

## 8.0 DETAILED OPTION DESCRIPTIONS

This part includes detailed descriptions of the most technically feasible options identified for reducing mercury releases. The process used to develop options is described in Part 4. This part is presented in sections that relate to different source categories:

- 8.1 Utility Sources
- 8.2 Taconite Sources
- 8.3 Products, Manufacturing and Waste Sources
- 8.4 Parking Lot option: Land Application of Wastewater sludge vs. Incineration

### 8.1 Utilities

A Utilities and Taconite (UTAC) subcommittee was formed to describe mercury reduction options for the electrical utility and taconite industries. The first task of the UTAC subcommittee was to make a comprehensive list of options for reducing mercury emissions from electric utilities. In this report, “utilities” refers to organizations that generate electricity. Representatives of the largest utilities in the state participated on the Utilities and Taconite Subcommittee: Northern States Power Company (NSP), Minnesota Power (MP), and Cooperative Power (CP). A utilities sub-subcommittee, with representatives from utility firms and environmental interest groups, narrowed the list of options to those considered most feasible, then looked for detailed information regarding the remaining “short-listed options, with an emphasis placed on each option’s reduction potential and cost-effectiveness.”<sup>1</sup>

The UTAC Subcommittee completed its work in 1998. Meanwhile, investigation and research into controlling mercury has continued. A description of research into mercury control technologies for utilities has been published by the Air and Waste Management Association of a critical review of mercury control for utilities<sup>2</sup>. This publication reviews the status of research into basic science of mercury emissions, measurement techniques, and different air pollution control techniques under development. The review also makes preliminary cost estimates for controlling mercury emissions nationwide from the electrical power utility industry.

Additional research is required to determine the interactions of gas temperature and composition, mercury concentration and speciation, and sorbent characteristics to accurately assess and improve their effectiveness.

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<sup>1</sup> For additional information regarding options for utilities, reference “Lake Superior Energy Efficiency Work Group: Report of Initial Findings” by the Wisconsin Energy Conservation Corporation, July 22, 1998, and the EPA Mercury Report to Congress, Volume VIII.

<sup>2</sup> Brown, T.D., Smith, D.N., Hargis, R.A., and O’Dowd, W.J. “1999 Critical Review Mercury Measurement and Its Control: What We Know, Have Learned, and Need to Further Investigate” Presented at the Air & Waste Management Association 92<sup>nd</sup> Annual Meeting and Exhibition, St. Louis, MO June 23, 1999. *Journal of the Air & Waste Management Association*. June 1999.

**General Comments:** Mercury emissions from coal-fired power plants are higher than mercury emissions from power plants that rely on natural gas, fuel oil, wood, but are most often lower than power plants or combustors burning municipal solid waste on a mass per megawatt basis. Federal and state rules are in effect or soon forthcoming for controlling mercury emissions from municipal waste combustors by up to 90 percent. Consideration of utility options is therefore focused on coal-fired power plants.

Four general types of options have been identified. The options are presented in Tables A-1 to A-4 below. Table A-1 describes options using other energy sources instead of coal. Table A-2 describes options using control technology to decrease mercury emissions from coal-fired power plants or coal cleaning. Table A-3 describes options for reducing the amount of coal burned by reducing the demand for electricity or increasing the amount of energy produced and used per ton of coal burned. Table A-4 describes options not related to fuel use.

Costs are not estimated for all options: (e.g., source monitoring that uses “continuous or discrete” methods). Research is needed to test methods for continuous, on-line monitoring of mercury emissions. Real-time data could be used to optimize injection systems/rates such that emission control goals are met without injecting too much sorbent material. Discrete measurement techniques – some of which are already available -- could be considered for use as an alternative.

**Table A-1. Energy Source Substitution and Fuel Switching Options  
for Reducing Mercury Emissions from Utilities**

<b>Energy Source or Fuel Switch</b>	<b>Consider in Detail?</b>
Solar	No <sup>1</sup> . This option has low potential for generating a large quantity of electricity (at least in Minnesota).
Wood/biomass Co-firing	Yes.
Petroleum coke	No. Further research is needed to determine the potential for co-firing petroleum coke to affect mercury emissions.
Solid waste	No. This option has low potential for generating a large quantity of electricity.
Wind	Yes.
Natural gas Co-firing	Yes.
Landfill gas	No. This option has low potential for generating large quantities of electricity.
Fuel cells	No. New technology which is currently high cost with low potential for generating significant electricity in near future (less than ten years), although long-term potential may exist.
Hydro	No. Hydro sources already developed. Further development not politically feasible. Potential mercury increases from flooded areas.
Petroleum	No. Cost per megawatt generated would be very high.
Nuclear	No. Politically infeasible due to lack of waste storage (although the potential for this source to provide a large, constant supply of energy is high).
Coal Source Switching	Yes.
Tire-derived Fuel	No. This option has low potential for generating large quantities of electricity.
Geothermal	No. Minnesota's geology is not conducive to this option.

1) A number of options are rejected because they have low potential for generating large quantities of electricity. Low potential for generating significant quantities of electricity translates to low potential for reducing mercury emissions, because to reduce mercury emissions from electrical generation, an option needs to replace existing capacity or to allow operators to avoid building new coal-fired generating capacity.

**Table A-2. Air Pollution Control Technology Options for Reducing Mercury Emissions from Utilities**

<b>Type</b>	<b>Consider in Detail?</b>
<b>Sorbent injection</b>	
Activated carbon injection	Yes.
Flyash re-injection	No. Limited information
Change mercury from elemental to ionic form.	No. Limited information
<b>Sorbent Beds and Filters</b>	
Gold technologies	No. Limited Information/Emerging Technology
Solid Selenium silt	No. Limited information
Fluid bed	
Carbon bed	
<b>Flue Gas Scrubbing Techniques</b>	
Wet scrubber	Yes. Consider in detail, especially addition of lime to increase removal of SO <sub>2</sub> and ionized mercury
Dry scrubber	
Scrubber modifications	
Additional towers	
Slipstream	
<b>Others/Emerging</b>	
Corona Discharge/plasma	No. Emerging technology
Condensing heat exchanger	No. Emerging technology
<b>Coal cleaning</b>	
Sub-bituminous	Yes. Consider in detail.
Lignite	Yes. Consider in detail.
<b>Coal drying</b>	No. Not applicable in Minnesota

**Table A-3. Energy Efficiency Options.**

These options were considered in general rather than as distinct options.

Type	Consider in Detail?
<b>Potential Demand-Side Management Programs</b>	
Consumer power conservation education	
Consumer rebates	
Energy conservation programs	
Industrial energy audits	
Energy services for new construction	
Increased energy efficiency at power plants: new or existing	
Industrial power conservation education	
Peak clipping programs	
Consumer energy audits	
Green lights (fluorescent light-bulb replacement programs) Education: Consumer or Provider	
Process change efficiencies	
Builder/operator training	
Co-generation: heat recovery or electric recovery	

**Table A-4. Ash and Product-related Options for Reducing Mercury Emissions from Utilities**

Type	Consider in Detail?
Reduce mercury volatilization from landfilled coal ash	No. Limited information, more research needed
Phase out of mercury containing equipment at utility facilities	Yes.
Purchase low/no mercury equipment and chemicals at utility facilities	Yes.

**1.1.1. Energy Source Substitution and Fuel Switching Options**

The UTAC Subcommittee did not consider the use of low-mercury energy sources at new power plants. Rather, the focus was on replacements for coal from existing sources. Three of these potential replacement sources, biomass, wind, and natural gas, are discussed in detail below. However, the Advisory Council should consider creating incentives for new energy sources to be low mercury emitters. Part 14.0 (Appendix G) briefly describes the process for public review of proposed new electric generating facilities.

The following comments are applicable to all energy source substitution or fuel switching options:

**Reduction Potential:**

- The energy source/fuel switching options replace existing coal-fired generation, though it would be appropriate to consider any fuel switching that would result in a decrease of mercury emissions.
- Analysis must account for the potential for mercury release from the alternative energy source.
- All options under this category would be permanent and could be considered a type of pollution prevention.
- The type of mercury release affected is mainly air emissions, although these options would also decrease the amount of mercury going to land.
- Emission source operators would determine the speciation (i.e., the chemical type) of mercury release prevented. In certain cases, such as co-firing petroleum coke, the speciation of remaining mercury emissions may be affected.

**Cost-Effectiveness:**

- Costs of using alternative energy sources to produce electricity at a new generating plant are lower than the costs of using the alternative source to replace existing capacity at a plant, which is still at “pre-retirement age.” If a coal-fired boiler is ready for replacement, the substitution options may be cost effective. For these options to reduce mercury emissions, use of existing coal-fired sources must be reduced. Therefore estimated costs, unless noted otherwise (as in the wind and gas examples), reflect neither capacity replacement costs or fuel replacement costs (e.g., natural gas) in existing boilers.
- The cost of co-firing is expected to be less than the cost of a full conversion to gas when the heat rate of the coal plant being replaced is relatively low and existing mercury control is high. This is because co-firing involves smaller capital expenditures for a smaller mercury benefit whereas conversion to 100% natural gas would typically require boiler replacement, decommissioning of existing pollution control devices, etc. in return for a mercury benefit that is 5 times the 20% co-fire case.
- The specific fuel switching option that is most cost effective will vary from plant to plant.

**References:**

- UTAC Subcommittee meeting notes, especially for January 23 and February 20, 1998.
- “Resource Plans” that are prepared by each utility as required by the state Public Utilities Commission (PUC) include relevant information.

**Implementation Issues:**

- The reliability of alternative energy sources is critical and could be a determining factor in a utility’s decision to change fuels.
- Contractual obligations may limit fuel switching options during the lifetime of the contracts.

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## Wood/Biomass Co-firing

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**Description:** Co-firing organic materials such as wood, wood waste, oat hulls, etc. with coal at a rate of 5-10% to replace a portion of the coal used at an existing coal-fired power plant.

**Technically Feasible:** *Yes*

This option is now technically feasible under certain conditions. For example, some facilities which historically have combusted coal for generating electricity have successfully been converted to burn wood, or to co-fire wood with coal. However, there are many implementation issues noted below, which make this option viable only to a limited extent and under specific conditions.

**Mercury Reduction Potential:** 70-140 lbs./year based on a 5-10% co-fire rate.

The mercury reduction potential depends on several factors, such as the mercury content and availability of the biomass fuel. Converting from coal to biomass could result in a reduction primarily in air emissions of mercury, with some potential for a reduction in land releases (less mercury to the ash ponds).

**Permanent:** *Yes*

**Cost Effectiveness:** *Unknown.* Cost estimates are highly dependent on factors noted below. In order to estimate costs, some assumptions would have to be made for several factors, such as the type of fuel, the quantity to be combusted, the need to retrofit a facility to burn the biomass, etc. For example, estimates show that closed loop biomass fuel costs are in the range of \$1.50 to \$4.00 per MBtu, and waste product fuel costs range from \$0.50 to \$1.50 per MBtu.

**Factors affecting cost:**

Distance between biomass source and power plant;  
Fuel type,  
Fuel handling characteristics,  
Partial conversion vs. 100% conversion,  
Fuel prices, which can vary depending on demand,  
Capital costs,  
Changes in O&M costs.

**Implementation Issues:**

- Cost of implementation is largely a function of boiler feed system design (e.g., a stoker spreader can be converted to burning biomass more easily than a unit fed pulverized coal).
- Depending on the biomass material, boiler operation may be affected, as well as performance of downstream emissions control devices.
- On anything other than a fluidized bed boiler, 5-10% co-firing is likely possible without adverse changes to the combustion process (e.g., sticky ash, etc.). However, pulverizers are not likely to be able to handle wood chips or other plant materials, so fuel feed systems

would have to be modified. A fluidized bed boiler may be able to co-fire at levels approaching 25% before encountering problems.

- The availability of significant quantities of biomass is unknown.
- “Lost resource opportunities”: the value of burning biomass versus the value of other uses of the biomass needs to be considered.
- There are potentially significant benefits related to greenhouse gas “sinks” created by planting more trees.

**Existing Incentives to Implement Option:** There is an economic incentive if the potential fuel is cheaper than the fuel it would offset. DOE has a program called “Biomass for Rural Development” which offers a tax incentive for closed-loop applications. This program could be expanded or improved to be available to waste product fuels.

**Research Needs:**

Develop more cost-effective methods for fuel transport, handling, and preparation

Solve technical problems with boiler operations and emission control devices.

Evaluate ways to increase biomass production for energy.

**Historical Use of Option:**

Minnesota Power’s Hibbard plant burns wood waste and railroad ties. The cost to convert Hibbard from coal to wood/wood waste was about \$40 million.

NSP’s Bayfront facility burns waste wood and railroad ties. Costs for conversion alone for NSP Bayfront plant were about \$10 million.

NSP’s French Island facility burns RDF, waste wood and railroad ties.

NSP’s Allen S King facility co-fired with wood.

NSP’s Wilmarth and Red Wing facilities were converted from coal to burn RDF.

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## Wind

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**Description:** Substitute 10 % of existing coal-fired generation with new wind power and back-up generation. This assumes utilities voluntarily set-aside ten per cent of their existing coal-fired capacity and replace it with new wind generation. Based on a 1995 Department of Public Service report indicating that approximately 28,000,000,000 kWh's are generated annually with coal-fired generation and assuming a 70% capacity factor (that is, a coal fired power plant is generating electricity 70% of a year) this correlates to approximately 4,600 MW's of generating capacity. Ten percent of this generating capacity is 460 MW, the amount of coal fired generation capacity to be substituted by wind in this option.

Wind turbines will only generate electricity when the wind is blowing whereas coal-fired generation can be produced upon demand. The capacity factor for wind, 35%, is lower than for coal fired generation (70%, as described above). Because utilities must have the capability to produce energy upon demand, backup generation has been added to the cost of this option. Backup generation is generation to be used when the wind is not blowing.

**Technically Feasible:** Yes.

Wind has been used for years to generate electricity, although not in quantities as large as the generation capacity of most coal-fired power plants.

**Mercury Release Reduction Potential:** 140 pounds annually.

This is ten percent of annual coal-fired mercury emissions in Minnesota. Emissions from the operation of back-up generation plants, if the backup fuel contains mercury, would decrease the overall reduction potential of this option.

**Permanent:** *Yes. Note: Natural gas/CT replacement would also be permanent.*

**Cost-Effectiveness:** \$537,000-\$937,000 per pound  
Annual Cost: \$75.2 million -\$131.2 million

Increase in the Cost of Generating Electricity: \$57.4 million -\$113.4 million annually

This cost estimate is based upon the higher cost to generate electricity from wind (\$0.03- \$0.05 per kilowatt hour) than from coal (average of \$0.0095 per kWh). This difference in cost results from the increased cost of generating electricity from wind.

Back-up Generation Costs: \$17.8 million annually

The equivalent of 460 MW's of coal-fired capacity is 910 MW's of wind capacity based on a wind capacity factor of 35%. With an accreditation level of 13.5%, this results in 123 MW's of accredited capacity which would necessitate 337 MW's of back-up generation to achieve the 460 MW's of coal-fired capacity set-aside. Assuming backup generation is a combustion

turbine with overnight capital costs of \$377 per kW, back-up generation capital costs would mount to \$127M. This results in carrying costs of \$17.8M annually, spread out over 30 years.

