Mercury Case Study – Wastewater Treatment on Lake Superior

As you complete this case study, imagine you are an Environmental Engineer working at a wastewater treatment plant trying to determine the best steps moving forward to reduce the mercury being discharged into the St. Louis River, a major tributary of Lake Superior. Your goal is to ultimately come up with a recommendation to give to the Board of Directors that oversees the wastewater treatment plant.

1. Mercury in the Environment

Mercury (chemical symbol Hg) is a naturally occurring element found everywhere in the environment. It can become airborne from natural processes, such as soil decomposition and volcanic eruption, and fall back to earth in dust, rain or snow. Human activities that release mercury to the environment include mining and smelting; burning fossil fuels and wood; cement and lime kiln production; crematories; petroleum refining; and incinerating solid waste or sludge. Mercury does not break down; once it enters the environment from any source, it remains there.

Lakes and rivers are contaminated when there is direct discharge of mercury containing industrial or municipal wastewater to them. In the water, mercury is converted to methyl mercury by bacteria or by chemical reactions. Tiny aquatic organisms absorb methyl mercury, and it can build up, or **bioaccumulate**, in an individual organism. The methyl mercury can get into fish from the organisms they eat. Eventually, the methyl mercury builds up to high levels in predatory fish at the top of the aquatic food chain. This increase in concentration of methyl mercury as you move higher in the food chain is called **biomagnification**. If humans eat fish that have methyl mercury, it can bioaccumulate in humans too. Since the mercury is distributed throughout the tissue, there is no method of cooking or cleaning fish that will remove the mercury.

Methyl mercury is neurotoxic; it affects the brain and spinal cord. In the brain, methyl mercury interferes with the way nerve cells function. High levels of mercury in infants can cause mental and physical retardation. Many states have developed guidelines for how often fish from the Great Lakes can be safely eaten.

Wildlife such as loons, eagles, otters, mink and ospreys eat large quantities of fish and incidentally consume mercury. It appears that loons are accumulating mercury to the point that reproduction is impaired. Body tissues in mink and otter populations also contain elevated mercury levels. An excess of mercury can lead to neurological impairment, especially damaging for predators who rely on speed and coordination to obtain food. Unfortunately, wildlife cannot change their eating habits in order to avoid mercury contamination.

Fish Consumption Guidelines for Men, Boys Age 15 and Over, and People Not Planning to be Pregnant

Species	Guidance	Contaminants
Carp	Limit to 1 meal/month, regardless of size	Mercury and PCBs
Crappie	Limit to 2 meals/Week, regardless of size *Limit to 1 meal/month, regardless of size	Mercury
Freshwater Drum	Limit to 1 meal/month, regardless of size	Mercury
Walleye	Limit to 1 meal/month, if 22" or longer	Mercury
Yellow Perch	Limit to 2 meals/Week, regardless of size	Mercury

* Guidelines for People Who Are or May Become Pregnant, People Who Are Breastfeeding or Plan to Breastfeed, and Children Under Age 15

Questions

a. List questions posed by your group.
b. How does mercury get into the environment?
c. What impact does mercury have when it is in the environment?
d. Studies have also been performed on mice and rats and have determined the LD_{50} is around 45 mg/kg. That means that 50% of mice would be killed if they consumed 45 mg Hg per kg of body mass. If an average mouse is 30 grams, how many milligrams of Hg is the LD_{50} for an individual mouse?
e. Why are there fish consumption guidelines?
f. How does mercury impact humans when it is consumed?
g. There is an asterisk (*) in the chart. Why might there be different guidelines for different people?

