Greenhouse Gas and Climate Change Evaluation

NorthMet Project

Prepared for
PolyMet Mining Inc.

June 2012

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1.0 Introduction

The first draft of a greenhouse gas (GHG) and climate change evaluation report was prepared and submitted in March of 2009 in support of the NorthMet Draft Environmental Impact Statement (DEIS). Comments on this draft were received from the Minnesota Pollution Control Agency (MPCA) and the Minnesota Department of Natural Resources (MDNR). A second draft of the report was submitted in June of 2009 to address comments on the initial draft. In early March 2011 PolyMet and Barr proposed the scope of its planned updated carbon footprint analysis for the Supplemental Draft Environmental Impact Statement (SDEIS) primarily aimed at aligning the report with draft guidance issued by the White House Council on Environmental Quality (CEQ) in February 2010 for addressing climate change and GHGs under the National Environmental Policy Act (NEPA). The final scope was developed through the Impact Assessment Planning (IAP) process by the Air IAP group. Notable changes and updates to the June 2009 submittal included in this report are as follows:

- Emission estimates have been expanded to address CEQ's inclusion of "all phases and elements of the proposed action" in estimates of direct GHG emissions. In the context of the NorthMet Project (Project), this phrase has been interpreted to mean that construction and closure phases of the Project should be included in GHG analysis, along with emissions during the operating phase. Therefore, combustion emissions associated with the construction phase of the Project as well as emissions associated with wastewater treatment activities and the use of peat materials in closure/reclamation activities have been included in the GHG analysis.
- While GHG emission calculations were completed for the June 2009 report using multiple references and guidance documents including: World Resources Institute Greenhouse Gas Protocol Standard (WRI), The Climate Registry's General Reporting Protocol (TCR), MPCA's General Guidance for Carbon Footprint Development in Environmental Review, Intergovernmental Panel on Climate Change recommendations (IPCC), EPA guidance, and the professional judgment of the report preparers, the CEQ guidance calls for the use of EPA GHG Mandatory Reporting Rule (MRR) methodologies as a primary resource for calculating emissions. Through the scoping process, it was determined that methodologies and emission factors used in the June 2009 report are reputable and comparable to those used in the MRR and that no changes were necessary in this area.
- In addition to annual emissions, the CEQ guidance recommends quantifying emissions over the entire life of the Project. An estimate of total emissions over the life of the Project has been added to this updated report.

- CEQ guidance identifies the need for an evaluation of climate change impacts that may affect the design of the proposed action and alternatives. The June 2009 Climate Change Evaluation report does not directly address this issue. Therefore, this updated report includes a qualitative discussion of the potential affect of climate change on the Project. During scoping discussions, it was determined that the co-lead agencies would make an assessment and decide which impact analyses should consider potential climate affects and the level of detail needed in those analyses to aid in the preparation of the SDEIS.

Several additional changes/additions beyond those associated with the CEQ guidance were requested during scoping and have been included in this revised report including:

- Addition of a discussion of potential links between climate change and ozone
- Addition of a discussion of the applicability of clean diesel strategies to construction and operation of the facility
- Updates to background information on climate change and GHG policy and regulation to reflect changes and developments during the past two years
- Removal of the calculation/section attempting to relate the CO_2 emissions from the Project to a specific change in atmospheric CO_2 concentration as this calculation was neither reliable nor required

This document is being provided as a stand-alone document for review and it will be integrated into the NorthMet Project Air Data Package after approval. Any discrepancy between this document and the NorthMet Project Air Data Package will be resolved in favor of this document.

The issue of climate change and anthropogenic GHG emissions is a complex and evolving topic from both a scientific and regulatory standpoint. The Project SDEIS is being prepared in the context of new and evolving state and federal guidance related to GHG and climate change in environmental review. The analysis that follows addresses the environmental effects of GHG emissions from the Project and of global climate change. The analysis also recognizes data and analytical limitations. GHGs and climate change are evaluated in a manner that is consistent with available, reliable, scientifically-based information and approaches. Project GHG emissions, alternatives, and energy efficiency have been quantitatively assessed. Additionally, despite the high level of uncertainty associated with their calculation, GHG emissions from surface wetland removal and peat stockpiling, loss of carbon from excavated peat used in reclamation activities, loss of aboveground biomass carbon in impacted areas, and reductions in carbon sequestration capacity due to wetland and upland forest ground cover disturbance have been quantitatively assessed. Given the limitations of climate models in addressing the impacts of GHG emissions at the project level on global, national, regional, and local climate, this impact analysis is largely qualitative in its treatment of the physical climate endpoints (e.g., temperature rise, frequency of precipitation events).

EPA has issued regulatory actions under the Clean Air Act and in some cases other statutory authorities to address issues related to climate change. These actions as well as state level actions are summarized in Section 2.1.1. Climate change policy and GHG regulation is a rapidly evolving issue and recent lawsuits, in addition to various pending congressional bills under which CO_2 emissions might be regulated will likely shape the future of GHG laws. The summary provided in Section 2.1.1 extends through December 2012 and cannot account for additional changes and developments that occur between the publication of this report and the development of the SDEIS document.

While the earth's climate naturally undergoes cyclical variations over time, increases in global average surface temperatures observed over recent decades have been attributed by the vast majority of climate scientists to observed increases in global atmospheric GHG concentrations resulting from anthropogenic GHG emissions. Some future climate change impacts have been projected to occur as the result of increases in global atmospheric GHG concentrations that have already occurred. The level of future global, national and regional anthropogenic GHG emissions will also likely exert a strong influence over the magnitude and extent of future climate change.

Minnesota is situated at the crossroads of four different biomes, a unique situation that makes Minnesota's ecological character particularly vulnerable to the potential effects of climate change. Climate change impacts such as temperature increases, changes in precipitation patterns, and shifts in the length of Minnesota's seasons could affect each of these unique biomes, impacting the type and distribution these ecosystems, quantity and quality of water resources, agricultural disposition and productivity, and human health over the next century.

Major components of the Project include mining, ore crushing/grinding and concentrating, and metal recovery. In metal recovery, the nickel-rich fraction of the flotation concentrate is routed to a pressurized autoclave as a part of the hydrometallurgical process. Energy is produced within the autoclave during sulfide oxidation and is used as the primary energy source for the hydrometallurgical process. This eliminates several steps typically associated with pyrometallurgical processing and reduces process energy demands. Overall, energy demand in hydrometallurgical processing such as PolyMet's proposed operation, is estimated to be about half of that associated with pyrometallurgical processes.

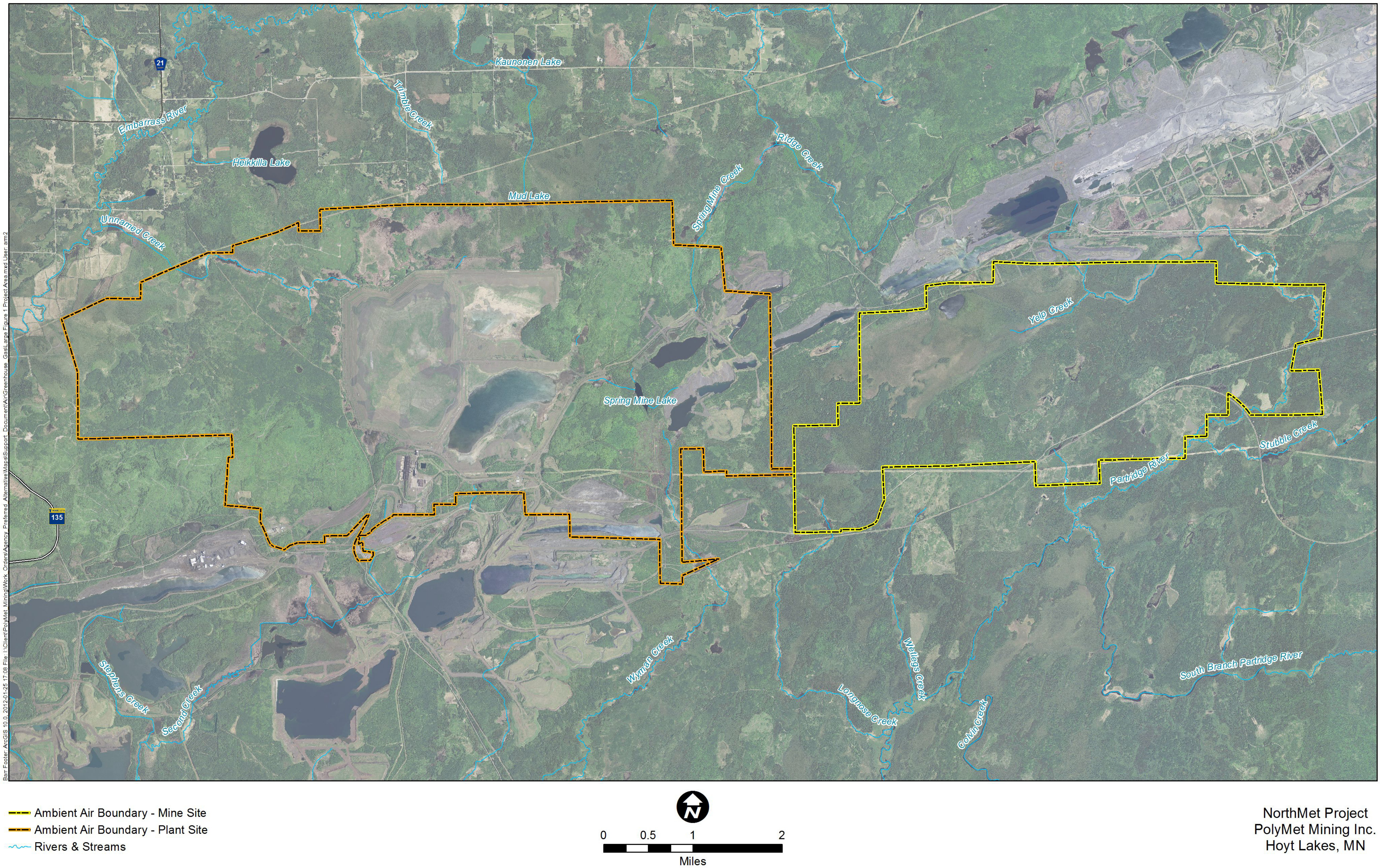
Total GHG emissions for the Project are comprised of direct emissions from the Mine Site, direct emissions from the Process Plant, and indirect emissions from the purchase of electricity. Additional emissions and effects on carbon sequestration due to the disturbance of ground cover may occur as described below. Figure 1 shows the location and layout of the Mine Site and Process Plant.

PolyMet is taking all practicable measures to minimize GHG emissions by ensuring a high level of energy and production efficiency. Whenever available, PolyMet will employ new premium efficiency motors rather than standard motors. Moreover, gravity transport of process slurries will be used where possible, instead of pumps. PolyMet also intends to configure the Process Plant such that the overall power factor for the facility is as close to one as practical. This will help minimize the current and therefore power losses on the power line servicing the facility. The primary production excavators and one of the two blast hole drills will be electric rather than diesel powered eliminating a source of direct GHG emissions. Instead of employing used conventional locomotives, PolyMet will purchase new Gen-Set locomotives, which are more efficient and use less fuel. Also, space heating in the Process Plant is a major contributor to total direct GHG emissions. To reduce GHG emissions, PolyMet will employ natural gas fired space heaters. Estimated maximum CO_2-equivalent (CO_2-e) emissions from natural gas are less than from other fuels, which will reduce direct and indirect GHG emissions. In addition to selecting a low emitting fuel for space heating, the exhaust from the emission controls utilizing cartridge type filtration will be recycled back into the buildings, where practical, to reduce heating demand.

Carbon cycle effects due to direct or indirect disturbance of site ground cover have been assessed separately, owing to the high levels of uncertainty surrounding their calculation. Quantitative assessments for six carbon cycle impact categories have been included in this report:

1. Total carbon stored in the above-ground vegetation of wetlands and forests that are lost to Project activities [treated as a one-time emission]
2. Total carbon stored in excavated peat, and annual emissions from its stockpiling
3. Potential carbon flux associated with removal of peat from stockpiles and use in cover material used for reclamation
4. Annual emissions from indirectly impacted wetlands due to lowered water levels
5. Loss of annual carbon sequestration capacity due to direct and indirect Project impacts on wetland and forest plant communities
6. Reduction in annual carbon sequestration capacity in indirectly impacted wetlands

The total above-ground carbon stock which is lost to Project activities represents a theoretical cap on the amount of carbon that can eventually be released from the above-ground vegetation. All vegetation in directly impacted areas has been assumed lost in this analysis. The only ongoing annual emission rates evaluated are those from peat excavation, stockpiling and use in reclamation, and indirectly impacted wetlands. The loss of carbon sequestration capacity differs from an emission rate in that it represents a loss of absorptive capacity rather than an actual emission; however, its net effect on atmospheric CO_2 levels is essentially the same. A summary of the terrestrial carbon cycle assessment is presented in Section 3.1.2 of this report. Detailed descriptions of the calculations used to derive these estimates can be found in Appendix A, along with a full quantitative analysis of GHG emissions, Project efficiency, and GHG reduction measures.



Barr Footer: ArcGIS 10.0, 2012-01-25 17:08 File: I:\Client\PolyMet_Mining\Work_Orders\Agency_Preferred_Alternative\Maps\Support_Document\Air\Greenhouse_Gas\Large Figure 1 Project Area.mxd User: arm2

NorthMet Project
PolyMet Mining Inc.
Hoyt Lakes, MN

Figure 1 **NorthMet Project Property Boundaries**

2.0 **Cumulative Effects**

2.1. Background Information on Climate Change

2.1.1. Climate Change and GHGs in Federal and State Policy and Law

Climate change policy and GHG regulation is a rapidly evolving issue. EPA has issued regulatory actions under the Clean Air Act (CAA) and in some cases other statutory authorities to address issues related to climate change. The MPCA has recently modified its air permit rules to incorporate new federal permit requirements for GHG emissions and currently requires an evaluation of GHG emissions in the environmental review process for proposers of projects that must obtain stationary source air permits. In addition, from the state level to the international level, many governments are setting goals and taking steps toward GHG emission reductions.

2.1.1.1 Federal Policy and Law

From a national policy perspective, consideration of GHG emission goals and targets has been ongoing since the United States' ratification of United Nations' Framework Convention on Climate Change (UNFCCC) in 1992. As a participating member of the UNFCC, the United States made a commitment to implement policies intended to help stabilize GHG concentrations in the atmosphere at a level that would "prevent dangerous anthropogenic interference with the climate system." The U.S. entered a non-binding agreement to gather and share information on GHG emissions and national policies and best practices. The United States also agreed to develop national strategies for addressing GHG emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries.[1]

In 1997, delegates from nearly 200 nations gathered in Kyoto, Japan, and made a collective commitment to reduce GHG emissions by about 5 percent below 1990 levels by 2012, under a treaty known as the Kyoto Protocol. The Clinton Administration participated in negotiations, but ultimately U.S. lawmakers declined to ratify the protocol.

The Kyoto protocol is set to expire at the end of 2012 and some major countries, including Canada, Japan and Russia, have indicated that their participation in any successor treaty to the protocol would hinge on more similar reduction requirements across developing and developed nations. The European Union, the

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[1] United Nations, 1992. United Nations Framework Convention on Climate Change (GE.05-62220 (E) 200705) (available at: http://unfccc.int/resource/docs/convkp/conveng.pdf)

major developing countries, and most African and Pacific island nations have suggested an extension of the Kyoto process as a prelude to a more ambitious, binding international agreement that would take effect 2020.

Efforts to resolve the fate of the Kyoto Protocol during an international gathering on climate change held in Durban, South Africa, in December 2011 resulted in an agreement, known as the Durban Platform, under which an Ad Hoc Working Group would be established to develop, by 2015, a replacement protocol for the Kyoto Protocol that would come into effect no later than 2020 and be binding on all industrial and developing nations. Under the Durban Platform, the Kyoto Protocol would remain in effect during the interim.

The Obama administration has pledged to reduce U.S. emissions 17 percent below 2005 levels by 2020, but their preferred approach, a nationwide cap-and-trade system, has not been approved by the Congress. 2010 efforts to pass a nationwide cap-and-trade bill resulted defeat in the Senate in after being passed by the House the year before.

At the federal regulatory level, EPA has taken regulatory action under the Clean Air Act and in some cases other statutory authorities to address issues related to climate change. Over the last several years, these measures have raised difficult regulatory questions and generated a great deal of discussion regarding the authority of the EPA to regulate GHGs under the CAA. In April 2007, the U.S. Supreme Court issued a decision in *Massachusetts v. EPA*, 549 U.S. 497, 127 S.Ct. 1438 (2007). EPA had denied a petition by a group of states and environmental organizations asking that EPA regulate GHG emissions from new motor vehicles under the CAA. In its decision, EPA found that the CAA does not authorize regulations to address global climate change and that, even if it was determined that EPA had the authority to issue such regulations, it would be unwise for EPA to regulate GHG emissions at this time. The Court held that GHGs satisfy the definition of air pollutant under the CAA and that EPA has the statutory authority to regulate GHG emissions from automobiles. The Supreme Court authorized EPA to regulate emissions from motor vehicles should EPA form a judgment that the emissions contribute to climate change.[2]. The Court remanded the decision to EPA for reconsideration.

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[2] 127 S.Ct. at 1462.

One year after the Supreme Court's decision in *Massachusetts***,** a petition for writ of mandamus was filed to force EPA to formally decide whether to regulate GHGs from vehicles under the CAA[3]. In July 2008 the EPA issued an Advance Notice of Proposed Rulemaking ("ANPRM") concerning the implementation of such regulations, which included extensive analysis of the science related to climate change, of technologies for reducing GHG emissions and of the statutory provisions that may be triggered by an endangerment finding under Section 202 of the CAA.[4]

Although *Massachusetts* dealt specifically with whether EPA must promulgate regulations for GHG emissions from motor vehicles, the ANPRM recognized that the opinion may have a broader application.[5] EPA's sister federal agencies provided comments expressing concern regarding the benefits of GHG regulation through the CAA. The U.S. Department of Energy noted that "improving our energy security and addressing global climate change are the most pressing challenges of our time" but urged that before EPA were to proceed down the path of CAA regulation of GHGs, there should be a full and fair discussion of the true burdens of that path.[6]

In November 2008, discussions of CO_2 regulation under CAA continued with the Sierra Club's administrative appeal of a prevention of significant deterioration (PSD) permit issued by EPA Region 8 to Deseret Power Electric Cooperative. The Sierra Club argued that, under the Supreme Court's ruling in *Massachusetts v. EPA*, the PSD permit should have included Best Available Control Technology (BACT) emission limits for $CO_{2.}$[7] With the Supreme Court's definition of CO_2 as an "air pollutant" under CAA, and given federal CO_2 monitoring and reporting requirements, the Sierra Club contended that CO_2

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[3] United States Court of Appeals For the District of Columbia Circuit. Commonweath of Massachusetts, et al. Petitioners, v. U.S. Environmental Protection Agency, et al. Respondents. Docket No. 0.-0361 (& consolidated cases) Petition for Wit of Mandamus to Compel Compliance with Mandate. (available at: http://www.atg.wa.gov/uploadedFiles/Home/News/Press_Releases/2008/Mass%20vs%20EPA%20Mandamus%20petition.pdf)

[4] 2-1A Treatise on Environmental Law Section 1A.05 ***Treatise on Environmental Law*** Copyright 2008, Matthew Bender & Company, Inc., a member of the LexisNexis Group.

[5] EPA 40 CFR Chapter I. EPA-HQ-OAR-2008-00318; FRL-8694-2. TIN 2060-AP12. Regulating Greenhouse Gas Emission s under the Clean Air Act. (available at http://www.epa.gov/climatechange/emissions/downloads/ANPRPreamble.pdf).

[6] Id at 26.

[7] Before the Environmental Appeals Board United States Environmental Protection Agency Washington, D.C. In re: Deseret Power Electric Cooperative PSD Permit No. PSD-OU-0002-02.00 PSD Appeal No. 07-03. Decided November 13, 2008. Order Denying Review in Part and Remanding in Part (Before Environmental Appeals Judges Edward E. Reich, Kathie A. Stein and Anna L. Wolgast (available at http://yosemite.epa.gov/oa/EAB_Web_Docket.nsf/PSD%20Permit%20Appeals%20(CAA)/C8C5985967D8096E85257500006811A7/$File/Remand...39.pdf).

qualified as an "air pollutant subject to regulation under the CAA."[8] Sierra Club argued that the permit violated Sections 165(a)(4) and 169(3) of the Act, which require BACT emission limits for "each air pollutant subject to regulation under the CAA."

EPA countered that it had the discretion to interpret the phrase "subject to regulation" and that historically, EPA interpreted the term to describe pollutants subject to statutory or regulatory emission controls. EPA argued that it did not have authority to impose a CO_2 BACT limit because CO_2 regulations under the CAA require only monitoring and reporting, not actual emission controls.

The EPA Environmental Appeals Board determined that EPA had the authority to interpret the term "subject to regulation," but found that the record was not sufficient to support EPA's interpretation.

In December 2008, former EPA Administrator Stephen L. Johnson issued a memorandum to all EPA Regional Administrators discussing the application of the CAA to GHG emissions.[9] EPA Administrator Johnson stated that under federal PSD regulations, EPA will interpret the definition of "regulated NSR pollutant" to exclude pollutants for which EPA has established only monitoring and reporting requirements. [10]

On October 30, 2009, the Final Mandatory GHG Reporting Rule was published in the *Federal Register* under 40 CFR part 98, commonly referred to as "Part 98".[11] The final rule requires certain facilities and suppliers to submit GHG emissions information and supporting information to quantify and verify the reported emissions. Part 98 requires facilities in 29 categories to report for calendar year 2010 and an additional 12 categories commence reporting for calendar year 2011.As initially proposed, the final rule required the first annual GHG emission report on March 31, 2011, for 2010 emissions. To allow EPA to further test the data submittal system and give industry proper time to test the submittal tool, on March 18, 2011 EPA extended the reporting deadline to September 30, 2011 for calendar year 2010. Subsequent reporting years will subject to a reporting deadline of March 31. Following publication of the Mandatory GHG Reporting Rule, the EPA has issued technical corrections and amendments to several subparts.

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[8] Part 70 of Title 40 of the Code of Federal Regulation adopted in accordance with section 821 of the Clean Air Act Amendment of 1990 requires monitoring of CO_2 from power plants

[9] United States Environmental Protection Agency Memorandum To: Regional Administrators From: Stephen L. Johnson, Administrator, Re: EPA's Interpretation of Regulations that Determine Pollutants Covered By Federal Prevention of Significant Deterioration PSD permit Program (available at: http://www.epa.gov/nsr/documents/psd_interpretive_memo_12.18.08.pdf)

[10] Under federal regulations only newly constructed or modified major sources that emit one or more New Source Review (40 C.F.R. 52.21(b)(50)) pollutants are subject to PSD program requirements including BACT.

[11] Part 98 of Title 40 of the Code of Federal Regulations – Mandatory Reporting of Greenhouse Gases Final Rule

The final rule requires that suppliers of fossil fuels or industrial GHGs, manufacturers of vehicles and engines, and facilities that emit 25,000 metric tons or more per year of GHG emissions submit annual reports to EPA. The gases covered by the final rule are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), sulfur hexafluoride (SF_6), and other fluorinated gases including nitrogen trifluoride (NF_3) and hydrofluorinated ethers (HFE).

In response to the 2007 Supreme Court ruling 549 U.S. 497 (2007), Proposed Endangerment and Cause or Contribute Findings for GHGs under the CAA were signed by the EPA administrator on April 17, 2009 and were open for public comment for a 60 day period following publication in the Federal Register. The proposals contained two findings regarding GHGs under section 202(a) of the CAA: that the current and projected concentrations of the mix of six key GHGs in the atmosphere threaten the public health and welfare of current and future generations; and that the combined emissions of CO_2, CH_4, N_2O, and HFCs from new motor vehicles and motor vehicle engines contribute to the atmospheric concentrations of these key GHGs and hence to the threat of climate change These findings were a prerequisite to finalizing the GHG standards for light-duty vehicles. On April 1, 2010, EPA and the Department of Transportation's National Highway Safety Administration issued the first national rule limiting GHG emissions from cars and light trucks. This rule confirmed that January 2, 2011 is the earliest date that a 2012 model year vehicle meeting these rule requirements may be sold in the United States.

Under the December 2008 "PSD Interpretive Memo" a pollutant is "subject to regulation" only if it is subject to either a provision in the CAA or regulation adopted by EPA under the CAA that requires actual control of emissions of that pollutant and that CAA permitting requirements apply to a newly regulated pollutant at the time a regulatory requirement to control emissions of that pollutant "takes effect". Based on this interpretation, the GHG requirements of the vehicle rule would trigger CAA permitting requirements for stationary sources on January 2, 2011. Under CAA rules, new major stationary sources and major modifications at existing major stationary sources that meet emissions applicability thresholds outlined in the CAA and in existing PSD regulations are required to obtain a PSD permit. Included is a requirement that PSD-permitted facilities apply BACT to GHG emitting sources. BACT is determined on a case-by-case basis taking into account, among other factors, the cost and effectiveness of the control.

On May 13, 2010, the EPA issued a final rule that set GHG thresholds for permits for new and existing facilities under the New Source Review Prevention of Significant Deterioration and Title V Operating Permit programs. The nation's largest GHG emitters are included, covering approximately 70% of national GHG emissions from stationary sources. This rule is commonly referred to as the GHG Tailoring Rule.

The rule establishes a schedule that will initially focus CAA permitting programs on the largest sources with the most CAA permitting experience. The rule then expands to cover the largest sources of GHG that may not have been previously covered by the CAA for other pollutants, as follows:

- **Step 1** (January 2, 2011- June 30, 2011): During this period, now past, no sources were subject to CAA permitting due solely to GHG emissions. Only sources currently then subject to the PSD permitting program were subject to permitting requirements for their GHG emissions under PSD, and among these only projects with GHG increases of ≥75,000 tpy CO2-e needed to determine BACT for GHG emissions. Similarly, for operating permits, only sources currently then subject to the program were subject to title V requirements for GHG.
- **Step 2** (July 1, 2011- June 30, 2013): During this period, new sources can be subject to CAA permitting solely due to GHG emissions if they meet certain thresholds. EPA estimates this will impact approximately 550 new title V permits and 900 additional PSD permitting actions each year. New construction projects that emit GHG emissions of at least 100,000 tpy will become subject to PSD and Title V and existing facilities that increase GHG emissions by at least 75,000 tpy will need to determine BACT.

EPA will undertake another rulemaking (to begin in 2011 and conclude no later than July 1, 2012) that will phase-in GHG permitting. This will not include sources with emissions below 50,000 tpy and no permits requirements for smaller sources will be considered by EPA until at least April 30, 2016.

EPA proposed two rules on August 12, 2010 to make sure that new, large facilities or major expansions are able to obtain NSR PSD permits that address GHGs. Under the CAA, states are required to develop and follow state implementation plans (SIPs), which include requirements for issuing PSD permits. In some states, neither the EPA nor the state has authority to issue a PSD permit for sources of GHGs. In the first proposed rule, EPA requires states to revise their SIPs so that state-administered PSD programs cover GHG emissions. In the second rule, EPA outlined a federal implementation plan (FIP) for those instances when a state is not able to submit SIP revisions. These rules were finalized on December 23, 2010.

On January 12, 2011 EPA proposed a three-year deferral to the plan that would require GHG permitting requirements for CO_2 emissions from biomass-fired and other biogenic sources.[12] This deferral was

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[12] US EPA Office of Air and Radiation, March 2011. Guidance for Determining best available Control Technology for Reducing Carbon Dioxide Emissions from Bioenergy Production.

finalized in July 2011. It is expected in late 2011 or early 2012, that EPA will promulgate emission standards for power plants and oil refineries.

Concurrent with EPA actions, a series of Congressional proposals at the national level have been developed in an attempt to shape the future of U.S. climate policy. GHG emissions legislation considered during the 109th and 110th sessions of the U.S. Congress ranged from carbon taxes to cap-and-trade and from energy efficiency requirements to moratoriums on coal fired power plant approvals[13]. Notable recent legislative actions include the following[14]:

- **Lieberman-Warner Climate Security Act of 2007 (S. 2191)**: This bill was reported by committee in December 2007, but never voted on. One aim of the bill was to direct the EPA Administrator to establish a program to decrease emissions of GHGs.
- **Boxer-Lieberman-Warner Climate Security Act Substitution Amendment (S. 3036)**: This bill was reported on by committee in May 2008. 157 amendments were made to the bill, but it was never voted on. The bill proposed 19% GHG reduction (from 2005) by 2020, 71% by 2050. The bill also included proposals for a federal GHG registry, cap-and-trade system and emissions monitoring/reporting, trading emission allowances, energy efficiency and HFC reductions.
- **American Clean Energy and Security Act of 2009 (Waxman-Markey – H.R. 2454)**: This bill passed in the House on June 26, 2010 (219:212) and has not received a Senate vote. The bill was considered to be more comprehensive and ambitious than Lieberman-Warner. It included titles for Clean Energy, Energy Efficiency, Reducing Global Warming Pollution, Transition to a Clean Energy Economy and Agricultural and forestry related offsets. The bill included proposals for cap-and-trade program to control GHG emissions, federal government limits on GHGs and a 17% reduction in GHGs below 2005 GHG levels by 2020
- **Clean Energy Jobs and American Power Act (Kerry-Boxer (S. 1733)):** This bill was reported by committee in November 2009. The bill included a proposed a cap-and-trade regime and emissions reductions (from 2005) of 20% by 2020 and 83% by 2050.
- **Kerry-Lieberman**: This bill was introduced as a bi-partisan bill on May 12, 2010, after eight months of negotiation. The bill proposed reduction targets from 2005 (17% by 2020; 83% by

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[13] Yacobucci, B., 2006. "Climate Change Legislation in the 109th Congress. CRS Report for Congress. Order Code RL32955; Parker et al.., 2007. "Greenhouse Gas Reduction: Cap-and-Trade Bills in the 110th Congress". CRS Report for Congress. Order Code RL33846

[14] This list is intended to provide a summary of notable policy actions as of June 2010. This does not provide an exhaustive listing, nor does it provide a complete and detailed account of all of the features of each action.

2050) under a cap-and-trade scheme. The bill targeted power plants first (2012) and other major industrial sources beginning in 2016. It proposed to generate revenue through sale of allowances with a price collar. The bill also proposed permanent pre-emption of states' ability to implement mandatory GHG reductions and restricted EPA's ability to regulate GHGs.

2.1.1.2 Minnesota State Policy and Law

At the state level, efforts to curb statewide and regional GHG emissions are underway. More than half of U.S. states have joined in regional efforts to reduce GHG emissions. Minnesota has committed (along with Illinois, Iowa, Kansas, Michigan, Wisconsin and Manitoba) to long term GHG reduction targets of 60 to 80 percent below current emission levels as part of the Midwestern Greenhouse Gas Reduction Accord. Participants have agreed to pursue the implementation of a regional cap and trade system as well as a consistent regional GHG emissions tracking system.[15]

In the last several years Minnesota has taken steps to address statewide GHG emissions. In December 2006, Minnesota Governor Pawlenty announced the state's Next Generation Energy Initiative, which included the development of an aggressive plan to reduce GHG emissions in Minnesota. Governor Pawlenty created the Minnesota Climate Change Advisory Group in April 2007 as a part of the Next Generation Energy Initiative § 216H.02, subd. 3.[16] The Next Generation Energy Act of 2007 articulates the "goal of the state to reduce statewide GHG emissions across all sectors" to a level of at least fifteen percent below 2005 levels by 2015, at least thirty percent below 2005 levels by 2025, and at least eighty percent below 2005 levels by 2050. Minn. Stat. § 216H.02, subd. 1 [17]

In January 2008, the Minnesota Climate Change Advisory Group announced its approval of a mixture of strategies to reduce the state's GHG emissions to a level at least 30 percent below 2005 levels by 2025. In April 2008, the Minnesota Climate Change Advisory Group issued its final report with recommendations to the Governor for reducing Minnesota's GHG emissions.[18] Following the release of the Minnesota Climate Change Advisory Group's final report, the Minnesota Senate and House approved bills setting

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[15] Midwest Governors Association, 2007. Energy, Security and Climate Stewardship Platform for the Midwest (available at: http://www.midwesterngovernors.org/Publications/MGA_Platform2WebVersion.pdf) and Midwest Governors Association, 2007. Midwestern Greenhouse Gas Accord (available at: http://www.midwesterngovernors.org/Publications/Greenhouse%20gas%20accord_Layout%201.pdf)

[16] Minnesota Statutes, 2008 Chapter 216H. Greenhouse Gas Emissions (available at https://www.revisor.leg.state.mn.us/statutes/?id=216H&view=chapter)

[17] Minnesota Statutes, 2008 Chapter 216H. Greenhouse Gas Emissions (available at https://www.revisor.leg.state.mn.us/statutes/?id=216H&view=chapter)

[18] Minnesota Climate Change Advisory, April 2008. Minnesota Climate Change Advisory Group Final Report: A Report the Minnesota Legislature (available at: http://www.mnclimatechange.us/MCCAG.cfm)

general guidelines for the Legislature's role in a regional, market-based system to control GHG emissions. The House version of the Green Solutions Act of 2008 directs the Legislature to approve any regional cap-and-trade accord and authorizes studies of the program's effects on the environment, the economy, and public health. In May 2008, the Governor signed legislation requiring the Minnesota Department of Commerce and the MPCA to track GHG emissions and to make interim reduction recommendations toward meeting the state's goal of reducing GHG emissions to a level at least fifteen percent below 2005 levels by 2015, thirty percent below 2005 levels by 2025, and eighty percent below 2005 levels by 2050.[19] Developments in Minnesota's climate change and GHG policy will likely continue to take shape as Minnesota strives to meet the GHG reduction goals established in the Next Generation Energy Act.

On January 24, 2011, MPCA issued temporary rules to implement the new GHG permit requirements set by the EPA. Permanent rules must be adopted within two years. Primarily this rulemaking requires calculation of GHG emissions to determine if a permit is required. Additionally, insignificant activities were revised to reflect the GHG regulations.[20] , The MPCA plans to implement EPA's final decision to defer including biogenic CO_2 emissions in permitting through permanent rulemaking for biogenic sources for PSD and Title V purposes in late 2012. However, MPCA's temporary rules do not exclude biogenic CO_2.

In addition to policies directed at reducing statewide GHG emissions, Minnesota has instituted policies requiring the evaluation of GHG emissions as a part of the environmental review process for certain projects that require stationary source air emissions permits. In July 2008, MPCA issued a General Guidance for Carbon Footprint Development in Environmental Review. The MPCA guidance requests that project proposers, in the course of environmental review under the Minnesota Environmental Policy Act, prepare a GHG inventory for proposed projects that will require stationary source air emissions permits.

2.1.1.3 Applicability of GHG Permitting Requirements to Project

PolyMet plans to permit the Project as a synthetic minor source of green house gasses by limiting emissions below 100,000 tons per year of carbon dioxide equivalents. The general proposed approach is described in version 2 of NorthMet Proposed Synthetic Minor Limits, submitted November 4, 2011.

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[19] Minnesota Statutes 216H.

[20] Minnesota Pollution Control Agency Environmental Analysis and Outcomes Division, 2010. Notice Document: Notice of Intent to Adopt Temporary Rules Under the Good Cause Exemption, Minnesota Statutes Section 14.388, Subdivision 1, Clause 2.

It is important to note that the scope of the carbon footprint assessment in this report is considerably broader than the emissions used to determine applicability under the Federal Prevention of Significant Deterioration (PSD) program. This report includes estimates for mobile source and biogenic emissions which are not included when determining PSD applicability. In addition, this document reports maximum potential emissions. A project proposer can request permit limits to reduce allowable emissions that are the basis for PSD applicability determinations for new facilities. In the case of the Project, projected actual greenhouse gas emissions are much lower than estimated maximum potential emissions and are below the PSD major source level, which indicates the practicality of accepting permit limits. Emission levels applicable to PSD permitting are shown in the Table 1 below. Note: for permitting purposes, emissions are expresses in short tons per year; the emissions are also provided in Table 1 in metric tons for comparison to the carbon footprint calculations in this report which follow the standard convention and are reported in metric tons. The emissions provided in Table 1 are based on the most recently submitted versions of the Mine Site and Plant Site emission inventory at the time of the preparation of this report (Version 8; May 29, 2012 and Version 5; May 29,2012 respectively). Additional revisions to the emission calculations may occur as a result of the completion of air dispersion modeling.

Table 1 Point Source Emissions Comparison to Major Source Level

Source	Maximum Potential Emissions (CO_2-e, metric tons/yr)	Maximum Potential Emissions (CO2-e short tons/yr)	PSD Permitting Threshold (CO_2-e short tons/yr)	Project Actual Emissions (CO_2-e short tons/yr)
Mine Site Point Sources	1,600	1,764		773
Plant Site Point Sources	138,641	152,825		64,316
Project Totals	140,241	154,589	100,000	65,089

The two main types of greenhouse gas emission sources associated with the Project are carbon dioxide emissions from the use of limestone for acid neutralization in the Hydrometallurgical Plant and fuel usage. The oxidation of sulfur in the Autoclave is used to provide energy to the hydrometallurgical process, so process fuel usage is minimal. Most of the Project fuel usage is for support operations such as building heat and backup power generation which are not run continuously at full capacity. Therefore, projected actual greenhouse gas emissions are much lower for fuel combustion sources than potential emissions. As an example, potential emissions from building heating are based on assuming that the space heaters run at full capacity 8760 hours per year. In actual operation, the heaters only run about six months out of the year and they will only run at full capacity on the coldest winter days.

2.1.2. The Science of Climate Change

The information presented in the sections that follow draws on scientific consensus documents and peer-reviewed publications including documents of the Intergovernmental Panel on Climate Change (IPCC Reports), U.S. Environmental Protection Agency, U.S. Climate Change Science Program, MPCA and MDNR. Data presented in the sections that follow was obtained from nationally and internationally recognized data sources as well as from the Minnesota State Climatology Office[21]. The growing level of international attention to climate change has resulted in a high level of ongoing scientific study and analysis. The body of scientific knowledge of the issue is evolving relatively rapidly. The information contained herein may become out-dated quickly, but serves as a "snapshot" of the state-of-knowledge at this time. The reports referenced herein, and any subsequent reports provided by IPCC or other governmental bodies, should be consulted for more detailed or the most up-to-date information.

2.1.2.1 Climate Change Overview

A growing body of evidence indicates that the Earth's atmosphere is warming. The past 100 years have seen global average temperature increases of about 1.5°F.[22] The global average temperature has increased by about 1.2 to 1.4° F since 1890, with the ten warmest years of the past century occurring between 1998 and 2011[23].

While Earth's climate has exhibited variability and has changed over time due to a variety of earth system processes, most of the observed global average surface temperature increases since the middle of the 20th century are very likely (greater than 90% probability)[24] attributable to the observed increases in global atmospheric GHG concentrations resulting from anthropogenic GHG emissions. Observations of widespread warming of the earth's atmosphere and oceans as well as observations of ice mass loss and changes in wind patterns and temperature extremes are very likely not attributable to natural causes alone.

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[21] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)].

[22] Weflen, 2001. "The Crossroads of Climate Change". Minnesota Conservation Volunteer. Minnesota Department of Natural Resources (available at http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html)

[23] Hansen et. al., January, 2012. "Global Temperature in 2011, Trends, and Prospects." NASA GISS Surface Temperature Analysis. (available at: http://data.giss.nasa.gov/gistemp/2011/).

[24] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)].

The discussion that follows highlights the processes that have regulated Earth's climate over geologic history as well as more recent anthropogenic impacts on the Earth's climate. The discussion of processes that have regulated Earth's climate over geologic history provided below is not intended to detract from the importance of anthropogenic climate forcings in the more recent term. The discussion of longer term climate systems is intended to provide important background and context to more clearly highlight the magnitude and extent of anthropogenic impacts on the Earth's climate system. It is primarily through study of natural forcings and climate trends over geologic history that climate scientists have been able to identify the extent of anthropogenic influence on the climate system, the deviation of current climate trends from expected climate cycles, and the potential risks of abrupt climate change. A discussion of anthropogenic climate change without knowledge of longer term climate drivers and climate trends would be unproductive and without context.

2.1.2.2 Causes of Climate Change

2.1.2.2.1 The greenhouse effect

The earth's climate is largely regulated by the presence of gases and particulates that trap heat inside the earth's atmosphere or shade it from the sun. In addition changes in the sun's intensity also affect the earth's climate. Energy from the sun enters the earth's atmosphere where some of this energy is absorbed, warming the earth's surface. Some of this solar radiation is reflected from the earth's surface back into the earth's atmosphere. A fraction of the outgoing solar radiation, as well as some of the energy that is emitted from the warmed surface of the earth, is trapped by atmospheric gases (water vapor, carbon dioxide, and other gases). This heat trapping mechanism helps stabilize the earth's energy balance keeping surface temperatures relatively stable and amenable to life (see Figure 2). Large amounts of aerosols and particulates released to the atmosphere (such as those released due to large volcanic eruptions) can also have a short term cooling effect due to shading from the sun.

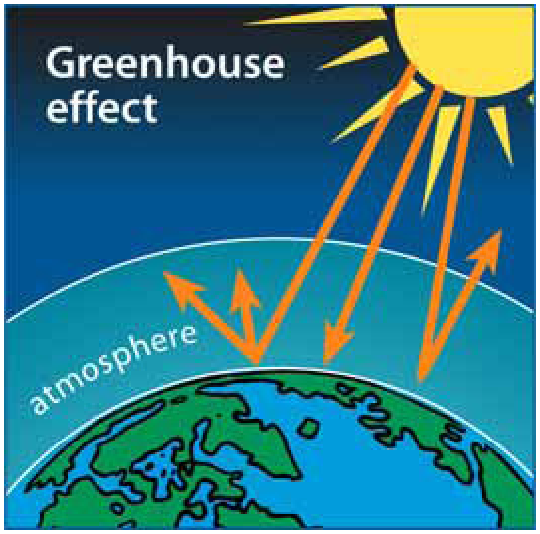

Figure 2 Diagram of the greenhouse effect[25]

2.1.2.2.2 Variations in Earth's orbit and solar intensity

Over long timescales, the earth's climate is controlled by interactions between solar radiation and the heat trapping constituents of the earth's atmosphere. Over geologic timescales, changes in the intensity of solar radiation, changes in the earth's orbit and tilt relative to the sun, and changes in the concentrations of the gasses in the earth's atmosphere that absorb, scatter and reflect solar radiation can result in changes in the earth's climate.

While information available from the EPA indicates that, "Changes occurring within (or inside) the sun can affect the intensity of the sunlight that reaches the Earth's surface. The intensity of the sunlight can cause either warming (for stronger solar intensity) or cooling (for weaker solar intensity)"[26], the magnitude of solar variability's impact on climate change is likely very small. The mechanisms and exact magnitude of the influence of solar variability on global climate change are uncertain and are the subject of ongoing scientific research and debate[27]. Over very long time scales changes in solar luminosity are hypothesized to have influenced Earth's radiation balance. Model calculations suggest that when the Sun first formed 4.6 billion years ago, it should have been approximately 70% as luminous as it is today. The

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[25] Minnesota Pollution Control Agency, 2007. "Global Climate Change. Air Quality #1.13 May 2007.

[26] http://epa.gov/climatechange/science/pastcc.html. (see Appendix B)

[27] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)]. (Section 2.7)

so-called "faint young sun paradox" points out that, if all other factors were constant, the early Earth would have been colder than it is today as a result of the lower intensity of the Sun.[28]

Solar variability over shorter timescales has received a great deal of attention due to the potential relevance of reliable estimates of solar influence in helping to isolate anthropogenic climate impacts. Available observations of total solar irradiance show variations ranging from a few days up to an 11 year solar cycle (variation between sunspot minimum and sunspot maximum of approximately 1 Wm^{-2}) and may or may not indicate a small drift on longer (e.g., 30 year) time scales[29]. The role of solar activity in climate changes remains an unproven and likely second-order effect, however, further observations and research are needed to improve the scientific understanding of solar forcing mechanisms and their impacts on the Earth's climate[30]. Nonetheless, uncertainties in solar radiative forcing are very small relative to the estimated radiative forcing due to anthropogenic changes, and modeled surface temperature impacts associated with the solar cycle are very small relative to anthropogenic changes.[31]

Changes in the Earth's orbit impact global climate via their influence on the radiation balance of the planet. Systematic, cyclical variations in the in the eccentricity (or ellipticity) of the Earth's orbit as well as the tilt and the precession (or the "wobble" in the earth's rotation about its axis) of the earth's orbit affect the earth's radiative budget over very long time scales as well. These natural changes in earth's orbital processes alter the proximity of the earth to the sun and the seasonal distribution of solar energy, a change of particular climatological importance at high latitudes and particularly in the northern hemisphere. These orbital processes function in cycles, known as Milankovitch cycles, of 100,000 (eccentricity), 41,000 (tilt), and 19,000 to 23,000 (precession) years and are hypothesized to be the primary drivers of ice ages.[32]

2.1.2.2.3 Geologic processes controlling natural levels of GHGs and aerosols

Natural geologic processes that occur on the earth's surface can exert a strong control over the concentration of GHG constituents present in the earth's atmosphere resulting in more efficient trapping of the sun's energy even under conditions where solar forcing is unchanged. Over geologic timescales,

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[28] Kump, Kasting and Crane. The Earth System. 2nd ed., 2004. Pearson Education, Upper Saddle River, NJ. (p. 14).

[29] Gray, L. J., et al. (2010), Solar influences on climate, Rev. Geophys., 48, RG4001, doi:10.1029/2009RG000282. Gray et al. point out that instrument stability and intercalibration must be studied in detail before one can be confident that the longer time scale drifts are real

[30] E. Bard, M. Frank, 2006. Earth and Planetary Science Letters 248, 1–14.

[31] Gray, L. J., et al. (2010), Solar influences on climate, Rev. Geophys., 48, RG4001, doi:10.1029/2009RG000282.

[32] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)]. (page 449)

for example, the large scale weathering of silicate minerals can result in a gradual draw down of atmospheric GHG concentrations and long term sequestration of carbon from the earth's atmosphere in carbonate minerals[33]. Similarly, over geologic timescales large amounts of organic carbon have been removed and sequestered from the earth's atmosphere as large deposits of organic material have decayed under anerobic conditions and have been trapped under high temperature and pressure. Changes in the size and distribution of land masses on earth have exerted a primary influence over earth's climate over geologic history. On shorter timescales, geologic events such as volcanic eruptions can affect climate due the release of aerosols, particulates, and carbon dioxide into the atmosphere. Volcanic aerosols tend to reflect the sun's radiation as it enters the earth's atmosphere, resulting in a short term cooling effect. The carbon dioxide emissions from volcanoes generate a longer term warming effect that persists well beyond the cooling effect generated by aerosol emissions. A number of other natural terrestrial processes contribute to variations in earth's climate due to their influence on atmospheric GHG levels. These processes include things such as natural variations in the types and extent of vegetation, large scale forest fires followed by periods of regrowth, and impacts of other natural disasters[34].

2.1.2.2.4 Earth system feedbacks

Warming which results from changes in earth's radiative balance can be exacerbated by numerous positive feedbacks in the earth's climate system. For example, greater amounts of incoming solar radiation can lead to warming which may trigger snow and ice melt and a corresponding loss of albedo[35], and even more warming. Or, for example, greater amounts on incoming solar radiation can lead to warming which may trigger outgassing of CO_2 from the world's oceans leading to higher levels of this GHG in the earth's atmosphere. This feedback might generate additional increases in temperature,

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[33] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)].(Chapter 7)

[34] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)]. (Chapter 7)

[35] Albedo is the fraction of solar radiation reflected by a surface of object, often expressed as a percentage. Snow-covered surfaces have a high albedo, the surface albedo of soils ranges from high to low, and vegetation-covered surfaces and oceans have a low albedo. The Earth's planetary albedo varies mainly through varying cloudiness, snow, ice leaf area and land cover changes. (IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)].)

snowmelt, loss of albedo and so on. These same feedbacks can work in the opposite direction to magnify slight changes in orbital forcing that create a cooling effect[36].

2.1.2.2.5 Anthropogenic GHG emissions

A growing body of scientific evidence points to anthropogenic GHG emissions as a key factor in recent global climate change. The IPCC's Fourth Assessment Report concluded that: "global atmospheric concentration of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years." A more detailed discussion of anthropogenic GHG emissions can be found below. Relatively rapid increases in global atmospheric CO_2 emissions, corresponding with the rise of the industrial revolution near the turn of the 19th century and continuing into the present, are evident in the record. The present atmospheric concentration of carbon dioxide has been judged to be higher than any time in the last 650,000 years. Approximately 650,000 years ago is the far limit of the time period over which atmospheric carbon dioxide estimates are available based on ice core data.

The strong relationship observed between rising atmospheric CO_2 levels and anthropogenic emissions of GHGs is further corroborated by observations of systematic shifts in the isotopic signature of atmospheric CO_2. Fossil fuel burning releases isotopically light carbon into the atmosphere. Fossil fuel emissions have $\delta^{13}C$ values between -20 and -30 parts per mil because they were created from organic materials which preferentially incorporate $\delta^{12}C$ into their tissues[37]. The massive anthropogenic release of this isotopically light carbon allows isotopic changes in the carbon cycle, as well as changes in reservoir masses of carbon to be traced. The signature of anthropogenic GHGs emitted to the atmosphere as the result of fossil fuel burning in the atmosphere can be observed via isotopic measurements of atmospheric carbon isotope (C-13) concentrations made on air collected in flasks at the CSIRO GASLAB[38] worldwide network. This data shows rising atmospheric CO_2 levels with a persistent anthropogenic fossil fuel GHG signature trending toward isotopically lighter $\delta^{13}C$. While this isotopic evidence may seem extraneous to some readers, the discussion has been included in this report to provide a more comprehensive

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[36] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)].

[37] Andres et al., 2000. Carbon Dioxide Emissions from Fossil Fuel Consumption and Cement Manufacture 1751-1995; and an Estimate of their Isotopic Composition and Latitudinal Distribution. The Carbon Cycle. Cambridge University Press.

[38] Allison, C.E., R.J. Francey and P.B. Krummel, April, 2003. del-13C in CO2 from sites in the CSIRO Atmospheric Research GASLAB air sampling network in Online Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center (CDIAC). Oak Ridge, TN

explanation of the link between anthropogenic emissions, rising atmospheric GHG levels, and climate change.

The IPCC Fourth Assessment Report concluded that most of the observed global average surface temperature increases since the middle of the 20th century are very likely attributable to the observed increases in global atmospheric GHG concentrations resulting from anthropogenic GHG emissions. The IPCC report also concludes that observations of widespread warming of the earth's atmosphere and oceans as well as observations of ice mass loss are best explained by a combination of natural and anthropogenic forcings and they note that the observed widespread warming of the earth's atmosphere and oceans are very likely (>90%) not due to natural causes alone (<10% probability). These trends as well as changes in wind patterns and temperature extremes are very likely not attributable to natural causes alone. According the fourth IPCC report it is likely (>66% probability) that anthropogenic forcing is responsible for increased temperatures of the most extreme hot nights, cold nights and cold days. It is likely that rapidly rising GHG concentration would have caused more than the observed warming if not for the offsetting effects of volcanic and anthropogenic aerosols. Observed trends toward tropospheric warming and stratospheric cooling are very likely due to the combined influences of anthropogenic GHG emissions and stratospheric ozone depletion.

2.1.2.3 Historic temperature trends

2.1.2.3.1 Earth's Equilibrium Temperature Sensitivity

The responsiveness of the Earth's climate system to perturbations in the Earth's radiation balance is key in assessing the potential implications of anthropogenic forcing. "Equilibrium climate sensitivity", the global mean surface warming in response to a doubling of the atmospheric CO_2 concentration after the system has reached a new steady state, is one measure of the sensitivity of the climate system to changing atmospheric greenhouse gas (GHG) concentrations. Equilibrium climate sensitivity is of particular interest because many model-simulated aspects of climate change scale approximately linearly with climate sensitivity[39].

The concept of climate sensitivity draws on the basic features of the energy balance of the Earth system. The difference between positive perturbations to the energy balance of the system (ΔF) and the increased

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[39] Knutti and Hegerl, 2008. The equilibrium sensitivity of the Earth's temperature to radiation changes, Review Article. Nature Geoscience 1, 735 – 743. Knutti and Hegerl point out however the importance of spatial and temporal aspects of climate change that equilibrium climate sensitivity does not necessarily capture.

outgoing long-wave radiation that is assumed to be proportional to the surface warming (ΔT) results in an increase in heat flux (ΔQ) in the system as illustrated in Equation (1) below:

$$\Delta Q = \Delta F - \lambda \Delta T \quad (1)$$

For a constant forcing, the system will reach an equilibrium state with ΔQ equal to zero and where radiative forcing is balanced by additional emitted long-wave radiation. The inverse of the ratio of forcing to equilibrium temperature change ($1/\lambda = \Delta T/\Delta F$) is defined as the climate sensitivity parameter (S) (in °C $W^{-1}m^2$) and the equilibrium climate sensitivity is the equilibrium temperature change associated with a doubling of atmospheric CO_2[40].

Climate sensitivity cannot be measured directly; rather, it is derived. One common approach is to use a “bottom–up” strategy, relying on present understanding of the physics of the climate system to model changes in radiation balance and associated positive and negative feedbacks, thereby arriving at an estimate of climate sensitivity. A second strategy is a “top–down” approach that relies on evidence of past climate responses to forcing to derive estimates of climate sensitivity. For example, existing work using this bottom-up approach has drawn on data for the last glacial maximum (LGM) to estimate climate sensitivity. Both approaches have advantages and disadvantages. As a potential way to capitalize on the benefits that each approach has to offer, one recent study has developed a “hybrid” approach, combining a basic understanding of the physics with data from past climate evolution, to generate an ensemble of many climate model versions that to span the range of uncertainty about the physics of the climate system, and then using the available data to constrain the range of model responses that are consistent with evidence of past climate behavior[41].

The results of these efforts are a range of potential values for climate sensitivity that vary, typically centering around a climate sensitivity value of about 3 °C, with a likely range of about 2–4.5 °C[42].

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[40] Knutti and Hegerl, 2008. The equilibrium sensitivity of the Earth’s temperature to radiation changes, Review Article. Nature Geoscience 1, 735 – 743. For more detailed explanation, caveats and further discussion please see this reference.

[41] T.S. von Deimling et al., 2006: Climate sensitivity estimated from ensemble simulations of glacial climate. Climate Dynamics 27: 149–163.

[42] IPCC, 2001: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton et. al., eds.]

However, the physics of the response and uncertainties in forcing lead to fundamental difficulties in ruling out higher values[43].

2.1.2.3.2 *Global temperature trends*

The last ice age, which occurred 18,000 years ago, yielded temperatures 7-10 degrees Fahrenheit cooler than they are today.[44] The past 17,000 years have been characterized by a slow increase in global temperatures from the ice age to the beginning of the 20th century. Scientists have identified three departures from these relatively stable climactic conditions. The Medieval Climate Anomaly was a global event with warming in Europe and Asia, drought in parts of North America and Africa, and wetter conditions in Central America. The Little Ice Age was a period of relative cooling in Europe and other effects in other parts of the world including drought in Central America and parts of China. The final anomaly begins with the Industrial Revolution. The Industrial Era has been characterized by emissions of GHGs from human activities. The past 100 years have seen average temperature increases of about 1.5°F.[45] The global average temperature has increased by about 1.2 to 1.4° F since 1890, with the ten warmest years of the past century occurring between 1997 and 2008[46]. Global temperature trends over the instrumental period and the global mean surface temperature anomaly are shown in Figure 3 that follows.

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[43] Knutti and Hegerl, 2008. The equilibrium sensitivity of the Earth's temperature to radiation changes, Review Article. Nature Geoscience 1, 735 – 743. For more detailed explanation, caveats and further discussion please see this reference.

[44] Minnesota Pollution Control Agency, 2007. "Global Climate Change. Air Quality #1.13 May 2007.

[45] Weflen, 2001. "The Crossroads of Climate Change". Minnesota Conservation Volunteer. Minnesota Department of Natural Resources (available at http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html)

[46] http://data.giss.nasa.gov/gistemp/2008/ (see Appendix B)

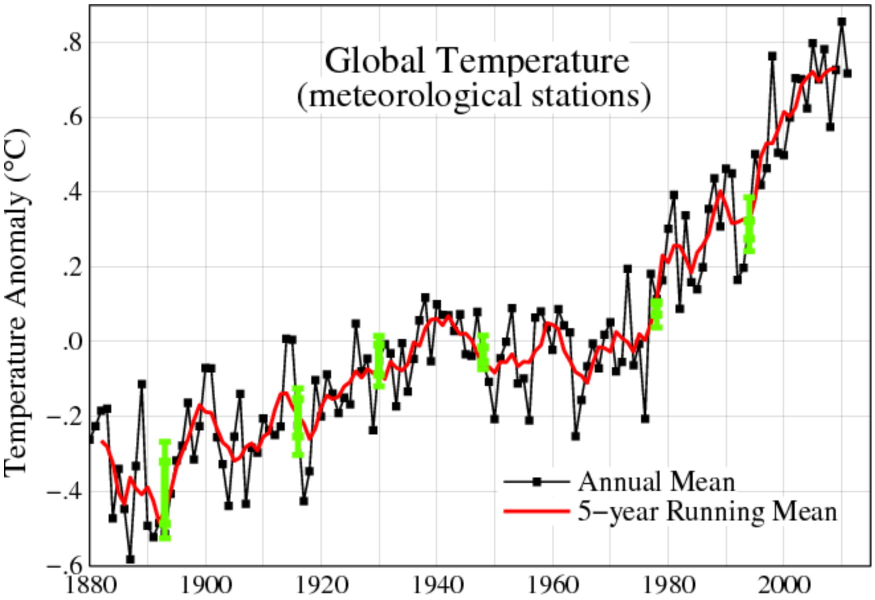

Figure 3 **Global temperature trends from the instrumental record**[47]

This warming trend has continued through the turn of the century, with records of the warmest years occurring in1998-2011.

