unit
Btu/hr	British Thermal Unit per hour
BWL	Board of Water and Light
CAA	Clean Air Act
CAAA	Clean Air Act Amendments of 1990
CAAAC	Clean Air Act Advisory Committee
CAIR	Clean Air Interstate Rule (EPA)
CAMR	Clean Air Mercury Rule (EPA)
CDC	Centers for Disease Control
CEMS	Continuous Emission Monitoring Systems
CFB	circulating fluidized bed
cm/s	centimeter per second
CNS	central nervous system
CO_2	carbon dioxide
COHPAC	Combined Hybrid Particulate Collector
CS-ESP	cold-side electrostatic precipitator
DEP	Department of Environmental Protection (Florida)
DLEG	Department of Labor and Economic Growth (Michigan)
DOE	U.S. Department of Energy
dw	dry weight
EAFs	electric arc furnaces
ECO	electro-catalytic oxidation

APPENDIX C: ACRONYMS AND THEIR DEFINITIONS

ACRONYM	DEFINITION
EGU	electric generating unit
EIA	Energy Information Administration
ELPC	Environmental Law and Policy Center
EPA	U.S. Environmental Protection Agency
EPRI	U.S. Electric Power Research Institute
ES&T	Environmental Science and Technology (Journal)
ESP	electrostatic precipitators
ESSD	Environmental Science and Services Division
FAMS	Flue Gas Adsorbent Mercury Speciation
FDA	U.S. Food and Drug Administration
FERC	Federal Energy Regulatory Commission
FF	fabric filter
FGD	flue gas desulfurization
g/L	gram per liter
GI	Gastrointestinal
GLBTS	Great Lakes Binational Toxics Strategy
GLPF	Great Lakes Protection Fund
GW	Gigawatt
H2E	Hospitals for a Healthy Environment
HAPs	hazardous air pollutants
HCl	hydrogen chloride
Hg	Mercury
Hg^0	elemental mercury
Hg(p)	particulate bound species of mercury
hr	Hour
HS-ESP	hot-side electrostatic precipitators
HSDB	Hazardous Substance Data Base
IARC	International Agency for Research on Cancer
ICR	Information Collection Request
IGCC	Integrated Gasification Combined-Cycle
km	Kilometer
kW	kilowatt (1000 watts)
kWh	kilowatt hours
L	Liter
LADCO	Lake Michigan Air Directors Consortium
lbs	Pounds
lbs/yr	pounds per year
LBWL	Lansing Board of Water and Light
LCA	level currently achievable
LMMBS	Lake Michigan Mass Balance Study
LOAEL	lowest-observed-adverse-effect level
m	Meter
m^2	meter squared

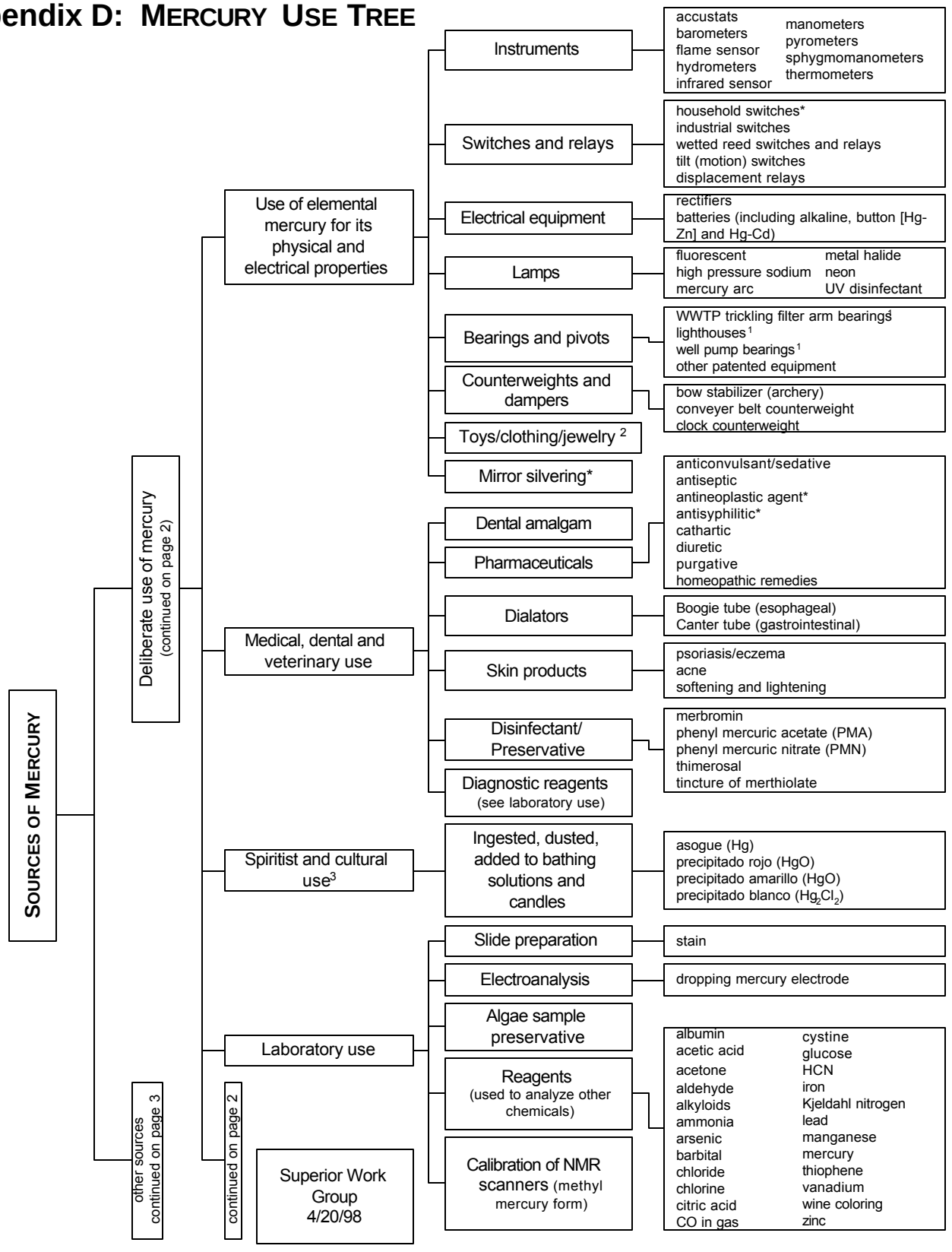
APPENDIX C: ACRONYMS AND THEIR DEFINITIONS

ACRONYM	DEFINITION
M2P2	Michigan Mercury Pollution Prevention (Task Force)
M2S2	Michigan Mercury Switch Sweep
MACT	maximum achievable control technology
MBtu	million Btu
MEC	Michigan Environmental Council
MDCH	Michigan Department of Community Health
MDEQ	Michigan Department of Environmental Quality
MDN	Mercury Deposition Network
MESB	Michigan Environmental Science Board
METAALICUS	Mercury Experiment to Assess Atmospheric Loadings In Canada and the United States
mg/kg	milligrams per kilogram
MI	Michigan
MISO	Midwest Independent System Operator
mm	Millimeter
MMacf	million actual cubic feet
MMAP	Michigan Mercury Action Plan
MMWR	Morbidity and Mortality Weekly Report
MPSC	Michigan Public Service Commission
MREP	Michigan Renewable Energy Program
MSCPA	Michigan South Central Power Agency
MSFB	multi-solid fuel fluidized bed boiler
MSU	Michigan State University
MUCC	Michigan United Conservation Clubs
MW	Megawatt
MWe	megawatt-electric
MWh	megawatt hour
NA	not applicable
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NAS	National Academy of Sciences
NEG/ECP	New England Governors and Eastern Canadian Premiers
NEI	National Emissions Inventory
NETL	National Energy Technology Laboratory, DOE
ng/L	nanograms per liter
ng/m^3	nanograms per cubic meter
NO_X	nitrogen oxide
NPDES	National Pollutant Discharge Elimination System
NREL	National Renewable Energy Laboratory
NWF	National Wildlife Federation
OHM	Ontario Hydro Method
P2	pollution prevention
PAC	powdered activated carbon (injection)

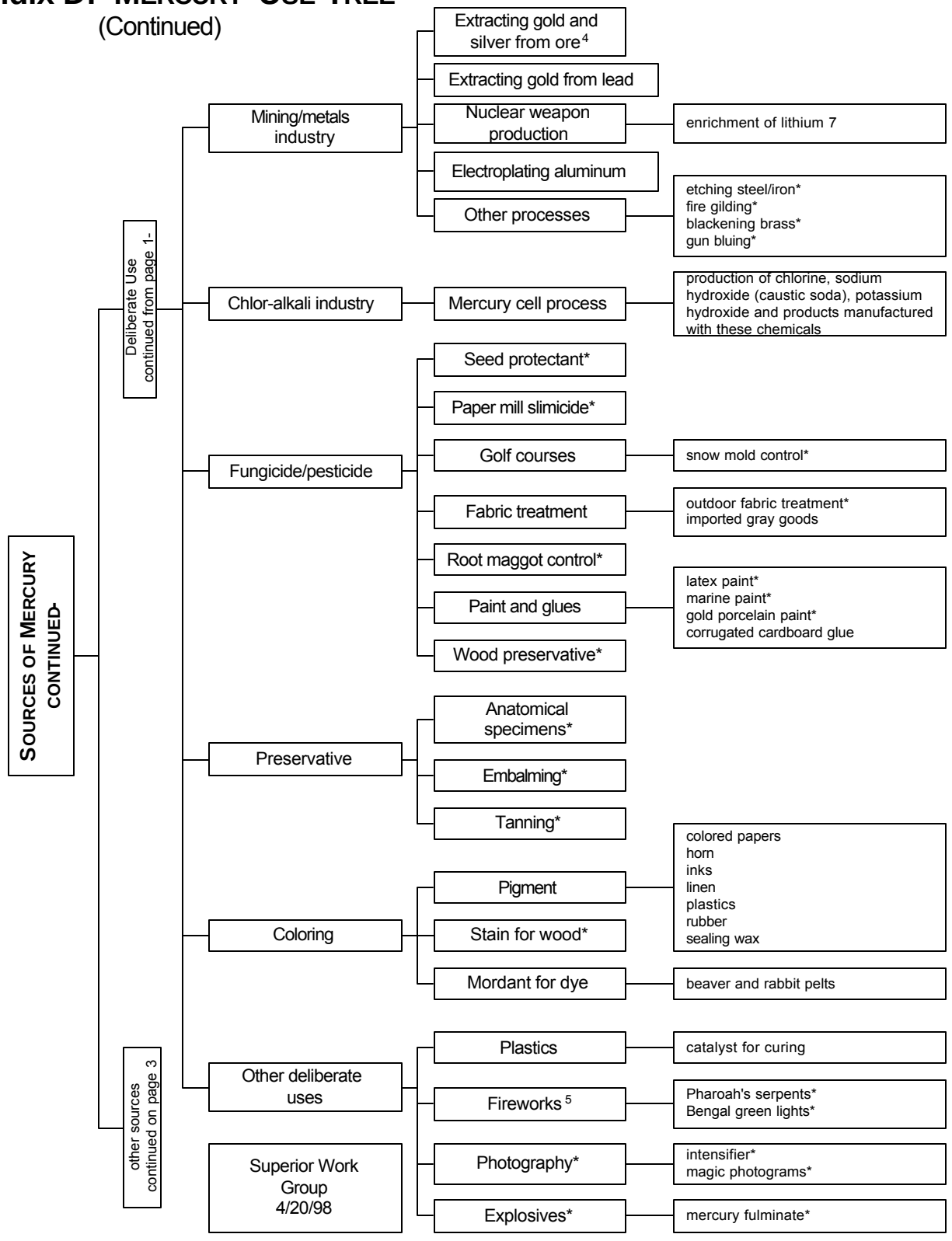
APPENDIX C: ACRONYMS AND THEIR DEFINITIONS

ACRONYM	DEFINITION
PBT	persistent bioaccumulative toxic
PC	pulverized coal
PCB	polychlorinated biphenyls
PEESP	Plasma-Enhanced Electrostatic Precipitators
pH	potential of Hydrogen (measurement of a solution)
PIRGIM	Public Interest Research Group in Michigan
PM	particulate matter
$PM_{2.5}$	particulate matter with a diameter of 2.5 microns or less
PM_{10}	particulate matter with a diameter of 10 microns or less
ppb	parts per billion
ppm	parts per million
PRB	Powder River Basin
PSC	Public Service Commission
RfD	reference dose – oral
RGM	reactive gaseous mercury; oxidized mercury; Hg(II); Hg^{2+}
RTO	regional transmission owner
SCA	Specific Collection Area
SCR	selective catalytic reduction
SDA	spray dryer absorbers
SEMCOG	Southeast Michigan Council of Governments
SIP	state implementation plan
SMD	Standard Market Design
SNCR	Selective Non-Catalytic Reduction
SO_2	sulfur dioxide
SO_X	oxides of sulfur
TBtu	trillion Btu
TMDL	total maximum daily load
TRI	Toxics Release Inventory
TWh	tetra watt-hour
U of M	University of Michigan
U.S.	United States
USGS	U.S. Geological Survey
WCMP	Water Chemistry Monitoring Project
WDNR	Wisconsin Department of Natural Resources
WQS	Water Quality Standard
yr	Year