2. Wastewater Treatment and Mercury Regulations

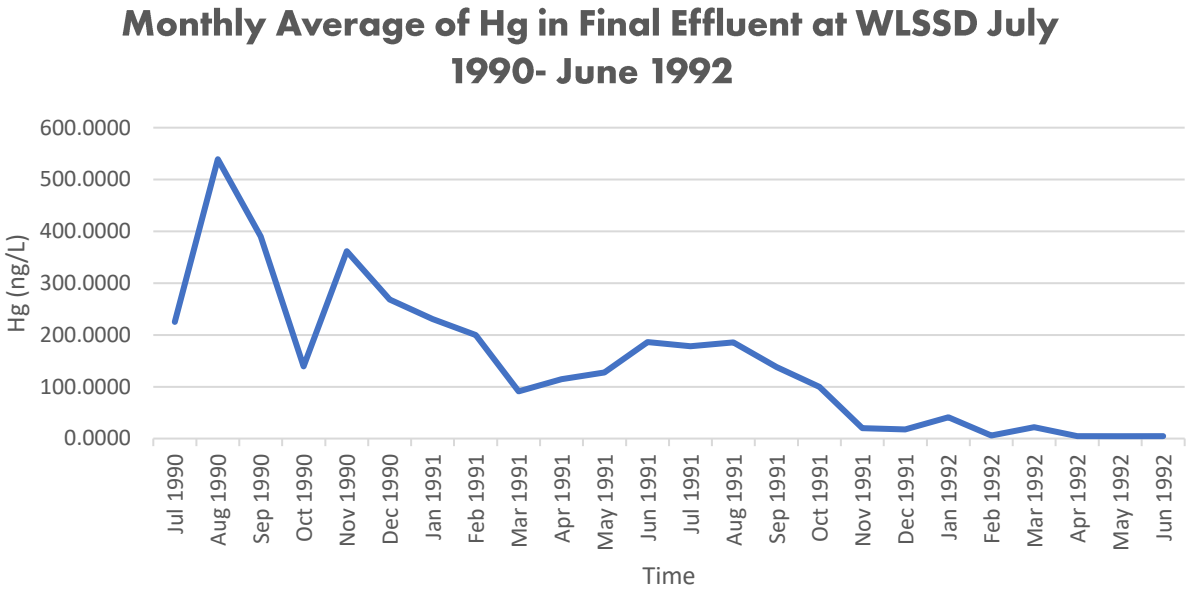
Wastewater treatment plants like Western Lake Superior Sanitary District (WLSSD) are tasked with removing pollutants from wastewater. Water from homes and businesses are sent to wastewater treatment plants where physical, biological, and chemical processes are used to treat the water before the water is released into the environment. The Clean Water Act of 1972 addresses water pollution by setting pollutant limits discharged by point source facilities into a 'water of the United States'. The limits are assigned through National Pollutant Discharge Elimination System (NPDES) permits and are determined so the discharge does not hurt water quality or people's health. Often these limits are very low concentrations measured in nanograms per liter (ng/L) which is the same as parts per trillion (ppt). To get a sense of scale, 1 ng/L is the equivalent of 1 drop of water in 20 Olympic size pools. That is a very small amount.

Since starting operations in 1978, WLSSD has received an NPDES permit from the Minnesota Pollution Control Agency (MPCA). Currently, mercury is a pollutant that is heavily regulated by the Environmental Protection Agency (U.S.EPA) and the MPCA. However, the first permit limiting mercury levels in effluent started in 1990.

The mercury limits set by the NDPES in 1990:

- 5.8 ng/L monthly average
- 7.4 ng/L daily average

The reason the permit allows a higher daily average limit than the monthly average limit is to allow for unexpected situations where there is an increase in mercury arriving at the wastewater treatment plant that could happen on any given day.



Questions:

a. List questions posed by your group.
b. What law led to pollutants from point sources being regulated?
c. What year were limits set for mercury levels in effluent (treated water leaving wastewater treatment plants)?
d. What were the limits?
e. What does ng/L stand for?
f. What happened to the Hg in the effluent at WLSSD after limits were in place?
g. Why might there be variation each month in the Hg measured in the effluent?

3. Great Lakes Initiative (GLI)

In 1995, The U.S. EPA published the Water Quality Guidance for the Great Lakes Watershed, commonly known as the Great Lakes Initiative (GLI). The Great Lakes Initiative was established to protect the sensitive waters of the Great Lakes. Part of this initiative was to further limit the discharges of mercury into the Great Lakes. WLSSD's permit for mercury limits were modified in order to meet the requirements set by this initiative:

- 1.8 ng/L monthly average
- 3.2 ng/L daily average

The Great Lakes watershed includes eight U.S. States: Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York.

Questions

a. List questions posed by your group.
b. Why was the Great Lakes Initiative established?
c. As a result of the Great Lakes Initiative, what were WLSSD's new limits for mercury?
d. WLSSD was not meeting these stricter limits. Brainstorm some ideas for what WLSSD might be able to do to better control mercury pollution and reduce mercury in the effluent.

