Northeast States for Coordinated Air Use Management

MERCURY EMISSIONS FROM COAL-FIRED POWER PLANTS

The Case for Regulatory Action

NESCAUM
Northeast States for Coordinated Air Use Management

October 2003

Northeast States for Coordinated Air Use Management
101 Merrimac Street
Boston, Massachusetts 02114
Phone: (617) 367-8540
http://www.nescaum.org

Founded in 1967, NESCAUM is a non-profit association of the state air quality divisions of the state departments of environmental protection of Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont. NESCAUM provides scientific, technical, and policy support to its member states in developing regionally consistent and cost-effective strategies to achieve clean air goals.

Project Manager
Praveen Amar, Ph.D., P.E.
Director, Science and Policy

Contents

Executive Summary

Mercury is a potent neurotoxin, particularly damaging to the development of the fetus, infant and young child. Coal-burning power plants are the largest source of mercury emissions related to human activity in the U.S. In December 2003, the Environmental Protection Agency (EPA) will issue a proposed regulation to control mercury emissions from these sources. Our ability to adequately protect the public from the adverse health effects associated with exposure to mercury is closely tied to the effectiveness and the stringency of this rule.

The EPA, Centers for Disease Control and Prevention, National Research Council of the National Academies of Sciences, and World Health Organization all agree that mercury exposure can present an unacceptable public health risk to some segments of the population. A survey conducted by the Centers for Disease Control and Prevention and published in early 2003 found that one in 12 (eight percent) American women of childbearing age had mercury in their blood above the levels considered safe by EPA. This could result in as many as 4.7 million women of childbearing age with elevated levels of mercury, and put approximately 322,000 newborns at risk for neurological deficits each year. Recent studies also suggest that mercury exposure can lead to adverse cardiovascular effects in adults. Further, mercury has a deleterious effect on fish-eating wildlife.

Exposure to methylmercury, the most toxic form of mercury to which humans and wildlife are regularly exposed, comes primarily from the consumption of contaminated fish and shellfish. Releases of mercury to the environment have contaminated fresh and saltwater fisheries to such an extent that forty-five states and one U.S. territory have issued advisories warning of the dangers of eating fish with elevated concentrations of mercury. Limiting fish intake due to concerns about mercury contamination also reduces the dietary benefits associated with fish consumption.

Mercury in the atmosphere comes from both human (or anthropogenic) and natural (e.g., volcanic activity) sources, with anthropogenic emissions far exceeding those from natural sources. In the U.S., coal-fired power plants are the largest unregulated source of mercury emissions and are responsible for approximately 40 percent of the country's industrial emissions. In part because other large domestic sources of mercury emissions such as municipal waste combustors are already subject to federal and more stringent state regulations, the proportion of U.S. mercury emissions attributable to coal-burning power plants is increasing. Moreover, mercury emissions from coal-fired power plants are expected to increase based on projections of energy production and coal use, absent any state and federal actions to require mercury emission reductions.

While the specific percentage of U.S. mercury deposition attributable to domestic sources varies regionally and is the subject of scientific uncertainty, EPA estimates that roughly two-thirds of all mercury deposited in the U.S. comes from domestic sources and that U.S. power plants account for about one-third of the mercury deposited in the country. Recent field studies suggest that reducing mercury emissions translates to measurable decreases in mercury deposition and subsequent reductions in fish mercury concentrations. Given the global nature of the problem, a significant reduction in U.S. power sector mercury emissions will be insufficient by itself to adequately address mercury contamination of fish and the resulting adverse health impacts. However, controlling mercury emissions from power plants represents a critical component of a comprehensive approach to minimizing the public health threat from this toxic pollutant.

Several states have already begun to address this problem by adopting stringent limitations on mercury emissions from new and existing power plants. These regulations and permits are based on an assessment of the feasibility of various control technologies. After a decade's delay, EPA is now required by a court-approved settlement agreement to issue proposed regulations limiting the mercury emissions of power plants on a national basis by December 2003 and final regulations by December 2004. Although the Clean Air Act would typically require compliance within three years of promulgation, that is, by December 2007, the Administration has already indicated that it may consider a one-year extension.

Among other things, the Clean Air Act requires that EPA establish a "MACT (Maximum Achievable Control Technology) floor" for existing sources. The MACT floor cannot be less stringent than the average emission limitation achieved by the best performing 12 percent of the existing sources for which EPA has emissions information and represents the minimum level of control required at a facility. If the coal-fired utility boilers for which EPA has data are ranked with reference to their percentage mercury reduction as measured from the mercury content of the coal they burn, the average of the top 12 percent is a 91 percent reduction. EPA has some discretion to adjust the average of the top 12 percent by subcategorizing coal-fired utility boilers based on class, type, or size of these units. A 91 percent reduction of the mercury contained in the combusted coal would result in annual mercury emissions from coal-fired power plants of approximately 7 tons (as compared to the current emissions of 48 tons from the industry). To put this in context, the stakeholder groups that participated in EPA's Utility MACT Working Group have recommended a range of standards that equate to annual national emissions from coal-fired utility boilers of between 2 and 28 tons.

While some utility company representatives argue that mercury reduction at the lower end of this range is unachievable, the existing data contradict these claims. There is increasing evidence, with regard to all coal types, that existing control devices designed to reduce other pollutants can deliver substantial mercury reductions (so-called "co-benefits"). For example, even without efforts at optimizing non-mercury control systems, some plants burning bituminous coal have obtained mercury reduction co-benefits of 95 percent; for subbituminous coal, co-benefits of over 70 percent have been documented using these

non-mercury controls. At present, co-benefits alone will allow some but not all plants to meet a stringent mercury standard.

Control technologies specific for reducing mercury emissions are also well on their way to commercial availability. For example, activated carbon injection technology is being successfully demonstrated in both pilot and full-scale applications. The results indicate that mercury control efficiency of over 90 percent is feasible for power plants, with costs that are comparable to the costs of NOx removal required under the federal program to achieve national ambient air quality standards for ozone.

While there are relevant differences between municipal waste combustors and power plants, most municipal waste combustors have reduced their mercury emissions by more than 90 percent through the application of activated carbon injection technology in the wake of federal and much more stringent state emission control requirements. Many municipal waste facilities that are also equipped with baghouses are achieving reductions of over 98 percent. Even when these differences are taken into account, the application of the activated carbon technology to coal-fired boilers appears to be simply a matter of traditional technology transfer to larger coal-fired boilers, which does not depend upon any new technology breakthrough.

A September 2000 report by the Northeast States for Coordinated Air Use Management (NESCAUM) documented the technology-forcing effects of environmental regulatory requirements and concluded that regulations with well defined targets and deadlines drive innovation in control technology, resulting in dramatically lower implementation costs than initially projected.

Given the current promising state of technology development for mercury-specific controls within this historical context, there is considerable reason for confidence that power plants will be able to comply with a stringent MACT standard for mercury in a timely and cost-effective manner. The existence of stringent state mercury standards for power plants raises a serious question as to how a less stringent federal standard for these sources could be justified.

Chapter 1
Human Health and Wildlife Impacts of Mercury Exposure

Human Health

The general population is exposed to various forms of mercury through inhalation, consumption of contaminated food or water, and exposure to substances containing mercury, such as pesticides. Different chemical types of mercury can adversely affect several organ systems, with the severity of effects depending largely on the magnitude and timing of the exposure (i.e., during fetal development or as a child or adult).[1] Outside of occupational settings, methylmercury is the most toxic form of mercury to which humans are regularly exposed and this form of mercury is the focus of the health impacts discussed in this chapter. Exposure to methylmercury in the U.S. comes primarily from the consumption of fish and shellfish.

There are extensive data that provide evidence of the adverse effects of methylmercury on the development of the brain (neurodevelopmental effects) in humans and animals. The most severe effects reported in humans followed high-dose poisoning episodes in Iraq and Japan. Children exposed to methylmercury in utero suffered various adverse effects including: mental retardation, cerebral palsy, deafness, blindness and dysarthria (a speech disorder that is due to a weakness or lack of coordination of the speech muscles). Sensory and motor impairment were also documented in adults.

Methylmercury Bioaccumulation

After mercury is deposited from the atmosphere, its greatest adverse impact occurs in the aquatic ecosystem.[a] In a series of chemical reactions, mercury can be converted by bacteria in the sediments to methylmercury, a form that is especially toxic to humans and wildlife. Fish absorb methylmercury from the water as it passes over their gills and as they feed on other organisms. As larger fish eat smaller ones, methylmercury concentrations increase in the bigger fish, a process known as bioaccumulation. Consequently, larger predator fish usually have higher concentrations of methylmercury from eating contaminated prey. Humans, birds and other wildlife that eat fish are exposed to methylmercury in this way.

[a] U.S. EPA, 1997b. Mercury Study Report to Congress, Volume III: Fate and Transport of Mercury in the Environment. EPA-452/R-97-005.

Poisoning episodes like those in Iraq and Japan are rare. In contrast, chronic low-dose methylmercury exposure from maternal consumption of fish is common and has been associated with subtle neurodevelopmental effects in children. The EPA, the Centers for Disease Control and Prevention, the National Research Council of the National Academies of Sciences, and the World Health Organization have all determined that potentially significant public health risks exist from widespread exposure to methylmercury in utero due to consumption of contaminated fish and shellfish. The available science also indicates that adverse health effects associated with methylmercury exposure may not be reversible, increasing the significance of the potential health risks.[2]

The adverse effects of methylmercury exposure have been studied in three large investigations in the Faroe Islands, the Seychelles Islands and New Zealand, as well as in other smaller studies in French Guiana and the Amazon. These studies looked at a wide range of effects, including age at achievement of development milestones, infant and preschool development, sensory and fine motor function and other endpoints in children. In the Faroe Islands and New Zealand studies, children exposed to methylmercury in utero appeared entirely normal during infancy, but later displayed neurological deficits when tested. These included poor performance on neurobehavioral tests, particularly on tests of attention, fine motor function, language, visual-spatial abilities (e.g., drawing), and memory. The findings of the Seychelles Island study conflict with the Faroe Island and New Zealand studies in that they do not show adverse neurodevelopment effects in children.

In 2000, Congress requested that the National Research Council of the National Academies of Sciences provide an independent scientific review of all of the available scientific data on human exposure to mercury. Ultimately, the National Research Council's review of all of the scientific data led to the conclusion that the positive findings of the Faroe Island study provide the most appropriate public health basis for developing the health guideline value for EPA.[3] This guideline value is used for a number of risk management decisions and regulatory policies including assessment of low-dose chronic exposure from consumption of mercury-contaminated fish and seafood. The NRC also concluded that neurobehavioral deficits of the magnitude reported in the Faroe Islands and New Zealand are likely to be associated with increases in the number of children who have to struggle to keep up in a standard classroom or who may require remedial classes or special education.[4]

Women of childbearing age (i.e., 15 to 44 years of age) and pregnant women are of special concern in terms of methylmercury exposure.[5] Methylmercury exposure prior to pregnancy can actually place the developing fetus at risk because methylmercury persists in body tissue and is only slowly excreted from the body. As a result, and in light of the fact that women often do not know they are pregnant until the pregnancy is past many of the critical stages of fetal development (e.g., six weeks), the fetus may be exposed to methylmercury concentrations of concern as a result of maternal exposure prior to pregnancy.

Infants may ingest methylmercury from breast milk and children are exposed through their diet. Children and infants are more sensitive than adults to the effects of methylmercury because their nervous systems continue to develop until about age 14. Children are also at greater risk than adults because they eat more food than adults relative to body weight. As a result, children face a higher risk of adverse health effects.[6]

There is also evidence that exposure to methylmercury can have adverse effects on the developing and adult cardiovascular system, blood pressure regulation, heart-rate variability, and may contribute to heart disease.[7] The effect of methylmercury on the immune system is poorly understood; however, laboratory and animal studies suggest that methylmercury exposure may increase human susceptibility to infectious disease and autoimmune disorders by damaging the immune system.[8]

Government Standards and Guidance for Methylmercury Exposure

In light of the human health risks associated with exposure to methylmercury, several government and international health agencies have developed health standards for methylmercury exposure. These standards are utilized in risk assessment, regulatory development and in issuing fish advisories. There is substantial agreement among these agencies on the level of methylmercury exposure that causes adverse effects, with the critical debate relating to how to characterize and quantify uncertainties. As a result of the use of different uncertainty factors (to provide the population with an ample margin of safety), agencies have arrived at a range of health standards, as shown in Table 1.1.