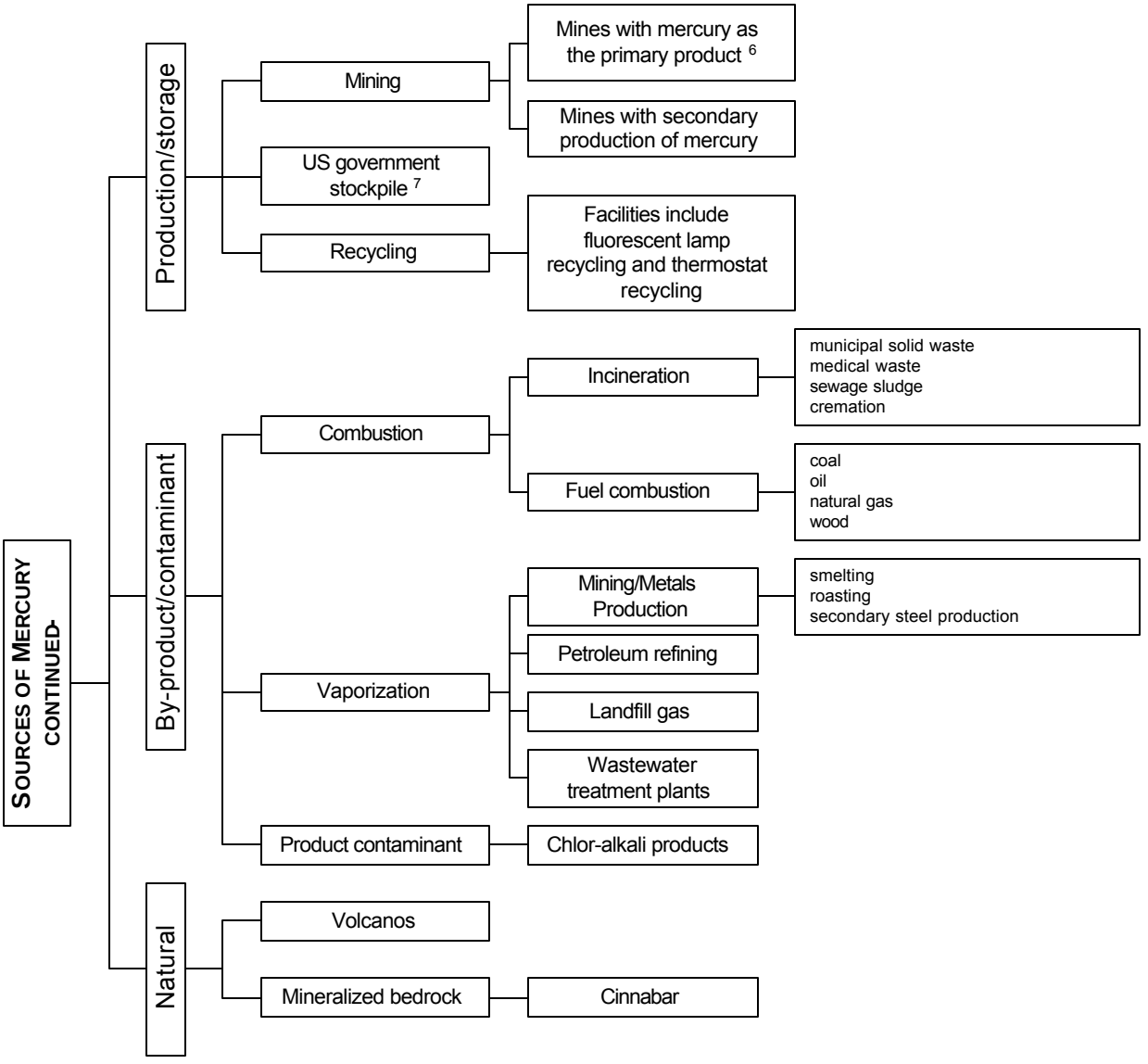
Appendix D: Mercury Use Tree



Appendix D: MERCURY USE TREE
(Continued)



Appendix D: MERCURY USE TREE (Continued)



* Use is known or assumed to be discontinued.
[1] Use has been discontinued in new equipment but old equipment may still be in use.
[2] These products are banned in some jurisdictions.
[3] Caribbean, Chinese, Central American, possibly Hmong.
[4] Use of mercury for gold and silver mining is discontinued in the US and Canada, except for recreational mining; use of mercury for commercial gold mining continues elsewhere (e.g., Brazil).
[5] Fireworks made in the US no longer contain mercury but imported fireworks may.
[6] Mercury mines existed in the US and Canada but have discontinued due to the market and environmental regulations. Globally, mercury mines continue to operate.
[7] The US Department of Defense suspended sales in 1994 and is consulting with EPA.

Superior Work Group
4/20/98

APPENDIX E: AER REPORT - MODELING DEPOSITION OF ATMOSPHERIC MERCURY IN MICHIGAN AND THE GREAT LAKES REGION

Atmospheric and Environmental Research, Inc.

MODELING DEPOSITION OF ATMOSPHERIC MERCURY

IN MICHIGAN AND THE GREAT LAKES REGION

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1. INTRODUCTION

This report describes the results from a modeling study conducted to investigate the fate and transport of atmospheric mercury and its deposition in Michigan and the Great Lakes region.

Mercury (Hg) is emitted into the atmosphere as gaseous or particulate species. Gaseous mercury can be either elemental, Hg(0), or divalent, Hg(II). Gaseous mercury can also adsorb to particulate matter (PM). In the atmosphere, mercury species can be converted from Hg(0) to Hg(II) and vice-versa. Most atmospheric Hg(II) occurs as inorganic compounds (with traces of organic monomethylmercury of unknown origin), while organic Hg(II) mostly occurs in water bodies.

Mercury is removed from the atmosphere via both wet deposition (precipitation) and dry deposition processes to the Earth's surface. The atmospheric lifetime of Hg(0) is believed to be on the order of several weeks. Hg(0) is not deposited rapidly to the Earth's surface and its atmospheric lifetime is, therefore, governed by oxidation to Hg(II). Gaseous Hg(II) species tend to have an atmospheric lifetime of several hours to a few days because of their high solubility in water and adsorption properties that favor their removal by wet and dry deposition. Particulate mercury is present mostly in the fine particle size section and, in the absence of precipitation, it can remain in the atmosphere for several days.

Once deposited to the Earth's surface, mercury can enter the aquatic food chain in surface water bodies where it may become methylated and bioaccumulate as methylmercury in fish. Sensitive human populations and wildlife that consume large amounts of fish may then be exposed to mercury concentrations that are potentially harmful to their health.

In this report, we first introduce the multiscale modeling system used to simulate the emissions, chemistry, transport and deposition of atmospheric mercury. The atmospheric mercury chemical kinetic mechanism employed in the model is discussed at length. We describe the model inputs including emissions, meteorology, initial and boundary conditions, and other parameters. Next, we present a performance evaluation of the modeling system by comparison with data. Then, we submit collated evidence for reduction of divalent gaseous mercury to elemental mercury in coal-fired power plant plumes. We evaluate the model again after incorporating the effect of this plume reduction. Finally, we present results from four modeling scenarios in terms of the spatial distribution of deposition fluxes of mercury and its deposition to and re-emission from the Great Lakes.

2. DESCRIPTION OF THE MODELING SYSTEM

The objective of this study is to model the atmospheric deposition of mercury (Hg) in Michigan and the Great Lakes region. Any study with such an objective must first simulate the global cycling of Hg as well as its deposition on a finer continental/regional scale. Such an approach is desirable because Hg is a global pollutant with long atmospheric residence times (Schroeder and Munthe, 1998). Therefore, the upwind boundary concentrations of mercury species are quite influential for modeling the atmospheric fate and transport of mercury at continental and regional scales. Since there is a paucity of data to specify such boundary conditions, particularly aloft, it is more reliable to obtain such boundary conditions from a global simulation, contingent upon satisfactory performance of the global model.

The multiscale modeling system used in this study consists of three nested chemical transport models (CTM): a global CTM, a continental CTM and a regional CTM. This system is "one-way": results at a given model scale drive boundary conditions at the next-smaller nested scale, but smaller scales do not determine larger-scale results. The global simulation of Hg provides the boundary conditions for modeling Hg at a continental scale. The results of the continental simulation, in turn, provide boundary conditions for modeling Hg at a regional scale. Seigneur *et al.* (2001) have described this modeling system and its initial application. The modeling system has been applied successfully in several studies of the transport and deposition of Hg over North America (Seigneur *et al.*, 2003a, 2004a, 2004b; Vijayaraghavan *et al.*, 2003, 2004). The atmospheric mercury chemistry used in the global and continental/regional CTMs in this study is described below.

2.1. Chemical Kinetic Mechanism of Atmospheric Mercury

Table 2-1 presents the atmospheric transformations among inorganic mercury species that are simulated in the multiscale modeling system. These transformations represent the current state of the science (Ryaboshapko *et al.*, 2002; Shia *et al.*, 1999; Seigneur *et al.*, 2001, 2004a, 2004b). They include the gas-phase oxidation of Hg(0) to Hg(II), the aqueous-phase oxidation of Hg(0) to Hg(II), the aqueous-phase reduction of Hg(II) to Hg(0), various aqueous-phase equilibria of Hg(II) species and the aqueous-phase adsorption of Hg(II) to PM.

Our knowledge of the atmospheric reactions of organic mercury is limited to the oxidation of dimethylmercury by OH (Niki *et al.*, 1983a), Cl (Niki *et al.*, 1983b), $O(^3P)$ (Lund-Thomsen and Egsgaard, 1986) and NO_3 (Sommar *et al.*, 1996). The first two reactions lead to the formation of monomethylmercury whereas the latter one leads to the formation of inorganic mercury. Atmospheric dimethylmercury, which originates primarily from the oceans, is rapidly converted to other species and, therefore, is not a major component of the global mercury cycle.

The atmospheric chemistry of mercury presented in Table 2-1 shows that aqueous-phase reactions (those that occur in clouds and fogs) can lead to either oxidation of Hg(0) to Hg(II) or reduction of Hg(II) to Hg(0). Such reduction-oxidation cycles affect the overall atmospheric lifetime of mercury. As mentioned above, the chemical atmospheric lifetime of Hg(0) is currently believed to be a few weeks. However, in non-precipitating clouds, Hg(II) may be reduced back to Hg(0), thereby extending the lifetime of mercury in the atmosphere. It is, therefore, important to differentiate between the chemical lifetime of a mercury species, which may range from several hours to several days for Hg(II) and Hg(p) and is several weeks for Hg(0), and the overall atmospheric lifetime of mercury (that can cycle among the various species), presently estimated to be on the order of several weeks. Further details on the mercury chemistry used in the modeling system may be found in Seigneur *et al.* (2004a).

It should be noted that there are considerable uncertainties in the current chemical kinetic mechanisms of atmospheric mercury (e.g., Ryaboshapko *et al*., 2002) and that our knowledge of mercury chemistry continues to evolve. As new laboratory data become available, the chemical kinetic mechanism used in the modeling system is continuously updated.

2.2. Global Mercury Chemical Transport Model

The formulation of the global Hg CTM has been described in detail elsewhere (Shia *et al*., 1999, Seigneur *et al*., 2001, 2004a). An overview of the model is presented here.

The multiscale modeling domains used in this study are illustrated in Figure 2-1. The global Hg model is based on the three-dimensional (3-D) CTM developed at the Goddard Institute for Space Studies (GISS), Harvard University, and the University of California at Irvine. The 3-D model provides a horizontal resolution of 8° latitude and 10° longitude and a vertical resolution of nine layers ranging from the Earth's surface to the lower stratosphere. Seven layers represent the troposphere (between the surface and ~12 km altitude), and two layers the stratosphere (between ~12 km and 30 km altitude). Transport processes are driven by the wind fields and convection statistics calculated every 4 hours (for 1 year) by the GISS general circulation model (Hansen *et al*., 1983). This 1-year data set is used repeatedly for multiyear simulations until steady state is achieved.

