NorthMet Project Greenhouse Gas and Climate Change Evaluation Report

Prepared for
PolyMet Mining Inc.

June 2009

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Climate Change Evaluation Report

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1.0 Introduction

The first draft of this report was submitted in March of 2009. Comments on the first draft were received from the Minnesota Pollution Control Agency (MPCA) and the Minnesota Department of Natural Resources (MDNR). This second draft of the report is being submitted to address the comments. The agency comments along with a brief description of how they have been addressed are included in Appendix C.

The issue of climate change and anthropogenic greenhouse gas emissions is a complex and evolving topic from both a scientific and regulatory standpoint. The NorthMet Project Draft EIS is being prepared in the context of new and evolving state and federal guidance related to greenhouse gases and climate change in environmental review. The analysis that follows addresses the environmental effects of greenhouse gas emissions from the NorthMet Project and of global climate change. The analysis also recognizes data and analytical limitations. Greenhouse gases and climate change are evaluated in a manner that is consistent with available, reliable, scientifically-based information and approaches. Project greenhouse gas emissions, alternatives, and energy efficiency have been quantitatively assessed. Additionally, despite the high level of uncertainty associated with their calculation, greenhouse gas emissions from surface wetland removal and stockpiling, 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 greenhouse gas 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).

Greenhouse gas emissions from the NorthMet Project are not currently subject to any emissions limits imposed by federal, state, or local laws. Climate change policy and greenhouse gas regulation is a rapidly evolving issue, however. Environmental Protection Agency (EPA) has recently been authorized to regulate CO_2 emissions from mobile sources under the Clean Air Act (CAA), and the MPCA now requires an evaluation of greenhouse gas 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 greenhouse gas emission reductions.

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 many scientists to observed increases in global atmospheric greenhouse gas concentrations resulting from anthropogenic greenhouse gas emissions. Some future climate change impacts have been projected to occur as the result of increases in global atmospheric greenhouse gas concentrations that have already occurred. The level of future global, national and regional anthropogenic greenhouse gas emissions may also exert a strong influence over the magnitude and extent of future climate change.

Minnesota is situated in a unique location that makes it 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 forest ecosystems, water resources, other unique ecosystems, agriculture, and human health over the next century.

Major components of the NorthMet Project include mining, ore crushing/grinding and concentrating, and metal recovery. A key feature of metal recovery is routing the concentrate to a pressurized autoclave (or parallel autoclaves) as part of the hydrometallurgical process. The energy from sulfide oxidation within the autoclave is used as the primary heat source. The hydrometallurgical process eliminates several steps typically associated with pyrometallurgical processing and the related energy demand associated with fuel for the pyrometallurgical process. Overall, hydrometallurgical processing, such as PolyMet's planned operation, is estimated to reduce total energy demand by 50% as compared with a pyrometallurgical process.

Total greenhouse gas 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 in the paragraph below. Figure 1 shows the location and layout of the Mine Site and Process Plant.

PolyMet is taking all practicable measures to minimize greenhouse gas 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 two of the three blast hole drills will be electric rather than diesel powered eliminating a source of direct greenhouse gas 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 greenhouse gas emissions. To reduce greenhouse gas 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 greenhouse gas emissions.

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 estimates for five carbon cycle impact categories have been calculated:

1) Total carbon stored in the above-ground vegetation of wetlands and forests which 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) Annual emissions from indirectly impacted wetlands due to lowered water levels

4) Loss of annual carbon sequestration capacity due to direct and indirect project impacts on wetland and forest plant communities

5) 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 calculated are those from peat excavation and stockpiling, and indirectly impacted wetlands. The loss of carbon sequestration capacity in directly and indirectly impacted wetlands differs from the emissions rates 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 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.

As the screening-level assessment in Appendix A explains, the emissions from the proposed NorthMet Project, excluding those from the terrestrial carbon cycle impacts, may result in global air concentrations of CO_2 to increase by only 0.00002 to 0.0001 ppm. For a full quantitative analysis of greenhouse gas emissions, project efficiency, and greenhouse gas reduction measures, please see Appendix A.

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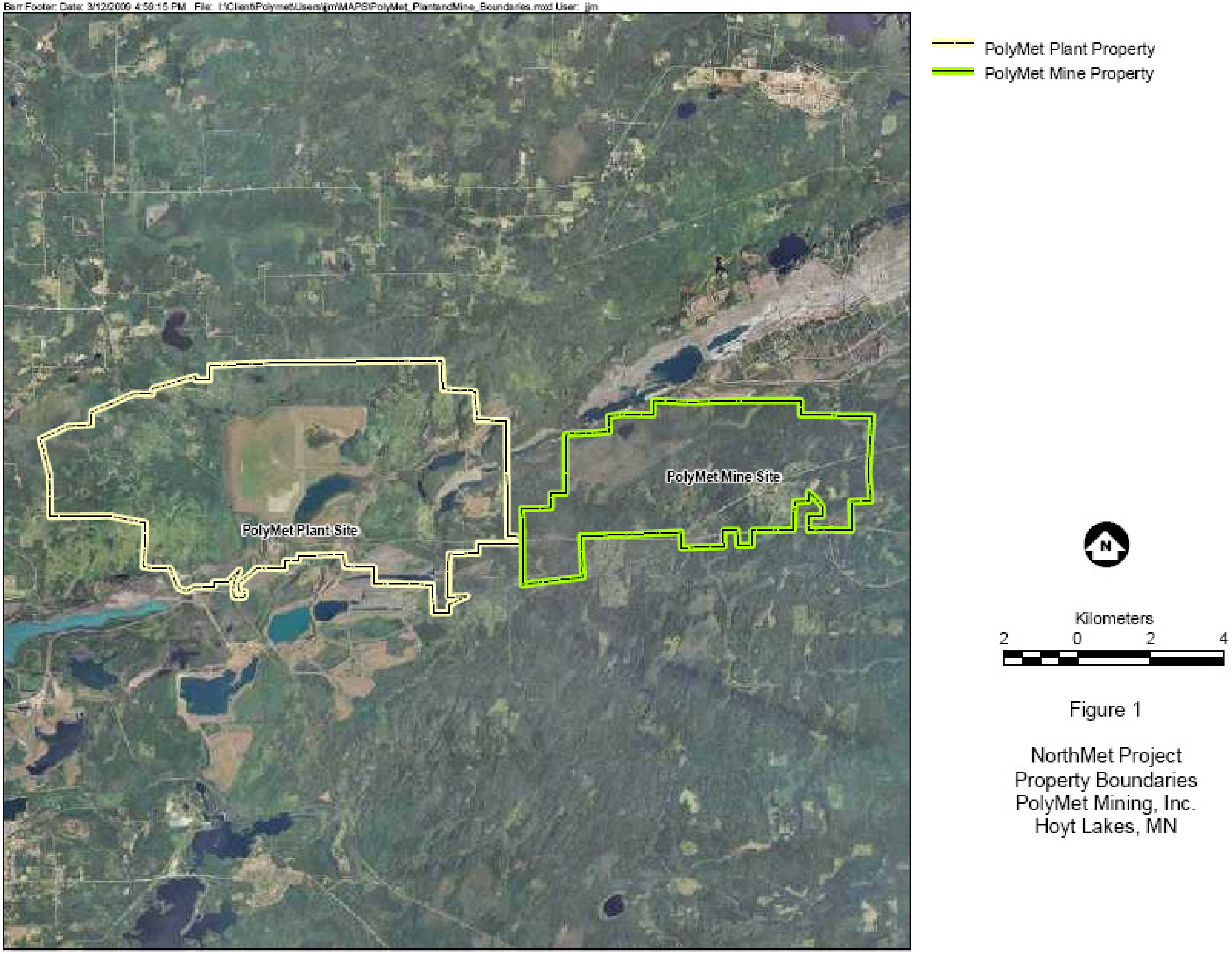

Figure 1

NorthMet Project
Property Boundaries
PolyMet Mining, Inc.
Hoyt Lakes, MN

2.0 Cumulative Effects

2.1. Background Information on Climate Change

2.1.1. Climate Change and Greenhouse Gases in Federal and State Policy and Law

Greenhouse gas emissions from the NorthMet Project are not currently subject to any emissions limits imposed by federal, state, or local laws. Climate change policy and greenhouse gas regulation is a rapidly evolving issue, however. EPA has recently been authorized to regulate CO_2 emissions from mobile sources under the CAA, and the MPCA) now requires an evaluation of greenhouse gas 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 greenhouse gas emission reductions.

2.1.1.1 Federal Policy and Law

From a national policy perspective, consideration of greenhouse gas 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 stabilization of greenhouse gas 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 greenhouse gas emissions and national policies and best practices. The United States also agreed to participate in launching national strategies for addressing greenhouse gas emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries.[1]

In 2001, the United States rejected mandatory domestic emissions reductions by declining to participate in the Kyoto Protocol to the UNFCCC. The Kyoto Protocol called for legally binding commitments by developed countries to reduce greenhouse gas emissions. Since then, U.S. climate change policy has focused on voluntary initiatives to reduce the growth in greenhouse gas emissions. During the past decade, a variety of voluntary and regulatory actions have been proposed or undertaken in the United States, including monitoring of electric utility carbon dioxide emissions, improved appliance efficiency, and incentives for developing renewable

[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)

energy sources. On February 14, 2002, President Bush announced his Global Climate Change policy, which aims to reduce the U.S.'s greenhouse gas intensity by 18 percent by 2012. The plan relies on technology improvements and dissemination, demand-side efficiency gains, voluntary programs with industry, and shifts to cleaner fuels to achieve reductions in greenhouse gas intensity.[2]

Since 2007 a series of legislative proposals at the national level have pushed ahead in shaping the future of U.S. climate policy. Carbon and greenhouse gas related legislation under consideration during the 109th and 110th sessions of the U.S. Congress included proposals ranging from carbon taxes to cap and trade regimes, and from energy efficiency requirements to moratoria on approvals for coal fired power plants.[3]

At the federal level, CO_2 and other greenhouse gases emitted from stationary sources are not subject to regulation at this time. Difficult regulatory questions and ongoing discussions regarding the authority of the EPA to regulate greenhouse gases under the CAA continue to dominate the discussion of federal law related to greenhouse gases. Three major regulatory questions have been confronted as part of this discussion: (1) Does the CAA confer on EPA the authority to regulate greenhouse gases to address climate change? (2) If EPA has such authority, does it have a duty to act? (3) Does the CAA preempt state authority to regulate motor vehicle emissions of greenhouse gases?

In April 2007, the U.S. Supreme Court issued a decision in *Massachusetts v. EPA*, 549 U.S. 497, 127 S.Ct. 1438 (2007). The decision rejects EPA's justification for denying a petition to regulate greenhouse gas emissions from new automobiles. The Court remanded the decision to EPA for reconsideration. This case arose from EPA's denial of a petition by a group of states and environmental organizations seeking that EPA regulate greenhouse gas emissions from new motor vehicles under the CAA.[4] EPA's denial was based on its conclusion that the CAA does not authorize regulations to address global climate change[5] and that, even if the EPA had the

[2] U.S. DOE, 2006. U.S. Climate Action Report – 2006: Fourth Climate Action Report to the UN Framework Convention on Climate Change (available at: http://www.state.gov/g/oes/rls/rpts/car/90324.htm). Section 5.
[3]Yacobucci, Brent, August 4, 2006. CRS Report for Congress: Climate Change Legislation in the 109th Congress (available at: http://www.usembassy.it/pdf/other/RL32955.pdf); http://www.eoearth.org/article/Climate_change:_greenhouse_gas_reduction_bills_in_the_110th_Congress (see Appendix B)
[4] Clean Air Act § 202
[5] CAA § 202(a)(1) directs EPA to prescribe standards to the emission of any air pollutant which causes or contributes to dangerous air pollution, where "air pollutant" includes "*any* air pollution agent or combination

authority to issue such regulations, it would be unwise to do so at this time. The Court held that greenhouse gases satisfy the definition of "air pollutant" under the CAA and that EPA has the statutory authority to regulate greenhouse gas emissions from automobiles. The Supreme Court determined that the CAA authorizes EPA to regulate greenhouse gas emissions from motor vehicles if EPA forms a "judgment" that the emissions contribute to climate change.[6]

One year after the Supreme Court's decision in *Massachusetts,* a petition for writ of mandamus was filed to force EPA to comply with the Supreme Court mandate to make a determination on whether to regulate greenhouse gases from vehicles under the CAA[7]. In July 2008, the EPA issued an Advance Notice of Proposed Rulemaking ("ANPRM") concerning the implementation of such regulations, including extensive analysis of the science related to climate change, technologies for reducing greenhouse gas emissions, and the statutory provisions that may be implicated by an endangerment finding under Section 202 of the CAA.[8]

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.[9] EPA's sister federal agencies provided comments expressing concern regarding the benefits of greenhouse gas regulation through the CAA. The U.S. Department of Transportation noted that using the CAA as a means for regulating greenhouse gas emissions presents insurmountable obstacles. 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 asked that before EPA proceeds down the path of CAA regulation of greenhouse gases, there should be a full and fair discussion of the true burdens of that path.[10]

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

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of such agents, including *any* physical, chemical . . . substance or matter which is emitted into or otherwise enters the ambient air . . . ."

[6] 127 S.Ct. at 1462.

[7] United States Court of Appeals For the District of Columbia Circuit. Commonwealth of Massachussets, 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)

[8] 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.

[9] http://www.epa.gov/climatechange/emissions/downloads/ANPRPreamble.pdf at 5.

[10] Id at 26.

Court's ruling in *Massachusetts v. EPA*, the PSD permit should have included Best Available Control Technology (BACT) emission limits for CO_2.[11] 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 qualified as an "air pollutant subject to regulation under the CAA."[12] 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. The Board emphasized it was not holding that the CAA required EPA Region 8 to impose a CO_2 BACT limit, but rather that the record did not support the reasoning offered by EPA for failing to impose the limit.

In December 2008, former EPA Administrator Stephen L. Johnson issued a memorandum to all EPA Regional Administrators discussing the application of the CAA to greenhouse gas emissions.[13] 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.[14]

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[11] 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 (Beofre 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.

[12] 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

[13] 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)

[14] 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.

Notwithstanding the landmark ruling in *Massachusetts v. EPA*, there are no stationary source emission limits for CO_2. In addition, CO_2 is not a criteria pollutant for which national ambient air quality standards (NAAQS) are set under Section 109 of the CAA (CAA § 109).[15] CO_2 is not subject to regulation under the national emission standards for hazardous air pollutants (NESHAPs),[16] the new source performance standards (NSPS),[17] Prevention of Significant Deterioration (PSD) air permitting, Title V of the CAA (operating air permits), nor Title VI of the CAA (ozone depleting substances).[18] Similarly, CO_2 and other greenhouse gases are not regulated under the major environmental regulatory programs that address hazardous substances or hazardous wastes, such as RCRA, CWA, CERCLA, or EPCRA.

In response to the FY2008 Consolidated Appropriations Act (H.R. 2764; Public Law 110–161), EPA recently proposed a rule that requires mandatory reporting of greenhouse gas (GHG) emissions from large sources in the United States. The proposed rule was signed by the Administrator on March 10, 2009, and was published in the *Federal Register* (www.regulations.gov) on April 10, 2009 under Docket ID No. EPA-HQ-OAR-2008-0508. In general, EPA proposes that suppliers of fossil fuels or industrial greenhouse gases, 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 proposed 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). The proposed rule would require the first annual GHG emission report to be submitted on March 31, 2011, for 2010 emissions. Public hearings on the proposed rule began on April 6, 2009.

In response to the 2007 supreme court ruling 549 U.S. 497 (2007), Proposed Endangerment and Cause or Contribute Findings for Greenhouse Gases under the CAA were signed by the EPA administrator on April 17, 2009 and was open for public comment for a 60 day period following publication in the Federal Register. The proposal makes two findings regarding greenhouse gases under section 202(a) of the CAA: The Administrator is proposing to find that the current and projected concentrations of the mix of six key greenhouse gases in the atmosphere threaten the

[15] EPA currently has NAAQS established for lead, sulfur dioxide, nitrogen oxide, carbon monoxide, particulate matter (both 2.5 and 10 micrograms), and ozone under CAA § 109, 42 USC § 7409.
[16] CAA § 112, 42 USC § 7412.
[17] CAA § 111, 42 USC § 7411.
[18] EPA listed air pollutants subject to federal permitting requirements, constituting regulated pollutants in its final NSR rules. 67 Fed. Reg. 80186, 80240 (Dec. 31, 2002).

public health and welfare of current and future generations. The Administrator is further proposing to find 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 greenhouse gases and hence to the threat of climate change. This proposed action, as well as any final action in the future, would not itself impose any requirements on industry or other entities. Additionally, an endangerment finding under one provision of the CAA would not by itself automatically trigger regulation under the entire Act.

Despite the change in policy and approach indicated by the proposed EPA mandatory reporting rule, CO_2 remains unregulated. CO_2 is not a criteria pollutant for which national ambient air quality standards (NAAQS) are set under Section 109 of the CAA (CAA § 109). CO_2 is not subject to regulation under the national emission standards for hazardous air pollutants (NESHAPs), the new source performance standards (NSPS), Prevention of Significant Deterioration (PSD) air permitting, Title V of the CAA (operating air permits), nor Title VI of the CAA (ozone depleting substances). Likewise, CO_2 and other greenhouse gases are not regulated under the major environmental regulatory programs that primarily address toxic and hazardous substances, including, RCRA, CWA, the CERCLA, or EPCRA. The Obama Administration, however, has announced several policy positions related to greenhouse gas emissions that may lead to additional regulation in the future.

2.1.1.2 Minnesota State Policy and Law

At the state level, efforts to curb statewide and regional greenhouse gas emissions are underway. More than half of U.S. states have joined in regional efforts to reduce greenhouse gas emissions. Minnesota has committed (along with Illinois, Iowa, Kansas, Michigan, Wisconsin and Manitoba) to long term greenhouse gas 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 greenhouse gas emissions tracking system.[19]

In the last several years Minnesota has taken steps to address statewide greenhouse gas emissions. In December 2006, Minnesota Governor Pawlenty announced the state's Next Generation Energy

[19] 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)

Initiative, which included the development of an aggressive plan to reduce greenhouse gas 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.[20] The Next Generation Energy Act of 2007 articulates the "goal of the state to reduce statewide greenhouse gas 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 [21]

In January 2008, Pawlenty outlined a four part energy initiative, emphasizing the key role of local projects and research and development assistance. The four part energy initiative includes plans to establish a 15 member panel (Clean Energy Technology Collaborative) appointed by the Governor that will work to develop a Clean Energy Technology Roadmap. In addition, the initiative calls for the establishment of the Minnesota Office of Energy Security to coordinate energy and climate issues throughout the Governor's administration.

Also in January 2008, the Minnesota Climate Change Advisory Group announced its approval of a mixture of strategies to reduce the state's greenhouse gas emissions to a level at least 30 percent below 2005 levels by 2025. Proposed strategies include the development of greenhouse gas inventories, forecasting, reporting, and a registry. In April 2008, the Minnesota Climate Change Advisory Group issued its final report with recommendations to the Governor for reducing Minnesota's greenhouse gas emissions.[22] Following the release of the Minnesota Climate Change Advisory Group's final report, the Minnesota Senate and House approved bills setting general guidelines for the Legislature's role in a regional, market-based system to control greenhouse gas 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 greenhouse gas emissions and to make interim reduction recommendations toward meeting the state's goal of reducing greenhouse gas emissions to a level at least eighty percent below 2005 levels by 2050.[23]

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[20]Minnesota Statutes, 2008 Chapter 216H. Greenhouse Gas Emissions (available at https://www.revisor.leg.state.mn.us/statutes/?id=216H&view=chapter)
[21] Minnesota Statutes, 2008 Chapter 216H. Greenhouse Gas Emissions (available at https://www.revisor.leg.state.mn.us/statutes/?id=216H&view=chapter)
[22] 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)
[23]U.S. Environmental Protection Agency Website on Climate Change – State and Local Governments: http://www.epa.gov/climatechange/wycd/stateandlocalgov/states/mn.html See Appendix B

Developments in Minnesota's climate change and greenhouse gas policy will likely continue to take shape as Minnesota strives to meet the greenhouse gas reduction goals established in the Next Generation Energy Act.

In addition to policies directed at reducing statewide greenhouse gas emissions, Minnesota has recently instituted policies requiring the evaluation of greenhouse gas 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 greenhouse gas inventory for proposed projects that will require stationary source air emissions permits.

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[24]. 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.

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.[25] The global average

[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.)].
[25] Minnesota Department of Natural Resources, http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html

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[26].

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)[27] attributable to the observed increases in global atmospheric greenhouse gas concentrations resulting from anthropogenic greenhouse gas 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.

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 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.

Causes of Climate Change

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. Radiative 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

[26] http://data.giss.nasa.gov/gistemp/2008/

[27] [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.)].

energy of this reflected solar radiation, as well as some of the radiative 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 1). 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.

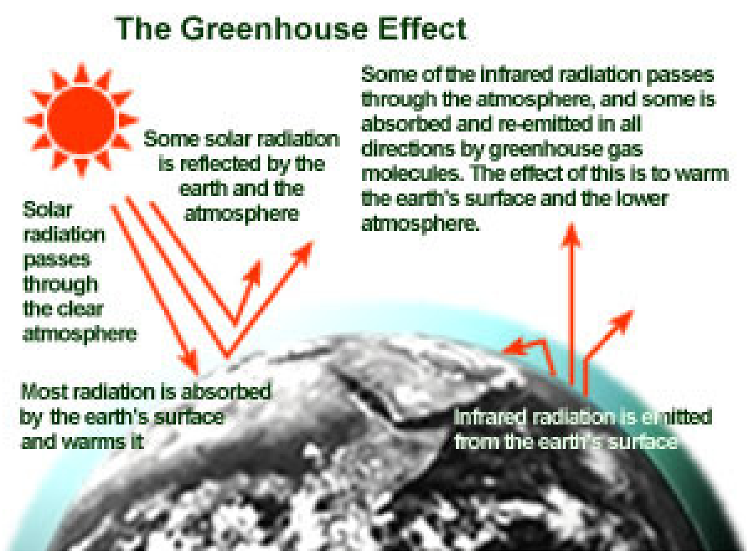

Figure 1. Diagram of the greenhouse effect[28]

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. 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.

[28] http://www.pca.state.mn.us/climatechange/

Internal changes in the sun can result in changes in the intensity of the sunlight that reaches the Earth's surface. Periods of higher solar intensity can cause warming while periods of weaker solar intensity can cause cooling. 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. These natural changes in earth's orbital processes alter the proximity of the earth to the sun and the distribution of solar energy over earth surfaces (ocean vs. land masses) with different radiative properties. 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.[29] Changes in solar intensity and variability in earth's orbit can result in modifications to the earth's energy balance via changes in the amount of solar energy that enters the earth's atmosphere.

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[30], 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 greenhouse gas in the earth's atmosphere. This feedback might generate additional increases in temperature, 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[31].

Geologic processes

Natural geologic processes that occur on the earth's surface can exert a strong control over the concentration of greenhouse gas 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.

[29] http://earthobservatory.nasa.gov/

[30] 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, Fourth Assessment Report, Working Group I: Climate Change 2007 The Physical Science Basis.)

[31] http://www.grida.no/publications/other/ipcc_tar/?src=/CLIMATE/IPCC_TAR/WG1/295.htm

Over geologic timescales, for example, the large scale weathering of silicate minerals can result in a gradual draw down of atmospheric greenhouse gas concentrations and long term sequestration of carbon from the earth's atmosphere in carbonate minerals[32]. 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 may even have exerted an 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 greenhouse gas 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[33].

Anthropogenic greenhouse gas emissions

In addition to the natural variations in solar forcing and natural greenhouse gas related climate impacts, a growing body of scientific evidence points to anthropogenic greenhouse gas 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 pro-industrial values determined from ice cores spanning many thousands of years." A more detailed discussion of anthropogenic greenhouse gas emissions can be found below. Relatively rapid increases in global atmospheric CO_2 emissions can be observed corresponding with the rise of the industrial revolution near the turn of the 19th century and continuing into the present. The atmospheric concentration of carbon dioxide observed in the year 2005 exceeded the natural range over the last 650,000 years.

The strong relationship observed between rising atmospheric CO_2 levels and anthropogenic emissions of greenhouse gases is further corroborated by observations of systematic shifts in the

[32] http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch07.pdf
[33] http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch06.pdf

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[34]. 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 greenhouse gases 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[35] worldwide network. This data shows rising atmospheric CO_2 levels with a persistent anthropogenic fossil fuel greenhouse gas signature trending toward isotopically lighter $\delta^{13}C$.

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 greenhouse gas concentrations resulting from anthropogenic greenhouse gas 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% probablility). 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 the impacts of increasing greenhouse gas 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 is very likely due to the combined influences of anthropogenic greenhouse gas emissions and stratospheric ozone depletion.

[34] (Andres et al., 2000)
[35] http://gcmd.nasa.gov/records/GCMD_CDIAC_TRENDS_C13_CSIRO_GASLAB.html

Historic temperature trends

Climate Sensitivity

Over geologic history, changes in climate have been strongly linked to changes in greenhouse gas levels in the earth's atmosphere. One of the most notable aspects of the paleoclimate record[36] is the strong correlation that can be observed between global average surface temperature and reconstructions of global atmospheric carbon dioxide concentrations[37] during the glacial cycles of the past several hundred thousand years. Figure 2 below shows the trend toward higher temperatures during periods of higher atmospheric CO_2 levels with lower temperatures generally corresponding to lower atmospheric CO_2 levels.

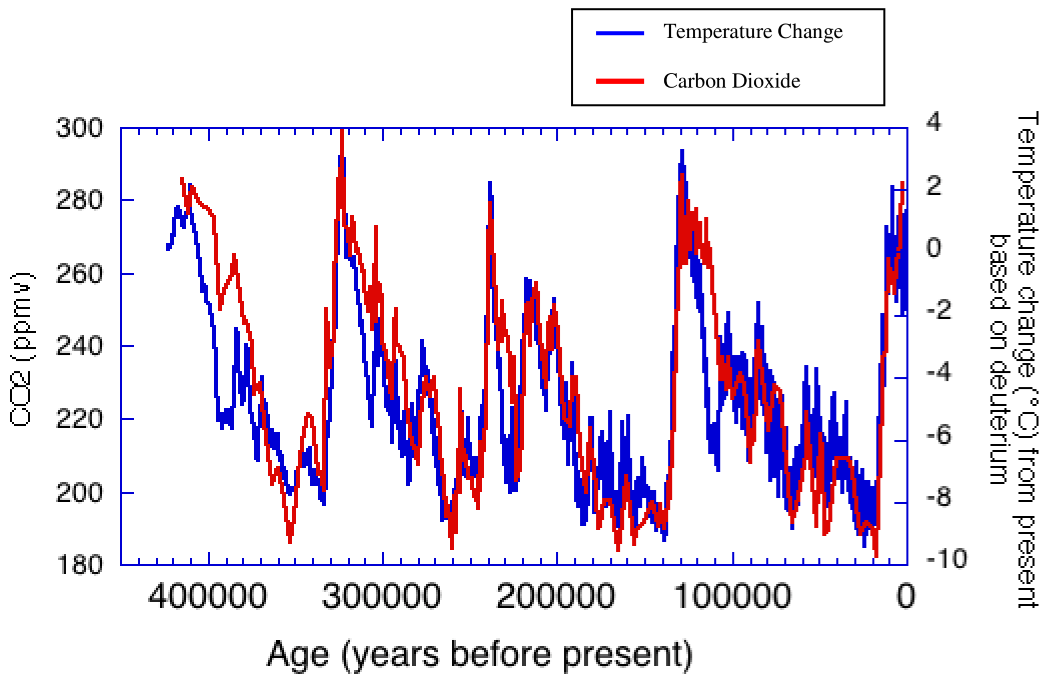

Figure 2. Temperature change and carbon dioxide change observed in ice core records[38]

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[36] Paleoclimate records include reconstructions of past temperature, precipitation, vegetation, streamflow, sea surface temperature, and other climatic or climate-dependent conditions which are reconstructed using climate proxy records such as δO18 records from coral, tree ring data, lake and ocean cores, ice cores and various other paleo records (http://www.ncdc.noaa.gov/paleo/recons.html)

[37] Bubbles trapped in ice cores in Greenland and Antarctica have been used to reconstruct atmospheric CO_2 levels over the last several glacial/interglacial cycles (http://earthobservatory.nasa.gov/Features/Paleoclimatology_IceCores/)

[38] (http://www.ncdc.noaa.gov/paleo/globalwarming/temperature-change.html). As shown in Figure 2 above, the Earth's past climate and CO_2 record suggests periods of stability as well as periods of rapid change. Recent climate research suggests that because of the complex feedbacks in the earth's climate,

A small part of the correlation that can be observed between global average surface temperature and global average atmospheric CO_2 levels is attributable to the relationship between temperature and the solubility of carbon dioxide in the surface ocean, but the majority of the observed correlation is consistent with the feedback between carbon dioxide and climate[39]. Other changes involved in these glacial/interglacial climate cycles, including altered vegetation, land surface characteristics, and ice-sheet extent complicate what may otherwise seem to be a simple cause and effect relationship between climate and global atmospheric CO_2 levels.

Taking these complicating factors into account, it is possible to draw on the relationships observed in these records of glacial and interglacial cycles to determine how much the temperature decreased when carbon dioxide was reduced, and use this scaling (termed climate sensitivity)[40] to determine how much temperature might increase as carbon dioxide increases. Estimates for the tropical ocean, indicate potential warming of 5°C (or 2.8 °F) for a doubling of carbon dioxide concentration in the atmosphere. Paleo data, including borehole data, tree ring data, ice cores and ocean cores, provide a valuable independent check on the sensitivity of climate models, and some studies indicate that this 5°C value to be consistent with many coupled climate models[41]. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicates that a doubling of atmospheric CO^2 is likely to produce temperature changes in the range of 2 to 4.5°C with a best estimate of about 3°C[42]. The IPCC report states that the earth's global average temperature response to a doubling of atmospheric CO^2 is unlikely to be less than 1.5°C and that while values substantially higher than 4.5°C cannot be excluded, model agreement with observations is not as reliable for climate sensitivities higher than 4.5 °C.

Global temperature trends

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interglacial climates tend to be more stable than cooler, glacial climates. Abrupt or rapid climate changes tend to frequently accompany transitions between glacial and interglacial periods (and vice versa). For example, a significant part of the Northern Hemisphere (particularly around Greenland) may have experienced warming ratesof 14-28ºF over several decades during and after the most recent ice age (IPCC, 2007).

[39] http://www.ncdc.noaa.gov/paleo/globalwarming/temperature-change.html
[40] Since the famous work of Arrhenius in 1896, the topic of climate sensitivity and the possibility of a net warming of the global climate due to increases in atmospheric carbon dioxide (CO_2) produced by the burning of fossil-fuel has been recognized. http://www.gfdl.noaa.gov/aboutus/article/aree_page3.html
[41] http://www.ncdc.noaa.gov/paleo/globalwarming/temperature-change.html
[42] http://ipcc-wg1.ucar.edu/wg1/wg1-report/AR4WG1_Print_TS.pdf

The last ice age, which occurred 18,000 years ago, yielded temperatures 7-10 degrees Fahrenheit cooler than they are today.[43] 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 period of relative warming in Europe, Asia, and surrounding regions that occurred roughly between 900 and 1300 AD. The extent and timing of the warming remain uncertain. The Little Ice Age was a period of relative cooling between 1500 and 1850 during which average temperatures may have been approximately 2° colder than they are today.[44] The final anomaly begins with the Industrial Revolution. The Industrial Era has been characterized by emissions of greenhouse gases 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 global mean surface temperature anomaly are shown in Figure 3 that follows.

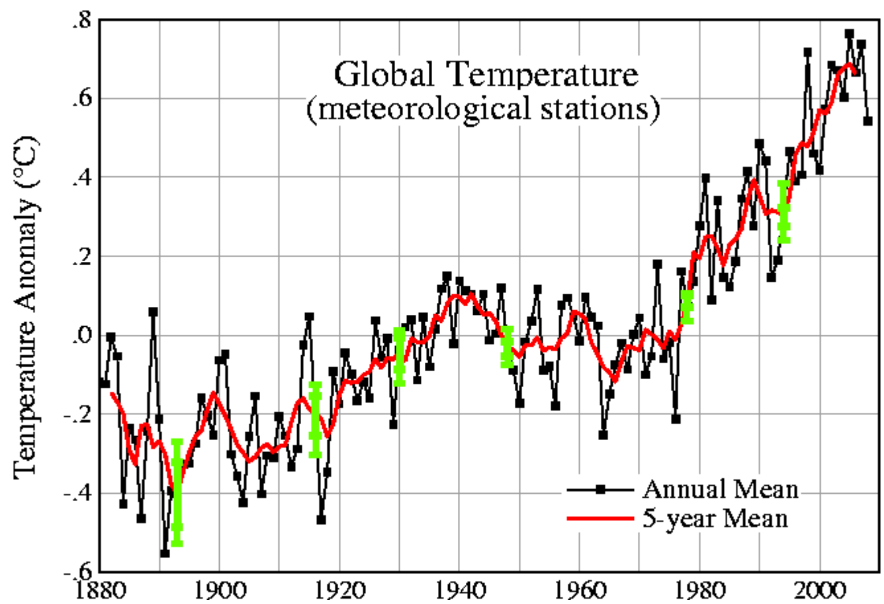

Figure 3. Global temperature trends from the instrumental record[47]

[43] Minnesota Pollution Control Agency, http://www.pca.state.mn.us/publications/aq1-31.pdf
[44] U.S. Environmental Protection Agency, http://epa.gov/climatechange/science/pastcc.html
[45] Minnesota Department of Natural Resources, http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html
[46] http://data.giss.nasa.gov/gistemp/2008/
[47] http://data.giss.nasa.gov/gistemp/graphs/ 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 et al. (2001).] Green ncertainty bars (95% confidence limits) are shown for both the annual and five-year means and account only for incomplete spatial sampling of data.

This warming trend has continued through the turn of the century, with records of the warmest years occurring in 2002-2007.[48] Generally night-time low temperatures are rising almost twice as fast as daytime highs, winters have seen greater temperature increases than summers, and urban areas have also shown more rapid warming than rural areas.[49]

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 past century temperatures in the United States have risen at an average rate of 0.11° F per decade. The past 25 years have seen temperatures increasing approximately 0.56° F per decade. A 2007 analysis of temperatures observed over five year averaged periods (pentads) during the instrumental record indicates that the most recent nine pentads were the warmest over the 113 year period of instrumental record[50]. In keeping with the global trend, 1998 was the warmest year on record for the U.S.[51] The greatest temperature increases have occurred in Alaska with increases of 3.3° F per century. Warming has been observed in the western United States since 1979[52], while the eastern portion has cooled slightly in the past 50 years. However, New England is still warmer than it was 100 years ago, due to faster warming in this region at the outset of the 20th Century.[53] Trends in average temperatures in the U.S. over the 20th century are shown in Figure 4. In keeping with the global trend, winters in the United States have warmed more dramatically than summers, with a marked decrease in the number of days that achieved below freezing temperatures.[54] The months of February and November show comparatively greater increases than other months, indicating the overall shortening of the winter season.[55]

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[48] Minnesota Pollution Control Agency, http://www.pca.state.mn.us/publications/aq1-31.pdf - according to the Earth Observatory of the National Aeronautics and Space Administration

[49] U.S. Environmental Protection Agency, http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ClimateTrendsTemperature.html

[50] http://www.ncdc.noaa.gov/oa/climate/research/2007/ann/us-summary.html#temp

[51] National Climactic Data Center, http://www.ncdc.noaa.gov/oa/climate/research/2007/ann/us-summary.html#temp

[52] U.S. Environmental Protection Agency, http://www.epa.gov/climatechange/science/recenttc.html#ref

[53] U.S. Environmental Protection Agency, http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ClimateTrendsTemperature.html

[54] U.S. Environmental Protection Agency, http://www.epa.gov/climatechange/science/recenttc.html

[55] NASA Earth Observatory, http://earthobservatory.nasa.gov/Features/GlobalWarm1999/

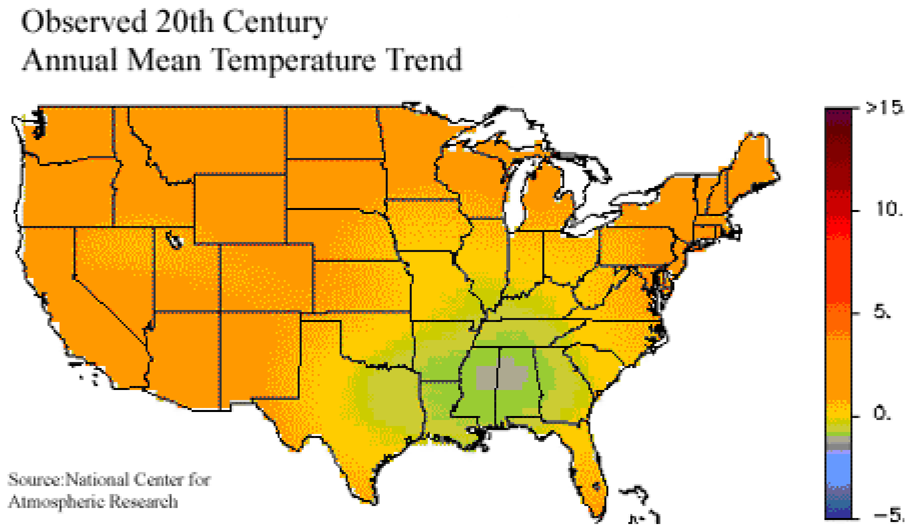
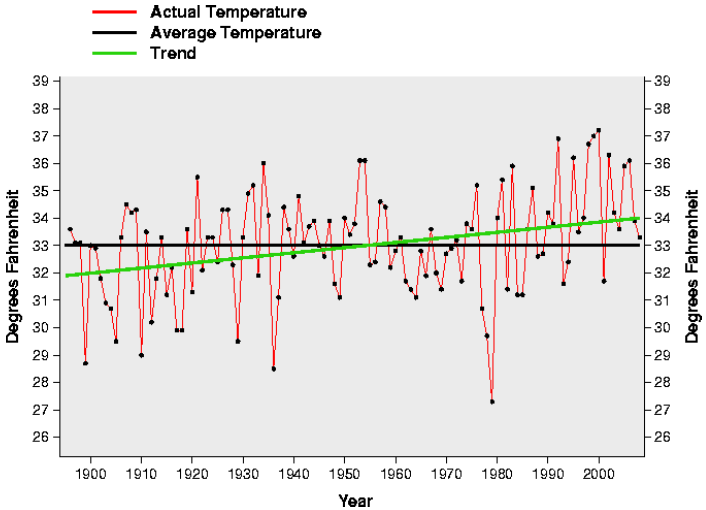


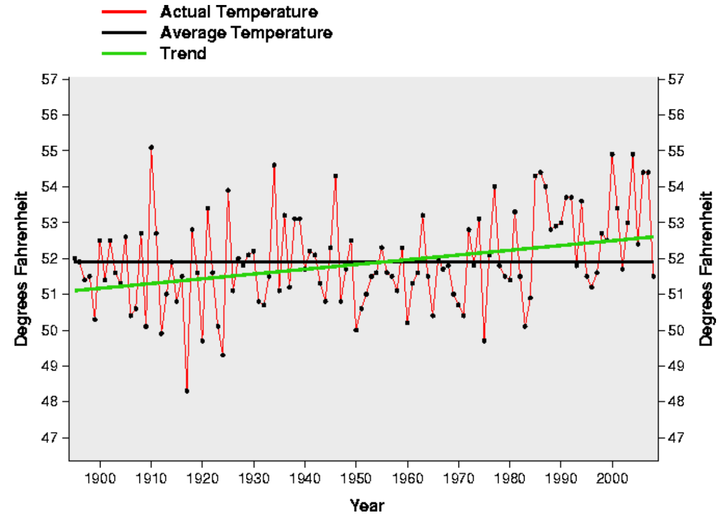
Figure 4. U.S. Mean Annual Temperature Trends[56]

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 0.18°F per decade trend over the period 1895-2008. Much of this temperature increase has occurred over the last few decades, with the period from 1988-2008 showing a temperature trend of 0.68°F/decade. Spring temperatures in the U.S. have increased an average of 0.13°F per decade over the period 1895-2008. Average U.S. summer temperatures have shown a slightly lower trend of 0.1°F average per decade, although the most recent three decades on record show a steeper trend of 0.41°F average per decade. Fall temperatures over the instrumental record show a trend of 0.07°F average per decade with the last three decades averaging a 0.50°F increase per decade[57]

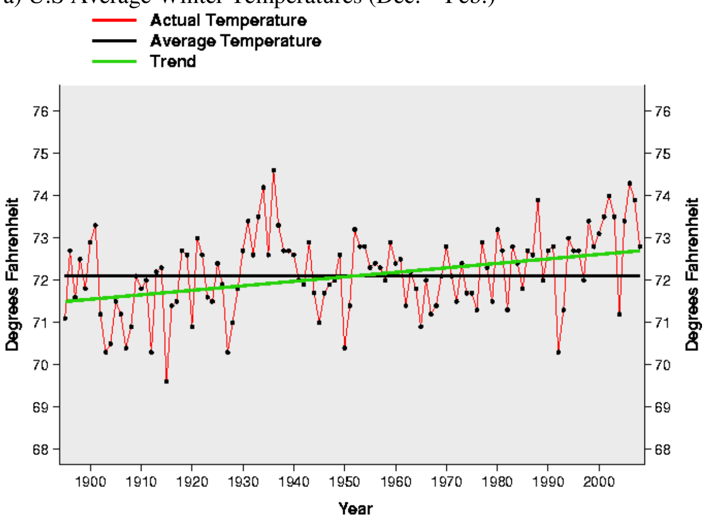
[56] http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ClimateTrendsTemperature.html
[57] http://www.ncdc.noaa.gov/oa/climate/research/cag3/na.html



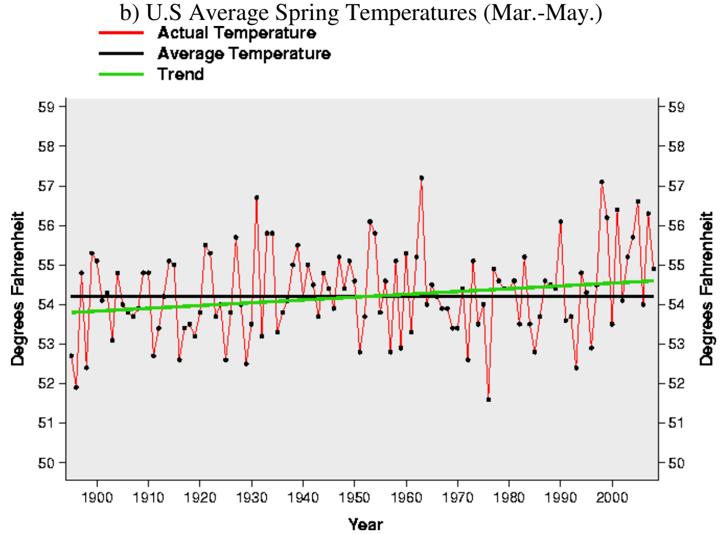
a) U.S Average Winter Temperatures (Dec. – Feb.)



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. (a-d) Seasonal Temperature Trends for U.S. over the instrumental period[58]

[58] http://www.ncdc.noaa.gov/oa/climate/research/2007/ann/us-summary.html#temp

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).[59] The winter season has brought even more dramatic increases of up to five degrees in parts of northern Minnesota.[60] 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° C when average statewide temperatures from only 1980 to the present are considered[61]. Departures in average 1997-2006 temperatures from the 1970-2000 normal in Minnesota are shown in Figure 6.

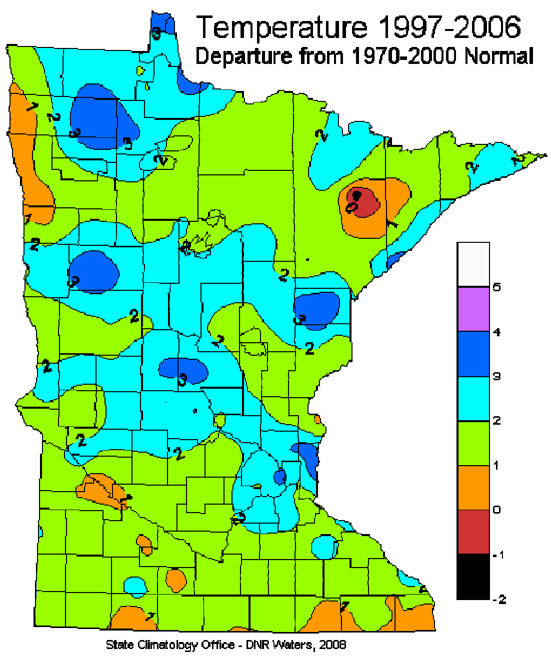


Figure 6. 1997-2006 average temperatures deviation from 1970-2000 normal[62]

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

[59] Minnesota Pollution Control Agency, http://www.pca.state.mn.us/climatechange/, measured in Minneapolis, MN
[60] Minnesota Pollution Control Agency, http://www.pca.state.mn.us/publications/aq1-31.pdf
[61] http://climate.umn.edu/climatechange/climatechangeobservedNu.htm
[62] http://www.pca.state.mn.us/climatechange/

were recorded in 1997, 1998, and 1999.[63] Seasonal temperature trends for summer and winter in Minnesota are shown in Figure 7.

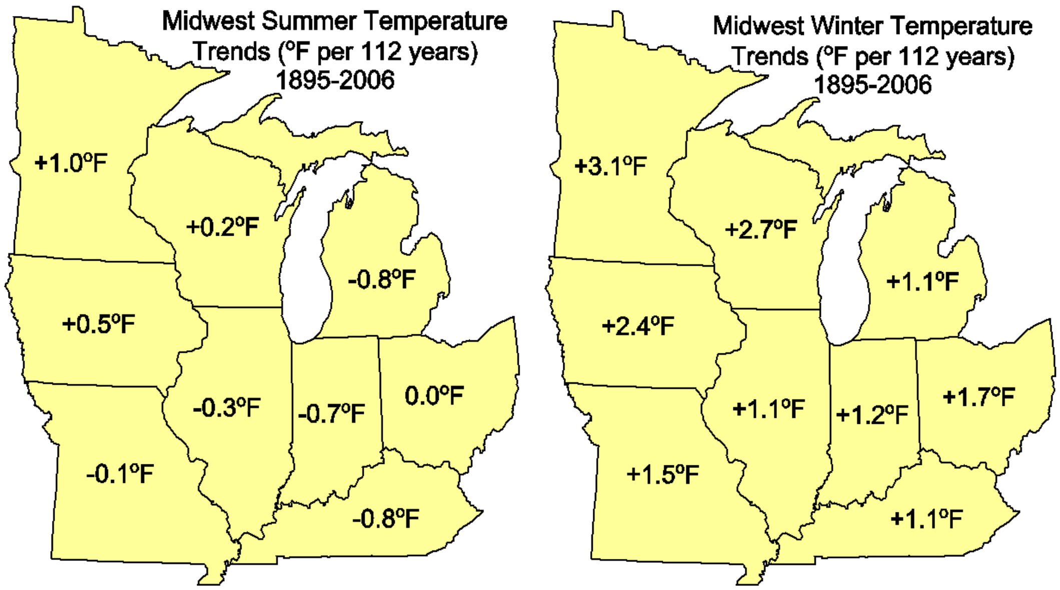


Figure 7. Temperature trends for winter and summer seasons in Minnesota 1895-2006[64]

[63] Minnesota Department of Natural Resources, http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html

[64] http://mrcc.sws.uiuc.edu/climate_midwest/mwclimate_change.htm#

Historic trends and projections of greenhouse gas emissions

Over the earth's history atmospheric greenhouse gas levels have fluctuated due to warming and feedbacks related to the earth's orbital cycles, volcanic events and other natural contributors to greenhouse gas 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 greenhouse gases (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)[65].

[65] http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf

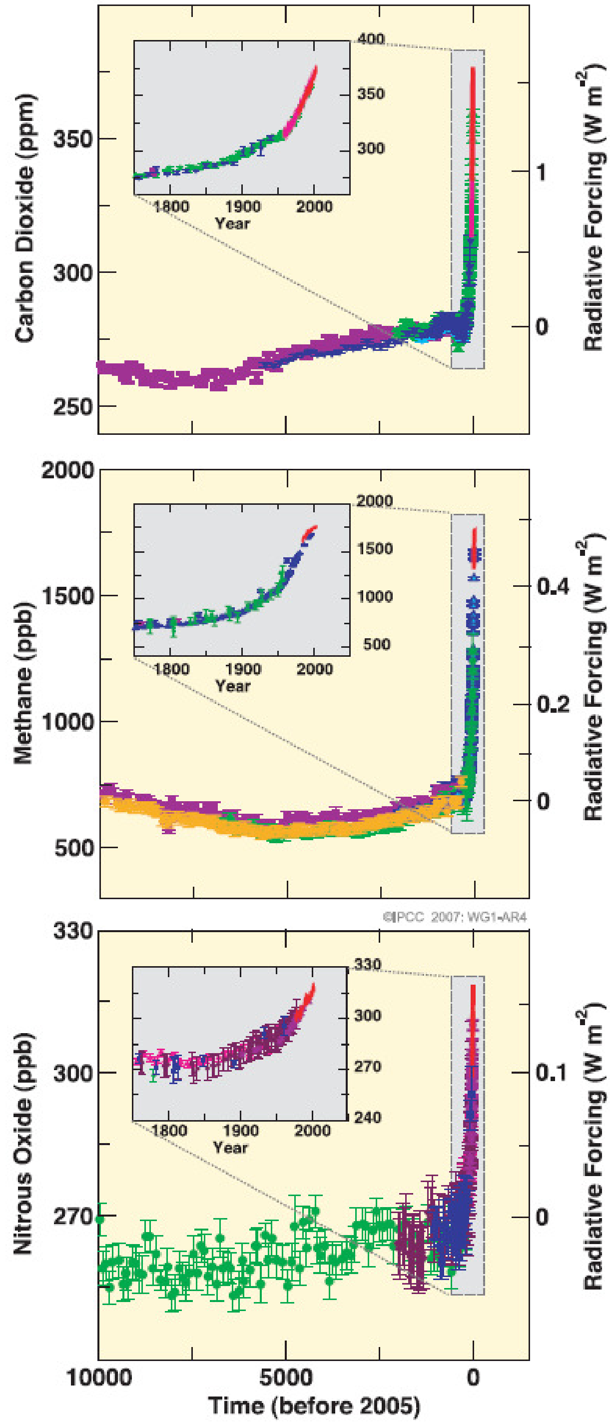


Figure 8. Global trends in greenhouse gas levels derived from paleo-proxy and instrumental records for the past several thousand years[66].

[66] http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf

At the global scale, anthropogenic greenhouse gas emissions result primarily from the burning of fossil fuels with land use and land use changes representing a secondary, but notable, source of anthropogenic greenhouse gas emissions. As shown in Figure 9, global anthropogenic emissions of CO_2 to the atmosphere have been steadily increasing since the turn of the 19^{th} century[67].

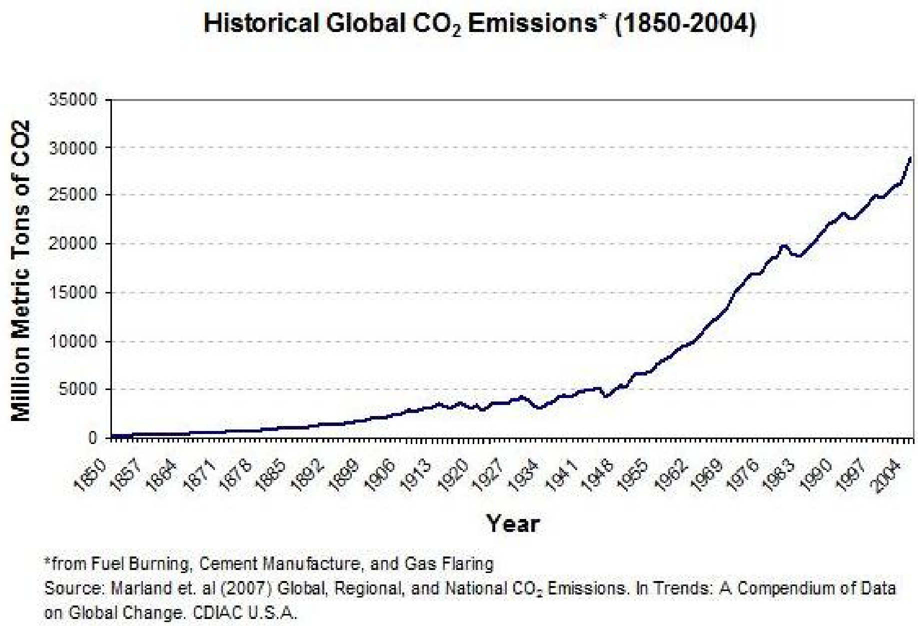


Figure 9. Global anthropogenic CO_2 emissions 1850 to 2004 due to fossil fuel burning, gas flaring and cement manufacture[68]

IPCC projections of future greenhouse gas 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 greenhouse gas emissions, and the development of new and more efficient energy sources. All projected scenarios show a trend toward increasing greenhouse gas emissions through the middle of this century[69].

