Appendix III

Mercury Emissions and Their Relationship to Energy Use

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Introduction

Mercury is a naturally occurring element in the environment. It is also used or produced in a variety of industries, and can enter the environment as a result of ore smelting, agricultural practices, production of chlorine and caustic soda and other human activities.

Mercury is a toxic pollutant; it can cause defects in the central nervous system. During the 1950s, industrial discharges of methyl-mercury into Minamata Bay in Japan resulted in the contamination of fish with methyl-mercury; and consequently the poisoning of thousands and deaths of hundreds of individuals.

Mercury has a complex biogeochemical cycle (Figure 1). It can transfer between different ecosystem reservoirs and exhibit chemical transformations that control its behavior and toxicity.

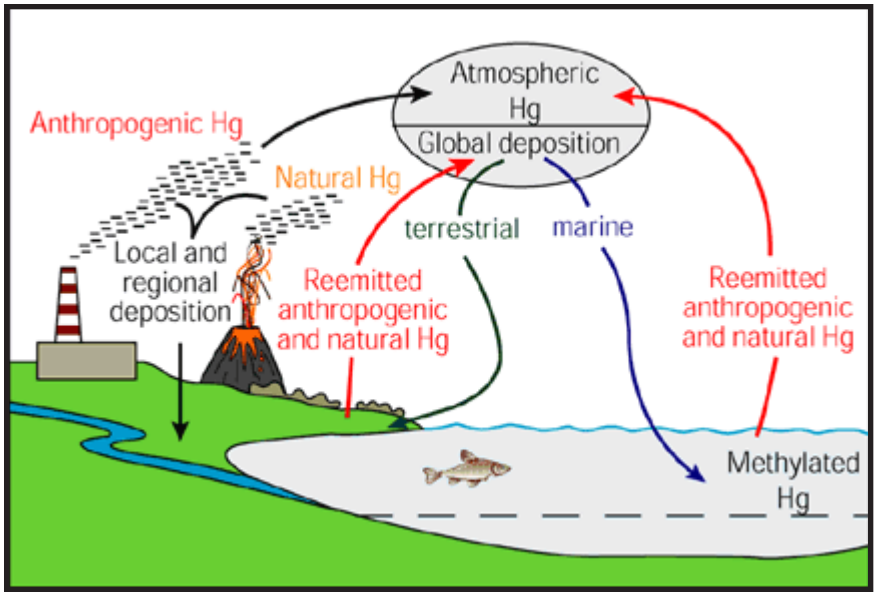


Figure 1. Biogeochemical cycle of mercury in the environment. Credit: USGS, 2008.

In the environment it occurs in various forms, including inorganic mercury ion (Hg^{2+}) , methyl-mercury (CH_3Hg^+) or dimethyl-mercury [$(CH3)_2Hg$]. Methylated mercury compounds are much more toxic then the inorganic mercury. The methylation of mercury results in increased solubility and volatility (of Hg) and increases its movement into the food chain. Methylated compounds are rapidly taken up by aquatic organisms where they bioaccumulate in the fatty tissue, and can become very harmful to that organism or others that consume it.

Mercury in the Environment

When mercury is released in to the atmosphere it falls on earth and runs into lakes, rivers and streams. Bacteria in the water transform the mercury into toxic methyl-mercury. When fish consume these bacteria they become contaminated. As this cycle moves up the food-chain the larger fish end up with higher concentrations of toxic mercury in their flesh. Humans are also exposed to methyl-mercury by eating contaminated fish.

Atmospheric deposition is the primary source of mercury to the water bodies in Minnesota. According to the Minnesota Pollution Control Agency (MPCA, 2005) about 99 percent of mercury that is deposited in Minnesota comes from atmospheric deposition.

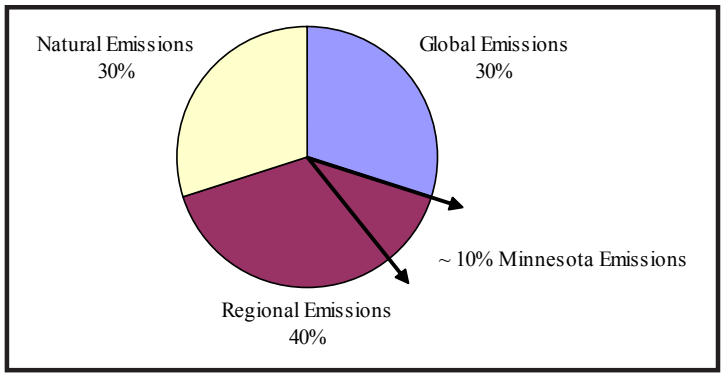


Figure 2. Sources of atmospheric mercury deposition to Minnesota. Credit: MPCA TMDL, 2007; Engstrom and Swain, 1997

Various modeling studies of global mercury cycling have concluded that natural emissions (e.g. volcanoes) contribute 30% to mercury deposition, while the other 70% is a result of human activities (MPCA Total Maximum Daily Loads (TMDL), 2007). Similarly, a recent scientific study in Minnesota (Engstrom and Swain, 1997) indicated that anthropogenic emissions account for 70% of mercury deposition in the state. The authors further stated that 30% of mercury deposition comes from global pollution and 40% comes from regional pollution.

According to the MPCA TMDL (2007) about 10% of total mercury deposition in Minnesota is due to emissions in the state. The sources of atmospheric mercury deposition in Minnesota are summarized and illustrated in Figure 2. Sector specific mercury emissions in the state are discussed in the following section.