2.1.2.3.3 U.S. temperature trends

The observed increases in global average surface temperature can also be seen in the records of average annual temperatures at the regional and state level. Over the period from 1901-2009 temperatures across the lower 48 states have risen at an average rate of 0.13° F per decade. Average temperatures have risen more quickly since the late 1970s (0.35 to 0.51°F per decade). Seven of the top 10 warmest years on record for the lower 48 states have occurred since 1990, and the last 10 five-year periods have been the 10 warmest five-year periods on record.[48] The North, the West, and Alaska have seen the greatest temperature increases, while some parts of the South have experienced little change. However, not all of these regional trends are statistically meaningful.[49] Temperatures in the U.S. over the period 1901-2009 are shown in Figure 4. In keeping with the global trend, winters in the United States have warmed more

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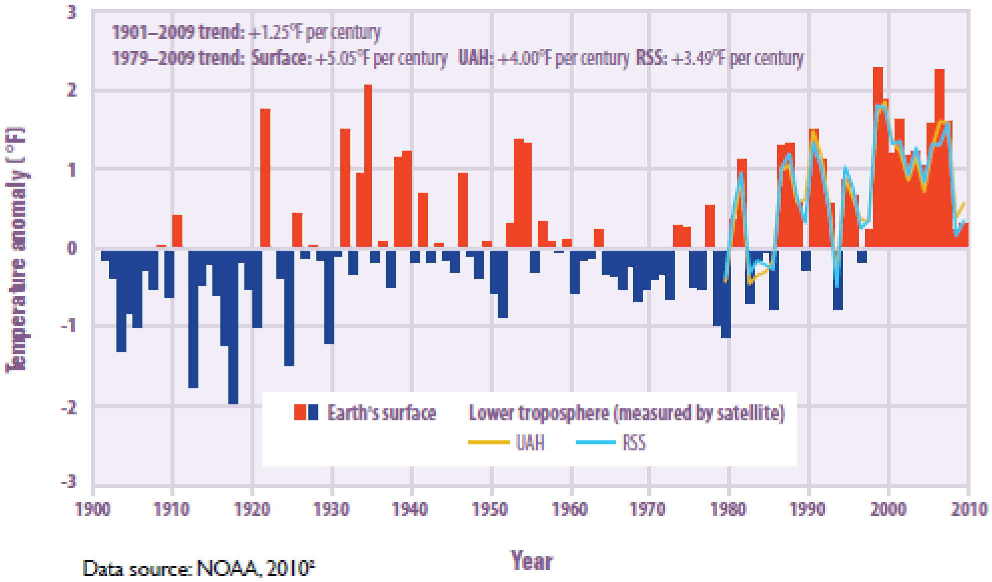
[47] http://data.giss.nasa.gov/gistemp/graphs/ (see Appendix B). This plot of global meteorological station data shows annual-mean surface air temperature change derived from the meteorological station network [This is an update of Figure 6(b) in Hansen, J.E., R. Ruedy, Mki. Sato, M. Imhoff, W. Lawrence, D. Easterling, T. Peterson, and T. Karl (2001), A closer look at United States and global surface temperature change, J. Geophys. Res., 106, 23947-23963, doi:10.1029/2001JD000354.] Green uncertainty bars (95% confidence limits) are shown for both the annual and five-year means and account only for incomplete spatial sampling of data.

[48] US EPA, 2010 Climate Change Indicators in the United States EPA-430-E-10-007

[49] US EPA, 2010 Climate Change Indicators in the United States EPA-430-E-10-007

dramatically than summers, with a marked decrease in the number of days that achieved below freezing temperatures.[50]



Data source: NOAA, 2010²

Figure 4 **Temperature anomaly in the lower 48 states, 1901-2009**[51]

Temperature trends can also be observed in seasonal average temperatures in the United States. Figure 5 below shows the spring, summer, winter and fall warming trends in national average temperatures over the instrumental record. Winters in the United States have shown the strongest trend in temperature increases with an estimated increase of 0.17°F per decade trend over the period 1895-2012. Much of this temperature increase has occurred over the last few decades, with the period from 1982-2012 showing a temperature trend of 0.46°F/decade. Spring temperatures in the U.S. have increased an average of 0.13°F per decade over the period 1895-2012. Average U.S. summer temperatures have shown a slightly lower trend of 0.11°F average per decade, although the most recent three decades on record show a steeper trend

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[50] U.S. Global Change Research Program, 2009. Global Climate Change Impacts in the United States: A state of Knowledge Report from the U.S. Global Change Research Program. Cambridge University Press. ISBN 978-0-521-14407-0

[51] Figure from US EPA, 2010 Climate Change Indicators in the United States EPA-430-E-10-007, the report notes: This figure shows how average temperatures in the lower 48 states have changed since 1901. Surface data come from land-based weather stations, while satellite measurements cover the lower troposphere, which is the lowest level of the Earth's atmosphere (see diagram on p. 20). "UAH" and "RSS" represent two different methods of analyzing the original satellite measurements. This graph uses the 1901 to 2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the trend.

of 0.52°F average per decade. Fall temperatures over the instrumental record show a trend of 0.08°F average per decade with the last three decades averaging a 0.65°F increase per decade.[52]

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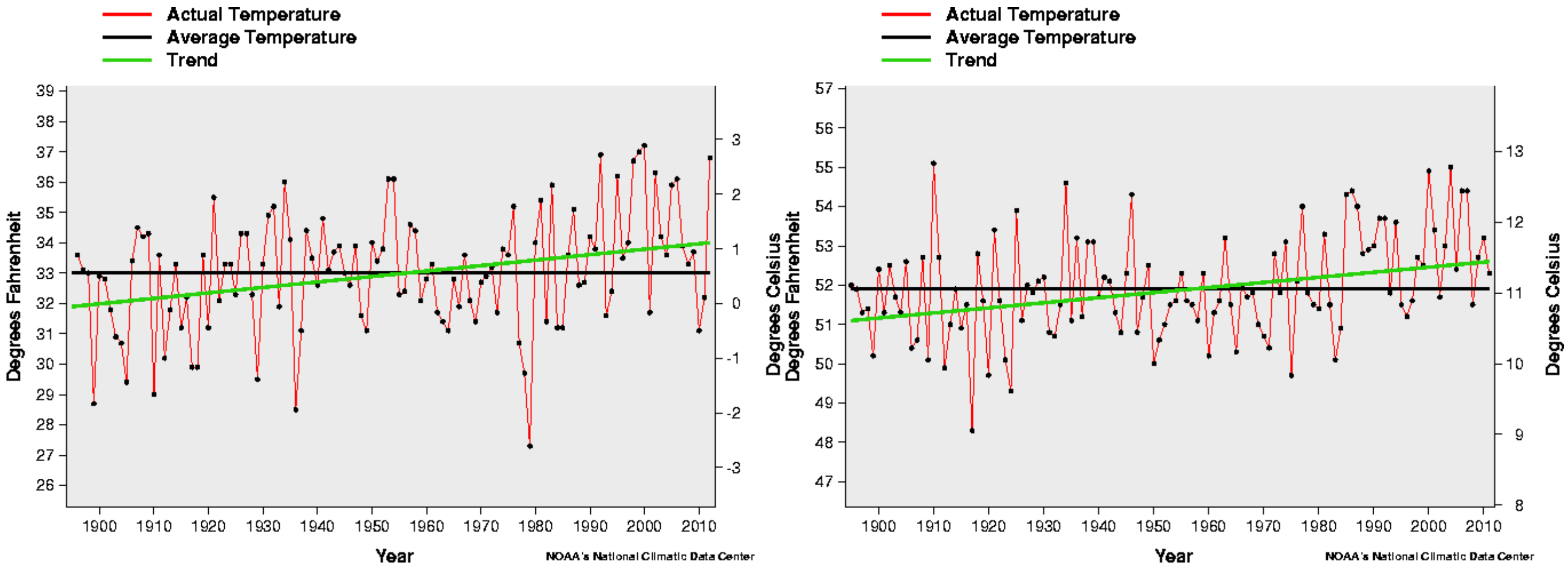
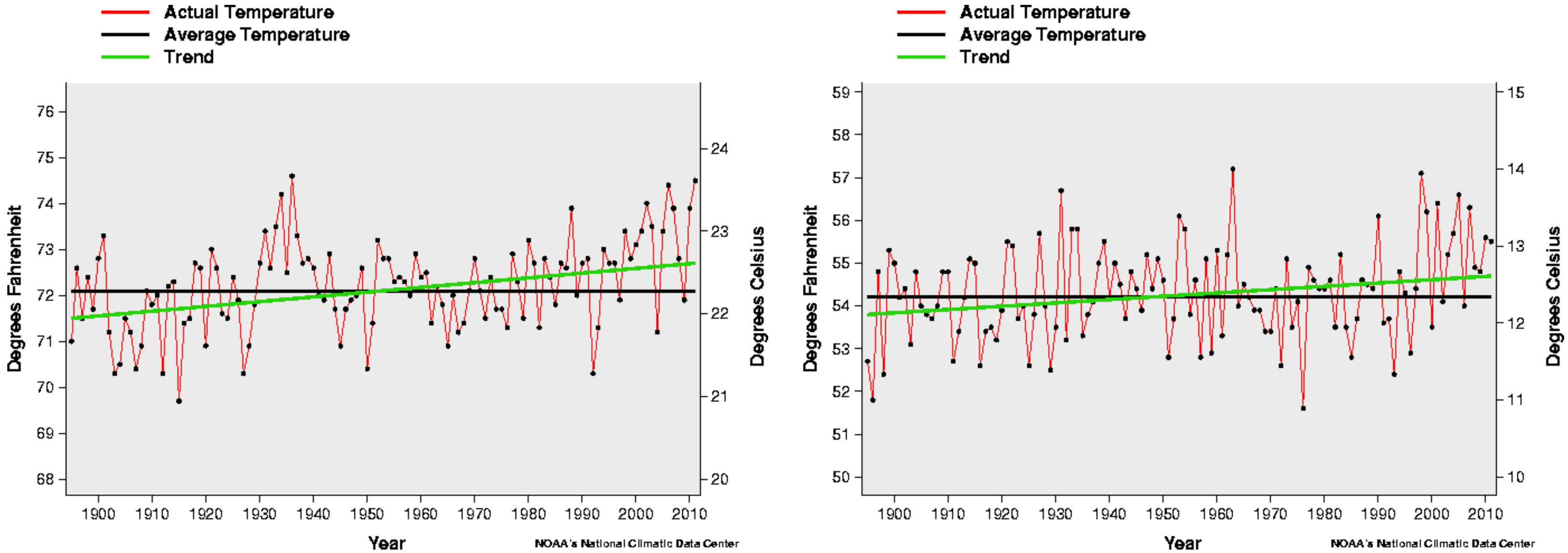
[52] http://www.ncdc.noaa.gov/oa/climate/research/cag3/na.html (see Appendix B)



a) U.S Average Winter Temperatures (Dec. – Feb.)

b) U.S Average Spring Temperatures (Mar.-May.)



c) U.S Average Summer Temperatures (Jun. – Aug.)

d) U.S Average Fall Temperatures (Sept.-Nov.)

Figure 5 **Seasonal Temperature Trends for U.S. over the instrumental period in Degrees Fahrenheit**[53]

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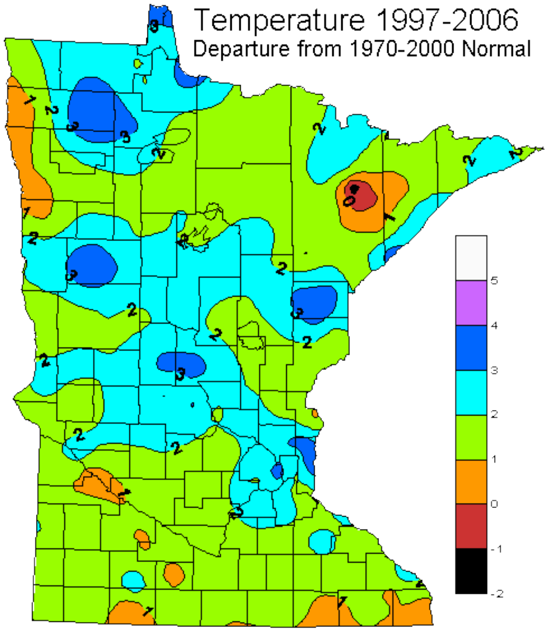
[53] http://www.ncdc.noaa.gov/oa/climate/research/cag3/na.html

2.1.2.3.4 Minnesota Temperature Trends

The annual average temperature of Minnesota has increased approximately one degree F in the last century, from 43.9° F (1888-1917 average) to 44.9° F (1963-1992 average).[54] The winter season has brought even more dramatic increases of up to 5°F in parts of northern Minnesota.[55] Much of the warming observed in Minnesota has occurred over the last few decades. The observed rate and total increase in temperatures appears more extreme when the more recent years on record are averaged. For example, the observed trend in warming is more than 5°F per century when average statewide temperatures from only 1980 to the present are considered[56]. Departures in average 1997-2006 temperatures from the 1970-2000 normal in Minnesota are shown in Figure 6.



State Climatology Office - DNR Waters, 2008

Figure 6 1997-2006 average temperatures deviation from 1970-2000 normal57

Shortened winter seasons have also been observed in the past two decades. Since 1981 Minnesota has recorded eight of the 20 warmest years in the state's history. Three of the warmest winters were recorded

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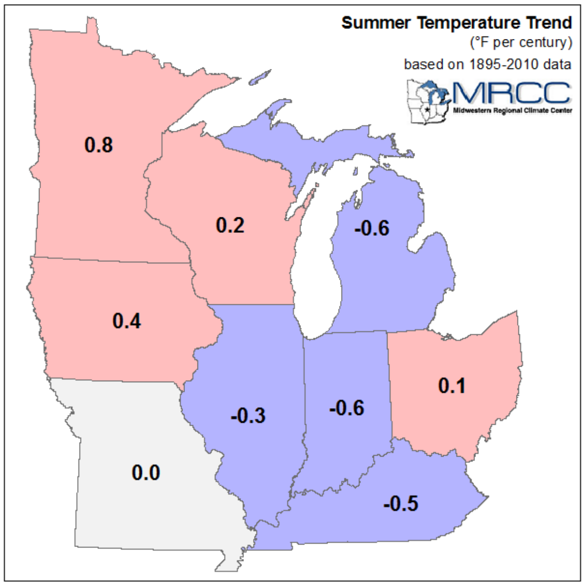
[54] Zandlo, 2008. Climate Change and the Minnesota State Climatology Office: Observing the Climate. Minnesota Climatology Working Group. (available at: http://climate.umn.edu/climatechange/climatechangeobservedNu.htm)

[55] Zandlo, 2008. Climate Change and the Minnesota State Climatology Office: Observing the Climate. Minnesota Climatology Working Group. (available at: http://climate.umn.edu/climatechange/climatechangeobservedNu.htm)

[56] Zandlo, 2008. Climate Change and the Minnesota State Climatology Office: Observing the Climate. Minnesota Climatology Working Group. (available at: http://climate.umn.edu/climatechange/climatechangeobservedNu.htm)

[57] Zandlo, 2008. Climate Change and the Minnesota State Climatology Office: Observing the Climate. Minnesota Climatology Working Group. (available at: http://climate.umn.edu/climatechange/climatechangeobservedNu.htm

in 1997, 1998, and 1999.[58] Seasonal temperature trends for summer and winter in Minnesota are shown in Figure 7.



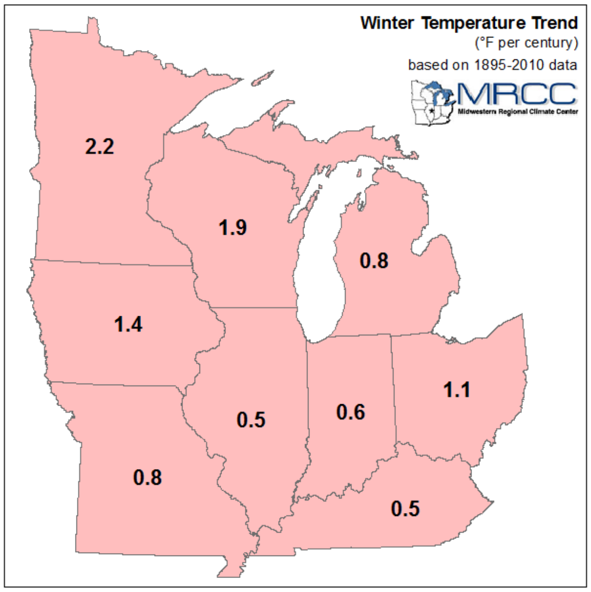


Figure 7 **Temperature trends for winter and summer seasons in Minnesota 1895-2010**[59]

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[58] Weflen, 2001. "The Crossroads of Climate Change". Minnesota Conservation Volunteer. Minnesota Department of Natural Resources (also available at http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html)

[59] http://mrcc.sws.uiuc.edu/climate_midwest/mwclimate_change.htm# (see Appendix B)

2.1.2.4 Historic trends and projections of GHG emissions

Over the earth's history atmospheric GHG levels have fluctuated due to warming and feedbacks related to the earth's orbital cycles, volcanic events and other natural contributors to GHG variability. Records of these atmospheric CO_2 variations over the last several glacial/interglacial cycles are shown in Figure 8 and are discussed in greater detail above. In more recent history, global atmospheric concentrations of three key GHGs (CO_2, N_2O and CH_4) have been increasing notably as a result of human activities since the turn of the 19th century (see Figure 9)[60].

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[60] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)] (Summary for Policymakers)

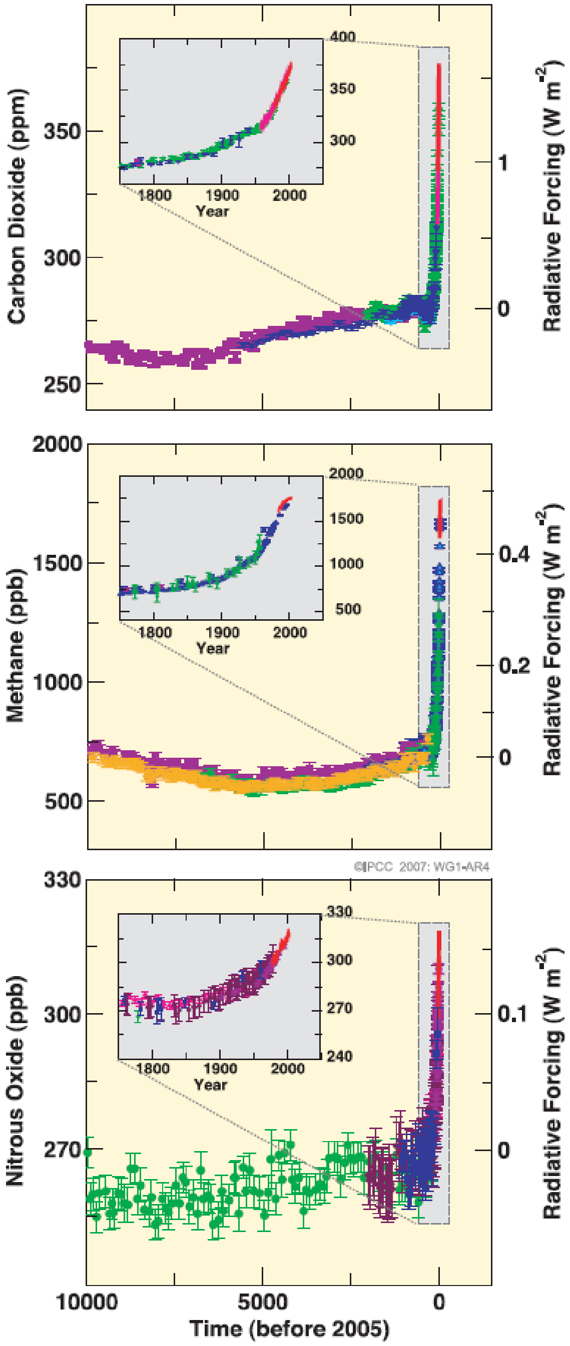

Figure 8 Global trends in GHG levels derived from paleo-proxy and instrumental records for the past several thousand years[61].

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[61] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)] (Summary for Policymakers)

At the global scale, anthropogenic GHG emissions result primarily from the burning of fossil fuels with land use and land use changes representing a secondary, but notable, source of anthropogenic GHG emissions. As shown in Figure 9, global anthropogenic emissions of CO_2 to the atmosphere have been steadily increasing since the turn of the 19th century[62].

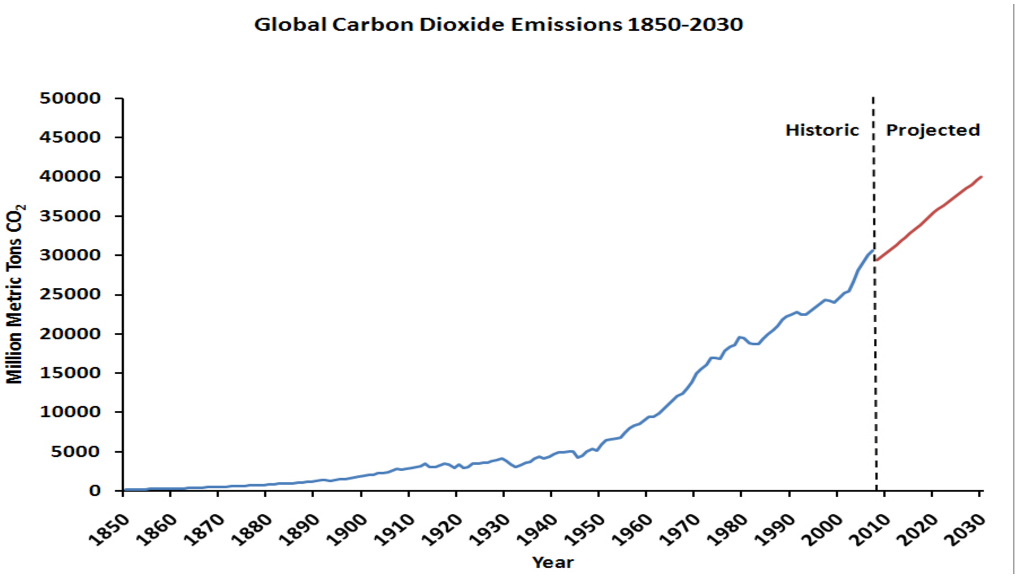

Figure 9 **Global anthropogenic CO2 emissions 1850 through 2010; predicted emissions extended to 2030[63]**

IPCC projections of future GHG emissions on the global scale (see Figure 10) are constructed for various scenarios that depend strongly on human population growth, global economic growth, the success of international efforts to curb growth in GHG emissions, and the development of new and more efficient energy sources. All projected scenarios show a trend toward increasing GHG emissions through the middle of this century[64]. The next IPCC report concerning these projected GHG emission scenarios is expected at the beginning of the year 2013.

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[62] http://www.pewclimate.org/facts-and-figures/international/historical (see Appendix B)

[63] http://www.pewclimate.org/facts-and-figures/international/historical (see Appendix B)

[64] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)] (Summary for Policymakers)

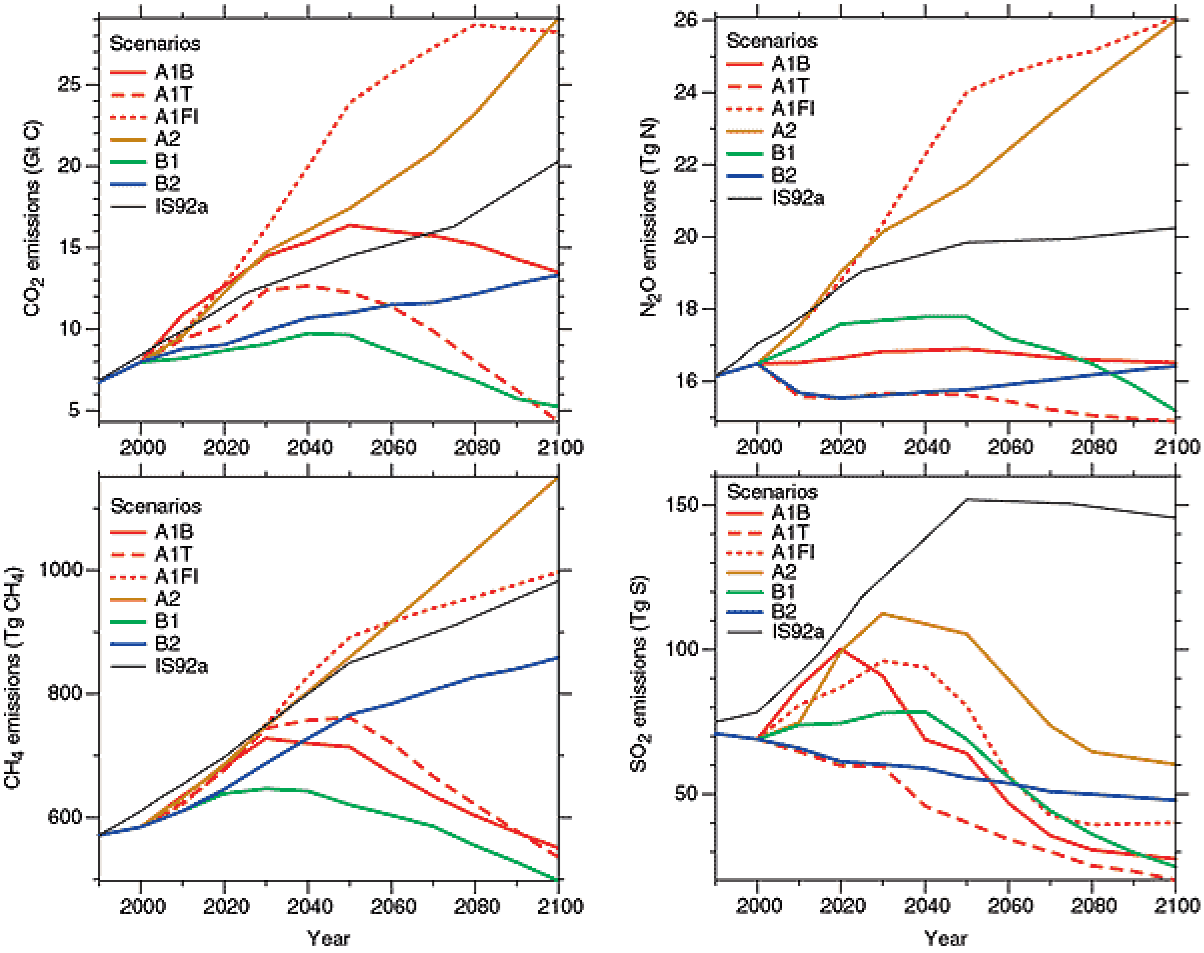

Figure 10 IPCC SRES Projections[65]

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[65] IPCC, 2001: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton et. al., eds.] (Figure 17). The Six IPCC Special Report on Emissions Scenarios (SRES) illustrative scenarios: A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the A1 and B1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

In 2009, total U.S. GHG emissions were 6,633.2 million metric tons CO_2-e, and net emissions were 5,618.2 million metric tons CO_2-e, which reflects the influence of sinks (the net CO_2 flux from land use, land use change, and forestry). While total U.S. emissions have increased by 7.3 percent from 1990 to 2009, emissions decreased from 2008 to 2009 by 6.1 percent (427.9 million metric tons CO_2-e). A decrease in economic output resulting in a decrease in energy consumption across all economic sectors as well as a decrease in the carbon intensity of fuels used to generate electricity (a phenomenon due to fuel switching as the price of coal increased, and the price of natural gas decreased significantly) are the most significant contributory factors in the reported GHG emission decrease. As the largest contributor to U.S. GHG emissions, CO_2 from fossil fuel combustion has accounted for approximately 79 percent of global warming potential (GWP) weighted emissions since 1990, from 77 percent of total GWP-weighted emissions in 1990 to 79 percent in 2009. Emissions from this source category grew by 9.9 percent (470.6 million metric tons CO_2-e) from 1990 to 2009 and were responsible for most of the increase in national emissions during this period. From 2008 to 2009, these emissions decreased by 6.4 percent (356.9 million metric tons CO_2-e). Overall, from 1990 to 2009, total emissions of CO_2 and CH_4 increased by 405.5 million metric tons CO2 CO_2-e (8.0 percent) and 11.4 million metric tons CO_2-e (1.7 percent), respectively, while N2O emissions decreased by 19.6 million metric tons CO_2-e (6.2 percent). Over the same period, aggregate weighted emissions of HFCs, PFCs, and SF6 rose by 54.1 million metric tons CO_2-e (58.8 percent)[66]. Historic estimated annual U.S. GHG emissions from anthropogenic are shown in Figure 11.

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[66] US EPA, 2011. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2009. Chapter 2: Trends in Greenhouse Gas Emissions. (http://epa.gov/climatechange/emissions/downloads11/US-GHG-Inventory-2011-Chapter-2-Trends.pdf)

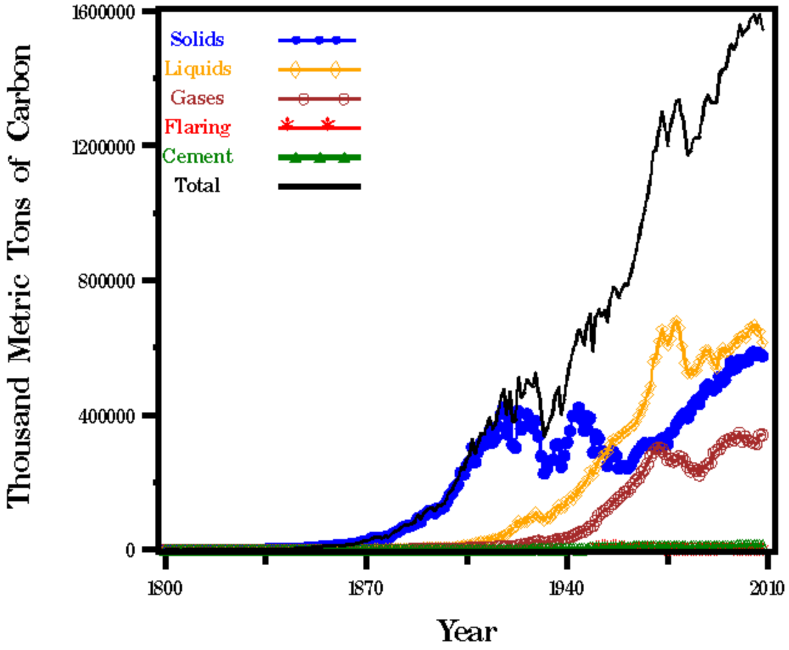

Figure 11 U.S. Carbon emissions 1800-2004[67]

Like global GHG emission projections, trends in future U.S. GHG emissions depend critically on future economic growth, population growth, and the success of alternative energy and energy efficiency measures. Through recent legislation, the Federal Government has agreed to and continues to work towards the goal of reducing its GHG pollution by 28 percent by the year 2020. This reduction and reporting of GHG pollution is meant to ensure that the Federal Government leads by example in building a clean energy economy. As the single largest energy consumer in the U.S. economy, the Federal Government spent more than $24.5 billion on electricity and fuel in 2008 alone. Achieving the Federal GHG pollution reduction target will reduce Federal energy use by the equivalent of 646 trillion BTUs[68].Estimates of historic GHG emissions in the state of Minnesota follow the global and national trend of generally increasing emission levels. Minnesota's GHG emissions are estimated to have increased about 20% since 1988.

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[67] Boden, Marland, and Andres, 2011. National CO2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2008. Carbon Dioxide Information Analysis Center Oak Ridge National Laboratory. Oak Ridge, TN. doi 10.3334/CDIAC/00001_V2011. (http://cdiac.ornl.gov/trends/emis/usa.html)

[68] White House Office of the Press Secretary, January 29, 2010. Press Release: "President Obama Sets Greenhouse Gas Emissions Reduction Target for Federal Operations. (http://www.whitehouse.gov/the-press-office/president-obama-sets-greenhouse-gas-emissions-reduction-target-federal-operations)

Trends in historic GHG emissions in Minnesota are tied to the same key economic and energy trends that play a strong role in global and national greenhouse emission trends. Historic emissions data for Minnesota presented in Figure 12 shows rapid growth in Minnesota's emissions over the period 1970 to 1979, coinciding with a period of robust economic expansion in Minnesota. During the period from the early to late 1980's economic troubles combined with de-industrialization, fuel switching and lower carbon energy sources resulted in gross reductions in statewide GHG emissions. Since the late 1980s Minnesota has trended toward rapid growth in GHG emissions.

According to MPCA: "Statewide GHG emissions increased by an estimated 51.5 million CO_2-e tons between 1970 and 2008, to a total of 159.5 million CO_2-e tons, 48 percent higher than emissions in 1970.

Between the years 1970 and 2008, the most significant growth in estimated statewide GHG emissions occurred in just two sectors: the electric power sector and the transportation sector. Emissions from transportation and electric power generation comprised roughly 41 percent of all Minnesota GHG emissions in 1970, and, by 2008, they accounted for 60 percent, more than doubling in absolute terms[69].

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[69] http://www.pca.state.mn.us/index.php/topics/climate-change/climate-change-in-minnesota/greenhouse-gas-emissions-in-minnesota.html (see Appendix B)

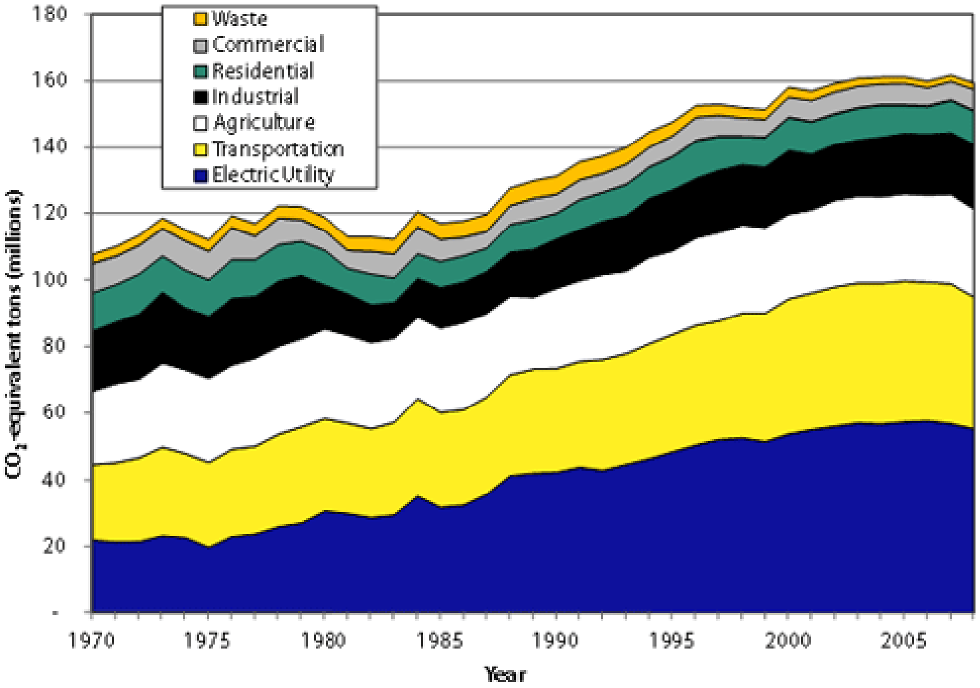

Figure 12 **GHG Emissions in Minnesota: 1970-2008**[70]

Recent state GHG reduction goals, energy efficiency targets and renewable portfolio standards will likely shape future GHG emissions in Minnesota. Minnesota is one of many states that have voluntarily joined The Climate Registry, committing to consistent and systematic monitoring of GHG emissions from state-owned properties and participating agencies. In 2007, Minnesota Governor Tim Pawlenty signed into law legislation that set a renewable energy requirement in Minnesota of 25 percent renewable generation by the year 2025. Additional 2007 legislation (Minnesota's Next Generation Energy Act) also initiates measures addressing global warming and energy efficiency. The Next Generation Energy Act sets new renewable portfolio standards for major electricity generators in the state, establishes new standards for ethanol fuel availability, sets statewide energy efficiency goals and sets per capita and total emission reduction goals for the state[71].According to the most recent data collected on Minnesota's GHG

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[70] According to MPCA: "Electric utility and transportation sectors are the primary sources of the long-term increase in greenhouse emissions in Minnesota. In 1960, these two sectors accounted for about 40 percent of all emissions from the state. By 1997, their contribution had risen to 60 percent. Increased use of electricity in homes, businesses and industry is largely responsible for the increase in emissions from the utility sector. Emissions from residences, businesses and industries that produce their own energy have remained relatively flat".

[71] Minnesota Session Laws. 2007, Regular Session. CHAPTER 136--S.F.No. 145

emissions, the MPCA has reduced GHG emissions reported to The Climate Registry in 2010 by 10% from its 2008 baseline[72].

2.1.2.5 Uncertainty in Climate Change Projection

While climate scientists have evidence to draw conclusions about certain aspects of climate change with confidence, other areas, particularly specific climate projections at the regional and local scales are less certain. At this point, scientific debate tends to center around the magnitude and spatial and temporal specifics of climate change projections with agreement among scientists regarding the causes of climate change and "virtual certainty" regarding a global warming trend[73].

According to the Intergovernmental Panel on Climate Change (IPCC), evidence has lead scientist to conclude with 99% certainty that human activities, particularly the burning of fossil fuels, have resulted in increases in the concentrations of GHGs in the Earth's atmosphere since preindustrial times. Similarly, scientists can conclude that because the major GHGs emitted by humans are known to have atmospheric residence times on the order of tens to hundreds of years, atmospheric GHG levels will continue to rise over the next few decades. The body of evidence has lead scientist to conclude with 99% certainty that higher levels of atmospheric GHG tend to warm the planet. Globally, an "unequivocal" warming of 1.0 to 1.7 °F occurred over the period 1905-2005. Warming is observed over the world's oceans and in both the Northern and the Southern hemispheres[74].

In the Fourth Assessment Report of the IPCC an international panel of more than 600 scientists concluded that "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations". The body of evidence from a growing number of scientific studies strongly suggests but cannot indisputably prove that rising levels of anthropogenic GHGs are contributing to climate change. The IPCC defines "very likely" as a greater than 90% chance the result is true. Scientists anticipate that if atmospheric concentrations of GHGs continue to rise, average global temperatures will also continue to rise and precipitation patterns will change.

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[72] Minnesota Department of Commerce and Minnesota Pollution Control Agency, January 2012. Annual Legislative Proposal Report on Greenhouse Gas Emission Reductions to the Minnesota Legislature. (available at: http://www.pca.state.mn.us/index.php/view-document.html?gid=17143)

[73] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)].

[74] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)].

Important uncertainties remain regarding the magnitude, extent and timeframe of warming. The response of other climate processes including precipitation patterns and storms is also very uncertain. Uncertainty in climate sensitivity and in future natural and anthropogenic forcing results in a broad range of projected climate outcomes. Shortcomings in the ability of models to match certain aspects of the climate system also make climate projections uncertain. As the network of observations, methods for analyzing these observations and techniques for using improved observations to inform climate models have all improved, climate scientists have been able to decrease uncertainty in some areas. In some areas more observations and better models are needed in order to improve confidence in model projections. Improvements are needed in understanding of natural climatic variations, changes in the sun's energy, land-use changes, the warming or cooling effects of pollutant aerosols, and the impacts of changing humidity and cloud cover. Determining the relative contribution to climate change of human activities and natural causes, narrowing the range of projected future greenhouse emissions and climate system responses and improving understanding of rapid or abrupt climate responses will likely also be essential components of improved climate projections.

2.1.2.6 Projected Environmental Effects of Climate Change in Minnesota

Climate change poses risks to Minnesota's current environment as Minnesota is situated in a unique location that makes it particularly vulnerable to the potential effects of climate change. Minnesota's diverse ecosystems encompass three major biomes (prairie, deciduous forest, and northern coniferous forest), and one biome with a relatively smaller spatial extent in Minnesota (Tallgrass Aspen Parkland). The boundaries between these biomes can change abruptly in response to even slightly different climactic conditions. Areas in Minnesota that support the different ecosystems sometimes differ by no more than four degrees (F) in temperature and six inches in precipitation.[75] These boundary areas function as transition zones between two different biomes and are thus more susceptible to changes induced by climate change. Minnesota's position in the northern latitudes also increases its vulnerability, because these areas have seen the greatest seasonal change over the past two decades.[76]

Throughout its geological history, Minnesota has undergone significant climactic changes, and evidence suggests a different and gradually changing landscape over the past 10,000 years. When glaciers still covered part of Minnesota spruce trees were abundant. As the glaciers retreated, these trees were replaced

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[75] Weflen, 2001. "The Crossroads of Climate Change". Minnesota Conservation Volunteer. Minnesota Department of Natural Resources (available at http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html)

[76] Weflen, 2001. "The Crossroads of Climate Change". Minnesota Conservation Volunteer. Minnesota Department of Natural Resources (also available at http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html)

with pines and oak trees. As summers became warmer, between 8,000 and 5,000 years ago prairie plants appeared in western Minnesota. Slight fluctuations in temperatures throughout the pollen record indicate a shifting back and forth of the prairie-forest border.[77]

At present, the most effective tools for climate change projection are Global Circulation Models (GCM) that effectively simulate the dynamics of the Earth's oceans, atmosphere and climate systems. When forced with similar future scenarios of natural and anthropogenic influences, many GCMs project similar climate change outcomes on a global scale. Climate projections on the regional and local scale are less consistent due to the imprecision involved in extrapolating from global to regional and local scales and the increase in model-simulated variability at these smaller scales[78]. The range of potential future anthropogenic forcing on the climate system adds an additional layer of uncertainty to climate model projections.

In 2004 a landmark study investigating climate trends and future climate changes in the Great Lakes Region was conducted using two widely accepted GCMs forced with a range of potential anthropogenic forcing futures[79]. This GCM output was then downscaled to a region and local level. They typical resolution of a GCM is on the order of 150 kilometers by 150 kilometers. This resolution limits precision and introduces new sources of uncertainty beyond those already present in the GCM output. Therefore, conclusions drawn from this work should be taken in a context of uncertainty. The study projects increasing average annual temperatures throughout the 21st century with some variation across the region and substantial variation by season. Modeled temperature projections from the study for the Midwest region during the summer and winter seasons are shown in Figure 13. The study projects more rapid increases in spring and summer temperatures, with summer temperatures likely exceeding current averages by 3-4 °F within the next 20 to 30 years. "Clear" increases in fall and winter temperatures are

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[77] Weflen, 2001. "The Crossroads of Climate Change". Minnesota Conservation Volunteer. Minnesota Department of Natural Resources (also available at http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html)

[78] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)].

[79] Kling et. al., 2003. The study Confronting Climate Change in the Great Lakes Region. A report of the Union of Concerned Scientists and the Ecological Society of America. (http://ucsusa.org/assets/documents/global_warming/greatlakes_final.pdf) relies on the results of the U.S. Department of Energy/U.S. National Center for Atmospheric Research GCM (Parallel Climate Model (PCM)) and the HadCM3 model developed by the U.S. Meteorological Office's Hadley Centre for Climate Modeling. When compared to the full range of current climate models the sensitivity (degree of warming projected in response to increases in atmospheric greenhouse gases) of the HadCM3 is moderate and the PCM's sensitivity is low) Anthropogenic forcing futures used in the model simulations span the range of business as usual projections detailed in the IPCC Special Report on Emission Scenarios (see footnote 62), thereby considering scenarios of high emissions associated with rapid economic growth and continued dependence on fossil fuels as well as lower emissions associated with a move toward more efficient technologies and sustainable economies.

apparent in model projections by the middle of the 21st century. Model results show potential winter temperature increases relative to current averages ranging from 6-14°F (averaged over the period 2070-2099) for the full range of emission scenarios evaluated. Summer temperatures show a broader range of potential temperature increases with average increases (2070-2099) in the range of 5-16 °F for the full range of emission scenarios evaluated. Fall and spring temperatures are projected to warm less than winter and summer temperatures.

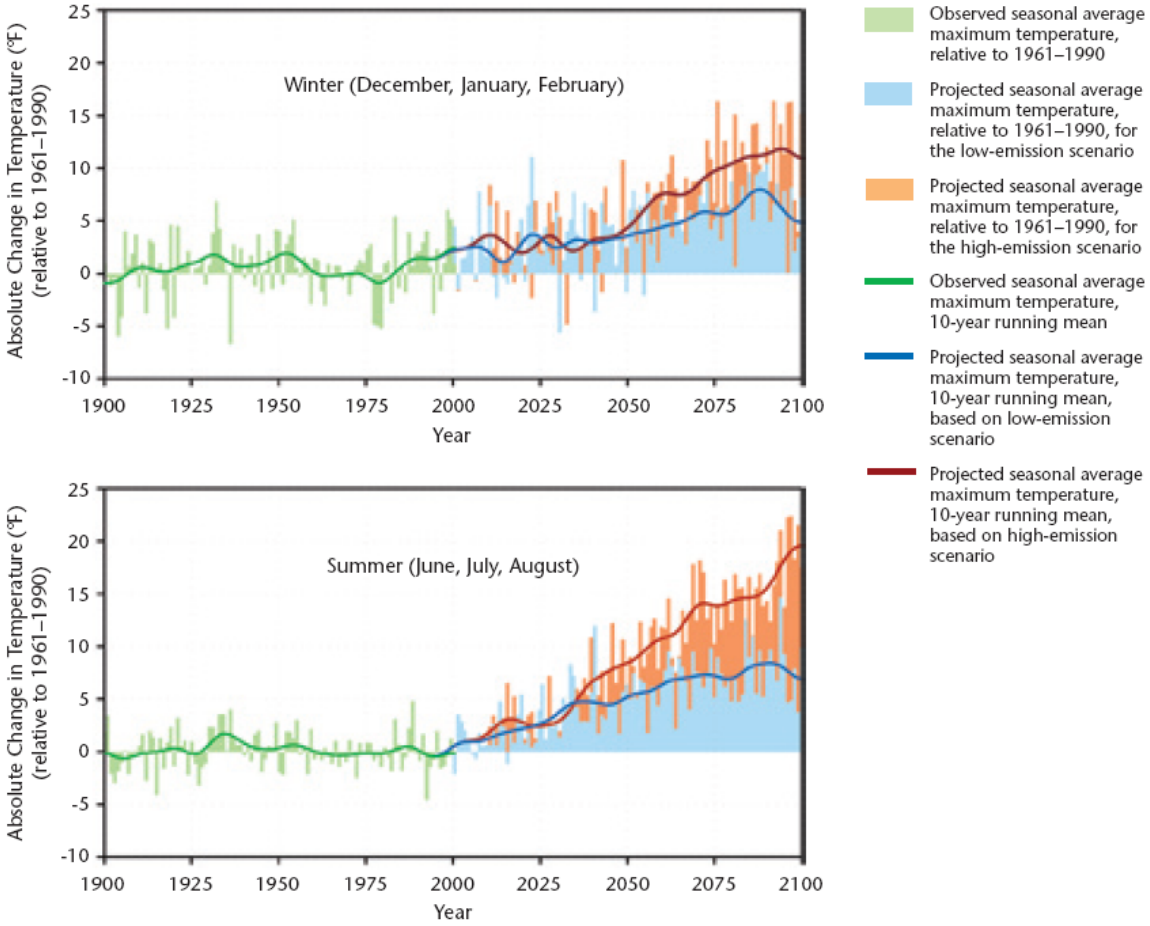

Figure 13 Great Lakes Region observed and projected average surface temperature[80]

Variation in temperature increases is likely to be observed across the region with areas centered near the great lakes showing smaller temperature increases (Figure 14). Summer warming is likely to most strongly impact the southwestern portions of the region including Southern Minnesota. Winter warming is will likely have the strongest impact on the region’s northern latitudes.

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[80] Kling et. al., 2003. The study Confronting Climate Change in the Great Lakes Region. A report of the Union of Concerned Scientists and the Ecological Society of America.

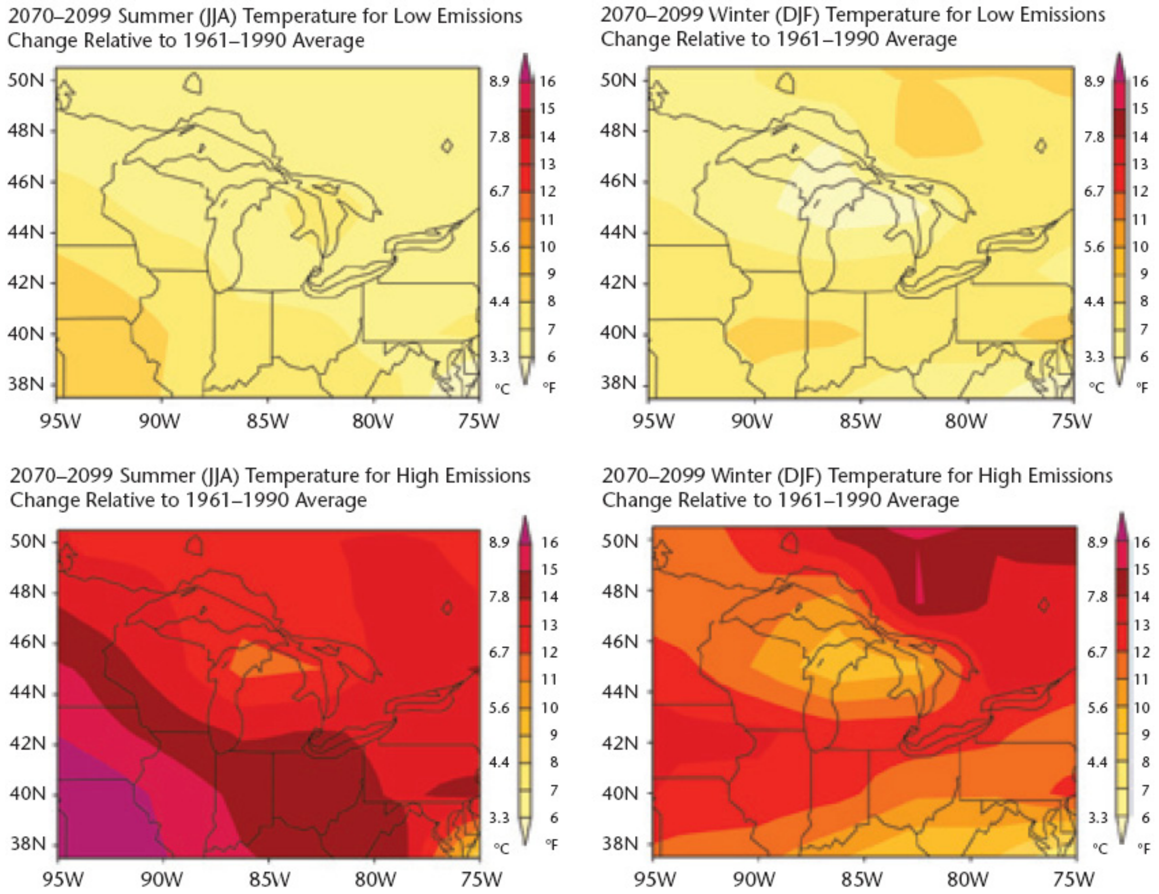

Figure 14 Projected summer and winter temperature changes 2070-2099[81]

Models project that average annual surface temperature in Minnesota will increase 6 to 10°F in the winter and 7 to 16°F in the summer by the end of the 21st century relative to the 1961-1990 baseline depending on the range of future anthropogenic GHG emissions.[82] Heat waves that are more frequent, more severe, and longer lasting are projected[83]. With this increase in temperature combined with the precipitation changes described below throughout the state, a generally wetter and more humid climate is expected for the state at least in the short term. Predictions for the long term climate of Minnesota are less certain, and include the possibility of a drier or what is referred to as a Great Plains climate, much like that found in

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[81] Kling et. al., 2003. The study Confronting Climate Change in the Great Lakes Region. A report of the Union of Concerned Scientists and the Ecological Society of America.

[82] Kling et. al., 2003. Minnesota Findings from Confronting Climate Change in the Great Lakes Region. A report of the Union of Concerned Scientists and the Ecological Society of America. (available at: http://ucsusa.org/assets/documents/global_warming/ucssummarymnfinal.pdf)

[83] US GCRP, Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009

Nebraska or a warmer, humid climate like that of Ohio.[84] Climate and vegetation zones are predicted to shift northward about 60 miles for each 1.8°F increase in temperature, indicating the potential for a complete change in the composition of Minnesota's climate affecting vegetation and wildlife.[85]

2.1.2.6.1 Precipitation

Like regional temperature projections, model projections of future precipitation changes are uncertain, particularly at the regional and local scales. Most models results indicate that precipitation in the upper Midwest region is projected to increase over the course of the 21st century with some degree of seasonal variability[86].

Under both low and high future emission scenarios analyzed for the Great Lakes Region using GCMs, precipitation is projected to rise by 10-20% above current averages by the end of the century[87]. Model projections indicate that this increase in average precipitation may be accompanied by seasonal changes as well as changes in the frequency of 24 hour and multi-day heavy precipitation events. This pattern is expected to lead to more frequent flooding, increasing infrastructure damage, and impacts on human health. Overall, winters are projected to become wetter and summers are projected to become drier across the region[88]. Winter and spring precipitation is likely to increase, especially in higher latitudes and downwind or (of?) the great lakes. Summer precipitation may decrease by as much as 50%. Projected seasonal precipitation changes are shown in Figure 15[89].

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[84] Minnesota Pollution Control Agency, 2007. "Global Climate Change. Air Quality #1.13 May 2007.

[85] Minnesota Pollution Control Agency, 2007. "Global Climate Change. Air Quality #1.13 May 2007.

[86] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)]. (Chapter 11)

[87] Kling et. al., 2003. The study Confronting Climate Change in the Great Lakes Region. A report of the Union of Concerned Scientists and the Ecological Society of America. see also footnote 133

[88] US GCRP, Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009

[89] Kling et. al., 2003. The study Confronting Climate Change in the Great Lakes Region. A report of the Union of Concerned Scientists and the Ecological Society of America., see also footnote 133

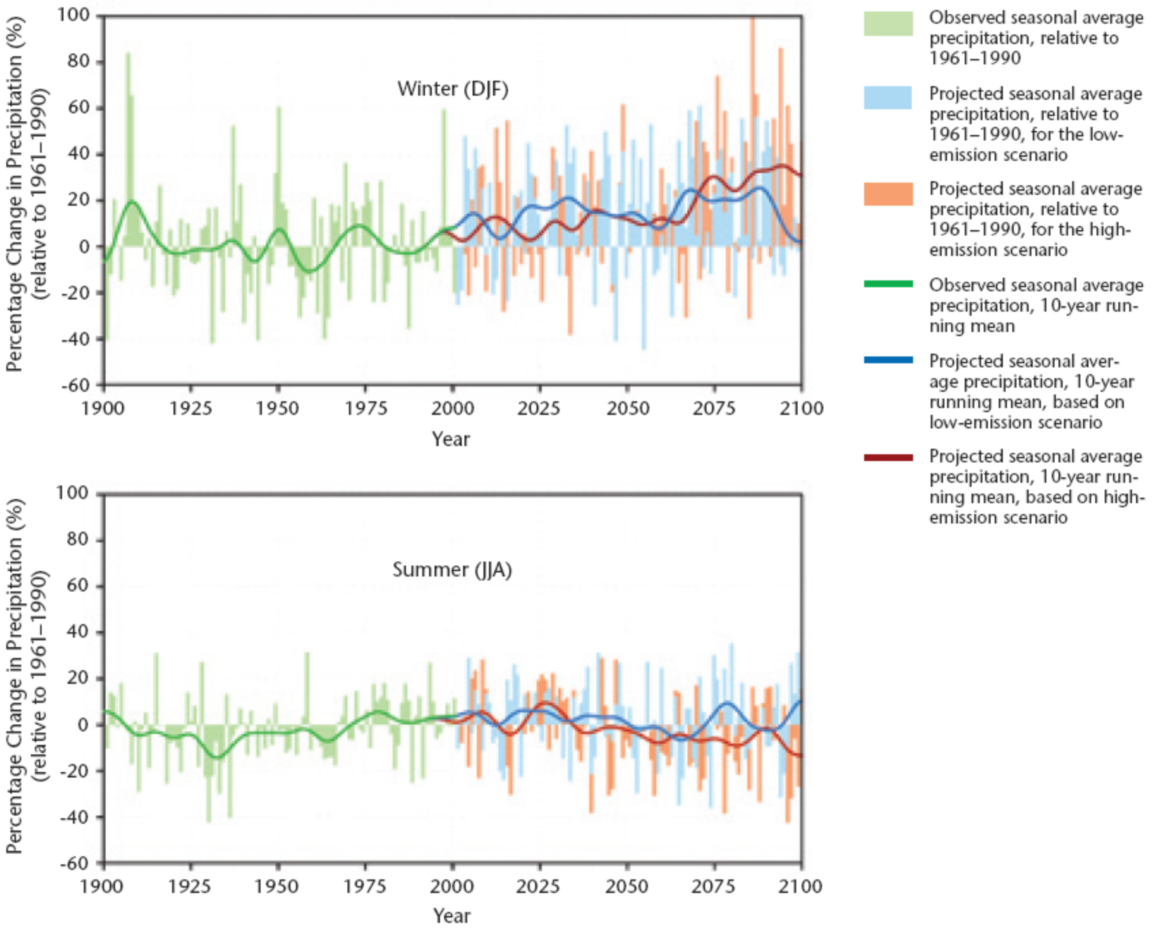

Figure 15 Observed and projected daily average precipitation for summer and winter seasons in the Great Lakes Region90

Winter, summer, and fall in Minnesota are expected to see an increase in precipitation of approximately 15% as climate change continues. Summer rainfalls of greater magnitude and frequency are projected to increase in keeping with this trend of general increase. Figure 16 shows projected changes in the frequency of heavy rainfall events for the Great Lakes Region[91]. It is possible that increased precipitation will also change patterns of severe weather events; however, these projected effects are uncertain.[92]

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[90] Kling et. al., 2003. The study Confronting Climate Change in the Great Lakes Region. A report of the Union of Concerned Scientists and the Ecological Society of America.

[91] Kling et. al., 2003. The study Confronting Climate Change in the Great Lakes Region. A report of the Union of Concerned Scientists and the Ecological Society of America., see also footnote 133

[92] Kling et. al., 2003. The study Confronting Climate Change in the Great Lakes Region. A report of the Union of Concerned Scientists and the Ecological Society of America.