4. Pollution Prevention

Traditional approaches to pollution control emphasize treating waste after it is generated. Often these treatment processes simply move pollutants around, creating hazardous residues that require disposal. Pollution prevention is based on a simple but powerful idea. It makes more sense to stop producing waste than to develop treatment and disposal technologies to manage it. Pollution prevention strategies focus on changing existing processes and replacing hazardous chemicals with alternatives to reduce the discharge of toxins to the environment.

There is no treatment method that can completely remove mercury from wastewater. Mercury control technology merely transfers the pollutant from wastewater to sludge, ash or into the air. Incineration, land application or landfilling of mercury-bearing sludge or ash results in a transfer of mercury to the environment. Pollution prevention is the best approach to achieving reductions in the release of mercury and other persistent organic pollutants (or POPs) that do not break down in the environment.

Did you know? The number one source of mercury entering the environment is from the burning of fossil fuels. It is released into the atmosphere and then can move around the world before being deposited onto the land.

It is important to consider the potential for cross-media transfer when designing a mercury-reduction program. In the case of mercury, cross-media transfer is simply the movement of a mercury from one place to another, but it does not reduce the mercury. The goal of pollution prevention is to eliminate mercury discharges, not transfer them from wastewater to solid waste, air or other media. In most cases, pollution prevention is less expensive than end-of-pipe treatment for mercury removal. In addition, pollution prevention changes behavior and practices, which result in the elimination of mercury discharges.

Questions:

a. List questions posed by your group.
b. What is pollution prevention?
c. What is the traditional approach for pollution control?
d. What are two benefits to pollution prevention?
e. Installing a new filter to remove Hg at a wastewater treatment plant is one example of pollution control. Is this a traditional approach? Or pollution prevention?
f. With your group, come up with three examples of possible pollution prevention measures WLSSD could undertake.

5. Mercury Reduction Solutions at WLSSD – Potlatch Corporation

WLSSD has a wastewater treatment plant that discharges the effluent water into the St. Louis River, a major tributary into Lake Superior. WLSSD receives wastewater from homes and businesses, as well as several industries. One of the major industries sending wastewater to WLSSD is the paper mill industry. In fact, over half of the wastewater that typically arrives at the treatment plant is coming from two paper mills.

Between the 1960's and early 2000's, Potlatch Corporation operated an integrated pulp and paper mill in Cloquet, Minnesota, that produced fine coated printing papers. After primary treatment (separation of solids – think larger tree bark pieces) at the paper mill, it discharges its effluent to WLSSD for additional treatment. In mid-1994, the mill and WLSSD identified mercury spikes as high as one part per billion (ppb) in wastewater from the mill. Potlatch accounts for about 35 percent of the flow to the WLSSD treatment plant, so this amount of mercury was a significant contribution. A pollution prevention assessment team consisting of Potlatch and WLSSD staff, along with chemical engineering students from the University of Minnesota-Duluth, was formed to identify the source of the mercury. Potlatch had previously implemented a pollution-prevention program that included extensive use of mercury-free alternatives and a mercury recycling program. Potlatch had also investigated sewer lines to ensure that mercury was not trapped in sewers where it could be released into the wastewater during high flow conditions.

The assessment team focused on mercury as a contaminant in raw materials. Rather than analyzing every feedstock chemical individually, wastewater effluent analysis was used to locate mercury sources within the manufacturing process. The mercury was traced to the bleaching process, and the feedstock chemicals analyzed for mercury included sodium hydroxide (caustic soda), sulfuric acid and chlorine dioxide. Based on these analyses, along with telephone surveys of chemical suppliers, the source was determined to be sulfuric acid. The mill was receiving sulfuric acid from a lead smelter and its mercury content was significantly higher than would normally be expected, as high as 10,000 ppb. As a result of switching to an alternative source of sulfuric acid, the mercury concentration in the mill's effluent was reduced by 98 percent.

Questions:

a. List questions posed by your group.
b. What did Potlach discover was the source of the mercury?
c. How did Potlach remedy this situation?
d. What was the mercury reduction with this change?
e. Imagine your group works for Potlach. What are strategies you would recommend to other paper mills or industries if they wanted help with pollution prevention?

6. Mercury Reduction Solutions at WLSSD – Dental Amalgam

Mercury-containing amalgam is used by dentists as a filling material for teeth. When combined with the other metals that make up the amalgam, mercury is not considered toxic, because the amalgam is a hard, stable material. However, waste amalgam sometimes is disposed of down the drain and transferred on to a wastewater treatment plant. Alternative filling materials are becoming increasingly available, but mercury amalgam remains in use because it is versatile, inexpensive and easy to use.