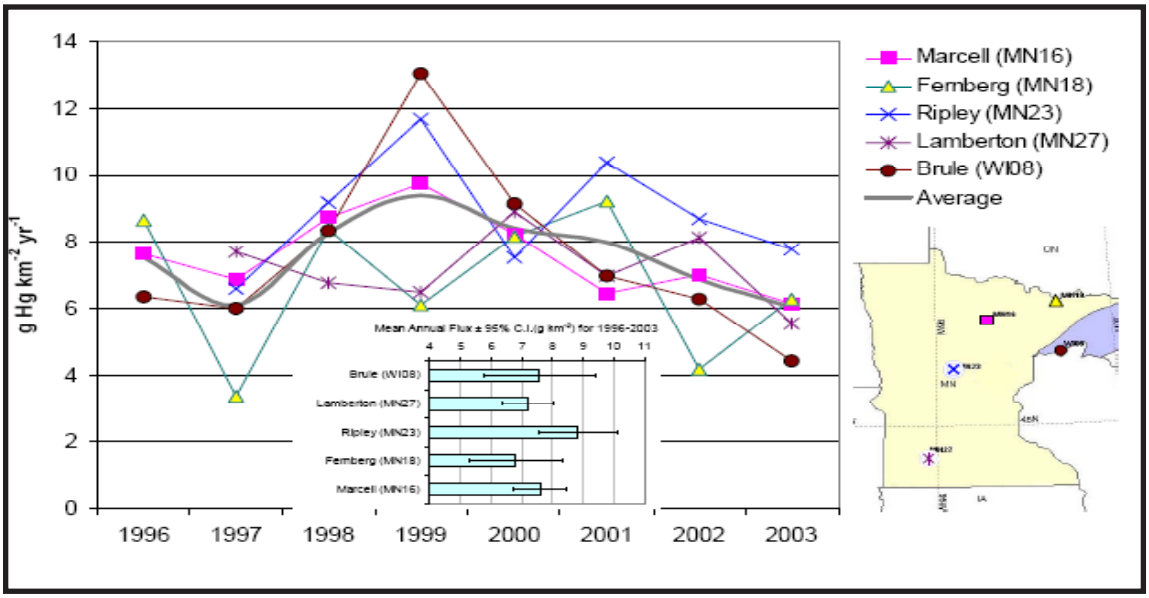


Figure 3. Annual mercury flux at mercury deposition network (MDN) sites in Minnesota. Credit: MPCA TMDL, 2007.

According to the MPCA TMDL (2007) wet deposition rates in Minnesota have not changed significantly since the mid 1990s. This information is presented in Figure 3 which shows an overlap in annual mercury deposition fluxes from fixed monitoring stations in Minnesota and Brule, Wisconsin. The figure also shows that the station mean annual fluxes are not significantly different in the ('96 to '03) period (MPCA TMDL, 2007).

Region	Eco-region	Wetlands (%)	Cultivated (%)	Hay/ Pasture (%)	Lake TP (µg/L)	Stream TP (µg/L)	Lake Chl *a* (µg/L)	Stream Chl *a* (µg/L)
NE	NMW	58.9	8.3	4.6	14 – 27	40 – 90	2-10	3.2
	NLF	26.9	3.6	6.5	14 – 27	20 – 50	2-10	2.1
SW	NCHF	14.9	35.0	23.4	23 – 50	60 – 150	5 – 22	15.8
	RRV	7.3	78.8	6.6	23 – 50	110 – 300	5 – 22	22.1
	NGP	4.6	73.5	16.5	130 – 250	90 – 250	30 – 55	27.1
	DA	4.5	23.8	27.1	N/A	60 – 150	N/A	N/A
	WCBP	2.9	76.8	12.2	65 – 150	160 – 330	30 – 80	23.6

NMW: Northern Minnesota Wetlands RRV: Red River Valley
NLF: Northern Lakes and Forests NGP: Northern Glaciated Plains
NCHF: North Central Hardwoods Forests DA: Driftless Area
WCBP: Western Corn Belt Plains

Land cover data from 1992 (USGS, 1999. Minnesota Land Cover Data Set)

Total phosphorus (TP) and chlorophyll *a* (Chl a) ranges are typical summer lake water quality conditions and typical annual stream water quality conditions for minimally impacted waters (MPCA. 2003. *Comparison of typical Minnesota water quality conditions.* http://www.pca.state.mn.us/publications/wq-s1-02.pdf). Lake data were collected 1985-1988 (Heiskary and Wilson 1989) and stream data were collected 1990-1992 (McCollor and Heiskary 1993).

Table 1. Regional differences in land cover and water quality. Credit: MPCA TMDL, 2007.

Mercury concentrations in fish depend on land cover and land use. Land cover and its use are very important in controlling and affecting (1) watershed transport of mercury, (2) background water chemistry and (3) nutrients (nutrients loading affect the bioavailability of mercury).

Wetlands are important sites of mercury methylation. The methylation occurs under anaerobic conditions which are usually found in wetland soils, and lake sediments (Zillioux *et al.*, 1993). Sulfate reducing bacteria reside in wetlands and are the primary methylators. Usually, wetland density is positively correlated with mercury concentration in fish and water (as seen in data presented in Table 1 and 2).

Cultivated lands are typically sources of suspended solids due to soil erosion. Mercury is associated with high suspended solids loads, but it has low bioavailability because only a small fraction is in the form of methyl-mercury. Table 1 shows regional differences in land use and water quality in Minnesota. The mercury concentrations in fish for the different regions in Minnesota are shown in Table 2.

	Northern Pike (55 cm)	Walleye (40 cm)
NE	0.320	0.268
SW	0.187	0.185
Average	**0.254**	**0.227**

Table 2. Median mercury concentrations for northern pike (NP) and walleye (WE) collected from 1970 to 2002. Credit: MPCA TMDL, 2007.

Mercury Emissions in Minnesota

The MPCA has estimated that mercury anthropogenic emissions from Minnesota sources totaled 3328 pounds (lbs) for 2005, the agency also projected emissions for 2010 (2718 lbs), and 2018 (2012 lbs) (MPCA, 2008). The emissions were divided into four categories: (1) emissions resulting from energy production, (2) emissions due to material processing largely as a result of taconite processing, (3) emission due to purposeful use of mercury, largely as a result of disposal of products and (4) mercury from difficult to categorize sources (i.e. fuel or materials). A summary of emissions sources within these categories is included in Table 3 (next page).

In 2005, 56% of Minnesota's emissions were from energy sources, 22% from taconite processing and 21% from purposeful use. The emissions for 2010 and 2018 are projected to decrease to 2718 and 2012 lb, respectively. Despite the overall reductions in mercury emissions, emissions from the taconite industry are expected to increase by about 14%.

Regulatory Overview

Mercury is released into the environment through emissions from manufacturing, use, or disposal activities. To protect the environment, the US Congress passes laws and oftentimes authorizes the Environmental Protection Agency (EPA) (and other government agencies) to create and enforce these regulations.