Table 1.1 Methylmercury Health Standards

Population Group	Highest acceptable level of mercury in maternal hair (parts per million)	Uncertainty Factor	Amount of methylmercury that can safely be consumed every day over a lifetime without effect
Women of Reproductive Age, Pregnant Women and Children			
U.S. EPA Reference Dose (RfD)	12	10	0.1 µg/kg/d[a]
ATSDR Minimal Risk Level (MRL)	15.3	4.5	0.3 µg/kg/d[b]
Canada Provisional Tolerable Daily Intake (pTDI)	10	5	0.2 µg/kg/d[c]
Joint FAO/WHO Expert Committee on Food Additives	14	6.4	0.23 µg/kg/d[d]
Adults			
FDA TDI	NA	NA	0.47 µg/kg/d[e]

[a]Based on Faroe Islands study to protect fetal brain development.
[b]Based on no observed effects in Seychelles study of infants up to 66 months of age.
[c]Based on no effect level in maternal hair from Iraq, New Zealand, Seychelles and Faroe Islands studies.
[d]Based on no effect level in umbilical cord blood and maternal hair from Iraq, New Zealand, Seychelles and Faroe Islands studies.
[e]Based on tolerable daily intake with a reasonable certainty of no harm to adults.

Fish Consumption Advisories

Widespread methylmercury contamination, primarily as a result the deposition of mercury from the atmosphere, has resulted in elevated levels of mercury in fish. In fact, methylmercury contamination of fish is so pervasive in the U.S. that health departments in 45 states and American Samoa have issued freshwater fish consumption advisories.[a] A consumption advisory may include recommendations to limit or avoid eating certain fish species caught from specific water bodies. In most cases, sensitive individuals – which may include pregnant women, nursing women, women of child-bearing age, children (typically under age 14) and consumers of large quantities of fish – are specifically targeted by the advisories. Eleven states have consumption advisories for every inland water body for at least one fish species; 10 states have consumption advisories for canned tuna; and eight southern states have statewide coastal marine advisories for king mackerel. Limitations on fish intake have public health impacts of their own, in light of the fact that fish is in most respects a healthful food source.

The amount of methylmercury in different fish varies considerably. High intake of methylmercury can occur from frequent consumption of fish with relatively low methylmercury levels, and/or infrequent consumption of fish species with high levels of methylmercury.[b]

EPA has issued a fish consumption advisory for women who are pregnant or may become pregnant, nursing mothers and young children. These populations are advised to limit consumption of fish from non-commercial sources to one meal per week. Consumers are also advised to check with their state and local health department for local information.

The Food and Drug Administration (FDA) does not have jurisdiction over freshwater bodies within state borders and its advisories are therefore limited to marine species. The FDA has issued a consumer advisory for pregnant women, women of childbearing age, nursing mothers and young children. These groups are advised not to eat swordfish, tilefish, shark and king mackerel because of high methylmercury levels.[c] In July 2002, an independent committee of food safety advisors convened by the FDA recommended that consumption advisories be issued for canned tuna, but the Agency has not yet acted on the recommendation.[d]

Health Canada and the British Food Standards Agency have also provided guidance to consumers about mercury exposure from fish consumption. Health Canada advises consumers to limit their consumption of swordfish, shark and fresh and frozen tuna to one meal per week. For young children and women of childbearing age, the recommended limit for swordfish, shark and fresh or frozen tuna is one meal per month. The advisory does not apply to canned tuna.[e] The British Food Standards Agency advises pregnant and breastfeeding women and women who intend to become pregnant to limit their consumption of tuna to no more than two medium-sized cans or one fresh tuna steak per week. These women are also advised to avoid eating shark, swordfish and marlin. Infants and children under 16 are advised to avoid eating shark, swordfish and marlin.[f]

[a] U.S. EPA. Fish Advisories Website. http://www.epa.gov/ost/fish

[b] U.S. EPA. An Assessment of Exposure to Mercury in the United States. Volume IV of Mercury Study Report to Congress. 1997e. (EPA-452/R-97-006).

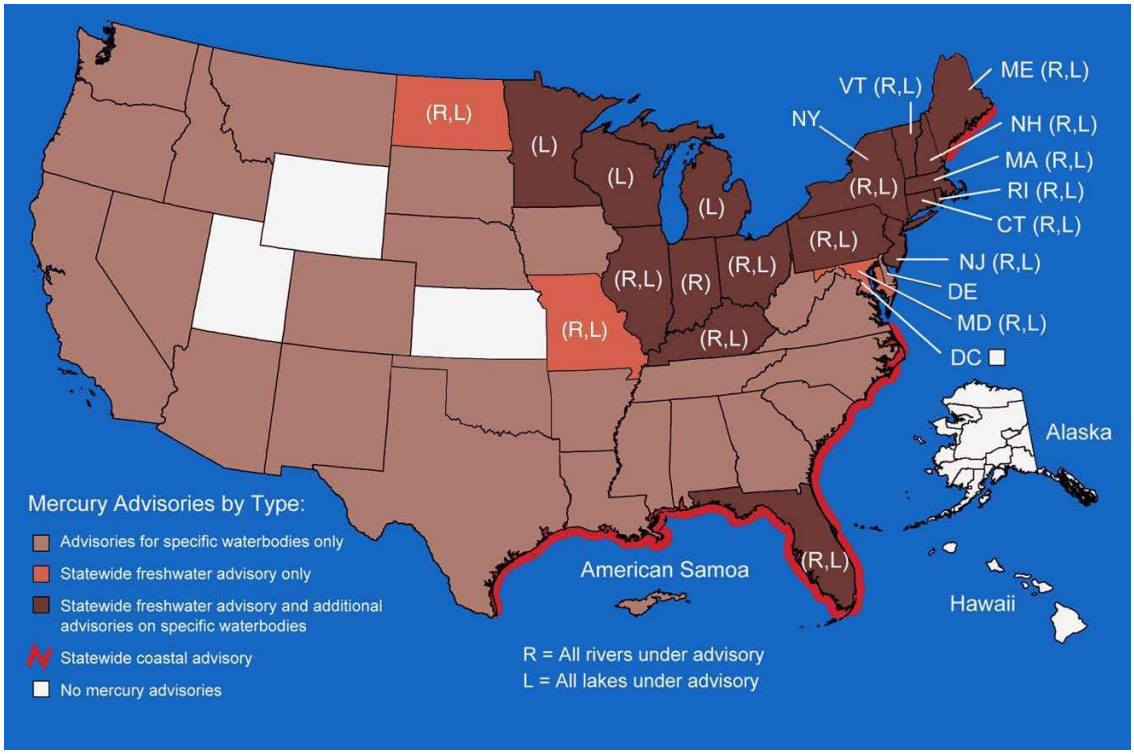
[c] FDA Consumer Advisory for Pregnant Women and Women of Child-bearing Age who may become Pregnant about the Risks of Mercury in Fish. March 2001. http://vm.cfsan.fda.gov/~dms/admehg.html

[d] Mercury Policy Project, 2003. Can the Tuna. http://www.mercurypolicy.org

[e] Canada Food Inspection Fact Sheet. http://www.inspection.gc.ca/english/corpaffr/foodfacts/mercurye.shtml

[f] Food Standards Agency. Agency updates advice to pregnant and breastfeeding women on eating certain fish. February 17, 2003. http://www.foodstandards.gov.uk/news/pressreleases/tuna_mercury

Figure 1.1 Mercury Fish Advisories in the U.S. (2002)



Source: U.S. EPA. Fish Advisories Website. http://www.epa.gov/ost/fish

EPA uses a reference dose (RfD) to assess the risk of methylmercury exposure. An RfD is a dose that can be ingested daily over a lifetime without harmful health effects. In 1997, EPA issued an RfD of 0.1 micrograms of methylmercury per kilogram of body weight per day, or 0.1 μg/kg/day, based on the data collected in Iraq. In 2000, a National Research Council committee, part of the National Academies of Sciences, reviewed all of the available scientific data on human exposure to methylmercury and concluded that EPA's RfD was scientifically justified.[9,10]

The Agency for Toxic Substances and Disease Registry (ATSDR, part of the Centers for Disease Control and Prevention) specifies a different risk level from EPA's RfD. The ATSDR's Minimal Risk Level (MRL) is 0.3 μg/kg/day, or three times less stringent than EPA's. As shown in Table 1.1, the MRL and RfD are in substantial agreement on the level of mercury in maternal hair that causes harm. The principal difference between the two is the application of uncertainty factors. The ATSDR calculated an uncertainty factor of 4.5, compared to the uncertainty factor of 10 used by the EPA. Importantly, the ATSDR, the MRL is not to be used as guidance for developing fish advisories, but rather to define substance-specific levels that pose minimal risk to public health at Superfund sites.[11]

The Food and Drug Administration (FDA) has established an "action level" of 1.0 part per million (ppm) for fish and shellfish sold in interstate commerce. Fish and shellfish with methylmercury concentrations above this limit are not to be sold. The action level was originally established in 1969 at 0.5 ppm. It was increased to 1.0 ppm in 1979 as the result of litigation brought by commercial fishing interests, which argued successfully that the action level should take into account the economic impacts of complying with the standard.[12] The action level takes into consideration the Tolerable Daily Intake (TDI) for methylmercury, which is analogous to EPA's RfD (i.e., the amount of methylmercury that can be consumed daily over a lifetime without harm). The FDA's TDI of 0.47 μg/kg/day is nearly five times less stringent than EPA's RfD and is higher than all other federal and international guidelines, as shown in Table 1.1. The TDI was calculated from data developed, in part, from studies of Japanese adults poisoned by contaminated fish.[13] Health Canada's TDI of 0.2 μg/kg/day is based on several different studies of poisoning episodes and low-level exposures.[14]

In June 2003, a joint panel of the United Nations' Food and Agriculture Organization and the World Health Organization halved the international standard for methylmercury consumption from 0.46 μg/kg/day to 0.23 μg/kg/day.[15] The key difference between the new international standard and EPA's RfD is, again, not the level of methylmercury that causes adverse effects. Rather, in calculating the margin of safety, EPA uses an uncertainty factor of 10, as compared to the World Health Organization's use of 6.4 as an uncertainty factor.

Methylmercury Exposure in the U.S.

Given the effects of methylmercury on fetal and child development, it is important to assess the amount of methylmercury to which the U.S. population is exposed. One approach for estimating methylmercury exposure from fish consumption is by combining fish consumption rates in the U.S. population with species-specific concentrations of methylmercury measured in fish. Using this approach in the 1997 *Mercury Study Report to Congress*, EPA estimated that 7 percent of women of childbearing age exceed the RfD primarily from seafood consumption.[16] Mercury exposure estimates for some groups that regularly consume freshwater fish has also been estimated to be in the range of mercury dosages that may cause adverse health effects. For example, a study conducted in the Northeast concluded that frequent ingestion (i.e., weekly) by a pregnant woman of eight ounces or less of freshwater fish containing methylmercury levels of 0.3 to 1.0 ppm (or more) can produce blood and hair levels in the range estimated to be of concern for some individuals.[17]

Another approach for estimating exposure to methylmercury is by sampling human blood and hair. In the first study of this kind (the 1999-2000 National Health and Nutrition Examination Survey (NHANES), the Centers for Disease Control and Prevention performed household interviews, physical examinations and blood mercury assessments on 705 children and 1,709 women. The survey revealed that one in 12 women of childbearing age (eight percent) tested above EPA's safe RfD.[18] This translates nationally to 4.7 million women of childbearing age with elevated levels of mercury and

approximately 322,000 newborns who are at risk of neurological effects from being exposed in utero to methylmercury. Blood mercury levels were four times higher in women who had eaten fish three or more times within the last 30 days, compared with women who ate no fish during that period.

Since the NHANES is designed to collect information on the general population, these findings are directly applicable only to those who eat average amounts of fish. Thus, subsistence and professional fishermen, certain ethnic groups like Asian Americans, and some sport anglers who eat more fish than the average American are likely to have even higher exposure than the individuals surveyed in the NHANES.