Some studies indicate that the magnitude of snowfall events and duration of snow may decrease in Minnesota as a consequence of climate change.[93]

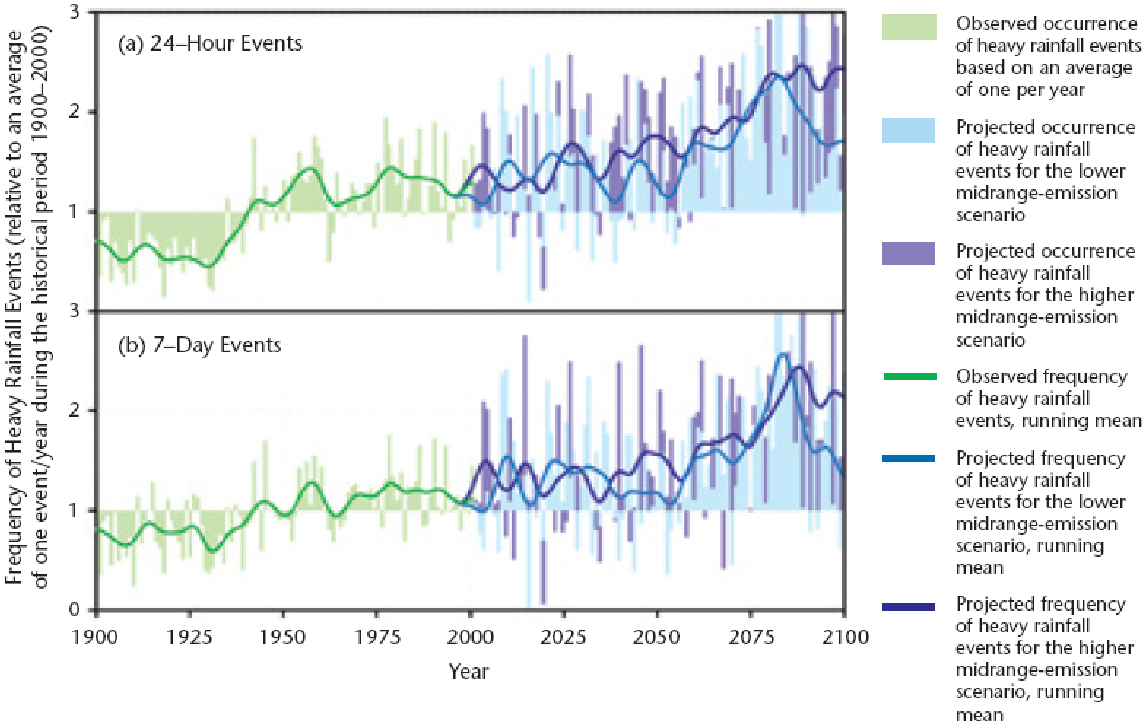

Figure 16 **Projected change in frequency of heavy rainfall events in the Great Lakes Region94**

2.1.2.6.2 Water Resources

Water resources are particularly sensitive to even slight changes in climatic conditions. As projected climate conditions in Minnesota are uncertain, the effect of this climate change on lakes and streams is also very uncertain

Increased carbon dioxide in the atmosphere can result in an increase in the amount of evaporation which is predicted to give way to significant decreases in lake, river, and stream levels of up to 12 inches[95]. Such decreases in surface water levels would likely place increased pressures on Minnesota's aquifers and other groundwater supplies. It is not clear whether increased precipitation would offset this loss, or

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[93] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)]. Chapter 11.

[94] Kling et. al., 2003. The study Confronting Climate Change in the Great Lakes Region. A report of the Union of Concerned Scientists and the Ecological Society of America.

[95] Weflen, 2001. "The Crossroads of Climate Change". Minnesota Conservation Volunteer. Minnesota Department of Natural Resources (also available at http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html)

whether moisture would be transported by the atmosphere, eventually falling as precipitation in other regions.[96] Shorter winters will result in decreased ice cover on lakes and streams and early ice breakup in the spring. Earlier ice-out may allow even higher levels of evapotranspiration, while earlier ice and snow melt may result in reduced summer flows.

Surface water temperatures may increase with increased air temperatures. Certain numerical modeling studies in which atmospheric carbon dioxide concentrations are doubled suggest a 3 to 4 °F increase in lake and stream temperatures[97]. However, a recent analysis of stream temperatures in the Pacific Continental United States indicates that western stream temperatures are not necessarily rising at the same rate as air temperatures. In fact, while some streams examined in the study show a warming trend, others showed a cooling trend, and still others showed no change at all. Snowmelt, interaction with groundwater, water flow and discharge rates, solar radiation, wind, and humidity have been identified as potential factors influencing these stream water temperature trends[98].

Warmer surface water temperatures, lower water levels and the side effects of increased evapotranspiration may have important implications for Minnesota's future water quality. While flood damage may be reduced by lower lake levels, shorelines may be more vulnerable to damage from erosion. Persistent high or low levels may reduce the diversity of plants and animals that live in, or depend on shoreline habitats. High water levels can result in flooding of near shore infrastructure[99]. Warmer and less oxygenated water may cause problems for aquatic ecosystems and lead to increased algal blooms. Reduced fresh water inflow into lakes, particularly Lake Superior, may threaten water quality.

2.1.2.6.3 Forests

Despite variation in projections of Minnesota's future environment under a regime of climate change, projections agree that forested areas of the state will undergo significant changes. The processes that typically accelerate these types of ecosystem changes such as fire and introduction of invasive species may be further exacerbated by climate change, and may catalyze changes initiated by climate change. If Minnesota's climate becomes much drier as it gets warmer, it is likely that forests will be replaced by

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[96] Weflen, 2001. "The Crossroads of Climate Change". Minnesota Conservation Volunteer. Minnesota Department of Natural Resources (also available at http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html)

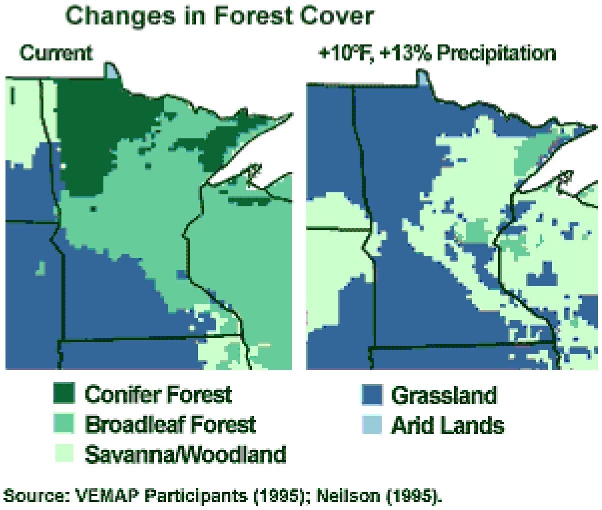
[97] Weflen, 2001. "The Crossroads of Climate Change". Minnesota Conservation Volunteer. Minnesota Department of Natural Resources (also available at http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html)

[98] 1.Ivan Arismendi, Sherri Johnson, Jason Dunham, Roy Haggerty, David Hockman-Wert. The paradox of cooling streams in a warming world: Regional climate trends do not parallel variable local trends in stream temperature in the Pacific continental United States. Geophysical Research Letters, 2012; DOI: 10.1029/2012GL051448

[99] J Wingfield, 2009. Lake Level Fluctuations: Causes and Implications. International Upper Great Lakes Study (IUGLS) Fact Sheet No. 4.

prairie ecosystems.[100] In this scenario, Minnesota's forested area could decrease by 50 to 70% (Figure 17). Drought and heat may naturally create more wildfires, further reducing the extent of Minnesota's forests.

Other climate projections anticipate that Minnesota will become wetter and forests will undergo a transition from conifers to hardwood trees that are more adapted to the wet conditions.[101] Pine, birch, and maple forests will be replaced with forest comprised of oak, elm, and ash. The transition will be manifested in the short term as oak, elm and ash gradually integrate into maturing Minnesota forests, and will leave behind a more dense, but less diverse mix of vegetation in the long run.[102]



Source: VEMAP Participants (1995); Neilson (1995).

Figure 17 Potential climate change impacts on Minnesota's forests

2.1.2.6.4 Other Ecosystems

Aquatic ecosystems may be particularly vulnerable to climate change in Minnesota. Shifts in ecosystem diversity and dominant species types would likely result if there are changes in surface water temperatures. Coldwater species can be expected to decline as cool and warm water species expand their range into warmer Northern Minnesota waters. Warmer temperatures, leading to more extreme summer stratification, and lower oxygen levels may contribute an additional threat to Minnesota's aquatic ecosystems.

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[100] Minnesota Pollution Control Agency, 2003. Minnesota Climate Change Action Plan. (http://www.pca.state.mn.us/publications/reports/mnclimate-action-plan.pdf)

[101] Weflen, 2001. "The Crossroads of Climate Change". Minnesota Conservation Volunteer. Minnesota Department of Natural Resources (also available at http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html)

[102] Weflen, 2001. "The Crossroads of Climate Change". Minnesota Conservation Volunteer. Minnesota Department of Natural Resources (also available at http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html)

Minnesota's wetland and bog ecosystems may also face challenges in a changing climate. Changes in precipitation, variations in the duration of wet and dry periods, and increases in the frequency of extreme precipitation may lead to changes in wetland type and distribution including wetland losses in some areas and wetland gains in other areas. Changing weather patterns may lead to higher levels of erosions and changes in flood pulses resulting in habitat disturbance and displacement of certain waterfowl, amphibians and other wetland fauna. Increased evaporation is also likely to result in accelerated CO_2 and methane release from wetland and peatland areas.

2.1.2.6.5 Agriculture

Changes in Minnesota's climate could have serious implications for agriculture in the state. Increasing temperatures and the resulting increased rates of evaporation decrease soil moisture and ultimately demand irrigation. This need for water may exacerbate the strain already placed on water supplies by warming, and lead to further deterioration of water quality.[103] Minnesota agriculture centers around corn, soybeans, and wheat. Projections indicate that wheat and soybeans could thrive in the warmer environment, and farm production may increase.[104] However, while the longer growing season provides the potential for increased crop yields, increases in heat waves, floods droughts, insects, and weeds will present increasing challenges to managing crops and livestock[105].

2.1.2.6.6 Human Health

Changes in Minnesota's climate and increased temperatures may cause increased likelihood of heat related illness and deaths. Warming temperatures also increase the likelihood of insect-borne illnesses, by creating more potential habitats for insects such as mosquitoes.[106] Another health-related issue arises from the fact that climate change can affect air quality. Warmer climate is projected in some studies to increase the natural emissions of VOCs, accelerate ozone formation, and increase the frequency and duration of stagnant air masses that allow pollution to accumulate, which will exacerbate health symptoms. If present-day levels of ozone-producing emissions are maintained, rising temperatures also imply declining air quality in urban areas such as those in California which already experience some of the worst air

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[103] US GCRP, Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009

[104] US GCRP, Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009

[105] US GCRP, Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009

[106] US GCRP, Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009

quality in the nation.[107]. In Addition, the last several years have witnessed an explosion in publication on the air quality impacts of climate change (see for example: http://pubs.acs.org/doi/abs/10.1021/es803650w, http://www.atmos-chem.phys.org/9/1111/2009/acp-9-1111-2009.html, http://www.atmos-chem-phys.net/8/871/2008/acp-8-871-2008.html, http://pubs.giss.nasa.gov/docs/2008/2008_Wu_etal_2.pdf, http://pubs.giss.nasa.gov/docs/2008/2008_Wu_etal_1.pdf, http://pubs.giss.nasa.gov/docs/2009/2009_Dawson_etal.pdf, http://pubs.giss.nasa.gov/docs/2008/2008_Dawson_etal.pdf, http://pubs.giss.nasa.gov/docs/2008/2008_Racherla_Adams.pdf, http://pubs.giss.nasa.gov/docs/2008/2008_Menon_etal_2.pdf, http://pubs.giss.nasa.gov/docs/2006/2006_Unger_etal_2.pdf, http://www.fypower.org/pdf/Stanford_CO2_Jacobson.pdf).

2.2. Proposed Project and Climate Change

The Project could have an effect on various resources near the Project site that may also be affected by climate change. This section includes a qualitative description of the Project's potential impacts on climate. The description is qualitative because there are no analytical or modeling tools to evaluate the incremental impact of the proposed Project's discrete GHG emissions on the global and regional climate. In addition, there are no analytical and modeling tools to evaluate any cascading impacts—that is, cumulative effects—from the proposed Project's GHG emissions on natural ecosystems and human economic systems in Minnesota or the Upper Midwest region.

This section assesses the interaction between climate change and the Project over the operating lifetime of the project, which is approximately 20 years. As noted earlier in the report, while subject to notable uncertainties, models projections suggest that the temperature may increase by 3 – 4 degrees F during the lifetime of the Project (including 20 year operating life and 60 year closure period). Models for precipitation indicate that precipitation may increase 10 – 20 percent by the end of the century, generally in the winter. As discussed in Section 2.1.2, model predictions at the spatial and temporal resolution relevant to the Project are subject to a great deal of uncertainty and the discussion below should be considered in the context of this uncertainty.

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[107] US GCRP, Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009

Details regarding the GHG emissions for the Project are discussed in Section 3.1 and in Appendix A. Based on this information, the Project is estimated to emit a total of 697,342 metric tons of CO_2-equivalent emissions per year, including both direct and indirect emissions. These emissions estimates reflect several measures already incorporated into the facility design to reduce GHG emissions. Estimated emissions from the Project will constitute 0.0014 percent of the total annual global GHG emissions estimated in 2004.[108] There may be additional emissions and lost sequestration capacity due to ground cover disturbance. An estimate of these effects is provided in Section 3.1.2 of this report.

Given the limitations of climate models in addressing the impacts of GHG emissions at the Project level on global, national, regional, and local climate, the impacts of Project GHG emissions cannot be accurately or meaningfully estimated. Project emissions represent a very small fraction of annual global GHG emissions. At present, projections of climate change impacts typically rely on Global Circulation Models (GCM) that attempt to simulate the dynamics of the earth's oceans, atmosphere, and climate systems. When forced with similar future scenarios of natural and anthropogenic influences, many of the GCMs can generate consistent projections of climate change at the global scale with global scale anthropogenic forcing. However, climate projections on the regional and local scale are less consistent because of the imprecision involved in extrapolating from global to regional and local scales, as well as the increase in model-simulated variability at these smaller scales.[109] The broad range of potential future global scale anthropogenic emission scenarios adds another layer of uncertainty to climate model projections. When compared to the internal variability in the suite of models used to project climate change impacts, the uncertainties associated with future forcing scenarios, and the limitations in model spatial and temporal resolution, Project emissions are not significant enough to allow a meaningful analysis of Project-related climate change impacts on a given environmental receptor.

Because there are no models to predict the exact impacts of GHG emissions from the Project, the following section provides a qualitative assessment of how the Project may affect the climate and how changes in climate may affect the Project. In addition to the information presented in this report, the potential effects of climate change on water quality modeling will be assessed as described in the Water Modeling Data Package Volume 1 – Mine Site, Section 5.9, and the Water Modeling Data Package

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[108] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)]

[109] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)]. Chapter 11.

Volume 2 – Plant site, Section 5.8. Beyond this, the affects of climate change are not currently being considered in any other Project impact analyses

2.2.1. Wetlands

The wetlands at the Project site are predominantly composed of coniferous bog, open bog, coniferous and hardwood swamp, and alder thicket wetlands. The impact climate change will have on wetlands in and near the Project site is uncertain. Climate changes that could affect wetlands include changes in precipitation along with changes in temperature. Precipitation is projected to increase with the increase in temperature across the state and there could be the potential for increased frequency and magnitude of rainfalls. In addition, warmer temperatures could lead to increased evapotranspiration.

It is possible that an increase in precipitation and more frequent and stronger storms combined with increased evapotranspiration could cause greater fluctuations in the water levels in the wetlands. The effects could be evident both seasonally and immediately after large storm events. Forested, bog, and shrub wetlands could see a larger increase in evapotranspiration than other wetland types. However, increased evapotranspiration could be offset by increased precipitation with minimal change in water level fluctuation. Furthermore, the coniferous bog and swamp environments that are prevalent near the Project site may be comparatively resilient to changing climates, as the forest canopy and a thick layer of sphagnum moss may act as a buffer against changes in temperature and evapotranspiration. In open water wetlands, fluctuations of water levels could change the competitive balance among the plants and invertebrates found in some wetland types. The majority of the wetlands present at the Project site, however, are associated with saturated soils and limited inundation. Invertebrates are generally less abundant in saturated wetlands than within wetlands containing standing water. Given the relatively limited presence of invertebrates and the buffer provided by the coniferous forest canopy and protective layer of sphagnum moss, it is unlikely that there would be a significant effect on invertebrates.

The increasing water temperature could impact wetland vegetation at the site. However, if coniferous forest continues to dominate the site, the shading of the forest canopy may minimize the potential for increased water temperatures. Over the period covered by the Project, it is difficult to determine what, if any, changes in species may occur. The only species that would likely have time to replace existing native northern species during the period of the Project would be invasive species. These species spread quickly under favorable conditions, both naturally and with the help of humans carrying seed from other places. Invasive species could potentially out-compete the natives and lead to a decrease in biodiversity over the lifetime of the Project.

The most current and accurate estimates of total wetland impacts expected to result from the Project are discussed in the NorthMet Project Wetland Data Package. Certain potential Project activities and influences on wetlands could be additive or even offset by climate change. Partial drainage of wetlands could be offset by increased precipitation or balanced by a potential increase in evapotranspiration. This balance, however, is dependent upon the climate change impacts on water availability, as increases in evapotranspiration are dependent upon water availability. In addition, climate change impacts on species diversity and invasive species could be accentuated by Project activities that result in wetland fragmentation. Fragmentation increases total wetland perimeter area and may enhance the potential for invasive species introduction.

GHG emissions due to the direct removal of organic matter from peatlands, and the reduction of carbon sequestration capacity due to the direct or indirect disturbance of wetland plant communities are assessed quantitatively in Section 3.1.2 as part of the overall carbon cycle impacts.

2.2.2. Water Resources

Potential regional climate changes may have an effect on the degree or type of impact from the Project on local and regional water resources, including the Partridge River, Colby Lake, and the Embarrass River. Potential climate changes predicted for the region include increased summer and winter air temperatures, increased average annual precipitation, changes in the frequency and intensity of storm events, decreased snow and ice cover, increased surface water temperatures, greater potential for flooding and erosion, increased evaporation, and reduction in coniferous forest. Currently available climate change models are unable to accurately quantify the effects of these changes on water resources at the spatial and temporal scales that are relevant to the Project. In the absence of the appropriate information to characterize the actual impacts on water resources driven by climate change, a preliminary qualitative assessment is provided below.

Increased air temperatures may result in wetter winters and either wetter or drier summers. Warmer temperatures in winter may reduce the duration of winter low flows in the Partridge or Embarrass Rivers, increase winter flows from additional melting, and reduce the magnitude and timing of spring snowmelt events. Higher winter flows would be less affected by chemical loads that might leak from stockpile liners or overflow from flooded mine pits, resulting in lower chemical concentrations than predicted in watercourses and water bodies during periods of critically low flows. Drier summers may increase the frequency of critically low flows in the summer months. Increased water temperatures could affect mercury methylation, although temperature is only one of several factors; fluctuations in the water table resulting from increased precipitation and evaporation may also affect mercury methylation.

Changes in precipitation could have multiple and potentially offsetting effects on regional hydrology and Project impacts. An increase in average annual precipitation would result in greater dilution of water chemistry effects on the Partridge River, Embarrass River, and Colby Lake. Conversely, average liner yields and liner leakage from stockpiles could increase. Greater average precipitation would accelerate the filling and improve the water quality of the West Pit. Hydrologic impacts may include higher average water levels in Colby Lake and reduced water level fluctuations in Whitewater Reservoir, as a higher level in Colby Lake will require less frequent pumping between Colby Lake and Whitewater Reservoir. The morphology of the upper reaches of the Partridge River may not be affected by increased streamflow; that section of the Partridge River has experienced high flows from past dewatering at the Northshore Mining facility. Increased average precipitation may also change the hydrologic regime of wetlands in and around the Mine Site, although this may be offset by increased evaporation.

Wetter summers (i.e., increased total precipitation, larger rainfall events) may have multiple impacts on water resources in Northern Minnesota. Larger rainfall events would likely produce more runoff from individual precipitation events (more precipitation in excess of interception and infiltration capacity). Higher event runoff could lead to higher peak streamflows, or at least higher high flows (peak flows in the Partridge River are periodically associated with snowmelt, as opposed to storm events). Greater cumulative precipitation or increased frequency of storms would likely lead to higher average streamflows. Extreme low flows typically occur in winter months, so impacts may be less apparent. More frequent/greater summer precipitation could lead to increased soil moisture, resulting in higher evapotranspiration and possibly increased groundwater recharge, ultimately observed as higher summer baseflow in streams. With respect to Project impacts, wetter summers could result in greater annual water storage in the West Pit and therefore higher discharge flows after the wild rice sensitive period. This could increase the geomorphic impacts of the Project on the receiving water bodies.

Increased frequency and magnitude of precipitation may result in potential overflows of process water systems to off-site waterbodies. Increased potential for greater head on stockpile liners from increased precipitation may also result in an increase in liner yield and leakage. Additional storm runoff could require additional capacity for wastewater treatment, larger culverts, ditches, sedimentation ponds, and process water sumps. Larger process water sumps and pond sizes could result in additional leakage to groundwater. Larger storm events may increase the risk of flood water entering the pits, requiring a shutdown of operations until flood waters are removed from work areas.

Climate change may include increased evaporation due to higher temperatures caused indirectly by additional carbon dioxide in the atmosphere. Greater evaporation may require additional modification of the Flotation Tailings Basin interior to maintain a pond in closure. In addition, the East and West Pits may take longer to flood. A decrease in the amount of liner yields may occur because of increased evaporation from the stockpile surfaces (both active and reclaimed), resulting in decreased liner leakage rates to groundwater. Other impacts could include changes in soil moisture, which may affect water chemistry of seepage at the Flotation Tailings Basin.

The Project site is located at the boundary of deciduous and coniferous forest ecosystems. The boundaries between these biomes can change abruptly in response to climatic factors. Climate change resulting in the transition of coniferous forests to deciduous forest or drier, prairie ecosystems may affect the success of coniferous reclamation cover of the Category 1 Waste Rock Stockpile.

2.2.3. Air Quality

A wetter and warmer climate and increased variability in weather patterns that may result from GHG induced climate change could potentially change the air quality impacts from the Project.

With a wetter and warmer climate the relative humidity could be higher, which could affect visibility directly as well as contribute to visibility impacts from enhanced secondary sulfate and nitrate formation. Visibility impairment in Minnesota's federal Class I areas (Voyageurs National Park and the Boundary Waters Canoe Area Wilderness) is greatly affected by sulfate and nitrate particles in the atmosphere. These particles are created when sulfur dioxide and nitrogen oxides react in the atmosphere to form ammonium sulfate and ammonium nitrate. NO_x will be emitted by combustion sources associated with the Project, including space heaters and mining vehicles. Sulfur dioxide will only be emitted in small amounts because of PolyMet's choice of processing technology and fuels. The sulfate and nitrate particles readily absorb water and grow rapidly. They grow to a size that is "disproportionately responsible for visibility impairment as compared with other particles that do not uptake water molecules."[110]

Changes or increased variability in weather patterns could potentially result in a different dispersion pattern of pollutants emitted from the Project. Different pollution dispersion patterns could affect the location and magnitude of ambient air quality impacts from criteria pollutants and the modeled visibility impacts. These changes could either increase or decrease the visibility impacts of the project on Class I areas. At this time there is no information available to predict possible changes in local wind patterns, so there is no method for predicting potential changes to visibility impacts.

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[110] Malm, William C. 1999. Introduction to Visibility. Prepared for the Cooperative Institute for Research in the Atmosphere.

Fugitive emissions from mining activities can affect local (Class II) modeled ambient air concentrations. Wetter conditions may lead to reductions in Project fugitive dust emissions and a reduction in impacts at the Project boundary.

The effect of any potential future changes in climate on the wet deposition of sulfates and nitrates in the Project area is uncertain. Wet deposition is influenced by precipitation amount and frequency (i.e., how often the material is washed out of the atmosphere), and the amount of SO_2 and NO_x (precursors to sulfate and nitrate aerosol, respectively) emitted to the atmosphere. As described earlier in this report, current predictions are that Minnesota's climate will become warmer and wetter. If the atmospheric concentration of sulfate and nitrate aerosols declines, at higher precipitation rates the amount of wet deposition that occurs in Minnesota will decline and if (at higher precipitation rate) the concentration of sulfate and nitrate aerosols increases, deposition will increase.

Monitoring data available from the NADP indicate that sulfate and nitrate wet deposition have declined in Minnesota. Sulfate wet deposition has declined since the mid-1980s. Declines in nitrate wet deposition are more recent, occurring since the late 1990s.[111] Based on foreseeable future regulations of SO_2 and NO_x emissions at the state and federal level, it is unlikely that wet sulfate and nitrate deposition would increase significantly in the future. In the absence of changes in precipitation amount or frequency, the most likely future scenario is that deposition stays the same, with a possible slight reduction.

The actual buffering capacity of Minnesota's ecosystems should also be considered in assessing potential future impacts. As reported by Eilers and Bernert[112] (1997), most lake systems in Minnesota have more buffering capacity against acid deposition than previously thought. Minnesota's lake systems are well-buffered against current and foreseeable levels of acid deposition[113]. It is likely that the inherent buffering capacity of Minnesota's ecosystems would help protect any future increases in acid deposition from climate change. The probability of which deposition scenario will actually occur is not known.

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[111] Barr Engineering. 2009. *Cumulative Impacts Analysis - Minnesota Iron Range Industrial Development Projects - Assessment of Potential Ecosystem Acidification Cumulative Impacts in Northeast Minnesota*. Prepared for U. S. Steel

[112] Eilers, J.M. and J.A. Bernert. 1997. *Temporal trends and spatial patterns in acid-base chemistry for selected Minnesota lakes.* Report to the Minnesota Pollution Control Agency.

[113] Eilers and Bernert (1997) citation (Item 1. P. ix). On P.87 of Eilers and Bernert: "The high concentrations of base cations and organic anions provides considerable buffering and neutralization capacity (Appendix F). Only under the most extreme conditions would it be possible to acidify any of these lakes from atmospheric sources." Note, in Eilers and Bernert and the NADP Monitoring data, sulfate and nitrate deposition were/are identified to be declining. Therefore, the "foreseeable levels of acid deposition" are expected to be lower than current levels, which are notably lower than in the early 1980s. Given that lakes are not showing effects from past deposition that was higher and current deposition, they should not see effects in the future with lower deposition of sulfate and nitrate.

When compared with similar metal mineral processing facilities, the emissions of NO_x and SO_2 from Project operations are estimated to be low. This is because the hydrometallurgical process proposed for the Project does not require supplemental fuel during normal operation and sulfur in the concentrate is leached out as acid in the autoclave before being precipitated in a stable form (gypsum) as opposed to being released to the air. Fuel is only used in stationary sources during startup of the autoclaves and for ancillary purposes, such as heating and backup power. Diesel fuel will also be used to power the haul trucks and some of the other large mining vehicles. The end result is that fuel usage will be lower for the Project than for metallic mineral processing facilities using techniques that require supplemental fuel combustion. Based on fuel use and an assessment of ecosystem acidification performed using current meteorological data, the Project is expected to have minimal contribution to ecosystem acidification with or without potential changes in climate.

2.2.4. Threatened, Endangered, and Special Concern Wildlife and Plants

Threatened and special concern wildlife, as well as their habitat and Minnesota listed plants, could potentially be impacted by climate change. However, it is not clear that any changes would occur over the 20 year lifetime of the Project.

The three wildlife species of interest for the Project are the gray wolf, Canada lynx, and bald eagle. The gray wolf and the bald eagle have a large range that covers many climate zones and are unlikely to be affected from an increase in temperature over the lifetime of the Project. Within the study area, local populations of Bald Eagles may or may not be affected, depending on changes in fish habitat. For the Canada lynx, northern Minnesota is the most southerly part of its range. Lynx critical habitat is primarily boreal forest. If climate change causes northward migration of the southern extent of boreal forest, lynx may migrate north as well and the numbers of lynx in Minnesota may decline. However, it is not clear that the temperature could change enough over the course of the next 20 years to cause this change.

No federal threatened or endangered plants were found onsite during the botanical survey performed for the proposed project. However, several Minnesota listed species were found, including Sparganium glomeratum, Botrychium pallidum, Botrychium rugulosum, Eleocharis nitida, Caltha natans, and Botrychium ascendens. It is impossible to determine exactly what will happen to any given species as a result of climate change. Given that northern Minnesota is at the southern end of the range for the Sparganium glomeratum, it is possible that this plant could be affected by a warmer, wetter climate.

The Iron Range represents most, or a significant portion of, the ranges of several of listed plant species in Minnesota, including B. ascendens, B. pallidum, and B. rugulosum. Outside of Minnesota, the species ranges are generally at higher latitudes and altitudes (B. ascendens and B. pallidum) or are found throughout the Great Lakes region (B. rugulosum). In many cases, the species occur in the Iron Range in early successional habitats resulting from mine disturbance and reclamation. The Iron Range likely presents a combination of habitat types, disturbance regimes, and climate that are conducive to these species. The distributional ranges suggest that climate change may reduce the abundance of these species in the state by altering biotic and abiotic factors to create more southerly conditions. In general, plant species closely associated with boreal forest communities could potentially see their southern range limit migrate northward with climate change. In general, the three species of Botrychium found on the site prefer mesic to dry areas, not wet areas. If climate changes cause the habitat to become wetter, the change could drive the Botrychium from its current locations. However, areas that are currently too dry to sustain the Botrychium could become hospitable, provided that other factors do not overwhelm the influence of added moisture.

2.2.5. Cover Types and Carbon Cycle Impacts

The Project will result in impacts to wetlands, forests, and other cover types that will affect carbon storage and sequestration in these ecosystems. However, reclamation and mitigation activities associated with the Project will offset carbon losses caused by Project activities. The magnitude of potential offset depends on many factors, including the types of impacted and restored cover types that are involved and the timescales over which restoration and re-sequestration occur. Given the uncertainty in sequestration capacities and rates in the particular ecosystems that the Project will affect and the lack of appropriate carbon storage and sequestration models, the net effect of Project activities and reclamation/mitigation activities on terrestrial carbon cycle processes is difficult to assess with precision. However, a quantitative assessment of potential terrestrial carbon cycle impacts from the direct or indirect disturbance of ground cover plant communities is provided in Section 3.1.2. An evaluation of the effect of the reclamation effort on the terrestrial carbon cycle is provided in Section 3.1.3.

2.2.5.1 Background

A February 2008 report to the MDNR detailing research conducted at the University of Minnesota indicates that the state’s wetland and forest resources are significant reservoirs of sequestered carbon.

Peatlands (including bogs, fens, marshes, and other wetlands) represent the single largest terrestrial carbon stock in the state of Minnesota. The University of Minnesota research summarized in the February 2008 report demonstrates that the 5.73 million acres of existing organic soils in “peatlands” in Minnesota contain an estimated 4,250 million metric tons of carbon (Anderson et al, 2008). This is the equivalent of approximately 745 metric tons of stored carbon per acre, based on the MDNR peatland inventory, the U.S. Department of Agriculture National Resources Conservation Service State Soil Geographic database and National Soil Information System database and, 1990 Land Management Information Center land cover data. By comparison, the University of Minnesota research estimates that in 2006, Minnesota's 16.21 million acres of forest contained 1,650 million metric tons of carbon or approximately 99 metric tons of carbon per acre.

Undisturbed peatland areas contain large, thick deposits of organic materials that have accumulated over long periods in saturated conditions where decomposition is minimal. Drainage and disturbance of these wetland areas introduce the accumulated organic material to oxygen, which results in comparatively rapid decomposition and a rapid release of CO_2 to the atmosphere. Wetland restoration, on the other hand, has the potential to sequester carbon from the atmosphere. This sequestration process occurs much more slowly than the carbon release associated with wetland disturbance but may ultimately result in total carbon accumulation that is comparable to an undisturbed wetland of a similar type. Peatlands in Minnesota have been accumulating carbon for on the order of 5,000 years and peatlands can continue to accrue carbon for millennia. Because carbon accumulation in wetlands occurs gradually and over long periods, a restored wetland must be preserved over very long timescales to offset carbon released from disturbance.

Other recently published University of Minnesota studies indicate that under certain conditions, wetland restoration may provide one of the best terrestrial sequestration options in Minnesota (in areas with enough hydric soils) (Lennon and Nater, 2006). In many areas of Minnesota, particularly in the "Prairie Pothole Region" of western Minnesota, wetlands restoration reestablishes conditions close to what prevailed prior to disturbance. This can lead to decreased rates of organic matter oxidation and potential increases in carbon sequestration. For example, restoring local hydrology and natural vegetation in previously drained wetland areas in the Prairie Pothole Region can sequester approximately 4.53 MT CO_2 $acre^{-1}$ yr^{-1} (1.2 ±1.9 MT C $acre^{-1}$ yr^{-1}) in the upper 15 cm of soil[114]. Other wetland areas have a more modest potential for carbon sequestration ranging from 0.4 to 1.1 MT CO_2 $acre^{-1}$ yr^{-1} (0.1 to 0.3 MT C $acre^{-1}$ yr^{-1}).

However, while wetlands do sequester carbon in biomass, the anaerobic decomposition that occurs in wetlands and peatlands results in the release of carbon as methane. Current research indicates that, with a few exceptions (e.g., forested upland peat and coastal wetlands), wetlands with permanently pooled water

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[114] Lennon and Nater, 2006. Biophysical Aspects of Terrestrial Carbon Sequestration in Minnesota. *Regents of the University of Minnesota.* Direct requests to the Water Resources Center, 612-624-9282.

probably result in small positive net forcing rates, based on the consideration of carbon equivalent fluxes of both CO_2 and CH_4.[115] Flooded soils can be ideal environments for CH_4 production because of their high levels of organic substrates, oxygen-depleted conditions, and moisture. The level of CH_4 emissions varies with soil conditions as well as climate. Some recent research has suggested that the opposite may be true: that in shallow lake systems, the balance between carbon withdrawals from the atmosphere (in the form of CO_2) and CH_4 emission may favor CO_2 withdrawal, implying a negative net forcing rate.[116] However, the applicability of this information to flooded wetland areas depends on the extent to which the shallow lake systems studied have carbon cycle dynamics similar to specific flooded wetland systems, an issue that is outside the scope of this report.

Fundamentally, the uncertainty surrounding wetlands' effects on the direction of the CO_2 and CH_4 fluxes, and the consequent net forcing, makes the long-term assessment of wetland degradation or removal highly uncertain from a climate change perspective. Despite this uncertainty, a quantitative analysis of the effect of wetlands impacts on the carbon cycle has been included in this report, ignoring the contribution of methane emission to net forcing as a conservative assumption.

As indicated in the February 2008 University of Minnesota study, undisturbed forest areas sequester large amounts of carbon in aboveground woody and leafy biomass as well as in below ground carbon stores. Forested areas accumulate carbon over comparatively short periods (an order of magnitude shorter than wetlands), with rapid accumulation in younger ecosystems that ultimately reaches a steady state as ecosystems reach maturity. Total accumulated carbon and sequestration rates depend on ecosystem type. In terms of total biomass production, red and white pine stands show the best carbon sequestration potential, with a steady and relatively rapid accumulation of carbon over a period of 90-120 years. Over these timescales afforested systems are effective at sequestering above-ground carbon in biomass,

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[115] IPCC fourth assessment, Report Ch. 4.4.6: "Decomposition under anaerobic conditions produces methane - a greenhouse gas. Wetlands are the largest natural source of methane to the atmosphere, emitting roughly 0.11 Gt CH_4 yr^{-1} of the total of 0.50-0.54 Gt CH_4 yr^{-1} (Fung et al., 1991). Using a Global Warming Potential (GWP) of 21 for CH_4, emissions of ~1.7 g CH_4 m^{-2} yr^{-1} will offset the CO2 sink equivalent to a 0.1 Mg C ha^{-1} yr^{-1} accumulation of organic matter. The range of CH_4 emissions from freshwater wetlands ranges from 7 to 40 g CH_4 m^{-2} yr^{-1}; carbon accumulation rates range from small losses up to 0.35 t C ha^{-1} yr^{-1} storage (Gorham, 1995; Tolonen and Turunen, 1996; Bergkamp and Orlando, 1999). Most freshwater wetlands therefore are small net GHG sources to the atmosphere. Two exceptions are forested upland peats, which may actually consume small amounts of methane (Moosavi and Crill, 1997) and coastal wetlands, which do not produce significant amounts of methane (e.g., Magenheimer et al., 1996)."

[116] The information in the Kenning PhD defense abstract regarding whether the high productivity of shallow lakes enables them to be CO_2 and/or CH_4 sinks indicates that both phytoplankton- to macrophyte-rich shallow lakes are annual CO_2 sinks and CH_4 sources during the growing season. The thesis abstract also indicates that the shallow lakes studied "appear to result in a net overall reduction in greenhouse gas warming because their uptake of CO_2 is 571-2845 times faster than their release of methane, even considering that methane is 25 × stronger as a greenhouse gas."

exhibiting carbon sequestration rates as high as 7.65 MT CO_2 $acre^{-1}$ yr^{-1} in Minnesota. Carbon sequestration rates for hybrid poplar biomass production are large as well, ranging in Minnesota from 5.05 MT CO_2 $acre^{-1}$ yr^{-1} in low-productivity stands to over 6.83 MT CO_2 $acre^{-1}$ yr^{-1} in high-productivity stands. However, most hybrid poplar biomass production sites reach peak production after 7 to 10 years (Anderson et. al, 2008).

2.2.5.2 Project Impacts on Cover Types

Project impacts on cover types at the Mine Site, Flotation Tailings Basin, Hydrometallurgical Residue Facility, and railroad/Dunka Road areas will range from removal of existing cover types to changes in existing land cover. The Mine Site consists almost entirely of native vegetation. The primary cover types at the Mine Site are mixed pine-hardwood forest on the uplands and black spruce swamp/bog in wetlands. Aspen, birch, jack pine, and mixed hardwoods comprise the remaining forest on the site. Impacts to vegetative cover types and species occur through clearing, filling, and other construction activities. Wetland impacts occur primarily through excavation, filling, and other activities that result in wetland loss or loss of wetland functions.

The most current and accurate estimates of total wetland impacts expected to result from the Project are discussed in the NorthMet Project Wetland Data Package. Wetland impacts are expected to occur primarily in the Mine Site area. Coniferous bog (Eggers and Reed Wetland Classification) is the most common type of wetland community that would be impacted. The majority of wetlands that will be impacted by the Project are given an overall wetland quality rating of "high" and are categorized as natural in origin. Carbon cycle impacts from wetland disturbances depend on a number of factors, including the amount of carbon stored in a given wetland environment, and the extent to which Project impacts will result in decreases in the rate of carbon sequestration in new biomass or even a release of stored carbon. Wetland carbon storage is known to vary by wetland type, because some wetland types are known to sequester carbon at much higher rates than others. Because wetlands tend to sequester carbon very slowly over long periods, the period over which a given wetland has been established and actively sequestering carbon also strongly impacts potential carbon releases. Appendix A has a breakdown of wetland carbon storage capacity and sequestration rates gathered from the current scientific literature.

There are a number of weaknesses in the current data surrounding wetland carbon storage capacity, sequestration rates, and emission rate upon disturbance. Studies detailing the carbon storage capacity of wetland types of a particular age are rare. The February 2008 University of Minnesota study, for example, lumps peatlands, bogs, fens, and marshlands of all ages together to arrive at an average carbon storage level of 745 metric tons of carbon per acre. The lack of specificity with regard to stand age, the length of time the wetland has been accumulating carbon, and other site characteristics makes the quantitative assessment of the total carbon storage and potential GHG fluxes that are likely to be associated with these wetland impacts imprecise. The total carbon release and the rate at which it will be released depend on several factors. First, the rate of release is highly dependent on the properties of the organic material. Variations in the age and recalcitrance of accumulated organic material will strongly influence the rate at which the carbon in stored in these materials will be broken down and returned to the atmosphere. Second, the fate of the material can strongly influence the rate and extent of carbon release. Organic materials that are buried, minimally disturbed, and used in other wetland restoration activities or stockpiled will have a greater tendency to continue to sequester stored carbon from the atmosphere because the introduction of oxygen in these settings is limited.

Despite the high degree of uncertainty in parameters that define the wetland carbon cycle, estimates of the total above-ground wetland carbon stock assumed lost due to Project activities, the total carbon stored in excavated peat and annual carbon emissions from its stockpiling, potential carbon flux associated with the use of stockpiled peat in reclamation activities, the loss of or reduction in carbon sequestration capacity of wetlands, and the annual emissions from indirectly impacted wetlands due to lowered water levels were derived and are reported in Section 3.1.2. Further descriptions of the calculations used to derive these estimates can be found in Appendix A.

Total Project impacts on non-wetland cover types are expected to affect approximately 2,100 acres, including mixed forest, deciduous forest, grassland, and shrubland. Forest clearing and disturbance may result in the loss of carbon sequestered in belowground biomass, in aboveground leafy biomass, and in aboveground woody biomass. The timescale of carbon lost from forest biomass depends on the end use of this material. Clearing and burning will result in a relatively rapid release of carbon to the atmosphere whereas manufacture of long-lived forest products such as lumber will delay the release. Because carbon accumulation in forest and grassland ecosystems occurs relatively quickly, afforestation, reforestation, and grassland restoration may offset forest disturbance over relatively short timescales.

As in the wetlands case, estimates of the total above-ground forest carbon stock assumed lost to Project activities , and the loss of carbon sequestration capacity in upland forests were derived and are reported in Section 3.1.2. Further descriptions of the calculations used to derive these estimates can be found in Appendix A.

2.2.5.3 Planned Restoration Activities

Compensatory mitigation will be undertaken for reasonably foreseeable impacts to wetlands. The primary goal of the planned wetland mitigation is to restore high quality wetland communities of the same type, quality, function, and value as those impacted by the Project. Given site limitations and technical feasibility, it is impracticable to replace all impacted wetland types with an equivalent area of in-kind wetlands. A more detailed discussion of the most recent and most accurate wetland mitigation plans can be found in the NorthMet Project Wetland Management Plan.

A qualitative comparison between total carbon released to the atmosphere as a result of Project wetland impacts and the total carbon that may be re-sequestered in mitigated wetland is not possible for two reasons.

First, the ability of restored wetlands to offset potential carbon cycle effects caused by Project wetland impacts depends on a variety of factors including the similarity of impacted and restored wetland types as well as the total acreage of each wetland type. Carbon sequestration varies considerably from one wetland type to another, with some wetland types acting as a net source of carbon and others acting as a strong sink for carbon. As noted in the 2008 University of Minnesota study, there is a dearth of measured data concerning carbon sequestration rates in restored wetlands. The study cites a potential carbon sequestration rate of 0.7 (±0.4) metric tons CO_2 per acre per year for peatland restoration and a potential sequestration rate of 4.5 (±6.9) metric tons CO_2 per acre per year for prairie pothole restoration. Studies investigating the carbon sequestration potential of wetlands at a level of detail that would make a precise comparison of the Project wetland impacts and planned mitigation possible are not available. However, studies do indicate that wetland areas with high water tables and limited drainage can tend to favor carbon accumulation as a result of anaerobic conditions. Wetland ecosystems with woody vegetation present can also tend to increase ecosystem carbon sequestration from carbon accumulation in aboveground biomass. The presence of recalcitrant mosses and other plant materials may result in higher carbon storage potential for certain wetland ecosystems.

Second, the long timescales over which wetland carbon sequestration takes place make it difficult to effectively compare potential carbon cycle effects of wetland impacts against the potential carbon cycle effects of mitigation. As discussed in Section 2.2.5.2, the timescale over which wetland impacts may result in release of carbon cannot be precisely determined given present scientific knowledge of these carbon cycle dynamics. However, wetlands tend to accumulate carbon at a relatively slow rate and some wetland/peatland areas can continue to accrue carbon for millennia. Reclamation and re-vegetation of non-wetland areas at the Mine Site and Plant Site will involve the placement of cover material suitable for vegetation over the former footprints, grading and sloping activities as needed and planting. It is anticipated that this cover material will be a soil mix that will include peat that was excavated and stockpiled during the development of the mine. The most accurate and up-to-date details regarding the requirements and sequencing of reclamation activities can be found in the NorthMet Project Reclamation Plan. As with wetland restoration, the net terrestrial carbon cycle effects of non-wetland Project impacts and restoration activities depends on the similarity of ecosystem types. As discussed above, total accumulated carbon and sequestration rates depend on ecosystem type and maturity. However, an effort has been made in this report to assess the carbon flux associated with reclamation activities, because peat extracted during mine development will comprise a fraction of the soil mixture used for cover in reclamation activities and the fate of the peat carbon stock in the Project area has been identified as an area of interest and concern during the development of the scope for this report. Further evaluation of this potential carbon flux is provided below.

3.1. Carbon Footprint for Proposed Project

3.1.1. Direct and Indirect Industrial Emission Impacts

The estimated maximum carbon footprint of the Project is based on the Project as currently proposed running at maximum capacity. The expected GHG emissions from the Project are calculated using The Climate Registry General Reporting Protocol and the MPCA General Guidance for Carbon Footprint Development in Environmental Review. As these documents suggest, GHG emissions are broken down into direct and indirect emissions. Emissions are calculated using default emission factors for specific fuels from the two documents. The carbon footprint is summarized in Table 2 and Table 3. Figure 1 shows the location and layout of the Plant Site and Mine Site. Refer to Appendix A, NorthMet Project Greenhouse Gas Emission Inventory and Energy and Efficiency Analysis, for more information on development of the carbon footprints. Detailed descriptions of emission sources at the Mine Site and Plant Site areas are also provided in Appendix A.

Table 2 Project GHG Emission Summary

Source	**Maximum Potential Direct Emissions [1]** (CO_2-e, m.t./yr) [2]	**Maximum Potential Indirect Emissions** (CO_2-e, m.t./yr)	**Maximum Potential Total Emissions [3]** (CO_2-e, m.t./yr)
Mines Site Point Source Emissions (generators, heaters)	1600		
Mine Site Mobile Source Emissions(mining equipment and vehicles, ore hauling by rail)	38,086		
Plant Site Point Source Emissions (ore crushing, concentrating, metal recovery, support equipment)	138,641		
Plant Site Mobile Source Emissions (, ongoing construction and support vehicles)	8,014		
Subtotal	186,342	511,000 **[4]**	697,342

Units = CO_2-e, m.t./yr = GHG emissions as CO_2-equivalents, in metric tons per year

[1] Direct emissions: Emissions from sources that are owned or controlled by the reporting entity, including stationary combustion emissions, mobile combustion emissions, process emissions, and fugitive emissions.

Potential direct emissions of GHGs for the Project use generally accepted emission factors and calculation methods of the World Resources Institute Greenhouse Gas Protocol Standard, International Panel on Climate Change (IPCC), and the MPCA General Guidance for Carbon Footprint Development in Environmental Review.

[2] CO_2-equivalents: The quantity of a given GHG multiplied by its total global warming potential. This is the standard unit for comparing emissions of different GHGs. For the purposes of emissions reporting, GHGs are the six gases identified in the Kyoto Protocol: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Global warming potential (100 year): The ratio of radiative forcing (degree of warming to the atmosphere) over a timescale of 100 years that would result from the emission of one unit of a given GHG compared to one unit of CO_2. Factors used in estimating CO_2-equivalent emissions: CO_2 = 1; N_2O = 298, CH_4 = 25.

As used in this analysis, emissions of N_2O have 298 times more impact than does CO_2.

[3] Total project emissions (direct + indirect) are derived by summing estimated direct project emissions of 186,342 m.t./yr with the estimate of 511,000 m.t./yr indirect emissions (186,342 + 511,000 = 697,342 metric tons).

[4] Indirect emissions: Emissions that are a consequence of the activities of the reporting entity, but that occur at sources owned or controlled by another entity. For example, emissions that occur at a power plant as a result of electricity being generated and subsequently used by a manufacturing company represent the manufacturer's indirect emissions. Electrical demand for the Project is estimated to be approximately 59.3 megawatts. The electricity to be used by the Project is planned to be generated by Minnesota Power. The emission factor used in the calculation of potential indirect emissions is from the MPCA General Guidance for Carbon Footprint Development in Environmental Review and is based on the Environmental Disclosure information filed annually by the electric utilities. See Appendix A for calculation details.

Table 3 Total Potential GHG Emissions Estimated over the lifetime of the project for the NorthMet Project Proposed to be Located near Hoyt Lakes, Minnesota

Source	Maximum Total Potential Direct Emissions (CO_2-e, m.t.)	Maximum Total Potential Indirect Emissions (CO_2-e, m.t.)	Maximum Potential Total (direct + indirect) Emissions [3] (CO_2-e, m.t.)
Mine Site [1] (mining equipment and vehicles, ore hauling, support equipment)	793,734		
Plant Site [1] (ore crushing, concentrating, metal recovery, ongoing construction and support vehicles)	2,933,103		
Construction Phase Emissions [2]	92,885		
Reclamation (Closure) Phase Emissions [3]	438,988		
Subtotal	4,258,710	10,220,000 **[4]**	14,478,710
Terrestrial carbon loss (aboveground wetland carbon stock, aboveground forest carbon stock, 20 years of emissions from stockpiled peat, emissions from peat used in reclamation)	199,591		199,591

Units = CO_2-e, m.t./yr = GHG emissions as CO_2-equivalents, in metric tons per year.

[1] Based on maximum annual emissions occurring for 20 year proposed operating life of Project

[2] Includes Phase 1 (flotation concentrate production only) and Phase 2 (Hydrometallurgical Plant) Construction

[3] Based on 20 year closure period for Plant Site and 60 year closure period for Mine Site.

[4] Indirect emissions: Emissions that are a consequence of the activities of the reporting entity, but that occur at sources owned or controlled by another entity. For example, emissions that occur at a power plant as a result of electricity being generated

and subsequently used by a manufacturing company represent the manufacturer's indirect emissions. Electrical load for the Project is estimated to be approximately 59.5 megawatts. The electricity to be used by the Project is planned to be generated by Minnesota Power. The emission factor used in the calculation of potential indirect emissions is from the MPCA General Guidance for Carbon Footprint Development in Environmental Review and is based on the Environmental Disclosure information filed annually by the electric utilities. See Attachment B for calculation details. Based on maximum annual emissions occurring for 20 year proposed operating life of Project

3.1.2. Terrestrial Carbon Cycle Impacts

In addition to the emissions of GHGs directly from the Project or indirectly as a result of electricity usage, other activities have the potential to release carbon into the atmosphere. Wetlands represent the single largest terrestrial carbon stock in the state of Minnesota. Undisturbed forest areas sequester large amounts of carbon in aboveground woody and leafy biomass as well as below ground carbon stores. The amount of stored carbon that may be released from these ecosystems as the result of Project activities is difficult to quantify. Based on Barr's understanding and the understanding reached in other adequate EIS work of the carbon cycle in wetlands and the potential impacts of the proposed project, it is likely that wetland carbon cycle impacts will include decreases in carbon sequestration capacity and a loss of some accumulated carbon, both from aboveground biomass and excavated peat. Additionally, some carbon losses from forest soils might occur. While some of the carbon released from terrestrial ecosystems as a result of Project activities will be restored over longer timescales as the site is reclaimed the analysis that follows is focused on potential releases of carbon and it is assumed that the eventual re-storage of this carbon represents a potential "better-case" scenario than the quantitative analysis indicates.

Despite possible uncertainties surrounding the extent and timing of Project activities on terrestrial carbon cycle processes, an effort has been made to quantitatively define the wetland carbon cycle impacts of the Project. Quantitative estimates for six wetland carbon cycle impact categories have been calculated and are reported in Table 4:

1. Total carbon stored in the above-ground vegetation of wetlands lost to Project activities [treated as a one-time emission]
2. Total carbon stored in excavated peat and annual emissions from its stockpiling
3. Possible carbon flux from peat used in reclamation activities
4. Annual emission rate for indirectly impacted wetlands due to potential water level drop
5. Loss of annual carbon sequestration capacity due to the disturbance of wetland plant communities discounting methane emissions from wetlands as a conservative assumption.
6. Reduction in annual carbon sequestration capacity in indirectly impacted wetlands

The total above-ground carbon stock lost to Project activities represents a theoretical cap on the amount of carbon that can eventually be released from the above-ground vegetation. All vegetation in directly impacted areas has been assumed lost in this analysis. The only ongoing annual emission rates calculated are those resulting from peat excavation and stockpiling, potential carbon flux associated with the use of excavated peat in reclamation activities, and indirect hydrologic impacts to wetlands. The loss of carbon sequestration capacity differs from emission rates in that it represents a loss of absorptive capacity rather than an actual emission. However, its net effect on CO_2 levels is essentially the same. Detailed descriptions of the calculations used to derive these estimates can be found in Appendix A.

Table 4 Wetlands Carbon Cycle Impacts Summary

Source	**Pollutant**	**Carbon Stock** (CO_2-e m.t.)	**Estimate Type [1]**
Total carbon stored in excavated peatlands [2]	CO_2	1,309,000	Central tendency
Source	**Pollutant**	**Single Emission** (CO_2-e m.t.)	**Estimate Type [1]**
Total aboveground carbon stock directly impacted by Project [3]	CO_2	65,495	High estimate
Source	**Pollutant**	**Emission Rate** (CO_2-e m.t./yr)	**Estimate Type [1]**
Stockpiled peatlands carbon emissions	CO_2	1,176	Central tendency
Wetland sequestration capacity loss from direct impacts	CO_2	1,168	Central tendency
Emissions from indirectly impacted wetlands [5]	CO_2	7.41/acre	High estimate
Wetland sequestration capacity reduction from indirect impacts [6]	CO_2	3.34/acre	Unknown

Units = CO_2-e, m.t. = GHG emissions as CO_2-equivalents, in metric tons

[1] High estimate: high degree of confidence that estimate is above actual value; Central tendency: best estimate of actual value based on available literature; Unknown: low level of confidence in relationship to actual value

[2] Based on site studies of peat in overburden.

[3] Assumes treatment of all aboveground carbon stored in impacted wetlands as a one-time carbon dioxide emission

[4] See Appendix A for full derivation

[5] Assumes carbon emission rate[117] of 500 g/m2/yr, which coincides with rates from drained and relatively undisturbed peat (See Appendix A for full derivation). Indirect wetland impacts calculated on a per acre basis as total indirect wetland impact areas were not determined at the time this report was prepared.

[6] The wetland capacity reduction in indirectly impacted wetlands is based on a reduction from 0.7 metric tons/ha/yr (sequestration rate for peatlands) to 0.33 metric tons/ha/yr (sequestration rate for mineral wetlands). Indirect wetland impacts calculated on a per acre basis as total indirect wetland impact areas were not determined at the time this report was prepared.

The aboveground wetland carbon stock that is directly impacted by the Project represents a theoretical cap on the amount of carbon dioxide stored in aboveground wetland vegetation that could hypothetically be emitted. This estimate should not be taken to mean that all wetland carbon will be emitted over a short timescale as CO_2.

Two estimates of potential annual CO_2 emissions from excavated and stockpiled peatlands have been provided: a high estimate based on data from fairly dry, harvested peat and stockpiles; and a lower estimate based on data from drained but relatively undisturbed peat. Additionally the loss of carbon sequestration capacity from directly impacted wetlands has been estimated, by matching estimates of sequestration capacity found in the scientific literature to acreages of indirectly and directly impacted wetlands determined during the wetland delineation study.[118] Methane emissions from wetlands were discounted in the calculation of net changes due to direct and indirect wetland impacts. Additional details, including the sources of sequestration rates and acreages, can be found in Appendix A.

An effort has also made to quantitatively define the forest carbon cycle impacts of the Project. Details of these calculations and the underlying assumptions can also be found in Appendix A. Table 5 below summarizes potential forest carbon cycle impacts from the Project.

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[117] Grønlund, A., A. Hauge, A. Hovde, and D.P. Rasse. 2008. Carbon loss estimates from cultivated peat soils in Norway: a comparison of three methods. Nutrient Cycling in Agroecosystems. 81(2):157-167.

[118] Barr Engineering Company. November 19, 2008. Updated Table 5-1.1-A. Original report - RS-14 Wetland Delineation and Functional Assessment, Draft-02, November 20, 2006. Minneapolis, MN.

Table 5 Forest Carbon Cycle Impacts Summary

Source	**Pollutant**	**Single Emission** (CO_2-e m.t.)	**Estimate Type [1]**
Total aboveground carbon stock directly impacted by Project [2]	CO_2	102,052	High estimate
Source	**Pollutant**	**Emission Rate** (CO_2-e m.t./yr)	**Estimate Type [1]**
Upland forest sequestration capacity loss from direct impacts	CO_2	1,814	Central tendency

Units = CO_2-e, m.t. = GHG emissions as CO_2-equivalents, in metric tons

[1] Theoretical max: maximum value possible given physical variables; High estimate: high degree of confidence that estimate is above actual value; Central tendency: best estimate of actual value; Unknown: low level of confidence in relationship to actual value

[2] Assumes treatment of all aboveground carbon stored in impacted forest as a one-time carbon dioxide emission

The aboveground forest carbon stock loss due to direct Project impacts is a theoretical maximum of the amount of carbon dioxide stored in the impacted forest vegetation. This estimate should not be taken to mean that all aboveground forest carbon will necessarily be emitted over a short timescale as CO_2. The net carbon cycle impact is highly dependent on the end-use of the cleared vegetation. The loss of carbon sequestration capacity from the directly impacted upland forest has been estimated. The loss of forest sequestration capacity was calculated by matching estimates of sequestration capacity found in the scientific literature to acreages of impacted forests determined during wildlife habitat surveys.[119] Additional details, including the sources of sequestration rates and acreages, can be found in Appendix A.

A summary of the carbon cycle results annualized over the Project life cycle is presented below in Table 6.

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[119] ENSR. March 22, 2004. Winter 2000 Wildlife Survey for the Proposed NorthMet Mine Site, St. Louis County, Minnesota. ENSR Document Number 5461-001-300. Golden, CO; ENSR. July 2004. NorthMet Mine Summer Fish and Wildlife Study. ENSR Document Number 05461-002-400. Redmond, WA.

Table 6 Terrestrial Carbon Cycle Annual Impacts Summary

Source	**Pollutant**	**Emission Rate** (CO_2-e m.t./yr)	**Estimate Type [1]**
Annualized aboveground carbon loss from wetlands [2]	CO_2	3,275	High estimate
Annualized aboveground carbon loss from forests [2]	CO_2	5,103	High estimate
Stockpiled peatlands carbon emissions (high)	CO_2	1,176	Central Tendency
Wetland sequestration capacity loss from direct impacts	CO_2	1,168	Central tendency
Forest sequestration capacity loss from direct impacts	CO_2	1,814	Central tendency
Wetland sequestration capacity reduction from indirect impacts [3]	CO_2	[3]	Unknown
Emissions from indirectly impacted wetlands [3]	CO_2	[3]	High estimate
Total emissions (with high stockpiled peatland estimate)	CO_2	*12,535*	*High estimate*

Units = CO_2-e, m.t. = GHG emissions as CO_2-equivalents, in metric tons

[1] Theoretical max: maximum value possible given physical variables; High estimate: high degree of confidence that estimate is above actual value; Central tendency: best estimate of actual value; Unknown: low level of confidence in relationship to actual value

[2] Annualized results are generated by dividing the assumed one-time aboveground carbon emissions by the 20-year Project life

[3] Indirect wetland impacts on a per acre basis only as indirect wetland impact areas were not finalized prior to drafting of this report. Sequestration capacity loss = 3.34 metric tons CO_2/acre/year. Annual carbon loss = 7.41metric tons CO_2-e./acre/yr

3.2. Alternatives Analysis: Hydrometallurgical vs. Pyrometallurgical Processing

Two main alternatives are available for processing a sulfide ore: 1) hydrometallurgical processing – as proposed for the Project and 2) pyrometallurgical processing – commonly referred to as smelting. A comparison was made between these processing options to evaluate the effect of the chosen processing method on the GHG emissions for the Project as well as overall environmental impacts. While the June 2009 NorthMet Project Climate Change Evaluation report included a quantitative comparison between the carbon intensity of the NorthMet process and carbon intensities for smelting process at facilities in Sweden and Finland, changes in the proposed NorthMet process since June 2009 have made a direct quantitative comparison problematic. However, Bateman Engineering (2005) estimated that the hydrometallurgical process has approximately 50% less energy demand than a copper smelting process.