Mercury emissions and contamination are addressed under the Clean Air Act (CAA), Clean Water Act (CWA), Resource and Conservation Recovery Act (RCRA), and Safe Drinking Water Act. Under the CAA mercury is listed as a hazardous air pollutant. In accordance with the CAA, power plants were to reduce mercury emission by 90% by 2008, however in 2005, the EPA decided to exempt the power plants from mercury controls until 2010. In February of 2008, the D.C. Circuit court voided EPA's rule to remove the power plants from the CAA's list of resources of hazardous air pollutants.

Under the CWA, water quality standards are set for rivers, lakes, streams and wetlands. The standards identify levels for pollutants including mercury that must be met in order to protect human health, fish and wildlife.

RCRA requires that the EPA manage hazardous wastes, including mercury wastes from the time they are generated, through storage and transportation, to their ultimate treatment and disposal. Safe Water Drinking Act sets standards for drinking water that apply to public water systems. These standards protect people by limiting levels of mercury and other contaminants in drinking water.

On March 15, 2005 the EPA issued a Clean Air Mercury Rule (CAMR) to permanently cap and reduce mercury emissions from coal-fired power plants for the first time. The CAMR would take effect after 2010 and a cap and trade mechanism would be designed to reduce mercury emissions by 70% by 2018. During the same period when CAMR was proposed the EPA made a decision to exempt power plants from mercury controls until 2010. On February 8, 2008 the D.C. Circuit court vacated the EPA's CAMR.

Incidental to Energy Production	*2005 (lbs)*	*2010 (lbs)*	*2018 (lbs)*
Coal-Electric Utility	1710.3	1040.1	414.1
Coal – Commercial, Institutional and Industrial	62.9	68.9	78.6
Volatilization from coal ash	0		
Petroleum Refining	12.9	13.6	14.8
Petroleum Product Utilization	39	41.3	44.9
Wood Combustion	39.4	41.7	45.3
Natural Gas Combustion	0.3	0.3	0.3
Subtotal: Incidental with energy production	**1864.7**	**1205.9**	**598**
% of total state emissions	**56%**	**44%**	**30%**
Largely Resulting from the Purposeful use of Mercury			
Volatilization: solid waste collection and processing	169	152.8	126.8
On site household waste incineration	40	36.2	30
Volatilization from spills and land dumping	24	21.7	18
Land volatilization	2.1	1.9	1.6
Volatilization: land applications of compost	0.2	0.2	0.2
Volatilization: land applications of sludge	1.6	1.3	0.8
Smelters that recycle cars and appliances	138.7	120	90.2
Recycling mercury from products within MN	65	71.3	81.3
Non-ferrous metal recycling (Al, Pb)	7	7.7	8.8
Dental Preparations	62.4	56.4	20.1
Cremation	80	80	80
Municipal solid waste combustion	49.2	38	38
Sewage Sludge Incineration	8.5	8.9	11.9
Medical waste incineration	1.8	2.5	3.7
Hazardous waste incineration	0.3	0.3	0.3
Class IV incinerations	0	0	0
SJE Rhombus switch, Detroit Lakes	42	38	31.5
General Laboratory Use	10	8.1	5
Volatilization from dissipative use	0.8	0.6	0.4
Subtotal: Associated with purposeful use of mercury	**702.6**	**645.8**	**548.3**
% of total state emissions	**21%**	**24%**	**27%**
Emissions Incidental to Material Processing			
Taconite Processing	734.8	840.6	840.6
Thermal treatment of soil	0.8	0.8	0.8
Subtotal: Emissions incidental to material processing	**735.6**	**841.4**	**841.4**
% of total state emissions	**22%**	**31%**	**42%**
Difficult to Categorize (is Hg from fuel or materials?)			
Asphalt Manufacturing	4.3	4.3	4.3
Agriculture, Food Kinder products	1.1	1.1	1.1
Mineral Products	13.8	13.8	13.8
Miscellaneous Industrial Process	0.2	0.2	0.2
Wood, Pulp & Paper, Publishing Products	5.1	5.1	5.1
Subtotal: Emissions from difficult to categorize	**24.6**	**24.6**	**24.6**
% of total state emissions	**1%**	**1%**	**1%**
GRAND TOTAL (lbs)	**3327.5**	**2717.7**	**2012.5**

Table 3. Estimated anthropogenic mercury emissions in Minnesota for 2005, 2010, and 2018. Credit: MPCA, 2008.

On March 15, 2005, the EPA issue the Clean Air Interstate Rule (CAIR), a rule that will dramatically reduce air pollution that moves across state boundaries. CAIR will permanently cap emissions from sulfur dioxide (SO_2) and nitrogen oxide (NO_X) in the eastern US. When the rule is implemented it will reduce SO_2 emissions by over 70% and NO_X emissions by 60% from 2003 levels. This rule affects 28 eastern states and Washington D.C. Minnesota is one of the affected states.

The Minnesota state legislature has set a mercury reduction goal (Minn. Stat. 116. 915) to reduce annual mercury emissions by 60% by 2000, and 70% by 2005 from 1990 levels (MPCA, 2005). According to MPCA estimates, the 1990 Minnesota mercury emissions were 11,272 lbs and 3,328 lbs in 2005 (MPCA, 2005). The goals have been met through a combination of federal and state initiatives, voluntary actions, and programs. It is important to note that majority of these reductions were related to the emissions from products containing mercury.

Additionally in 1999, the MPCA established a voluntary mercury-reducing agreement program. The program aims to reduce emissions from electrical utilities, and it has four actions that when implemented will reduce annual mercury emissions from facilities by 275 lbs:

- In 2000, Minnesota Power switched to low mercury coal (reduction by 70 lbs)
- In 2003, Xcel Energy replaced two coal burning units at Black Dog plant with natural gas fired turbine generators (reduction 35 lb)
- By 2009, under (MERP) Xcel Energy's Allen S King, High Bridge and Riverside plants will switch to natural gas and add scrubbers and fabric filters to the King plant (reduction of 170 lbs)

In 2006, under the direction of Gov. Tim Pawlenty, the MPCA and selected stakeholders (electrical utilities, environmental groups, and government agencies) developed the Minnesota Mercury Emissions Reduction Act. When fully implemented it will result in a 90% reduction from generation units at Minnesota's three largest coal fired power plants. These include the Xcel Energy Sherco and Allen S. King plants, and the Minnesota Power Clay – Boswell plant. The plan should be fully implemented by 2014 (MPCA, 2006).