[67] http://www.pewclimate.org/facts-and-figures/international/historical
[68] http://www.pewclimate.org/facts-and-figures/international/historical
[69] http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission/

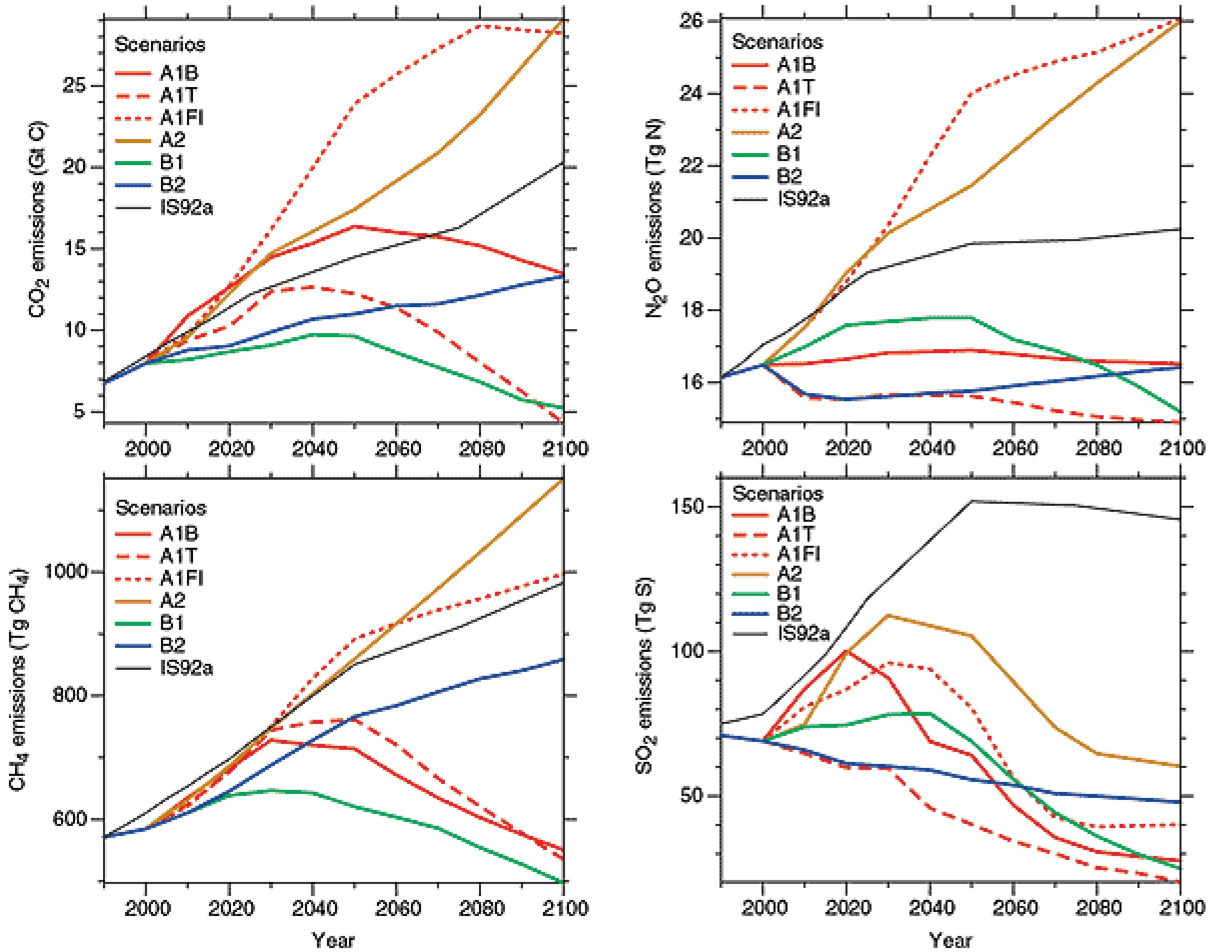


Figure 10. IPCC SRES Projections[70]

[70] http://www.ipcc.ch/ipccreports/tar/vol4/english/wg1figts-17.htm. 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,

In the United States, greenhouse gas emissions are primarily generated in the combustion of fossil fuels for energy. Fossil fuels burned to run cars and trucks, heat homes and businesses, and produce electricity are responsible for about 98% of U.S. carbon dioxide emissions, 24% of methane emissions, and 18% of nitrous oxide emissions. In 2006, total U.S. greenhouse gas emissions were 7,054.2 Teragrams CO_2 equivalent. Overall, total U.S. emissions have risen by 14.7 percent from 1990 to 2006. Emissions fell slightly from 2005 to 2006, decreasing by 1.1 percent (75.7 Tg CO_2 Eq.). The Fourth U.S. Climate Action Report[71] concluded that U.S. carbon dioxide emissions have increased by approximately 20 percent over the period 1990-2004. Over this same period, methane and nitrous oxide emissions have decreased by 10 percent and 2 percent, respectively. In 2006, carbon dioxide emissions, resulting from the energy related combustion of petroleum, coal, and natural gas represented 82 percent of total U.S. anthropogenic greenhouse gas emissions. Anthropogenic methane emissions from landfills, coal mines, oil and natural gas operations, and agriculture represented 9 percent of total U.S. anthropogenic greenhouse gas emissions in 2006 emissions. During this same period, nitrous oxide emitted through the use of nitrogen fertilizers, from burning fossil fuels and from certain industrial and waste management processes represented 5 percent of total U.S. anthropogenic greenhouse gas emissions[72]. Historic estimated annual U.S. greenhouse gas emissions from anthropogenic are shown in Figure 11.

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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.

[71] http://www.state.gov/documents/organization/89652.pdf

[72] http://www.eia.doe.gov/bookshelf/brochures/greenhouse/Chapter1.htm

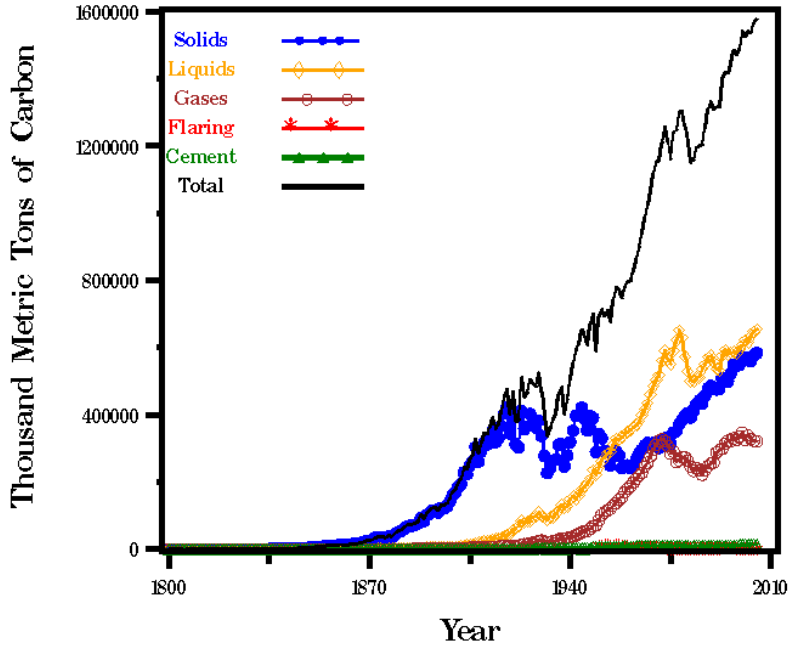

Figure 11. U.S. Carbon emissions 1800-2004.[73]

Like global greenhouse gas emission projections, trends in future U.S. greenhouse gas emissions depend critically on future economic growth, population growth, and the success of alternative energy and energy efficiency measures. Figure 12 shows historic U.S. greenhouse gas emissions and projected U.S. greenhouse gas emissions under two potential futures for the years 2012 and 2020. These projections consider national trends in population growth, long-term economic growth potential, historical rates of technology improvement, normal weather patterns, and reductions in emissions due to implemented policies and measures. The *Full Implementation of Climate Programs and Measures* scenario presented in Figure 12 highlights the potential greenhouse gas intensity reductions associated with fulfillment of President Bush's commitment to reduce greenhouse gas intensity and represents a 4 percentage point improvement in absolute terms over the projected U.S. *Business As Usual* greenhouse intensity projections. This corresponds to a 367 Teragram reduction in U.S. carbon dioxide equivalents by 2012 relative to *Business As Usual* projections. Under both the *Business As Usual* path and the *Full*

[73] http://cdiac.ornl.gov/trends/emis/usa.html

Implementation of Climate Programs and Measures path, gross emissions are projected to rise under both scenarios due to continued population and economic growth[74].

U.S. GHG emissions from energy consumption and other anthropogenic sources are projected to grow from historic levels, although emissions projected with the *Full Implementation of Climate Programs and Measures* are lower than under the *Business As Usual* baseline.

GREENHOUSE GASES	HISTORICAL GHG EMISSIONS			PROJECTED GHG EMISSIONS			
	Business As Usual			Business As Usual		Full Implementation of Climate Programs and Measures[7]	
	2000[1]	2002[1]	2004[1]	2012[2]	2020	2012[2]	2020
Energy-Related CO_2[3]	5,534	5,502	5,657	6,318	6,931	6,060	6,447
Nonenergy CO_2[4]	331	314	331	361	396	361	396
Methane	567	560	557	621	667	599	621
Nitrous Oxide	416	407	387	383	399	380	397
High GWP Gases	135	133	143	434	622	312	417
Adjustments[5]	0	0	0	-3	52	-3	52
Total Gross Emissions	**6,982**	**6,916**	**7,074**	**8,115**	**9,067**	**7,709**	**8,330**
Sinks[6]	-760	-769	-780	-776	-675	-806	-709
Total Net Emissions	**6,223**	**6,147**	**6,294**	**7,340**	**8,392**	**6,903**	**7,621**
GROSS GHG INTENSITY							
GDP (billions of 2000 dollars)		$10,075		$13,793		$13,793	
Gross GHG Intensity		686		588		559	
2002–12 Gross GHG Intensity Reduction				-14.3%		-18.6%	

Notes:
[1] Historical emissions and sinks data are from U.S. EPA/OAP 2006c. Bunker fuels and biomass combustion are not included in inventory calculations.
[2] 2012 data are interpolated when specific data are unavailable.
[3] Energy-related CO_2 projections are calculated from U.S. DOE/EIA 2006a CO_2, with any CO_2 from nonenergy sources removed.
[4] Nonenergy CO_2 includes emissions from nonenergy fuel use and other industrial emission sources.
[5] Adjustments include international bunker fuels and emissions in U.S. territories.
[6] Sinks projections are extrapolated from U.S. EPA/OAP 2006c, with programs and measures projections from the U.S. Department of Agriculture.
[7] Programs and measures reductions for 2002 are presented in Chapter 4, but are not shown in this table because historical data are used to calculate the GHG intensity in 2002. Programs and measures reductions shown in this table are net of 2002 reductions for the purpose of calculating the reduction in emissions intensity from the initial implementation of the President's policy in 2002.

Figure 12. Projected U.S. Greenhouse Gas Emissions[75]

Estimates of historic greenhouse gas emissions in the state of Minnesota follow the global and national trend of generally increasing emission levels. Minnesota's greenhouse gas emissions are estimated to have increased about 20% since 1988.

Trends in historic greenhouse gas 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 13 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

[74] http://www.state.gov/g/oes/rls/rpts/car/90324.htm
[75] http://www.state.gov/g/oes/rls/rpts/car/90324.htm

in statewide greenhouse gas emissions. Since the late 1980s Minnesota has trended toward rapid growth in greenhouse gas emissions. The ten-year average annual rate of growth in emissions from 1988 to 1997 is about 2 percent per year[76].

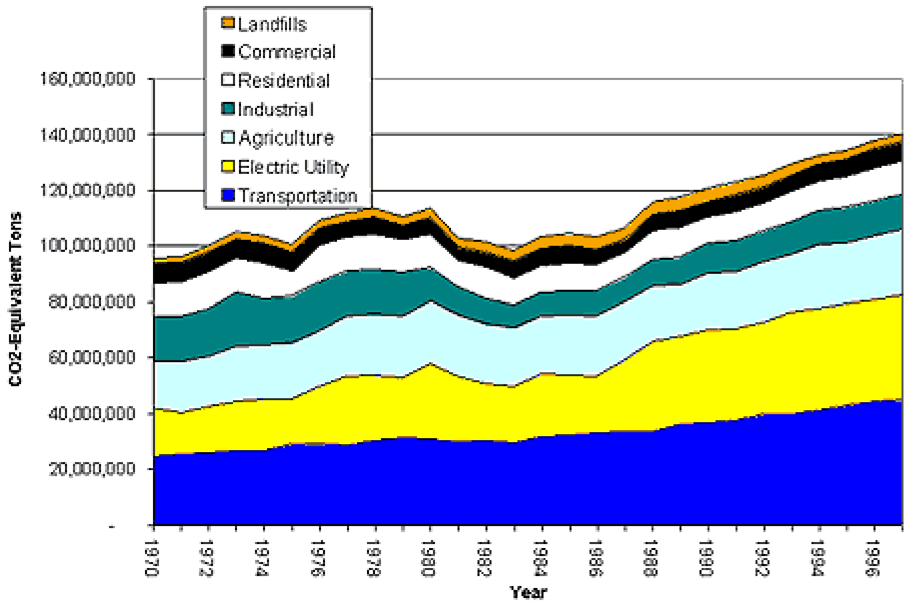

Figure 13. Greenhouse Gas Emissions in Minnesota: 1970-1997[77]

Recent state greenhouse gas reduction goals, energy efficiency targets and renewable portfolio standards will likely shape future greenhouse gas emissions in Minnesota. Minnesota is one of many states that have voluntarily joined The Climate Registry, committing to consistent and systematic monitoring of statewide greenhouse gas emissions. 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.

[76] http://www.pca.state.mn.us/climatechange/

[77] 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".

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[78].

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[79].

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 greenhouse gases in the Earth’s atmosphere since preindustrial times. Similarly, scientists can conclude that because the major greenhouse gases emitted by humans are known to have atmospheric residence times on the order of tens to hundreds of years, atmospheric greenhouse gas 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 greenhouse gas 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[80].

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 greenhouse gas concentrations". The body of evidence from a growing number of scientific studies strongly suggests but cannot indisputably prove that rising levels of anthropogenic greenhouse gases 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 greenhouse gases continue to rise, average global temperatures will also continue to rise and precipitation patterns will change.

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[78] http://www.pca.state.mn.us/publications/aq1-31.pdf
[79] http://www.epa.gov/climatechange/science/stateofknowledge.html
[80] 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.

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. 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 in temperature and six inches in precipitation.[81] 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.[82]

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,

[81] Minnesota Department of Natural Resources, http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html
[82] Minnesota Department of Natural Resources, http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html

these trees were replaced 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.[83]

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[84]. The range of potential future anthropogenic forcing on the climate system adds an additional layer of uncertainty to climate model projections.

A recent 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[85]. Model projections indicate that average annual temperatures in the great lakes region are expected to increase throughout the 21st century with some variation across the region and substantial variation by season. Model temperature projections for the region during the summer and winter seasons are shown in Figure 14. Model results project 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 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

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[83] Minnesota Department of Natural Resources, http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html

[84] IPCC 2007, Fourth Assessment Report, Working Group 1 Climate Change 2007: The Physical Science Basis.

[85] The study Confronting Climate Change in the Great Lakes Region (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.

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.

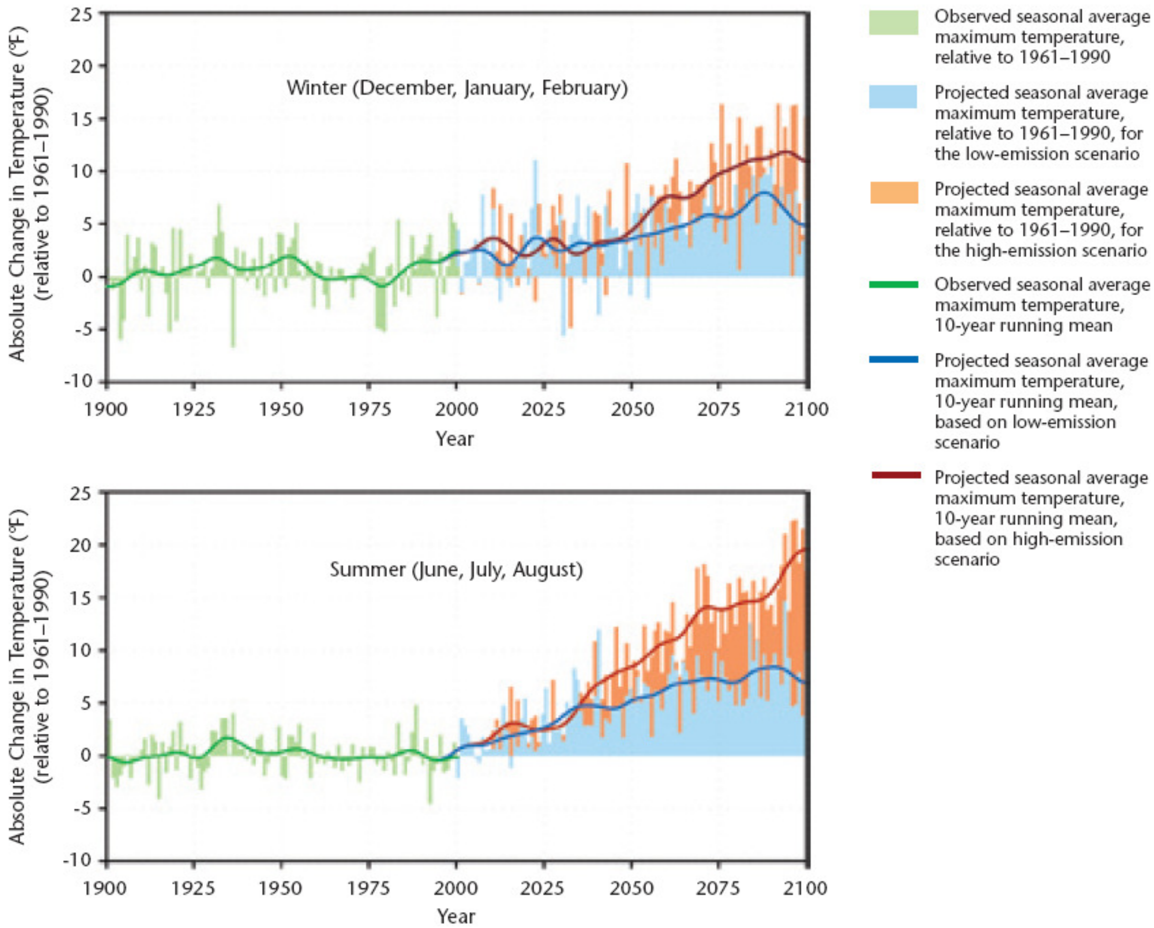

Figure 14. Great Lakes Region observed and projected average surface temperature[86]

Variation in temperature increases is likely to be observed across the region with areas centered near the great lakes showing smaller temperature increases (Figure 15). 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.

[86] http://ucsusa.org/assets/documents/global_warming/greatlakes_final.pdf

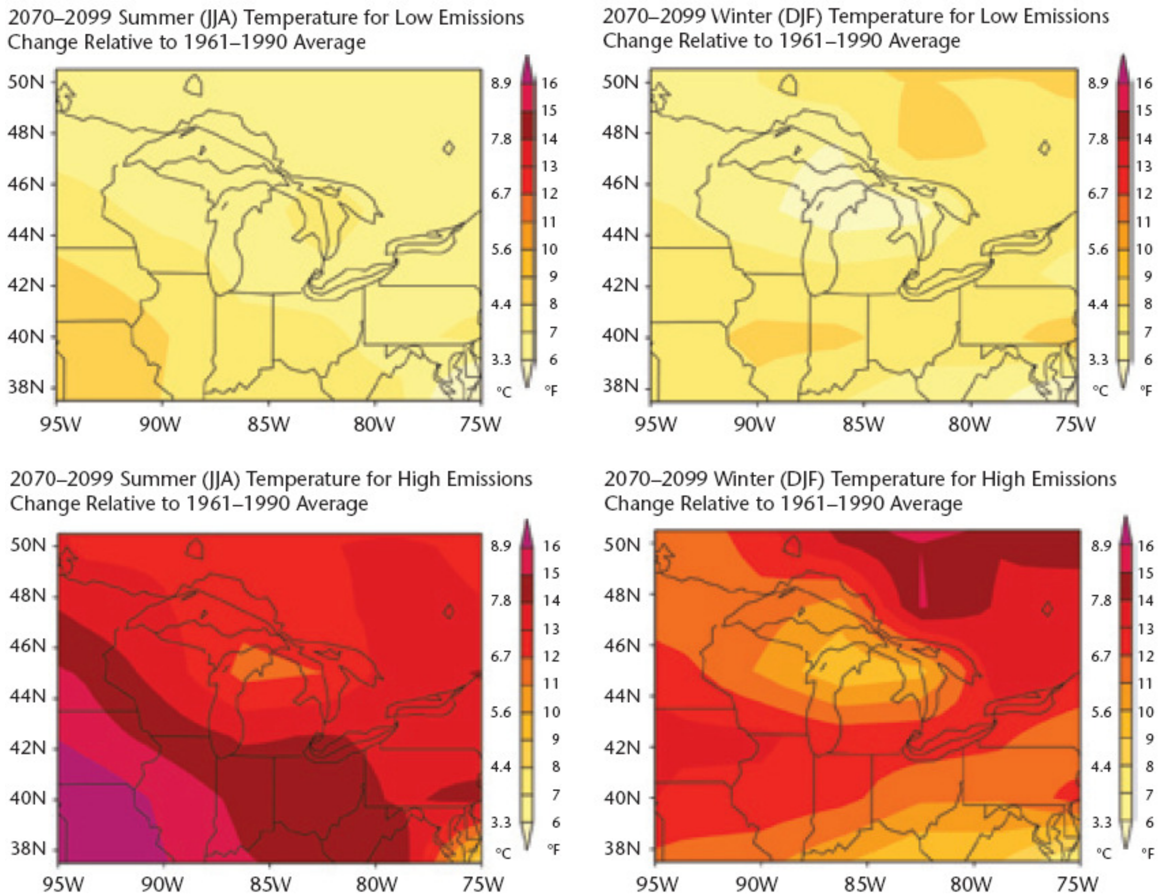

Figure 15. Projected summer and winter temperature changes 2070-2099[87]

A Minnesota-specific compilation of model results for the Great Lakes Region suggests that surface temperatures in Minnesota are projected to 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 greenhouse gas emissions.[88] 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 Nebraska or a warmer, humid climate like that of Ohio.[89] Climate and vegetation zones are predicted to shift northward about

[87] http://ucsusa.org/assets/documents/global_warming/greatlakes_final.pdf
[88] Minnesota – Confronting Climate Change in the Great Lakes Region, http://ucsusa.org/assets/documents/global_warming/ucssummarymnfinal.pdf
[89] Minnesota Pollution Control Agency, http://www.pca.state.mn.us/publications/aq1-31.pdf

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.[90]

Precipitation

Like regional temperature projections, model projections of future precipitation changes are uncertain, particularly at the regional and local scales. However, most regional model 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[91].

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[92]. 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. Overall, winters are projected to become wetter and summers are projected to become drier across the region. Winter and spring precipitation is likely to increase, especially in higher latitudes and downwind or the great lakes. Summer precipitation may decrease by as much as 50%. Projected seasonal precipitation changes are shown in Figure 16[93].

[90] Minnesota Pollution Control Agency, http://www.pca.state.mn.us/publications/aq1-31.pdf
[91] IPCC, http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch11.pdf
[92] Confronting Climate Change in the Great Lakes Region (http://ucsusa.org/assets/documents/global_warming/greatlakes_final.pdf), see also footnote 133
[93] Confronting Climate Change in the Great Lakes Region (http://ucsusa.org/assets/documents/global_warming/greatlakes_final.pdf), see also footnote 133

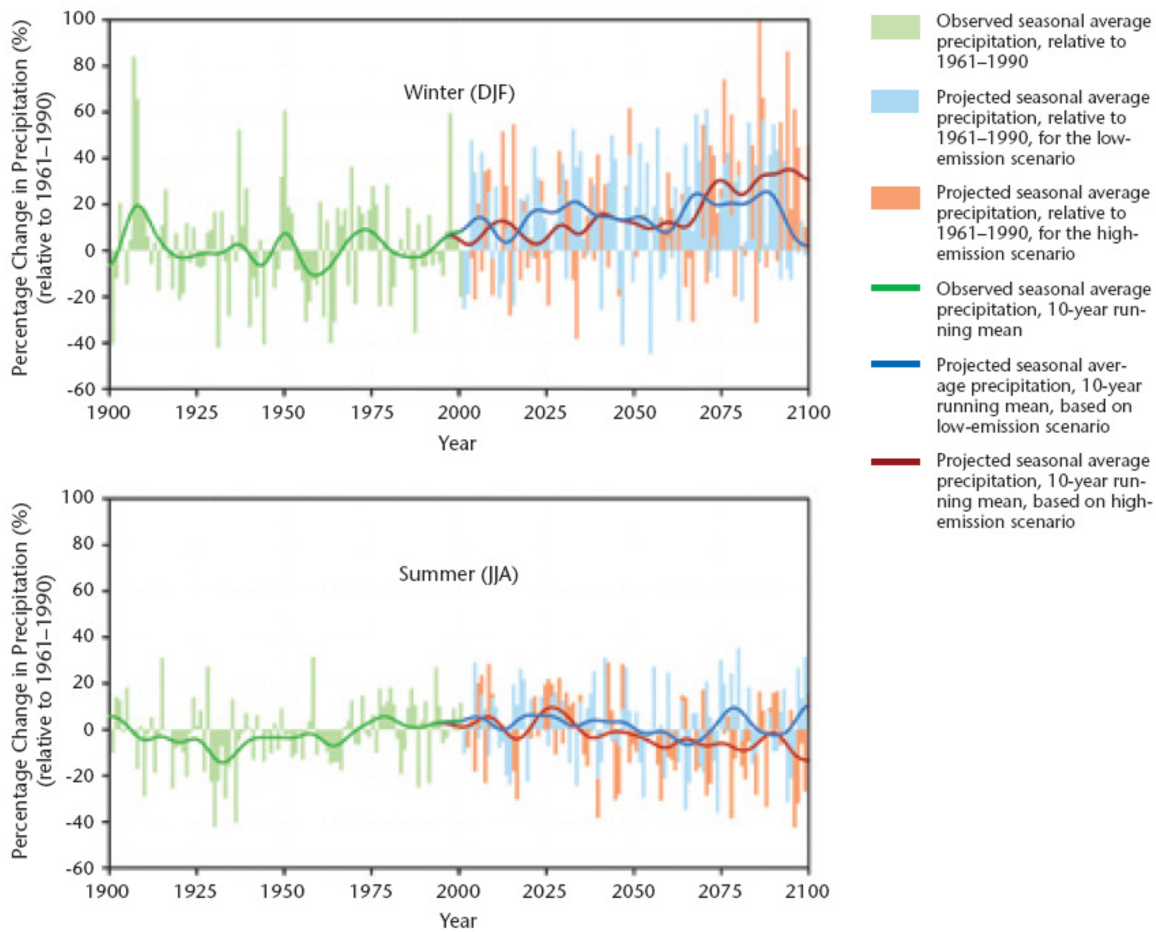

Figure 16. Observed and projected daily average precipitation for summer and winter seasons in the Great Lakes Region[94]

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 17 shows projected changes in the frequency of heavy rainfall events for the Great Lakes Region[95]. It is possible that increased precipitation will also change patterns of severe weather events; however, these projected effects are uncertain.[96] Some studies indicate that the magnitude of

[94] http://ucsusa.org/assets/documents/global_warming/greatlakes_final.pdf
[95] Confronting Climate Change in the Great Lakes Region (http://ucsusa.org/assets/documents/global_warming/greatlakes_final.pdf), see also footnote 133
[96] Minnesota Pollution Control Agency http://www.pca.state.mn.us/climatechange/#minnesota

snowfall events and duration of snow may decrease in Minnesota as a consequence of climate change.[97]

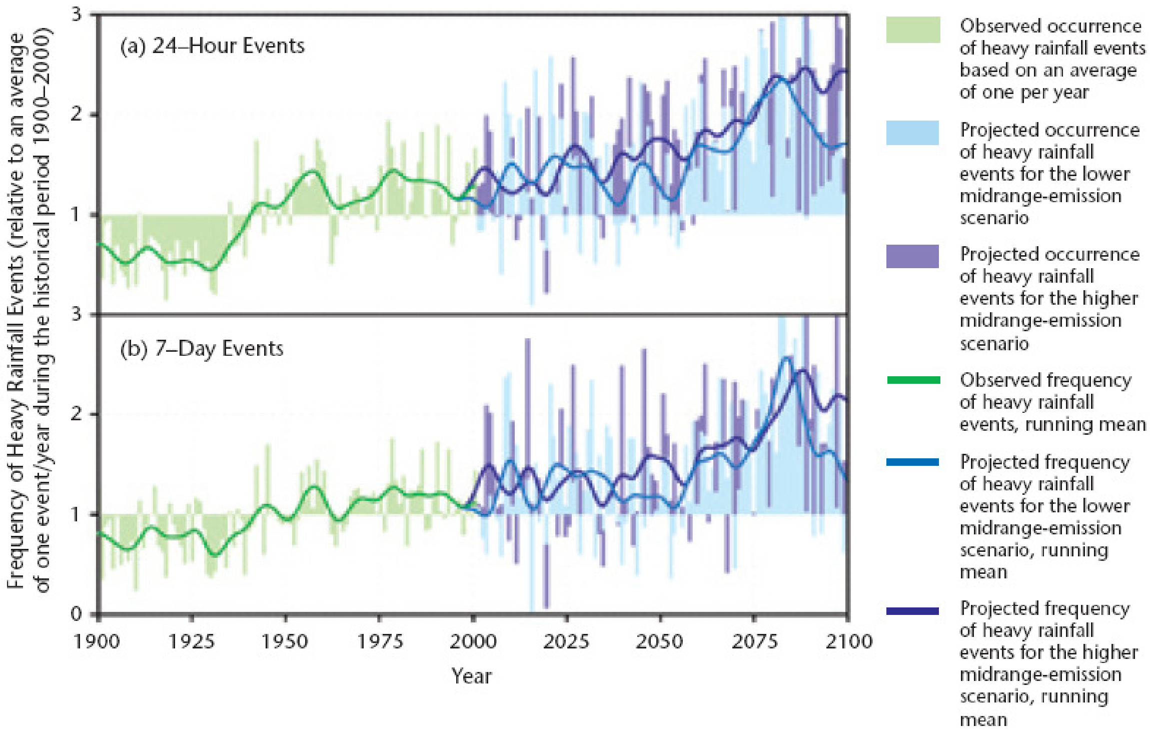

Figure 17. Projected change in frequency of heavy rainfall events in the Great Lakes Region[98]

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[99]. 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 whether moisture would be transported by the atmosphere,

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[97] IPCC, http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch11.pdf
[98] http://ucsusa.org/assets/documents/global_warming/greatlakes_final.pdf
[99] http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html

eventually falling as precipitation in other regions.[100] If water lost as the result of enhanced evapotranspiration is returned to Minnesota's ecosystems in the form of increased precipitation, this could create the potential for increased flooding throughout Minnesota.[101]

Surface water temperatures are also likely to increase with increased air temperatures. Estimates that double atmospheric carbon dioxide concentrations indicate a resulting 3 to 4 °F increase in lake and stream temperatures. If the forests of Minnesota are replaced with prairie ecosystems, surface waters that depended on forest cover for shade could see temperature increases of 11 to 14 °F[102].

Shortening winters may enhance these warmer surface water temperatures. 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.

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. 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.

Forests

Minnesota's northern coniferous forests are already showing potentially climate related signs of decline as spruce trees in northern forests have begun to die. 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. In comparison to the timeline of earth processes, these changes will occur rapidly, with forests transitioning in the course of a single generation.[103] 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 drier as it gets

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[100] Minnesota Department of Natural Resources, http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html
[101] Minnesota Pollution Control Agency http://www.pca.state.mn.us/climatechange/#minnesota
[102] http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html
[103] Minnesota Pollution Control Agency, http://www.pca.state.mn.us/climatechange/#minnesota

warmer, it is likely that forests will be replaced by prairie ecosystems.[104] In this scenario, Minnesota's forested area could decrease by 50 to 70% (Figure 18). 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.[105] 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.[106]

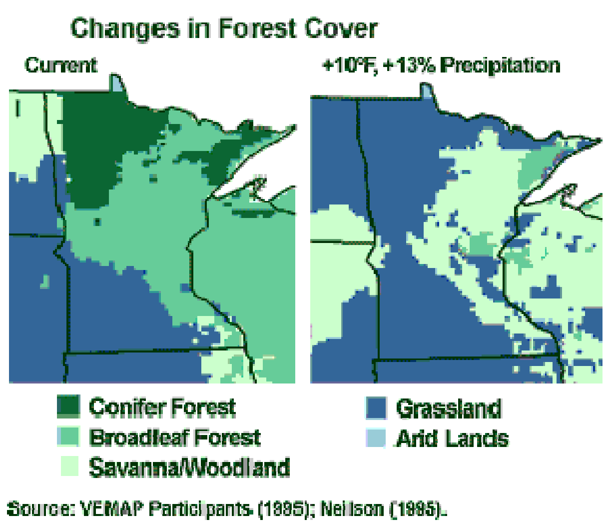

Figure 18. Potential climate change impacts on Minnesota's forests

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,

[104] Minnesota Pollution Control Agency, http://www.pca.state.mn.us/publications/reports/mnclimate-action-plan.pdf
[105] Minnesota Pollution Control Agency http://www.pca.state.mn.us/climatechange/#minnesota
[106] Minnesota Department of Natural Resources, http://www.dnr.state.mn.us/volunteer/janfeb01/warming.html

leading to more extreme summer stratification, and lower oxygen levels may contribute an additional threat to Minnesota's aquatic ecosystems.

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.

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.[107] 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.[108]

Human Health

Changes in Minnesota's climate and increased temperatures may cause increased likelihood of heat related illness and deaths. A Minneapolis study indicates the possibility that 3°F summer warming could coincide with a tripling in the rate of heat-related deaths in Minnesota.[109] Warming temperatures also increase the likelihood of insect-borne illnesses, by creating more potential habitats for insects such as mosquitoes.[110] Malaria, dengue fever, and yellow fever are all transported by mosquitoes, whose territory climate change could effectively expand northward into Minnesota.[111]

2.2. Proposed Project and Climate Change

The proposed NorthMet 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

[107] Minnesota Pollution Control Agency http://www.pca.state.mn.us/climatechange/#minnesota
[108] Minnesota Pollution Control Agency, http://www.pca.state.mn.us/climatechange/#minnesota
[109] Minnesota Pollution Control Agency, http://www.pca.state.mn.us/climatechange/#minnesota
[110] http://proteus.pca.state.mn.us/oea/reduce/climatechange.cfm
[111] Minnesota Pollution Control Agency, http://www.pca.state.mn.us/climatechange/#minnesota

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 greenhouse gas 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 greenhouse gas 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 lifetime of the project, which is approximately 20 years. As noted earlier in the report, models suggest that the temperature may increase by 3 – 4 degrees F during the lifetime of this project. 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.

Details regarding the greenhouse gas emissions for this project are discussed in Section 3.1 and in Appendix A. Based on this information, the proposed project is estimated to emit a total of 744,648 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 greenhouse gas emissions. Estimated emissions from the proposed project will constitute 0.0019 percent of the total annual global greenhouse gas emissions estimated in 2004.[112] 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 greenhouse gas emissions at the project level on global, national, regional, and local climate, the impacts of project greenhouse gas emissions on an individual environmental receptor cannot be accurately or meaningfully estimated. Project emissions represent a very small fraction of annual global greenhouse gas 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

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

regional and local scales, as well as the increase in model-simulated variability at these smaller scales.[113] 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. In addition, most of the predictions made regarding changes to global, national, regional, and state climate include assumptions about increases in greenhouse gas emissions. Therefore, these predictions to some extent already encompass the proposed NorthMet Project.

Because there are no models to predict the exact impacts of greenhouse gas emissions from this 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.

2.2.1. Wetlands

The wetlands at the PolyMet 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 PolyMet 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

[113] 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.

levels could change the competitive balance among the plants and invertebrates found in some wetland types. The majority of the wetlands present at the PolyMet 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 increase in air and water temperature and shorter winter season could lead to a change in the types of plants in the wetlands. 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 this 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 wetland impacts expected to result from the project cover a total of 897 acres (869 acres of direct impact and 28 acres of indirect wetland hydrologic impacts) [From Table 5.1-A: Total Wetland Impact Detail; Revised November 19, 2008 - included as Attachment E in Appendix A of this report] . 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.

Greenhouse gas emissions due to the direct removal and stockpiling 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 NorthMet 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 this 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 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 seep 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 wide-reaching 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 greater flow through 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.

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 additional carbon dioxide in the atmosphere. Greater evaporation may require additional modification of the basin interior to maintain a pond in closure. In addition, the East and West Pits may take longer to fill. A decrease in the amount of liner yields may occur because of increased evaporation from the stockpile surfaces (both active and reclaimed), resulting in smaller liner leakage rates to groundwater. Other impacts could include changes in soil moisture, which may affect water chemistry of seepage at the 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 greenhouse gas induced climate change could potentially change the air quality impacts from the NorthMet 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."[114]

Changes or increased variability in weather patterns could potentially result in a different dispersion pattern of pollutants emitted from the NorthMet 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 on the 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.

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. There are two potential deposition scenarios that could occur under this type of change in Minnesota's climate.

1) No change (or slight decrease). Two important assumptions for this scenario are a) that current trends in SO_2 and NO_x emissions, and foreseeable regulatory actions, continue such that SO_2 and NO_x emissions do not increase significantly in the future; and b) the frequency of precipitation events in Minnesota increases. If there is an increase in precipitation from an increase in frequency of events, frequent wash-out of sulfate and nitrate aerosols from the atmosphere over Minnesota and the project area may occur. The result may be an overall decrease in the concentration of sulfate and nitrate aerosols in the individual precipitation events, which may reduce wet deposition. However, based on monitoring data available from the National Atmospheric Deposition Program (NADP) for several locations in the United States,

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

it is likely that any decrease in sulfate or nitrate concentration in precipitation may be offset by the increased precipitation volume. As a result, there may be no change in deposition.

2) Increasing deposition. An important assumption for this scenario is the same as in scenario 1 above, that current trends in SO_2 and NO_x emissions and foreseeable regulatory actions continue such that SO_2 and NO_x emissions do not increase significantly in the future. A second assumption is that the frequency of precipitation events does not increase, but rather, the individual events have more associated rainfall. A third critical assumption is that sulfate and nitrate aerosol concentrations in the atmosphere would be similar to current levels, and that the sulfate and nitrate concentration in each precipitation event do not change appreciably from current levels (this assumption is reasonable if SO_2 and NO_x emissions do not increase significantly and precipitation frequency does not increase). If all three assumptions are valid, then it is possible that wet deposition in Minnesota could increase because of the increase in rainfall. Monitoring data from the NADP indicate that locations with similar sulfate and nitrate concentrations in precipitation but higher precipitation levels have higher deposition. Therefore, it is possible that sulfate and nitrate deposition in the project area may increase under future conditions.

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.[115] 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[116] (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. 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.

When compared with similar metal mineral processing facilities, the emissions of NO_x and SO_2 from NorthMet operations are estimated to be low. This is because the hydrometallurgical

[115] 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

[116] 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.

process proposed for the NorthMet 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 NorthMet 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 NorthMet 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 NorthMet Project.

The three wildlife species of interest for this 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 this project. However, if the water becomes warmer as a result of climate change and leads to a decrease in fish population, this could affect the bald eagle as its main food source is fish. Conversely, warmer water could be hospitable to different species of fish which could be as beneficial to the eagle population as current fish species. 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 causes 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 NorthMet Project will result in impacts to wetlands, forests, and other cover types that are likely to affect carbon storage and sequestration in these ecosystems. However, reclamation and mitigation activities associated with the project can work to offset carbon losses caused by project activities. The magnitude of potential offset depends on many factors, including impacted and restored cover types and 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 a high degree of 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. The effect of the reclamation effort on the terrestrial carbon cycle is not quantitatively assessed in this report.

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 Northern Minnesota, restoring wetlands re-establishes the original hydrologic conditions. 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. 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 probably result in small positive net forcing rates, based on the consideration of carbon equivalent fluxes of both CO_2 and CH_4.[117] 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. Recent research has pointed to similar ecosystems, namely shallow lake systems, being sinks that result in negative net forcing rates.[118] 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. Additionally, some tentative conclusions can be drawn about the value

[117] 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)."

[118] 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."

of possible wetland mitigation options: Given their limited/seasonal pooling, restoration of type 1 and 2 ephemeral wetlands may yield the strongest potential for generating a net carbon sink with low rates of CH_4 emission, and thus a negative net rate of forcing.

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 short 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. Carbon sequestration rates for hybrid poplar biomass production are large as well, ranging 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 in Minnesota. However, most hybrid poplar biomass production sites reach peak production after 7 to 10 years.

2.2.5.2 Project Impacts on Cover Types

Project impacts on cover types at the Mine Site, Tailings Basin, 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 covering 3,016 acres. 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.

Approximately 897 acres of wetland resources will be impacted by the proposed project (869.3 acres of direct impacts, 28 acres of indirect hydrologic impacts). 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 (596 acres at the Mine Site). 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 mined 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 greenhouse gas 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, 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 1,151 acres, including 603 acres of impacted mixed pine-hardwood forest, 164 acres of impacted jackpine forest, 98 acres of impacted aspen forest/aspen-birch forest, and 230 acres of impacted grass/brushland. 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

Compensitory 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. According to the PolyMet Mining Wetland Mitigation Plan (Barr Engineering Co., RS20-T Draft-03, January 15, 2008) 1,123 acres of off-site wetland restoration mitigation have been planned. This mitigation will take place primarily at two sites in Northern Minnesota. Assuming a 1.25:1 replacement ratio for wetlands of the same type, a 1.5:1 ratio for wetlands of different types and 1:4 ratio for upland buffer, off-site mitigation is expected to provide direct compensatory wetland mitigation for 897 acres of projected impacts. In terms of total area, offsite mitigation acreage is expected to exceed impacted acreage for all wetland types except for Type 8 (open bog and coniferous bog). In terms of total compensated impacts, mitigated acres of wetland Type 1 (seasonally flooded), Type 2 (fresh wet meadow and sedge meadow), Type 3 (shallow marsh), Type 4 (deep marsh), Type 5 (shallow, open water), Type 6 (shrub-carr and alder thicket) and Type 7 (hardwood swamp and coniferous swamp) will exceed project impacts on wetlands of these types. This additional mitigation of wetland types other than Type 8 (open and coniferous bog) will contribute to compensating for the project's impacts on Type 8 wetlands.

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 NorthMet 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. Attempting to compare carbon cycle effects of project wetland impacts and mitigation measures raises complex and potentially subjective issues regarding the how possible short-term carbon releases from wetland disruption should be weighed against future sequestration.

Reclamation and re-vegetation of non-wetland areas at the Mine Site will involve vegetative succession on stockpiles and at the East Pit. Stockpiles will be planted with red pine on the slopes and seeded with grasses/forbs at the tops and bench flats (to minimize the potential for deep-rooted trees from penetrating the cap). Within a few decades, these areas should be occupied by forest. 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.

Terrestrial carbon cycle timescales and temporal delays in restoration may also impact the net carbon cycle effects of the project and restoration activities. 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 wetland disturbance. Carbon accumulation in forest ecosystems, on the other hand, occurs relatively quickly, and afforestation and reforestation may offset forest disturbance over relatively short timescales. Temporal delay in wetland mitigation, therefore, results in slightly lower "foregone" carbon sequestration for each year of delayed sequestration than a delay in forest restoration. Over longer timescales, however, wetlands have greater potential for continued sequestration.

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 greenhouse gas 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, greenhouse gas 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 1 below. 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 1 Project Greenhouse Gas (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)
Mine Site (mining equipment and vehicles, ore hauling by rail)	41,989		
Plant Site (ore crushing, concentrating, metal recovery)	193,659		
Subtotal	235,648	509,000 **[4]**	744,648

Units = CO_2-e, m.t./yr = Greenhouse gas 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 NorthMet 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 235,648 m.t./yr with the estimate of 509,000 m.t./yr indirect emissions (235,648 + 509,000 = 744,648 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 NorthMet Project is estimated to be approximately 59.3 megawatts. The electricity to be used by the NorthMet 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.

3.1.2. Terrestrial Carbon Cycle Impacts

In addition to the emissions of greenhouse gases directly from the NorthMet facility 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. Based on the wetland delineation for the NorthMet Project[119], approximately 869 acres of wetland resources will directly impacted by the proposed project. Based on the figures provided in recent wildlife habitat surveys[120], it is expected that the project will impact approximately 1,152 acres of forested land. 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 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. Project activities will likely result in partial or

[119] 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.
[120] 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.

total loss of aboveground forest carbon and some loss of carbon sequestration capacity. Additionally, some carbon losses from forest soils might occur.

Despite the many 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 four wetland carbon cycle impact categories have been calculated and are reported in Table 2:

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) Annual emissions from indirectly impacted wetlands due to potential water level drop
4) Loss of annual carbon sequestration capacity due to the disturbance of wetland plant communities discounting methane emissions from wetlands as a conservative assumption.
5) 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, and indirect hydrologic impacts to wetlands. The loss of carbon sequestration capacity in directly and indirectly impacted wetlands) 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.

It is assumed that upon closure the CO_2 emissions from the stockpiled peat and indirectly impacted wetlands would decrease and potentially result in net carbon sequestration over time. Most of the stockpiled peat is anticipated to be stored permanently in stockpiles, which will be planted over in situ. A number of processes may contribute to a diminution and even reversal of the net CO_2 emission rate, including the compaction of stockpiles and consequent removal of air pockets rich in oxygen, and the growth of vegetation on the surface of the stockpile, which will both utilize peat carbon and act as a net atmospheric carbon sink. The majority of the indirectly impacted wetlands, which are located by the West Pit, will recover much of their pre-project watershed through the filling in of the drainage ditch to the north. With this precipitation input restored, it is possible for the wetlands to return to being a net CO_2 sink over time. The restoration of carbon sequestration in both these cases is subject to significant temporal and physical uncertainty, as was the case with all of the quantified terrestrial carbon cycle impacts. However, the potential post-closure emissions from these sources are thought to be short-lived.

Table 2 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	1,780,000	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	135,000	High estimate
Source	**Pollutant**	**Emission Rate** (CO_2-e m.t./yr)	**Estimate Type [1]**
Stockpiled peatlands carbon emissions (high) [4]	CO_2	3271	High estimate
Stockpiled peatlands carbon emissions (low) [5]	CO_2	467	Unknown
Wetland sequestration capacity loss from direct impacts	CO_2	768	Central tendency
Emissions from indirectly impacted wetlands [5]	CO_2	208	High estimate
Wetland sequestration capacity reduction from indirect impacts [6]	CO_2	15	Unknown

Units = CO_2-e, m.t. = Greenhouse gas 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 which estimated the removal of 986,000 tons of peat from the Mine Site stockpile footprints and pits, 39,300 tons from storage areas and dikes, and 66,400 tons of peat from the Tailings Basin; not treated as a onetime emission. Other estimates of potential CO_2 storage in the mine site peat from stockpile footprints and pits range from 748,000 metric tons to 2.73 million metric tons. This estimate is not representative of an actual or assumed emission.

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

[4] Assumes carbon emission rate[121] of 3500 $g/m^2/yr$ (See Appendix A for full derivation)

[121] Ahlholm U. and J. Silvola.1990. CO2 release from peat-harvested peatlands and stockpiles. p. 1-12. In Posters. International Conference on peat production and use, June 11-15 1990. Jyvaskyla, Finland.

[5] Assumes carbon emission rate[122] of 500 $g/m^2/yr$, which coincides with rates from drained and relatively undisturbed peat (See Appendix A for full derivation)

[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)

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.

Similarly, the carbon stored in peat should not be assumed to all be emitted over a short time frame. Because some of this material will be stockpiled directly, some will be mixed with other overburden material and stockpiled, and the rest will be buried under roads and other constructed features, it will likely be a net emitter. However, the annual amounts will be dependent on a number of factors, including the stockpile surface area, water table level, levels of precipitation, and end use of cleared biomass.

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.[123] 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 3 below summarizes potential forest carbon cycle impacts from the project.

[122] 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.
[123] 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 3 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	217,000	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	1190	Central tendency

Units = CO_2-e, m.t. = Greenhouse gas 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.[124] 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 4.

[124] 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 4 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	6,770	High estimate
Annualized aboveground carbon loss from forests [2]	CO_2	10,800	High estimate
Stockpiled peatlands carbon emissions (high)	CO_2	3271	High estimate
Stockpiled peatlands carbon emissions (low)	CO_2	467	Unknown
Wetland sequestration capacity loss from direct impacts	CO_2	768	Central tendency
Forest sequestration capacity loss from direct impacts	CO_2	1190	Central tendency
Wetland sequestration capacity reduction from indirect impacts	CO_2	15	Unknown
Emissions from indirectly impacted wetlands	CO_2	208	High estimate
Total emissions (with high stockpiled peatland estimate)	*CO_2*	*23,000*	*High estimate*

Units = CO_2-e, m.t. = Greenhouse gas 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

The total annualized emissions due to groundcover disturbance for the project are 23,000 metric tons of CO_2 per year. This represents approximately 3.1% of the total direct and indirect CO_2 emissions from the project (744,648 metric tons of CO_2 per year). The total carbon stock impacted by the project is given below in Table 5. The carbon stored in stockpiles of peat was separated out into peat that will be stockpiled at the Mine Site and peat that will be stockpiled at the Tailings Basin.

Table 5 Impacted Terrestrial Carbon Stock Summary

Source	Pollutant	Carbon Stock (CO_2-e m.t.)
Aboveground carbon in impacted wetlands [1]	CO_2	135,000
Aboveground carbon in impacted forests [1]	CO_2	217,000
Total carbon stored in mine site peatland stockpile [2]	CO_2	1,671,000
Total carbon stored in Tailings Basin peatland stockpile [3]	CO_2	108,000
Total directly impacted carbon stock [4]	CO_2	2,066,000

Units = CO_2-e, m.t. = carbon stock as CO_2-equivalents, in metric tons

[1] Annualized results are generated by dividing the assumed one-time aboveground carbon emissions by the 20-year project life.

[2] Based on site studies of peat in overburden which estimated the removal of a total of 1,025,300 tons of peat at the Mine Site; not treated as a onetime emission.

[3] Based on estimated excavation of peat at the tailings basin

[4] The total does not include belowground carbon stock for non-peat wetlands and upland forests.

3.2. Changes in Carbon Footprint to Potential Alternative and Mitigation

A potential mitigation measure at the Tailings Basin and an alternative at the Mine Site are being considered for the NorthMet Project. Neither of these options is expected to significantly affect the carbon footprint for the project. The Tailings Basin mitigation measure, referred to as Tailings Basin Alternative, involves the installation of wells and pumping equipment on the benches of the existing tailings basin and installation of a pipeline from the Flotation Tailings Basin to the Partridge River. The alternative being considered at the Mine Site, referred to as RA1, involves the placement of the waste rock with the potential to generate acid in the East Pit after it has been mined out. Further details for both are provided below.