The Hg transformation processes include gas-phase transformations, gas/droplet equilibria, ionic equilibria, solution/particle adsorption equilibrium, and aqueous-phase transformations as described above. The chemical species reacting with Hg are input to the model as described by Seigneur *et al.* (2001). Dry and wet deposition calculations are performed as outlined by Seigneur *et al.* (2004). The global CTM provides boundary conditions for the continental/regional model that is described in the next section.

Table 2-1. Equilibria and reactions of atmospheric mercury.

Equilibrium Process or Chemical Reaction	**Equilibrium or Rate Parameter[a]**	**Reference**
$Hg(0)\ (g) \rightleftarrows Hg(0)\ (aq)$	$0.11\ M\ atm^{-1}$	Sanemasa, 1975; Clever *et al*., 1985
$HgCl_2\ (g) \rightleftarrows HgCl_2\ (aq)$	$1.4 \times 10^{6}\ M\ atm^{-1}$	Lindqvist and Rodhe, 1985
$Hg(OH)_2\ (g) \rightleftarrows Hg(OH)_2\ (aq)$	$1.2 \times 10^{4}\ M\ atm^{-1}$	Lindqvist and Rodhe, 1985
$HgCl_2\ (aq) \rightleftarrows Hg^{2+} + 2\ Cl^{-}$	$10^{-14}\ M^{2}$	Sillen and Martell, 1964
$Hg(OH)_2\ (aq) \rightleftarrows Hg^{2+} + 2\ OH^{-}$	$10^{-22}\ M^{2}$	Sillen and Martell, 1964
$Hg^{2+} + SO_3^{2-} \rightleftarrows HgSO_3$	$2.1 \times 10^{13}\ M^{-1}$	van Loon *et al*., 2001
$HgSO_3 + SO_3^{2-} \rightleftarrows Hg(SO_3)_2^{2-}$	$1.0 \times 10^{10}\ M^{-1}$	van Loon *et al*., 2001
$Hg(II)\ (aq) \rightleftarrows Hg(II)\ (p)$	34 l/g	Seigneur *et al*., 1998
$Hg(0)\ (g) + O_3\ (g) \longrightarrow Hg(II)\ (g)$	$3 \times 10^{-20}\ cm^{3}\ molec^{-1}s^{-1}$	Hall, 1995 [b]
$Hg(0)\ (g) + HCl(g) \longrightarrow HgCl_2(g)$	$10^{-19}\ cm^{3}\ molec^{-1}\ s^{-1}$	Hall and Bloom, 1993
$Hg(0)\ (g) + H_2O_2\ (g) \longrightarrow Hg(OH)_2\ (g)$	$8.5 \times 10^{-19}\ cm^{3}\ molec^{-1}s^{-1}$	Tokos *et al*., 1998
$Hg(0)\ (g) + Cl_2(g) \longrightarrow HgCl_2(g)$	$2.6 \times 10^{-18}\ cm^{3}\ molec^{-1}s^{-1}$	Ariya *et al*., 2002
$Hg(0)\ (g) + OH(g) \longrightarrow Hg(OH)_2(g)$	$8.0 \times 10^{-14}\ cm^{3}\ molec^{-1}s^{-1}$	Sommar *et al*., 2001
$Hg(0)\ (aq) + O_3\ (aq) \longrightarrow Hg^{2+}$	$4.7 \times 10^{7}\ M^{-1}\ s^{-1}$	Munthe, 1992
$Hg(0)\ (aq) + OH\ (aq) \longrightarrow Hg^{2+}$	$2.0 \times 10^{9}\ M^{-1}\ s^{-1}$	Lin and Pehkonen, 1997
$HgSO_3\ (aq) \longrightarrow Hg(0)\ (aq)$	$0.0106\ s^{-1}$	van Loon *et al*., 2000
$Hg(II)\ (aq) + HO_2\ (aq) \longrightarrow Hg(0)\ (aq)$	$1.7 \times 10^{4}\ M^{-1}\ s^{-1}$	Pehkonen and Lin, 1998[c]
$Hg(0)\ (aq) + HOCl\ (aq) \longrightarrow Hg^{2+}$	$2.09 \times 10^{6}\ M^{-1}\ s^{-1}$	Lin and Pehkonen, 1998
$Hg(0)\ (aq) + OCl^{-} \longrightarrow Hg^{2+}$	$1.99 \times 10^{6}\ M^{-1}\ s^{-1}$	Lin and Pehkonen, 1998

Hg(II) refers to divalent Hg species

[a] The parameters are for temperatures in the range of 20 to 25°C, see references for exact temperature; temperature dependence information is available for the Henry's law parameter of Hg(0) and for the kinetic rate parameter of the $HgSO_3$ reaction.

[b] The kinetics of this reaction was recently re-evaluated to be about 25 times faster by Pal and Ariya, 2004; this would lead to a greater relative contribution from Hg(0) and a lesser relative contribution of Hg(II) primary emissions to mercury deposition.

[c] This reaction was recently challenged by Gardfeldt and Johnson, 2003; however, an alternative has not been proposed

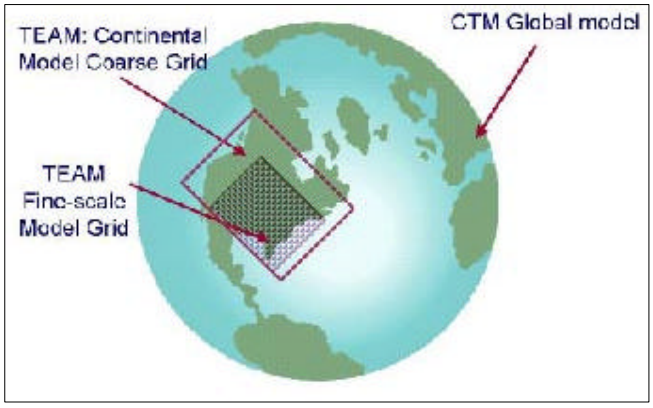

Figure 2-1: Multiscale modeling domain with global and continental/regional grids.

2.3. Continental/Regional Mercury Chemical Transport Model

The formulation of the continental/regional model, TEAM, has been described in detail elsewhere (Pai *et al.*, 1997; Seigneur *et al.*, 2001, 2004a). We present here an overview of the model.

TEAM is a 3-D Eulerian model that simulates the transport, chemical and physical transformations, wet and dry deposition of Hg species. In this application, TEAM is applied on a continental scale over North America and on a regional scale over the central and eastern United States. The regional fine grid also covers the Great Lakes region and adjoining portions of Canada. The horizontal grid resolution is 100 km for the continental grid and 20 km for the regional grid. The vertical resolution consists of six layers from the surface to 6 km altitude with finer resolution near the surface (the layer interfaces are at 60, 150, 450, 850 and 2000 m). Transport processes include transport by the 3-D mean wind flow and dispersion by atmospheric turbulence. The module that simulates the chemical and physical transformations of Hg was described above and is the same module as that used in the global model. Three Hg species, Hg(0), Hg(II) and Hg(p), are simulated. Hg(II) actually consists of several chemical species in the gas phase and in cloud droplets; Hg(II) can also adsorb to PM. The calculation of dry and wet deposition in TEAM has been described earlier (Seigneur *et al.*, 2004a; Vijayaraghavan *et al.*, 2003). The continental CTM and regional CTM are run for one datum year, in this case, 1998. Figure 2-2 shows the continental and regional nested domains with horizontal resolutions of 100 km and 20 km, respectively.

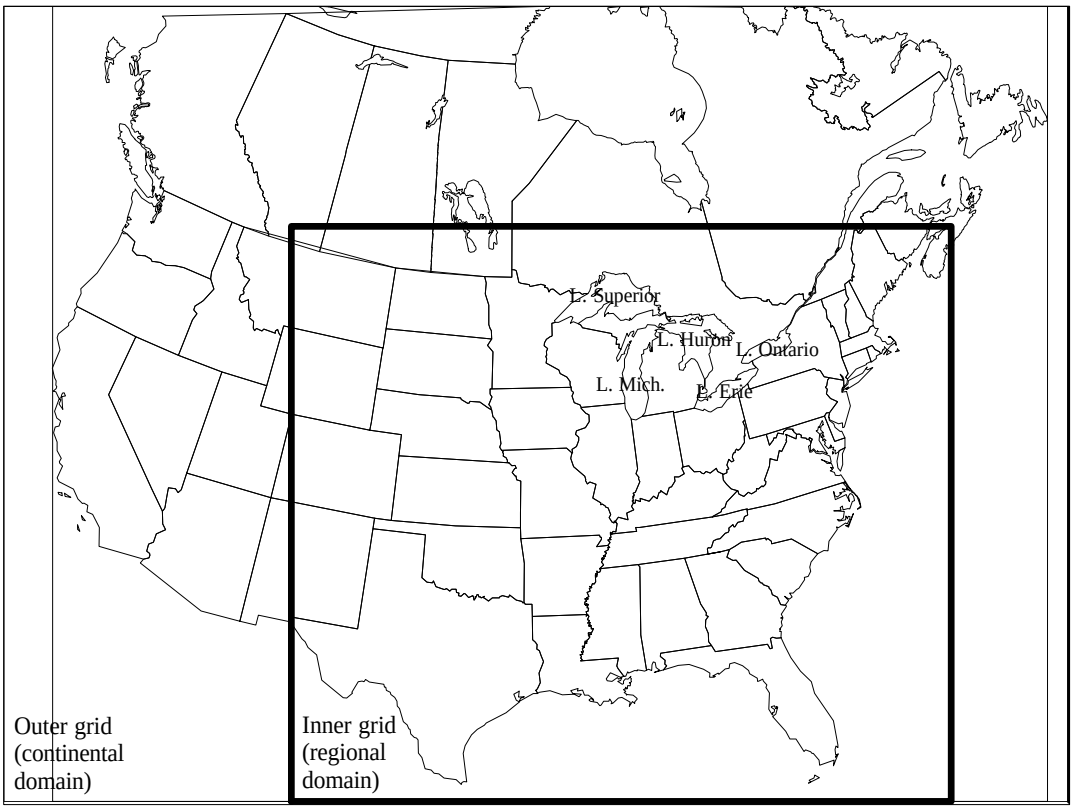

Figure 2-2. Continental and regional modeling domains (with horizontal resolution of 100 km and 20 km respectively; locations of the Great Lakes shown)

While use of a fine (20-km) grid resolution helps to better characterize the emission and fate of mercury, it should be noted that 3-D regional Eulerian models, such as this one, are not designed to simulate localized impacts of point sources at the grid-cell level as precisely as atmospheric dispersion models, which more realistically represent plume behavior due to wind and temperature. Consequently, the local impact in the model grid cell corresponding to the location of a point source is likely to be misrepresented by the regional model, as discussed in Section 5.3.

3. CONFIGURATION OF THE MODELING SYSTEM AND INPUT FILES

The global mercury CTM is run until steady state is achieved between emissions of mercury into the atmosphere and deposition to the earth, while the continental/regional models are each run for one year. The modeling year for the base case applications in this study is 1998. The atmospheric emissions and chemistry of mercury are the same in both global and continental/regional models. The configuration of the global mercury CTM and its input files have been discussed in the literature (Shia *et al.*, 1999; Seigneur *et al.*, 2001, 2004a). The preparation of input files for the continental/regional model, TEAM, has also been reviewed earlier (Seigneur *et al.*, 2001, 2004a; Vijayaraghavan *et al.*, 2003). A brief overview of the preparation of input for TEAM is presented below.

3.1 Emissions Inventory

The North American anthropogenic mercury emission inventory used in this modeling study has been summarized earlier (Pai *et al.*, 2000, Seigneur *et al.*, 2001, 2004a). In particular, new estimates of mercury emissions from coal-fired electric utilities were provided by EPRI (Levin, 2001). This inventory reflected the recent data on mercury coal content collected at all coal-fired power plants and stack measurements of speciated mercury conducted at over eighty power plants as part of the U.S. Environmental Protection Agency (EPA) Information Collection Request (ICR, 1999) program. The North American anthropogenic mercury emission inventory in the continental domain is summarized by source category in Table 3-1. Corresponding emissions in the regional modeling domain (over the central and eastern United States) are shown in Table 3-2. The regional domain also encompasses parts of Canada and Mexico with anthropogenic Hg emissions of 6.9 and 14.8 Mg/yr respectively. The category for waste incineration shown in Tables 3-1 and 3-2 includes municipal and medical waste incinerators. The values in parentheses represent updated Hg emissions after MACT implementation on these incinerators. These updates are discussed further in a later section. Hg emissions from commercial incinerators are included in the "other sources" category in Tables 3-1 and 3-2. This category also includes sources such as electric arc furnaces, electric lamp breakage, cement manufacturing, oil burning, wood burning, iron-ore roasting, landfills and others. Mercury emissions from electric arc furnaces are from the 1996 EPA National Emission Inventory (NEI) and are believed to be underestimated (CCC, 2004). Total Hg emissions from coal-fired electric utilities in Michigan are about 1.1 Mg/yr (of which about 45% is elemental and 55% oxidized mercury).