Section 303 (d) of the Federal CWA requires every state to prepare a list of impaired waters. In the state's 2004 303 (d) list of impaired waters (MPCA TMDL, 2007), about 66% of the 1,892 impaired lakes and river reaches were impaired due to mercury contamination (fish tissue, water column or both). The CWA requires that each impaired water body have a total maximum daily loads (TMDL) study. The TMDL is an evaluation of (1) pollution sources; (2) pollutant load reduction needs to meet water quality standards and (3) allocation of the acceptable load to all sources (TMDL, 2007). The Minnesota TMDL plan was approved by the EPA in 2007, and it established a new goal for mercury emissions of 789 lbs/yr.

The state of Minnesota has clearly demonstrated its commitment to reducing mercury loads into the environment through both voluntary and regulatory approaches. As discussed previously in the report the state emissions contribute a relatively small percentage to the overall mercury deposition in the state. Although welcome and important, the state actions will not be enough. The previous discussions illustrate the importance for the development and implementation of a national program that regulates emissions from existing and future mercury sources.

Mercury Fish Concentrations

Currently, the link between mercury emissions and bioaccumulation in the fish and biota cannot be modeled accurately. In the absence of such models that correctly incorporate the complexities of atmospheric chemistry, watershed transport, methylation and bioaccumulation, researchers depend on the following assumptions (Jackson *et al.*, 2000):

- A reduction in emissions from sources in a given source area (local, regional or global) results in a proportional reduction in the rate of deposition in Minnesota attributable to those sources.
- A reduction in deposition results in a proportional reduction in mercury loading to water bodies.
- Within a given water body, a proportional reduction in mercury loading in the water results in a proportional reduction in mercury concentrations in fish.

Proportionality between mercury deposition and bioaccumulation assumes that bioavailability of mercury is constant, and is unaffected by the rate of atmospheric mercury deposition. These models assume that mercury in the terrestrial watershed and sediments will equilibrate and reach a new steady state proportional to atmospheric deposition.

For the purpose of this report, we will use the EPA's Mercury Maps model to predict the effects of mercury reductions (in air) on mercury concentrations in fish. The Mercury Maps tool (EPA, 2001) has the following features:

> *"Mercury Maps is a tool that relates changes in mercury air deposition rates to changes in mercury fish tissue concentrations, on a national scale. The tool utilizes a reduced form of accepted mercury fate and transport models applied to watersheds in which air deposition is the sole significant source…The Mercury Maps model states that for long-term steady state conditions, reductions in fish tissue concentrations are expected to track linearly with reductions in air deposition watershed loads."*

The Mercury Maps report describe the relationship as:

$$\frac{C_{fish,t2}}{C_{fish,t1}} = \frac{(L_{air,t2} + L_{other,t2})}{(L_{air,t1} + L_{other,t1})} \quad (1)$$

where $C_{fish,t1}$ and $C_{fish,t2}$ are the mercury concentrations in fish at times 1 and 2, which could be the baseline and target times; $L_{air,t1}$ and $L_{air,t2}$ are the air deposition mercury loads at each time to a water body, including direct deposition and indirect deposition via the watershed; and L_{other} is loading from other sources (MPCA TMDL, 2007).

Air deposition can be describe as:

$$L_{air} = D_y * (A_L * r + A_W) \quad (2)$$

where D_y is the annual air deposition flux of mercury (g km^{-2} y^{-1}); r is the runoff coefficient (also known as the delivery ratio); A_L and A_W are the areas of land and water (km^2). Assuming areas and r for each region do not

change from t_1 to t_2, this definition of L_{air} can be substituted into equation 1, areas will not change from t_1 to t_2 and, therefore areas drop out of the equation (MPCA TMDL, 2007).

Combining Equations 1 and 2, and including the bioavailability factor, the relationship becomes:

$$\frac{C_{fish,t2}}{C_{fish,t1}} = \frac{D_{y,t2} * r_{t2} * b_{t2}}{D_{y,t1} * r_{t1} * b_{t1}} \quad (3)$$

where *b* is the bioavailability factor.

We are assuming *r* and *b* do not change over time; therefore, their ratios at times 2 and 1 equal one and drop out of the equation. Therefore, Equation 3 simplifies to:

$$\frac{C_{fish,t2}}{C_{fish,t1}} = \frac{D_{y,t2}}{D_{y,t1}} \quad (4)$$

Rearranging the equation to solve for fish concentration at time t2:

$$C_{fish,t2} = \frac{D_{yt2}}{D_{yt1}} * C_{fish,t1} \quad (5)$$

According to the data in the MPCA TMDL (2007) the most recent measurement of total mercury deposition (wet and dry) in Minnesota was based on lake sediment cores collected in 1990. The best estimate of total mercury deposition around 1990 was 12.5 g km^{-2} yr^{-1} (MPCA TMDL, 2007).

	Baseline (1988-1992) fish concentrations (ppm)	
	Northern Pike (55 cm)	Walleye (40 cm)
NE	0.293	0.262
SW	0.203	0.218
Average	**0.248**	**0.240**

Table 4. Baseline fish concentrations in Minnesota for northern pike and walleye. Credit: MPCA TMDL, 2007.

Using baseline data from the MPCA TMDL (2007) and mercury emissions from MPCA (2008) we evaluated the impacts of various mercury reduction scenarios on concentrations of mercury in fish. These findings are presented below.

Scenario 1

2010 Fish Mercury Concentrations

- Assumption
  - Only MN emissions changed (regional, national and global contributions to deposition stayed the same)
- In 2010, MN Hg emissions = 2718 lbs
  - that is 75.89% reduction from baseline established in 1990 (11272 lbs)
  - Assuming that 50% of MN emissions deposited in the state; total mercury deposition in the state was reduced by 7.59%
  - The deposition rate changed from 12.5 g km^2/yr to 11.55 g km^2/yr

$$C_{fish,\,t2} = \frac{D_{y,t2}}{D_{y,t1}} \cdot C_{fish,\,t1}$$

$$C_{NP}(2010) = \frac{11.55 \text{ g km}^2\text{/yr}}{12.5 \text{ g/km}^2\text{/yr}} \cdot 0.248 = 0.229 \text{ ppm}$$

$$C_{WE}(2010) = \frac{11.55 \text{ g km}^2\text{/yr}}{12.5 \text{ g/km}^2\text{/yr}} \cdot 0.240 = 0.222 \text{ ppm}$$