#### Costs not itemized:

Currently, production tax credits of about \$0.01-\$0.02 per kWh exist for wind farms, but are scheduled to lapse in 1999. If the production tax credits were eliminated, wind generation costs would be expected to increase \$0.02-\$0.03 per kWh, which will affect the economic viability of this option. After 1999, it is uncertain whether or not they will be available. Efforts are underway to extend the credits.

The costs represented above do not include costs for interconnection and transmission facilities. With transmission and interconnection facilities, costs would rise approximately \$0.005-\$0.007 per kWh. Additional transmission facilities would be required to deliver the wind generation to areas of demand.

Other costs not itemized in this analysis: the cost of producing energy by the back-up generation source (which might include higher fuel prices if fuel must be purchased on the spot market) and the value of the useful life of the coal-generating capacity that is set aside.

#### **Implementation Issues:**

- Other environmental benefits from generating electricity from wind should be considered in a general economic analysis.
- There will be impacts on spinning and non-spinning reserve requirements.
- Costs may be incurred to replace generation voltage support
- Limited to areas with good wind resources.
- Wildlife issues need to be considered, i.e. migratory flyways, etc.

#### **Existing Incentives to Implement Option:**

- Production tax credits
- The Resource Planning process requires utilities to qualitatively evaluate mercury emissions.
- The expected customer preference for green power

#### **Research Needs:**

- Wind generation's impact on spinning and non-spinning reserve requirements.
- Forecasting models for wind generation.
- Identification of viable wind generating sites, considering wind resources, population centers, wildlife issues, etc.
- Better technologies for energy storage to take advantage of wind peaks, so that available power is leveled, deliverable, dispatchable power.

#### **Historical/Planned Use of Option:**

As of early 1999, NSP has 294.5 MW of wind generation installed or under development. NSP plans to have 425 MW in place by 2002.

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## Natural Gas Co-firing

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**Description:** Burn natural gas to replace twenty percent of coal burned at existing coal-fired power plants. For purposes of calculating effects of this option, it is assumed enough gas is used to replace coal such that mercury emissions are reduced by twenty per cent. Twenty per cent as the percentage of natural gas burned was selected to provide a rough estimate of reduction potential. The actual percentage of gas co-firing needed to achieve a twenty per cent reduction in mercury emissions would depend on whether higher- or lower-emitting coals were being replaced, changes in boiler efficiency associated with co-fire, etc.

**Technically Feasible:** Yes

**Mercury Release Reduction Potential:** 280 pounds per year.

This estimate is based upon a 20 percent reduction in coal-fired emissions in the state of Minnesota and assumes zero contribution of mercury emissions from the combustion of natural gas. Because the mercury content of natural gas is extremely low, the reduction potential of this option is estimated to be equal to the per cent of natural gas burned times current actual mercury emissions.

**Permanent:** Yes.

**Cost-Effectiveness:** \$410,000 - \$922,000 per pound

This cost estimate is based solely upon incremental fuel costs. The cost effectiveness of this option will vary from unit to unit dependent upon the coal to natural gas fuel price differential and the existing mercury emission rate.

**Costs not included in analysis:**

- Pipeline upgrade costs may range from \$0- \$50 million per site dependent upon existing pipeline capacity to that site.
- Equipment upgrades may be required dependent upon the existing capability of the unit to burn natural gas.
- A reduction in O&M costs would be expected possibly reaching the level of co-firing.
- Potential heat rate impacts.

**Implementation Issues:**

- High volume gas supply lines may need to be constructed to the power plant.
- Winter curtailment of gas would affect reliability as an energy source. "Firm" gas contracts would raise gas costs.
- Natural gas supplies are not infinite. Is this an appropriate use of natural gas? Coal supplies are also limited, but estimates indicate coal supplies are plentiful relative to gas. If power plants started burning large quantities of natural gas, the overall cost of natural gas could increase as a result. Some Advisory Council members stated that the biggest unknowns in the use of natural gas are the long-term availability and costs.

- Secondary pollutant benefits (e.g. reductions in sulfur dioxide emissions) are not included in the estimate; these should be considered if an economic analysis is conducted on this option

**Existing Incentives:** Since burning gas over coal would lower particulate matter and sulfur dioxide emissions (along with mercury), lowering emissions may ease complying with other environmental regulations and permitting requirements.

**Research Needs:**

- To what degree does co-firing natural gas affect a generation facility's capacity to generate electricity?
- Estimates of the unit-specific effects of gas co-firing on boiler performance.

**Historical Use of Option:** MP Hibbard currently co-fires with natural gas.

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## **Coal Source Switching**

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**Description:** In some cases, switching from one coal source to another may reduce mercury emissions. This could occur either due to the new coal source containing less mercury or to changes in coal characteristics that improves the mercury collection efficiency of existing control equipment.

**Technically Feasible:** Yes

This option is technically feasible to the extent that facilities can burn coal from different sources, provided that the coal characteristics (e.g., heating content, sulfur and ash content) are compatible with the facility design and other environmental requirements.

**Cost Effectiveness:** Unknown

Cost effectiveness cannot be determined because facility-specific testing is needed to determine the results of coal switching.

**Reduction Potential:** Unknown

Reduction potential cannot be determined because facility-specific testing is needed to determine the results of coal switching.

**Implementation Issues:**

- Coal choice is site-specific. Ash, sulfur, sodium and Btu content generally influence fuel choice, and would typically matter more than mercury emissions when coal is being selected.
- Lower mercury coals wouldn't necessarily lead to lower emissions in all cases - speciation influences the mercury control efficiency and fate of mercury emissions. It would likely be necessary to conduct facility-specific tests with different fuel blends to determine impact of switching on mercury emissions.

- While there are differences in the average mercury content of coals from different mines, there can be significant variations within a given mine or seam, making it difficult to ensure a given level of effectiveness.

**Existing Incentives:**

There are no direct incentives. For reasons cited under implementation issues, sources may switch to lower mercury coals for a variety of reasons.

**Research Needs:**

Understand impacts of fuel switching on mercury emissions and other parameters on specific boilers.

**Resources:**

Finkelman, Robert, B. “Concentration, Distribution, and Modes of Occurrence of Mercury in Coal: How to Use This Information to Reduce Mercury Emissions,” presentation at *Mercury and Utilities: Science and Technology Roundtable*, Center for Clean Air Policy, Chicago, January 27, 1997.

Katrinak, Karen A., Steven A. Benson, Kevin R. Henke and David J. Hasset, “Mercury in North Dakota Lignite,” *Fuel Processing Technology* 39 (1994) 35-45.

**1.1.2 Air Pollution Control Technology-Related Options**

The technology-based options identified in Table A-2 that were considered most feasible are described in detail below.

It should be noted that cost estimates for these options are very rough. None of the listed technologies have been used to date to control mercury emissions from coal-fired boilers in Minnesota, and, with the exception of coal cleaning which is currently used on Eastern coals to reduce sulfur content, these options have not been used at full scale elsewhere in the United States. A 20-year period was typically used to amortize capital investments. As a result, cost estimates for options that require installation of new equipment would also be higher than cost estimates for plants that operate for less than 20 years. However, costs may drop if demand for a technology increases, as a result of research and innovation, and/or if regulatory requirements develop.

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**Activated Carbon Injection**

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**Description:** Research has shown that activated carbon can be used as a sorbent to capture mercury contained in flue gases from coal fired boilers. By injecting powdered activated carbon into exhaust gases upstream of a particulate collection device (typically a bag house or ESP) mercury-laden carbon is captured along with fly ash. The collected ash and carbon is then typically landfilled or disposed of in ash ponds, although some ash utilization methods may still be viable.

Activated carbon injection is effective at flue gas temperatures below 325 degrees F. At high flue gas temperatures (above 325 ° F), the activated carbon becomes ineffective at capturing the mercury. In cases where exhaust gas temperature exceeds 300° to 325° F it is more economical to cool the gases prior to carbon injection than increasing the carbon injection rate.

Activated carbon can't be used with wet scrubbers unless it is used upstream with its own particulate collection device.

The percentage of mercury that can be collected by this method (collection efficiency) varies depending on a number of variables, including:

- The overall concentration of mercury in flue gases;
- The type of mercury species present in the flue gas (Hg+2, Hg(o) or particulate Hg). Oxidized mercury in fuel gas at coal fired boilers varies from 12 to 99 percent, with a national average of 79 percent.<sup>3</sup> Elemental mercury varies from 0.8 to 87.5 percent, with a national average of 21 percent. Sub-bituminous coal, the majority coal type burned in Minnesota, is believed to have a higher concentration of elemental mercury and a lower concentration of ionic mercury than the national averages.
- flue gas composition (SOx, HCl, H2O...);
- process conditions such as gas flow rate, temperature, and residence time,
- particulate control equipment design;
- sorbent characteristics such as size, shape, and surface area, and
- the presence of other surfaces which could act as sorbents or catalysts.

**Technically Feasible:** Unknown.

Carbon injection is in the pilot-project stage (late 1999). Full-scale installation is technically feasible, however, the collection efficiency that would be achieved can only be roughly predicted. Some degree of success with increasing mercury collection could be considered likely but not guaranteed.

**Mercury Release Reduction Potential:** 55 lbs. per year with 30 percent control  
200 lbs. per year with 60 percent control  
520 lbs. per year with 90 percent control

Pilot scale research has shown collection efficiencies ranging from 0 to 90 percent. Cost and reduction potential estimates have been developed for three different rates of collection efficiency: 30, 60, and 90 percent overall control efficiency (i.e., including control efficiency provided by existing control equipment). Reduction potential estimates assume that the current emissions from coal-fired boilers in MN equipped with ESPs or baghouses (not wet scrubbers) total approximately 640 lb./year. Because the control efficiency already achieved has been taken into account, the reduction potential estimates are less than 30, 60 or 90 percent of the total. The maximum collection efficiency, which could be achieved at a given plant, may not reach the assumed percentages.

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<sup>3</sup> EPA Mercury Report to Congress, Volume 8, page 2-34.

**Permanent:** No.

This option does not permanently prevent release of mercury to the environment. It shifts mercury releases from air emissions to a waste material. It is expected, however, to slow significantly the rate of release. The permanence of the option is therefore rated at moderate. Additional research is underway to determine the stability and rate of release of the mercury in landfills and utility applications. A question that undoubtedly will have to be answered is: What rate of release/re-emission is acceptable or is considered permanent reduction?

**Cost Effectiveness:**

\$37,000- \$200,000 per lb. with 30 percent control

\$11,000-\$110,000 per lb. with 60 percent control

\$ 9,000- \$275,000 per lb. with 90 percent control

**Cost Basis:** To account for the fact that costs vary significantly, UTAC reviewed the design of Minnesota's largest coal-fired boilers and divided them into four "prototypes." A model, under development by the Energy and Environmental Research Center (EERC), estimated costs for each prototype. The low end of the cost-effectiveness range equals 75 percent of the cost predicted by the model. To account for potential costs which were not included (see list below), the cost estimates generated by EERC have been multiplied by a factor of two for the 30 percent control scenario and by 2.5 for the 60 percent and 90 percent control scenarios. In general, the cost estimate uncertainty increases as collection efficiency increases. Some committee members believe that the upper range shown may still underestimate costs for some facilities, and that a multiplier of three would better estimate potential costs.

The minimum cost estimate for 30 percent control is higher than the 60 and 90 percent cases because injection equipment is not utilized to its fullest capability if only a small amount of mercury is being captured. Additionally, some prototypes are already able to achieve 30 percent reduction with existing equipment.

Note that the flue gas mercury concentration and gas flow rates significantly affect cost effectiveness. A certain amount of carbon must be injected for every cubic foot of gas flow to ensure adequate diffusion, mixing, and contact with the mercury. If the mercury concentration is low, then the amount that can be collected is lower and the cost per pound removed increases.

Cost estimates are based upon a cost for activated carbon of 50 cents/lb. Research is currently being conducted to identify lower priced sorbents. However, in order to obtain the 90 percent removal rates estimated above, a more expensive sorbent may be required. The accuracy of these estimates is expected to improve as research by EERC, Electric Power Research Institute (EPRI), EPA and Department of Energy (DOE) reveals new information.

The cost estimates are based on information from EPA's Mercury Report to Congress, Electric Power Research Institute, Department of Energy, Energy and Environment Research Center, experimental and field data, engineering assumptions and calculations, and typical utility

operating data. Installation costs assumed are two times greater than the estimates shown in the EPA Mercury Report to Congress<sup>4</sup>. This adjustment is made to account for scale effects, inexperience with installation of injection systems at utility power plants, possible retrofit difficulties, and different operating practices. An economic life of 20 years was assumed. Site-specific information would improve cost estimates.

**Potential costs that are site specific and not included:**

- insufficient room to install new equipment on existing ductwork
- increased operation and maintenance costs due to increased corrosion in exhaust gas ductwork, i.e., the impact of gas cooling on the formation of SO<sub>3</sub>, and downstream effects.
- increased cost of ash disposal, if ash which is currently put into use (e.g., as a concrete mix additive) can no longer be used due to the presence of carbon
- the need to install and operate additional particulate control devices downstream of existing devices (e.g., ESP) to avoid corrosion or ash disposal problems, although if one were going to add another device, then cooling upstream of existing equipment wouldn't be required. One would cool and inject carbon after existing particulate matter control equipment and before any add-on equipment to capture injected carbon.
- Licensing fees and royalties.
- The effects of cooling on particulate removal devices, increased pressure drop, bag failures, etc.
- Higher annual costs when a generating unit has a remaining life of less than 20 years.

**Implementation Issues:**

- As with any new technology, there are unknowns associated with the first installations.
- A number of implementation issues are shown above under “potential costs not included.” In summary, the main issues are: lack of current availability of the technology; uncertainty regarding achievable control efficiency; impacts on the ability to sell fly ash; impacts on operation of particulate control equipment; and increased corrosion at utility boilers that require flue gas cooling.
- One potential impact of carbon/sorbent injection is the impact on ESP and baghouse performance. Carbon could impact the overall particulate collection efficiency of the ESP and some fixes may be needed to bring the ESP within opacity compliance. Carbon could also impact baghouse pressure and baghouse maintenance costs.
- Cooling exhaust gas does not always negatively effect ESP control efficiency. Cooling in many cases improves ESP performance because it reduces flue gas volume and lowers flyash resistivity, both helping to make ESP's work better<sup>5</sup>
- Secondary pollutant benefits of carbon injection for coal-fired boilers are limited. Collection of chlorine, and trace metals may increase. Carbon injection at waste combustors collects dioxin, however, dioxin emissions from coal-fired boilers are relatively low.

**Existing Incentives:** None.

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<sup>4</sup> Based on statements by Tom Brown, Department of Energy, to John Pavlish, EERC.

<sup>5</sup> Based on Comments by Ramsey Change, EPRI.

**Research needed:**

Commercially available sorbents are very temperature sensitive, requiring increasingly higher feed rates as gas temperatures increase above 300°F. Most Minnesota utilities operate at or above this temperature and will, therefore, require flue gas cooling to lower gas temperatures prior to sorbent injection. The impacts of gas cooling need to be identified, quantified in terms of costs and impact on operations, and resolved.