3.2.1. Tailings Basin Alternative

This alternative will involve the placement wells and pumping equipment on the benches of the existing tailings basin and installation of a pipeline from the Flotation Tailings Basin to the Partridge River downstream from Colby Lake. There would be a small incremental increase in the electrical load for the project resulting from the operation of the pumps. This will not significantly affect the total indirect emissions for the project if this alternative is adopted. The pipeline will be routed to the south through an existing pipeline easement from the Process Plant to the Canadian National Railway tracks. From this point the pipeline will proceed to the west along the railway easement to the Partridge River. This chosen route will help minimize wetland impacts. The magnitude and nature of the wetland impacts is currently being evaluated, but the effect of these impacts on the overall project carbon footprint is expected to be minimal.

The small electrical load for the pumps and the small additional wetland impacts from the pipeline will not significantly affect the carbon footprint for the project.

3.2.2. RA1 – No Long Term Water Treatment at Mine Site

Reasonable Alternative RA1 (no long term water treatment option at Mine Site) consists of the placement of potentially acid generating rock in temporary stockpiles during the first 11 years of mine operation. Thereafter, the potentially acid generating rock will be placed in the East Pit, which will be mined out after Year 11. Between Year 12 and closure, the rock in the temporary stockpiles will be transferred to the East Pit. This will result in a certain amount of "double handling" of rock that raised concerns over possible increases in air pollutant emissions. After the rock has been removed from the Category 2/3 (originally Category 3) waste rock and Category 3 lean ore stockpiles, these footprints will be used for permanent placement of Category 1 waste rock that was planned to be disposed in the East Pit under the proposed project.

Ton-miles (product of tons hauled and haul distance) has been used as a surrogate for air emissions, and therefore impacts, related to RA1. It was demonstrated that the ton-miles for RA1 will not exceed the ton-miles for the worst case emission years for the Mine Site for the proposed project (see RS57E). Ton-miles are an indication of fuel consumption, which would be related to greenhouse gas emissions. Because the ton-miles will not increase for RA1, and the haul trucks represent a significant portion of the Mine Site fuel usage, it can be assumed that the maximum annual greenhouse gas emissions from fuel consumption will not increase significantly.

The effect of wetland impacts on the carbon footprint for the project has also been evaluated in this report. RA1 results in a smaller stockpile footprint for the Category 3 Lean Ore Stockpile, with the same footprints for the other stockpiles and the mine pits (See June 15, 2009 memo from Christie Kearney and Stephen Day to Stuart Arkley). This will result in slightly less wetland impacts and therefore a smaller carbon footprint for the project.

Based on the fact that the maximum ton-miles for the haul trucks will not increase and that wetland impacts will decrease slightly if RA1 is implemented, no significant affect related to greenhouse gas emissions is expected.

3.3. Alternatives Analysis: Hydrometallurgical vs. Pyrometallurgical Processing

Two main alternatives are available for processing a sulfide ore: 1) hydrometallurgical processing – as proposed for the NorthMet 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 greenhouse gas emissions for the project as well as overall environmental impacts.

Two types of comparisons were made between hydrometallurgical processing and smelting: 1) total energy usage, and 2) carbon intensity based on direct greenhouse gas emissions from metal recovery. Energy usage was evaluated because energy usage is generally proportional to greenhouse gas emissions. Total energy usage was considered to be the sum of fuel combustion and electricity usage. The carbon intensity based on direct emission from metal recovery was also evaluated because this allowed for a reasonable comparison of the two technologies with a minimum of influence from secondary factors (e.g. ore grade). Limitations in this comparison are also discussed.

3.3.1. Comparison of Energy Usage

The energy demand for the NorthMet Project was compared to other metals processing facilities which use a pyrometallurgical process, such as smelting. Bateman Engineering determined that for the NorthMet Project, smelting would use 50% more energy than a hydrometallurgical process (Bateman, 2005). Additional data sources were also considered, which provided similar results. *See* Appendix A for further details.

3.3.2. Comparison of Carbon Intensity

When directly comparing two facilities it is not always accurate to examine emissions alone. A more accurate way of directly comparing one process to another is to calculate a "carbon intensity". Typically, an estimate of carbon intensity is derived by dividing greenhouse gas emissions by a unit of production. Generally, a lower carbon intensity indicates a more efficient process with regard to greenhouse gas emissions. The lower the carbon intensity, the smaller the amount of greenhouse gas emitted per unit of material processed.

Greenhouse gas emissions from smelters were not obtainable from U.S. emission registries. However, direct CO_2 emissions for smelting at some facilities are reported to the European Pollutant Emission Register (EPER) and that information is used in this analysis. Indirect emission data for the European smelters were unavailable and, therefore, are not included in this comparison. Concentrate feed rate was chosen as the indication processing rate used in the calculation of carbon intensity because this is the intermediate product that is fed to the metal recovery operation in both pyrometallurgical and hydrometallurgical processes. Emissions from mining and the processing steps to produce concentrate from ore (crushing, grinding and flotation) were not included in the analysis because these are independent of the metal recovery method selected. In addition, EPER does not include data from these steps that would make such a comparison possible. Also, most smelters are not co-located with the mining and ore processing operations and it is not uncommon for multiple mines to supply a single smelter. Therefore, it is believed that focusing on the metal recovery operations allows for the most useful comparison. It should be noted that using the concentrate feed rate as the measure of processing rate resulted in some complications for smelters that also process scrap copper. This is discussed further below.

The carbon intensity of the NorthMet Project, for the metal recovery portion of the operation, is approximately 0.24 using either maximum potential emissions or predicted actual emissions (i.e. the greenhouse gas emission rate is directly proportional to the concentrate feed rate). In comparison, based upon data reported to the European Pollutant Emission Register (EPER) carbon intensities are 0.28 and 0.21 for smelters at facilities in Sweden and Finland, respectively.

As can be seen from the above data, the carbon intensity for the hydrometallurgical process proposed for the NorthMet Project falls between the two European smelters evaluated. However, there are some additional factors that should be considered along with this comparison:

- Smelter emissions can vary greatly between facilities due to different technologies and characteristics of feedstock.
- The emission data for smelters is presumably for copper anode production. Further refining is required, typically at a separate facility, to produce a copper cathode product similar to the very high purity product that would be produced by the NorthMet Project.

- The use of the hydrometallurgical process allows for maximization of copper recovery from the ore. In other words, for each ton of ore mined, and the associated environmental impacts, additional copper can be recovered when the concentrate will be fed to a hydrometallurgical process as compared to a smelter.
- The use of the hydrometallurgical process allows for the efficient recovery of gold and platinum group metals, which is more difficult with smelters.
- Smelters are not typically collocated with the mining and beneficiation operations. Therefore, concentrate must be shipped to the smelter, in addition to the shipping of the finished product, as opposed to the proposed process for the NorthMet project which will only require shipping of the finished product (copper cathode). Even if the total distance traveled is the same, only shipping the copper cathode will be less energy intensive because it is less bulky (i.e. almost no impurities) than the concentrate.
- The Swedish smelter used for comparison purposes processes concentrate and copper scrap. Both were included in the calculation of the carbon intensity, because insufficient data were available to separate greenhouse gas emissions due to the two raw materials. Scrap is added later in the process and presumably would have a lower carbon intensity than concentrate. Therefore, the carbon intensity for the Swedish facility when it is processing concentrate may be underestimated.
- There are inherent differences between smelters and hydrometallurgical facilities that may make comparisons difficult, such as the fact that the majority of the greenhouse gas emissions from the hydrometallurgical process planned for the NorthMet Project come from solution neutralization and raffinate neutralization versus fuel usage at smelters.
- Smelting results in significant sulfur oxide (SO_x) emissions, which can affect air quality, visibility, and acid deposition. Estimated SO_x emissions for the NorthMet Process Plant, including support equipment, are less than 40 tons per year. On a per ton of concentrate feed rate basis, the emission are 0.1 kg SO_2/mton concentrate compared to 4.5 kg/mton and 6.4 kg/mton for the Swedish and Finnish facilities used for comparison of carbon intensity respectively.

3.4. Conclusions

The potential annual direct and indirect greenhouse gas emissions from the NorthMet Project are estimated as follows (as metric tons CO_2-e): direct = 235,648, indirect = 509,000, total = 744,648.

Carbon intensity is used as a measure of energy efficiency for a facility and is calculated by dividing estimated CO_2-e emissions by a unit of production. For direct emissions from metal recovery, the carbon intensity of the NorthMet Project is approximately 0.24 using maximum potential emissions or predicted actual emissions. The carbon intensity of the metal recovery process of the NorthMet Project falls between the carbon intensities calculated using data reported to the EPER for two smelting facilities, but there are other factors that would seem to make hydrometallurgical processing a better overall alternative for the NorthMet Project from an environmental impact perspective.

A hydrometallurgical process uses approximately 50% less energy than a smelting process (Bateman Engineering, 2005). Energy usage is generally an indicator of greenhouse gas emissions, but this is not conclusive evidence that the hydrometallurgical process proposed for the NorthMet Project has lower greenhouse gas 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 quantitative data available for this report show similar carbon intensities between NorthMet's hydrometallurgical process and specific smelting processes. However, due to data limitations emissions from European smelters, these carbon intensity comparisons focus on a very small component of the metal production process. If additional information was available, it is not certain which process would show a lower carbon intensity, however given the additional metal recoveries allowed by the choice of the hydrometallurgical process and other factors described above, it seems apparent that absent strong evidence to the contrary, the hydrometallurgical process is better choice from a greenhouse gas perspective for the NorthMet Project in particular. This would certainly seem to be the case if all environmental impacts are considered, given the much higher sulfur dioxide emissions from smelting operations.

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 industrial emissions. In this analysis, large one-time emissions from the loss of aboveground wetland and upland forest biomass, approximately 350,000 metric tons of CO_2, only equates to 2.4% of the overall annual industrial emissions when annualized over 20 years. 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 annual industrial emissions. 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 Greenhouse Gas Reductions

4.1. Project greenhouse gas reduction measures

As part of the NorthMet Project, PolyMet has considered and is taking measures to reduce greenhouse gas 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. In addition, PolyMet is reducing greenhouse gas 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 significant 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 two of the three blast hole drills will be electric rather than diesel powered, eliminating a direct source of greenhouse gas 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 greenhouse gas emissions. To reduce greenhouse gas 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 greenhouse gas emissions.

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

4.2. Alternative greenhouse gas reduction measures

A number of other greenhouse gas 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.[125] 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 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.[126]

4.2.1.1 Afforestation

According to the Kyoto protocol, the carbon sequestration of existing forests in Minnesota cannot be considered a carbon credit because the forests would sequester carbon regardless of management. Only carbon sequestration associated with practices such as afforestation (planting of trees where trees have not existed for a defined period of time) are considered for carbon

[125] 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/

[126] Nater, 2007, personal communication.

credits. 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 short 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 until 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).[127] 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.

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

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[127] 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/

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. CO_2 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. Brokers advertising on the Internet are currently asking \$5 MT CO_2 per year and up for verified offsets. Here, for example, are web links to two reputable brokers in the U.S.: http://www.climatetrust.org/, http://www.carbonfund.org. The current price on the Chicago Climate Exchange (CCX) is about \$2 MT CO_2-equivalent. The price has varied between \$2 and \$10 over the past year. Forward markets up to 2010 are currently available on the CCX, but only members of the exchange may buy offsets directly. Non-members must use a third party broker, as mentioned above

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 wetland mitigation activities which may offer an opportunity to create wetland 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 greenhouse gas 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 greenhouse gas emissions. As discussed above, PolyMet will purchase energy efficient equipment when available, such as premium efficiency motors and Gen-Set locomotives. Most emissions units used will run on the lowest CO_2 emitting fuel option for the type of equipment.

Appendices

Appendix A

Greenhouse Gas Emission Inventory and Alternatives Report

NorthMet Project Greenhouse Gas Emission Inventory & Energy and Efficiency Analysis

Prepared for
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NorthMet Project Carbon Dioxide (CO_2) Emission Footprint and Comparisons to Copper-Nickel Smelting Facilities

June 2009

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1.0 Introduction and Summary

Greenhouse gas (GHG) emissions from PolyMet Mining Inc.'s NorthMet Project are not currently subject to emission limits imposed by federal, state, or local laws or regulations. However, GHG emissions will be evaluated during the environmental review process. This document presents a calculation of expected GHG emissions from the NorthMet 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).

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). Carbon dioxide is the most prevalent GHG, so emissions are expressed in units of carbon dioxide equivalents (CO_2-e). For the NorthMet 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 or the TCR GRP. Information from the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (2006) is used when the MPCA guidance or the TCR GRP do not provide needed guidance. The NorthMet Project will not emit HFCs, PFCs, or SF_6.

Global warming potentials used for NorthMet's estimation of CO_2-equivalents are taken from the MPCA document *General Guidance for Carbon Footprint Development*, Appendix A. The global warming potentials are listed below.

Table 1 GHG CO_2-equivalence Values Used in Calculations

Greenhouse Gas (Chemical Formula)	CO_2-equivalence or global warming potential (100 year)
CO_2	1
CH_4	25
N_2O	298

Major components of the NorthMet Project include mining, ore crushing/grinding and concentrating, and metal recovery. A key feature of metal recovery is routing the flotation concentrate to a pressurized autoclave or autoclaves as part of the hydrometallurgical process. The energy from sulfide oxidation within the autoclaves is used as the primary heat source. The hydrometallurgical process eliminates several steps typically associated with pyrometallurgical processing and the related energy demand. 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 greenhouse gas emissions related to process design and equipment used. Energy efficient equipment will be purchased when available. For example, the PolyMet facility 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 have the option to produce flotation concentrate for sale from all or a portion of the ore processed, which would reduce the project's direct and indirect greenhouse gas emissions from those estimated in this report during the limited times that option is expected to operate.

Using MPCA guidance and TCR GRP, the maximum total potential direct and indirect GHG emissions from the NorthMet Project were calculated. Direct emissions are GHG's generated by processes at the plant and mine. The potential maximum direct GHG emissions from the NorthMet Project, from mining through metal recovery at the process plant, are estimated to be approximately 235,648 metric tons per year. CO_2 emissions account for 99.0% of the estimated GHG emissions at the Mine Site and 99.8% of the estimated GHG emissions for the Plant Site. Direct GHG emissions potentially associated with the project are less than 0.2% of estimated 2005 statewide emissions, approximately 0.003% of estimated 2005 U.S. emissions (CDIAC 2005), and approximately 0.0005% 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 509,000 metric tons per year. As shown in Table 3, 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] = 352,000 metric tons of CO_2

2) Annual emissions from the stockpiling of excavated peat = 430 – 3010 metric tons of CO_2 per year

3) Annual emissions from indirectly impacted wetlands = 208 metric tons of CO_2 per year

4) The loss of annual carbon sequestration capacity due to the disturbance of wetland and forest plant communities = 1960 metric tons of CO_2 per year

5) The reduction in annual carbon sequestration capacity in indirectly impacted wetlands = 15 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: The sum of the annual carbon cycle impacts excluding aboveground carbon loss and using the highest estimate of emission from stockpiled peat is equivalent to approximately 0.7% of the sum of 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. In response to the first caveat, the loss estimate can be normalized over the 20-year life of the project. The resulting total annual emission rate (using the high estimate from stockpiled peat) is 23,200 metric tons of CO_2 per year, or 3.1% of the sum of direct and indirect industrial emissions. 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. For the purpose of comparison with international carbon intensity data, the carbon intensity from the metal recovery component of the NorthMet process has been calculated. The carbon intensity for the metal recovery component of the NorthMet Project is approximately 0.24 using maximum potential emissions or predicted actual emissions. In comparison, based on data reported to the European Pollutant Emission Register (EPER) carbon intensities are 0.28 and 0.21 for the smelting process at facilities in Sweden and Finland, respectively.

The finding that the NorthMet Project has a similar carbon intensity to specific European smelting operations does not discount the findings from other assessments 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 NorthMet's process come from neutralization, not energy use. The quantitative data available for this report show similar carbon intensities between NorthMet's hydrometallurgical process and *specific* smelting processes.

The project's potential for impact on global atmospheric CO_2 concentrations and climate is evaluated in a screening-level assessment. The potential incremental increase in global CO_2 air concentration as a result of the project is estimated to range from approximately 0.00002 to 0.0001 ppm.

2.0 Greenhouse Gas Emission Estimation Methodology

Because there is no mandatory or uniform method for calculating GHG emissions (CO_2, N_2O and CH_4), potential emissions from the NorthMet 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 Mine Site property boundary will encompass approximately 7,500 acres. The sources of greenhouse gas emissions related to Mine Site activities are as follows[1]:

- Wastewater Treatment Facility Backup Generator
- Wastewater Treatment Facility Propane Fired Space Heaters

[1] The wastewater treatment process for the NorthMet 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.

- Mining Related Equipment
    - Mining Vehicles, including excavators, haul trucks, dozers, and graders.
        - PolyMet vehicle emissions and potential Contractor vehicle emissions are aggregated together for these calculations.
    - Locomotives (hauling ore from the Mine Site to the Plant Site)

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 41,989 metric tons per year.

2.2 Plant Site

As described in the Detailed Project Description (January 2007; July 2007 update), the project will use a pressure oxidation hydrometallurgical process to recover metals from the sulfide ore. 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 metal-rich solution is tapped off and the metals are recovered. Final products are copper metal, 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 greenhouse gases:

- High Pressure Natural Gas Boiler
- Oxygen Plant Adsorber Regeneration Heater
- Space Heaters
- Backup Generators and Fire Pumps
- Zinc Pots

- Autoclaves
- Solution Neutralization and Raffinate Neutralization Tanks
- Vehicle traffic, including heavy haul trucks and light trucks
- Locomotive used to move railcars in the switchyard

Emissions for the High Pressure Natural Gas Boiler, the Oxygen Plant Adsorber Regeneration Heater, the Space Heaters, the Backup Generators and Fire Pumps, and the Zinc Pots 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, Solution Neutralization Tank, and Raffinate Neutralization Tanks are calculated from information on the weight fraction CO_2 in the gaseous phase taken from the process flow simulation model (MetSim version U3), 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 193,659 metric tons per year.

2.3 Sale of Flotation Concentrate

The emission calculations used in this analysis assume that all flotation concentrate will be processed through the Hydrometallurgical Plant. This assumption yields a maximum greenhouse gas emissions scenario for the proposed project. However, the facility may not always process 100 percent of the flotation concentrate in the Hydrometallurgical Plant. For example, the facility may produce flotation concentrate for sale from all or a portion of the ore processed at certain periods, such as during construction of the Hydrometallurgical Plant, when one of the two autoclaves is down for maintenance, or when PolyMet could sell reserved power at very high rates. Greenhouse gas emissions from the NorthMet facility will be lower when producing flotation concentrate for sale, rather than processing the concentrate in the Hydrometallurgical Plant. As a result, Appendix A overstates the proposed project's greenhouse gas emissions when the facility is selling flotation concentrate rather than processing it in the Hydrometallurgical Plant.

3.0 Summary of NorthMet Project Greenhouse Gas Emission Estimates

Project-related GHG emissions on a CO_2-equivelent basis are summarized below and in Table 1.

- Maximum direct GHG emissions from the NorthMet Project are estimated at 235,648 metric tons per year. Of these direct emissions, 18% are from the Mine Site operations and 82% are from Plant Site operations. Additional calculation details are provided in Attachment A. For the Mine Site, CO_2 emissions account for approximately 99.0% 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 99.8% of the estimated GHG emissions.

- Potential indirect GHG emissions from power production for the project are estimated at approximately 509,000 metric tons per year. This calculation is based on project power needs of approximately 59.3 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 project GHG emissions, combining direct and indirect emissions, are estimated to be approximately 744,648 metric tons per year (Table 2). Approximately 32% of the total GHG emissions are from direct emissions and 68% 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 3 shows that the NorthMet Project's direct GHG emissions will be approximately 0.2% of statewide emissions estimated from available MPCA data (2003), approximately 0.003% of national emissions estimated by the EPA (2007), and approximately 0.0005% of global emissions. Also shown in Table 3, 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 Greenhouse Gas Emissions Estimated for the NorthMet Project Proposed to be Located near Hoyt Lakes, Minnesota.

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)	41,989		
Plant Site (ore crushing, concentrating, metal recovery)	193,659		
Subtotal	235,648	509,000 **[4]**	744,648

Units = CO_2-e, m.t./yr = Greenhouse gas 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 NorthMet 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 = 298, CH_4 = 25.
As used in this analysis, emissions of N_2O have 298 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 NorthMet Project is estimated to be approximately 59.3 megawatts. The electricity to be used by the NorthMet 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. Estimated Statewide, National, and Global Greenhouse Gas Emissions Compared to the Potential Emissions from the NorthMet Project Proposed to be Located near Hoyt Lakes, Minnesota.

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	235,648		
Indirect Emissions	509,000		
TOTAL	744,648		
Minnesota (year 2005) [2]	150,000,000	0.16	0.62
United States (year 2007) [3]	7,282,400,000	0.003	0.01
Global (year 2004) [4]	49,000,000,000	0.0005	0.002

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

[1] Potential direct emissions of GHGs for the NorthMet 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 NorthMet Project is estimated to be approximately 59.3 megawatts. The electricity to be used by the NorthMet 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] MPCA 2003. Minnesota Climate Change Action Plan: A framework for climate change action. Minnesota Pollution Control Agency, February 2003. Estimated GHG emissions in 2005 are based on information for Minnesota sources in MPCA (2003) calculations. Estimated emissions in 2005 assume a 1.7% increase per year from 2000 to 2005, based on the MPCA's calculated increases from 1990 to 2000 (MPCA, 2003).

[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 NorthMet 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 NorthMet Project are small.

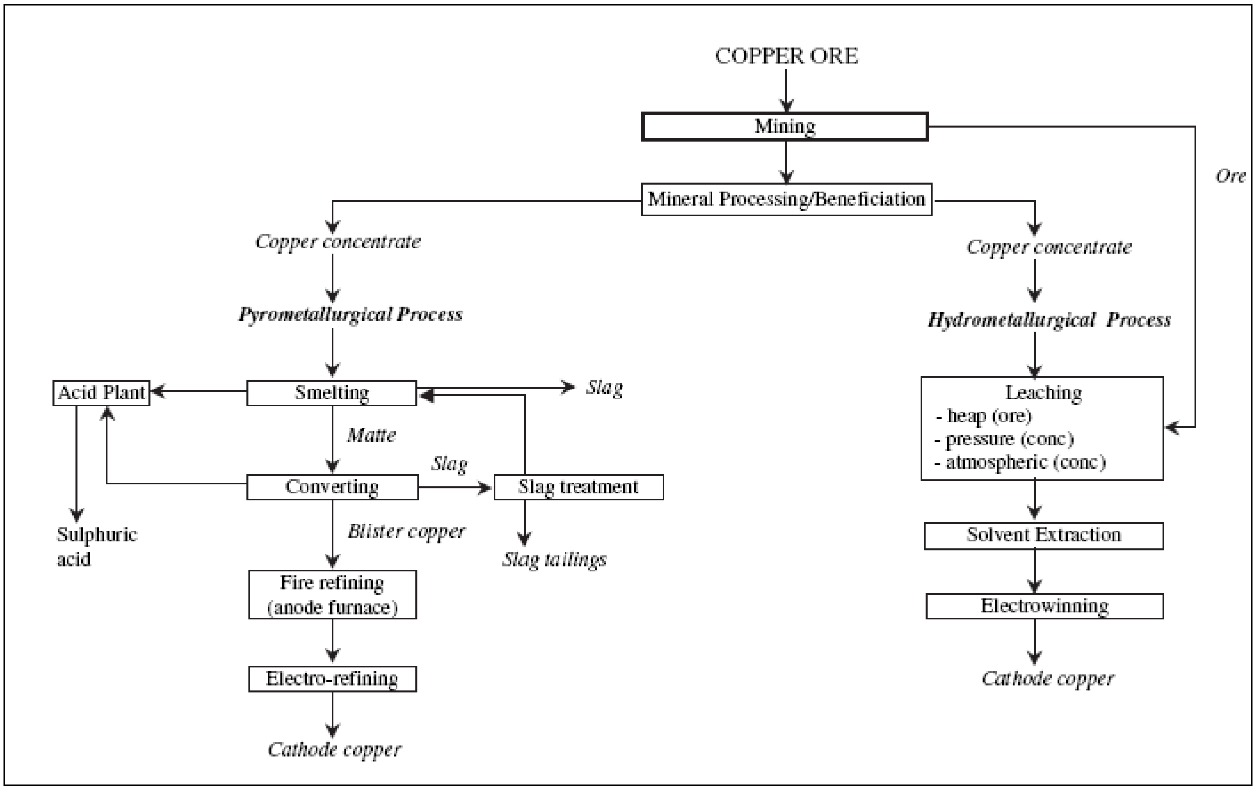
4.0 NorthMet's Hydrometallurgical Process vs. Smelting Facilities

Major components of the NorthMet Project include mining, ore crushing/grinding and concentrating, and metal recovery. A key feature of metal recovery is routing the flotation concentrate to pressurized autoclaves as part of the hydrometallurgical process. The energy from sulfide oxidation within the autoclaves is used as the primary heat source. The hydrometallurgical process eliminates several steps typically associated with pyrometallurgical processing and the related energy demand. Overall, hydrometallurgical processing such as PolyMet's planned operation is estimated to reduce energy demand by 50% (Bateman 2005).

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. …"*. Figure 1 provides a general flow diagram that shows the major differences between the hydrometallurgical and pyrometallurgical processes. It should be noted that for purposes of comparison, Figure 1 focuses on copper production. In addition, the hydrometallurgical process proposed for the NorthMet Project will also produce gold and platinum group metal (AuPGM) and nickel/cobalt hydroxide concentrate products.

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 greenhouse gas emissions and possibly a lower carbon intensity.

The Bateman memo presents an energy usage of 27,945 Btu/lb of copper produced for smelting, not including transportation of intermediate products between facilities. This value was compared to other available information. An energy use value for copper smelting was calculated from data in Appendix H of *A Lifecycle Emissions Model (LEM): Lifecycle Emissions From Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials* (Delucchi, 2003) with a result of 35,697 Btu/lb. If the additional intermediate product transportation typically associated with smelters were to be included, it is expected that the analysis would show a greater advantage in energy efficiency for the Hydrometallurgical Plant alternative.



From: Norgate et al. (2006).

Figure 1. Main Processing Routes for Copper Production: Hydrometallurgical and Pyrometallurgical Processing.

Notes:

[1] The NorthMet Project will process a polymetallic ore. However, cathode copper is one of the main products, along with a nickel/cobalt concentrate and AuPGM concentrate that will be further refined by offsite processing.

[2] For the NorthMet Project the flotation concentrate will be routed to pressurized autoclaves as part of the hydrometallurgical refining process. The energy from sulfide oxidation within the autoclaves is used as the primary heat source. The hydrometallurgical process eliminates several steps typically associated with pyrometallurgical processing and the energy associated with those pyrometallurgical processing steps. Overall, hydrometallurgical processing is estimated to have 50% less energy demand than a pyrometallurgical process (Bateman 2005).

Emissions vary from operation to operation based on a number of factors, including copper and nickel concentrations in the concentrate and concentrate processing rate. To standardize emissions to a common scale for direct comparison between facilities and operations, GHG emissions are typically compared on a "carbon intensity" basis. Carbon intensity is a measure of the efficiency of a process or facility regarding GHG emissions (as CO_2-equivalents) where estimated air emissions are divided by a unit of production. In general, a lower carbon intensity indicates a more efficient process.

For this analysis, an estimate of carbon intensity for the proposed NorthMet Project metal recovery operation was obtained by dividing the estimated annual metric tons of direct GHG emissions (as CO_2-equivalents) by the annual metric tons of concentrate processed. Emissions were calculated based on both the maximum emissions each source has the potential to emit and predicted actual emission from each source. The concentrate processed is based on the expected processing rate as obtained from the MetSim process flow simulation developed for the project (revision U3). Due to limitations in the data available for smelting facilities, only emissions from metal recovery are included; mining, ore hauling, ore processing, space heating, emergency equipment, and traffic emissions are not included. Using these criteria, the carbon intensity for PolyMet's metal recovery process is approximately 0.24 using maximum potential emissions or predicted actual emissions (Table 4). The greenhouse gas emissions from the Hydrometallurgical Plant are directly proportional to the concentrate feed rate, therefore the carbon intensity is essentially the same regardless of the actual quantity of concentrate processed.

An information search, including a search of the Internet, was conducted to determine whether GHG emissions data and carbon intensities are available for copper or copper-nickel smelting facilities. GHG emission registries were targeted in the information search. Greenhouse gas emissions from smelters were not obtainable from U.S. emission registries[2]. CO_2 emissions for some European smelting facilities are reported to the European Pollutant Emission Register (EPER) and that information is used in this analysis. For these facilities, CO_2 emissions from smelting are reported to the EPER but emissions related to mining, ore hauling, and concentrating are not reported. Table 4 compares the carbon intensity for sample facilities with available data reported to EPER to the carbon intensity for the NorthMet Project.

The carbon intensities calculated for direct emissions are based on the available data for each facility. Therefore, each calculation has some associated uncertainty and a comparison of carbon intensities is most appropriately made on a relative basis. Indirect emissions for the smelting operations are not included in Table 4 because these emissions are not reported to the European Pollutant Emission Register (EPER). Therefore, the only comparison between the NorthMet Project and the smelters reporting data to the EPER is for direct emissions.

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[2] A USGS (2004) report provides a summary for 30 smelting operations that represent approximately 65% of the world-wide smelting capacity. In most cases, mass balance techniques are used to derive an estimate of potential CO_2 emissions for a specific facility in the USGS report. Differences between greenhouse gas emissions provided in the USGS report and those reported to the EPER for the same facilities raised concerns with the accuracy of the data in the USGS report. Therefore, for this NorthMet project report, the preference is to use emissions data reported by a company to a GHG pollutant registry.

Table 4. Greenhouse Gas Emissions and Estimated "Carbon Intensity" For the NorthMet Project Hydrometallurgical Process

Direct Emission Source	**Maximum Potential GHG Emissions (CO_2-e, m.t./yr)**	**Throughput (concentrate processed) (m.t./yr)**	**Carbon Intensity [1]**
Autoclave vent (2 units)	*406*		
Solution Neutralization Tank 1 Vent	*34,932*		
Solution Neutralization Tank 2 Vent	*27,824*		
Solution Neutralization Tank 3 Vent	*507*		
Raffinate Neutralization Tanks	*36,370*		
Total NorthMet Project Hydrometallurgical Process	100,039	409,352	0.24
	Predicted Actual GHG Emissions (CO_2-e, m.t./yr)		
Total NorthMet Project Hydrometallurgical Process	90,035	368,417	0.24
	Reported Actual GHG Emissions (CO_2-e, m.t./yr)		
Swedish Smelter – copper-nickel [2]	210,000	774,824	0.28
Finnish Smelter – copper-nickel [2]	109,000	531,057	0.21

Units: CO_2-e, m.t./yr = green house gas emissions as CO_2-equivalents, in metric tons per year
m.t./year = metric tons per year

[1] Carbon Intensity is a measure of the efficiency of a process or facility operations with regard to GHG emissions. Estimated GHG emissions are divided by a unit of production.

Carbon Intensity = CO_2-equivalent emissions in metric tons per year ÷ annual concentrate processing rate in metric tons per year. Copper scrap is included in the operating rate data when it is fed to the smelter.

The carbon intensities calculated for direct emissions are based on the available data for each facility. Therefore, each calculation has some associated uncertainty and the comparison of carbon intensities should be made on a relative basis with less weight given to the specific calculated value.

[2] The intent of this analysis is to provide a generic comparison of GHG emissions from copper-nickel smelters with the NorthMet Project's hydrometallurgical process. The comparison is not intended to be a specific comparison of individual facilities to the NorthMet Project. Therefore, the names of the other facilities used in the comparisons are not identified in this report.

For the two smelting facilities, emissions are as reported to the European Pollutant Emission Register (EPER). Indirect GHG emissions from power production for the smelting operations are not reported by the respective facilities to the EPER.

Based on carbon intensities for PolyMet's hydrometallurgical process and the sample smelting facilities which had available information, the two processes seem to be similarly efficient regarding GHG emissions. However, data is not available to compare the total emissions, both direct and indirect, from the entire NorthMet Project, both the Mine Site and the Plant Site. Based on the supplemental information from Bateman (2005), it is likely that NorthMet Project's hydrometallurgical process will have approximately 50% less energy demand than a smelting process. The difference is that a majority of the direct emissions used to calculate PolyMet's carbon intensity are from solution neutralization and raffinate neutralization using limestone, which are not related to energy consumption. Solution neutralization and raffinate neutralization is further discussed in Section 6 of this report. As explained in that section, there are no reasonable substitutions for the NorthMet Project that would eliminate or reduce these emissions.

The quantitative data available for this report shows similar carbon intensities between direct emissions from NorthMet's hydrometallurgical process and direct emissions from *specific* smelting processes. However, there are a number of factors that may make this comparison incomplete. Several of these factors are listed below:

- Smelter emissions can vary greatly between facilities due to different technologies and characteristics of feedstock.
- The emission data for smelters is presumably for copper anode production. Further refining is required, typically at a separate facility, to produce a copper cathode product similar to the very high purity product that would be produced by the NorthMet Project.
- The use of the hydrometallurgical process allows for maximization of copper recovery from the ore. In other words for each ton of ore mined, and the associated environmental impacts, additional copper can be recovered when the concentrate will be fed to a hydrometallurgical process as compared to a smelter.
- The use of the hydrometallurgical process allows for the efficient recovery of gold and platinum group metals, which is more difficult with smelters.
- Smelters are not typically collocated with the mining and beneficiation operations. Therefore, concentrate must be shipped to the smelter, in addition to the shipping of the finished product, as opposed to the proposed process for the NorthMet project which will only require shipping of the finished product (copper cathode). Even if the total distance traveled is the same, only shipping the copper cathode will be less energy intensive because it is less bulky (i.e. almost no impurities) than the concentrate.
- The Swedish smelter used for comparison purposes processes concentrate and copper scrap. Both were included in the calculation of the carbon intensity, but scrap is added later in the process and presumable would have a lower carbon intensity than concentrate. Therefore, the carbon intensity for the Swedish facility when it is processing concentrate may be underestimated.
- There are inherent differences between smelters and hydrometallurgical facilities that may make comparisons difficult, such as the fact that the majority of the greenhouse gas emissions from the hydrometallurgical process planned for the NorthMet Project come from solution neutralization and raffinate neutralization versus fuel usage at smelters.

- Smelting results in significant sulfur oxide (SO_x) emissions, which can affect air quality, visibility, and acid deposition. Estimated SO_x emissions for the NorthMet Process Plant, including support equipment, are less than 40 tons per year. On a per ton of concentrate feed rate basis, the emission are 0.1 kg SO_2/mton concentrate compared to 4.5 kg/mton and 6.4 kg/mton for the Swedish and Finnish facilities used for comparison of carbon intensity respectively.

Based on the available data and the above factors, there is good evidence that for the NorthMet Project, hydrometallurgical processing is at least as good a processing choice from a greenhouse gas emission perspective as smelting. When other environmental impact factors are considered, it becomes clear that hydrometallurgical processing is the preferred technology for this project.

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 squared times R) 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 PolyMet plant facility. 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.

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 65.7 MW[3]. The 94 pieces of new electrical equipment planned for the Process Plant that were evaluated have a total electrical load of 32.9 MW, which is greater than 50% of the total load for the Process Plant.

Almost all of this equipment utilizes electric motors. A notable exception is the rectiformer used in the copper electrowinning process which has an electrical load of 7927 kW. This unit consists of a transformer plus a solid state AC-DC converter. There are no moving parts, so it is an inherently efficient piece of equipment.

Two other 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. As with the rectiformer, these units have no moving parts and are inherently efficient.

The remaining 91 pieces of equipment evaluated will have new electric motors. This equipment includes 32 agitators, 27 pumps, 15 fans and blowers, nine HVAC units, three compressors, the Limestone Crusher, the Lime Slaker, the Primary Limestone Mill, and the Copper Cathode Stripping Machine.

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%

[3] 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.

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 94 pieces of equipment evaluated are 75 hp. There are seven motors of this size on the list, 20 at about 100 hp or less, 28 between 100 and 150 hp, eight between 150 and 250 hp, 24 between 250 and 500 hp, and seven 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 plan has an electrical load of 10.5 MW or about 16% of the total load for the Process Plant.

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 5.7 MW[4]. 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.

[4] The average actual power draw is estimated as 2.7 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 greenhouse gas emissions for the project and elements of the proposed project that help minimize greenhouse gas emissions. There are other potential ways to reduce greenhouse gas 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 greenhouse gas emissions from these rejected alternatives are included where the data is available to calculate them.

Electric Drive Mine Haul Trucks

Trucks with either mechanical transmission or electric drives can be used to haul material at a mine site. Electric drives offer the possibility of trolley assist, which reduces diesel fuel consumption and therefore direct greenhouse gas emissions. Trolley assist is only practical where there is a significant amount semi-permanent transport runs. The geography of the ore body at the NorthMet Mine Site will result in steep inclines (i.e. deep, narrow pits), which raises concerns over the maintainability of electric drive trucks. Also, there will not be sufficient semi-permanent runs at the NorthMet Mine Site to make Trolley Assist a practical alternative. Based on these factors, it is most likely that mechanical transmission haul trucks will be specified for the NorthMet Mine Site.

Electric Locomotives

If electric locomotives are used, this eliminates diesel fuel combustion in the locomotives and a source of direct greenhouse gas 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.

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.

This replacement would be cost prohibitive. 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.

Flotation

The proposed 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.

Smelting

Smelting is a potential alternative to the hydrometallurgical process proposed for this 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.

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 5.1.1.

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 18.5% of the total direct GHG emissions. Options for space heating are ranked below in order of estimated maximum annual emissions.

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	35,488	No	No
2	Natural Gas Heaters	55,450	Yes	Yes
3	Propane Heaters	162,958	Yes	No
4	Electric Heaters	305,366	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. Waste heat recovery could result in an approximately 36% reduction in the amount of the natural gas required for heating; however, this option could negatively affect the overall project water balance. PolyMet has chosen to use natural gas fired space heaters, which will emit significantly fewer GHGs than using propane or electricity for heating.

7.1.2 Area 1 Shop & Area 2 Shop Space Heating

Options for space heating are shown 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.

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	10,428	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 greenhouse gas 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 NorthMet Project are calculated assuming that the equipment will be diesel powered. Other fuel options are ranked below in order of GHG emission factors.

Options for Mobile Sources, Generators, and Fire Pumps				
Rank	**Fuel**	**CO_2 Emission Factor**[4] (kg CO_2 / MMBtu)	**Feasible?**	**PolyMet Selection**
1	Biodiesel[1]	79.97	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)
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, the table above ranks biodiesel first (that is, the option with fewest GHG emissions).

However, biodiesel fueled trucks and equipment are not feasible for the NorthMet 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 NorthMet Project's mobile sources, generators, and fire pumps.

7.2.1 Light Truck Traffic

It should be noted that the light truck traffic associated with the NorthMet Project will most likely include gasoline fueled vehicles as well as diesel fueled vehicles. However, because the majority of light truck traffic will involve NorthMet personnel using personal vehicles, PolyMet is uncertain of how many light truck vehicles run on which fuel. As shown below, gasoline and diesel emission factors are very similar. To be conservative, emissions are calculated with a diesel emission factor.

Fuels Comparison for Light Truck Traffic	
Fuel	**CO_2 Emission Factor[2]** (kg CO_2 / MMBtu)
Gasoline[1]	70.44
Diesel	73.18

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.

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 Zinc Pots

The zinc pots are only used when needed for maintenance on the crushers. The facility has existing zinc pots which are fuel oil fired. Other potential fuel options for zinc pots are listed below.

Zinc Pot Fuel Ranking					
Rank	**Fuel**	**Estimated Max Emissions[1]** (m.t. CO_2 –e / yr)	**Estimated Actual Emissions[1]** (m.t. CO_2 –e / yr)	**Feasible?**	**NorthMet Selection**
1	Natural Gas	1628	163	Yes	No
2	Fuel Oil	2109	211	Yes	Yes
3	LPG	4605	461	Yes	No
4	Electricity	8371	837	Yes	No

1. Please see Appendix D, Table D-4 for calculation details.

Maximum estimated emissions using fuel oil are about 0.8% of the total direct emissions. Furthermore, the calculated emissions are based on 8760 hours per year operation and the zinc pots are estimated to operate only about 10% of the time. The projected utilization would result in a contribution of less than 0.1% to total direct emissions. Given the zinc pot's limited use, it is not cost-effective for PolyMet to buy new natural gas fired zinc pots to reduce CO_2-equivalent emissions by an estimated 48 metric tons CO_2-equivalent emissions per year.

7.4 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 PolyMet 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 CO_2 emissions.

8.0 Direct Emissions from Sulfuric Acid Neutralization

The major sources of direct CO_2 emissions are the solution neutralization and raffinate neutralization tanks, which will neutralize sulfuric acid in PolyMet's 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, PolyMet's 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 and raffinate is typically 80-180 g/l and can be concentrated by a solvent extraction process. However, the final concentration obtained is well short of being sold commercially as sulfuric acid, which is typically 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 hydrate 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 NorthMet Project's separate metal streams (copper, nickel/cobalt and AuPGM) 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 NorthMet Project.

9.0 Indirect Emissions from Power Production

Potential indirect CO_2 emissions from power production for the NorthMet Project are estimated to be approximately 509,000 metric tons per year (Table 2; Attachment B). Indirect emissions from power production for the European smelting operations are not provided in Table 4 above because those emissions are not reported to the European Pollutant Emission Register. To estimate the indirect CO_2 emissions from smelting facilities in other countries or regions would require coupling CO_2 emission factors for electricity generation with more detailed information about the electricity consumption by each facility. However, information on the electrical demand for smelting facilities in other countries is not reported to the European Pollutant Emission Register and is not readily available. Therefore, estimates of indirect CO_2 emissions or total (direct + indirect) CO_2 emissions for specific European smelting facilities are not included in Table 4.

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

This project is expected to require 59.3 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.

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.

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.

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 utilities 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.

§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.

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.

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 PolyMet.

Applicability to PolyMet

The §216B.42, Subd. 1 exception does not apply to PolyMet in this case for two regulatory reasons, as well as two practical reasons. First, Minnesota Power's proposed point of delivery to PolyMet's 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.

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. There is also a recent initiative by the Midwest Governor's Association to reduce CO_2 emissions in the region by 80% from 2005 levels by 2050. There may be additional reductions of GHG emissions from individual Minnesota power plants through voluntary actions 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 the currently planned use of biomass fuels (e.g., Minnesota Power's Syl Laskin plant and the Laurentian Energy Project), as well as from energy efficiencies 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 NorthMet 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.

10.0Terrestrial 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 five 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) Annual emissions from indirectly impacted wetlands due to lowered water levels

4) Loss of annual carbon sequestration capacity due to the disturbance of wetland and forest plant communities – ignoring methane emissions from wetlands.

5) Reduction in annual carbon sequestration capacity in indirectly impacted wetlands

The effect of on the proposed project tailings basin design on 55 acres of directly impacted wetlands has not been included in this analysis, with the exception of the emissions from stockpiled peat. The area in question is a previously disturbed mine site with limited forest cover. These specific plant communities along with the small comparative footprint limit the amount of carbon likely contained in aboveground vegetation, as well as the present carbon sequestration capacity. It is expected that this part of the proposed project will be a minimal addition to the overall terrestrial carbon impacts quantified in this section.

The acreage of wetlands with indirect impacts from the project assessed in this report is based on the evaluation completed by Barr Engineering Company, which indicates that the wetland area with indirect hydrologic impacts is 27.9 acres. It should be noted that the EIS contractor has identified an additional 290 acres of indirect wetland impacts that are related to noise, dust, etc. These additional impacts would not have material impacts to the carbon storage or sequestration capacity of the affected wetlands, so they are not included in the analysis in this section.

It is assumed that upon closure the CO_2 emissions from the stockpiled peat and indirectly impacted wetlands would decrease and potentially result in net carbon sequestration over longer timescales. Most of the stockpiled peat is anticipated to be stored permanently in stockpiles, which will be planted over in situ. A number of processes may contribute to a diminution and even reversal of the net CO_2 emission rate, including the compaction of stockpiles and consequent removal of air pockets rich in oxygen, and the growth of vegetation on the surface of the stockpile, which will both utilize peat carbon and act as a net atmospheric carbon sink. The majority of the indirectly impacted wetlands, which are located by the West Pit, will recover much of their pre-project watershed through the filling in of the drainage ditch to the north. With this precipitation input restored, it is possible that the wetlands will return to being a net CO_2 sink over time. The restoration of carbon sequestration in both these cases is subject to significant temporal and physical uncertainty, as was the case with all of the quantified terrestrial carbon cycle impacts. However, the potential post-closure emissions from these sources are thought to be short-lived, and, consequently, are not included in the analyses below.

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 NorthMet Project, this vegetation will likely be buried or removed at some point in time during the 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, we assume 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.

Wetland areas were defined by the onsite wetland delineation (Barr, 2008). US Forest Service soil maps were used to characterize wetlands as primarily organic or mineral soils. Herbaceous wetlands were assumed to have no long term carbon storage in biomass. For shrub wetlands and non-forested peatlands, biomass carbon storage was estimated from Bridgham et al. (2006, 2007) for combined non-permafrost peatlands and freshwater mineral soil wetlands in the conterminous United States. For forested wetlands, historic aerial photos were used to estimate stand ages. Data from COLE 2009 were used to estimate carbon storage rates. Carbon estimates in COLE 2009 are given for monotypic stands. For mixed forests, averages of common tree species were used to estimate stand-level carbon storage values.

In the case of upland forests, habitats consisted of forests dominated by aspen, birch, jack pine, red pine, and balsam fir. Habitat maps from wildlife studies were used to characterize forest types (ENSR 2004a, 2004b). Historic aerial photos were used to estimate stand ages. Data from COLE 2009 were used to estimate the carbon storage value. Carbon estimates in COLE 2009 are given for monotypic stands. For mixed forests, averages of common tree species were used to estimate stand-level carbon storage values. Areas identified as upland grass and shrub lands were assumed to be early successional (5 and 15 year old) aspen/birch stands.

The carbon storage values 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 5. The details of the aggregated results, including the carbon stock per unit area measures and acreage for the various wetland and forest communities, can be found in Attachment E. 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 6 Emissions from Wetlands and Upland Forest Aboveground Carbon

Source	**Pollutant**	**Emission Rate** (CO_2-e m.t./yr)	**Estimate Type [1]**
Emissions from indirectly impacted wetlands [2]	CO_2	208	High estimate
Source	**Pollutant**	**Single Emission** (CO_2-e m.t.)	**Estimate Type [1]**
Total aboveground wetland carbon stock directly impacted by project [3]	CO_2	135,000	High estimate
Total aboveground forest carbon stock directly impacted by project [4]	CO_2	217,000	High estimate
Source	**Pollutant**	**Carbon Stock** (CO_2-e m.t.)	**Estimate Type [1]**
Total carbon stored in excavated peatlands [5]	CO_2	1,780,000	Central tendency

Units = CO_2-e, m.t. = Greenhouse gas 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 (See Appendix A for full derivation)\

[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 which estimated the removal of 986,000 tons of peat from the Mine Site stockpile footprints and pits, 39,300 tons from storage areas and dikes, and 66,400 tons of peat from the Tailings Basin; not treated as a onetime emission.

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.

[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 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.

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.

For non-forested, mineral soil wetlands, carbon sequestration values were taken from Bridgham et al. (2006, 2007). For non-forested peatlands, a carbon sequestration rate of 0.7 Mt/ha/yr was used, based on Lennon and Nater (2006) review citing a range of values between 0.6 and 0.8 Mt/ha/yr for Minnesota peatlands. For forested wetlands, historic aerial photos were used to estimate stand ages. Data from COLE 2009 were used to estimate sequestration rates. Carbon estimates in COLE 2009 are given for monotypic stands. For mixed forests, averages of common tree species were used to estimate stand-level carbon sequestration values. Indirectly impacted wetlands were treated in a slightly different manner. It was assumed that their carbon sequestration capacity would drop from that of a peatland (0.7 metric tons per hectare per year) to that of a mineral wetland (0.33 metric tons per hectare per year).

For upland forests, data from COLE 2009 were used to estimate carbon sequestration rates. Carbon estimates in COLE 2009 are given for monotypic stands. For mixed forests, averages of common tree species were used to estimate stand-level carbon sequestration values. Areas identified as upland grass and shrub lands were assumed to be early successional (5 and 15 year old) aspen/birch stands.

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 6. The details of the aggregated results, including the carbon sequestration rate per unit area and acreage for the various wetland and forest communities, can be found in Attachment E.

Table 7 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	768	Central tendency
Wetland sequestration capacity reduction from indirect impacts [2]	CO_2	15	Unknown
Upland forest sequestration capacity loss from direct impacts	CO_2	1190	Central tendency

Units = CO_2-e, m.t. = Greenhouse gas 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)

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.

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 NorthMet 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.

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. Five different estimates of total C removed were generated, ranging from slightly over 200,000 tons to nearly 750,000 tons (Fig. 2). The methodologies behind these estimates are described below in detail.

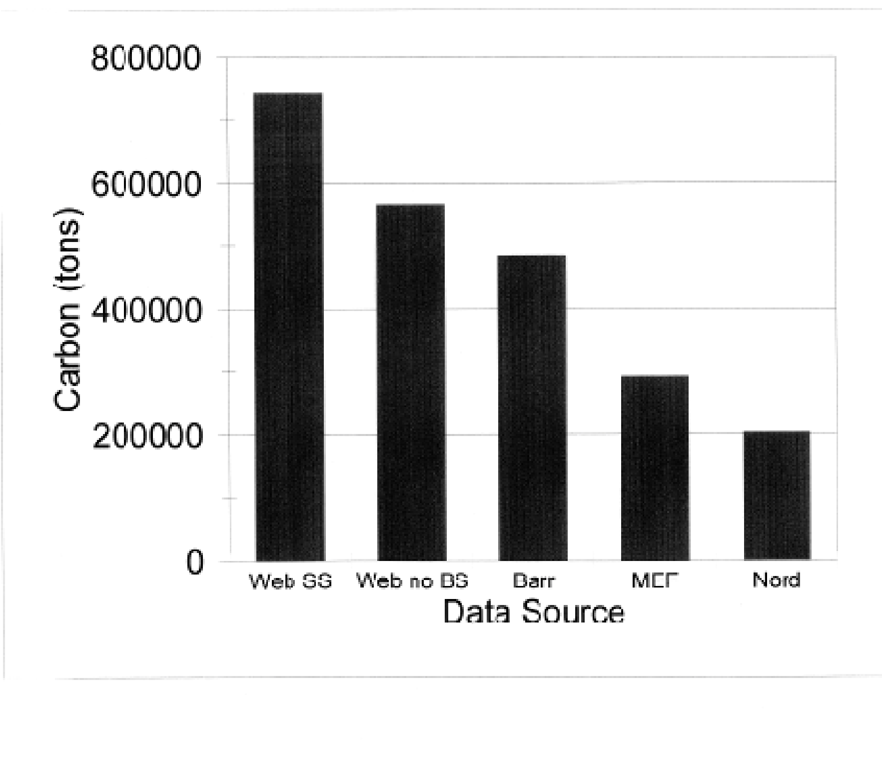

Figure 2. Total mass of carbon removed with peat stripping over a 20-year period. Web SS = estimate based on data derived from Web Soil Survey; Web no BS = estimate based on data derived from Web Soil Survey, but

without data from Bowstring; Barr = estimate by Barr Engineering; MEF = estimate from detailed analysis of representative peat pedons extrapolated to mapping units; and Nord = estimate based on detailed data from nine peatlands in northern Minnesota

Web SS

The Web Soil Survey, sponsored by the Natural Resources Conservation Service (NRCS) provides data for soil mapping units based on queries (USDA). The data for the Embarrass portion of St. Louis County, which includes the mine site, were accessed and a request made for soil mapping units from the vicinity of the mine site. These were nearly exclusively organic soils (peat – Histosols), including the Rifle (unit 1021A), Greenwood (1022A), Bowstring (1020A), Tacoosh (F129A), Cathro (F34A), Mooselake (F116A), Merwin (F32A), Dora (F187A), and Daisybay (B47A). The query was for summarized data by depth (both 24 and 72 inches) for both organic matter (in percent) and bulk density (g cm^{-3}) for each soil mapping units.

These data were converted to mass of organic matter per unit area by multiplying organic matter with bulk density and appropriate conversion factors. To convert organic matter to C, a linear relationship developed from samples of peat that had been collected in intensive studies at the Marcell Experimental Forest (MEF) in Itasca County and the Cedar Creek Natural History Area in Isanti County was used. A simple linear regression was developed relating organic matter (expressed as loss on ignition – LOI) in percent as the independent variable and C in percent as the dependent variable. In the initial analysis, the y-intercept was not significantly different than 0 and so the regression was re-run, forcing the intercept through 0. The result was

Peat C (%) = 0.55 * LOI (%), n = 82, with $r^2 = 0.91$.

This factor (C = LOI * 0.55) was used to convert the data from the Web Soil Survey (depth, % organic matter, and bulk density) to the mass of C per unit area. The data were then converted to tons per acre per either two foot or six foot depth. Results ranged from about 540 tons per acre for the Greenwood mapping unit to 3900 tons per acre for the Bowstring unit. The latter estimate seems to be an outlier, and was about 2.5 times greater than the next highest estimate (Merwin at 1560 tons per acre).

The mean of the estimates to the two foot and six foot depths were used in a computation of the total mass of carbon removed with peat stripping over a 20-year period provided by PolyMet. The estimated mass of C removed was 744,000 tons using the average for all mapping units, or 565,000 tons using an average without the Bowstring mapping unit (Fig. 2)

Barr

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 (986,000 tons). A table showing details of the calculations for the peat removal estimate is includes in Attachment F. The 986,000 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 483,000 tons (Fig. 2).

MEF

As part of a study of C balance at MEF in Itasca County, estimates of C mass in soil mapping units on the forest were made. These estimates were not based on the Web Soil Survey. Because those estimates are relatively general, more detailed data were used to estimate C. Detailed data for 73 pedons, representing 16 taxonomic units, were 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. Other sources, for specific taxonomic units, included Balogh (1983), Grigal et al. (1974), Kolka (1993), and Alban and Perala (1990). Carbon was computed for both the upper 25 cm (10 inches) and the upper meter (40 inches) of the pedons in the detailed database. These data were then summarized by soil mapping units of the MEF, based on the tabulated taxonomic composition of those units. Organic mapping units included Borosaprists, depressional; Cathro muck; Greenwood peat; Loxely peat; Mooselake and Lupton mucky peats; Sago and Roscommon soils; and the Seelyeville-Bowstring association. The data were linearly interpolated to compute C mass per unit area for the two-foot depth, and linearly extrapolated for the six-foot depth. Results ranged from about 880 tons per acre for the Sago and Roscommon soils to 2160 tons per acre for the Loxely peat. The mean of the estimates to the two foot and six foot depths was used in a computation of the total mass of carbon removed with peat stripping over a 20-year period, which was 291,000 tons (Fig. 2)

Nord

The final estimate of C removed was based on the study by Grigal and Nord (1983). The sampled peatlands included the Arlberg bog in St. Louis County; the Baudette fen in Lake Of The Woods County; the Bureau of Mines site in Koochiching County; the Wilderness Valley Farms Fens site in St. Louis County; the MacGregors S. peatland in Aitkin County; the Meadowlands site in St. Louis County; the Pine Island bog in Koochiching County; the Red Lake area fen in Beltrami County; the Salol bog in Roseau County; and the Toivola bog in St. Louis County. A total of 46 sites (433 samples) were visited. Both ash (ash = 100 - LOI) and bulk density were determined by 25-cm depth increments as described earlier. Data were available to 200 cm (80 inches) for all peatlands except Salol, where bulk densities were missing. That site was excluded from further computation. Organic matter mass was computed and converted to C using the relationship described above (C = LOI * 0.55). Data were summed by each 25-cm depth increment, and then interpolated for the two-foot and six-foot estimates (e.g., the estimate for the two-foot increment was the sum of the 0 to 25 (0 to 10-inch) and 25 to 50 cm (10 to 20-inch) increments, plus the interpolated value between 20 and 30 inches).

Results ranged from about 245 tons per acre for the Pine Island site to 620 tons per acre for the Meadowlands site. The mean of the estimates to the two foot and six foot depths were used in a computation of the total mass of carbon removed with peat stripping over a 20-year period, and the estimated mass of C removed was 204,000 tons (Fig. 2)

In summary, a reasonable estimate of the amount of C removed due to mining activity over 20 years was developed by Barr Engineering: aproximately 484,000 dry tons of C from about 550 acres. This estimate is intermediate among the five different estimates given in Figure 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 stored in the overburden/ Cat 1/2 waste rock stockpile. This peat will be mixed with other overburden material prior to storage in the stockpile, ensuring that there will be minimal areas of 100% peat. The maximum fraction of overburden excavated that is peat during the various stages of the project is 20%. The surface area of the overburden/Cat 1/2 stockpile where overburden is at the surface was calculated and 20% of this value was used as an estimate the surface area that would be peat. The result is 1,559,454 ft^2 of surface that is peat.

Total peat surface area at the Mine Site = 986,501 ft^2 + 1,559,454 ft^2 = 2,545,955 ft^2 or 236,527 m^2 or 58 acres.

This estimated surface area will be larger than the effective surface area over most of the project timeframe in that it assumes the stockpiles are always at their 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.

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.

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.

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.

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 CO2 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 $g/m^2/yr$.

CO_2 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.

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

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

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.

Conclusion

If the area of storage of the excavated peat from the mine site is approximately 58 acres (236,527 m^2), then the annual emissions of C (using the estimate from stockpiles – 3500 g/m^2/yr) would be 822 metric tons of C per year, or 3010 metric tons of CO_2 per year. This is about 1.3 percent of the direct emissions from the project (235,648 metric tons/year), or about 0.4 percent of total emissions including power generation (744,648 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 PolyMet site will consequently minimize emissions from these other sources.

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 58 acres for a total peat stockpile surface area of 63 acres.

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 can be accommodated at the Cat 1/2 and overburden stockpile, so additional peat stockpile surface area did not have to be accounted for. The mass of carbon in this peat was calculated in the same manner as the stockpile footprint and mine pit peat and the result was added to the total.

11.0 Estimate of the Potential for Impact

The discussion in Section 4.0 of this report demonstrates that the hydrometallurgical process requires approximately 50% less energy than a pyrometallurgical process and results in lower CO_2 emissions (Bateman Engineering 2005). In addition, the NorthMet Project's GHG emissions are small when compared with statewide, national, and global emissions (Table 2).

Below is a screening-level assessment, which provides a quantitative estimate of the potential for the project to affect CO_2 air concentrations. Specifically, a potential incremental change in mean global CO_2 air concentration is estimated for the project. This assessment does not include the impacts to the terrestrial carbon cycle because the substantial uncertainty in those estimates outweighs their utility in a cumulative assessment.

Uncertainty

The potential impact of the NorthMet Project is evaluated based on impacts of greenhouse gas emissions from the project on its own and in combination with past, present, and reasonably foreseeable future projects that could impact climate change. Unfortunately, there are no analytical or modeling tools to evaluate the incremental impact of a project's discrete greenhouse gas 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 a particular project's greenhouse gas emissions on natural ecosystems and human economic systems in a given state or region. Despite these gaps in knowledge, this section attempts to quantify the change in CO_2 concentration due to project-specific activity. A more detailed discussion of uncertainty is found in the NorthMet Project Greenhouse Gas and Climate Change Evaluation Report, which references this GHG emission inventory analysis.

Potential for Project Impact on CO_2 Air Concentrations

Two estimates of potential incremental CO_2 air concentrations are provided. One estimate is based on long term data, and the other is based on a known significant emission event. Both estimates rely on the assumption of proportionality between current global CO_2 air concentrations and global anthropogenic emissions. By assuming proportionality between the global CO_2 air concentration and global anthropogenic emissions, it is possible to estimate a potential incremental increase in CO_2 air concentrations that may be associated with the NorthMet Project. Neither calculation accounts for sinks of CO_2 that might decrease potential air concentrations.

Project-Related Air Concentration Estimate Based on Global Emissions and Air Concentration

Input values for the calculation are as follows:

- Factor Development: accumulation of CO_2 in the atmosphere (in ppm) per metric ton of CO_2 emitted. It is assumed that all accumulated CO_2 in the atmosphere is a result of anthropogenic activity.
    - Accumulated atmospheric CO_2 = Current atmospheric CO_2 – Background CO_2

      Current global atmospheric CO_2 = 384 ppm (Tans 2008).

      Background CO_2, pre-industrial, interglacial periods = 280 ppm (Barnola 2003).

      Accumulated CO_2 in the atmosphere = 384 ppm – 280 ppm = 104 ppm
    - Global emissions contributing to CO_2 increase = 1.73E+12 metric tons CO_2

      Emissions Increase = 1.16E+12 m.t. fossil fuel combustion (Marland et al. 2007) + 5.72E+11 m.t. land use change (Houghton and Hackler 2002) = 1.73E+12 m.t. CO_2
    - Factor = anthropogenic CO_2 in the atmosphere (ppm) / metric ton CO_2 emitted)

      = 104 ppm / 1.73E+12 metric tons = 6.02E-11 ppm CO_2 / metric ton CO_2
- Estimated NorthMet Project direct emissions = 256,879 m.t./yr (Table 2)
- Calculation – Project Related Air Concentration:

  CO_2 Air Concentration = 256,879 m.t. CO_2/year x 6.02E-11 ppm/m.t. CO_2 = 0.00002 ppm/year

The potential incremental increase of 0.00002 ppm in global CO_2 air concentration is small compared to the global CO_2 concentration background of greater than 380 ppm, however it is presumed to be an underestimate for the following reasons: The factor that relates the global atmospheric CO_2 concentration increase to the aggregated emissions of CO_2 is generated over a timescale longer than a century. Because the half-life of CO_2 in the atmosphere is on the order of 30 years, emitted CO_2 would have partitioned substantially into its sinks over this timescale. If the emitted CO_2, the denominator in this factor, was held constant and assumed to be an instantaneous one-time release into the atmosphere, the concentration change would be much greater, as is shown in the estimate to follow.

Project-Related Air Concentration Estimate Based on a Significant Individual Event

In 1997 and 1998, large fires in Indonesia, covering thousands of square miles and including significant areas of peatlands, were identified as a primary contributor to elevated CO_2 air concentrations being measured in 1998 (Page et al. 2002). In 1998, the global incremental CO_2 air concentration was measured to be approximately 3 ppm (Tans 2008). The incremental average increase in the 5 years prior to 1998 was approximately 1.7 ppm based on available data from Tans (2008). The incremental average increase in the 5 years after 1998 was approximately 1.8 ppm, also based on data from Tans (2008). Therefore, the global incremental CO_2 air increase of 3 ppm in 1997/1998 is a notable increase (Page et al. 2002; Langmann and Heil 2004). It is assumed that 100% of the increase above the incremental average increase was a result of the 1997/1998 Indonesian vegetation and peatland fires. The fires potentially contributed approximately 1.3 ppm of the measured incremental increase of 3 ppm.

The potential emissions from the 1997/1998 fires in Indonesia have been estimated by a number of researchers (Page et al. 2002; Langmann and Heil 2004), with the most recent estimate being 1136 Teragrams carbon (1,136,000,000 m.t. carbon) (Heil et al. 2007). Langmann and Heil (2004) estimated that CO_2 contributed approximately 83% of the carbon. Converting the carbon emissions to CO_2 results in an estimate of approximately 3,454,000,000 metric tons CO_2 associated with the 1997/1998 Indonesian fires.

The estimated contribution of the Indonesian fires to the global incremental CO_2 air concentration in 1997/1998 provides perspective on the potential for the impact on CO_2 air concentrations from other sources of CO_2 emissions, such as the NorthMet Project. The calculation below again assumes a proportionality between air concentrations and emissions.

Input data for the calculation is as follows:

- CO_2 air concentration associated with a known emission event = 1.3 ppm
- CO_2 emissions from the 1997/1998 Indonesian peatland fires = ~3,454,000,000 m.t./yr
- NorthMet Project direct emissions = 256,879 m.t./yr (Table 2)
- Calculation – Project Related Air Concentration:

  The general equation for the calculation is as follows:

  Event-related CO_2 air concentration (ppm) = "X", Project-related CO_2 air conc. (ppm)

Event CO_2 emissions (m.t./yr) NorthMet Project CO_2 emissions (m.t./yr)

Using the input values discussed above and solving for “X”, “X” = 0.0001 ppm.

A potential incremental increase of 0.0001 ppm in global CO_2 air concentration is also small compared to the global CO_2 background concentration. This estimate is probably a more appropriate approximation of the actual atmospheric concentration change from the direct and indirect project CO_2 emissions because the peat fires (1) happened over a timescale comparable to the project, and (2) the equation above is based on a rate of emission rather than the total mass of emission.

Summary

The intent of this screening-level assessment is to provide perspective on the potential CO_2 emissions from the NorthMet Project in relation to global emissions and global climate change. The findings from the screening assessment include the following:

- Direct CO_2 emissions potentially associated with the NorthMet Project are estimated at 235,648 metric tons per year. This is approximately 0.0005% of estimated global emissions (Table 2).

- The NorthMet Project’s potential CO_2 emissions are approximately 0.007% of the 1997/1998 Indonesian peat fires, which were considered a significant emission event with over 3 billion metric tons of CO_2 emissions. Land conversion and wild land fires continue to be an important and large source of CO_2 air emissions.

- The potential incremental change in CO_2 air concentration associated with the project is estimated to be approximately 0.00002 to 0.0001 ppm. This is small in comparison to the global annual estimated CO_2 air concentration of 384 ppm and is a fraction of the seasonal fluctuations in CO_2 air concentrations of 3 to 9 ppm.

In summary, based on the screening calculations, the potential GHG emissions associated with the NorthMet Project are small when compared to significant global events such as the Indonesian peat fires of 1997/1998.

12.0 Conclusions

The potential annual direct and indirect GHG emissions from the NorthMet Project are estimated as follows (as metric tons CO_2-e): direct = 235,648, indirect = 509,000, total = 744,648. A comparison of the estimated direct GHG emissions for the NorthMet Project to statewide, national, and global GHG emissions shows that the potential GHG emissions from the NorthMet Project are a small fraction of those emissions. The GHG emissions from the NorthMet Project are approximately 0.2% of estimated statewide emissions, 0.003% of national emissions, and 0.0005% of global emissions (Table 3).

Carbon intensity is used as a measure of energy efficiency for a facility and is calculated by dividing estimated CO_2-e emissions by a unit of production. For direct emissions from metal recovery, the carbon intensity for the NorthMet Project is approximately 0.24 using both maximum potential emissions and predicted actual emissions (Table 4). In comparison, using data reported to the European Pollutant Emission Register (EPER) carbon intensities are 0.28 and 0.21 for smelters at facilities in Sweden and Finland, respectively. Available information from Bateman (2005) and identifies that hydrometallurgical processes have 50% lower energy demand than a pyrometallurgical process.

The majority of the GHG emissions from NorthMet's metal recovery process come from neutralization, not energy use. Therefore, the finding that the NorthMet Project has a similar carbon intensity to specific European smelting operations does not discount the findings from other assessments that a hydrometallurgical process uses approximately 50% less energy than a smelting process (Bateman Engineering 2005. The majority of the GHG emissions from NorthMet's metal recovery process come from solution neutralization and raffinate neutralization. These processes do not use energy. Rather, these processes produce CO_2 as a result of controlling sulfuric acid. The quantitative data available for this report shows similar carbon intensities between NorthMet's hydrometallurgical process and *specific* smelting processes.

The carbon intensity of the metal recovery process of the NorthMet Project falls between the carbon intensities calculated using data reported to the EPER for two smelting facilities, but there are 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 NorthMet 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

NorthMet 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 NorthMet Project.

A screening-level assessment was conducted to estimate the project's potential impact on climate. A potential incremental increase in CO_2 air concentration from the project ranges from 0.00002 to 0.00009 ppm. Considering the current average global CO_2 air concentration is currently 384 ppm and that there is an annual fluctuation of 3 to 9 ppm in the Northern Hemisphere as a result of the growing season, potential GHG emissions estimated for the NorthMet Project are not anticipated to have any discernable impact on global atmospheric CO_2 concentrations.

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] = 352,000 metric tons of CO_2

2) Annual emissions from the stockpiling of excavated peat = 430 – 3010 metric tons of CO_2 per year

3) Annual emissions from indirectly impacted wetlands due to lowered water levels = 208 metric tons of CO_2 per year

4) The loss of annual carbon sequestration capacity due to the disturbance of wetland and forest plant communities = 1960 metric tons of CO_2 per year

5) The reduction in annual carbon sequestration capacity in indirectly impacted wetlands = 15 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: The sum of the annual carbon cycle impacts excluding aboveground carbon loss and using the highest estimate of emission from stockpiled peat is equivalent to approximately 0.7% of the sum of 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. In response to the first caveat, the loss estimate can be normalized over the 20-year life of the project. The resulting annual emission rate is 23,200 metric tons of CO_2 per year, or 3.1% of the sum of direct and indirect industrial emissions.

Potential GHG emissions estimated for the NorthMet 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 ID	Emission Unit Description	APCD ID	Throughput Maximum (Units/hr)	Note	Throughput Maximum (Units/yr)	Note	Throughput Projected Actual (Units/yr)	Note	Units	Pollutant	Emission Factor (kg/Unit)	Note	Max. Emissions [1] (kg/hr)	Max. Emissions [1] (m.t./yr)	Projected Actual Emissions [2] (m.t./yr)	CO2-e Factor (Global Warming Potential)[3]	Max. Emissions (CO2-e)[4] (kg/hr)	Max. Emissions (CO2-e)[4] (m.t./yr)	Projected Actual Emissions (CO2-e) [5] (m.t./yr)
Mine Point Sources																				
SV 326	EU 332	WWTP Back up Generator	NA	5.236	[201]	2,618	[301]	2,618	[401]	MMBtu	CO_2	72.37	[101]	378.93	189	189.47	1	378.93	189.47	189.47
SV 337	EU 344	Generator to Move Electrical Equipment	NA	1100	[202]	550,000	[302]	114,400	[402]	hp	CO_2	0.18	[102]	203	101	21.08	1	202.72	101.36	21.08
WWTP	EU 331	WWTF Propane Fired Space Heaters	NA	0.0907	[203]	795	[303]	397.31	[403]	Mgal	CO_2	5,740	[103]	521	4,561	2,281	1	520.68	4,561.14	2,280.57
WWTP				0.0907	[203]	795	[303]	397.31	[403]	Mgal	CH_4	0.08	[104]	0.01	0.065	0.03	25	0.19	1.64	0.82
WWTP				0.0907	[203]	795	[303]	397.31	[403]	Mgal	N_2O	0.37	[104]	0.03	0.291	0.15	298	9.89	86.67	43.33
Mine Fugitive Sources																				
N/A	N/A	Secondary Production Excavator	NA	9.64	[204]	83,295	[304]	83,295	[401]	gal	CO_2	10.15	[105]	98	845	845.44	1	98	845	845.44
N/A				9.64	[204]	83,295	[304]	83,295	[401]	gal	CH_4	5.80E-04	[105]	0.01	0.048	0.05	25	0.14	1.21	1.21
N/A				9.64	[204]	83,295	[304]	83,295	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.022	0.02	298	0.75	6.45	6.45
N/A	N/A	240 ton Haul Trucks	NA	219.15	[204]	1,893,421	[304]	1,893,421	[401]	gal	CO_2	10.15	[105]	2,224	19,218	19,218.22	1	2,224	19,218	19,218.22
N/A				219.15	[204]	1,893,421	[304]	1,893,421	[401]	gal	CH_4	5.80E-04	[105]	0.13	1.098	1.10	25	3.18	27.45	27.45
N/A				219.15	[204]	1,893,421	[304]	1,893,421	[401]	gal	N_2O	2.60E-04	[105]	0.06	0.492	0.49	298	17	147	146.70
N/A	N/A	Tracked Dozer	NA	33.39	[204]	288,476	[304]	288,476	[401]	gal	CO_2	10.15	[105]	339	2,928	2,928.03	1	339	2,928	2,928.03
N/A				33.39	[204]	288,476	[304]	288,476	[401]	gal	CH_4	5.80E-04	[105]	0.02	0.167	0.17	25	0.48	4.183	4.18
N/A				33.39	[204]	288,476	[304]	288,476	[401]	gal	N_2O	2.60E-04	[105]	0.01	0.075	0.08	298	3	22	22.35
N/A	N/A	Wheel Dozer	NA	5.96	[204]	51,490	[304]	51,490	[401]	gal	CO_2	10.15	[105]	60	523	522.62	1	60	523	522.62
N/A				5.96	[204]	51,490	[304]	51,490	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.030	0.03	25	0.09	0.75	0.75
N/A				5.96	[204]	51,490	[304]	51,490	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.013	0.01	298	0.46	3.99	3.99
N/A	N/A	Grader	NA	8.61	[204]	74,391	[304]	74,391	[401]	gal	CO_2	10.15	[105]	87	755	755.07	1	87	755	755.07
N/A				8.61	[204]	74,391	[304]	74,391	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.043	0.04	25	0.12	1.08	1.08
N/A				8.61	[204]	74,391	[304]	74,391	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.019	0.02	298	0.67	5.76	5.76
N/A	N/A	Water Truck / Misc. Trucks	NA	8.76	[204]	75,723	[304]	75,723	[401]	gal	CO_2	10.15	[105]	89	769	768.59	1	89	769	768.59
N/A				8.76	[204]	75,723	[304]	75,723	[401]	gal	CH_4	5.80E-04	[105]	0.01	0.044	0.04	25	0.13	1.10	1.10
N/A				8.76	[204]	75,723	[304]	75,723	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.020	0.02	298	0.68	5.87	5.87
N/A	N/A	Wheel Loader (const, site rehab and misc.)	NA	6.37	[204]	55,016	[304]	55,016	[401]	gal	CO_2	10.15	[105]	65	558	558.41	1	65	558	558.41
N/A				6.37	[204]	55,016	[304]	55,016	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.032	0.03	25	0.09	0.80	0.80
N/A				6.37	[204]	55,016	[304]	55,016	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.014	0.01	298	0.49	4.26	4.26
N/A	N/A	Blast Hole Drill	NA	17.56	[204]	151,716	[304]	151,716	[401]	gal	CO_2	10.15	[105]	178	1,540	1,539.92	1	178	1,540	1,539.92
N/A				17.56	[204]	151,716	[304]	151,716	[401]	gal	CH_4	5.80E-04	[105]	0.01	0.088	0.09	25	0.25	2.20	2.20
N/A				17.56	[204]	151,716	[304]	151,716	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.039	0.04	298	1.36	11.75	11.75
N/A	N/A	Backhoe w/ hammer	NA	0.43	[204]	3,678	[304]	3,678	[401]	gal	CO_2	10.15	[105]	4	37	37.33	1	4	37	37.33
N/A				0.43	[204]	3,678	[304]	3,678	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.002	0.00	25	0.01	0.05	0.05
N/A				0.43	[204]	3,678	[304]	3,678	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.001	0.00	298	0.03	0.28	0.28
N/A	N/A	Tailings Dozer	NA	4.24	[204]	36,645	[304]	36,645	[401]	gal	CO_2	10.15	[105]	43	372	371.94	1	43	372	371.94
N/A				4.24	[204]	36,645	[304]	36,645	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.021	0.02	25	0.06	0.53	0.53
N/A				4.24	[204]	36,645	[304]	36,645	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.010	0.01	298	0.33	2.84	2.84
N/A	N/A	Integrated Tool Carrier	NA	0.80	[204]	6,942	[304]	6,942	[401]	gal	CO_2	10.15	[105]	8	70	70.47	1	8	70	70.47
N/A				0.80	[204]	6,942	[304]	6,942	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.004	0.00	25	0.01	0.10	0.10
N/A				0.80	[204]	6,942	[304]	6,942	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.002	0.00	298	0.06	0.54	0.54
N/A	N/A	Man Bus	NA	0.60	[204]	5,207	[304]	5,207	[401]	gal	CO_2	10.15	[105]	6	53	52.86	1	6	53	52.86
N/A				0.60	[204]	5,207	[304]	5,207	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.003	0.00	25	0.01	0.08	0.08
N/A				0.60	[204]	5,207	[304]	5,207	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.001	0.00	298	0.05	0.40	0.40
N/A	N/A	Pickup Trucks	NA	4.46	[204]	38,573	[304]	38,573	[401]	gal	CO_2	10.15	[105]	45	392	391.52	1	45	392	391.52
N/A				4.46	[204]	38,573	[304]	38,573	[401]	gal	CH_4	5.80E-04	[105]	0.00	0.022	0.02	25	0.06	0.56	0.56
N/A				4.46	[204]	38,573	[304]	38,573	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.010	0.01	298	0.35	2.99	2.99
N/A	N/A	Other Miscellaneous Equipment Fuel Use	NA	32.00	[204]	276,457	[304]	276,457	[401]	gal	CO_2	10.15	[105]	325	2,806	2,806.04	1	325	2,806	2,806.04
N/A				32.00	[204]	276,457	[304]	276,457	[401]	gal	CH_4	5.80E-04	[105]	0.02	0.160	0.16	25	0.46	4.01	4.01
N/A				32.00	[204]	276,457	[304]	276,457	[401]	gal	N_2O	2.60E-04	[105]	0.01	0.072	0.07	298	2.48	21.42	21.42
N/A	N/A	Switching Locomotive	NA	16.75	[205]	146,730	[303]	146,730	[401]	gal	CO_2	10.15	[105]	170	1,489	1,489.31	1	170	1,489	1,489.31
N/A				16.75	[205]	146,730	[303]	146,730	[401]	gal	CH_4	5.80E-04	[105]	0.01	0.085	0.09	25	0.24	2.128	2.13
N/A				16.75	[205]	146,730	[303]	146,730	[401]	gal	N_2O	2.60E-04	[105]	0.00	0.038	0.04	298	1.30	11.37	11.37
N/A	N/A	Main Line Ore Haulage Locomotives	NA	49.04	[206]	429,605	[303]	429,605	[401]	gal	CO_2	10.15	[105]	498	4,360	4,360.49	1	498	4,360	4,360.49
N/A				49.04	[206]	429,605	[303]	429,605	[401]	gal	CH_4	5.80E-04	[105]	0.03	0.249	0.25	25	0.71	6.229	6.23
N/A				49.04	[206]	429,605	[303]	429,605	[401]	gal	N_2O	2.60E-04	[105]	0.01	0.112	0.11	298	4	33	33.29

PolyMet - Hoyt Lakes, Minnesota

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

Stack ID	Emission Unit ID	Emission Unit Description	APCD ID	Throughput Maximum (Units/hr)	Note	Throughput Maximum (Units/yr)	Note	Throughput Projected Actual (Units/yr)	Note	Units	Pollutant	Emission Factor (kg/Unit)	Note	Max. Emissions [1] (kg/hr)	Max. Emissions [1] (m.t./yr)	Projected Actual Emissions [2] (m.t./yr)	CO2-e Factor (Global Warming Potential)[3]	Max. Emissions (CO2-e)[4] (kg/hr)	Max. Emissions (CO2-e)[4] (m.t./yr)	Projected Actual Emissions (CO2-e) [5] (m.t./yr)
Greenhouse Gas Totals											CO_2			5,343	41,568	39,207		5,343	41,568	39,207
											CH_4			0.25	2.16	2.13		6.24	54.09	53.27
											N_2O			0.14	1.23	1.09		42	367	324
											TOTAL GHGs								41,989	39,584

% of total		Max. Emissions (CO2-e) (m.t./yr)	Projected Actual Emissions (CO2-e) (m.t./yr)
	CO_2	99.0%	99.0%
	CH_4	0.1%	0.1%
	N_2O	0.9%	0.8%

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] Emission factors taken from MPCA General Guidance for Carbon Footprint Development in Environmental Review, Table 4, Diesel Fuel. Converted from lb/MMBtu to kg/MMBtu by multiplying by a factor of 0.45359.

[102] Emission factors taken from MPCA General Guidance for Carbon Footprint Development in Environmental Review, Table 4, Diesel Fuel. Conveted to metric units.

[103] Emission factors taken from the Climate Registry General Reporting Protocol (Version 1.1) Table 12.1.

[104] Emission factors taken from Table 12.7 of The Climate Registry's General Reporting Protocol, May 2008. Converted from g/MMBtu to kg/Mgal by multiplying by factors of 91.5 MMBtu/Mgal and 1000 g/kg.

[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, heating demand can be supplied by propane space heaters with a maximum hourly heat input of 8.3 MMBtu/hr. This can be converted to Mgal propane/hr by: 8.3 MMBtu/hr / 91.5 MMBtu/Mgal = 0.0907 MGal/hr. A conservative estimate of annual emissions was made by assuming 50% utilization for the heaters.

[204] Based on available information on fuel consumption. Fuel consumption numbers are based on expected typical mine equipment and vehicles. Actual vehicles and equipment may vary slightly. See table below.

Unit	Manufacturer	Model	Engine	Engine Power	Max Daily Fuel Usage (gal)	Max Annual Fuel Usage
Secondary Production Excavator	Caterpillar	994	Cat 3516	1577 hp	231.4	83,295
240 ton Haul Truck	Caterpillar	830E	Cat 793C	2500 hp	5259.5	1,893,421
Tracked Dozer	Caterpillar	D10R	Cat 3412E	646 hp	801.3	288,476
Wheel Dozer	Caterpillar	834G	Cat 3456	481 hp	143.0	51,490
Grader	Caterpillar	16H	Cat 3406	275 hp	206.6	74,391
Water Truck / Misc. Trucks	Caterpillar	777D	3408 B	938 hp	210.3	75,723
Wheel Loader (const, site rehab and misc.)	Caterpillar	990	990	627 hp	152.8	55,016
Blast Hole Drill	Atlas Copco	PV 351	Cummins QSK45 / Cat 3512	1550 hp	421.4	151,716
Backhoe w/ hammer	Caterpillar	446D	3114 DIT	110 hp	10.2	3,678
Tailings Dozer	Unknown	Unknown	Unknown	Unknown	101.8	36,645
Integrated Tool Carrier	Caterpillar	IT62H	C7 ACERT Tier 3	203 hp	19.3	6,942
Man Bus	Unknown	Unknown	Unknown	Unknown	14.5	5,207
Pickup Trucks	Unknown	Unknown	Unknown	Unknown	107.1	38,573
Other Miscellaneous Equipment Fuel Use	-	-	-	-	767.9	276,457

Note: Specific engine information for Tailings Dozer, Man Bus, and 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] Based on fuel usage estimates for the ore haul locomotives in RS57D, Table 8. Actual fuel usage may vary.

Switching Locomotive

Daily Estimate Total Fuel Usage	402	gallons/day
Hourly Average Fuel Use	16.75	gph

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		Max. Emissions [1]		Projected Actual Emissions [2]	CO_2-e Factor (Global Warming Potential)[3]	Max. Emissions (CO_2-e)[4]		Projected Actual Emissions (CO_2-e) [5]
	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)

[206] Based on fuel usage estimates in RS57D, Table 8. Actual fuel usage may vary.

Daily Estimate Total Fuel Usage	1177	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 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			(kg/Unit)	Note	(kg/hr)	(m.t./yr)	(m.t./yr)		(kg/hr)	(m.t./yr)	(m.t./yr)
Plant Site Point Sources																				
SV 301	EU 301	High Pressure Boiler	NA	0.048	[201]	419	[301]	25.13	[401]	MM cu. ft.	CO_2	53,171.0	[100]	2,542	22,271	1,336	1	2,542	22,271	1,336
SV 301		Natural gas		0.048	[201]	419	[301]	25.13	[401]	MM cu. ft.	N_2O	0.92	[101]	0.044	0.385	0.023	298	13.08	114.59	6.88
SV 301				0.048	[201]	419	[301]	25.13	[401]	MM cu. ft.	CH_4	0.92	[101]	0.044	0.385	0.023	25	1.10	9.61	0.58
SV 328	EU 335	Oxygen Plant Adsorber Regeneration Heater	NA	0.002	[202]	17	[301]	11.40	[402]	MM cu. ft.	CO_2	53,171.0	[100]	104	909	606	1	103.81	909.38	606
SV 328				0.002	[202]	17	[301]	11.40	[402]	MM cu. ft.	N_2O	0.92	[101]	0.002	0.016	0.010	298	0.53	4.68	3.12
SV 328				0.002	[202]	17	[301]	11.40	[402]	MM cu. ft.	CH_4	0.92	[101]	0.002	0.016	0.010	25	0.04	0.39	0.26
Conc B V	EU 302	Space Heating (Various, Natural Gas Fired)	NA	0.057	[203]	495	[301]	197.98	[403]	MM cu. ft.	CO_2	53,171.0	[100]	3,004.173	26,316.558	10,527	1	3,004	26,317	10,527
Conc B V				0.057	[203]	495	[301]	197.98	[403]	MM cu. ft.	N_2O	0.92	[101]	0.052	0.454	0.182	298	15.46	135.40	54.16
Conc B V				0.057	[203]	495	[301]	197.98	[403]	MM cu. ft.	CH_4	0.92	[101]	0.052	0.454	0.182	25	1.30	11.36	4.54
Reag V	EU 302	Space Heating (Various, Natural Gas Fired)	NA	0.030	[203]	261	[301]	104.41	[403]	MM cu. ft.	CO_2	53,171.0	[100]	1,584	13,879	5,552	1	1,584	13,879	5,552
Reag V				0.030	[203]	261	[301]	104.41	[403]	MM cu. ft.	N_2O	0.92	[101]	0.027	0.240	0.096	298	8.15	71.41	28.56
Reag V				0.030	[203]	261	[301]	104.41	[403]	MM cu. ft.	CH_4	0.92	[101]	0.027	0.240	0.096	25	0.68	5.99	2.40
EW V	EU 302	Space Heating (Various, Natural Gas Fired)	NA	0.011	[203]	97	[301]	38.84	[403]	MM cu. ft.	CO_2	53,171.0	[100]	589	5,163	2,065	1	589	5,163	2,065
EW V				0.011	[203]	97	[301]	38.84	[403]	MM cu. ft.	N_2O	0.92	[101]	0.010	0.089	0.036	298	3.03	26.56	10.63
EW V				0.011	[203]	97	[301]	38.84	[403]	MM cu. ft.	CH_4	0.92	[101]	0.010	0.089	0.036	25	0.25	2.23	0.89
Addit V	EU 302	Space Heating (Various, Natural Gas Fired)	NA	0.005	[203]	44	[301]	17.48	[403]	MM cu. ft.	CO_2	53,171.0	[100]	265	2,324	930	1	265	2,324	930
Addit V				0.005	[203]	44	[301]	17.48	[403]	MM cu. ft.	N_2O	0.92	[101]	0.005	0.040	0.016	298	1.36	11.96	4.78
Addit V				0.005	[203]	44	[301]	17.48	[403]	MM cu. ft.	CH_4	0.92	[101]	0.005	0.040	0.016	25	0.11	1.00	0.40
CarDmp V	EU 302	Space Heating (Various, Natural Gas Fired)	NA	0.000	[203]	3	[301]	1.31	[403]	MM cu. ft.	CO_2	53,171.0	[100]	20	174	70	1	19.88	174.15	70
CarDmp V				0.000	[203]	3	[301]	1.31	[403]	MM cu. ft.	N_2O	0.92	[101]	0.000	0.003	0.001	298	0.10	0.90	0.36
CarDmp V				0.000	[203]	3	[301]	1.31	[403]	MM cu. ft.	CH_4	0.92	[101]	0.000	0.003	0.001	25	0.01	0.08	0.03
SXV	EU 302	Space Heating (Various, Natural Gas Fired)	NA	0.016	[203]	143	[301]	57.12	[403]	MM cu. ft.	CO_2	53,171.0	[100]	867	7,593	3,037	1	867	7,593	3,037
SXV				0.016	[203]	143	[301]	57.12	[403]	MM cu. ft.	N_2O	0.92	[101]	0.015	0.131	0.052	298	4.46	39.07	15.63
SXV				0.016	[203]	143	[301]	57.12	[403]	MM cu. ft.	CH_4	0.92	[101]	0.015	0.131	0.052	25	0.37	3.28	1.31
SV 108	EU 128	Existing Backup Generator 1	NA	11.300	[204]	5,650	[302]	2712	[404]	MMBtu	CO_2	72.37	[102]	818	409	196	1	817.78	408.89	196.27
SV 109	EU 129	Existing Backup Generator 2	NA	11.300	[204]	5,650	[302]	2712	[404]	MMBtu	CO_2	72.37	[102]	818	409	196	1	817.78	408.89	196.27
SV 304	EU 304	Fire Pump #1	NA	0.532	[205]	4,660	[301]	34.05	[405]	MMBtu	CO_2	72.37	[103]	39	337	2.464	1	38.50	337.27	2.46
SV 305	EU 305	Fire Pump #2	NA	0.532	[205]	4,660	[301]	34.05	[405]	MMBtu	CO_2	72.37	[103]	39	337	2	1	38.50	337.27	2.46
SV 306	EU 306	Zinc Pot #1	NA	0.012	[207]	105	[301]	10.51	[406]	Mgal	CO_2	10,034	[105]	120	1,055	105	1	120.40	1,054.74	105.47
SV 306				0.012	[207]	105	[301]	10.51	[406]	Mgal	N_2O	0.042	[109]	0.001	0.004	0.0004	298	0.15	1.32	0.13
SV 306				0.012	[207]	105	[301]	10.51	[406]	Mgal	CH_4	0.42	[104]	0.005	0.044	0.004	25	0.13	1.10	0.11
SV 307	EU 307	Zinc Pot #2	NA	0.006	[207]	53	[301]	5.26	[406]	Mgal	CO_2	10,034	[105]	60	527	53	1	60.20	527.37	52.74
SV 307				0.006	[207]	53	[301]	5.26	[406]	Mgal	N_2O	0.042	[109]	0.0003	0.002	0.0002	298	0.08	0.66	0.07
SV 307				0.006	[207]	53	[301]	5.26	[406]	Mgal	CH_4	0.42	[104]	0.003	0.022	0.002	25	0.06	0.55	0.06
SV 308	EU 308	Zinc Pot #3	NA	0.006	[207]	53	[301]	5.26	[406]	Mgal	CO_2	10,034	[105]	60	527	53	1	60.20	527.37	52.74
SV 308				0.006	[207]	53	[301]	5.26	[406]	Mgal	N_2O	0.042	[109]	0.0003	0.002	0.0002	298	0.08	0.66	0.07
SV 308				0.006	[207]	53	[301]	5.26	[406]	Mgal	CH_4	0.42	[104]	0.003	0.022	0.002	25	0.06	0.55	0.06
Area1BV	EU 334	Area 1 Shop Space Heaters (propane fired)	NA	0.098	[208]	859	[301]	429.67	[407]	Mgal	CO_2	5,740	[106]	563	4,933	2,466	1	563.08	4,932.62	2,466
Area1BV				0.098	[208]	859	[301]	429.67	[407]	Mgal	CH_4	0.1	[106]	0.008	0.071	0.035	25	0.20	1.77	0.88
Area1BV				0.098	[208]	859	[301]	429.67	[407]	Mgal	N_2O	0.4	[106]	0.036	0.315	0.157	298	10.70	93.73	46.86
Area2BV	EU 130	Area 2 Shop Space Heaters (propane fired)	NA	0.109	[209]	957	[301]	478.69	[407]	Mgal	CO_2	5,740	[106]	627	5,495	2,748	1	627.32	5,495.34	2,748
Area2BV				0.109	[209]	957	[301]	478.69	[407]	Mgal	CH_4	0.1	[106]	0.009	0.079	0.039	25	0.23	1.97	0.99
Area2BV				0.109	[209]	957	[301]	478.69	[407]	Mgal	N_2O	0.4	[106]	0.040	0.350	0.175	298	11.92	104.42	52.21
SV 2532	EU 2012	Autoclave vent (2 units)	CE 201-203	16.524	[210]	144,750	[303]	130,275	[408]	ton gas	CO_2	2.81	[107]	46	406	366	1	46.38	406.31	365.68
SV 8003	EU 3502	Solution Neutralization Tank 1 Vent	CE 204	4.442	[210]	38,912	[303]	35,021	[408]	ton gas	CO_2	898	[107]	3,988	34,933	31,440	1	3,988	34,933	31,440
SV 8003	EU 3512	Solution Neutralization Tank 2 Vent	CE 204	3.652	[210]	31,992	[303]	28,792	[408]	ton gas	CO_2	869.80	[107]	3,177	27,826	25,044	1	3,177	27,826	25,044
SV 8003	EU 3522	Solution Neutralization Tank 3 Vent	CE 204	0.068	[210]	596	[303]	536.11	[408]	ton gas	CO_2	849.80	[107]	58	506	456	1	57.79	506.21	455.59
SV 8003	EU 6275	Raffinate Neutralization Tanks (4 tanks, 4 vents)	CE 204	4.7208	[210]	41,354	[303]	37,219	[408]	ton exh.	CO_2	879.47	[107]	4,152	36,370	32,733	1	4,152	36,370	32,733
																			100041.48	
Plant Site Fugitive Sources																				
FS 038	FS 038	Plant Site Paved Roads - Limestone Haul	NA	7.62	[211]	47,580	[304]	47,580	[409]	VMT	CO_2	1.45	[108]	1.10E+01	6.90E+01	68.99	1	10.94	68.30	68.99
FS 038				7.62	[211]	47,580	[304]	47,580	[409]	VMT	CH_4	5.10E-06	[108]	3.89E-05	2.43E-04	2.43E-04	25	9.72E-04	6.07E-03	6.07E-03
FS 038				7.62	[211]	47,580	[304]	47,580	[409]	VMT	N_2O	4.80E-06	[108]	3.66E-05	2.28E-04	2.28E-04	298	1.09E-02	6.81E-02	6.81E-02
FS 012	FS 012	Haul Truck Traffic	NA	7.92	[212]	2,775	[305]	2,775	[409]	VMT	CO_2	1.45	[108]	1.15E+01	4.02E+00	4.02	1	11.48	4.02	4.02
FS 012		(accounts for both Plant Site and Mine Site)		7.92	[212]	2,775	[305]	2775	[409]	VMT	CH_4	5.10E-06	[108]	4.04E-05	1.42E-05	1.42E-05	25	1.01E-03	3.54E-04	3.54E-04
FS 012				7.92	[212]	2,775	[305]	2775	[409]	VMT	N_2O	4.80E-06	[108]	3.80E-05	1.33E-05	1.33E-05	298	1.13E-02	3.97E-03	3.97E-03
FS 012		Light Truck Traffic	NA	228.63	[213]	225,820	[306]	225,820	[409]	VMT	CO_2	0.68	[108]	1.55E+02	1.53E+02	152.80	1	154.70	152.80	152.80
FS 012		(accounts for both Plant Site and Mine Site)		228.63	[213]	225,820	[306]	225,820	[409]	VMT	CH_4	1.10E-06	[108]	2.51E-04	2.48E-04	2.48E-04	25	6.29E-03	0.01	6.21E-03
FS 012				228.63	[213]	225,820	[306]	225,820	[409]	VMT	N_2O	1.70E-06	[108]	3.89E-04	3.84E-04	3.84E-04	298	1.16E-01	0.11	1.14E-01
FS 012		Fuel Tanker Travel	NA	5.67	[214]	12,426	[307]	12,426	[409]	VMT	CO_2	1.45	[108]	8.23E+00	1.80E+01	18.02	1	8.23	18.02	18.02
FS 012		(accounts for both Plant Site and Mine Site)		5.67	[214]	12,426	[307]	12,426	[409]	VMT	CH_4	5.10E-06	[108]	2.89E-05	6.34E-05	6.34E-05	25	7.23E-04	1.58E-03	1.58E-03
FS 012				5.67	[214]	12,426	[307]	12,426	[409]	VMT	N_2O	4.80E-06	[108]	2.72E-05	5.96E-05	5.96E-05	298	8.12E-03	1.78E-02	1.78E-02
FS 012		WWTF Trucks	NA	6.65	[215]	4,159	[308]	4,159	[409]	VMT	CO_2	1.45	[108]	9.65E+00	6.03E+00	6.03	1	9.65	6.03	6.03
FS 012				6.65	[215]	4,159	[308]	4,159	[409]	VMT	CH_4	5.10E-06	[108]	3.39E-05	2.12E-05	2.12E-05	25	8.48E-04	5.30E-04	5.30E-04
FS 012				6.65	[215]	4,159	[308]	4,159	[409]	VMT	N_2O	4.80E-06	[108]	3.19E-05	2.00E-05	2.00E-05	298	9.52E-03	5.95E-03	5.95E-03

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

Stack ID	Emission Unit ID	Emission Unit Description	APCD ID	Throughput Maximum (Units/hr)	Note	Throughput Maximum (Units/yr)	Note	Throughput Projected Actual (Units/yr)	Note	Units	Pollutant	Emission Factor (kg/Unit)	Note	Maximum Emissions [1] (kg/hr)	Maximum Emissions [1] (m.t./yr)	Projected Actual Emissions [2] (m.t./yr)	CO2-e Factor (Global Warming Potential)[3]	Max. Emissions (CO2-e)[4] (kg/hr)	Max. Emissions (CO2-e)[4] (m.t./yr)	Projected Actual Emissions (CO2-e) [5] (m.t./yr)
FS 016	FS 016	Tailings Basin Traffic	NA	63.17	[216]	43,046	[309]	43,046	[409]	VMT	CO_2	1.45	[108]	9.16E+01	6.24E+01	62.42	1	91.60	62.42	62.42
FS 016				63.17	[216]	43,046	[309]	43,046	[409]	VMT	CH_4	5.10E-06	[108]	3.22E-04	2.20E-04	2.20E-04	25	8.05E-03	5.49E-03	5.49E-03
FS 016				63.17	[216]	43,046	[309]	43,046	[409]	VMT	N_2O	4.80E-06	[108]	3.03E-04	2.07E-04	2.07E-04	298	9.04E-02	6.16E-02	6.16E-02
Plant Site Totals																				
Greenhouse Gas Totals											CO_2			23,827	193,014	120,294		23,827	193,013	120,294
											CH_4			0.18	1.60	0.50		4.57	39.91	12.52
											N_2O			0.23	2.03	0.75		69.35	605.60	223.72
											TOTAL GHGs								193,659	120,531
														% of total		CO2			99.7%	99.8%
																N2O			0.0%	0.0%
																CH4			0.31%	0.19%

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>

[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] Emission factors taken from MPCA General Guidance for Carbon Footprint Development in Environmental Review, Table 4, Natural Ga

[101] Emission factors from Table 12.7 of The Climate Registry's General Reporting Protocol, May 2008. Converted from g/MMBtu to kg/MMCF by multiplying by the AP-42 factor of 1020 MMBtu/MMscf for natural gas and 1000 g/k

[102] Emission factors taken from MPCA General Guidance for Carbon Footprint Development in Environmental Review, Table 4, Diesel Fuel. Converted from lb/MMBtu to kg/MMBtu by multiplying by a factor of 0.4535

[103] Emission factors taken from MPCA General Guidance for Carbon Footprint Development in Environmental Review, Table 4, Diesel Fuel. Converted from lb/MMBtu to kg/MMBtu by multiplying by a factor of 0.4535

[104] 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 140 MMBtu/Mgal for distillate oil and 1000 g/k

[105] Emission factor taken from MPCA General Guidance for Carbon Footprint Development in Environmental Review, Table 4, Fuel Oil no. 1-

[106] Emission factors taken from the Climate Registry General Reporting Protocol (Version 1.1) Table 12.1

[107] CO2 emission factors where applicable were calculated from information on the weight fraction CO2 in the gaseous phase taken from the process flow simulation (MetSim version U3). The CO2 weight fractions were determined based on material balance and knowledge of process chem

[108] Emission factors 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 truc

	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

[109] Emission factors from The Climate Registry's General Reporting Protocol Table 12.7, Residual Fuel Oil Boilers. Converted to kg/Mgal using 140 MMBtu/Mgal and 1000 g/k

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 ca

Hourly heat input is: 600 kW * 0.94783 (Btu/sec)/kW * 3600 sec/hour / 10^6 MMBtu/Btu = 2.05 MMBtu/hr.

[203] Total plant heating input 125 MMBtu/hr per Paul Stavnes of NORAMCO in a May 1, 2006 e-mail. Heating will be provided by natural gas fired space heaters. The total heat input was apportioned to the various buildings based on footprint are

Maximum fuel consumption is: 125 MMBtu/hr / 1050 MMBtu/MMcu.ft. (heating value of natural gas) = 0.119 MMcf/hr natural gas. Actual emissions based on 40% utilizatio

[204] PolyMet has acquired the two existing backup generators on site from Cliffs Erie. A fuel consumption test was performed on the generators before they were delivered with a result of 587 lb fuel/hr @ 100% pow

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. Each generator is powered by a 1600 hp diesel engin

Therefore, AP 42 Section 3.4 is applicable for emission calculations

[205] Existing fire pumps will be replaced with two Clarke JU4H-UF58 diesel powered pumps. Maximum fuel consumption rate is 3.8 gal/hr per data obtained from the manufacturer. Heat input = 3.8 gal/hr * 140,000 Btu/gallon / 10^6 Btu/MMBtu = 0.532 MMBtu/

[206] Maximum throughput is equivalent to maximum fuel consumption for both fire pumps or 3.8 gallons/hr * 2 = 7.6 gallons/h

[207] Maximum fuel oil consumption rate from calculations for LTVSMC facility

[208] 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 / 91.5 MMBtu/Mgal propane = 0.098 Mgal propane/h

[209] 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 per Title V permit application for LTVSMC). The heaters are expected to have a lower maximum heat input than the existing boil

Fuel consumption rate is then 10 MMBtu/hr / 91.5 (MMBtu / Mgal) = 0.1093 MGal/hr.

[210] Max. Hourly Throughput (ton gas/hr) represents the exhaust generated by the emission unit as obtained from the process flow simulation (MetSim Rev. U3). All emissions from this unit are in the gas phase per the process flow simulatio

The basis for the data in the process flow simulation is the daily processing rate of 32,000 tpd divided by the anticipated operating hours of 21.6 hr/day or 1482 t/hr or

[211] Per Krech Ojard, 50 trucks per day will deliver limestone to the plant when the truck haul option is utilized. The distance traveled along paved roads within PolyMet's property was estimated as 2946 meters or 1.83 mi

The hourly VMT is then: 50 trucks/day / 24 hrs/day * 1.83 miles/day * 2 trips/round trip = 7.62 VMT/hr

[212] The one way travel distance, on roads on PolyMet controlled land, from the haul roads at the mine to the Area 1 shops where the haul truck maintenance will be performed was estimated from aerial photographs with a result of 2.9066 mi

Note: the heavy equipment will be diverted to a route through former mining areas to avoid mixing with light truck traffic. Based on information obtained from PolyMet, 8 trucks would be used for mine hauling and 2 for construction purposes, for a total of 10 trucks. Based on Barr's knowledg

mining operations, we assumed that maintenance would be required on each truck every 250 hours. The maintenance interval in days, assuming worst case 24 hr/day continuous operation is 250/24 = 10.42 da

Trips per day are then 1/10.42 trips/truck/day * 10 trucks = 0.9597 trips/day. A conservative worst case hourly VMT was estimated as having 2 trucks make a one way trip in the hour or 3.9609 miles/trip * 2 trips/hr = 7.92 VMT/hr ma

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 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			(kg/Unit)	Note	(kg/hr)	(m.t./yr)	(m.t./yr)		(kg/hr)	(m.t./yr)	(m.t./yr)

[213] Estimates of light truck traffic on the portions of the Dunka Rd. surrounded by land that will be controlled by PolyMet were made based on information in the 43-101 document, the DFS executive summary, Summary Description of Proposed Mining Operations (2004) and communications
PolyMet. Personnel traveling to the mine site and Area 2 are assumed to be as follow
The above staff were assigned to shifts as shown in the table below. The road segments traveled are also include

Category	Location	1st shift	2nd Shift	3rd Shift	Road Segments Traveled
Mine Ops	Mine	64	43	42	A, B, B2, B3, C, D, H
Mine Tech Serv	Mine	4	4	4	A, B, B2, B3, C, D, H
Mine Tech Serv	Area 2	4	2	0	D, H
Mine Manage.	Area 2	3	0	0	D, H
RR Ops	Area 2	13	9	3	D, H
EHS	PP to mine	3	0	0	A, B, B2, B3, C, D, E, F
Total		91	58	49	

Road Segment	Dist. (miles)	Max Hourly Trips	Max Daily Trips	Hourly VMT	Annual VMT	Daily VMT
A	0.366	33	90	12.09	12034.15	32.97
B	1.940	33	90	64.02	63725.13	174.59
B2	0.160	33	90	5.27	5250.60	14.39
B3	1.166	33	90	38.49	38316.15	104.98
C	1.928	33	90	63.62	63326.89	173.50
D	0.148	171	456	25.24	24566.69	67.31
E	0.722	3	6	2.17	1580.93	4.33
F	0.370	3	6	1.11	810.25	2.22
H	0.114	146	390	16.62	16208.90	44.41
Total	6.914			228.63	225,820	618.68

The distance for each road segment was estimated from an aerial photograph. It was assumed that the mine operations personnel would travel to Area 2 in personal vehicles and then be shuttled in 6 passenger vans to the mine site. All ot
personnel were assumed to drive a vehicle all the way to their destination. The maximum daily and hourly trips are shown in the table above as well as the hourly and annual mi

[214] Based on Barr's knowledge of mining operations, we have assumed that three 7,500 gallon fuel tankers per day would be needed. Only one trip per hour would likely be completed. The distance from the public road south of the plant to the M
Site on roads on land controlled by PolyMet was estimated as 5.674 miles from aerial photographs. These emissions incorporate both Mine Site and Plant Site trav

[215] Maximum throughput for waste water treatment facility estimated as 5,000 tpy lime in and 10,000 tpy sludge out. Lime will be transported from Plant Site in 40 ton over the road trucks with 24 ton payload. Similar trucks will haul sludge back to Pla
Site. Assume different trucks used as worst case. Annual trips = (5000 ton + 10000 ton) /24 ton/truck = 625 trips/yr. Assume 5 day per week, 52 week per year trucking schedule: 625 / (5 * 52) = 2.4 truck per day, round up to 3 trucks per d
Assume maximum hourly rate is one round trip. Maximum VMT for each time period calculated by multiplying the number of trips times 2 for round trips and times the appropriate segment length : B2 = 0.16 miles, C = 1.928 miles, D = 0.148 mi
E = 0.722 miles, and F = 0.370 miles, for a total of 6.654 miles

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

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/y
[302] As recommended by EPA guidance, 500 hours per year operation was assumed for emergency generators. Annual throughput is then hourly throughput * 500 hours/ye
[303] Assume max. Annual exhaust = Max. Hourly Exhaust * 8,760 hr/yr. Projected utilization varies by process area , but all will be less than 8760 hr/y
[304] Per Krech Ojard 50 trucks per day, 5 days per week, will deliver limestone when the truck haul option is utilized. The distance traveled over paved roads on PolyMet's property was estimated from aerial photographs as 1.83 mil
Annual VMT are then 50 trucks per day * 5 days/week * 52 weeks / year * 1.83 miles/trip * 2 trips/round trip = 47580 VMT/yı
[305] The one way travel distance, on roads on land controlled by PolyMet, from the mine roads to the Area 1 shops where the haul truck maintenance will be performed was estimated from aerial photographs with a result of 3.9609 mi
Note: the heavy equipment will be diverted to a route through former mining areas to avoid mixing with light truck traffic. Based on information obtained from PolyMet, 8 trucks will be used for mine hauling and 2 trucks for construction and o
purposes for a total of 10. Based on Barr's knowledge of mining operations, we assumed that maintenance would be required on each truck every 250 hours. The maintenance interval in days, assuming worst case 24 hr/day continuous opera
is 250/24 = 10.42 days. Trips per day are then 1/10.42 trips/truck/day * 10 trucks = 0.9597 trips/day. The annual VMT is then: 3.9609 miles per trip * 2 trips/round trip * 0.9597 trips/day * 365 days/yr = 2774.9
[306] See note 213 above.
[307] Based on Barr's knowledge of mining operations, we have assumed that three 7,500 gallon fuel tankers would be needed per day. The total annual VMT is then: 6 trips/day * 5.674 miles/trip (1 way) * 365 days/yr = 12,426.1 VMT/
[308] Total annual truck trips = (5000 ton lime + 10000 ton sludge) / 24 ton/truck = 625 trips/yr. Number of trips multiplied by 2 for round trips and by the length of the appropriate segment: B2 = 0.16 miles, C = 1.928 miles, D = 0.148 miles, E = 0.722 miles, and F = 0.370 miles, for a yearly total of 4,159 mil
[309] 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/da
The Cliffs Erie VMT estimate was based on estimated odometer readings for vehicles used in the tailings basi

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] Projected actual emissions based on 40% utilization of space heaters. This is a conservative estimate based on historic heating demand at the site with adjustments for changes to the operatio
[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 outa
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 inpu
[406] Projected actual emissions based on 10% utilization
[407] Projected actual emissions based on 50% utilization, a conservative assumption for heating systems
[408] The projected actual throughput is equivalent to the hourly throughput times the projected operating hours for the Hydrometallurgical plant, 7884 hours/y
[409] Projected actual emissions are equivalent to potential emissions.

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 NorthMet Project's electrical needs, which are anticipated to be approximately 59.3 megawatts of power. CO_2 emissions are estimated using MPCA guidance emission factors for Minnesota electricity providers, as documented in the attached Table B-1.

Table B-1. Potential Indirect Emissions from Electricity Generated for the NorthMet Project by a Coal-fired Power Plant in the MAPP Region.

Electrical Load (MWh Total)[1]	Emission Factor (m.t. CO_2 / MWh)[2,3]	CO_2 Emissions (m.t./yr)
519,500	0.98	509,000

(1) Total demand is 59.3 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

Carbon Intensity Calculations

Table C-1. Comparison of Estimated Direct CO_2 Emissions for PolyMet's Hydrometallurgical Process to Emissions from Copper or Copper-Nickel Smelting Facilities

Country	Products	Type	Direct Emissions (m.t. CO_2)[A]	Indirect Emissions (m.t. CO_2)	Annual Conc. Throughput (m.t.)	Intensity (m.t. CO_2 / m.t. throughput)[B]	Year	Notes	Report Identifier
Sweden	Copper, Lead, Gold, Silver, Zinc, Palladium	Smelter	210,000	unknown	744,824	**0.28**	2004	[1]	Sweden
Finland	Copper, Nickel, Gold, Silver	Smelter	109,000	unknown	531,057	**0.21**	2001	[2]	Finland
European		Smelters	885,000		3,920,000	**0.23**	2002	USGS	
USA	Copper, Nickel, Cobalt, Platinum, Palladium, Gold	Mine/Electrowinning	90,035	509,000	368,417	**0.24**	-	[3]	PolyMet

[A] Emissions from European Pollutant Emission Register (EPER).
[B] Intensity only calculated from direct emissions.

Notes:
[1] Emissions do not include mining or initial concentrate operations or emissions resulting from transport of materials from the offsite mine and concentrator.
[2] Emissions do not include mining or initial concentrate operations or emissions resulting from transport of materials from the offsite mine and concentrator.
[3] Emissions are from the autoclave vents and neutralization tanks only.

Attachment D

Combustion Fuel Alternatives Emissions

PolyMet - Hoyt Lakes, Minnesota
Appendix A
Attachment D: Alternative Combustion Fuel Scenarios

Space Heating in Processing Plant (EU 302)

Natural Gas			
Hourly Max Throughput (MMCF/hr)	Annual Max Throughput (MMCF/yr)	Demand (MMBtu/hr) (1)	Emissions (m.t.CO2-e / yr)
0.119	1042.857	125	55450

Autoclave Waste Heat & Remaining Natural Gas			
Demand (MMBtu/hr) (4)	Demand Reduction (MMBtu/hr)	Annual Max Throughput (MMCF/yr)	Emissions (m.t.CO2-e / yr)
80	45	687	35488

Propane (5, 6)		
Hourly Max Throughput (Mgal/hr)	Annual Max Throughput (Mgal/yr)	Emissions (m.t.CO2-e / yr)
1.37	11967	162958

Electricity		
Hourly Max Throughput (kWh/hr) (3)	Annual Max Throughput (kWh/yr)	Emissions (m.t.CO2-e / yr) (2)
36635	311756825	305366

(1) Conversion of 1050 Btu/SCF for natural gas
(2) 0.9795 m.t. CO2 / MWh electricity from MPCA Guidance. MN Power will be the electricity provider for PolyMet
(3) Conversion factor of 3412 Btu / kWh
(4) Using waste heat is expected to reduce heating demand from 125 MMBtu/hr to 80 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.

Diesel Sources

Fuel	Emission Factor From TCR GRP Table 13.1		($kg\ CO_2$ / MMBtu)	Heat Content	
Biodiesel	9.46	kg CO2/gal	79.97	118296	Btu/gal (1)
CNG	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

PolyMet - Hoyt Lakes, Minnesota
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Zinc Pots

Fuel Oil				
Hourly Max Throughput (Mgal/hr)	Annual Max Throughput (Mgal/yr)	Demand (MMBtu/hr) (1)	Max Emissions (m.t.CO2-e / yr)	Actual Emissions (m.t.CO2-e / yr) (6)
0.024	210.240	3.329	2109.471	211

Natural Gas			
Hourly Max Throughput (MMCF/hr) (4)	Annual Max Throughput (MMCF/yr)	Max Emissions (m.t.CO2-e / yr) (5)	Actual Emissions (m.t.CO2-e / yr) (6)
0.0032	28	1628	163

Electricity				
Hourly Max Throughput (kWh/hr) (3)	Annual Max Throughput (kWh/yr)	Annual Expected Throughput (kWh/yr)	Max Emissions (m.t.CO2-e / yr) (2)	Actual Emissions (m.t.CO2-e / yr) (6)
976	8545775	854578	8371	837

LPG			
Hourly Max Throughput (MMBtu/hr)	Annual Max Throughput (MMBtu/yr)	Max Emissions (m.t.CO2-e / yr) (7)	Actual Emissions (m.t.CO2-e / yr) (6)
3.33	29158	4605	461

(1) MPCA General Guidance for Carbon Footprint Development in Environmental Review, Table 4, 138.69 MMBtu/Mgal fuel oil

(2) 0.9795 m.t. CO2 / MWh electricity from MPCA Guidance. MN Power will be the electricity provider for PolyMet

(3) Conversion factor of 3412 Btu / kWh

(4) Conversion 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

(6) Actual use of zinc pots is expected to be 10% of max capacity

(7) MPCA General Guidance for Carbon Footprint Development in Environmental Review, Table 4, 348.19 lbs CO2 / MMBtu LPG

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Appendix A
Attachment D: Alternative Combustion Fuel Scenarios

Propane Space Heaters

Propane			
Hourly Max Throughput (Mgal/hr)	Annual Max Throughput (Mgal/yr)	Demand (MMBtu/hr) (1)	Max Emissions (m.t.CO2-e / yr)
0.207	1816.719	19	10428

Electricity		
Hourly Max Throughput (kWh/hr) (3)	Annual Max Throughput (kWh/yr)	Max Emissions (m.t.CO2-e / yr) (2)
5562	48719156	47720

Natural Gas		
Hourly Max Throughput (MMCF/hr) (4)	Annual Max Throughput (MMCF/yr)	Max Emissions (m.t.CO2-e / yr) (5)
0.02	158	8416

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

(2) 0.9795 m.t. CO2 / MWh electricity from MPCA Guidance. MN Power will be the electricity provider for PolyMet

(3) Conversion factor of 3412 Btu / kWh

(4) Conversion 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 E

Impacted Wetlands Detail

Table E-1. Total Projected Wetland Impact Detail

Revised November 19, 2008

NorthMet Mine/PolyMet Mining Co.

Project Area	Wetland ID	Dominant Circular 39 Type	Total Wetland Area (acres)	Direct Wetland Impacts	Projected Indirect Wetland Impacts (acres)	Dominant Community Type	Vegetative Diversity/ Integrity	Overall Wetland Quality	Disturbance Level	Disturbance Type	Wetland Origin	Field Delineated	Impact Type (Direct/Indirect)
Mine Site	1	3	0.42	0.42	0.00	shallow marsh	Moderate	Moderate	High	Impounded	Natural	Y	Direct
Mine Site	3	3	0.35	0.35	0.00	shallow marsh	Moderate	Moderate	High	Impounded	Natural	N	Direct
Mine Site	5	2	0.61	0.61	0.00	wet meadow	High	High	Low		Natural	Y	Direct
Mine Site	6	3	0.62	0.62	0.00	shallow marsh	Moderate	Moderate	High	Impounded	Natural	Y	Direct
Mine Site	7	2	0.07	0.07	0.00	wet meadow	Moderate	Moderate	High	Impounded	Natural	N	Direct
Mine Site	8	2	6.16	6.16	0.00	sedge meadow	Moderate	Moderate	High	Impounded/Fill	Natural	Y	Direct
Mine Site	9	3	1.82	0.54	0.00	shallow marsh	High	High	Moderate	Impounded	Natural	Y	Direct
Mine Site	10	2	1.17	1.17	0.00	sedge meadow	High	High	Low		Natural	Y	Direct
Mine Site	11	8	8.88	0.00	0.00	coniferous bog	High	High	Low		Natural	Y	None
Mine Site	12	6	0.13	0.00	0.00	alder thicket	High	High	Low		Natural	Y	None
Mine Site	13	2	5.03	0.26	0.00	wet meadow	High	High	High	Impounded	Natural	Y	Direct
Mine Site	14	2	0.33	0.33	0.00	wet meadow	High	High	Low		Natural	Y	Direct
Mine Site	15	8	2.79	0.00	0.00	coniferous bog	High	High	Low		Natural	Y	None
Mine Site	16	3	0.30	0.19	0.11	shallow marsh	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	18	3	18.89	18.89	0.00	shallow marsh	High	High	Moderate	Impounded	Natural	Y	Direct
Mine Site	19	3	1.68	1.68	0.00	shallow marsh	High	High	Low		Natural	Y	Direct
Mine Site	20	2	21.89	21.34	0.55	sedge meadow	High	High	Low		Natural	N	Direct/Indirect
Mine Site	22	3	2.51	0.00	0.00	shallow marsh	High	High	Low		Natural	Y	None
Mine Site	24	6	0.80	0.80	0.01	alder thicket	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	25	8	1.95	0.00	0.00	coniferous bog	High	High	Low		Natural	Y	None
Mine Site	27	8	1.07	1.07	0.00	coniferous bog	Moderate	Moderate	High	Road Fill	Natural	Y	Direct
Mine Site	29	3	12.01	2.34	0.00	shallow marsh	High	High	Low		Natural	Y	Direct
Mine Site	32	8	69.89	63.56	2.23	coniferous bog	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	33	6	23.91	8.45	0.00	alder thicket	High	High	Low		Natural	Y	Direct
Mine Site	34	6	0.99	0.99	0.00	alder thicket	High	High	Low		Natural	Y	Direct
Mine Site	37	6	2.39	2.39	0.00	shrub carr	High	High	Low		Natural	N	Direct
Mine Site	43	6	8.33	8.26	0.04	alder thicket	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	44	6	3.26	1.98	0.00	alder thicket	High	High	Low		Natural	Y	Direct
Mine Site	45	6	30.58	20.63	1.43	alder thicket	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	47	8	0.54	0.54	0.00	open bog	High	High	Low		Natural	Y	Direct
Mine Site	48	8	98.44	40.21	0.92	coniferous bog	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	51	6	2.91	2.91	0.00	alder thicket	High	High	Low		Natural	Y	Direct
Mine Site	52	6	3.88	2.74	1.13	alder thicket	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	53	6	24.24	2.68	0.48	alder thicket	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	54	6	4.85	0.00	0.00	alder thicket	High	High	Low		Natural	Y	None
Mine Site	55	6	3.91	3.59	0.32	alder thicket	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	56	8	2.78	0.00	0.00	coniferous bog	High	High	Low		Natural	Y	None
Mine Site	57	7	78.01	54.70	0.00	coniferous swamp	High	High	Low		Natural	Y	Direct
Mine Site	58	6	33.29	0.13	0.00	alder thicket	High	High	Low		Natural	Y	Direct
Mine Site	60	6	5.95	5.95	0.00	alder thicket	High	High	Low		Natural	Y	Direct
Mine Site	61	7	0.45	0.00	0.00	coniferous swamp	High	High	Low		Natural	Y	None
Mine Site	62	8	12.13	0.00	0.00	coniferous bog	High	High	Low		Natural	Y	None
Mine Site	64	7	0.31	0.00	0.00	hardwood swamp	High	High	Low		Natural	N	None
Mine Site	68	7	20.05	7.30	0.25	hardwood swamp	High	High	Low		Natural	N	Direct/Indirect
Mine Site	72	7	1.38	0.59	0.79	coniferous swamp	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	74	7	6.12	6.12	0.00	hardwood swamp	High	High	Low		Natural	Y	Direct
Mine Site	76	8	3.38	2.42	0.00	coniferous bog	High	High	Low		Natural	Y	Direct
Mine Site	77	8	13.00	7.82	0.08	coniferous bog	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	78	8	0.81	0.81	0.00	coniferous bog	High	High	Low		Natural	Y	Direct
Mine Site	79	8	2.39	0.00	0.00	coniferous bog	High	High	Low		Natural	Y	None
Mine Site	80	8	0.29	0.29	0.00	coniferous bog	High	High	Low		Natural	Y	Direct
Mine Site	81	7	1.68	1.21	0.47	coniferous swamp	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	82	8	61.52	60.16	1.36	coniferous bog	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	83	8	3.99	3.69	0.00	open bog	High	High	Low		Natural	Y	Direct
Mine Site	84	8	1.33	1.33	0.00	coniferous bog	High	High	Low		Natural	Y	Direct
Mine Site	85	8	1.41	1.41	0.00	coniferous bog	High	High	Low		Natural	Y	Direct
Mine Site	86	8	2.47	2.47	0.00	coniferous bog	High	High	Low		Natural	Y	Direct
Mine Site	88	8	5.57	4.00	1.57	coniferous bog	High	High	Low		Natural	N	Direct/Indirect

Project Area	Wetland ID	Dominant Circular 39 Type	Total Wetland Area (acres)	Direct Wetland Impacts	Projected Indirect Wetland Impacts (acres)	Dominant Community Type	Vegetative Diversity/ Integrity	Overall Wetland Quality	Disturbance Level	Disturbance Type	Wetland Origin	Field Delineated	Impact Type (Direct/Indirect)
Mine Site	90	8	184.68	71.88	0.18	open bog	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	95	8	2.54	2.54	0.00	coniferous bog	High	High	Low		Natural	N	Direct
Mine Site	96	8	17.29	16.35	0.94	coniferous bog	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	97	8	3.53	1.66	1.88	coniferous bog	High	High	Low		Natural	N	Direct/Indirect
Mine Site	98	8	15.49	15.49	0.00	coniferous bog	High	High	Low		Natural	Y	Direct
Mine Site	99	8	1.40	0.55	0.85	coniferous bog	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	100	8	192.25	117.74	2.05	coniferous bog	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	101	8	15.09	7.18	0.00	coniferous bog	High	High	Low		Natural	Y	Direct
Mine Site	103	8	125.89	116.40	9.49	coniferous bog	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	104	8	3.57	3.12	0.46	coniferous bog	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	105	8	15.47	0.00	0.00	coniferous bog	High	High	Moderate	Logged	Natural	Y	None
Mine Site	107	8	65.79	42.14	0.39	coniferous bog	High	High	Low		Natural	Y	Direct/Indirect
Mine Site	109	6	6.03	6.03	0.00	alder thicket	High	High	Low	Partly cleared	Natural	Y	Direct
Mine Site	114	8	0.73	0.73	0.00	coniferous bog	High	High	Low		Natural	Y	Direct
Mine Site	120	3	0.58	0.58	0.00	shallow marsh	Moderate	Moderate	Moderate	Impounded	Natural	Y	Direct
Mine Site	200	7	6.36	6.36	0.00	hardwood swamp	High	High	Low		Natural	Y	Direct
Mine Site	201	2	13.48	13.48	0.00	wet meadow	High	High	Low		Natural	Y	Direct
Mine Site	202	7	5.67	5.67	0.00	coniferous swamp	High	High	Low		Natural	Y	Direct
Mine Site Subtotal	**59**		**1301.74**	**804.05**	**27.95**		**52/59 High 7/59 Medium**	**52/59 High 7/59 Medium**					
Railroad	R-1	2	1.05	0.00	0.00	wet meadow	High	High	Moderate	Road fill	Natural	Y	None
Railroad	R-2	3	1.65	0.00	0.00	shallow marsh	High	High	Moderate	Road fill	Natural	Y	None
Railroad	R-3	7	0.63	0.10	0.00	hardwood swamp	High	High	Moderate	Road fill	Natural	Y	Direct
Railroad	R-4	6	3.50	0.17	0.00	shrub carr	High	High	Low		Natural	Y	Direct
Railroad	R-5	3	24.41	0.00	0.00	shallow marsh	High	High	Moderate	Impounded	Natural	Y	None
Railroad	R-6	3	10.42	0.00	0.00	shallow marsh	High	High	Low		Natural	Y	None
Railroad	R-7	6	12.14	0.00	0.00	shrub carr	High	High	Moderate	Impounded	Natural	Y	None
Railroad	R-8	6	3.00	0.00	0.00	shrub carr	High	High	Moderate	Impounded	Natural	Y	None
Railroad Subtotal	**8**		**56.80**	**0.27**	**0.00**		**8/8 High**	**8/8 High**					
Tailings Basin Drain System	None	None	None	0.00	0.00	None							
Tailings Basin Subtotal				**0.00**	**0.00**								
Dunka Road & Water Pipeline	4000	3		0.78	0.00	shallow marsh	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4001	3		0.45	0.00	shallow marsh	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4002	3		0.30	0.00	shallow marsh	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	22	3		0.47	0.00	shallow marsh	High	High	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4004	3		0.01	0.00	shallow marsh	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4005	4		0.25	0.00	deep marsh	Moderate	Moderate	Moderate	Impounded	Natural	Y	Direct
Dunka Road & Water Pipeline	4006	5		0.05	0.00	open water	Moderate	Moderate	Moderate	Impounded	Natural	Y	Direct
Dunka Road & Water Pipeline	4007	6		0.88	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4008	6		1.28	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4009	6		0.03	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4010	6		0.68	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4011	6		1.27	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4012	6		0.06	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct

Project Area	Wetland ID	Dominant Circular 39 Type	Total Wetland Area (acres)	Direct Wetland Impacts	Projected Indirect Wetland Impacts (acres)	Dominant Community Type	Vegetative Diversity/ Integrity	Overall Wetland Quality	Disturbance Level	Disturbance Type	Wetland Origin	Field Delineated	Impact Type (Direct/Indirect)
Dunka Road & Water Pipeline	4013	6		0.92	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4014	6		0.29	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4015	6		0.19	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	54	6		0.48	0.00	alder thicket	High	High	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4017	6		0.04	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4018	6		0.20	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4019	6		0.27	0.00	shrub carr	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4021	7		0.45	0.00	coniferous swamp	High	HIgh	Low		Natural	Y	Direct
Dunka Road & Water Pipeline	4023	deepwater		0.45	0.00	deepwater	High	HIgh	Low		Natural	Y	Direct
Water Pipeline Subtotal	**22**			**9.77**	**0.00**		**2/20 Medium 18/20 High**	**2/20 Medium 18/20 High**					
East Basin Expansion Area	T1	5		0.17	0.00	open water	Low	Low	High	Impounded	Natural	Y	Direct
East Basin Expansion Area	T2	5		0.90	0.00	open water	Low	Low	High	Impounded	Natural	Y	Direct
East Basin Expansion Area	T3	2		0.09	0.00	wet meadow	Low	Low	High	Ditch	Created	Y	Direct
East Basin Expansion Area	T4	2		1.02	0.00	wet meadow	Low	Low	High	Road Fill	Created	Y	Direct
East Basin Expansion Area	T5	2		0.24	0.00	wet meadow	Low	Low	High	Road Fill	Created	Y	Direct
East Basin Expansion Area	T6	6		0.07	0.00	shrub carr	Low	Low	High	Road Fill	Created	Y	Direct
East Basin Expansion Area	T7	3		0.92	0.00	shallow marsh	Low	Low	High	Impounded	Created	Y	Direct
East Basin Expansion Area	T8	2		0.04	0.00	wet meadow	Low	Low	High	Seepage	Created	Y	Direct
East Basin Expansion Area	T9	2		0.38	0.00	wet meadow	Low	Low	High	Seepage	Created	Y	Direct
East Basin Expansion Area	T10	5		1.48	0.00	open water	Low	Low	High	Impounded	Natural	Y	Direct
East Basin Expansion Area	T11	5		0.96	0.00	open water	Low	Low	High	Impounded	Natural	Y	Direct
East Basin Expansion Area	T12	3		0.39	0.00	shallow marsh	Low	Low	High	Impounded	Created	Y	Direct
East Basin Expansion Area	T13	4		0.60	0.00	deep marsh	Low	Low	High	Impounded	Natural	Y	Direct
East Basin Expansion Area	T14	4		10.06	0.00	deep marsh	Low	Low	High	Impounded	Natural	Y	Direct
East Basin Expansion Area	T15	3		1.70	0.00	shallow marsh	Low	Low	High	Impounded	Created	Y	Direct
East Basin Expansion Area	T31	7		0.03	0.00	coniferous swamp	Low	Low	High	Impounded	Natural	Y	Direct
TB Mitigation Alternative East Basin Expansion Area	**16**		**0.00**	**19.05**	**0.00**								
TB Mitigation Alternative - Buttress Area	T16	4		9.03	0.00	deep marsh	Low	Low	High	Ditch	Created	Y	Direct
TB Mitigation Alternative - Buttress Area	T17	7		1.18	0.00	coniferous swamp	Low	Low	High	Impounded	Natural	Y	Direct

Project Area	Wetland ID	Dominant Circular 39 Type	Total Wetland Area (acres)	Direct Wetland Impacts	Projected Indirect Wetland Impacts (acres)	Dominant Community Type	Vegetative Diversity/ Integrity	Overall Wetland Quality	Disturbance Level	Disturbance Type	Wetland Origin	Field Delineated	Impact Type (Direct/Indirect)
TB Mitigation Alternative - Buttress Area	T18	4		4.07	0.00	deep marsh	Low	Low	High	Impounded	Natural	Y	Direct
TB Mitigation Alternative - Buttress Area	T19	4		18.91	0.00	deep marsh	Low	Low	High	Ditch / Impounded	Natural	Y	Direct
TB Mitigation Alternative - Buttress Area	T20	7		0.45	0.00	coniferous swamp	Low	Low	High	Impounded	Natural	Y	Direct
TB Mitigation Alternative - Buttress Area	T21	6		0.48	0.00	shrub carr	Low	Low	High	Impounded	Natural	Y	Direct
TB Mitigation Alternative - Buttress Area	T23	7		0.22	0.00	coniferous swamp	Low	Low	High	Impounded	Natural	Y	Direct
TB Mitigation Alternative - Buttress Area	T24	7		0.33	0.00	coniferous swamp	Low	Low	High	Impounded	Natural	Y	Direct
TB Mitigation Alternative - Buttress Area	T25	6		0.01	0.00	shrub carr	Low	Low	High	Impounded	Natural	Y	Direct
TB Mitigation Alternative - Buttress Area	T26	6		1.38	0.00	shrub carr	Low	Low	High	Impounded	Natural	Y	Direct
TB Mitigation Alternative - Buttress Area	T27	7		0.03	0.00	coniferous swamp	Low	Low	High	Impounded	Natural	Y	Direct
TB Mitigation Alternative - Buttress Area	T28	6		0.05	0.00	shrub carr	Low	Low	High	Impounded	Natural	Y	Direct
TB Mitigation Alternative - Buttress Area	T29	2		0.00	0.00	wet meadow	Low	Low	High	Ditch	Created	Y	None
TB Mitigation Alternative - Buttress Area	T30	6		0.02	0.00	shrub carr	Low	Low	High	Impounded	Natural	Y	Direct
TB Mitigation Alternative Buttress Area	**14**		**0.00**	**36.16**	**0.00**		**14/14 Low**	**14/14 Low**					
Project Total	**119**		**1358.54**	**869.30**	**27.95**								

Attachment F

Mass of Peat Removed over Project Life Calculations

Table F-1. Proposed Mine Plan Overburden Stripping and Peat Removal

	Year 1					
	Total Overburden Stripped	Peat Acreage included in Total Overburden Stripped		Peat Volume*		
	Acres	2 ft depth	6 ft depth	**ELT 2 CY**	**ELT 6 CY**	**tons****
Overburden Storage	0	0.00	0.00	0	0	0
Overburden/Cat 1/2 Stockpile	173.33	10.42	31.20	33,636	302,011	71,831
Cat 4 LO	54.53	7.07	1.29	22,828	12,459	8,323
Cat 4	4.47	0.00	4.42	0	42,782	8,984
Cat 3 LO	35.37	2.06	7.65	6,649	74,091	17,222
Cat 3	5.92	3.11	2.14	10,039	20,742	6,866
Pits	119.24	6.70	39.32	21,619	380,618	85,334
Year 1 Totals	**392.86**	**29.37**	**86.02**	**94,772**	**832,703**	**198,561**
	Year 2-5					
	Total Overburden Stripped	Peat Acreage included in Total Overburden Stripped		Peat Volume		
	Acres	2 ft depth	6 ft depth	**ELT 2 CY**	**ELT 6 CY**	**tons****
Overburden Storage	0	0.00	0.00	0	0	0
Overburden/Cat 1/2 Stockpile	312.43	24.25	179.95	78,251	1,741,875	385,357
Cat 4 LO	0.00	0.00	0.00	0	0	0
Cat 4	35.51	1.33	9.77	4,294	94,553	20,930
Cat 3 LO	28.40	0.00	8.89	-3	86,027	18,065
Cat 3	19.68	5.65	4.53	18,226	43,884	13,772
Pits	99.20	0.49	20.08	1,567	194,405	41,217
Year 2-5 Totals	**495.22**	**31.72**	**223.22**	**102,336**	**2,160,743**	**479,340**
	Year 6-10					
	Total Overburden Stripped	Peat Acreage included in Total Overburden Stripped		Peat Volume		
	Acres	2 ft depth	6 ft depth	**ELT 2 CY**	**ELT 6 CY**	**tons****
Overburden Storage	0	0.00	0.00	0	0	0
Overburden/Cat 1/2 Stockpile	77.99	24.39	5.92	78,698	57,306	31,709
Cat 4 LO	0.00	0.00	0.00	0	0	0
Cat 4	23.36	0.00	3.58	2	34,630	7,273
Cat 3 LO	33.97	5.70	6.57	18,405	63,627	17,963
Cat 3	21.25	1.81	1.97	5,850	19,112	5,476
Pits	110.35	1.79	55.60	5,767	538,204	114,464
Year 6-10 Totals	**266.92**	**33.69**	**73.64**	**108,722**	**712,878**	**176,885**
	Year 11-15					
	Total Overburden Stripped	Peat Acreage included in Total Overburden Stripped		Peat Volume		
	Acres	2 ft depth	6 ft depth	**ELT 2 CY**	**ELT 6 CY**	**tons****
Overburden Storage	0	0	0	0	0	0
Overburden/Cat 1/2 Stockpile	0	0	0	0	0	0
Cat 4 LO	0	0	0	0	0	0
Cat 4	0	0	0	0	0	0
Cat 3 LO	59.00	7.52	15.44	24,262	149,483	37,457
Cat 3	25.10	0.00	7.51	0	72,692	15,265
Pits	121.87	14.24	33.16	45,933	320,942	78,881
Year 11-15 Totals	**205.97**	**21.75**	**56.11**	**70,195**	**543,117**	**131,603**
	Year 16-20					
	Total Overburden Stripped	Peat Acreage included in Total Overburden Stripped		Peat Volume		
	Acres	2 ft depth	6 ft depth	**ELT 2 CY**	**ELT 6 CY**	**tons****
Overburden Storage	0	0	0	0	0	0
Overburden/Cat 1/2 Stockpile	0	0	0	0	0	0
Cat 4 LO	0	0	0	0	0	0
Cat 4	0	0	0	0	0	0
Cat 3 LO	0	0	0	0	0	0
Cat 3	0	0	0	0	0	0
Pits	0	0	0	0	0	0
Year 16-20 Totals	**0**	**0**	**0**	**0**	**0**	**0**

Table F-2. Proposed Plan - Timeline of Overburden with Peat Stripping Acreages

		Year 1	Year 2-5	Year 6-10	Year 11-15	Year 16-20	Totals
Overburden Stripping Including Peat	acres	392.86	495.22	266.92	205.97	0.0	1,361
Peat 2' depth	acres	29.37	31.72	33.69	21.75	0.0	117
Peat 6' depth	acres	86.02	223.22	73.64	56.11	0.0	439
ELT 2	cu-yds	94,771.75	102,336.16	108,722.39	70,195.39	0.0	376,026
ELT 6	cu-yds	832,703	2,160,743	712,878	543,117	0.0	4,249,442
Peat Mass	tons	198,561	479,340	176,885	131,603	0.0	986,389

Attachment G

Aboveground Carbon Stock and Sequestration Capacity Loss Calculations

Table G-1. Aboveground Carbon Storage and Carbon Sequestration Rates for Wetland and Upland Forest Habitats

					Project Impact Area				Project Impacts		
Ecosystem Type	Predominant Soils	General Habitat	Detailed Habitat	Carbon Estimation Habitat	Acres	Hectares	Biomass Carbon Storage (Metric tonnes/ha)	Carbon Sequestration (Metric tonnes/ha/yr)	Biomass Carbon Lost (metric tonnes)	Carbon Sequestration Lost (Metric tonnes/year)	Notes
Upland	Mineral	Other	Disturbed	Disturbed	56.58	22.90	0.00	0.00	0.00	0.00	Habitat consists of roads, railroads, and rights-of-way. Assume carbon sequestration and storage are negligible.
		Jack pine forest	Forest conifer mature	70 year old jack pine forest	5.19	2.10	69.25	0.23	359.27	0.47	Storage and sequestration based on jack pine monotypic stands from COLE.
		Jack pine forest	Forest conifer pole	30 year old jack pine forest	158.81	64.27	55.29	0.48	8,780.60	30.85	Storage and sequestration based on jack pine monotypic stands from COLE.
		Aspen/aspen-birch forest	Forest decidous mature (12+" dbh)	60 year old aspen/birch forest	0.00	0.00	65.68	0.35	0.00	0.00	Storage and sequestration based on average of aspen and birch monotypic stands from COLE.
		Aspen/aspen-birch forest	Forest decidous pole (5-12" dbh)	40 year old aspen/birch forest	64.11	25.95	59.40	0.73	3,808.25	18.84	Storage and sequestration based on average of aspen and birch monotypic stands from COLE.
		Aspen/aspen-birch forest	Forest decidous sapling (0-4" dbh)	20 year old aspen/birch forest	33.91	13.72	37.10	1.33	1,258.02	18.25	Storage and sequestration based on average of aspen and birch monotypic stands from COLE.
		Mixed pine/hardwood forest	Forest mixed pole	40 year old aspen/birch/red pine forest	437.78	177.16	61.10	0.69	26,748.11	122.95	Storage and sequestration based on average of aspen, birch, red pine, jack pine and balsam fir monotypic stands from COLE.
		Mixed pine/hardwood forest	Forest mixed mature	60 year old aspen/birch/red pine forest	164.95	66.75	72.20	0.50	11,909.68	33.24	Storage and sequestration based on average of aspen, birch, red pine, jack pine and balsam fir monotypic stands from COLE.
		Other	Grassland	5 year old aspen/birch forest	68.19	27.60	19.10	0.75	1,302.51	20.75	Storage and sequestration based on average of aspen and birch monotypic stands from COLE.
		Other	Shrubland	15 year old aspen/birch forest	162.16	65.63	30.50	1.22	4,946.00	80.19	Storage and sequestration based on average of aspen and birch monotypic stands from COLE.
				Upland Total	**1,151.68**	**466.07**			**59,112.45**	**325.55**	
Wetland	Mineral	Mixed hardwood swamp	Palustrine scrub shrub	Wetland shrub scrub	18.74	7.59	48.00	0.33	899.71	2.50	Biomass storage value for peatlands/mineral soil wetlands from Bridgham et al. 2006. Sequestration value for freshwater mineral soil wetlands from Bridgham et al. 2006.
		Black spruce dominated wetland	Palustrine forest conifer mature	70 year old black spruce forest	0.00	0.00	67.39	0.12	0.00	0.00	Storage and sequestration based on black spruce monotypic stands from COLE.
		Black spruce dominated wetland	Palustrine forest conifer pole	60 year old black spruce forest	14.40	5.83	66.20	0.17	953.54	0.99	Storage and sequestration based on black spruce monotypic stands from COLE.
		Black spruce dominated wetland	Palustrine forest conifer sapling	30 year old black spruce forest	0.00	0.00	59.53	0.23	0.00	0.00	Storage and sequestration based on black spruce monotypic stands from COLE.
		Black spruce dominated wetland	Palustrine forest dead	Dead 30 year old black spruce forest	0.00	0.00	29.77	0.70	0.00	0.00	Storage and sequestration based on black spruce monotypic stands from COLE. Assumed 50% carbon storage value of 30 year old black spruce stand. Assumed general sequestration rate for peatlands based on studies cited by Lennon and Nater 2006.
		Mixed hardwood swamp	Palustrine forest deciduous pole (5-12" dbh)	35 year old aspen/red maple/black ash forest	0.00	0.00	53.68	0.85	0.00	0.00	Storage and sequestration based on black ash/American elm/red maple stands from COLE.
		Mixed hardwood swamp	Palustrine forest deciduous sapling (0-4" dbh)	30 year old aspen/red maple/black ash forest	12.66	5.12	49.42	0.70	625.56	3.57	Storage and sequestration based on black ash/American elm/red maple stands from COLE.
		Mixed hardwood swamp	Palustrine forest mixed mature	60 year old black spruce/paper birch forest	0.00	0.00	66.02	0.24	0.00	0.00	Storage and sequestration based on average of aspen and black spruce monotypic stands from COLE.
		Mixed hardwood swamp	Palustrine forest mixed pole	30 year old black spruce/paper birch forest	0.00	0.00	54.93	0.63	0.00	0.00	Storage and sequestration based on average of aspen and black spruce monotypic stands from COLE.
		Other	Wetland	Herbaceous emergent wetland	13.92	5.63	0.00	0.33	0.00	1.86	Assume negligible long term storage in biomass in herbaceous vegetation. Sequestration value for freshwater mineral soil wetlands from Bridgham et al. 2006.
				Mineral Wetland Total	**59.73**	**24.17**			**2,478.82**	**8.92**	
	Peat	Black spruce dominated wetland	Palustrine emergent (bog/marsh)	Bog	595.80	241.11	48.00	0.70	28,598.35	168.78	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.
		Black spruce dominated wetland	Palustrine forest conifer mature	70 year old black spruce forest	0.00	0.00	67.39	0.12	0.00	0.00	Storage and sequestration based on black spruce monotypic stands from COLE.
		Black spruce dominated wetland	Palustrine forest conifer pole	60 year old black spruce forest	47.77	19.33	66.20	0.17	3,162.37	3.29	Storage and sequestration based on black spruce monotypic stands from COLE.
		Black spruce dominated wetland	Palustrine forest conifer sapling	30 year old black spruce forest	0.00	0.00	59.53	0.23	0.00	0.00	Storage and sequestration based on black spruce monotypic stands from COLE.
		Black spruce dominated wetland	Palustrine forest dead	Dead 30 year old black spruce forest	0.00	0.00	29.77	0.70	0.00	0.00	Storage and sequestration based on black spruce monotypic stands from COLE. Assumed 50% carbon storage value of 30 year old black spruce stand. Assumed general sequestration rate for peatlands based on studies cited by Lennon and Nater 2006.
		Mixed hardwood swamp	Palustrine forest deciduous pole (5-12" dbh)	35 year old aspen/red maple/black ash forest	0.00	0.00	53.68	0.85	0.00	0.00	Storage and sequestration based on black ash/American elm/red maple stands from COLE.
		Mixed hardwood swamp	Palustrine forest deciduous sapling (0-4" dbh)	30 year old aspen/red maple/black ash forest	7.12	2.88	49.42	0.70	351.92	2.01	Storage and sequestration based on black ash/American elm/red maple stands from COLE.
		Mixed hardwood swamp	Palustrine forest mixed mature	60 year old black spruce/paper birch forest	0.00	0.00	66.02	0.24	0.00	0.00	Storage and sequestration based on average of aspen and black spruce monotypic stands from COLE.
		Mixed hardwood swamp	Palustrine forest mixed pole	30 year old black spruce/paper birch forest	0.00	0.00	54.93	0.63	0.00	0.00	Storage and sequestration based on average of aspen and black spruce monotypic stands from COLE.
		Other	Wetland	Herbaceous emergent wetland	44.98	18.20	0.00	0.70	0.00	12.74	Assume negligible long term storage in biomass in herbaceous vegetation. Sequestration value for peatlands based on studies cited by Lennon and Nater 2006.
		Mixed hardwood swamp	Palustrine scrub shrub	Wetland shrub scrub	48.78	19.74	48.00	0.70	2,341.63	13.82	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.
				Peat Wetland Total	**744.46**	**301.27**			**34,454.28**	**200.63**	
				Wetland Total	**804.19**	**325.44**			**36,933.09**	**209.55**	
				Grand Total	**1,955.87**	**791.51**			**96,045.54**	**535.10**	

Appendix B

Website References Used in this Report

Footnote 3.
http://www.eoearth.org/article/Climate_change:_greenhouse_gas_reduction_bills_in_the_110th_Congress

Encyclopedia of Earth

Climate change: greenhouse gas reduction bills in the 110th Congress

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Introduction

Climate change is generally viewed as a global issue, but proposed responses generally require action at the national level. In 1992, the United States ratified the United Nations Framework Convention on Climate Change (UNFCCC), which called on industrialized countries to take the lead in reducing the six primary greenhouse gases to 1990 levels by the year 2000.[1] For more than a decade, a variety of voluntary and regulatory actions have been proposed or undertaken in the United States, including monitoring of power plant carbon dioxide emissions, improved appliance efficiency, and incentives for developing renewable energy sources. However, carbon dioxide emissions have continued to increase.

In 2001, President George W. Bush rejected the Kyoto Protocol, which called for legally binding commitments by developed countries to reduce their greenhouse gas emissions.[2] He also rejected the concept of mandatory emissions reductions. Since then, the Administration has focused U.S. climate change policy on voluntary initiatives to reduce the growth in greenhouse gas emissions. In contrast, in 2005, the Senate passed a Sense of the Senate resolution on climate change declaring that a mandatory, market-based program to slow, stop, and reverse the growth of greenhouse gases should be enacted at a rate and in a manner that "will not significantly harm the United States economy" and "will encourage comparable action" by other nations.[3]

A number of congressional proposals to advance programs designed to reduce greenhouse gases have been introduced in the 110th Congress. These have generally followed one of three tracks. The first is to improve the monitoring of greenhouse gas emissions to provide a basis for research and development and for any potential future reduction scheme. The second is to enact a market-oriented greenhouse gas reduction program along the lines of the trading provisions of the current acid rain reduction program established by the 1990 Clean Air Act Amendments. The third is to enact energy and related programs that would have the added effect of reducing greenhouse gases; an example would be a requirement that electricity producers generate a portion of their electricity from renewable resources (a renewable portfolio standard). This report focuses on the second category of bills.

Proposed Legislation in 110th Congress

In the 110th Congress, six bills have been introduced that would impose controls on emissions of greenhouse gases. A comparison of major provisions is provided in Appendix 1.

S. 280, introduced January 12, 2007, by Senator Lieberman, would cap emissions of the six greenhouse gases specified in the United Nations Framework Convention on Climate Change, at reduced levels, from the electric generation, transportation, industrial, and commercial sectors — sectors that account for about 85% of U.S. greenhouse gas emissions. The reductions would be implemented in four phases, with an emissions cap in 2012 based on the affected facilities' 2004 emissions (for an entity that has a single unit that emits more than 10,000 metric tons of carbon dioxide equivalent); the cap steadily declines until it is equal to one-third of the facilities' 2004 levels. The program would be implemented through an expansive allowance trading program to maximize opportunities for cost-effective reductions, and credits obtained from increases in carbon sequestration, reductions from non-covered sources, and acquisition of allowances from foreign sources could be used to comply with 30% of reduction requirements. The bill also contains an extensive new infrastructure to encourage innovation and new technologies.

S. 309, introduced January 16, 2007, by Senator Sanders, would cap greenhouse gas emissions on an economy-wide basis beginning in 2010. Beginning in 2020, the country's emissions would be capped at their 1990 levels, and then proceed to decline steadily until they were reduced to 20% of their 1990 levels in the year 2050. The Environmental Protection Agency (EPA) has the discretion to employ a market-based allowance trading program or any combination of cost-effective emission reduction strategies. The bill also includes new mandatory greenhouse gas emission standards for vehicles and new powerplants, along with a new energy efficiency performance standard. The bill would establish a renewable portfolio standard (RPS) and a new low-carbon generation requirement and trading program.

S. 317, introduced January 17, 2007, by Senator Feinstein, would cap greenhouse gas emissions from electric generators over 25 megawatts.

Beginning in 2011, affected generators would be capped at their 2006 levels, declining to 2001 levels by 2015. After that, the emission cap would decline 1% annually until 2020, when the rate of decline would increase to 1.5%. The allowance trading program includes an allocation scheme that provides for an increasing percentage of all allowances to be auctioned, with 100% auctioning in 2036 and thereafter. The cap-and-trade program allows some of an entity's reduction requirement to be meet with credits obtained from foreign sources and a variety of other activities specified in the bill.

S. 485, introduced February 1, 2007, by Senator Kerry, would cap greenhouse gas emissions on an economy-wide basis beginning in 2010. Beginning in 2020, the country's emissions would be capped at their 1990 levels. After 2020, emissions economy-wide would be reduced 2.5% annually from their previous year's level until 2031, when that percentage would increase to 3.5% through 2050. The allowance trading system includes an allocation scheme that requires an unspecified percentage of allowances to be auctioned. The bill also includes new mandatory greenhouse gas emission standards for vehicles, along with a new energy efficiency performance standard. The bill would establish a renewable portfolio standard (RPS), increase biofuel mandates under the Renewable Fuels Standard, and mandate new infrastructure for biofuels. Finally, the bill expands and extends existing tax incentives for alternative fuels and advanced technology vehicles, and establishes a manufacturer tax credit for advanced technology vehicle investment.

H.R. 620, introduced February 7, 2007, by Representative Olver, is a substantially modified version of S. 280. Using the same basic structure as S. 280, the emission caps under H.R. 620 are more stringent. Reductions from affected sectors (electric generation, transportation, industrial, and commercial) would be set at 2004 levels in 2012 and then steadily decline until the cap is equal to about onefourth of facilities' 2004 levels. Although H.R. 620 permits affected entities to comply with the reduction requirements with credits from foreign sources, sequestration, and reductions from non-covered entities, these sources are limited to 15% of the source's reduction requirement.

H.R. 1590, introduced March 20, 2007, by Representative Waxman, is similar to S. 485. H.R. 1590 would cap greenhouse gas emissions on an economy-wide basis beginning in 2010. Beginning in 2020, the country's emissions would be capped at their 1990 levels. After 2020, emissions economy-wide would be reduced by roughly 5% annually from their previous year's level through 2050, when emissions levels would be capped at 80% below 1990 levels. The allowance trading system includes an allocation scheme that requires an unspecified percentage of allowances to be auctioned. The bill also includes new mandatory greenhouse gas emission standards for vehicles, along with a new energy efficiency performance standard. The bill would also establish a renewable portfolio standard (RPS).

Appendix A: comparison of key provisions of greenhouse gas reduction bills

Appendix A: comparison of key provisions of greenhouse gas reduction bills

Appendix B: common terms

Allocation schemes (upstream and downstream). Regulatory approaches to allocating allowances (as opposed to auction schemes) can choose different points and participants along the production process to assign allowances and the resulting compliance responsibility. Upstream allocation schemes establish emission caps and assign allowances at a production, importation, or distribution point of products that will eventually produce greenhouse emissions further down the production process. For example, in the natural gas sector, emission caps could be established and allowances assigned at processing facilities where facilities and participants shrink from about 400,000 wells and 8,000 companies to 500 plants and 200 companies. In contrast, downstream allocation schemes establish emission caps and assign allowances at the point in the process where the emissions are emitted. In the case of the natural gas industry, to achieve the same coverage as the upstream scheme, this would involve assigning allowances to natural gas-fired electric generators, industry, and even residential users. Thus, some downstream proposals choose either to exempt certain sectors (such as residential use) from a cap-and-trade program or to employ a hybrid allocation scheme where some of the allowances are allocated upstream and others downstream (such as the electric generators).

Appendix A: comparison of key provisions of greenhouse gas reduction bills

Allowance. An allowance is generally defined as a limited authorization by the government to emit 1 ton of pollutant. In the case of greenhouse gases, an allowance generally refers to a metric ton of carbon dioxide equivalent. Although used generically, an allowance is technically different from a credit. A credit represents a ton of pollutant that an entity has reduced in excess of its legal requirement. However, the terms tend to be used interchangeably, along with others, such as permits.

Appendix A: comparison of key provisions of greenhouse gas reduction bills

Auctions. Auctions can be used in market-based pollution control schemes in several different ways. For example, Title IV of the 1990 Clean Air Act Amendments uses an annual auction to ensure the liquidity of the credit trading program. For this purpose, a small percentage of the credits permitted under the program are auctioned annually, with the proceeds returned to the entities that would have otherwise received them. Private parties are also allowed to participate. A second possibility is to use an auction to raise revenues for a related (or unrelated) program. For example, the Regional Greenhouse Gas Initiative (RGGI) is exploring an auction to implement its public benefit program to assist consumers or pursue strategic energy purposes. A third possibility is to use auctions as a means of allocating some, or all, of the credits mandated under a GHG control program. Obviously, the impact that an auction would have on cost would depend on how extensively it was used in any GHG control program, and to what purpose the revenues were expended.

Banking. Although allowances are generally allocated on an annual basis, most cap-and-trade programs do not require participants to either use the allowance that year or else lose it. Under many proposals, allowances can be banked by the receiving participant (or traded to another participant who can use or bank it) to be used or traded in a future year. Banking reduces the absolute cost of compliance by making annual emission caps flexible over time. The limited ability to shift the reduction requirement across time allows affected entities to better accommodate corporate planning for capital turnover, allow for technological progress, control equipment construction schedules, and respond to transient events such as weather and economic shocks.

Bubble. A bubble is a regulatory device that permits two or more sources of pollutants to be treated as one for the purposes of emission compliance.

Cap-and-trade program. A cap-and-trade program is based on two premises. First, a set amount of pollutant emitted by human activities can be assimilated by the ecological system without undue harm. Thus, the goal of the cap-and-trade program is to impose a ceiling (i.e., an emissions cap) on the total emissions of that pollutant at a level below the assimilative capacity. Second, a market in pollution licenses (i.e., allowances) between polluters is the most cost-effective means of reducing emissions to the level of the cap. This market in allowances is designed so that owners of allowances can trade those allowances with other emitters who need them or retain (bank) them for future use or sale. In the case of the sulfur dioxide program contained in the 1990 Clean Air Act Amendments, most allowances were allocated free by the federal government to utilities according to statutory formulas related to a given facility's historic fuel use and emissions; other allowances have been reserved by the government for periodic auctions to ensure market liquidity.

Carbon tax. A carbon tax is generally conceived as a levy on natural gas, petroleum, and coal according to their carbon content, in the approximate ratio of 0.6 to 0.8 to 1, respectively. However, proposals have been made to impose the tax downstream of the production process when the carbon dioxide is actually released to the atmosphere. In contrast to a cap-and-trade program, in which the quantity of emissions is limited and the price is determined by an allowance marketplace, with a carbon tax, the price is limited and the quantity of emissions is determined by the participants based on the cost of control versus the cost of the tax.

Coverage. Coverage is the breadth of economic sectors covered by a particular greenhouse gas reduction program.

Emissions cap. A mandated limit on how much pollutant (or greenhouse gases) an affected entity can release to the atmosphere. Caps can be either an absolute cap, where the amount is specified in terms of tons of emissions on an annual basis, or a rate-based cap, where the amount of emissions produced per unit of output (such as electricity) is specified but not the absolute amount released. Caps may be imposed on an entity, sector, or economy-wide basis.

Generation performance standard (GPS). Also called an output-based allocation, allowances are allocated gratis to entities in proportion to their relative share of total electricity generation in a recent year.

Grandfathering. Grandfathering generally refers an allocation scheme in which allowances are distributed to affected entities on the basis of historic emissions. These allowances are generally distributed free-of-charge by the government to the affected entities. Grandfathering can also refer to entities that because of age or because they have met an earlier standard, or other factors, are exempted from a new regulatory requirement.

Greenhouse gases. The six gases recognized under the United Nations Framework Convention on Climate Change are carbon dioxide (CO_2), methane (CH_4) nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFC), and perfluorocarbons (PFC).

Hybrid Program. Generally a greenhouse gas reduction program that allows emitters to choose between complying with the reduction requirement of a cap-andtrade program or paying a set price (safety valve price) to the government in lieu of making reductions.

Leakage. Decreases in greenhouse gas-related reductions or benefits outside the boundaries set for defining a project's or program's net greenhouse gas impact resulting from mitigation activities. For example, emissions could be reduced in an area with greenhouse gas controls by moving an emitting industry to an area without such controls.

"No regrets" policy. A "no regrets" policy is one of establishing programs for other purposes that would have concomitant greenhouse gas reductions. Therefore, only those policies that reduce greenhouse gas emissions at no cost are considered. Offsets. Offsets generally refer to emission credits achieved by activities not directly related to the emissions of an affected source. Examples of offsets would include forestry and agricultural activities that absorb carbon dioxide, and reduction achieved by entities that are not regulated by a greenhouse gas reduction program. Revenue recycling. Some greenhouse gas reduction programs create revenues through auctions, compliance penalties, or imposition of a carbon tax. Revenue recycling refers to how a program disposes of those revenues. How a program handles revenues received can have a significant effect on the overall cost of the program to the economy.

Safety valve. Devices designed to prevent or to respond to unacceptably high compliance costs for greenhouse gas reductions. Generally triggered by prices in the allowance markets, safety valve approaches can include (1) a set price alternative to making reductions or buying allowances at the market price, (2) a slowdown in tightening the emissions cap, and (3) lengthening of the time allowed for compliance. Depending on the interplay between the emissions cap and safety valve and actual compliance costs, a safety valve can affect the integrity of the emissions cap. Sequestration. Sequestration is the process of capturing carbon dioxide from emission streams or from the atmosphere and then storing it in such a way as to prevent its release to the atmosphere.

Notes

1. ^ Under the United Nations Framework Convention on Climate Change (UNFCCC), those gases are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6). Some greenhouse gases are controlled under the Montreal Protocol on Substances that Deplete the Ozone Layer, and are not covered under UNFCCC.
2. ^ For further information, see CRS Report RL30692, Global Climate Change: The Kyoto Protocol, by Susan R. Fletcher.
3. ^ S.Amdt. 866, passed by voice vote after a motion to table failed 43-54, June 22, 2005.

Further Reading

- Larsen, John, 2007. Global Warming Legislation in the 110th Congress]. World Resource Institute 2007, Washington D.C.

- Pew Center on Global Climate Change, 2007. Legislation in the 110th Congress Related to Global Climate Change. Pew Center, Arlington, VA.

Citation

Congressional Research Service (Content source); Mark McGinley (Topic Editor). 2007. "Climate change: greenhouse gas reduction bills in the 110th Congress." In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published in the Encyclopedia of Earth October 16, 2007; Last revised October 17, 2007; Retrieved January 19, 2009]. <http://www.eoearth.org/article/Climate_change:_greenhouse_gas_reduction_bills_in_the_110th_Congress>

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Footnote 23: U.S. Environmental Protection Agency Website on Climate Change – State and Local Governments: http://www.epa.gov/climatechange/wycd/stateandlocalgov/states/mn.html

http://www.epa.gov/climatechange/wycd/stateandlocalgov/states/mn.html
Last updated on Thursday, November 13th, 2008.

Climate Change - State and Local Governments

You are here: EPA Home Climate Change What You Can Do State and Local Governments State Actions State and Regional Climate Policy Maps Minnesota

- State Climate Actions
- State and Regional Climate Policy Maps
- State Climate Action Plans
- State Climate Action Plans Database

Minnesota

Planning and Measurement | Targets and Caps | Reporting | Power Sector | Transportation Sector

Many of the sites listed on this page are not on the EPA Web site.
Please see our disclaimer information. EXIT Disclaimer

Related Links

- State Clean Energy Policies Matrix and Maps
- State and Regional Climate Policy Maps
  - State Planning and Measurement
  - State Targets and Caps
  - State Reporting
  - State Power Sector
  - State Transportation Sector

Definitions

- Climate policy definitions
- Status definitions

Planning and Measurement

State Advisory Board

Status: Completed

Details: Minnesota Governor Tim Pawlenty outlined a four-part energy initiative on January 17, 2008, which emphasizes local projects and research and development assistance. The Governor plans to create, via Executive Order, the Clean Energy Technology Collaborative-a 15-member panel appointed by the Governor that will develop a Clean Energy Technology Roadmap. In addition, he hopes to establish the Minnesota Office of Energy Security, which will coordinate energy and climate issues throughout the Governor's administration.
Governor Tim Pawlenty created the Climate Change Advisory Group established in April 2007 as a part of his Next Generation Energy Initiative.

- http://www.governor.state.mn.us/mediacenter/pressreleases/PROD008626.html
- http://www.mnclimatechange.us/MCCAG.cfm

Regional Initiatives

Status: Completed/Further Work Proposed

Details: On April 23, 2008, the Minnesota Senate and House approved bills setting general guidelines for the Legislature's role in a regional, market-based system to control greenhouse gas 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 on the program's effects on the environment, the economy, and public health and on how program revenue would be handled.
An advisory panel created by Minnesota Governor Tim Pawlenty approved a mixture of strategies on January 24, 2008, that would reduce the state's GHG emissions by up to 30% by 2025. The panel recommended that the state participate in a regional cap-and-trade system for carbon GHG emissions.
Member of the Midwestern Regional Greenhouse Gas Reduction Accord, signed on November 15, 2007.
Powering the Plains Participant - Participants meet quarterly to develop and implement strategies, policies, initiatives and projects in energy and agriculture that add value to the region's economy while reducing the risk of climate change and other environmental concerns. Specific focus areas include renewable energy development, hydrogen production, carbon sequestration, coal gasification, and environmental credit trading.
Member of Lake Michigan Air Directors Consortium (LADCO) Regional GHG Registry.

- https://www.revisor.leg.state.mn.us/bin/bldbill.php?bill=ccrhf3195.html&session=ls85
- http://www.mnclimatechange.us/MCCAG.cfm
- http://www.midwesternaccord.org/midwesterngreenhousegasreductionaccord.pdf

GHG Inventory

Status: Completed

Details: Senate File 3337, passed by the Governor on May 12, 2008, requires the state's Department of Commerce and Pollution Control Agency to track greenhouse gas emissions and make interim reduction recommendations toward meeting the state's goal of reducing emissions by 80% by 2050.
An advisory panel created by Minnesota Governor Tim Pawlenty approved a mixture of strategies on January 24, 2008 that would reduce the state's GHG emissions by up to 30% by 2025. One of the proposed strategies is the development of GHG inventories, forecasting, reporting, and a registry. Minnesota completed an initial inventory in 1995.

- https://www.revisor.leg.state.mn.us/bin/bldbill.php?bill=S3337.3.html&session=ls85
- http://www.mnclimatechange.us/ewebeditpro/items/O3F13507.pdf
- http://www.epa.gov/climatechange/emissions/downloads/MNSummary.PDF

Climate Change Action Plan

Status: Completed

Details: In April 2008, the Minnesota Climate Change Advisory Group issued its final report with recommendations to the Governor for reducing Minnesota's GHG emissions. In December 2006, Governor Pawlenty announced the state's Next Generation Energy Initiative, including development of an aggressive plan to reduce GHG emissions in Minnesota. The original state plan was developed in February 2003 by the Minnesota Pollution Control Agency through an EPA grant.

- http://www.mnclimatechange.us/MCCAG.cfm
- http://www.pca.state.mn.us/publications/reports/mnclimate-action-plan.pdf
- http://www.governor.state.mn.us/mediacenter/pressreleases/2006/december/PROD007863.html

Targets and Caps

Lead by Example Target

Status: No Activity Identified

Statewide GHG Target

Status: Completed

Details: The Next Generation Energy Act of 2007, signed by Minnesota Governor Tim Pawlenty on May 25, 2007, outlines goals for statewide GHG emissions reductions: 15% by 2015; 30% by 2025; and 80% by 2050.
Member of the Midwestern Regional Greenhouse Gas Reduction Accord, signed on Nov. 15, 2007. Under the Accord, members agree to establish regional GHG reduction targets, including a long-term target of 60% to 80% below current emissions levels, and develop a multi-sector cap-and-trade system to help meet the targets.

- http://www.revisor.leg.state.mn.us/bin/bldbill.php?bill=S0145.2.html&session=ls85
- http://www.wisgov.state.wi.us/docview.asp?docid=12497

Statewide GHG Cap

Status: Proposed

Details: Member of the Midwestern Regional Greenhouse Gas Reduction Accord, signed on November 15, 2007. Under the Accord, members agree to establish regional GHG reduction targets, including a long-term target of 60% to 80% below current emissions levels, and develop a multi-sector cap-and-trade system to help meet the targets.

- http://www.midwesterngovernors.org/Publications/Greenhouse%20gas%20accord_Layout%201.pdf
- http://www.midwesterngovernors.org/govenergynov.htm

Reporting

Electricity Disclosure

Status: Completed

Details: In September 2002, the Minnesota Public Utilities Commission issued an order requiring utilities to disclose information on fuel mix and emissions to customers semi-annually.

- http://www.pca.state.mn.us/programs/electricity.html
- http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=MN08R&state=MN&CurrentPageID=1&RE=1&EE=1

GHG Registry

Status: In Progress

Details: On April 3, 2008, the Minnesota Senate passed Senate File 3341, which would create a form for businesses to voluntarily track their energy use and efficiency.
An advisory panel created by Minnesota Governor Tim Pawlenty approved a mixture of strategies on January 24, 2008, that would reduce the state's GHG emissions by up to 30% by 2025. One of the proposed strategies is the development of GHG inventories, forecasting, reporting, and a registry.
Member of The Climate Registry – a collaboration aimed at developing and managing a common GHG emissions reporting system across states, provinces, and tribes. It will provide an accurate, complete, consistent, transparent, and verified set of GHG emissions data from reporting entities, supported by a robust accounting and verification infrastructure. Members released a final General Reporting Protocol in May 2008. The Climate Registry plans to start accepting data in summer 2008.

- https://www.revisor.leg.state.mn.us/bin/bldbill.php?bill=S3341.1.html&session=ls85
- http://www.mnclimatechange.us/MCCAG.cfm
- http://www.theclimateregistry.org

Mandatory GHG Reporting

Status: No Activity Identified

Power Sector

CO_2 Offset Requirements

Status: Proposed

Details: On September 7, 2007, seven regional utilities that propose building a $1.6 billion coal-fired power plant announced that they have agreed to offset the CO2 emissions of the plant's Minnesota customers. Under the agreement, the seven utilities would be allowed to choose their own methods to offset the carbon. No activity listed in association with this development because it is not a requirement.
In December 2006, Governor Pawlenty proposed, as a part of his Next Generation Energy Initiative, that Minnesota utilities begin offsetting carbon emissions from new fossil-fuel generation sources.

- http://www.governor.state.mn.us/mediacenter/pressreleases/2006/PROD007863.html
- http://www.tcdailyplanet.net/article/2007/11/14/big-stone-ii-coal-plant-debate-turns-carbon-regulation.html

GHG Performance Standard

Status: No Activity Identified

Advanced Coal Technology

Status: Completed/Further Work Proposed

Details: An advisory panel created by Minnesota Governor Tim Pawlenty approved a mixture of strategies on January 24, 2008, that would reduce the state's GHG emissions by up to 30% by 2025. One of the proposed strategies would create advanced fossil fuel technology incentives, support, or requirements including carbon capture and storage.
Minnesota law (passed in 2003) provides for incentives for "innovative energy projects" using coal as fuel in a highly efficiency combined cycle configuration and that significantly reduce emissions of criteria pollutants.

- http://www.mnclimatechange.us/MCCAG.cfm
- http://www.revisor.leg.state.mn.us/bin/getpub.php?type=s&num=216B.1694

Power Sector GHG Cap and Trade

Status: Proposed

Details: In April 2008, the Minnesota Climate Change Advisory Group issued its final report with recommendations for a climate action plan. The advisory group recommended that the state join with i regional Midwestern Accord Partners to create a multi-sector cap-and-trade program. The Next Generation Energy Act of 2007, signed by Minnesota Governor Tim Pawlenty in May 2007, called for th development of the action plan.

- http://www.mnclimatechange.us/MCCAG.cfm
- http://www.revisor.leg.state.mn.us/bin/bldbill.php?bill=S0145.2.html&session=ls85
- http://www.governor.state.mn.us/mediacenter/pressreleases/2007/PROD008146.html

Transportation Sector

GHG Auto Standards

Status: Proposed

Details: An advisory panel created by Minnesota Governor Tim Pawlenty approved a mixture of strategies on January 24, 2008, that would reduce the state's GHG emissions by up to 30% by 2025. One of the proposed strategies requires the adoption of California's vehicle emissions standards.

- http://www.mnclimatechange.us/MCCAG.cfm

Low Carbon Fuel Standard

Status: No Activity Identified

Footnote 24: U.S. Environmental Protection Agency Website on Climate Change – State of Knowledge: http://www.epa.gov/climatechange/science/stateofknowledge.html

State of Knowledge

What's Known | What's Very Likely | What's Not Certain

As with any field of scientific study, there are uncertainties associated with the science of climate change. This does not imply that scientists do not have confidence in many aspects of climate science. Some aspects of the science are known with virtual certainty[1], because they are based on well-known physical laws and documented trends. Current understanding of many other aspects of climate change ranges from "very likely" to "uncertain."

Related Links

CCSP

- Product 5.2 - Best practice approaches for characterizing, communicating, and incorporating scientific uncertainty in decisionmaking
- Vision for the Program and Highlights of the Scientific Strategic Plan

What's Known

Scientists know with virtual certainty that:

- Human activities are changing the composition of Earth's atmosphere. Increasing levels of greenhouse gases like carbon dioxide (CO_2) in the atmosphere since pre-industrial times are well-documented and understood.
- The atmospheric buildup of CO_2 and other greenhouse gases is largely the result of human activities such as the burning of fossil fuels.
- An "unequivocal" warming trend of about 1.0 to 1.7°F occurred from 1906-2005. Warming occurred in both the Northern and Southern Hemispheres, and over the oceans (IPCC, 2007).
- The major greenhouse gases emitted by human activities remain in the atmosphere for periods ranging from decades to centuries. It is therefore virtually certain that atmospheric concentrations of greenhouse gases will continue to rise over the next few decades.
- Increasing greenhouse gas concentrations tend to warm the planet.

What's Very Likely?

The Intergovernmental Panel on Climate Change (IPCC) has stated "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" (IPCC, 2007). In short, a growing number of scientific analyses indicate, but cannot prove, that rising levels of greenhouse gases in the atmosphere are contributing to climate change (as theory predicts). In the coming decades, scientists anticipate that as atmospheric concentrations of greenhouse gases continue to rise, average global temperatures and sea levels will continue to rise as a result and precipitation patterns will change.

What's Not Certain?

Important scientific questions remain about how much warming will occur, how fast it will occur, and how the warming will affect the rest of the climate system including precipitation patterns and storms. Answering these questions will require advances in scientific knowledge in a number of areas:

- Improving 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.
- Projecting future greenhouse emissions and how the climate system will respond within a narrow range.
- Improving understanding of the potential for rapid or abrupt climate change.

Addressing these and other areas of scientific uncertainty is a major priority of the U.S. Climate Change Science Program (CCSP). The CCSP is developing twenty-one Synthesis and Assessment products to advance scientific understanding of these uncertainty areas by the end of 2008. More information.

References

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

[1] Throughout the science section of this Web site, use of "virtual certainty" (or virtually certain) conveys a greater than 99% chance that a result is true. Other terms used to communicate confidence include “extremely likely” (greater than 95% chance the result is true), "very likely" (greater than 90% chance the result is true), "likely" (greater than 66% chance the result is true), “more likely than not” (greater than 50% chance the result is true), “unlikely” (less than 33% chance the result is true), “very unlikely” (less than 10% chance the result is true), and “extremely unlikely” (less than 5% chance the result is true). These judgmental estimates originate from the Intergovernmental Panel on Climate Change (IPCC, 2007).

Footnote 28, 33,45,79,88& 89: Minnesota Pollution Control Agency, May 2007. Air Quality/ #1.31 Global Climate Change (available at: http://www.pca.state.mn.us/publications/aq1-31.pdf

Minnesota Pollution Control Agency

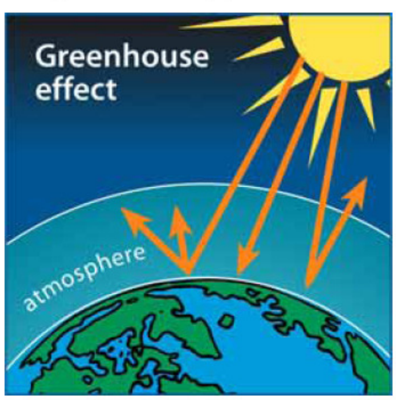
Global Climate Change

Air Quality/ #1.31• May 2007

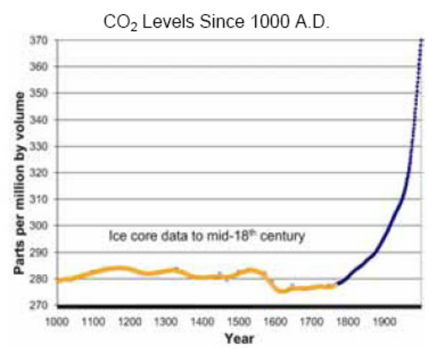
Climate change, also called global warming, refers to any significant change in climate lasting for decades or longer. A certain amount of climate change can result from natural factors, such as variations in the sun's intensity or, over very long periods of time, changes in the earth's orbit or position of the continents. But scientists believe that the changes now going on are primarily a result of human activities. As a result, the earth is expected to warm substantially during just a few decades, returning it to conditions not seen for hundreds of thousands or even millions of years.

The greenhouse effect

The earth's atmosphere acts like a pane of glass in a greenhouse, trapping the sun's heat in the lower atmosphere and causing temperatures at the surface to warm. Life depends on this natural greenhouse effect; without it, average temperatures would be 60 degrees Fahrenheit (F) colder.



Some of the atmospheric or greenhouse gases that trap heat include water vapor, carbon dioxide (CO_2), methane, nitrous oxide, ozone and certain synthetic fluorocarbons. Some of these occur naturally, but since the industrial age began, more gases have been added to natural levels. Studies of ice cores show that CO_2 levels have risen by a third since the pre-industrial era. Most of that increase comes from burning fossil fuels, including coal and petroleum, to run our cars, factories and power plants.



About seven billion metric tons of carbon are released through human activity every year. CO_2 added today remains in the atmosphere for 100 years or more, which means that the atmosphere is thrown more and more out of balance each year. Since scientists say that CO_2 is responsible for three-fourths of any predicted warming, temperature increases are inevitable.

Contents

Minnesota Pollution Control Agency • 520 Lafayette Rd. N., St. Paul, MN 55155-4194 • www.pca.state.mn.us
651-296-6300 • 800-657-3864 • TTY 651-282-5332 or 800-657-3864 • Available in alternative formats

What's the evidence?

- The average temperature of the Earth's surface has increased by about 1.2 to 1.4 degrees F since 1900. Other aspects of the climate are also changing, such as precipitation patterns, snow and ice cover, and sea level.
- The 20th century's 10 warmest years all occurred in the last 15 years of the century. 1998, 2002, 2003, 2005 and 2006 were the warmest years on record, according to the Earth Observatory of the National Aeronautics and Space Administration.
- The arctic ice pack has lost about 40 percent of its thickness during the past 40 years.
- Alaska's permafrost is thawing, causing the ground to drop 30 feet in places.
- In 2002, a massive Antarctic ice shelf known as Larsen B thawed and collapsed into the sea, causing 1,255 square miles of ice to disintegrate into thousands of melting icebergs.
- Mountain glaciers the world over are receding, from Europe's Alps to Asia's Himalayas to North America's Rocky Mountains. The glaciers in Montana's Glacier National Park are expected to be gone by 2030; the extensive glaciers on Tanzania's Mount Kilimanjaro will be gone even sooner.
- Malaria-bearing mosquitoes are appearing in elevations formerly too cool to support them (7,000 feet).
- Sea level has risen four to 10 inches worldwide in the last century. The Pacific island of Western Samoa loses more than a foot of land to the rising sea every year.

Forecast for the future

In 1988, an international scientific body, the Intergovernmental Panel on Climate Change (IPCC), was created by the World Meteorological Organization and the United Nations. The IPCC has forecast a mean global temperature change of two to seven degrees F. by the year 2100. This rate of warming is two to seven times greater than the warming observed during the 20th century. In 2006, an IPCC report said that the likelihood that warming in the past and future was due to human activity was 90 percent.

It is important to remember that what sound like small temperature changes can have big consequences. At the peak of the last ice age, 18,000 years ago, it was only seven to 10 degrees F colder than today, and glaciers covered most of North America. A temperature seven degrees warmer than today will no doubt bring equally dramatic environmental changes — and at a rate perhaps 100 times faster than any previous climate changes.

- Warming will not be evenly distributed around the globe; northern latitudes, including Minnesota, will warm more than equatorial or southern latitudes.
- Winters will warm more than summers.
- Because warmer temperatures lead to increases in atmospheric moisture, precipitation is expected to increase during the next 100 years.
- Beachfront and low-lying property will begin to flood during the 21st century due to a sea level rise of eight to 23 inches. This is due to:
  - ocean water that expands as it warms
  - melting mountain glaciers worldwide
  - melting Greenland and west Antarctic ice sheets

The estimate is uncertain because it is affected by the speed at which the Greenland and west Antarctic ice sheets melt. Each one contains enough ice to raise sea levels 20 feet.

What does climate change mean for Minnesota?

Minnesota has warmed an average of about one degree F during the last 100 years. Parts of northern Minnesota have warmed five degrees F or more in winter. As the warming continues, northern cities like Hibbing may grow to look more like Albert Lea or even Des Moines.

Precipitation has already increased 20 percent in the southern half of the state since 1900. This fits with the climate change scenario that predicts a generally wetter and more humid Minnesota climate. Minnesota may come to look more like Missouri. We may lose our northern coniferous forests through warmth-induced disease, fires and a massive dieback already underway in Canada and Alaska; and our cold-loving creatures like trout and moose will disappear. As a general rule of thumb, climate zones and vegetation zones shift northward about 60 miles for each one degree Celsius (1.8 degrees F) increase in temperature. Minnesota farmers will gain a longer growing season, and hay fever sufferers will sneeze a few more weeks each year.

What is Minnesota doing?

On February 22, 2007, Governor Tim Pawlenty signed into law bipartisan legislation that set a renewable energy requirement in Minnesota of 25 percent by the year 2025. The Governor also signed the landmark Next Generation Energy Act on May 25, 2007, which also addresses global warming and energy efficiency. Since fossil fuel use is responsible for most CO_2 emissions, this law will help reduce those emissions and fight climate change. Many of these steps are already underway. The new legislation will:

- Require Minnesota electric utilities to generate at least 25 percent of the electricity Minnesotans use from renewable resources by 2025. Xcel Energy, which supplies half the electricity in the state, is required to provide 30 percent of its electricity from renewable resources by 2020.
- Establish a new "E85 Everywhere" program to double the number of E85 pumps in the state from the current nation-leading 300 to 600.
- Use improved energy conservation, rate design and appliance standards to achieve annual energy savings equal to 1.5 percent of annual retail energy sales of electricity and natural gas.
- Invest more than $35 million in new energy projects and research, including ones for biofuels such as cellulosic ethanol, and advanced bio-gas (gasification of biomass) technologies.
- Reduce Minnesota's per capita fossil fuel energy use by 15 percent by 2015, through conservation and renewable energy alternatives.
- Set a goal of 1,000 Energy Star commercial buildings to be built by 2010 (there are currently 87).

The legislation established statewide greenhouse gas reduction goals of 15 percent by 2015, 30 percent by 2025 and 80 percent by 2050.

A comprehensive climate change strategy is currently being developed by the Minnesota Climate Change Advisory Group. This group is made up of representatives from industry, environmental groups, local and tribal governments, agriculture and transportation.

What can each of us do?

Greenhouse gas emissions in Minnesota have increased about 20 percent since 1988 alone. About a quarter of each Minnesota household's annual CO_2 emissions come from the family car. Another 30 percent comes from home heating. Home electric and gas demands, including water heaters, refrigerators and lights, account for another 30 percent. To cut your CO_2 emissions:

- **On the road — use your vehicle less and use it more efficiently**
  - bike, bus, carpool or telecommute at least once a week
  - keep your car tuned and your tires inflated
  - use ethanol-based E85 fuel
  - don't idle your car
  - buy fuel-efficient vehicles
- **In the home — use less electricity or choose cleaner sources**
  - buy renewable or green power; contact your electric utility for details
  - install high-efficiency furnaces and air conditioners
  - turn down your thermostat in winter, set it higher in summer
  - buy energy-efficient appliances with the Energy Star label
  - replace incandescent light bulbs with compact fluorescents
  - reduce, reuse and recycle to save energy and resources

More information

For more tips on reducing your contributions to CO_2 emissions, visit:

- Minnesota Department of Commerce at www.state.mn.us/portal/mn/jsp/content.do?subchannel=-536881511&id=-536881350&agency=Commerce

For more information on climate change, visit

- U.S. Environmental Protection Agency at http://epa.gov/climatechange/index.html
- International Governmental Panel on Climate Change at www.ipcc.ch/
- National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center at www.ncdc.noaa.gov/oa/ncdc.html
- Woods Hole Oceanographic Institution's Ocean and Climate Change Institute at www.whoi.edu/institutes/occi/viewTopic.do?o=read&id=501

Footnote 29, 38: U.S. Environmental Protection Agency Website on Climate Change – Science: http://epa.gov/climatechange/science/pastcc.html

Past Climate Change

Causes of Change | Rates of change | The Last 2,000 Years

The Earth's climate has changed throughout history. From glacial periods (or "ice ages") where ice covered significant portions of the Earth to interglacial periods where ice retreated to the poles or melted entirely - the climate has continuously changed.

Scientists have been able to piece together a picture of the Earth's climate dating back decades to millions of years ago by analyzing a number of surrogate, or "proxy," measures of climate such as ice cores, boreholes, tree rings, glacier lengths, pollen remains, and ocean sediments, and by studying changes in the Earth's orbit around the sun.

This page contains information about the causes of climate change throughout the Earth's history, the rates at which the climate has changed, as well as information about climate change during the last 2,000 years.

Related Links

CCSP: Product 3.4 - Abrupt Climate Change

NASA: Paleoclimatology Site

NOAA

- Climate Timeline
- Paleoclimatology Program
- Abrupt Climate Change Web site

Causes of Change Prior to the Industrial Era (pre-1780)

Known causes, "drivers" or "forcings" of past climate change include:

- **Changes in the Earth's orbit:** Changes in the shape of the Earth's orbit (or eccentricity) as well as the Earth's tilt and precession affect the amount of sunlight received on the Earth's surface. These orbital processes -- which function in cycles of 100,000 (eccentricity), 41,000 (tilt), and 19,000 to 23,000 (precession) years -- are thought to be the most significant drivers of ice ages according to the theory of Mulitin Milankovitch, a Serbian mathematician (1879-1958). The National Aeronautics and Space Administration's (NASA) Earth Observatory offers additional information about orbital variations and the Milankovitch Theory.
- **Changes in the sun's intensity:** 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). According to NASA research, reduced solar activity from the 1400s to the 1700s was likely a key factor in the "Little Ice Age" which resulted in a slight cooling of North America, Europe and probably other areas around the globe. (See additional discussion under The Last 2,000 Years.)
- **Volcanic eruptions:** Volcanoes can affect the climate because they can emit aerosols and carbon dioxide into the atmosphere.
    - **Aerosol emissions:** Volcanic aerosols tend to block sunlight and contribute to short term cooling. Aerosols do not produce long-term change because they leave the atmosphere not long after they are emitted. According to the United States Geological Survey (USGS), the eruption of the Tambora Volcano in Indonesia in 1815 lowered global temperatures by as much as 5°F and historical accounts in New England describe 1816 as "the year without a summer."

- **Carbon dioxide emissions:** Volcanoes also emit carbon dioxide (CO_2), a greenhouse gas, which has a warming effect. For about two-thirds of the last 400 million years, geologic evidence suggests CO_2 levels and temperatures were considerably higher than present. One theory is that volcanic eruptions from rapid sea floor spreading elevated CO_2 concentrations, enhancing the greenhouse effect and raising temperatures. However, the evidence for this theory is not conclusive and there are alternative explanations for historic CO_2 levels (NRC, 2005). While volcanoes may have raised pre-historic CO_2 levels and temperatures, according to the USGS Volcano Hazards Program, human activities now emit 130 times as much CO_2 as volcanoes (whose emissions are relatively modest compared to some earlier times).

These climate change “drivers” often trigger additional changes or “feedbacks” within the climate system that can amplify or dampen the climate's initial response to them (whether the response is warming or cooling). For example:

- **Changes in greenhouse gas concentrations:** The heating or cooling of the Earth's surface can cause changes in greenhouse gas concentrations. For example, when global temperatures become warmer, carbon dioxide is released from the oceans. When changes in the Earth's orbit trigger a warm (or interglacial) period, increasing concentrations of carbon dioxide may amplify the warming by enhancing the greenhouse effect. When temperatures become cooler, CO_2 enters the ocean and contributes to additional cooling. During at least the last 650,000 years, CO_2 levels have tended to track the glacial cycles (IPCC, 2007). That is, during warm interglacial periods, CO_2 levels have been high and during cool glacial periods, CO_2 levels have been low (see Figure 1).

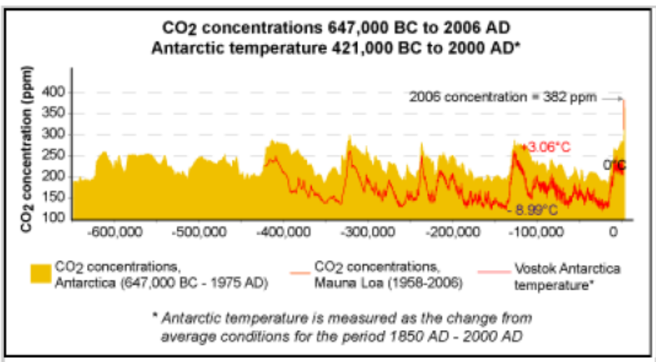


Figure 1: Fluctuations in temperature (red line) and in the atmospheric concentration of carbon dioxide (yellow) over the past 649,000 years. The vertical red bar at the end is the increase in atmospheric carbon dioxide levels over the past two centuries and before 2007. Click on thumbnail for a full-size image and references.

- **Changes in ocean currents:** The heating or cooling of the Earth's surface can cause changes in ocean currents. Because ocean currents play a significant role in distributing heat around the Earth, changes in these currents can bring about significant changes in climate from region to region.

Rates of Change

Studies of the Earth's previous climate suggest periods of stability as well as periods of rapid change. Recent climate research suggests:

- Interglacial climates (such as the present) tend to be more stable than cooler, glacial climates. For example, the climate during the current and previous interglacials (known as the Holocene and Eemian interglacials) has been more stable than the most recent glacial period (known as the Last Glacial Maximum). This glacial period was characterized by a long string of widespread, large and abrupt climate changes (NRC, 2002).
- Abrupt or rapid climate changes tend to frequently accompany transitions between glacial and interglacial periods (and vice versa). For example, a significant part of the Northern Hemisphere (particularly around Greenland) may have experienced warming ratesof 14-28^{o}F over several decades during and after the most recent ice age (IPCC, 2007).

While abrupt climate changes have occurred throughout the Earth's history, human civilization arose during a period of relative climate stability.

The Last 2,000 Years

During the last 2,000 years, the climate has been relatively stable. Scientists have identified three departures from this stability, known as the Medieval Climate Anomaly (also referred to as the Medieval Warm Period), the Little Ice Age and the Industrial Era:

- **The Medieval Climate Anomaly**: Between roughly 900 and 1300 AD, evidence suggests Europe, Greenland and Asia experienced relative warmth. While historical accounts and other evidence document the warmth that occurred in some regions, the geographical extent, magnitude and timing of the warmth during this period is uncertain (NRC, 2006). The American West experienced very dry conditions around this time.
- **The Little Ice Age**: A wide variety of evidence supports the global existence of a "Little Ice Age" (this was not a true "ice age" since major ice sheets did not develop) between about 1500 and 1850 (NRC, 2006). Average temperatures were possibly up to 2^{o}F colder than today, but varied by region.
- **The Industrial Era:** An additional warm period has emerged in the last 100 years, coinciding with substantially increasing emissions of greenhouse gases from human activities (see Recent Climate Change for more information).

Prior to the Industrial Era, the Medieval Climate Anomaly and Little Ice Age had defined the upper and lower boundaries of the climate's recent natural variability and are a reflection of changes in climate drivers (the sun's variability and volcanic activity) and the climate's internal variability (referring to random changes in the circulation of the atmosphere and oceans).

The issue of whether the temperature rise of last 100 years crossed over the warm limit of the boundary defined by the Medieval Climate Anomaly has been a controversial topic in the science community. The National Academy of Sciences recently completed a study to assess the efforts to reconstruct temperatures of the past one to two millennia (see Figure 2) and place the Earth's current warming in historical context (NRC, 2006).

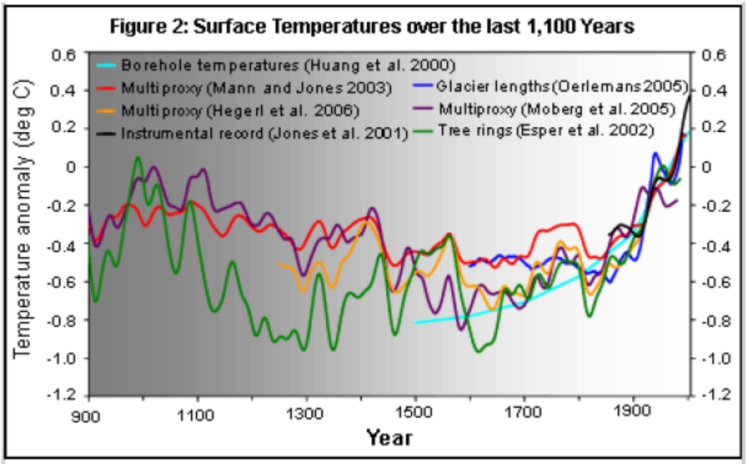


Figure 2: Reconstructions of (Northern Hemisphere average or global average) surface temperature variations from six research teams (in different color shades) along with the instrumental record of global average surface temperature (in black). Each curve illustrates a somewhat different history of temperature changes, with a range of uncertainties that tend to increase backward in time (as indicated by the shading). Reference: NRC, 2006. (Figure reprinted with permission from Surface Temperature Reconstructions© (2006) by the National Academy of Sciences, Courtesy of the National Academies Press EXIT Disclaimer , Washington, D.C.)

According to the study EXIT Disclaimer (NRC, 2006):

- There is a high level of confidence that the global average temperature during the last few decades was warmer than any comparable period during the last 400 years.
- Present evidence suggests that temperatures at many, but not all, individual locations were higher during the past 25 years than any period of comparable length since A.D. 900. However, uncertainties associated with this statement increase substantially backward in time.
- Very little confidence can be assigned to estimates of hemisphere average or global average temperature prior to A.D. 900 due to limited data coverage and challenges in analyzing older data.

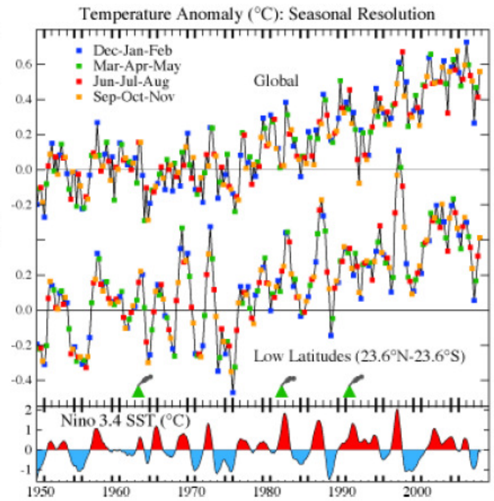
References

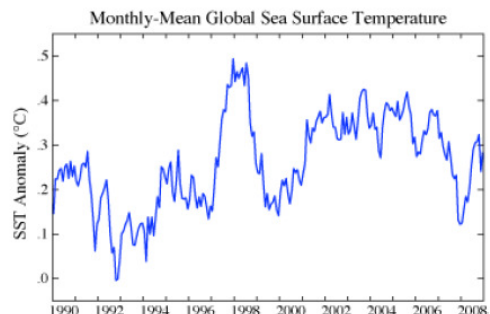
- IPCC, 2007: Climate Change 2007: The Physical Science Basis. EXIT Disclaimer Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)].
- National Research Council (NRC), 2002: Abrupt Climate Change, Inevitable Surprises. EXIT Disclaimer National Academy Press, Washington, DC. National Academy Press, Washington, DC
- National Research Council (NRC), 2005: Radiative Forcing of Climate Change. EXIT Disclaimer National Academy Press, Washington, DC. National Academy Press, Washington, DC
- National Research Council (NRC), 2006. Surface Temperature Reconstructions For the Last 2,000 Years. EXIT Disclaimer National Academy Press, Washington, DC.

Footnote 31 & 32: NASA Goddard Institute for Space Studies Datasets and images, GISS Surface Temperature Analysis http://data.giss.nasa.gov/gistemp/2008/

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).





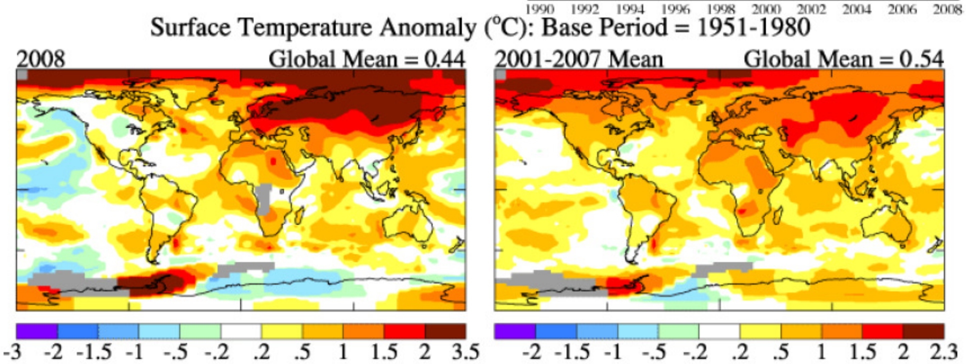


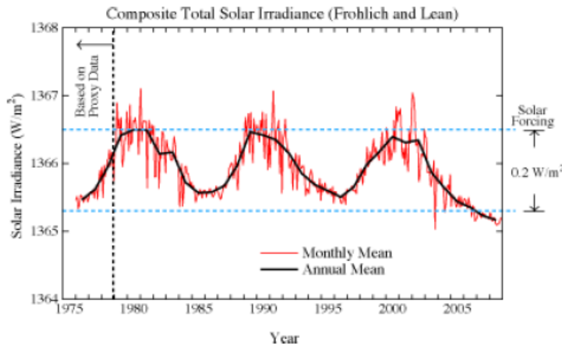
Figure 3 above. Comparison of 2008 (left) temperature anomalies with the mean 2001-2007 (right) anomalies. Notice that a somewhat different color bar has been used than in Figure 1 to show more structure in the right-hand map). (Click for PDF.)

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 dynamical variability: The largest contribution is the Southern Oscillation, the El Niño-La Niña cycle. The Niño 3.4 temperature anomaly (the bottom line in the top panel of Fig. 2), suggests that the La Niña may be almost over, but the anomaly fell back (cooled) to -0.7°C last month (December). It is conceivable that this tropical cycle could dip back into a strong La Niña, as happened, e.g., in 1975. However, for the tropical 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 century, so it is unlikely. 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 2008 news releases: NOAA, WMO, and Hadley Center.

Past NASA news releases: 2007, 2006, 2005, and 2004.

Note: There was no summation written for 2006; see NASA news release for that year instead. Also, there was no NASA news release for 2008.

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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.

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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

Footnote 34 & 41: U.S. Environmental Protection Agency Website on Global Warming - Climate: http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ClimateTrendsTemperature.html

Please see EPA's Climate Change site for current information on climate change and global warming. EPA no longer updates EPA's Global Warming Site, but is maintaining this archive for historical purposes. Thank you for visiting the archive of EPA's Global Warming Site.

Temperature

Global temperatures are rising. Observations collected over the last century suggest that the average land surface temperature has risen 0.8-1.0°F (0.45-0.6°C) in the last century. The surface of the ocean has also been warming at a similar rate. Studies that combine land and sea measurements have generally estimated that global temperatures have warmed 0.5-1.0°F (0.3-0.6°C) in the last century. About two-thirds of this warming took place between 1900 and 1940. Global temperatures declined slightly from the 1940s through the 1970s; but have risen more rapidly during the last 25 years than in the period before 1940.

Surface temperatures are not rising uniformly. Night-time low temperatures are rising on average about twice as rapidly as daytime highs. The winters in areas between 50 and 70° North Latitude (the latitude of Canada and Alaska) are warming relatively fast, while summer temperatures show little trend. Urban areas are warming somewhat more rapidly than rural areas, because of both the changes in land cover and the consumption of energy that take place in densely developed areas (a feature known as the "urban heat island" effect).

Associated Pages

Temperature

Precipitation

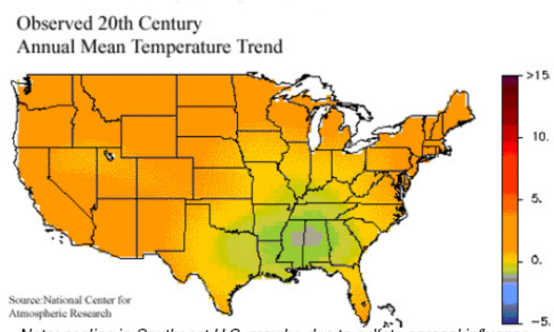
Sea Level

See Also

Temperature Tracker

IPCC Third Assessment Report - The Scientific Basis - Summary for Policymakers (323 KB)

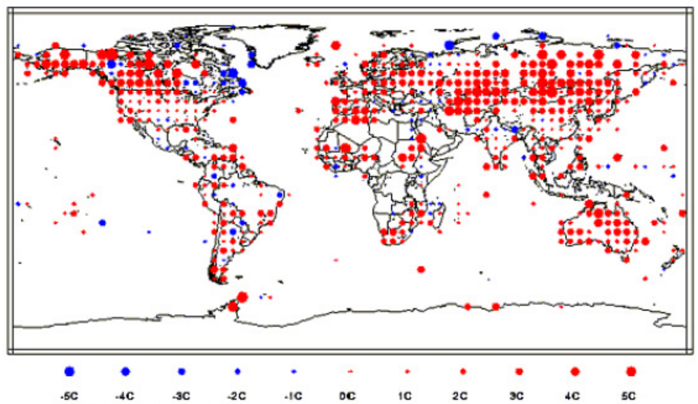
National Academy of Sciences - Climate Change Science: An Analysis of Some Key Questions(305 KB)



Note: cooling in Southeast U.S. may be due to sulfate aerosol influence.

In the United States, temperatures in the last 50 years have cooled in the East while warming in the West. Over the last 100 years, the pattern is similar, except that New England is warmer than 100 years ago because it warmed more in the first half of the 20th century by more than it cooled in the second half. This pattern of warming and cooling may be part of a worldwide pattern: while most of the earth has warmed, the regions that are downwind from major sources of sulfur dioxide emissions have generally cooled (see the discussion on sulfates in the *Atmospheric Change* section). This pattern is evident when one compares the two world maps below. The first map of the world shows the areas that have warmed and cooled from 1951-99. The second map of the world shows the amount of incoming solar radiation blocked by the cloud of atmospheric sulfates downwind from industrial emissions of sulfur dioxide.

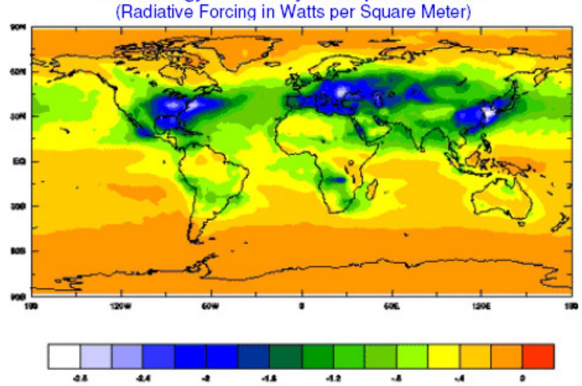
Global Annual Mean Temperature Trend, 1950-1999



Source: Global Historical Climate Network,
National Oceanic and Atmospheric Administration

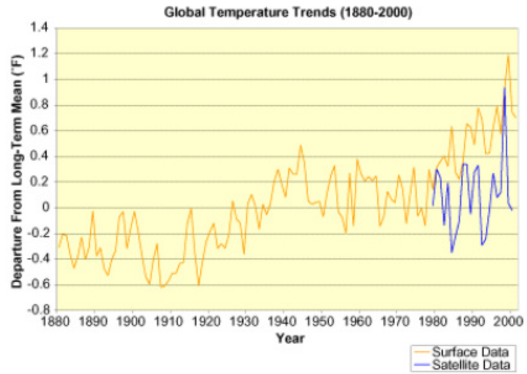
Red circles reflect warming — blue circles reflect cooling.

Solar Energy Blocked By Atmospheric Sulfates
(Radiative Forcing in Watts per Square Meter)



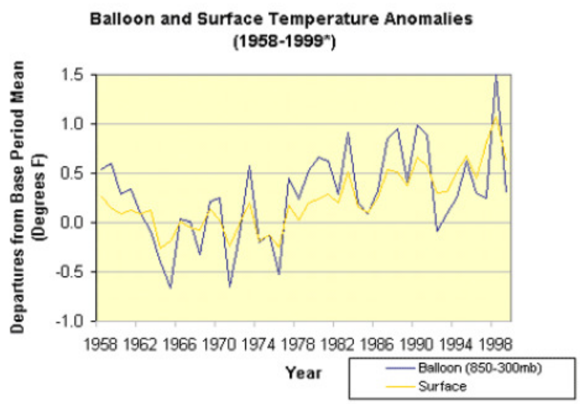
Source: Jeffrey Kiehl National Center For Atmospheric Research

Although scientists have incontrovertible evidence that the surfaces of the land and oceans have been warming, some scientists are not yet convinced that the atmosphere is also warming. Satellite data on temperatures in the lower 4.8 miles of the atmosphere, spanning a period from 1979 to the present, show little if any warming trend compared with the surface-based record during the same period. However, the 1979-2000 satellite data series may be too short to show a trend in atmospheric temperature. There also are physical reasons (such as the different responses of the atmosphere and surface to stratospheric ozone depletion and El Niño events) to expect that changes in atmospheric temperatures may not exactly match temperature changes on the surface during this period.

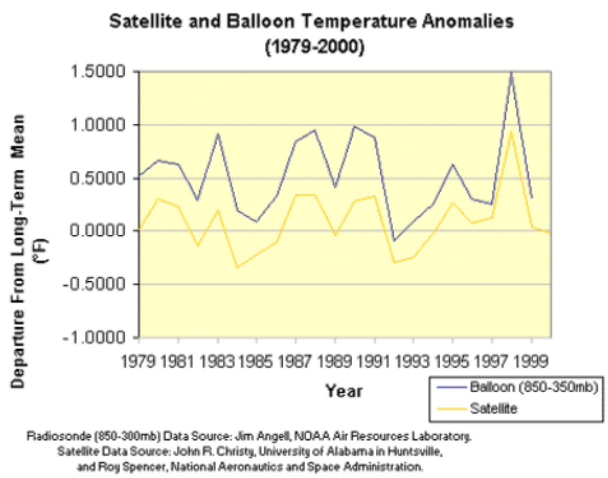


Surface Data Source: National Climatic Data Center, 2001.
Satellite Data Source: John R. Christy, University of Alabama in Huntsville, and Roy Spencer, National Aeronautics and Space Administration.

Balloon-borne instruments, which researchers have used to measure temperatures in the lower 4.8 miles of the atmosphere since 1958, show an overall warming trend from 1958-2000 similar to that of the surface record. But when just the period 1979-2000 is considered, the balloon data resemble the satellite data (see the charts below). This finding suggests that atmospheric and surface temperature trends may diverge in the short term.



* Meteorological Year (December through November), Base Period = 1958-1977
Surface Data Source: Surface Data Source: National Climatic Data Center, 2001.
Radiosonde (850-300mb) Data Source: Jim Angell, NOAA Air Resources Laboratory.

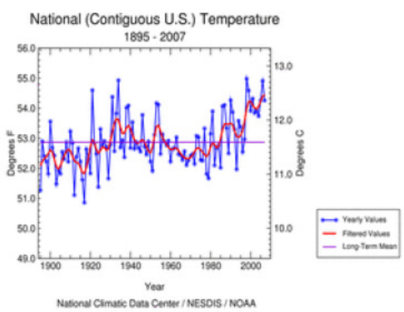


Measurement errors associated with the satellite-based technology, and short-term variations in temperature due to ozone depletion and El Niños (see glossary), may be responsible for the lack of a warming trend in the relatively short satellite record. Nevertheless, to many scientists, the absence of a warming trend in the satellite data provides an important caution that there is still much to learn about the global climate.

Footnote 35 and 36: U.S. Department of Commerce, 2007. National Climatic Data Center. 2007 Annual Climate Review U.S. Summary (http://www.ncdc.noaa.gov/oa/climate/research/2007/ann/us-summary.html#temp)

2007 Annual Climate Review
U.S. Summary

National Climatic Data Center
Asheville, North Carolina
Updated 08 May 2008



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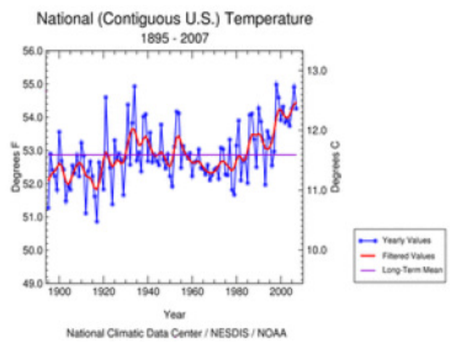
National Temperature

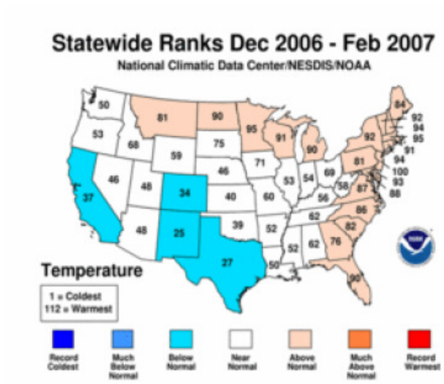
Based on data through the end of the year, 2007 was the 10th warmest year on record for the U.S. with a nationally averaged temperature of 54.2°F (12.4°C). This value is 1.4°F (0.8°C) above the 20th century (1901-2000) mean.

	TOP 10 WARMEST YEARS (U.S.)	
1.	1998	55.00



2.	2006	54.91
3.	1934	54.91
4.	1999	54.59
5.	1921	54.59
6.	1931	54.38
7.	2001	54.32
8.	1990	54.27
9.	2005	54.26
10.	2007	54.24

The last nine 5-year periods (2003-2007, 2002-2006, 2001-2005, 2000-2004, 1999-2003, 1998-2002, 1997-2001, 1996-2000, and 1995- 1999), were the warmest 5-year periods (i.e. pentads) in the last 113 years of national records, demonstrating the anomalous warmth of the last decade. The 8th warmest pentad was a tie between 1995-1999 and in the 1930s (1930-34), when the western U.S. was suffering from an extended drought coupled with anomalous warmth. The warmest year on record for the U.S. was 1998, where the record warmth was concentrated in the Northeast as compared with the Northwest in 1934. For the year as a whole, much above average temperatures are concentrated in the western U.S. and in parts of the East.



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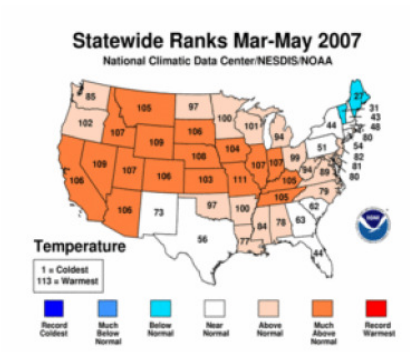
Seasonal Analysis:
The temperature for the 2006-2007 winter season (Dec-Feb) was the 39th warmest such period on record (1896-2007), with warmer than average temperatures along the Eastern Seaboard and the northern tier of states. Winter temperatures were below normal in Texas, New Mexico, Colorado and California.

Spring (March-May) temperatures were



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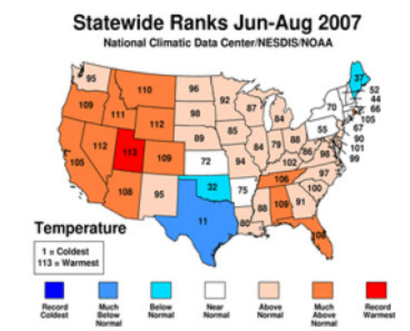

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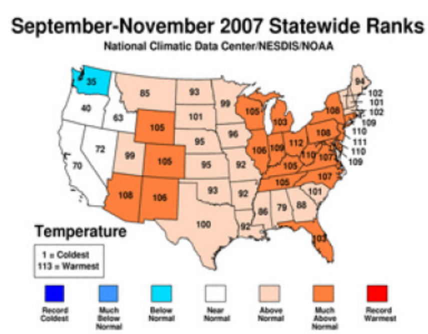

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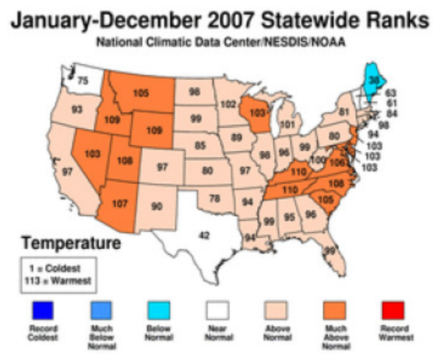
8th warmest for the nation, with much above average temperatures across the central and western parts of the contiguous U.S. No states were record warmest or coldest during the spring, although Missouri was third warmest on record during this period.

Warm temperatures persisted into the Summer (June-August), as the nation ranked 6th warmest in the last 113 years. Much above average temperatures were spread across much of the West and Rocky Mountain areas, along with Tennessee, Alabama and Florida. Five regions had much warmer than average temperatures, and the West had its third-warmest summer on record.

Many locations in the Central and Southeastern U.S. broke records for the most days above 90°F and 100°F during a heat wave in August. Over 70 all-time record high temperatures were set or tied in these drought-plagued areas, breaking records which had stood as long as 83 years.

During October, unseasonably warm temperatures affected most of the country and five Northeast states set record warm temperatures for the month. November temperatures were somewhat closer to normal in the East, but warm in the West, where Arizona set a new record high average temperature. The resulting 2007 fall season (September-November) ranked 6th warmest on record.

Much warmer than average temperatures affected much of the mountain west and parts of the East during 2007. This was the 10th warmest January-December in the 113-year record. Both Kentucky and Tennessee had the 4th warmest years on record. Forty-three of the lower 48 states were either warmer or much warmer than average in 2007. Maine alone ranked below average during the 2007 year-to-date period.



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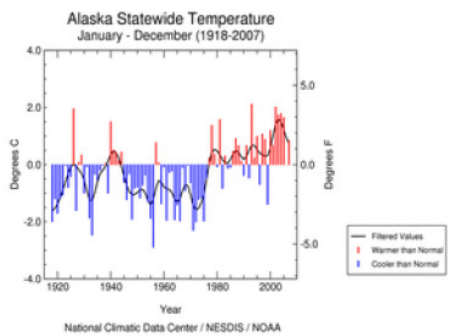

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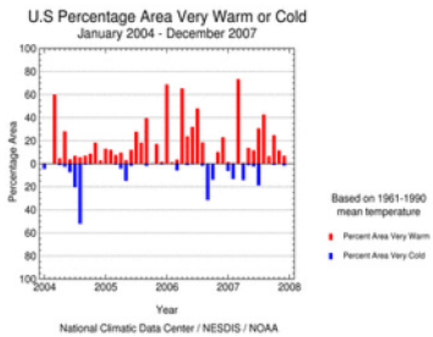
Annual temperatures averaged across the state of Alaska during 2007 ranked 15th warmest since 1918. Winter temperatures in 2007 were above average for the 8th consecutive year. Spring was slightly below average, summer was warmer than average, and fall was significantly warmer than the 1918-2000 average.

Wildfires across Alaska were not as widespread as in recent years, with the exception of the Anaktuvuk River wildfire, which set a new record for the largest fire on the North Slope. For additional information on the U.S. wildfire season, please see the Wildfire Season Summary.

More details of individual monthly and seasonal reports for 2007 can be found in NCDC's monthly and seasonal reports.

The figure below shows the percentage of the contiguous U.S. that was very warm and the percentage that was very cold during each of the past 47 months. During 2007, only one month (July) averaged very cold over nearly 20% or more of the country.



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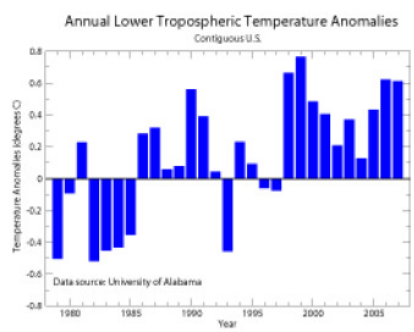
In contrast, over 20% of the U.S. was very warm in four months of 2007. March was the second warmest on record across the U.S., with over 60% of the U.S. ranked as very warm. Very warm and very cold conditions are defined as the warmest and coldest ten percent of recorded temperatures, respectively.

The anomalous warmth affecting the U.S. in 2007 is also reflected in temperatures in the lower troposphere. Data collected by NOAA's TIROS-N polar-orbiting satellites and adjusted for time-dependent biases by NASA and the Global Hydrology and Climate Center at the University of Alabama in Huntsville indicate that temperatures in the lower half of the atmosphere (lowest 8 km of the atmosphere) over the U.S. were warmer than the 20-year (1979-1998) average for the 10th consecutive year.

With a temperature anomaly of 1.1 °F (0.61°C), the 2007 lower troposheric temperature over the contiguous U.S. ranked as the 4th warmest year since this satellite record began in 1979.



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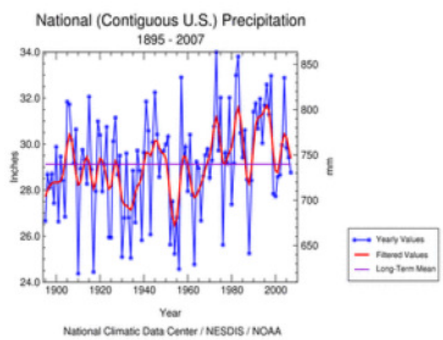
National Precipitation

Precipitation in the United States during 2007 was variable throughout much of the country with periods of excessive rainfall, especially across the central third of the U.S., and persistent and developing drought in the southeastern quarter of the country and the far western states.

Winter was relatively wet in the South and North Central regions and relatively dry in the West and Southeast. In the **spring**, it was the driest March-May on record in the Southeast. The West was ranked 6th driest and the West North Central region had its 3rd wettest spring on record. In **summer**, the remnants of Tropical Storm Erin brought excessive rain to Texas, Oklahoma and Kansas, giving the South its wettest summer on record. Meanwhile, much of the Southeast continued to suffer in drought with its 11th driest summer on record, following the driest spring. Precipitation across the U.S. during the **fall** ranked 37th driest, although no regions ranked much above or much below normal.

For the contiguous U.S. as a whole, seven months in 2007 were drier than average. Combined with unusually warm temperatures in the Southeast, this exacerbated drought conditions across much of the southeastern quadrant of the country. By August, over 40% of the contiguous U.S. was in moderate to extreme drought, as reported by the U.S. Drought Monitor. Increased October precipitation helped decrease this percentage to near 30% by the end of November. Despite above-average precipitation again in December, U.S. precipitation in 2007 was below the long-term mean, ranking as the 47th driest year on record. The average annual precipitation was 28.9 inches (733 mm), which is 0.3 inches (7 mm) below the 20th century (1901-2000) average.



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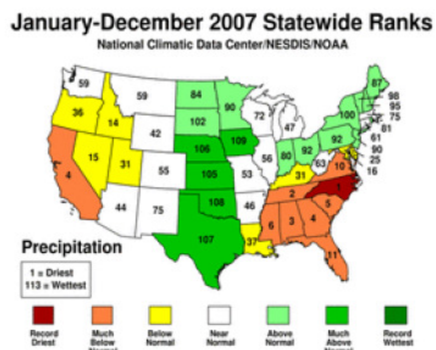

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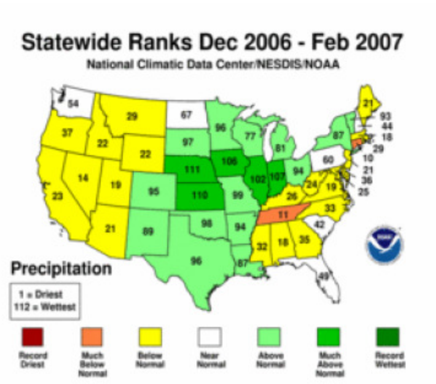
Below average precipitation occurred

across portions of the western and southeastern states during the winter. Several states in the middle of the country, including Nebraska and Kansas, had much above normal winter precipitation. A dry winter exacerbated the drought conditions across the Southwest and foreshadowed the upcoming dry year in the Tennessee Valley region.



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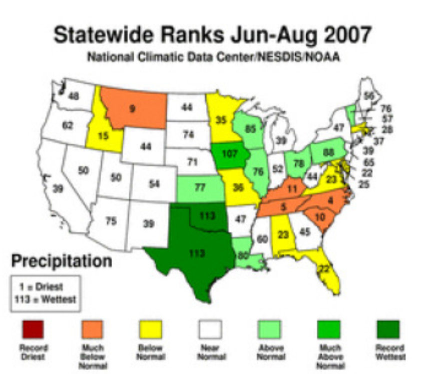
The West Coast, Southeast and southern Mississippi valley states were exceptionally dry during the spring, whereas much of the central corridor of the country had much above normal precipitation. Both Mississippi and Georgia had their driest springs on record, and Alabama and Tennessee had their second driest. In contrast, both North Dakota and Nebraska had their third wettest springs on record.

larger image

Summer precipitation across the southern plains was much above average, with both Oklahoma and Texas record wettest, partially due to the remnants of Tropical Storm Erin in August. Flooding was widespread across portions of central Oklahoma after the storm brought seven to eleven inches of rain in some places along with wind gusts as high as 82 mph (132 km/hr) in this land-locked state. In the Southeast, continuing rainfall deficits across this region were not helped by a relative lack of tropical activity in this area.



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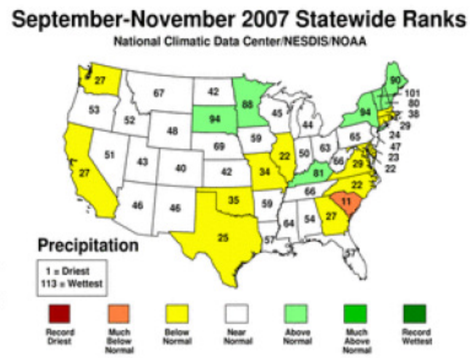
Precipitation received during the fall was below average across the nation. Only the Northeast Climate Region had more precipitation than normal this season. Above normal precipitation across much of Alabama, Kentucky and western Tennessee in late October helped relieve some of the Moderate to Exceptional Drought conditions in these areas. Exceptional drought continued to affect parts of Alabama, Georgia, Tennessee, the Carolinas and a tiny portion of western Virginia by the beginning of December.



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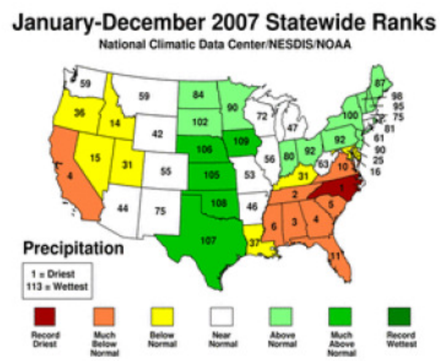

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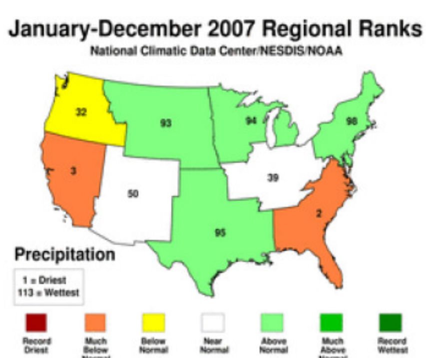
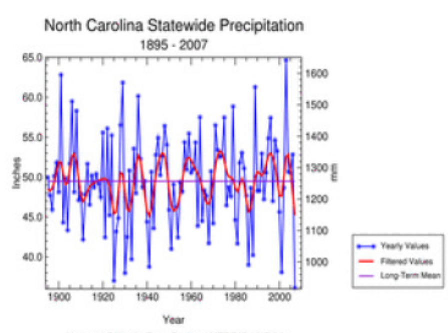
2007 precipitation (see map above right) ranked North Carolina the driest and Tennessee the 2nd driest on record. In fact, this was the 2nd driest such period for the Southeast and the third driest for the West. Conversely, only five states and no climate regions received much above normal rainfall in 2007.





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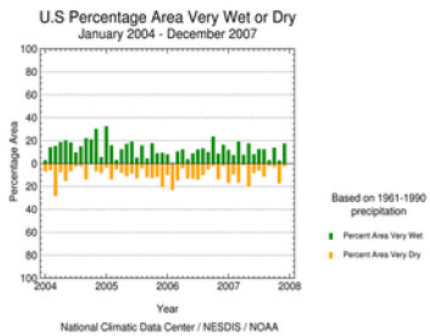

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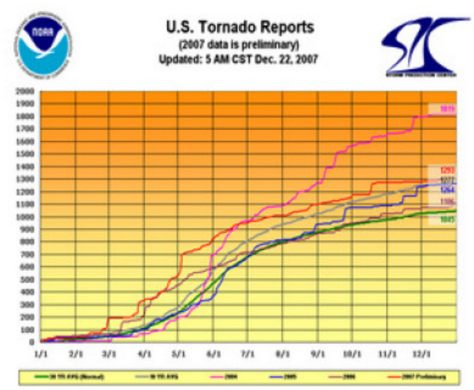
The adjacent figure shows the percent of the contiguous U.S. that was very wet and the percent that was very dry during each of the past 48 months. During 2007, more than a tenth of the country was very dry during January, March, May, August and November.

Nearly 20% of the contiguous U.S. was very wet in March, and over 10% of the U.S. was also very wet during January, May, July, August, October and December. Very wet and very dry conditions are defined as the wettest and driest ten percent of recorded precipitation values, respectively.

Severe Storms

According to NOAA's Storm Prediction Center, preliminary estimates indicate that there have been nearly 1300 reported tornadoes from January-December 2007, which is slightly above the ten-year average and well above the 30-year average. Note that these numbers represent preliminary tornado reports and not the number of total tornadoes.



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Spring in the central and southern parts of the country was punctuated by several severe weather outbreaks producing over 600 reported tornadoes and leading to nearly 50 deaths during March through May 2007. The first large tornado outbreak occurred on February 24, when 21 tornadoes were reported, mostly in Louisiana, Arkansas, and Mississippi. The next outbreak less than a week later, when over 70 tornadoes were reported across the Gulf Coast region, Missouri, Illinois and South Carolina on March 1. Later that month, 80 reported tornadoes occurred across the western Great Plains from Texas to Nebraska on the 28th. The next large outbreak occurred on May 5, when 111 tornadoes were reported from the Texas panhandle through Iowa, Nebraska, and South Dakota.

larger image - Greensburg, KS tornado damage

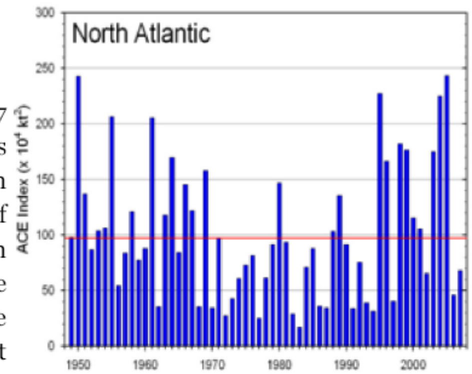
larger image - Greensburg, KS Tornado Path

The most devastating tornado of 2007 was the EF5 tornado that hit Greensburg, Kansas shortly before 10 pm CDT on the night of Friday, May 4, 2007. The tornado, given the rating of five on the Enhanced Fujita scale, was the first to receive the EF5 classification and the first tornado to earn a 5-rating since the May 3, 1999 Moore/ Oklahoma City, OK tornado. At least ten fatalities were reported from this devastating storm, which damaged or destroyed an estimated 95% of the town of Greensburg. The tornado was on the ground for 22 miles (35.4 km) and had a maximum path width of 1.7 miles (2.7 km), moving north-northeast until it turned northward upon reaching Greensburg and later curved back to the west. Despite the tornado's strength, the 32-minute warning lead time given by the Dodge City NWS office and the quick reaction of the people of Greensburg kept the number of fatalities in the town of over 1600 persons down to a minimum.

Atlantic Hurricanes

The 2007 Atlantic basin hurricane season was below the 1950-2000 average with 15 named storms, of which 6 were hurricanes, including 2 major hurricanes. The ACE index of hurricane activity indicates a somewhat below-average season, with a preliminary value of approximately 68 $x10^4$ $knots^2$. An average season is anywhere from 66 x 10^4 $knots^2$ to 103 x 10^4 $knots^2$. The relatively less active season in 2007 was attributed in part to a large Bermuda high, which acted to suppress conditions conducive to hurricanes in the western Atlantic.

The first storm of the official 2007 Atlantic hurricane season was Subtropical Storm Andrea, which developed off the southeastern coast of the U.S. on May 9th. Hurricane Dean became the first major hurricane of the Atlantic season in mid-August and made landfall as a Category 5 storm on August 21 on the Yucatán Peninsula of Mexico.



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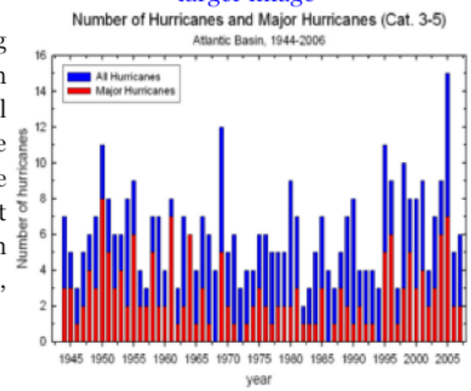
Olga was the last named storm during the 2007 season. Olga transformed from a sub-tropical storm into a tropical cyclone on December 11th before it made landfall along the eastern coast of the Dominican Republic that evening. At least 24 people lost their lives to Olga in the Caribbean, mostly from flash floods, before it dissipated on December 13.



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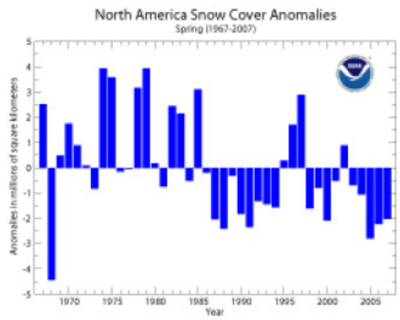
Three tropical depressions (Barry, Erin, TD 10), one tropical storm (Gabrielle), and a weak hurricane (Humberto) made landfall with the mainland U.S. during 2007. Tropical Depression Barry and TD 10 made landfall in Florida, Erin and Humberto in Texas, and Gabrielle moved across the Outer Banks of North Carolina. More details about these and all the 2007 Atlantic tropical systems can be found on NCDC's Atlantic hurricane page.

Snow Season

Generally near to above average snowfall blanketed the Northern Cascades, Big Horn Mountains in Wyoming, and the Colorado Front Range during the 2006-2007 snow season, while the Sierra Nevada, Wasatch (UT), and the mountains of Arizona suffered from well



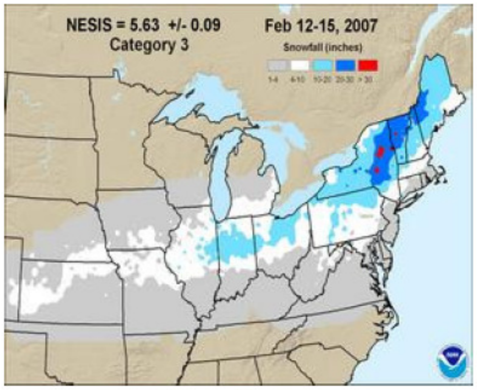
Data courtesy of Rutgers University Global Snow Lab

below average accumulations. Slightly above average snow accumulations covered the North American continent as a whole over the winter, with a well below average snowpack in the spring, consistent with a recent trend towards reduced spring snow cover for North America as shown in the adjacent image.

Several notable winter storms affected the continental U.S. in 2007. The first great ice storm that occurred January 11-16 paralyzed areas from the Rio Grande Valley to New England and southeastern Canada. Two subsequent storms affected the southern U.S. and later the southern Plains and mid-Atlantic states. The ice left hundreds of thousands of residents without power, resulted in at least 85 deaths across 12 states and three Canadian provinces, and caused numerous flight cancellations out of busy airports such as Dallas-Ft. Worth. Up to two inches of ice and additional layers of sleet and snow accumulated in some areas during the first storm. Record-breaking cold temperatures followed these storms in many western states.

In mid-February, a large snow storm reaching from the Mid-Mississippi Valley into the Mid-Atlantic and New England areas brought from four to twenty inches of snow across much of the Central U.S. and up to thirty inches of snow in parts of eastern New York and northern Vermont. The Northeast Snowfall Impact Scale (NESIS) classified this as a Category 3 (major) storm and ranked it as the 14th most intense snow storm on record for the Northeast. See map of event below left.

A few weeks later, two winter storms struck the Upper Midwest in late February and early March, bringing heavy and record-breaking amounts of snowfall in some areas from February 23



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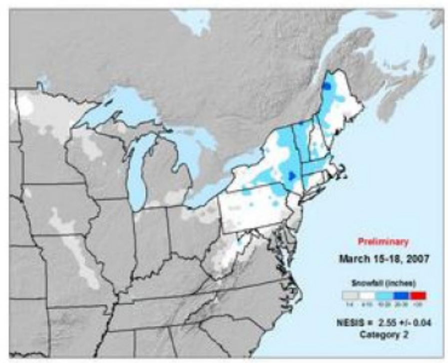
to March 2. More details of these and other snow and ice events are available in the annual summary of significant events.

A Category 2 (significant) St. Patrick's Day winter storm caused travel problems across parts of the Northeast on the 16th and 17th. More than 1000 flights were cancelled in New York City as more than 5 inches of snow fell in Central Park. Eight inches fell in Frostburg, Maryland and up to 2 feet of snow accumulated in the northern Catskills of New York. Farther to the south, freezing rain and ice accumulated from northern Virginia throughout much of Pennsylvania and into parts of southern New York, making driving conditions hazardous.



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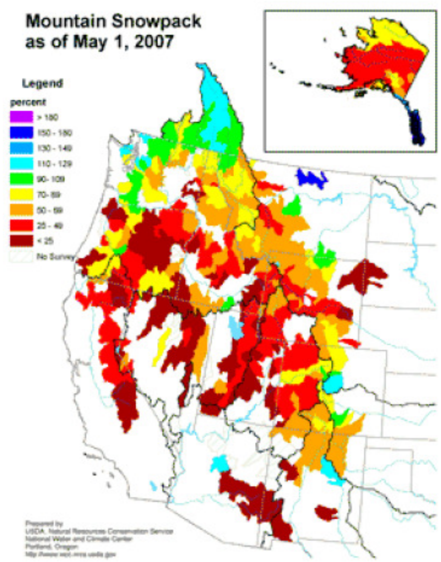
Well below normal snowfall amounts fell over much of the West in the first several months of 2007. Near the end of spring, few areas had above average snowpack, while accumulations less than 50% of average were widespread from Oregon to the Southwest. See map of May 1 snowpack below left. Many western states rely on melting mountain snowpack for municipal and agricultural water supplies, and the below-average conditions left many areas with far less than the snow required to replenish reservoirs.

The 2007-2008 snow season began with above average snowfall across parts of the Southwest and well-below-normal



amounts in the Sierra Nevadas, Cascades, and the Bear River (ID, UT) and Salt River Ranges. A major ice storm hit parts of the south-central U.S. in the second week of December, leaving over 600,000 residents in Oklahoma without power and causing 27 fatalities across five states. Several back-to-back midlatitude cyclones brought significant snowfall from the Great Plains through New England in mid- and late December.

larger image

More details on snow across the US and the Northern Hemisphere can be found on the 2006-2007 snow and ice page and the 2007-2008 snow and ice page.

More details of weather and climate in individual months and seasons in 2007 can be found on NCDC's monthly pages.

NOAA's National Climatic Data Center is the world's largest active archive of weather data. The preliminary temperature and precipitation rankings are available from the center by calling: 828-271-4800.

NOAA works closely with the academic and science communities on climate-related research projects to increase the understanding of El Niño and improve forecasting techniques. NOAA's Climate Prediction Center monitors, analyzes and predicts climate events ranging from weeks to seasons for the nation. NOAA also operates the network of data buoys and satellites that provide vital information about the ocean waters, and initiates research projects to improve future climate forecasts.

For further information, contact:

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fax: 828-271-4328
email: Jay.Lawrimore@noaa.gov

Footnote 37 & 39: U.S. Environmental Protection Agency Website on Climate Change - Science: http://www.epa.gov/climatechange/science/recenttc.html#ref

http://www.epa.gov/climatechange/science/recenttc.html
Last updated on Wednesday, December 17th, 2008.

Climate Change - Science

You are here: EPA Home Climate Change Science Recent Climate Change Temperature Changes

- Recent Climate Change
- Atmosphere
- Temperature
- Precipitation and Storms
- Sea Levels

Temperature Changes

Surface Temperature Change | Tropospheric Temperature Change | Stratospheric Temperature Change | Recent Scientific Developments

Temperatures are changing in the lower atmosphere - from the Earth's surface all the way through the stratosphere (9-14 miles above the Earth's surface). Scientists are working to document temperature trends and determine their causes.

Surface Temperature Change

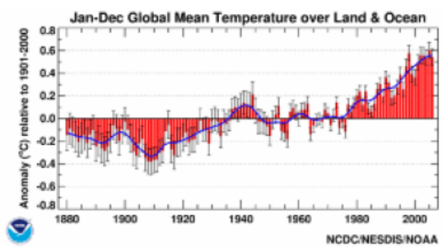


Figure 1: Annual Average Global Surface Temperature Anomalies 1880-2006. Courtesy NOAA (Surface temperature records such as the one shown here have been quality controlled to remove the effects of urbanization at observing stations in and around cities.
Click on Thumbnail for full size image.

Records from land stations and ships indicate that the global mean surface temperature warmed by between 1.0 and 1.7°F since 1850 (see Figure 1). These records indicate a near level trend in temperatures from 1880 to about 1910, a rise to 1945, a slight decline to about 1975, and a rise to present (NRC, 2006). The Intergovernmental Panel on Climate Change (IPCC) concluded in 2007 that warming of the climate system is now "unequivocal," based on observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC, 2007).

Related Links

EPA: Future Temperature Changes

CCSP: Product 1.1 - Temperature Trends in the Lower Atmosphere Steps for Understanding and Reconciling Differences

NASA: Global Institute for Space Studies Surface Temperature Observations

NOAA 2007 State of the Climate

United States Surface Temperature Trends

Observations compiled by NOAA's National Climatic Data Center indicate that over the past century, temperatures rose across the contiguous United States at an average rate of 0.11°F per decade (1.1°F per century). Average temperatures rose at an increased rate of 0.56°F per decade from 1979 to 2005. The most recent eight-, nine-, and ten-year periods were the warmest on record.

Warming occurred throughout most of the U.S., with all but three of the eleven climate regions showing an increase of more than 1°F since 1901. The greatest temperature increase occurred in Alaska

(3.3°F per century). The Southeast experienced a very slight cooling trend over the entire period (-0.04°F per century), but shows warming since 1979.

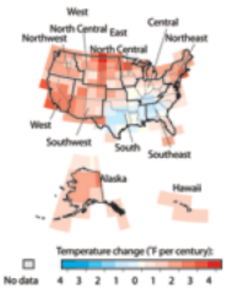


Figure 2: Annual Mean Temperature Anomalies 1901-2005. Click on Thumbnail for full size image. Data courtesy NOAA's National Climatic Data Center.

According to the National Oceanic and Atmospheric Administration's (NOAA) 2007 State of the Climate Report and the National Aeronautics and Space Administration's (NASA) 2007 Surface Temperature Analysis:

- Since the mid 1970s, the average surface temperature has warmed about 1°F.
- The Earth's surface is currently warming at a rate of about 0.32°F/decade or 3.2°F/century.
- The eight warmest years on record (since 1850) have all occurred since 1998, with the warmest year being 2005.

Additionally (from IPCC, 2007):

- The warming trend is seen in both daily maximum and minimum temperatures, with minimum temperatures increasing at a faster rate than maximum temperatures.
- Land areas have tended to warm faster than ocean areas and the winter months have warmed faster than summer months.
- Widespread reductions in the number of days below freezing occurred during the latter half of the 20th century in the United States as well as most land areas of the Northern Hemisphere and areas of the Southern Hemisphere.
- Average temperatures in the Arctic have increased at almost twice the global rate in the past 100 years.

The IPCC has concluded that most of the observed warming in global average surface temperature that has occurred since the mid-20th century is very likely a result of human activities (IPCC, 2007). During the first half of the last century, there was likely less human impact on the observed warming, and natural variations, such as changes in the amount of radiation received from the sun, likely played a more significant role.

Tropospheric Temperature Change

Measurements of the Earth's temperature taken by weather balloons (also known as radiosondes) and satellites from the surface to 5-8 miles into the atmosphere - the layer called the troposphere - also reveal warming trends. According to NOAA's National Climatic Data Center:

- For the period 1958-2006, temperatures measured by weather balloons warmed at a rate of 0.22°F per decade near the surface and 0.27°F per decade in the mid-troposphere. The 2006 global mid-troposphere temperatures were 1.01°F above the 1971-2000 average, the third warmest on record.
- For the period beginning in 1979, when satellite measurements of troposphere temperatures began, various satellite data sets for the mid-troposphere showed similar rates of warming — ranging from 0.09°F per decade to 0.34°F per decade, depending on the method of analysis.

Stratospheric Temperature Change

Weather balloons and satellites have also taken temperature readings in the stratosphere –

the layer 9-14 miles above the Earth's surface. This level of the atmosphere has cooled. The cooling is consistent with observed stratospheric ozone depletion since ozone is a greenhouse gas and has a warming effect when present. It's also likely that increased greenhouse gas concentrations in the troposphere are contributing to cooling in the stratosphere as predicted by radiative theory (Karl et al., 2006).

Recent Scientific Developments

The U.S. Climate Change Science Program (CCSP) recently published the report "Product 1.1 Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences," which addresses some of the long-standing difficulties in understanding changes in atmospheric temperatures and the basic causes of these changes. According to the report:

- There is no discrepancy in the rate of global average temperature increase for the surface compared with higher levels in the atmosphere. This discrepancy had previously been used to challenge the validity of climate models used to detect and attribute the causes of observed climate change.
- Errors identified in the satellite data and other temperature observations have been corrected. These and other analyses have increased confidence in the understanding of observed climate changes and their causes.
- Research to detect climate change and attribute its causes using patterns of observed temperature change shows clear evidence of human influences on the climate system due to changes in greenhouse gases, aerosols and stratospheric ozone.
- An unresolved issue is related to the rates of warming in the tropics. Here, models and theory predict greater warming higher in the atmosphere than at the surface. However, greater warming higher in the atmosphere is not evident in three of the five observational data sets used in the report. Whether this is a result of uncertainties in the observed data, flaws in climate models, or a combination of these is not yet known.

References

- IPCC, 2007: Climate Change 2007: The Physical Science Basis. EXIT Disclaimer Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)].
- National Research Council (NRC), 2006. Surface Temperature Reconstructions For the Last 2,000 Years. EXIT Disclaimer National Academy Press, Washington, DC.
- Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences. Thomas R. Karl, Susan J. Hassol, Christopher D. Miller, and William L. Murray, editors, 2006. A Report by the Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

Footnote 40: NASA Earth Observatory Gottard Institute for Space Studies, 1999. Global Temperature Trends: Continued Warmth in 1999 http://earthobservatory.nasa.gov/Features/GlobalWarm1999/

Global Temperature Trends:

Continued Warmth in 1999

BY THE GODDARD INSTITUTE FOR SPACE STUDIES

Global surface temperatures in 1999 fell back from the record setting high level of 1998, which was the warmest year in the period of instrumental data, report researchers at the NASA Goddard Institute for Space Studies who analyze data collected from several thousand meteorological stations around the world. But 1999 was still one of the warmest years of the century, as shown in Figure 1.

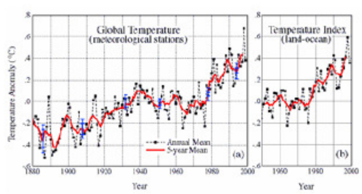


Figure 1: (a) Near-global annual-mean surface air temperature change, based on meteorological station network, (b) global land-ocean surface temperature index, which combines sea surface temperature measurements for ocean areas with surface air temperature measurements at meteorological stations. **(Click on any figure for a larger version.)**

Although global temperature fluctuates considerably from year to year due to chaotic variability of the atmosphere and ocean, there has been a long-term global warming trend underway since the early 1960s, as illustrated in Figure 1. The 1999 data are consistent with a continuation of that warming trend, with 1999 being approximately the sixth warmest year in the record. The ranking of years is approximate because of incomplete global coverage of measurement stations and small errors in the measurements.

Most parts of the world were warmer than normal, i.e., warmer than the 30-year period 1951-1980, as illustrated in Figure 2. It was particularly warm across most of North America (except the West Coast) and most of Eurasia. However, the tropical Pacific Ocean was cool due to a strong La Niña. During a La Niña the near equatorial region is cooled by upwelling of cool water from the deep ocean.

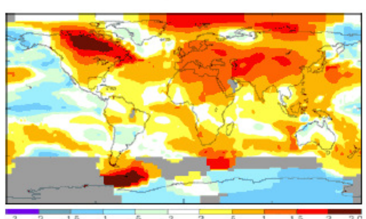
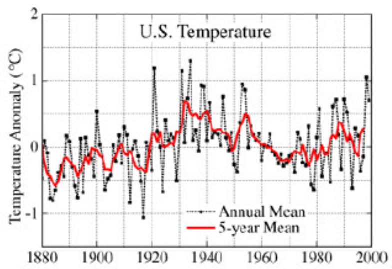


Figure 2: Surface temperature anomaly for the 1999 calendar year derived from measurements at several thousand meteorological stations and satellite measurements of the ocean surface. (Hansen et al., 1999; Reynolds and Smith, 1994)

Figure 3: Temperature anomaly (deviation from the 1951-80 average) for calendar years for the contiguous United States.



The temperature in the United States was also warm, about 0.7°C above the 1951-1980 average (Figure 3). 1999 was approximately the 10th warmest year of the century. The warmest years in the United States occurred during the dust bowl era, with 1934 being the warmest year.

Our analyzed temperature, in the United States and the rest of the world, includes corrections for urban effects on the record. Nearby rural stations are used to adjust the long-term trends at urban stations, as described by Hansen et al. (1999) (see references below).

The temperature anomalies fluctuate substantially from month to month, as illustrated for the United States in Figure 4.

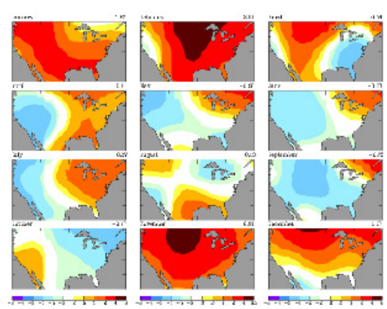


Figure 4: Monthly temperature anomalies (relative to 1951-80 average) in the United States during 1999.

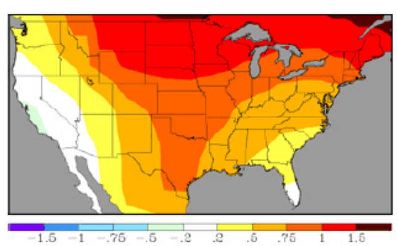


Figure 5: Annual temperature anomaly (relative to 1951-80 average) in the United States for 1999.

February and November were both exceptionally warm in the United States. Averaged over the year, most of the United States was warm in 1999 (Figure 5), except the West Coast and Florida.

These maps for the United States illustrate that even with the level of warmth that occurred in the United States in 1999, the local warming trend is less than natural year-to-year fluctuations of monthly mean temperature. Thus for any given location in the United States there are generally at least a few months in the year that are cooler than normal. But the overall tendency toward warming is enough that it is beginning to effect the probability of a month or a season being warmer than normal. In our discussion of 1998 temperatures (see below) we discussed this concept that the climate "dice" are being "loaded" to a degree that is beginning to be noticeable to people.

References:

1. Hansen, J., R. Ruedy, J. Glascoe, and M. Sato 1999. GISS analysis of surface temperature change. *J. Geophys. Res.* **104**, 30997-31022.

2. Reynolds, R.W. and T.M. Smith 1994. Improved global sea surface temperature analyses. *J. Climate* **7**, 929-948.

The data used in this study are available in one or more of NASA's Earth Science Data Centers.

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Footnote 44, 47, 50, 77, 94, 96, 101, 103, 104, 107-111: Minnesota Pollution Control Agency Website – Global Climate Change and Its Impact on Minnesota: http://www.pca.state.mn.us/climatechange/, measured in Minneapolis, MN

Minnesota Pollution Control Agency

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Minnesota Climate Change Action

Governor Pawlenty introduced the Next Generation Energy Initiative on December 12, 2006. The initiative includes strategies to increase renewable energy use, increase energy conservation and decrease carbon emissions from Minnesota. The Governor's proposal to reach a goal where 25% of energy comes from renewable sources by 2025 is supported by increasing E85 pumps, raising the state's Renewable Energy Objective, and promoting cellulosic ethanol and other biomass technology.

Energy conservation can be achieved by increasing Energy Star buildings throughout the state, and Minnesotans were asked to reduce fossil fuel energy use 15% by 2015. Other steps that will help Minnesota reduce carbon emissions are joining the Chicago Climate Exchange or another national greenhouse gas registry, and beginning a stakeholder process with the Center for Climate Strategies to identify ways that we can reduce our emissions efficiently and cost-effectively.

- Next Generation Energy Initiative WEB
- The Climate Registry WEB
- Center for Climate Strategies WEB

Climate Science

While some scientists may disagree about the causes and extent of global climate change, few doubt that the Earth's climate is warming. Some University of Minnesota researchers predict that if trends continue, Minnesota could look a lot like Nebraska in the coming years.

During the last century, the average temperature in Minneapolis, Minnesota, has increased slightly from 43.9°F (1888-1917 average) to 44.9°F (1963-1992

Panel on Climate Change

U.S. Climate Action Report, May 2002

Impacts of Climate Change:

Confronting Climate Change in the Great Lakes Region

Acting to Slow Climate Change:

Energy Efficiency and Renewable Energy Network

This Web site contains PDF documents that require Adobe Acrobat for viewing.

average), and precipitation in some areas of the state has increased by up to 20%, especially in the southern half.

During the next century, Minnesota's climate may change even more. According to an international scientific body known as the Intergovernmental Panel on Climate Change, the earth's average temperatures will rise between two and 10 degrees Fahrenheit by the year 2100, with northern latitudes like Minnesota at the upper end of the range.

In addition, carbon dioxide, the principal greenhouse gas, persists in the atmosphere for hundreds of years. So once global warming begins, its effects will continue for hundreds of years, too.

The Problem with Climate Change

Global climate change poses risks to human health and to ecosystems. Important economic resources such as agriculture, forestry, fisheries, and water resources also may be affected.

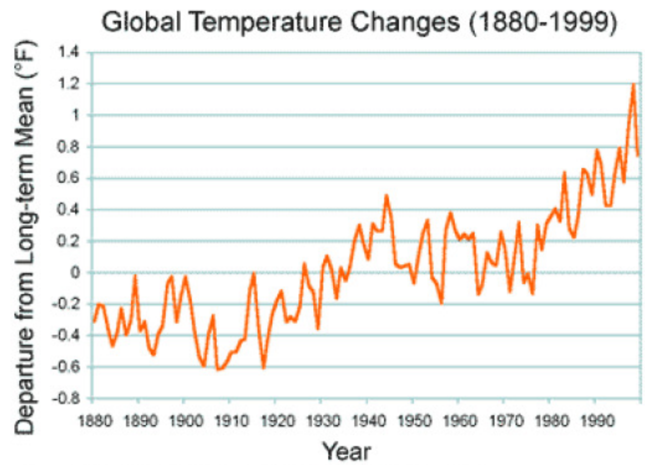
Warmer temperatures, more severe droughts and floods, and sea level rise could have a wide range of impacts. These stresses can add to existing stresses on resources caused by population growth, land-use changes, and pollution.

Similar global temperature changes have occurred in the past, but the previous changes took place over centuries or millennia instead of decades. The ability of some plants and animals to migrate and adapt appears to be much slower than the predicted rate of climate change.

Our Changing Climate

The 20th century's 10 warmest years all occurred in the last 15 years of the century. Of these, 1998 was the warmest year on record. The snow cover in the Northern Hemisphere and floating ice in the Arctic Ocean have decreased.

Globally, sea level has risen 4-10 inches over the past century. Worldwide precipitation over land has increased by about one percent. The frequency of extremely heavy rainfalls has increased throughout much of the United States.

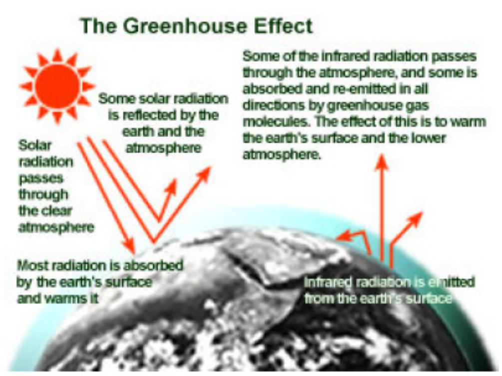


Source: National Climatic Data Center, 2000. Climate of 1999 - Annual Review. Online at http://www.ncdc.noaa.gov/ol/climate/research/1999/ann/ann99.html

What Is Causing the Change?

Most scientists believe human activities are altering the chemical composition of the atmosphere through the buildup of greenhouse gases - primarily carbon dioxide, methane and nitrous oxide. The heat-trapping property of these gases is undisputed. Although uncertainty exists about exactly how earth's climate responds to these gases, global temperatures are rising.

Energy from the sun drives the earth's weather and climate, and heats the earth's surface; in turn, the earth radiates energy back into space. Atmospheric greenhouse gases (water vapor, carbon dioxide, and other gases) trap some of the outgoing energy, retaining heat somewhat like the glass panels of a greenhouse.



Without this natural "greenhouse effect," temperatures would be much lower than they are now, and life as we know it today would not be possible. Instead, thanks to greenhouse gases, the earth's average temperature is a more hospitable 60°F. However, problems may arise when the atmospheric concentration of greenhouse gases increases.

And greenhouse gases, like carbon dioxide, are increasing. Scientists generally believe that the combustion of fossil fuels and other human activities are the primary reason for the increased concentration of carbon dioxide. Fossil fuels burned to run cars and trucks, heat homes and businesses, and produce electricity are responsible for about 98% of U.S. carbon dioxide emissions, 24% of methane emissions, and 18% of nitrous oxide emissions.

Increased agriculture, deforestation, landfills, industrial production, and mining also contribute a significant share of emissions. In 1997, the United States emitted about one-fifth of total global greenhouse gases. The U.S. now generates at one-quarter of the world's carbon dioxide emissions.

Greenhouse Gas Emission Trends in Minnesota

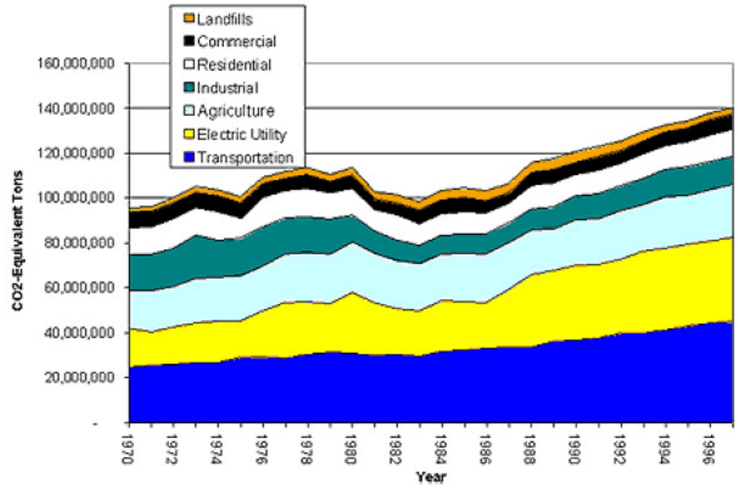
Greenhouse gas emissions in Minnesota are increasing. They have increased about 20% since 1988.

Three distinct phases are evident from the emissions data presented in the chart below: a period of rapid growth in emissions from 1970 to 1979, a period of contraction from 1980 through 1987, and a return to rapid growth in emissions from 1988 to 1997.

The first of these periods coincided with a decade of robust economic expansion, both nationally and statewide, that ended with a deep recession in 1981/1982; the second, with a period of de-industrialization and fuel-switching from coal to natural gas throughout Minnesota industry. Also important in the contraction of emissions in the mid-1980s was the large-scale substitution of in-state electricity generation by electricity purchases from out-of-state sources.

The period since 1988 has been characterized by a return to greater reliance on in-state electricity generation sources, rapid growth in emissions from transportation sources, and, in the middle and late 1990s, robust economic growth. The ten-year average annual rate of growth in emissions from 1988 to 1997 is about 2 percent per year.

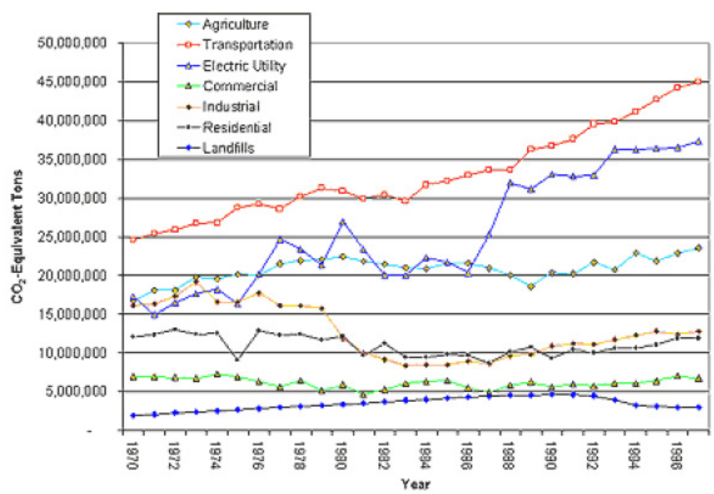
Greenhouse Gas Emissions in Minnesota: 1970-1997



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.

Greenhouse Gas Emissions in Minnesota by Economic Sector



Potential Effects of Climate Change on Minnesotans and their Environment

Given the wide variety of factors that must be taken into account, it is difficult to predict how climate change will ultimately affect Minnesota. The following potential impacts are from the U.S. Environmental Protection Agency's Global Warming Web site. WEB

Human Health

Higher temperatures and increased frequency of heat waves may increase the number of heat-related deaths and the incidence of heat-related illnesses. Minnesota, with its irregular, intense heat waves, seems somewhat susceptible.

In Minneapolis, one study projects that a 3°F warming could triple heat-related deaths from 60 during a typical summer to about 180 (although increased air conditioning use may not have been fully accounted for). The elderly, particularly those living alone, are at greatest risk.

Warming and other climate changes could expand the habitat of disease-carrying insects, primarily mosquitoes. This may increase the potential for transmission of diseases such as malaria, dengue ("break bone") fever and St. Louis encephalitis.

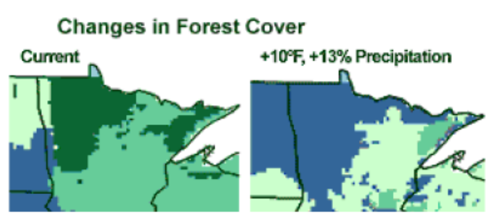
Also, the mosquitoes that carry yellow fever, Eastern equine encephalitis, and La Crosse encephalitis recently have spread as far north as Chicago. Global warming could shift the region where these mosquitoes breed and overwinter farther north. If conditions become warmer and wetter, mosquito populations can increase, thereby increasing the risk of transmission of these diseases.

Forests

Trees and forests are adapted to specific climate conditions, and as climate warms, forests will change. These changes could include changes in species, geographic extent, and health and productivity.

If conditions also become drier, the current range and density of forests could be reduced and replaced by grasslands and pasture. Even a warmer and wetter climate would lead to changes - trees that are better adapted to warmer conditions, such as oaks and southern pines, would prevail. Under these conditions, forests could become more dense.

These changes could occur during the lifetimes of today's children, particularly if they are accelerated by other stresses such as fire, pests, and diseases. Some of these stresses would themselves be worsened by a warmer and drier climate.



With changes in climate, the extent of forested areas in Minnesota could change little or decline by as much as 50-70%. The uncertainties depend on many factors, including whether soil becomes drier and, if so, by how much. Hotter, drier weather could increase the frequency and intensity of wildfires.

Mixed forests better adapted to warmer conditions could replace the unique boreal forests in the northern part of the state and in the Boundary Waters Canoe Area. The mixed aspen, birch, beech, maple, and pine forests in the northern and eastern areas of the state would shrink in range and be replaced by a combination of grasslands and hardwood forests consisting of oak, elm, and ash.

Grasslands and savanna eventually could replace much of the forests and woodlands in the state. These changes would significantly affect the character of Minnesota forests and the activities that depend on them.

Water Resources

Water resources are affected by changes in precipitation as well as by temperature, humidity, wind, and sunshine. Changes in streamflow tend to magnify changes in precipitation.

Because evaporation is likely to increase with warmer climate, it could result in lower river flow and lower lake levels, particularly in the summer. In addition, more intense precipitation could increase flooding. If streamflow and lake levels drop, ground water - the primary source of drinking water in Minnesota - also could be reduced.

If climate warms, the ice cover on Minnesota's lakes and streams would not last as long as it does today. Streamflows could peak sooner in the spring because of earlier snowmelt and ice breakup. Reduced summer flows could decrease water quality. Lake surface temperatures would be warmer in the summer, although the temperature changes generally would be less than the increase in air temperature. As a result, lake evaporation would increase considerably, perhaps by as much as 20% for a 4°F warmer climate.

Shorter ice-cover seasons and increased lake evaporation could have major effects on Lake Superior. Fresh water flowing into Lake Superior could decrease with global warming, potentially reducing lake levels and degrading water quality.

Flood damage may be reduced with lower lake levels, but shorelines could be more susceptible to erosion damage from wind and rain. Reduced fresh water in the Great Lakes could negatively affect shipping to and from Duluth, for example, primarily because of lower water levels in the shipping channels connecting the lower Great Lakes. However, this could be offset by a longer ice-free season.

Precipitation

Precipitation is projected to increase by around 15% in

winter, summer, and fall, with little change projected for spring.

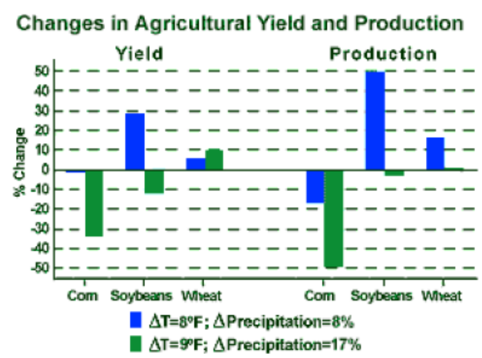
The number of heavy rainfalls in summer most likely would increase. The frequency of extremely hot days in summer is expected to increase along with the general warming trend. It is not clear how severe storms would change.

Agriculture

The mix of crop and livestock production in any part of the country is influenced by climate conditions and water availability. As climate warms, production patterns will shift northward.

Increases in climate variability could make adaptation by farmers more difficult. Warmer climates and less soil moisture due to increased evaporation may increase the need for irrigation. However, these same conditions could decrease water supplies, which also may be needed by natural ecosystems, urban populations and other economic sectors.

Understandably, most studies have not fully accounted for changes in climate variability, water availability, and imperfect responses by farmers to changing climate. Including these factors could substantially change modeling results.



Source: Mendelsohn and Neumann (in press); McCarl (personal communication).

Analyses based on changes in average climate and which assume farmers effectively adapt suggest that aggregate U.S. food production will not be harmed, although there may be significant regional changes.

In Minnesota, agriculture is about a $7 billion annual industry, 50% of which comes from crops. The principal crops are corn, soybeans, and wheat.

If climate warms, corn yields could remain unchanged or could decrease by up to 34%. Wheat yields could increase by 6-10%, and projected soybean yields are mixed: they could increase by up to 28% or decrease by 12%.

While crop yields could increase, the number of acres farmed could fall by 12-18%, and farm income could decrease by 10-25%.

About 2% of the state's farm acres are currently irrigated. Irrigated acreage could increase. This could further stress water supplies, which could be lower in the summer, and water quality could be degraded further.

Ecosystems

The prairie potholes of Minnesota are the single most important breeding areas for North American waterfowl such as mallards, pintails, and blue-winged teals. The drying effects of climate change could reduce the size and number of prairie potholes, with damaging effects to the waterfowl.

A copy of the recently released, "Preparing for a Changing Climate: a Great Lakes Overview" is now available from the Great Lakes Regional Assessment Team. WEB

A full copy of "Climate Change and Minnesota," from which much of this material was taken is available from the U.S. Environmental Protection Agency's Web site. WEB

What Can We Do?

We as individuals can do our part to reduce greenhouse gas emissions by making less-polluting choices.

On the road:

- Purchase a fuel-efficient car or alternative fuel vehicle. Go to the MPCA's motor vehicle pollution page for more ideas.
- Do all your errands in one trip rather than several.
- Keep your car tuned and your tires fully inflated.
- Consider alternative means of transportation, such as the bus, your bike or just walking.
- Telecommute to work.

In your home:

- Turn off lights, TVs and other electronic devices when not in use.
- Purchase energy efficient appliances that display the Energy Star label. Visit the Energy Star Web site more additional information.
- Replace incandescent lights with energy efficient fluorescent bulbs or light fixtures.

In your yard:

- Plant deciduous trees to shade your house. Trees can also remove 50 pounds of carbon from the air each year.
- Use a pushmower.
- Compost your lawn clippings and leaf waste.

Today, action is occurring at many levels of government to reduce, avoid and better understand the risks associated with climate change. Many cities and states across the country have prepared greenhouse gas inventories and many are actively pursuing programs and policies that will result in greenhouse gas emission reductions.

At the national level, the U.S. Global Change Research Program (USGCRP) coordinates the world's most extensive research effort on climate change. In addition, EPA and other federal and state agencies are actively engaging the private sector, states, and municipalities in partnerships based on a win-win philosophy aimed at addressing the challenge of global warming while, at the same time, strengthening the economy.

In Minnesota, the MPCA has made significant progress in reducing emissions of some pollutants - but not necessarily greenhouse gas emissions - from large, stationary sources. It is now broadening its focus to reduce emissions from a much larger number of smaller sources, including gas stations, on- and off-road vehicles and woodstoves.

The MPCA will use three approaches to reduce emissions from these smaller, "nonpoint" sources of pollution. The agency intends to take actions that:

- reduce fuel and energy consumption,
- substitute cleaner fuels for existing ones, and
- increase the use of technologies that reduce air pollution.

Reducing pollutants from these sources depends not only on cleaner fuels, energy and technologies, but also upon the choices that consumers and citizens make each day.

Note: Much of the above text and graphics on this Web page are from the U.S. Environmental Protection Agency, Global Warming Program.

Learn More About Global Warming - MPCA Fact Sheets and Reports

- Results of the Minnesota Climate Change Advisory Group - Presentation to MPCA staff (February 19, 2008) - The Minnesota Climate Change Advisory Group has made its final recommendations on effective and cost-efficient policies to reduce the emissions of greenhouse gases in Minnesota. The presentation made to MPCA and other state staff includes a general overview of the process and the ranking of various options by net reductions and the cost of reductions.

- Global Climate Change - Fact Sheet. (May 2007) This fact sheet describes the evidence for global climate change, possible climate change effects that would impact Minnesota, and actions that the state and all Minnesotans can use to reduce greenhouse gas emissions.

- Air Emissions Impacts of Plug-in Hybrid Vehicles in Minnesota's Passenger Fleet. (March 2007) MPCA staff prepared a report on air emissions from alternative vehicles for the legislature and the Plug-In Hybrid Electric Vehicle Task Force. The report looks at the possible future emissions from conventional vehicles, hybrid vehicles, and plug-in hybrid vehicles using different mixes of coal- and wind-based electricity. Carbon dioxide, carbon monoxide, nitrogen oxides, sulfur dioxide, volatile organic compounds, and particulate matter emissions were evaluated. Using alternative vehicle technology generally reduces emissions of pollutants and switching from gasoline to electricity changes the emissions profile; using coal-based electricity has the potential to increase emissions of sulfur dioxide.

- Anaerobic Digestion of Livestock Manure for Pollution Control and Energy Production: A Feasibility Assessment. (March 2001) Anaerobic digestion has been applied to the treatment of organic wastes for several decades; this natural process degrades complex organic molecules into stabilized waste and methane and carbon dioxide gases. The environmental benefits of anaerobic digestion include reducing biological oxygen demand, reducing odors, destroying pathogens, and controlling hydrogen sulfide and methane. The methane produced by anaerobic digestion can also be combusted in order to produce energy, meeting on-farm electricity demands, or for sale to the electrical grid. Combustion of methane also destroys a potent greenhouse gas. This study demonstrates the economic viability of anaerobic digesters in Minnesota.

- Minnesota Climate Change Action Plan: A Framework for Climate Change Action. (February 2003) The MPCA has prepared a climate change action plan framework for Minnesota, joining more than 25 other states that have developed such plans with funding assistance from the U.S. EPA. To develop this framework, the MPCA developed greenhouse gas emissions information and forecasts, as well as a carbon sequestration inventory. The MPCA also conducted a survey to learn what a broad group of stakeholders (e.g., industry, non-profit groups, and government) thinks the role of state government should be in this issue. In addition, a list was gathered of existing state programs that may be relevant to greenhouse gas control. To aid in communicating this issue with other agencies, the MPCA and Office of Environmental Assistance also conducted a survey of government agencies to learn about their beliefs about climate change. The ideas put forth in this report are based on a synthesis of the information gathered. The suggested short-term actions fall into a few key areas, with reduced greenhouse emissions through energy use efficiency increases as the primary focus and an emphasis on improving carbon sequestration.

- Global Warming and Climate Change in Minnesota - Fact Sheet. (December 2002) This fact sheet describes the potential impacts of climate change and lists examples of actions you can take to reduce emissions of greenhouse gases. Prepared by the Minnesota Office of Environmental Assistance, Minnesota Pollution Control Agency, Minnesota Department of Commerce, and Minnesota Department of Natural Resources.

- Global Climate Change Technical Index. (January 2001) MPCA staff prepared answers to a number of questions related to global warming and climate change as part of the 2001 MPCA legislative report titled, "Air Quality in Minnesota: Problems and Approaches." This index contains answers to many common questions about climate change.

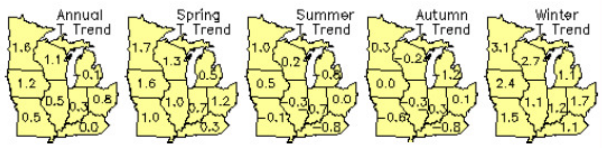
- Preliminary Climate Change Action Plan Submitted to the Legislature. (February 2008)

Footnote 49: Midwestern Regional Climate Center, Climate Change and Variability in the Midwest: http://mrcc.sws.uiuc.edu/climate_midwest/mwclimate_change.htm#

Climate Change & Variability in the Midwest

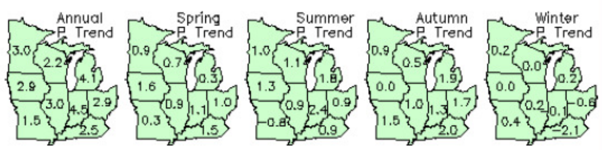
The climate of the Midwest has changed over time since the beginning of modern records in 1895. Presented here are maps of the state average annual and seasonal temperature and precipitation trends between 1895 and 2006. Temperature trends are given in Degrees Fahrenheit change over 112 years, and precipitation trends are reported as inches of precipitation change over 112 years. The state averages used in calculating the trends came from the National Climatic Data Center Climate Division Dataset. Click the image to see in a larger size.

Temperature Trends, 1895-2006



Annual Spring Summer Autumn Winter

Precipitation Trends, 1895-2006



Annual Spring Summer Autumn Winter

Footnote 51: NASA Earth Observatory Feature Articles:
http://earthobservatory.nasa.gov/Features/Milankovitch/

MILUTIN MILANKOVITCH (1879-1958)

The Serbian astrophysicist Milutin Milankovitch is best known for developing one of the most significant theories relating Earth motions and long-term climate change. Born in 1879 in the rural village of Dalj (then part of the Austro-Hungarian Empire, today located in Croatia), Milankovitch attended the Vienna Institute of Technology and graduated in 1904 with a doctorate in technical sciences. After a brief stint as the chief engineer for a construction company, he accepted a faculty position in applied mathematics at the University of Belgrade in 1909—a position he held for the remainder of his life.

Milankovitch dedicated his career to developing a mathematical theory of climate based on the seasonal and latitudinal variations of solar radiation received by the Earth. Now known as the Milankovitch Theory, it states that as the Earth travels through space around the sun, cyclical variations in three elements of Earth-sun geometry combine to produce variations in the amount of solar energy that reaches Earth:

1. Variations in the Earth's orbital eccentricity—the shape of the orbit around the sun.
2. Changes in obliquity—changes in the angle that Earth's axis makes with the plane of Earth's orbit.
3. Precession—the change in the direction of the Earth's axis of rotation, i.e., the axis of rotation behaves like the spin axis of a top that is winding down; hence it traces a circle on the celestial sphere over a period of time.

Together, the periods of these orbital motions have become known as Milankovitch cycles.

next: Orbital Variations

Print this Entire Article

"MILANKOVITCH DEDICATED HIS CAREER TO DEVELOPING A MATHEMATICAL THEORY OF CLIMATE."

On the Shoulders of Giants

Images
Top: A portrait of Milutin Milankovitch. (Drawing by Hailey King)

Footnote 57: Bubbles trapped in ice cores in Greenland and Antarctica have been used to reconstruct atmospheric CO_2 levels over the last several glacial/interglacial cycles (http://earthobservatory.nasa.gov/Features/Paleoclimatology_IceCores/)

Paleoclimatology: The Ice Core Record

by Holli Riebeek · design by Robert Simmon · December 19, 2005

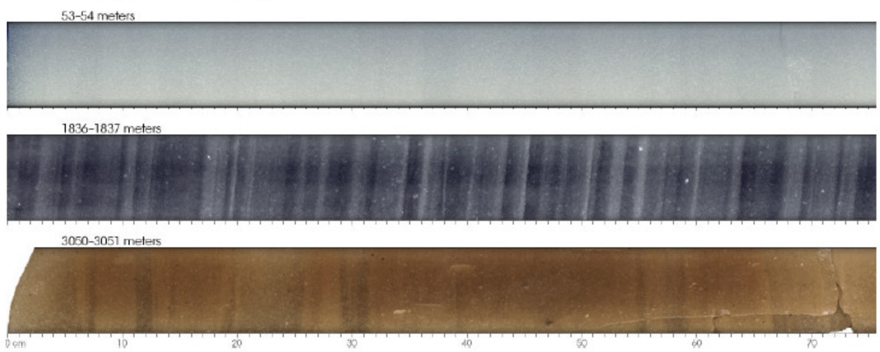
Richard Alley might have envied paleoceanographer Jerry McManus' warm, ship-board lab. (See previous installment: "A Record from the Deep.") One of the researchers in the Greenland Ice Sheet Project 2 (GISP2), Alley huddled in a narrow lab cut into the Greenland Ice Sheet, where "the temperature stayed at a 'comfortable' twenty below [Fahrenheit]," he wrote in his book about his research, *The Two-Mile Time Machine*. An assembly line of science equipment lined the twenty-foot-deep trench that served as a makeshift lab. For six weeks every summer between 1989 and 1993, Alley and other scientists pushed columns of ice along the science assembly line, labeling and analyzing the snow for information about past climate, then packaging it to be sent for further analysis and cold storage at the National Ice Core Laboratory in Denver, Colorado. Nearby, a specially built drill bored into the thick ice sheet twenty-four hours a day under the perpetual Arctic sun. Essentially a sharpened pipe rotating on a long, loose cable, the drill pulled up cores of ice from which Alley and others would glean climate information.

Ice sheets contain a record of hundreds of thousands of years of past climate, trapped in the ancient snow. Scientists recover this climate history by drilling cores in the ice, some of them over 3,500 meters (11,000 feet) deep. These photographs show experimental drilling on the Greenland Ice Cap in summer 2005. (Photographs copyright Reto Stöckli, NASA GSFC)

Throughout each year, layers of snow fall over the ice sheets in Greenland and Antarctica. Each layer of snow is different in chemistry and texture, summer snow differing from winter snow. Summer brings 24 hours of sunlight to the polar regions, and the top layer of the snow changes in texture—not melting exactly, but changing enough to be different from the snow it covers. The season turns cold and dark again, and more snow falls, forming the next layers of snow. Each layer gives scientists a treasure trove of information about the climate each year. Like marine sediment cores, an ice core provides a vertical timeline of past climates stored in ice sheets and mountain glaciers.

Blue light filtered through the wall of an Antarctic snow pit illuminates "Tuck," the mascot for Tuckahoe Elementary School in Henrico County, Virginia. The furry white owl accompanied scientists to Antarctica as part of an educational program. In the wall of the pit, dark and light bands of slowly compacted snow distinguish snow deposited in the winter from snow deposited in the summer. (Photograph courtesy Christopher Shuman, NASA GSFC)

The seasonal snow layers are easiest to see in snow pits, writes Alley, the Evan Pugh Professor in the Environment Institute and Department of Geosciences at Pennsylvania State University. To see the layers, scientists dig two pits separated by a thin wall of snow. One pit is covered, and the other is left open to sunlight. By standing in the covered pit, scientists can study the annual snow layers in the snow wall as the sunlight filters through the other side. "I have stood in snow pits with dozens of people—drillers, journalists, and others—and so far, every visitor has been impressed. The snow is blue, something like the blue seen by deep sea divers, an indescribable, almost achingly beautiful blue," writes Alley. "The next thing most people notice is the layering."

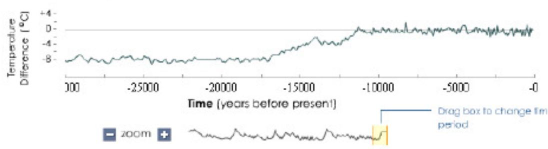


The gradually increasing weight of overlying layers compresses deeply buried snow into ice, but annual bands remain. Relatively young and shallow snow becomes packed into coarse and granular crystals called *firn* (top: 53 meters deep). Older and deeper snow is compacted further (middle: 1,836 meters). At the bottom of a core (lower: 3,050 meters), rocks, sand, and silt discolor the ice. (Photographs courtesy U.S. National Ice Core Laboratory)

To pry climate clues out of the ice, scientists began to drill long cores out of the ice sheets in Greenland and Antarctica in the late 1960s. By the time Alley and the GISP2 project finished in the early 1990s, they had pulled a nearly 2-mile-long core (3,053.44 meters) from the Greenland ice sheet, providing a record of at least the past 110,000 years. Even older records going back about 750,000 years have come out of Antarctica. Scientists have also taken cores from thick mountain glaciers in places such as the Andes Mountains in Peru and Bolivia, Mount Kilimanjaro in Tanzania, and the Himalayas in Asia.

Researchers retrieve climate records from mountain glaciers in addition to the records from polar ice sheets. Drilling sites around the world help distinguish trends in local climate from trends in global climate. This drilling station is located at an elevation of 6,425 meters (21,080 feet) on the summit of Nevado Coropuna in the Peruvian Andes. (Photograph copyright Jason Box, Ohio State University/Byrd Polar Research Center)

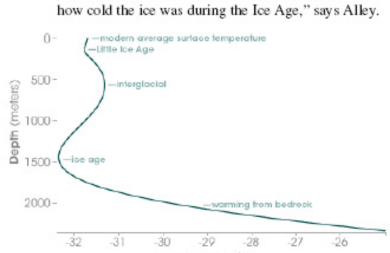
The ice cores can provide an annual record of temperature, precipitation, atmospheric composition, volcanic activity, and wind patterns. In a general sense, the thickness of each annual layer tells how much snow accumulated at that location during the year. Differences in cores taken from the same area can reveal local wind patterns by showing where the snow drifted. More importantly, the make-up of the snow itself can tell scientists about past temperatures. As with marine fossils, the ratio of oxygen isotopes in the snow reveals temperature, though in this case, the ratio tells how cold the air was at the time the snow fell. In snow, colder temperatures result in higher concentrations of light oxygen. (See The Oxygen Balance.)



The ice core recovered from Vostok, Antarctica, records over 400,000 years of climate history. This interactive graph shows temperature measurements derived from the core. Temperatures equal to or greater than the recent average (gray line) delineate interglacial periods, while colder temperatures indicate ice ages.

Scroll the graph in time by dragging the slider on the miniature graph (lower). Zoom in and out on the data with the plus and minus buttons (lower left). [Interactive designed by Kristin Henry, (Galaxy Goo) and Robert Simmon (NASA GSFC)]

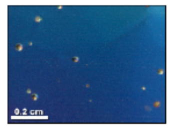
Scientists can confirm these chemistry-based temperature measurements by observing the temperature of the ice sheet directly. The ice sheet's thickness makes its temperature much more resistant to change than the six inches of snow that might fall on your driveway during a winter snowstorm. As Alley explained to the Earth Observatory, the ice sheet can be compared to a frozen roast that is put directly into the oven. The outside heats up quickly, but the center remains cold, close to the temperature of the freezer, for a long time. Similarly, the ice sheet has warmed somewhat since the Ice Age, but not completely. The top has warmed as global temperatures have warmed, while the bottom has been warmed by heat flow from deep inside the Earth. But in the middle of an ice sheet, the ice remains close to the Ice Age temperatures at which it formed. "Because we understand how heat moves in ice, [and] we know how cold the ice is today, we can calculate how cold the ice was during the Ice Age," says Alley.



Scientists measure the temperature of an ice sheet directly by lowering a thermometer into the borehole that was drilled to retrieve the ice core. Like an insulated thermos, snow and ice preserve the temperature of each successive layer of snow, which reflects general atmospheric temperatures when the layer accumulated. Close to the surface of the bedrock, the lowest layers of the ice are warmed by the heat of the Earth. These physical temperature measurements help calibrate the temperature record scientists obtain from oxygen isotopes. (Graph based on data provided by Gary Clow, United States Geological Survey)

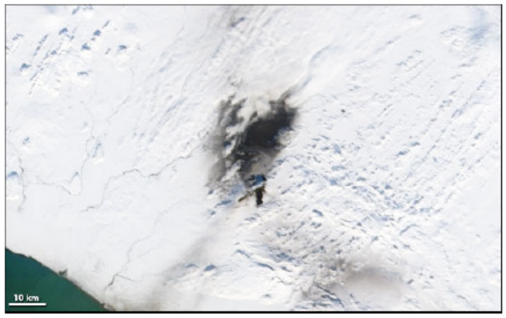
When scientists lower an ultra-precise thermometer into a hole in the ice, they can detect the temperature variations that have occurred since the Ice Age. The near-surface ice temperature, like the atmosphere today, is warm, and then the temperature drops in the layers formed roughly between AD 1450 and 1850, a period known as the Little Ice Age, one of several cold snaps that briefly interrupted the overall warming trend ongoing since the end of the Ice Age. As the thermometer goes deeper into the ice sheet, the temperature warms again, and then plummets to the temperatures indicative of the Ice Age. Finally, the bottom layers of the ice sheet are warmed by heat coming from the Earth. These directly measured temperatures represent a rough average—a record of trends, not variable, daily temperatures—but climatologists can compare the thermometer temperatures with the oxygen isotope record as a way to calibrate those results.

As valuable as the temperature record may be, the real treasure buried in the ice is a record of the atmosphere's characteristics. When snow forms, it crystallizes around tiny particles in the atmosphere, which fall to the ground with the snow. The type and amount of trapped particles, such as dust, volcanic ash, smoke, or pollen, tell scientists about the climate and environmental conditions when the snow formed. As the snow settles on the ice, air fills the space between the ice crystals. When the snow gets packed down by subsequent layers, the space between the crystals is eventually sealed off, trapping a small sample of the atmosphere in newly formed ice. These bubbles tell scientists what gases were in the atmosphere, and based on the bubble's location in the ice core, what the climate was at the time it was sealed. Records of methane levels, for example, indicate how much of the Earth wetlands covered because the abundance of life in wetlands gives rise to anaerobic bacteria that release methane as they decompose organic material. Scientists can also use the ice cores to correlate the concentration of carbon dioxide in the atmosphere with climate change—a measurement that has emphasized the role of carbon dioxide in global warming. (see "Explaining the Evidence.")



Air bubbles trapped in the ice cores provide a record of past atmospheric composition. Ice core records prove that current levels of carbon dioxide and methane, both important greenhouse gases, are higher than any previous level in the past 400,000 years. (Photograph courtesy U.S. National Ice Core Laboratory)

Finally, anything that settles on the ice tends to remain fixed in the layer it landed on. Of particular interest are wind-blown dust and volcanic ash. As with dust found in sea sediments, dust in ice can be analyzed chemically to find out where it came from. The amount and location of dust tells scientists about wind patterns and strength at the time the particles were deposited. Volcanic ash can also indicate wind patterns. Additionally, volcanoes pump sulfates into the atmosphere, and these tiny particles also end up in the ice cores. This evidence is important because volcanic activity can contribute to climate change, and the ash layers can often be dated to help calibrate the timeline in the layers of ice.



Ash from volcanic eruptions becomes trapped in ice sheets along with snow and dust. Scientists use the volcanic ash found in ice cores to date the cores and to estimate the intensity of past volcanic activity. This satellite image shows black ash from the eruption of Hekla on top of bright white Icelandic snow on February 29, 2000. (NASA image courtesy Jesse Allen)

Though ice cores have proven to be one of the most valuable climate records to date, they only provide direct evidence about temperature and rainfall where ice still exists, though they hint at global conditions. Marine sediment cores cover a broader area—nearly 70 percent of the Earth is covered in oceans—but they only give tiny hints about the climate over the land. Soil and rocks on the Earth's surface reveal the advance and retreat of glaciers over the land surface, and fossilized pollen traces out rough boundaries of where the climate conditions were right for different species of plants and trees to live. Unique water and rock formations in caves harbor a climate record of their own. To understand the Earth's climate history, scientists must bring together all of these scattered threads into a single, seamless story.

References:

Alley, R., 2000: *The Two-Mile Time Machine*, Princeton University Press, Princeton, New Jersey.

Bradley, R., 1999: *Paleoclimatology*, Academic Press, Harcourt Brace and Company, San Diego, California.

Imbrie, J. and K. P. Imbrie, 1979: *Ice Ages*, Enslow Publishers: Hillside, New Jersey.

Links:

Byrd Polar Research Center

NOAA Paleoclimatology Program

Paleoclimatology

Footnote 58, 51, 61: U.S. Department of Commerce National Climatic Data Center. World Data Center for Paleoclimatology (http://www.ncdc.noaa.gov/paleo/globalwarming/temperature-change.html)

NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)
National Climatic Data Center U.S. Department of Commerce

WDC for Paleoclimatology

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A Paleo Perspective... ...on Global Warming

Temperature change and carbon dioxide change

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The Story
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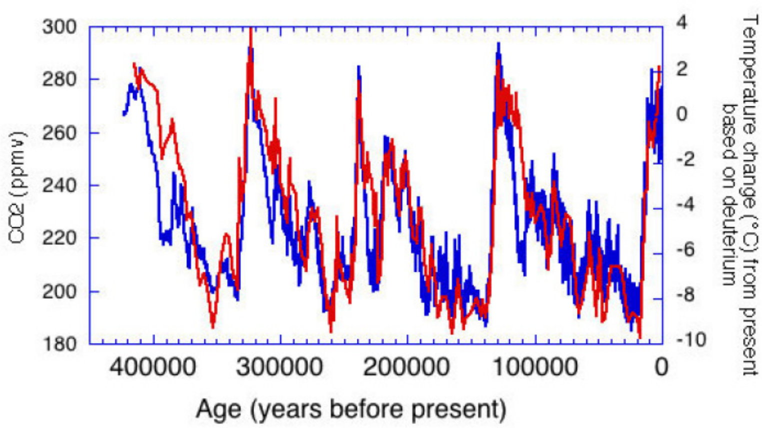
One of the most remarkable aspects of the paleoclimate record is the strong correspondence between temperature and the concentration of carbon dioxide in the atmosphere observed during the glacial cycles of the past several hundred thousand years. When the carbon dioxide concentration goes up, temperature goes up. When the carbon dioxide concentration goes down, temperature goes down. A small part of the correspondence is due to the relationship between temperature and the solubility of carbon dioxide in the surface ocean, but the majority of the correspondence is consistent with a feedback between carbon dioxide and climate. These changes are expected if the Earth is in radiative balance, and are consistent with the role of greenhouse gases in climate change. While it might seem simple to determine cause and effect between carbon dioxide and climate from which change occurs first, or from some other means, the determination of cause and effect remains exceedingly difficult. Furthermore, other changes are involved in the glacial climate, including altered vegetation, land surface characteristics, and ice-sheet extent.



Temperature change (blue) and carbon dioxide change (red) observed in ice core records Many other records are available

Taking these different influences into account, it is possible to determine how much the temperature decreased when carbon dioxide was reduced, and use this scaling (termed climate sensitivity) to determine how much temperature might increase as carbon dioxide increases. An estimate from the tropical ocean, far from the influence of ice sheets, indicates that the tropical ocean may warm 5°C for a doubling of carbon dioxide. The paleo data provide a valuable independent check on the sensitivity of climate models, and the 5°C value is consistent with many of the current coupled climate models.

Other paleo proxies help us understand the role of the oceans in past and future climate change. The ocean contains 60 times more carbon than the atmosphere, and as expected, the changes in carbon dioxide in the atmosphere were paralleled by changes in carbon in the ocean over the past several hundred thousand years. While the ocean changes much more slowly than the atmosphere, the ocean played an essential role in past variations in carbon dioxide, and will also play a role in the future over thousands of years.

Finally, the paleo data reveal that climate change is not just about temperature. As carbon dioxide has changed in the past, many other aspects of climate changed too. During glacial times, snow-lines were lower, continents were drier, and the tropical monsoons were weaker. Some of these changes may be independent, others tightly coupled to the changing level of carbon dioxide. Understanding which of these changes might occur in the future, and how large those changes might be, remains a topic of vigorous research. The Paleoclimatology Program exists to help scientists document these changes that have occurred in the past as one approach to understanding future climate change.

On to... "Abrupt Climate Change"
Back to... "Paleo Data Before 2000 Years Ago"

Footnote 64: http://gcmd.nasa.gov/records/GCMD_CDIAC_TRENDS_C13_CSIRO_GASLAB.html

Record Search Query:

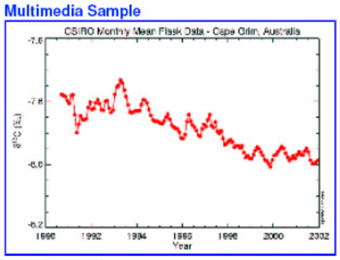
Atmospheric Carbon Isotope (C-13) Concentrations from the CSIRO GASLAB Flask Sampling Network, in CDIAC Online Trends
Entry ID: CDIAC_TRENDS_C13_CSIRO_GASLAB

[View Brief Record] [Get Data] [Update this Record]

Summary

Measurements have been made on air collected in flasks at the CSIRO GASLAB worldwide network. Flasks are filled with air at each site and returned to the CSIRO GASLAB for analysis. For stable isotope analysis, CO2 was extracted from the air in the flasks using an automated cryogenic trapping system. Prior to stable isotopic analysis, the concentrations ... Click to View Full Summary

Multimedia Sample



View full image
Caption: CSIRO Monthly Mean Flask Data from Cape Grim, Australia

Geographic Coverage

Spatial coordinates Click to view more

Data Set Citation
Dataset Creator: Allison, C.E., R.J. Francey and P.B. Krummel
Dataset Title: del-13C in CO2 from sites in the CSIRO Atmospheric Research GASLAB air sampling network

Dataset Series Name: Online Trends: A Compendium of Data on Global Change
Dataset Release Date: April 2003
Dataset Release Place: Oak Ridge, TN
Dataset Publisher: Carbon Dioxide Information Analysis Center (CDIAC)
Online Resource: http://cdiac.ornl.gov/trends/co2/allison-csiro/allcsiro_gaslab.html

Temporal Coverage
Start Date: 1991-06-01
Stop Date: 2001-12-31
Click to view more

Location Keywords
CONTINENT > NORTH AMERICA > CANADA > Alert, NWT

CONTINENT > NORTH AMERICA > CANADA > Estevan Point, BC
Click to view more

Data Resolution

Latitude Resolution: point
Longitude Resolution: point
Temporal Resolution: monthly

Science Keywords

ATMOSPHERE > ATMOSPHERIC CHEMISTRY > TRACE GASES/TRACE SPECIES
ATMOSPHERE > ATMOSPHERIC CHEMISTRY > CARBON AND HYDROCARBON COMPOUNDS > CARBON DIOXIDE > CARBON ISOTOPE

ISO Topic Category

CLIMATOLOGY/METEOROLOGY/ATMOSPHERE

Platform

GROUND STATIONS

Instrument

FLASKS
GAS CHROMATOGRAPHS

Access Constraints

None

Use Constraints

None

Ancillary Keywords

del-13 C
C-13
Click to view more

Data Set Progress

IN WORK

Originating Center

CDIAC

Data Center

Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, U. S. Department of Energy description
Data Center URL: http://cdiac.esd.ornl.gov/

Data Center Personnel

Name: CARBON DIOXIDE INFORMATION ANALYSIS CENTER
Phone: (865) 574-3645
Fax: (865) 574-2232
Email: CDIAC at ORNL.GOV
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Carbon Dioxide Information Analysis Center (CDIAC)
Oak Ridge National Laboratory
P.O.. Box 2008
City: OAK RIDGE
Province or State: TENNESSEE
Postal Code: 37831-6335
Country: USA

Distribution

Distribution Media: online WWW, ftp

Distribution Format: ASCII
Fees: None

Personnel

C. E. ALLISON
Role: INVESTIGATOR
Contact Address:
CSIRO Division of Atmospheric Research'
Private Bag No. 1
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Province or State: Victoria
Country: Australia
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Related URL

Link: GET DATA
Description: Access to documentation and C-13 data for Alert, NWT
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Publications/References

Allison, C. E., and R.J. Francey, 1995. High precision stable isotope measurements of atmospheric trace gases, In Reference and intercomparison materials for stable isotopes of light elements: proceedings of a consultants meeting, Vienna (IAEA-TECDOC-825). Vienna, Austria: International Atomic Energy Agency. p. 131-153.

Allison, C.E., R.J. ... **Click to view more**

Creation and Review Dates

DIF Creation Date: 2003-02-13
Last DIF Revision Date: 2003-10-23

- Reformat as FGDC document
- View Text Only Format

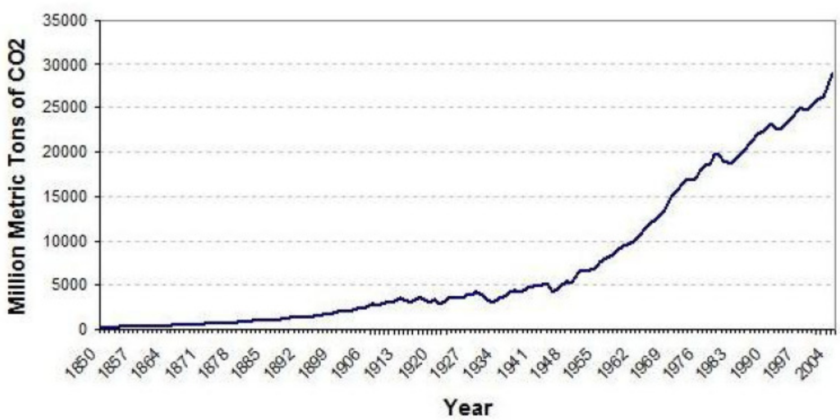
[View Brief Record] [Get Data] [Update this Record]

Footnote 68 & 69: (see Appendix B) http://www.pewclimate.org/facts-and-figures/international/historical

Historical Global CO2 Emissions

Greenhouse gas emissions, largely CO_2 from the combustion of fossil fuels, have risen dramatically since the start of the industrial revolution. Globally, energy-related CO_2 emissions have risen approximately 145-fold since 1850 - from 200 million tons to 29 billion tons a year.

Historical Global CO_2 Emissions* (1850-2004)



*from Fuel Burning, Cement Manufacture, and Gas Flaring
Source: Marland et. al (2007) Global, Regional, and National CO_2 Emissions. In Trends: A Compendium of Data on Global Change. CDIAC U.S.A.

Footnote 74: http://cdiac.ornl.gov/trends/emis/usa.html

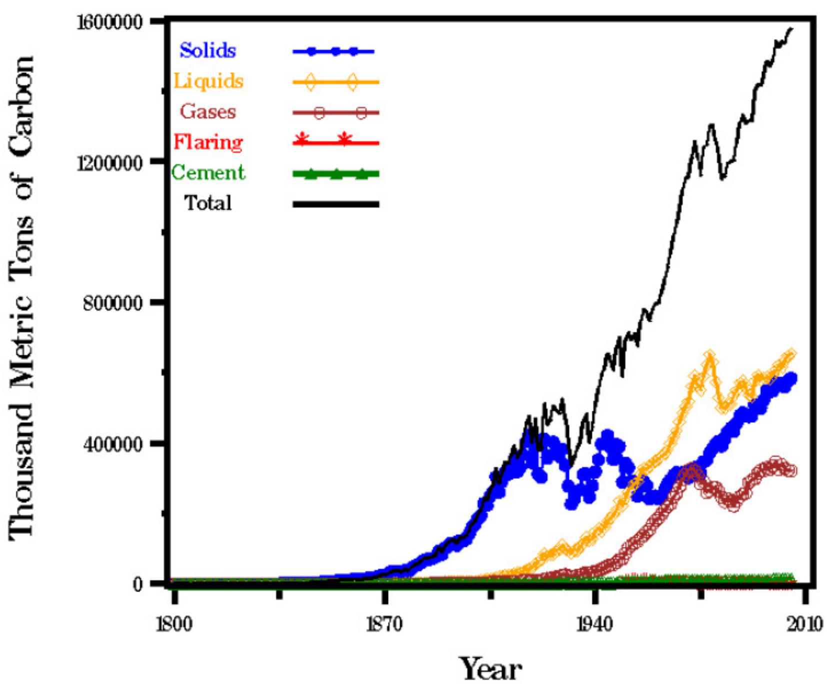
CDIAC
Carbon Dioxide Information Analysis Center
Oak Ridge National Laboratory
http://cdiac.ornl.gov

Fossil-Fuel CO_2 Emissions » Regional » North America » U.S.A. Graphics

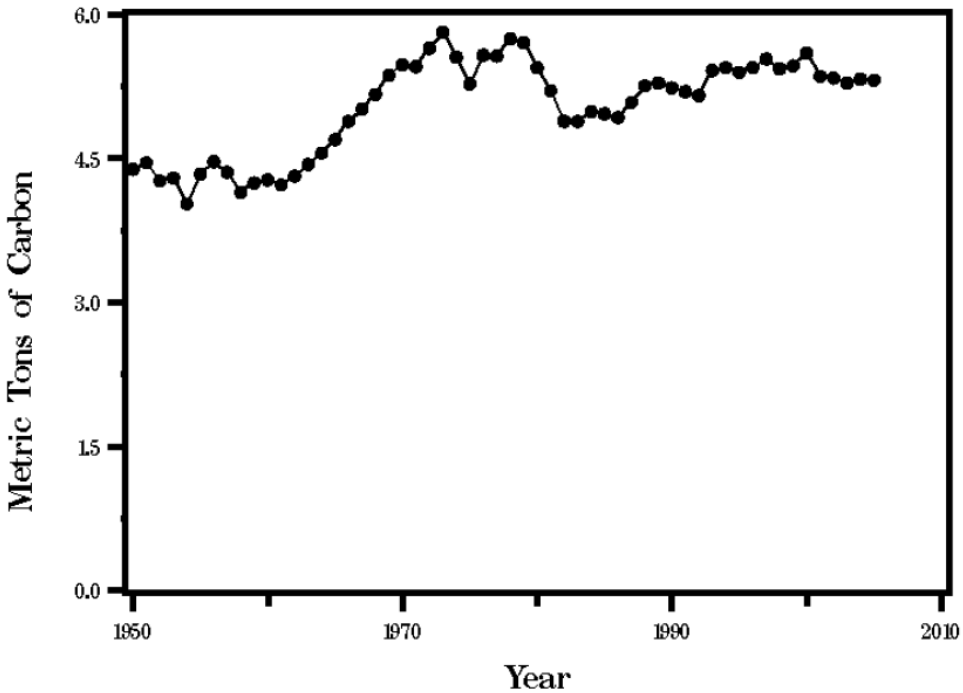
Fossil-Fuel CO_2 Emissions from the United States of America

Digital Data

CO_2 Emissions from the United States of America



Per capita CO_2 Emission Estimates for the United States of America


6.0
4.5
3.0
1.5
0.0
Metric Tons of Carbon
1950
1970
1990
2010
Year

Appendix C

Response to Agency Comments on March 2009 NorthMet Project Greenhouse Gas and Climate Change Evaluation Report

Comment #	Page	Paragraph/ Location	Comment	Proposed Response
			DNR COMMENTS	
1	2		The paragraph about solution concentrate is too specific for an introduction and needs a thorough explanation about solution concentrate to be helpful.	This discussion was removed from the introduction and placed in Appendix A.
2	3		The sentence "This possible increase is insignificant. Therefore, the NorthMet project is not expected to have any significant impact on the climate" should not be considered valid. It is inappropriate to say that the project GHG impact is insignificant based on a percent of total emissions. As climate change is due to global inputs, there would be few things that would rise to the level of a significant percentage of global emissions. If global total GHG emissions are forecast to be a problem, all GHG sources must be viewed as contributing to a significant impact.	All discussion of significance of impacts has been removed from the report.
3	6	all section 2.1.2	The focus should be on the general changes that are likely (e.g., precipitation, temperature). By titling this section 'Uncertainty', it gives the reader the false impression that little is agreed upon concerning climate change. Although details and timing may be uncertain, this is not the basis for the likely regulation of GHGs. It is agreed that these changes are likely, though location and extent are not agreed upon.	This section has been reorganized and a sub-section, Uncertainty in Climate Change Projection, has been placed towards the end of the discussion
4	48	1st paragraph	Report does not justify the assertion that flooded wetlands are a carbon source. It needs to be clarified whether the author means carbon, or whether the authors are converting other emissions (e.g., methane) to CO2 equivalents. Fair treatment to the uncertainty in predictions of carbon emissions from wetlands is needed. Recent work by Kenning and Cotner (abstract attached) indicates that shallow lakes reduce the effects of greenhouse warming even after methane is considered.	New information has been added to Section 2.2.5.1 about wetland carbon emissions. The assertion that flooded wetlands are a carbon source is based on the consideration of carbon equivalent fluxes of both CO2 and CH4 from wetland environments. As noted in the 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 CH4 yr-1 of the total of 0.50-0.54 Gt CH4 yr-1 (Fung et al., 1991). Using a Global Warming Potential (GWP) of 21 for CH4, emissions of ~1.7 g CH4 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 CH4 emissions from freshwater wetlands ranges from 7 to 40 g CH4 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)." The research noted by the commenter has been added to the uncertainty discussion. However, a detailed study of the intricacies of flooded wetland carbon dynamics goes beyond the scope of this evaluation.
5	49	middle	Carbon sequestration rates for wetlands do exist in the literature, particularly for peatlands. Rates that do exist should be summarized better.	The revised report attempts to qualitatively assess many of the terrestrial carbon cycle impacts, breaking down the various carbon storage and sequestration values for impacted wetlands and forests. Section 3.1.2 of the revised report present the findings of the analysis. Additionally, Chapter 10 and Attachment G of Appendix A go into more detail with regards to the calculations.
6	4	Appendix A	It is not possible to attribute a certain amount of temperature increase to the project's GHG emissions, due to complex interactions in modeling. This should not be considered valid.	This section has been removed from the report
7	22	Appendix A	There is no explanation why MN Power must be chosen as the energy supplier.	New information has been added to Chapter 7 of Appendix A regarding the inability of PolyMet to use another electricity provider. The crux of the issue is the mine and plant sites locations within the municipal boundaries of Babbitt and Hoyt Lakes, respectively. Statutory language makes it clear that they must use electricity from the municipality's provider.

Comment #	Page	Paragraph/ Location	Comment	Proposed Response
8	24	Appendix A	The stated inability of models to predict exact consequences of GHGs means that the calculation of PolyMet's emissions on climate is impossible to determine. Despite this, the report states the temperature increase attributable to the project on p. 4 of App A. The authors of the report need to be consistent in their statement of the limitations of modeling. If the models cannot predict the impact of a specific project, then the amount of warming caused by the project also cannot be calculated.	This section has been removed from the report
9	24	Appendix A	The focus on uncertainty in climate models is unproductive. Instead, the focus should be on what is agreed upon by the majority of scientists: that GHGs contribute to climate change. The authors could then proceed to put the proposed project's GHG emissions in context with global emissions.	Please see response to comment 3.
10	26, top of page	Appendix A	It is inappropriate to say that the project GHG impact is insignificant based on a percent of total emissions. As climate change is due to global inputs, there would be few things that would rise to the level of a significant percentage of global emissions. If global total GHG emissions are forecast to be a problem, all GHG sources must be viewed as contributing to a significant impact.	Please see response to comment 2.
11	27	Appendix A, formula at center of page	The citation for this is chapter 6 from the IPCC 4th assessment report. There are three working group reports comprising the overall assessment report on the IPCC web site, all with a chapter 6.	The citation now lists the IPCC 4th Assessment Report: Climate Change 2007 The Physical Science Basis (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, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.)
12	general		No assessment is made of the GHG emissions associated with destruction and disturbance of natural systems (e.g., wetlands), and their impact on reduction in carbon sequestration prior to their replacement. An estimate of this should be included.	Please see response to comment 5
			MPCA COMMENTS	
13		Section 2.2.5	Section 2.2.5, 'Cover Types and Carbon Cycle Impacts,' discusses the loss of 869 acres of wetlands and 611 acres of forestland as a result of the NorthMet Project. These systems are rich in organic carbon. It is possible that, upon land clearance, this carbon will be oxidized to CO_2 and emitted to the atmosphere. At least some of this carbon—the peatland carbon, has been in storage for thousands of years. In the *Evaluation Report* , no effort is made to evaluate these emissions. It is claimed that, since the project proposer has not yet decided on how this ecosystem carbon is to be disposed, these emissions cannot be evaluated. The project proposer should evaluate the land use emissions of the proposed project as a pulse emission in the initial year of the project. Average values for per acre carbon density are given in the text. These can be used to evaluate the emission consequences. Since the recovery times of the systems are long in relation to the project lifetime, no offset from wetlands mitigation during the projects lifetime need be considered. The text notes that the peatlands on the site have been formed only slowly over the last 5,000 years.	Please see response to comment 5

Comment #	Page	Paragraph/ Location	Comment	Proposed Response
14		Appendix A, Section 2.1	Section 2.1 of the 'Greenhouse Gas Emission Inventory and Energy and Efficiency Analysis' makes reference to wastewater treatment activities on-site. Industrial wastewater treatment is a source of CH_4 emissions to the atmosphere. No further mention is made of wastewater treatment in the text. If wastewater treatment at the NorthMet project is not a source of CH_4 emissions, this should be stated. If emissions are likely, they should be evaluated.	There will actually be two waste water treatment facilities. The one currently addressed in the report is the process water treatment facility at the Mine Site. There will also be a sanitary treatment plant onsite. At the Mine Site WWTF Water collected from mine pits and stockpiles will be treated prior to being pumped to the tailings basin adjacent to the process plant. CH4 emissions from the Waste Water Treatment Facility (WWTF) at the Mine Site are not expected because the process water will contain little or no organic carbon. The primary constituents of concern will be inorganic dissolved solids, including sulfate and metals. Carbon dioxide will be used for pH adjustment in the WWTF, but it will be injected in the form of pre-equilibrated carbonic acid, so off-gassing is expected to be minimal. A preliminary estimate of the daily CO2 usage rate is 4100 pounds. The existing sanitary treatment plant at the Plant Site will be replaced or upgraded to meet current construction and performance standards. Depending on the final configuration, a small amount of methane may be emitted from this operation. A footnote has been added to the discussion of Mine Site greenhouse gas sources in Appendix A to clarify why the process waste water treatment facility is not considered a greenhouse gas source.
15		Section 2.1.1.1	The long-rumored endangerment finding is set to be signed and made public on April 16, 2009. Under this finding, greenhouse gases will be declared pollutants under the Clean Air Act with uncertain regulatory implications. Since construction on this project is set to begin long after the issuance of the endangerment finding, the project proposer should be prepared to amend the *NorthMet Project Greenhouse Gas and Climate Change Evaluation Report* to reflect the changing regulatory status of greenhouse gases.	The end of Section 2.1.1.1 is devoted to a discussion of the endangerment finding and the current and future policy implications.
16		Section 3.0	The 'Greenhouse Gas Emission Inventory and Energy and Efficiency Analysis' does not address alternatives that might lead to a reduced project emission profile. The Report addresses only alternatives that might lead to enhanced GHG emissions. Under the MPCA Guidance document, the efficiency report is intended to elicit information on how the proposed project might have been designed for lower GHG emissions and why, knowing that options were available to lower emissions, the project proposers chose not to pursue them. Under the Guidance Document, reasons for not pursuing enhanced levels of control might be: technical infeasibility, economic cost, and contractual and regulatory constraints. It seems possible that, in the project design, the proposers have chosen the optimal design for the facility beyond which no GHG emission reductions are possible. This is not likely, but it is possible. The consultant, however, makes no effort to demonstrate that this is in fact the case. One way to show that this situation holds would an exhaustive review of the list of all possible energy-end use technologies and plant configurations. While the consultant did review the energy-use technologies and the plant configuration that were proposed, it did not review the larger universe of end-use technologies that is available. Because of this, the reader has no way to know to evaluate the implicit claim of the consultant that the proposed set of technologies and plant configurations represent most optimal set of technologies and plant configurations. A greater effort on the part of the consultant to 'shows its work' would be helpful. What alternative technologies were reviewed? Is this a categorical list? What were the results and with what documentation? As it is written, the little review of those measures that were reviewed (pages 16-19) is cursory and nonquantitative.	Section 6.0 of Appendix A includes some potential alternatives to the proposed project design and why they were not adopted. Additional discussion of electrical efficiency is also now inlcuded in Section 5.0 of Appendix A.

Comment #	Page	Paragraph/ Location	Comment	Proposed Response
17		Section 4.1	The document does note that the use of waste heat from the proposed project's autoclaves for space heating would lower GHG emissions. The project proposer chose not to quantitatively assess those emission reductions because, the document notes, that project is still in a preliminary planning and no decisions on waste heat utilization have been made. This seems to run directly counter the MPCA guidance memorandum, which is looking for analysis of exactly this type, e.g., analysis of the emissions consequences of measures not taken that might reduce emissions.	The use of waste heat to heat the hydrometallurgical plant buildings is not longer being considered due to concerns over possible changes to the water balance. This discussion will be removed from the report.
18		Appendix A Section 7.0	Most emissions are associated with the generation of purchased electricity. The consultant did not consider the possibility that the facility owner/operator might procure power from a source other than Minnesota Power. According to the consultant, 'physical limitations'preclude power purchases from another source. Nothing more was offered by way of explanation or documentation. There is no way of knowing of what these physical limitations consist or how long they should be assumed to persist. Since almost three-quarters of all direct and indirect facility emissions are tied to these purchases, much more obviously is needed from the consultant than what the consultant has supplied. We need to understand the nature of these 'physical limitation.' If power purchases from other power providers are not possible because of these limitations, the consultant should work systematically through the list of potential power providers, demonstrating in each case the source of the insurmountable physical limitation and how and at what cost it might be overcome. The range of possible alternative power sources that may be open to the project owner/operators includes: Manitoba Hydroelectric, Ontario Hydroelectric, Great River Energy, Silver Bay Power Co., Sappi-Cloquet paper pulpmill, Ainsworth-Bemidji OSB mill, and Excel Energy. Some consideration also should be given to the possibility that green power purchases from Minnesota Power and Excel Energy might constitute a way to minimize emissions associated with the generation of purchased power.	Please see response to comment 7

Comment #	Page	Paragraph/ Location	Comment	Proposed Response
19		Appendix A, Page 13-14	Finally, much weight is placed on a comparison of emissions at the proposed facility and emissions at European facilities. The discussion is muddled. Upon sorting through the competing claims in the text, the facts seem to be the following: • treating only process emissions, the emission intensity of the NorthMet facility is worse than the Finnish facility cited and the set of European facilities cited by the USGS, but better than the one Swedish facility cited (Table 4, pages 13-14, Appendix A and text on page 13, Appendix A) • the comparison offered in Table 4 treats emissions from both fuel use and industrial processes, or the sum total of all emissions; for our purposes, this is the quantity in which we are interested and offers the best means to compare competing processes. • while it is asserted in the text that the NorthMet project would have a lower emission intensity once front-end emissions associated with mining, crushing and transport are considered (page 14, Appendix A), no analysis is offered of the effect on this emission intensity parameter of adding in front-end emissions associated with mining, crushing and transport. This appears to be an instance where the consultant needs to show its work. It is possible that, in fact, the emission intensity of the NorthMet facility will be lower than those for competing facilities once front-end emissions associated with mining, crushing and transport are considered. However, this is not rigorously demonstrated; it is only asserted. Since this is the linch-pin in the argument that the project proposer has chosen the lowest emitting plant configuration possible, the consultant needs to do more on this topic. If not, the discussion might best be delete din its entirety.	The presentation of the smelter comparision along with the discussion of the results has been modified to better reflect reasonsable conclusions that can be drawn from the available information. Sufficient data were not available to compare indirect plus direct emissions from smelting and hydrometallurgical processes, so the comparision continues to focus on direct emissions along with a general discussion of overall energy usage in both types of processes.
20		Calculations	PolyMet used an incorrect CO2 emission factor (13,617 kg CO2/thousand gallon of liquid fuel) for propane/LPG combustion in its spreadsheet file, cell M12 of "GHGs Mine Site" tab, and cells M45 and M48 of "GHGs Plant" tab. The correct value, taken from the Climate Registry General Reporting Protocol (Version 1.1) Table 12.1, is 5,740 kg CO2/thousand gallon of liquid fuel. The MPCA general guidance for carbon footprint development in environmental review (July 2008) will be revised/updated to correct, among other things, the wrong values of 15.01 tons CO2/thousand gallon of LPG and 348.19 lb CO2/million Btu of LPG.	This will be corrected in the final version of the GHG inventory.
21		Calculations	For "GHGs Plant" tab, there are three old LTV zinc pots (#1, #2, and #3). Cell M40 gives the CH4 emission factor for Zinc Pot #1, 3*104/1000 = 0.42 kg CH4/thousand gallon of fuel oil. I wonder what would happens, if the N2O emission factor, 0.3*140/1000 = 0.042 kg N2O/thousand gallon of fuel oil, is applied to all three zinc pots.	Zinc pot N2O emission calculations will be added in the final version of the GHG inventory using an emission factor of 0.3 g N2O/MMBtu for Residula Fuel Oil Boilers from Table 12.7 of TCR GRP (converted to to kg/thousand gallsons of fuel oil as follows: 0.3*140/1000 = 0.042 kg N2O/thousand gallon of fuel oil. This comes out to approximately a maximum additional 0.13 metric tons CO2-equivalent per year from each zinc pot or a projected actual additional 1.32 metric tons CO2-equivalent per year from each zinc pot.