Scenario2

2018 Fish Mercury Concentrations

- Assumption
  - Only MN emissions changed (regional, national and global contributions to deposition stayed the same)
- In 2018, MN Hg emissions = 2012 lbs
  - that is 82% reduction from baseline established in 1990 (11272 lbs)
  - Assuming that 50% of MN emissions deposited in the state; total mercury deposition in the state was reduced by 8.2%
  - The deposition rate changed from 12.5 g km^2/yr to 11.47 g km^2/yr

$$C_{fish,\,t2} = \frac{D_{y,t2}}{D_{y,t1}} \cdot C_{fish,\,t1}$$

$$C_{NP}(2018) = \frac{11.47 \text{ g km}^2\text{/yr}}{12.5 \text{ g/km}^2\text{/yr}} \cdot 0.248 = 0.228 \text{ ppm}$$

$$C_{WE}(2018) = \frac{11.47 \text{ g km}^2\text{/yr}}{12.5 \text{ g/km}^2\text{/yr}} \cdot 0.240 = 0.220 \text{ ppm}$$

Scenario 3

2018 Fish Mercury Concentration

- Assumption
  - MN emissions changed
- In 2018, MN Hg emissions = 2012 lbs
  - that is 82% reduction from baseline established in 1990 (11272 lbs)
  - Assuming that 50% of MN emissions deposited in the state; total mercury deposition in the state was reduced by 8.2%
- Assumption
  - US emissions changed (decreased by 20%)
  - Assuming that US emissions contribute 30% to mercury deposition in the state (15% Midwest and 15% outside Midwest) then the projected reduced deposition in MN is by 6% (20% of 30%)
- The deposition rate changed from 12.5 g km^2/yr to 10.7 g km^2/yr

$$C_{fish,\,t2} = \frac{D_{y,t2}}{D_{y,t1}} \cdot C_{fish,\,t1}$$

$$C_{NP}(2018) = \frac{10.7 \text{ g km}^2/\text{yr}}{12.5 \text{ g/km}^2/\text{yr}} \cdot 0.248 = 0.212 \text{ ppm}$$

$$C_{WE}(2018) = \frac{10.7 \text{ g km}^2/\text{yr}}{12.5 \text{ g/km}^2/\text{yr}} \cdot 0.240 = 0.205 \text{ ppm}$$

Scenario 4

2018 Fish Mercury Concentration

- Assumption
  - MN emissions changed
- In 2018, MN Hg emissions = 2012 lbs
  - that is 82% reduction from baseline established in 1990 (11272 lbs)
  - Assuming that 50% of MN emissions deposited in the state; total mercury deposition in the state was reduced by 8.2%
- Assumption
  - US emissions changed (decreased by 30%)
  - Assuming that US emissions contribute 30% to mercury deposition in the state (15% Midwest and 15% outside Midwest) then the projected reduced deposition in MN is by 9% (30% of 30%)
- The deposition rate changed from 12.5 g km^2/yr to 10.35 g km^2/yr

$$C_{fish,\,t2} = \frac{D_{y,t2}}{D_{y,t1}} \cdot C_{fish,\,t1}$$

$$C_{NP}(2018) = \frac{10.35 \text{ g km}^2/\text{yr}}{12.5 \text{ g/km}^2/\text{yr}} \cdot 0.248 = 0.205 \text{ ppm}$$

$$C_{WE}(2018) = \frac{10.35 \text{ g km}^2/\text{yr}}{12.5 \text{ g/km}^2/\text{yr}} \cdot 0.240 = 0.199 \text{ ppm}$$

Scenario 5

2018 Fish Mercury Concentration

- Assumption
  - MN emissions changed
- In 2018, MN Hg emissions = 2012 lbs
  - that is 82% reduction from baseline established in 1990 (11272 lbs)
  - Assuming that 50% of MN emissions deposited in the state; total mercury deposition in the state was reduced by 8.2%
- Assumption
  - US emissions changed (decreased by 40%)
  - Assuming that US emissions contribute 30% to mercury deposition in the state (15% Midwest and 15% outside Midwest) then the projected reduced deposition in MN is by 12% (40% of 30%)
- The deposition rate changed from 12.5 g km^2/yr to 9.98 g km^2/yr

$$C_{fish,\,t2} = \frac{D_{y,t2}}{D_{y,t1}} \cdot C_{fish,\,t1}$$

$$C_{NP}(2018) = \frac{9.98 \text{ g km}^2/\text{yr}}{12.5 \text{ g/km}^2/\text{yr}} \cdot 0.248 = 0.198 \text{ ppm}$$

$$C_{WE}(2018) = \frac{9.98 \text{ g km}^2/\text{yr}}{12.5 \text{ g/km}^2/\text{yr}} \cdot 0.240 = 0.192 \text{ ppm}$$

Scenario 6

2018 Fish Mercury Concentration

- Assumption
  - MN emissions changed
- In 2018, MN Hg emissions = 2012 lbs
  - that is 82% reduction from baseline established in 1990 (11272 lbs)
  - Assuming that 50% of MN emissions deposited in the state; total mercury deposition in the state was reduced by 8.2%
- Assumption
  - US emissions changed (decreased by 50%)
  - Assuming that US emissions contribute 30% to mercury deposition in the state (15% Midwest and 15% outside Midwest) then the projected reduced deposition in MN is by 15% (50% of 30%)
- The deposition rate changed from 12.5 g km^2/yr to 9.6 g km^2/yr

$$C_{fish,\,t2} = \frac{D_{y,t2}}{D_{y,t1}} \cdot C_{fish,\,t1}$$

$$C_{NP}(2018) = \frac{9.6 \text{ g km}^2/\text{yr}}{12.5 \text{ g/km}^2/\text{yr}} \cdot 0.248 = 0.190 \text{ ppm}$$

$$C_{WE}(2018) = \frac{9.6 \text{ g km}^2/\text{yr}}{12.5 \text{ g/km}^2/\text{yr}} \cdot 0.240 = 0.184 \text{ ppm}$$

The previous mercury reduction scenarios show trends in fish concentrations under various circumstances. Present day concentrations of mercury in Northern Pike average 0.248 ppm. Full implementation of the Mercury Reduction Act in Minnesota would decrease these average concentrations to 0.228 ppm. If mercury emissions from outside Minnesota decreased by 50%, average mercury concentrations in Northern Pike would decrease to 0.190 ppm. This shows that the greatest reductions occur when reductions in mercury emissions occur on the national scale and not just within the state.