Other studies raise even more serious concerns. In New Jersey, a study of pregnant women found 13 percent with hair mercury concentrations greater than EPA's RfD.[19] In Arkansas, 236 individuals were screened to evaluate blood mercury levels in people who ate fish caught from mercury contaminated waters. The average blood mercury level of this group was higher than the EPA RfD.[20] A one-year survey of an internal medicine practice in San Francisco found 89 percent of patients with diets high in fish had blood mercury levels above the EPA RfD.[21]

Wildlife Impacts

Studies of the environmental, as opposed to public health, effects of mercury have focused almost exclusively on wildlife impacts. In the same way that humans who eat fish assume the largest risk from mercury exposure, fish-eating birds and mammals at the top of the food web are at risk from consuming elevated concentrations of mercury. As with humans, the young and unborn are much more sensitive than adults, and low-level dietary exposures that have no apparent impact on adults can severely impair the survival of the young.[22]

In its 1997 *Mercury Study Report to Congress*, EPA attempted to assess the impacts of airborne mercury on wildlife.[23] In doing so, it focused on the effects of mercury on entire wildlife populations or species, on a nationwide basis. Although a population-focus is the accepted approach to wildlife and ecological risk assessment, EPA itself raised the question as to whether national assessments allow for useful conclusions. As to species-wide impacts, EPA concluded that field data are insufficient to reach a conclusion that entire wildlife populations are at risk except, possibly, for the Florida panther. However, while EPA concluded that entire species of highly exposed fish-eating animals (e.g., kingfishers, bald eagles) are not at risk, individual animals have suffered toxic effects from the consumption of mercury-contaminated fish and certain subpopulations may be at risk.

Since the *Mercury Study Report to Congress* was published, a number of studies have emerged that describe regional and local impacts of fish mercury contamination on various species that depend on a fish diet. While these studies do not necessarily signal the decline of entire species, they do illustrate the adverse impact on wildlife of mercury contamination in different regions of the U.S.

For a number of practical reasons, the common loon has emerged as a species on which investigation of mercury exposures has focused.[24] Compared to other species, loons are relatively easy to study since they are territorial, long-lived (up to 30 years), and consume large amounts of fish. When fish consumption is expressed as a percentage of body mass, the rate of fish consumption of a common loon exceeds that of a human by a factor of 100.[25] Research on loons is valuable not only for its own sake, but also because it may be possible to use the loon as an indicator species, thus signaling where there may be impacts on other species with high fish diets.[26]

A study of common loons in Minnesota, Wisconsin and Michigan found that chicks had elevated concentrations of mercury in their blood if they were reared on acidic lakes containing prey fish with higher mercury levels compared to nearby, less acidic lakes.[27] Loons in north-central Wisconsin had the highest average blood mercury concentrations – concentrations capable of impairing the survivability of young loons.[28] Also in Wisconsin, loon chick production showed a decline in lakes where the mercury content of chick blood was elevated.[29]

While significantly more field research has been conducted on loons, the results may be relevant to understanding the impacts of methylmercury consumption on other birds whose fish diet also places them at high risk for mercury exposure. Most notable of these are merganser ducks, osprey, eagles, herons and kingfishers.[30]

Mammals whose diets contain large quantities of mercury-contaminated fish also have high levels of mercury in their fur, brains, livers and kidneys. Mercury has been found in the highest concentrations in fish-eating mink and otter.[31,32] In areas where mercury deposition levels are high there is some evidence of reduced survivorship in otters.[33]

Relatively little is known about the health impacts of methylmercury on fish populations. Fish embryos experience toxic effects at mercury levels that are much lower than (perhaps as low as one to 10 percent of) levels required to cause similar effects in adults.[34] Lower hatching success and reduced survival of embryos were associated with high methylmercury concentrations in walleye eggs from two northern Wisconsin lakes. Because walleyes in at least eight other acidified Wisconsin lakes have higher methylmercury loads than those in the two lakes studied, it is possible that the impact on fish reproduction may be more widespread.[35]

Conclusions

Human exposure to methylmercury results mainly from the consumption of fish and shellfish. Chronic low-dose methylmercury exposure from maternal consumption of fish is common and has been associated with neurodevelopmental effects in children. Infants may also ingest methylmercury from breast milk; children, whose nervous systems continue to develop until about age 14, are exposed through their diet. Additionally, there is evidence that exposure to methylmercury can adversely affect the developing and adult cardiovascular system and may contribute to heart disease in adults. Methylmercury contamination of fish is so pervasive in the U.S. that health departments in 45 states and

American Samoa have issued fish consumption advisories. Limitations on fish intake pose public health impacts of their own, in light of the beneficial role of fish intake in a healthy diet.

Different government and international health agencies have developed health standards for methylmercury exposure. Significantly, there is substantial agreement among these agencies on the level of methylmercury exposure that causes adverse effects. To the extent that the standards diverge, it is largely a consequence of scientific debate as to how to quantify uncertainties. A national survey conducted by the Centers for Disease Control and Prevention found that one in 12, or eight percent, of American women of childbearing age had amounts of mercury in their blood above the levels that EPA considers safe. A number of other studies in the U.S. document even higher exposures.

Studies of the environmental effects of airborne mercury have focused almost exclusively on wildlife impacts. Although the studies do not generally signal the decline of entire species, they do illustrate the adverse impact on wildlife of mercury contamination in different regions of the U.S. For example, loon chick production in Wisconsin has shown a decline on lakes where the methylmercury content of chick blood was elevated. There is also evidence of reduced survivorship in otters in areas where mercury deposition levels are high.

Endnotes

[1] U.S. EPA. Health Effects of Mercury and Mercury Compounds. Volume V of Mercury Study Report to Congress. 1997f, (EPA-452/R-97-007).

[2] Brown, D. and M. Tatsutani. Northeast States and Eastern Canadian Provinces Mercury Study: A Framework for Action. Chapter III: Health Effects of Mercury and Strategies to Protect Public Health. February 1998.

[3] Committee on the Toxicological Effects of Methylmercury. Board on Environmental Studies and Toxicology. Commission on Life Sciences. National Research Council. Toxicological Effects of Methylmercury, 2000. National Academy Press. Online. Available: http://www.nap.edu/books/0309071402/html/

[4] Committee on the Toxicological Effects of Methylmercury. Board on Environmental Studies and Toxicology. Commission on Life Sciences. National Research Council. Toxicological Effects of Methylmercury, 2000. National Academy Press. Online. Available: http://www.nap.edu/books/0309071402/html/

[5] U.S. EPA. Characterization of Human and Wildlife Risks from Mercury Exposure in the United States. Volume VII of Mercury Study Report to Congress. 1997b. (EPA-452/R-97-009).

[6]U.S. EPA. Characterization of Human and Wildlife Risks from Mercury Exposure in the United States. Volume VII of Mercury Study Report to Congress. 1997b. (EPA-452/R-97-009).

[7]U.S. EPA. Characterization of Human and Wildlife Risks from Mercury Exposure in the United States. Volume VII of Mercury Study Report to Congress. 1997b. (EPA-452/R-97-009).

[8] Committee on the Toxicological Effects of Methylmercury. Board on Environmental Studies and Toxicology. Commission on Life Sciences. National Research Council. Toxicological Effects of Methylmercury, 2000. National Academy Press. Online. Available: http://www.nap.edu/books/0309071402/html/

[9] Committee on the Toxicological Effects of Methylmercury. Board on Environmental Studies and Toxicology. Commission on Life Sciences. National Research Council. Toxicological Effects of Methylmercury, 2000. National Academy Press. Online. Available: http://www.nap.edu/books/0309071402/html/

[10] U.S. EPA, Integrated Risk Information System. www.epa.gov/iris

[11] Agency for Toxic Substances and Disease Registry. Qs and As for release of ATSDR's Toxicological Profile on Mercury to Supplement Information in the Key Communication Points. April 19, 1999. USFDA Center for Food Safety and Applied Nutrition. Online. Available: http://www.cfsan.fda.gov/~acrobat/hgstud17.pdf

[12] 44 *Fed. Reg.* 3990 (19 January 1979).

[13] U.S. EPA. Health Effects of Mercury and Mercury Compounds. Volume V of Mercury Study Report to Congress. December 1997. (EPA-452/R-97-007).

[14] "Meeting the Challenges of Continental Pollutant Pathways Mercury Case Study." Final Report to the Secretariat of the CEC. February 1999. Online. Available: http://www.eman-rese.ca/eman/reports/publications/99_mercurywkshp/page3.html

[15] FAO/WHO, 2003: Summary and conclusions of the sixty-first meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Rome, 10-19 June 2003. (JECFA/61/SC) Online. Available: ftp://ftp.fao.org/es/esn/jecfa/jecfa61sc.pdf

[16] U.S. EPA. Characterization of Human Health and Wildlife Risks from Mercury Exposure in the United States. Volume VII of Mercury Study Report to Congress. December 1997. (EPA-452/R-97-009).

[17] Brown, D. and M. Tatsutani. Northeast States and Eastern Canadian Provinces Mercury Study: A Framework for Action. Chapter III: Health Effects of Mercury and Strategies to Protect Public Health. February 1998.

[18] Schober, S.E. et al. "Blood Mercury Levels on US Children and Women of Childbearing Age, 1999-2000." 2003. JAMA Vol. 289, No 13 (April 2, 2003): 1667-1674.

[19] Stern, A.H., M. Gochfeld, C. Weisel and J. Berger. "Mercury and Methylmercury Exposure in the New Jersey Pregnant Population." Arch. Environ. Health Vol. 56 (Jan/Feb.2001): 4-10.

[20] Burge, P. and S. Evans. "Mercury Contamination in Arkansas Gamefish: a Public Health Perspective." J Ark Med Soc. Vol. 90, No. 11 (April 1994): 542-544.

[21] Hightower, J. "Mercury Levels in High-End Consumers of Fish." Environmental Health Perspectives. November 1, 2002. Online. Available: Ehponline.org.

[22] Scheuhammer, A. M., "Effects of Acidification on the Availability of Toxic Metals and Calcium to Wild Birds and Mammals." Environmental Pollution 17 (1991): 329-375.

[23] U.S. EPA. An Ecological Assessment for Anthropogenic Mercury Emissions in the United States. Volume VI of Mercury Study Report to Congress. December 1997. (EPA-452/R-97-008).

[24] Evers, D., J. Kaplan, M. Meyer, P. Reaman, W. E. Braselton, A. Major, N. Burgess and A.M. Scheuhammer. "Geographic Trend in Mercury Measured in Common Loon Feathers and Blood." Environmental Toxicology and Chemistry Vol 17 Number 2(1998): 173-183.

[25] Krabbenhoft, D.P., and J.G. Weiner, "Mercury Contamination: A Nationwide Threat to Our Aquatic Resources, and a Proposed Research Agenda for the U.S. Geological Survey," *in* Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the technical meeting, Charleston, S.C., March 8-12, 1999: U.S. Geological Survey Water Resources Investigation Report 99-4018B.

[26] Meyer, M., D. Evers, J. Hartigan and P. Rasmussen. "Patterns of Common Loon (*Gavia Immer*) Mercury Exposure, Reproduction, and Survival in Wisconsin, USA." Environmental Toxicology and Chemistry Volume 17 Number 2 (1998): 184-190.

[27] Evers, D., J. Kaplan, M. Meyer, P. Reaman, W. E. Braselton, A. Major, N. Burgess and A.M. Scheuhammer. "Geographic Trend in Mercury Measured in Common Loon Feathers and Blood." Environmental Toxicology and Chemistry Volume 17 Number 2 (1998): 173-183.

[28] Evers, D., J. Kaplan, M. Meyer, P. Reaman, W. E. Braselton, A. Major, N. Burgess and A.M. Scheuhammer. "Geographic Trend in Mercury Measured in Common Loon Feathers and Blood." Environmental Toxicology and Chemistry Volume 17 Number 2 (1998): 173-183.

[29] Meyer, M., D. Evers, J. Hartigan and P. Rasmussen.. "Patterns of Common Loon (*Gavia Immer*) Mercury Exposure, Reproduction, and Survival in Wisconsin, USA." Environmental Toxicology and Chemistry Volume 17 Number 2 (1998): 184-190.

[30] Scheuhammer, A. M. "Methylmercury Exposure and Effects in Piscivorous Birds." in Proceedings 1995 Canadian Mercury Network Workshop. York University, Toronto, Ontario, 1995.

[31] Schreiber, R. K. and J. Newman. "Effects of Air Pollution on Wildlife: A Synthesis." in Proceedings XIX World Congress, International Union of Forest Research Organizations. 1990. 180-191.

