Best Available Mercury Reduction Technology Analysis and Proposed Alternative Mercury Emissions Reduction Plan

Prepared for
United States Steel Corporation, Minnesota Ore Operations - Keetac

December 2018

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Acronyms and Abbreviations

Acronym	**Description**
ACI	Activated Carbon Injection
AMERP	Alternative Mercury Emissions Reduction Plan
BACT	Best Available Control Technology
BAMRT	Best Available Mercury Reduction Technology
Barr	Barr Engineering Co.
BART	Best Available Retrofit Technology
$CaBr_2$	Calcium Bromide
$CaCl_2$	Calcium Chloride
CCM	EPA Air Pollution Control Cost Manual
CEMS	Continuous Emission Monitoring System
CMM	Continuous Mercury Monitor
DEDTC	Diethyl Dithiocarbamate
DNR	Minnesota Department of Natural Resources
EERC	Energy & Environmental Research Center
EGU	Electrical Generating Units
EPA	U.S. Environmental Protection Agency
ESP	Electrostatic Precipitator
FAMS	Flue-gas Absorbent-trap Mercury Speciation
GLRI	Great Lakes Restoration Initiative
gph	gallons per hour
gpm	gallons per minute
H_2O_2	Hydrogen Peroxide
HBr	Hydrogen Bromide
HCl	Hydrogen Chloride
HEDT	High Energy Dissociation Technology
HTC	Hibbing Taconite Company
ICI	Industrial, Commercial, and Institutional
Keetac	United States Steel Corporation, Minnesota Ore Operations - Keetac
MACT	Maximum Achievable Control Technology
MATS	Mercury and Air Toxics Standards
ME2C	Midwest Energy Emissions Corporation
Minn. R.	Minnesota Rules
Minntac	United States Steel Corporation, Minnesota Ore Operations - Minntac
Minorca	ArcelorMittal Minorca Mine Inc.
MPCA	Minnesota Pollution Control Agency
NaBr	Sodium Bromide
NaCl	Sodium Chloride
$NaClO_2$	Sodium Chlorite

NESHAP	National Emission Standards for Hazardous Air Pollutants
NSR	New Source Review
OHM	Ontario Hydro Method
PAC	Powdered Activated Carbon
PM	Particulate Matter
PSD	Prevention of Significant Deterioration
RATA	Relative Accuracy Test Audit
SAM	Sulfuric Acid Mist
SO_2	Sulfur Dioxide
TMDL	Total Maximum Daily Load
UTAC	United Taconite LLC

1 Executive Summary

In accordance with Minn. R. 7007.0502, United States Steel Corporation, Minnesota Ore Operations - Keetac (Keetac) evaluated potentially available mercury emissions reduction technologies to achieve a 72% reduction of mercury air emissions from the facility’s indurating furnaces. This report describes the background and methods used in the Best Available Mercury Reduction Technology (BAMRT) analysis, the alternative mercury emissions reduction evaluation, and the alternative mercury emissions reduction plan (AMERP) proposed by Keetac for its taconite processing plant located in Keewatin, Minnesota.

The taconite processing industry completed an evaluation of potentially available mercury emissions reduction technologies by adapting an approach similar to the U.S. Environmental Protection Agency (EPA)-approved Best Available Retrofit Technology (BART) analysis and top-down Best Available Control Technology (BACT) analysis. The BAMRT analysis sought to determine if mercury reductions required by Minn. R. 7007.0502, subp. 6, are technically achievable, using the adaptive management and acceptable environmental impacts criteria. The steps of this evaluation are outlined below. The details of each step, including the methods used to analyze acceptability of each step, are discussed further in Sections 4.1 through 4.8.

The BAMRT analysis evaluated the following potentially available mercury emissions reduction technologies:

- Mercury capture by existing wet scrubbers with solids removal
- Mercury oxidation and capture by wet scrubbers
    - Halide injection
    - In-scrubbers oxidation
    - High energy dissociation technology (HEDT)
- Activated carbon injection (ACI)
    - ACI with existing scrubbers
    - ACI with electrostatic precipitator (ESP)
- Fixed carbon beds
- GORE^{TM} (previously known as Monolithic Polymer Resin Adsorption (Reference (1)))
- Monolithic honeycomb adsorption

The purpose of the BAMRT analysis was to determine if the 72% mercury emissions reduction required by Minn. R. 7007.0502, subp. 6, was technically achievable by any of the potentially available mercury emissions reduction technologies. The BAMRT analysis results are included in Table ES-1 below. Full details of the BAMRT analysis are included in Section 4 and Figure 4-1 illustrates the steps in both the BAMRT analysis and the alternative mercury emissions reduction evaluation.

Keetac determined the 72% mercury emissions reduction for the indurating furnace was not technically achievable by any of the potentially available mercury emissions reduction technologies evaluated in the BAMRT analysis. One reduction technology, mercury capture by existing wet scrubbers with solids removal, moved on for further evaluation in the alternative mercury emissions reduction evaluation.

The purpose of the alternative mercury emissions reduction evaluation was to determine what level of mercury emissions reduction is technically achievable. Full details of the alternative mercury emissions reduction evaluation are included in Section 5.

Keetac determined that mercury emissions reductions of 30% are technically achievable. Keetac's AMERP was prepared in accordance with Minn. R. 7007.052, subp. 5(A)(2) with full details included in Section 6. Appendix A includes the completed Minnesota Pollution Control Agency (MPCA) Form aq-ei2-04a (referred to as MPCA's Ferrous Mercury Reduction Plan Form in the remainder of this document).

Table ES-1 Summary of the BAMRT Evaluation Results

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
List available reduction technologies	**Is the technology commercially available?**	**Does the technology operate without impairing pellet quality or production?**	**Does the technology cause excessive corrosion to pellet furnaces or associated ducting or emission control equipment?**	**Does the technology present unacceptable environmental impacts?**	**Can the technology consistently meet the 72% reduction per the rule?**	**Is the technology cost effective?**
Mercury capture by existing wet scrubbers with solids removal	Yes	Yes	No	No	No – Technology proceeds to alternative mercury emissions reduction evaluation (refer to Section 5)	NA – See Step 6
Halide Injection	Yes	Likely yes, however only short term testing has been completed	Likely no, however only short term testing has been completed	Yes - Increased likelihood of local mercury deposition, eliminated from further consideration (refer to Section 4.5.1)	NA - see Step 5	NA - see Step 5
In-scrubber oxidation – Not considered a potential technology based on previous industry testing (refer to Section 4.1.4.2)	NA – See Step 1	NA – See Step 1	NA – See Step 1	NA – See Step 1	NA – See Step 1	NA – See Step 1
HEDT	No, eliminated from further consideration (refer to Section 4.2.1)	NA - see Step 2	NA - see Step 2	NA - see Step 2	NA - see Step 2	NA - see Step 2

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
List available reduction technologies	**Is the technology commercially available?**	**Does the technology operate without impairing pellet quality or production?**	**Does the technology cause excessive corrosion to pellet furnaces or associated ducting or emission control equipment?**	**Does the technology present unacceptable environmental impacts?**	**Can the technology consistently meet the 72% reduction per the rule?**	**Is the technology cost effective?**
ACI with existing scrubbers	Yes	Likely yes, however only short term testing has been completed	Likely no, however only short term testing has been completed	Yes - Increased likelihood of local mercury deposition; jeopardizes compliance with existing limits. Eliminated from further consideration (refer to Section 4.5.2)	NA - see Step 5	NA - see Step 5
ACI with ESP	Yes	Likely yes, however no testing has been conducted	Likely no, however no testing has been conducted	Likely no	Likely yes	No, eliminated from further consideration (refer to Section 4.7.2)
Fixed carbon bed	Yes	Likely yes, however the limited information available does not allow for a definitive answer	Likely no	Likely no	Likely yes, based on limited test data	No, eliminated from further consideration (refer to Section 4.7.2)
GORE^{TM}	Yes	Likely yes, however the limited information available does not allow for a definitive answer	Likely no	Likely no, however mercury in water increased which would need to be removed and waste generation managed	Likely yes if sufficient SO_2 is present	No, eliminated from further consideration (refer to Section 4.7.2)
Monolithic honeycomb adsorption	No, eliminated from further consideration (refer to Section 4.2.2)	NA - see Step 2	NA - see Step 2	NA - see Step 2	NA - see Step 2	NA - see Step 2

2 Introduction

This section discusses the purpose and background information associated with this BAMRT report. In addition, a description of Keetac's process is included for context in the mercury emissions reduction technology evaluations.

2.1 Purpose

This section outlines the history of the Minnesota Total Maximum Daily Load (TMDL), mercury reduction research, and rulemaking for the taconite processing industry. The background information explains why Keetac is completing this BAMRT analysis.

2.1.1 Mercury Reduction Research from Minnesota Taconite Processing

The taconite processing industry in northeastern Minnesota has actively researched methods to reduce mercury emissions from processing taconite ore to produce taconite pellets for use in blast furnaces. Facilities that have participated in the ongoing efforts to reduce mercury emissions from operations include Hibbing Taconite Company (HTC), ArcelorMittal Minorca Mine Inc. (Minorca), Northshore Mining Company, United Taconite LLC (UTAC), United States Steel Corporation, Minnesota Ore Operations – Minntac (Minntac), and Keetac. Mercury is a naturally occurring element present in taconite ore and certain indurating furnace fuels in trace amounts.

During the development of the Minnesota statewide mercury emissions reduction goals, a cooperative effort between the taconite processing facilities, the MPCA, and the Minnesota Department of Natural Resources (DNR) focused research on mercury emissions from Minnesota taconite processing facilities and ways to reduce these emissions. In 2003, efforts focused on the speciation of mercury from taconite processing and total mercury levels emitted from taconite processing operations. Research conducted in 2005 studied the generation, distribution, and fate of mercury emissions from taconite processing facilities. Between 2006 and 2009, research focused on the capture of mercury from taconite processing combustion streams. The industry worked with the DNR, MPCA, and other interested stakeholders to obtain Great Lakes Restoration Initiative (GLRI) funding. Utilizing a mix of industry and GLRI funding, a comprehensive evaluation of multiple control technologies was conducted by various vendors and academic researchers. Facilities actively tested several methods to capture mercury released from the induration process by existing wet scrubbers. These tests showed mixed results for mercury capture and reduction from taconite processing, identifying data gaps that would benefit from a more complete evaluation of the technology. Ultimately this broad suite of testing helped to better define a narrower band of potential solutions to evaluate. However, the State of Minnesota continued to move forward with statewide mercury emissions reduction goals through the development and implementation of a statewide mercury TMDL.

2.1.2 Minnesota Statewide Mercury Total Maximum Daily Load

MPCA developed a statewide mercury TMDL to address mercury concentrations in fish tissue in Minnesota's lakes and streams, which was approved by the EPA in March 2007. The TMDL (authorized by

MN Statute 114D.25) addresses impaired waters by evaluating the sources of mercury pollution, the reduction necessary to meet water quality standards (in Minnesota, the water quality standard is a fish tissue mercury concentration of 0.2 milligrams per kilogram [mg/kg]), and the allowable levels of mercury emissions in the future. According to MPCA's findings in Minnesota, mercury is primarily introduced to surface waters through atmospheric deposition, the vast majority of which originates from outside of Minnesota. See Figure 2-1 below for details.

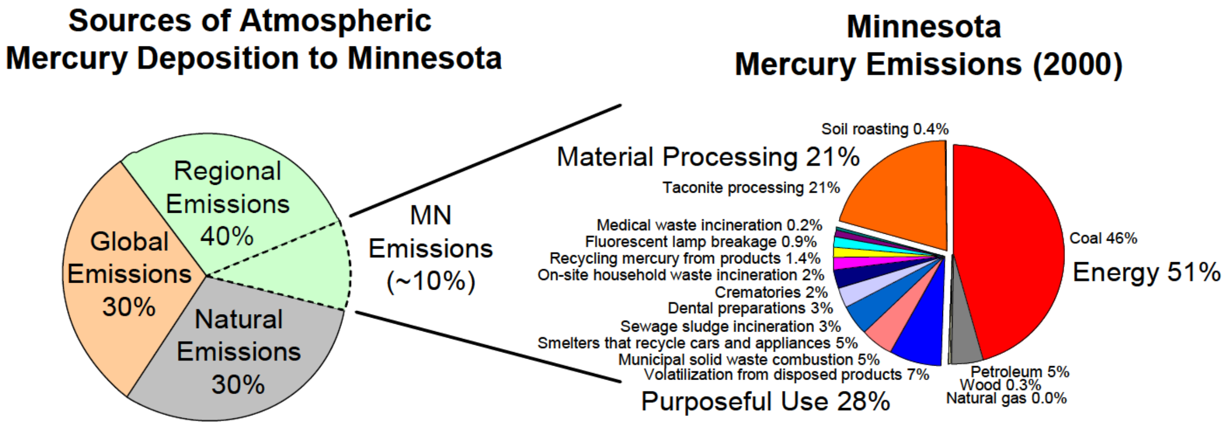


Figure 2-1 Sources of Mercury Deposition and Estimated Mercury Emission Sources in Minnesota (Reference (2))

The TMDL specifies that, in order to meet water quality standards, a 93% reduction from 1990 human-caused, air-deposited mercury levels is required. Attainment of this goal is only possible through global and national reductions because 90% of mercury deposition in Minnesota is from sources outside of Minnesota (Reference (2)). Even if all reduction goals in Minnesota are met, the mercury impairment will still exist in many water bodies throughout the state. In accordance with the TMDL, the Minnesota taconite processing industry endeavored to research mercury reduction technologies with a goal of a 75% reduction of mercury emissions by 2025 compared to 2010 estimates (Reference (3)).

The MPCA has estimated mercury air emissions for the taconite industry as 734.8 pounds per year for 2005, 648.5 pounds per year for 2008, and 745.4 pounds per year for 2011 (Reference (4)). The estimated emissions for the taconite industry represent about 23% of statewide emissions for the cited years, depending on various assumptions and the year calculated.

Under current operating conditions, nearly all of the mercury emitted to the air from taconite processing is elemental (93.3%), along with a small amount of oxidized (6.6%) and particulate-bound (0.1%) mercury (Reference (5)). Elemental mercury emissions are widely dispersed, travel thousands of miles, and remain in the atmosphere for several months to a year (Reference (6)). Accordingly, very little of the elemental mercury emitted to the air is deposited locally, which is why 90% of mercury deposited in Minnesota comes from external sources and mercury in the atmosphere is largely (95%) elemental mercury (Reference (7)). Both oxidized and particulate-bound mercury have a higher probability of being deposited to the local environment than elemental mercury (References (8), (9)). Mercury deposition to land and water is predominantly in the form of oxidized mercury compounds, gaseous oxidized mercury or oxidized mercury attached to particles, both of which are due to the direct deposition of gas phase species, and through wet deposition of oxidized mercury in precipitation (Reference (10)). Particulate-bound mercury is generally thought to be deposited in a range of 30-50 miles from the point of emission to the atmosphere, and oxidized mercury reacts with other environmental constituents within a few miles of the emission location (Reference (6)). Additional discussion on the potential impacts of mercury local deposition from reduction technologies are addressed in Section 4.5 and in the Local Deposition Evaluation (refer to Appendix B).

The 2016 emission estimates provided by MPCA show that regional sources (i.e. coal fired utility boilers) have reduced mercury emissions beyond the 2018 emission projections of the TMDL implementation plan (References (3), (4)). While the taconite processing facilities have been unable to meet the ambitious 75% reduction goal, the reduction of mercury emissions from other sources is more significant compared to the taconite processing sector emissions and thus has a greater impact.

Mercury pollution is a global phenomenon with air emissions from international sources travelling thousands of miles and ultimately impacting Minnesota’s water bodies. The MPCA, in its 2007 TMDL Executive summary, noted that “99 percent of mercury load to Minnesota’s lakes and streams is from atmospheric deposition” (Reference (2)). Total international global mercury emissions are estimated between 12,100,000 and 13,200,000 pounds per year, of which between 4,000,000 and 4,800,000 pounds are anthropogenic sources (Reference (11)). Minnesota’s total air emissions account for less than 0.03% of total international, anthropogenic mercury emissions.

As MPCA recognized in its February 2013 factsheet, *Sources of Mercury Pollution and the Methylmercury contamination of fish in Minnesota*, mercury contamination of lakes and streams in Minnesota “will not be solved until the United States and other countries greatly reduce mercury releases from all sources including mining, product disposal, and coal-fired power plants” (Reference (12)). More specifically, a 50% reduction in anthropogenic mercury emissions from Minnesota sources will only reduce deposition in Minnesota by 5% and a 50% reduction in U.S. emissions will only reduce deposition in Minnesota by 21% (Reference (13)).

The TMDL Implementation Plan (Reference (3)) notes, “mercury-reduction technology does not currently exist for use on taconite pellet furnaces. Therefore, achieving the 75% mercury reduction target will incorporate the concept of adaptive management by focusing on research to develop the technology in the near term and installation of mercury emission control equipment thereafter.”

Additionally, the TMDL Implementation Plan requires the mercury reduction technology to be technically and economically feasible, it must not impair pellet quality, and it must not cause excessive corrosion to pellet furnaces or associated ducting or emission control equipment, also known as adaptive management criteria. As part of the BAMRT analysis for Keetac, all adaptive management criteria discussed above are evaluated to ensure that a suitable technology can be identified.

2.1.3 State of Minnesota Air Quality Rules for Mercury Air Emissions Reduction and Reporting Requirements

On September 29, 2014, the State of Minnesota amended the air quality rules related to mercury air emissions reporting and reductions requirements. During the rulemaking process, MPCA indicated that the rule must be considered in concert with the TMDL and use the adaptive management criteria when evaluating mercury reduction technologies (the technology must be technically feasible; it must be economically feasible; it must not impair pellet quality; and it must not cause excessive corrosion to pellet furnaces or associated ducting or emission control equipment). As part of the BAMRT evaluation for Keetac, all adaptive management criteria discussed above are evaluated to ensure that a suitable technology can be identified. If a technology cannot be identified that will meet these criteria while also reducing emissions by 72% of the baseline as required by the rule, then Keetac will propose an alternative Mercury Emissions Reduction Plan to reduce mercury emissions, according to Minn. R. 7007.0502, subp. 5(A)(2). Note, the taconite processing industry originally endeavored to research mercury reduction technologies with a goal of a 75% reduction of mercury emissions by 2025 compared to 2010 estimates. However, the actual MPCA rulemaking required a 72% reduction of 2008 or 2010 emissions, whichever is higher.

In addition, Minn. R. 7007.0502, subp. 4(B) requires the submittal of a Mercury Emissions Reduction Plan by December 30, 2018, for approval and inclusion in a permit or other enforceable document. Further, the Mercury Emissions Reduction Plan must include the following:

> ***7007.0502 Subp. 5. Mercury Emissions Reduction Plan Elements and Format***
>
> *A. The owners or operators of an existing mercury emission source must submit a mercury emissions reduction plan that complies with this item:*
>
> *(1) The plan must be submitted in a format specified by the commissioner and must contain:*
>
> *a. description of the specific control equipment, processes, materials, or work practices that will be employed to achieve the applicable control efficiencies, reductions, or allowable emissions and work practices listed in subpart 6 and a schedule for adopting the processes or installation of equipment;*
>
> *b. the mercury reduction, control efficiency, or emission rate that each emissions unit will achieve once the plan for that emissions unit is fully implemented;*
>
> *c. a description of how operating parameters will be optimized to maintain the mercury control efficiency in the plan;*
>
> *d. a proposed periodic monitoring and record-keeping system for proposed control equipment, processes, materials, or work practices or citation to an applicable requirement for monitoring and record keeping consistent with chapter 7017. An*

evaluation of the use of a continuous mercury emission monitoring system must be included in the plan;

   e. *if the plan includes elements that meet the definition of a modification under part 7007.0100, subpart 14, or requires an air permit amendment or notification under part 7007.1150, a projected schedule for submitting the appropriate permit applications; and*

   f. *the date that the mercury reductions proposed in the plan will be demonstrated. This date must be no later than January 1, 2025, or as specified in subpart 6; or*

(2) *if the owner or operator determines that the mercury reductions listed in subpart 6, if applicable, are not technically achievable by the identified compliance date, the owners or operators may submit an alternative plan to reduce mercury emissions, in a format specified by the commissioner. The alternative plan must contain:*

   a. *the plan elements in item A, substituting the owners' or operators' proposed reduction for the requirements under subpart 6;*

   b. *a detailed explanation of why the mercury reductions listed in subpart 6 are not technically achievable;*

   c. *a demonstration that air pollution control equipment, work practices, or the use of alternative fuels or raw materials have been optimized such that the source is using the best controls for mercury that are technically feasible; and*

   d. *an estimate of the annual mass of mercury emitted under the requirements of subpart 6 and the proposed alternative plan.*

B. *The commissioner shall identify plan deficiencies and notify the owners or operators of the deficiencies.*

Minnesota's taconite industry must include in the Mercury Emissions Reduction Plan the minimum mercury control requirements for source categories listed in Minn. R. 7007.0502, subp. 6(A):

7007.0502 Subp. 6. Mercury Control and Work Practices

A. *For ferrous mining or processing:*

(1) *the plan must address the indurating furnace or kiln of a taconite processing facility or the rotary hearth furnace of a direct-reduced iron facility and must demonstrate that by January 1, 2025, mercury emissions from the indurating furnace or kiln or rotary hearth furnace do not exceed 28 percent of the mercury emitted in 2008 or 2010, whichever is greater. The commissioner shall determine the mercury emitted in 2008 and 2010. If the facility held a Minnesota Pollution Control Agency construction permit but was operating in 2010 at less than 75 percent of full capacity, the operating furnace must*

> *not exceed 28 percent of the mercury potential to emit included in the permit authorizing construction; and*
>
> *(2) the plan may accomplish reductions as:*
>
> *a. 28 percent of 2008 or 2010 emissions for each furnace;*
>
> *b. 28 percent of 2008 or 2010 emissions across all furnaces at a single stationary source; or*
>
> *c. 28 percent of 2008 or 2010 emissions across furnaces at multiple stationary sources.*
>
> *Owners of the stationary sources must enter into an enforceable agreement as provided by Minnesota Statutes, section 115.071, subdivision 1, to reduce mercury emissions between the stationary sources. If this option is selected, the reduction plan must include the enforceable agreement. Execution of an enforceable agreement under this part does not relieve the owner or operator of the obligation to obtain a permit or permit amendment if otherwise required under this chapter.*

The BAMRT analysis helps Keetac develop the facility's Mercury Emissions Reduction Plan by determining if a potential mercury reduction technology is suitable for application at Keetac to achieve the required 72% reduction from baseline levels. If no technology can be identified that reduces mercury emissions by 72% while also satisfying the adaptive management criteria, then Keetac will propose an alternative plan to reduce mercury emissions, according to Minn. R. 7007.0502, subp. 5(A)(2). The details of the BAMRT analysis are described in Section 4.

2.2 Facility Description

Keetac mines iron ore (magnetite) and produces taconite pellets that are shipped to steel producers for processing in blast furnaces. The iron ore is crushed and routed through several concentration stages including grinding, magnetic separation, and thickening.

A concentrated iron ore slurry is dewatered by vacuum disc filters, mixed with bentonite, and conveyed to balling drums. Greenballs produced in the balling drums are fed to the traveling grate prior to entering the kiln. The traveling grate consists of drying and preheat zones. After greenballs pass through the traveling grate, they enter the kiln where pellets are heated to approximately 2,400 degrees Fahrenheit to facilitate the conversation of magnetite to hematite. After the kiln, the fired pellets are sent to an annular cooler where ambient air is blown through the pellets, which allows them to be safely discharged onto rubber belting. The heated waste gas from the kiln and annular cooler are used for the drying and heating zones on the traveling grate.

Keetac operates a single preheat grate/induration kiln (grate-kiln) furnace (EU 030). Waste gas from the furnace is controlled by dual venturi wet scrubbers (CE 110 and CE 111) and is vented through a single stack (SV 051).

Figure 2-2 includes a sketch of Keetac’s grate-kiln furnace design.

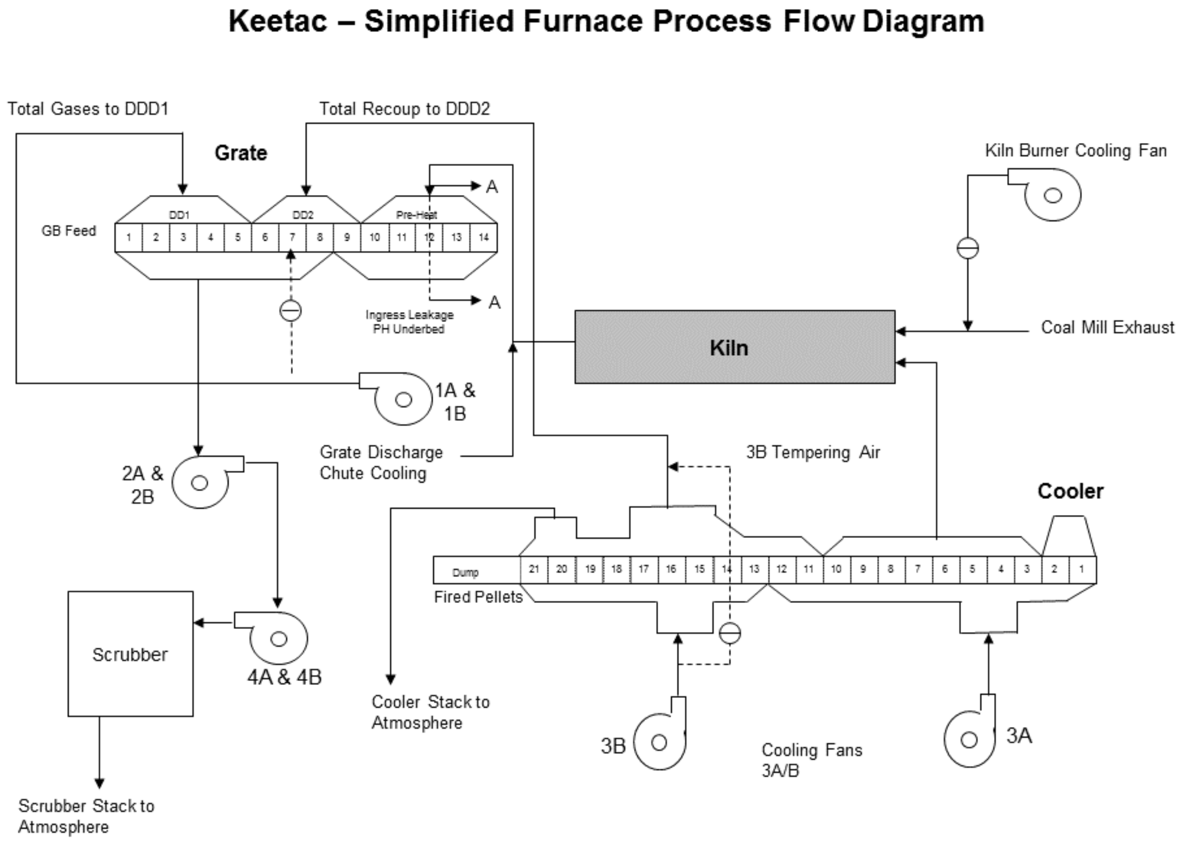

Keetac – Simplified Furnace Process Flow Diagram

Figure 2-2 Grate-Kiln Furnace Diagram

Mercury entering the process is released from the ore. Based on mass balance sampling at Keetac, approximately 85% of the mercury is rejected from the process in tailings streams prior to induration (Reference (14)). The remaining mercury exits the process in scrubber solids or stack emissions from the indurating furnace. Stack emissions are dependent on the mercury content of the greenballs and the rate that the greenballs are fed to the furnace. Mercury is emitted to the atmosphere through the exhaust stack mentioned above as mercury is liberated from the greenballs during the induration process. Combustion of coal can add small amounts of mercury to the stack emissions, but previous sampling has shown that this is insignificant compared the mercury entering the furnace with the greenballs. The mercury concentration of coal fired at Keetac is approximately 0.04 ug/g (Reference (15)). Mercury concentration in the greenballs is close to 0.016 ug/g (Reference (14)). However, the mass of greenballs entering the furnace is several orders of magnitude higher than the mass of coal entering the furnace. Therefore, the amount of mercury added to the furnace from coal combustion is insignificant relative to the greenballs.

3 Analysis of Baseline Mercury Emissions

This section describes how Keetac calculated the annual mass of mercury emitted (i.e. baseline emissions) per the requirements of Minn. R. 7007.0502, subp. 6 (question 3b on MPCA's Ferrous Mercury Reduction Plan Form).

The TMDL Implementation Plan estimated Keetac's mercury emissions to be 146.9 pounds per year for 2005 and 105.8 pounds per year for 2010 and 2018 (Reference (3)). These estimates were based on mercury volatilization emission factors from a report titled *Mercury Emissions from Induration of Taconite Concentrate Pellets – Stack Testing Results from Facilities in Minnesota* (Reference (16)). However, emission testing conducted in 2017 (required by Minn. R. 7019.3050) shows that the most recent testing data differs from the TMDL emissions estimates (Reference (17)). The stack testing conducted in 2017 was in accordance with currently approved EPA test methods and is more representative of current operations; therefore, Keetac considers the 2017 Method 29 emission test rate to be more representative than the TMDL emission rate estimate. Keetac applied the emission factor from the 2017 emission test (pounds of mercury per long ton of pellet production) to annualized pellet production quantities (calculated as described below) to find the annual mass of mercury emitted.

Keetac does not always operate at high production rates due to factors including, but not limited to: permit requirements, weather related issues, ore variability, work stoppages, and changing market conditions. It is inappropriate to use actual pellet production data from 2008 and 2010 because it would underestimate Keetac's baseline emissions if the furnace were to operate for an extended duration at production rates closer to capacity. Therefore, looking exclusively at 2008 or 2010 actual production and associated mercury emissions would risk generating unrealistic baseline values for Keetac simply because they were not at full production (due to market or other conditions). U. S. Steel commented on the rule that 2008 was an inappropriate baseline year because of market conditions. MPCA responded to the comment by including 2010 in the rule as an alternate, assuming that resolved the comment. Although 2010 is also not an appropriate year, U. S. Steel had no avenue to submit public comment on the use of that year. Instead, we communicated the issue to MPCA at the earliest possible time. As a result, Keetac determined baseline emissions using concepts from Step 1 of a New Source Review (NSR) Prevention of Significant Deterioration (PSD) analysis and EPA PSD guidance. Keetac annualized the highest demonstrated monthly pellet throughput (24-month rolling maximum) in each year during 2008-2017, as an approximation of the annual level of production that unit was capable of accommodating. Supporting information is included in Appendix C.

Example calculation for 2014:

Keetac was capable of accommodating production of 6,036,216 long tons of pellets in 2014. This is based on the maximum month of actual pellet production from January 2013-December 2014 (maximum actual production in this period was 503,018 long tons in July 2014). Keetacs's 2014 baseline emissions (120 lb/yr) were calculated using Keetac's emission factor (1.98E-05 lb/Lton) and the 2014 capable of accommodating production rate.

This method allows for Keetac's baseline emissions to account for varying production rates due to changing market conditions. Refer to Table 3-1 for details.

Table 3-1 Summary of Mercury Emissions for Each Baseline Period

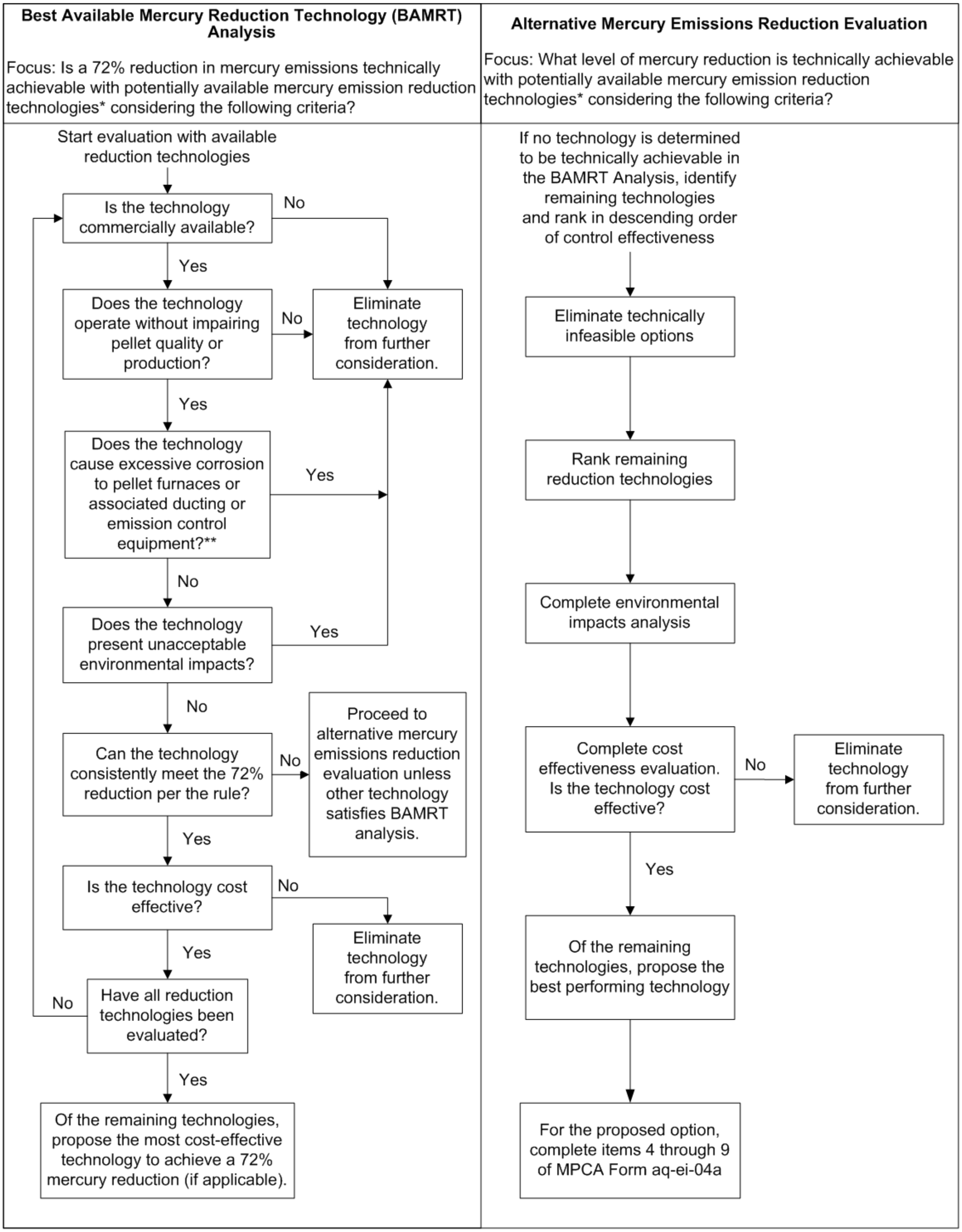
Parameter	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Emission Factor (lb mercury per long ton of pellets)[1]	1.98E-05									
Capable of Accommodating Production (long ton per year)[2]	4,945,232	4,945,232	4,945,232	4,847,411	5,491,768	5,612,207	6,036,216	6,036,216	6,036,216	5,795,232
Capable of Accommodating Emissions (lb mercury per year)	98	98	98	96	109	111	120	120	120	115

Notes:
1: based on 2017 Method 29 emission test
2: pellet production increased after 2011 due to changing market conditions

Based on the approach to the baseline calculations described above, the proposed baseline of mercury emitted, calculated per the requirements of Minn. R. 7007.0502, subp. 6, is 120 lb per year.

4 Best Available Mercury Reduction Technology Analysis

The purpose of the BAMRT analysis was to determine if the 72% mercury emissions reduction required by Minn. R. 7007.0502, subp. 6, was technically achievable by any of the potentially available mercury emissions reduction technologies. Any technologies that did not meet the mercury reductions required by Minn. R. 7007.0502, subp. 6, and were not eliminated from future consideration based on the adaptive management criteria were considered for the facility's alternative mercury emissions reduction evaluation. Figure 4-1 below provides additional detail on the process Keetac used to evaluate the potentially available mercury emissions reduction technologies.



*Potentially available mercury emission reduction technologies include specific control equipment, processes, materials or work practice standards that may be considered to achieve the required mercury reduction.

**Excessive corrosion is to be defined by the owner or operator.

Figure 4-1 **Determination of Technically Achievable Mercury Reductions**

Keetac completed an evaluation of potentially available mercury reduction technologies by adapting an approach similar to the EPA-approved BART analysis and top-down BACT analysis as a benchmark methodology to develop the BAMRT analysis. The BAMRT analysis sought to determine if mercury reductions required by Minn. R. 7007.0502, subp. 6, were technically achievable using the adaptive management criteria and acceptable environmental impacts criteria. The steps of this evaluation are outlined below. The details of each step, including the methods used to analyze acceptability of each step, are discussed further in Sections 4.1 through 4.8.

The sequence of the analysis was established by ordering the evaluation criteria such that the majority of potentially available mercury emissions reduction technologies proceed through the detailed analysis. Considerable effort was required to conduct site-specific evaluations for technologies as well as cost analyses. In addition, the MPCA expressed interest in evaluating how certain technologies performed (ACI with existing wet scrubbers and halide injection) and the existing structure allows for a direct evaluation of the adaptive management and environmental impacts criteria. Adjusting the sequence would increase the level of effort and cost of this analysis while having no effect on the conclusions. For example, if Step 6 were placed before Step 5 (environmental impacts), additional technologies would be carried to the alternative mercury emissions reduction evaluation in Section 5, while having no effect on the conclusions because the unacceptable environmental impacts still remain.

Step 1 – Identification of potentially available mercury reduction technologies

The first step in the BAMRT analysis was to identify all potentially available mercury reduction technologies for the taconite processing industry as the first stage of evaluating the technical feasibility of reduction technologies. Unlike BART, where only technologies that have been permitted and installed need to be evaluated, the industry included any known technology at the time that may have conducted bench or pilot scale testing. This is because mercury reduction technologies did not previously exist in the taconite processing industry. Reduction technologies include specific control equipment, processes, materials or work practice standards that may be considered to achieve the required mercury reduction. Details on each potentially available mercury reduction technology identified can be found in Section 4.1.

Step 2 – Determine if the technology is commercially available

The second step in the BAMRT analysis was to determine if the potentially available mercury reduction technologies identified in Step 1 were commercially available as the second stage of evaluation the technical feasibility of reduction technologies. Details on how commercial availability for each technology was determined can be found in Section 4.2. Any technologies that were not commercially available were eliminated from further consideration.

Step 3 – Determine if the technology can operate without impairing pellet quality or production

The third step in the BAMRT analysis was to eliminate technologies that would impair pellet quality or production. Pellet quality parameters must be acceptable in order to produce marketable pellets, and must not be adversely impacted by the mercury reduction technology. Details can be found in Section 4.3. Any technology that impairs pellet quality or production was eliminated from further consideration.

Step 4 – Determine if the technology causes excessive corrosion

The fourth step in the BAMRT analysis was to determine if the technology causes excessive corrosion to pellet furnaces or associated ducting or emission control equipment. Details on how corrosion was evaluated can be found in Section 4.4. Any technology that causes unacceptable corrosion was eliminated from further consideration.

Step 5 – Determine if the technology presents unacceptable environmental impacts

The fifth step of the BAMRT analysis was to determine if the technology presents unacceptable environmental impacts. Most technologies will have some kind of environmental impact (i.e., waste disposal, water, or air implications). However, impacts that can be mitigated through other treatment methods were not used to eliminate a technology from further consideration. Rather, an example of an unacceptable environmental impact was considered something that contradicts the goals of the TMDL or other state or federal regulations. For example, a reduction technology that increases particulate-bound mercury emissions would be unacceptable because mercury is more likely to be deposited locally, which is contrary to the goals of the TMDL. Details on how each technology was evaluated for environmental impacts can be found in Section 4.5. Any technology that causes unacceptable environmental impacts was eliminated from further consideration.

Step 6 – Determine if the technology can consistently meet the 72% reduction per the MN rule

Any technology that cannot consistently achieve a 72% reduction per the rule was not carried into the next step of the BAMRT analysis. Details on the determination of percent reduction for each technology can be found in Section 4.6. Any technology that makes it to Step 6 of the BAMRT analysis, but cannot consistently achieve a 72% reduction (Minn. R. 7007.0502, subp. 6(A)(1)) is evaluated in Keetac's alternative mercury emissions reduction evaluation (Minn. R. 7007.0502, subp. 5(A)(2)) if it is needed as determined in Step 8.

Step 7 – Determine if the technology is cost effective

The seventh step of the BAMRT analysis documented the cost effectiveness of each mercury reduction technology not eliminated in Steps 1 through 6. This step compared the annualized cost per pound of mercury ($/lb) removed for the remaining technologies. Details on the cost effectiveness procedure can be found in Section 4.7.

If Keetac demonstrated that the control cost exceeded the established cost effectiveness threshold, then the technology was not considered cost effective. Any technology that was not considered cost effective was eliminated from future consideration.

Step 8 – Determination of Best Available Mercury Reduction Technology

The final step in the BAMRT analysis documented the best technology selected for Keetac by using the results from Steps 1 through 7. After completing Steps 1 through 7, Keetac determined that the 72%

reduction in mercury emissions was not technically achievable with the potentially available mercury emissions reduction technologies. Therefore, Keetac completed an alternative mercury emissions reduction evaluation, according to Minn. R. 7007.0502, subp. 5(A)(2). Technologies that cannot achieve a 72% reduction in mercury emissions and have not been eliminated from further consideration from Steps 1-5 are evaluated in Keetac's alternative mercury emissions reduction evaluation, as described in Section 5.

4.1 Step 1 – Identification of Potentially Available Mercury Emissions Reduction Technologies

Technologies identified for evaluation in the BAMRT analysis are discussed in the following sections.

4.1.1 Mercury Emissions Reduction Technology Selection Process

The BAMRT analysis contains an evaluation of potentially available mercury emissions reduction technologies. The list of potentially available mercury emissions reduction technologies was compiled based on a full review of historical research and testing that has been completed at both the industry and site-specific levels. The historical review covered each of the following "stages" of mercury reduction studies that have been completed:

- Pre-TMDL Implementation Plan DNR Research (Pre-TMDL research)
- Phase I – Minnesota Taconite Mercury Control Advisory Committee (Phase I)
- Phase II – Extended Testing of ACI (Phase II)
- Gore Technology Demonstrations (GORE^{TM})
- Site-specific Evaluations

Each of the stages listed above included a number of individual research projects that were reviewed as part of the analysis. The reports for each project have been included in Appendix B.

Pre-TMDL research evaluated potential mercury controls for the taconite processing industry and was coordinated with the DNR. This stage of research sought to conduct a broad review of all potential reduction technologies utilized in other industries. It was concluded that the chemical oxidation and sorbent injection methods used or considered for the power industry might be able to be adapted by the taconite processing industry (Reference (18)). Therefore, the taconite processing industry focused on these technologies during Phase I. Testing from Phase I research projects showed that ACI had the highest potential to reduce mercury emissions from the taconite processing industry. This led to Phase II ACI testing at several taconite facilities, including Keetac. However, Phase II testing did not achieve anticipated reductions and it revealed issues such as increased particulate emissions from the wet scrubbers during ACI. During Phase II testing, the taconite processing industry became aware of an emerging sorbent technology known as GORE^{TM}. Pilot studies of this technology were conducted at UTAC, Minorca, and Minntac. GORE^{TM} demonstrated that it had the potential to reduce mercury emissions by 72% under specific conditions, but presented additional concerns such as mercury and sulfate laden wash water.

Previous testing left several unanswered questions and data gaps. However, in order to address these issues, Minntac conducted an additional chemical oxidation site-specific evaluation.

4.1.2 Potentially Available Mercury Emissions Reduction Technologies

Table 4-1 lists all the potentially available mercury emissions reduction technologies that were evaluated as part of the BAMRT analysis along with a short summary on the theory behind the technology's mercury reductions. This summary also includes background information and considerations from previous testing that will be addressed in later steps of the BAMRT analysis. Sections 4.1.3 through 4.1.7 summarize each technology in more detail.

Table 4-1 Potentially Available Mercury Emissions Reduction Technologies

Reduction Technology		Basis of Technology	Section #
Mercury capture by existing wet scrubbers with solids removal		Oxidized mercury can be captured in wet scrubbers. To prevent captured mercury from re-entering the system, the scrubber solids can be removed from the process.	4.1.3
Mercury oxidation for capture by wet scrubbers	Halide injection	Halide injection increases mercury oxidation and subsequent capture.	4.1.4.1
	In-scrubber oxidation	Addition of oxidation chemicals to the scrubbers to increase mercury oxidation and subsequent capture.	4.1.4.2
	High energy dissociation technology (HEDT)	Generation of reactive halogens at high temperatures outside of the process prior to injection downstream of the furnace, which aid in mercury oxidation and subsequent capture.	4.1.4.3
Activated carbon injection	With existing scrubbers	Powdered activated carbon (PAC) adsorbs mercury and is then removed in the wet scrubbers or ESP. Injection at a lower rate with the existing scrubbers may still achieve mercury reduction while reducing environmental impacts.	4.1.5.1
	With ESP		4.1.5.2
Fixed carbon bed		Flue gas is routed through a carbon bed, which adsorbs the mercury.	4.1.6
GORE$^{\text{TM}}$		GORE$^{\text{TM}}$ technology is a fixed sorbent polymer composite, which doesn't require injection of powder sorbents or chemicals, capturing both elemental and oxidized mercury in particulate and gas phase.	4.1.7
Monolithic Honeycomb Adsorption		Activated carbon and elemental sulfur are mechanically fixed into a honeycomb structure that may include additives to enhance mercury capture. The cells of the monolith are plugged at their ends intermittently to force gas flow through the walls of the structure.	4.1.8

4.1.3 Mercury Capture by Existing Wet Scrubbers with Solids Removal

The majority of mercury contained in the greenballs is vaporized during the indurating process and becomes entrained in the furnace flue gas. Flue gas mercury is naturally present as either elemental (majority) or oxidized (minority) mercury; oxidized mercury can be more readily captured in the existing facility's wet scrubbers because it is water soluble and adsorbs (or adheres) to particles (Reference (19)). Mercury adsorbed to particles in the flue gas has a better chance of being captured by the wet scrubbers due to the scrubbers' ability to reduce particulate emissions. Mercury captured in the wet scrubbers is discharged with the scrubber water. Removing scrubber solids from the process prevents captured mercury from being recycled back into the process and re-emitted into the flue gas. However, removing the scrubber solids also discards residual iron material and ultimately increases the cost per ton of iron. Pre-TMDL research and testing evaluated eliminating scrubbers solids from the recycle loop as a method of mercury reduction and found that the mercury should remain with the solids and not leach if sent to the tailings basin (Reference (19)).

At most taconite processing facilities, scrubber water is typically concentrated and the solids are recycled back into the process in order to recover residual iron materials. However, Keetac's equipment layout is unique. At Keetac, new wet scrubbers were installed and began operating in 2005. Scrubber discharge water is sent to a thickener. The thickened solids are routed to a filter press where the scrubber solids are dewatered, collected and sent offsite for disposal. Keetac is not able to further reduce mercury emissions beyond their current operations by mercury capture by wet scrubbers and solids separation. Keetac considers this to be a potential reduction technology that is already being implemented. It is important to note that this system of mercury elimination has been ongoing at Keetac since 2005. Keetac estimated that this resulted in a 30% reduction in stack mercury emissions from (Reference (20)). Therefore, by the time the compliance date for the MN Mercury Rule is reached, Keetac will have been reducing mercury emissions for almost 20 years.

4.1.4 Mercury Oxidation for Capture by Wet Scrubbers

Oxidized mercury has the potential to be captured in a wet scrubbers because it is water-soluble and adsorbs to particles (Reference (19)). Therefore, in principle, increased mercury oxidation of the flue gas should result in increased mercury capture at the wet scrubbers.

A number of methods to increase mercury oxidation are available, including halide injection, in-scrubber oxidation, and HEDT. The majority of the Pre-TMDL research focused on these methods, while Phase I work elaborated on halide injection and in-scrubber oxidation. In addition, Minntac conducted additional halide injection testing in 2018.

4.1.4.1 Halide Injection

Oxidizing agents, typically halogens, convert elemental mercury to oxidized mercury through an oxidation reaction. Oxidizing agents can be applied directly to the greenballs before the indurating process or they can be injected into the flue gas stream. A number of chloride and bromide salts have been tested in the taconite industry. Injection locations and halide compounds that were tested at Keetac and other taconite processing facilities are listed below. Note, the term "halide injection" encompasses all chemicals and injection (or addition) locations that have been tested to reduce mercury emissions in the taconite industry discussed below:

- Sodium chloride (NaCl) addition to greenballs - This potential mercury reduction method was tested at HTC Line 3 and at UTAC Line 2 (Reference (21)). Both continuous mercury monitors (CMMs) and flue-gas absorbent-trap mercury speciation (FAMS) traps were placed on the stacks to measure the mercury concentration. It was assumed that the decrease in mercury concentration recorded by the monitor corresponded to the total mercury reduction. Injection rates were 0.5 and 1 lb/long ton of greenballs.

- NaCl addition to preheat zone - This potential mercury reduction method was tested at HTC Line 3 (Reference (21)). A CMM was used to monitor mercury stack emissions. It was assumed that the decrease in mercury concentration recorded by the monitor corresponded to the total mercury reduction. The NaCl injection rate tested was 50 lb/hr.

- Sodium bromide (NaBr) addition to greenballs - This potential mercury reduction method was tested at Minntac Line 3 (Reference (22)). Mercury reduction efficiencies were based on CMMs placed in the scrubber feed duct and on the stack.

- NaBr addition to preheat zone - This potential mercury reduction method was tested at HTC Line 3 (Reference (21)). A CMM was used to monitor mercury stack emissions. It was assumed that the decrease in mercury concentration recorded by the monitor corresponded to the total mercury reduction. The NaBr injection rate tested was 50 lb/hr.

- Calcium chloride ($CaCl_2$) addition to preheat zone - This potential mercury reduction method was tested at HTC Line 3 (Reference (21)). A CMM was used to monitor mercury stack emissions. It was assumed that the decrease in mercury concentration recorded by the monitor corresponded to the total mercury reduction. The $CaCl_2$ injection rate tested was 50 lb/hr.

- Calcium bromide ($CaBr_2$) addition to preheat zone - This potential mercury reduction method was tested at HTC Line 3 and Minorca during the pre-TMDL research (References (21), (23)). A CMM was used to monitor mercury stack emissions. It was assumed that the decrease in mercury concentration recorded by the monitor corresponded to the total mercury reduction. The $CaBr_2$ injection rates tested were 50 lb/hr at HTC and 0.09 gallons per minute (gpm) at 48 wt.% solution of $CaBr_2$ at Minorca.

- $CaBr_2$ addition to flame end of kiln - This potential mercury reduction method was tested at Keetac, Minntac Line 3, and UTAC Line 2 during the pre-TMDL research (References (22), (23)). A CMM was used to monitor mercury stack emissions. It was assumed that the decrease in mercury concentration recorded by the monitor corresponded to the total mercury reduction. The $CaBr_2$ injection rates tested were 0.4 gpm of 25 wt.% and 37.5 wt.% solutions of $CaBr_2$ at Keetac, 0.6 gpm of 48 wt.% solution of $CaBr_2$ at Minntac, and 36 – 48 lb/hr $CaBr_2$ on a dry weight basis for UTAC.

- $CaBr_2$ addition above the drying zone - Minntac conducted another site-specific evaluation of halide injection on Line 6. During the pre-screening phase of this testing, Minntac evaluated multiple injection rates to determine the optimal rate for long-term injection using EPA Method 30B to monitor mercury stack emissions. A 52 wt. % solution of CaBr2 was injected at rates of 0.1, 0.25, 0.5, 0.75, and 1.5 gallons per hour (gph). The injection rates of 0.75 and 1.5 gph resulted in the highest reductions in mercury. An injection rate of 0.75 gph was chosen for long-term testing because stack testing indicated an increase in unreacted bromide emissions at a 1.5 gph injection rate. In addition, the higher injection rate yielded only a small increase in mercury reduction relative to 0.75 gph (Reference (24)). The chemical was injected above the drying zone, prior to the waste gas scrubber. Ontario Hydro and Method 30B (sorbent trap) stack tests were conducted during the baseline (no halide injection) and long-term injection trials to evaluate the change in speciation of mercury (i.e. concentration changes in oxidized, elemental, and particulate-bound mercury) and the total mercury reduction. Due to the duration between baseline testing and injection testing, Minntac conducted additional Method 30B testing on Line 7 (without halide injection) for comparison. The baseline and long-term Ontario Hydro tests were conducted months apart, whereas the Method 30B testing on Lines 6 and 7 were completed within a day. Comparing Line 6 to Line 7 may be appropriate because both production lines have identical equipment and process conditions and the pellet production rates for each line were similar throughout testing. In addition, both Line 6 and 7 use the same iron ore concentrate to form greenballs. Thus, the mercury concentration in the greenballs fed to each line should be the same. The test conducted was short term in duration for many reasons, one being the difficulty to operate the equipment. Multiple issues arose including the need for hard piping to be installed due to the elevated temperatures of the injection equipment and continual plugging of the injection nozzles, which had to be replaced or cleaned several times. While it may be possible to engineer solutions to some of the issues, it remains an unknown as to how the system would perform on a full-scale installation when it was extremely difficult to keep the testing equipment in operation for the duration of the trials.

Halide injection testing has demonstrated that the halide injection to the greenballs is an inferior control method compared to direct injection into the induration furnaces. Of the evaluated chemicals, NaCl and $CaCl_2$ consistently resulted in less mercury reductions compared to brominated salts such as $CaBr_2$, NaBr, and hydrogen bromide (HBr) (Reference (21)). Of those, $CaBr_2$ achieved the highest reductions (Reference (23)). Additionally, HBr is a highly toxic chemical that presents significant safety concerns for handling and use. Therefore, only $CaBr_2$ injection into the furnace or associated ducting is used for evaluation throughout the BAMRT analysis.

Halide injection has the added concerns of potential pellet quality degradation and/or excess corrosion to plant equipment. Oxidizing chemicals may oxidize plant equipment rather than the mercury in the flue gas, decreasing the effective life of furnace equipment. Due to these concerns, corrosion was evaluated by the taconite processing industry.

During the Pre-TMDL research work, the Energy & Environmental Research Center (EERC) completed bench-scale exposure experiments, in simulated taconite flue gases, to help understand if and how bromine-induced corrosion occurs. Testing was completed in environments that mimicked the preheat zone, the drying/cooling zone, and the discharge zone. The final report from August 28, 2009 was titled *Assessment of Potential Corrosion Induced by Bromine Species used for Mercury Reduction in a Taconite Facility* (Reference (25)). The short term small scale testing showed that 40 ppm HBr in a simulated taconite process flue gas environment caused slight surface corrosion. However, bromine deposition and losses of Fe, Ni, and Cr were mainly confined to the surface. Further, the testing was time limited (30 days) and was carried out in simulated flue gas environments that did not necessarily represent actual operating conditions of the taconite process. In addition, testing lacked a control sample to compare the corrosion from temperature and simulated flue gas constituents.

Other Pre-TMDL research reports discuss potential corrosion impacts from chemical injection to oxidize mercury, but they do not provide detailed technical concerns nor do they demonstrate actual test results that indicate excessive corrosion or equipment degradation is an issue of concern. Only one report reviewed discussed the potential impacts to pellet quality. The *Mercury Transport in Taconite Processing Facilities: (I) Release and Capture During Induration* report from August 15, 2005 (Reference (26)) noted that it is “unlikely the iron-oxide mineralogy would be strongly affected by the presence or absence of small amounts of HCl in process gases.” However, “small amounts” is a general term and is not quantified.

As part of the Phase I – Minnesota Taconite Mercury Control Advisory Committee work, one of the research projects (Reference (27)) focused on the evaluation of bromine- and chlorine-induced metal corrosion under simulated taconite operating conditions. It was found that temperature is very critical to corrosion, and under elevated temperatures (500°– 950°C), active oxidation is a main corrosion mechanism. HBr showed a higher rate of corrosion when compared to hydrogen chloride (HCl).

4.1.4.2 In-scrubber Oxidation

In-scrubber oxidation consists of adding oxidizing chemicals directly to the scrubber water (rather than to the flue gas) as an alternative way of oxidizing flue gas elemental mercury for capture in a wet scrubbers. As part of the Pre-TMDL research and portions of the Phase I work, three different oxidizing chemicals were evaluated at taconite processing facilities: hydrogen peroxide (H_2O_2), diethyl dithiocarbamate (DEDTC) and a proprietary reagent (sodium chlorite – $NaClO_2$) on slip-stream furnace off-gases as discussed below:

H_2O_2 Testing at Keetac: Keetac conducted slip-stream testing using H_2O_2. This test demonstrated that H_2O_2 decreased the simulated scrubber solution’s ability to oxidize and capture mercury compared to baseline conditions. The report stated ”H_2O_2 is not a likely candidate for in-scrubber oxidation at taconite processing plants and that, perhaps, it even interferes with the background mercury oxidation process that takes place when no oxidant is added to the water” (Reference (21)). H_2O_2 was not further developed or tested again for the taconite processing industry. Therefore, Keetac does not consider the addition of H_2O_2 to scrubber water to be a potential reduction technology.

DEDTC Testing at Minntac: Minntac tested DEDTC by dosing scrubber water. However, there was no observable reduction in mercury emissions at the stack during the test (Reference (28)). Therefore, Keetac does not consider the addition of DEDTC to scrubber water to be a potential reduction technology.

$NaClO_2$ Testing

- $NaClO_2$ Testing at Keetac: Keetac conducted slip-stream testing using $NaClO_2$. This test demonstrated that $NaClO_2$ had the potential to be effective as a scrubber additive to reduce mercury emissions (Reference (21)).
- $NaClO_2$ Testing at Minntac: Minntac added $NaClO_2$ to their wet scrubber on Line 3. Minntac used CMMs to determine a reduction efficiency. Testing only saw a minimal reduction in mercury emissions in the stack gas. It was postulated in the Pre-TMDL research report *On the Measurement of Stack Emissions at Taconite Processing Plants* (Reference (22)) that the oxidant addition appeared to interfere with the particulate's ability to adsorb mercury.
- $NaClO_2$ Testing at Minorca: Minorca added $NaClO_2$ to their wet scrubber water. Minorca used CMMs to determine a reduction efficiency. Mercury emissions actually increased by approximately 25% during this test and decreased back to baseline after injection ceased (Reference (29)).

As demonstrated by the testing above, mercury control with the use of $NaClO_2$ is unpredictable and as seen at Minorca, may even increase mercury emissions out of the stack by hampering the existing scrubbers' ability to capture any mercury from the flue gas. For the reasons discussed above, in-scrubber oxidation was not considered as a potential control technology for Keetac and, therefore was not evaluated throughout the remainder of the BAMRT analysis.

4.1.4.3 HEDT

HEDT is an EERC proprietary technology in which reactive halogens are generated at high temperatures outside of the taconite process and injected downstream of the furnace. The technology works by dissociating halogen salts, allowing the use of benign compounds to create halogen radicals that oxidize flue gas mercury (Reference (30)). This technology was tested during the Pre-TMDL research, and was evaluated as a potential reduction technology for Keetac.

Corrosion concerns associated with halide injection are still a concern with HEDT. However, due to the fact the halides are injected after the furnace, corrosion impacts should be mitigated, as the chemicals never encounter the high temperatures of the furnace.

4.1.5 Activated Carbon Injection (ACI)

4.1.5.1 ACI with Existing Scrubbers

ACI works by introducing powdered activated carbon (PAC) into the flue gas stream where it adsorbs gas phase mercury. The PAC is then captured, along with the mercury, downstream in the wet scrubbers. Both elemental and oxidized forms of mercury can be adsorbed onto the PAC. Since mercury is adsorbed onto the PAC in the ductwork, prior to the particulate control device, the distance from the PAC injection point to the particulate control device (i.e., the residence time) has a significant impact on the level of achievable control. This depends on the specific configuration of each individual facility. Adding halogens, such as bromine, iodine, or chlorine, to the activated carbon can increase the mercury oxidation, which in turn increases capture in the particulate control device (see above discussions).

As part of the Phase I and Phase II research and testing, both PAC and brominated PAC were evaluated for effectiveness at taconite processing facilities. Injection locations tested included:

- Greenball (brominated PAC only) - This potential mercury reduction method was not actually tested at a taconite facility. Rather, greenball samples from HTC, UTAC, Minntac, Keetac, and Minorca were studied to determine if brominated PAC affects the oxidation characteristics of mercury during induration (Reference (31)). Oxidized mercury was measured using the Ontario Hydro Method (OHM) and a Horiba mercury analyzer. The reported bench-scale reduction efficiency assumes that 100% of the oxidized mercury would be captured by the wet scrubbers, if this method were applied at the full scale. Additional evaluations of this injection method were ceased because the addition of carbon to the greenballs decreased the compression strength of the fired pellet and thus, impairing the pellet quality (Reference (32)).

- Preheat zone - Minntac's Line 3 was used to test PAC and brominated PAC injection into the furnace preheat zone (Reference (28)). A CMM and the OHM were used to determine the mercury reduction efficiency. Standard PAC injection rates tested were 50, 100, and 150 lb/hr. Brominated PAC injection rates tested were 50, 75, 100, and 150 lb/hr. Brominated PAC was injected in two separate locations: the preheat fans and the preheat grate. Higher reductions were achieved by injecting the brominated PAC at the preheat grate. Finally, it is important to note that the mercury reductions achieved during standard PAC injection were believed to be due to fluctuations in baseline values and not due to the PAC injection.

- Flue gas - This potential mercury reduction method was tested during Phases I and II (References (33), (34)). HTC Line 1 was tested during Phase I using PAC and brominated PAC. Brominated PACs achieved a greater reduction in mercury (Reference (33)). Therefore, all subsequent testing was with brominated PACs. Phase II tested brominated PAC injection and included UTAC Line 2, Minorca, Keetac, Minntac Line 7, and HTC Line 3. Mercury reduction efficiency was monitored using a continuous emission monitoring system (CEMS) and sorbent traps. Phase I PAC injection rates tested were 1 and 5 lb/MMacf and 1, 2, 3, 4, and 5 lb/MMacf for brominated PAC. Phase II brominated PAC injection rates in lb/MMacf are as follows: HTC - 3, Keetac - 7, Minntac - 7 and 9, Minorca - 3, and UTAC - 5 and 8. Testing at several of the facilities showed that particulates from the PAC injection were passing through the wet scrubbers. At Keetac, even lower screening injection rates (3 and 5 lb/MMacf) yielded higher than normal particulate emission rates out of the stack. In addition, the mercury reductions achieved with the lower injection rates were considerably lower than what was achieved with the 7 lb/MMacf injection rate (Reference (34)). Therefore, lower injection rates were not evaluated due to the low mercury reductions and elevated particulate emissions out of the stack compared to normal operating conditions.

Based on the Phase I and Phase II testing reports, it is unclear what the full impacts of ACI would be on the current operations of the facility. However, ACI increases the particulate loading at the wet scrubbers. This concern was evaluated against the BAMRT criteria to determine if ACI could technically achieve the 72% reduction. In addition, Keetac's wet scrubbers are relatively new high efficiency scrubbers as they were installed in 2005. Therefore, new high efficiency scrubbers are unlikely to address the increased particulate loading to the scrubbers and elevated particulate emissions observed with ACI.

4.1.5.2 ACI with Electrostatic Precipitator (ESP)

As discussed above, ACI can adsorb elemental and oxidized mercury from the flue gas to form particulate-bound mercury. However, smaller particulates are less likely to be captured by the existing wet scrubbers. Therefore, smaller PAC particles containing adsorbed mercury have the potential to be emitted as particulate-bound mercury. In addition, the existing scrubbers cannot handle an increase in particulate loading while maintaining the same level of particulate control. To address this issue, an enhanced particulate control equipment could replace the existing scrubbers. The net effect of installing new controls is to increase the capture efficiency of particulates and thereby increase the overall mercury reduction of ACI.

A study from Phase I, *Project 4: Evaluation of a Slipstream Baghouse for the Taconite Industry* (Reference (35)) evaluated the possibility of using enhanced particulate control with a baghouse to capture the PAC. CMMs and sorbent traps were used to measure mercury reduction efficiency. PAC injection rates tested were 1.1, 2, and 2.2 lb/MMacf. Brominated PAC injection rates tested were 0.6 and 1.1 lb/MMacf. In addition, Keetac conducted an additional test with a mini slipstream fabric filter (Reference (34)); a mercury CEMS was used to measure the mercury reduction efficiency. PAC was injected at rates of 3.6 and 7 lb/MMacf.

An ESP can provide a similar level of particulate control compared to a baghouse and can operate without additional equipment to handle the temperature and moisture of the flue gas coming off the drying zone. For this analysis, Keetac evaluated an ESP to enhance particulate control and capture, for use in conjunction with ACI, to allow for a more adaptable operation.

4.1.6 Fixed Bed Carbon Adsorption

Fixed bed carbon adsorption consists of routing flue gases through a vessel packed with activated carbon. The flue gas passes through a series of vessels where the fixed carbon beds remove the mercury from the flue gas. The carbon contains many pores with active adsorption sites, which capture mercury as the flue gas flows through.

Although a fixed carbon bed would be installed after all existing processing equipment, there is still a concern that implementation has the potential to negatively impact the process due to the expected large differential pressure across the adsorption bed. The induced backpressure has the potential to cause reduced indurating airflow that could jeopardize pellet quality or production rates. Considerable, facility-specific, mechanical upgrades would be needed in order to design and install the required equipment to be able to overcome the resistance through the adsorption beds. In addition to the resistance of the beds, the space constraints at Keetac may present significant installation challenges due to the large footprint required. The system would need to be installed in areas with limited space while still allowing safe access. Installing a fixed carbon bed downstream of the existing wet scrubbers is not appropriate because a water-saturated waste gas stream would block adsorption sites with moisture and reduce the carbon bed's ability to reduce mercury. In addition, this reduction technology requires enhanced particulate control to avoid plugging the carbon beds. Therefore, Keetac would need to utilize a baghouse that replaces the existing wet scrubbers prior to the fixed carbon beds to optimize the filterable particulate control and avoid issues with waste gas that is water-saturated.

Based on the Pre-TMDL research of bench scale results from the June 17, 2009 EERC testing (*Demonstration of Mercury Capture in a Fixed Bed*, Reference (36)), fixed bed carbon adsorption is an effective method of removing mercury from flue gas. However, the testing was carried out on a small scale and in simulated flue gas environments that do not necessarily represent actual operating conditions of the taconite process. In August 2012, as part of the Phase 1 work, additional testing was completed at HTC, Minorca, and UTAC; see *Developing Cost-Effective Solutions to Reduce Mercury Emissions from Minnesota Taconite Plants* (Reference (37)) to further review the potential of a fixed bed carbon adsorption system. 2012 results indicated a high level (>75%) of control was achievable based on laboratory scale slipstream testing. However, on a full-scale operation, costs and other site-specific factors may be too large to overcome in order for fixed carbon beds to be a viable reduction technology and therefore requires further evaluation.

4.1.7 GORE™

The GORE™ technology is a fixed sorbent polymer composite, which does not require injection of powder sorbents or chemicals, capturing both elemental and oxidized mercury, and removing sulfur dioxide (SO_2) as a co-benefit. During the Phase I evaluations, this technology was previously referred to as Monolithic Polymer Resin Adsorption (Reference (1)). The system includes wash equipment to remove particulate material from the pleated sorbent panels. When used in high SO_2 environments, the SO_2 converts to sulfuric acid mist (SAM) which helps to clean the filter/panels and prevent plugging. However, material build-up in the GORE™ unit is expected when SO_2 levels are low, resulting in lower mercury reductions and more frequent wash cycle requirements. The panels are housed in modules that may be placed in series to increase the removal efficiency of the system. This potential reduction technology was evaluated after the Phase II research.

GORE™ pilot testing pulled a slipstream of air through the test skid modules (updraft) and through a fan, which returned the slipstream into the waste gas stack. Demonstrations took place on three different induration furnaces: Minntac – Line 7, Minorca, and UTAC – Line 2. The facilities where the demonstration took place contracted with TRC Solutions Emissions Testing Services to perform the mercury and SO_2 analysis. Samples for mercury and SO_2 were taken before and after the test skid modules to determine the amount of reduction. The mercury samples were analyzed using Method 30B. All results were excluded from testing if the paired traps were not within 10% of each other. SO_2 was analyzed using a CEMS. Water was used in the system to spray the GORE™ modules to remove particulate and any other build-up. The long-term effects of increased build-up could cause unacceptable differential pressure increases across the GORE™ unit, thereby reducing indurating airflow and jeopardizing pellet quality or production rates. In addition, results of mercury concentration in the GORE™ membrane wash water effluent ranged from 2,460 ng/L – 30,300 ng/L. The wash water influent mercury concentrations ranged from non-detect to approximately 10 ng/L. This represents a significant increase in mercury loading to the plants' process water systems. Coupled with an increase in the plant water system (TDS, sulfate), consideration of a full-scale implementation of the GORE^{TM} technology for mercury reduction requires the evaluation of additional wastewater treatment for the increased loading of mercury, sulfate, TDS and other constituents that may be captured by the wash water. Much like the fixed carbon bed, the GORE technology would need to be installed in an area with limited access. Due to the large airflows and velocity of the airstream, potentially thousands of modules would need to be installed. This would result in extended production downtime (i.e. loss of production) when the units need to be rotated. It also would result in extreme safety issues as employees would need to be protected from falls, lifting hazards and pinch points when rotating modules. All mercury reduction technologies require some level of maintenance or repair, but the GORE technology has more frequent and labor-intensive maintenance requirements than most. This is because it is a best practice to rotate the modules to maintain the optimal control efficiency over time.

The taconite processing facilities produce either acid or flux pellets (limestone added to the greenballs). The additional limestone for flux pellet production absorbs SO_2 and results in lower SO_2 emissions from the furnace. The GORE^{TM} modules' mercury control effectiveness decreases with decreasing SO_2 concentrations as demonstrated by the lower mercury reduction effectiveness from the Minorca pilot test results (lower SO_2 concentrations) and UTAC and Minntac test results (higher SO_2 concentrations) (Reference (38)). Minorca burns inherently low sulfur natural gas in its indurating furnace and was producing flux pellets (SO_2 scrubbing) during the GORE^{TM} pilot testing. Keetac is permitted to burn coal and produces a low-flux pellet (1.5 percent by weight of the pellet weight), therefore mercury reduction effectiveness from the Minntac test results are assumed to be comparable to what Keetac would realize with the GORE^{TM} modules.

The taconite industry has been in communication with GORE^{TM} since 2015 pilot testing to discuss follow up questions and concerns observed (wash water contamination, plugging, pressure drop, etc.) while using the GORE^{TM} GEN2 modules. The BAMRT analysis is based on the next generation GORE^{TM} GEN3 modules, which have a higher control efficiency per module, thus reducing the overall footprint and capital cost. In September 2018, taconite industry representatives met with GORE^{TM} representatives to discuss recent developments with their technology. Comments from the meeting and updated quotes have been incorporated into the full-scale design and cost evaluation for the BAMRT analysis.

Keetac considers this to be a potential reduction technology, which was further evaluated under Step 2 (Section 4.1.8).

4.1.8 Monolithic Honeycomb Adsorption

Monolithic honeycomb adsorption was never tested at a taconite facility, but was previously reviewed as a potential reduction technology. Activated carbon and elemental sulfur are mechanically fixed into a honeycomb structure that may include additives to enhance mercury capture. The cells of the monolith are plugged at their ends intermittently to force gas flow through the walls of the structure (Reference (1)). This plugging configuration improves contact between the flue gas and the porous wall of the monolith.

Keetac considers this to be a potential reduction technology, which was further evaluated under Step 2 (Section 4.1.8).

4.2 Step 2 – Determine if the Technologies are Commercially Available

Commercial availability was determined by contacting vendors to determine whether the materials needed to implement each technology were readily available for purchase at the time this report was created (2018). The commercial availability of potentially available mercury emissions reduction technologies is summarized in Table 4-2.

Table 4-2 Commercial Availability of Potentially Available Mercury Emissions Reduction Technologies

Reduction Technology		Commercially Available?
Mercury capture by existing wet scrubbers with solids removal		Yes
Mercury oxidation for capture by existing wet scrubbers	Halide injection	Yes
	HEDT	No
Activated carbon injection	With existing scrubbers	Yes
	With ESP	Yes
Fixed carbon bed		Yes
GORE™		Yes
Monolithic honeycomb adsorption		No

HEDT and monolithic honeycomb adsorption were not commercially available and were therefore eliminated from further consideration as discussed in Sections 4.2.1 and 4.2.2.

4.2.1 HEDT

Testing of this technology by the EERC in 2008 was based on a prototype design. EERC sold the patent rights to Midwest Energy Emissions Corporation (ME2C). However, ME2C confirmed that this technology was not commercially available. Therefore, HEDT was eliminated from further consideration.

4.2.2 Monolithic Honeycomb Adsorption

This technology was previously under development by MeadWestvaco and Corning Incorporated. However, development was halted prior to becoming commercially available (Reference (1)). Therefore, monolithic honeycomb adsorption was eliminated from further consideration.

4.3 Step 3 – Determine if the Technology Can Operate without Impairing Pellet Quality or Production

The expected impact on pellet quality of each potentially available mercury reduction technology is summarized in Table 4-3.

Table 4-3 Impact on Pellet Quality or Production from Potentially Available Mercury Emissions Reduction Technologies

Reduction Technology		Impair Pellet Quality or Production?
Mercury capture by existing wet scrubbers with solids removal		No
Mercury oxidation for capture by existing wet scrubbers	Halide injection	No
Activated carbon injection	With existing scrubbers	No
	With ESP	No
Fixed carbon bed		No
GORE$^{\text{TM}}$		No

There was no evidence from previous testing to suggest that the remaining reduction technologies impaired pellet quality parameters or production. However, testing has not been long enough in duration to observe all possible process impacts and should any of these potentially available mercury emissions reduction technologies be considered for full-scale installation, this criterion would need to be further evaluated. Keetac reserves the right to revisit this evaluation and subsequent resulting conclusion when new information becomes available. Therefore, for the purposes of the analysis, all remaining technologies proceeded to Step 4.

4.4 Step 4 – Determine if the Technology Causes Excessive Corrosion to Pellet Furnaces or Associated Ducting or Emission Control Equipment

Prior to testing each technology, industry conducted research to determine if the potential for increased corrosion existed (refer to Table 4-4). Based on the available information at the time, both ACI and halide injection were thought to have the potential to create additional corrosion. While conducting ACI testing, maintenance personnel at Minntac mentioned that the process fans did not appear the same, almost a blue color with a buildup. The testing conducted has been short-term in duration. Therefore, it is unknown if excessive corrosion of production equipment or ducting will occur for a full-scale installation. High rates of corrosion are an operational concern with long-term halide injection testing. However, corrosion testing was relatively short-term. Thus, it is nearly impossible to determine all the long-term impacts.

Table 4-4 Potential for Corrosion from Potentially Available Mercury Emissions Reduction Technologies

Reduction Technology		Potentially Cause Excessive Corrosion?
Mercury capture by existing wet scrubbers with solids removal		No
Mercury oxidation for capture by existing wet scrubbers	Halide injection	Possibly
Activated carbon injection	With existing wet scrubbers	No
	With ESP	No
Fixed carbon bed		No
GORE™		No

None of the remaining reduction technologies, except possibly halide injection, are expected to induce corrosion to production equipment above an acceptable threshold. This threshold is pursuant to existing preventative maintenance practices (i.e. does the technology significantly increase the required preventative maintenance to plant equipment). However, testing has not been long enough in duration to observe all possible process or equipment impacts and should any of these potentially available mercury emissions reduction technologies be considered for full-scale installation, this criterion would need to be further evaluated. Keetac reserves the right to revisit this evaluation and subsequent resulting conclusion when new information becomes available. Therefore, for the purpose of the BAMRT analysis, all remaining technologies proceeded to Step 5

4.5 Step 5 – Determine if the Technology Presents Unacceptable Environmental Impacts

Reduction technologies may have limited environmental impacts (i.e., additional wastewater treatment, solid waste disposal, etc.). These impacts are not considered unacceptable because they could be reasonably mitigated with well-established management techniques. However, the TMDL sought to reduce mercury concentrations in fish tissue (Reference (2)). Therefore, any technology that results in environmental impacts contrary to this goal is considered unacceptable. A summary of the results of Step 5 are summarized in Table 4-5.

Table 4-5 Environmental Impacts of Remaining Mercury Emissions Reduction Technologies

Reduction Technology		Unacceptable Environmental Impacts?	Continue to Next Step?
Mercury capture by existing wet scrubbers with solids removal		No	Yes
Mercury oxidation for capture by wet scrubbers	Halide injection	Yes– increased likelihood of local mercury deposition	No – See Section 4.5.1
Activated carbon injection	With existing scrubbers	Yes– increased likelihood of local mercury deposition and compliance risk for Maximum Achievable Control Technology (MACT) limits	No – See Section 4.5.2
	With ESP	Likely no	Yes
Fixed carbon bed		Likely no	Yes
GORE$^{\text{TM}}$		Likely no, however mercury in water increased which would need to be removed and waste generation managed	Yes

Halide injection and ACI with the existing scrubbers were considered to pose unacceptable environmental impacts, which is discussed in detail below. The other reduction technologies may have limited environmental impacts (i.e., additional wastewater treatment, solid waste disposal, etc.). However, these were not considered unacceptable because they could be mitigated with the installation of additional equipment or mitigation methods.

4.5.1 Halide Injection

Halide injection was originally tested during the pre-TMDL research and recently at Minntac Line 6. Minntac was able to achieve a reduction in total mercury emissions during their most recent halide injection testing in 2018 on Line 6. The long-term test plan consisted of a baseline period (no halide injection) followed by a $CaBr_2$ injection period. Ontario Hydro stack tests were conducted during the long-term testing in order to analyze the speciation changes of particulate-bound, oxidized, and elemental mercury due to halide injection. The results indicate that the oxidized mercury percentage increased compared to the baseline. Particulate matter levels were also tested and no significant change was noticed during the test as compared to the baseline. This reinforces that the scrubbers were operating in proper condition. Similarly, HTC conducted halide injection testing in 2017 and saw a more significant increase in oxidized mercury emissions compared to baseline emissions (Reference (39)). Keetac has not tested halide injection since the 2008, but it is expected that oxidized mercury emissions out of the stack would increase similar to Minntac and HTC with the application of halide injection.

It is not surprising that oxidized mercury emissions out of the stack would be elevated above baseline conditions. This is because halide injection is supposed to oxidize the elemental mercury in the flue gas to be more readily captured by the wet scrubbers. However, if the wet scrubbers cannot capture the increased oxidized mercury from halide injection then this would result in an increase in oxidized mercury out of the stack. An increase in oxidized mercury emissions has unacceptable environmental impacts contrary to the goals of the TMDL. Refer to Table 4-6 for estimates that show what the emissions profile may look like if halide injection were applied at Keetac.

Table 4-6 Estimated Mercury Emissions Reduction and Speciation Changes with Halide Injection at Keetac

Parameter	Particulate	Elemental	Oxidized
Baseline emissions, lb/hr (% of total)(1)	0.0001 (0.8%)	0.0120 (99.2%)	
Estimated oxidized and elemental emissions with no halide injection, lb/hr (% of total)(2)	N/A	0.0107 (88.1%)	0.0013 (11.1%)
Including halide injection, lb/hr (% of total)(3)	0.0004 (4.0%)	0.0087 (96.0%)	
Difference, lb/hr (% of baseline)	0.0003 (290.1%)	-0.0033 (-27.4%)	
Estimated oxidized and elemental emissions with halide injection, lb/hr(4)	N/A	0.0047 (52.0%)	0.0040 (44.0%)
Increase/Decrease in emissions (lb/yr)(5)	**2.21**	**-48.68**	**21.68**

(1) Emissions are from the 2017 Method 29 testing data (Reference (17)).

(2) Elemental and Oxidized emissions during the baseline are estimated by applying the industry average ratio of elemental to oxidized mercury under existing conditions to the gas phase mercury emissions from Method 29 (back-half). Refer to Table 1 of the Local Deposition Evaluation for details (Reference (39)). Method 29 cannot differentiate between elemental and oxidized mercury.

(3) Emission rates with halide injection were estimated by applying the mercury reduction achieved at Minntac with halide injection to the total baseline emission rate. This value was split into particulate (Method 29 front-half) and gas phase (Method 29 back-half) portions by applying the industry average speciation particulate and gas phase mercury fractions observed during halide injection testing. Refer to Table 1 of the Local Deposition Evaluation for details (Reference (39)).

(4) Elemental and Oxidized emissions during with halide injection are estimated by applying the industry average ratio of elemental to oxidized mercury under halide injection testing conditions to the gas phase mercury emissions. Refer to Table 1 of the Local Deposition Evaluation for details (Reference (39)). Method 29 cannot differentiate between elemental and oxidized mercury.

(5) Assumes 8,200 hours of annual furnace operation

The taconite industry and third party technical experts reviewed the impact of mercury reduction technologies (halide injection and ACI) on local mercury deposition and provided a summary memo with the results (Local Deposition Evaluation, Reference (39)) Screening calculations indicate that increased particulate or oxidized mercury emissions from halide injection would increase local mercury deposition to the Northeast Region (defined by the TMDL, which includes the Iron Range) even if the technology decreased total mercury emissions (Reference (39)). Elemental mercury (the majority of mercury emissions under baseline conditions) can remain in the atmosphere for long periods of time and travel great distances. It is unlikely for elemental mercury to be deposited near the emission source (Reference (39)). Therefore, the estimated reduction in elemental mercury emissions are unlikely to have any impact on local mercury deposition or improve the mercury impairment of Minnesota waters even though the estimated decrease in elemental mercury emissions (-48.68 lb/yr) was more significant than the increase in oxidized mercury emissions (21.68 lb/yr). However, Table 2 of the Local Deposition Evaluation (Reference (39)) demonstrates that even a small increase in oxidized mercury emissions with a corresponding decrease in elemental mercury can increase local mercury deposition. In contrast to elemental mercury, oxidized mercury is water soluble and readily deposited through precipitation at the local level (i.e. within a few miles of the emission source) (Reference (39)).

The local deposition of oxidized mercury and its role in elevated fish tissue mercury concentrations has been documented in several regions of the U.S., for example in the southeast (Reference (40)) and in New England (References (41), (42)). In the evaluation by Florida Department of Environmental Protection (Reference (40)), oxidized mercury accounted for more than 50% of the emissions from the facilities being evaluated. King et al. found that local mercury deposition due to emissions of oxidized mercury was a factor of 4 to 10 times greater than rural background deposition (Reference (42)). Associated with increased local deposition of mercury, fish tissue mercury concentrations were elevated in nearby water bodies (References (40), (42)). As a result, an increase in oxidized mercury air emissions can result in increased local deposition with an associated increase in fish tissue mercury concentrations. As discussed above, this is true even if elemental mercury emissions decrease. Table 2 of the Local Deposition Evaluation (Reference (39)) demonstrates that even a small increase in oxidized mercury emissions can increase local deposition of mercury and loading to the environment. As demonstrated by Table 4-6, halide injection is likely to increase oxidized mercury emissions.

Halide injection resulted in significantly increased oxidized mercury emissions (Table 4-6), which directly contradicts the purpose of the TMDL to reduce mercury concentrations in fish tissue. Since the environmental impacts at a reduced halide injection rate were considered unacceptable, then the increased halide injection rates used during the Pre-TMDL research would yield similar or more severe environmental impacts.

In addition, Keetac considers the potential increase in particulate-bound mercury emissions observed during halide injection testing at other facilities (Reference (39)) as an unacceptable environmental impact. This is because particulate-bound mercury has a higher likelihood of being deposited locally, similar to oxidized mercury (Reference (39)). Table 2 of the Local Deposition Evaluation demonstrates that even a small increase in particulate mercury speciation may increase local deposition, which has the potential to increase mercury concentrations in fish tissue (Reference (39)).

The increase in oxidized and particulate mercury emissions from halide injection directly contradicts the purpose of the TMDL to reduce mercury concentrations in fish tissue. Therefore, Keetac considers this to be an unacceptable environmental impact and halide injection is eliminated from further consideration.

4.5.2 ACI with Existing Scrubbers

Keetac was able to achieve a reduction in mercury emissions during the Phase II ACI testing. However, particulate emissions out of the stack were elevated during screening and long-term tests. This indicates that the PAC was not completely captured by the wet scrubbers, which could result in an increase in particulate-bound mercury emissions. Refer to Table 4-7 for details.

Table 4-7 Particulate Emission Rates and Vapor Phase Mercury Reductions with and without ACI at Keetac (References (34), (43), (44), and (45))

Parameter	Value	Vapor Phase Mercury Reduction (%)
Stack Filterable Particulate Concentration with no ACI (gr/dscf)		N/A
2013 compliance testing	0.0060	N/A
2017 compliance testing	0.0033	N/A
Average of 2013 and 2017 compliance testing	**0.0047**	N/A
Stack Filterable Particulate Concentration with ACI (gr/dscf)		N/A
BPAC screening test (3 lb/MMacf)	0.0114	42%
BPAC screening test (5 lb/MMacf)	0.0129	56%
BPAC screening test (7 lb/MMacf)	0.0140	63%
BPAC Fine screening test (3 lb/MMacf)	0.010	39%
BPAC Fine screening test (5 lb/MMacf)	0.0097	55%
BPAC Fine screening test (7 lb/MMacf)	0.010	75%
BPAC Coarse screening test (5 lb/MMacf)	0.0085	57%
BPAC Coarse screening test (7 lb/MMacf)	0.0091	62%
Fast PAC Premium screening test (7 lb/MMacf)	0.0103	59%
BPAC long-term stack test #1 (7 lb/MMacf)	0.0093	82%
BPAC long-term stack test #2 (7 lb/MMacf)	0.0097	
Average of all screening and long-term ACI testing	**0.0104**	N/A
Stack particulate concentration increase with ACI (gr/dscf)	0.0057	N/A
% increase with ACI	121%	N/A

The increase in particulate-bound mercury with ACI is due to a portion of the PAC passing through the wet scrubbers. The PAC that is not captured by the wet scrubbers contains adsorbed mercury from the furnace waste gas. As noted by DNR's review of the Phase II report (Reference (46)), ACI increases the particulate loading to the wet scrubbers and mercury bound to PAC particles was slipping past the wet scrubbers. The DNR stated in reference to the Phase II reports "the reports do provide relatively strong evidence that re-emission of particulate-bound mercury is a pervasive issue that must be solved before brominated activated carbon injection methods can be considered suitable for the taconite industry." Keetac considers this an unacceptable environmental impact because particulate-bound mercury emissions are more likely to be deposited locally compared to elemental mercury, similar to oxidized mercury. Table 2 of the Local Deposition Evaluation demonstrates that even a small increase in particulate mercury speciation may increase local deposition. Increased local deposition of particulate mercury has the potential to increase fish tissue mercury concentrations. This is contrary to the purpose of the TMDL, which seeks to reduce mercury deposition in Minnesota. Table 4-7 shows that this adverse impact is true even at the lower PAC injection rates.

Under normal operating conditions with no ACI, Keetac can consistently maintain compliance with its existing 40 CFR 63 Subpart RRRRR (Taconite Maximum Achievable Control Technology [MACT]) filterable particulate limit (0.01 gr/dscf). During ACI testing, particulate loading to the scrubbers increased such that the filterable particulate concentration at the stack nearly exceeded the MACT limit. This demonstrated that ACI, in addition to the existing particulate concentration from the furnace operations, exceeded the existing scrubbers' particulate loading capacity. Full-scale utilization of ACI would jeopardize Keetac's ability to consistently comply with its Taconite MACT limit.

Keetac considers the potential for increased local mercury deposition and the increase in particulate emissions to be unacceptable environmental impacts. This is because it directly contradicts the purpose of the TMDL and jeopardizes compliance with the Taconite MACT limit for Keetac. Therefore, ACI with the existing scrubbers was eliminated from further consideration.

4.6 Step 6 – Determine if the Technology Can Consistently Meet the 72% Reduction per the MN Rule

Table 4-8 summarizes the control effectiveness of the remaining mercury emissions reduction technologies.

Table 4-8 Control Effectiveness of Remaining Mercury Emissions Reduction Technologies

Reduction Technology		Total Mercury Control Efficiency	Continue to Next Step?
Mercury capture by existing wet scrubbers with solids removal		30%(1)	No
Activated carbon injection	With ESP	80%(2)	Yes
Fixed carbon bed		99%(3)	Yes
GORE™		73%(4)	Yes

(1) 30% wet scrubbers mercury control efficiency established in Keetac Title V permit issued February 2, 2005 (Reference (20)).
(2) Equipment design by vendor estimated 80% mercury control.
(3) Vendor estimated control efficiency and most literature for fixed bed controls cite a control efficiency greater than 99%. This has never been tested on a full-scale at a taconite facility. Therefore, Keetac assumes a 99% control efficiency for the purposes of this analysis.
(4) Testing at Minntac indicated that a 72% reduction per the rule might be achievable (Reference (38)). Keetac will assume that this technology can reduce mercury emissions by 73% (average during testing)

Only mercury capture by existing wet scrubbers with solids removal cannot meet the mercury reduction required by Minn. R. 7007.0502, subp. 6. This technology will be evaluated in the facility's alternative mercury emissions reduction evaluation. All other mercury emissions reduction technologies listed in Table 4-8 can meet a 72% reduction in mercury emissions and move on to the next step.

4.7 Step 7 – Determine if the Technology is Cost Effective

ACI with an ESP, fixed carbon beds, and GORE^{TM} are the only remaining technologies for the BAMRT analysis that were evaluated for cost effectiveness.

4.7.1 Cost Effectiveness Threshold

EPA has considered the cost effectiveness of mercury reductions while setting "beyond-the-floor" MACT standards in the rulemaking process for a variety of source categories under the National Emission Standards for Hazardous Air Pollutants (NESHAP) listed in Table 4-9. While developing these NESHAPs, EPA sets a MACT "floor" based on the best performing facilities within a source category and incorporates the technologies or work practices used at those facilities in the regulation. When EPA considers setting "beyond-the-floor" MACT standards, it is required to consider the cost effectiveness of these additional emissions reductions.

In rule development for the Mercury Cell Chlor-Alkali Plant MACT, EPA stated that "EPA has not established a clear cost effectiveness level for mercury reductions that are considered acceptable" (Reference (47)). EPA stated that the cost effectiveness of brominated ACI and polishing baghouse for ferromanganese production was "within the range of cost effectivenesses we have determined are reasonable for mercury control in other rulemakings. Furthermore, no other significant economic factors were identified that would indicate these limits would be inappropriate or infeasible […]" (Reference (48)).

Table 4-9 Cost Effectiveness Values Considered by EPA in MACT Rule Development

Cost Effectiveness ($ per lb mercury)	Accepted by EPA	Regulation	Standard Considered
$1,300 (Reference (49))	Proposed	Gold Mining MACT 40 CFR 63 Subpart 7E	Beyond the floor, refrigeration unit (or condenser) and a carbon adsorber on autoclaves
$2,000 (Reference (50))	Yes	Portland Cement MACT 40 CFR 63 Subpart LLL	Recalculated floor from 58 to 55 lb mercury/MMtons clinker
$7,100 (Reference (48))	Yes	Ferroalloys Production MACT 40 CFR 63 Subpart XXX	Beyond the floor, brominated ACI and polishing baghouse; FeMn furnace operating 100% of year
$13,600 (Reference (48))	Yes	Ferroalloys Production MACT 40 CFR 63 Subpart XXX	Beyond the floor, brominated ACI and polishing baghouse; FeMn furnace operating 50% of year
$20,000 (Reference (51))	Proposed	Mercury Cell Chlor-Alkali Plant MACT 40 CFR 63 Subpart IIIII	Non-mercury technology option
$27,016 (Reference (52))	Yes	Mercury and Air Toxics Standards (MATS) (existing Electrical Generating Units [EGUs]) 40 CFR 63 Subpart UUUUU	Beyond the floor standard of 4 lb mercury/ TBtu using brominated ACI
$44,000 (Reference (49))	No	Gold Mining MACT 40 CFR 63 Subpart 7E	Beyond the floor, non-carbon concentrate process with second carbon adsorber in series on melt furnaces
$74,000 (Reference (53))	No	Brick and Structural Clay MACT 40 CFR 63 Subpart JJJJJ	Beyond the floor, make existing units meet limits for new units
$14,000 - $127,000 (Reference (54))	No	Taconite MACT 40 CFR 63 Subpart RRRRR	Beyond the floor, wet scrubbers wasting
$61,000 - $183,500 (Reference (55))	No	MATS (new EGUs) 40 CFR 63 Subpart UUUUU	Beyond the floor, hypothetical new plant with ACI and fabric filter
$80,000 - $100,000 (Reference (56))	No	Sewage Sludge Incinerator MACT	Beyond the floor, afterburners, ACI, and fabric filters
$100,000 (Reference (49))	No	Gold Mining MACT 40 CFR 63 Subpart 7E	Beyond the floor, carbon process with second carbon adsorber in series on autoclaves
$420,000-540,000 (Reference (57))	No	Portland Cement MACT 40 CFR 63 Subpart LLL	Beyond the floor, additional ACI system

Following EPA's approach for evaluating the economic acceptability of mercury reduction options, the taconite processing industry reviewed the cost effectiveness of mercury reduction options found to be acceptable in other regulations; see Table 4-9 with cost effectiveness values from federal MACT regulations. The taconite processing industry considers $7,100 per pound of mercury reduced to be an acceptable cost effectiveness guide for mercury reduction, based on the strong similarities between the taconite processing source category and the ferromanganese production source category regulated under the Ferroalloys Production MACT. The $7,100 cost effectiveness value is equal to the cost effectiveness value EPA found to be acceptable for new and reconstructed ferromanganese production furnaces using brominated activated carbon injection with a polishing baghouse in the Ferroalloys Production MACT.

The taconite processing and the ferromanganese production source categories both serve niche markets and are not able to pass increased costs on to their customers because of the competitive nature of the commodity market. Both source categories have limited options to reduce mercury emissions because the main source of mercury is the variable mercury content of their respective raw materials (iron ore or manganese ore). Conversely, there are several different viable mercury reduction options for Industrial, Commercial, and Institutional (ICI) boilers which have a more constant mercury concentration in their raw materials. In addition, the cost effectiveness evaluation for the boiler industry is likely an upper-bound estimate based on what is likely to be the most expensive mercury reduction option (ACI retrofit).

From the review of MACT standards (Table 4-9), there are only two standards with EPA-accepted cost effectiveness values higher than those found in the Ferroalloys MACT. The $20,000 cost effectiveness value for the mercury cell chlor-alkali plant MACT does not provide a strong basis of comparison because the mercury reduction option being considered was a completely new process that eliminated the use of mercury altogether. The $27,016 cost effectiveness value for the Mercury Air Toxics Standard at existing electric generating units also is not a clear analogue because power generation is a much larger market and cost increases can more readily be passed on to consumers, unlike the taconite industry.

4.7.2 Economic Evaluation of Remaining Mercury Control Technologies

The annualized cost includes both capital and operating costs. Economic impacts were analyzed using the procedures found in the EPA Air Pollution Control Cost Manual (CCM, References (58), (59)). The most up to date CCM sections were used whenever possible as new updates have been published since the release of the 6th edition of the CCM. Vendor cost estimates were used when available. If vendors did not respond to bid requests, capital costs were estimated using literature cost factors or data from other projects with adjustments for inflation and size.

Table 4-10 details the expected costs associated with the installation of the above mercury reduction technologies for installations on Keetac's furnace. Equipment design was based on mercury control efficiencies outlined in Table 4-8, baseline values determined in Section 3, vendor estimates, and the CCM. Capital costs were based on recent vendor quotes, if available, or cost factors. Direct and indirect costs were estimated as a percentage of the fixed capital investment using the CCM, unless provided by a vendor. Operating costs were based on 100% utilization and 8,200 annual hours of operation. Operating costs of consumable materials, such as electricity, water, and chemicals were established based on the

CCM and engineering experience. The detailed cost analysis and design assumptions are provided in Appendix D.

Due to space considerations, a 50% markup of the total capital investment (i.e. 1.5 retrofit factor) was included in the costs to account for the retrofit installation. Retrofit installations have increased difficulty in equipment handling and erection for many reasons. Access for transportation, laydown space, etc. for new equipment is significantly impeded or restricted. This is because the spaces surrounding the furnace and existing control equipment are congested, or the areas surrounding the building support frequent vehicle traffic or crane access for maintenance. This would significantly impede access for transportation, laydown space, etc. for new equipment. The structural design of the existing building would not support additional equipment on the roof. Additionally, the evaluated technologies are very complex due to all of the ancillary equipment requirements, piping, structural, electrical, demolition, etc. Therefore, these costs provide estimates of additional construction costs due to the expected difficulty in handling and erection to accommodate new equipment within the facility. The use of a retrofit factor has been justified by the MPCA and previous projects with Keetac (Reference (60)). Therefore, the markup on the capital investment is appropriate. Finally, the CCM notes that retrofit installations are subjective because the plant designers may not have had the foresight to include additional floor space and room between components for new equipment (References (58), (59)). Retrofits can impose additional costs to “shoe-horn” equipment in existing plant space, which is true for Keetac.

The estimates include additional site-work and construction costs to accommodate new equipment within the facility. In addition, a site-specific estimate of site preparation, buildings, and ductwork was added to arrive at the total installed cost. Based on the scale of the proposed equipment installations, it was assumed that it would take 14 additional days beyond a typical annual outage to tie-in the new equipment and resume normal operations. The cost calculations account for the lost production for this time. The conservative estimate was based on Barr’s experience on other projects.

Keetac applied a 30 percent contingency to the purchased equipment costs. As a project progresses through the design process, the estimates for the project costs become progressively more accurate. For the current feasibility/conceptual design phase where fewer project details have been defined, a 30% contingency is appropriate. In addition, these cost estimates most closely resemble a Class 4 estimate, with expected accuracy ranging from -30% to +50%, to account for unknowns without detailed engineering (Reference (61)). Note, the CCM does not consider contingencies to be the same as uncertainty or retrofit factor costs and are treated separately (Reference (58)).

For fixed carbon beds, the wet scrubbers would be replaced by a new baghouse. Installing a baghouse downstream of a wet scrubbers is infeasible because the moisture from the scrubbers would plug the bags. Installing a fixed carbon bed downstream of the existing wet scrubbers is not appropriate because a water-saturated waste gas stream would block adsorption sites with moisture and reduce the carbon bed’s ability to reduce mercury. In addition, this reduction technology requires enhanced particulate control to avoid plugging the carbon beds. Therefore, Keetac would need to utilize a baghouse that replaces the existing wet scrubbers prior to the fixed carbon beds to optimize the filterable particulate control and avoid issues with waste gas that is water-saturated.

For ACI with an ESP and fixed carbon beds, the wet scrubbers would be replaced by new particulate controls (ESP or baghouse, respectively). The existing scrubbers control SO_2 emissions and thus removing them would cause Keetac to be out of compliance with their existing permit and federal regional haze limits. Therefore, Keetac accounted for the cost of new SO_2 controls to maintain the current level of SO_2 removal due to the existing scrubbers (does not apply to GORE^{TM}).

Table 4-10 Cost Effectiveness of Mercury Reduction Technologies

Mercury Reduction Technology	Total Capital Investment with Retrofit Factor ($)	Total Annual Cost ($/yr)	Annualized Pollution Control Cost ($/lb)	Cost Effective
ACI with ESP	$64,780,000	$14,380,000	$149,800	No
Fixed Carbon Bed	$89,660,000	$13,890,000	$116,900	No
GORE^{TM}	$69,150,000	$8,770,000	$100,300	No

Appendix D contains the detailed cost evaluation. The cost effectiveness of the remaining mercury reduction technologies for the facility varies from $100,300 to $149,800 per pound of mercury removed. The costs for all of the evaluated technologies exceeded the $7,100 per pound of mercury removed cost effectiveness guide several times over (refer to Section 4.7.1). Therefore, the remaining technologies were eliminated from further consideration.

4.8 Step 8 – Determination of BAMRT for Keetac

After evaluating all potentially available mercury reduction technologies against the criteria outlined in Section 4, no technologies proceeded to Step 8. Therefore, Keetac has not identified a reduction technology as BAMRT to achieve the 72% reduction in mercury emissions. ACI with an ESP, fixed carbon beds, and GORE^{TM} were all eliminated from consideration because they are not cost effective. All other technologies evaluated were eliminated from further consideration based on the other adaptive management criteria, with the exception of mercury capture by existing wet scrubbers with solids removal, which will be evaluated in the alternative mercury emissions reduction evaluation in Section 6.

5 Alternative Mercury Emissions Reduction Evaluation

In accordance with Minn. R. 7007.052, subp. 5(A)(2), Keetac determined that the 72% reduction is not technically achievable. Therefore, Keetac evaluated if any mercury reduction technologies could achieve an alternate removal rate. Only one technology, mercury capture by existing wet scrubbers with solids removal, did not reduce emissions by 72% but still satisfied the other adaptive management criteria and continued on to the alternative mercury emissions reduction evaluation. The purpose of the alternative mercury emissions reduction evaluation was to determine what percent reduction of mercury air emissions is technically achievable from Keetac's indurating furnace. Figure 4-1 summarizes the alternative mercury emissions reduction evaluation process and its connection to the BAMRT analysis. MPCA's Ferrous Mercury Reduction Plan Form, Item 3(a) provides six steps to evaluate mercury reduction technologies and determine which reduction strategy to include in Keetac's proposed AMERP; details are included in Sections 5.1 through 5.6 below.

5.1 Step 1 – Identify and Rank Technologies from BAMRT

Table 5-1 summarizes the potentially available mercury emissions reduction technologies, ranked in descending order of control effectiveness.

Keetac currently sends scrubbers discharge water to a thickener. The thickened solids are routed to a filter press where the scrubber solids are dewatered, collected and sent offsite for disposal.

Table 5-1 Rank Remaining Reduction Technologies with Less Than 72% Control Efficiency

Reduction Technology	Total Mercury Control Efficiency	Continue to Next Step?
Mercury capture by existing wet scrubbers with solids removal	30%(1)	Yes

(1) Refer to Table 4-8.

5.2 Step 2 – Eliminate Technically Infeasible Technologies

Mercury capture by existing wet scrubbers with solids removal is technically feasible and moves on to Step 4 of the alternative mercury emissions reduction evaluation. Ranking in Step 3 is not necessary because there is only one reduction technology being considered.

5.3 Step 3 – Rank Remaining Technologies

Mercury capture by wet scrubbers and solids removal proceeds to Step 4 of the alternative mercury emissions reduction evaluation.

5.4 Step 4 – Complete an Environmental Impacts Analysis

Mercury capture by existing wet scrubbers with solids removal was evaluated to determine if it caused unacceptable environmental impacts. MPCA's Ferrous Mercury Reduction Plan Form suggests evaluating the environmental impacts in Sections 5.4.1 through 5.4.4.

5.4.1 Solid/Hazardous Waste Generation

No impact: The wet scrubber solids removed from the taconite process are not a hazardous waste.

5.4.2 Water Discharge

No impact: Scrubbers water is recovered and re-used as process water; no scrubber water is directly discharged from the facility.

5.4.3 Demand on Local Water Resources

No impact: Mercury capture by existing wet scrubbers with solids removal will have no additional impacts on local water resources. The scrubbers are existing equipment and the facility will not increase water usage.

5.4.4 Other Regulated Air Pollutants

No impact: Removing scrubber solids does not impact process emissions of other regulated air pollutants.

5.4.5 Results of Environmental Impacts Analysis

Mercury capture by existing wet scrubbers with solids removal does not impose unacceptable environmental impacts. The technology proceeds Step 5 of the alternative mercury emissions reduction evaluation.

5.5 Step 5 – Complete a Cost Effectiveness Evaluation

Mercury capture by existing wet scrubbers with solids removal is considered cost effective because Keetac already has the equipment installed to remove the scrubber solids from the process. This technology proceeds to Step 6 of the alternative mercury emissions reduction evaluation.

5.6 Step 6 – Select Mercury Reduction Strategy

Keetac determined 30% mercury emissions reductions are technically achievable using mercury capture by existing wet scrubbers with solids removal. Keetac’s proposed AMERP, presented in Section 6, incorporates this mercury reduction strategy.

6 Alternative Mercury Emissions Reduction Plan (AMERP)

Keetac proposes to continue to reduce mercury by 30% with mercury capture by existing wet scrubbers with solids removal.

U. S. Steel will conduct a literature review and/or vendor screening between May 1, 2020 and July 31, 2020 to determine if any new mercury emissions reduction technologies (New Technologies) have been commercially developed and put into use in other industries. The results of the review will be used to fully evaluate only the New Technologies by using the same methodology as employed in the 2018 BAMRT analysis. If no New Technologies are identified, U. S. Steel will submit notification to MPCA that the review has been completed and no New Technologies were identified.

6.1 Annual Mercury Emissions and Emissions Reductions under AMERP (MPCA Form items 3b-c)

MPCA's Ferrous Mercury Reduction Plan Form, items 3b and 3c requests an estimate of the annual mass of mercury emitted under the requirements of Minn. R. 7007.0502, subp. 6 and an estimate of the annual mass of mercury emitted and percent reduction achieved under the proposed alternative plan. Table 6-1 contains the Facility's emissions before and after employing the proposed alternative reduction strategy.

Table 6-1 Mercury Emissions and Emissions Reductions under AMERP

Emission Unit	Baseline Emissions lb/yr	Percent Reduction	Estimated Emissions lb/yr
EU 030	134	30%	N/A – Keetac's baseline already accounts for reduction from mercury capture by existing wet scrubbers with solids removal

6.2 Description of Mercury Reduction Action (MPCA Form item 4)

Complete the following table for each emission unit that emits mercury. Use a separate row for each specific control, process, material or work practice that will be employed to achieve the applicable control efficiencies, reductions or allowable emissions. Provide a written summary below as needed for context or background. Minn. R. 7007.0502, subp. 5(A)(1)(a), 5(A)(1)(b), or 5(A)(2)(a).

Table 6-2 Alternative Mercury Reduction Plan

Emission Unit	Reduction Element(1)	Reduction, control efficiency, emission limit, operating limit, or work practice(2)	Describe element in detail(3)
EU 030	Mercury capture by existing wet scrubbers with solids removal	30% mercury control	See Section 4.1.3
EU 030	Literature Review and/or vendor screening with BAMRT analysis, as needed	TBD	See Section 6.2.1

(1) Control device, work practice, etc.
(2) Indicate units, i.e., lb. mercury/ton material, % control; The permit or enforceable document will include the proposed control efficiency, emission limits, or other requirements that achieve the reduction.
(3) Attach manufacturer's information and other resources used to document the reduction

6.2.1 Literature Review and/or Vendor Screening with BAMRT Analysis

U. S. Steel will conduct a literature review and/or vendor screening exercise between May 1, 2020 and July 31, 2020 to determine if any new mercury emission reduction technologies (New Technologies) have been commercially developed and put into use in other industries in the United States. If any New Technologies have been commercially developed and put into use, U. S. Steel will determine if on-site testing is needed to further investigate the suitability and performance of only the New Technologies. The results of the literature review, vendor screening, and on-site testing, if necessary, will be used to fully evaluate only the New Technologies by using the same methodology as employed in the 2018 BAMRT analysis. The New Technologies BAMRT analysis will determine if any New Technology satisfies the adaptive management and environmental impacts criteria and if it is potentially capable of reducing mercury emissions by 72%. If a 72% mercury reduction cannot be met, the same BAMRT evaluation process will be used for any alternative reduction analysis. The New Technologies BAMRT evaluation and updated AMERP, if necessary, will be submitted to MPCA no later than June 1, 2022. U. S. Steel will not re-evaluate technologies or outcomes already considered in the 2018 BAMRT or AMERP.

6.3 Schedule (MPCA Form item 5)

For each reduction element (specific control, process, material or work practice) described in Item 4 that will be employed as part of the mercury reduction plan, complete the following table.

The proposed schedule in Table 6-3 is dependent on the MPCA's approval of this AMERP pursuant to Minn. R. 7007.0502, subp. 4(B). Should the MPCA be delayed in the decision making process, milestone dates below are subject to change. The schedule listed below is preliminary and the estimates are Keetac's attempt to layout the future compliance schedule. There are many unknowns at this point about equipment and monitoring details. Therefore, more detail can be provided as Keetac approaches the compliance date.

Table 6-3 Schedule

Emission Unit	Reduction Element	Anticipated Installation date[1]	Anticipated Startup date[2]	Target Reduction Demonstration[3]	Target Reduction Deadline[4]	Anticipated Permit Application Submittal[5]
EU 030	Mercury capture by existing wet scrubbers with solids removal	N/A - already in practice at the Facility				
EU 030	Literature Review and/or vendor screening with BAMRT analysis, as needed	U. S. Steel will conduct a literature review and/or vendor screening between May 1, 2020 and July 31, 2020. U. S. Steel will revise and resubmit the AMERP if necessary or notify the MPCA that the review has been completed by no later than June 1, 2022.				

(1) Pending receipt of permit or enforceable document, and assuming no permit appeals.
(2) As soon as practicable, assuming on schedule equipment delivery and no significant issues during commissioning.
(3) Six months after startup or as stipulated in permit or enforceable document.
(4) Deadline per Min R. 7007.0502, subp. 3 or as stipulated in permit or enforceable document.
(5) Anticipated submittal schedule pending agency approval of the Keetac's AMERP.

6.4 Calculation Data (MPCA Form item 6)

Include all mercury emission calculations for each emissions unit listed in item 4 in an editable electronic spreadsheet. Provide calculations showing the mercury reduction, control efficiency, or emission rate that each emissions unit will achieve once the plan for that emissions unit is fully implemented.

Emission calculations are included in Appendix E.

6.4.1 Emission Factors (MPCA Form item 6a)

Identify the emission factors and sources of the emission factors used to determine mercury emissions in item 3 in the following table. Please include the rationale behind your decision. Minn. R. 7007.0502, subp. 5(A)(1)(b) or Minn. R. 7007.0502, subp. 5(A)(2)(d).

Emission factors used to calculate the mercury emission rate are included in Section 3.

6.5 Operation, Monitoring, and Recordkeeping Plan (MPCA Form item 7)

6.5.1 Operation and Optimization Plan (MPCA Form item 7a)

For each control device used to achieve the overall mercury reduction of the plan, describe how you will operate the control system such that mercury reductions are maintained. Explain how an operator might adjust the control system at the facility. Describe system alarms or safeguards to ensure optimal operation of the mercury control system. Optimization also includes training of individuals responsible for operating the control system, and the development and upkeep of operation and maintenance manuals. The MPCA is not requesting that such programs or manuals be included here, rather that they are summarized. Discuss potential variability of mercury emissions and how operations will be monitored to address variability. Minn. R. 7007.0502, subp. 5(A)(1)(c) or Minn. R. 7007.0502, subp. 5(A)(2)(c)

Mercury capture by wet scrubbers and solids removal is the current practice at the Facility. The mercury reductions are maintained because Keetac must remove scrubber solids from its process by permit condition. In the event of an upset, the scrubber solids would be routed to the basin. Therefore, there is no opportunity to optimize or improve the operation of the existing mercury control technology.

Minn. R. 7007.0502, subp. 5(A)(2)(c) requires a demonstration that (1) air pollution control equipment, (2) work practices, (3) the use of alternative fuels, or (4) raw materials have been optimized such that the source is using the best controls for mercury that are technically feasible. Each of the four listed processes are already optimized and are further described below:

1. Keetac already operates existing MACT wet scrubbers, which have been optimized to reduce air emissions and demonstrate compliance with the U.S. EPA Taconite Iron Ore Processing NESHAP which includes mercury emissions. The Facility will continue to maintain the current control efficiency and demonstrate continued optimization through compliance with the air emission permit and associated compliance plans.

2. Keetac will continue to operate and maintain control equipment and the indurating furnace in a manner consistent with good air pollution control practices and in accordance with manufacturer and industry best management practices.

3. Keetac has the ability to combust coal or natural gas. Coal firing accounts for an insignificant amount of mercury to the overall mercury emissions. In addition, natural gas is inherently low in mercury. Therefore, changing fuel sources would have an insignificant impact on the overall mercury emissions from the indurating furnace.

4. Keetac mines taconite near its indurating furnace from controlled and limited mineral deposits. It is not feasible for the Facility to consider an alternative ore feed. Additionally, the fluxstone added to the concentrate prior to the indurating furnace has an immaterial amount of mercury.

6.5.2 Proposed Monitoring and Recordkeeping (MPCA Form item 7b)

For each reduction element (specific control equipment, emission limit, operating limit, material or work practice), describe monitoring to provide a reasonable assurance of continuous control of mercury emissions. If the plan includes control equipment, attach MPCA Air Quality Permit Forms GI-05A and CD-05. Minn. R. 7007.0502, subp. 5(A)(1)(d).

Keetac proposes to conduct stack testing once every five years using EPA approved test methods. This is consistent with Minn. R. 7019.3050(E)(5).

Table 6-4 Monitoring and Recordkeeping

Emission Unit	Reduction Element	Reduction, Control Efficiency or Emission Rate	Operating Parameters	Monitoring Method	Monitoring Frequency	Proposed Recordkeeping	Discussion of Why Monitoring is Adequate
EU 030	Mercury capture by existing wet scrubbers with solids removal	30% mercury reduction	Mercury stack emissions	Periodic stack testing	Every 5 years	Keep stack test reports onsite for 5 years	Approach is consistent with Minn. R. 7019.3050(E)(5)

6.5.3 Evaluation of CEMS (MPCA Form item 7c)

Evaluate the use of CEMS for mercury, both the sorbent tube method (U.S. Environmental Protection Agency [EPA] Method 30B) and an extractive "continuous" system. Describe if either method has been used at the mercury emissions source for parametric monitoring or for compliance determination. If CEMS is selected for monitoring of mercury emissions, please include in item 6a above. If it is not selected for monitoring of mercury emissions, please discuss the evaluation of the use of CEMS below.

Keetac used temporary extractive CMMs to monitor mercury reduction during the screening tests for various activated carbon types and injection rates during Phase II of the mercury reductions study in 2013 and during the pre-TMDL halide injection testing (References (23), (34)). Since the CMMs only measure vapor phase mercury, issues arose with the increase of particulate-bound mercury in the stack gas during the ACI injection and the inability of the CMMS to measure the particulate-bound mercury fraction.

Keetac determined that it is not appropriate to use CMMs for compliance determination (neither the sorbent tube system nor a CMM) due to the reasons listed below:

- **Appropriateness of monitoring frequency**
    - Minn. R. 7007.0502 and MPCA's Ferrous Mercury Reduction Plan Form require the facility to meet a limitation of an annual mass of mercury emitted. Therefore, continuous data collection would be excessive and burdensome. Minute-by-minute data is not appropriate or necessary for an annual emission limit or for a pollutant that does not cause environmental impacts following short-term spikes. Similar to other pollutants monitored at the facilities such as particulate matter (PM), periodic stack testing is a more appropriate method based on the requirement of the rule to reduce emissions on an annual basis.
    - The goal of the statewide mercury reduction effort is to address mercury concentrations in fish tissue in Minnesota’s lakes and streams, which is a chronic mercury deposition issue. Continuous monitoring is not appropriate because small short-term spikes in mercury emissions would not cause significant adverse environmental impacts.
- **Designed for vapor phase mercury only**
    - Method 30B and CMMs are designed for the measurement of vapor phase mercury only.
- **Susceptible to interference**
    - CMMs are susceptible to interference from gas emission constituents that are common to the industry such as SO_2, NO_X, and water vapor.
    - Sorbent tube measurements can be adversely impacted by stack gas moisture which is typically near the saturation point in most taconite facilities’ waste gas.
- **Reliability at low concentrations**
    - CMMs are not well suited to measuring trace/low mercury concentrations. Although CMMs are available with low detection limits (i.e. 0.05 µg mercury per cubic meter), emission measurement professionals recommend other measurement approaches, such as periodic performance testing, at the expected mercury concentrations (<1 µg mercury per cubic meter).
- **Reference method and calibration techniques**
    - If EPA Procedure 5 (Reference (62)) is used, it is possible that the quality control criteria could allow the monitor to differ from the actual emissions value by a large margin of error that could impact data accuracy at the expected low-level concentrations.
- **Cost prohibitive**
    - The capital investment costs are high, especially at facilities with more than one stack.

- CMMs are challenging to install and operate and require knowledgeable on-site staff for calibrations, maintenance, sample analysis, etc.

The cost for periodic performance testing is much less than the initial investment and operating costs for a sorbent tube system or CMM. An outside contractor would still be required for one mobilization per year to conduct a Relative Accuracy Test Audit (RATA).

6.6 AMERP Enforceability (MPCA Form item 8)

The elements of the reduction plan will be included in your air emissions permit. If a permit amendment is needed in order to install or implement the control plan, please explain.

Keetac does not need to submit a permit application to make the scrubbers solids removal enforceable because this is already an existing permit requirement. The proposed schedule for the literature review and/or vendor screening (refer to Table 6-3) is dependent on the MPCA's approval of this AMERP pursuant to Minn. R. 7007.0502, subp. 4(B). Should the MPCA be delayed in the decision making process, the proposed dates may need to be changed. In addition, U. S. Steel proposes to enter into an enforceable compliance agreement to meet the proposed literature review and/or vendor screening and associated deadlines described in Section 6.3.

7 References

1. **Stantec Consulting Ltd.** Evaluation of Mercury Control Options - Taconite Industry. Regina, Saskatchewan , Canada : s.n., August 14, 2012.

2. **Minnesota Pollution Control Agency.** Minnesota Statewide Mercury Total Maximum Daily Load. March 27, 2007.

3. —. Implementation Plan for Minnesota's Statewide Mercury Total Maximum Daily Load. October 2009.

4. —. Statewide Mercury TMDL emission inventory for Minnesota (pounds per year). St. Paul, MN : Minnesota Pollution Control Agency, September 2017.

5. —. Mercury speciation profiles. Personal communication, email from Minnesota Pollution Control Agency staff to Barr Engineering Company. October 11, 2006.

6. **Florida Department of Environmental Protection - Division of Environmental Assessment and Remediation.** Mercury TMDL for the State of Florida. Final Report. October 24, 2013.

7. **Butler, T., et al.** Mercury in the environment and patterns of mercury deposition from NADP/MDN Mercury Deposition Network. Final Report. January 2007.

8. *Contributions of global and regional sources to mercury deposition in New York State.* **Seigneur, C., et al.** 2003, Environmental Pollution, Vol. 123, pp. 365-373.

9. *Modeling atmospheric mercury deposition in the vicinity of power plants.* **Seigneur, C., Jansen, J. and Levin, L.** 2006, Journal of the Air & Waste Management Association, Vol. 56, pp. 743-751.

10. **United Nations Environment Programme/Artic Monitoring and Assessment Programme.** Technical Background Report for the Global Mercury Assessment. 2013.

11. **Swain, Edward B., et al.** Socioeconomic Consequences of Mercury Use and Pollution. s.l. : Royal Swedish Academy of Sciences, February 2007. Vol. 36, 1.

12. **Minnesota Pollution Control Agency.** Sources of mercury pollution and the methylmercury contamination of fish in Minnesota. 2013.

13. **Rae, Douglas.** Impact of Mercury Reductions in Minnesota. September 1997.

14. **Barr Engineering Co.** Keetac Facility Mercury Mass Balance. Duluth, MN : Barr Engineering Co., August 21, 2018.

15. **Global Coal Sales Group, LLC.** 2016 Typical Coal Quality. [Online] 2016. http://globalcoalsales.com/wp-content/uploads/2016/09/2016-Typical-Coal-Quality.pdf.

16. **Jiang, Hongming, Arkley, Stuart and Wickman, Trent.** Mercury Emissions from Induration of Taconite Concentrate Pellets – Stack Testing Results from Facilities in Minnesota. 2000.

17. **Barr Engineering Co.** Results of the April 5, 2017 Mercuy and Lead Emissions Tests at the U.S. Steel Corporation - Keetac Agglomerator Facility Located in Keewatin Minnesota. Minneapolis : s.n., 2017.

18. **Laudal, Dennis L. and Dunham, Grant E.** Mercury control technologies for the taconite industry. Grand Forks, ND : Energy & Environmental Research Center, June 2007.

19. **Berndt, Michael E., Engesser, John and Johnson, Andrea.** On the distribution of mercury in taconite plant scrubber systems. St. Paul, MN : Minnesota Department of Natural Resources. Division of Lands and Minerals, October 15, 2003.

20. **Minnesota Pollution Control Agency.** Air Emission Permit No. 13700063-003. 2005.

21. **Berndt, Michael E. and Engesser, John.** Mercury Transport in Taconite Processing Facilities: (III) Control Method Test Results. St. Paul, MN : Minnesota Department of Natural Resources. Division of Lands and Minerals, December 31, 2007.

22. **Berndt, Michael E.** On the Measurement of Stack Emissions at Taconite Processing Plants. St. Paul, MN : Minnesota Department of Natural Resources. Division of Lands and Minerals, May 30, 2008.

23. —. A Brief Summary of Hg Control Test Results for Br Injection into Taconite Induration Furnaces. St. Paul, MN : Minnesota Department of Natural Resources, April 10, 2011.

24. **Barr Engineering Co.** Minntac Line 6 Halide Injection Testing June - August 2018. Duluth : s.n., 2018.

25. **Zhuang, Ye, Dunham, David J. and Pavlish, John H.** Assessment of potential corrosion induced by bromine species used for mercury reduction in a taconite facility. Grand Forks, ND : Energy & Environmental Research Center, August 2009.

26. **Berndt, Michael and Engesser, John.** Mercury Transport in Taconite Processing Facilities: (I) Release and Capture During Induration. St. Paul, MN : Minnesota Department of Natural Resources. Division of Lands and Minerals, August 15, 2005.

27. **Zhuang, Ye, Dunham, David J. and Pavlish, John H.** Continuation of corrosion potential of bromide injection under taconite operating conditions. Grand Forks, ND : Energy & Environmental Research Center, March 2012.

28. **Benson, Steven A., et al.** Evaluation of Scrubber Additives and Carbon Injection to Increase Mercury Capture. Grand Forks, ND : University of North Dakota Institute for Energy Studies, August 17, 2012.

29. **Berndt, Mike.** Data from previous mercury reduction research. Email communication to Ryan Siats, Barr Engineering Co. September 15, 2016.

30. **Pavlish, J. H. and Zhuang, Y.** Proof-of-concept Testing of Novel Mercury Control Technology for a Minnesota Taconite Plant. Final Report. July 2008.

31. **Benson, Steven A., et al.** Phase two final report. Grand Forks, ND : University of North Dakota. Institute for Energy Studies, July 26, 2012.

32. **Berndt, Michael.** Minnesota Taconite Mercury Control Advisory Committee: Summary of Phase One Research Results (2010 - 2012). St. Paul, Minnesota : s.n., November 29, 2012.

33. **Miller, J., et al.** Mercury Control for Taconite Plants Using Gas-Phase Brominated Sorbents. Final Report. s.l. : Albemarle Environmental Division, July 9, 2012.

34. **Bowell, Kyle, et al.** Minnesota taconite Phase II research - evaluation of carbon injection to increase mercury capture. U.S. Steel, Keetac. Final Report. Prepared for Iron Mining Association of Minnesota. Highlands Ranch, CO : ADA-ES, Inc., May 16, 2013.

35. **Laudal, Dennis L.** Evaluation of a Slipstream Baghouse for the Taconite Industry. Revised Final Report. Grand Forks, ND : University of North Dakota Energy & Environmental Research Center, January 2012.

36. **Dunham, Grant E. and Miller, Stanley J.** Demonstration of Mercury Capture in a Fixed Bed. Draft Final Report. Grand Forks, ND : University of North Dakota Energy & Environmental Research Center, June 2009.

37. **Schlager, Richard, Amrhein, Jerry and Bowell, Kyle.** Developing Cost-Effective Solutions to Reduce Mercury Emissions from Minnesota Taconite Plants. United Taconite Plant. Highlands Ranch, CO : ADA Environmental Solutions, September 2012.

38. **Barr Engineering Co.** Minnesota Taconite Mercury Reduction Research. GORE(TM) Demonstrations Summary Report. Duluth, MN : Barr Engineering Co., September 24, 2015.

39. —. Summary of emissions speciation change on potential mercury loading to northeast Minnesota. Minneapolis : s.n., 2018.

40. **Florida Department of Environmental Protection.** Integrating atmospheric mercury deposition with aquatic cycling in South Florida: An approach for conducting a Total Maximum Daily Load analysis for an atmospherically derived pollutant. November 2003.

41. **Evers, D.C., et al.** Biological mercury hotspots in the northeastern United States and southeastern Canada. BioScience. 2007. pp. 29-43, 57.

42. *Reducing mercury in the northeast United States.* **King, S, S Hochbrunn, P Miller, J. Graham, T Goldberg, A Wienert, and M Wilcox.** May 2008, Air & Waste Mangement, pp. 9-13.

43. **Barr Engineering Co.** Results of the May 7, 8, and 29, 2013 Title V and MACT Tests Performed at the U. S. Steel Corporation - Keetac Pellet Plan Located in Keewatin, Minnesota. Minneapolis : s.n., 2013.

44. —. Results of the March 30 through May 19, 2017 MACT and Title V Performance Tests at the U. S. Steel Corporation - Keetac Faclities Located in Keewatin, Minnesota. Minneapolis : s.n., 2017.

45. —. Results of the August 6 - 26, 2013 Particulate Matter, Hydrogen Bromide and Bromine Emissions Engineering Tests Performed During the Phase II Mercury Reduction Study at U. S. Steel Corporation - Keetac Located in Keewatin Minnesota. Minneapolis : s.n., 2014.

46. **Berndt, Michael E.** Review of Phase II Hg Control Reports. Letter to Hongming Jiang, Pollution Control Agency. St. Paul, MN : Minnesota Department of Natural Resources, October 31, 2014.

47. **U.S. Environmental Protection Agency.** National Emission Standards for Hazardous Air Pollutants: Mercury Emissions From Mercury Cell Chlor-Alkali Plants (proposed rule, to be codified at 40 CFR Part 63). *Federal Register.* March 14, 2011. Vol. 76, 49, p. 13862. EPA–HQ–OAR–2002–0017.

48. —. National Emissions Standards for Hazardous Air Pollutants: Ferroalloys Production (final rule, to be codified at 40 CFR Part 63). *Federal Register.* June 30, 2015. Vol. 80, 125, p. 37384. EPA–HQ–OAR–2010–0895.

49. —. National Emission Standards for Hazardous Air Pollutants: Gold Mine Ore Processing and Production Area Source Category and Addition to Source Category List for Standards (proposed rule, to be codified at 40 CFR Parts 9 and 63). *Federal Register.* April 28, 2010. Vol. 75, 81, p. 22483. EPA–HQ–OAR–2010–0239.

50. —. National Emission Standards for Hazardous Air Pollutants for the Portland Cement Manufacturing Industry and Standards of Performance for Portland Cement Plants (proposed rule, to be codified at 40 CFR Parts 60 and 63). *Federal Register.* July 18, 2012. Vol. 77, 138, p. 42373. EPA–HQ–OAR–2011–0817.

51. —. National Emission Standards for Hazardous Air Pollutants: Mercury Emissions From Mercury Cell Chlor-Alkali Plants (proposed rule, to be codified at 40 CFR Part 63). March 14, 2011. Vol. 76, 49, p. 13858. EPA–HQ–OAR–2002–0017.

52. —. Emission Reduction Costs for BTF Hg Rate for Existing EGUs Designed to Burn Low Rank Virgin Coal. *National Emission Standards for Hazardous Air Pollutants for Coal- and Oil-fired Electric Utility Steam Generating Units, Supporting Documents.* December 21, 2011. p. 4. EPA-HQ-OAR-2009-0234.

53. —. NESHAP for Brick and Structural Clay Products Manufacturing; and NESHAP for Clay Ceramics Manufacturing (proposed rule, to be codified at 40 CFR Part 63). *Federal Register.* December 18, 2014. Vol. 79, 243, p. 75638. EPA–HQ–OAR–2013–0290 and EPA–HQ–OAR-2013-0291.

54. —. National Emission Standards for Hazardous Air Pollutants: Taconite Iron Ore Processing (final rule, to be codified at 40 CFR Part 63). *Federal Register.* October 30, 2003. Vol. 68, 210, p. 61880. OAR 2002–0039.

55. —. NESHAP Beyond the MACT Floor Beyond the Floor Analysis for Revised Emission Standards for New Source Coal-and Oil fired Electric Utility Steam Generating Units. *National Emission Standards for Hazardous Air Pollutants for Coal- and Oil-fired Electric Utility Steam Generating Units, Supporting Documents.* April 2, 2013. p. 4. EPA-HQ-OAR-2009-0234.

56. —. Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Sewage Sludge Incineration Units (final rule, to be codified at 40 CFR Part 60). *Federal Register.* March 21, 2011. Vol. 76, 54, p. 15394. EPA–HQ–OAR–2009–0559.

57. —. National Emission Standards for Hazardous Air Pollutants From the Portland Cement Manufacturing Industry (proposed rule, to be codified at 40 CFR Parts 60 and 63). *Federal Register.* May 6, 2009. Vol. 74, 86, p. 21149. EPA–HQ–OAR–2002–0051.

58. —. EPA Air Pollution Control Cost Manual, Sixth Edition. [Online] January 2002. https://www3.epa.gov/ttn/ecas/docs/c_allchs.pdf. EPA/452/B-02-001.

59. —. EPA Air Pollution Control Cost Manual, Section 1, Chapter 2. *Cost Estimation: Concepts and Methodology.* 2017.

60. **Barr Engineering Co.** Keetac BART Report. 2006.

61. **International, AACE.** Cost Estimate Classification System - As Applied in Enginering, Procurement, and Construction for the Process Industries. 2005. Vols. AACE International Recommended Practice No. 18R-97.

62. **U.S. Environmental Protection Agency.** Procedure 5: Quality Assurance Requirements For Vapor Phase Mercury Continuous Emissions Monitoring Systems And Sorbent Trap Monitoring Systems Used For Compliance Determination At Stationary Sources. August 7, 2017.

Appendices

Appendix A

MPCA Form: Mercury Reduction Plan Submittal (Ferrous Mining/Processing)

aq-ei2-04a

MINNESOTA POLLUTION CONTROL AGENCY
520 Lafayette Road North
St. Paul, MN 55155-4194

Mercury Reduction Plan submittal (Ferrous mining/processing)

Air Quality Permit Program
Minn. R. 7007.0502, subp. 3

Doc Type: Regulated Party Response

Instructions:

- Complete this form to meet the Mercury Reduction Plan requirements for owners and operators of ferrous mining or processing facilities subject to Minn. R. 7007.0502, subp. 3.
- Attach any additional explanatory information, for example, editable spreadsheets with calculations, stack test reports, engineering or design reports, and any other information supporting your reduction plan. Data that is considered to be confidential information must follow the procedures described in item 9 of this form.
- This reduction plan must be approved by the Minnesota Pollution Control Agency (MPCA) prior to submittal of a permit amendment application or development of an enforceable document. It is not a substitution for a permit amendment application.
- **Please submit form to:** Statewide Mercury Total Maximum Daily Load (TMDL) Coordinator, Hassan Bouchareb, Minnesota Pollution Control Agency, 520 Lafayette Road North, St. Paul, Minnesota 55155.

Mercury Reduction Plan

The goal of the Mercury TMDL is to reduce statewide mercury air emissions to 789 pounds per year. To achieve this goal, the MPCA undertook rulemaking and adopted rules regarding mercury reduction plans in Minn. R. 7007.0502. These rules established a mercury emission reduction, for ferrous mining or processing, of 72% from the amount of mercury emitted in 2008 or 2010. As stated in the Mercury TMDL Implementation Plan and reiterated in the MPCA's Response to Comments for the rulemaking, "*The technology developed to achieve the target must be technically and economically feasible, it must not impair pellet quality, and it must not cause excessive corrosion to pellet furnaces and associated ducting and emission-control equipment. Criteria for determining economic feasibility will be developed through a collaborative effort by the taconite industry and the MPCA.*"

Minn. R. 7007.0502 requires the owners or operators of a ferrous mining or processing facility to prepare a mercury reduction plan that addresses reductions for each indurating furnace or kiln of a taconite processing facility or the rotary hearth furnace of a direct-reduced iron facility. The reduction plan may accomplish reductions at each furnace, across all furnaces at a single stationary source, or across furnaces at multiple stationary sources. The mercury reduction plan submittal and compliance deadlines are shown in the table below.

Mercury Reduction Plan submittal and compliance deadlines

Type of source	Mercury Reduction Plan submittal deadline	Compliance deadline
Ferrous mining or processing	December 30, 2018	January 1, 2025

1. Facility information

1.a. Facility name: **U. S. Steel, Keetac**

1.b. AQ facility ID number: **13700063**

1.c. Facility contact for this reduction plan: **Ms. Chrissy L. Bartovich**

1.d. Agency Interest ID number: **142828**

1.e. Facility contact email address: **clbartovich@uss.com**

1.f. Facility contact phone number: **218-749-7364**

2. Determination of technically achievable

Has the facility determined that the reductions listed in Minn. R. 7007.0502, subp. 6, are technically achievable by the January 1, 2025, compliance date?

☐ Yes Skip item 3. Go to item 4.

☒ No Proceed to item 3.

3. Proposal of alternative reduction

If the owner or operator determines that the mercury reductions listed in Minn. R. 7007.0502, subp. 6 are not technically achievable by the identified compliance date; an alternative plan may be submitted under Minn. R. 7007.0502, subp. 5(A)(2). If you are proposing an alternative plan to reduce mercury emissions, please complete the following:

a) Complete Steps 1 through 6 below:

Step 1. Identify all available technologies and rank in descending order of control effectiveness.

One reduction technology, mercury capture by existing wet scrubber with solids removal did not reduce emissions by 72% but still satisifed the other adaptive management and environmental impacts criteria. The associated control effectiveness is as follows:

(1) Mercury capture by existing wet scrubbers with solids removal = 30% Total Mercury Control Efficiency

This technology proceeds to Step 2.

Refer to Section 5.1 of the Alternative Mercury Emissions Reduction Plan for more information.

Step 2. Eliminate technically infeasible technologies.

Include references and citations supporting the basis for the determination that the reductions are not technically achievable by the compliance date. If the mercury reductions are not technically achievable based solely or partly on economic factors, include references and citations supporting the basis for the determination that the reductions are not economically feasible.

The reduction technology is technically feasible. Mercury capture by existing wet scrubbers with solids removal proceeds to Step 3.

Refer to Section 5.2 of the Alternative Mercury Emissions Reduction Plan for more information.

Step 3. Rank remaining technologies in descending order of control effectiveness.

Ranking in Step 3 is not necessary because there is only one reduction technology being considered.

Refer to Section 5.3 of the Alternative Mercury Emissions Reduction Plan for more information.

Step 4. Complete an environmental impacts analysis.

Provide an analysis of environmental impacts. Focus on impacts other than direct impacts due to emissions of mercury, such as solid or hazardous waste generation, discharges of polluted water from a control device, demand on local water resources, and emissions of other regulated air pollutants.

The reduction technology does not impose unacceptable environmental impacts. The technology proceeds to Step 5.

Refer to Section 5.4 of the Alternative Mercury Emissions Reduction Plan for more information.

Step 5. Complete a cost effectiveness evaluation.

Calculate the cost effectiveness of each control technology (in dollars per pound of mercury emissions reduced). This cost effectiveness must address both an average basis for each measure and combination of measures. If multi-pollutant control strategies were considered that have implications on cost, such as the control technology also reducing emissions of other regulated air pollutants, please provide that information as well. The costs associated with direct energy impacts should be calculated and included in the cost analysis. Direct energy consumption impacts include the consumption of fuel and the consumption of electrical or thermal energy. The emphasis of this analysis is on the cost of control relative to the amount of pollutant removed, rather than economic parameters that provide an indication of the general affordability of the control alternative relative to the source.

Mercury capture by existing wet scrubbers with solids removal is considered cost effective because Keetac already has the equipment installed to remove the

scrubbers solids from the process. This technology proceeds Step 6.

Refer to Section 5.5 of the Alternative Mercury Emissions Reduction Plan for more information.

Step 6. Of the remaining technologies, propose the best-performing control strategy. Describe the selection of the control strategy.

Keetac determined 30% mercury emissions reductions are technically achievable using mercury capture by existing wet scrubbers with solids removal.

Refer to Section 5.6 of the Alternative Mercury Emissions Reduction Plan for more information.

b) Provide an estimate of the annual mass of mercury emitted under the requirements of Minn. R. 7007.0502, subp. 6.

Keetac's baseline emissions = 134 lb Hg/yr

Refer to Section 3 and Section 6.1 of the Alternative Mercury Emissions Reduction Plan for more information.

c) Provide an estimate of the annual mass of mercury emitted and percent reduction achieved under the proposed alternative plan.

Estimated Emissions (Percent Reduction %):

NA - baseline already accounts for reduction from mercury capture by existing wet scrubber with solids removal

Keetac has been utilizing this mercury reduction technology since 2005 and estimates emissions are reduced by 30%.

Refer to Section 6.1 of the Alternative Mercury Emissions Reduction Plan for more information.

d) Complete the information in items 4 through 9 for your alternative proposal.

4. Description of mercury reduction action

Complete the following table for each emission unit that emits mercury. Use a separate row for each specific control, process, material or work practice that will be employed to achieve the applicable control efficiencies, reductions or allowable emissions. Provide a written summary below as needed for context or background. Minn. R. 7007.0502, subp. 5(A)(1)(a), 5(A)(1)(b), or 5(A)(2)(a).

Emission unit	Element to reduce mercury (control device, work practice, etc.)	Reduction, control efficiency, emission limit, operating limit, or work practice* (indicate units, i.e., lb. hg/ton material, % control)	Describe element in detail (include manufacturer's data** as applicable)
EU 030	**Mercury capture by existing wet scrubber with solids removal**	**Work Practice of mercury capture by existing wet scrubber with solids removal.** **(Refer to Table 4-6 for basis of 30% mercury control target)**	**See Section 4.1.3 for element details.**
EU 030	**Literature Review and/or vendor screening with BAMRT analysis, as needed**	**TBD**	**See Section 6.2.1 for element details.**
Refer to Section 6.2 of the Alternative Mercury Emissions Reduction Plan for more information.			

*The permit or enforceable document will include the proposed control efficiency, emission limits, or other requirements that achieve the reduction.
**Attach manufacturer's information and other resources used to document the reduction

Written description:

Refer to Section 6.2 of the Alternative Mercury Emissions Reduction Plan for more information.

5. Schedule

For each reduction element (specific control, process, material or work practice) described in Item 4 that will be employed as part of the mercury reduction plan, complete the following table. *To create a new row, place your cursor in the last column of the last row, hit tab.*

Emission unit	Reduction element	Anticipated element construction/installation date (mm/dd/yyyy)	Anticipated startup date (mm/dd/yyyy)	Anticipated date for demonstrating reduction target (mm/dd/yyyy)	Date reduction needs to be met (mm/dd/yyyy)	Anticipated date of permit application submittal (if necessary) (mm/dd/yyyy)
EU 030	**Mercury capture by existing wet scrubber with solids removal**	**N/A – Already in place at Keetac.**				
EU 030	**Literature Review and/or vendor screening with BAMRT analysis, as needed**	**U. S. Steel will conduct a literature review and/or vendor screening between May 1, 2020 and July 31, 2020. U. S. Steel will revise and resubmit the AMERP if necessary or notify the MPCA that the review has been completed by no later than June 1, 2022.**				
Refer to Section 6.3 of the Alternative Mercury Emissions Reduction Plan for more information.						

6. Calculation data

Include all mercury emission calculations for each emissions unit listed in item 4 in an editable electronic spreadsheet. Provide calculations showing the mercury reduction, control efficiency, or emission rate that each emissions unit will achieve once the plan for that emissions unit is fully implemented.

6a. Emission factors

Identify the emission factors and sources of the emission factors used to determine mercury emissions in item 3 in the following table. Please include the rationale behind your decision. Minn. R. 7007.0502, subp. 5(A)(1)(b) or Minn. R. 7007.0502, subp. 5(A)(2)(d). *To create a new row, place your cursor in the last column of the last row, hit tab.*

Emission unit	Emission factors for current mercury emissions rate, if applicable	Source of emission factor	Target emission rate	Source of emission factors for target emission rate
EU 030	**1.98E-05 lb Hg / long ton of pellets**	**2017 Method 29 Emission Test**	**134 lb/yr**	**2017 Method 29 Emission Test**
Refer to Section 6.4.1 of the Alternative Mercury Emissions Reduction Plan for more information.				

7. Operation, monitoring, and recordkeeping plan

7a. Operation and optimization plan

For each control device used to achieve the overall mercury reduction of the plan, describe how you will operate the control system such that mercury reductions are maintained. Explain how an operator might adjust the control system at the facility. Describe system alarms or safeguards to ensure optimal operation of the mercury control system. Optimization also includes training of individuals responsible for operating the control system, and the development and upkeep of operation and maintenance manuals. The MPCA is not requesting that such programs or manuals be included here, rather that they are summarized. Discuss potential variability of mercury emissions and how operations will be monitored to address variability. Minn. R. 7007.0502, subp. 5(A)(1)(c) or Minn. R. 7007.0502, subp. 5(A)(2)(c).

Mercury capture by wet scrubbers and solids removal is the current practice at the Facility. The mercury reductions are maintained because the Facility must remove scrubbers solids from its process by permit condition. In the event of an upset, the scrubbers solids would be routed to the basin. Therefore, there is no opportunity to optimize or improve the operation of the existing mercury control technology.

Refer to Section 6.5.1 of the Alternative Mercury Emissions Reduction Plan for more information.

7b. Proposed monitoring and recordkeeping

For each reduction element (specific control equipment, emission limit, operating limit, material or work practice), describe monitoring to provide a reasonable assurance of continuous control of mercury emissions. If the plan includes control equipment, attach MPCA Air Quality Permit Forms GI-05A and CD-05. Minn. R. 7007.0502, subp. 5(A)(1)(d).

Emission Unit	Reduction Element	Reduction, Control Efficiency or Emission Rate (include units)	Operating Parameters	Monitoring Method	Parameter Range (include units, if applicable)	Monitoring Frequency	Proposed Recordkeeping	Discussion of Why Monitoring is Adequate
EU 030	**Mercury capture by existing wet scrubbers with solids removal**	**30% mercury reduction**	**Mercury stack emissions**	**Periodic stack testing**	**N/A**	**Every 5 years**	**Keep stack test reports onsite for 5 years**	**Approach is consistent with Minn. R. 7019.3050(E)(5)**
Refer to Section 6.5.2 of the Alternative Mercury Emissions Reduction Plan for more information.								

Additional Discussion:

N/A

7c. Evaluation of the use of Continuous Emissions Monitoring Systems (CEMS).

Evaluate the use of CEMS for mercury, both the sorbent tube method (U.S. Environmental Protection Agency [EPA] Method 30B) and an extractive “continuous” system. Describe if either method has been used at the mercury emissions source for parametric monitoring or for compliance determination. If CEMS is selected for monitoring of mercury emissions, please include in item 6a above. If it is not selected for monitoring of mercury emissions, please discuss the evaluation of the use of CEMS below:

Method 30B (sorbent tube system) and/or temporary extractive CMMs are appropriate for reduction technology evaluations (periodic stack testing). However, these methods are not appropriate for a full-scale continuous compliance demonstration.

Refer to Section 6.5.3 of the Alternative Mercury Emissions Reduction Plan for more information.

8. Mechanism to make reduction plan enforceable.

The elements of the reduction plan will be included in your air emissions permit. If a permit amendment is needed in order to install or implement the control plan, please explain:

Keetac does not need to submit a permit application to incorporate the AMERP provisions in accordance with the regulatory requirements as scrubbers solids removal is already permitted to operate in this manner. The proposed schedule for the literature review and/or vendor screening (refer to item 5) is dependent on the MPCA’s approval of this AMERP pursuant to Minn. R. 7007.0502, subp. 4(B). Should The MPCA be delayed in the decision making process, the proposed dates may need to be changed. In addition, U. S. Steel proposes to enter into an enforceable compliance agreement to meet the proposed literature review and/or vendor screening and associated deadlines described in item 5.

Refer to Section 6.6 of the Alternative Mercury Emissions Reduction Plan for more information.

9. Additional information

Please provide additional information that will assist in reviewing your Mercury Reduction Plan.

N/A

10. Confidentiality

If your mercury reduction plan submittal includes confidential information, submit two versions of the mercury reduction plan. One version with the confidential information and one public version with the confidential information redacted.

10a. Confidentiality statement

☒ This submittal does not contain material claimed to be confidential under Minn. Stat. §§ 13.37 subd. 1(b) and 116.075. Skip item 10b, go to item 11.

☐ This submittal contains material which is claimed to be confidential under Minn. Stat. §§ 13.37 subd. 1(b) and 116.075. Complete Item 10b. Your submittal must include both Confidential and Public versions of your submittal.

☐ Confidential copy of submittal attached ☐ Public copy of submittal attached

10b. Confidentiality certification

To certify data for the confidential use of the MPCA, a responsible official must read the following, certify to its truth by filling in the signature block in this item, and provide the stated attachments.

☐ I certify that the enclosed submittal(s) and all attachments have been reviewed by me and do contain confidential material. I understand that only specific data can be considered confidential and not the entire submittal. I certify that I have enclosed the following to comply with the proper procedure for confidential material:

- ☐ I have enclosed a statement identifying which data contained in my submittal I consider confidential, and I have explained why I believe the information qualifies for confidential (or non-public) treatment under Minnesota Statutes.
- ☐ I have explained why the data for which I am seeking confidential treatment should not be considered "emissions data" which the MPCA is required to make available to the public under federal law.
- ☐ I have enclosed a submittal containing all pertinent information to allow for review and approval of my submittal. This document has been clearly marked "confidential."
- ☐ I have enclosed a second copy of my submittal with the confidential data blacked out (not omitted or deleted entirely). It is evident from this copy that information was there, but that it is not for public review. This document has been clearly marked "public copy."

Permittee responsible official

Print name: ______

Title: ______ Date ______

Signature: ______

Phone: ______ Fax: ______

Co-permittee responsible official (if applicable)

Print name: ______

Title: ______ Date: ______

Signature: ______

Phone: ______ Fax: ______

11. Submittal certification

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete.

Permittee responsible official

Print name: Lawrence Sutherland

Title: General Manager – Minnesota Ore Date ______

Signature: Wet ink signature page included as hard copy

Phone: 218-749-7592 Fax: 218-749-7293

Co-permittee responsible official (if applicable)

Print name: ______

Title: ______ Date: ______

Signature: ______

Phone: ______ Fax: ______

Appendix B

Historical Mercury Reduction Research Reports

See Appendix B_Keetac BAMRT and AMERP FINAL File

Appendix C

Keetac Mercury Baseline Evaluation

U. S. Steel Corporation, Minnesota Ore Operations - Keetac
Alternative Mercury Emissions Reduction Plan
Appendix C
Baseline Emission Evaluation

Table 1
Barr 2017 Mercury Testing - EPA Method 29

Line	HgT	
	lb/Lton	lb/hr
1	1.98E-05	1.20E-02

[1] HgT = Hg measured in the front half (HgP) and backhalf (HgG) of the EPA Method 29 stack test performed on 4/5/2017.

Table 2
Summary of Annual HgT Emissions From Furnace

Annual Hg Emissions		
Year	Annual Pellet Production Capable of Accommodating	Hg Emission Rate Based on Pellet Production Capable of Accomodating [1]
	Lt/yr	lb/yr
2008	4,945,232	98
2009	4,945,232	98
2010	4,945,232	98
2011	4,847,411	96
2012	5,491,768	109
2013	5,612,207	111
2014	6,036,216	120
2015	6,036,216	120
2016	6,036,216	120
2017	5,795,232	115

[1] A mercury emissions factor in lb Hg / Lton pellet is calculated using stack test data and the pellet throughput data collected during the test. The Hg emissions factor is multiplied by the maximum annual furnace throughput capable of accommodating.

U. S. Steel Corporation, Minnesota Ore Operations - Keetac
Alternative Mercury Emissions Reduction Plan
Appendix C
Pellet Production

Date	Total Pellets (T)	Total Pellets (LT)	2 Year Rolling Max By Month	Max COA Annually
Jan-08	432,153	385,851		
Feb-08	395,414	353,048		
Mar-08	447,241	399,322		
Apr-08	238,298	212,766		
May-08	447,198	399,284		
Jun-08	444,524	396,896		
Jul-08	461,555	412,103		
Aug-08	434,992	388,386		
Sep-08	416,866	372,202		
Oct-08	442,175	394,799		
Nov-08	392,579	350,517		
Dec-08	17,541	15,662	412,103	4,945,232
Jan-09	0	0		
Feb-09	0	0		
Mar-09	0	0		
Apr-09	0	0		
May-09	0	0		
Jun-09	0	0		
Jul-09	0	0		
Aug-09	0	0		
Sep-09	0	0		
Oct-09	0	0		
Nov-09	0	0		
Dec-09	17,608	15,721	412,103	4,945,232
Jan-10	388,307	346,703	412,103	
Feb-10	355,784	317,664	412,103	
Mar-10	413,589	369,276	412,103	
Apr-10	256,787	229,274	412,103	
May-10	403,214	360,013	412,103	
Jun-10	428,598	382,677	412,103	
Jul-10	452,425	403,951	403,951	
Aug-10	436,768	389,971	403,951	
Sep-10	432,274	385,959	403,951	
Oct-10	374,907	334,738	403,951	
Nov-10	438,839	391,821	403,951	
Dec-10	450,102	401,877	403,951	4,945,232
Jan-11	376,635	336,281	403,951	
Feb-11	409,068	365,239	403,951	
Mar-11	444,177	396,587	403,951	
Apr-11	339,183	302,842	403,951	
May-11	318,598	284,463	403,951	
Jun-11	450,580	402,304	403,951	
Jul-11	441,851	394,510	403,951	
Aug-11	443,534	396,013	403,951	
Sep-11	424,527	379,042	403,951	
Oct-11	403,108	359,918	403,951	
Nov-11	443,396	395,889	403,951	
Dec-11	432,349	386,026	403,951	4,847,411
Jan-12	440,350	393,170	403,951	
Feb-12	418,710	373,848	403,951	
Mar-12	452,453	403,976	403,976	

U. S. Steel Corporation, Minnesota Ore Operations - Keetac
Alternative Mercury Emissions Reduction Plan
Appendix C
Pellet Production

Date	Total Pellets (T)	Total Pellets (LT)	2 Year Rolling Max By Month	Max COA Annually
Apr-12	270,699	241,696	403,976	
May-12	451,082	402,752	403,976	
Jun-12	441,123	393,860	403,976	
Jul-12	456,059	407,196	407,196	
Aug-12	457,585	408,558	408,558	
Sep-12	512,565	457,647	457,647	
Oct-12	397,999	355,356	457,647	
Nov-12	435,378	388,730	457,647	
Dec-12	444,686	397,041	457,647	5,491,768
Jan-13	501,122	447,430	457,647	
Feb-13	447,056	399,157	457,647	
Mar-13	488,818	436,445	457,647	
Apr-13	244,158	217,998	457,647	
May-13	474,814	423,941	457,647	
Jun-13	493,198	440,355	457,647	
Jul-13	514,329	459,222	459,222	
Aug-13	514,452	459,332	459,332	
Sep-13	523,806	467,684	467,684	
Oct-13	430,998	384,820	467,684	
Nov-13	497,941	444,590	467,684	
Dec-13	499,091	445,617	467,684	5,612,207
Jan-14	484,186	432,309	467,684	
Feb-14	415,472	370,957	467,684	
Mar-14	472,219	421,624	467,684	
Apr-14	348,305	310,987	467,684	
May-14	408,148	364,418	467,684	
Jun-14	490,340	437,804	467,684	
Jul-14	563,380	503,018	503,018	
Aug-14	552,233	493,065	503,018	
Sep-14	531,047	474,149	503,018	
Oct-14	479,837	428,426	503,018	
Nov-14	513,264	458,271	503,018	
Dec-14	537,391	479,813	503,018	6,036,216
Jan-15	536,829	479,312	503,018	
Feb-15	470,030	419,670	503,018	
Mar-15	516,652	461,296	503,018	
Apr-15	337,473	301,315	503,018	
May-15	0	0	503,018	
Jun-15	0	0	503,018	
Jul-15	0	0	503,018	
Aug-15	0	0	503,018	
Sep-15	0	0	503,018	
Oct-15	0	0	503,018	
Nov-15	0	0	503,018	
Dec-15	0	0	503,018	6,036,216
Jan-16	0	0	503,018	
Feb-16	0	0	503,018	
Mar-16	0	0	503,018	
Apr-16	0	0	503,018	
May-16	0	0	503,018	
Jun-16	0	0	503,018	

U. S. Steel Corporation, Minnesota Ore Operations - Keetac
Alternative Mercury Emissions Reduction Plan
Appendix C
Pellet Production

Date	Total Pellets (T)	Total Pellets (LT)	2 Year Rolling Max By Month	Max COA Annually
Jul-16	0	0	493,065	
Aug-16	0	0	479,813	
Sep-16	0	0	479,813	
Oct-16	0	0	479,813	
Nov-16	0	0	479,813	
Dec-16	0	0	479,312	6,036,216
Jan-17	0	0	461,296	
Feb-17	55,410	49,473	461,296	
Mar-17	449,336	401,193	401,193	
Apr-17	467,719	417,606	417,606	
May-17	517,243	461,824	461,824	
Jun-17	522,458	466,480	466,480	
Jul-17	540,888	482,936	482,936	
Aug-17	530,050	473,259	482,936	
Sep-17	510,085	455,433	482,936	
Oct-17	421,471	376,313	482,936	
Nov-17	523,118	467,070	482,936	
Dec-17	538,318	480,641	482,936	5,795,232

Appendix D

Mercury Reduction Technology Control Cost Evaluation Workbook

Appendix D - BAMRT Mercury Control Cost Effectiveness
U. S. Steel - Keetac
Table 1 - Cost Evaluation Summary

Hg Control Technology Description

Technology Name		**Fixed Carbon Beds**	**GORE**	**ACI with an ESP**
Expected Equipment Life (years)	[1]	20	20	20
Expected Utilization Rate (% of Capacity)	[1]	100%	100%	100%
Expected Annual Hours of Operation (hr/year)	[1]	8,200	8,200	8,200
Notes on Technology				

Control Equipment Costs

Capital Costs				
Direct Capital Costs (DC)	[2]	$51,621,644	$38,499,402	$35,366,623
Indirect Capital Costs (IC)	[2]	$12,395,135	$10,690,882	$10,910,177
Total Capital Investment (TCI = DC + IC)	[2]	$64,016,779	$49,190,285	$46,276,800
Total Capital Investment (TCI = DC + IC) with Retrofit Factor	[2]	$89,662,111	$69,150,369	$64,780,142
Operating Costs				
Direct Operating Costs ($/year)	[3]	$2,490,132	$252,863	$6,347,228
Indirect Operating Costs ($/year)	[3]	$11,397,185	$8,521,257	$8,037,112
Total Annual Cost ($/year)	[4]	$13,887,317	$8,774,120	$14,384,340

This cost estimate most closely resembles a Class 4 estimate, based on the classification system outlined in *AACE International Recommended Practice No. 18R-97* [5]

Hg Emission Controls

Baseline Hg Emission Rate (lb/year)	[6]	120

Hg Control Efficiency (mass%)	[7]	99.00%	72.90%	80.00%
Controlled Hg Emission Rate (lb Hg/year)	[8]	1.20	32.52	24.00
Hg Mass Removed from Exhaust (lb Hg/year)	[9]	118.80	87.48	96.00
Hg Control Cost Effectiveness ($/lb Hg removed)	[10]	$116,897	$100,299	$149,837

Appendix D - BAMRT Mercury Control Cost Effectiveness

U. S. Steel - Keetac

Table 1 - Cost Evaluation Summary

Footnotes

[1] Documentation of technology parameters noted

Parameter	*Documentation of Parameter*		
Expected Equipment Life	Assumed	Assumed	Assumed
Expected Utilization Rate	Assumed	Assumed	Assumed
Expected Hours of Operation	Keetac estimate of annual operating hours of furnace	Keetac estimate of annual operating hours of furnace	Keetac estimate of annual operating hours of furnace

[2] See Table 2 - Capital Costs

[3] See Table 3 - Operating Costs

[4] Total Annual Cost = Direct Operating Costs + Indirect Operating Costs

[5] Class 4 Estimate: Study or Feasibility with -30%/+50% accuracy range according to *AACE International Recommended Practice No. 18R-97, TCM Framework: 7.3 - Cost Estimating and Budgeting, 2005* .

[6] Site-specific baseline emission rate. Refer to Section 3.0 of the Alternative Mercury Emissions Reduction Plan for Details.

[7]

Documentation of Hg Control Efficiency for each control technology.	Vendor stated that they typically guarantee >99% control. This is consistent with most sources which cite 99% control or higher.	GORE testing at U. S. Steel Minntac indicated that a 72% reduction per the rule may be achievable. Keetac will assume that this technology can reduce mercury emissions by 72.9%, per vendor guidance.	*US Steel MOO Line #6 Dry Off-Gas System FEL-2 Study* designed for brominated PAC injection of 80% control at U. S. Steel Minntac.

[8] Controlled Hg Emission Rate = (1 - Hg Control Efficiency) * Baseline Hg Emissions

[9] Hg Mass Removed from Exhaust = Baseline Hg Emissions - Controlled Hg Emission Rate

[10] Hg Control Cost Effectiveness = Total Annual Cost / Hg Mass Removed from Exhaust

Appendix D - BAMRT Mercury Control Cost Effectiveness
U. S. Steel - Keetac
Table 2 - Capital Costs

Hg Control Technology Description

Technology Name	**Fixed Carbon Beds**	**GORE**	**ACI with an ESP**
Expected Equipment Life (years)	20	20	20
Notes on Technology			

Current Chemical Engineering Plant Cost Index (CEPCI)	572.9	572.9	572.9
CEPCI of Equipment Cost Estimate Year	N/A	536.4	585.7
Direct Capital Costs (DC)	**$51,621,644**	**$38,499,402**	**$35,366,623**

Purchased Equipment Costs				
Equipment Costs	[1]	$14,125,510	$15,124,149	$10,917,000
Instrumentation	[2]	$1,412,551	$1,512,415	$1,091,700
Sales Tax	[3]	$971,129	$1,039,785	$750,544
Freight	[4]	$706,275	$756,207	$545,850
Generalized Installation Costs				
Basis for Installation Costs	[5] [6]	Fabric Filter	Carbon Adsorber System	Electrostatic Precipitator
Foundations and Supports	[5]	$688,619	$1,474,604	$532,204
Handling & Erection	[5]	$8,607,732	$2,580,558	$6,652,547
Electrical	[5]	$1,377,237	$737,302	$1,064,408
Piping	[5]	$172,155	$368,651	$133,051
Insulation	[5]	$1,205,083	$184,326	$266,102
Painting	[5]	$688,619	$184,326	$266,102
Site-Specific Installation Costs				
Site Preparation (Grade & Level)	[13]	$214,000	$128,000	$139,000
Ductwork	[13]	$6,342,619	$1,292,763	$3,339,000
Buildings	[13]	$2,384,000	$746,200	$399,000
Initial Carbon Charge	[13]	$3,456,000	N/A	N/A
GORE Wastewater Treatment	[13]	N/A	$3,100,000	N/A
Lost Production During Installation	[13]	$9,270,116	$9,270,116	$9,270,116
Extended Downtime Days for Tie-in and Restart	[13]	14	14	14

Indirect Capital Costs (IC)		**$12,395,135**	**$10,690,882**	**$10,910,177**
Basis for Installation Costs	[5] [6]	Fabric Filter	Carbon Adsorber System	Electrostatic Precipitator
Engineering & Supervision	[5]	$1,721,546	$1,843,256	$2,661,019
Construction & Field Expenses	[5]	$3,443,093	$921,628	$2,661,019
Contractor Fees	[5]	$1,721,546	$1,843,256	$1,330,509
Start-Up Costs	[5]	$172,155	$368,651	$133,051
Performance Test	[5]	$172,155	$184,326	$133,051
Contingency	[5]	$5,164,639	$5,529,767	$3,991,528
Contingency Percentage - Site-Specific	[5]	30%	30%	30%

Retrofit Factor	[7]	1.50	1.50	1.50
Total Capital Investment (TCI)	[7]	**$64,016,779**	**$49,190,285**	**$46,276,800**
Total Capital Investment (TCI) with Retrofit Factor	[7]	**$89,662,111**	**$69,150,369**	**$64,780,142**

Capital Recovery

Interest Rate	[8]	7.0%	7.0%	7.0%
Expected Equipment Life		20	20	20
Capital Recovery Factor (CRF)	[9]	9.44%	9.44%	9.44%
Cost of Replacement Parts	[10]	$4,497,678	$8,452,600	
Adjusted TCI for Capital Recovery	[11]	$85,164,432	$60,697,769	$64,780,142
Capital Recovery Cost (CRC)	[12]	$8,038,920	$5,729,440	$6,114,787

Footnotes

[1]

Documentation of Capital Cost for Hg control technology.	Vendor estimate for fixed bed equipment and baghouse. Fan costs were scaled using *Chemical Engineering Economics* , by Donald E, Garrett, Appendix 1 page 281 from a recent vendor quote. Included ACI system price, scaled for injection rate using the 0.6 power law, for dry sorbent injection system. Also includes cost of a new stack. Compressor cost provided by vendor.	Vendor quote provided for GORE capital. Fan costs were scaled using *Chemical Engineering Economics* , by Donald E, Garrett, Appendix 1 page 281 from a recent vendor quote. Also includes cost of a new stack.	Vendor quote for new ESPs, fans, motors, activated carbon injection system, and lime injection system.

[2] Per *EPA Air Pollution Control Cost Manual,* 6th edition, 2002. Section 1, Chapter 2, Table 2.4. Instrumentation ranges between 5% and 30% of the quoted Equipment Cost, with a typical value of 10%.

[3] MN sales tax is 6.875% of sale price, applied to the Equipment Costs (MN Department of Revenue, 4/25/2018).

[4] Per *EPA Air Pollution Control Cost Manual,* 6th edition, 2002. Section 1, Chapter 2, Table 2.4. Freight ranges between 1% and 10% of the quoted Equipment Cost, with a typical value of 5%.

[5] Per *EPA Air Pollution Control Cost Manual,* 6th edition, 2002, various chapters for each control technology.

Capital Cost Factors for Specific Control Equipment Factor applied to Purchased Equipment Cost	**Carbon Adsorber System**	**Fabric Filter**	**Venturi Scrubber**	**Electrostatic Precipitator**
Direct Installation Costs				
Foundations & Supports	0.08	0.04	0.06	0.04
Handling & Erection	0.14	0.50	0.40	0.50
Electrical	0.04	0.08	0.01	0.08
Piping	0.02	0.01	0.05	0.01
Insulation	0.01	0.07	0.03	0.02
Painting	0.01	0.04	0.01	0.02
Indirect Installation Costs				
Engineering	0.10	0.10	0.10	0.20
Construction & Field Expenses	0.05	0.20	0.10	0.20
Contractor Fees	0.10	0.10	0.10	0.10
Start-Up	0.02	0.01	0.01	0.01
Performance Test	0.01	0.01	0.01	0.01
Contingency determined by U. S. Steel due to the uncertainty and preliminary design of the proposed installation				

[6]

Documentation of reason for selecting the control technology's Capital Cost Factors from table in Footnote [5].	Technology is a carbon adsorber, but requires a baghouse/fabric filter for enhanced particulate control prior to the fixed carbon beds.	GORE functions similar to a carbon adsorber system, so it was assumed that these factors would provide the most appropriate installation cost factor basis.	Technology is an electrostatic precipitator.

[7] Total Capital Investment (TCI) = Direct Capital Costs (DC) + Indirect Capital Costs (IC). U. S. Steel included a retrofit factor to account for significant space and installation constraints.

[8] Standard interest rate specified by the U.S. Office of Management and Budget (OMB).

[9] Per *EPA Air Pollution Control Cost Manual,* 6th edition, 2002. Section 1, Chapter 2, Equation 2.8a.

$$CRF = \left(\frac{i \times (1+i)^n}{(1+i)^n - 1}\right)$$

Where: i = interest rate
n = number of years

[10] See 'Table 4 - Replacement Parts ' for details.

[11] Adjusted TCI for Capital Recovery = TCI - Capital Cost of Replacement Parts

[12] Per *EPA Air Pollution Control Cost Manual,* 6th edition, 2002. Section 1, Chapter 2, Equation 2.8.

$$CRC = NPV \times CRF$$

In this case, the Net Present Value (NPV) factor is replaced with the TCI for the Hg control technology.

[13] Documentation of other items which should be included in the capital cost, but may not be covered by the Purchased Equipment Costs, Generalized Installation Costs, or Indirect Capital Costs.

Parameter	*Documentation of Parameter*		
Site Preparation (Grade & Level)	Site-specific engineering estimate	Site-specific engineering estimate	Site-specific engineering estimate
Ductwork	Site-specific engineering estimate	Site-specific engineering estimate	Site-specific engineering estimate
Buildings	Site-specific engineering estimate	Site-specific engineering estimate	Site-specific engineering estimate
Initial Carbon Charge	Initial carbon loading cost provided by vendor	N/A	N/A
GORE Wastewater Treatment	N/A	Design and cost estimate for treatment of the GORE effluent is an engineering estimate based on previous project experience. Value is installed capital cost.	N/A
Lost Production During Installation	Lost production for extended downtime to install new retrofit equipment. Based on production rates and publically available financial data.	Lost production for extended downtime to install new retrofit equipment. Based on production rates and publically available financial data.	Lost production for extended downtime to install new retrofit equipment. Based on production rates and publically available financial data.
Extended Downtime Days for Tie-in and Restart	Estimate based on engineering experience. The downtime is the number of days beyond a typical annual outage.	Estimate based on engineering experience. The downtime is the number of days beyond a typical annual outage.	Estimate based on engineering experience. The downtime is the number of days beyond a typical annual outage.

Appendix D - BAMRT Mercury Control Cost Effectiveness
U. S. Steel - Keetac
Table 3 - Operating Costs

Hg Control Technology Description

Technology Name	**Fixed Carbon Beds**	**GORE**	**ACI with an ESP**
Expected Utilization Rate (%)	100%	100%	100%
Expected Annual Hours of Operation (hr/year)	8,200	8,200	8,200
Notes on Technology			

Direct Annual Costs (DAC, $/year)			**$2,490,132**	**$252,863**	**$6,347,228**
Raw Materials					
Powdered Activated Carbon (HPAC)	Demand (lb/year)	[1]			3,665,638.43
	Retail Price ($/lb)	[2]			$1.12
	Cost Per Year ($/year)	[3]			$4,105,515
Hydrated Lime	Demand (ton/year)	[1]	5,120.04		2,560.02
	Retail Price ($/ton)	[2]	$250.00		$250.00
	Cost Per Year ($/year)	[3]	$1,280,010.63		$640,005.32
Utilities					
Electricity	Demand (kW-hr/year)	[4]	7,678,144.5	1,576,884.5	13,645,141.1
	Retail Price ($/kW-hr)	[2]	$0.069	$0.069	$0.069
	Cost Per Year ($/year)	[3]	$530,560	$108,963	$942,879
Operating Labor					
Operator	Worked Hours Per Year (hr/year)	[5]	2,050	513	2,050
	Cost Per Hour ($/hr)	[2]	$26.26	$26.26	$26.26
	Cost Per Year ($/year)	[3]	$53,833	$13,458	$53,833
Supervisor	Cost Per Year ($/year)	[6]	$8,075	$2,019	$8,075
Maintenance					
Labor	Worked Hours Per Year (hr/year)	[7]	1,025	513	1,025
	Cost Per Hour ($/hr)	[2]	$27.73	$27.73	$27.73
	Cost Per Year ($/year)	[3]	$28,423	$14,212	$28,423
Materials	Cost Per Year ($/year)	[8]	$28,423	$14,212	$28,423
Waste Management					
Non-Haz Solid Waste Offsite Disposal	Waste Production Rate (ton/year)	[9]	19,670.53		18,943.32
	Transport Demand (ton-mile/year)	[10]	0.00		0.00
	Disposal Fee ($/ton)	[2]	$28.51		$28.51
	Transport Fee ($/ton-mile)	[2]			
	Cost Per Year ($/year)	[11]	$560,807		$540,074
GORE Wastewater Treatment					
	Cost Per Year ($/year)	[3]		$100,000	
Product Loss					
Taconite Pellets	Product Lost (ton/year)	[12]	0.00	0.00	0.00
	Retail Price ($/ton)	[2]			
	Cost Per Year ($/year)	[3]			

Indirect Annual Costs (IAC, $/year)		**$11,397,185**	**$8,521,257**	**$8,037,112**
Overhead	[13]	$71,253	$26,340	$71,253
Administration	[14]	$1,280,336	$983,806	$925,536
Property Tax	[15]	$640,168	$491,903	$462,768
Insurance	[16]	$640,168	$491,903	$462,768
Capital Recovery for Replacement Parts	[17]	$726,342	$797,866	N/A
Capital Recovery	[18]	$8,038,920	$5,729,440	$6,114,787

Total Annual Costs (TAC = DAC + IAC, $/year)	**$13,887,317**	**$8,774,120**	**$14,384,340**

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Footnotes

[1] Source of information for the demand of each raw material for each Hg control technology.

Raw Material Demand	***Documentation of Demand Calculation***		
Powdered Activated Carbon (HPAC)			*US Steel MOO Line #6 Dry Off-Gas System FEL-2 Study* indicated that brominated PAC could achieve an 80% control at U. S. Steel Minntac with an 8.4 lb/mmacf injection rate.
Hydrated Lime	Lime injection rates maintain the current level of SO2 control achieved by the existing scrubbers (assumed 50%). Vendor data from previous project experience determined the normalized stoichiometric ratios.		Lime injection rates maintain the current level of SO2 control achieved by the existing scrubbers (assumed 50%). Vendor data from previous project experience determined the normalized stoichiometric ratios.

[2] See 'Table 5 - Raw Material, Utility, and Waste Disposal Costs ' for details.

[3] Cost per year = Demand/year * Retail Price; for GORE Wastewater Treatment the cost is equal to the annual operating expenses

[4] Source of information for the demand of each utility for each Hg control technology.

Utility Demand	***Documentation of Demand Calculation***		
Electricity	6" pressure drop from baghouse and 6" pressure drop through carbon beds per vendors. Also included pressure drop due to ducting. EPA Air Pollution Control Cost Manual 6th Ed 2002, Chapter 1 equation 1.14. Electricity demand is only incremental amount above baseline conditions because the existing waste gas fans would be replaced. Includes the electricity demand for a new compressor.	Assumed 1.04" pressure drop through modules per vendor quote for vertical arrangement. Also included pressure drop due to ducting. EPA Air Pollution Control Cost Manual 6th Ed 2002, Chapter 1 equation 1.14. Electricity demand is only incremental amount above baseline conditions because the existing waste gas fans would be replaced.	22" pressure drop through GSA-ESP system (including pressure drop due to ducting) per vendor information. EPA Air Pollution Control Cost Manual 6th Ed 2002, Chapter 1 equation 1.14 Electricity demand is only incremental amount above baseline conditions because the existing waste gas fans would be replaced.

[5] Assumed 0.5 and 2.0 hrs of operator attention per 8 hr shift of unit operation for units with a carbon adsorber and baghouse basis respectively.

[6] 15% of operator costs per *EPA Air Pollution Control Cost Manual,* 6th Ed., 2002.

[7] Assumed 0.5 and 1.0 hrs of operator attention per 8 hr shift of unit operation for units with a carbon adsorber and baghouse basis respectively.

[8] 100% of maintenance labor per *EPA Air Pollution Control Cost Manual,* 6th Ed., 2002.

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Table 3 - Operating Costs

[9] Source of information for the waste production rate for each Hg control technology.

Waste Disposal Demand	*Documentation of Demand Calculation*		
Non-Haz Solid Waste Offsite Disposal	Assumes that all of the solids captured by the baghouse would be disposed of as solid waste. Includes waste due to sorbent injection.		Assumes that all of the solids captured by the ESP would be disposed of as solid waste. Includes waste due to sorbent injection.
GORE Wastewater Treatment		Annual operating costs of WWTP required to treat and reuse GORE wash water effluent to vendor recommended water quality standards. Water contaminant concentrations based on pilot testing data.	

[10] Transport fees are included in the disposal fee, so transport demand equals 0.

[11] Cost per year = Demand/year * Retail Price + Transport Demand * Transport Fee

[12] Source of information for the product loss for each control technology.

Product Loss From Control Technology	***Documentation of Product Loss Calculation***		
Taconite Pellets			

[13] Overhead estimated as 60% of total labor and maintenance materials per *EPA Air Pollution Control Cost Manual,* 6th Ed., 2002.

[14] Administration estimated as 2% of Total Capital Investment (TCI) per *EPA Air Pollution Control Cost Manual,* 6th Ed., 2002.

[15] Property tax estimated as 1% of Total Capital Investment (TCI) per *EPA Air Pollution Control Cost Manual,* 6th Ed., 2002.

[16] Insurance estimated as 1% of Total Capital Investment (TCI) per *EPA Air Pollution Control Cost Manual,* 6th Ed., 2002.

[17] See 'Table 4 - Replacement Parts ' for details.

[18] See 'Table 2 - Capital Costs ' for details.

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U. S. Steel - Keetac

Table 4 - Replacement Parts

Hg Control Technology Description

Technology Name		**Fixed Carbon Beds**	**GORE**	**ACI with an ESP**
Notes on Technology				

Cost of Replacement Parts ($)		**$4,497,678**	**$8,452,600**	
Capital Recovery for Replacement Parts($/year)		**$726,342**	**$797,866**	
Replacement Part Name		Filter Bags	Gore Module	
Interest Rate	[1]	7.0%	7.0%	
Expected Life of Replacement Part (years)	[2]	5.00	20.00	
Cost of Replacement Part ($/replacement)	[2]	$816,283	$8,377,600	
Cost of Labor for Replacement ($/replacement)	[2]	$30,634	$75,000	
CRF_P	[3]	24.39%	9.44%	
CRC_P ($/year)	[4]	$206,555	$797,866	
Replacement Part Name		Carbon Change		
Interest Rate	[1]	7.0%		
Expected Life of Replacement Part (years)	[2]	10		
Cost of Replacement Part ($/replacement)	[2]	$3,468,219		
Cost of Labor for Replacement ($/replacement)	[2]	$182,543		
CRF_P	[3]	14.24%		
CRC_P ($/year)	[4]	$519,786		

Appendix D - BAMRT Mercury Control Cost Effectiveness
U. S. Steel - Keetac
Table 4 - Replacement Parts

Footnotes

[1] Standard interest rate specified by the U.S. Office of Management and Budget (OMB).

[2] Documentation of parameters noted for replacement parts above.

Name	***Filter Bags***	***Gore Module***	
Documentation of Life Expectancy	Provided by baghouse manufacturer	Assumed 20 year equipment life.	
Documentation of Replacement Part Cost, including sales tax and freight.	Provided by baghouse manufacturer. Equipment life of 5 years at $110/bag. Scaled linearly for Keetac air flow.	Vendor quote. Includes vendor estimated disposal cost of $45/module	
Documentation of Labor Costs for Replacement Part	EPA Air Pollution Control Cost Manual 6th Ed 2002 Chapter 1.5.1.4. Assumes 10 minutes per bag and U. S. Steel specific labor rates.	Vendor estimate	
Name	***Carbon Change***		
Documentation of Life Expectancy	10 years per vendor, due to contamination from flue gas		
Documentation of Replacement Part Cost, including sales tax and freight.	Cost includes new carbon and non-hazardous waste disposal of spent carbon.		
Documentation of Labor Costs for Replacement Part	Assumes 16 person days per 50,000 lb per EPA Control Cost Manual Section 3, Chapter 1, Section 1.4.1.4		

[3] Capital Recovery Factor for Replacement Parts. Per *EPA Air Pollution Control Cost Manual* , 6th edition, 2002. Section 1, Chapter 2, Equation 2.8a.

$$CRF = \left(\frac{i \times (1+i)^n}{(1+i)^n - 1}\right)$$

Where: i = interest rate
n = number of years

[4] Capital Recovery Cost of Replacement Parts. Per *EPA Air Pollution Control Cost Manual,* 6th edition, 2002. Section 1, Chapter 2, Equation 2.11.

$$CRC_p = \left(C_p + C_{pl}\right) \times CRF_p$$

Where: C_p = initial cost of replacement parts including sales and freight
C_{pl} = cost of labor for parts-replacement
CRF_p = capital recovery factor for replacement parts

Appendix D - BAMRT Mercury Control Cost Effectiveness
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Table 5 - Raw Material, Utility, and Waste Disposal Costs

Raw Material Costs

Raw Material	*Cost Per Unit*	*Unit*	*Year Basis*	*Footnote*	*Cost Index*	*Cost Index for Base Year*	*Cost Index for 2018*	*Adjusted Cost ($/Unit)*
Powdered Activated Carbon (HPAC)	$1.12	lb	2018	[1]	Assume 3% Inflation	100	100	$ 1.12
Baghouse Filter Bags	$110.00	ea	2018	[9]	Assume 3% Inflation	100	100	$ 110.00
Hydrated Lime	$250.00	ton	2018	[12]	Assume 3% Inflation	100	100	$ 250.00

Utility Costs

Utility	*Cost Per Unit*	*Unit*	*Year Basis*	*Footnote*	*Cost Index*	*Cost Index for Base Year*	*Cost Index for 2018*	*Adjusted Cost ($/Unit)*
Electricity	$0.07	kW-hr	2018	[3]	Assume 3% Inflation	100	100	$0.07
Natural Gas	$4.36	MMBtu	2018	[4]	Assume 3% Inflation	100	100	$4.36
Compressed Air	$0.25	mscf	1998	[5]	Assume 3% Inflation	100	181	$0.45

Labor Costs

Occupation	*Cost Per Unit*	*Unit*	*Year Basis*	*Footnote*	*Cost Index*	*Cost Index for Base Year*	*Cost Index for 2018*	*Adjusted Cost ($/Unit)*
Operator	$26.26	hour	2018	[2]	Assume 3% Inflation	100	100	$26.26
Maintenance	$27.73	hour	2018	[10]	Assume 3% Inflation	100	100	$27.73
Supervisor	$28.31	hour	2018	[11]	Assume 3% Inflation	100	100	$28.31

Waste Disposal Costs

Disposal Type	*Cost Per Unit*	*Unit*	*Year Basis*	*Footnote*	*Cost Index*	*Cost Index for Base Year*	*Cost Index for 2018*	*Adjusted Cost ($/Unit)*
Solid Waste Disposal	$28.51	ton	2018	[6]	NA	100	100	$28.51
Hazardous Waste Disposal	$250.00	ton	2002	[7]	Assume 3% Inflation	100	160	$401.18

Finished Products

Product	*Cost Per Unit*	*Unit*	*Year Basis*	*Footnote*	*Cost Index*	*Cost Index for Base Year*	*Cost Index for 2018*	*Adjusted Cost ($/Unit)*
Finished Pellets	$38.49	ton	2018	[8]	NA	100	100	$38.49

Footnotes

[1] Delivered price from vendor for HPAC.

[2] Median hourly wage for "Continuous Mining Machine Operators" in Metal Ore Mining industry as of May 2017, per US Bureau of Labor Statistics.
http://www.bls.gov/oes/current/oes475041.htm

[3] U.S. Energy Information Administration (EIA), Average Retail Price of Electricity for the Industrial Sector in Minnesota for 2017.
https://www.eia.gov/electricity/data/browser/#/topic/7?agg=2,0,1&geo=g&freq=M

[4] U.S. Energy Information Administration (EIA), Average Retail Price of Natural Gas for the Industrial Sector for the first four months of 2018.
http://www.eia.gov/totalenergy/data/monthly/pdf/sec9_15.pdf

[5] *EPA Air Pollution Control Cost Manual* , 6th Ed, 2002, Section 6, Chapter 1, Paragraph 1.5.1.8.
http://www.epa.gov/ttncatc1/dir1/c_allchs.pdf

[6] U.S. Steel site-specific solid waste disposal cost.

[7] *EPA Air Pollution Control Cost Manual,* 6th Ed 2002, Section 2, Chapter 2.5.5.5.
Section 2 lists $200 - $300/ton. Assumed median value of $250/ton.

[8] USS does not publish pellet specific production costs. Therefore, costs per ton are based on Cleveland Cliffs reports, Third Quarter 2018 Results

[9] Filter bag cost provided by vendor.

[10] Median hourly wage for "Industrial Machinery Installation, Maintenance, and Repair Occupations" in Metal Ore Mining industry as of May 2017, per US Bureau of Labor Statistics.
https://www.bls.gov/oes/current/naics4_212200.htm#49-0000

[11] Median hourly wage for "First-Line Supervisors of Production and Operating Workers" in Metal Ore Mining industry as of May 2014, per US Bureau of Labor Statistics.
http://www.bls.gov/oes/current/oes511011.htm

[12] Vendor provided delivered hydrated lime cost.

Appendix E

Mercury Emission Reduction Calculations

U. S. Steel Corporation, Minnesota Ore Operations - Keetac
Alternative Mercury Emissions Reduction Plan
Appendix E
Mercury Emission Reductions

Mercury Emissions Reductions under AMERP

Emission Unit	Baseline Emissions (lb/yr)	Percent Reduction [1]	Estimated Emissions (lb/yr)
EU 030	120.0	30%	120[2]

[1] 30% wet scrubber mercury control efficiency established in Keetac Title V permit issued February 2, 2005.

[2] Estimated emissions are the same as baseline because the technology is already implemented at Keetac. Thus, the baseline emissions includes the reduction already.