The background emissions of Hg(0) include natural emissions from active volcanoes and from the mercuriferous crustal formations of western North America, as well as re-emissions of deposited mercury. We assume that 50% of deposited mercury is re-emitted (see detailed discussion on re-emissions in Seigneur *et al.*, 2004a).

Table 3-3 shows the estimated global mercury emissions inventory (from Seigneur *et al.*, 2001; Seigneur *et al.*, 2004a) for comparison.

Table 3-1. Anthropogenic Hg emissions (Mg/yr) in the North American domain

Source Category	**United States**	**Southern Canada**	**Northern Mexico**	**Total**
Electric Utilities	41.5	1.3	9.9	52.7
Waste Incineration	28.8 (*8.2*[a])	(b)	(b)	28.8 (*8.2*[a])
Mobile Sources	24.8	(b)	(b)	24.8
Nonutility coal burning	12.8	(b)	(b)	12.8
Chlor-alkali facilities	6.7	0.05	(b)	6.8
Mining	6.4	0.3	(b)	6.7
Other Sources	30.9	13.0	23.6	67.5
Total	151.9 (131.3[a])	14.7	33.5	200.1 (*179.5*[a])

(a) Values in parentheses are Hg emissions after MACT implementation on incinerators
(b) included in "other sources"

Table 3-2. Anthropogenic emissions (Mg/yr) in the central and eastern United States

Source Category	**Emissions**
Electric utilities	39.3
Mobile sources	22.1
Non-utility coal burning	11.9
Waste incineration	27.2 (7.6[a])
Chloralkali facilities	6.1
Other	26.6
Total	133.2 (113.6[a])

(a) Values in parentheses are Hg emissions after MACT implementation on incinerators

Table 3-3. Global Hg Emissions (Mg/yr) (from [a]Seigneur, *et al.*, 2001; [b]Seigneur, *et al.*, 2004a)

Anthropogenic Emissions [a]	**Total Hg**
North America	205.0
South & Central America	176.2
Europe	508.3
Asia	1117.2
Africa	246.1
Oceania	48.3
Total direct anthropogenic [a]	2301.1
Natural emissions [b]	
Total (land+water)	1067

3.2 Meteorology

Meteorological fields are derived from the 3-D output of a prognostic meteorological model, the Nested Grid Model (NGM) of the National Oceanic and Atmospheric Administration (NOAA). Meteorology from 1998 is used. The NGM data set was obtained from the National Center for Atmospheric Research (NCAR, 2000). The cloud fields were also obtained from NCAR. Precipitation data were obtained from NCAR, the National Atmospheric Deposition Program (NADP)/Mercury Deposition Network (MDN), and the Canadian Climate Network and were combined to construct precipitation fields (see Seigneur *et al*., 2001). The preparation of meteorological inputs to TEAM is described in detail elsewhere (Seigneur *et al.*, 2001).

3.3 Initial Conditions

We use constant initial conditions of 1.6 ng m^{-3}, 80 pg m^{-3}, and 10 pg m^{-3} for Hg(0), Hg(II) and Hg(p), respectively, for model layers (typically layers 1-3) in the atmospheric boundary layer. Above the boundary layer, Hg(II) and Hg(p) concentrations are allowed to decrease rapidly with height to a value of 0.1% of the boundary layer value at the model top. This decrease accounts for the effective scavenging of Hg(II) and Hg(p) by clouds. The vertical variation of Hg(0) is more gradual, to account for the fact that Hg(0) is a relatively long-lived species and has a longer residence time in the atmosphere. A spin-up period of ten days is used in each modeling run to minimize the influence of the initial conditions.

3.4 Boundary Conditions

The results of the global model simulation (Seigneur *et al.*, 2001, 2004a) are used to provide the boundary conditions for the TEAM application to North America. These boundary conditions consist of the concentrations of Hg(0), Hg(II) and Hg(p) as a function of location, height and season. The global grid cells used for these boundary conditions range from 20 to 68 degrees latitude north and from 45 to 145 degrees longitude west. Five of the nine layers in the global model extend from the surface to 6 km altitude. These layers are mapped into the six layers of TEAM. The boundary conditions vary according to season. The values simulated by the global model for January, April, July and October are used to represent winter, spring, summer and fall conditions, respectively.

The global CTM provides spatially-distributed and temporally-resolved fields of background mercury species concentrations and the continental CTM uses these background concentrations along with the mercury emissions within the continental domain to calculate mercury fate and transport at a spatial resolution finer than that of the global CTM. Results of the continental model simulation are, in turn, used to provide hourly concentrations of Hg(0), Hg(II) and Hg(p) for each boundary cell of the regional grid over the eastern United States.

3.5 Other Model Inputs

Land cover and terrain fields for the TEAM domain in polar stereographic projection were developed from the USGS Global Land Cover Characteristics database (GLCC) and global digital elevation database (GTOPO30) respectively. The chemical species reacting with Hg are obtained from 3-D CTM simulations for O_3, SO_2, OH, HO_2 and H_2O_2 or assumed based on available data for HCl, Cl_2 and PM as described by Seigneur *et al*. (2001). The concentrations of O_3, SO_2, OH, HO_2 and H_2O_2 are spatially and temporally varying. The concentrations of HCl and PM are spatially and temporally constant. The concentrations of Cl_2 are zero over land and temporally and spatially varying in the vertical direction over the oceans.

The mercury modeling system used in this study differs from that utilized by EPA in a few respects. The Regional Modeling System for Aerosols and Deposition (REMSAD) used in EPA modeling studies pre-assigns values to the boundary concentrations of Hg based on typical global background concentrations. Moreover, REMSAD uses meteorology driven by fields (winds, temperature, pressure, precipitation etc.) derived from an MM5 (the Penn State/NCAR Mesoscale Model) model simulation. Wet deposition fluxes are highly influenced by precipitation fields. TEAM uses daily precipitation fields from NCAR and refines them using annual precipitation data from the NADP/MDN database. REMSAD uses predicted precipitation fields from MM5 which may not be as accurate.

4. PERFORMANCE EVALUATION OF THE MODEL

4.1 Spatial Distribution of Mercury Deposition

The TEAM simulation of Vijayaraghavan *et al.* (2003, 2004) for 1998 was used as the base case simulation for this study. This fine-grid (20 km horizontal resolution) simulation covers the central and eastern United States, including Michigan and the Great Lakes region (see Figure 2-2 shown earlier). It uses 1998 meteorology, a 1998/1999 emission inventory developed by AER, and boundary conditions generated by a multiscale global/continental simulation (Seigneur *et al.*, 2004a).

Figure 4-1 illustrates the modeled dry, wet, and total (i.e., dry plus wet) mercury deposition fluxes in the 1998 base case simulation over the central and eastern United States. In this figure (and all others in this report), the fluxes shown exclude Hg(0) which is assumed to be eventually re-emitted and thus does not enter the watershed mercury cycle. Simulated annual dry deposition typically ranged between 5 and 25 $\mu g/m^2$ east of the Mississippi river. Dry deposition fluxes were less than 5 $\mu g/m^2$-yr over most of northern Michigan and mostly between 5 and 15 $\mu g/m^2$-yr in the central and southern parts of the state. Simulated annual dry deposition fluxes were above 15 $\mu g/m^2$-yr in some regions of the state near Detroit and on the eastern shore of Lake Michigan. Dry deposition fluxes were highest in the northeastern United States resulting from the impacts of a greater number of local/regional emission sources in the generally upwind direction. The highest simulated dry deposition was 204 $\mu g/m^2$ in Massachusetts. This is due to the impact of several municipal and medical waste incinerators nearby emitting more than 1 Mg/y of mercury. Less than 1% of the grid cells in the modeling domain have dry deposition greater than 25 $\mu g/m^2$.

Annual wet deposition was between 10 and 15 $\mu g/m^2$ in most of the eastern United States. Wet deposition fluxes were higher in Florida, and in urban areas such as Chicago, Detroit, along the Ohio River valley, and in the northeastern United States. The high fluxes result from the influence of local/regional sources (e.g., in the Northeast) or high precipitation (e.g., Florida). Less than one-half of one percent of the model grid cells have wet deposition fluxes greater than 25 $\mu g/m^2$. The highest wet deposition was 128 $\mu g/m^2$ near Baltimore, MD resulting from a combination of high local emissions (e.g., municipal waste combustor), regional contributions, and global background. Hg emissions have decreased significantly from the municipal waste incinerators in Baltimore and other locations since the modeled year (1998) due to implementation of MACT controls on that source category. The total deposition fluxes shown at the bottom of Figure 4-1 reflect the characteristics mentioned above for the wet and dry deposition fluxes.

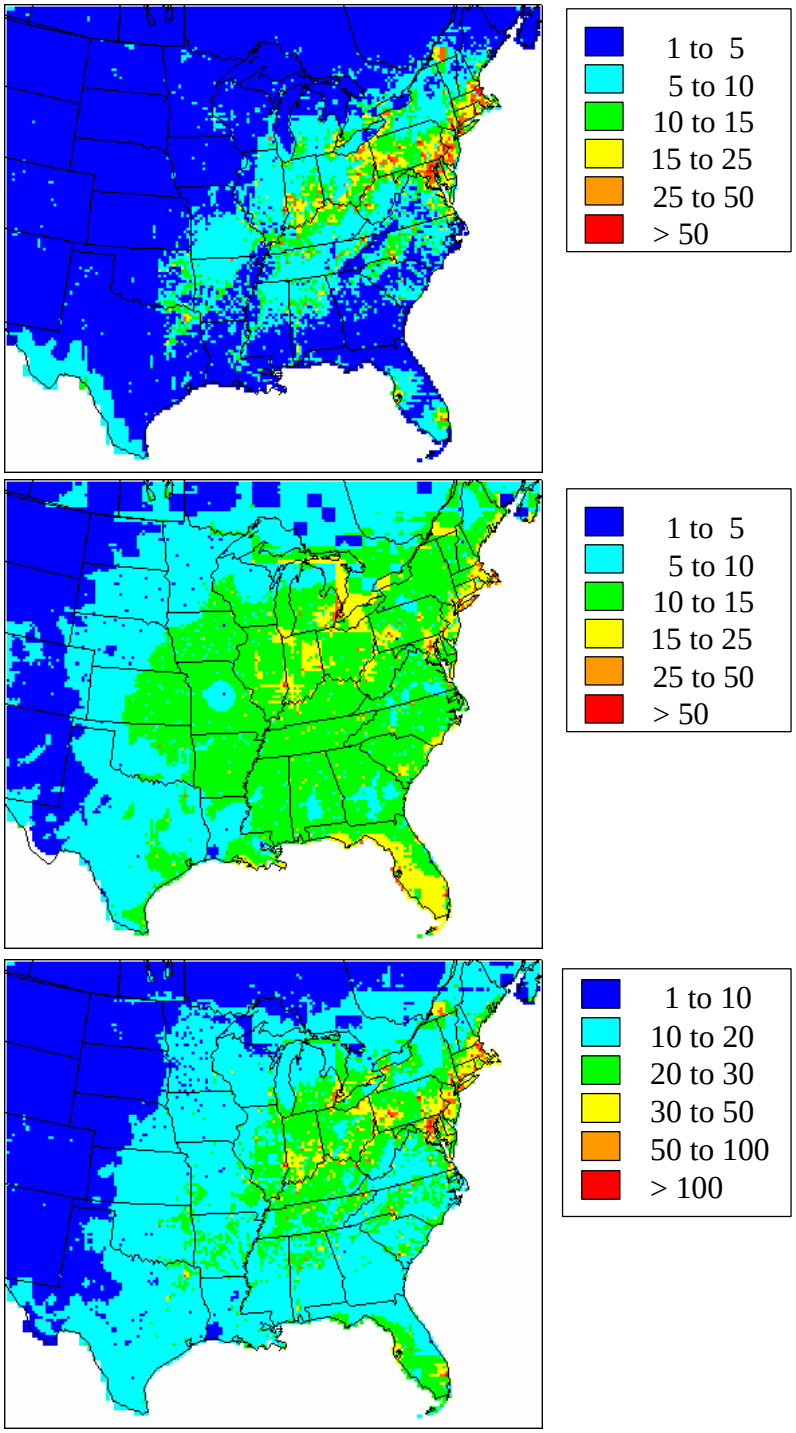

Figure 4-1. Simulated Hg dry deposition flux (µg/m^2-yr, top), wet deposition flux (µg/m^2-yr, middle), and total deposition flux (µg/m^2-yr, bottom) in the 1998 base case.