[32] Facemire, C.F. "Mercury in Wildlife." in U.S. EPA, National Forum on Mercury in Fish: Proceedings. 1995. (EPA 823-RR-95-002).

[33] Mierle, G., E. Addison, K.S. MacDonald and D.G. Joachim. "Mercury Levels in Tissues of Otters from Ontario, Canada: Variation with Age, Sex and Location." Environmental Toxicology and Chemistry Volume 19 Number 12 (2000): 3044-3051.

[34] Wisconsin Department of Natural Resources. Mercury in Wisconsin's Environment. A Status Report. 1996.

[35] Lathrop, R.C. et al. Mercury Levels in Walleyes from Wisconsin Lakes of Different Water and Sediment Chemistry Characteristics. Wisconsin Department of Natural Resources, Technical Bulletin No. 163. 1989.

Chapter 2
Mercury Emissions and Deposition in the U.S.

Mercury Emissions by Industrial Sector

In its 1997 *Mercury Study Report to Congress*, EPA identified sources in the U.S. that emit mercury to the air. EPA estimated for the 1990 to 1994 timeframe, these sources emitted 158 tons per year.[1] The Agency has recently released an updated national mercury inventory with a 1999 estimate of 117.3 tons per year.[2] As shown in Table 2.1, coal-fired power plants remain the largest source type in the inventory. They were estimated in 1999 to emit about 48 tons per year, or over 40 percent of the U.S. inventory from anthropogenic sources. In addition, mercury emissions from coal-fired power plants are expected to increase based on projections of energy production and coal use, absent any state or federal actions to require mercury emission reductions.

Since the 1994 inventory, certain source categories, most notably hazardous and municipal waste combustors and medical waste incinerators, have been required to significantly reduce their mercury emissions. Mercury emissions from medical waste incinerators and municipal waste combustors have declined considerably since 1990 on account of plant closures, reduction in the mercury content of the waste stream and federal and state regulatory actions. (See Chapter 4.)

The use of mercury in consumer products is also declining. Both the use and disposal of mercury in these products are coming under increasing state regulation. As of July 2003, 19 states had passed legislation concerning either the use, sale or labeling of mercury-containing products. Local ordinances are in effect in some states as well.[3]

Past industrial uses of mercury are not considered in the inventory, but many have left a legacy of significant mercury contamination. Some of these include the use of mercury fungicides in textiles, pulp and paper production, turf grass applications, and interior and exterior paint. As a result of these gaps, actual mercury emissions may be higher than the inventory suggests.

Table 2.1 1999 National Emissions Inventory for Mercury by Source Type

Source Category	1999 Estimated Emissions (tons/year)	Percent of Total U.S. Inventory (%)
Utility Boilers	48.7	41.6
Coal	*47.8*	*40.8*
Oil	*0.50*	*0.4*
Natural gas	*0.44*	*0.4*
Municipal waste combustors	5.1	4.3
Commercial/Industrial boilers	9.73	8.3
Medical waste incinerators	2.84	2.4
Hazardous waste combustors	2.94	2.5
Residential boilers	1.23	1.1
Coal	*0.08*	*0.1*
Oil	*1.15*	*1.0*
Wood-fired boilers	0.69	0.6
Crematories	0.13	0.1
Chlorine manufacturing	6.53	5.6
Portland cement	2.36	2.0
Pulp and paper	1.69	1.4
All Other	35.36	30
TOTAL	**117.3**	**100**

Source: U.S. EPA, Office of Air Quality Planning and Standards. 1999 National Emissions Inventory for Hazardous Air Pollutants. http://www.epa.gov/ttn/chief/net/1999inventory.html#final3haps.

Given these considerations, it is difficult to determine the exact percentage of U.S. mercury emissions attributable to coal-fired power plants. However, in light of the fact that all emission inventories represent a snapshot in time, the figure of 41 percent (approximately 48 tons) should be considered EPA's best and most current estimate of the contribution of coal-fired power plants to the national inventory of anthropogenic emissions.

Industrial Sources in the Global Context

Current releases of mercury add to the global inventory in the biosphere. Generally speaking, there are four types of mercury emissions that must be accounted for in the global inventory:[4]

- Current anthropogenic (i.e., associated with human activity) releases from the mobilization of mercury impurities in raw materials such as fossil fuels –

particularly coal, and to a lesser extent oil – and other extracted, treated and recycled minerals;

- Current anthropogenic releases resulting from mercury used intentionally in products and processes, due to releases during manufacturing, leaks, disposal or incineration of spent products or other releases;
- Re-mobilization of historic anthropogenic mercury releases previously deposited in soils, sediments, water bodies, landfills and waste/tailings piles; and
- Natural sources - releases due to natural mobilization of naturally occurring mercury from the earth's crust, such as volcanic activity and weathering of rocks.

Mercury in the global inventory continuously cycles—it is mobilized, deposited on land and water, and re-mobilized. The only long-term sinks for removal of mercury from the biosphere are deep sediments and, possibly, controlled landfills in which the mercury is physically or chemically immobilized and remains undisturbed.

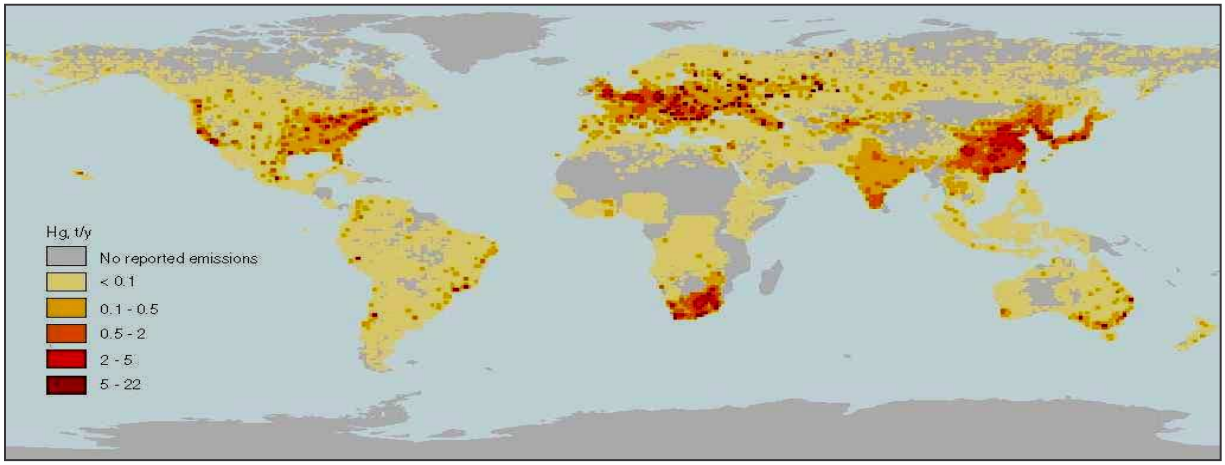
A recent estimate of annual global mercury releases is 4,840 metric tons (3,300 metric tons from anthropogenic sources and 1,540 metric tons from natural releases).[5] The estimate of anthropogenic releases includes 440 tons of re-emitted mercury from the oceans. Thus, current annual global anthropogenic emissions are approximately 2,860 metric tons.

According to the United Nations' Environment Programme Global Mercury Assessment:

> The emissions from stationary combustion of fossil fuels (especially coal) and incineration of waste materials accounts for approximately 70 percent of the total quantified atmospheric emissions from significant anthropogenic sources. As combustion of fossil fuels is increasing in order to meet the growing energy demands of both developing and developed nations, mercury emissions can be expected to increase accordingly in the absence of the deployment of control technologies or the use of alternative energy sources.[6]

The spatial distribution of global mercury emissions has changed since 1990. Emissions in Europe and North America decreased substantially between 1990 and 1995, whereas in India and China mercury emissions increased significantly. In 1990, Asian sources contributed about 30 percent of the global inventory, compared to 56 percent in 1995. Estimates are that China saw an increase of more than 250 metric tons between 1990 and 1995, related to the increase in coal combustion.[7] Figure 2.1 illustrates the spatial distribution of global mercury emissions to the air (from UNEP, 2002).

Figure 2.1 Spatial Distribution of Global Mercury Emissions



Source: UNEP, Chemicals Global Mercury Assessment, 2002. Geneva, Switzerland: Inter-Organization Programme for the Sound Management of Chemicals (IOMC), 2002.

Fate and Transport of Mercury in the Atmosphere

Mercury is emitted from power plants as a vapor in a mixture of three chemical states or species: in the elemental form, as oxidized mercury (typically as mercuric chloride in the presence of chlorine), and adsorbed to particulates. Each power plant has a different speciation profile, with the difference related primarily to the type of coal burned and the plant's pollution control devices.

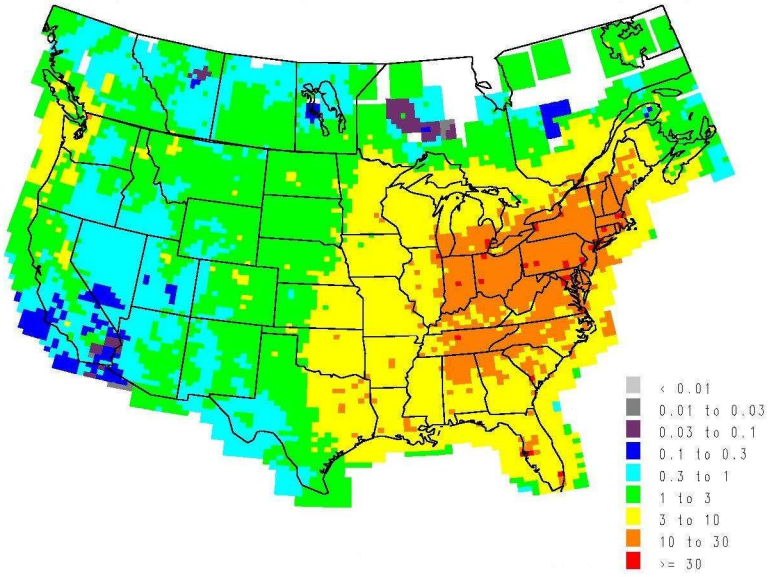
Each of the mercury species has a different fate in the atmosphere. Gaseous elemental mercury can be transported over very long distances, even globally, with the air masses. The atmospheric residence time of elemental mercury is in the range of months to roughly one year. Thus, emissions in any continent can contribute to deposition in other continents.[8] The global pool of mercury is almost entirely elemental mercury. Oxidized mercury and particle-bound mercury have a much shorter atmospheric lifetime than elemental mercury and deposit by wet or dry deposition within roughly a few days, or within 50 to 500 miles of the source. Significant conversion between mercury species may occur during atmospheric transport (or even in the plume from the stack), which affects the transport distance.

Since mercury in the atmosphere originates from local, regional and global sources, there is considerable interest in how much domestic sources contribute to mercury deposition in the U.S. relative to global inputs. A number of estimates have been made relating to the sources of mercury deposited in the U.S. There are critical variables in the various deposition models that can lead to different results, especially estimates of natural and global emissions and of the atmospheric transformation of mercury species. EPA has estimated that roughly 66 percent of all of the mercury deposited in the U.S. comes from U.S. sources, and that 34 percent comes from sources outside of the U.S. According to

the modeling of intercontinental mercury transport performed by the Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe, up to 50 percent of anthropogenic mercury deposited in North America is from external sources.[9] In a recent analysis, the Electric Power Research Institute (EPRI) estimated that, depending on location, 20 to 80 percent of the mercury deposited in the U.S. comes from domestic sources. According to EPRI, most of the mercury that deposits west of Minnesota comes from non-U.S. sources.[10]

Figure 2.2 shows the geographical areas in the U.S. that have the highest modeled mercury deposition. As illustrated, the most highly impacted areas are the southern Great Lakes and Ohio Valley, the Northeast, including southern New England, and scattered areas in the South. According to EPA, U.S. power plants account for about 33 percent of the mercury deposited in the country.[11]

Figure 2.2 Total Mercury Deposition (micrograms per square meter per year)



Source: U.S. EPA. Fate and Transport of Mercury in the Environment. Volume III of Mercury Study Report to Congress. December 1997. (452/R-97-005).