Reductions in mercury emissions and deposition should result in reduced fish contaminations (Harbik and Watras, 2002). Although it is difficult to monitor and report on mercury concentrations in fish because levels vary by species and size, it is possible to monitor and report trends by reporting on one species and within that species normalizing concentrations to a standard length.

Renewable Energy

The energy sector is a major source of mercury emissions into the environment. In Minnesota, electrical generators powered by fossil fuels are responsible for more then half of all mercury emissions resulting from human activity. Switching a substantial fraction of Minnesota electrical generating capacity from fossil fuels to renewable technologies such as biomass, solar or wind-powered turbines would help to reduce mercury emission from this sector. Table 5 shows the amounts of mercury emissions for each generation option. However, due to their relatively high cost, renewable energy can produce only a small percentage of total electrical power in the state and the nation.

Generation options	*Mercury emissions (kg Hg/TWh)*
Natural Gas c.c. (turbines)	0.3 to 1
Bituminous coal: modern	1 to 360
Lignite: old plant	2 to 42
Heavy oil: no scrubbers	2 to 13
Hydropower run-of-river	
Biomass combustion	0.5 to 2
Nuclear	
Wind power	0
Solar photovoltaic	0

Table 5. Electrical generation options and their impact on mercury emissions. Credit: EPA, 1997.

Increased biomass utilization would have enormous environmental and human health benefits. Compared with coal, biomass feedstock would have lower levels of sulfur and sulfur compounds, thus substituting biomass for coal in power plants has an effect of reducing sulfur dioxide (SO_2) emission. Additionally, biomass co-firing with coal has been demonstrated to reduce nitrogen oxide (NO_X) emissions (Huss and Tilman, 2000). The most significant environmental benefit of biomass is a potential reduction in carbon dioxide (CO_2) emissions.

Emerging renewable energy sources such as biofuel for ethanol, wind or solar power may require large land areas. This may be in conflict with population growth which requires more land for farms, cities and industries. Studies show that relative to coal, renewable sources of energy require a lot more land (Gagnon *et al.*, 2002). Land constraints may limit the future development of renewable energy sources. The limitations may depend on many factors including population density, compatibility of project with other land uses such as for recreation, forestry or agriculture, competition with food production.

It is important to note that many researches find that most renewable energy projects will have little negative impact on agriculture. For wind-power, the land around the windmills may be used for agriculture. Solar energy can be developed on rooftops or arid areas where agriculture is absent (Gagnon *et al.*, 2002).

For the purpose of this report we examined several different scenarios that estimated the amounts of biomass and acres of land that may be needed in order to produce a specific amount of energy in the state. Electrical demand in Minnesota was projected as a function of personal income up to 2050 (See Section IV of Energy Production and Use Report). We assumed that in-state coal would generate 62.4% of electrical demand every year (an average from 1970 - 2005). From these data we estimated amounts of biomass needed if 10, 20, 30,

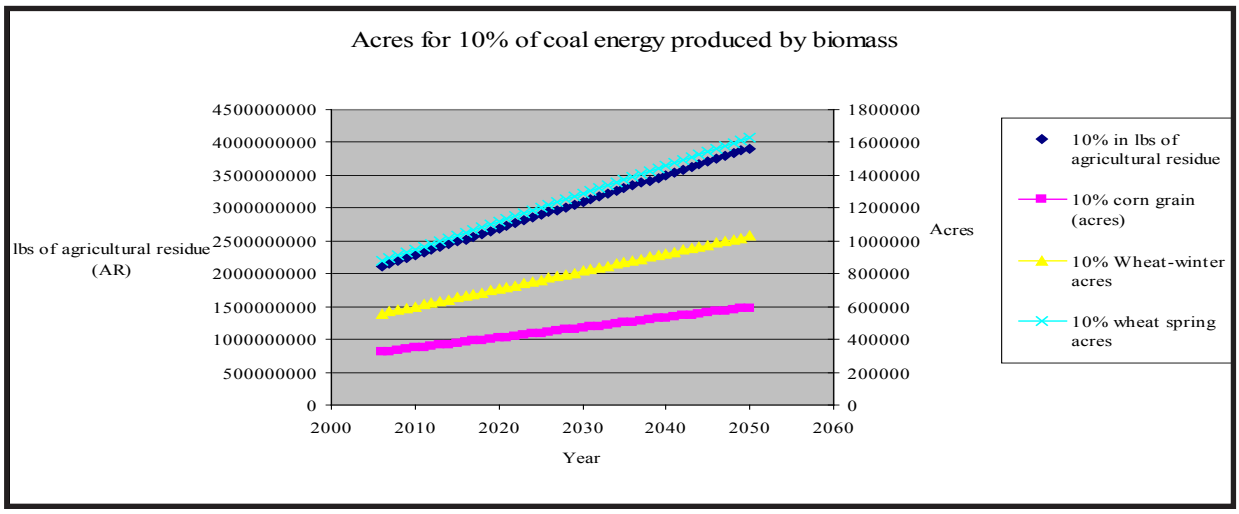
Crop	**Acres harvested or reserved**	**Product Yield**	**Fiber Yield**	**Residue Yield**	**Total crop-land plant mass**	**Total residue produced**
	million acres	dry tons/acre/year			million dry tons/year	
Corn Grain	68.8	3.3	NA	3.3	450.0	225.0
Sorghum	8.6	1.4	NA	1.4	24.8	12.4
Barley	4.3	1.2	NA	1.8	12.8	7.7
Oats	1.9	0.8	NA	1.7	4.8	3.2
Wheat-winter	31.3	1.1	NA	1.9	95.4	60.1
Wheat-spring	17.5	0.9	NA	1.2	35.5	20.1
Soybeans	73.0	1.1	NA	1.6	193.0	115.8
Rice	3.3	2.9	NA	4.3	23.7	14.2
Cotton lint	13.8	0.3	NA	1.0	17.7	13.3
Alfalfa	23.8	3.0	NA	0.0	70.6	0.0
Other hay	39.7	1.7	NA	0.0	67.4	0.0
Silage corn	6.1	6.6	NA	0.0	40.8	0.0
Silage sorghum	0.3	4.4	NA	0.0	1.5	0.0
Other Crops	20.1	1.0	NA	1.0	20.1	20.1
Crop failure	10.0	0.5	NA	0.0	5.0	0.0
Summer fallow	21.0	0.0	NA	0.0	0.0	0.0
Grasses (CRP)	25.4	2.0	NA	0.0	50.8	0.0
Trees (CRP)	2.2	2.0	NA	0.0	4.4	0.0
Environment (CRP)	6.4	2.0	NA	0.0	12.7	0.0
Unaccounted	3.0	0.0	NA	0.0	0.0	0.0
Pasture	67.5	1.5	NA	0.0	101.3	0.0
Wood fiber	0.1	0.0	6.0	2.0	0.8	0.2
Perennials	0.0	0.0	0.0	0.0	0.0	0.0
Totals	**448.1**				**1233.1**	**492.1**

Table 6. National statistics for acres of crop harvested and resulting biomass production. Credit: U.S. Department of Energy and USDA, 2005.

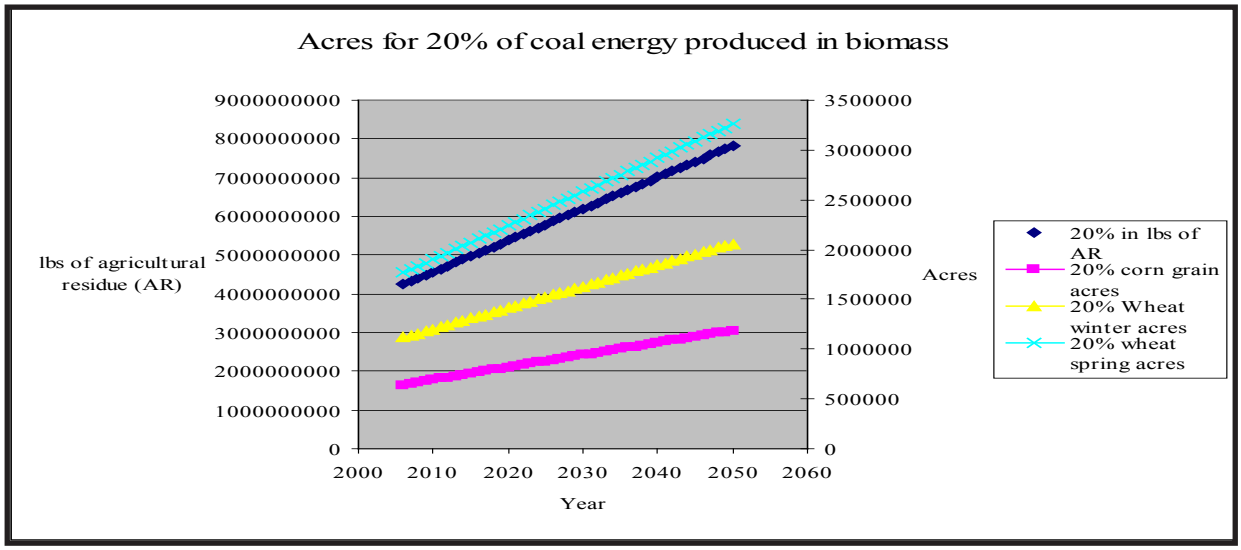
40 and 50% of Minnesota's coal generated electricity was produced from renewable sources. For each percentage we estimated the acreage needed if biomass came from corn grain residue, wheat residue (spring and summer). It was assumed that energy content of agricultural residue was 5,800 Btu/lb. This number is an average taken from data for energy content of agricultural residue provided by the US. Dept. of Energy. The average number is taken because energy content depends on the moisture content of biomass. To estimate the acreage needed to produce the biomass we used data provided in Table 6 (US Department of Energy and US Department of Agriculture, 2005).

Acreage estimates and biomass requirements for replacing coal based electricity are presented below:

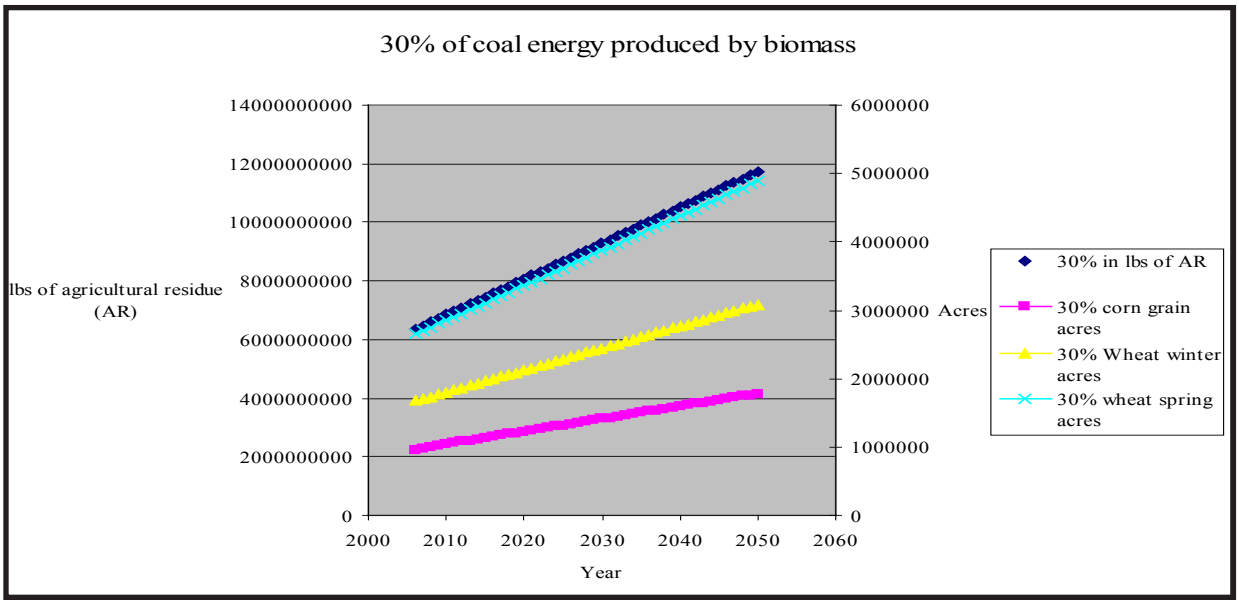
Scenario 1



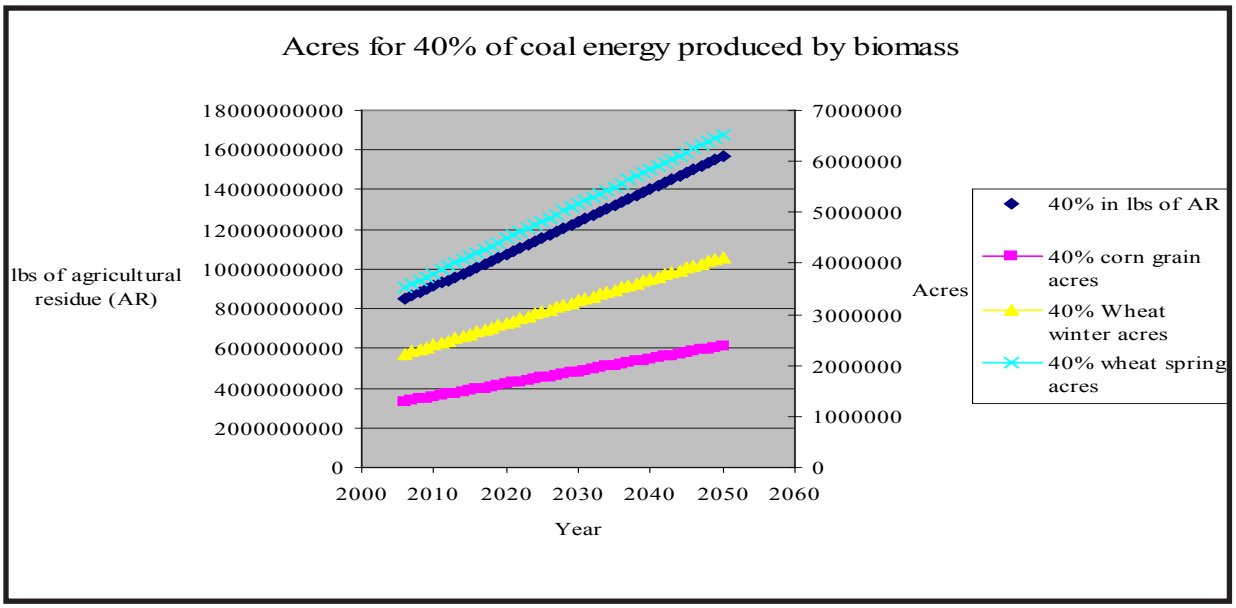
Scenario 2



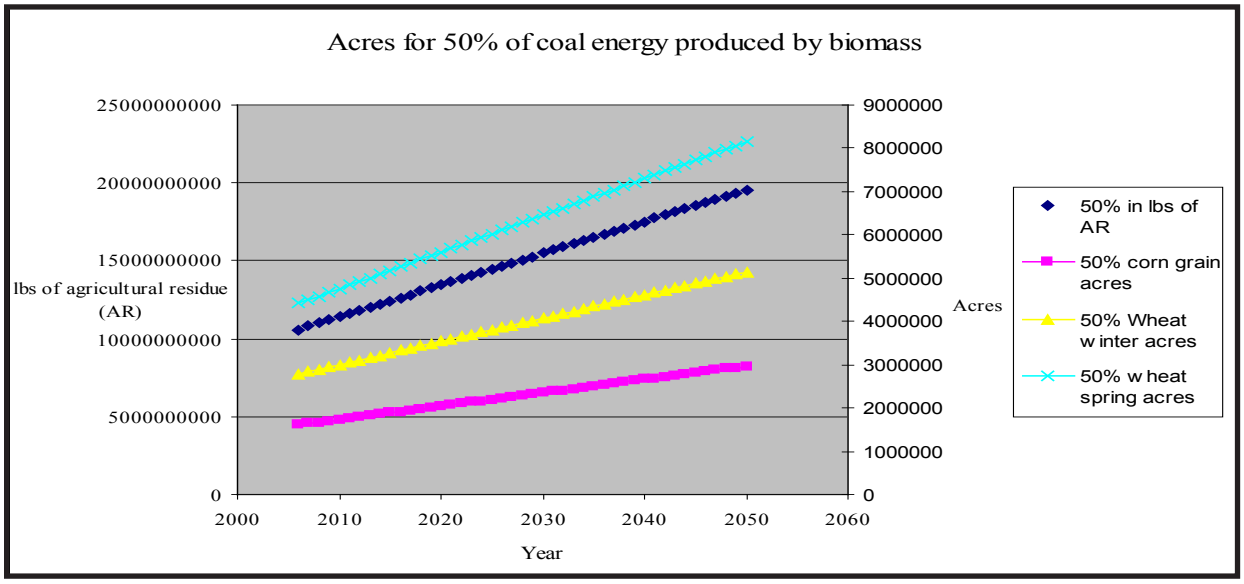
Scenario 3



Scenario 4



Scenario 5



Depending on the scenario, the amount on agricultural residue needed to replace the coal generated electricity varies between $2x10^9$ lbs to $2x10^{10}$ pounds The acreage to produce the biomass also varies depending on the scenario. Agricultural residue from corn grain requires smallest amount of acres.

Conclusions

Mercury is a naturally occurring toxic pollutant. It is also released into the environment by human activities. Mercury is an environmental problem because it bio-accumulates in fish tissue, and can adversely affect human health and wildlife.

For the most part, environmental concentrations of mercury depend on anthropogenic emissions, and reductions in the anthropogenic emissions will lead to reductions in environmental concentrations.

Minnesota has taken both voluntary initiatives and regulatory action to reduce mercury loads into the environment. Although somewhat difficult to measure, the experimental data shows that the reduction strategies have been successful in decreasing environmental mercury contamination; specifically this reduction is seen in fish mercury levels.

Scientific research has shown that the state contributes very little to the overall deposition of mercury in the state. Although these reductions are beneficial, reductions at the national/regional/global scale would have a much greater impact, because mercury is transported by the atmosphere to lakes and rivers around the world.

In Minnesota, electrical generators are the major source of mercury emissions into the environment. Switching to renewable technologies such as biomass, wind or solar power would reduce significantly reduce mercury emissions from the state and the nation if applied on a regional/national level.