4.2 Performance Evaluation of the Base Case Simulation

A comprehensive performance evaluation of the global and continental/regional models has been conducted and presented earlier (Seigneur *et al.*, 2004a, Vijayaraghavan *et al.*, 2003). The measurements for wet deposition of mercury in 1998 in the Mercury Deposition Network (NADP/MDN, 2003) are shown in Figure 4-2. The simulated wet deposition fluxes illustrated in Figure 4-1 follow the general spatial patterns seen in the wet deposition measurements depicted in Figure 4-2. The simulated Hg wet deposition fluxes for 1998 were compared with measurements at all the MDN sites for which data were available for 1998. Note that comparisons with 2003 MDN data cannot be made unless 2003 meteorology was used in TEAM; this work was outside the scope of this study. The 1998 MDN database includes 27 sites in the United States and 3 sites in Canada. Figure 4-3 presents a comparison of simulated with measured wet deposition fluxes with a coefficient of determination (r^2) of 0.55, a normalized absolute error of 26%, and a normalized bias of 12% (normalized error = $\frac{1}{N}\sum_{i=1}^{N}\left|\frac{P_i - O_i}{O_i}\right|$; normalized bias = $\frac{1}{N}\sum_{i=1}^{N}\left(\frac{P_i - O_i}{O_i}\right)$ where P_i = prediction, O_i = observation; N: number of samples). As part of model performance evaluation, fine grid simulation results were used for MDN sites within the fine grid domain, while for stations outside this domain, the previous results of Seigneur *et al.* (2004a) were used.

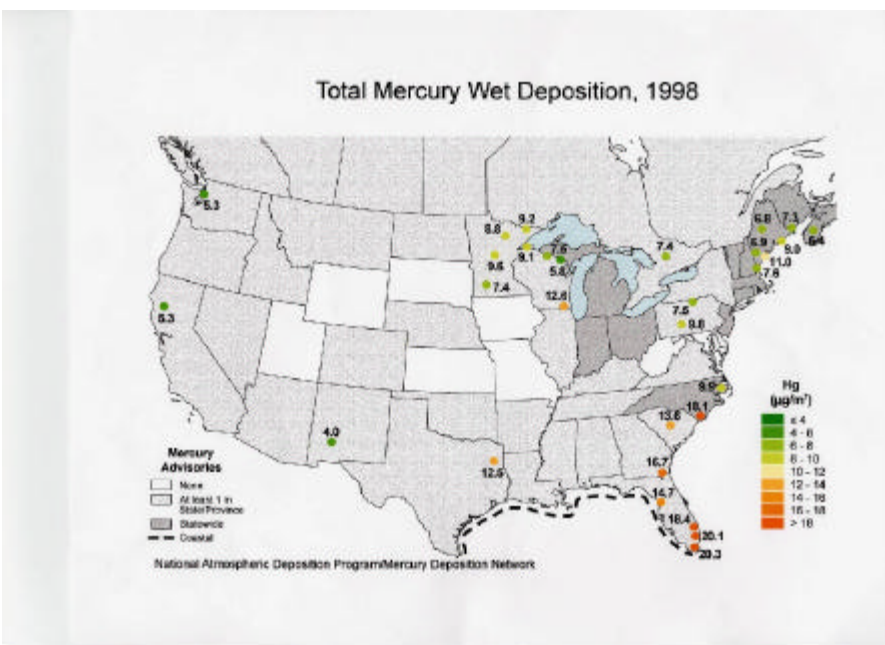

Figure 4-2. Wet deposition of Hg in 1998 at sites in the Mercury Deposition Network (NADP/MDN, 2003).

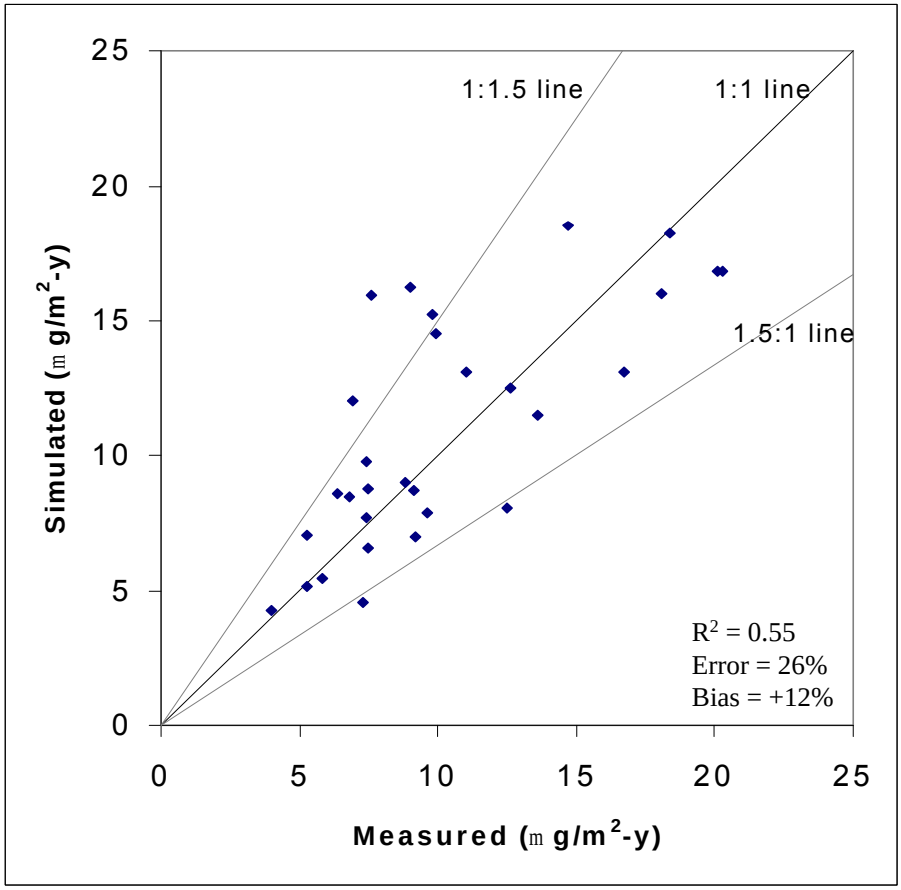

Figure 4-3. Comparison of measured and simulated Hg wet deposition fluxes ($\mu g/m^2$-yr) in 1998 at MDN sites.

A comparison of observed and simulated concentrations of atmospheric mercury is presented in Table 4-1 for several locations in the United States and Canada for which data were available for 1998. Simulated values shown in the table are either annual averages for 1998 or averages for a particular month depending on the measurement period. Reactive gaseous mercury (RGM) and total particulate mercury (TPM) are analogous to Hg(II) and Hg(p) in TEAM. In the base case simulation, the model slightly overpredicts Hg(0) and RGM while correctly estimating TPM in Chesapeake Bay. At the measurement site in Dexter, Michigan, the simulated value of total gaseous mercury (TGM, i.e., Hg(0) + Hg(II)) in 1998 is higher than the measured value in September 1998, while simulated and measured values of TPM are more comparable. In Canada, the model shows good agreement for TGM and exhibits errors between 1 and 20% at all eight sites.

Table 4-1. Comparison of observed and simulated mercury concentrations (ng/m^3).

Location	Period	Mercury species	Observation[a]	Base case simulation	Alternative speciation simulation	Reference for observation
United States						
Chesapeake Bay, MD	97-99	Hg(0)	1.89 ± 0.94	2.09	2.09	(b)
		RGM	0.04 ± 0.05	0.06	0.05	(b)
		TPM	0.02 ± 0.05	0.02	0.02	(b)
Dexter, MI	9/98	TGM	1.5 ± 0.1	2.1	2.1	(c)
		TPM	0.013 ± 0.007	0.016	0.016	(c)
Canada						
Burnt Island, ON	97-99	TGM	1.58	1.73	1.73	(d)
St. Anicet, QC	97-99	TGM	1.72	1.68	1.68	(d, e)
St. Andrews, NB	97-99	TGM	1.43	1.66	1.66	(d)
Kejimkujik, NS	97-99	TGM	1.33	1.60	1.60	(d)
Egbert, ON	97-99	TGM	1.65	1.68	1.68	(d)
Point Petre, ON	97-99	TGM	1.90	1.82	1.82	(d)
L'Assomption, QC	98	TGM	1.79	1.74	1.74	(e)
Villeroy, QC	98	TGM	1.62	1.63	1.63	(e)

(a) Mean or Mean ± Standard deviation
(b) Sheu and Mason, 2001
(c) Malcolm and Keeler, 2002
(d) Kellerhals *et al.*, 2003
(e) Poissant, 2000

4.3 Evidence for Plume Reduction of Mercury

Mercury emissions from various sources are a combination of the different speciated forms of mercury, namely, Hg(0), Hg(II) and Hg(p). The Michigan Environmental Science Board has stated in a science report on mercury in Michigan's

environment (Fischer *et al.*, 1993) that there was some evidence for reduction of Hg(II) to Hg(0) in power plant plumes. Several recent experimental studies also provide direct and circumstantial evidence of reduction of Hg(II) to Hg(0) in power plant plumes. This potential reaction is very significant, because it can significantly affect deposition predictions downwind of power plants with high oxidized mercury emissions. We briefly discuss the relevant studies below.

First, the University of North Dakota Energy and Environmental Research Center and Frontier Geosciences, Inc. conducted experiments where the exhaust flue gases from a coal-fired power plant stack were sampled, diluted and analyzed in a Teflon-lined dispersion chamber. These experiments showed a lower Hg(II)/Hg(0) ratio in the chamber than in the stack (Laudal, 2001). The interpretation of those results is complicated by the fact that some Hg(II) is scavenged by the walls of the chamber. Nevertheless, the discrepancy in mercury speciation between the stack and the chamber suggests that some reactions reducing Hg(II) to Hg(0) are taking place. If such reactions also take place in the power plant plume, they would lower the mercury deposition rate and amount in the near field downwind of the source from that expected in the absence of the reactions.

Second, ambient sampling of Hg species (Hg(II), Hg(0), and Hg(p)), NO_x and SO_2 was conducted with continuous monitors downwind of coal-fired power plants in the Atlanta region (Edgerton *et al*., 2002; Jansen, 2004). The SO_2/NO_x ratio can be used as a signature of individual power plants assuming that there is little oxidation and deposition of SO_2 and NO_x between the stacks and the sampling site. Then, the corresponding speciated mercury measurements can be compared with the mercury speciated emissions estimated from the Information Collection Request (ICR) program. The results from this study suggest that the Hg(II)/Hg(0) ratio downwind from several power plants is lower than the Hg(II)/Hg(0) ratio estimated from the ICR data for the stack emissions while total mass of Hg does not vary significantly between the two locations. An average 14% reduction per hour of Hg(II) to Hg(0) was observed across different seasons, various power plants and different plume travel times ranging up to 15 hours depending on the source and meteorological conditions.

Third, aircraft measurement campaigns performed near the Bowen plant in Georgia and the Pleasant Prairie plant in Wisconsin indicate that such conversion of Hg(II) to Hg(0) indeed takes place in power plant plumes. Preliminary results from the campaign near Bowen indicate about 40% reduction after 3 hours (Levin, 2004). There is likely more reduction for several more hours. Preliminary results from airplane measurements near Pleasant Prairie seem to indicate about 67% reduction of Hg(II) to Hg(0) in plumes at a distance of about 15 km from the stack (Laudal, 2004).

Finally, the MDN data along a west-to-east transect from Minnesota to Pennsylvania show no significant spatial gradient in mercury annual wet deposition fluxes although the Ohio Valley includes several large mercury emission sources located, under prevailing wind conditions, upwind of Pennsylvania. One potential reason is that atmospheric transformations take place that convert Hg(II) to Hg(0), thereby reducing mercury deposition since Hg(0) has an atmospheric lifetime of a few months. Note that

other possible reasons include a significant contribution from dry deposition in Pennsylvania and an underestimation of mercury emissions in the upper Midwest (Seigneur *et al.*, 2003b).

4.4 Performance Evaluation of the Plume Mercury Reduction Case

An emission sensitivity simulation was conducted to incorporate the effect of reduction of Hg(II) to Hg(0) observed in power plant plumes. The speciation profile of mercury emissions from all coal-fired power plants in the central and eastern United States were modified to reflect a reduction of Hg(II) to Hg(0) in power plant plumes. We assumed that 67% of Hg(II) is reduced within a certain distance from the source (based on available experimental data described in the earlier section) and modified the emission speciation profile accordingly. The Hg(II) emissions were decreased by 67% and the Hg(0) emissions increased by the corresponding amount so that total Hg emissions remained unchanged. This change in mercury speciation corresponds to values observed far downwind in one plume from a coal-fired power plant and, therefore, is used here as an approximation for Hg(II) reduction in plumes from similar power plants. This simulation, hereafter referred to as the alternative speciation simulation, was compared to the base simulation described earlier. The percent change in dry, wet, and total deposition of Hg from the base case is illustrated in Figure 4-4. Incorporating the effect of plume mercury reduction decreases deposition by about 5% on average in central and southern Michigan. The largest impact of plume Hg(II) reduction is seen in Pennsylvania, downwind of large Hg sources in the Ohio valley, where simulated total deposition decreases by up to 59% compared to the base case.

Table 4-2 shows the effect of using the alternative emission speciation on the model performance statistics. Model performance improves on incorporating the effect of plume Hg reduction. The coefficient of determination (r^2) increases from 0.55 to 0.57, error decreased from 26% to 24%, and the bias decreased from 12% to 8%. The impact of using alternative speciation on prediction of ambient Hg concentrations is seen in Table 4-1. The fit to observed RGM improves at Chesapeake Bay while fits to Hg(0) and TPM remain unchanged. Mercury concentrations in Michigan do not change on implementing the effect of plume Hg(II) reduction. Modifying the emissions speciation of coal-fired electric utilities in the United States has no impact on simulated mercury concentrations at the measurement sites in Canada. This is likely because atmospheric mercury there is dominated by background Hg(0).

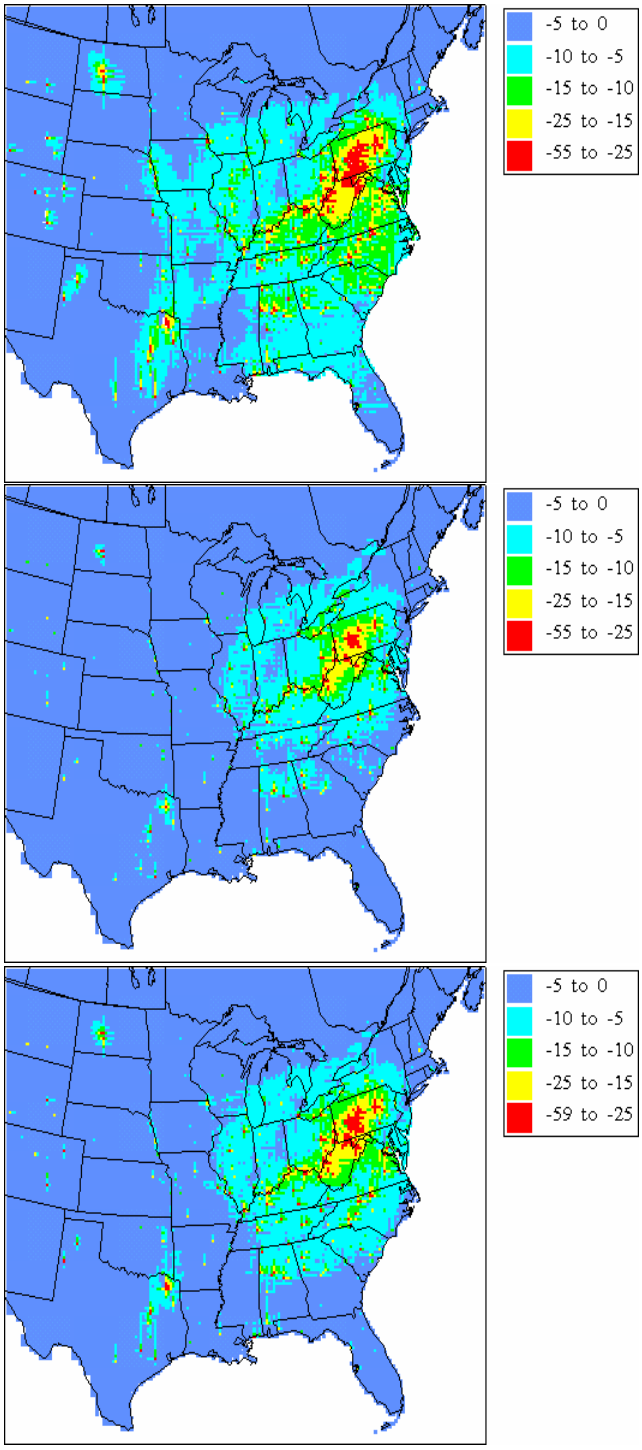

Figure 4-4. Impact of 67% reduction of Hg (II) to Hg(0) on simulated Hg dry deposition flux of Hg (top), wet deposition flux (middle), and total deposition flux (bottom).

Table 4-2. Impact of changing Hg emission speciation (i.e. incorporating the effect of plume Hg reduction) on model performance.

Performance Statistics*	Base Case	Alternative speciation
R^2	0.55	0.57
Error	26%	24%
Bias	12%	8%

* Statistics at 30 sites (for definitions, see text)

5 MODELING SCENARIOS

5.1 Simulation with Updated Incinerator Emissions

Municipal waste incinerators and medical waste incinerators have historically been major source categories for mercury emissions. The chemical speciation was studied, for example, by Dvonch *et al*. (1999) and was found to be dominated by Hg(II) (Hg(p) was not measured and was assumed to represent only 1% of the emissions). Since the chemical speciation is likely to be predominantly Hg(II), emissions from those sources should tend to deposit locally. However, the installation of emission control equipment (e.g., through the implementation of Maximum Available Control Technology, MACT) has significantly reduced incinerator emissions in the United States.

Since mercury emissions from incinerators are lower today than in our 1998 inventory, we modified the emission inventory for municipal and medical waste incinerators to reflect the implementation of MACT. We used actual stack test data for 2003 from the Michigan Department of Environmental Quality, MDEQ (Brunner, 2004) for the Detroit municipal incinerator (Greater Detroit Resource Recovery Facility). We used data from the 1999 National Emission Inventory (U.S. EPA, 2003) for information on mercury emissions from other incinerators in the country.

5.1.1 Spatial distribution of mercury deposition

A new base case simulation was conducted after updating our inventory with the new incinerator emissions data described earlier. Figure 5-1 presents the results of this new base case simulation in terms of spatial maps of annual mercury dry, wet and total deposition fluxes. Spatial patterns of mercury deposition are similar to those seen in the earlier base case shown in Figure 4-1. However, some significant decreases (~25 $\mu g/m^2$-yr) in dry deposition are simulated due to MACT implementation on incinerators in Maryland, New Jersey and Massachusetts. Wet deposition fluxes, which are also influenced by precipitation, decrease by about 5 to 10 $\mu g/m^2$-yr in these states. At the location of the Detroit municipal incinerator, the simulated dry deposition flux decreases from about 25 to 15 $\mu g/m^2$-yr. A formal statistical performance evaluation of this simulation was not conducted because of the discrepancy between the meteorological year (1998) and the more recent year(s) of the incinerator emissions.

5.1.2 Estimation of mercury deposition over the Great Lakes

The modeling domain used in this study covers all five Great Lakes. The locations of these lakes (Erie, Huron, Michigan, Ontario and Superior) in the domain are shown in Figure 2-2. The polar stereographic projection used in the model results in a distortion of the true surface area of each lake. Moreover, the contours of each lake may not be adequately captured with a grid resolution of 20 km. So, the following approach was used to determine the annual wet and dry mercury deposition totals over each of the Great Lakes. The average Hg deposition flux over a lake was first calculated from the sum of the deposition fluxes over all grid cells corresponding to the lake. The average

deposition flux was then multiplied by the true water surface area of the lake (U.S. Environmental Protection Agency and Government of Canada, 1995) to determine the total atmospheric deposition of mercury to the lake.

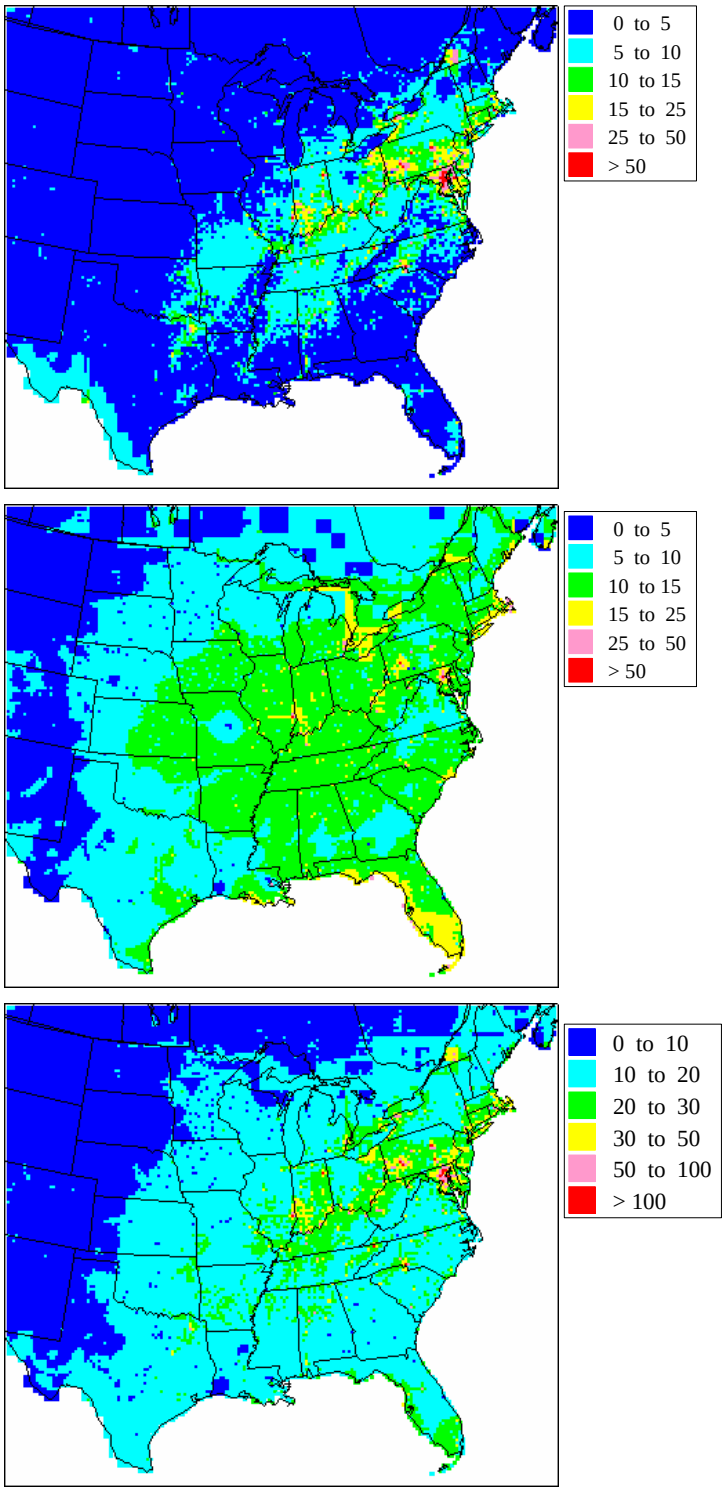

Figure 5-1. Simulated dry deposition flux of Hg ($\mu g/m^2$-yr, top), wet deposition flux ($\mu g/m^2$-yr, middle), and total deposition flux ($\mu g/m^2$-yr, bottom) in the updated base case.

The simulated atmospheric deposition of Hg to Lake Michigan is displayed in Table 5-1. Columns 2 and 3 show the mercury deposition simulated in this study with and without MACT implementation on waste incinerators respectively. Also shown in Table 5-1 are estimates published by Landis and Keeler (2002) and Vette and co-workers (2002) for deposition to Lake Michigan during the Lake Michigan Mass Balance Study (LMMBS) from July 1994 to October 1995. Wet deposition, Hg(II) dry deposition and total deposition estimates are comparable between the current study with the 1998 inventory and that of Landis and Keeler. Re-emissions (evasion) of Hg(0) are also similar between this study and that of Landis and Keeler.

Table 5-1. Estimated atmospheric Hg deposition (kg/yr) to Lake Michigan.