The deposition of mercury in the vicinity of a power plant is highly variable and is influenced by the amount of oxidized and particulate-bound mercury in the flue gas. Because elemental mercury is thought to remain in the atmosphere for extended periods of time, it does not play a large role in local deposition. On the other hand, oxidized and particulate forms of mercury substantially contribute to deposition close to the source. Other factors also influence deposition and, ultimately, human and wildlife exposure. These include: the physical characteristics of the power plant, such as the size of the facility and how much coal it burns; stack height; and the type of air pollution control devices in place. Tall stacks typically cause the plume to disperse further from the facility. The location of the plant is also important because climate, wind direction and terrain (among other factors) all influence the amount of mercury that deposits locally.[12]

National-scale analyses are not able to predict how a particular ecosystem will respond to increases or decreases in mercury loading. Local differences simply cannot be incorporated into national scale models. Studies of mercury deposition that measure, rather than model, the response of local environments to decreases in mercury loading are much more informative. In that regard, analyses of sediment cores in the upper Midwest reveal that mercury deposition in the region is decreasing, in all likelihood because of air pollution controls on incinerators, reduced use of mercury in industrial processes, and reduced reliance on coal for residential heating.[13]

In addition, two recent studies support a quantitative link between decreases in mercury deposition and mercury levels in fish. Wisconsin researchers found that changes in atmospheric mercury deposition can have rapid effects on the fish mercury concentrations.[14] They found that a 10 percent decrease in mercury deposition resulted in a five percent decrease in fish tissue mercury levels. It is postulated that the addition of "new" mercury to the ecosystem is an important indicator of how much mercury will be available for introduction into the food web. Similarly, in a South Florida study, significantly lower levels of mercury in water and fish tissue were associated with decreased mercury deposition over a four-year period.[15] These limited studies are encouraging and suggest that, in the studied ecosystems, reducing emissions results in measurable decreases in mercury deposition and subsequent reductions in fish mercury concentrations.

As federal and state lawmakers move towards enacting legislation to limit mercury releases to the air, some industry stakeholders argue that reducing emissions from power plants will not make a difference in reducing levels of mercury in fish tissue.[16,17] They claim that foreign emissions are primarily responsible for mercury contamination within the U.S. and that power plants are but one of many sources in the U.S. and globally. Among other things, this claim completely ignores regional differences within the country: in the eastern U.S., for example, the predominant sources of mercury deposition are domestic. A mixture of local, regional and global emissions always contributes to mercury deposition at a given location. In rural areas with few point sources, the regional and global components are more likely to dominate deposition. In industrialized areas, the local sources are more likely to predominate. Moreover, as research studies indicate, there is evidence that reducing emissions from domestic sources results in a measurable decrease in domestic mercury deposition. Thus, reducing domestic sources of mercury emissions is key to reducing mercury contamination within the U.S.

It is also the case that the U.S. power industry has the opportunity to demonstrate the technical and economic feasibility of measures to minimize emissions of mercury. For example, consider U.S. leadership in reducing automobile tailpipe emissions and removal of lead in gasoline, which has resulted in widespread adoption of similar measures in countries around the world.

While a significant reduction in U.S. power sector mercury emissions will not be sufficient by itself to solve the problem, it is unquestionably necessary to address mercury contamination of our fish and the resulting adverse health impacts.

Conclusions

The proportion of U.S. mercury emissions attributable to coal-burning power plants is increasing, both because of increased energy production and because of reductions in mercury emissions from other industry sectors. EPA's best available estimate is that coal-burning power plants are responsible for over 40 percent of domestic mercury emissions.

Contributions to the global inventory of mercury come from anthropogenic and natural sources, with anthropogenic emissions dominating the inventory. In global terms, U.S. industrial sources account for a decreasing proportion of mercury emissions, largely because of increases in India and China related to those countries' growing use of coal.

Mercury is emitted from power plants in different chemical species, with each species having a different fate in the atmosphere. Climate, wind direction and terrain also play a role in the transport of mercury emissions. For this and other reasons, it is difficult to model deposition patterns or to predict the transport patterns of emissions. However, EPA has estimated that roughly 66 percent of all of the mercury deposited in the U.S. comes from U.S. sources and that domestic. power plants account for about 33 percent of the mercury deposited in the country. Limited recent studies suggest a quantitative link between decreases in mercury deposition and mercury levels in fish. Thus, notwithstanding the contribution of natural and foreign emissions sources, it is evident that reductions from domestic emissions sources—and power plants in particular—are critical.

Endnotes

[1] U.S. EPA. An Inventory of Anthropogenic Mercury Emissions in the United States Volume II of Mercury Study Report to Congress. 1997 (EPA-452/R-97-004).

[2] U.S. EPA, Office of Air Quality Planning and Standards. 1999 National Emissions Inventory for Hazardous Air Pollutants. http://www.epa.gov/ttn/chief/net/1999inventory.html#final3haps.

[3] Reindl, J., Recycling Manager Dane County, WI Department of Public Works. "Status of Local, State and Federal Mercury Product Legislation and Laws. 2001-2002 Legislative Sessions." October 11, 2002.

[4]UNEP. Chemicals. Global Mercury Assessment. Geneva, Switzerland: Inter-Organization Programme for the Sound Management of Chemicals (IOMC), 2002.

[5]Lamborg, C. H., W. F. Fitzgerald, J. O'Donnell, and T. Torgersen. "A non-steady-state compartmental model of global-scale mercury biogeochemistry with interhemispheric atmospheric gradients." Geochimica et Cosmochimica Acta Volume 66 Issue 7 (2002): 1105-1118.

[6] UNEP, Chemicals Global Mercury Assessment, 2002. Geneva, Switzerland: Inter-Organization Programme for the Sound Management of Chemicals (IOMC), 2002.

[7] Pirrone, N., P. Costa, J.M.Pacyna and R. Ferrara. "Atmospheric Mercury Emissions from Anthropogenic and Natural Sources in the Mediterranean Region." Atmospheric Environment 35 (2001): 2997-3006.

[8] UNEP, Chemicals Global Mercury Assessment, 2002. Geneva, Switzerland: Inter-Organization Programme for the Sound Management of Chemicals (IOMC), 2002.

[9] Travnikov, O. and A. Ryaboshapko. (2002): Modelling of mercury hemispheric transport and depositions. *EMEP/MSC-E Technical Report* 6/2002, Meteorological Synthesizing Centre - East, Moscow, Russia *as cited in* UNEP, Chemicals Global Mercury Assessment, 2002. Geneva, Switzerland: Inter-Organization Programme for the Sound Management of Chemicals (IOMC), 2002.

[10] Levin, L., Electric Power Research Institute. "Mercury Science: An Update." Presentation to the Edison Electric Institute. December 4, 2002.

[11] U.S. EPA. Fate and Transport of Mercury in the Environment. Volume III of Mercury Study Report to Congress. December 1997. (452/R-97-005).

[12] U.S. EPA. Fate and Transport of Mercury in the Environment. Volume III of Mercury Study Report to Congress. December 1997. (EPA-452/R-97-005).

[13] Engstrom, D.R. and E.B. Swain. "Recent Declines in Atmospheric Mercury Deposition in the Upper Midwest." Envir. Sci. Technol. 31 (1997): 960-967.

[14] Hrabik, T.R. and C.J. Watras. "Recent Declines in Mercury Concentration in a Freshwater Fishery: Isolating the Effects of De-acidification and Decreased Atmospheric Mercury Deposition in Little Rock Lake." The Science of the Total Environment. 2002. In press.

[15] U.S. EPA. South Florida Ecosystem Assessment: Phase I/II – Everglades Stressor System Interactions: Hydropatterns, Eutrophication, Habitat Alteration and Mercury Contamination. September 2001 (EPA 904-R-01-002).

[16] Lutter, R. and E. Irwin "Mercury in the Environment: a Volatile Problem." Environment, (November 2002).

[17] Seigneur, C. et al. Modeling the Atmospheric Fate and Transport of Mercury Over North America. Atmospheric and Environmental Research, Inc. Undated.

Chapter 3
Legal Requirements to Regulate Mercury Emissions from Power Plants

Federal Requirements

Section 112(n)(1)(A) of the Clean Air Act Amendments of 1990 required EPA to conduct a study of hazardous air pollutant ("HAP") emissions from electric utility steam generating units by 1993 and, after considering the results of that study, to determine whether regulation limiting those emissions was appropriate and necessary.

The results of EPA's study were finally documented in February 1998 in the *Study of Hazardous Air Pollutant Emissions from Electric Utility Steam Generating Units: Final Report to Congress*.[1] In that report, EPA stated that, for the utility industry, mercury from coal-fired electric utility steam generating units was the HAP of greatest concern for public health.[2] However, the report did not include a regulatory determination, which EPA deferred to a later unspecified date. Because EPA did not make a regulatory finding when the report was issued, environmental groups sued to require the Agency to: (1) collect additional information on mercury emissions and control technologies; (2) issue a regulatory finding by December 15, 2000; (3) issue a proposed regulation (in the case of a positive regulatory determination) by December 15, 2003; and (4) issue a final regulation by December 15, 2004. EPA entered into a judicially approved settlement agreement accepting these conditions.[3]

After a data collection effort for mercury emissions from coal-fired power plants, further study of the health effects of mercury[4] and additional testing of various mercury emission control technologies, EPA announced in December 2000 that regulation of HAP emissions from oil- and coal-fired electric utility steam generating units was necessary and appropriate.[5]

Section 112 of the Clean Air Act establishes a two-part process for regulating hazardous air pollutant emissions. In the first phase of this process, sources within defined source categories are required to comply with emission standards that reflect maximum achievable control technology ("MACT"), as defined by Section 112(d). These are the MACT regulations that EPA is required to propose by December 2003. The second phase of the

regulatory process—the so-called residual risk assessment—occurs within eight years after MACT standards have been finalized for the subject source category.[6]

For existing sources, MACT cannot be less stringent than the average emission limitation achieved by the best performing 12 percent of the existing sources for which the Administrator has emissions information. This is known as the "MACT floor." For new sources, MACT is defined as the maximum degree of emission reduction achieved by the best-controlled similar source in the source category. Cost of control does not factor into the definition of the MACT floor. However, for "beyond the floor" analyses (i.e., emission limits more stringent than the MACT floor), the Administrator must take into account the cost of achieving such emissions reductions, any non-air quality health and environmental impacts and energy requirements.[7]

The issue of what emission limitation the best performing 12 percent of sources actually achieve is complicated. EPA's data collection efforts included emission tests from about 80 coal-fired boilers. These boilers can be ranked with reference either to their mercury emission rate or to their percent reduction as measured from the mercury content of the combusted coal. If the boilers are ranked by percent reduction, the average of the top 12 percent is a 91 percent reduction from the mercury in the combusted coal, as shown on Table 3.1.[8] This is not necessarily the end of the inquiry, as EPA has the discretion to subcategorize source categories based on class, type, and size of boilers[9]. However, standing alone (i.e., without adjustment for subcategorization) and using the current estimate of mercury in the coal combusted by all coal-fired power plants of about 75 tons, a 91 percent reduction would result in mercury emissions from coal-fired power plants of about seven tons.

Table 3.1 Determination of MACT Floor Based on Percent Reduction in Mercury
Top 12% (10 Plants) from EPA 1999 ICR Data

Plant Name	Calculated Hg Reduction (% from coal)
1 **Scrubgrass Generating Company, L.P.**	99
2 **Clover Plant Station**	97
3 **Mecklenburg Cogeneration Facility**	96
4 **Logan Generating Plant**	96
5 **Dwayne Collier Battle Cogeneration Facility**	92
6 **Stockton Cogen Company**	90
7 **SEI - Birchwood Power Facility**	87
8 **Clay Boswell**	86
9 **Intermountain**	84
10 **Big Bend**	84
Average of Top 12%	**91.1%**

Source: Memo to the Utility MACT Workgroup from the Ranking Subgroup. February 5, 2002. Online. Available: http://www.epa.gov/ttn/atw/combust/utiltox/feb5memo.pdf.

In order to receive input on appropriate regulation of HAP emissions from power plants, EPA formed and co-chaired the Utility MACT Working Group. This group consisted of representatives of industry, the states and tribes, and environmental organizations, and met from August 2001 to March 2003.[10] The Working Group made its final recommendations to EPA in October 2002.[11] The most stringent standard recommended would result in a 96 percent reduction in U.S. power plant mercury emissions, while the least stringent scenario would produce slightly less than a 40 percent reduction in current emissions. Given current estimated national mercury coal-fired power plant emissions of about 48 tons, this translates into national power plant mercury emissions of between approximately two and 28 tons.