New sorbents need to be developed that operate over a wider temperature range, which would avoid problems associated with cooling flue gases. Research and development should also minimize sorbent injection rates, which would help reduce sorbent costs.

Additional research is required to determine the interactions of gas temperature and composition, mercury concentration and speciation, and sorbent characteristics to accurately assess and improve their effectiveness.

Activated carbon injection needs to be demonstrated and cost verified using plant specific data, since small deviations in fuel characteristics and operating conditions can significantly impact the cost of control.

The mercury trapped by the carbon needs to be evaluated for stability and mobility in landfill and pond disposal, and utilization options.

**Historical Use:** Carbon injection is used at Minnesota municipal and medical waste combustors to control mercury emissions. However, the same technology is not directly transferable to coal-fired boilers because of differences in flue gas characteristics. In particular, a waste combustor exhaust gas stream is much lower in flow volume and relatively higher in mercury concentration. Also, the speciation of most mercury from combustors is ionic, which is more easily captured than elemental mercury.

**Resources/References:**

Letter from Leonard Levin, EPRI, to Bill Maxwell of EPA dated November 27, 1996, listing five concerns regarding the EPA mercury report  
EPA Mercury Report to Congress  
UTAC meeting notes  
Cost estimate modeling by EERC

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**Lowering Exhaust Gas Temperature**

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**Description:** Under this option, a facility operator would install a gas cooling system with the intent of improving the collection efficiency of the existing particulate control equipment. It has been shown that, at cooler temperatures, carbon and fly ash already present in the flue gas are more effective at collecting mercury. What is not known, is to what degree this

phenomenon is consistent for all plants. The 1997 EPA Mercury Report to Congress states<sup>6</sup> that mercury is found predominantly in the vapor phase in coal-fired boiler flue gases. If the vapor-phase mercury were condensed onto or attached to the particulate matter, the mercury could be removed with the particulate matter using existing control equipment. Theoretically, based on partial pressures and assuming equilibrium conditions, cooler temperatures will increase mercury condensation onto particulate matter.

A combination of gas cooling and “pulsed energization” of the flue gas stream is a related option in the research stage that may be able to achieve greater removal efficiencies than cooling alone. Preliminary research indicates a mercury reduction of 40 to 50 percent.<sup>7</sup>

Water injection would typically be used for gas cooling or mechanical heat exchangers, assuming a need to recover the energy and cost-effectiveness. Water injection would cost more since it involves a heat transfer surface that must be integrated into the system. Additionally, there would be corrosion on the heat transfer material. Other systems would also require maintenance.

**Technically Feasible:** Unproven.

Cooling boiler exhaust gases is technically feasible. However, cooling gases for the main purpose of reducing mercury emissions is an option that is still in the research stage. Therefore, option implementation is technically feasible, but its effectiveness is uncertain.

**Reduction Potential:** 0 to 375 lb.

Basis: the estimated reduction potential is 0 percent to 50 percent of annual emissions from coal-fired power plants, excluding facilities with wet scrubbers, based on improvement in control efficiency. As noted above, effectiveness is uncertain. Pilot-scale and full-scale tests have shown a wide range of effectiveness, from a decrease in mercury collection efficiency to an increase in collection efficiency of approximately 50 percent.

**Permanent:** No.

This option does not permanently prevent release of mercury. Additional research is underway to determine the stability of the mercury in landfill situations and utility applications.

**Cost Effectiveness:** \$25,000 per pound to \$125,000 per pound

Costs are a function of the percent control achieved, which research indicates could be zero at some facilities, in which case the cost per pound would be infinitely high. Cooling costs are based on EERC estimates of carbon injection costs. The cost for a reduction of 10 percent would be in the range of \$100,000-\$125,000 per pound of mercury. If a 50 percent reduction could be achieved, the cost would be reduced significantly to approximately \$25,000 per pound.

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<sup>6</sup> U.S. Environmental Protection Agency, Mercury Report to Congress. Vol. VIII, page 2-32.

<sup>7</sup> The percentage increase over existing removal efficiencies is unclear; reference the EPA Hg report page 2-58 of Volume VIII.

**Implementation Issues:**

- Saturation temperatures are extremely low if concentrations are also low. It is unlikely that the mercury will condense out. Additionally, fly ash and unburned carbon may become more effective at capturing mercury. Experimental data show that activated carbon is more effective at lower temperatures, than reducing flue gas temperature further.
- Potential Drawbacks: Available space in exhaust gas ductwork, changes in particulate matter resistivity caused by cooling gases, which could negatively affect ESP control efficiency, and clogging ductwork with concrete formed by mixing fly ash with water below a certain temperature are also potential problems.
- Benefits: Cooling, without gas conditioning, improves particulate matter control efficiency. Flue gas humidification is a form of flue gas conditioning, which in most cases will improve particulate mater control. However, not all ashes need to be conditioned. In some cases, conditioning (for a different reason) may cause deterioration in performance.

**Existing Incentives:** None.

**Research Needs:**

Pilot and full scale testing to see if this is a viable technology, and for what types of facilities it has the best potential, is needed.

Cost-estimates could be refined using existing information.

**Resources:**

2-20-98 UTAC meeting notes, EPA Mercury Report to Congress, EERC cost estimates for carbon injection. John Pavlish, of EERC, expressed skepticism regarding the data contained in the EPA report and its interpretation.

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**Increase Wet Scrubber Efficiency**

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**Description:** Some utility boilers have wet scrubbers installed for the purpose of removing particulate matter, SO<sub>2</sub>, or both. Tests of boilers with wet scrubbers indicate that some scrubbers capture a portion of the mercury in the flue gas. However, this effect varies significantly between facilities, with research indicating a mercury removal efficiency of anywhere from 0 percent to 90 percent. This is to be expected since the proportion of elemental and oxidized mercury varies from plant to plant. Elemental mercury is virtually insoluble and the oxidized form is highly soluble. It has been shown, based on limited experiments, that wet scrubbers are effective at removing the oxidized form (mercury (II)) at essentially the same efficiency as the SO<sub>2</sub> is removed for wet scrubbers designed for SO<sub>2</sub> removal (1). Conversely, it has been shown that wet scrubbers are not effective at removing the elemental form of mercury.

For this option, it is assumed that if lime or limestone is added to the scrubber to increase the percentage of SO<sub>2</sub> removed the same percentage increase in the amount of mercury (II) removed would occur (see limitations to this assumption for particulate scrubbers in the

“Implementation Issues” section below). For this option, it was also assumed that SO<sub>2</sub> removal is increased to 90 per cent (up from about 70 per cent) and that 20 per cent of the total mercury in the flue gas is mercury (II) thus resulting in a total removal efficiency of mercury (II) of 18 percent. The 20 percent mercury (II) is estimated based on the relatively low chloride content of the coal currently consumed by Minnesota utilities (low chloride coals tend to correlate with low mercury (II) in the flue gas).

**Technically Feasible:** Unknown.

The technology exists for increasing the removal of SO<sub>2</sub> across a wet scrubber. However, because wet scrubbers are theoretically limited to collecting only the oxidized form of mercury, additional testing and research is needed to quantify the speciated mercury forms (and variability) that currently exists so that the potential merits of this option can be fully evaluated. Also, testing and research is needed to determine the ability to modify particulate scrubbers for chemical addition, and whether additional mercury (II) capture would result.

**Reduction Potential:** 30 pounds per year primarily from air to land (likely to be landfilled or placed in ash ponds). A small portion may be discharged to water. Based on the mercury inventory information developed for Minnesota utility boilers, approximately 700 pounds of mercury were emitted in 1995 from those utility boilers equipped with wet scrubbers. Of this amount, approximately 30 pounds of mercury could be captured annually by increasing scrubber efficiency to 90 percent, based on the assumptions, as described below.

For the MN boilers with wet scrubbers, the current SO<sub>2</sub> removal efficiency ranges from 35 percent to 85 percent, with the larger facilities in the upper end of that range. The weighted average of SO<sub>2</sub> removal efficiency in Minnesota is approximately 70 per cent. As previously stated, the mercury (II) component of the total mercury is assumed to be 20 percent. Since the scrubbers are currently removing the majority of the SO<sub>2</sub>, the majority of the mercury (II) is already being removed as well, based on our assumption that there is a linear relationship between the percentage of SO<sub>2</sub> removal and the percentage of mercury (II) removal. As stated previously, the current estimate for emissions from wet scrubbed units in the state is approximately 700 pounds annually (based on 1995 emission estimates). Based on these assumptions and unit specific information on control efficiency and mercury emissions, the statewide total mercury in the flue gas, prior to being scrubbed, is estimated to be 815 pounds annually, so approximately 160 pounds are in the form of mercury (II) (815\*0.2). Of this, approximately 115 pounds of mercury are already being removed by the scrubbers (815lbs. – 700 lbs.). It is assumed that the 115 pounds removed is mercury (II). Of the remaining 45 pounds (160 lbs.-115 lbs.), another 30 pounds, approximately, would be captured by increasing the SO<sub>2</sub> removal efficiency to 90 percent for all of the Minnesota boilers currently equipped with wet scrubbers.

**Permanent:** *No.*

This option is not a pollution prevention effort. Instead, it results in a transfer of mercury from air emissions, to ash (land) and, to a small degree, water. Little is known about the long-term stability of the mercury in the ash, however, it is anticipated that the rate of release from the ash would be much slower than the current emission rate.

**Cost Effectiveness:** \$62,000 to \$258,000 /lb.

For the prototype plants, the cost to increase SO<sub>2</sub> removal through addition of lime/limestone was estimated to be an additional \$100 to \$250 per ton. The \$100 dollar per ton figure is based only on adding lime/limestone to achieve greater SO<sub>2</sub> removal. The estimate assumes that the existing scrubber has the capability to increase its SO<sub>2</sub> removal rate to 90 percent, and assumes that no additional equipment or modifications are needed. The \$250 per ton estimate is based on requiring additional capital expenditures to retrofit a particulate scrubber to allow lime/limestone addition, or using caustic soda to achieve greater SO<sub>2</sub> removal. In both cases, the initial capital investment of the scrubber is not included. Based on the assumption that the cost to increase SO<sub>2</sub> removal would be \$100 per ton, it was calculated that the cost for mercury removal would be \$62,000 to \$103,000 per pound of mercury removed. At \$250 per ton of SO<sub>2</sub> removed, the cost range would be \$156,000 to \$258,000 per pound of mercury removed. These costs do not reflect the initial capital expenditure in the wet scrubber, so the estimate applies only to those boilers, which currently have wet scrubbers in operation.

### **Implementation Issues:**

- An environmental benefit would be a reduction in SO<sub>2</sub> emissions.
- This evaluation was based on certain assumptions in order to be able to develop cost estimates and reduction potential. In reality, the scrubbed units in the state vary considerably in type of scrubber installed (whether for particulate matter or SO<sub>2</sub> removal), the form of mercury at the scrubber inlet, and other factors. Given these assumptions, the actual cost and reduction potential for a particular unit may vary significantly from the values quoted here.
- Half of the units equipped with wet scrubbers in Minnesota have scrubbers that were installed for particulate removal, however they do achieve significant SO<sub>2</sub> removal as well. These units are not designed to handle lime/limestone addition to increase SO<sub>2</sub> removal (and thus mercury (II)). They would require costly equipment retrofits, or the use of more reactive agents (e.g. caustic soda), which are much more expensive. The \$250 per ton of SO<sub>2</sub> removed value is applicable to these types of units.
- The mercury reduction potential of a wet scrubber closely follows its removal efficiency for SO<sub>2</sub> only if the SO<sub>2</sub> removal by the wet scrubber is mass transfer controlled. Particulate scrubbers may be mass transfer controlled for particulate removal but not SO<sub>2</sub> removal (chemical reaction limited). Adding lime to the particulate scrubber can improve SO<sub>2</sub> removal but may not improve mercury capture because it does not improve mass transfer of the mercury to the liquid. Thus, the premise that adding lime to a particulate scrubber will improve mercury removal proportionately may be incorrect.
- Additional research is needed to determine the amount and variability of the various mercury forms, in particular mercury (II). Research is also needed to determine the relationship between lime addition and increased mercury (II) removal. For this option, it was assumed that the relationship between additional lime/limestone and the mercury (II) removal rate would be comparable to that for SO<sub>2</sub> removal, however, more research is needed to confirm this. Test data suggest that this relationship is valid; however, testing has not been done on Minnesota plants. Additionally, particulate scrubbers are not

designed specifically for SO<sub>2</sub> control therefore this relationship may not be linear. There are no test data that support or refute the linearity assumption.

- It may not be possible to simply add more lime or limestone to get better removal from an existing scrubber even if it is designed for lime/limestone addition. For example, a scrubber designed for 70 percent reduction may not have adequate spray levels/nozzles. To increase the removal efficiency to the assumed removal rate of 90 percent may require more pumping capacity, more spray levels, additional de-misters, additional slurry handling, and additional de-watering. These additional potential costs have not been included in the cost estimates. In order to verify that simple reagent addition will increase mercury (II) removal would require further facility-specific review.

**Existing Incentives to Implement Option:** There currently are no incentives in place to encourage increasing scrubber efficiency for the purpose of mercury removal. Additional federal or state requirements for haze, acid rain or fine particulates would provide an incentive for improved scrubber efficiency.

**Research Needs:** In order to develop information on this option, which goes beyond the theoretical, additional research is needed to:

- determine mercury speciation, variability of mercury forms, and operating parameters that influence variability,
- ascertain the relationship of lime/limestone additive rates, SO<sub>2</sub> removal, and mercury reduction, as well as other scrubber parameters which may play a role,
- evaluate design changes and equipment modifications that may be needed to achieve 90 percent, or greater, reduction,
- evaluate the permanence of the mercury capture,
- evaluate the impact of the additional mercury on the utilization of the scrubber byproducts, and
- determine techniques available to enhance the formation of oxidized mercury.

**Historical Use of Option:** Wet scrubbers are currently in use on several utility boilers in Minnesota and elsewhere for particulate matter and/or SO<sub>2</sub> removal. None have been installed on utility boilers specifically for mercury removal.

**Resources:** Correlate Coal/Scrubber Parameters with Hg Removal and Species in Flue Gas, Matt DeVito, CONSOL Inc., Subhash Bhagwat, Illinois State Geological Survey, presented at Center for Air Toxic Metals Fourth Annual Meeting, September 16-17, 1997.

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## **Intense Conventional Coal Cleaning (and Other Cleaning Options)**

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**Description:** Intense conventional coal cleaning involves the use of physical cleaning processes to reduce the amount of ash and sulfur in coal. In addition to removing ash and sulfur compounds, intense conventional coal cleaning processes can also reduce concentrations of mercury and other pollutants. Technologies used in intense conventional cleaning have been used commercially for many years. Other coal cleaning options discussed here include

chemical cleaning and combined chemical and intense conventional cleaning. These processes have not been used as extensively.