Type	This study (1998 inventory + updated incinerator emissions)	This study (1998 inventory)	Landis and Keeler[a] (2002)	Vette et al.[b] (2002)
Wet deposition	582	670	614 ± 186	
Dry deposition of Hg(II)	181	236	490 ± 139	320 - 959
Dry deposition of Hg(p)	8	8	69 ± 38	
Total deposition [c]	844	988	1173 ± 235 [d]	
Re-emissions of Hg(0)	422	494	453 ± 144	286 - 797

[a] Annualized mean ± standard deviation
[b] Range of values at different ratios of RGM/TGM concentrations
[c] Total deposition also includes dry deposition of Hg(0)Range of values at different ratios of RGM/TGM concentrations
[d] Approximate standard deviation estimated from square root of sum of squares of standard deviations of components

Some differences in deposition amounts may arise because the current study simulates deposition using modeled atmospheric concentrations of Hg over the entire surface of the lake while the LMMBS calculates deposition from interpolated atmospheric measurements of Hg at 4 land-based sites around Lake Michigan and 3 over-water locations near the southern shore. Landis and Keeler have indicated that the uncertainty of their RGM dry deposition estimate is unknown and potentially large, in part because they did not measure RGM. Precipitation events could also vary between the two modeling periods (1994-95 and 1998) thus resulting in different wet deposition. The lower value for dry deposition of Hg(p) simulated by TEAM compared to that calculated by Landis and Keeler is probably due to the following difference in dry deposition calculations. In TEAM, the dry deposition of Hg(p) is treated similarly to that of fine particles. In contrast, Landis and Keeler assign 30% of the total Hg(p) to the coarse fraction based on their size-resolved measurements; coarse particles have a higher dry deposition velocity than fine particles, thereby resulting in more particulate dry deposition. The dry deposition estimated in this study for Hg(II) is lower than the range for reactive gaseous mercury (RGM) dry deposition estimated by Vette *et al*. (2002); note, however, that Vette and co-workers did not measure RGM but estimated it from

total gaseous Hg (TGM) concentration measurements. The differences between the amounts of Hg deposition simulated in this study with and without updated incinerator emissions indicate the contribution of waste incinerators to mercury deposition in Lake Michigan.

The simulated atmospheric loading of Hg to Lake Superior is shown in Table 5-2 along with estimates published by Rolfhus *et al*. (2003). The total deposition estimated in the current study is 905 kg/yr. This differs slightly from the estimate by Rolfhus and co-workers (740 kg/yr) who assumed a total (i.e. wet plus dry) flux of 9 $\mu g/m^2$-yr based on the work of Fitzgerald *et al*. (1991) at a site in northern Wisconsin. The estimated re-emissions from Lake Superior in this study are lower than the value suggested by Rolfhus and co-workers. Table 5-3 lists the estimated Hg deposition to Lake Ontario. The wet deposition of 258 kg/yr simulated by TEAM is higher than the value of 133 kg/yr estimated by the U.S. Environmental Protection Agency and Environment Canada (U.S. EPA and Environment Canada, 2002) in the 2002 Lakewide Management Plan (LaMP) report for Lake Ontario. The LaMP value is an approximate estimate based on deposition data at the two MDN stations nearest Lake Ontario. The atmospheric Hg deposition amounts to Lakes Huron and Erie simulated in the current study are shown in Tables 5-4 and 5-5. Also shown in Table 5-4 is the total deposition estimate of 500-5000 kg/yr presented at the State of the Lakes Ecosystem Conference (1994) as cited in the 2002 Lake Huron Initiative Action Plan by the Michigan Department of Environmental Quality. This is a rough approximation based on old or very limited data.

Table 5-2. Estimated atmospheric Hg deposition (kg/yr) to Lake Superior.

Type	This study (updated incinerator emissions)	Rolfhus et al. (2003)
Wet deposition	648	
Dry deposition of Hg(II)	152	
Dry deposition of Hg(p)	7	
Total deposition[(a)]	905	740
Re-emissions of Hg(0)	453	720

(a) Total deposition also includes dry deposition of Hg(0)

Table 5-3. Estimated atmospheric Hg deposition (kg/yr) to Lake Ontario.

Type	This study (updated incinerator emissions)	U.S. Environmental Protection Agency and Environment Canada (2002)
Wet deposition	258	133
Dry deposition of Hg(II)	102	
Dry deposition of Hg(p)	12	
Total deposition [(a)]	411	

(a) Total deposition also includes dry deposition of Hg(0)

Table 5-4. Estimated atmospheric Hg deposition (kg/yr) to Lake Huron.

Type	This study (updated incinerator emissions)	SOLEC (1994) as cited by Michigan Department of Environmental Quality (2002)
Wet deposition	717	
Dry deposition of Hg(II)	148	
Dry deposition of Hg(p)	6	
Total deposition	947 [(a)]	500 - 5000 [(b)]

(a) Total deposition also includes dry deposition of Hg(0)
(b) Rough approximation based on old or very limited data

Table 5-5. Estimated atmospheric Hg deposition (kg/yr) to Lake Erie.

Type	This study (updated incinerator emissions)
Wet deposition	373
Dry deposition of Hg(II)	132
Dry deposition of Hg(p)	9
Total deposition	556

(a) Total deposition also includes dry deposition of Hg(0)

5.2 Simulation with Updated Incinerator Emissions and Plume Mercury Reduction

An emission sensitivity simulation was conducted using updated waste incinerator emissions and alternative emissions speciation for all coal-fired power plants in the modeling domain. The latter was implemented to reflect 67% reduction of Hg(II) to Hg(0) in power plant plumes. Figure 5-2 illustrates the simulated dry, wet, and total (i.e., dry plus wet) mercury deposition fluxes over the central and eastern United States. The percent change in total mercury deposition between this simulation and the updated base case (described in section 5.1) is depicted in Figure 5-3. Incorporating the effect of plume mercury reduction decreases total (i.e. dry plus wet) deposition of mercury by less than 10% in most of Michigan. Most of the northeastern United States exhibit more than 10% decreases with large areas in Pennsylvania, Ohio and West Virginia experiencing deposition decreases between 20 and 59%.

5.3 Simulations with No Mercury Emissions from Michigan Coal-fired Power Plants

Two emission sensitivity simulations were conducted with zero mercury emissions from all coal-fired power plants in Michigan. In the first, the original emission speciation was used for all other coal-fired power plants in the modeling domain. The second simulation employed an alternative emissions speciation for those plants to reflect 67% reduction of Hg(II) to Hg(0) in the plumes from those stacks. Note that deposition impacts from the first simulation will be an overestimate because plume mercury reduction is not considered. Comparison of the results of the second simulation with the simulation discussed in section 5.2 provides an upper-bound estimate of the effect of Michigan power plants on mercury deposition in Michigan and the Great Lakes region.

5.3.1 Impact on the spatial distribution of mercury deposition

Figure 5-4 presents the simulated percent change in total (i.e. dry+wet) mercury deposition with zero mercury emissions from all coal-fired power plants in Michigan. The top and bottom portions of the figure illustrate upper-bound estimates on mercury deposition impacts in the absence and presence of plume mercury reduction respectively. Since plume mercury reduction from power plants has been measured in several experimental studies, as described in Section 4.3, the impacts shown in the top portion of the figure are not realistic estimates; they are presented only for comparison purposes and will not be discussed further.

The northern parts of Michigan experience less than 1% decrease in total deposition of mercury when Michigan coal-fired power plant emissions are set to zero. Most parts of central and southern Michigan exhibit less than 5% decreases in total deposition of mercury. Isolated areas near Detroit, southeastern Michigan and on the eastern shore of Lake Michigan show simulated impacts on mercury deposition between 10 and 24%. Regional models of the atmospheric fate and transport of mercury, such as the one used in this study, likely over-estimate local deposition of mercury in the model grid cell corresponding to the source since they assume the plumes from point sources are instantaneously diluted in a model grid cell resulting in higher deposition closer to the source. Hence, within these 20 by 20km grid cells with large emission sources, the results provided in this study should be considered an upper-bound estimate of the effect of Michigan power plants on mercury deposition in Michigan and the Great Lakes region. Elsewhere and over the state as a whole the model results are expected to be reasonable estimates of deposition.

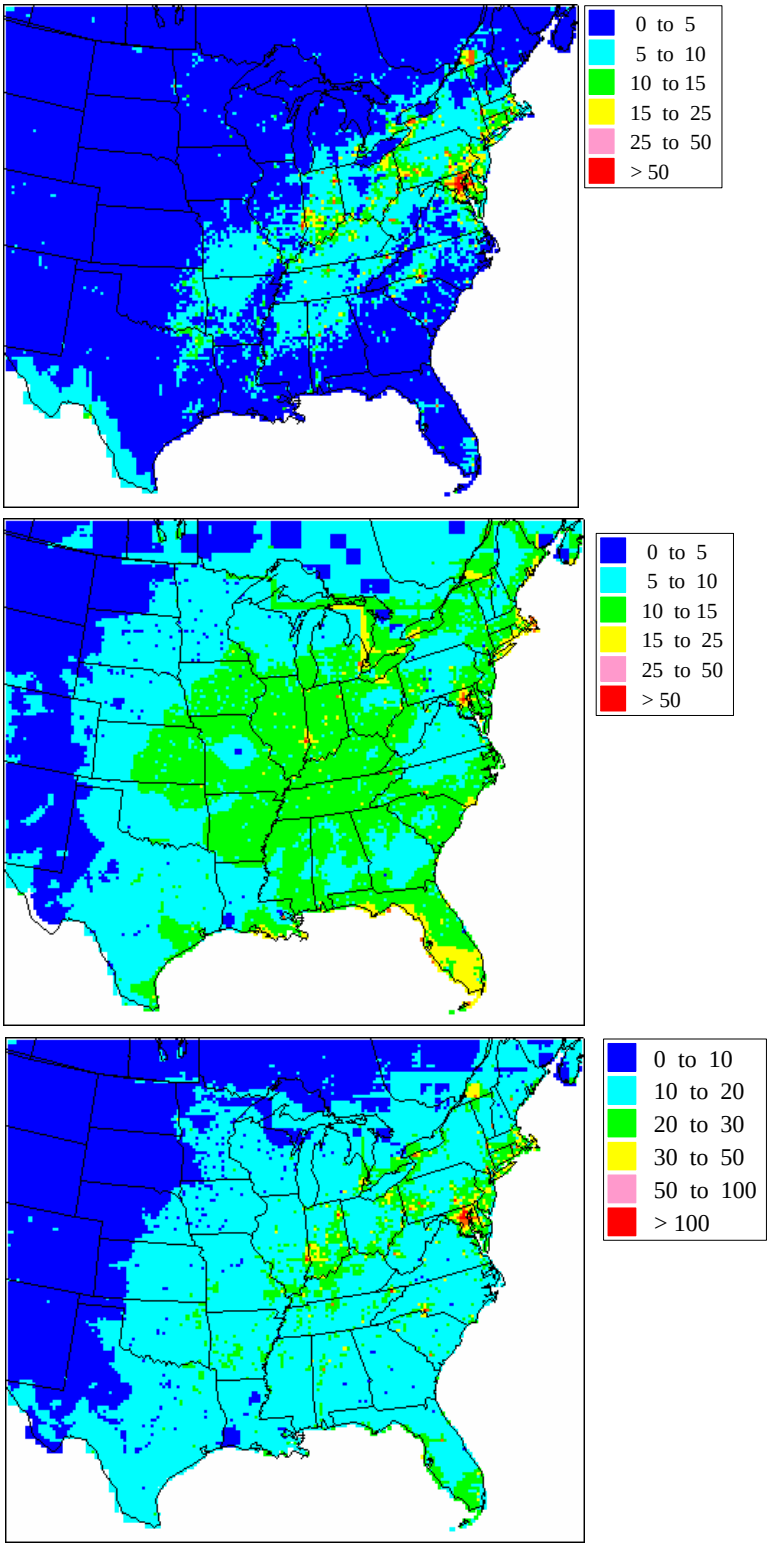

Figure 5-2. Simulated Hg dry deposition flux (μg/m^2-yr, top), wet deposition flux (μg/m^2-yr, middle), and total deposition flux (μg/m^2-yr, bottom) in the updated base case with plume Hg(II) reduction.

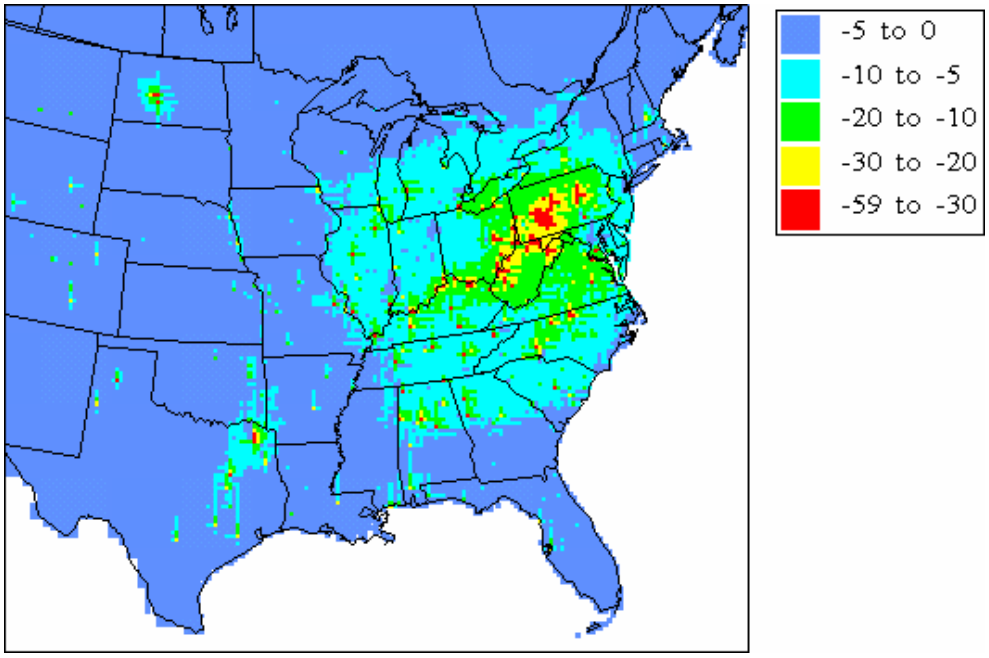

Figure 5-3. Percent change in total deposition flux of Hg between the updated base cases with and without plume Hg(II) reduction.

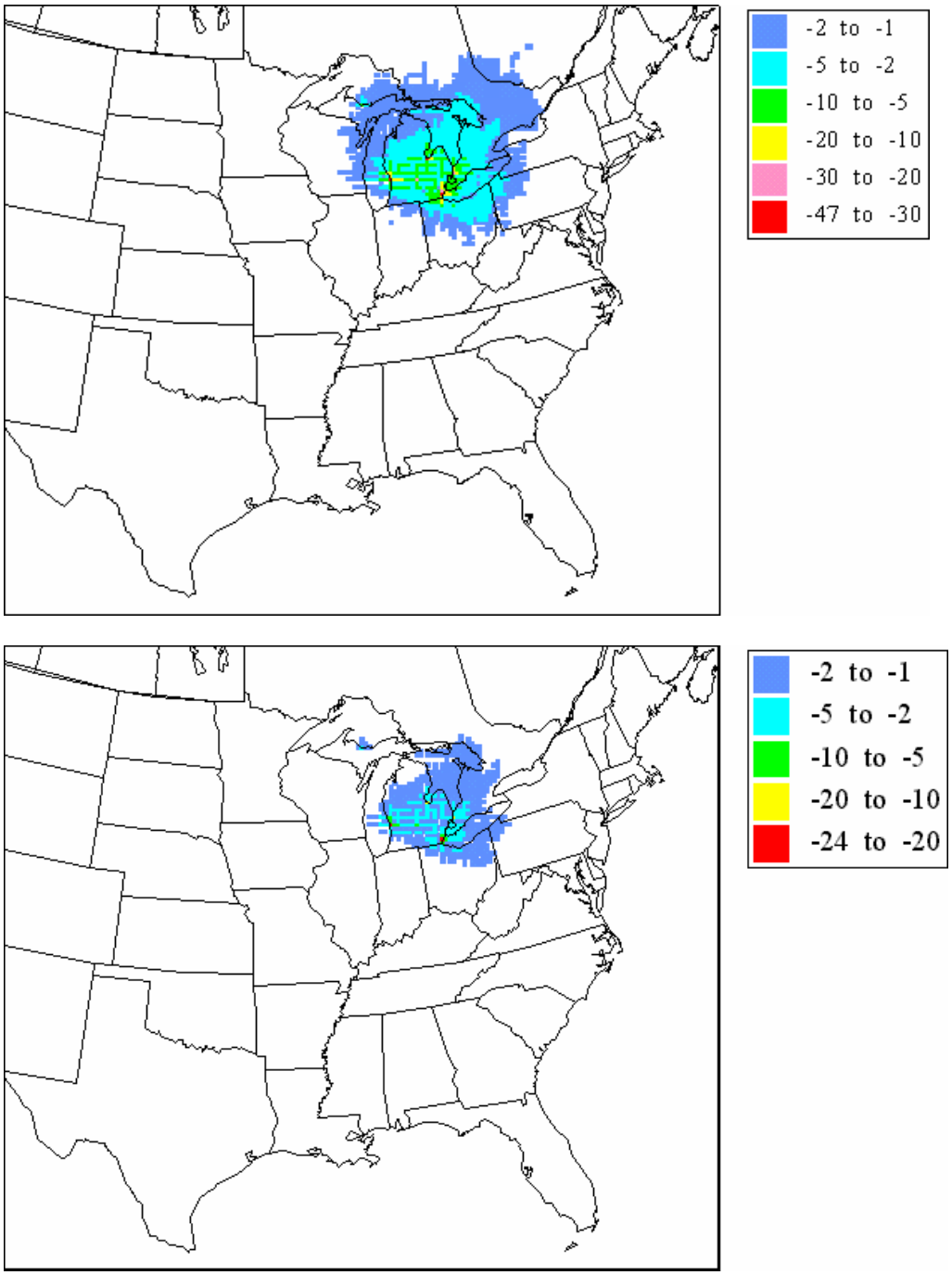

Figure 5-4. Percent change in Hg total deposition flux with zero mercury emissions from coal-fired power plants in Michigan while ignoring plume mercury reduction (top) and including plume mercury reduction (bottom) from other plants in the modeling domain. *(Note that regional Eulerian models, such as the one used in this study, overestimate mercury deposition in the immediate vicinity of large point sources due to instantaneous plume dilution)*

5.3.2 Impact on total mercury deposition over the Great Lakes

The results illustrated in the bottom half of Figure 5-4 indicate that zeroing out mercury emissions from coal-fired power plants in Michigan results in little or no impact on modeled mercury deposition fluxes in Lakes Superior and Ontario. Most parts of Lake Michigan experience negligible impact while a few areas exhibit less than 5% decrease in mercury deposition fluxes. The impact on deposition fluxes over Lake Huron is typically between 1 and 2% with a few isolated areas showing up to a 5% decrease. The majority of Lake Erie experiences decreases in deposition fluxes between 1 and 2% with some areas showing up to a 5% decrease and less than 3% of the lake experiencing between 5 and 10% impact. Table 5-6 presents a closer analysis of the estimated amounts of mercury deposited over each of the Great Lakes in the model simulations. Columns 4 and 5 show the atmospheric deposition of mercury over the lakes with and without mercury emissions from MI coal-fired electric utilities while including the effect of plume Hg reduction. Also shown for reference in columns 2 and 3 are similar values when plume Hg reduction is not considered. A comparison of columns 4 and 5 indicates that, on incorporating the effect of plume mercury reduction, mercury emissions from coal-fired power plants in Michigan contribute 0.5-1.5% to total mercury deposition over each of the Great Lakes.

Table 5-6. Estimated total atmospheric Hg deposition (kg/yr) to the Great Lakes in the modeling scenarios.

	Base Case	No Hg emissions from MI coal-fired power plants and ignoring plume Hg reduction for other power plants	Base Case including plume Hg reduction for all power plants	No Hg emissions from MI coal-fired power plants and including plume Hg reduction for other power plants
Lake Erie	556	538	490	483
Lake Huron	947	918	898	886
Lake Michigan	844	831	792	786
Lake Ontario	411	407	385	383
Lake Superior	905	897	892	886

5.3.3 Impact on total mercury deposition over Michigan

Table 5-7 presents the estimated total atmospheric mercury deposition over the state of Michigan in each of the modeling scenarios. Column 1 shows total mercury deposition over Michigan in the base case (with updated incinerator emissions) while ignoring the effect of plume mercury reduction. Column 2 lists the corresponding value when we zero out Michigan coal-fired power plant emissions while ignoring the effect of

plume mercury reduction from other power plants in the modeling domain. Column 3 presents the total deposition over Michigan in the modified base case wherein we incorporate the effect of plume mercury reduction in all coal-fired power plants in the domain. Column 4 has results from the scenario where we zero out mercury emissions from Michigan coal-fired power plants and incorporate the effect of Hg reduction in plumes from other plants in the domain. The simulations indicate that the total estimated mercury deposition over Michigan decreases from 3.95 to 3.85 Mg/yr (2.5% decrease) when we zero out Michigan coal-fired power plant emissions but ignore the effect of plume mercury reduction and from 3.82 to 3.77 Mg/yr (1.3% decrease) when we incorporate the effect of plume mercury reduction. Thus coal-fired power plants in Michigan are estimated to contribute between 1 and 3% to total mercury deposition within the state. More than 97% of mercury deposited in Michigan is a combination of deposition estimated due to emissions from: (a) non-power plant sources in Michigan, (b) mercury sources outside Michigan such as those in other states in the United States, in Canada and from the global background, and (c) natural sources in North America and elsewhere.

Table 5-7. Estimated total atmospheric Hg deposition (Mg/yr) over Michigan in the modeling scenarios

Base Case	No Hg emissions from MI coal-fired power plants and ignoring plume Hg reduction for other power plants	Base Case including plume Hg reduction for all power plants	No Hg emissions from MI coal-fired power plants and including plume Hg reduction for other power plants
3.95	3.85	3.82	3.77

6 CONCLUSION

TEAM was used to conduct several one-way nested grid simulations in which a fine grid with a horizontal resolution of 20 km was imbedded within the coarse 100 km resolution grid used in previous applications (Seigneur *et al*., 2004). Boundary conditions for the coarse grid were obtained from the results of a global mercury chemistry transport model. The coarse model grid covered North America while the high-resolution (20 km) fine grid covered the central and eastern United States including the Great Lakes region and adjoining parts of Canada. Meteorology for 1998 was used for the simulations. Utility emissions were based on data on mercury coal content collected at all coal-fired power plants and stack measurements of speciated mercury conducted at over eighty power plants as part of the U.S. Environmental Protection Agency (EPA) Information Collection Request in 1999. The spatial distributions of simulated dry, wet, and total Hg deposition fluxes were analyzed and a comparison made of model results with observations for the base case. Overall, model performance was considered satisfactory for wet deposition fluxes at MDN sites and atmospheric mercury concentrations at various locations in the United States and Canada.

Results from several recent experimental studies suggest that there is some reduction of Hg(II) to Hg(0) in coal-fired power plant plumes that is not currently simulated in mercury models. The effect of this plume reduction was approximated in this study by modifying the mercury emissions speciation from coal-fired power plants such that Hg(II) emissions were decreased by 67% and Hg(0) emissions increased accordingly. Use of this alternative emission speciation improved model performance. The coefficient of determination (r^2) improved from 0.55 to 0.57, error decreased from 26% to 24%, and the bias decreased from 12% to 8%.

An updated base case simulation was conducted after modifying the emission inventory for municipal and medical waste incinerators to reflect the implementation of MACT. Actual stack test data for 2003 from the Michigan Department of Environmental Quality (MDEQ) was used for the Detroit municipal incinerator (Greater Detroit Resource Recovery Facility). Data from the 1999 National Emission Inventory (U.S. EPA, 2003) were used for mercury emissions from other incinerators in the country. Significant decreases in simulated dry deposition (up to 25 $\mu g/m^2$-yr) occurred in Maryland, New Jersey and Massachusetts due to MACT implementation on incinerators. At the location of the Detroit municipal incinerator, the simulated dry deposition flux decreased from about 25 to 15 $\mu g/m^2$-yr.

TEAM was also used to determine the atmospheric wet, dry, and total (i.e., wet plus dry) deposition of Hg to the five Great Lakes. Wet deposition, Hg(II) dry deposition and total deposition estimates are comparable between the current study with the 1998 inventory (before MACT implementation on waste incinerators) and that of Landis and Keeler from the Lake Michigan Mass Balance Study in 1994-95. Re-emissions of Hg(0) are also similar between this study and that of Landis and Keeler. Some differences in deposition estimates over the Great Lakes between this study and others in the literature

are believed to be due to differences in the modeling time period and the methodology used to estimate total deposition over the lake.

An emission sensitivity simulation was conducted using updated waste incinerator emissions and alternative emissions speciation for all coal-fired power plants in the modeling domain. Two additional emission sensitivity simulations were conducted with no mercury emissions from all coal-fired power plants in Michigan. In the first, the original emission speciation was used for all other coal-fired power plants in the modeling domain. The second simulation employed an alternative emissions speciation for those plants to reflect 67% reduction of Hg(II) to Hg(0) in the plumes from those utilities. Deposition impacts from the first simulation will be an overestimate because observed plume mercury reduction is not included; hence, the second simulation was used to provide an upper-bound estimate of the contribution of Michigan power plants to mercury deposition in Michigan and the Great Lakes region.

Mercury emissions from Michigan coal-fired power plants contribute less than 2% to mercury deposition fluxes in northern Michigan and less than 5% to deposition fluxes in central and southern Michigan. Isolated areas near Detroit, southeastern Michigan and on the eastern shore of Lake Michigan that comprise less than 3% of the state's land mass and are near major emission sources show simulated contributions to mercury deposition fluxes that are between 10 and 24%. However, the 3-D Eulerian model employed in this study likely overestimates mercury deposition in the immediate vicinity of large point sources due to the fact that the plumes are assumed to be diluted immediately within the model grid cell.

Mercury emissions from Michigan coal-fired power plants are calculated to contribute between 0.5 and 1.5% to total mercury deposition over each of the Great Lakes and about 2% statewide.

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