In 1993, WLSSD staff sampled the wastewater discharge from a medical building housing several dental practices and found a mercury concentration of 35 parts per billion (ppb). This represented approximately 0.3 grams of mercury discharged by each dentist each day. Staff approached the local professional organization, the *Northeast District Dental Society*, and suggested that they work together to raise awareness in the profession and to keep mercury out of the wastewater. The focus was on "capturing" mercury instead of allowing it to be flushed down the drain.

With assistance from the Dental Society, WLSSD staff produced a manual of "best management practices" with information on proper disposal of mercury, amalgam and other dental office wastes. The manual was distributed to all dentists in the WLSSD service area. Subsequent monitoring of the same building in 1995 found the effluent mercury concentration reduced to 0.086 grams of mercury per dentist per day. This reduction was attributed to the outreach program and changes in waste handling practices at the dental offices.

In 1995, WLSSD staff returned to the dentists to conduct waste audits. These audits disclosed that while amalgam waste captured in dental offices was no longer being disposed down the drain, it was still being placed in the solid waste or medical waste container. Inappropriate disposal of medical waste containing mercury can create mercury pollution. For example, landfill leachates may enter the water table and autoclave discharge is sewered. This is an example of cross-media transfer of a pollutant–from solid waste to the sewage stream.

WLSSD staff worked with medical waste contractors in the region and a mercury recycling firm to set up a pilot program to collect chairside traps for recycling. Several dentists agreed to work with WLSSD staff to field test equipment designed to remove amalgam from the wastewater generated from dental vacuum systems. Currently, properly designed amalgam separation units remove up to 99 percent of the amalgam from dental wastewater. The fine particulate waste collected in these units can be removed by dental staff, in most cases, and recycled at WLSSD for a small fee or through commercial recycling operations.

Cooperation between WLSSD staff and the Dental Society has been the key to this project's success. District staff have attended professional meetings to discuss the mercury issue, and drafts of all findings and documents were reviewed by the dental community. WLSSD continues to work with the Dental Society to evaluate amalgam removal equipment and to provide ongoing pollution prevention education for the dental community.

Questions:

a. List questions posed by your group.
b. What is dental amalgam?
c. Why is mercury found in dental amalgam?
d. How does mercury from dental amalgam enter wastewater at a dentist office?
e. How can the cross-media transfer with mercury occur?
f. Why do you think cooperation between WLSSD staff and the Dental Society has been important?

7. WLSSD – pilot studies, featuring CLEARAS

While pollution prevention has helped lower the amount of mercury entering the wastewater treatment plant, there is still more that needs to be captured to meet the NPDES permit limits. WLSSD has studied dozens of potential mercury reduction technologies, and even tested some of the technologies on site to try and find a viable option to meet the permit limits. In 2020, WLSSD partnered with a company called Clearas to experiment with their technology in a way never before studied. The Clearas system is designed to remove nutrients from the wastewater. Could the process also remove the elusive last bit of mercury remaining after our treatment process?

The Clearas ABNR (Advanced Biological Nutrient Removal) system uses algae to remove nitrogen and phosphorus from the wastewater. The pilot study was set up in a greenhouse structure at WLSSD. A pilot study is a small feasibility study designed to test various aspects of the methods before implementing a large-scale project.

Below highlights the parts of the system:

1. Mix Phase:
Wastewater and algae are combined in mixing tanks.

2. Nutrient Recovery Phase:
The mixture enters a series of glass tubes called the photobioreactor (top right) that is housed in a green house providing warmth and light sunlight that algae requires to grow (bottom right). Algae consumes and removes nutrients (i.e. phosphorus and nitrogen) from wastewater.

3. Separation Phase:
Wastewater is separated from the algae, returned back into the treatment process, and discharged into the river.

4. Harvest Phase:
The algae is harvested, dried and sold to vendors in a wide variety of diversified markets. A system at WLSSD could generate up to 3,500 dry tons/day.