Less energy demand is one indicator of potentially lower GHG emissions and possibly a lower carbon intensity.

3.3. Conclusions

The potential annual direct and indirect GHG emissions from the Project are estimated as follows (as metric tons CO_2-e): direct = 186,342 indirect = 511,000, total = 697,342.

A hydrometallurgical process uses approximately 50% less energy than a smelting process (Bateman Engineering, 2005). Energy usage is generally an indicator of GHG emissions, but this is not conclusive evidence that the hydrometallurgical process proposed for the Project has lower GHG emissions than a smelting operation because the majority of the GHG emissions from the metal recovery component of NorthMet's process come from neutralization, not energy use.

The calculation of terrestrial carbon cycle impacts from the Project is an imprecise undertaking; however, a number of conclusions can be drawn. The first is that the total impacts normalized over the 20-year lifespan of the Project are fairly small compared to the impacts from fuel use and the industrial process components of Project emissions. The second is that, despite the large amount of carbon contained in the excavated peat and conservative assumptions used in their calculation, annual CO_2 emissions from stockpiled peat represent less than 0.5% of the emissions from fuel use and nonfuel industrial processes for the Project. This is not to say that higher emission rates for these specific carbon cycle impact categories are not possible but that they are unlikely given the conservative assumptions embedded in this analysis.

4.0 **GHG Reductions**

4.1. Project GHG reduction measures

As part of the Project, PolyMet has considered and is taking measures to reduce GHG emissions and decrease the carbon intensity of production by improving both energy and production efficiency. As noted in Section 3.2 of this report, PolyMet's choice to implement a hydrometallurgical process rather than a pyrometallurgical process results in an expected reduction in energy usage. This may or may not reduce project GHG emissions below levels that are typical at existing pyrometallurgical facilities. In addition, PolyMet is reducing GHG emissions by choosing equipment which runs on low CO_2 emitting fuel options and implementing process designs which maximize energy efficiency.

When new motors are required, PolyMet will purchase premium efficiency motors rather than standard motors. Motor efficiencies will vary depending on motor size and load. Small (1 hp) motors will have an estimated of maximum efficiency of 85%, larger motors (250 hp) will have an estimated maximum efficiency of 96%. A portion of the overall electrical load will come from new, larger motors, so this will help maximize overall efficiency. In addition, gravity transport of process slurries will be used where possible, instead of pumps. PolyMet also intends to configure the Process Plant such that the overall power factor for the facility is as close to one as practical. This will help minimize the current and therefore power losses on the power line servicing the facility.

The primary production excavators and one of the two blast hole drills will be electric rather than diesel powered, eliminating a direct source of GHG emissions. Instead of employing used conventional locomotives, PolyMet will purchase new Gen-Set locomotives, which are more efficient and use less fuel. Also, space heating in the Process Plant is a major contributor to total direct GHG emissions. To reduce GHG emissions, PolyMet will employ natural gas fired space heaters. Estimated maximum CO_2-equivalent (CO_2-e) emissions from natural gas are less than other fuels, which will reduce direct and indirect GHG emissions.

In addition to selecting a low emitting fuel for space heating, the exhaust from the emission controls utilizing cartridge type filtration for the Coarse Crusher, Drive House #1, Fine Crusher and Concentrator Buildings will be recycled back into the buildings, where practical, and reduce the amount of ambient make up air drawn into the building. Any emission control system exhaust recycled back into a building will pass through a supplemental HEPA filter. Two potential suppliers of HEPA filters have been contacted. Both indicate that these filters are capable of achieving 99.97% efficiency on 0.3 micron particles. The recycling back into the building is seasonally dependent for some collectors, while others will discharge back into the building year round. The recycling of emission control exhaust will reduce the space heating requirements at the Plant Site as it allows for reuse of air that has already been heated, rather than only passing it through the system one time. This will reduce fuel usage and therefore GHG emissions.

Estimated heating fuel usage, and therefore greenhouse gas emissions, have been further reduced by the proposed installation of additional insulation in the existing 1950's vintage Coarse Crusher, Drive House #1, Fine Crusher and Concentrator Buildings at the Process Plant.

A more detailed description of energy efficiency and actions designed to reduce GHG emissions is found in Appendix A, NorthMet Project Greenhouse Gas Emission Inventory & Energy and Efficiency Analysis. Information on methods of reducing GHG emissions that were considered, but found to be infeasible, is also in Appendix A.

4.2. Alternative GHG reduction measures

A number of other GHG reduction options have been evaluated as methods for minimizing the carbon footprint of the Project. Two options include biological sequestration strategies and carbon offsets. While biological sequestration options have been explored, more scientific research is needed to resolve uncertainty surrounding the viability, quality, and sequestration rate of certain biological offset methods. The option of purchasing carbon credits poses several potential issues, given the limited extent of current carbon markets and trading opportunities, as well as uncertainty regarding the structure of potential future carbon regulations.

4.2.1. Biological carbon sequestration

The primary source of published data on biological sequestration options and economics in the Project area are two recent University of Minnesota studies prepared for the Minnesota Terrestrial Carbon Sequestration Project.[120] These studies and personal communication with the authors indicate that the two most promising biological sequestration methods in Minnesota appear to be (1) changed management of existing forest land or (2) growing high-productivity trees such as poplar on areas not previously forested (afforestation). This research also indicates that several other approaches show some promise for

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[120] Lennon, Megan J, and Edward A. Nater, 2006 *Biophysical Aspects of Terrestrial Carbon Sequestration in Minnesota*, University of Minnesota White Paper available at http://wrc.umn.edu/outreach/carbon/; Polasky, Stephen, and Yang Liu, 2006, *The Supply of Terrestrial Carbon Sequestration in Minnesota*, available at http://wrc.umn.edu/outreach/carbon/

biological carbon sequestration, including the conversion of row-crop acreage to grasslands or pasture, the use of cover crops in row-crop agriculture, wetland restoration, and agroforestry.

Some of the biological sequestration options appear to be based on more solid experimental evidence than others. Better documented methods include agroforestry, afforestation, and grassland establishment programs, such as the Conservation Reserve Program (CRP). The data backing other options is sparse. For example, recent data indicate that the use of a winter cover crop such as rye has less potential to sequester carbon than indicated by earlier studies.[121]

4.2.1.1 Afforestation

In Minnesota, marginal farmlands are likely to offer the most promise for afforestation projects. In terms of total biomass production, red and white pine stands show the best carbon sequestration potential, with a steady and relatively rapid accumulation of carbon over a period of 90-120 years. Over these timescales afforested systems are effective at sequestering above-ground carbon in biomass, exhibiting carbon sequestration rates as high 7.65 MT CO_2 acre^{-1} yr^{-1} in Minnesota. However, this sequestration potential is limited once the system reaches its steady state.

4.2.1.2 Wetland Sequestration

Recently published University of Minnesota studies indicate that under certain conditions, wetland restoration may provide one of the best terrestrial sequestration options in Minnesota (in areas with enough hydric soils).[122] In many areas of Minnesota, particularly in the "Prairie Pothole Region" of Northern Minnesota, restoring wetlands re-establishes the original hydrologic conditions, which may lead to decreased rates of organic matter oxidation and potential increases in carbon sequestration. Restoring local hydrology and natural vegetation in previously drained wetland areas can sequester approximately 4.53 MT CO_2 acre^{-1} yr^{-1} in the upper 15 cm of soil. However, while wetlands do sequester carbon in biomass, the anaerobic decomposition that occurs in wetlands and peatlands results in the release of carbon as methane. Current research indicates that wetlands with permanently pooled water are net carbon sources as a result of methane production. If wetland restoration is considered as a carbon sequestration strategy, a focus on restoration efforts on Type 1 and 2 ephemeral wetlands is recommended, as they show the strongest potential for generating a net carbon sink.

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[121] Nater, 2007, personal communication.

[122] Lennon, Megan J, and Edward A. Nater, 2006 *Biophysical Aspects of Terrestrial Carbon Sequestration in Minnesota*, University of Minnesota White Paper available at http://wrc.umn.edu/outreach/carbon/

4.2.1.3 Perennial Grassland

Extensive loss of prairie and grassland areas has occurred since the time Minnesota was originally settled, making restoration of former prairie areas to perennial grassland a good potential avenue for carbon offset. Increases in soil organic carbon resulting from the establishment of perennial grassland is attributed to decreased physical disturbance from tilling (lower aeration and organic matter decomposition rates) and increased above- and below-ground biomass inputs.

The greatest sequestration result is seen in the conversion of land currently in cultivation of row crops to grassland. This type of conversion has been estimated to produce sequestration rates between 1.48 and 4.45 MT CO_2 $acre^{-1}$ yr^{-1}. On the other hand, the rate of carbon sequestration resulting from conversion of marginal pasture or croplands to grassland in Minnesota is estimated at 1.04 MT CO_2 $acre^{-1}$ yr^{-1}. Although more research is needed, current studies indicate that perennial grassland systems may reach a steady state between 50 and 148 years, after which carbon sequestration benefits are negligible.

4.2.2. Carbon offset credits

Under this option, PolyMet could purchase verified, retired offsets every year instead of implementing and owning a sequestration project. However, there are a wide variety of brokers and quality of offsets available. CO2 offset “quality” has been a recurring problem in this so-far voluntary market. There is a danger that purchased offsets will neither be formally recognized by any future state or federal regulatory program, nor recognized as legitimate by local environmental groups.

4.3. Conclusions

Biological carbon sequestration may hold potential in the future, particularly as the science advances regarding wetland and forest sequestration options. As part of the proposed Project, PolyMet will undertake various mitigation activities which may offer an opportunity to create environments with high carbon sequestration rates. As the science in this area advances there will likely be more clearly defined opportunities for biological carbon sequestration in the region of Minnesota where the Project is located.

The option of purchasing carbon credits from verified brokers has many potential pitfalls given the voluntary nature of carbon markets and the ongoing debate surrounding the quality of certain types of carbon credits. With rapidly developing carbon dioxide and GHG goals and policies in the Midwest, it is difficult to assess whether the small voluntary markets currently in place may be integrated into new markets if cap and trade policies are established, or if these existing markets are abandoned and replaced.

PolyMet has taken several process design and equipment measures to reduce GHG emissions as discussed above.

Appendices

Appendix A

Greenhouse Gas Emission Inventory and Alternatives Report

Greenhouse Gas Emission Inventory and Energy and Efficiency Analysis

NorthMet Project

Prepared for
PolyMet Mining Inc.

June 2012

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Greenhouse Gas Emission Inventory and Energy and Efficiency Analysis

June 2012

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1.0 Introduction and Summary

Greenhouse gas (GHG) emissions from PolyMet Mining Inc.'s NorthMet Project (Project) will be evaluated during the environmental review process. This document presents a calculation of expected GHG emissions from the Project based on a memorandum from James Warner, Minnesota Pollution Control Agency (MPCA), dated July 16, 2008. The memorandum mandates that all new projects requiring an Air Emission Risk Analysis (AERA) or Part 70 permit also include a calculation of the expected GHG emissions from the project using The Climate Registry (TCR) General Reporting Protocol (GRP) (March 2008). On February 18, 2010 the Whitehouse Council on Environmental Quality (CEQ) published draft guidance on the consideration of the effects of climate change and GHG emissions under the National Environmental Policy Act (NEPA). This draft guidance was also considered in the development of the project GHG emission inventory and in the energy and efficiency analysis.

For the purposes of this report, GHGs are the six gases identified in the Kyoto Protocol: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6). Carbon dioxide is the most prevalent GHG, so emissions are generally expressed in units of carbon dioxide equivalents (CO_2-e). For the Project, emissions of CO_2, N_2O, and CH_4 are estimated on a CO_2-equivalent basis using generally accepted emission factors and following generally accepted calculation methods, primarily from the MPCA guidance, the TCR GRP, or the Environmental Protection Agency's (EPA's) mandatory reporting rule (MRR) (Code of Federal Regulations (CFR) Title 40 Part 98). Information from the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (2006) is used when the MPCA guidance, TCR GRP, and/or 40 CFR Part 98 do not provide needed guidance. The Project will not emit HFCs, PFCs, or SF_6.

Global warming potentials used for estimation of CO2-equivalents for the Project are taken from 40 CFR Part 98. The global warming potentials are listed in Table 1.

Table 1 GHG CO2-equivalence Values Used in Calculations

GHG (Chemical Formula)	CO_2-equivalence or global warming potential (100 year)
CO_2	1
CH_4	21
N_2O	310

Major components of the Project include mining, ore crushing/grinding and concentrating, and metal recovery. During metal recovery, the nickel-rich fraction of the flotation concentrate is routed to a pressurized autoclave. Energy is produced during sulfide oxidation within the autoclaves and is used as the primary heat source for the hydrometallurgical process. The hydrometallurgical process eliminates several steps typically associated with pyrometallurgical processing and the related energy demand and SO_2 emissions. Overall, hydrometallurgical processing such as PolyMet's planned operation is estimated to reduce energy demand and by 50% as compared with a pyrometallurgical process (Bateman 2005).

PolyMet has taken several other measures to reduce GHG emissions related to process design and equipment used. Energy efficient equipment will be purchased when available. For example, the Project will employ premium efficiency motors and Gen-Set locomotives. In addition, most emissions units used will run on the lowest CO_2 emitting fuel option for the type of equipment. The facility will also initially produce flotation concentrate for sale from all of the ore processed, which would reduce the Project's direct and indirect GHG emissions from those estimated in this report during the limited times operating in that mode.

Using MPCA guidance and TCR GRP, the maximum total potential direct and indirect GHG emissions from the Project were calculated. Direct emissions are GHG's generated by processes at the Plant Site and Mine Site. The potential maximum direct GHG emissions from the Project, from mining through metal recovery at the Process Plant, are estimated to be approximately 186,342 metric tons per year. CO_2 emissions account for 99.1% of the estimated GHG emissions at the Mine Site and 99.6% of the estimated GHG emissions for the Plant Site. Direct GHG emissions potentially associated with the Project are less than 0.12% of estimated 2005 statewide emissions, approximately 0.003% of estimated 2007 U.S. emissions (US DOE 2008), and approximately 0.00038% of estimated global GHG emissions of more than 49 billion metric tons per year (IPCC 2007). Potential indirect GHG emissions related to power production for the Project are estimated at 511,000 metric tons per year. As shown in Table 4, the total potential Project emissions (direct + indirect) are also a fraction of the estimated statewide, national, and global GHG emissions.

In addition to the direct and indirect industrial CO_2 emissions, quantitative estimates for five carbon cycle impacts were calculated:

1) Total carbon stored in the above-ground vegetation of wetlands and forests lost to Project activities [treated as a one-time emission] = 167,546 metric tons of CO_2
2) Annual emissions from the stockpiling of excavated peat = 1,176 metric tons of CO_2 per year

3) Possible carbon loss from peat used in reclamation activities = 8,524 metric tons of CO_2
4) Annual emissions from indirectly impacted wetlands = 7.41 metric tons of CO_2 per acre per year
5) The loss of annual carbon sequestration capacity due to the disturbance of wetland and forest plant communities = 2,982 metric tons of CO_2 per year
6) The reduction in annual carbon sequestration capacity in indirectly impacted wetlands = 3.34 metric tons per year

Apart from the one-time aboveground carbon loss estimate, these impacts are minimal compared to the direct and indirect industrial emissions: Additionally, the aboveground carbon lost (a) will not take place as an actual one-time CO_2 emission event but will be a staged development of the Project; and (b) is a likely overestimate given the value of long-lived forest products that will be potentially available for harvest. Temporal issues surrounding the project-specific impacts, such as the change in CO_2 emission rate from stockpiled peatlands after closure, are discussed in Section 10.

GHG emissions may vary from facility to facility as a result of a number of factors that make direct comparisons difficult. Calculating a "carbon intensity" for GHG emissions is a way to directly compare facilities. Typically, an estimate of carbon intensity is derived by dividing GHG emissions by a unit of production. Generally, a lower carbon intensity indicates a more efficient process with regard to GHG emissions and the lower the carbon intensity the fewer GHGs emitted per unit of material processed. While the June 2009 NorthMet Project Climate Change Evaluation report included a quantitative comparison between the carbon intensity of the Project and carbon intensities for smelting process at facilities in Sweden and Finland, changes in the proposed NorthMet process since June 2009 have made a direct quantitative comparison problematic.

However, studies suggest that a hydrometallurgical process uses approximately 50% less energy than a smelting process (Bateman Engineering, 2005). The majority of the GHG emissions from the metal recovery component of the Project come from neutralization, not energy use.

2.0 GHG Emission Estimation Methodology

Potential emissions from the Project are estimated on a CO_2-equivalents basis using several available methods and emission factors, including:

- World Resources Institute Greenhouse Gas Protocol Standard;
- The Climate Registry's May 2008 General Reporting Protocol (GRP);
- MPCA's General Guidance for Carbon Footprint Development in Environmental Review;
- International Panel on Climate Change (IPCC); and
- U.S. Environmental Protection Agency (EPA).

Attachment A provides the details of the emission calculations.

Indirect emissions related to generating electric power for the Project are also estimated. These calculations use emission rates for the principal Minnesota electric utility providers found in the MPCA General Guidance for Carbon Footprint Development in Environmental Review. Indirect emission calculations are provided in Attachment B.

2.1 Mine Site

The Mine Site is located approximately 8 miles to the east of the Plant Site, approximately 6 miles south of the city of Babbitt, Minnesota. The sources of GHG emissions related to Mine Site activities are as follows[1]:

- Wastewater Treatment Facility Backup Generator
- Wastewater Treatment Facility Propane Fired Space Heaters
- Mining Related Equipment
    - Generator to Move Large Electric Mine Equipment
    - Mining Vehicles, including excavators, haul trucks, dozers, and graders.
        - PolyMet owned vehicle emissions and potential Contractor vehicle emissions are aggregated together for these calculations.
    - Locomotives (hauling ore from the Mine Site to the Plant Site)

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[1] The wastewater treatment process for the Project is not included as a source of greenhouse gas emissions. It is not expected to be a source because the process water will contain little or no organic carbon.

Emissions from the generator and space heaters are calculated using maximum capacities and emission factors from the MPCA General Guidance for Carbon Footprint Development in Environmental Review. Emissions from the mining vehicles are calculated using maximum annual fuel consumption numbers over the anticipated mine life and emission factors for worst case fuel scenarios from The Climate Registry's GRP. Total direct CO_2-equivalent emissions from the mine site are estimated to be 39,687 metric tons per year.

2.2 Plant Site

As described in the March, 2011 Draft Alternative Summary for the NorthMet Project environmental impact statement and the NorthMet Project Description Version 3 Submitted September 13, 2011, the Project will use froth flotation to produce a copper rich and nickel rich flotation concentrate from the sulfide ore. A pressure oxidation hydrometallurgical process will be used to recover metals from the nickel-rich flotation concentrate. The process injects oxygen into a pressure vessel (autoclave) where the bulk sulfide concentrate is submerged in an acidic solution. The sulfide minerals are oxidized and the metals are taken into solution. The metals are recovered from the metal-rich solution. Final products are copper concentrate, a nickel-cobalt hydroxide, and a platinum group metals (PGM)/gold concentrate. Worldwide, pressure oxidation is a proven technology for base metal extraction. PolyMet's major change to this technology is the addition of a small amount of chloride to facilitate the dissolution and enable the recovery of gold and PGM (AuPGM).

The Plant Site has the following sources of GHGs:

- Autoclave Startup Boiler
- Oxygen Plant Adsorber Regeneration Heater
- Space Heaters
- Backup Generators and Fire Pumps
- Autoclave
- Solution Neutralization and Iron and Aluminum Precipitation Tanks
- Vehicle traffic, including heavy haul trucks going to the Area 1 Shop for maintenance, construction trucks at the Tailings Basin and light trucks
- Locomotive used to move railcars in the switchyard

Emissions for the Autoclave Startup Boiler, the Oxygen Plant Adsorber Regeneration Heater, the Space Heaters, the Backup Generators and Fire Pumps, are calculated using the maximum capacities of each unit and appropriate emission factors for combustion taken from either the MPCA guidance document or

The Climate Registry's GRP. The CO_2 emissions from the Autoclave and Iron and Aluminum Precipitation Tanks are calculated from information on the weight fraction CO_2 in the gaseous phase taken from the MetSim process flow simulation model transmitted by Bateman via a spreadsheet, and vent flow rates. The CO_2 weight fractions are determined based on material balance and knowledge of process chemistry. Emissions from vehicle traffic are based on vehicle miles traveled using emission factors for worst case fuel scenarios from The Climate Registry's GRP. Total direct CO_2-equivalent emissions from the Process Plant are estimated to be 146,655 metric tons per year.

2.3 Construction and Closure Emissions

Construction emissions have been calculated for both the Mine Site and the Plant Site based on the same information as used for the operating emissions, with the exception of tailpipe emissions from vehicles used for Process Plant construction. The Process Plant construction emissions were estimated using the Urbemis2007 program version 9.2.4 available from www.urbemiss.com. Emissions were estimated based on the footprint of new buildings to be constructed and estimated intensity of emissions from upgrading existing buildings. Construction emissions include Plant Site point and mobile sources, Mine Site point and mobile sources as well as other miscellaneous construction sources. All construction emissions were calculated for Year 0 of the Project and include emissions from equipment used for new building construction as well as paving and grading. Closure emissions have been estimated for a potential closure period of 20 years for the Plant Site and 60 years for the Mine Site and include emissions for mobile equipment as well as point sources at both the Mine Site and Plant Site. The primary emission generating activities during the closure period will be related to waste water treatment.

2.4 Sale of Flotation Concentrate

The emission calculations used in this analysis assume that all nickel-rich flotation concentrate will be processed through the Hydrometallurgical Plant. This assumption yields a maximum GHG emissions scenario for the Project. However, the facility may not always process 100 percent of the nickel-rich flotation concentrate in the Hydrometallurgical Plant. For example, the facility may produce flotation concentrate for sale from all of the ore processed at certain periods, such as during construction of the Hydrometallurgical Plant, when the Autoclave is down for maintenance, or when PolyMet could sell reserved power at very high rates. GHG emissions from the Project will be lower when producing flotation concentrate for sale, rather than processing nickel-rich concentrate in the Hydrometallurgical Plant. As a result, Appendix A may overstate the Project's GHG emissions under actual conditions.

3.0 Summary of Project GHG Emission Estimates

Project-related GHG emissions on a CO_2-equivelent basis are summarized below and in Table 2 and Table 3.

- Maximum direct GHG emissions from the Project operation are estimated at 186,342 metric tons per year. Of these direct emissions, 21% are from the Mine Site operations and 79% are from Plant Site operations. Additional calculation details are provided in Attachment A. For the Mine Site, CO_2 emissions account for approximately 99.1% of the estimated GHG emissions, with N_2O accounting for approximately 0.8% of the estimated emissions. For the Plant Site, CO_2 emissions account for approximately 99.6% of the estimated GHG emissions.
- Potential indirect GHG emissions from power production for the Project are estimated at approximately 511,000 metric tons per year. This calculation is based on Project power needs of approximately 59.5 megawatts, which is planned to be provided by Minnesota Power. An emission factor of 2159.5 pounds CO_2 per megawatt hour for all electricity provided by Minnesota Power is used in the calculation. Additional calculation details are provided in Appendix B.
- Total potential construction emissions are estimated as 92,885 metric tons. Closure GHG emissions are estimated as 438,988 metric tons based on a 60 year closure period for the Mine Site and a 20 year closure period for the Plant Site. Further details on these emissions are provided in Tables A-3 and A-3 in Attachment A.
- Total potential Project GHG emissions, e.g., after construction, but before plant closure, are an estimated 697,342 metric tons per year (Table 2). Approximately 30% of the total GHG emissions are from direct emissions and 70% are from indirect emissions.

The estimated GHG emissions from the project, both direct emissions and total (direct + indirect), are small in comparison to statewide (Minnesota), national, and global GHG emission estimates. Table 4 shows that the Project's direct GHG emissions will be approximately 0.12% of statewide emissions estimated from available MPCA data (2003), approximately 0.003% of national emissions estimated by the EPA (2007), and approximately 0.00038% of global emissions. Also shown in Table 4, when indirect emissions are accounted for, the potential total GHG emissions for the Project (direct + indirect) are still small and only a fraction of the estimated statewide, national, and global emissions.

Table 2 **Summary of Maximum Potential Annual GHG Emissions Estimated for the Project***

Source	**Maximum Potential Direct Emissions [1] (CO_2-e, m.t./yr) [2]**	**Maximum Potential Indirect Emissions (CO_2-e, m.t./yr)**	**Maximum Potential Total (direct + indirect) Emissions [3] (CO_2-e, m.t./yr)**
Mine Site (mining equipment and vehicles, ore hauling)	39,687		
Plant Site (ore crushing, concentrating, metal recovery)	146,655		
Subtotal	186,342	511,000 **[4]**	697,342

Units = CO_2-e, m.t./yr = GHG emissions as CO_2-equivalents, in metric tons per year.

* Terrestrial carbon cycle impacts have not been added to this table due to critical differences in the origin and temporal component for terrestrial emissions. See terrestrial carbon calculations and discussions in subsequent sections

[1] Direct emissions: Emissions from sources that are owned or controlled by the reporting entity, including stationary combustion emissions, mobile combustion emissions, process emissions, and fugitive emissions.

Potential direct emissions of GHGs for the Project are estimated using generally accepted emission factors and calculation methods of the World Resources Institute Greenhouse Gas Protocol Standard, International Panel on Climate Change (IPCC), and the MPCA General Guidance for Carbon Footprint Development in Environmental Review.

[2] CO_2-equivalents: The quantity of a given GHG emission is multiplied by its total global warming potential. This is the standard unit for comparing emissions of different GHGs. For the purposes of emissions reporting, GHGs are the six gases identified in the Kyoto Protocol: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Global warming potential (100 year): The ratio of radiative forcing (degree of warming to the atmosphere) over a 100 year timescale that would result from the emission of one unit of a given GHG compared to one unit of CO_2. Factors used in estimating CO_2-equivalent emissions: $CO_2 = 1$; $N_2O = 310$, $CH_4 = 21$.

As used in this analysis, emissions of N_2O have 310 times more impact than do CO_2 emissions over 100 years.

[3] Total Project emissions (direct + indirect) are derived by summing estimated direct Project emissions with the estimate of indirect emissions.

[4] Indirect emissions: Emissions that are a consequence of the activities of the reporting entity, but that occur at sources owned or controlled by another entity. For example, emissions that occur at a power plant as a result of electricity being generated and subsequently used by a manufacturing company represent the manufacturer's indirect emissions. Electrical load for the Project is estimated to be approximately 59.5 megawatts. The electricity to be used by the Project is planned to be generated by Minnesota Power. The emission factor used in the calculation of potential indirect emissions is from the MPCA General Guidance for Carbon Footprint Development in Environmental Review and is based on the Environmental Disclosure information filed annually by the electric utilities. See Attachment B for calculation details.

Table 3 Total Potential GHG Emissions Estimated over the lifetime of the Project

Source	Maximum Total Potential Direct Emissions (CO_2-e, m.t.)	Maximum Total Potential Indirect Emissions (CO_2-e, m.t.)	Maximum Potential Total (direct + indirect) Emissions [3] (CO_2-e, m.t./yr)
Mine Site [1] (mining equipment and vehicles, ore hauling)	793,734		
Plant Site [1] (ore crushing, concentrating, metal recovery)	2,933,103		
Construction Phase Emissions [2]	92,885		
Reclamation (Closure) Phase Emissions [3]	438,988		
Subtotal	4,258,710	10,220,000 **[4]**	14,478,710
Terrestrial carbon loss (aboveground wetland carbon stock, aboveground forest carbon stock, 20 years of emissions from stockpiled peat, emissions from peat used in reclamation)	199,591		199,591

Units = CO_2-e, m.t./yr = GHG emissions as CO_2-equivalents, in metric tons per year.

[1] Based on maximum annual emissions occurring for 20 year proposed operating life of Project

[2] Includes Phase 1 (flotation concentrate production only) and Phase 2 (Hydrometallurgical Plant) Construction

[3] Based on 20 year closure period for Plant Site and 60 year closure period for Mine Site.

[4] Indirect emissions: Emissions that are a consequence of the activities of the reporting entity, but that occur at sources owned or controlled by another entity. For example, emissions that occur at a power plant as a result of electricity being generated and subsequently used by a manufacturing company represent the manufacturer's indirect emissions. Electrical load for the Project is estimated to be approximately 59.5 megawatts. The electricity to be used by the Project is planned to be generated by Minnesota Power. The emission factor used in the calculation of potential indirect emissions is from the MPCA General Guidance for Carbon Footprint Development in Environmental Review and is based on the Environmental Disclosure information filed annually by the electric utilities. See Attachment B for calculation details. Based on maximum annual emissions occurring for 20 year proposed operating life of Project

Table 4 Estimated Statewide, National, and Global GHG Emissions Compared to the Potential Emissions from the Project

Source Category	Estimated GHG Emissions (CO_2-e, m.t./yr)	NorthMet Project Direct GHG Emissions as a Percent of Total	NorthMet Project Total (direct + indirect) GHG Emissions as a Percent of Total
NorthMet Project [1]			
Direct Emissions	186,342		
Indirect Emissions	511,000		
TOTAL	697,342		
Minnesota (year 2008) [2]	159,400,000	0.12	0.44
United States (year 2007) [3]	7,282,400,000	0.003	0.01
Global (year 2004) [4]	49,000,000,000	0.00038	0.0014

Units = CO_2-e, m.t./yr = GHG emissions as CO_2-equivalents, in metric tons per year

[1] Potential direct emissions of GHGs for the Project are estimated using generally accepted emission factors and calculation methods of the World Resources Institute Greenhouse Gas Protocol Standard, International Panel on Climate Change (IPCC), and the MPCA General Guidance for Carbon Footprint Development in Environmental Review. See Attachment A for calculation details.

Indirect emissions: Electrical load for the Project is estimated to be approximately 59.5 megawatts. The electricity to be used by the Project is planned to be generated by Minnesota Power. The emission factor used in the calculation of potential indirect emissions is from the MPCA General Guidance for Carbon Footprint Development in Environmental Review and is based on the Environmental Disclosure information filed annually by the electric utilities. See Attachment B for calculation details.

[2] http://www.pca.state.mn.us/index.php/topics/climate-change/climate-change-in-minnesota/greenhouse-gas-emissions-in-minnesota.html.

[3] Energy Information Administration, Official Energy Statistics from the US Government. Emissions of Greenhouse Gases Report. Released December 3, 2008. http://www.eia.doe.gov/oiaf/1605/ggrpt/

[4] IPCC 2007, Fourth Assessment Report, Working Group 1 Climate Change 2007: Synthesis Report

Estimated GHG emissions for the Project are a fraction of statewide emissions. In turn, Minnesota's estimated statewide GHG emissions are small on a national and global basis. Minnesota's emissions are approximately 2% of the estimated U.S. emissions and 0.3% of global emissions. These comparisons further emphasize that the potential GHG emissions from the Project are small**.**

4.0 NorthMet's Hydrometallurgical Process vs. Smelting Facilities

Major components of the Project include mining, ore crushing/grinding and concentrating, and metal recovery. During metal recovery, the nickel-rich flotation concentrate is routed to a pressurized autoclave. Energy is produced during sulfide oxidation within the autoclaves and is used as the primary energy source for the hydrometallurgical process. The hydrometallurgical process eliminates several steps typically associated with pyrometallurgical processing and the related energy demand.

The traditional method to recover copper and nickel involves smelting, where the concentrate is subjected to high temperatures for the recovery of copper and nickel products. As described by the United States Geological Survey (USGS 2004), *"... Technically, smelting means to melt and fuse. With regard to copper smelting, it means to melt and fuse copper-bearing materials, which include concentrates, dust (circulating load), fluxes (slagmaking materials), and revert (circulating load) in a furnace. Heat is required for the melting and fusing and can be generated by several means, such as electric current, fuel combustion, or mineral oxidation. ...".* The hydrometallurgical process proposed for the Project will produce copper concentrate as well as gold and platinum group metals (AuPGM) and nickel/cobalt hydroxide concentrate products.

While the June 2009 NorthMet Project Climate Change Evaluation report included a quantitative comparison between the carbon intensity of the Project and carbon intensities for smelting process at facilities in Sweden and Finland, changes in the Project since June 2009 have made a direct quantitative comparison problematic. However, Bateman Engineering (2005) estimated that the hydrometallurgical process has approximately 50% less energy demand than a copper smelting process. Less energy demand is one indicator of potentially lower GHG emissions and possibly lower carbon intensity.

5.0 Electrical Efficiency

5.1 Process Plant

PolyMet is taking several steps in the design of the Process Plant to increase electrical efficiency. These steps include designing the facility to operate with a power factor as close to one as practical, and the specification of high efficiency motors for the new motors to be installed. Additional details are provided below.

5.1.1 Power Factor

The power loss on a power line serving a facility is a function (I^2R) of the resistance of the line (R) and the current in the line (I). The current in the line is the current required to serve all of the loads at the facility. There are three types of load – resistive load (load required to spin a motor, light a light or heat a heater), inductive load (load required to set up magnetic fields that allow equipment like motors and transformers to function) and capacitive load (load required because of electric fields developed by transmission lines and other equipment). The relationship (KW/KVA) between resistive load (KW) and total (resistive + inductive + capacitive) load (KVA) is called Power Factor. The inductive and capacitive loads are in opposite directions, so, if they are equal at a facility, the current on the power line serving the facility will be only that required to serve the resistive load and the Power Factor will be one.

A large industrial facility can have a significant inductive load component due to the many electric motors used. This results in a current in the power line serving the facility that is higher than that required to serve the resistive load only. In PolyMet's case, the existing Cliffs Erie Plant has synchronous motors (special motors that can be adjusted to have resistive plus inductive or resistive plus capacitive loads) driving the rod and ball mills and power factor correction capacitors at the main power substation. This means that the overall Power Factor of the facility can be adjusted to be near to one, which results in the minimum current (and therefore power loss) on the power line serving the Process Plant. PolyMet intends to set up the synchronous motors and power factor correction capacitors such that the overall facility Power Factor is a close to one as practical.

Quantification of the emission reduction from achieving a Power Factor close to one requires several assumptions. To estimate the low end of the potential emission reduction, it was assumed that all power was coming from the nearest power plant, Laskin Energy Center, which is about 5.7 miles away. The estimated reduction in average electrical load is 16,500 Watts, with an estimated annual reduction in indirect CO_2 emissions of about 140 metric tons.

5.1.2 Efficiency of Electrical Equipment

A review of the equipment that corresponds to 50% of the total electrical load at the process plant was conducted. The total connected electrical load for the process plant is estimated as 42.4 MW[2]. The 96 pieces of new electrical equipment planned for the Process Plant that were evaluated have a total electrical load of 21.3MW, which is greater than 50% of the total load for the Process Plant.

Almost all of this equipment utilizes electric motors.

Two pieces of equipment that do not have electric motors are on the list of equipment evaluated: the Power and Light Distribution Board in the Oxygen Plant and the Caustic Tank Heater. These units have no moving parts and are inherently efficient.

The remaining 94 pieces of equipment evaluated will have new electric motors. This equipment includes 26 agitators, 43 pumps, 10 fans and blowers, six HVAC units, four compressors, the Limestone Crusher, the Lime Slaker, the Primary Limestone Mill, the caustic tank heater and the make-up air heater.

All motors purchased new by PolyMet will be high efficiency. The efficiency of each specific motor will vary greatly depending on size and load. Table 5 provides the expected low end range of efficiencies based on motor size and load.

Table 5 Low End Range of Motor Efficiency by Size and Load

	Loading		
Motor Size	50%	75%	100%
1 HP	81.5%	84.0%	85.5%
250 HP	94.1%	95.6%	95.8%
1000 HP	93.6%	94.4%	94.1%

The design of the Process Plant will size the new electric motors such that the operating load is 75 – 100% of the motor capacity. This will allow for efficient operation of the motors. This design will account for the fact that motors are not available in every conceivable size.

The smallest motors included in the 96 pieces of equipment evaluated are 75 hp. There are seven motors of this size on the list, 68 at about 100 hp or less, 16 between 100 and 150 hp, two between 150 and

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[2] Note: the total connected load is the sum of the power required for all primary equipment at its expected electrical load. The estimated average hourly power draw, which takes into account the anticipated run time for each piece of equipment was used to estimate indirect greenhouse gas emissions in Section 9.0.

250 hp, two between 250 and 500 hp, and eight greater than 1000 hp. The larger motors make up a significant portion of the total electrical load, so this will result in a higher overall efficiency. For example, the air compressor in the oxygen plant has an electrical load of 5.3 MW or about 12% of the total load for the Process Plant.

The electrical demand reduction at the Plant Site from using premium efficiency motors where new motors will be purchased is estimated as 213 kW. This corresponds to an annual electrical usage savings of 1,864 MWh, which is equivalent to a reduction about 1800 metric tons of CO_2 emissions per year.

5.2 Mine Site

Electrical efficiency is also being incorporated into the design of the Mine Site. The total connected load at the Mine Site is much lower than the Plant Site at 5.7MW[3]. Almost half of the load comes from the electric powered excavators and blast hole drill rigs used in the mining operation. The remaining load is from pumps, heaters, the Waste Water Treatment Facility, the Rail Transfer Hopper and other miscellaneous equipment.

High efficiency electric motors will be specified for all equipment at the Mine Site. In addition, high efficiency transformers and lighting will be installed. The Waste Water Treatment Plant will have electric heaters. The building insulation will be designed to minimize heat loss and therefore power consumption.

The annual emission reduction at the Mine Site from using premium efficiency motors where new motors will be purchased is estimated as about 19 metric tons of CO_2 per year.

5.3 Gravity Feed

The existing and proposed facilities will make use of gravity flows where practical to help maximize the efficiency of the proposed operation. Use of gravity flows in the concentrator avoids the need to install two additional 500 horsepower pumps. The annual savings in electricity usage is estimated at about 5,500 MWh which results in an estimated reduction in greenhouse gas emissions of 5400 metric tons of carbon dioxide per year.

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[3] The average actual power draw is estimated as 2.6 MW. This value was used in the indirect greenhouse gas emission calculation.

6.0 Infeasible GHG Emission Reduction Methods

This report in general focuses on the GHG emissions for the Project and elements of the Project that help minimize GHG emissions. There are other potential ways to reduce GHG emissions that have not been incorporated into the Project design because they are considered infeasible. Examples of these options are provided below along with the rationale for why they are infeasible in the context of the Project. Estimates of potential reductions in GHG emissions from these rejected alternatives are included where the data is available to calculate them.

6.1 Electric Drive Mine Haul Trucks

Trucks with either mechanical drive trains or diesel electric drives can be used to haul material at a mine site. Some diesel electric drive trucks offer the possibility of trolley assist, which enables the haul truck to receive electrical power from conductors located above the haulroad. The trolley concept is similar to the system in use for some light rail transit systems where the locomotive is powered by an overhead power source running the length of the tracks. The trolley assist systems used in mining are located on long, permanent or semi-permanent haulroad ramps where the haul truck would be hauling a load up grade. When the haul truck approaches the ramp it engages the overhead trolley power lines increasing the power available to the electric wheel motors, enabling the truck to maintain faster speeds when traveling up the grade. While the truck is traveling under trolley assist the diesel engine may be idling which reduces diesel fuel consumption and therefore direct GHG emissions. The decision to install a trolley assist system is based on the development plans of the mine, the layout of mine road system and economics. The savings associated with reduced fuel consumption and the production benefits of faster haul truck speeds on haulroad ramps must be greater than the installation costs as well as the ongoing maintenance and relocation costs of the trolley assist overhead lines, the increased maintenance costs of the haulroad under the trolley assist conductors and the maintenance costs of the pantograph and electrical systems on the haul trucks. The cost differential between diesel fuel and electric power must also be included in the economic analysis. There are also operating and production cost considerations, such as proactively disassembling the overhead system to prevent damage from blasting as well as the occasional, unexpected delay due to blast damage.

The Project Mine Plan results in the pits reaching their full surficial footprint relatively quickly and then deepening the pits. Mining will proceed downward as well as parallel to the surface. This will result in haulroads that are both regularly being increased in length and being developed into ramps for deepening the pits. As the pit matures some of the haulroads may be considered semi-permanent or permanent and the economics of installing a trolley assist on those stretches will have to be analyzed taking into account the factors previously mentioned.

Therefore, while trolley assist electric drive trucks do provide a reduction in diesel fuel consumption and a reduction in direct greenhouse gas emissions the decision to install a trolley assist system is economically driven based on many factors.

Given that changing nature of the mine haul roads in the early years of the mine life, the use of trolley assist would not be practical at this point in the operation. After the mine pits have been developed to the point where there are permanent or semi-permanent haul roads in the pits, PolyMet can reconsider if the haul road configuration and economics would be favorable.

6.2 Electric Locomotives

If electric locomotives are used, this eliminates diesel fuel combustion in the locomotives and a source of direct GHG emissions. Electric locomotives require trolley electric power delivery. PolyMet does not own the track between the Mine Site and the Plant Site (PolyMet has trackage rights), and it would not be possible to install trolley system on track owned by others. The diesel Gen-Set locomotives that will be specified for the Project are among the most efficient diesel locomotives available. The use of electric ore haul locomotives could reduce direct CO_2 emissions by 4,400 metric tons of CO_2 equivalents per year.

6.3 Newer Mill Technology

Newer mill technology featuring larger mills would reduce power consumption. Installation of larger mills would require revision of structures and very expensive replacement of existing equipment.

If larger mills were installed, they would be semi-autogenous grinding mills or SAG mills. This type of mill would also eliminate the need for the fine crushing stage and require associated changes to the material handling equipment. The cost to retrofit the existing Crushing/Concentrating Plant with SAG mills would approach the cost of building new facilities due to the extensive modification that would be required to the existing buildings. The total estimated cost is about $100 million (+/- 50%).

To put this into perspective, this cost can compared to the estimated startup capital cost for the entire Project. The initial capital cost required prior to first production and sales for the Project is $312 million. Replacing the existing mills with larger SAG mills would increase the initial capital cost by almost one-third, which would have a significant adverse affect on project economics.

In addition to the high capital cost, the SAG mill design would likely use more power than the existing multi-stage crushing/rod mill/ball mill design.

Based on the above, replacement of the existing mills will larger SAG mills and making associated modification to the crushing and material handling equipment would adversely affect the project economics and not provide a clear reduction in power usage or indirect greenhouse gas emissions. All new motors will be high efficiency and gravity flows will be used where possible to help maximize the efficiency of the proposed facility. The reuse of existing equipment also eliminates the carbon footprint associated with the manufacture and transportation of new equipment.

6.4 Flotation

The Project includes flotation equipment to separate the metal bearing minerals (concentrate) from the waste material (tailings). There is no other technology commercially available to perform this operation. New flotation equipment specific to sulfide ores will be installed by PolyMet with high efficiency motors. This will help make the flotation process as efficient as possible.

6.5 Smelting

Smelting is a potential alternative to the hydrometallurgical process proposed for the Project. However, the hydrometallurgical process is expected to provide better metal recoveries for the NorthMet ore and result in lower environmental impacts due to much lower SO_x emissions. In the smelting process, sulfur in the concentrate is emitted to the air in oxide form, while in the hydrometallurgical process, sulfur ends up in the leach solution exiting the autoclave prior to being converted to a stable solid gypsum form. More details on the comparison between smelting and hydrometallurgy are presented in Section 4.0 of this report.

6.6 Waste Heat

The use of waste heat from the autoclaves to heat the Hydrometallurgical Plant buildings was considered to reduce fuel usage for space heating. This option would have resulted in a potential reduction of 19962 metric tons of CO_2 equivalents per year, but it is no longer being considered due to concerns over possible changes to the Project water balance. This option is discussed further in Section 7.1.1.

The recovery of heat from the Autoclave exhaust would involve a heat exchanger in the gas stream. The autoclave exhaust is at a relatively low temperature and contains mostly water. Therefore, the recovery of heat would condense water out of the exhaust stream. A overall design objective for the Project is to keep the Hydrometallurgical Plant (closed system – lined residue facility) and beneficiation (closed system –

unlined tailings facility – excess water treated and discharged) water separate because of the very different natures of the water. Adding condensed water from the autoclave exhaust to the Hydrometallurgical Plant water would adversely affect the Hydrometallurgical Plant water balance (i.e. there would be a surplus of water). Also exchanging heat from the relatively low temperature vent stream is unlikely to be very efficient. Detailed design for the heating system in the Hydrometallurgical Plant has not been completed to date, but heat radiated from the hydrometallurgical process would reduce the heating demand, so some heat would be recovered even without installation of a dedicated heat exchanger.

The combination of uncertain benefits and negative effects on the Hydrometallurgical Plant water balance make the recovery of waste heat from the Autoclave exhaust technically infeasible.

7.0 Direct Emissions from Fuel Combustion

7.1 Space Heater Emissions

7.1.1 Process Plant Space Heating

Emissions from natural gas fired space heaters in the Process Plant account for a majority of the fuel combustion emissions. These emission units contribute approximately 34% of the total direct GHG emissions. Options for space heating are ranked in Table 6 below in order of estimated maximum annual emissions.

Table 6 Process Plant Space Heating Source Ranking

Rank	Source	Estimated Max Emissions [1] (m.t. CO_2 –e / yr)	Feasible?	NorthMet Selection
1	Autoclave Waste Heat Recovery & Natural Gas Heaters	52,289	No	No
2	Natural Gas Heaters	63,819	Yes	Yes
3	Propane Heaters	162,355	Yes	No
4	Electric Heaters	313,184	Yes	No

1. Please see Appendix D, Table D-1 for calculation details.

The Project's options for space heating include natural gas or propane fueled heaters, as well as electric heaters. Another potential option is to recover waste heat from the autoclave exhaust for building heat in the Hydrometallurgical Plant. Of these options, only autoclave waste heat recovery affords an opportunity for space heating-related emissions reductions. Waste heat recovery (and subsequent use in building space heating) could result in an approximately 18% reduction in the amount of the natural gas required for heating. However, this option could negatively affect the Project water balance (see Section 6.6. for details). PolyMet has chosen to use natural gas fired space heaters, which will emit significantly fewer GHGs than using propane or electricity for heating

In addition to selecting a low emitting fuel for space heating, the Project design will recycle, where practical, the exhaust from the emission controls utilizing cartridge type filtration for the Coarse Crusher, Drive House #1, Fine Crusher and Concentrator Buildings thereby reducing the amount of unheated ambient make up air drawn into the building. Any emission control system exhaust recycled back into a building will pass through a supplemental HEPA filter. Two potential suppliers of HEPA filters have been contacted. Both indicate that these filters are capable of achieving 99.97% efficiency on 0.3 micron particles. The recycling back into the building is seasonally dependent for some collectors, while others will discharge back into the building year round. The recycling of emission control exhaust will reduce the space heating requirements at the Plant Site as it allows for reuse of air that has already been heated, rather than only passing it through the system one time. This will reduce fuel usage and therefore GHG emissions. The estimated reduction in potential fuel usage is 197.2 MMcf/yr which results in reduced potential GHG emissions of 11,052 metric tons of CO_2 equivalents per year.

The installation of additional insulation in the existing 1950's vintage Coarse Crusher, Drive House #1, Fine Crusher and Concentrator Buildings at the Process Plant has also been incorporated into the Project design. This will result in a reduction in potential natural gas usage of 298.7 MMcf/yr, which results in reduced potential GHG emissions of 16,736 metric tons of CO_2 equivalents per year.

7.1.2 Area 1 Shop & Area 2 Shop Space Heating

Options for space heating are shown in Table 7 below for the Area 1 Shop and Area 2 Shop, truck maintenance and railroad maintenance shops, respectively. Area 2 will also be used as the Mine Site operations headquarters and personnel staging area.

Table 7 Area 1 Shop & Area 2 Shop Space Heating Source Ranking

Rank	Source	Estimated Max Emissions [1] (m.t. CO_2 –e / yr)	Feasible?	NorthMet Selection
1	Natural Gas Heaters	8,416	No	No
2	Propane Heaters	10,486	Yes	Yes
3	Electric Heaters	47,720	Yes	No

1. Please see Appendix D, Table D-3 for calculation details.

Space heating in the Area 1 Shop and Area 2 Shop will be provided by propane fired space heaters. Natural gas is not available to heat the Area 1 Shop and Area 1 Shop locations. The natural gas line extends only to the main plant site, and the Area 1 and Area 2 shops are not in that location. Because the heaters in the shop account for only a small amount of the Project's total GHG emission totals, PolyMet believes that running a natural gas line to the shops is not worth the environmental and safety risks, and is not cost-effective.

7.2 Emissions from Diesel Powered Sources

GHG emissions from mobile sources, generators, and fire pumps involved with the Project are calculated assuming that the equipment will be diesel powered. Other fuel options are ranked in Table 8 in order of GHG emission factors.

Table 8 Options for Mobile Sources, Generators, and Fire Pumps

Rank	Fuel	CO_2 Emission Factor[4] (kg CO_2 / MMBtu)	Feasible?	NorthMet Selection
1	Biodiesel[1]	0	No	No
2	Compressed Natural Gas[2]	52.58	No	No
3	Diesel[3]	73.18	Yes	Yes

1. Based on Factor from Table 13.1 of The Climate Registry GRP, using National Biodiesel Board heating value of 118,296 Btu/gal for B100. (http://www.biodiesel.org/pdf_files/fuelfactsheets/BTU_Content_Final_Oct2005.pdf), biogenic CO_2 emissions from biodiesel combustion would be 79.97 kg CO2/MMBtu

Note that CO_2 emissions from biodiesel combustion are considered "biogenic" and reported separately.

2. Factor from Table 13.1 of The Climate Registry GRP, converted using 1,027 Btu/scf from Table 12.2.
3. "Distillate Fuel Oil No. 1 and 2" Factor from Table 13.1 of TCR GRP.
4. Please see Appendix D, Table D-2 for calculation details.

Though the biodiesel emission factor is the largest, emissions from biodiesel combustion are considered biogenic, meaning that the source of carbon was recently contained in living organic matter. The Climate Registry GRP guidance requires that CO_2 emissions from biodiesel combustion be tracked and reported separately. Because biodiesel is typically produced from soybeans, which during their growth consume CO_2 from the atmosphere and are renewable, Table 8 above ranks biodiesel first (that is, the option with fewest GHG emissions).

However, biodiesel fueled trucks and equipment are not feasible for the Project because availability of the fuel is limited and because of operational issues with biodiesel at low temperatures.

Compressed natural gas (CNG) trucks are also infeasible because their availability is limited and because they are not cost-effective. Natural gas fired trucks would also have higher NO_x emissions, which would potentially increase visibility impacts.

Therefore, diesel fueled equipment is proposed for the Project's mobile sources, generators, and fire pumps.

EPA's National Clean Diesel Campaign (NCDC) promotes clean air strategies by working with manufacturers, fleet operators, air quality professionals, environmental and community organizations, and state and local officials to reduce diesel emissions. EPA recommends a wide range of emission reduction strategies for diesel vehicles, vessels, locomotives, or equipment.[4] Clean diesel technologies relevant to GHG emission reduction are primarily centered around improved fuel economy or idle reduction strategies. PolyMet will work throughout the life of the Project to achieve maximum fuel economy and reduce idling time.

7.2.1 Light Truck Traffic

It should be noted that the light truck traffic associated with the Project will most likely include gasoline fueled vehicles as well as diesel fueled vehicles. However, PolyMet is uncertain of how many light truck vehicles will utilize which fuel. As shown in Table 9 below, gasoline and diesel emission factors are very similar. To be conservative, emissions are calculated with a diesel emission factor.

Table 9 Fuels Comparison for Light Truck Traffic

Fuel	CO_2 Emission Factor[2] (kg CO_2 / MMBtu)
Gasoline[1]	70.44
Diesel	73.18
E85	66.70

1. Based on Factor from Table 13.1 of The Climate Registry GRP, and heat content of 125.07 MMBtu/Mgal from MPCA General Guidance for Carbon Footprint Development in Environmental Review.
2. Please see Appendix D, Table D-2 for calculation details.

An additional option for gasoline powered vehicles would be to use E85 (i.e. 85% ethanol blended with 15% gasoline). PolyMet is willing to consider use of E85 in the Project light vehicle fleet, but its usage would be contingent on the availability of appropriate fleet vehicles for purchase or lease, relative operating costs and warranty and maintenance issues.

The estimated annual gasoline usage for the project is about 51,000 gallons. Gasoline will be stored in two above ground tanks. It is likely that at least one tank would remain in gasoline service to refuel vehicles that are not capable of burning E85.

The potential effect of using E85 would be a reduction of about 26 metric tons of direct greenhouse gas emissions. Beyond this, of the estimated 421.3 metric tons per year of greenhouse gas emissions from E85 usage, 84% would be classified as biomass emissions (from ethanol combustion) for the purpose of

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[4] http://www.epa.gov/cleandiesel/basicinfo.htm

calculating carbon footprint. The carbon neutrality of biomass emissions is contingent on the details of how efficiently the ethanol is produced. Fuels and fertilizer used in corn farming and other fossil fuel usage during ethanol production can result in ethanol having a net carbon footprint.

Regardless of the details of the carbon footprint analysis, projected emissions from gasoline usage only contribute 0.2% of the total direct greenhouse gas emissions for the Project. With a relatively small and uncertain benefit from the use of E85, PolyMet is willing to substitute this fuel where economics and operational performance is similar or superior to gasoline.

7.2.2 Electric Mining Equipment

PolyMet plans on using some electric mining equipment instead of diesel where feasible. The two primary excavators are electric and there are also two electric drill rigs which will be used. However, the diesel powered secondary production excavator and one blast hole drill rig will need to operate at times where electric hookups are not yet available in newly developed mining areas.

7.3 Locomotive Emissions

There are few feasible options for reducing GHG emissions from PolyMet's Switching Locomotive and Main Line Ore Haulage Locomotives. However, PolyMet has investigated alternate locomotives and has elected to purchase new Gen-Set locomotives instead of used conventional locomotives. The conventional locomotives have a single 2,000Hp to 3,000Hp diesel engine driving a single electric generator that powers electric traction motors. The Gen-Set locomotives have three or four 700Hp to 750Hp diesel engines that meet EPA Tier III off-road standards, driving individual electric generators that power electric traction motors. The Gen-Set diesel engines start and stop automatically as required by loading demands. For example, when at idle, one 700 or 750Hp engine is running, when pulling uphill, loaded, all three or four engines may be running. The Project application involves hauling loaded cars uphill (high loading demand), hauling empty cars downhill (low loading demand) and moving trains one car length at a time for loading at the rail transfer hopper and unloading at the coarse crusher (low loading demand). This variable demand results in improved efficiency and lower fuel usage for the Gen-Set locomotives when compared to conventional locomotives, and lower fuel usage corresponds to reduced emissions of CO_2 and other greenhouse gasses. The estimated annual greenhouse gas reduction from using the Gen-Set locomotives for ore hauling is 1,588 metric tons of carbon dioxide equivalents.

8.0 Direct Emissions from Sulfuric Acid Neutralization

The largest single sources of direct CO_2 emissions at the Process Plant will be the solution neutralization and iron and aluminum precipitation tanks, which will neutralize sulfuric acid in the Hydrometallurgical Plant. The sulfuric acid can be managed by one of four methodologies, described below.

One option would be to not produce sulfuric acid. By design, the Project pressure oxidation process essentially fully oxidizes all sulfur present in the flotation concentrate to sulfate (sulfuric acid) using high temperature, pressure, and oxygen gas. This approach is efficient and is capable of leaching gold and platinum group metals (AuPGM). There are low and medium temperature leaching technologies that do not fully oxidize sulfur to sulfate, but they produce elemental sulfur that would have to be recovered. Further, iron is leached as a sulfate, which requires further processing before being converted into a stable species (such as hematite) and stored in the Hydrometallurgical Residue Facility. These low and medium temperature processes are incapable of leaching AuPGM, which is a significant component of the valuable metals for the Project. Therefore, the low and medium temperature processes do not meet the purpose of the Project.

A second option is to use sulfuric acid to leach another compound that might consume the sulfuric acid in the process. This may or may not emit GHGs, depending upon the compound leached. A common method is to use acid in spent raffinate of pregnant liquor to leach an oxide ore as part of a heap leach operation. The leach liquor is returned to the main process plant for recovery of metals from solution. However, PolyMet is not proposing heap leaching or any other process step that would consume sulfuric acid, so this methodology cannot be applied.

Sulfuric acid could also be recovered and sold. The acid in leach liquors is typically 80-180 g/l. However, the final concentration obtained is not of commercial quality for sulfuric acid, e.g., 98% (w/w). Because a marketable product would not be produced, this methodology cannot be applied.

Finally, the sulfuric acid could be destroyed. It is a common practice to neutralize sulfuric acid using limestone to form stable inert gypsum ($CaSO_4.2H_20$) and carbon dioxide gas (CO_2). Hydrated lime may also be used to destroy the sulfuric acid. Unlike limestone, hydrated lime does not generate CO_2 on contact with sulfuric acid. However, because hydrated lime is a strong base, it increases pH levels in solution well above those levels that limestone generates. The increased pH would precipitate all metals from solution at once. Precipitating metals from solution separately in separate reaction tanks is critical to generating the Project's separate metal streams and waste streams. Neutralizing with hydrated lime does not meet the purpose of the Project.

Based on this investigation, neutralization of the sulfuric acid with limestone is the only practicable solution for the Project.

9.0 Indirect Emissions from Power Production

Potential indirect CO_2 emissions from power production for the Project are estimated to be approximately 511,000 metric tons per year (Table B-1; Attachment B).

The limited available data do not allow for a quantitative comparison of potential indirect emissions related to electric power generation for the Project and European smelting operations. Therefore, it is uncertain whether smelting operations would have lower or higher electrical demand than the Project.

The Project is expected to require 59.5 MW of power, which will be supplied by Minnesota Power. According to the MPCA General Guidance for Carbon Footprint Development in Environmental Review, Minnesota Power has the second highest CO_2 emissions per megawatt-hour among Minnesota electrical providers as shown in Table 10.

Table 10 Minnesota Electrical Provider Ranking

Minnesota Electrical Provider Ranking				
Rank	**Electricity Provider**	**CO_2 Emission Factor** (lb CO_2 / MWH)	**Connection Feasible?**	**NorthMet Selection**
1	Xcel Energy	1,317.17	No	No
2	Alliant Energy	1,782.2	No	No
3	Otter Tail Power	2,099.9	No	No
4	Minnesota Power	2,159.5	Yes	Yes
5	Great River Energy	2,202.2	No	No

PolyMet's ability to change electricity suppliers—whether to reduce their indirect carbon emissions or for other reasons—is limited by variety of legal and practical barriers. First, in 1999 and 2000, at about the same time federal regulators were restructuring the wholesale electricity industry, Minnesota regulators and legislature also considered deregulating the *retail* electricity industry. See, e.g., Minnesota Public Utility Restructuring Docket No. E, G-999/CI-99-687. However, that state initiative ended by 2001 with the collapse of Enron and the California energy crisis. As a result, with some limited exceptions, retail customers in Minnesota still must purchase their electricity from their state-designated electricity provider. Second, as summarized below, none of the exceptions in Minn. Stat. §216B.40 are likely applicable to PolyMet.

9.1 Exclusive Electric Service Territories

In order to promote "the orderly development of economical statewide electric service" the 1974 Minnesota legislature granted electric utilities exclusive service rights within designated service areas. Minn. Stat. §216B.37.

9.2 Service Territory Exceptions

Under Minn. Stat. §216B.40, a utility must serve every customer within its assigned service area and must not serve any customer located anywhere else. However, Minnesota's service territory statute also carved out the following four exceptions to the general rule:

1) If the other utility consents in writing. Minn. Stat. §216B.40
2) In order to serve one utility's property and facilities, even if the property and facilities were in another utility's assigned service area. Minn. Stat. § 216B.42, subd. 2.
3) In order to serve buildings located within another utility's assigned service area if those buildings (a) were located on homestead property that lay at least in part within the assigned service area of the utility seeking to serve; and (b) were under construction as of April 11,1974. Minn. Stat. §216B.421
4) In order to serve very large customers located outside municipalities and within other utilities' assigned service areas, if the Commission found such service to be in the public interest after notice and hearing and consideration of six statutory factors. Minn. Stat. §216B.42, subd. 1.

9.3 §216B.42 Exception

Minn. Stat. §216B.42, subd. 1 provides a list of six factors that the Minnesota Public Utilities Commission is to use to evaluate whether to apply the exception:

Subdivision 1. Large customer outside municipality.

Notwithstanding the establishment of assigned service areas for electric utilities provided for in section 216B.39, customers located outside municipalities and who require electric service with a connected load of 2,000 kilowatts or more shall not be obligated to take electric service from the electric utility having the assigned service area where the customer is located if, after notice and hearing, the commission so determines after consideration of following factors:

1) the electric service requirements of the load to be served;
2) the availability of an adequate power supply;
3) the development or improvement of the electric system of the utility seeking to provide the electric service, including the economic factors relating thereto;
4) the proximity of adequate facilities from which electric service of the type required may be delivered;
5) the preference of the customer;
6) any and all pertinent factors affecting the ability of the utility to furnish adequate electric service to fulfill customers' requirements.

9.4 Municipal Exclusion

At the time that the legislation was passed in 1974, some municipalities were concerned that rural cooperatives would use the law to move into areas already served by municipal electric utilities. Therefore, the law makes it clear that the exception only applies to rural areas located outside municipal boundaries.

9.5 Public Utility Commission Application of §216B.42

The §216B.42, Subd. 1 exception has been used only infrequently. However, the few times the Minnesota Public Utilities Commission has addressed the issue, it has consistently denied the request on public policy grounds. See, e.g., *In the Matter of the Exception to the Assigned Service Area Agreement Between Northern States Power Company d/b/a Xcel Energy and Wright-Hennepin Cooperative Electric Association*, Docket No. E-002, 148/SA-01-1123, (August 13,1996) (Order Rejecting Challenge to Exception Agreement); and *In the Matter of Otter Tail Corporation d/b/a Otter Tail Power Company to serve the ethanol plant being developed by Otter Tail Ag Enterprises, LLC*, Docket No. E-119,017/SA-06-665 (Request denied, overturning Administrative Law Judge Recommendation).

In the 2007 *OtterTail* decision, for example, the Public Utilities Commission emphasized that the exclusive service territory rules:

> "have been the quid pro quo for utilities' obligations to build, buy, or lease the capacity necessary to serve all comers. That is why the Legislature considered exclusive service arrangements essential to the development of reliable and adequate electric service

> throughout the state. The centrality of assigned service areas to Minnesota energy policy means not only that Otter Tail has the burden of proof in this case but that proper analysis of its petition must occur within the context of the broad public policy goals articulated in Minn. Stat. § 216B.37."

Also, as summarized in the *OtterTail* decision, the Commission has not historically read § 216B.42, subd. 1 as a statute designed primarily to facilitate customer choice. Instead, the Commission has primarily read the exception as one designed to ensure that new industrial customers in rural areas receive adequate electric service without (a) imposing hardship on small rural utilities, who might be incapable of serving large new loads without unreasonably high levels of new investment or (b) imposing hardship on new industrial customers, who might otherwise face the excessive rates required to support unreasonably high levels of new investment. Neither of these conditions appear to apply to the Project.

9.6 Applicability to the NorthMet Project

The §216B.42, Subd. 1 exception does not apply to the Project in this case for two regulatory reasons, as well as two practical reasons. First, Minnesota Power's proposed point of delivery to the Plant Site is located within the City of Hoyt Lakes, and the proposed point of delivery for the Mine Site is in the City of Babbitt. Therefore, the §216B.42, Subd. 1 exception does not apply because the service delivery point is located within the municipalities. Second, even if the points of delivery were located outside of municipalities, the Commission is not likely to grant the exception based on public policy grounds, as described above. Third, the exception is intended primarily to address service territory extensions between neighboring service providers, not to allow a large customer to purchase retail electricity directly from a remote generator or supplier. Fourth, PolyMet already has an existing Electric Services Agreement with Minnesota Power that has been approved by the Commission.

9.7 Self-Generation Exception

PolyMet could also decide to construct and operate its own electricity generation facility. However, PolyMet is not in the electricity generation business, and the technical and business complications involved in developing a self-generation option is outside the scope of reasonable alternatives to reducing its carbon emissions at this time. (The potential for self-generation, however, did trigger legislation allowing utilities to negotiate separate rate agreements to defer the construction of such generation facilities. See Minn. Stat. §216B.1621; and *In the Matter of the Application by Koch Refining Company for Certification of the Pine Bend Cogeneration Project*, MPUC Docket, No. IP 2/CN-95-1406.

It is expected that the Minnesota Power emission factor for electricity purchases will be lowered over time as more biofuels and renewable energy sources are used for power production at those facilities. The Next Generation Energy Act of 2007 requires that 25% of the energy used in the State of Minnesota be derived from renewable resources by 2025. Under a consent agreement, EPA is obliged to issue guidance that requires the states to implement performance standards for GHGs for existing power plants under Section 111d of the CAA. Additional reductions of GHG emissions may be developed at individual Minnesota power plants through voluntary actions designed to meet GHG emission reduction goals (15% by 2015, 30% by 2025, 80% by 2050) in the Next Generation Energy Act. Similarly, reductions may come from energy efficiency improvements or new fuels developed through new energy projects or research funded under the Next Generation Energy Act.

As the GHG emissions from power production decline, the potential indirect CO_2 emissions for the Project may also decline. It is currently uncertain as to how much an individual facility using power from the Mid-Continent Area Power Pool (MAPP) grid will benefit from GHG emission reductions at specific electric generating facilities. However, the overall effect of the initiatives discussed above is likely to be a reduction in GHG emissions related to power production.

10.0 Terrestrial Carbon Cycle Impacts

Terrestrial carbon cycle impacts encompass any carbon emissions or loss of carbon sequestration capacity from disturbed terrestrial ecosystems over time due to Project activity. The present estimates of carbon cycle impacts are highly uncertain and use simplifying assumptions about wetlands and forest, many of which lack site-specificity. In addition, some of the emission sources documented may be longer lived than the Project and may change substantially over time, resulting in temporal uncertainties that complicate the quantification of carbon cycle impacts. Despite these uncertainties, quantitative estimates for six carbon cycle impacts are calculated in this section:

1) Total carbon stored in the above-ground vegetation of wetlands and forests lost to Project activities [treated as a one-time emission]
2) Total carbon stored in excavated peat and annual emissions from its stockpiling
3) Possible carbon flux from peat used in reclamation activities
4) Annual emission rate for indirectly impacted wetlands due to potential water level drop
5) Loss of annual carbon sequestration capacity due to the disturbance of wetland and forest plant communities discounting methane emissions from wetlands as a conservative assumption.
6) Reduction in annual carbon sequestration capacity in indirectly impacted wetlands

10.1 Aboveground Carbon Lost from Impacted Forests and Wetlands

Wetlands and especially forests hold substantial proportions of their overall carbon in aboveground vegetation. For areas directly impacted by the Project, this vegetation will likely be buried or removed at some point in time during the preliminary construction period or 20 year period of operations. Despite the likelihood that some substantial proportion of this biomass will be buried or used to produce long-lived products (e.g., lumber) and that the vegetation may be removed in stages over a prolonged period, this assumes that all of this carbon is emitted as a one-time release of CO_2. The aboveground wetland and upland forest carbon stock loss due to direct Project impacts is a theoretical maximum of the amount of carbon dioxide stored in this aboveground vegetation. Values for the total amount of carbon stored per unit surface area have been developed from the scientific literature and combined with plant community-specific surface area in order to generate total carbon stock estimates.

The carbon storage values from the literature (see Attachment E for more detailed assumptions and calculations) were multiplied by the corresponding acreage, surface area conversion factors, and carbon-to-CO_2 conversion factors to generate a potential CO_2 stock, which is summarized in Table 11. It should be noted that some of the values available were based on wetland and forest types that were not an exact match to those documented at the Project site, but were deemed to be close in terms of age, vegetation, and other characteristics.

In addition to wetland and forest aboveground carbon, we present the central estimate of carbon contained in excavated and stockpiled peatlands. This estimate places the aboveground carbon estimates in the context of the much larger carbon stock contained in the layers of peat. Unlike much of the aboveground biomass, it is known that the majority of this peat will have its exposure to the atmosphere minimized through stockpiling, thereby reducing the rate of oxidation to CO_2.

Table 11 Emissions from Wetlands and Upland Forest Aboveground Carbon

Source	**Pollutant**	**Emission Rate** (CO_2-e m.t./acre/yr)	**Estimate Type [1]**
Emissions from indirectly impacted wetlands [2]	CO_2	7.41	High estimate
Source	**Pollutant**	**Single Emission** (CO_2-e m.t.)	**Estimate Type [1]**
Total aboveground wetland carbon stock directly impacted by the Project [3]	CO_2	65,495	High estimate
Total aboveground forest carbon stock directly impacted by the Project [4]	CO_2	102,052	High estimate
Source	**Pollutant**	**Carbon Stock** (CO_2-e m.t.)	**Estimate Type [1]**
Total carbon stored in excavated peatlands [5]	CO_2	1,309,000	Central tendency

Units = CO_2-e, m.t. = GHG emissions as CO_2-equivalents, in metric tons

[1] Theoretical max: maximum value possible given physical variables; High estimate: high degree of confidence that estimate is above actual value; Central tendency: best estimate of actual value; Unknown: low level of confidence in relationship to actual value

[2] Assumes carbon emission rate[5] of 500 $g/m^2/yr$, which coincides with rates from drained and relatively undisturbed peat

[3] Assumes treatment of all aboveground carbon stored in impacted wetlands as a one-time carbon dioxide emission

[4] Assumes treatment of all aboveground carbon stored in impacted upland forest as a one-time carbon dioxide emission

[5] Based on site studies of peat in overburden.

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[5] Grønlund, A., A. Hauge, A. Hovde, and D.P. Rasse. 2008. Carbon loss estimates from cultivated peat soils in Norway: a comparison of three methods. Nutrient Cycling in Agroecosystems. 81(2):157-167.

The aboveground carbon estimates should not be interpreted as a mass of CO_2 emitted to the atmosphere over a specific timescale, but rather should represent the upper limit on carbon dioxide that could hypothetically result from the disturbance of aboveground biomass in site wetlands and forests. The probability of all disturbed wetland and forest aboveground carbon being converted to CO_2 over a short timescale (e.g., 1 year) is low, given the value of long-lived forest products (e.g., lumber), the recalcitrance of much of the woody forest material, and the fact that the impacts may take place in stages over the course of operations.

The section, "Emission from Stockpiled Wetlands" below, details the calculation of the annual emissions from the peatland stockpiling, which presents more realistic estimates of the annual emissions likely to result from impacted peatlands than the assumption of a one-time loss of all peatland carbon. Due to uncertainty about the treatment of non-stockpiled wetland and upland forest biomass, the same sort of analysis was not done for materials from these ground cover types.

10.2 Carbon Sequestration Capacity Loss in Impacted Wetlands and Forests

Carbon sequestration capacity represents the expected flux of CO_2 into wetland or forest systems for use in a number of processes, including photosynthesis and chemosynthesis, which incorporate the inorganic carbon into stable organic material. When wetlands and forests are disturbed, this can drastically affect the amount of carbon that they can take up. The analysis that we present assumes that all of the carbon sequestration capacity in directly impacted areas is lost. This is an overestimate of the expected loss of capacity for two reasons: (1) the impacts on wetlands and forest will not all take place instantaneously, and some areas may not be impacted until quite a bit later in the project; and (2) the degree of overall impact is not likely to be a complete loss of biological function and carbon sequestration, especially for lightly impacted wetlands and forests. See Attachment E for more detailed assumptions and calculations.

The carbon sequestration rates were multiplied by the corresponding acreage, surface area conversion factors, and carbon-to-CO_2 conversion factors to generate the potential loss of carbon sequestration capacity, which is summarized in Table 12.

Table 12 Loss or Reduction of Carbon Sequestration Capacity

Source	**Pollutant**	**Capacity Loss** (CO_2-e m.t./yr)	**Estimate Type [1]**
Wetland sequestration capacity loss from direct impacts	CO_2	1,168	Central tendency
Wetland sequestration capacity reduction from indirect impacts	CO_2	[2]	Unknown
Upland forest sequestration capacity loss from direct impacts	CO_2	1,814	Central tendency

Units = CO_2-e, m.t. = GHG emissions as CO_2-equivalents, in metric tons

[1] Theoretical max: maximum value possible given physical variables; High estimate: high degree of confidence that estimate is above actual value; Central tendency: best estimate of actual value; Unknown: low level of confidence in relationship to actual value

[2] The wetland capacity reduction in indirectly impacted wetlands is based on a reduction from 0.7 metric tons C/ha/yr (sequestration rate for peatlands) to 0.33 metric tons C/ha/yr (sequestration rate for mineral wetlands), 3.34 metric tons CO_2/acre/year.

The loss of carbon sequestration capacity is treated here as a separate issue from the potential for post-disturbance carbon emissions, though, mechanistically, emission/sequestration are just opposite directions of carbon flux from a defined ground surface area. Carbon sequestration loss for indirectly impacted wetlands is expressed on a per acre basis as total indirect wetland impact acreages were not finalized at the time of this report was drafted.

10.3 Emissions from Stockpiled Wetlands

Emissions from the direct removal and stockpiling of wetland material alone and mixed with other overburden material have been calculated using fundamental information about the surface area of the stockpiles, the carbon content of and oxygen diffusion into representative wetland organic material, and pertinent data from disturbed wetlands emissions studies. Below, an analysis of the potential carbon emissions that may occur upon dredging wetlands and relocating the dredged material to stockpiles during the life of the Project is presented. Dr. David Grigal, Professor Emeritus in Soil Science at the University of Minnesota, provided assistance in estimating the quantity of carbon excavated and carbon dioxide emissions from dewatered and stockpiled peat at the Mine Site. The analysis described in detail is for the peat that will be excavated under the stockpile footprints and at the mine pits. Additional peat will be excavated at the tailings basin and for dike and ditch construction at the Mine Site. These additional quantities are described following the detailed description.

The Project will involve the excavation of peat as part of the mining operation, causing the release of long stored carbon. This peat will be stored in stockpiles for a period of time and then used in site reclamation upon closure. In order to calculate the potential carbon emissions from this material, two parameters must be estimated: the amount of wetland carbon removed, and the fraction of this disturbed material that is emitted as CO_2.

10.3.1 Amount of Wetland Carbon Removed due to Mining Activities

In order to calculate the amount of carbon released during such peat removal processes, a reasonable estimate of the total mass of carbon (C) that will be disturbed by the mining operation must be generated. In the June 2009 NorthMet Project Climate Change Evaluation Report, five different estimates of total C removed were generated, ranging from slightly over 200,000 tons to nearly 750,000 tons. The methodologies behind these estimates are described in detail in the June 2009 report. The report concludes that the methodology developed by Barr for estimating the mass of peatland C disturbed by the Project is an appropriate methodology and produces results that are in line with the results of alternate methodologies. For this report, the “Barr” methodology has been used to update the estimate of carbon removed. This methodology is described in further detail below.

10.3.1.1 “Barr” Methodology

The “Barr” estimate of C removed was based on the results of total estimated peat removal from estimates of peat stripping over a 20-year period (728,450 tons). The quantity of peat excavated to construct stockpile foundation and liner systems and at the mine pits is based on the peat volume values in Table 4-1 of the NorthMet Project Mine Plan (Version 1, November 29, 2011), which lists the total volume of peat excavated as 2,491,000 cubic yards. A density value of 0.25 tons per cubic yard was used to arrive at the total mass per the recommendation of the Project soil scientists with a result of 622,750 tons of peat. An additional 66,400 tons of peat will be excavated at the Tailings Basin and an additional 39,200 tons will be excavated at the Mine Site for miscellaneous purposes as described below. The total peat excavated then equals 728,450 tons. The 728,450 tons was converted to tons of organic matter, and then to tons of C. To convert the peat mass to organic matter, summary data from a comprehensive study of 10 northern Minnesota peatlands, sampled with an average of four detailed cores per peatland, was used (Grigal and Nord, 1983). The peatlands were evenly divided between bogs and fens, and organic material ranged from hemic to fibric. Sampling was done by 25-cm (10-inch) depth increments. Average ash content of all samples to a 200-cm depth (80 inches) was 10.9 percent, so that LOI was 89.1 percent of peat mass. That mass was converted to C using the relationship described above (C = LOI * 0.55). The resulting estimated mass of C removed was 357,000 tons (Fig. 2).

10.3.2 Surface Area of Stockpiled Wetland Material

The surface area of the peat stockpiles at the Mine Site was calculated using information from discussions with PolyMet regarding a peat stockpiling plan. A footprint of approximately 22 acres has been allocated for a peat stockpile with a maximum height of 40 feet. The volume and surface area of the stockpile exposed to the air was estimated based on two assumptions: 1) there would be no ramp needed for access; 2) the slopes of the sides of the stockpile would be 3.5:1. The resulting volume of this stockpile is 1,029,493 yd^3, and the surface area is 986,501 ft^2.

The balance of peat would be used for ongoing reclamation activities during mine operations. As indicated above, the total volume of peat excavated is estimated at about 2.5 million cubic yards, so the volume used for reclamation during operations is about 1.5 million cubic yards.

This estimated stockpile surface area will be larger than the effective surface area over most of the Project timeframe in that it assumes the stockpile is always at its maximum size. During the early years of the project, the surface area would be substantially less. Therefore, calculation of an annual CO_2 emission rate based on the above peat surface area will result in a maximum value.

10.3.3 Amount of Carbon Released from Stockpiled Wetland Material

In order to estimate the amount of carbon eventually released to the atmosphere due to the removal and stockpiling of wetland material, assumptions must be made about physical characteristics of the stockpiling process. As described in the previous section, the surface area for storage of the removed and stockpiled wetland material is assumed to be approximately 58 acres, including both a stockpile exclusively for peat (22 acres), and for peat intermixed with mineral overburden (with peat at the surface over about 36 acres). This estimate represents a maximum surface area, because the actual surface area at any point in time would be the sum of additions during the stripping operation and removals for site remediation/reclamation, and would often be less than this value.

10.3.3.1 Carbon Emissions from Organic Materials

The characteristics of the organic material are critically important when considering C emissions. Organic material varies in its recalcitrance, resistance to microbial degradation. Very fresh material, high in nutrients and especially in nitrogen (such as fresh leaves), will be broken down quite quickly, emitting nearly all the C that it contains. However, other organic materials (such as wood) break down slowly. Similarly, organic materials from wetlands (peat) can be considered relatively recalcitrant. They are the residual remaining after a long period of microbial degradation, and as such are the most resistant fraction of the original material.

For example, in peatlands in Itasca County in northern Minnesota, long-term rates of peat accumulation (over the last approximately 9000 years) are uniform at about 0.25 tons/ac/yr (Gorham et al., 2003). This is only about 20% of annual production on such peatlands (Grigal and Bates, in preparation; Reich et al., 2001; Weishampel et al., 2009). This remaining 20% of production is the most recalcitrant material; less resistant material has been broken down by microorganisms with release of CO_2. Stockpiles of peat material will therefore not break down (and release C as CO_2) as quickly as would stockpiles of fresh organic materials such as lawn clippings and leaf litter.

10.3.3.2 Approaches

There are at least three approaches to estimating C loss from peat piles from stripping operations. They should provide boundary conditions on rates of such loss:

1) Measured rates of peat loss following drainage for agriculture or forestry,
2) Information on CO_2 emissions from stockpiles of peat from peat mining operations, and finally
3) A simple model of rates of oxygen movement (diffusion) into peat, which can be used to evaluate the reasonableness of the reported rates of C emission. Oxygen is required by microorganisms as they oxidize organic materials to CO_2.

10.3.3.3 Peat loss following drainage

There have been many studies of loss of peat mass or elevation following drainage, primarily in northern Europe. Loss of elevation of peat, termed peat subsidence, results from the combined effects of both compaction and C loss as CO_2 through activity of microorganisms. Subsidence due to compaction occurs primarily during the first few years following drainage, as soil pores that were originally filled with water collapse. This is largely a phenomenon of surface peat; subsurface peat is more compact because it has already been compressed because of the mass of overlying material. Long-term rates of subsidence, following the initial period of peat compression, generally reflect C loss.

Reported long-term rates of subsidence include 7 mm/yr (Netherlands), 10 to 20 mm/yr (both Russia and Scandinavia), 10 to 14 mm/yr (Poland), and 11 to 22 mm/yr (Germany) (Bradof, 1992). Measured subsidence in drained areas of the Red Lake Peatland, northern Minnesota, averaged 3 to 10 mm/yr since 1916. All these rates are surprisingly similar, and 10 to 20 mm per year seems to be a reasonable average.

That rate can be translated to C loss with an estimate of peat mass per unit depth. Three sources from Minnesota were used to provide that estimate, including the Web Soil Survey sponsored by the Natural

Resources Conservation Service (NRCS) (USDA). Data used were for the Embarrass portion of St. Louis County, which includes the mine site. The second source of data was a comprehensive study of 10 northern Minnesota peatlands, sampled with an average of four detailed cores per peatland (Grigal and Nord, 1983). Finally, detailed data for peat soils was collected from a variety of sources but primarily from the soil characterization database of the Natural Resources Conservation Service (NRCS) (Soil Survey Staff 1997) and from characterization data from the University of Minnesota Department of Soil, Water, and Climate.

The resulting average mass of C per unit peat depth was approximately 1 metric ton (Mg) per hectare per mm, or almost 0.5 tons/acre per mm. Loss of C from soil via CO_2 emissions is commonly measured in units of grams of C per square meter per year ($g/m^2/yr$), which is equivalent to 100 Mg C/ha/yr or about 45 tons C/acre/yr. The long-term rate of C loss, based on literature-derived subsidence data cited above, therefore ranges from about 1000 to 2000 $g/m^2/yr$.

A review of the literature from Europe reported average rates of C emissions from drained peatlands ranged from 300 $g/m^2/yr$ for drained grasslands to 550 $g/m^2/yr$ for drained small grains to 1900 g/m2/yr for drained row crops (Kasimir-Klemedtsonn et al., 1997). These data indicate that rates of loss increase with soil manipulation; minimally-manipulated grasslands having relatively low rates of loss.

Finally, a detailed study in Norway used three independent methods to estimate C losses from drained and cultivated peatlands: (1) long-term monitoring of subsidence rates, (2) changes in ash contents, and (3) direct CO_2 flux measurements (Grønlund et al., 2008). The three approaches provide independent checks of one-another, and consistency in the estimates would provide some degree of confidence in the results. The three approaches yielded estimates of C emissions of 800, 860, and 600 $g/m^2/yr$, respectively, or an average of 750 $g/m^2/yr$.

In summary, this variety of studies of C loss from peat following drainage set a range of from about 300 to 2000 $g/m^2/yr$, with losses associated with minimal manipulation of the surface of about 500 $g/m^2/yr$.

10.3.3.4 CO2 emissions from peat stockpiles

In contrast to the abundant data on C loss from drained peatlands, there has been limited work carried out to assess C loss from peat stockpiles. Work has been carried out in Finland, and the stockpiles are associated with temporary storage of mined peat before consumption for fuel (Sarkkola, 2007). Monitoring over the period in which CO_2 emissions occur (May through November) indicated losses of 3000 mg CO_2 /m^2 of stockpile per hr, or 3500 g $C/m^2/yr$ (Ahlholm and Silvola, 1990). This emission rate is per surface area of the stockpile, not of the entire disturbed peatland.

These emission rates are considerably higher than those based on peat drainage (300 to 2000 versus 3500 $g/m^2/yr$). It is important to understand that the stockpiles in these cases are very temporary, are not vegetated, and that dry peat is a preferred fuel. All these factors would logically lead to emission rates that are higher than those of drained but less disturbed peatlands.

10.3.3.5 Oxygen diffusion into peat

Oxygen is required by microorganisms as they oxidize organic materials to CO2, and a simple model of rates of oxygen movement (diffusion) into peat can be used to provide some idea of the reasonableness of the rates of C loss from peat as reported above. Microbial respiration consumes O_2 via the basic reaction

$$[CH_2O] + O_2 \rightarrow CO_2 + H_2O \qquad [1]$$

where $[CH_2O]$ represents the basic unit of an organic molecule, such as organic matter from peat.

The result of the reaction described in Eq. [1] is that one mole of O_2 is required and consumed for every mole-equivalent of organic matter that is oxidized and a mole of CO_2 is produced. The efflux of that CO_2 from soil is the vehicle of C loss. The basic question is to what depth O_2 can be supplied to achieve the reported rates of C loss from peat.

To approximate an O_2 gradient into the soil, a steady-state approximation of diffusion can be used. That approximation is,

$$F_{surface} = D_e * dC_O/dx \quad [2]$$

where $F_{surface}$ is the annual flux of O_2 from the atmosphere into the soil surface, D_e is the effective diffusion coefficient, and dC_O/dx is the O_2 concentration (C_O) gradient from the atmosphere to the ultimate "sink" for O_2 consumption. This assumes a linear gradient that is maintained by a constant source and sink over a sufficient time for equilibrium to occur. By simplifying the computation, these assumptions allow a multiplicity of approximate solutions to be calculated.

Eq. [2] can be reformulated to calculate

$$dC_O = F_{surface} * dx/D_e \quad [3]$$

This dC_O is the change in O_2 concentration over a specific depth (x) that is required to achieve the appropriate flux rate from the atmosphere into the soil. Because the surface concentration of O_2 is approximately 209.5 mL L^{-1} (Machta, 1970), then the O_2 concentration at the depth of the O_2 sink is

$C_{Osink} = 209.5\ \text{mL L}^{-1} - dC_O \quad [4]$

A spreadsheet was constructed, using as inputs measured or estimated C flux from soil (in g C/m^2/yr), the average temperature during period of C efflux, the actual number of months of efflux (biologically active, frost-free season), the measured or estimated soil pore space (in cm^3/cm^3), and the measured or estimated volumetric water content (also in cm^3/cm^3). The spreadsheet uses those data to compute the average O_2 concentration at any desired sink depth.

Based on the assumptions implicit in the spreadsheet, and using the average summer temperature of Babbitt, Minnesota, the literature-derived rate of C flux from drained and relatively undisturbed peat (500 g/m^2/yr) can be achieved at nearly any peat water content. If the peat is very wet, however, at field capacity (volumetric water = 0.8 cm^3/cm^3), then O_2 would be wholly consumed in the upper eight inches of peat, so that the predicted rate of loss probably would be unlikely to be achieved. When a liberal estimate of the rate of C flux from stockpiles (4000 g/m^2/yr) is evaluated, those rates can only be sustained if the peat were dry (less than 0.35 cm^3/cm^3 water content). If peat were "moist" (about 0.6 cm^3/cm^3 water content), O_2 diffusion would be limited to the upper six inches of peat and those rates are not be likely to be sustainable. In other words, as peat water content increases, rates of C emission are likely to go down.

In summary, C loss from stockpiled peat at rates of 3500 g/m^2/yr are only likely to be achieved if the peat is quite dry.

10.3.3.6 Conclusion

If the area of storage of the excavated peat from the mine site is approximately 22.6 acres (91,649 m^2), then the annual emissions of C (using the estimate from stockpiles – 3500 g/m^2/yr) would be 321 metric tons of C per year, or 1,176 metric tons of CO_2 per year. This is about 0.6 percent of the direct emissions from the Project (210,261 metric tons/year), or about 0.2 percent of total emissions including power generation (721,261 metric tons/year).

Because the stockpiled peat is not likely to be disturbed until used for reclamation, rates will likely be lower than the conservative estimate given above and are likely to approach those for drained peatlands (500 g/m^2/yr). In addition, as stated earlier, the actual surface area of stored peat would likely be smaller than 58 acres because of the on-going additions during the stripping operation.

With respect to the global carbon cycle, it is important to understand that another effect of using this local material in reclamation is that its use will reduce or eliminate use of other organic materials. All organic horticultural amendments, and especially high-organic materials such as “peat moss” that are commonly used for such remediation, originate in wetlands. Mining of those wetlands for horticultural purposes releases CO_2 to the atmosphere. Use of peat material from the Project site will consequently minimize emissions from these other sources.

10.3.4 Additional Peat Stockpiling at Tailings Basin

Additional peat is expected to be excavated along the pipeline route between the Mine Site and the Tailings Basin and at the tailings basin. This peat will be stockpiled at the tailings basin. The quantity was estimated by assuming that 100% of the peat located in the buttress construction area would be excavated and 25% of the peat in the East Basin Expansion Area would be excavated. The balance would be buried or inundated with water. The estimated excavated volume for the Tailings Basin and the pipeline is 265,615 cubic yards with a mass of 66,400 tons. The carbon content was estimated in the same manner as described above and added to the totals reported.

The surface area of a stockpile 40 feet high with a 3.5:1 slope with the necessary volume was calculated with a result of 5 acres. This was added to the stockpile surface area at the Mine Site of 22.6 acres for a total peat stockpile surface area of 27.6 acres.

10.3.5 Additional Peat Excavation at the Mine Site

In addition to the excavation under the stockpile footprints and at the mine pits, excavation will be performed at the Mine Site at the overburden storage area and to construct the dikes and trenches. The total quantity was estimated as 175,476 cubic yards or 39,300 tons. This quantity is assumed to be used in reclamation activities. .

10.4 Carbon Flux Associated with Peat Use in Reclamation Activities

The carbon balance resulting from reclamation activities is a function of both rate of carbon loss (decay) from the peat materials added as a soil amendment, and the rate of carbon gain in soil and vegetation occupying the site. For the purposes of this evaluation, the primary concern is with the potential for additional carbon losses from previously stockpiled peat that will become a component in the admixture used for reclamation, however, a look at the carbon flux over time and the balance between carbon loss and carbon gain can aid in assessing the potential for additional loss of peat carbon stores. Below is an analysis of the carbon flux associated with reclamation activities. Dr. David Grigal, Professor Emeritus in Soil Science at the University of Minnesota, provided assistance in estimating the potential flux for various reclamation cover types at the Mine Site.

10.4.1 Carbon Loss from Peat Used in Admixture

Olson (1963) described the rate of decomposition of organic materials as a simple negative exponential:

$$Y = \exp(-k*T) \qquad [5]$$

where Y is the decimal fraction of mass remaining, T is time in years, and k is a constant. This expression is similarly used to describe decay of organic material. This simple model, however, appears to overestimate loss in later stages of decomposition, and Wieder and Lang (1982), for example, proposed a double exponential model that they considered to provide the most realistic description of observed decomposition data,

$$Y = A \exp(-k1*T) + (1 - A) \exp(-k2*T) \; [6]$$

where A is (usually) an easily decomposable fraction with a faster rate of decomposition (-k1) and (1 - A) is a more recalcitrant fraction with a slower rate (-k2). Although eqn. [6] may fit the data better, eqn. [5] is probably adequate for approximation.

Peat, by definition, is residual material remaining after hundreds or thousands of years of decomposition. Gorham (1991) estimated that only about 8 to 9% of net primary production is ultimately stored in the peat; the remaining 90+% of material is lost by decomposition. It is likely that most of the loss occurs in the partially-aerobic acrotelm (peat surface layer), with extremely slow rates of loss in the anaerobic catotelm.

No quantitative data on rates of C loss from peat additions to mineral soils could be located. However, a line of evidence for rates of peat decomposition under aerobic conditions is that of C emissions from drained peatlands, which are discussed in greater detail above.

To use these data to estimate a rate of C loss, it can be assumed that the source of the emissions cited above (700 g/m2/yr) is the upper 24 inches of peat. The mass of peat to that depth is about 900 Mg C/ha based on a density of 0.23 tons/cy (moist). This combination of emissions and mass yields an exponential rate constant (k) of -0.0076 and a half-life of 90 years. This is a reasonable rate of loss for partially-decomposed peat. A rate constant of –0.0005 was used by Grigal et al. (2011) in a simulation model for decay of the 0 to 25 cm (10 inch) layer of peat in a peatland in Minnesota. The rate used here (-0.0076) for peat added to mineral soil is 15 times greater.

10.4.2 C Gain in Reclaimed Areas

10.4.2.1 Soil

The purpose of admixing peat with mineral material is to enhance the restoration of a functioning ecosystem on disturbed areas at the Mine Site; e.g., Category 1 rock stockpile. Leisman (1957) carried out a landmark study of soil and vegetation changes on waste piles on the Mesabi Range. He provided detailed data on soil C, and sampled soils on multiple dumps at 2, 4, and 9 inches. If his sampling is assumed to represent the soil depth to 12 inches (2-inch sample represents 0 to 2 inches, 4-inch sample represents 2 to 6 inches, and 9-inch sample represents 6 to 12 inches), then a function of change in soil C with time can be computed. The result is a linear relationship,

Soil C (Mg/ha) = 2.14 + 0.494 * time (years), r2 = 0.99, n = 5. [7]

The oldest stripping dumps sampled by Leisman were 51 years old, and thus the relationship is assumed to be applicable for about 50 years.

10.4.2.2 Vegetation

The upland cover types that are likely to develop on disturbed areas at the mine site include: aspen woodland, red pine woodland, and herbaceous ground cover. The estimated carbon balance associated with each of these cover types is described below.

10.4.2.2.1 Aspen Woodland

In addition to measuring soil properties, Leisman also monitored revegetation. He stated, “The stripping spoil bank succession usually led to a fairly uniform woodland community with Populus tremuloides and P. balsamifera being the conspicuous members of the overstory.” He collected data on cover and frequency of vegetation, but unfortunately those data cannot be easily used to calculate C storage.

For estimation of C accretion in aspen stands, empirical yield tables for Minnesota collected as part of the Forest Inventory and Analysis (FIA) program, coordinated by the USDA Forest Service, were used. The yield tables were compiled from data gathered on 8,807 commercial forest land plots established during the 1977 inventory of Minnesota's four Forest Survey Units. The tables provide the average stand basal area by age and site quality class, and the number of observations for each average, for 14 forest types. Traditionally, yield tables used in forestry are based on carefully selected forest stands of uniform age and composition. In contrast, these empirical yield tables are based on a random sample of “real world” forests. The sampled stands contain a variety of species, and the stocking (density) may not be optimal. In fact, Hahn and Raile point out that the stocking of the tabulated aspen stands 51 to 60 years old in the

61- to 70-site index class is only about half of optimum. Because of their source, these tables provide a conservative estimate of rates of C accretion with time.

The data from the tables for all site quality classes for the aspen forest type (from 3496 stands) were fit to a logistic function describing basal area change over time,

$$BA = a/(1+\exp((b * (T - c))), \qquad [8]$$

where BA is stand basal area in m^2 ha-1, T is stand age in years, and a, b, and c are constants. The constant a is the maximum BA at infinite time, b is the rate at which the function approaches maximum BA (a), and c can be considered a lag term. To determine the constants, the data for each age class (10-year classes) were weighted by the number of plots in each class. Observed and predicted BA were strongly correlated, with r2 (r^2?) = 0.94. Basal area data were converted to above-ground stand biomass from a database of 409 aspen-birch stands.

Carbon content of all biomass data was assumed to be 48% (Hahn, 1982, Alban and Perala, 1990). The ratio of root mass to above-ground mass for forested types is 0.3 (root mass is 0.3 times above-ground mass) (Perala and Alban, 1994, Whittaker and Marks, 1975, Santantonio et al, 1977), and that ratio was used to compute total vegetation C.

10.4.2.2.2 Red Pine Woodland

An identical approach was used to compute C accretion of the red pine woodland. The 1977 forest inventory sampled many fewer red pine plots (95) than aspen plots. Basal area data were fit to the logistic function, and observed and predicted BA were correlated with $r^2 = 0.69$. A database of 105 red pine stands was used to convert basal area data to above-ground stand C (Grigal et. al, 2011). As with aspen, the root:shoot ratio of 0.3 was used to compute total vegetation C.

10.4.2.2.3 Herbaceous Cover

To determine the rate of C accretion under herbaceous cover, biomass data for leaves, roots, and stems from a 35-field chronosequence spanning the first 60 years of secondary succession on a Minnesota sand plain were used (Gleeson and Tilman, 1990). Although the sequence represents secondary succession, Gleeson and Tilman (1990) argue that their work in the "unproductive, nitrogen-depleted sandy soils" of Cedar Creek Natural History Area may have more in common with primary successions than with secondary succession on richer soils.

Their data were collected from 22 formerly farmed fields and an additional 13 sampling sites that were sequentially abandoned. Gleeson and Tilman (1990) presented the biomass data graphically, and the data were extracted from their figures. Apparently because of complete overlap of two points, only 34 data points were found on each of the three figures (leaf, stem, and root biomass). Component data for each of the 34 fields were summed and fit to the logistic function. In contrast to a linear function (as used by Gleeson and Tilman), the logistic function provides a logical asymptote of mass accumulation with time. Observed and predicted biomass were correlated with $r^2 = 0.49$.

10.4.3 Results – C Balance

The estimated rate of peat addition to the overburden is based on a criterion used for quality topsoil of 2-5% organic material by weight. As a result, a goal of 5% peat mixture was chosen. While the disturbed areas may vary in area and slope, the rate of peat addition will be at about 550 cubic yards of peat per acre (information from Christie Kearney, Barr Engineering, 12 October 2011). This is equivalent to about 145 Mg of C /ha.

In contrast to both the data from Leisman (1957) and Gleeson and Tilman (1990) that was specific to year, the data from the empirical yield tables was by 10-year age classes (Hahn and Raile, 1982). The first data point was the midpoint of the 0 to 10 year class, or 5 years. The C accretion of the woody vegetation for the first five years of site occupancy was simply extrapolated from 0 to the five-year data point. The assumption was that at time = 0 there was no vegetation, and hence no C, and at 5 years and beyond the vegetation C was as estimated by the logistic function.

The resulting balance of gain and loss of C can be examined by cumulative changes. The loss of C from peat, under all scenarios, is nearly linear with time because the material is primarily recalcitrant organic matter (Fig. 3). Soil C shows a monotonic increase, based on Leisman's (1957) data. The continual increase in both soil and vegetation C more than balances the loss of C from the added peat in the woodland scenarios, but not in the herbaceous scenario.

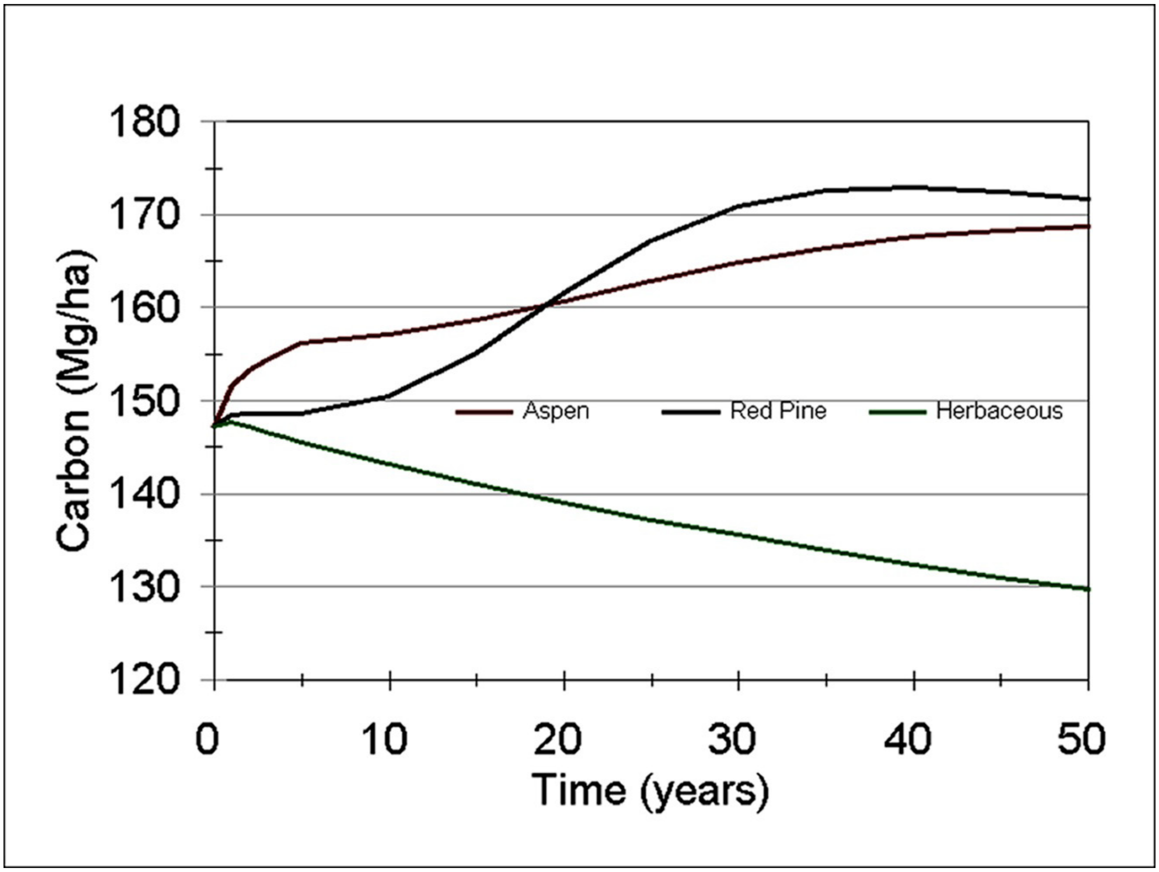

Figure 1 **Cumulative ecosystem carbon change with time on disturbed areas with a 5% peat admixture revegetating to three alternative scenarios**

Under the scenario of herbaceous cover, the ecosystem loses about 10% of its C over a 50-year period (Fig. 3). Although the herbaceous cover shows a net negative C flux over time, herbs are a transient vegetation type in northern Minnesota. Vegetation succession in the region is clearly to woody cover. The critical question is the time-sequence of woody invasion. Gleeson and Tilman (1990) state that the outcome of succession at their site is generally assumed to be oak savannah or oak forest, based on both the pre-agricultural vegetation of the site and the slow, but significant, increase in woody plant biomass during succession. Based on Leisman’s (1957) work, woody cover development on revegetated areas at the mine site would likely consist of quaking aspen and balsam poplar. Based on Leisman’s work, combined with input from Barr botanists familiar with vegetation succession in the iron-range area of Minnesota, woody cover development on revegetated areas at the mine site would likely be underway within five years of reclamation and seeding with an herbaceous mix. Based on this succession and a loss of approximately 5Mg/ha over the first five years after reclamation, Attachment D provides a rough estimate of potential additional carbon losses associated with the first 5 years after reclamation for each of the reclaimed areas at the site of about 8,500 metric tons.

10.4.4 Caveats

This analysis is based on limited data, and therefore there is uncertainty in the details regarding its analyses. The rate of C loss from the peat may be higher or lower than the estimate used here. There is no question that hemic peat is recalcitrant, and the rate used here indicates loss of about one-third of the C in 50 years, a reasonably rapid rate. The actual rate of vegetation regrowth is also uncertain. At the mine site, fertilization and other management techniques will be used to enhance vegetation growth, and the data used in this analysis did not include those measures. However, from simple consideration of the general rates of C accumulation in forested ecosystems relative to the modest rates of C flux to the atmosphere from the use of peat as a reclamation aid, it appears that the use of the peat amendment will not result in net C flux to the atmosphere under those scenarios. The herbaceous scenario, if cover is maintained in herbs, shows a net C loss, but the inevitable succession to woodlands will lead to net C accumulation. There is uncertainty, however, in the temporal sequence of those changes.

11.0 Conclusions

The potential annual direct and indirect GHG emissions from the Project are estimated as follows (as metric tons CO_2-e): direct = 186,342, indirect = 511,000, total = 697,342. A comparison of the estimated direct GHG emissions for the Project to statewide, national, and global GHG emissions shows that the potential GHG emissions from the Project are a small fraction of those emissions. The GHG emissions from the Project are approximately 0.12% of estimated statewide emissions, 0.003% of national emissions, and 0.00038% of global emissions (Table 4).

Available information from Bateman (2005) and identifies that hydrometallurgical processes have 50% lower energy demand than a pyrometallurgical process.

There are also other factors, such as improved metal recoveries and reduced SO_x emissions that would seem to make hydrometallurgical processing a better overall alternative for the Project from an environmental impact perspective. Aside from using a hydrometallurgical process rather than a smelting process, there are limited options available to further reduce GHG emissions from the Project. However, PolyMet will purchase energy efficient equipment when available and choose the lowest CO_2 emitting fuel option for most emission units.

Indirect emissions of GHGs related to power production are important for all mining and manufacturing facilities in Minnesota and elsewhere. Because of legal limitations, PolyMet does not have an option for an electricity provider and must use Minnesota Power. As alternative energy sources become more prominent in electricity production, indirect emissions from power production will likely decrease and thereby decrease the potential indirect emissions associated with the Project.

In addition to the direct and indirect industrial CO_2 emissions, quantitative estimates for six carbon cycle impacts were calculated:

1) Total carbon stored in the above-ground vegetation of wetlands and forests lost to Project activities [treated as a one-time emission] = 167,546 metric tons of CO_2
2) Annual emissions from the stockpiling of excavated peat = 1,176 metric tons of CO_2 per year
3) Possible carbon loss from peat used in reclamation activities = 8,524 metric tons of CO_2
4) Annual emissions from indirectly impacted wetlands = 7.41 metric tons of CO_2 per acre per year

5) The loss of annual carbon sequestration capacity due to the disturbance of wetland and forest plant communities = 2,982 metric tons of CO_2 per year
6) The reduction in annual carbon sequestration capacity in indirectly impacted wetlands = 3.34 metric tons per year

Apart from the one-time aboveground carbon loss estimate, these impacts are minimal compared to the direct and indirect industrial emissions: Additionally, the aboveground carbon lost (a) will not take place as an actual one-time CO_2 emission event but will be a staged process; and (b) is a likely overestimate given the value of long-lived forest products that will be potentially available for harvest.

Potential GHG emissions estimated for the Project are small compared to state, national, and global GHG emissions.

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Attachments

Attachment A

Mine Site and Plant Site Emission Calculations
PolyMet Mining Inc., NorthMet Project
Direct Emissions of Greenhouse Gases:

PolyMet - Hoyt Lakes, Minnesota

Table A-1: Estimate of Potential Greenhouse Gas Emissions at the Mine Site

Stack ID	Emission Unit		APCD ID	Throughput							Pollutant	Emission Factor		Maximum Emissions [1]		Projected Actual Emissions [2]	CO2-e Factor (Global Warming Potential)[3]	Max. Emissions (CO2-e)[4]		Projected Actual Emissions (CO2-e) [5]
	ID	Description		Maximum				Projected Actual		Units										
				(Units/hr)	Note	(Units/yr)	Note	(Units/yr)	Note			(lb/Unit)	Note	(lb/hr)	(ston/yr)	(ston/yr)		(lb/hr)	(ston/yr)	(ston/yr)
Mine Point Sources																				
SV 326	EU 332	WWTF Back up Generator	NA	5.236	[201]	2,618	[301]	2,618	[401]	MMBtu	CO2	161.30	[101]	844.54	211	211.14	1	844.54	211.14	211.14
SV 337	EU 344	Generator to Move Electrical Equipment	NA	7.7	[202]	3,850	[302]	801	[402]	MMBtu	CO2	161.30	[102]	1,242	310	64.58	1	1,241.98	310.49	64.58
WWTP	EU 331	WWTF Propane Fired Space Heaters	NA	0.0219	[203]	191	[303]	95.74	[403]	Mgal	CO2	12,725	[103]	278	1,218	609.12	1	278.14	1,218.25	609.12
WWTP				0.0219	[203]	191	[303]	95.74	[403]	Mgal	CH4	0.18	[104]	0.00	0	0.01	21	0.08	0.37	0.18
WWTP				0.0219	[203]	191	[303]	95.74	[403]	Mgal	N2O	0.81	[104]	0.02	0	0.04	310	5.47	23.95	11.97

Mine Sources Subject to PSD Permitting

	Pollutant			Maximum Emissions [1]		Projected Actual Emissions [2]	CO2-e Factor (Global Warming Potential)[3]	Max. Emissions (CO2-e)[4]		Projected Actual Emissions (CO2-e) [5]
				(lb/hr)	(ston/yr)	(ston/yr)		(lb/hr)	(ston/yr)	(ston/yr)
Greenhouse Gas Totals (short tons)	CO_2			2,365	1,739.9	885	1	2,365	1,740	885
	CH_4			0.00	0.02	0.01	21	0.08	0.37	0.18
	N_2O			0.02	0.08	0.04	310	5.47	23.95	11.97
	TOTAL GHGs							2,370	1,764	897

Mine Sources Subject to PSD Permitting

	Pollutant			Maximum Emissions [1]		Projected Actual Emissions [2]	CO2-e Factor (Global Warming Potential)[3]	Max. Emissions (CO2-e)[4]		Projected Actual Emissions (CO2-e) [5]
				(kg/hr)	(m.t./yr)	(m.t./yr)		(kg/hr)	(m.t./yr)	(m.t./yr)
Greenhouse Gas Totals (metric tons)	CO_2			1,072	1,578	803	1	1,072	1,578	803
	CH_4			0	0.02	0.01	21	0	0.33	0.17
	N_2O			0	0.07	0.04	310	2	21.72	10.86
	TOTAL GHGs							1,075	1,600	814

Mine Site Mobile Sources

Stack ID	Emission Unit		APCD ID	Throughput							Pollutant	Emission Factor		Max. Emissions		Projected Actual Emissions	CO2-e Factor (Global Warming Potential)	Max. Emissions (CO2-e)		Projected Actual Emissions (CO2-e)
	ID	Description		Maximum				Projected Actual		Units										
				(Units/hr)	Note	(Units/yr)	Note	(Units/yr)	Note			(kg/Unit)	Note	(kg/hr)	(m.t./yr)	(m.t./yr)		(kg/hr)	(m.t./yr)	(m.t./yr)
N/A	N/A	Mine Haul Trucks	NA	275.28	[204]	2,378,436	[304]	2,378,436	[401]	gal	CO_2	10.15	[105]	2,795	24,145	24,145.26	1	2,795	24,145	24,145.26
N/A				275.28	[204]	2,378,436	[304]	2,378,436	[401]	gal	CH_4	5.80E-04	[105]	0.16	1.379	1.38	21	3.35	28.97	28.97
N/A				275.28	[204]	2,378,436	[304]	2,378,436	[401]	gal	N_2O	2.60E-04	[105]	0.07	0.618	0.62	310	22.19	191.70	191.70
N/A	N/A	Diesel Drill	NA	19.49	[204]	168,394	[304]	168,394	[401]	gal	CO_2	10.15	[105]	198	1,709	1,709.49	1	198	1,709	1,709.49
N/A				19.49	[204]	168,394	[304]	168,394	[401]	gal	CH_4	5.80E-04	[105]	0.01	0.098	0.10	21	0.24	2.05	2.05
N/A				19.49	[204]	168,394	[304]	168,394	[401]	gal	N_2O	2.60E-04	[105]	0.01	0.044	0.04	310	2	14	13.57
N/A	N/A	Secondary Production Excavator	NA	8.49	[204]	73,389	[304]	73,389	[401]	gal	CO_2	10.15	[105]	86	745	745.02	1	86	745	745.02
N/A				8.49	[204]	73,389	[304]	73,389	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.043	0.04	21	0.10	0.894	0.89
N/A				8.49	[204]	73,389	[304]	73,389	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.019	0.02	310	1	6	5.92
N/A	N/A	Track Dozer	NA	33.39	[204]	288,476	[304]	288,476	[401]	gal	CO_2	10.15	[105]	339	2,929	2,928.53	1	339	2,929	2,928.53
N/A				33.39	[204]	288,476	[304]	288,476	[401]	gal	CH_4	5.80E-04	[105]	0.02	0.167	0.17	21	0.41	3.51	3.51
N/A				33.39	[204]	288,476	[304]	288,476	[401]	gal	N_2O	2.60E-04	[105]	0.01	0.075	0.08	310	2.69	23.25	23.25
N/A	N/A	Grader	NA	8.61	[204]	74,391	[304]	74,391	[401]	gal	CO_2	10.15	[105]	87	755	755.20	1	87	755	755.20
N/A				8.61	[204]	74,391	[304]	74,391	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.043	0.04	21	0.10	0.91	0.91
N/A				8.61	[204]	74,391	[304]	74,391	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.019	0.02	310	0.69	6.00	6.00
N/A	N/A	Rubber Tire Dozer	NA	5.85	[204]	50,585	[304]	50,585	[401]	gal	CO_2	10.15	[105]	59	514	513.53	1	59	514	513.53
N/A				5.85	[204]	50,585	[304]	50,585	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.029	0.03	21	0.07	0.62	0.62
N/A				5.85	[204]	50,585	[304]	50,585	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.013	0.01	310	0.47	4.08	4.08
N/A	N/A	Transfer Loader	NA	2.56	[204]	22,097	[304]	22,097	[401]	gal	CO_2	10.15	[105]	26	224	224.32	1	26	224	224.32
N/A				2.56	[204]	22,097	[304]	22,097	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.013	0.01	21	0.03	0.27	0.27
N/A				2.56	[204]	22,097	[304]	22,097	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.006	0.01	310	0.21	1.78	1.78
N/A	N/A	Backhoe With Hammer	NA	0.08	[204]	723	[304]	723	[401]	gal	CO_2	10.15	[105]	1	7	7.33	1	1	7	7.33
N/A				0.08	[204]	723	[304]	723	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.000	0.00	21	0.00	0.01	0.01
N/A				0.08	[204]	723	[304]	723	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.000	0.00	310	0.01	0.06	0.06
N/A	N/A	Water/Sand Truck	NA	9.86	[204]	85,158	[304]	85,158	[401]	gal	CO_2	10.15	[105]	100	864	864.50	1	100	864	864.50
N/A				9.86	[204]	85,158	[304]	85,158	[401]	gal	CH_4	5.80E-04	[105]	0.01	0.049	0.05	21	0.12	1.04	1.04
N/A				9.86	[204]	85,158	[304]	85,158	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.022	0.02	310	0.79	6.86	6.86
N/A	N/A	Integrated Tool Handler	NA	0.80	[204]	6,942	[304]	6,942	[401]	gal	CO_2	10.15	[105]	8	70	70.48	1	8	70	70.48
N/A				0.80	[204]	6,942	[304]	6,942	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.004	0.00	21	0.01	0.08	0.08
N/A				0.80	[204]	6,942	[304]	6,942	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.002	0.00	310	0.06	0.56	0.56
N/A	N/A	Pickup Trucks	NA	4.46	[204]	38,573	[304]	38,573	[401]	gal	CO_2	10.15	[105]	45	392	391.59	1	45	392	391.59
N/A				4.46	[204]	38,573	[304]	38,573	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.022	0.02	21	0.05	0.47	0.47
N/A				4.46	[204]	38,573	[304]	38,573	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.010	0.01	310	0.36	3.11	3.11
N/A	N/A	Other Miscellaneous Equipment Fuel Use	NA	36.89	[204]	318,716	[304]	318,716	[401]	gal	CO_2	10.15	[105]	374	3,236	3,235.52	1	374	3,236	3,235.52
N/A				36.89	[204]	318,716	[304]	318,716	[401]	gal	CH_4	5.80E-04	[105]	0.02	0.185	0.18	21	0.45	3.88	3.88
N/A				36.89	[204]	318,716	[304]	318,716	[401]	gal	N_2O	2.60E-04	[105]	0.01	0.083	0.08	310	2.97	25.69	25.69
N/A	N/A	Main Line Ore Haulage Locomotives	NA	24.52	[206]	211,841	[303]	211,841	[401]	gal	CO_2	10.15	[105]	249	2,151	2,150.55	1	249	2,151	2,150.55
N/A				24.52	[206]	211,841	[303]	211,841	[401]	gal	CH_4	5.80E-04	[105]	0.01	0.123	0.12	21	0.30	2.580	2.58
N/A				24.52	[206]	211,841	[303]	211,841	[401]	gal	N_2O	2.60E-04	[105]	0.01	0.055	0.06	310	2	17	17.07

Mine Site Mobile Sources

	Pollutant			Max. Emissions		Projected Actual Emissions	CO2-e Factor	Max. Emissions (CO2-e)		Projected Actual Emissions (CO2-e)
Greenhouse Gas Totals (metric tons)	CO_2			4,368	37,741.32	37,741.32		4,368.21	37,741.32	37,741.32
	CH_4			0.25	2.21	2.16		5.24	45.28	45.28

PolyMet - Hoyt Lakes, Minnesota

Table A-1: Estimate of Potential Greenhouse Gas Emissions at the Mine Site

	N_2O			0.11	1.19	0.97		34.68	299.65	299.65
	TOTAL GHGs								38,086	38,086

				Max. Emissions		Projected Actual Emissions	CO2-e Factor (Global Warming Potential)	Max. Emissions (CO2-e)		Projected Actual Emissions (CO2-e)
Mine Site Totals				(kg/hr)	(m.t./yr)	(m.t./yr)		(kg/hr)	(m.t./yr)	(m.t./yr)
Greenhouse Gas Totals (metric tons)	CO_2			5,441	39,320	38,544	1	5,441	39,320	38,544
	CH_4			2.2	21.0	5.3	21	45.4	46	45
	N_2O			1.0	310.0	37.2	310	310.5	321	311
	TOTAL GHGs								39,687	38,900
					% of total		CO_2		99.1%	99.1%
							CH_4		0.1%	0.1%
							N_2O		0.8%	0.8%

PolyMet - Hoyt Lakes, Minnesota

Table A-1: Estimate of Potential Greenhouse Gas Emissions at the Mine Site

Notes:

General References:

[1] Max. Emissions (kg/hr) = EF (kg/unit) x Max. Hourly Throughput (units/hr).
Max. Uncontrolled Emissions (m.t./yr) = EF (kg/unit) x Max. Annual Throughput (units/yr) / 1,000 (kg/m.t.).
[2] Projected Actual Emissions (m.t./yr) = EF (kg/unit) x Projected Actual Throughput (units/yr) / 1,000 (kg/m.t.).
[3] Global Warming Potentials from MPCA as listed in the July 2008 "General Guidance for Carbon Footprint Development in Environmental Review", <http://www.eia.doe.gov/oiaf/1605/gwp.html>
[4] Max. Emissions (CO2-e) (kg/hr) = Max. Uncontrolled Emissions (kg/hr) x (CO2-e Factor).
Max. Controlled Emissions (m.t./yr) = Max. Uncontrolled Emissions (m.t./yr) x (CO2-e Factor).
[5] Projected Actual Emissions (CO2-e) (m.t./yr) = EF (kg/unit) x Projected Actual Throughput (units/yr) / 1,000 (kg/m.t.)

Emission Factor References:

[101] From Climate Registry General Reporting Protocol (Version 1.1, May 2008) Table 12.1 (Distillate Fuel Oil). Emission factor converted from kg/MMBtu to lb/MMBtu by kg/MMBtu * 2.205 lb/kg. This emission factor source is generally used for carbon footprint assessment and is applicable for air permitting. AP-42 factors are similar.
[102] From Climate Registry General Reporting Protocol (Version 1.1, May 2008) Table 12.1 (Distillate Fuel Oil). Emission factor converted from kg/MMBtu to lb/MMBtu by kg/MMBtu * 2.205 lb/kg. This emission factor source is generally used for carbon footprint assessment and is applicable for air permitting. AP-42 factors are similar.
[103] From Climate Registry General Reporting Protocol (Version 1.1, May 2008) Table12.1. Emission factor converted from kg/MMBtu to lb/Mgal by kg/MMBtu * 2.205 lb/kg * 91.5 MMBtu/Mgal. This emission factor source is generally used for carbon footprint assessment and is applicable for air permitting. AP-42 factors are similar.
[104] From Climate Registry General Reporting Protocol (Version 1.1, May 2008) Table 12.7. Factors converted from g/MMBtu to lb/Mgal by lb/Mgal = g/MMBtu * (1 lb/453.59 g) * 91.5 MMBtu/Mgal. This emission factor source is generally used for carbon footprint assessment and is applicable for air permitting. AP-42 factors are similar.
[105] Emission factors taken from The Climate Registry's General Reporting Protocol, May 2008, Tables 13.1 and 13.6.

	CO2	CH4	N2O
Diesel Emissions (kg/gal):	10.15		
Construction / Large Utility Non-highway Vehicles, diesel (g/gal):		0.58	0.26
Construction / Large Utility Non-highway Vehicles, gasoline (g/gal):		0.5	0.22

Maximum Hourly Throughput References:

[201] Based on preliminary design of waste water treatment facility by Barr, critical power demand is about 500 kW. It was assumed that a Caterpillar Standby 500 ekW would be installed. Based on literature available on the manufacturer's website, the fuel consumption at maximum load is 37.4 gallons/hr. This is converted to MMBtu/hr by 37.4 gal/hr * 140,000 Btu/gallon / 10^6 Btu/MMBtu = 5.236 MMBtu/hr.
[202] A portable generator will be used to provide temporary power to move large electric powered mining vehicles (e.g. excavators and drills). The generator will only provide power while the equipment is moved from one location with available electrical power to another. It was estimated that a 1100 hp engine would provide sufficient power for this operation.
[203] Based on preliminary design of waste water treatment facility by Barr, maximum heating demand for propane fired heaters is 2 MMBtu/hr.
This can be converted to Mgal propane/hr by: 2.0 MMBtu/hr / 91.5 MMBtu/Mgal = 0.022 MGal/hr. A conservative estimate of annual usage was made by assuming 40% utilization for the heaters; detailed calculations for other heaters at the Plant Site showed a significantly lower percent utilization (10 - 20%).
[204] Annual fuel usage based on fuel consumption modeling performed by mining consultant. Mining schedule of 360 days/year assumed in hourly fuel usage calculation.

Unit	Manufacturer	Model	Engine	Engine Power	Max Daily Fuel Usage (gal)	Max Annual Fuel Usage (gal)
Mine Haul Trucks	Caterpillar	830E	Cat 793C	2300 hp	6606.8	2,378,436
Diesel Drill	Atlas Copco	PV 351	Cummins QSK45 / Cat 3512	1550 hp	467.8	168,394
Secondary Production Excavator	Caterpillar	994	Cat 3516	1577 hp	203.9	73,389
Track Dozer	Caterpillar	1D10R	Cat 3412E	646 hp	801.3	288,476
Grader	Caterpillar	16H	Cat 3406	275 hp	206.6	74,391
Rubber Tire Dozer	Caterpillar	834G	Cat 3456	481 hp	140.5	50,585
Transfer Loader	Caterpillar	990	990	800 hp	61.4	22,097
Backhoe With Hammer	Caterpillar	446D	3114 DIT	110 hp	2.0	723
Water/Sand Truck	Caterpillar	777D	3408 B	938 hp	236.5	85,158
Integrated Tool Handler	Caterpillar	IT62H	C7 ACERT Tier 3	230 hp	19.3	6,942
Pickup Trucks	Unknown	Unknown	Unknown	Unknown	107.1	38,573
Other Miscellaneous Equipment Fuel Use	-	-	-	-	885.3	318,716

Note: Specific engine information for Pickup Trucks is not known at this time. Fuel estimates by Gordon Zurowski in a November 2007 email, or from Wardrop, 35 gal/min, Year 6-20 worst case (Year 10).
"Other Miscellaneous Equipment Fuel Use" has been estimated as 10% of the total fuel use among equipment and is intended to reflect any unforeseen equipment not included in the emission calculation estimates.
[205] Load factor assume the same as for ore haul locomotives (15%), but with only a single 700 hp engine. Annual usage equals daily usage times 360 mining days per year.

Switching Locomotive

Daily Estimate Total Fuel Usage	131	gallons/day
Hourly Average Fuel Use	5.45	gph

[206] Fuel usage for each ore haul locomotive calculated by PolyMet. Annual usage equals daily usage times 360 mining days per year.

Daily Estimate Total Fuel Usage	1,177	gallons/day
Hourly Average Fuel Use	49.04	gph

Maximum Annual Throughput References:

[301] As recommended by EPA guidance, annual fuel usage for calculating potential emissions for the emergency generator is based on 500 hours per year of operation.
[302] Use of this equipment has an inherent restraint as with emergency generators. The generator is intended to provide temporary power for relocating large electrical mining vehicles, an inherently infrequent activity. As allowed for emergency generators, potential emissions were calculated based on 500 hours per year of operation.
[303] Maximum annual throughput = maximum hourly throughput * 8760 hours per year.
[304] Maximum annual throughput = maximum hourly throughput * 24 hours per day * 360 days per year. See number 204 above.

Projected Actual Throughput References

[401] Projected actual emissions are equivalent to potential emissions.
[402] Actual operation estimated as two hours per week or 104 hours per year.
[403] Projected actual emissions based on 50% utilization, a conservative assumption for heating systems.

PolyMet - Hoyt Lakes, Minnesota
Table A-2: Calculation of Potential Greenhouse Gas Emissions at Processing Plant

Stack ID	Emission Unit		APCD ID	Throughput							Pollutant	Emission Factor		Maximum Emissions [1]		Projected Actual	CO2-e Factor (Global	Max. Emissions (CO2-e)[4]		Projected Actual
	ID	Description		Maximum				Projected Actual		Units										
				(Units/hr)	Note	(Units/yr)	Note	(Units/yr)	Note			(lb/Unit)	Note	(lb/hr)	(ston/yr)	(ston/yr)		(lb/hr)	(ston/yr)	(ston/yr)
Plant Site Point Sources																				
SV 301	EU 301	Autoclave Startup Boiler - Natural Gas	NA	0.048	[201]	418.861	[301]	25.132	[401]	MM cu. ft.	CO2	122,847.165	[100]	5,873.966	25,728	1,543.678	1	5,873.966	25,727.973	1,543.678
SV 301		Natural gas		0.048	[201]	418.861	[301]	25.132	[401]	MM cu. ft.	N2O	2.083	[101]	0.100	0.436	0.026	310	30.881	135.260	8.116
SV 301				0.048	[201]	418.861	[301]	25.132	[401]	MM cu. ft.	CH4	2.083	[101]	0.100	0.436	0.026	21	2.092	9.163	0.550
SV 328	EU 335	Oxygen Plant Adsorber Regeneration Heater	NA	0.002	[202]	17.103	[301]	11.402	[402]	MM cu. ft.	CO2	122,847.165	[100]	239.844	1,050.519	700.346	1	239.844	1,050.519	700.346
SV 328				0.002	[202]	17.103	[301]	11.402	[402]	MM cu. ft.	N2O	2.083	[101]	0.004	0.018	0.012	310	1.261	5.523	3.682
SV 328				0.002	[202]	17.103	[301]	11.402	[402]	MM cu. ft.	CH4	2.083	[101]	0.004	0.018	0.012	21	0.085	0.374	0.249
CoarseCrush	EU 302	Space Heating (Natural Gas Fired-total direct)	NA	0.009	[203]	78.840	[301]	10.561	[403]	MM cu. ft.	CO2	122,847.165	[100]	1,105.624	4,842.635	648.674	1	1,105.624	4,842.635	648.674
CoarseCrush				0.009	[203]	78.840	[301]	10.561	[403]	MM cu. ft.	N2O	2.083	[101]	0.019	0.082	0.011	310	5.813	25.459	3.410
CoarseCrush				0.009	[203]	78.840	[301]	10.561	[403]	MM cu. ft.	CH4	2.083	[101]	0.019	0.082	0.011	21	0.394	1.725	0.231
CoarseCrush1	EU 302	Space Heating (Natural Gas Fired- Indirect RB AHU 1)	NA	0.000	[203]	0.000	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	0.000	0.000	0.000	1	0.000	0.000	0.000
CoarseCrush1				0.000	[203]	0.000	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.000	0.000	0.000	310	0.000	0.000	0.000
CoarseCrush1				0.000	[203]	0.000	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.000	0.000	0.000	21	0.000	0.000	0.000
CoarseCrush2	EU 302	Space Heating (Natural Gas Fired- Indirect AHU 2)	NA	0.001	[203]	8.343	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	116.997	512.448	0.000	1	116.997	512.448	0.000
CoarseCrush2				0.001	[203]	8.343	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.002	0.009	0.000	310	0.615	2.694	0.000
CoarseCrush2				0.001	[203]	8.343	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.002	0.009	0.000	21	0.042	0.183	0.000
CoarseCrush3	EU 302	Space Heating (Natural Gas Fired- Indirect Off/CR)	NA	0.000	[203]	0.250	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	3.510	15.373	0.000	1	3.510	15.373	0.000
CoarseCrush3				0.000	[203]	0.250	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.000	0.000	0.000	310	0.018	0.081	0.000
CoarseCrush3				0.000	[203]	0.250	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.000	0.000	0.000	21	0.001	0.005	0.000
DH1	EU 302	Space Heating (Natural Gas Fired- Indirect DH AHU 1)	NA	0.000	[203]	3.587	[301]	2.607	[403]	MM cu. ft.	CO2	122,847.165	[100]	50.309	220.353	160.111	1	50.309	220.353	160.111
DH1				0.000	[203]	3.587	[301]	2.607	[403]	MM cu. ft.	N2O	2.083	[101]	0.001	0.004	0.003	310	0.264	1.158	0.842
DH1				0.000	[203]	3.587	[301]	2.607	[403]	MM cu. ft.	CH4	2.083	[101]	0.001	0.004	0.003	21	0.018	0.078	0.057
DH2	EU 302	Space Heating (Natural Gas Fired- Indirect DH AHU 2)	NA	0.000	[203]	3.587	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	50.309	220.353	0.000	1	50.309	220.353	0.000
DH2				0.000	[203]	3.587	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.001	0.004	0.000	310	0.264	1.158	0.000
DH2				0.000	[203]	3.587	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.001	0.004	0.000	21	0.018	0.078	0.000
DH3	EU 302	Space Heating (Natural Gas Fired- Indirect DH AHU 3)	NA	0.000	[203]	3.587	[302]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	50.309	220.353	0.000	1	50.309	220.353	0.000
DH3				0.000	[203]	3.587	[302]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.001	0.004	0.000	310	0.264	1.158	0.000
DH3				0.000	[203]	3.587	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.001	0.004	0.000	21	0.018	0.078	0.000
DH4	EU 302	Space Heating (Natural Gas Fired- Indirect DH AHU 4)	NA	0.000	[203]	3.587	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	50.309	220.353	0.000	1	50.309	220.353	0.000
DH4				0.000	[203]	3.587	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.001	0.004	0.000	310	0.264	1.158	0.000
DH4				0.000	[203]	3.587	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.001	0.004	0.000	21	0.018	0.078	0.000
FineCrush	EU 302	Space Heating (Natural Gas Fired-total direct)	NA	0.008	[203]	67.869	[301]	40.778	[403]	MM cu. ft.	CO2	122,847.165	[100]	951.773	4,168.766	2,504.737	1	951.773	4,168.766	2,504.737
FineCrush				0.008	[203]	67.869	[301]	40.778	[403]	MM cu. ft.	N2O	2.083	[101]	0.016	0.071	0.042	310	5.004	21.917	13.168
FineCrush				0.008	[203]	67.869	[301]	40.778	[403]	MM cu. ft.	CH4	2.083	[101]	0.016	0.071	0.042	21	0.339	1.485	0.892
FineCrush1	EU 302	Space Heating (Natural Gas Fired- Indirect FTCF AHU 1)	NA	0.001	[203]	5.840	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	81.898	358.714	0.000	1	81.898	358.714	0.000
FineCrush1				0.001	[203]	5.840	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.001	0.006	0.000	310	0.431	1.886	0.000
FineCrush1				0.001	[203]	5.840	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.001	0.006	0.000	21	0.029	0.128	0.000
FineCrush2	EU 302	Space Heating (Natural Gas Fired- Indirect FTCF AHU 2)	NA	0.001	[203]	5.840	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	81.898	358.714	0.000	1	81.898	358.714	0.000
FineCrush2				0.001	[203]	5.840	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.001	0.006	0.000	310	0.431	1.886	0.000
FineCrush2				0.001	[203]	5.840	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.001	0.006	0.000	21	0.029	0.128	0.000
FineCrush3	EU 302	Space Heating (Natural Gas Fired- Indirect FMF AHU 1)	NA	0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	224.635	983.900	0.000	1	224.635	983.900	0.000
FineCrush3				0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.004	0.017	0.000	310	1.181	5.173	0.000
FineCrush3				0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.004	0.017	0.000	21	0.080	0.350	0.000
FineCrush4	EU 302	Space Heating (Natural Gas Fired- Indirect FMF AHU 2)	NA	0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	224.635	983.900	0.000	1	224.635	983.900	0.000
FineCrush4				0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.004	0.017	0.000	310	1.181	5.173	0.000
FineCrush4				0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.004	0.017	0.000	21	0.080	0.350	0.000
FineCrush5	EU 302	Space Heating (Natural Gas Fired- Indirect FMF AHU 3)	NA	0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	224.635	983.900	0.000	1	224.635	983.900	0.000
FineCrush5				0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.004	0.017	0.000	310	1.181	5.173	0.000
FineCrush5				0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.004	0.017	0.000	21	0.080	0.350	0.000
FineCrush6	EU 302	Space Heating (Natural Gas Fired- Indirect FMF AHU 4)	NA	0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	224.635	983.900	0.000	1	224.635	983.900	0.000
FineCrush6				0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.004	0.017	0.000	310	1.181	5.173	0.000
FineCrush6				0.002	[203]	16.018	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.004	0.017	0.000	21	0.080	0.350	0.000
Conc B V1	EU 302	Space Heating (Natural Gas Fired- Indirect CLL AHU 1)	NA	0.002	[203]	20.023	[301]	98.394	[403]	MM cu. ft.	CO2	122,847.165	[100]	280.794	1,229.876	6,043.724	1	280.794	1,229.876	6,043.724
Conc B V1				0.002	[203]	20.023	[301]	98.394	[403]	MM cu. ft.	N2O	2.083	[101]	0.005	0.021	0.102	310	1.476	6.466	31.774
Conc B V1				0.002	[203]	20.023	[301]	98.394	[403]	MM cu. ft.	CH4	2.083	[101]	0.005	0.021	0.102	21	0.100	0.438	2.152
Conc B V2	EU 302	Space Heating (Natural Gas Fired- Indirect CLL AHU 2)	NA	0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	280.794	1,229.876	0.000	1	280.794	1,229.876	0.000
Conc B V2				0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.005	0.021	0.000	310	1.476	6.466	0.000
Conc B V2				0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.005	0.021	0.000	21	0.100	0.438	0.000
Conc B V3	EU 302	Space Heating (Natural Gas Fired- Indirect CLL AHU 3)	NA	0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	280.794	1,229.876	0.000	1	280.794	1,229.876	0.000
Conc B V3				0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.005	0.021	0.000	310	1.476	6.466	0.000
Conc B V3				0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.005	0.021	0.000	21	0.100	0.438	0.000
Conc B V4	EU 302	Space Heating (Natural Gas Fired- Indirect CLL AHU 4)	NA	0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	280.794	1,229.876	0.000	1	280.794	1,229.876	0.000
Conc B V4				0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.005	0.021	0.000	310	1.476	6.466	0.000
Conc B V4				0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.005	0.021	0.000	21	0.100	0.438	0.000
Conc B V5	EU 302	Space Heating (Natural Gas Fired- Indirect CLL AHU 5)	NA	0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	280.794	1,229.876	0.000	1	280.794	1,229.876	0.000
Conc B V5				0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.005	0.021	0.000	310	1.476	6.466	0.000
Conc B V5				0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.005	0.021	0.000	21	0.100	0.438	0.000
Conc B V6	EU 302	Space Heating (Natural Gas Fired- Indirect CLL AHU 6)	NA	0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	280.794	1,229.876	0.000	1	280.794	1,229.876	0.000
Conc B V6				0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.005	0.021	0.000	310	1.476	6.466	0.000
Conc B V6				0.002	[203]	20.023	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.005	0.021	0.000	21	0.100	0.438	0.000
Conc B V7	EU 302	Space Heating (Natural Gas Fired- Indirect CML AHU 1)	NA	0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	355.672	1,557.842	0.000	1	355.672	1,557.842	0.000
Conc B V7				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.006	0.026	0.000	310	1.870	8.190	0.000
Conc B V7				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.006	0.026	0.000	21	0.127	0.555	0.000
Conc B V8	EU 302	Space Heating (Natural Gas Fired- Indirect CML AHU 2)	NA	0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	355.672	1,557.842	0.000	1	355.672	1,557.842	0.000
Conc B V8				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.006	0.026	0.000	310	1.870	8.190	0.000
Conc B V8				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.006	0.026	0.000	21	0.127	0.555	0.000
Conc B V9	EU 302	Space Heating (Natural Gas Fired- Indirect CML AHU 3)	NA	0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	355.672	1,557.842	0.000	1	355.672	1,557.842	0.000

PolyMet - Hoyt Lakes, Minnesota

Table A-2: Calculation of Potential Greenhouse Gas Emissions at Processing Plant

Stack ID	Emission Unit		APCD ID	Throughput							Pollutant	Emission Factor		Maximum Emissions [1]		Projected Actual	CO2-e Factor	Max. Emissions (CO2-e)[4]		Projected Actual
	ID	Description		Maximum				Projected Actual		Units										
				(Units/hr)	Note	(Units/yr)	Note	(Units/yr)	Note			(lb/Unit)	Note	(lb/hr)	(ston/yr)	(ston/yr)	(Global	(lb/hr)	(ston/yr)	(ston/yr)
Conc B V9				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.006	0.026	0.000	310	1.870	8.190	0.000
Conc B V9				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.006	0.026	0.000	21	0.127	0.555	0.000
Conc B V10	EU 302	Space Heating (Natural Gas Fired- Indirect CML AHU 4)	NA	0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	355.672	1,557.842	0.000	1	355.672	1,557.842	0.000
Conc B V10				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.006	0.026	0.000	310	1.870	8.190	0.000
Conc B V10				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.006	0.026	0.000	21	0.127	0.555	0.000
Conc B V11	EU 302	Space Heating (Natural Gas Fired- Indirect CML AHU 5)	NA	0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	355.672	1,557.842	0.000	1	355.672	1,557.842	0.000
Conc B V11				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.006	0.026	0.000	310	1.870	8.190	0.000
Conc B V11				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.006	0.026	0.000	21	0.127	0.555	0.000
Conc B V12	EU 302	Space Heating (Natural Gas Fired- Indirect CML AHU 6)	NA	0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	355.672	1,557.842	0.000	1	355.672	1,557.842	0.000
Conc B V12				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.006	0.026	0.000	310	1.870	8.190	0.000
Conc B V12				0.003	[203]	25.362	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.006	0.026	0.000	21	0.127	0.555	0.000
Conc B V13	EU 302	Space Heating (Natural Gas Fired- Indirect CUBAN)	NA	0.001	[203]	8.343	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	116.997	512.448	0.000	1	116.997	512.448	0.000
Conc B V13				0.001	[203]	8.343	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.002	0.009	0.000	310	0.615	2.694	0.000
Conc B V13				0.001	[203]	8.343	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.002	0.009	0.000	21	0.042	0.183	0.000
Conc B V14	EU 302	Space Heating (Natural Gas Fired- Indirect CUBAS)	NA	0.000	[203]	3.629	[301]	0.000	[403]	MM cu. ft.	CO2	122,847.165	[100]	50.894	222.915	0.000	1	50.894	222.915	0.000
Conc B V14				0.000	[203]	3.629	[301]	0.000	[403]	MM cu. ft.	N2O	2.083	[101]	0.001	0.004	0.000	310	0.268	1.172	0.000
Conc B V14				0.000	[203]	3.629	[301]	0.000	[403]	MM cu. ft.	CH4	2.083	[101]	0.001	0.004	0.000	21	0.018	0.079	0.000
Flot V	EU 302	Space Heating (Natural Gas Fired)	NA	0.003	[204]	26.481	[301]	5.972	[403]	MM cu. ft.	CO2	122,847.165	[100]	371.362	1,626.564	366.812	1	371.362	1,626.564	366.812
Flot V				0.003	[204]	26.481	[301]	5.972	[403]	MM cu. ft.	N2O	2.083	[101]	0.006	0.028	0.006	310	1.952	8.551	1.928
Flot V				0.003	[204]	26.481	[301]	5.972	[403]	MM cu. ft.	CH4	2.083	[101]	0.006	0.028	0.006	21	0.132	0.579	0.131
Reagent V	EU 302	Space Heating (Natural Gas Fired)	NA	0.002	[204]	17.825	[301]	4.002	[403]	MM cu. ft.	CO2	122,847.165	[100]	249.968	1,094.858	245.813	1	249.968	1,094.858	245.813
Reagent V				0.002	[204]	17.825	[301]	4.002	[403]	MM cu. ft.	N2O	2.083	[101]	0.004	0.019	0.004	310	1.314	5.756	1.292
Reagent V				0.002	[204]	17.825	[301]	4.002	[403]	MM cu. ft.	CH4	2.083	[101]	0.004	0.019	0.004	21	0.089	0.390	0.088
Conc Dewa V	EU 302	Space Heating (Natural Gas Fired)	NA	0.001	[204]	7.835	[301]	1.831	[403]	MM cu. ft.	CO2	122,847.165	[100]	109.872	481.239	112.448	1	109.872	481.239	112.448
Conc Dewa V				0.001	[204]	7.835	[301]	1.831	[403]	MM cu. ft.	N2O	2.083	[101]	0.002	0.008	0.002	310	0.578	2.530	0.591
Conc Dewa V				0.001	[204]	7.835	[301]	1.831	[403]	MM cu. ft.	CH4	2.083	[101]	0.002	0.008	0.002	21	0.039	0.171	0.040
Conc LO V	EU 302	Space Heating (Natural Gas Fired)	NA	0.000	[204]	2.996	[301]	0.727	[403]	MM cu. ft.	CO2	122,847.165	[100]	42.018	184.040	44.664	1	42.018	184.040	44.664
Conc LO V				0.000	[204]	2.996	[301]	0.727	[403]	MM cu. ft.	N2O	2.083	[101]	0.001	0.003	0.001	310	0.221	0.968	0.235
Conc LO V				0.000	[204]	2.996	[301]	0.727	[403]	MM cu. ft.	CH4	2.083	[101]	0.001	0.003	0.001	21	0.015	0.066	0.016
Rebuild V	EU 302	Space Heating (Natural Gas Fired)	NA	0.007	[204]	61.028	[301]	13.237	[403]	MM cu. ft.	CO2	122,847.165	[100]	855.837	3,748.567	813.045	1	855.837	3,748.567	813.045
Rebuild V				0.007	[204]	61.028	[301]	13.237	[403]	MM cu. ft.	N2O	2.083	[101]	0.015	0.064	0.014	310	4.499	19.707	4.274
Rebuild V				0.007	[204]	61.028	[301]	13.237	[403]	MM cu. ft.	CH4	2.083	[101]	0.015	0.064	0.014	21	0.305	1.335	0.290
Main WH V	EU 302	Space Heating (Natural Gas Fired)	NA	0.003	[204]	22.930	[301]	3.452	[403]	MM cu. ft.	CO2	122,847.165	[100]	321.557	1,408.419	212.049	1	321.557	1,408.419	212.049
Main WH V				0.003	[204]	22.930	[301]	3.452	[403]	MM cu. ft.	N2O	2.083	[101]	0.005	0.024	0.004	310	1.691	7.405	1.115
Main WH V				0.003	[204]	22.930	[301]	3.452	[403]	MM cu. ft.	CH4	2.083	[101]	0.005	0.024	0.004	21	0.115	0.502	0.076
Spares WH V	EU 302	Space Heating (Natural Gas Fired)	NA	0.002	[204]	18.698	[301]	2.843	[403]	MM cu. ft.	CO2	122,847.165	[100]	262.220	1,148.522	174.622	1	262.220	1,148.522	174.622
Spares WH V				0.002	[204]	18.698	[301]	2.843	[403]	MM cu. ft.	N2O	2.083	[101]	0.004	0.019	0.003	310	1.379	6.038	0.918
Spares WH V				0.002	[204]	18.698	[301]	2.843	[403]	MM cu. ft.	CH4	2.083	[101]	0.004	0.019	0.003	21	0.093	0.409	0.062
Hydromet V	EU 302	Space Heating (Natural Gas Fired)	NA	0.007	[204]	57.886	[301]	12.895	[403]	MM cu. ft.	CO2	122,847.165	[100]	811.775	3,555.576	792.032	1	811.775	3,555.576	792.032
Hydromet V				0.007	[204]	57.886	[301]	12.895	[403]	MM cu. ft.	N2O	2.083	[101]	0.014	0.060	0.013	310	4.268	18.693	4.164
Hydromet V				0.007	[204]	57.886	[301]	12.895	[403]	MM cu. ft.	CH4	2.083	[101]	0.014	0.060	0.013	21	0.289	1.266	0.282
Heat Pl V	EU 302	Space Heating (Natural Gas Fired)	NA	0.004	[204]	35.773	[301]	7.776	[403]	MM cu. ft.	CO2	122,847.165	[100]	501.663	2,197.285	477.660	1	501.663	2,197.285	477.660
Heat Pl V				0.004	[204]	35.773	[301]	7.776	[403]	MM cu. ft.	N2O	2.083	[101]	0.009	0.037	0.008	310	2.637	11.552	2.511
Heat Pl V				0.004	[204]	35.773	[301]	7.776	[403]	MM cu. ft.	CH4	2.083	[101]	0.009	0.037	0.008	21	0.179	0.783	0.170
Gen Shop V	EU 302	Space Heating (Natural Gas Fired)	NA	0.029	[204]	257.858	[301]	55.646	[403]	MM cu. ft.	CO2	122,847.165	[100]	3,616.107	15,838.547	3,417.973	1	3,616.107	15,838.547	3,417.973
Gen Shop V				0.029	[204]	257.858	[301]	55.646	[403]	MM cu. ft.	N2O	2.083	[101]	0.061	0.269	0.058	310	19.011	83.268	17.969
Gen Shop V				0.029	[204]	257.858	[301]	55.646	[403]	MM cu. ft.	CH4	2.083	[101]	0.061	0.269	0.058	21	1.288	5.641	1.217
SV 108	EU 128	Existing Backup Generator 1	NA	11.300	[205]	5,650.000	[302]	2,712.000	[404]	MMBtu	CO2	161.296	[102]	1,822.642	455.660	218.717	1	1,822.642	455.660	218.717
SV 109	EU 129	Existing Backup Generator 2	NA	11.300	[205]	5,650.000	[302]	2,712.000	[404]	MMBtu	CO2	161.296	[102]	1,822.642	455.660	218.717	1	1,822.642	455.660	218.717
SV 304	EU 304	Fire Pump #1	NA	0.532	[206]	266.000	[303]	34.048	[405]	MMBtu	CO2	161.296	[102]	85.809	21.452	2.746	1	85.809	21.452	2.746
SV 305	EU 305	Fire Pump #2	NA	0.532	[206]	266.000	[303]	34.048	[405]	MMBtu	CO2	161.296	[102]	85.809	21.452	2.746	1	85.809	21.452	2.746
SV 427	EU 413	Aministration Building New Boiler	NA	0.023	[207]	201.049	[304]	33.000	[406]	Mgal	CO2	12,724.846	[103]	292.046	1,279.160	209.960	1	292.046	1,279.160	209.960
SV 427				0.023	[207]	201.049	[304]	33.000	[406]	Mgal	CH4	0.182	[104]	0.004	0.018	0.003	21	0.088	0.383	0.063
SV 427				0.023	[207]	201.049	[304]	33.000	[406]	Mgal	N2O	0.807	[104]	0.019	0.081	0.013	310	5.741	25.145	4.127
SV 430	EU 417	Adminstration Building Old Boiler (Backup)	NA	0.018	[208]	160.361	[304]	0.000	[407]	Mgal	CO2	12,724.846	[103]	232.941	1,020.282	0.000	1	232.941	1,020.282	0.000
SV 430				0.018	[208]	160.361	[304]	0.000	[407]	Mgal	CH4	0.182	[104]	0.003	0.015	0.000	21	0.070	0.306	0.000
SV 430				0.018	[208]	160.361	[304]	0.000	[407]	Mgal	N2O	0.807	[104]	0.015	0.065	0.000	310	4.579	20.056	0.000
Area1BV	EU 334	Area 1 Shop Space Heaters (propane fired)	NA	0.118	[209]	1,031.210	[301]	515.605	[408]	Mgal	CO2	12,724.846	[103]	1,497.944	6,560.994	3,280.497	1	1,497.944	6,560.994	3,280.497
Area1BV				0.118	[209]	1,031.210	[301]	515.605	[408]	Mgal	CH4	0.182	[104]	0.021	0.094	0.047	21	0.449	1.966	0.983
Area1BV				0.118	[209]	1,031.210	[301]	515.605	[408]	Mgal	N2O	0.807	[104]	0.095	0.416	0.208	310	29.446	128.972	64.486
Area2BV	EU 130	Area 2 Shop Space Heaters (propane fired)	NA	0.109	[210]	957.377	[301]	478.689	[408]	Mgal	CO2	12,724.846	[103]	1,390.694	6,091.238	3,045.619	1	1,390.694	6,091.238	3,045.619
Area2BV				0.109	[210]	957.377	[301]	478.689	[408]	Mgal	CH4	0.182	[104]	0.020	0.087	0.043	21	0.417	1.825	0.913
Area2BV				0.109	[210]	957.377	[301]	478.689	[408]	Mgal	N2O	0.807	[104]	0.088	0.386	0.193	310	27.337	119.738	59.869
SV 428	EU 415	Tailings Basin WWTP Process Fuel Combustion - natural gas (if needed)	NA	0.000	[211]	0.000	[305]	0.000	[409]	MM cu. ft.	CO2	122,847.165	[100]	0.000	0.000	0.000	1	0.000	0.000	0.000
SV 428				0.000	[211]	0.000	[305]	0.000	[409]	MM cu. ft.	N2O	2.083	[101]	0.000	0.000	0.000	310	0.000	0.000	0.000
SV 428				0.000	[211]	0.000	[305]	0.000	[409]	MM cu. ft.	CH4	2.083	[101]	0.000	0.000	0.000	21	0.000	0.000	0.000
TBWWTPBV	EU 414	Tailings Basin WWTP Space Heaters (natural gas fired)	NA	0.008	[212]	69.246	[305]	27.698	[410]	MM cu. ft.	CO2	122,847.165	[100]	971.078	4,253.320	1,701.328	1	971.078	4,253.320	1,701.328
TBWWTPBV				0.008	[212]	69.246	[305]	27.698	[410]	MM cu. ft.	N2O	2.083	[101]	0.016	0.072	0.029	310	5.105	22.361	8.944
TBWWTPBV				0.008	[212]	69.246	[305]	27.698	[410]	MM cu. ft.	CH4	2.083	[101]	0.016	0.072	0.029	21	0.346	1.515	0.606
SV 426	EU 412	Tailings Basin WWTP Back-up Generator	NA	5.236	[213]	2,618.000	[303]	2,618.000	[411]	MMBtu	CO2	161.296	[102]	844.545	211.136	211.136	1	844.545	211.136	211.136
SV 2532	EU 2012	Autoclave vent (1 unit)	CE 201	4.941	[214]	43,284.836	[301]	38,956.352	[412]	ton gas	CO2	0.064	[105]	0.316	1.384	1.245	1	0.316	1.384	1.245
SV 2532	EU 3512	Iron and Aluminum Precipitation Tanks (3)	CE 204	10.616	[215]	92,998.361	[301]	83,698.525	[412]	ton gas	CO2	882.279	[106]	9,366.500	41,025.270	36,922.743	1	9,366.500	41,025.270	36,922.743

Sources Subject to PSD Permitting

Greenhouse Gas Totals (short tons)	CO_2			39,097	151,994	64,074	1	39,097	151,994	64,074
	CH_4			0.42	1.82	0.43	21	9	38	9
	N_2O			0.58	2.56	0.75	310	181	793	233

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Table A-2: Calculation of Potential Greenhouse Gas Emissions at Processing Plant

Stack ID	Emission Unit		APCD ID	Throughput							Pollutant	Emission Factor		Maximum Emissions [1]		Projected Actual	CO2-e Factor (Global	Max. Emissions (CO2-e)[4]		Projected Actual
	ID	Description		Maximum				Projected Actual		Units										
				(Units/hr)	Note	(Units/yr)	Note	(Units/yr)	Note			(lb/Unit)	Note	(lb/hr)	(ston/yr)	(ston/yr)		(lb/hr)	(ston/yr)	(ston/yr)
											TOTAL GHGs							39,287	152,825	64,316

Sources Subject to PSD Permitting

	Pollutant			Maximum Emissions [1]		Projected Actual	CO2-e Factor (Global	Max. Emissions (CO2-e)[4]		Projected Actual
				(kg/hr)	(m.t./yr)	(m.t./yr)		(kg/hr)	(m.t./yr)	(m.t./yr)
Greenhouse Gas Totals (metric tons)	CO_2			17,731	137,887	58,127	1	17,731	137,887	58,127
	CH_4			0.19	2	0	21	3.96	35	8
	N_2O			0.26	2	1	310	82.06	719	212
	TOTAL GHGs							17,817	138,641	58,347

Plant Site Fugitive Sources

Stack ID	Emission Unit		APCD ID	Throughput							Pollutant	Emission Factor		Maximum Emissions [1]		Projected Actual	CO2-e Factor (Global	Max. Emissions (CO2-e)[4]		Projected Actual
	ID	Description		Maximum				Projected Actual		Units										
				(Units/hr)	Note	(Units/yr)	Note	(Units/yr)	Note			(kg/Unit)	Note	(kg/hr)	(m.t./yr)	(m.t./yr)		(kg/hr)	(m.t./yr)	(m.t./yr)
FS 012	FS 012	Haul Truck Traffic	NA	0.97	[216]	21.33	[306]	21.33	[413]	VMT	CO_2	1.45	[107]	1.41E+00	3.09E-02	0.03	1	1.41	0.03	0.03
FS 012		(accounts for both Plant Site and Mine Site)		0.97	[216]	21.33	[306]	21.33	[413]	VMT	CH_4	5.10E-06	[107]	4.95E-06	1.09E-07	1.09E-07	21	1.04E-04	2.28E-06	2.28E-06
FS 012				0.97	[216]	21.33	[306]	21.33	[413]	VMT	N_2O	4.80E-06	[107]	4.65E-06	1.02E-07	1.02E-07	310	1.44E-03	3.17E-05	3.17E-05
FS 012		Light Truck Traffic	NA	63.18	[217]	43,046.24	[307]	43,046.24	[413]	VMT	CO_2	0.68	[107]	4.28E+01	2.91E+01	29.13	1	42.75	29.13	29.13
FS 012		(accounts for both Plant Site and Mine Site)		63.18	[217]	43,046.24	[307]	43,046.24	[413]	VMT	CH_4	1.10E-06	[107]	6.95E-05	4.74E-05	4.74E-05	21	1.46E-03	0.00	9.94E-04
FS 012				63.18	[217]	43,046.24	[307]	43,046.24	[413]	VMT	N_2O	1.70E-06	[107]	1.07E-04	7.32E-05	7.32E-05	310	3.33E-02	0.02	2.27E-02
FS 012		Fuel Tanker Travel	NA	2.09	[218]	4,571.83	[308]	4,571.83	[413]	VMT	CO_2	1.45	[107]	3.03E+00	6.63E+00	6.63	1	3.03	6.63	6.63
FS 012		(accounts for both Plant Site and Mine Site)		2.09	[218]	4,571.83	[308]	4,571.83	[413]	VMT	CH_4	5.10E-06	[107]	1.06E-05	2.33E-05	2.33E-05	21	2.24E-04	4.90E-04	4.90E-04
FS 012				2.09	[218]	4,571.83	[308]	4,571.83	[413]	VMT	N_2O	4.80E-06	[107]	1.00E-05	2.19E-05	2.19E-05	310	3.11E-03	6.80E-03	6.80E-03
FS 012		WWTF Trucks	NA	6.65	[219]	15,337.74	[309]	15,337.74	[413]	VMT	CO_2	1.45	[107]	9.65E+00	2.22E+01	22.24	1	9.65	22.24	22.24
FS 012				6.65	[219]	15,337.74	[309]	15,337.74	[413]	VMT	CH_4	5.10E-06	[107]	3.39E-05	7.82E-05	7.82E-05	21	7.13E-04	1.64E-03	1.64E-03
FS 012				6.65	[219]	15,337.74	[309]	15,337.74	[413]	VMT	N_2O	4.80E-06	[107]	3.19E-05	7.36E-05	7.36E-05	310	9.90E-03	2.28E-02	2.28E-02
FS 016	FS 016	Tailings Basin Traffic	NA	63.18	[217]	43,046	[307]	43,046	[413]	VMT	CO_2	1.45	[107]	9.16E+01	6.24E+01	62.42	1	91.61	62.42	62.42
FS 016				63.18	[217]	43,046	[307]	43,046	[413]	VMT	CH_4	5.10E-06	[107]	3.22E-04	2.20E-04	2.20E-04	21	6.77E-03	4.61E-03	4.61E-03
FS 016				63.18	[217]	43,046	[307]	43,046	[413]	VMT	N_2O	4.80E-06	[107]	3.03E-04	2.07E-04	2.07E-04	310	9.40E-02	6.41E-02	6.41E-02
MDS 604	NA	Locomotive Switcher	NA	5.45	[221]	47,730	[301]	47,730	[413]	gal	CO2	10.15	[107]	5.53E+01	4.84E+02	484.45	1	55.30	484.45	484.45
				5.45	[221]	47,730	[301]	47,730	[413]	gal	CH4	5.80E-04	[107]	3.16E-03	2.77E-02	2.77E-02	21	6.64E-02	5.81E-01	5.81E-01
				5.45	[221]	47,730	[301]	47,730	[413]	gal	N2O	2.60E-04	[107]	1.42E-03	1.24E-02	1.24E-02	310	4.39E-01	3.85E+00	3.85E+00
MDS 603	NA	Locomotive Ore Haul	NA	24.52	[222]	211,841	[301]	211,841	[413]	gal	CO2	10.15	[107]	2.49E+02	2.15E+03	2150.18	1	248.86	2,150.18	2150.18
				24.52	[222]	211,841	[301]	211,841	[413]	gal	CH4	5.80E-04	[107]	1.42E-02	1.23E-01	1.23E-01	21	2.99E-01	2.58E+00	2.58E+00
				24.52	[222]	211,841	[301]	211,841	[413]	gal	N2O	2.60E-04	[107]	6.37E-03	5.51E-02	5.51E-02	310	1.98E+00	1.71E+01	1.71E+01
MDS 605	NA	Tailings Basin Haul Trucks - Tier 4 (59.9 ton payload)	NA	420	[223]	462,000	[310]	462,000	[413]	gal	CO2	10.15	[107]	4.26E+03	4.69E+03	4689.30	1	4,263.00	4,689.30	4689.30
				420	[223]	462,000	[310]	462,000	[413]	gal	CH4	5.80E-04	[107]	2.44E-01	2.68E-01	2.68E-01	21	5.12E+00	5.63E+00	5.63E+00
				420	[223]	462,000	[310]	462,000	[413]	gal	N2O	2.60E-04	[107]	1.09E-01	1.20E-01	1.20E-01	310	3.39E+01	3.72E+01	3.72E+01
MDS 605	NA	Track Dozer	NA	8.07	[224]	8,879	[310]	8,879	[413]	gal	CO2	10.15	[107]	8.19E+01	9.01E+01	90.12	1	81.92	90.12	90.12
				8.07	[224]	8,879	[310]	8,879	[413]	gal	CH4	5.80E-04	[107]	4.68E-03	5.15E-03	5.15E-03	21	9.83E-02	1.08E-01	1.08E-01
				8.07	[224]	8,879	[310]	8,879	[413]	gal	N2O	2.60E-04	[107]	2.10E-03	2.31E-03	2.31E-03	310	6.51E-01	7.16E-01	7.16E-01
MDS 605	NA	Grader		6.84	[224]	7,522	[310]	7,522	[413]	gal	CO2	10.15	[107]	6.94E+01	7.64E+01	7.64E+01	1	6.94E+01	7.64E+01	7.64E+01
				6.84	[224]	7,522	[310]	7,522	[413]	gal	CH4	5.80E-04	[107]	3.97E-03	4.36E-03	4.36E-03	21	8.33E-02	9.16E-02	9.16E-02
				6.84	[224]	7,522	[310]	7,522	[413]	gal	N2O	2.60E-04	[107]	1.78E-03	1.96E-03	1.96E-03	310	5.51E-01	6.06E-01	6.06E-01
MDS 605	NA	Compactor		5.40	[224]	5,936	[310]	5,936	[413]	gal	CO2	10.15	[107]	5.48E+01	6.03E+01	6.03E+01	1	5.48E+01	6.03E+01	6.03E+01
				5.40	[224]	5,936	[310]	5,936	[413]	gal	CH4	5.80E-04	[107]	3.13E-03	3.44E-03	3.44E-03	21	6.57E-02	7.23E-02	7.23E-02
				5.40	[224]	5,936	[310]	5,936	[413]	gal	N2O	2.60E-04	[107]	1.40E-03	1.54E-03	1.54E-03	310	4.35E-01	4.78E-01	4.78E-01
MDS 605	NA	Tailings Basin Excavator (8 yd^3 bucket)	NA	24.33	[224]	26,764	[310]	26,764	[413]	gal	CO2	10.15	[107]	2.47E+02	2.72E+02	271.65	1	246.96	271.65	271.65
				24.33	[224]	26,764	[310]	26,764	[413]	gal	CH4	5.80E-04	[107]	1.41E-02	1.55E-02	1.55E-02	21	2.96E-01	3.26E-01	3.26E-01
				24.33	[224]	26,764	[310]	26,764	[413]	gal	N2O	2.60E-04	[107]	6.33E-03	6.96E-03	6.96E-03	310	1.96E+00	2.16E+00	2.16E+00

Plant Site Mobile Sources

Greenhouse Gas Totals (metric tons)	CO_2			5168.67	7942.75	7942.75	1	5168.67	7942.75	7942.75
	CH_4			0.29	0.45	0.45	21	6.03	9.39	9.39
	N_2O			0.13	0.20	0.20	310	40.01	62.23	62.23
	TOTAL GHGs							5,215	8,014	8,014

Plant Site Totals

Greenhouse Gas Totals (metric tons)	CO_2			22,900	145,830	66,070	1	22,900	145,830	66,070
	CH_4			0.48	2.10	0.84	21	10.00	44.10	17.62
	N_2O			0.39	2.52	0.88	310	122.07	781.24	273.98
	TOTAL GHGs								146,655	66,361

% of total	CO2	99.4%	99.6%
	N2O	0.0%	0.0%
	CH4	0.53%	0.41%

Notes:

General References:

[1] Max. Emissions (kg/hr) = EF (kg/unit) x Max. Hourly Throughput (units/hr).
Max. Uncontrolled Emissions (m.t./yr) = EF (kg/unit) x Max. Annual Throughput (units/yr) / 1,000 (kg/m.t.).

[2] Projected Actual Emissions (m.t./yr) = EF (kg/unit) x Projected Actual Throughput (units/yr) / 1,000 (kg/m.t.).

[3] Global Warming Potentials from 2001 IPCC Guidelines, found through "Comparison of Global Warming Potentials from the Second and Third Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC)"
<http://www.eia.doe.gov/oiaf/1605/gwp.html>

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Table A-2: Calculation of Potential Greenhouse Gas Emissions at Processing Plant

Stack ID	Emission Unit		APCD ID	Throughput							Pollutant	Emission Factor		Maximum Emissions [1]		Projected	CO2-e	Max. Emissions		Projected
	ID	Description		Maximum				Projected Actual		Units						Actual	Factor	(CO2-e)[4]		Actual
				(Units/hr)	Note	(Units/yr)	Note	(Units/yr)	Note			(lb/Unit)	Note	(lb/hr)	(ston/yr)	(ston/yr)	(Global	(lb/hr)	(ston/yr)	(ston/yr)

[4] Max. Emissions (CO2-e) (kg/hr) = Max. Uncontrolled Emissions (kg/hr) x (CO2-e Factor).
Max. Controlled Emissions (m.t./yr) = Max. Uncontrolled Emissions (m.t./yr) x (CO2-e Factor).

[5] Projected Actual Emissions (CO2-e) (m.t./yr) = EF (kg/unit) x Projected Actual Throughput (units/yr) / 1,000 (kg/m.t.)

Emission Factor References:

[100] From Climate Registry General Reporting Protocol (Version 1.1, May 2008) Table12.1 (Weighted U.S. Average Entry). Emission factor converted from kg/MMBtu to lb/MMcf by kg/MMBtu * 2.205 lb/kg * 1050 MMBtu/MMcf. This emission factor source is generally used for carbon footprint assessment and is applicable for air permitting. AP-42 factors are similar.

[101] From Climate Registry General Reporting Protocol (Version 1.1, May 2008) Table 12.7. Factors converted from g/MMBtu to lb/Mgal by lb/Mgal = g/MMBtu * (1 lb/453.59 g) * 1050 MMBtu/MMcf. This emission factor source is generally used for carbon footprint assessment and is applicable for air permitting. AP-42 factors are similar.

[102] From Climate Registry General Reporting Protocol (Version 1.1, May 2008) Table 12.1 (Distillate Fuel Oil). Emission factor converted from kg/MMBtu to lb/MMBtu by kg/MMBtu * 2.205 lb/kg. This emission factor source is generally used for carbon footprint assessment and is applicable for air permitting. AP-42 factors are similar.

[103] FFrom Climate Registry General Reporting Protocol (Version 1.1, May 2008) Table12.1. Emission factor converted from kg/MMBtu to lb/Mgal by kg/MMBtu * 2.205 lb/kg * 91.5 MMBtu/Mgal. This emission factor source is generally used for carbon footprint assessment and is applicable for air permitting. AP-42 factors are similar..

[104] From Climate Registry General Reporting Protocol (Version 1.1, May 2008) Table 12.7. Factors converted from g/MMBtu to lb/Mgal by lb/Mgal = g/MMBtu * (1 lb/453.59 g) * 91.5 MMBtu/Mgal. This emission factor source is generally used for carbon footprint assessment and is applicable for air permitting. AP-42 factors are similar.

[105] CO2 emission rate taken from MetSim flow simulation results transmitted by Glenn Stieper of Bateman as a spreadsheet attached to a February 9, 2011 e-mail. Rate = 0.000143 Mtons/hour * 1.1023 Mton/ston = 0.000158 ston/hr * 2000 lb/ton = 0.315 lb/hr. Emission factor is emission rate divided by ton/hr exhaust gas flow.

[106] CO2 emission rate taken from MetSim flow simulation results transmitted by Glenn Stieper of Bateman as a spreadsheet attached to a February 9, 2011 e-mail. Rate = 4.2486 Mtons/hour * 1.1023 Mton/ston = 4.6832 ston/hr * 2000 lb/ton = 9366.5 lb/hr. Emission factor is emission rate divided by ton/hr exhaust gas flow.

[107] For Diesel Heavy-Duty Vehicles and Diesel Light Trucks: Emission factors taken from The Climate Registry's General Reporting Protocol, May 2008, Tables 13.1 and 13.3. For conversion purposes, truck efficiency assumed at 7 mpg for haul trucks and 15 mpg for light trucks.
For Non-Highway Vehicles: Emission factors taken from The Climate Registry's General Reporting Protocol, May 2008, Tables 13.1 and 13.6.

	CO2	CH4	N2O
Diesel Emissions (kg/gal):	10.15		
Diesel Heavy-Duty Vehicles, uncontrolled (g/mi):		0.0051	0.0048
Diesel Light Trucks, uncontrolled (g/mi):		0.0011	0.0017
Construction / Large Utility Non-highway Vehicles, diesel (g/gal):		0.58	0.26
Construction / Large Utility Non-highway Vehicles, gasoline (g/gal):		0.5	0.22

Maximum Hourly Throughput References:

[201] Max. Hourly Capacity = 52,970 MJ/hr per Clayton as communicated in May 3, 2006 e-mail from Mike Wardell-Johnson of Bateman.
Fuel usage: 52,970 MJ/hr * 10^6 J/MJ * 9.47831 * 10^-4 Btu/J / 10^6 Btu/MMBtu / 1,050 MMBtu/MMcu.ft. (heating value of natural gas) = 0.0478 MMcf/hr.

[202] Heating demand for adsorber regeneration estimated as 600 kW by engineer working on oxygen plant design. Heater may be electric or natural gas fired. Assumed natural gas fired as worst case.
Hourly heat input is: 600 kW * 0.94783 (Btu/sec)/kW * 3600 sec/hour / 10^6 MMBtu/Btu = 2.05 MMBtu/hr.

[203] Design heater capacity and annual actual fuel usage estimates taken from Phase I design work completed by mechanical design contractor. Heating capacity separated into direct fired, which will vent out general bulding vents, and invididual indirect fired units, which will have separate stacks, for use in refined modeling if needed.

[204] Total design space heating capacity for new buildings estimated by Barr based on available data. Actual annual fuel usage estimated with historic temperature data from a nearby location.

[205] Based a fuel consumption test performed on the generators before they were delivered with a result of 587 lb fuel/hr @ 100% power. From AP-42 Section 3.4.1, footnote "a", the heat content of diesel fuel is 19,300 btu/lb. The maximum heat input is then 587 lb fuel/hr * 19,300 Btu/lb / 10^6 Btu/MMBtu = 11.3 MMBtu/hr.

[206] Existing fire pumps will be replaced with two Clarke JU4H-UF58 diesel powered pumps. Maximum fuel consumption rate is 3.8 gal/hr (0.0038 Mgal/hr) per data obtained from the manufacturer. Heat input = 3.8 gal/hr * 140,000 Btu/gallon / 10^6 Btu/MMBtu = 0.532 MMBtu/hr.
Annual potential heat input based on 500 hours per year based on EPA guidance for equipment used for emergency purposes.

[207] New boiler has a maximum heat input of 2.1 MMBtu/hr per manufacturer information.

[208] Burner capacity based on information from Manufacturer.

[209] Total heat input of the propane fired space heaters at the Area 1 Shop based on a quotation for upgrade of the system from 1990. Heat input = 8.976 MMBtu/hr.

[210] New propane fired infrared space heaters will be installed in the Area 2 shops. Maximum capacity assumed the same as existing boiler (10 MMBtu/hr). The heaters are expected to have a lower maximum heat input than the existing boiler due to higher efficiency.

[211] The preferred option for the WWTP is to ship brine offsite, but if this is not feasible, an evaporator/crystallizer would be operated on-site. It may be electric or natural gas fired. As the worst case of the alternatives under consideration, a gas fired unit is assumed in the emission calculations. Based on design work completed to date for comparison of alternatives, the maximum energy usage is 5 MMBtu/hr; assuming 80% efficiency, the maxmum heat input for a gas fired unit is 6 MMBtu/hr. A 10 MMBtu unit was assumed to provide a safety factor.

[212] Based on preliminary design of Mine Site waste water treatment facility for DEIS by Barr, maximum heating demand for natural gas fired heaters is estimated as 8.3 MMBtu/hr. The MIne Site heater rating has since been refined and this value may be as well as design work proceeds.
A conservative estimate of annual usage was made by assuming 40% utilization for the heaters; detailed calculations for other heaters at the Plant Site showed a significantly lower percent utilization. Assumes natural gas line will be extended to WWTP.

[213] Based on preliminary design of Mine Site waste water treatment facility by Barr, critical power demand is about 500 kW. This was considered a conservative estimate of critical power demands at the Area 5 WWTF. It was assumed that a Caterpillar Standby 500 ekW would be installed. Based on literature available on the manufacturer's website, the fuel consumption at maximum load is 37.4 gallons/hr (0.0374 Mgal/hr). This is converted to MMBtu/hr by 37.4 gal/hr * 140,000 Btu/gallon / 10^6 Btu/MMBtu = 5.236 MMBtu/hr.

[214] Gas exhaust rate taken from MetSim flow simulation results transmitted by Glenn Stieper of Bateman as a spreadsheet attached to a February 9, 2011 e-mail. Rate = 4.4826 Mtons/hour * 1.1023 Mton/ston = 4.9411 ston/hr.

[215] Total gas exhaust rate for three tanks taken from MetSim flow simulation results transmitted by Glenn Stieper of Bateman as a spreadsheet attached to a February 9, 2011 e-mail. Rate = 9.631 Mtons/hour * 1.1023 Mton/ston = 10.616 ston/hr.

[216] The NorthMet Project Description (Version 2, April 15, 2011) indicates that haul trucks would be expected to go to Area 1 for maintenance two times per year for major repairs and that a maximum of 9 haul trucks will be used for mining. Two additional haul trucks may be used for mining for a total of 11.
Total annual trips are then 2 round trips/year/truck * 11 trucks = 22 round trips * 2 trips/round trip = 44 trips. The approximate average maintenance interval in days is 365/2 = 180 days. Average trips per day are then 1/180 trips/truck/day * 11 trucks = 0.06 trips/day. A conservative worst case hourly VMT was estimated as having 2 trucks make a one way trip in the hour. This was also assumed to be the daily maximum. Haul Trucks use Road Segments: B2, J, and J2; the hourly VMT =(0.16 mi +0.09 mi+ 0.24mi) x 2 trips/hr. See Note [220].

[217] Hourly light truck traffic at tailings basin estimated by scaling data from when the tailings basin was operated by Cliffs Erie. The previous estimates of VMT were scaled by the relative quantity of tailings produced or 30,887 ton/day / 66,000 ton/day. Tailings generation rate taken from MetSim Rev. U3. The Cliffs Erie VMT estimate was based on a maximum of 9 trucks traveling 15 mph. Annual light truck traffic at tailings basin estimated by scaling data from when the tailings basin was operated by Cliffs Erie. The previous estimates of VMT were scaled by the relative quantity of tailings produced or 30,881 ton/day / 66,000 ton/day.

[218] Three 7,500 gallon fuel tankers per day would be needed. Only one trip per hour would likely be completed. Annual trips = 3 tankers/day * 2 trips/round trip * 365 days/year = 2190 trips/year. Fuel Tankers use road segments: B2, C, and H; the hourly VMT = (0.16 mi + 1.928 mi) * 1 trip/hr. See Note [220].

[219] Maximum throughput for waste water treatment facility estimated as approximately 4,500 tpy lime in and 27,000 tpy sludge out. Lime will be transported from Plant Site in 40 ton over the road trucks with 20 ton payload. Similar trucks will haul sludge back to Plant Site. Assume different trucks used as worst case. Annual trips = (4500 ton + 27000 ton) /20 ton/truck = 1575 round trips/yr * 2 = 3150 trips/year. Assume 5 day per week, 52 week per year trucking schedule: 1575 / (5 * 52) = 6.06 truck per day, round up to 7 trucks per day.
Additonally, in Years 1-3, 2 truck per day will tranport brine from the Plant Site WWTP to the Mine Site WWTF for a total of: 2 trucks/day * 2 trips/round trip * 365 days/year = 1460 trips/year. Grand total is 3150 + 1460 = 4610 trips/year.
WWTF trucks use road segments: B2, C, D, E, and F; the hourly VMT = (0.16 mi + 1.928 mi + 0.148 mi + 0.722 mi + 0.370 mi) * 2 trips/hr. See Note [220].

[220] All mine personnel will drive personal vehicles to Area 2. From there, equipment operators and others who work all day at the mine will be transported by bus to the Mine Site. Other staff based at Area 2 will travel to the Mine Site during the work day as indicated by the number of trips in the table above. The road segments traveled are also included in the table. Maximum hourly emissions will occur at shift changes where the vehicles transporting both shifts could be on the road during the same hour. To be conservative it was assumed that all travel would occur between the eight hour shifts although at least some railroad personnel will be working 12 hour shifts and other personnel may travel at other times. The maximum daily and hourly trips are shown in the table above as well as the hourly and annual miles.
Only segments B2, C, D, E, F and H are at the Plant Site. Emissions from other segments are included with the Mine Site Calcs. All of segment H on PolyMet property is paved.

Category	Location	1st shift	2nd Shift	3rd Shift	Road Segments Traveled
Mine Ops	Mine (Bus)	1	1	1	A, B2, B3, C, D
Mine Tech Serv	to Mine	4	0	0	A, B2, B3, C, D
Mine Manage.	to Mine	7	2	2	A, B2, B3, C, D
RR Ops	to Mine	6	4	4	A, B2, B3, C, D
Other	to Mine	2	0	0	A, B2, B3, C, D
Total Employees	to Area 2	28	35	28	D, H
EHS	PP to mine	3	0	0	A, B2, B3, C, D, E, F
Total		51	42	35	

Road Segment	Dist. (miles)	Max Hourly Trips	Max Daily Trips	Hourly VMT	Annual VMT	Daily VMT
A	0.800	23	74	18.40	21613.40	59.21
B2	0.160	23	74	3.68	4317.16	11.83
B3	1.166	23	74	26.82	31493.66	86.28
C	1.928	23	74	44.34	52068.78	142.65
D	0.148	64	256	9.45	13791.83	37.79

PolyMet - Hoyt Lakes, Minnesota
Table A-2: Calculation of Potential Greenhouse Gas Emissions at Processing Plant

Stack ID	Emission Unit		APCD ID	Throughput							Pollutant	Emission Factor		Maximum Emissions [1]		Projected Actual	CO2-e Factor	Max. Emissions (CO2-e)[4]		Projected Actual
	ID	Description		Maximum				Projected Actual		Units										
				(Units/hr)	Note	(Units/yr)	Note	(Units/yr)	Note			(lb/Unit)	Note	(lb/hr)	(ston/yr)	(ston/yr)	(Global	(lb/hr)	(ston/yr)	(ston/yr)

E	0.722	3	6	2.17	1580.93	4.33
F	0.370	3	6	1.11	810.25	2.22
H	0.000	93	182	0.00	0.00	0.00
Total	5.293			106.0	125676	344.3

Miscellaneous Road Lengths	
Description	Length (miles)
J	0.09
J2	0.24
TB WWTP	0.60

[221] Load factor assume the same as for ore haul locomotives (15%), but with only a single 700 hp engine. Annual usage equals daily usage times 360 mining days per year.

Switching Locomotive

Daily Estimate Total Fuel Usage	131	gallons/day
Hourly Average Fuel Use	5.45	gph

[222] Fuel usage for each ore haul locomotive calculated by PolyMet. Annual usage equals daily usage times 360 mining days per year.

Daily Estimate Total Fuel Usage	1,177	gallons/day
Hourly Average Fuel Use	49.04	gph

[223] Fuel usage based on operations at a taconite tailings basin with the same model truck. Estimated fuel consumption is 15 gallons/hr times maximum 28 trucks = 420 gallons per hour. Annual and daily consumption based on construction schedule of one 10 hour shift for 110 day construction season.

[224] Hourly fuel consumption estimated by assuming same load factor as primary production excavators at Mine Site, rounded up to the nearest 5%, although Mine Site units are electric and Tailings Basin units will be diesel powered. Annual and daily consumption based on construction schedule of one 10 hour shift for 110 day construction season.

Maximum Annual Throughput References:

[301] Max. Annual Fuel Usage (or heat input) = Max. Hourly Fuel Usage (or heat input) * 8,760 hr/yr. Projected utilization varies by process area , but all will be less than 8760 hr/yr.

[302] Assumes 140,000 Btu/gal No. 2 Fuel Oil. As recommended by EPA guidance, 500 hours per year operation was assumed for emergency generators. Annual throughput is then hourly throughput * 500 hours/year.

[303] As recommended by EPA guidance, 500 hours per year operation was assumed for emergency generators. Annual throughput is then hourly throughput * 500 hours/year.

[304] Assume 91.5 MMBtu/Mgal propane. Annual usage is 8,760 hrs/year

[305] Assume 1050 MMBtu/MMscf NG. Annual usage is 8,760 hrs/year

[306] The NorthMet Project Description (Version 2, April 15, 2011) indicates that haul trucks would be expected to go to Area 1 for maintenance two times per year for major repairs and that a maximum of 9 haul trucks will be used for mining. Two additional haul trucks may be used for mining for a total of 11. Total annual trips are then 2 round trips/year/truck * 11 trucks = 22 round trips * 2 trips/round trip = 44 trips. Haul Trucks use Road Segments: B2, J, and J2; the Annual VMT =(0.16 mi +0.09 mi+ 0.24mi) x 44 trips/yr. See Note [220].

[307] Annual light truck traffic at tailings basin estimated by scaling data from when the tailings basin was operated by Cliffs Erie. The previous estimates of VMT were scaled by the relative quantity of tailings produced or 30,881 ton/day / 66,000 ton/day.

[308] Annual trips = 3 tankers/day * 2 trips/round trip * 365 days/year = 2190 trips/year. Fuel Tankers use road segments: B2, C, and H; the hourly VMT = (0.16 mi + 1.928 mi) * 2190 trips/yr. See Note [220].

[309] Annual trips = (4500 ton + 27000 ton) /20 ton/truck = 1575 round trips/yr * 2 = 3150 trips/year. WWTF trucks use road segments: B2, C, D, E, and F; the hourly VMT = (0.16 mi + 1.928 mi + 0.148 mi + 0.722 mi + 0.370 mi) * 3150 trips/yr. See Note [220].

[310] Annual based on constructions schedule of one 10 hour shift for 110 day construction season

Projected Actual Throughput References

[401] Estimated actual emissions based on 6% utilization as per specification prepared by Bateman dated 2/17/06.

[402] Projected actual emissions based on 16 hours per day operation.

[403] Design heater capacity and annual actual fuel usage estimates taken from Phase I design work completed by mechanical design contractor. Heating capacity separated into direct fired, which will vent out general bulding vents, and invididual indirect fired units, which will have separate stacks, for use in refined modeling if needed. Actual annual fuel usage not split out by individual unit, but is arbitrarily assigned to the first entry for each building.

[404] Projected actual emissions assume 10 days per year or 240 hours operation. This is expected to be a conservative assumption since most operation will be for testing and occasionally to safely shut down plant during power outage. Annual throughput = 240 hours * hourly heat input rate.

[405] Annual actual operating hours estimated as 1 hour per week for testing and 12 hours per year operation for a total of 64 hours. Annual throughput = 64 * hourly heat input.

[406] Annual usage estimated from historic fuel usage with old boiler.

[407] Annual projected usage is 0 because this boiler is a backup unit for EU 413, so all fuel usage is assigned to that unit.

[408] Projected actual usage based on 50% utilization for the heating system, a conservative assumption.

[409] Actual fuel usage assumed to be 80% of potential as a conservative estimate.

[410] A conservative estimate of annual usage was made by assuming 40% utilization for the heaters.

[411] Assumes actual use is 500 hours per year

[412] Actual annual emissions assume 90% availability or 7884 hours per year

[413] Projected acutal emissions are equivalent to potential emissions

PolyMet - Hoyt Lakes, Minnesota
Table A-3: Calculation of Potential NorthMet Greenhouse Gas Emissions from Construction Activities

	Potential Emissions (tpy)				Projected Actual Emissions (tpy)			
Year 0	CO2	N2O	CH3	CO2e	CO2	N2O	CH4	CO2e
Plant Site Point	90129	2.2	1.5	90829	20931.1	0.6	0.3	21132
Plant Site Mobile	5450	0.1	0.3	5499	5449.6	0.1	0.3	5499
Mine Site Point	310	0.0	0.0	310	64.6	0.0	0.0	65
Mine Site Mobile	2605	0.1	0.1	2629	2605.5	0.1	0.1	2629
Other Construction [3]	2062	0.1	0.1	2081	2061.9	0.1	0.1	2081
Total	100557	2.4	2.1	101349	31112.8	0.9	0.9	31406

	Potential Emissions (tpy)				Projected Actual Emissions (tpy)			
Year 2	CO2	N2O	CH3	CO2e	CO2	N2O	CH4	CO2e
Plant Site Point (tpy)	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]
Plant Site Mobile (tpy)	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]
Mine Site Point	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]
Mine Site Mobile	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]
Other Construction [3]	1031	0.0	0.1	1040	1031	0.0	0.1	1040
Total	1031	0.0	0.1	1040	1031	0.0	0.1	1040
Total Project (Stons)				102389				32447
Total Project (mt)				92885				29435

Global Warming Potentials

CO2	1
CH4	21
N2O	310

Details on Estimated Emissions from Other Construction Activities [2]

Phase I Construction (Flotation Concentrate - Year 0)

New Buildings		
Fine Grading	2335	lbs/day
Paving/grading	3545	lbs/day
Paving/grading/building	5728	lbs/day
Building	2183	lbs/day
Building/Coating	2248	lbs/day
Coating	66	lbs/day
Max Daily Emissions	5728	lbs/day
Conservative Annual Estimate [4]	1031	Tons/year
Work on existing buildings [5]	1031	tons/year
Total	2062	tons/year

Phase 2 Hydrometallurgical Plant Construction (Same footprint as Year 0 new Buildings - about 125,000 ft^2)

New Buildings		
Fine Grading	2335	lbs/day
Paving/grading	3545	lbs/day
Paving/grading/building	5728	lbs/day
Building	2183	lbs/day
Building/Coating	2248	lbs/day
Coating	66	lbs/day
Max Daily Emissions	5728	lbs/day
Conservative Annual Estimate	1031	Tons/year
Work on existing buildings [6]	0	tons/year
Total	1031	tons/year

[1] Point and mobile source emissions included in Tables A-1 and A-2 for operating years.

[2] Estimated with Urbemis 2007 Version 9.2.4

[3] Urbemis only estimates CO2 emissions, ratio of N2O and CH4 assumed to be same as that for mobile sources

[4] As a conservative estimate of total emissions assumed maximum emissions rate for 360 days per year.

[5] Assumed work on existing buildings has same carbon footprint as new building construction

[6] Work on existing buildings completed during Phase I

PolyMet - Hoyt Lakes, Minnesota
Table A-4: Calculation of Potential NorthMet Greenhouse Gas Emissions for Reclamation Period

	Potential Emissions (tpy)				Projected Actual Emissions (tpy)			
Plant Site	CO2	N2O	CH3	CO2e	CO2	N2O	CH4	CO2e
Plant Site Point	18937.57	0.96	0.28	19241.46	7901.79	0.41	0.11	8030.87
Plant Site Mobile	558.63	0.01	0.03	563.54	534.11	0.01	0.03	538.99
Total	19496	1.0	0.3	19805	8436	0.4	0.1	8570
Estimated Years of Reclamation	20							
Total Reclamation Emissions	389924	20	6	396100	168718	8	3	171397

	Potential Emissions (tpy)				Projected Actual Emissions (tpy)			
Mine Site	CO2	N2O	CH3	CO2e	CO2	N2O	CH4	CO2e
Mine Site Point	1429.38	0.08	0.02	1453.70	698.44	0.03	0.01	708.16
Mine Site Mobile	9.68	0.00	0.00	9.69	9.68	0.00	0.00	9.69
Total	1439.07	0.08	0.02	1463.39	708.12	0.03	0.01	717.85
Estimated Years of Closure	60							
Total Closure Emissions	86344	5	1	87803	42487	2	0	43071

Global Warming Potentials

CO2	1
CH4	21
N2O	310

Total for Project (stons)	483904		214469
Total for Project (mt)	438988		194562

Attachment B

Indirect Emission Calculations

Indirect Emission Calculations

Indirect Emissions Related to Generating Electricity for the project

PolyMet Mining, Inc. (PolyMet), will purchase electricity to meet the Project's electrical needs, which are anticipated to be approximately 59.5megawatts of power. CO_2 emissions are estimated using MPCA guidance emission factors for Minnesota electricity providers.

Table B-1. Potential Indirect Emissions from Electricity Generated for the Project

Electrical Load (MWh Total)(1)	Emission Factor (m.t. CO_2 / MWh)(2,3)	CO_2 Emissions (m.t./yr)
521,220	0.98	511,000

(1) Total demand is 59.5 MW, assumed at full operation (8760 hours/year)

(2) Following MPCA's General Guidance for Carbon Footprint Development in Environmental Review. Electricity provider Minnesota Power in Table 5 of the document.

Minnesota Power Emission Factor: 2159.5 lb CO_2 / MWh

The MPCA's values are based on the Environmental Disclosure information filed annually by the electric utilities.

(3) A conversion of 2204.6 lb per metric ton is used: (2159.5 lb CO_2 / MWh) * (1 m.t. CO_2 / 2204.6 lb CO_2) = 0.98 m.t. CO_2 / MWh

Attachment C

Combustion Fuel Alternatives Emissions

Table C-1. Comparison of Emissions from Potential Sources for Space Heating in PolyMet's Process Plant

Natural Gas (1)

Hourly Max Throughput (MMCF/hr)	Annual Max Throughput (MMCF/yr)	Demand (MMBtu/hr)	Emissions (m.t.CO2-e / yr)
0.119	1039	125	63819

Propane (5, 6)

Hourly Max Throughput (Mgal/hr)	Annual Max Throughput (Mgal/yr)	Emissions (m.t.CO2-e / yr)
1.36	11923	162355

Autoclave Waste Heat & Remaining Natural Gas (4)

Demand (MMBtu/hr)	Demand Reduction (MMBtu/hr)	Annual Max Throughput (MMCF/yr)	Emissions (m.t.CO2-e / yr)
102	23	876	52289

Electricity (2,3)

Hourly Max Throughput (kWh/hr)	Annual Max Throughput (kWh/yr)	Emissions (m.t.CO2-e / yr)
36500	319738403	313184

(1) Conversion factor of 1050 Btu/SCF for natural gas

(2) 0.9795 m.t. CO2 / MWh electricity from MPCA General Guidance for Carbon Footprint in Environmental Review. Minnesota Power will be the electricity provider for PolyMet

(3) Conversion factor of 3412 Btu / kWh; efficiency assumed similar for natural gas fired and electric space heaters.

(4) Using waste heat is expected to reduce heating demand from 125 MMBtu/hr to 102 MMBtu.hr

(5) AP-42 Factor of 91.5 MMBtu/Mgal for propane

(6) Emission factors from Table 12.7 of The Climate Registry's General Reporting Protocol, May 2008. Converted from g/MMBtu to kg/Mgal by multiplying by the AP-42 factor of 91.5 MMBtu/Mgal for propane and 1000 g/kg.

Table C-2. Comparison of Emissions from Potential Fuels for PolyMet's Mobile Sources, Generators, and Fire Pumps

Fuel	Emission Factor			Heat Content	
	TCR GRP Table 13.1 Units		(kg CO_2 / MMBtu)		
Biodiesel	9.46	kg CO2/gal	79.97	118296	Btu/gal (1)
Compressed Nat. Gas	0.054	kg CO2/scf	52.58	1027	BTU/scf
Diesel	10.15	kg CO2/gal	73.18	138.69	MMBtu/Mgal (2)
Gasoline	8.81	kg CO2/gal	70.44	125.07	MMBtu/Mgal (2)

(1) National Biodiesel Board heating value of 118,296 Btu/gal for B100. (http://www.biodiesel.org/pdf_files/fuelfactsheets/BTU_Content_Final_Oct2005.pdf)

(2) MPCA General Guidance for Carbon Footprint Development in Environmental Review

Table C-3. Comparison of Emissions from Potential Fuels for PolyMet's Area 1 Shop & Area 2 Shop Space Heating

Propane(1)				Natural Gas (4,5)			Electricity (2,3)		
Hourly Max Throughput (Mgal/hr)	Annual Max Throughput (Mgal/yr)	Demand (MMBtu/hr)	Max Emissions (m.t.CO2-e/yr)	Hourly Max Throughput (MMCF/hr)	Annual Max Throughput (MMCF/yr)	Max Emissions (m.t.CO2-e/yr)	Hourly Max Throughput (kWh/hr)	Annual Max Throughput (kWh/yr)	Max Emissions (m.t.CO2-e/yr)
0.227	1989	21	12652	0.02	173	9212	6088	53328169	52235

(1) AP-42 Factor of 91.5 MMBtu/Mgal for propane

(2) 0.9795 m.t. CO2 / MWh electricity from MPCA General Guidance for Carbon Footprint in Environmental Review. Minnesota Power will be the electricity provider for PolyMet

(3) Conversion factor of 3412 Btu / kWh; efficiency assumed similar for natural gas fired and electric space heaters.

(4) Conversion factor of 1050 Btu/SCF for natural gas

(5) MPCA General Guidance for Carbon Footprint Development in Environmental Review, Table 4, 58.61 tons CO2/MMCF natural gas

Attachment D

Calculations of Carbon Flux for Peat Used in Restoration

Table D-1. Estimated Carbon Loss From Peat Used in Reclamation

Project Year	Restored Acreage	Estimated Peat Carbon Loss (metric tons C) [1]	Notes
0	0	0	
1	0	0	
2	63	127	63 acres Cat 1
3	0	0	
4	29	59	29 acres Cat 1
5	14	28	14 acres Cat 1
6	23	47	23 acres Cat 1
7	0	0	
8	0	0	
9	41	83	41 acres Cat 1
10	0	0	
11	76	154	10 Cat 4 Stockpile that does not become the Central Pit, 4 acres Cat 4 Ponds, 2 acres of Haul Roads, 60 acres Cat 1
12	11	22	11 acres of Haul Roads
13	328	664	328 acres Cat 1
14	0	0	
15	31	63	31 acres Cat 2/3
16	33	67	30 acres Cat 2/3, 3 acres Cat 2/3 Ponds & Sumps
17	30	61	30 acres Cat 2/3
18	32	65	30 acres Cat 2/3, 2 acres Cat 2/3 Ponds & Sumps
19	30	61	30 acres Cat 2/3
20	57	115	30 acres Cat 2/3, 5 acres Cat 2/3 Ponds & Sumps, 22 acres of Haul Roads
21	31	63	10 acres of remaining PW Ponds and sumps (OSP, Haul Roads, OSLA, RTH), 21 acres of stormwater ponds
22	320	647	45 acres OSLA, 32 acres OSP, 4 acres RTH, 190 acres East/Central Pit, 49 acres of Haul Roads
Total Metric Tons (as carbon)		2,325	
Total Metric Tons (as CO2e)		8,525	

[1] Estimated carbon loss based on 5 Mg/ha loss during first five years after restoration. Net sequestration assumed to occur as succesional forest develops on reclaimed areas. This assumes all reclaimed areas are originally planted in herbaceous cover as a "worst case' scenario

Attachment E

Aboveground Carbon Stock and Sequestration Capacity Loss Calculations

Table E-1. Aboveground Carbon Storage and Sequestration Impacts

Ecosystem Type	Habitat Type	Project Impact Areas (acres) by Location					Total Impact Area		Biomass Carbon Storage (Metric tonnes/ha)	Carbon Sequestration (Metric tonnes/ha/yr)	Project Impacts		Notes & Assumptions
		Dunka Road/TWP	Hydromet Residue Facility	Mine Site	Railroad Connection	Tailings Basin	Total Acres	Total Hectares			Biomass Carbon Lost (Metric tonnes)	Carbon Sequestration Lost (Metric tonnes/year)	
Upland	Bare	51.81	18.26	13.49	9.41	512.19	605.16	244.90	0	0	0.00	0.00	*Habitat consists of roads, railroads, and rights-of-way. Assume carbon storage and sequestration are negligible.
	Deciduous Forest	11.32	62.88	324.07	8.99	174.81	582.07	235.56	41.53	1.3	9,782.63	306.22	Assume aspen represents the majority of tree cover in this type (birch does not likely represent a significant enough portion to exert an influence on carbon storage). Aspen is present in varying stages of regeneration - used 25 years as an average age of aspen - used carbon storage number for 25-year old aspen from COLE. Calculated carbon sequestration rate from COLE carbon stock data for 25 year old aspen.
	Grassland	0.24	0	0	0	222.39	222.63	90.10	0	0.7	0.00	63.07	*Assume negligible long-term storage in biomass of herbaceous vegetation. Use "MN specific conversion of marginal agricultural land to perennial grassland" for sequestration values.
	Mixed Forest	21.27	0	635.91	0	0	657.18	265.95	66.24	0.45	17,616.11	119.68	This forest type is some combination of black spruce (average of 25%), white spruce (average of 15%), balsam fir (average of 30%), jack pine (average of 14%), aspen (average of 7%), red pine (average of 5%), and white pine (average of 4%). The numbers associated with each species represent average relative dominance for each based on field reconnaissance and best professional judgement. Used a weighted average based on these relative abundances for each species using the average COLE storage numbers for these species. Did a weighted average using calculated carbon sequestration rates from COLE carbon stock data - used average rate across 100 years for each species.
	Shrubland	15.22	0	0	0.58	47.97	63.77	25.81	16.80	0.22	433.56	5.68	Shrublands are typically very young regenerating aspen - likely under 10 years old - assume an average of 5 year old aspen. Used carbon storage number for 5-year old aspen from COLE. Calculated carbon sequestration rate from COLE carbon stock data for 5 year old aspen.
							2,130.81	**862.31**			**27,832.30**	**494.64**	
Wetland	Coniferous Bog	0.63	0	525.02	0	0	525.65	212.72	62.58	0.70	13,311.16	148.91	Assume black spruce represents an average of 75% of the tree cover and tamarack represents an average of 25% of the tree cover in bogs. Used a weighted average based on these relative abundances using the average COLE storage numbers for black spruce and tamarack. Used the average of lower and upper bound for "Minnesota peatlands" for sequestration value.
	Coniferous Swamp	0.74	0	68.73	0.24	5.38	75.09	30.39	71.43	0.37	2,170.46	11.24	Assume black spruce represents an average of 50% of the tree cover, tamarack represents an average of 25% of the tree cover, and northern white cedar represents an average of 25% of the tree cover in coniferous swamps. Did a weighted average based on these relative abundances using the average COLE storage numbers for black spruce, tamarack, and northern white cedar. Did a weighted average using calculated carbon sequestration rates from COLE carbon stock data - used average rate across 100 years for each species.
	Hardwood Swamp	0	0	12.39	0	0	12.39	5.01	66.60	0.62	333.94	3.11	Assume black ash represents the majority of tree cover in this type (other species are likely not present in significant enough numbers to exert influences on carbon storage). Used average carbon storage number for black ash from COLE (this number is the same for black ash, American elm, and red maple). Calculated carbon sequestration rate from COLE black ash carbon stock data using the average rate across 100 years.
	Herbaceous Emergent Wetland	0.34	35.06	61.48	0.07	345.72	442.67	179.14	0.00	0.70	0.00	125.40	*Assume negligible long-term storage in herbaceous vegetation. Use "MN specific conversion of marginal agricultural land to perennial grassland" for sequestration values.
	Open Water	0	0	0	0	509.11	509.11	206.03	0.00	0.00	0.00	0.00	Assume neglibible long-term storage in any herbaceous vegetation growing in open water habitats.
	Shrub Scrub	2.7	0	101.87	0.49	0.3	105.36	42.64	48.00	0.70	2,046.61	29.85	*Biomass value for peatlands/mineral soil wetlands from Bridgham et al. 2006. Sequestration value for peatlands based on studies cited by Lennon and Nater 2006.
							1,670.27	**675.94**			**17,862.17**	**318.50**	
Grand Total							**3,801.08**	**1,538.25**			**45,694.46**	**813.15**	

Totals as CO2e

	Carbon Storage	Sequestration Loss
Upland	102052	1814
Wetland	65495	1168
Grand Total	167546	2982

Appendix B

Website References Used in this Report

Climate Change

Causes of Climate Change

ON THIS PAGE

Earth’s temperature is a balancing act

Earth’s temperature depends on the balance between energy entering and leaving the planet’s system . When incoming energy from the sun is absorbed by the Earth system, Earth warms. When the sun’s energy is reflected back into space, Earth avoids warming. When energy is released back into space, Earth cools. Many factors, both natural and human, can cause changes in Earth’s energy balance, including:

- Changes in the greenhouse effect, which affects the amount of heat retained by Earth’s atmosphere
- Variations in the sun’s energy reaching Earth
- Changes in the reflectivity of Earth’s atmosphere and surface

Key Points

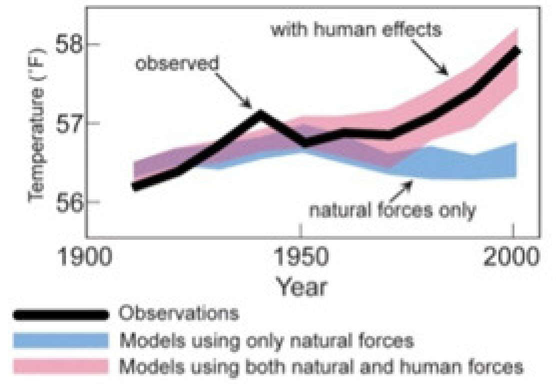
- Both natural and human factors change Earth’s climate.
- Before humans, changes in climate resulted entirely from natural causes such as changes in Earth’s orbit, changes in solar activity, or volcanic eruptions.
- Since the Industrial Era began, humans have had an increasing effect on climate, particularly by adding billions of tons of heat-trapping greenhouse gases to the atmosphere.
- Most of the observed warming since the mid-20th century is due to human-caused greenhouse gas emissions.

These factors have caused Earth’s climate to change many times.

Scientists have pieced together a picture of Earth’s climate, dating back hundreds of thousands of years, by analyzing a number of indirect measures of climate such as ice cores, tree rings, glacier lengths, pollen remains, and ocean sediments, and by studying changes in Earth’s orbit around the sun. [1]

The historical record shows that the climate system varies naturally over a wide range of time scales. In general, climate changes prior to the Industrial Revolution in the 1700s can be explained by natural causes, such as changes in solar energy, volcanic eruptions, and natural changes in greenhouse gas (GHG) concentrations. [1]

Recent climate changes, however, cannot be explained by natural causes alone. Research indicates that natural causes are very unlikely to explain most observed warming, especially warming since the mid-20th century. Rather, human activities can very likely explain most of that warming. [1]



Hegerl *et al.*49

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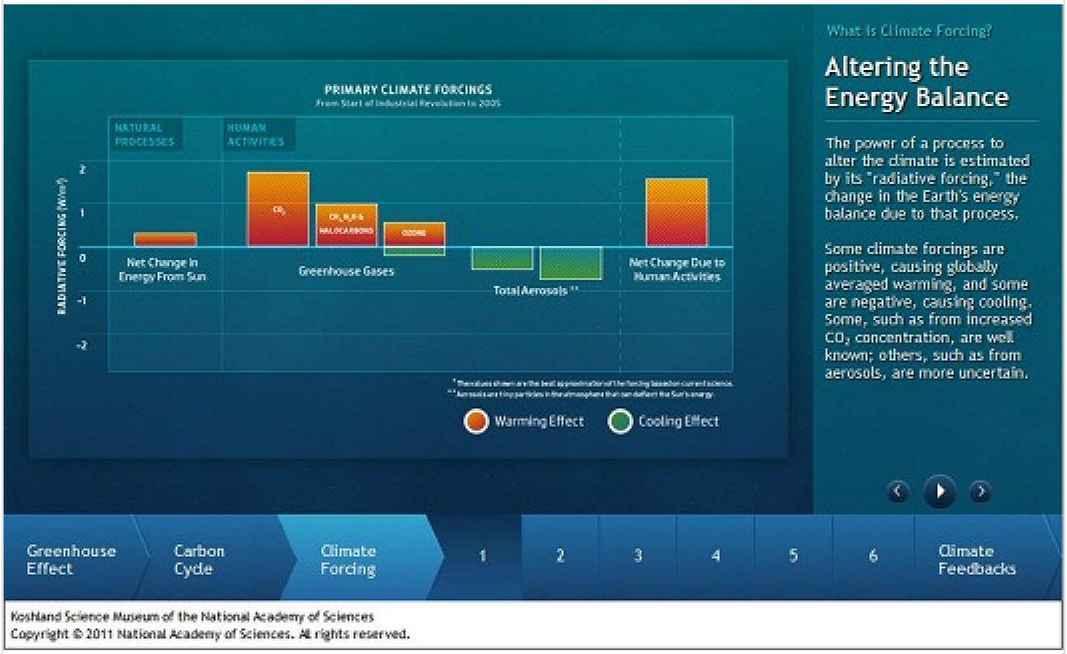
Models that account only for the effects of natural processes are not able to explain the warming over the past century. Models that also account for the greenhouse gases emitted by humans are able to explain this warming.
Source: USGRCP (2009)



Altering the Energy Balance

The power of a process to alter the climate is estimated by its "radiative forcing," the change in the Earth's energy balance due to that process.

Some climate forcings are positive, causing globally averaged warming, and some are negative, causing cooling. Some, such as from increased CO_2 concentration, are well known; others, such as from aerosols, are more uncertain.

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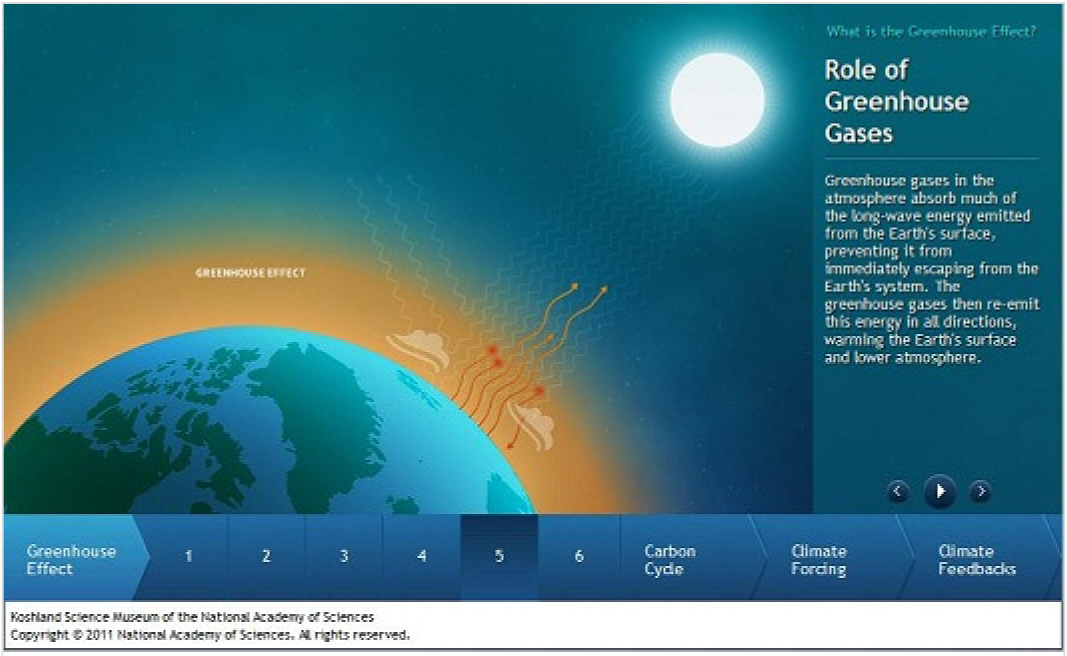
Click on the image to open a lightbox that explains radiative forcing. The discussion includes both natural and human-induced climate forcings.

The Greenhouse Effect causes the atmosphere to retain heat

When sunlight reaches Earth's surface, it can either be reflected back into space or absorbed by Earth. Once absorbed, the planet releases some of the energy back into the atmosphere as heat (also called infrared radiation). Greenhouse gases (GHGs) like water vapor (H2O), carbon dioxide (CO_2), and methane (CH_4) absorb energy, slowing or preventing the loss of heat to space. In this way, GHGs act like a blanket, making Earth warmer than it would otherwise be. This process is commonly known as the "greenhouse effect".



What is the Greenhouse Effect?

Role of Greenhouse Gases

Greenhouse gases in the atmosphere absorb much of the long-wave energy emitted from the Earth's surface, preventing it from immediately escaping from the Earth's system. The greenhouse gases then re-emit this energy in all directions, warming the Earth's surface and lower atmosphere.

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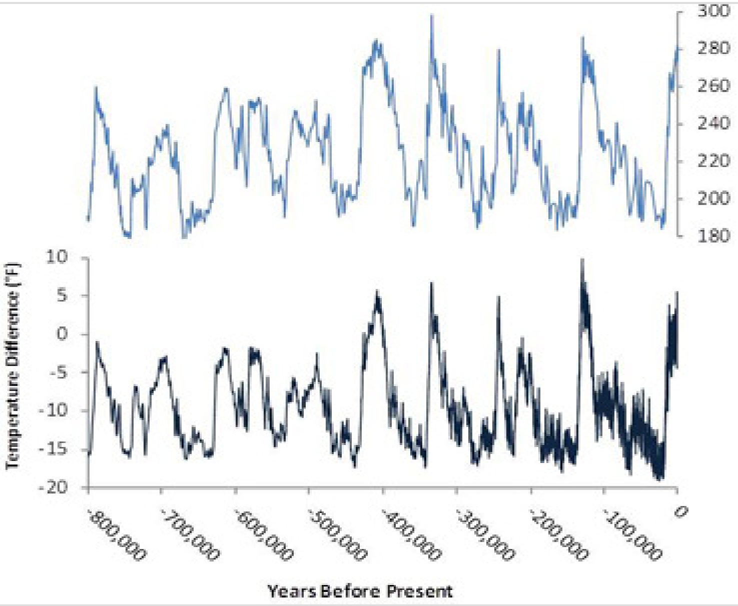
This slideshow explains the Greenhouse Effect, among other topics.

The Role of the Greenhouse Effect in the Past

In the distant past (prior to about 10,000 years ago), CO_2 levels tended to track the glacial cycles. During warm 'interglacial' periods, CO_2 levels have been higher. During cool 'glacial' periods, CO_2 levels have been lower. [1] [2] This is because the heating or cooling of Earth's surface can cause changes in greenhouse gas concentrations. [1] These changes often act as a positive feedback, amplifying existing temperature changes. [1]



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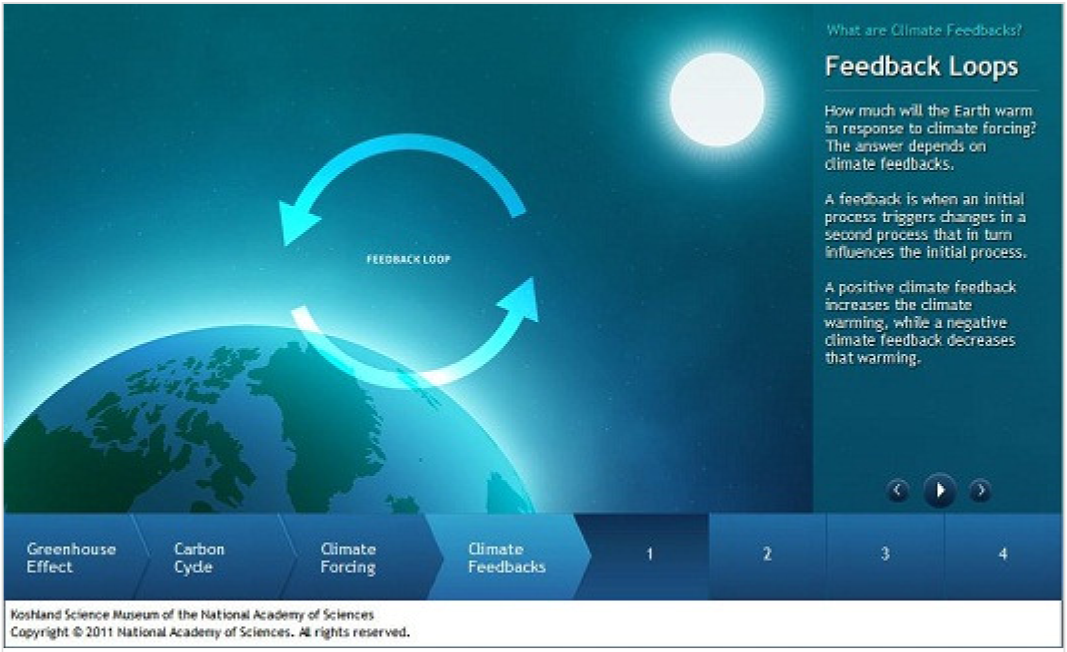
Estimates of the Earth's changing carbon dioxide concentration (top) and Antarctic temperature (bo based on analysis of ice core data extending bac 800,000 years. Until the past century, natural fac caused atmospheric CO_2 concentrations to vary range of about 180 to 300 parts per million by vol (ppmv). Warmer periods coincide with periods of high CO_2 concentrations. NOTE: The past centur temperature changes and rapid CO_2 rise (to 390 2010) are not shown here. Increases over the pa century are shown in the Recent Role section Source: Based on data appearing in NRC (2010)



What are Climate Feedbacks?

Feedback Loops

How much will the Earth warm in response to climate forcing? The answer depends on climate feedbacks.

A feedback is when an initial process triggers changes in a second process that in turn influences the initial process.

A positive climate feedback increases the climate warming, while a negative climate feedback decreases that warming.

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Click on the image to open a lightbox that explains radiative forcing.

The Recent Role of the Greenhouse Effect

Since the Industrial Revolution began around 1750, human activities have contributed substantially to climate change by adding CO_2 and other heat-trapping gases to the atmosphere. These greenhouse gas emissions have increased the greenhouse effect and caused Earth's surface temperature to rise. The primary human activity affecting the amount and rate of climate change is greenhouse gas emissions from the burning of fossil fuels.

The Main Greenhouse Gases

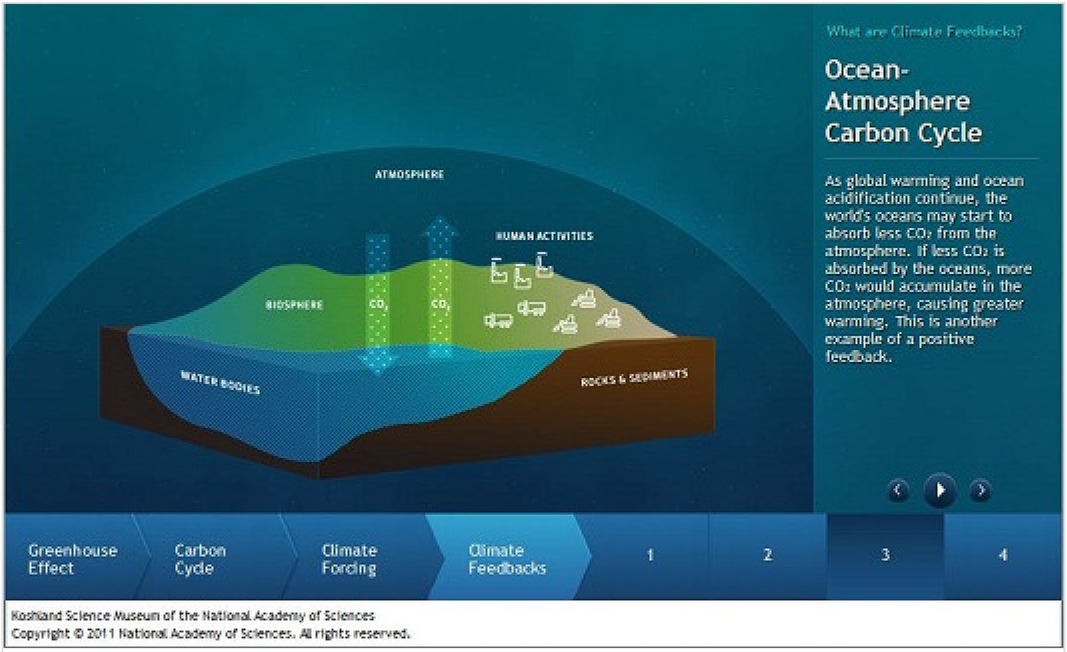
The most important GHGs directly emitted by humans include CO_2, CH_4, nitrous oxide (N_2O), and several others. The sources and recent trends of these gases are detailed below.

Related Links:

- NRC America's Climate Choices Reports EXIT Disclaimer
- IPCC Fourth Assessment Report EXIT Disclaimer
- USGCRP *Global Climate Change Impacts in the United States*
- NRC *Abrupt Climate Change: Inevitable Surprises* EXIT Disclaimer
- UNEP/WMO *Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decision Makers* EXIT Disclaimer

Carbon dioxide

Carbon dioxide is the primary greenhouse gas that is contributing to recent climate change. CO_2 is absorbed and emitted naturally as part of the carbon cycle, through animal and plant respiration, volcanic eruptions, and ocean-atmosphere exchange. Human activities, such as the burning of fossil fuels and changes in land use, release large amounts of carbon to the atmosphere, causing CO_2 concentrations in the atmosphere to rise.



What are Climate Feedbacks?

Ocean-Atmosphere Carbon Cycle

As global warming and ocean acidification continue, the world's oceans may start to absorb less CO_2 from the atmosphere. If less CO_2 is absorbed by the oceans, more CO_2 would accumulate in the atmosphere, causing greater warming. This is another example of a positive feedback.

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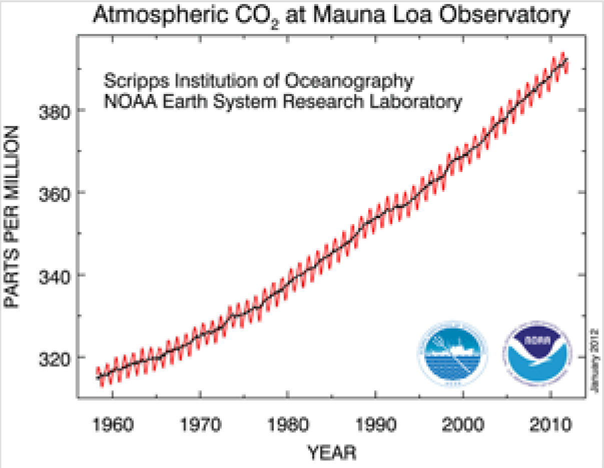
This slideshow describes the carbon cycle, among other topics. {Click to play.}



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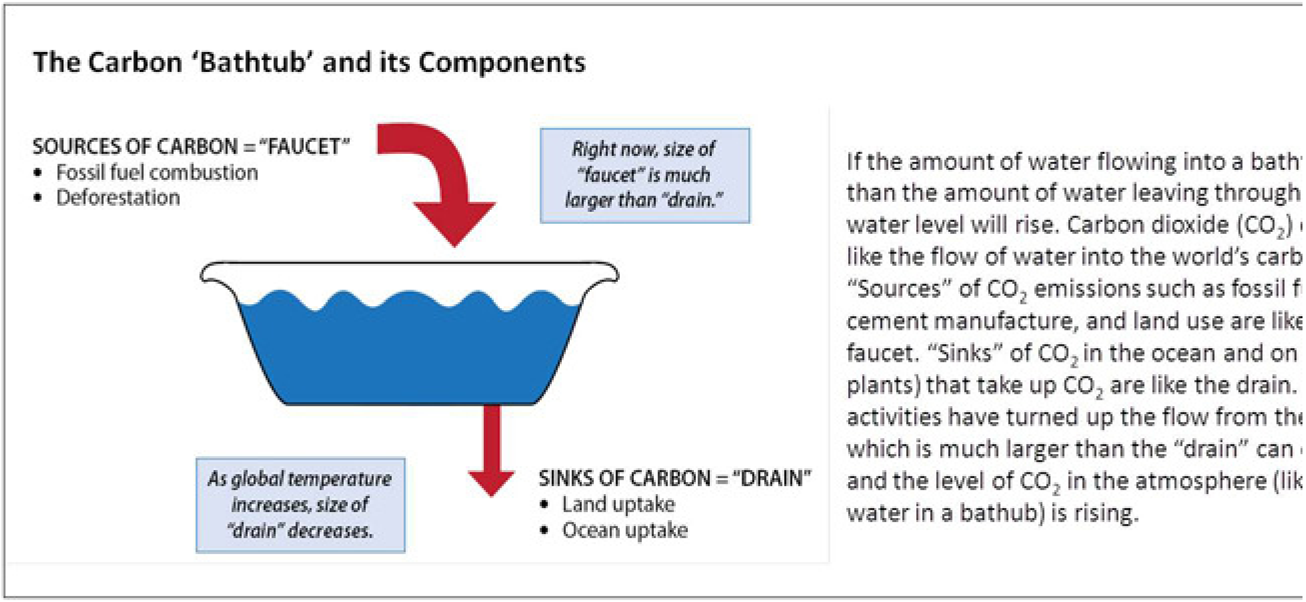
Carbon dioxide concentration has risen from pre-industrial levels of 280 parts per million by volume (ppmv) to about 390 ppmv in 2010. Since 1958 alone (shown here), concentrations have risen by 75 ppmv. Source: NOAA

Atmospheric CO_2 concentrations have increased by almost 40% since pre-industrial times, from approximately 280 parts per million by volume (ppmv) in the 18th century to 390 ppmv in 2010. The current CO_2 level is higher than it has been in at least 800,000 years.[1]

Some volcanic eruptions released large quantities of CO_2 in the distant past. However, the U.S. Geological Survey (USGS) reports that human activities now emit more than 135 times as much CO_2 as volcanoes each year.

Human activities currently release over 30 billion tons of CO_2 into the atmosphere every year.[1] This build-up in the atmosphere is like a tub filling with water, where more water flows from the faucet than the drain can take away.



The Carbon ‘Bathtub’ and its Components

SOURCES OF CARBON = “FAUCET”
- Fossil fuel combustion
- Deforestation

Right now, size of “faucet” is much larger than “drain.”

As global temperature increases, size of “drain” decreases.

SINKS OF CARBON = “DRAIN”
- Land uptake
- Ocean uptake

If the amount of water flowing into a bath
than the amount of water leaving through
water level will rise. Carbon dioxide (CO_2)
like the flow of water into the world’s carb
“Sources” of CO_2 emissions such as fossil f
cement manufacture, and land use are like
faucet. “Sinks” of CO_2 in the ocean and on
plants) that take up CO_2 are like the drain.
activities have turned up the flow from th
which is much larger than the “drain” can
and the level of CO_2 in the atmosphere (lik
water in a bathub) is rising.

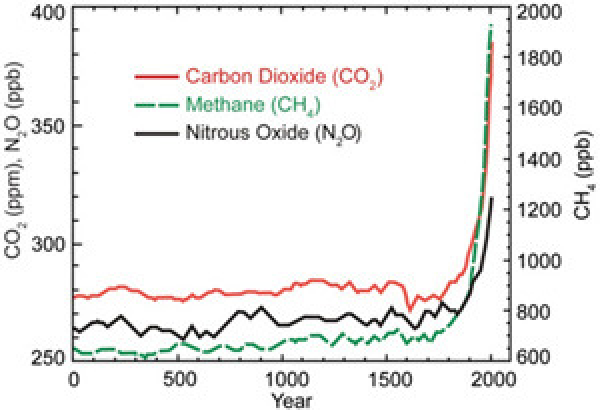
For more information on the human and natural sources and sinks of CO2 emissions, see the Carbon Dioxide page in the Greenhouse Gas Emissions section of the website.

Methane

Methane is produced through both natural and human activities. For example, natural wetlands, agricultural activities, and fossil fuel extraction and transport all emit CH4.

Methane is more abundant in Earth’s atmosphere now than at any time in at least the past 650,000 years. [2] Due to human activities, CH4 concentrations increased sharply during most of the 20th century and are now more than two-and-a-half times pre-industrial levels. In recent decades, the rate of increase has slowed considerably. [1]

For more information on CH4 emissions and sources, and actions that can reduce emissions, see EPA’s Methane page in the Greenhouse Gas Emissions section of the website.



View enlarged image

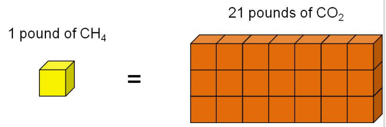
This graph shows the increase in greenhouse gas (GHG) concentrations in the atmosphere over the last 2,000 years. Increases in concentrations of these gases since 1750 are due to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion molecules of air.
Source: USGCRP (2009)

Nitrous oxide

Nitrous oxide is produced through natural and human activities, mainly through agricultural activities and natural biological processes. Fuel burning and some other processes also create N2O. Concentrations of N2O have risen approximately 18% since the start of the Industrial Revolution, with a relatively rapid increase towards the end of the 20th century. [3] In contrast, the atmospheric concentration of N2O varied only slightly for a period of 11,500 years before the onset of the industrial period, as shown by ice core samples. [3] For more information on N2O emissions and sources, and actions that can reduce emissions, see EPA’s Nitrous Oxide page in the Emissions section of the website.

Other Greenhouse Gases

Click on the image to open a lightbox that explains how global warming potentials describe the impact of each gas.



- Water vapor is the most abundant greenhouse gas and also the most important in terms of its contribution to the natural greenhouse effect, despite having a short atmospheric lifetime. Some human activities can influence local water vapor levels. However, on a global scale, the concentration of water vapor is controlled by temperature, which influences overall rates of evaporation and precipitation. [1] Therefore, the global concentration of water vapor is not substantially affected by direct human emissions.
- Tropospheric ozone (O3), which also has a short atmospheric lifetime, is a potent greenhouse gas. Chemical reactions create ozone from emissions of nitrogen oxides and volatile organic compounds from automobiles, power plants, and other industrial and commercial sources in the presence of sunlight. In addition to trapping heat, ozone is a pollutant that can cause respiratory health problems and damage crops and ecosystems.
- Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6), together called F-gases, are often used in coolants, foaming agents, fire extinguishers, solvents, pesticides, and aerosol propellants. Unlike water vapor and ozone, these F-gases have a long atmospheric lifetime, and some of these emissions will affect the climate for many decades or centuries.

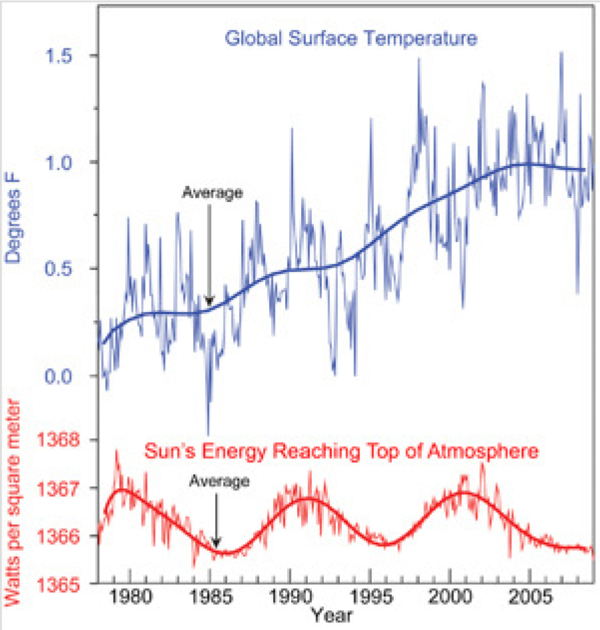
For more information on greenhouse gas emissions, see the Greenhouse Gas Emissions section. To learn more about actions that can reduce these emissions, see the What You Can Do section.

Changes in the sun's energy affect how much energy reaches Earth's system

Climate is influenced by natural changes that affect how much solar energy reaches Earth. These changes include changes within the sun and changes in Earth's orbit.

Changes occurring in the sun itself can affect the intensity of the sunlight that reaches Earth's surface. The intensity of the sunlight can cause either warming (during periods of stronger solar intensity) or cooling (during periods of weaker solar intensity). The sun follows a natural 11-year cycle of small ups and downs in intensity, but the effect on Earth's climate is small. [1] [5]

Changes in the shape of Earth's orbit as well as the tilt and position of Earth's axis can also affect the amount of sunlight reaching Earth's surface. [1] [2]



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The sun's energy received at the top of Earth's atmosphere has been measured by satellites since 1978. It has followed its natural 11-year cycle of small ups and downs, but with no net increase (bottom). Over the same period, global temperature has risen markedly (top).
Source: USGCRP (2009)

The Role of the Sun's Energy in the Past

Changes in the sun's intensity have influenced Earth's climate in the past. For example, the so-called "Little Ice Age" between the 17th and 19th centuries may have been partially caused by a low solar activity phase from 1645 to 1715, which coincided with cooler temperatures. The "Little

Ice Age" refers to a slight cooling of North America, Europe, and probably other areas around the globe. [1] [2]

Changes in Earth's orbit have had a big impact on climate over tens of thousands of years. In fact, the amount of summer sunshine on the Northern Hemisphere, which is affected by changes in the planet's orbit, appears to control the advance and retreat of ice sheets. These changes appear to be the primary cause of past cycles of ice ages, in which Earth has experienced long periods of cold temperatures (ice ages), as well as shorter interglacial periods (periods between ice ages) of relatively warmer temperatures. [1] [2]

Click on the image to open a lightbox that explains how rates of climate change have varied over time.

The Recent Role of the Sun's Energy

Changes in solar energy continue to affect climate. However, solar activity has been relatively constant, aside from the 11-year cycle, since the mid-20th century and therefore does not explain the recent warming of Earth. Similarly, changes in the shape of Earth's orbit as well as the tilt and position of Earth's axis affect temperature on relatively long timescales (tens of thousands of years), and therefore cannot explain the recent warming.

Changes in reflectivity affect how much energy enters Earth's system

When sunlight reaches Earth, it can be reflected or absorbed. The amount that is reflected or absorbed depends on Earth's surface and atmosphere. Light-colored objects and surfaces, like snow and clouds, tend to reflect most sunlight, while darker objects and surfaces, like the ocean, forests, or soil, tend to absorb more sunlight.

The term albedo refers to the amount of solar radiation reflected from an object or surface, often expressed as a percentage. Earth as a whole has an albedo of about 30%, meaning that 70% of the sunlight that reaches the planet is absorbed. [1] Absorbed sunlight warms Earth's land, water, and atmosphere.

Reflectivity is also affected by aerosols. Aerosols are small particles or liquid droplets in the atmosphere that can absorb or reflect sunlight. Unlike greenhouse gases (GHGs), the climate effects of aerosols vary depending on what they are made of and where they are emitted. Those aerosols that reflect sunlight, such as particles from volcanic eruptions or sulfur emissions from burning coal, have a cooling effect. Those that absorb sunlight, such as black carbon (a part of soot), have a warming effect.

The Role of Reflectivity in the Past

Natural changes in reflectivity, like the melting of sea ice or increases in cloud cover, have contributed to climate change in the past, often acting as feedbacks to other processes.

Volcanoes have played a noticeable role in climate. Volcanic particles that reach the upper atmosphere can reflect enough sunlight back to space to cool the surface of the planet by a few tenths of a degree for several years. [1] These particles are an example of cooling aerosols. Volcanic particles from a single eruption do not produce long-term change because they remain in the atmosphere for a much shorter time than GHGs. [1] [7]

The Recent Role of Reflectivity

Human changes in land use and land cover have changed Earth's reflectivity. Processes such as deforestation, reforestation, desertification, and urbanization often contribute to changes in climate in the places they occur. These effects may be significant regionally, but are smaller when averaged over the entire globe.

In addition, human activities have generally increased the number of aerosol particles in the atmosphere. Overall, human-generated aerosols have a net cooling effect offsetting about one-third of the total warming effect associated with human greenhouse gas emissions. Reductions in overall aerosol emissions can therefore lead to more warming. However, targeted reductions in black carbon emissions can reduce warming. [1] [8]

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WCMS
Last updated on Monday, June 04, 2012

National Aeronautics and Space Administration
Goddard Institute for Space Studies

GISS Surface Temperature Analysis

Global Temperature Trends: 2008 Annual Summation

Originally posted Dec. 16, 2008, with meteorological year data. Updated Jan. 13, 2009, with calendar year data.

Calendar year 2008 was the coolest year since 2000, according to the Goddard Institute for Space Studies analysis [see ref. 1] of surface air temperature measurements. In our analysis, 2008 is the ninth warmest year in the period of instrumental measurements, which extends back to 1880 (left panel of Fig. 1). The ten warmest years all occur within the 12-year period 1997-2008. The two-standard-deviation (95% confidence) uncertainty in comparing recent years is estimated as 0.05℃ [ref. 2], so we can only conclude with confidence that 2008 was somewhere within the range from 7th to 10th warmest year in the record.

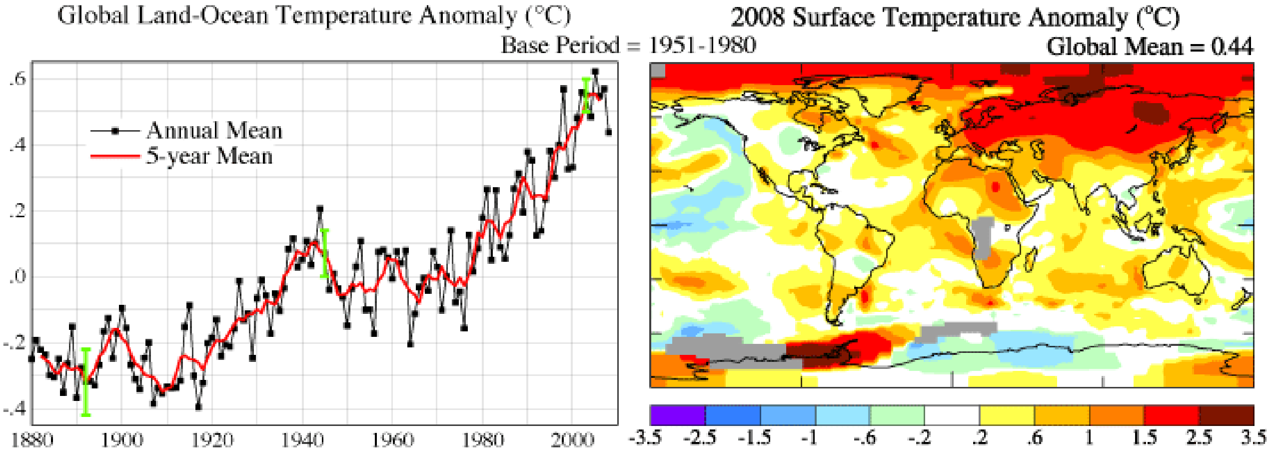


Figure 1 above. Left: Annual-means of global-mean temperature anomaly **Right:** Global map of surface temperature anomalies, in degrees Celsius, for 2008. (Click for PDF.)

The map of global temperature anomalies in 2008 (right panel of Fig. 1), shows that most of the world was either near normal or warmer than in the base period (1951-1980). Eurasia, the Arctic and the Antarctic Peninsula were exceptionally warm, while much of the Pacific Ocean was cooler than the long-term average. The relatively low temperature in the tropical Pacific was due to a strong La Niña that existed in the first half of the year. La Niña and El Niño are opposite phases of a natural oscillation of tropical temperatures, La Niña being the cool phase.

Figure 2, at right. Top: Seasonal-mean global and low latitude temperature anomalies relative to the 1951-1980 base period. (Click for large GIF or PDF.) **Bottom:** Monthly-mean global-ocean surface temperature anomaly, based on satellite temperature analyses of Reynolds and Smith (ref. 4). (Click for large GIF or PDF.)

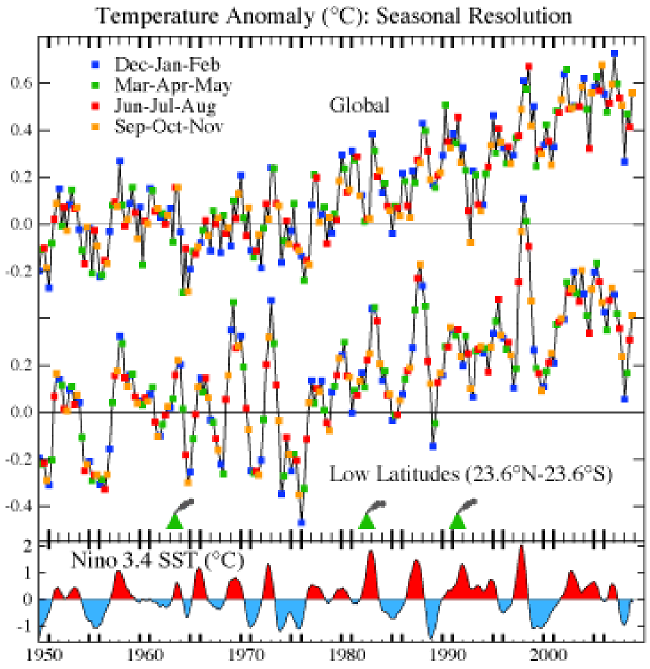
The top of Fig. 2 provides seasonal resolution of global and low latitude surface temperature, and an index that measures the state of the natural tropical temperature oscillation. The figure indicates that the La Niña cool cycle peaked in early 2008. The global effect of the tropical oscillation is made clear by the average temperature anomaly over the global ocean (bottom of Fig. 2). The "El Niño of the century", in 1997-98, stands out, as well as the recent La Niña.

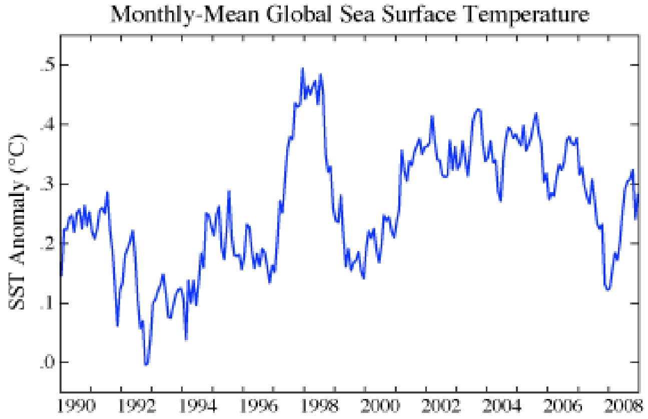
Figure 3 compares 2008 with the mean for the first seven years of this century. Except for the relatively cool Pacific Ocean, most of the world was either near normal or unusually warm in 2008. The temperature in the United States in 2008 was not much different than the 1951-1980 mean, which makes 2008 cooler than all of the previous years this decade. As shown by the right side of Fig. 3, most of the United States averaged between 0.5 and 1℃ warmer than the long-term mean during 2001-2007.

The GISS analysis of global surface temperature, documented in the scientific literature [refs. 1 and 2], incorporates data from three data bases made available monthly: (1) the Global Historical Climatology Network (GHCN) of the National Climate Data Center [ref. 3], (2) the satellite analysis of global sea surface temperature of Reynolds and Smith [ref. 4], and (3) Antarctic records of the Scientific Committee on Antarctic Research (SCAR) [ref. 5].

In the past our procedure has been to run the analysis program upon receipt of all three data sets and make the analysis publicly available immediately. This procedure worked very well from a scientific perspective, with the broad availability of the analysis helping reveal any problems with input data sets. However, because confusion was generated in the media after one of the October 2008 input data sets was found to contain significant flaws (some October station records inadvertently repeated September data in the October data slot), we have instituted a new procedure. The GISS analysis is first made available internally before it is released publicly. If any suspect data are detected, they will be reported back to the data providers for resolution. This process may introduce significant delays. We apologize for any inconvenience due to this delay, but it should reduce the likelihood of instances of future confusion and misinformation.

Note that we provide the rank of global temperature for individual years because there is a high demand for it from journalists and the public. The rank has scientific significance in some cases, e.g., when a new record is established. However, otherwise rank has limited value and can be misleading. As opposed to the rank, Fig. 3 provides much more information about how the 2008 temperature compares with previous years, and why it was a bit cooler (again, note the change in the Pacific Ocean region).





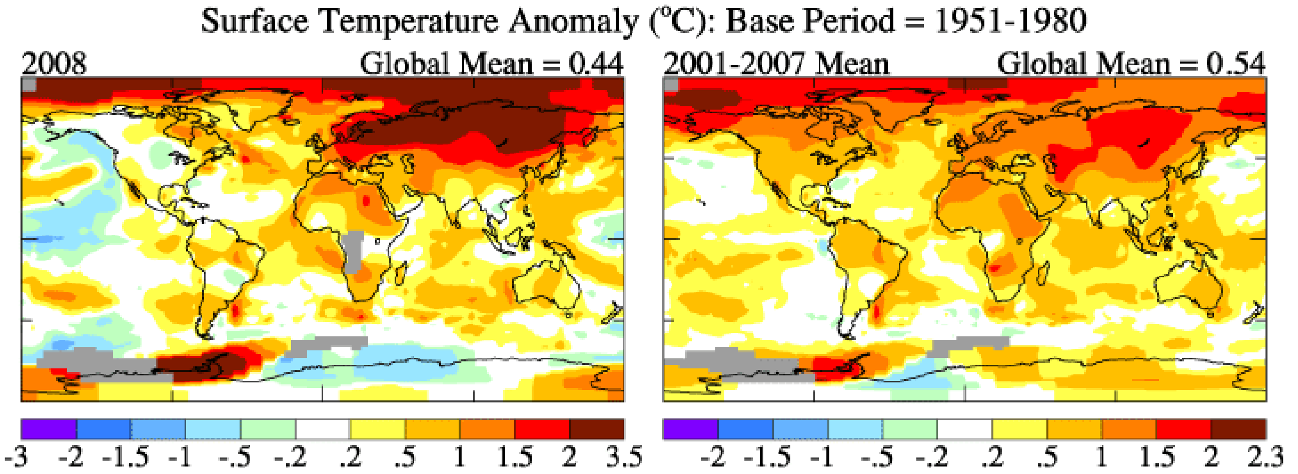


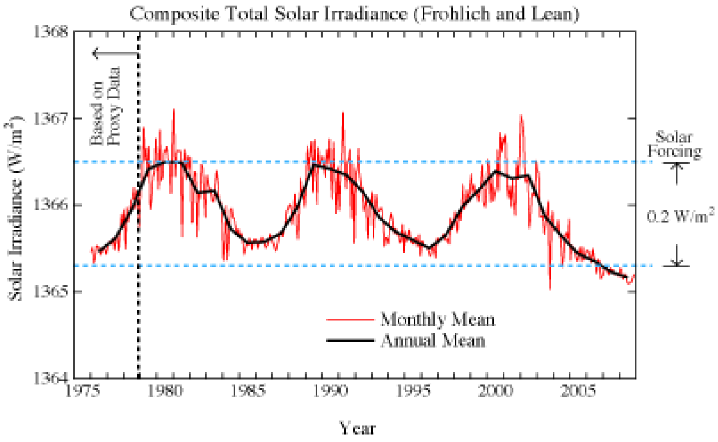
Figure 3 above. Comparison of 2008 (left) temperature anomalies with the mean 2001-2007 (right) anomalies. Notice that a somewhat different color bar has been used than in Figure 1 to show more structure in the right-hand map). (Click for PDF.)

Finally, in response to popular demand, we comment on the likelihood of a near-term global temperature record. Specifically, the question has been asked whether the relatively cool 2008 alters the expectation we expressed in last year's summary that a new global record was likely within the next 2-3 years (now the next 1-2 years). Response to that query requires consideration of several factors:

Natural d[illegible]al variability: The largest contribution is the Southern Oscillation, the El Niño-La Niña cycle. The Niño 3.4 temperature anomal[illegible] line in th[illegible] top panel of Fi[illegible]. 2), suggests that the La Niña may be almost over, but the anomaly fell back (cooled) to -0.7°C [illegible]ecember. It is [illegible] [illegible]opical cycle could dip back into a strong La Niña, as happened, e.g., in 1975. Howeve[illegible] [illegible]opical Pacific to stay in that mode for both 2009 and 2010 would require a longer La Niña phase than has existed in the past half ce[illegible]y, so it is unlikel[illegible]. Indeed, subsurface and surface tropical ocean temperatures suggest that the system is "recharged", i.e., poised, for the next El Niño, so there is a good chance that one may occur in 2009. Global temperature anomalies tend to lag tropical anomalies by 3-6 months.

Solar irradiance: The solar output remains low (Fig. 4), at the lowest level in the period since satellite measurements began in the late 1970s, and the time since the prior solar minimum is already 12 years, two years longer than the prior two cycles. This has led some people to speculate that we may be entering a "Maunder Minimum" situation, a period of reduced irradiance that could last for decades. Most solar physicists expect the irradiance to begin to pick up in the next several months — there are indications, from the polarity of the few recent sunspots, that the new cycle is beginning.

Figure 4, at right. Solar irradiance through November 2008 from Frohlich and Lean [ref. 8]. (Click for large GIF or PDF.)



However, let's assume that the solar irradiance does not recover. In that case, the negative forcing, relative to the mean solar irradiance is equivalent to seven years of CO_2 increase at current growth rates. So do not look for a new "Little Ice Age" in any case. Assuming that the solar irradiance begins to recover this year, as expected, there is still some effect on the likelihood of a near-term global temperature record due to the unusually prolonged solar minimum. Because of the large thermal inertia of the ocean, the surface temperature response to the 10-12 year solar cycle lags the irradiance variation by 1-2 years. Thus, relative to the mean, i.e, the hypothetical case in which the sun had a constant average irradiance, actual solar irradiance will continue to provide a negative anomaly for the next 2-3 years.

Volcanic aerosols: Colorful sunsets the past several months suggest a non-negligible stratospheric aerosol amount at northern latitudes. Unfortunately, as noted in the 2008 Bjerknes Lecture [ref. 9], the instrument capable of precise measurements of aerosol optical depth depth (SAGE, the Stratospheric Aerosol and Gas Experiment) is sitting on a shelf at Langley Research Center. Stratospheric aerosol amounts are estimated from crude measurements to be moderate. The aerosols from an Aleutian volcano, which is thought to be the primary source, are at relatively low altitude and high latitudes, where they should be mostly flushed out this winter. Their effect in the next two years should be negligible.

Greenhouse gases: Annual growth rate of climate forcing by long-lived greenhouse gases (GHGs) slowed from a peak close to 0.05 W/m^2 per year around 1980-85 to about 0.035 W/m^2 in recent years due to slowdown of CH_4 and CFC growth rates [ref. 6]. Resumed methane growth, if it continued in 2008 as in 2007, adds about 0.005 W/m^2. From climate models and empirical analyses, this GHG forcing trend translates into a mean warming rate of ~0.15°C per decade.

Summary: The Southern Oscillation and increasing GHGs continue to be, respectively, the dominant factors affecting interannual and decadal temperature change. Solar irradiance has a non-negligible effect on global temperature [see, e.g., ref. 7, which empirically estimates a somewhat larger solar cycle effect than that estimated by others who have teased a solar effect out of data with different methods]. Given our expectation of the next El Niño beginning in 2009 or 2010, it still seems likely that a new global temperature record will be set within the next 1-2 years, despite the moderate negative effect of the reduced solar irradiance.

Further Information

GISS Surface Temperature Analysis (GISTEMP)

Past global temperature annual summations: 2007, 2005, 2004, 2003, 2002, and 2001.

Related NASA news releases: 2008, 2007, 2006, 2005, and 2004.

Other related 2008 news releases: NOAA, WMO, and Hadley Center.

Note: There was no summation written for 2006; see NASA news release for that year instead.

References

1. Hansen, J., R. Ruedy, J. Glascoe, and Mki. Sato, 1999: GISS analysis of surface temperature change. *J. Geophys. Res.*, **104**, 30997-31022, doi:10.1029/1999JD900835.

2. Hansen, J., M. Sato, R. Ruedy, K. Lo, D.W. Lea, and M. Medina-Elizade, 2006: Global temperature change. *Proc. Natl. Acad. Sci.*, **103**, 14288-14293, doi:doi:10.1073/pnas.0606291103.

3. Peterson, T.C., and R.S. Vose, 1997: An overview of the Global Historical Climatology Network temperature database. *Bull. Amer. Meteorol. Soc.* **78**, 2837-2849.

3. Reynolds, R.W., and T.M. Smith, 1994: Improved global sea surface temperature analyses. *J. Climate* **7**, 929-948.

5. Scientific Committee on Antarctic Research (SCAR), www.scar.org.

6. Hansen, J., and M. Sato, 2004: Greenhouse gas growth rates. *Proc. Natl. Acad. Sci.*, **101**, 16109-16114, doi:doi:10.1073/pnas.0406982101

7. Tung, K.K., J. Zhou, and C.D. Camp, 2008. Constraining model transient climate response using independent observations of solar-cycle forcing and response. Geophys. Res. Lett., **35**, L17707, doi:10.1029/2008GL034240.

8. Frohlich, C., and J. Lean, 2004. Solar radiative output and its variability: Evidence and mechanisms. *Astron. Astrophys. Rev.*, **12**, 273-320, doi:10.1007/s00159-004-0024-1.

9. Hansen, J.E., 2008: Climate Threat to the Planet: Implications for Energy Policy and Intergenerational Justice. Bjerknes Lecture presented at American Geophysical Union, San Francisco, on Dec. 17. Available at www.columbia.edu/~jeh1.

Contacts
Please address all inquiries regarding GISS surface temperature trends analysis to Dr. James E. Hansen.

Return to GISTEMP homepage

NASA Official: James E. Hansen
GISS Website Curator: Robert B. Schmunk

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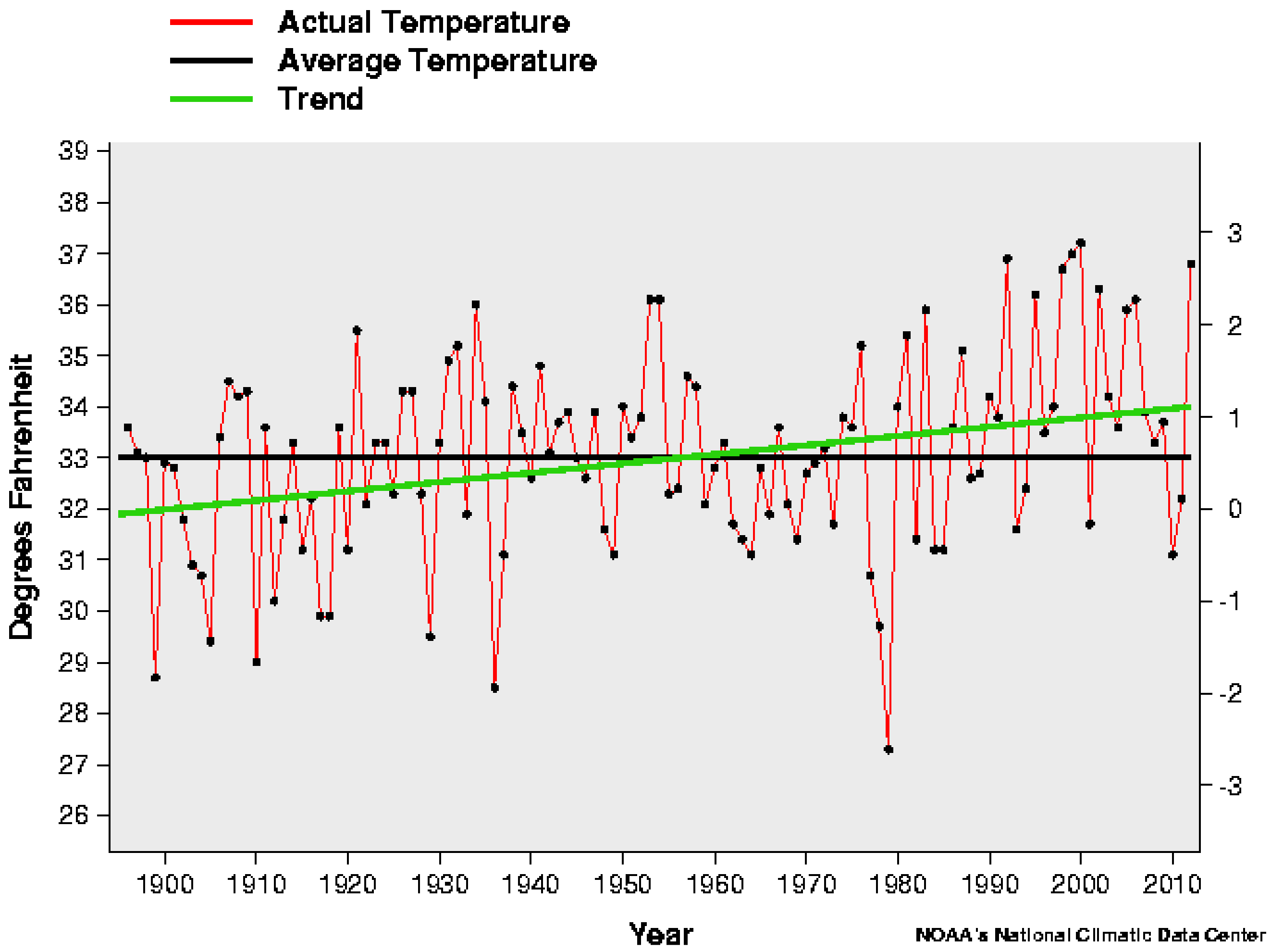
Winter (Dec-Feb) Temperature Contiguous United States

Some of the following data are preliminary and have not been quality controlled.
For official data, please contact the NCDC Climate Services and Monitoring Division at
ncdc.orders@noaa.gov.

Winter (Dec-Feb) 1895 - 2012 Data Values:

Winter (Dec-Feb) 2012: 36.83 degF Rank: 114

Winter (Dec-Feb) 1901 - 2000 Average = 32.97 degF
Winter (Dec-Feb) 1895 - 2012 Trend = 0.17 degF / Decade



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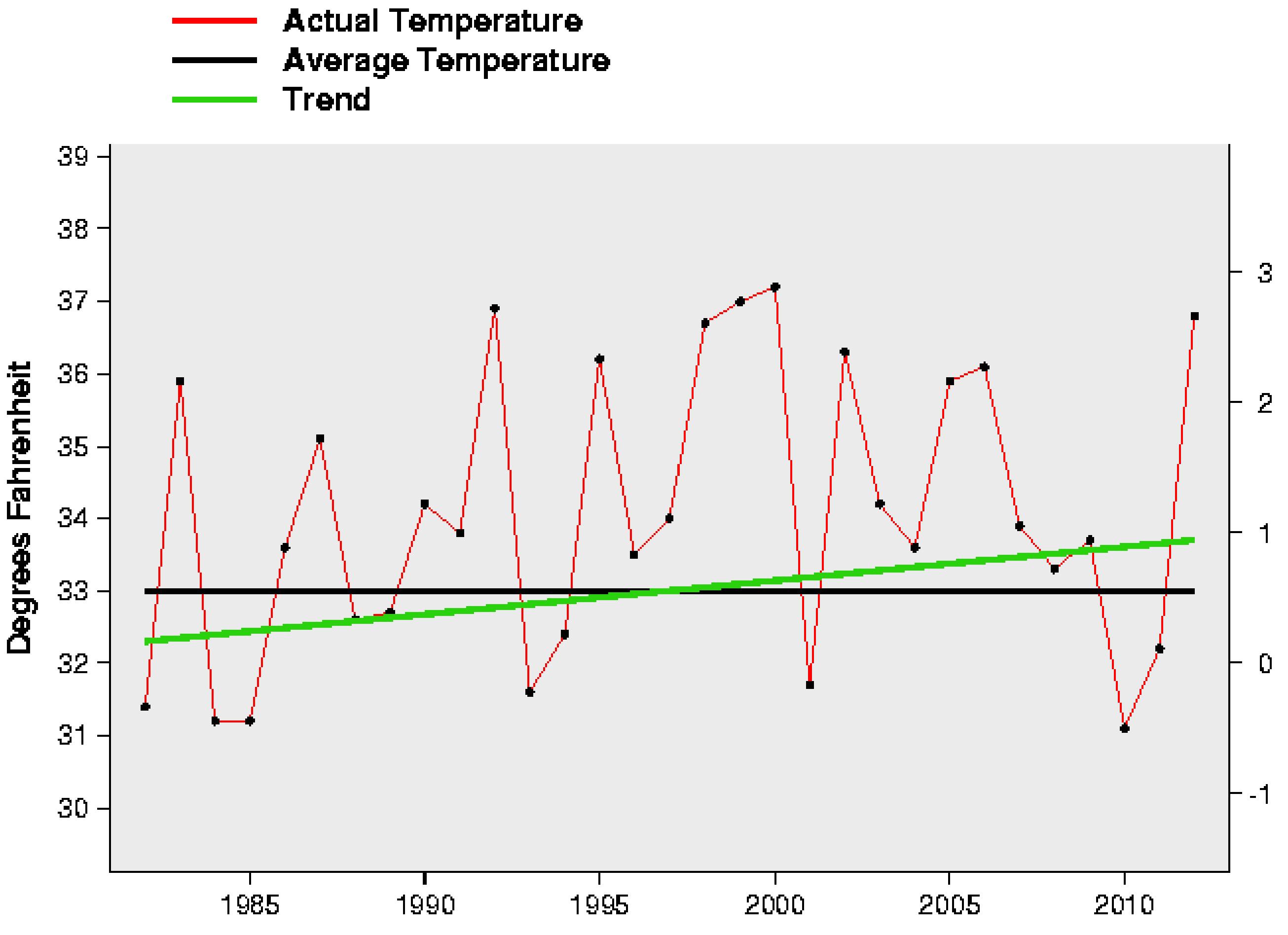
Winter (Dec-Feb) Temperature Contiguous United States

Some of the following data are preliminary and have not been quality controlled.
For official data, please contact the NCDC Climate Services and Monitoring Division at ncdc.orders@noaa.gov.

Winter (Dec-Feb) 1982 - 2012 Data Values:

Winter (Dec-Feb) 2012: 36.83 degF Rank: 28

Winter (Dec-Feb) 1901 - 2000 Average = 32.97 degF
Winter (Dec-Feb) 1982 - 2012 Trend = 0.46 degF / Decade



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Spring (Mar-May) Temperature Contiguous United States

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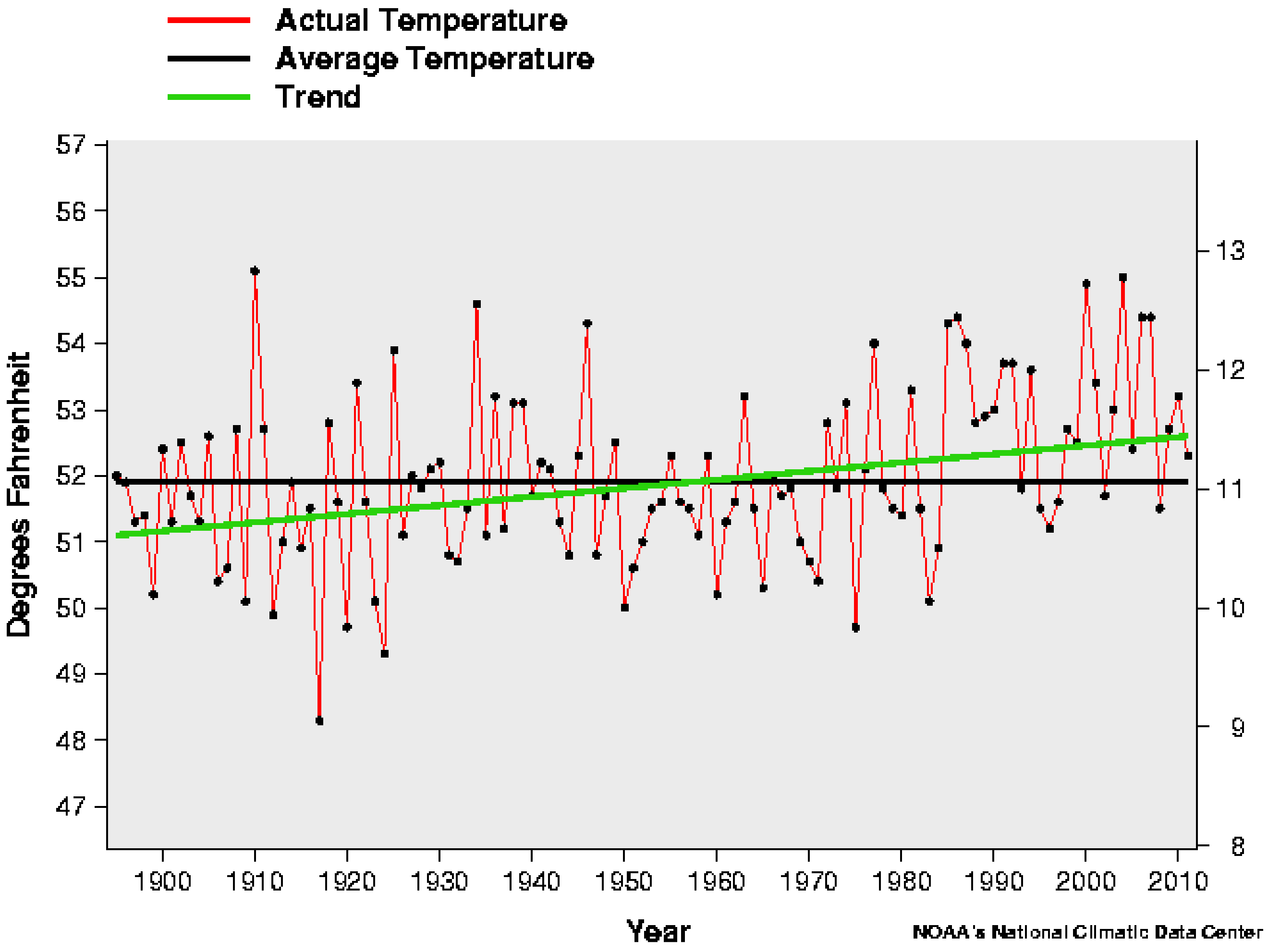
Spring (Mar-May) 1895 - 2011 Data Values:

Spring (Mar-May) 2011: 52.34 degF Rank: 76

Spring (Mar-May) 1901 - 2000 Average = 51.87 degF
Spring (Mar-May) 1895 - 2011 Trend = 0.13 degF / Decade



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Climate At A Glance

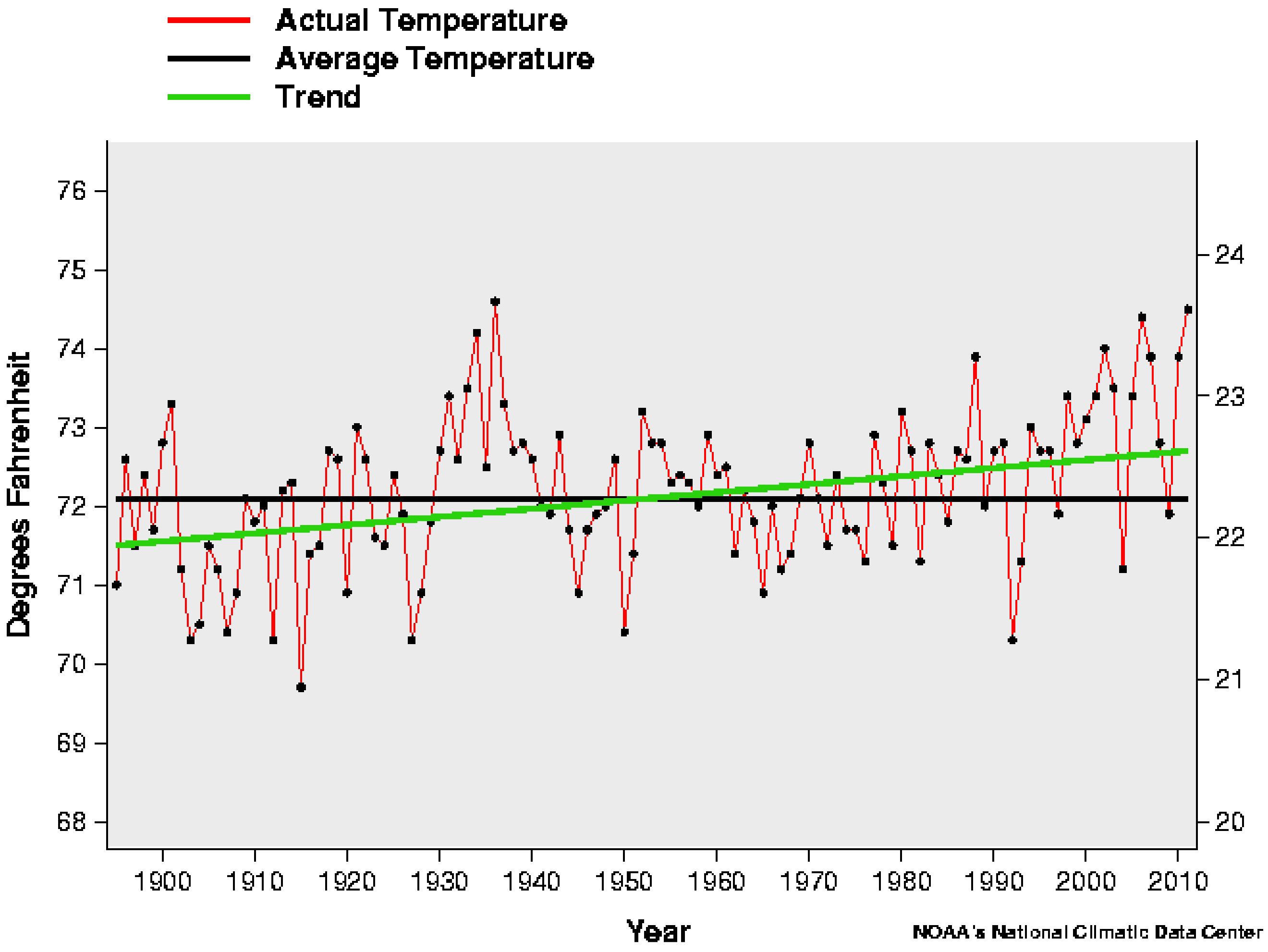
Summer (Jun-Aug) Temperature
Contiguous United States

Some of the following data are preliminary and have not been quality controlled.
For official data, please contact the NCDC Climate Services and Monitoring Division at ncdc.orders@noaa.gov.

Summer (Jun-Aug) 1895 - 2011 Data Values:

Summer (Jun-Aug) 2011: 74.49 degF	Rank: 116	🟦

Summer (Jun-Aug) 1901 - 2000 Average = 72.10 degF
Summer (Jun-Aug) 1895 - 2011 Trend = 0.11 degF / Decade



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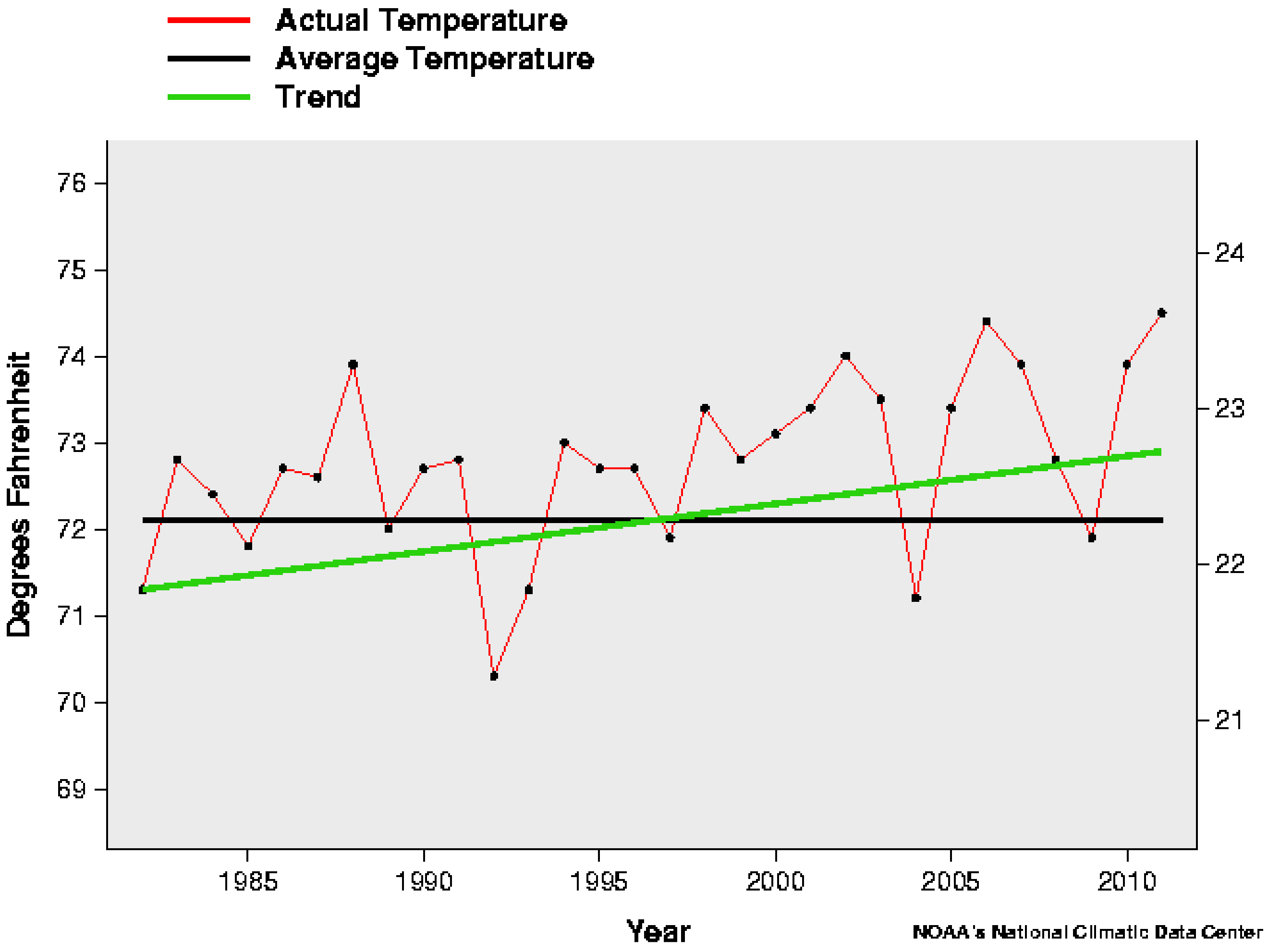
Summer (Jun-Aug) Temperature
Contiguous United States

Some of the following data are preliminary and have not been quality controlled.
For official data, please contact the NCDC Climate Services and Monitoring Division at
ncdc.orders@noaa.gov.

Summer (Jun-Aug) 1982 - 2011 Data Values:

Summer (Jun-Aug) 2011: 74.49 degF Rank: 30

Summer (Jun-Aug) 1901 - 2000 Average = 72.10 degF
Summer (Jun-Aug) 1982 - 2011 Trend = 0.52 degF / Decade



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Fall (Sep-Nov) Temperature
Contiguous United States

Some of the following data are preliminary and have not been quality controlled.
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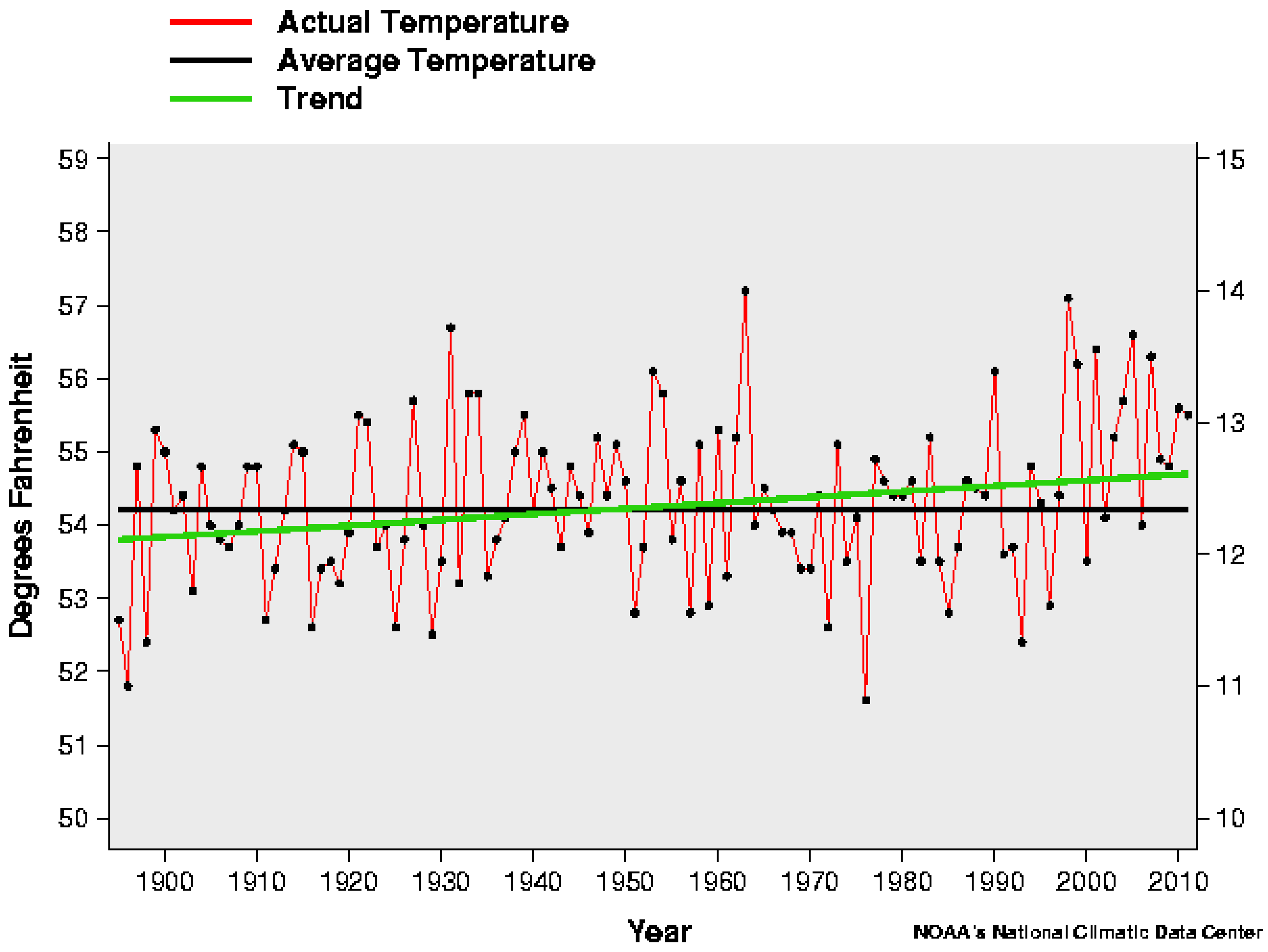
ncdc.orders@noaa.gov.

Fall (Sep-Nov) 1895 - 2011 Data Values:

Fall (Sep-Nov) 2011: 55.55 degF Rank: 102

Fall (Sep-Nov) 1901 - 2000 Average = 54.23 degF
Fall (Sep-Nov) 1895 - 2011 Trend = 0.08 degF / Decade



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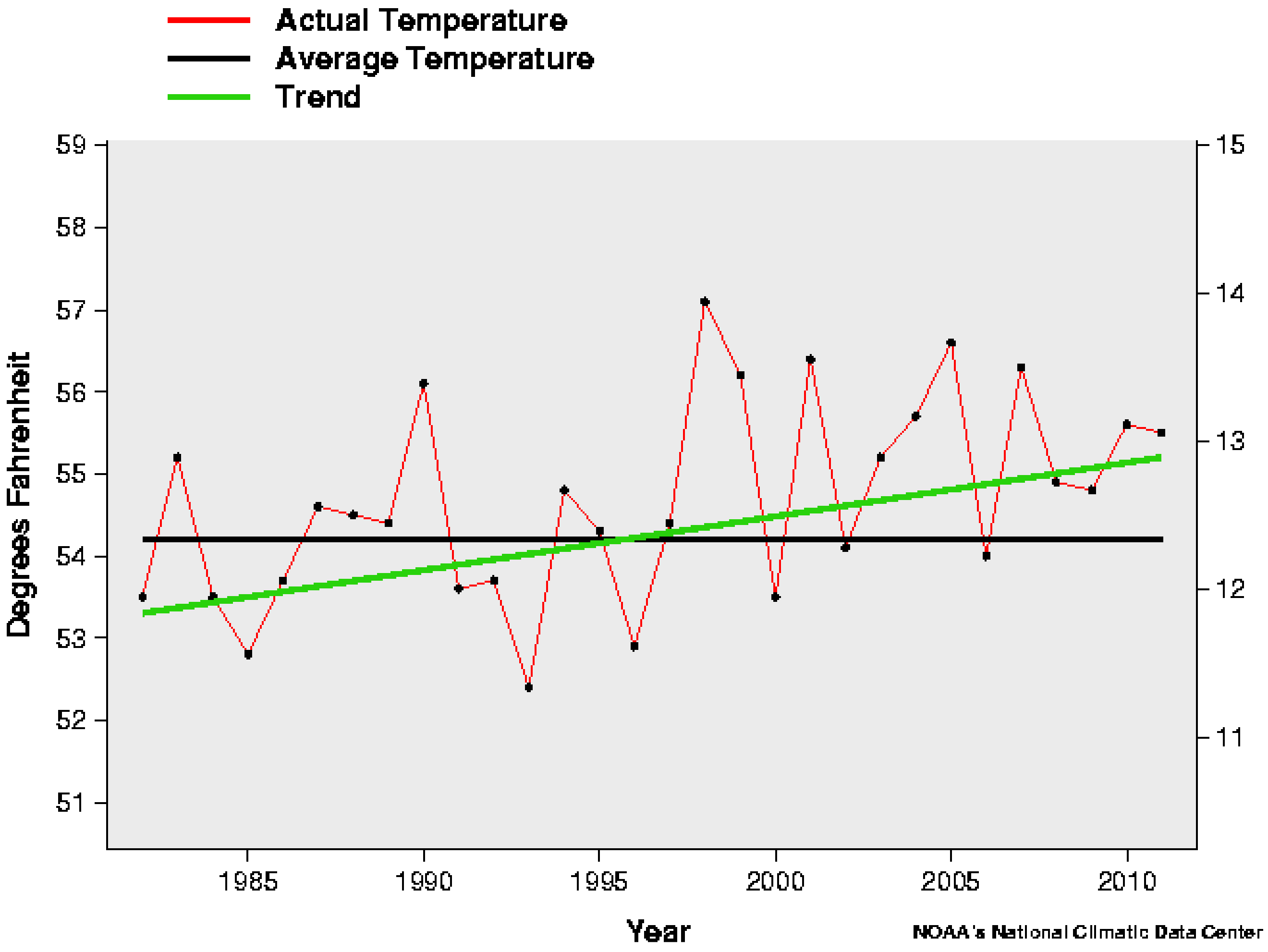
Fall (Sep-Nov) Temperature
Contiguous United States

Some of the following data are preliminary and have not been quality controlled.
For official data, please contact the NCDC Climate Services and Monitoring Division at ncdc.orders@noaa.gov.

Fall (Sep-Nov) 1982 - 2011 Data Values:

Fall (Sep-Nov) 2011: 55.55 degF Rank: 22

Fall (Sep-Nov) 1901 - 2000 Average = 54.23 degF
Fall (Sep-Nov) 1982 - 2011 Trend = 0.65 degF / Decade



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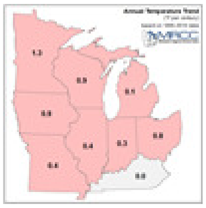
Climate Change & Variability in the Midwest

The climate of the Midwest has changed over time since the beginning records in 1895. Presented here are maps of the state average annu temperature and precipitation trends between 1895 and 2010. Tempe shown in degrees Fahrenheit change per century, and precipitation tr as inches of precipitation change per century. The monthly state aver calculate the trends came from the National Climatic Data Center. Clic see a larger version of the image.

Temperature Trends, 1895-2010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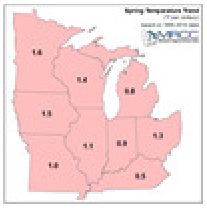
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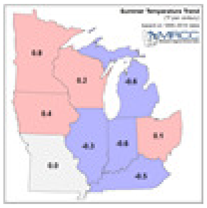
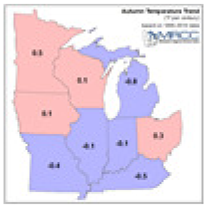

Summer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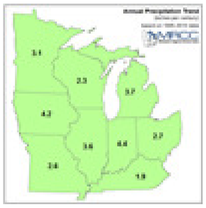
Precipitation Trends, 1895-2010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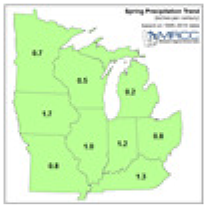
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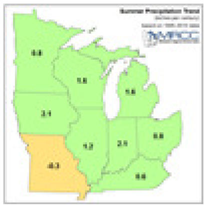
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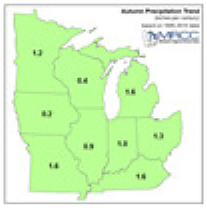
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How the Trend Values Were Calculated:
The values displayed on the maps are linear trends in units per century. Mo state was averaged (temperature) or totaled (precipitation) into seasonal or Linear regressions were computed from the seasonal and annual data. The resulting regression coefficients (slopes) were multiplied by 100 to compute century which are displayed on the maps.

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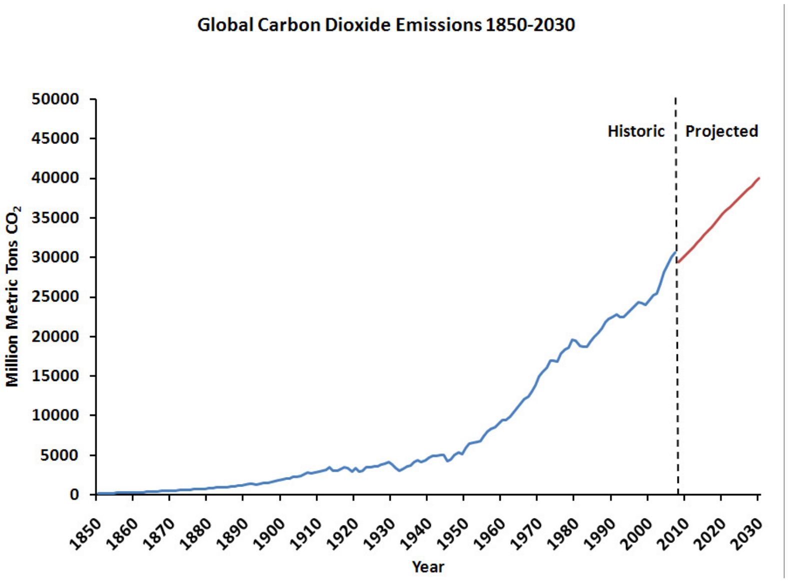
HISTORICAL GLOBAL CO2 EMISSIONS

Greenhouse gas emissions, largely CO2 from the combustion of fossil fuels, have risen dramatically since the start of the industrial revolution.



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Minnesota Pollution Control Agency http://www.pca.state.mn.us/

Home > Quick Links > Topics > Climate Change > Climate Change in Minnesota

Climate Change: Greenhouse Gas Emissions in Minnesota

Under Minnesota statute (Minn. Stat. § 216H.07, subd. 3), the Minnesota Pollution Control Agency (MPCA) is obligated to report on statewide progress toward the greenhouse gas (GHG) reduction goals enumerated in the Next Generation Energy Act (Minn. Stat. § 216H.02). The Next Generation Energy Act established the following GHG reduction goals: 15 percent reduction from 2005 levels by 2015; 30 percent reduction by 2025; and 80 percent reduction by 2050.

Emissions are estimated for all years from 1970 to 2008. Emissions are grouped in the agricultural, commercial, electric generation, industrial, residential, transportation, and waste sectors, and into major activity groups by energy use and fuel production, agricultural process, industrial process, and waste management emissions.

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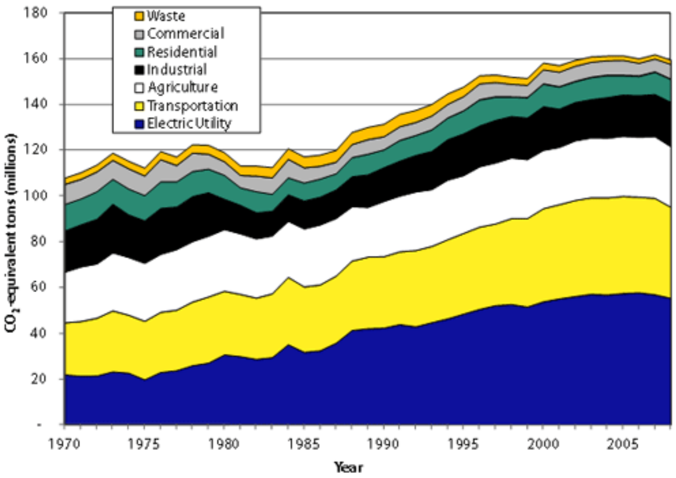
Greenhouse Gas Emissions by Economic Sector

Greenhouse Gas Emissions from Minnesota by Economic Sector

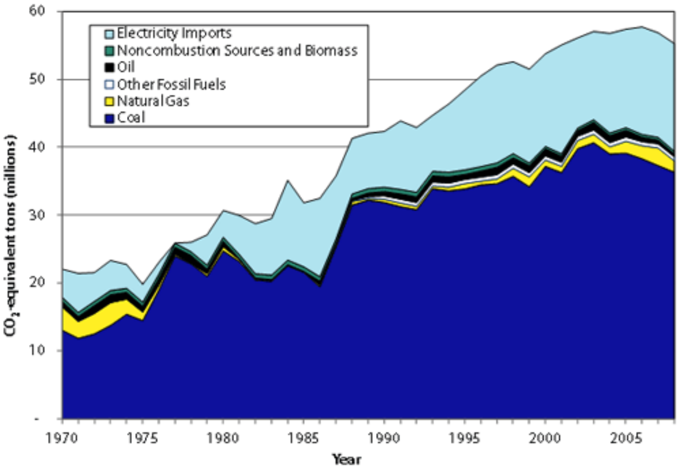


Statewide GHG emissions increased by an estimated 51.5 million CO2-equivalent tons between 1970 and 2008, to a total of 159.5 million CO2-equivalent tons, 48 percent higher than emissions in 1970. Total emissions in the baseline year, 2005, were an estimated 161.3 million CO2-equivalent tons.

Between 1970 and 2008, the majority of the growth in estimated statewide GHG emissions occurred in just two sectors: the electric power sector and the transportation sector. Emissions from transportation and electric power generation comprised roughly 41 percent of all Minnesota GHG emissions in 1970, and, by 2008, they accounted for 60 percent, more than doubling in absolute terms.

Electric Generation Sector

Greenhouse Gas Emissions from the Electric Generation Sector in Minnesota

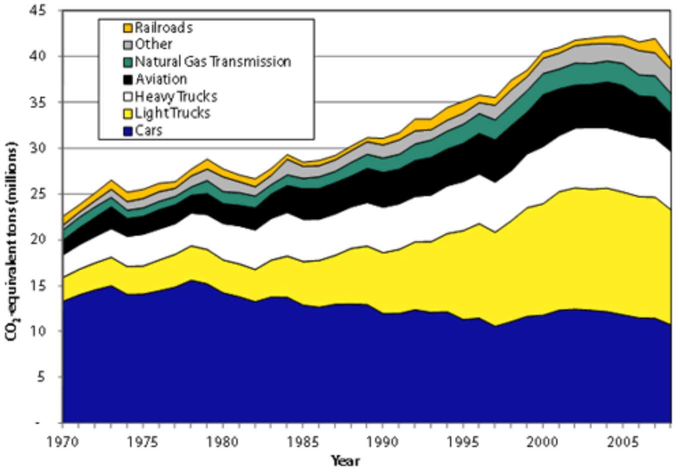


Emissions from electric generation have risen at an average annual rate of 3.5 percent between 1970 and 1988, and 1.5 percent per year between 1988 and 2008. Since 2000, emissions from electricity generation have increased about three percent, rising at an average annual rate of 0.3 percent per year.

Between 2005 and 2008, total GHG emissions from the electric sector decreased 2.1 million CO2-equivalent tons. Emissions associated with energy produced outside of the state increased by 1.4 million CO2-equivalent tons as emissions from in-state generation have decreased.

Transportation Sector

Greenhouse Gas Emissions from Transportation Sector in Minnesota

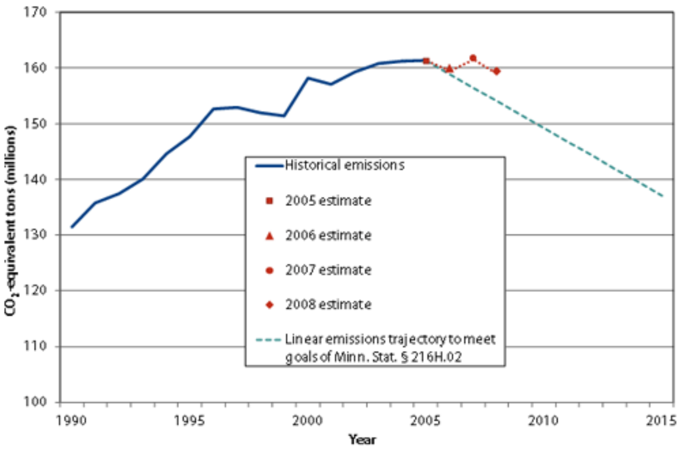


In 2008, GHG emissions from transportation were an estimated 39.7 million CO2-equivalent tons, not quite double 1970 emissions. Between 2005 and 2008, total transportation emissions decreased by 2.6 million CO2-equivalent tons.

Progress to Meeting Next Generation Energy Act Goals

- Statewide GHG emissions totaled 161.3 million CO$_2$-equivalent tons in the baseline year, 2005, falling to 159.5 million CO$_2$-equivalent tons in 2008.

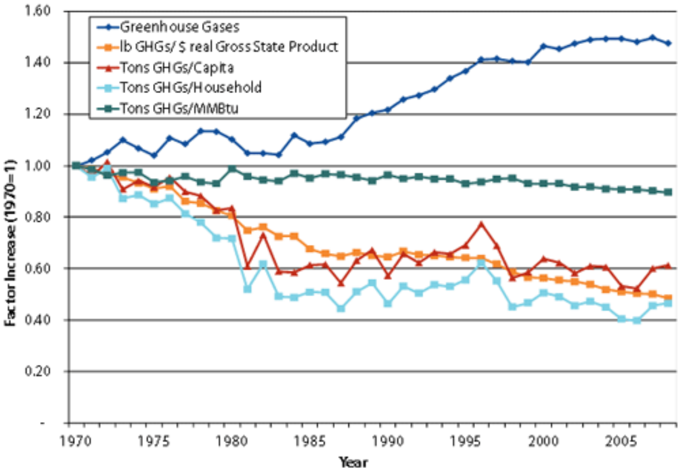
Tracking Progress on Minnesota Greenhouse Gas Emissions



Indicators and Explanation of Trends

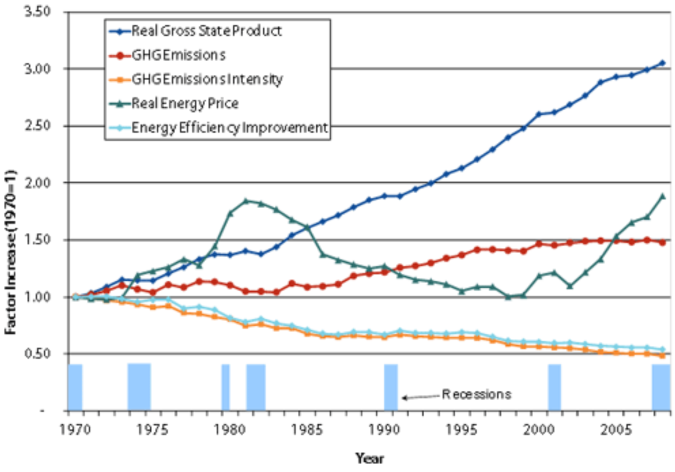
Measures of emission intensity are useful in understanding what has or has not happened and why. It is common to express emissions in relation to total population, household numbers, economic output, total energy consumption and other social and economic indicators of interest. The trend in emissions in relation to each of these indicators is shown in the figure below as a factor increase above 1970 levels of emission intensity.

Indicators of Greenhouse Gas Emission Intensity



The figure below summarizes the trend from 1970 to 2008 in GHG emissions as a factor increase compared to 1970 levels, along with parallel trends for state economic output (real gross state output), GHG emission intensity, energy efficiency, and real energy prices. Real energy prices peaked in 1981, remained at high levels through 1985, and then declined to the late 1990s. After 1998, real energy prices began a slow climb. Energy use efficiency declined rapidly, 1970-1985, stabilized from 1985-1998, then resumed its earlier pattern of decline. GHG emission intensity followed a similar pattern. Real economic output showed an inverse pattern, growing slowly through 1983, accelerating from 1983 to 1997, and then slowing after 1997.

Minnesota Greenhouse Gas Emissions, Emissions Intensity, Economy, and Real Energy Prices



Full Report

- Greenhouse Gas Emissions in Minnesota: 1970-2008 (p-gen4-08) (January 2012). A report on statewide progress toward greenhouse gas reduction goals enumerated in the Next Generation Energy Act, including a summary of emissions by economic sector and by major activities, with long term trends and social and economic indicators.
- Greenhouse Gas Emissions in Minnesota: 1970-2006 (p-gen4-05) (June 2009). A report on statewide progress toward greenhouse gas reduction goals enumerated in the Next Generation Energy Act, including a summary of emissions by economic sector and by major activities, with long term trends and social and economic indicators.
- Data Summary for Greenhouse Gas Emissions in Minnesota: 1970-2006 (p-gen4-06). This spreadsheet contains the summarized data for all years from 1970 through 2006 that was used in the report. Keys for organizing the data into the same economic sectors and activities as in the report are included. It is important to note that the numbers in this spreadsheet and subsequent iteration of the analysis are subject to change if methods or original data are updated. (Posted October 2, 2009)

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