Generally, sources subject to a MACT standard must comply with the standard as expeditiously as practicable, but with some opportunity for extensions, no later than three years after the promulgation date of the standard.[12] Thus, assuming that EPA complies with its legal obligation to promulgate a utility MACT regulation in late 2004, compliance will be required by late 2007. However, the Administration has recently indicated that it may consider a one-year extension.

State Requirements

In light of the slow pace of federal activity, a number of states have tackled the problem of mercury emissions from power plants, thereby raising a serious question as to how a less stringent federal standard for the relevant subcategory could be justified. Among these are:

Connecticut: In June 2003, Connecticut enacted legislation that requires coal-fired units in the state to meet an emission limit of 0.6 lbs/TBtu or a 90 percent removal efficiency (i.e., across the control device), whichever is more readily achievable by July 1, 2008.[13]

Massachusetts: In September 2003, Massachusetts released proposed regulations to limit mercury from four power plants in the state. Under the proposal, facilities will have the choice of meeting removal efficiencies or emissions rates for each of two phases:

Phase I - by October 1, 2006, either:

- 85 percent removal of mercury contained in the combusted coal, or
- an output based mercury emissions rate of 0.0075 lbs/GWh.

Phase II - by October 1, 2012, either:

- 95 percent removal of mercury contained in the combusted coal, or
- an output based mercury emission rate of 0.0025 lbs/GWh.

Averaging across units at a facility is permitted, but neither emissions trading nor averaging across units at different power plants is permitted. Facilities can comply with the emission rate limitations by achieving offsite (but within Massachusetts) reductions until December 31, 2009.[14]

Wisconsin: The rules adopted by the Wisconsin Natural Resources Board require major electric utilities in the state to reduce their current emissions (based on the mercury content of coal) by 40 percent beginning in 2010, and by 80 percent beginning in 2015.[15] The Wisconsin legislature has asked the Natural Resources Board to re-evaluate certain aspects of the rules.

New Jersey: New Jersey is expected to propose a revised mercury rule, which would include emission limits on coal-fired electric generating units, in the fall of 2003.

Iowa: Based on a determination by the Iowa Department of Natural Resources, in June 2003 the MidAmerican Energy Company took an enforceable permit condition on a new 790 MW coal-fired utility boiler burning western subbituminous coal. The preconstruction permit requires a mercury reduction of 83 percent, based on the use of activated carbon injection.[16]

Conclusions

In a congressionally mandated study, EPA has concluded that among hazardous air pollutants, mercury emissions are the greatest concern for public health from coal-fired electric utility units. A decade later than anticipated by Congress when it enacted the 1990 Clean Air Act Amendments, EPA is now formulating its MACT standard for mercury emissions from power plants. The Agency is required by a court-approved settlement agreement to promulgate a draft rule by December 15, 2003 and a final rule by December 15, 2004. Compliance will be required by late 2007, although there is some indication that the Administration may consider a one-year extension.

The debate about the standards is currently focused on establishing the "MACT floor" for existing sources. As prescribed in the Clean Air Act, the MACT floor cannot be less stringent than the average emission limitation achieved by the best performing 12 percent of the existing sources for which the Administrator has emissions data. If the coal-fired boilers for which EPA has data are ranked with reference to their percent reduction from the mercury content of coal, the average of the top 12 percent is a 91 percent reduction. EPA has some discretion to adjust the average of the top 12 percent (i.e., subcategorization based on class, type, and size of sources). A 91 percent reduction would result in mercury emissions from coal-fired power plants of about seven tons nationally.

This figure can be put in context by reviewing the recommendations for a standard made by various stakeholders in EPA's Utility MACT Working Group. The most stringent standard recommended would result in a 96 percent reduction in U.S. power plant mercury emissions, while the least stringent scenario would produce slightly less than a 40 percent reduction. These standards translate to a reduction of national power plant mercury emissions from 48 tons to between approximately two and 28 tons.

In light of the slow pace of federal activity, states such as Connecticut, Iowa, Massachusetts, Wisconsin and New Jersey are setting their own limits on mercury emissions from new and existing power plants. The existence of stringent state standards

raises a serious question as to how a less stringent federal standard for the relevant subcategory could be justified.

Endnotes

[1] U.S. EPA. Study of Hazardous Air Pollutant Emissions from Electric Steam Generating Units: Final Report to Congress. Volume 1. February 1998. (EPA 453/R-98-004a).

[2] The report noted that nickel emissions from oil-fired units and other HAP emissions (e.g., dioxins, hydrochloric and hydrofluoric acids, chromium, arsenic, nickel and cadmium) from coal-fired units were also of concern.

[3] Natural Resources Defense Council, Inc. v. Environmental Protection Agency, No. 92-1415 (D.C. Cir. Jan. 13, 1999).

[4] Pursuant to Congressional direction in connection with EPA's 1999 funding, the National Academy of Sciences (NAS) conducted an 18-month study of the available data on the health effects of methylmercury and provided EPA a report in July 2000, finding that EPA's health effects threshold was justified; this allowed the EPA to proceed with power plant HAP regulation.

[5] 65 *Fed. Reg.* 79825 (Dec. 20, 2000).

[6] Clean Air Act, 42 U.S.C. sec. 112(f).

[7] Clean Air Act, 42 U.S.C. sec. 112(d).

[8] Memo to the Utility MACT Workgroup from the Ranking Subgroup. February 5, 2002. Online. Available: http://www.epa.gov/ttn/atw/combust/utiltox/feb5memo.pdf

[9] Clean Air Act, 42 U.S.C. sec. 112 (d)(1).

[10] The Utility MACT Working Group was formed under the existing Permits, New Source Reviews, and Toxics Subcommittee of the Clean Air Act Advisory Committee (CAAAC), established under the Federal Advisory Committee Act (FACA).

[11] Working Group on the Utility MACT. Clean Air Act Advisory Committee Subcommittee for Permits/New Source Reviews/Toxics. Recommendations for the Utility Air Toxics MACT. Final Working Group Report. Submitted to the Clean Air Act Advisory Committee. October 2002. Online. Available: http://www.epa.gov/ttn/atw/combust/utiltox/utoxpg.html#CAAAC.

[12] Clean Air Act, 42 U.S.C. sec. 112(i).

[13] Connecticut Public Act 02-64.

[14] Massachusetts Draft Proposed Regulation modifying 310 CMR 7.29.

[15]Wisconsin Department of Natural Resources. Revised Mercury Rules. June 25, 2003. Online. Available: http://www.dnr.state.wi.us/org/aw/air/reg/mercury/AM2701_10.pdf

[16] Iowa Department of Natural Resources Environmental Services Division Air Quality Bureau. Prevention of Significant Deterioration (PSD) Permit Review Technical Support Document Issuance of PSD Permits for Project Number 02-528, Plant Number 78-01-026. MidAmerican Energy Company.

Chapter 4
Status of Technology to Control Mercury Emissions from Power Plants

Faced with the imminent prospect of an emission standard limiting mercury emissions from coal-burning power plants, some companies within the electric generating industry claim that the technology to reduce emissions from these sources is unavailable.[1] However, the evidence suggests with respect to all coal types that existing control devices designed to control pollutants other than mercury (e.g., oxides of nitrogen, sulfur dioxide, and particulate matter) can deliver substantial mercury reductions, and that mercury-specific control technologies are well on their way to commercial availability. Further, extremely successful field experience with the control of mercury emissions from municipal waste combustors gives additional reason for confidence as to the potential for controlling mercury emissions from the electric sector to stringent levels.

It is useful to think of mercury control technologies as divided into two major categories:

- Technologies designed to control pollutants other than mercury ($NO_x/SO_2/PM$), which provide some mercury control (so called "co-benefits" or incidental benefits); and
- Technologies specifically designed to control mercury or a combination of mercury and other pollutants (so called multi-pollutant control technologies).

With respect to the first category, the most comprehensive set of information is EPA's Information Collection Request (ICR) database. The ICR data have emissions information for 80 units representing a variety of boiler types, coals, and existing control technologies that were tested for mercury emissions.

The Fate of Mercury in Combustion Waste

Though not the focus of this report, it is also important to acknowledge the fate of mercury in coal combustion systems. Because mercury is a metal, it is not destroyed. When captured by the air pollution control device it is transferred to other waste streams. There is need for additional research on the fate of mercury in combustion waste (i.e., in terms of its potential for leaching or re-emission). Both current coal combustion waste containing mercury and the added waste that will be created after controls are installed must be appropriately managed to ensure the mercury they contain is not released to the environment.

The second category includes technologies at various stages of development or demonstration, ranging from early-stage R&D to full-scale demonstrations. An enormous amount of activity is being focused on mercury and multi-pollutant technologies, and activity will undoubtedly accelerate when federal regulatory drivers are in place (see Chapter 5 for a detailed discussion.) These technologies include but are not limited to activated carbon injection (ACI), enhanced wet scrubbing, approaches such as KFX's K-Fuel® and Powerspan's ECO™, several new sorbent developments, amalgamation (e.g., gold-plated structures) approaches such as EPRI's MerCAP™, and a variety of mercury oxidation approaches. These developments are discussed below.

Co-Benefit Technologies

All coal-fired power plants have at least some air pollution control devices, such as electrostatic precipitators or baghouses (also known as fabric filters) for particulate control; wet or dry scrubbers for SO_2 control; and low-NOx burners, selective catalytic reduction (SCR), or selective non-catalytic reduction (SNCR) for NOx control. Most of these controls can have impacts on mercury emissions and speciation; thus far, electrostatic precipitators, fabric filters and wet and dry scrubbers show particular promise in this regard.

A number of power plants already achieve impressive mercury reductions with technologies that are designed to control other pollutants. For example:

- Four bituminous coal-fired plants with dry scrubbers and fabric filters each captured more than 95 percent of the mercury contained in the combusted coal during emission tests (Mecklenburg Cogeneration Facility in Virginia, Dwayne Collier Battle Cogeneration Plant in North Carolina, Logan Generating Plant in New Jersey, and SEI Birchwood in Virginia).[2]

Some plants burning subbituminous coal that are equipped with fabric filters and other stack controls achieved capture of 74 to 86 percent of the mercury in the combusted coal during emission tests.[3] For example:

- 86 percent mercury reduction was measured at Clay Boswell (in Minnesota) at a boiler equipped with a fabric filter and low NOx burner;
- 74 percent mercury reduction was measured at AES Hawaii, Inc., at a boiler using limestone injection and a fabric filter; and
- 84 percent mercury reduction was measured at Intermountain Power Agency in Utah, which burns subbituminous and bituminous coal in a boiler equipped with a low NOx burner, wet scrubber, and a fabric filter.

As these examples illustrate, mercury co-benefits from existing air pollution control technologies can be substantial. Moreover, at the time of these emissions tests, there was no attempt to optimize mercury removal. Thus, there exists the potential to increase

mercury removal substantially using various optimization strategies with existing controls.[4] However, it is still not possible to predict or guarantee the removal capabilities of the various types of controls across all plant configurations and coal types. In practical terms, this means that, at least for the present, co-benefits alone will allow some but not all plants to meet a stringent mercury standard.

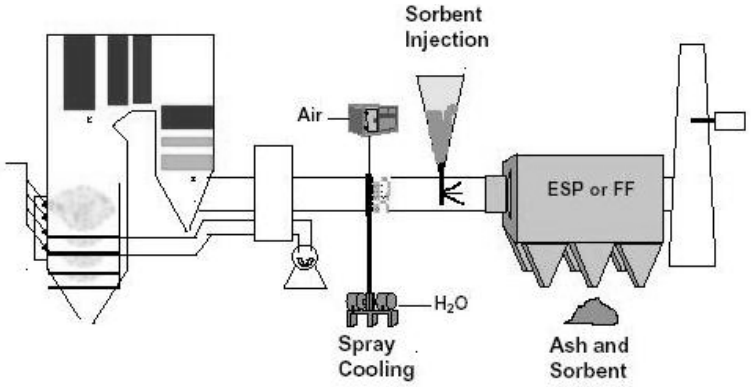
Mercury-Specific Control Technologies

This discussion focuses on some of the technologies closest to commercial availability.