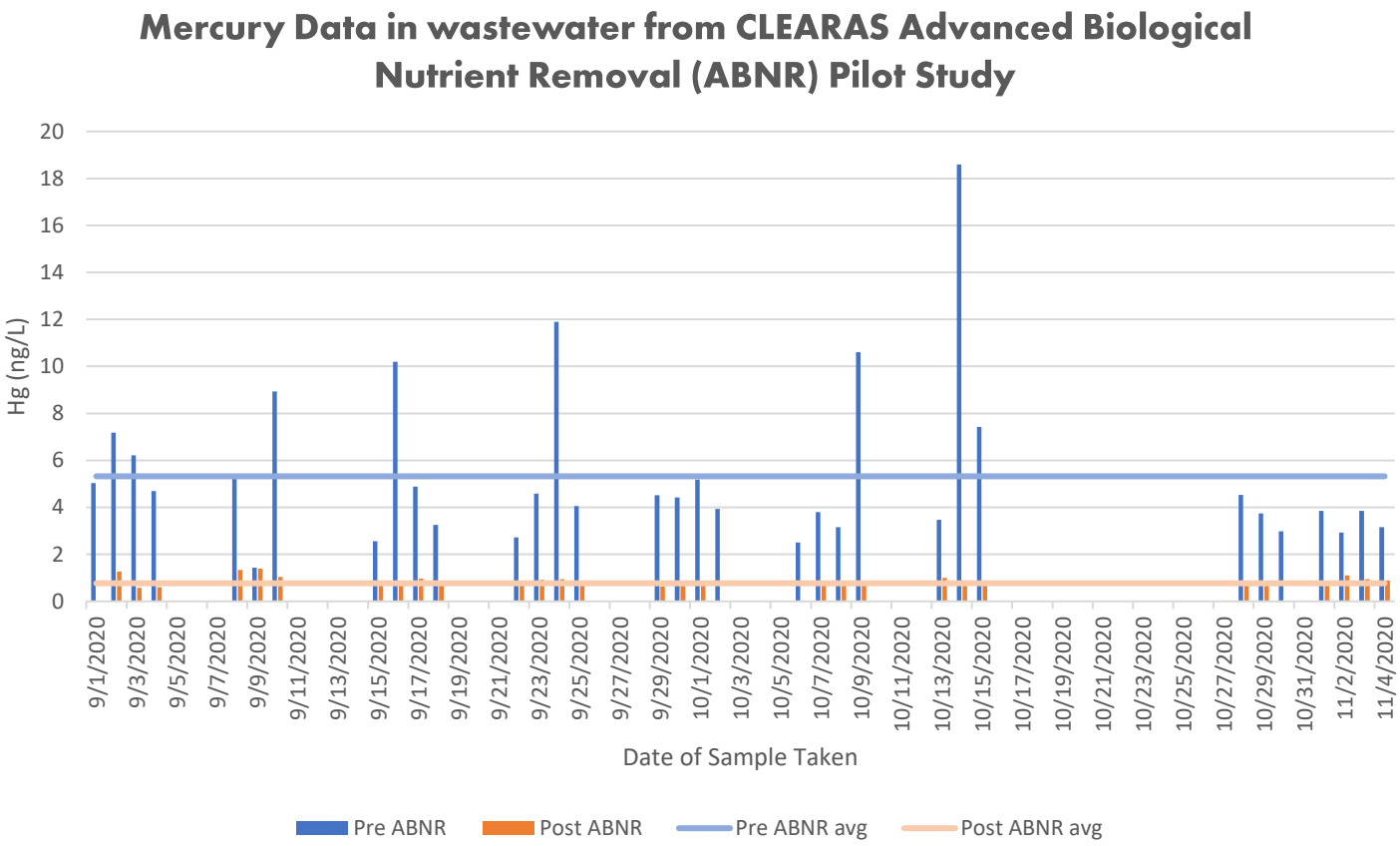
Algae consumes nutrients in the Photobioreactor.

The greenhouse provides sunlight for the algae to grow.

Questions:

a. List questions posed by your group.
b. What does algae need to grow?
c. Describe how the Clearas ABNR system works to remove nutrients.
d. Where does the Mercury end up?

8. CLEARAS Mercury Data



Question:

a. What is being measured in this graph?
b. What do the vertical bars on the graph show?
c. What do the horizontal bars represent?
d. What do you notice about the differences between the blue and the red data?
e. Is there more mercury in the wastewater before or after the ABNR treatment during the pilot study?
f. Where is the mercury ending up?
g. WLSSD has permit limits of 1.8 ng/L Hg in the wastewater it discharges into the river. Is WLSSD likely to meet the permit limits with this system?
h. Based on the information you have, do you think WLSSD should invest in an ABNR system for all their wastewater? Why or why not? What additional information would you want to know to help make that decision?