**Technically Feasible:** Unproven on sub-bituminous coals

Coal cleaning technologies are widely used in the eastern United States to reduce ash and sulfur compounds in bituminous coals. There is less experience with cleaning in the western United States on sub-bituminous coals and North Dakota lignites. Minnesota utilities consume, for the most part, western sub-bituminous coals, especially from Powder River Basin. Lignite coals are also consumed in the region. More detailed cleaning analyses are needed to better estimate the feasibility, cost and mercury emission reduction potential for cleaning Powder River Basin coals and North Dakota lignite. In particular, additional study would be helpful to confirm the effects of coal cleaning on mercury reduction, and determine the effects of coal cleaning on speciation and removal across existing control technologies such as ESP's and baghouses. Other items likely to require further study on a site-specific basis include alterations to fuel physical/chemical characteristics leading to issues related to fuel handling and transport, combustion, ash impacts, and impacts on other pollution control equipment such as scrubbers. Further site-specific research may be needed with respect to thermal drying (i.e., the optimal moisture content of the final product) which affects energy recovery and transportation issues and costs.

**Reduction Potential:** 425 lbs. with chemical cleaning

540 lbs. with chemical plus convention cleaning methods.

Data used in EPA's Mercury Study Report to Congress indicate that conventional coal cleaning methods reduce mercury concentrations in eastern coal by 0-64 percent, with an overall average reduction of 21 percent. According to a preliminary laboratory analysis conducted on Powder River Basin coal,<sup>8</sup> intense conventional coal cleaning may be able to achieve an 11 percent reduction in mercury emissions.

Chemical and chemical plus conventional cleaning methods applied to Powder River Basin coals may reduce annual mercury emissions in Minnesota by 29 percent (425 lbs.) and 37 percent (540 lbs.), respectively.

**Permanent:** Unproven

Mercury removed from coal as a result of physical cleaning processes is expected to remain trapped in naturally occurring minerals in the waste material. According to coal experts, the long-term stability of naturally occurring minerals is generally understood from geologic studies, allowing the design of waste disposal facilities with minimal risk of mercury release to ground or surface waters or the atmosphere. However, the permanence of intense conventional coal cleaning should be confirmed through testing. There are more questions pertaining to the permanence of chemical cleaning. It is theoretically possible that chemical cleaning methods would alter the physical, chemical, and/or mineralogical forms of the coal resulting in increased potential of re-emission or leaching. The permanence of chemical cleaning should similarly be confirmed through testing. As well, the speciation of emissions reduced is unknown.

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<sup>8</sup> Akers, "Economics of Coal Cleaning for Control of Mercury Emissions.

**Cost-Effectiveness:** \$46,000 per pound with chemical cleaning  
 \$47,000 per pound with intense conventional coal cleaning  
 \$58,000 per pound with chemical and intense conventional coal cleaning

If the value of SO<sub>2</sub> credits is taken into consideration, the cost-effectiveness range for intense conventional coal cleaning of Powder River Basin coals is \$10,000 - \$47,000 per pound of mercury removed, depending on the assumed value of SO<sub>2</sub> credits. The Powder River Basin estimates are based on theoretical rather than actual costs (high quality lab data using PRB coals were used rather than materials flow sheets). The range of cost-effectiveness estimates for chemical and chemical plus intense conventional coal cleaning is \$44,000 to \$58,000 per pound of mercury removed taking into consideration the value of SO<sub>2</sub> allowances.

**Cost-effectiveness of coal cleaning for mercury**

Type of Cleaning	“Best Estimates” for PRB Coals		Range (+/- 25%)
	SO <sub>2</sub> = \$200/ton	SO <sub>2</sub> = \$0/ton	
<b>Intense Conventional</b>	\$10,000	\$47,000	(low end includes SO <sub>2</sub> credit = \$200)
<b>Chemical</b>	\$46,000	\$46,000	\$7,500 to \$58,750
<b>Chemical + Conventional</b>	\$44,000	\$58,000	\$34,500 to \$57,500
			\$33,000 to \$72,500

In order to present information on the various options in a consistent manner in the summary table, the point estimate for cost-effectiveness is presented without consideration of SO<sub>2</sub> credits. In other words, the point estimates in the summary table assume that SO<sub>2</sub> credits are valued at \$0 per ton. (The actual value of SO<sub>2</sub> credits is now approximately \$190/ton.) The coal cleaning ranges listed in the summary table, by contrast, incorporate a +/- 25 percent error band around the best estimates for coal cleaning. These estimates incorporate the value of the SO<sub>2</sub> allowances that are earned after coal cleaning.

**Cost Data:**

Assuming that coal cleaning takes place at the mine, the cost to the power plant is the change in price of the cleaned fuel--no capital investments are needed by the utility. However, the mine itself would incur some capital costs, a portion of which would be passed on to the consumer in the form of higher coal costs.

The cost estimate used in a preliminary analysis developed for an EPRI report includes:

- a) infrastructure costs<sup>9</sup>,

<sup>9</sup> Researchers assumed the plant would be sited at the mine, and that the mine already has raw coal storage and shipping capabilities.

- b) the increased heating value of coal,
- c) the value of SO<sub>2</sub> credits generated (one scenario assumes the value of SO<sub>2</sub> credits at \$87/ton and the other assumes SO<sub>2</sub> credits increase in value to \$200/ton), and
- d) reduced transportation and handling cost.

The cost estimate also includes a factor for waste disposal costs at the mine based on typical costs for bituminous coals, but does not include new costs associated with acquiring the necessary permits for a disposal site. Permitting costs may be more for chemical cleaning than for intense conventional coal cleaning. The preliminary analysis does not include the savings associated with reduced ash collection and disposal costs at the boiler nor does it include savings associated with improved boiler efficiency.

The biggest uncertainty in the capital cost estimate is that the estimate was not based on any particular site. Various aspects of a site, including as-mined storage pile, loadout, availability of water and power utilities and the existence of a level site for construction can have an effect on costs--an unusually difficult site would raise costs and an unusually easy site would lower costs.

#### **Other Impacts:**

##### *Non-Mercury Environmental Impacts:*

In addition to reducing mercury emissions, coal cleaning reduces emissions of SO<sub>2</sub> and various hazardous air pollutants (HAPs). HAP reduction benefits have not been incorporated in the cost estimates.

While coal cleaning reduces power plant emissions and the amount of ash generated during combustion, cleaning will result in an increase in tailings and other wastes at coal cleaning facilities. Waste disposal costs at the mine have already been incorporated into the analysis. Cleaned coal could improve boiler efficiency and reduce transportation costs, leading to other environmental advantages.

#### **Implementation Issues:**

- There is presently no market for cleaned or reduced mercury coals. There would need to be a demand for clean western fuels to create an incentive for the mines to purchase the needed equipment.
- Cost and reduction potential estimates for sub-bituminous coals have been developed using general rather than site-specific assumptions. Site specific studies (as suggested under the feasibility section) that confirm the more generalized estimates would be needed prior to implementation.
- According to the Lignite Energy Council, the hydrophilic nature of low-rank coals (which includes sub-bituminous coals) does not lend itself to conventional coal cleaning practices. Low-rank coals are typically low sulfur and more uniform.
- Conventional coal cleaning may increase the probability of mercury contamination of water bodies.

**Existing Incentives:** Fine particulate requirements and the second phase of the acid rain law could lead to a greater demand for cleaned coal.

**Research Needs:**

More detailed cleaning analyses are needed to better estimate the cost and emission reduction potential numbers for Powder River Basin coals and North Dakota lignite. In particular, additional study would be helpful to determine the effects of coal cleaning on mercury speciation and removal using existing control technologies such as ESP's and baghouses. The permanence of mercury in coal cleaning by-products should be confirmed through testing. Other items that are likely to require further study on a site-specific basis include alterations to fuel physical/chemical characteristics leading to issues related to fuel handling and transport, combustion, ash impacts, and impacts on other pollution control equipment such as scrubbers. Further research may be needed with respect to thermal drying.

**Resources:**

Akers, David J. and Toole-O'Neil, Barbara, "Coal Cleaning for HAP's Control: Cost and Performance," to be presented at the International Technical Conference on Coal Utilization and Fuel Systems, March 9-13, 1998.

Akers, David J., Draft Table "Economics of Coal Cleaning for Control of Mercury Emissions," to be published in EPRI report.

Akers, David J., "Coal cleaning controls HAP emissions," *Power Engineering*, June 1996.

EPA, Mercury Study Report to Congress, Volume 8, December 1997. pp. 2-11 to 2-13.

**1.1.3. Energy Efficiency Options.**

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**Demand-Side Management**

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**Description:** Demand-side management (DSM) involves implementation of programs to change the timing or to reduce the amount of energy consumed. DSM often entails the application of energy efficiency measures that enable electricity consumers to perform the same function with less energy.

Where DSM measures can be implemented to offset the demand for fossil-fired electricity, mercury emissions will be avoided. Many DSM measures were identified as potential reduction options. Due to the uncertainties of DSM measures' effectiveness after a period of five years (and longer), DSM measures were evaluated as whole end-uses (e.g., residential lighting and refrigeration, industrial) rather than individually. DSM measures are, to varying degrees, already implemented by utilities in Minnesota. The level of DSM implemented by NSP and Minnesota Power is determined through two different regulatory proceedings: the Integrated Resource Planning Process and the Conservation Improvement Program.

**Technically Feasible?** Yes.

**Cost Effectiveness and Reduction Potential:** Cost-effectiveness and reduction potential of increased DSM efforts will vary from utility to utility dependent upon levels of DSM already in

place. In general, the most cost-effective DSM efforts are implemented first and therefore, costs are likely to rise as levels increase. The reduction potential will depend upon the specific level of DSM implemented.

In order to evaluate reduction potential and cost-effectiveness, two NSP scenarios were evaluated. The Proposed Scenario evaluates reduction potential and cost-effectiveness based upon the levels of DSM NSP has proposed to implement in its Resource Plan Filing. These are incremental efforts that go beyond programs currently in place. The Double Rebate Scenario evaluates cost-effectiveness and reduction potential based upon the differential between the Proposed Scenario and additional DSM efforts above the Proposed Scenario. These numbers are specific to NSP and have not been extrapolated statewide.

**NSP Reduction Potential:**

NSP Proposed Scenario: 7-17 lbs. per year (108-171 pounds over 10-15 years)

NSP Double Rebate Scenario: 6-12 additional lbs. per year (98-115 pounds additional over lifetime, 10-15 years)

**Cost Effectiveness:** NSP Proposed DSM Levels: \$493,000- \$810,000 per pound  
NSP Double Rebate DSM Levels: \$1.7 million - \$2.8 million per pound

**Implementation Issues:**

- The reduction potential and the cost-effectiveness of implementing more DSM programs will be utility specific and dependent upon the levels of DSM currently implemented by the given utility. The form of generation offset by DSM will be dependent upon a given utility's generation mix and energy demand at the time that the program is in effect.
- Environmental benefits, such as reduction in emissions of SO<sub>2</sub>, NO<sub>x</sub> and CO<sub>2</sub>, should be taken into consideration if an economic analysis is conducted on this option.
- The double-rebate method may result in "free riders" and the desired level of reductions may not actually be achieved. An alternate analysis would explore more strategic market transformation efforts (such as building commissioning, code enforcement, etc.) and target these for further analysis. These matters are addressed in other regulatory forums: the Conservation Improvement Program Process and the Integrated Resource Planning Process. It was decided that it was appropriate to allow these forums to determine the appropriate levels of incremental DSM levels to evaluate.
- The analyses take into consideration the economic benefits of reduced operation and maintenance cost and fuels saving.
- The cost-effectiveness numbers detailed below are based solely on application of additional DSM programs on the NSP system. Costs and cost-effectiveness will vary from utility to utility dependent upon selection of programs applicable to each utility's customer base.
- In the NSP 1998 Resource Plan Filing two scenarios were presented in Table V-7 Impacts and Cost of Double Rebate and Proposed DSM Plans. This Table identifies the costs of a proposed DSM plan and a Double Rebate scenario that significantly increases monetary incentives to customers for installing DSM measures. The table outlines costs and impacts by category. The "Process" category and the totals across all DSM programs proposed

were evaluated to determine the costs and reduction potentials associated with these two categories. Cost-effectiveness and reduction potential were determined in two ways: 1) conservatively based on NSP's mercury emission rate from its fossil fired generation and 2) more realistically based on NSP's system mercury emission rate. The differentials between the NSP proposed scenario and the Double Rebate scenario were evaluated for both the Process DSM Category and the Total DSM Category.

Process DSM Category (Industrial)

Double Rebate: Incremental

*Increased cost between Proposed and Double Rebate: \$368.3M-\$87.5M= \$280.8M*

Change in MW impact: 146.4 MW- 75.5 MW= 70.9 MW

Incremental cost between Proposed and Double Rebate: \$280.8M/70.9MW= \$3,960/kW

Cumulative Totals (10-15 years, program specific): 6,034.5 gWh – 3, 172.5 gWh = 2,862 gWh

Incremental cost = \$280.8M/2,862 gWh = \$0.098/kWh

1) Cumulative mercury savings based on NSP fossil emission rate:

2,862,000 MWh \* 0.000054 #/MWh = 155 pounds over lifetime

1) Cumulative \$/pound = \$280.8M/155 pounds = \$1,811,613 per pound

2) Cumulative mercury savings based on NSP system emission rate:

2,862,000 MWh \* 0.00003417 #/MWh = 98 pounds over lifetime

2) Cumulative \$/pound = \$280.8M/98 pounds = \$2,865,306 per pound

*Proposed:*

NSP's proposed Process scenario would reduce 171 pounds over the lifetime of the programs at a cost of \$87.5 M for a rate of \$511,695 per pound based on the fossil emission rate. Based upon the system emission rate the reduction would be 108 pounds for a cost effectiveness of \$810,185.

All DSM Programs

Double Rebate: Incremental

Increased cost between Proposed and Double Rebate: \$1,178.5M - \$502M= \$676.5M

Change in MW impact: 1,156.4 MW- 896.5MW= 259.5 MW

Incremental cost between Proposed and Double Rebate: \$676.5M/259.5 MW= \$2,607/kW

Cumulative Totals (10-15 years, program specific): 26,280 gWh – 18,893 gWh = 7,387 gWh

*Incremental cost = \$676.5M/7,387 gWh = \$0.092/kWh*

1) Cumulative mercury savings based on NSP fossil emission rate:

7,387,000 MWh \* 0.000054 #/MWh = 399 pounds over lifetime

1) Cumulative \$/pound = \$676.5M/ 399 pounds = \$1,695,489 per pound

2) Cumulative mercury savings based on NSP system emission rate:

7,387,000 MWh \*0.00003417 #/MWh = 252 pounds over lifetime

2) Cumulative \$/pound = \$676.5M/252 pounds = \$2,684,524 per pound

*Proposed:*

NSP's proposed Total DSM scenario would reduce emissions by 1,020 pounds over the lifetime of the programs at a cost of \$503.5M for a cost-effectiveness of \$493,627 per pound

based on NSP's fossil emission rate. Based upon the system emission rate the reduction would be 646 pounds with a cost-effectiveness rate of \$779,412 per pound.

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## Co-Generation

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**Description:** Co-generation is the simultaneous production of heat and electric power. Co-generation can be accomplished in a number of ways, but most commonly involves using waste heat from the production of steam for an industrial process to turn an electric turbine. Co-generation is also common in district heating systems where again the waste heat from the steam or hot water line is used to generate electricity. Smaller, "packaged" co-generation systems are also available for use in applications such as swimming pool heaters. Co-generation improves the efficiency of electric production and overall energy use by recapturing waste heat that would otherwise be exhausted. Efficiency improvements of up to 50 percent are possible depending on the energy needs of the steam host, type of fuel, and equipment employed. Actual savings are therefore highly site-specific. Translating efficiency improvements into mercury reductions requires a comparison to a non-co-generation, fossil fuel electric source.

**Technically Feasible:** Yes.

Co-generation is already in use in many applications. Technical feasibility in Minnesota is limited only by the number of co-located thermal hosts (industrial sites) and electric generation and transmission facilities. In many instances, however, power plants are located at significant distances from potential steam hosts, making co-generation too costly for existing coal-fired power plants.

**Reduction Potential:** Not determined.

As noted above, reduction potential is difficult to estimate given the site-specific nature of efficiency improvements resulting from a co-generation application. Significant mercury reduction potential exists through better using the energy that is produced from coal plants, although the degree of reduction depends on the type of fuel saved.

To produce energy in the form of electricity, most coal-fired power plants are limited to an efficiency of 30 – 40 percent, with the remaining 60 to 70 percent of the energy being waste heat. Consumers and other industries could use most of this waste heat. Fuel-to-energy conversion efficiencies of up to 80-90 percent could be achieved with co-generation. By doubling the energy efficiency (that is, producing twice the amount of energy with the same amount of fuel), air emissions could be reduced by ½. To accomplish this, the overall energy production-consumption process must be more tightly integrated. By combining electrical production with industrial processes, much higher efficiencies can be achieved.<sup>10</sup>

**Permanent:** Yes.

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<sup>10</sup> Comments from John Pavlish, Energy and Environmental Research Center, Grand Forks, North Dakota.

**Cost Effectiveness:** Not estimated. Not determined for existing coal-fired facilities. Co-generating should be low or no cost for new facilities depending on the proximity to a host site. In many cases co-generation should be profitable.

**Implementation Issues:**

- Co-generation is used in Minnesota. The NSP Sherco plant in Becker co-generates and provides steam to LPI and excess heat to a nearby greenhouse. NSP's High Bridge facility historically co-generated providing the steam to Rock-Tenn (and their predecessor's). While steam is still supplied from the High Bridge facility, there currently is no electricity generation associated with the production of that steam. NSP's King plant has provided steam to the Minnesota State Correctional Facility in Oak Park Heights. Plans for installing new co-generation capacity by major oil/refinery companies are under way. Minnesota's other large coal-fired power plants are not currently located with thermal energy users, and thus make the cost-effective transport of the waste heat difficult and potentially infeasible.
- There are regulatory hurdles, which may be disincentives. For example, modifications to existing boilers may subject the project to New Source Review air quality regulations and potential air quality control equipment changes.
- With the movement towards smaller generation plants co-generation will become more viable.
- Integrated energy use options need to be encouraged.
- Co-generation reduces greenhouse gas emissions and other pollutants.

**Existing Incentives:** Cost savings.

**References/Resources:** The Environmental Impact Statement (EIS) for the University of Minnesota steam plant upgrade may be referred to for more information, particularly regarding assumptions that had to be made regarding "what energy source is being replaced by co-gen?"

## **8.2 Options for Taconite Industry**

Taconite plants are represented on the Utilities and Taconite subcommittee by Hibbing Taconite Co. and US Steel-Minntac, which also represented the Iron Mining Association. National Steel Pellet Company is not represented by the Iron Mining Association.

Because taconite processing was only recently identified as a source of mercury emissions, research is needed to evaluate mercury reduction options. Therefore, no cost estimates have been provided for the taconite options.

**Options for controlling mercury emissions from the taconite industry.**

<b>Type</b>	<b>Consider in detail</b>
Energy Source Substitution/Fuel Switching	
Conventional Control—Current	
Conventional Control—New and Emerging	
Chemicals/Additives Replacement	
Mine Area Modifications	This is not considered a feasible option.
Plant Area Modifications	

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**Energy Source Substitution / Fuel Switching**

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**Description**

The primary fuel used to fire (indurate) the taconite pellets is natural gas. Other fuels include fuel oils, coal, wood and petroleum coke. No facility is utilizing solid waste, TDF (Tire Derived Fuel) or RDF (Refuse Derived Fuel). This option therefore would involve eliminating the use of the fuels currently in use that have higher emissions than natural gas. As natural gas is assumed to contain the least amount of mercury, any reduction in mercury would have to be obtained from the switch from the other fuels to natural gas.

**Technical Feasibility:** Yes

All of the pellet indurating furnaces have the capability of burning alternate fuels; i.e., switching from coal, petroleum or wood to natural gas. However, the taconite facilities must maintain the ability to fire alternate fuels. The other fuels are used during natural gas curtailments or when the alternate fuel is less expensive. The taconite facilities operate 24 hours/day, 365 days/year, and it is necessary to have the alternate fuel sources.

**Mercury Emission Reduction Potential:** 1 pound per year

Data for this option was developed through the Coleraine Minerals Research Laboratory (CMRL) September 1997 Mercury study. The mercury present in natural gas is shown to be negligible. Analysis of wood from Minntac indicates 6.01 ng Hg/g or 0.10-0.17 ng Hg/g of pellets produced. Analysis of coal from Northshore indicates 15.61 ng Hg/g or 0.07 ng Hg/g of acid pellets produced and 0.12 ng Hg/g of flux pellets produced. Analysis of No. 6 fuel oil (Bunker C) from HibTac indicates less than 0.2 ng Hg/g or less than 0.002 ng Hg/g of pellets produced. Specific mercury analysis on the other fuels is not presently available; however, the contribution of mercury due to fuel consumption of alternative fuels is insignificant. If the taconite facilities were to solely use natural gas, the reduction potential would equate to one (1) pound/year (approximately 5 million tons of pellets/year are produced with fuels other than natural gas).

**Permanent:** Yes.

Mercury not emitted due to only firing natural gas is a permanent reduction. However, as mentioned previously, each taconite facility must maintain the option of using an alternate fuel during natural gas curtailments.

**Cost Effectiveness:** \$175,000 per pound

Fuel Cost:

The incremental cost to the taconite facility is the amount saved by using an alternate fuel (coal or wood) over the cost of natural gas. Switching from coal to natural gas is estimated to increase the cost per MMBtu by \$0.10 (average 1997 cost comparison) in operating cost. All capital costs of the alternative fuel systems have been fully depreciated. Switching from wood to natural gas is also estimated to increase the cost per MMBtu by \$0.10 in operating cost. The total cost per mercury reduction (1 #) is therefore 5 million Tons x 0.350 MMBtu/Ton x \$0.10/MMBtu = \$175,000.

Production Cost:

If the natural gas supply is lost, the cost of lost production to the smallest taconite producer is \$0.2million/day (assuming 7500 Tons pellets at \$30/ton) and \$1.2 million/day to the largest (42,000 Tons pellets). If the gas supply is curtailed, the facility has the option of paying the extra demand rate. The demand rate varies based on natural gas supply and demand.

### **Implementation Issues**

- In addition to reducing mercury emissions, fuel switching may reduce emissions of SO<sub>2</sub> and various hazardous air pollutants (HAPs).
- Fuel switching may also increase the amount of other pollutants (NO<sub>x</sub>) and may require permitting and capital expenditures.
- Emissions and facility emissions fee may actually increase if a facility was to utilize natural gas as the only fuel source.

### **Existing Incentives**

There is presently no incentive for a facility to switch from coal, wood, or fuel oil to natural gas other than the cost of the fuel.

### **Research Needs**

If the option of requiring only natural gas to be burned during non-curtailment periods is pursued, ensure that all pellet indurating furnaces have the capacity to switch to an alternate fuel during natural gas curtailments.

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## **Conventional Controls - current**

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### **Description**

Existing controls at the taconite facilities on the pellet indurating furnaces for waste gases consist of ESPs, Wet Scrubbers and Multiclones. Through stack testing which has already been conducted by the taconite facilities, it has been shown that with existing controls there is some collection of mercury.

### **Technically Feasible: Yes**

One taconite facility's stack test demonstrated 87 percent control efficiency with an ESP. Another's stack test demonstrated 35 percent control efficiency with a venturi scrubber.

### **Reduction Potential: Not Determined**

These tests show that existing controls collect some mercury. However, because little is known about the speciation of the mercury in the stack tests and it is known that there are differences in the ore across the Mesabi Iron Range, one type of control may not be efficient for all taconite facilities. Additional stack testing will be conducted to determine what control efficiencies can be obtained from emission control equipment. A review of the impingers in a Method 29 sampling train for one facility's stack test indicated that most, if not all, of the mercury was elemental in the stack exhaust.

### **Permanent: No**

The existing controls collect the mercury from the stack gases, and transfer the mercury and other solids to scrubber water. In most cases, the scrubber water is recycled back to previous beneficiation processes. For example, some facilities transfer this material back to the concentrate thickener. Some others transfer the scrubber water back to the concentrating mill. In both cases, the reason for doing this is to recover the iron in the scrubber water. Some of the mercury in the scrubber water will cycle back with the concentrate, while some will flow directly into the enclosed tailing basin. As indicated in the September 1997 CMRL Study, the mercury content of the tailing basin water is approximately the same as background lakes. This indicated that the mercury, when scrubbed out of the gas, attaches to solids and settles out according to the tailing deposition in each basin. There is little biological activity in the solids that settle (primarily non-metallic minerals) so the biological conversion, or re-volatilization, of mercury should not occur.

### **Cost Effectiveness: Not Determined**

Before estimating cost-effectiveness for conversion of collection equipment on the indurating furnace to an ESP, the taconite facilities need information about existing control equipment and mercury speciation. Without those data, estimating the increase in mercury capture through an ESP versus venturi scrubber would not lead to an accurate cost-effectiveness analysis.

### **Implementation Issues**

- Changing controls may also have multimedia implications; e.g., higher emissions of another type of pollutant, changing the form of the mercury and type of medium that it may be transferred to.
- The electrical power requirement for an ESP is greater than other, less power-intensive means of controlling emissions.
- Existing facilities may not be able to physically accommodate other control technologies.
- Large capital expenditures could be required for changing the type of control technology.

**Existing Incentives: None.**

### **Research Needs**

An outside party should review stack tests and additional testing should occur to confirm the original numbers at all of the taconite facilities.

A study on the speciation of the mercury in the inlet and outlet in the pellet indurating furnace stacks.

A study to confirm that the mercury scrubbed out of the indurating furnace gases stays with the solids, settles out as a solid, and does not get re-emitted to the atmosphere.

4. The taconite industry does not have data to properly speciate the mercury emitted during the induration process. Until speciation is known, end of pipe control technologies can not be further evaluated.

Note: EPA/MPCA are evaluating the MACT Standard process for the taconite industry which may dictate what types of control equipment facilities must have to comply with emission rate limits for HAPs. The scheduled promulgation date is November of 2000.

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## **Conventional Controls - New and Emerging Technology**

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### **Description**

New controls to collect the mercury in the stack exhaust from the pellet indurating furnace include the following: Activated Carbon Injection, Sorbent Beds and Filters, Plasma Discharge, Flyash Injection, Iron Concentrate Injection.

### **Technically Feasible: No**

The feasibility of adding these types of new controls is unknown, as there is not much information on how the activated carbon will react with the stack exhaust. Also, most taconite facilities do not have the capability of adding large equipment due to space constraints.

### **Reduction Potential: Unknown**

**Permanent: No**

**Cost Effectiveness: Unknown.**

## **Implementation Issues**

- Changing controls may also have multimedia implications; e.g., higher emissions of another type of pollutant, changing the form of the mercury and type of medium that it may be transferred to.
- The electrical power requirement new controls may be greater than other less power intensive means of controlling emissions.
- Actual mercury reduction with a control device will vary from facility to facility since it has been demonstrated that each facility has different concentrations of mercury in the taconite concentrate. (see last section's comments)
- Existing facilities may not be able to physically accommodate other control technologies.
- Large capital expenditures could be required for changing the type of control technology.
- The requirement to install new pollution control types could put Minnesota mines at an economic disadvantage in regards to mines in Michigan, Canada, and the rest of the world.

**Existing Incentives: None.**

### **Research Needs:**

1. A study to determine the interactions of stack exhaust metals, acid gases, and other pollutants with the activated carbon and how that affects the capture efficiency of mercury.
2. A study of and possibly testing activated carbon injection to control mercury emissions.

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## **Chemicals/Additives Replacement**

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### **Description**

The CMRL Study evaluated the mercury content in the additives (limestone, bentonite and organic binders), and found that these materials contain a concentration of mercury equal to or less than that of the concentrate. Therefore they do not appear to increase or diminish the amount of mercury that is volatilized during induration. Limestone is added from 0 - 11%<sub>wt</sub> depending if the facility produces a flux pellet. Also, some facilities use a small percentage (doping) of limestone to increase pellet quality parameters. Bentonite, or other binders, is generally added at a 15 to 20 lbs./long ton rate (<1%<sub>wt</sub>).

It is not known at this time what the concentration of mercury is in the flotation chemicals. For some types of chemicals this could depend if it was manufactured in a mercury cell, i.e. caustic soda. It is also not known at this time what the concentration of mercury is in the dust control materials that are used at the facilities. Some of these include magnesium chloride, calcium chloride, lignosulfonate and water.

### **Technically Feasible: Yes**

It is not known if there are materials that contain less mercury. The current Material Safety Data Sheet reporting system only requires a material to be listed if it contains more than one percent of a hazardous substance, or 0.1 percent of a carcinogen. Without the requirement for a

less restrictive mercury reporting level on a Material Safety Data Sheet, evaluating a type of material for mercury content cannot be done in a cost-effective manner.

**Reduction Potential: 9 pounds per year**

Assuming a 25 percent reduction, that the average of all of the plant use 4 percent limestone (5 ng Hg/g), the binding agent rate is 17.5 #/Lt (15 ng Hg/g) and 50 million LT of pellets annually, a 25 percent reduction in mercury content would equate to potential mercury reduction of ~ 9 #/yr. Also, we do not know if there are such products available and if so, at what cost. For other products with lower usage, flotation and dust suppressant, any reduction, if possible, would be even lower.

**Permanent: Unknown.**

It is dependent on finding a long-lasting low mercury content material.

**Cost Effectiveness: Not estimated.**

**Implementation Issues**

- Changing types of additives or chemicals may introduce other pollutants into the process. It may also change the speciation of mercury and affect the media that mercury may be transferred to. The specific dust suppressants, chemicals, and detergents and usages are all permitted through each facility's NPDES water permit. Any change would require approval of the MPCA.
- The availability of low mercury content additives and chemicals.

**Existing Incentives: None.**

**Research Needs**

To determine the availability and cost of chemical additives that have very little mercury.

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**Mine Area Modifications**

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**Description**

If the individual mining area is found to be high in mercury content in one area, do not mine that area. If the level of mercury in an ore type (or stratification) is found to be high in mercury, process the other ore types. Only mine areas of 'low' mercury content.

**Technically Feasible: No.**

It is not feasible to mine different ore bodies. Each taconite processing facility is designed for the ore near its pit. For example, the processing facilities located in the west are not designed to process the ores of the east range. The east range ores are typically finer and harder requiring more processing steps in the concentrator (crushing, grinding, and flotation). Permitting is required if one of the east range taconite processing facilities would increase

output to replace the pellets not produced from a west range facility. Permit rules may not allow a plant to make a modification of that size.

It is not feasible to mine only certain stratifications of ore. The processing of taconite ore requires that a mixture of the ore types remain in relatively the same ratios. It may not be feasible to mine a specific area or stratification based on the following chemical and physical parameters: iron content, silica content, ore hardness, and grain size. To require mining in only specific areas of the mine, while technically feasible, is not operationally feasible. It would keep the mine from producing a consistent product and lower productivity.

**Reduction Potential: Unknown.**

It depends on the concentration of ore currently being mined and what ore may be technically, operationally, and financially feasible to mine and process.

**Permanent: Yes**

**Cost-Effectiveness: Not estimated.**

**Implementation Issues**

Changing where a plant mines the ore it processes may require additional energy because processing in the east range is generally more power dependent than it is in the west range.

The selective mining of certain areas or stratifications makes mining more inefficient.

Mine area modifications entail creating more removal of surface and lean ore and increasing the amount of haul truck miles and its associated energy demands.

If an individual taconite plant was shutdown due to mercury concerns, the economic, social and political ramifications must also be taken into account.

If an individual facility is forced to mine selective areas of the mine, the life of the mine is greatly shortened. It would also increase the cost of production.

**Existing Incentives: None.**

**Research Needs**

Is there a noticeable mercury concentration difference in the individual mining areas at a taconite mine?

Is there a noticeable mercury concentration difference in the stratifications of the iron ore?

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**Plant Area Modifications**

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**Description:**

Modify the ore concentrating process to increase the mercury rejection to the tailing. Route scrubber water outside of the process to reduce the recycling effect of mercury in the beneficiation process.

**Technically Feasible: Unknown**

This would be taconite's equivalent to coal cleaning for utilities. However, it is very unlikely that a material separation process can be found that will separate mercury from crude ore because mercury concentrations are so low. Any increase in mercury separation in the iron concentration process will most likely come from improving the weight recovery of iron. This is primarily achieved through additional stages of grinding and flotation. Flotation may also increase the amount of mercury rejected to the tailing. The CMRL study also showed evidence that elevated sulfide levels increased the amount of mercury rejected with the tailing. Not all plants have the same sulfide levels in the ore. Mercury may also be closely tied to other minerals that may influence the separation process.

**Reduction Potential: Unknown.**

It depends on the concentration of the ore currently being mined and what processes may be modified at an individual plant.

**Permanent: Yes.**

As indicated in the September 1997 CMRL Study, the mercury content of the water in tailing basins is approximately the same as the water in background lakes. This indicated that the mercury, when rejected with the tailing, attaches to other solids and settles out. There is little biological activity in the solids that settle, primarily non-metallic minerals, so biological conversion, or revolatization of, mercury should not occur.

**Cost Effectiveness: Not estimated.**

Cost-effectiveness is likely to be high (millions of dollars per pound) if mercury is the only reason for installing additional equipment or processes.

### **Implementation Issues**

- Adding new equipment or processes may require additional energy.
- Adding flotation chemicals to processes that do not currently use them would require permitting by water quality.
- If an individual taconite plant is required to install additional stages of crushing/grinding or flotation to influence the separation of mercury, that plant would be placed at a financial disadvantage.
- It is uncertain how much mercury can be collected in the concentrating mill.

**Existing Incentives: None.**

### **Research Needs**

A concentrator model is needed to determine at what point mercury is rejected when the ore is separated.

A study is needed to confirm that the mercury rejected in the tailings stays with the solids, settles out as a solid, and does not get re-emitted to the atmosphere.

A study of in-pit tailing disposal is in the final stages. Mercury is one of the parameters being studied.

A study is needed to determine what forms of mercury are present with the tailings. Further investigation to determine which minerals mercury is closely tied to and what can be optimized in the taconite process.

**Reduction Potential: Unknown.**

It depends on the concentration of the ore currently being mined and what processes may be modified at an individual plant.

**Permanent: Yes.**

As indicated in the September 1997 CMRL Study, the mercury content of the water in tailing basins is approximately the same as the water in background lakes. This indicated that the mercury, when rejected with the tailing, attaches to other solids and settles out. There is little biological activity in the solids that settle, primarily non-metallic minerals, so biological conversion, or revolatization of, mercury should not occur.

**Cost Effectiveness: Not estimated.**

Cost-effectiveness is likely to be high (millions of dollars per pound) if mercury is the only reason for installing additional equipment or processes.

### **8.3. Options for Products, Manufacturing and Waste-Related Sources**

Products, manufacturing, and waste (PMW) include sources with mercury releases resulting from intentional uses of mercury in products or in manufacturing. The PMW subcommittee divided sources into two types: primary sources, where mercury emissions result from manufacturing or from the use of mercury in products, and secondary sources, where mercury emissions result from processing waste (solid waste or wastewater) containing mercury that originates from products or intentional use of mercury in a process.

The PMW Subcommittee began by creating a list of mercury sources related to products, manufacturing and waste. Subcommittee members then were assigned to look for reduction options for the sources with the highest expected mercury emissions. The subcommittee used the feasibility criterion to shorten its list of sources considered.

The committee identified options and strategies according to state and federal waste management hierarchies, which call for: pollution prevention, recovery and recycling, treatment (to immobilize, sequester, or otherwise prevent release into the environment), and retirement.

Sectors most likely to use mercury:

- Dental
- Medical
- Veterinary
- Educational institutions
- Utilities
- Industrial boilers

Laboratories-all types  
 Automotive manufacture and maintenance  
 Major Appliance manufacture and maintenance  
 Telecommunications  
 Dairy Farms (manometers)  
 Building and HVAC systems and controls  
 Chemical manufacturers

General points of note from the PMW Subcommittee:

Retirement needs to be discussed as a strategy for recovered mercury and recovery/recycling firms need to have a retirement option that is legally, technically, economically viable. As mercury use diminishes and mercury-bearing products are removed from service, surplus mercury must be dealt with responsibly.

Education, outreach, and dissemination of information are seen as integral to all strategies and options. All government, non-government organizations, associations, and private sector groups have a responsibility for this.

Some type of strategy is needed for dealing with identification, proper use, maintenance, and removal of installed equipment containing encapsulated mercury. Though we wish to discourage the purchase and installation of new mercury-containing products, a strategy is needed for dealing with what is currently installed and in use. It may not be necessary or possible to remove these items from service. However, they must be identified and a procedure should be established to ensure labeling, proper use, maintenance, and eventual removal from service. Where mercury is not encapsulated or there is a risk of breakage or release, some type of immediate action should be taken to prevent release or the risk of release, which may be removal from service

For a detailed list of mercury-containing products, reference “Mercury Products Study: A report to the U.S. Environmental Protection Agency - Region V”, John Gilkeson, Senior Planner, Minnesota Pollution Control Agency, April 16, 1996, revised August 1998.

**Options for Reducing Mercury in all business/industry sectors**

<b>type</b>	<b>consider in Detail</b>
Reduce the Amount of Mercury in Feedstock Chemicals	
Replace Mercury-containing items	
Purchase and use fewer mercury-containing items	
Reduce mercury in consumer products	

### Options for Reducing Mercury in Laboratories, Dental Practices

Type	comment
Pollution Prevention	
Collect Bulk mercury from dental offices	
Increase recycling of chairside traps	
increase recycling of vacuum system filters	
install additional amalgam capture equipment	
reduce the use of mercury dental amalgam	

Schools: Collect mercury Chemicals and Compounds in College and High School laboratories

### Options for reducing mercury from waste management/disposal systems

Enhance air pollution control on municipal waste combustors	
Construct and operate waste material separation equipment before final disposal	
Treat air pollution control scrubbing water at wastewater treatment plant sludge incinerators	
Apply Best Available treatment at all wastewater treatment plants.	

#### 8.3.1 Options Applicable to Multiple Industries

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#### **Reduce the Amount of Mercury Used in Feedstock Chemicals**

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**Description:** Industrial chemicals: caustic soda, potassium hydroxide, and sulfuric acid and other chemicals used throughout a variety of industries can be contaminated with low concentrations of mercury that can be passed along to wastewater treatment or as an air emission from waste boilers. Clean alternatives (pollution prevention) are available that will eliminate the potential for mercury release.

**Technically Feasible? Yes.**

This pollution prevention opportunity is being used by several industries.

**Reduction Potential:** 100 lbs./yr.

Example: A single paper mill was able to reduce its mercury discharge in its wastewater by 7 pounds per month by switching to a low mercury sulfuric acid in its bleaching process.

In addition, increased demand for clean chemicals could encourage the chlor-alkali industry to discontinue its use of mercury in the production process, thereby ending that industry's discharges to air, water, and land. This would reduce annual mercury releases by many thousands of pounds per chlor-alkali facility that uses mercury cells.

**Permanent:** Yes

Using cleaner alternatives would permanently prevent release of mercury from a specific facility. However, the high mercury product would likely be sold elsewhere.

**Speciation:** Ionic and metallic.

**Cost and Cost Effectiveness:** Not estimated.

Currently consumers incur no increased cost for using membrane grade caustic soda versus mercury cell grade caustic soda. Low mercury sulfuric acid can also be obtained with no additional cost. There may be increased operational costs related to changing chemicals. (Potlatch says presently mercury cell caustic is \$30 / ton more expensive than membrane grade) The price of caustic soda varies based on demand for chlorine and caustic soda, but membrane and mercury cell grade prices have been generally equal. However, as demand for clean caustic soda increases supplies may be harder to obtain and prices are likely to increase.

**Implementation Issues:**

- The substitute chemical may not be a viable alternative in all applications (e.g., membrane grade caustic does not perform as well as mercury cell caustic in some demineralizer applications.
- Incentives for implementing this option could take a number of forms:
- Educate customers to request low mercury feed stocks
- Require disclosure of mercury content in industrial chemicals
- Require labeling of mercury content of industrial chemicals.
- Change Material Safety Data Sheets to cover mercury concentrations down to 10 ppb.
- Manufacturers of chemicals that are higher in mercury may oppose this measure.
- Some chemicals would be hard to test to 10 ppb.

**Historical Information:**

Western Lake Superior Sanitary District (WLSSD) has found varying levels of mercury in industrial customers' wastewater discharges. Most customers have been able to use alternatives and eliminate the problem. In the past, problem chemicals have been caustics, acids, and ferric chloride.

**References:** Vulcan Chemical, Hawkins Chemical, WLSSD, Potlatch, LSPI, Haarmann & Reimer

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**Replace Mercury-Containing Items**

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**Description:** Mercury is found in many products used in schools, laboratories, mining, and manufacturing processes. Mercury-bearing products include switches, art supplies, appliances, industrial machinery, thermometers, manometers, chemicals and relays with non-mercury items. These products are all potential sources of mercury release when they are misused or discarded. If these products were replaced with non-mercury containing items and the mercury disposed of properly, the potential releases would be avoided.

**Technically Feasible? Yes.**

Non-mercury alternatives are currently available for most products, although in a few cases the alternatives may not be equivalent in performance to the mercury-containing products they replace.

**Mercury Release Reduction Potential:** 580 lb./yr. to air; 3,900 lb./yr. total to all media

The total amount of mercury contained in products statewide in 1995 is estimated to be roughly 60 to 100 tons. According to the "Fate Tree for Mercury in Products" presented in Part 6.1, releases of mercury from new and existing products was estimated at 11,065 lb./yr. to all media, and 1,655 lb./yr. to air. Assuming that 1) half of these releases are associated with industrial uses of mercury-containing products which could be targeted for replacement, and 2) existing laws and voluntary actions have led to a 30 percent decrease from 1995 release rates, then reduction potential =  $[(11,065 - .30(11,065)) \times (0.5)] = 3,900$  lb./yr. to all media, and 580 lb./yr. to air.

**Permanent: Yes.**

**Speciation:** Almost all elemental, unless the products are incinerated, which creates some oxidized mercury emissions.

**Cost Effectiveness:** \$10-\$1,000 per pound

The cost estimates for replacing mercury switches, gauges, etc. in use at electric utilities at the end of their useful life is approximately \$10 per pound.<sup>11</sup> Cost estimates for replacing equipment before it reaches the end of its useful life are higher, about \$1,000 per pound. Estimates include labor and, for pre-end of useful life replacement, the cost of replacement parts. It could also be argued that the avoided cost of spill cleanup could lead to replacement of mercury items being a cost saving.

**Implementation Issues:**

- Education and program building would be important, including determining the best entity and approach for providing education. Target audience must know what items contain mercury and what are the non-mercury substitutes.
- A negative aspect of mercury containing products is that spills of mercury can occur that can cause both environmental and direct human health concerns. Alternatively some feel that a mercury switch is fail safe and provides a level of safety in some applications that the alternatives do not. (i.e. boiler controls in schools or hospitals)

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<sup>11</sup> Data from Mary Dieltz of NSP.

- Many of the users of mercury containing products may not be willing to spend the money necessary to replace the mercury containing equipment.
- Bans regarding mercury disposal are already in existence in Minnesota.
- This is a relatively simple option in that no technology is needed.

**Incentives:** Existing mercury disposal bans; threat of regulation: for example, wastewater treatment plants could decide to regulate mercury discharges from more sources.

**Historical Information:** Schools, hospitals, and industrial facilities have been sites of spills. Health effects & cleanup costs of spills can potentially be significant.

**Resources/References:** WLSSD, UMD study, NSP.

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## **Purchase and Use Fewer Mercury-Containing Products**

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### **Description:**

This option calls for consumers, both at home and at work, to not buy mercury-containing products. If fewer mercury products were purchased, less mercury would end up in waste. A secondary benefit of this would be that consumer demand for non-mercury alternatives should improve supply and reduce the price of alternatives.

**Technically Feasible:** Yes, in most cases.

There are alternatives available for most, although not all, mercury-containing products.

**Reduction Potential:** 1,000 lb./yr. to air; 7,000 lb./yr. total

According to the “Fate Tree for Mercury in Products” discussed in Part 6.1, in 1995 total annual release to the environment from mercury-containing products was 11,065 lb./yr., including 1,655 lb./yr. to air. Assuming that 90 percent of the current intentional uses are avoidable, and that a 30 percent decrease has occurred since 1995 in the quantity of mercury in products, then the reduction potential = (11065 lb./yr.) (.70) (.90) = 7,000 lb./yr. total. Air emission reduction potential = 15 percent of total = 1,000 lb./yr.. It would take a number of years to reach this reduction potential. If the mercury concentration of waste reduced by 0.1 ppm each year, this would equate to a reduction of approximately 150 lb./yr. in air emissions for each 0.1 ppm.

**Permanent:** Yes.

**Cost-Effectiveness:** \$10 to \$100/lb.

The cost of this option has not been specifically quantified, but is expected to be relatively low cost.

### **Implementation Issues**

- Identifying mercury-containing products and locating suitable alternatives can take a lot of time. Education and product labeling would make this easier.

- To maximize the permanence of this option, a drop in demand for mercury-bearing products would have to be widespread. Otherwise, product manufacturers in many cases would sell the mercury products in locations where the demand for them persists.

**Existing Incentives:** The American Hospital Association signed an agreement with EPA that calls on hospitals to work toward virtual elimination of mercury use and disposal.

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## **Reduce Mercury Use in Consumer Products**

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**Description:** This option calls for reformulation of consumer products to avoid use of mercury. This has many obvious advantages over options that are not directly related to Pollution Prevention. It could eliminate the need to educate consumers and label products.

**Technically Feasible:** Yes, in many cases.

Some commercial products will continue to require mercury as an essential component of the formula, but there are alternatives for most. Many products can be manufactured using substitutes that are non-toxic. Manufacturer take-back or deposit programs can be designed to reduce mercury uses to the essentials.

**Reduction Potential:** 1,000 lb./yr. to air; 7,000 lb./yr. total

According to the “Fate Tree for Mercury in Products” discussed in Part 6.1, in 1995 total annual release to the environment from mercury-containing products was 11,065 lb./yr., including 1,655 lb./yr. to air. Assuming that 90 percent of the current intentional uses are avoidable, and that a 30 percent decrease has occurred since 1995 in the quantity of mercury in products, then the reduction potential =  $(11065 \text{ lb./yr.}) (.70) (.90) = 7,000 \text{ lb./yr. total}$ . Air emission reduction potential = 15 percent of total = 1,000 lb./yr. It would take a number of years to reach this reduction potential. If the mercury concentration of waste reduced by 0.1 ppm each year, this would equate to a reduction of approximately 150 lb./yr. in air emissions.

**Permanent:** Yes.

This option exhibits a high level of permanence since the mercury is never purchased or used in the first place.

**Cost-Effectiveness:** \$10 to \$100/lb.

The cost of this option is difficult to quantify and would vary substantially depending on the specific manufacturing application.

**Implementation Issues:**

- Mercury-containing goods are manufactured in many different countries and exported worldwide; the option would have to be implemented globally to achieve the reduction potential estimate shown above. Implementing this option will require mandates, which are almost never popular. If a mandate becomes law, it must be enforced to be effective. Enforcement not only requires staff to determine compliance, but administrative and

judicial support to carry out enforcement actions. Incentives are typically more popular than mandates and do not require enforcement.

**Existing Incentives:**

Bans on mercury in certain types of products (e.g., clothing)

**Research Needs:**

Alternative materials must be identified that can safely be used as substitutes for mercury. In some cases, altered manufacturing processes may be required.

**Historical Use of Option:**

This option has been successfully used in the reformulation of latex paint, mercury containing batteries, pesticides, and tennis shoes.

**References:**

Olmsted County Department of Public Works staff (Rob Dunnette, Scott Martin)

**8.3.2 Laboratories**

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**Pollution Prevention in Laboratories**

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**Definition:** There are many wastes from laboratories that contain mercury.

Laboratories, including labs in schools, hospitals, and commercial labs, could use alternative chemicals and instruments that don't contain mercury.

**Technically Feasible: Yes.**

**Reduction Potential:** 10 to 25 lb. to air; 1 to 5 lb./yr. to water; 70 to 170 lb./yr. total  
1-5 pounds to water via wastewater treatment plants due to sewerage of laboratory chemicals and spilled mercury; 10-50 lbs. per year to air from improper disposal and spills; roughly 70 to 170 lb. total to all media.

**Permanent: Yes.**

**Cost-Effectiveness:** \$700 to \$6,600/lb. to air; \$100 to 1,000/lb. total  
\$100-1000 /lb. is estimated to cover disposal and replacement cost. The University of Minnesota Duluth chemistry department found that they could replace all mercury and mercury containing equipment for about \$100 per pound collected, excluding administrative and labor costs. This estimate has been divided by 0.15 to create an estimate for cost-effectiveness of reducing emissions to air.

**Implementation Issues:**

- Identification of alternative products can be time consuming and costly.

- In some cases, alternatives may not exist or use of mercury compounds may be required, e.g., some EPA standard test procedures use mercury compounds.
- Should this be voluntary or regulatory? If regulatory, who would enforce the program? MPCA, the wastewater treatment facility, or hazardous waste manufacturers?
- An educational program would be needed.
- Support or acceptance from labs is needed, even if the program is regulatory.
- Wastewater with a mercury concentration above 1 ppm mercury is a hazardous waste. Discharges from laboratories usually have a much lower concentration but yet can be a significant loading to a WWTP.

**Existing Incentives:**

WWTPs have the regulatory power to limit the discharge of pollutants to the sewer. Only some dischargers are forced to meet local limits and only some cities have pretreatment programs. The discharge limit for the largest WWTP in Minnesota is being lowered from 100 ug/l (0.1 ppm) to 2 ug/l (0.002 ppm). These limits could be used to drive laboratories towards activities that could reduce mercury use and discharge.

**8.3.3 Dental Practices**

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**Collect Bulk Mercury from Dental Offices**

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**Description:** In years past, dental offices purchased mercury in bulk and then mixed the mercury with other metals in the dental office to make dental amalgam. Today, dentists use amalgam that is pre-proportioned and encapsulated, negating the need for a dentist to purchase mercury in bulk. Some dental offices are likely to have in storage small quantities of bulk mercury from those earlier years. A one-time collection program that promotes the opportunity to turn in bulk mercury for proper handling would take the mercury out of dental offices and make it available for reuse.

**Technically Feasible: Yes.**

The state of Michigan has successfully conducted a bulk mercury collection program. On a smaller scale, the Western Lake Superior Sanitary District has conducted a bulk mercury collection program. So, a bulk mercury collection program has been demonstrated to be feasible. However, considerable planning is necessary to establish collection points around the state, to arrange for the proper handling of the collected mercury, and to promote the program.

**Reduction Potential:** 2 to 8 lbs./yr. to air; 15 to 50 lbs./yr. to all media over the next 10 to 20 years.

Based on the experiences of Michigan and WLSSD, about seven percent of the dentists would provide an average of 3.375 pounds of mercury. In Minnesota, this would equal about 530 pounds of mercury from a one-time collection program. Using the assumption from the “Fate Tree for Mercury in Products,” discussed in Part 6.1, that 3 to 10 percent of the mercury in use is removed from use each year, collecting 530 lb. of mercury that is currently “sitting on the

shelf” would equate to an avoided annual release of 15 to 50 lb./year to all media. Using the estimate that 15 percent of total releases are air emissions, the reduction potential to air would be 2 to 8 lb./yr..

**Cost Effectiveness:** \$125/lb. for air reductions; \$20/lb. for reductions to all media  
Costs include labor for handling collections, “disposal” costs, and promotional printing and mailing costs. About \$10,000 would be needed to cover these costs if there is substantial volunteer participation for collection, transportation, and planning. Because the collection would be accomplished through a one-time event and one-time expenditure, the cost effectiveness has been calculated based on the total amount reduced:  
 $\$10,000 / 530 \text{ lb.} = \$20/\text{lb.}$ ; air reductions:  $\$10,000 / 0.15 (530) = \$125/\text{lb.}$

**Implementation Issues:**

- Finding reasonably dispersed collection points where proper handling of excess bulk mercury can occur.
- Providing convenient locations and times for the dental offices,
- Making arrangements for amalgam recycling from each collection point, and
- Program coordination

**Research Needs:** none

**Historical Use:** WLSSD and Michigan DEP have used this option.

**Resources:** WLSSD and Michigan DEP

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### **Increase Recycling of Chairside Traps**

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**Description:** Chairside traps capture about 65 percent of the amalgam waste produced during dental procedures. Some, but not all, dental offices currently manage amalgam waste collected by chairside traps by separating the waste for recycling. Information about proper procedures for managing the traps should be provided to all dental offices in a concerted fashion. Training programs should be developed. Recycling infrastructure identified or established in all areas of the state.

**Technically Feasible:** Yes.

**Reduction Potential:** 110 lb./yr. to air; 325 lb./yr. to all media  
An estimate of total mercury to be recovered from vacuum system recycling is about 647 pounds per year. If the current recycling rate is 50 percent, the reduction potential would be 325 pounds per year of additional mercury recovery and recycling.

The potential reduction in air emissions depends on the fate of non-recycled amalgam waste. Some traps are emptied into garbage cans or infectious waste containers, while others are sewered. Sewered mercury, according to the “Fate Tree for Mercury in Products,” discussed in

Part 6.1, would have a 56 percent likelihood of becoming an air emission via sludge combustion. Mercury in MSW is roughly 10 percent likely to be released to air via combustion. Assuming that half of the dental offices mismanaging traps empty them into garbage while the other half sewer the waste, the reduction potential for air emissions is estimated to be:

$$(325 \text{ lb./yr.}) (0.5) (0.56) + (325 \text{ lb./yr.}) (0.5) (0.10) = 91 + 16 = 107 \text{ lb./yr. (round to 110)}$$

Reductions of discharge of mercury in wastewater due to this option are estimated to be close to zero because the mercury is associated with particles that are captured by filter and settling systems at a WWTP.

**Permanent: No.**

Collected mercury waste would be recycled or retired.

**Cost-Effectiveness:** \$110/lb. for air reductions; \$40/lb. total

**Cost:** \$12,000/yr.

The additional cost of recycling another 325 pounds per year would be about \$8,000 per year. However, there would be additional costs for collection system development and informational programs. A comprehensive program to research recycling and transport opportunities around the state, develop informational materials, conduct training sessions, and enhance recycling and transport opportunities around the state would cost about \$75,000 on a one-time basis. Spreading the set-up costs over 20 years = \$3,750/yr., for a total cost of \$11,750/yr..

**Implementation Issues:**

- Amalgam recycling opportunities vary by geographic location, as do transport mechanisms. Understanding and communicating these opportunities throughout the state to all dental offices will take a concerted effort of research and communication.

**Research Needs:**

The identity of local recyclers and transporters will require research in all major geographic areas of the state. The amount of mercury from amalgam waste that is emitted into the air, water, and land has been minimally studied, is mostly unknown, and is the subject of widely divergent estimates. These estimates should be improved so that collection programs can be designed with efficiency.

**Historical Use:** Historical recycling of amalgam has been limited by the capacities of recyclers and transporters.

**Resources:** Minnesota Dental Association

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**Increase the Recycling of Vacuum System Filters.**

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**Description:** Vacuum system filters capture about 30 percent of the amalgam waste produced during dental procedures. Information about proper procedures for managing the traps should be provided to all dental offices in a concerted fashion. Training programs should be developed. Recycling infrastructure identified or established in all areas of the state.

**Technically Feasible: Yes.**

**Reduction Potential:** 50 lb./yr. to air; 150 lb./yr. total to all media

An estimate of total mercury to be recovered statewide from vacuum system recycling is about 300 pounds per year. If the current level of recycling mercury from vacuum systems is 50 percent, the reduction potential would be 150 pounds per year of additional mercury recovery if 100 percent proper waste management was achieved.

The potential reduction in air emissions depends on the fate of non-recycled amalgam waste. Some mismanaged filters are emptied into garbage cans or infection waste containers, while others are sewerred. Sewerred mercury, according to the "Fate Tree for Mercury in Products," discussed in Part 6.1, would have a 56 percent likelihood of becoming an air emission via sludge combustion. Mercury in MSW is roughly 10 percent likely to be released to air via combustion. Assuming that half of the dental offices mismanaging filters empty them into garbage while the other half sewer the waste, the reduction potential to air is estimated to be:  $(150 \text{ lb./yr.}) (0.5) (0.56) + (150 \text{ lb./yr.}) (0.5) (0.10) = 42 + 8 = 50 \text{ lb./yr.}$

Reductions to discharge of mercury in wastewater due to this option are estimated to be close to zero because the mercury is associated with particles that are captured by filter and settling systems at a WWTP.

**Permanent: No.**

Collected mercury waste would be recycled or retired. (same as above)

**Cost-Effectiveness:** \$880/lb. to air; \$300/lb. total to all media

**Cost:** \$44,000/yr.

The additional cost of recycling another 150 pounds per year would be about \$40,000 per year. However, there would be additional costs for collection system development and informational programs. A comprehensive program to research recycling and transport opportunities around the state, develop informational materials, conduct training sessions, and enhance recycling and transport opportunities around the state would cost about \$75,000 on a one-time basis. Spreading the set-up costs over 20 years = \$3,750/yr., for a total cost of approximately \$44,000/yr.

**Implementation Issues:**

- Amalgam recycling opportunities vary by geographic location, as do transport mechanisms.
- Understanding and communicating these opportunities throughout the state to all dental offices will take a concerted effort of research and communication.

**Research Needs:**

Identification of all recyclers and transporters will require statewide study. The amount of mercury from amalgam waste that is emitted into the air, water, and land has been minimally studied, is mostly unknown, and is the subject of widely divergent estimates.

**Historical Use:**

Recycling of amalgam has been based on the availability of convenient and cheap recyclers and transporters. Good waste management will require proper practice regardless of the convenience.

**Resources:** Minnesota Dental Association

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**Install additional amalgam capture equipment in dental offices**

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**Description:** A variety of technologies have recently been developed for capturing amalgam waste that is not captured by the chairside traps and the vacuum system filters. The technologies use a variety of techniques including settling systems, filters, and centrifuges. These technologies are largely untried and untested but manufacturers typically claim to capture anywhere from 90 percent to 99+ percent of the total generation in a dental office.

**Technically Feasible: Unproven.**

Amalgam capture equipment is new to the market and is largely untested in terms of effectiveness and cost effectiveness. Testing of such equipment and technology in dental offices and/or pursuant to an ISO standard needs to be completed before broad-based installation in dental offices occurs.

**Reduction Potential:** 17 lb./yr. to air; 50 lb./yr. total to all media

An estimate of total mercury to be recovered statewide from advanced capture technologies is about 50 pounds per year. Estimated reduction potential for air emissions, using the same approach as used for other options for collecting dental amalgam, is 17 lb./yr..

**Permanent: No.**

Collected mercury waste would be recycled or retired.

**Cost-Effectiveness:** \$15,000/lb. to \$618,000/lb. to air; \$5,000/lb. to \$210,000/lb. to all media

**Cost:** \$250,000/yr. to \$10,500,000/yr.

The additional cost of capturing and recycling another 50 pounds per year would range from about a quarter of a million dollars per year to about \$10.5 million depending on the cost of the equipment utilized. In addition, there would be additional costs for collection system development and informational programs. A comprehensive program to research recycling and transport opportunities around the state, develop informational materials, conduct training sessions, and enhance recycling and transport opportunities around the state would cost about \$75,000 on a one-time basis.

**Implementation Issues:**

- The ability of dental office vacuum systems to work compatibly with the emerging technologies is a key question for dental offices. Also, issues of maintenance and the availability of collection and recycling systems are all key questions that need to be addressed.
- New technologies will be accepted in the marketplace only when adequate testing and information is available to dentists. There should be a safeguard so that the addition of such systems would not cause equipment failure during dental procedures and adversely affect the delivery of dental care or the safety of the patient.

**Research Needs:**

A comprehensive program to research the cost effectiveness and other questions identified under “Implementation Issues” needs to occur.

**Historical Use:**

Amalgam capture equipment is an emerging technology. Historical patterns and experiences do not yet exist.

**Resources:** Minnesota Dental Association

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**Reduce Use of Mercury Dental Amalgam**

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**Description:** This option calls for dentists to either use alternatives to mercury amalgam or to use less mercury in the amalgam mix. This option relates to a strategy that calls for reduced use of dental amalgam through research and by changing insurance coverage. The description of that strategy covers costs, reduction potential, and other information.

**Implementation Issues:**

- Dentists prefer that the decision to use alternatives to mercury amalgam be made by the dentist and patient, not dictated by outside parties. There are a number of issues that influence the filling material selection, including strength of the filling.

**8.3.4 Schools**

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**Collect Mercury Chemicals and Compounds in College and High School Laboratories**

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**Description:** A number of college and high school laboratories have elemental mercury, in bulk, in instruments (e.g. thermometers), or in chemicals and compounds. If this mercury is not managed properly it can make its way into the environment, usually through wastewater. Avoiding use of mercury containing products is covered by a separate option. This option calls for schools and universities to collect and properly manage existing stocks of mercury and mercury-containing chemicals in laboratories, and then to eliminate future purchasing and use. Mercury collection should include cleaning out mercury contained in sink traps.

**Technically Feasible: Yes.**

**Reduction Potential:** 10 lb./yr. to air; 60 lb./yr. to all media

Estimates show 300 pounds of mercury in high school laboratories and at least the same amount in college laboratories. In Minnesota, this would total about 600 pounds of mercury, and constitute a “one-time” reduction. Using the assumption from the “Fate Tree for Mercury in Products,” discussed in Part 6.1, that up to 10 percent of the mercury in use is removed from use each year, collecting 600 lb. of mercury that is currently “sitting on the shelf” would equate to an avoided annual release of 60 lb./year, to all media, over a 10-year period. Using the estimate that 15% of total releases are air emissions, the reduction potential to air would be about 10 lb./yr.

**Permanent: Yes and no.**

Collected existing mercury would be recycled, which is not considered a permanent reduction. Not buying mercury for school laboratory use would be a permanent reduction.

**Cost-Effectiveness:** \$700/lb. to air; \$100/lb. total to all media

Note: Administrative and labor costs are not included in the \$100/ pound figure.

UMD Numbers: \$5/pound for disposal, \$100/pound for replacement.

Exposure to potential clean up costs of spill would be reduced.

(UMD numbers: (\$9,324/90lbs.) (trap cleaning \$20/trap or more)

**Implementation Issues:**

- Requires backing of schools if voluntary collection programs are in place.
- Educational opportunities are in place.
- Many schools have had spills of mercury that have disrupted classes. This may be an important motivation to school officials.
- Other mercury-containing items used in school buildings could be included.

**Historical Information:**

The University of Minnesota runs a statewide program for collecting wastes from school laboratories. About 80 percent of schools have used this program.

**References:**

U.S. EPA mercury group

U of M Chemical Safety Day Program Gary Johnston (612)-626-1553

Western Lake Superior Sanitary District

**8.3.5 Municipal Waste Combustion (mass burn and RDF)**

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**Enhanced Air Pollution Controls (APC)**

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**Description:** Air pollution controls at municipal waste combustors (MWC) could be installed or enhanced using various technologies (mainly injection of powdered activated carbon) to increase mercury collection.

**Technically Feasible: Yes.**

**Reduction Potential:** 200 lb./yr.

The reduction potential varies with the APC system selected, and with the mercury concentration of the solid waste stream. As the concentration of mercury in solid waste declines, the amount of mercury controlled is reduced.

The reduction potential estimates provided are calculated over and above the existing regulatory emission limit (80 ug/dscm) which will become effective around the year 2000. This mandate will limit mercury emissions from all Minnesota MWC's to less than 275 pounds per year.

Two scenarios have been analyzed. In the first scenario, it is assumed that source reduction and material separation efforts are sufficient to meet limits and that no additional post-combustion controls are required. The second scenario assumes that source reduction and material separation efforts alone will not bring MWC's into compliance with the limits requiring post-combustion controls.

**Scenario 1** Source Reduction and Material Separation initiatives reduce mercury emissions such that post combustion controls are not required. Under this scenario, it is assumed that an enhanced pollution control system will be used to reduce mercury emissions to a level below the regulatory limit. The relatively low mercury concentration (less than 80 ug/dscm) reduces the collection efficiency of the APC system to an assumed 70 percent value. If Minnesota MWC's emit mercury at the limit, approximately 275 pounds of mercury would be emitted. Thus, under this scenario, approximately 192.5 pounds of mercury would be collected each year.

**Scenario 2** Source Reduction and Material Separation initiatives reduce mercury emissions, but not sufficiently to forego the need for enhanced post combustion controls. Under this scenario, it is assumed that an enhanced pollution control system will be used to reduce mercury emissions from a level of approximately twice the regulatory limit (160 ug/dscm) to some level below the limit. Since the mercury concentration in this scenario is relatively high, it is assumed that 90 percent collection efficiency will be achieved. If Minnesota MWC's emit mercury at twice the limit, approximately 550 pounds of mercury will be emitted each year. Thus, approximately 495 pounds of mercury would be collected each year; 220 pounds of which would not have been controlled by an emission limit.

**Permanent: No.**

All mercury controlled is transferred from an air emission to an ash medium and stored/disposed in ash monofills. Based on available data, mercury is not readily released from a monofilled ash matrix.

**Cost-Effectiveness:** \$3,400 to \$7,600/lb.

When costs for control are apportioned to all pollutants controlled (e.g., for carbon injection, mercury and dioxins), Scenario 1 and Scenario 2 control mercury at a cost ranging from \$1,700 to \$2,700 per pound (year 2000) and \$2,500 to \$3,800 per pound (2005).

The cost per pound of mercury controlled is a function of 1) the type of APC system used, and 2) the concentration of mercury in the feedstock. As the mercury concentration in MSW drops, the cost per pound removed increases proportionately.

The cost of mercury control has been calculated using the following assumptions:

- a. Cost is based on a Class C (<250 tons/day) Municipal Waste Combustor.
- b. Cost includes capital, debt service (6 percent for 20 years), operations, maintenance, and stranded capital value of APCs retired prematurely.
- c. All pollutant control benefits of system operation are taken into account, with the costs being apportioned according to the assumptions noted.
- d. All costs are in 1998 dollars; no inflation adjustment has been calculated.

Assumed control efficiencies for various APC systems are given in the attached table "APC Mercury Control Efficiency".

#### **Implementation Issues:**

- All municipal waste combustors will be required to comply with new, more stringent, state and federal mandates. Most facilities will enhance the existing air pollution control systems in order to do so. The cost of these projects, in combination with flow control issues, may result in the closing some facilities.

**Existing Incentives:** State and federal rules limiting mercury emission levels from waste combustors.

**Research Needs: None.**

**Historical Use of Option:** The pollution control systems described above are available and have proven track records in applications on municipal waste combustors. In Minnesota, mercury control has been in use for five or more years at the Hennepin Energy Resource Company (HERC) and Mayo Clinic. In Fall of 1998 two <250 ton per day (Class C) combustors installed carbon injection systems that operate in conjunction with the existing electrostatic precipitators (ESPs) for the dual purposes of controlling dioxin and mercury.

#### **References:**

From Olmsted County Department of Public Works (Rob Dunnette, Scott Martin, Bob Irelan): Costs are provided in the summary and table and graph "Mercury Control Cost 1990-2005;" the apportionment of APC benefits and cost is given in the table "Distribution of APC Cost"; the annual APC operating costs attributable to mercury control for various systems are given in the

table "Annual APC Cost Apportioned to Mercury". Additional calculations by Ed Swain, Anne Jackson, and Peter Torkelson of the MPCA staff.

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## **Waste Material Separation and Proper Management**

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**Description:** Material recovery facilities of various types (process separation recycling plants, household hazardous waste collection centers, appliance recycling facilities, etc.) separate and collect mercury, which is then recycled (if possible) or disposed in compliance with special or hazardous waste rules.

**Technically Feasible: Yes.**

**Reduction Potential:**

Statewide reduction potential from all waste management activities: 580 lb./yr. to air, 3,870 lb./yr. total to all media. For waste combustors alone: 130 lb./yr. to air, 860 lb. to all media. Aggressive material separation programs have documented mercury diversion rates approximating 50 percent of the potential mercury available in the waste stream. Assuming a statewide program that attains the 50 percent figure, and a current annual mercury release rate from products of 7,700 lb./yr. (70 percent of 1995 levels), the mercury release reduction potential would be approximately 3,870 pounds per year total, 580 lb./yr. (15 percent) to air.

These figures represent reduction overall which result from all waste processing and disposal activities, including loss during transport, illegal backyard burning, and other sources shown in the "Fate Tree for Mercury in Products" discussed in Part 6.1. The potential reduction from the waste combustion sector alone would be less.

**Permanent: No.**

Permanence of this approach is limited since the mercury collected would, in most cases, be recycled making it available for subsequent release.

**Cost and Cost-Effectiveness:** \$200 to \$500/lb.

Household hazardous waste facility operators estimate a cost-effectiveness ratio of \$200 to \$500 per pound. Cost estimates include collection, recycling or disposal, and a share of the public education budget that supports successful source separation efforts. No data was available from process-type material recovery facilities.

**Implementation Issues:**

- Many counties have hazardous waste collection facilities. Capital assistance grants for new hazardous waste facilities are available through the Office of Environmental Assistance (OEA). This type of program is popular, but requires an aggressive campaign of public relations and education. Placing a bounty on mercury containing waste is a possible strategy to encourage implementation, with the amount of the bounty being set by the next most cost-effective means of control.

**Existing Incentives:**

Municipal waste combustors (unlike other waste management facilities) are required to have some kind of mercury control plan in effect in order to obtain an operating permit. OEA provides capital grants for material separation facility construction. In some cases MPCA provides operating assistance to help defray the cost of disposal.

**Research Needs: None.**

**Historical Use of Option:**

Material recovery facilities of various types (process separation recycling plants, hazardous waste collection centers, appliance recycling facilities, etc.) are already performing this type of service and have done so successfully.

**References:**

Olmsted County Department of Public Works staff (Rob Dunnette, Scott Martin); Polk County staff (Bill Wilson)

**8.3.6 Sludge Incineration**

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**Treating Scrubber Water from Sludge Incinerators**

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**Definition:** The Metropolitan Council Environmental Services (MCES) Metro plant removes 96 percent of the mercury it receives from incoming wastewater. This mercury is captured in the plant's primary and secondary sludge, which is then incinerated. Wet scrubbers that capture particulate matter control flue gas from the incinerators. The wet scrubbers remove 40 percent of the mercury released.

Spent wet scrubber water containing elevated mercury concentration is returned to the wastewater treatment plant without prior treatment. The mercury associates once more with sludge solids, and returns to the incinerators. Thus, the mercury loading to the incinerators is 60 percent higher than the mercury loading to the wastewater treatment plant itself. The mercury finally escapes the system when the sludge is combusted in the incinerators. MPCA staff estimate that 95 percent of the mercury coming into the plant is released to the atmosphere via the incinerators. A sampling and analysis program was completed at the Metro plant demonstrating that if the wet scrubber discharge was removed from the wastewater treatment plant, and rerouted for separate treatment, about 120 pounds per year of mercury would be removed from the atmosphere.

According to EPA, sewage sludge incinerators often use wet scrubbers to control emissions. The internal recycling of spent scrubber water is typical. Separating recycled scrubber water at municipal wastewater treatment plants nationwide may result in substantial reductions of atmospheric releases of mercury.

MPCA staff members are currently revising the air emissions permit for the MCES facility. The proposed permit calls for MCES to prepare a detailed plan that evaluates options for

reducing mercury emissions. Because this report is not yet available, the cost and reduction potential estimates shown below have been approximated by WLSSD and MPCA staff.

**Technically Feasible: Yes.**

**Reduction Potential:** At MCES Metro: 120 pounds per year from atmosphere

**Permanent: No.**

This process transfers mercury from air or water to land.

**Cost Effectiveness:** \$2,000/pound to \$20,000/lb. of mercury removed

**Implementation Issues:**

- In some cases, as occurred at WLSSD and may be available at Metro, existing unused or underused settling equipment may be available for treating scrubber water.
- Sludge dewatering equipment could be needed at Metro. In order to landfill sludge, the sludge would likely need to meet a “paint-filter” test--no liquid can freely drain from the sludge. MPCA staff estimates assume that a belt filter press must be constructed in order to dewater sludge.
- Final sludge is subject to industrial waste landfilling requirements: it must meet the TCLP criteria test. Failing the TCLP would greatly increase sludge disposal costs. At this point, WLSSD, which treats wet scrubber sludge for landfilling, has never had its wet scrubber sludge fail the TCLP test.
- The cost of this option is related to the volume of water that requires treatment and the need to dewater sludge. A significant portion of the annual operating cost relates to using large amounts of polymer, which is directly affected by the flowrate. Further evaluation of the wet scrubber to potentially treat smaller sidestreams rather than the complete discharge, and of sludge characteristics would reduce the amount of polymer needed, and lower the overall cost of this option.

**References:** “MCES Metro Cost analysis” by MPCA staff, 1998.

### **8.3.7 Wastewater Treatment Plants**

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#### **Best Available Treatment for WWTP Discharges**

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**Definition:** This option calls for using “best available treatment” at wastewater treatment plants. “Best available treatment” means chemical reduction and precipitation followed by ion exchange. This process captures dissolved mercury. Information herein is based on a 43 MGD secondary treatment plant (WLSSD). Those figures are then used to determine statewide costs.

**Technically Feasible? Unproven**

**Mercury Release Reduction Potential:** 31 lb./yr.

Decreasing the discharge water concentration from 0.020 ug/l (1995) to <0.001ug/l at WLSSD would result in a release reduction of 2.5 lbs./yr. to water. This can be extrapolated statewide to

31 lbs./yr. to water, assuming the same concentrations as WLSSD and that the total quantity of wastewater treated is 500 mgd.

**Permanent: No.**

There would be a transfer of mercury from water to a solid waste (sludge). It is assumed the mercury would have a low leaching potential from sludge, but little is known about air emissions or stability of the wastes generated from this treatment process.

**Speciation:**

Mercury release collected in sludge is assumed to be less than five percent methylmercury. The rest is likely to be ionic mercury.

**Cost Effectiveness:** \$5.5 million per pound

**Cost:** \$170 million total cost statewide

Estimates for WLSSD:

Capital costs \$51.4 million

O&M costs \$9.4 million

20 yr. @5.5 is 13.7 million annualized

= \$5.48 million per lb. of mercury removed

STATEWIDE extrapolation:

500 mgd/40mgd x cost = 12.5 x \$13.7/year = \$170 million total

\*Information based on WLSSD/ENSR study and 1993 dollars.

For smaller treatment plants the cost per million gallons treated would be even higher.

**Implementation Issues:**

- This treatment technology has not been used on this large of a scale.
- Increased electrical demand.
- In order to meet the limits of the Great Lakes Initiative through end of pipe technology these are the magnitude of costs required. {*explain*}
- Mercury waste would be transferred to another medium.
- This option is less preferable to source reduction, since elimination of sources can cost less and result in large and permanent reductions in comparison.

**8.4 “Parking Lot” of Options not considered in detail:**

**Option: Land Application of Wastewater Sludge versus Incineration:**

The SRFRS committee decided that this is such a site-specific proposal that it should be put in the parking lot. Analyses by MCES have found that incinerators are more cost effective for MCES than land application due to hauling costs, heat recovery issues, and fuel costs. There is a research need to determine if mercury in incinerated sludge is less stable than mercury in sludge that is applied to land.