Activated Carbon Injection (ACI)

ACI refers to the injection of dry, powdered activated carbon into the flue gas duct between the air preheater and the electrostatic precipitator or baghouse, typically in the 250 to 350 degree Fahrenheit range. (See Figure 4.1.) Mercury is adsorbed onto the activated carbon, which is then collected in the electrostatic precipitator or baghouse. The mercury/activated carbon interaction continues to occur in the electrostatic precipitator or baghouse, where additional adsorption takes place. Baghouses achieve higher mercury removal than electrostatic precipitators because of the buildup of a carbon layer on the bag filters. Since ESPs are less efficient in removing mercury, a more stringent requirement to remove mercury would require retrofitting some ESP-equipped units with baghouses. (See later discussion and Figure 4.2.) The ACI technology can be used in conjunction with flue gas temperature control to optimize the temperature at which the activated carbon-mercury adsorption occurs.

Figure 4.1 Activated Carbon Injection System



Source: Michael Durham, ADA-Environmental Solutions

Various configurations of the basic technology are possible, with the simplest being the injection of activated carbon directly ahead of an existing electrostatic precipitator. This is the least costly approach in terms of capital expenditures, since no new particulate control device is required; however, the trade-off between capital and sorbent costs may favor other configurations when life-cycle, levelized costs are considered.

One configuration is based on the combination of an electrostatic precipitator and a particular type of baghouse known as a COHPAC, with ACI introduced between the two particulate control devices. An important feature of this type of configuration is that it allows the raw flyash in the flue gas to be collected prior to the injection of the activated carbon, thereby keeping the flyash free from activated carbon (and available for re-use, which is an important economic consideration for some power plants).

Enhanced Wet Scrubbing

The goal of this technology is to promote the oxidation of elemental mercury in the flue gas prior to entering the scrubber, such that as high a fraction as possible of the total mercury is in the oxidized state and hence more easily removed in the scrubber vessel. Many approaches are under development to accomplish this goal, including those using chemical reagents, fixed catalysts and high-energy oxidation.

K-Fuel® Technology

KFX's K-Fuel® is a processed coal derived from western subbituminous coals. It is lower in ash, higher in BTU value, and produces lower pollutant emissions than the parent coals. K-Fuel® is processed in two-steps – physical separation and thermal processing – to produce a fuel that is higher value and "cleaner" than the original coal. The process involves elevated temperature and pressure, greatly reducing the moisture content of the coal. The mercury is volatilized and subsequently captured in a carbon-bed reactor.

Powerspan – ECO™

Powerspan-ECO™ is a post-combustion multi-pollutant control technology. It consists of a high-energy oxidation reactor followed by an ammonia-based scrubber and a wet electrostatic precipitator, which captures the products of oxidation. Fertilizer byproducts are produced (e.g., ammonia nitrate and sulfate), which should contribute to the overall economics of the technology.

Demonstrations and Results

Activated Carbon Injection (ACI)

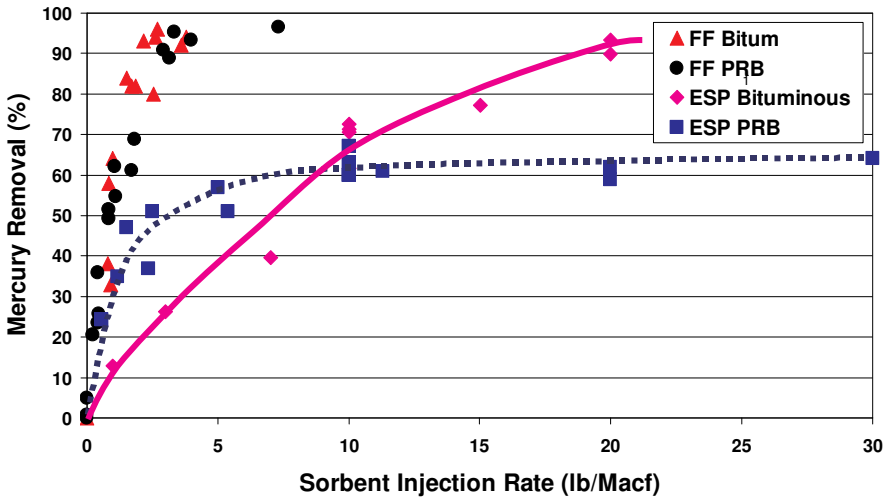
The Department of Energy has sponsored several full-scale demonstrations of ACI technology[5]:

- Alabama Power, Gaston Plant – baghouse (COHPAC) - bituminous coal;
- WEPCO, Pleasant Prairie – electrostatic precipitator - subbituminous coal;
- PGE NEG, Salem Harbor Station – electrostatic precipitator - bituminous coal; and
- PGE NEG, Brayton Point Station – two electrostatic precipitators in series - bituminous coal.

While not covering all possible plant/controls/coal configurations, the testing program includes several variables, such as coal rank, boiler type, electrostatic precipitator and baghouse configurations, as well as several other site-specific attributes and operating conditions, to provide reasonable breadth of information for ACI technology. Additionally, the MidAmerican Energy Company has proposed building a new western subbituminous coal-fired plant in Iowa that incorporates ACI technology. The preconstruction permit issued by the Iowa Department of Natural Resources in June 2003 imposes a mercury reduction requirement of 83 percent.[6]

The results from the Department of Energy and other smaller scale projects have been widely presented and discussed. Figure 4.2 summarizes the mercury capture results.[7]

Figure 4.2 Percent Mercury Removal vs. Activated Carbon Injection Rate



"FF" stands for fabric filter, which is the same as a baghouse; "PRB" refers to Powder River Basin, which is a subbituminous coal; and "Macf" stands for million actual cubic feet.

[1]Includes EPRI data on small-scale PRB/FF tests

Source: Durham, M. "Tools for Planning and Implementing Mercury Control Technology", American Coal Council. 2003. pp. 43-46.

The figure indicates mercury reductions in the 60 to 90-plus percent range across control devices for both electrostatic precipitators and baghouses, and both bituminous and subbituminous coals. As expected, higher capture efficiency (i.e., higher mercury reduction at lower sorbent usage) is associated with the baghouse configuration. This is due to the increased contact between the mercury in the flue gas and the activated carbon sorbent that occurs in a baghouse as compared to an electrostatic precipitator. In light of the limited data, it may be prudent to assume that electrostatic precipitators may not typically be able to achieve the 90 percent reductions shown in the figure for the "ESP Bituminous" example, but are more likely to have limits in the 60 to 70 percent range. For reductions in the 90 percent range, the use of a baghouse will probably be required or desirable.

While data for lignite-fired plants are even more limited, recent pilot-scale testing indicates that lignite and subbituminous coals are similar with respect to mercury speciation and control. Therefore, at present it seems appropriate to include lignites within a broader low-rank coal category – subbituminous and lignites – for purposes of understanding mercury control options.[8]

With this background, consider the following cost implications associated with the control of mercury using ACI, a baghouse, or both:

- From Figure 4.2, it is apparent that 90 percent mercury removal requires a sorbent injection rate of about 20 lb/Macf (million actual cubic feet) with an electrostatic precipitator and about 4 lb/Macf with a baghouse. In other words, to get to 90 percent removal requires *five times* more sorbent with an ESP than with a baghouse.
- This higher sorbent rate translates to an increase in sorbent cost of about two mills per kWh for a typical coal-fired plant, or about $6 million per year for a 500 megawatt (MW) plant (based on current costs of activated carbon of about $0.50 per pound).[9]
- By contrast, the capital cost of a baghouse is approximately $30-40 per kW, or about $15-20 million for the same 500 MW plant.[10]
- This translates to a payback period for a baghouse of three to four years, which should prove to be a very cost-effective option in many cases, especially where very high levels of mercury reductions are required.

It is important to note that the use of baghouses is also beneficial for very high capture of fine particulates, including other hazardous air pollutants from coal-fired plants such as arsenic, chromium, lead, manganese and nickel.

It's also important to note that when the costs of controlling mercury with ACI - with or without a baghouse - are expressed in terms of cost to the ratepayer (e.g., mills per kWh of electricity), they are quite comparable to the costs currently being incurred for control of pollutants such as NOx. (See Table 4.1.) Note that the table reflects mercury control costs for control strategies that do *not* involve significant capital costs such as those that would be associated with the addition of a baghouse. As indicated in the discussion above, the levelized cost of a baghouse would contribute an additional 0.5 to 1.5 mills per kWh to the values in the table.

Table 4.1 Comparison of Mercury Control Costs with NOx Control Costs

Control Type	Total Annual Cost (mills/kWh)
Mercury Controls	0.18 – 1.15
Low-NOx Burners	0.21 – 0.83
Selective Catalytic Reduction	1.85 – 3.62

Source: Srivastava, R.K., C.B. Sedman, and J.D. Kilgroe. "Preliminary Performance and Cost Estimates of Mercury Emission Control Options for Electric Utility Boilers." AWMA 93rd Annual Conference & Exhibition, Salt Lake City, UT, 2000.

Although ACI technology is well on its way to widespread commercial availability, a number of issues remain, including concerns about the universal applicability of the test demonstrations, operational impacts on equipment such as electrostatic precipitators and fabric filters (which may require more frequent cleanings), unintended environmental and cost impacts (such as contamination of flyash with activated carbon), and stability of the mercury after capture. Notwithstanding these issues, it is worth noting that many years after wide deployment, low-NOx burners still produce high amounts of unburned carbon, SNCR produces "ammonia slip," and N_2O and SCR increases SO_3 in the flue gas, all undesirable side effects but insufficient to preclude their applicability for NOx control.

Enhanced Wet Scrubbing

Another DOE-sponsored program has focused on demonstrating mercury oxidation technology for application in plants with scrubber systems. Two major demonstrations using technology developed by Babcock & Wilcox and McDermott Technology, Inc. were conducted at Michigan South Central Power Agency's Endicott and at Cinergy's Zimmer stations.[11,12] This approach involves the addition of a proprietary chemical reagent to the scrubber system, which is designed to oxidize the elemental mercury present in the flue gas. Removal efficiencies varied considerably between the two sites (about 75 to 80 percent at Endicott versus about 50 percent at Zimmer). Several factors are probably responsible for this variability, including different scrubber chemistries between the two plants. One of the benefits of this approach for plants with scrubber technology is the absence of activated carbon to contaminate the ash. While there is less information about the costs of this technology, Babcock & Wilcox claim its costs should be lower than for a similarly sized ACI-based application.[13]

K-Fuel® Technology

KFX's K-Fuel® technology has been tested in small-scale facilities and a commercial plant, including at the Southern Research Institute and American Electric Power's Clifty Creek Station in Indiana. The first large commercial production plant is being built at the Black Thunder mine in Wright, Wyoming, with expected operation in 2004. This facility will be capable of producing over 700,000 tons per year of K-Fuel.® Results from testing to date have shown mercury reductions of up to about 70 percent.[14]

Powerspan-ECO™

Powerspan-ECO™ tests to date suggest that mercury removals of greater than 80 percent are possible. The technology is currently being demonstrated at an approximately 2 MW size at First Energy's Burger Station in Ohio. It is being scaled up to 50 MW at the Burger Station with expected operation in 2004.[15]

Federal and State Mercury Controls on Waste Combustors

Considering the control of mercury emissions from power plants, it is worth emphasizing that municipal waste combustors (MWCs) have now complied with stringent mercury control requirements for over five years. For example, New Jersey set mercury limits on MWCs that resulted in ACI being installed on 13 units in 1995. EPA finalized New Source Performance Standards for mercury emissions from MWCs in 1995, with compliance required in 1998. MWCs are now required to comply with a federal standard of 0.08 mg/dscm (or 80 micrograms per cubic meter).[16]

MWCs have met this standard and in some cases have been required to meet far more stringent emission limits. Several states (for example, Massachusetts, New Hampshire, Connecticut and New Jersey) have promulgated mercury standards that are almost three times more stringent than the federal standard.[17] MWCs have routinely achieved emission levels far below even the most stringent state standards by using ACI technology. Baghouse-equipped units are achieving emission rates as low as two micrograms per cubic meter. This means that MWCs have reduced their mercury emissions by more than 90 percent - with some facilities achieving reductions of over 98 percent - in the wake of federal and substantially more stringent state emission control requirements.[18]

There are, to be sure, relevant differences between MWCs and power plants, such that the MWC experience is not entirely applicable to coal-fired boilers. For example, the volume of flue gas to be treated is higher at a power plant, the mercury concentration in power plant flue gas is lower than in MWCs, and the chlorine content of coal is generally lower than the chlorine content of municipal waste (resulting in more emissions of elemental mercury, which is harder to control than the oxidized mercury formed in the MWC flue gas). Even when these differences are taken into account, the application of the ACI technology to coal-fired boilers appears to be simply an issue of technology transfer to larger units, which does not depend on any new technology breakthrough.

These differences are, in part, responsible for the absence of fully commercialized mercury-specific technologies for the control of mercury emissions from power plants. Perhaps more important, however, as we discuss in the next chapter, is the fact that federal and state activities on the regulatory front have begun to signal to the marketplace to engage in significant investments in applying these technologies to the power plant sector.

Conclusions

There is increasing evidence that existing control devices designed to control pollutants other than mercury can deliver substantial mercury reductions, and that mercury-specific control technologies are being successfully demonstrated in full-scale field tests. Even without efforts to optimize existing controls, several bituminous coal-fired plants with dry scrubbers and fabric filters have achieved more than 95 percent mercury capture during emission tests, and a number of plants burning subbituminous coal that are equipped with fabric filters and other stack controls achieved over 70 percent mercury capture. Although data for lignite-fired plants are more limited, recent pilot-scale testing indicates that lignite and subbituminous coals are similar with respect to mercury speciation and control.

Mercury-specific controls are developing rapidly toward commercialization. Full-scale demonstrations of ACI technology indicate that mercury removal of over 90 percent is feasible, with costs that are comparable to the costs of NOx removal. For example, pursuant to a recently issued state permit, ACI has been specified as the required control technology for a proposed MidAmerican Energy Company coal-fired plant in Iowa burning subbituminous coal. Other mercury-specific control technologies, including enhanced wet scrubbing, K-Fuel® technology, and Powerspan-ECO™, among them, also show great promise. Enhanced wet scrubbing resulted in removal efficiencies ranging from 50-80 percent. Results from testing of K-Fuel® technology on subbituminous coals show mercury reductions of up to about 70 percent. Powerspan-ECO™ test results are in the 80 percent removal range.

Further, highly successful experience with the control of mercury emissions from municipal waste combustors gives additional reason for confidence regarding our ability to control mercury emissions from the electric sector.

Endnotes

[1] Monroe, L. S., Southern Co. "Senate Environment and Public Works Committee Subcommittee on Clean Air, Climate Change and Nuclear Safety Hearing on S. 485, the Clear Skies Act." June 5, 2003. Online. Available: http://epw.senate.gov/108th/Monroe_060503.htm

[2] Memo to the Utility MACT Workgroup from the Ranking Subgroup. February 5, 2002. Online. Available: http://www.epa.gov/ttn/atw/combust/utiltox/feb5memo.pdf

[3] Memo to the Utility MACT Workgroup from the Ranking Subgroup. February 5, 2002. Online. Available: http://www.epa.gov/ttn/atw/combust/utiltox/feb5memo.pdf

[4] Pavlish, J.H. "Status Review of Mercury Control Options for Coal-Fired Power Plants." Accepted for publication in a special issue of Fuel Processing Technology.

[5] Durham, M., et al, "Full-Scale Evaluation of Sorbent Injection for Mercury Control on Power Plants Burning Bituminous and Subbituminous Coals", Powergen International 2002, Orlando, FL.

[6] Iowa Department of Natural Resources Environmental Services Division Air Quality Bureau. Prevention of Significant Deterioration (PSD) Permit Review Technical Support Document Issuance of PSD Permits for Project Number 02-528, Plant Number 78-01-026. MidAmerican Energy Company.

[7] Durham, M., et al, "Full-Scale Evaluation of Sorbent Injection for Mercury Control on Power Plants Burning Bituminous and Subbituminous Coals", Powergen International 2002, Orlando, FL.

[8] Sjostrom, S. "Analyses of Key Parameters Impacting Mercury Control on Coal-Fired Boilers," Air Quality IV, September 22-24, Arlington, VA; Pavlish, J. "Mercury Control Technologies for Electric Utilities Burning Lignite Coals," NETL, Mercury Control Technology Program Review Meeting, August 12-14, Pittsburgh, PA.

[9] Peltier, R. "Mercury Removal Standards are Coming. Where's the Technology?" POWER, Vol 147, No 4 (May 2003).

[10] Durham, M. "Tools for Planning and Implementing Mercury Control Technology", American Coal Council. 2003. pp 43-46.

[11]Peltier, R. "Mercury Removal Standards are Coming. Where's the Technology?" POWER, Vol 147, No 4 (May 2003).

[12] Farthing, G. "Full Scale Testing of Enhanced Mercury Control Technologies for Wet FGD Systems." NETL Mercury Control Technology R&D Program Review Meeting, Pittsburgh, PA, August 12-13, 2003.

[13] Peltier, R. "Mercury Removal Standards are Coming. Where's the Technology?" POWER, Vol 147, No 4 (May 2003).

[14] Black & Veatch. "Effective Mercury Reduction Strategy for Western Coal/K-Fuel Technology," Report to EPA. March 2003. Online. Available: http://www.kfx.com/index.htm

[15] McLarnon, C. "Mercury Removal in a Non-Thermal Plasma Based Multi-Pollutant Control Technology for Utility Boilers." NETL Mercury Control Technology R&D Program Review Meeting, Pittsburgh, PA, August 12-13, 2003.

[16] 40 C.F.R. 60.33b (2002). Online. July 1, 2002 edition. Online. Available: http://a257.g.akamaitech.net/7/257/2422/14mar20010800/edocket.access.gpo.gov/cfr_2002/julqtr/pdf/40cfr60.33b.pdf

[17] Massachusetts: 310 CMR 7.00; Connecticut: RCSA 22a-174-38; New Jersey: NJAC Title 7, Chapter 27, Subchapter 27.

[18] NESCAUM. Survey of Field Experience with Mercury Control for Municipal Waste Combustors in the Northeast. August 2003.

Chapter 5
Effect of Regulatory Drivers on Technology Development and Costs

Many of the objections being raised by the electric power industry for a stringent requirement to control mercury emissions from coal-fired utility boilers center on the likely availability and cost of control technologies that are not yet fully commercialized, on the limited experience with these technologies, and on the mixed results obtained from research and development. In this regard, the current mercury debate is consistent with earlier regulatory debates relating to control of emissions from this and other industry sectors.

It is illuminating to view this controversy in the context of the encouraging relationship evident over the last several decades between environmental regulatory drivers and technological development. In a September 2000 study entitled "*Environmental Regulation and Technology Innovation: Controlling Mercury Emissions from Coal-Fired Boilers*," NESCAUM undertook case studies regarding the development of control technologies for NOx and SO_2 from power plants and of the control of automobile emissions through the use of technologies and fuels.[1] The major finding of this NESCAUM report was that innovation in control technologies has consistently occurred only *after* regulatory drivers with well-defined targets and deadlines were adopted.

Since compliance costs are an important factor in most regulatory decisions, the NESCAUM report also reviewed the cost histories associated with all three cases. In every case, early estimates consistently overstated actual compliance costs, often by a factor of two or more. Likely reasons included poor or incomplete information, overly conservative assumptions (generally motivated by the industry's desire to bolster the case against regulation), and a failure to account for the technological innovation that appears only after concrete regulatory drivers are in place. Even "independent" estimates tended to exhibit these biases, though typically to a lesser degree. A recent study by researchers at Carnegie Mellon University concurs with NESCAUM's conclusion that environmental regulations stimulate innovations in control technology.[2]

The experience with requirements for the control of NOx and SO_2 emissions from power plants is instructive. Total costs, including both capital and operating and maintenance costs, tended to fall dramatically as control technologies passed from the development

phase to full-scale demonstration and commercialization. In the case of NOx, cost estimates declined by as much as 90 percent (on a cost per ton of NOx removed basis) for SCR technology between 1989 and 1998.[3]

The cost trend for Phase II of the national Acid Rain Program is similarly striking. In 1989, industry estimated that annual compliance costs would range from $4.7 to $6.6 billion per year with trading. A year later, EPA put the range at $1.6 to $5.3 billion per year. By 1997, the estimate of the Electric Power Research Institute had fallen to $1.5 to $2.1 billion per year, three to four times lower than the figures widely cited in the Congressional debates that shaped the 1990 Clean Air Act Amendments.[4]

Overall, the case studies offer these basic insights:

- Costs almost always decline substantially once regulatory mandates are introduced and control technologies are commercialized. A troubling implication of this finding is that there is a risk of enacting weak regulatory drivers that provide a lower level of environmental protection than is reasonably affordable, if policies are established reflecting initial cost over estimates. The Acid Rain Program's requirement of only 50 percent SO_2 control (when more than 90 percent control was reasonable from the perspective of cost and technical feasibility) is a good example of this unfortunate outcome.
- The stringency and timing of emissions reduction requirements strongly influence subsequent technology choices. Weak standards can prove inefficient by promoting investment in control technologies that ultimately achieve inadequate emissions reductions.
- A variety of unpredictable factors can profoundly affect future technology choices. Hence, the most successful regulations have avoided picking technology "winners." Instead, they have focused on establishing well-defined performance requirements and let companies choose optimal technologies.
- A combination of aggressive performance requirements and flexible attainment mechanisms has proven extremely successful in terms of reducing emissions and costs in the past.

Whatever technology or mix of technologies ultimately emerges as optimal for the control of mercury emissions from the electric power sector, one thing is clear: electric industry testing of mercury controls to-date, as well as the experience with controlling mercury emissions from municipal waste combustors, gives no reason to expect that achieving mercury emissions reductions from power plants will pose technological or economic hurdles different in nature or degree from those examined in the NESCAUM report.

Conclusions

A September 2000 NESCAUM report undertook case studies of control technologies for NOx and SO_2 from power plants and of the control of automobile emissions through the use of technologies and fuels. NESCAUM concluded that regulatory drivers with well

defined targets and deadlines are necessary to drive innovation in control technologies. Thus, the report concluded that technological innovation follows, rather than precedes, regulatory requirements. Additionally, in each case early cost estimates dramatically overstated actual compliance costs. Caution must be exercised not to establish emission reduction requirements on the basis of these initial cost estimates, less they lead to weak regulatory policies that provide a lower level of environmental protection than is reasonably affordable.

Endnotes

[1] Amar, P. (Project Director), NESCAUM report. Environmental Regulation and Technology Innovation: Controlling Mercury Emissions from Coal-Fired Boilers. September 2000.

[2] Taylor, M. R., E. S. Rubin, and D. A. Hounshell. "Effect of Government Actions on Technological Innovation for SO_2 Control". Environmental Science and Technology, published online, doi:10.1021/es034223b (2003).

[3] Amar, P. (Project Director), NESCAUM report. Environmental Regulation and Technology Innovation: Controlling Mercury Emissions from Coal-Fired Boilers. Chapter V. September 2000.

[4] Amar, P. (Project Director), NESCAUM report. Environmental Regulation and Technology Innovation: Controlling Mercury Emissions from Coal-Fired Boilers. Chapter V. September 2000.

Conclusion

More than a decade has passed since Congress required EPA to study the effects of mercury emissions from power plants and determine whether regulation is necessary to protect public health. The Agency has determined that such regulation is indeed necessary. In a survey conducted by the Centers for Disease Control and Prevention, one in 12 American women of childbearing age were found to have amounts of mercury in their blood above the levels that EPA considers safe. Forty-five states and American Samoa have issued fish consumption advisories warning of the dangers of eating mercury-contaminated fish. U.S. power plants alone are estimated to account for approximately one-third of the mercury deposited in the country. Their contribution is expected to increase both proportionally and in absolute terms—unless EPA takes appropriate action.

EPA is obligated by a court-approved settlement agreement to issue proposed regulations in December 2003 and final regulations in December 2004 limiting mercury emissions from power plants. The Clean Air Act requires that the standards for existing plants be set with reference to the emission limitations achieved by the best performing plants. Some industry representatives claim that such stringent levels of mercury reduction are unachievable. Mounting evidence regarding mercury control technologies points to the contrary. Further, decades of experience suggest that stringent regulations will lead to both additional innovation in technology and decreased compliance costs.