9. CLEARAS Environmental Impact Analysis

After completion of the pilot study, a consulting firm was hired to complete a Feasibility Report that includes an Environmental Impact Analysis. The below figure shows simplified model of the flow of CO_2 and Mercury at WLSSD pre-pilot study (A) and with the proposed ABNR Treatment System (B).

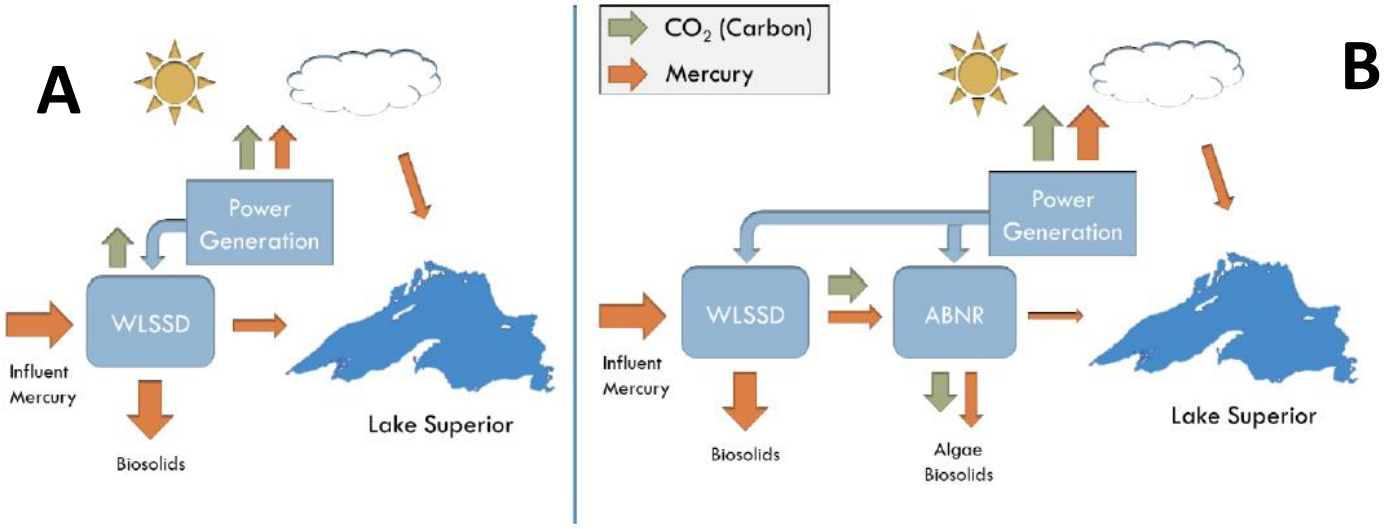


Figure 3-1: Qualitative Carbon and Mercury Flux With and Without ABNR Treatment System

Questions:

a. List questions posed by your group.
b. What does side A show?
c. What does side B show?
d. The size of the arrows is related to the amount of CO_2 and mercury flow. On side B, circle the arrows that are new as well as those that have changed sizes and/or directions.
e. Which version (A or B) leads to more CO_2 into the atmosphere?
f. Which version leads to more Mercury into the air?
g. Which version leads to more Mercury into the water?

10. Recommendation Report – Claim-Evidence-Reasoning

The Environmental Impact Analysis found mixed results with carbon and mercury emissions. During the wastewater treatment process, WLSSD emits carbon onsite. This would be captured by the algae in the ABNR system and lead to lower direct carbon emissions at WLSSD. Additionally, mercury would be captured in the ABNR system, resulting in lower mercury discharge into Lake Superior. However, the ABNR system would require a major increase in energy consumption to heat and provide lighting for the greenhouses that would contain the algae. As a result, it was estimated the increased use of energy would lead to an additional 23,000 tons of carbon dioxide being emitted annually into the atmosphere due to the burning of fossil fuels. Additionally, burning these fossil fuels would lead to approximately the equivalent amount of mercury entering the atmosphere that was captured by the ABNR system. To summarize, the ABNR system would lead to increased carbon emissions, and equivalent mercury emissions, although less mercury being discharged directly into Lake Superior.

Based on what you have learned, write a recommendation report to the board.

Recommendation:

Claim:

Evidence:

Reasoning: