Report No. CSS05-07

April 8, 2005

Center for Sustainable Systems
University of Michigan

Michigan Greenhouse Gas Inventory 1990 and 2002

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Prepared for

Michigan Department of Environmental Quality

April 2005

Report No. CSS05-07

Document Description

MICHIGAN GREENHOUSE GAS INVENTORY 1990 AND 2002

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Center for Sustainable Systems, Report No. CSS05-07, University of Michigan, Ann Arbor, Michigan, April 8, 2005.
128 pp., tables, figures, 11 appendices

This document is available online: http://css.snre.umich.edu

A project submitted in partial fulfillment of the requirements for the degree of Master of Science (Natural Resources and Environment) at the University of Michigan

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PROJECT FUNDING

This project was made possible through grants provided by these organizations:
Energy Foundation
DTE Energy Foundation
Center for Sustainable Systems
State of Michigan, Pollution Prevention Retired Engineer Technical Assistance Program (RETAP)
Student Internship Program
Education Foundation of America

ACKNOWLEDGEMENTS

Michigan Department of Environmental Quality:
David Mason, Environmental Quality Analyst, Modeling and Meteorology Unit, Air Quality Division

U.S. EPA :
Andrea Denny, Environmental Protection Specialist, State & Local Capacity Building Branch

Michigan Environmental Council:
David Gard, Energy Policy Specialist

Center for Sustainable Systems:
Helaine Hunscher, Center for Sustainable Systems Program Coordinator

Acknowledgements
Dr. David Ellsworth, Assistant Professor of Plant Ecophysiology, U-M School of Natural Resources and Environment

Abstract

Global climate change is said to be the greatest forthcoming human-environmental problem of the 21st Century. This report is the first greenhouse gas emissions inventory developed for the State of Michigan, providing estimates of the emissions of the most important anthropogenic greenhouse gases (carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, perfluorocarbons and hydrofluorocarbons) in the years 1990 and 2002.

This inventory was developed in accordance with methodologies outlined by the U.S. EPA's State and Local Capacity Building Branch and the Emission Inventory Improvement Program (EIIP). The State Greenhouse Gas Inventory Tool (SIT) was used to calculate emissions for these gases from energy related activities (stationary and mobile combustion of fossil fuels and fugitive emissions), industrial processes (non-energy related activities), agricultural activities, land-use change (carbon sequestration resulting from land-use change, excluding forestry) and waste (solid waste and wastewater management activities).

Our results indicate that the total Michigan greenhouse gas emissions increased nine percent from 57.42 million metric tons carbon equivalent (MMTCE) in 1990 to 62.59 MMTCE in 2002. This increase was largely driven by an absolute gain in CO_2 emissions from transportation. Overall, CO_2 from fossil fuel combustion was responsible for over 85 percent of the total for both years. The largest contributor to the overall emissions was the electricity generation sector (33 percent of the total emissions in 2002), followed by the transportation sector (26 percent of the total emissions in 2002). Per capita emissions were 6.23 MTCE in 2002. This inventory serves as a resource for government, the public and business in the state to assist in developing policies and implementing strategies to reduce greenhouse gas emissions.

Table of Contents

Executive Summary

This report is the first greenhouse gas emissions inventory developed for the State of Michigan. Activities generating greenhouse gas emissions are compared to establish an emissions baseline and reveal trends across economic sectors within the state. The inventory highlights major sources of emissions by sector and by greenhouse gas for 1990 and 2002.

Global climate change is said to be the greatest forthcoming human-environmental problem of the 21st Century. Greenhouse gas emissions resulting from anthropogenic activities over the past two centuries have led to an accelerating build-up of heat-trapping gases in the atmosphere. With greater heat energy in the atmosphere, dramatic changes are likely in the coming decades concerning the earth's global climate, sea level and sea ice, and the ocean thermohaline system. According to the leading international consortium of climate scientists, the Intergovernmental Panel on Climate Change (IPCC), "We have clear evidence that human activities have affected concentrations, distributions and life cycles of these gases."[i] Expected climate changes in Michigan over the next century will likely show warmer average temperatures with longer periods of drought, most notably during the summer. The growing season is likely to extend by as much as ten weeks. Of significant cultural and economic concern to Michigan are the Great Lakes. It is estimated that the water levels of the Lakes will continue to decline, which could potentially be very costly to Michigan's fishing, tourism, and shipping industries.[ii]

The United States is the world's largest emitter of greenhouse gases, responsible for nearly one-quarter of all greenhouse gas emissions worldwide. Absent federal leadership on confronting global climate change, the task of reducing greenhouse gas emissions in the United States is left to individual states. A greenhouse gas inventory for Michigan is a necessary first step for the state in developing a meaningful plan to address global climate change.

[i] IPCC (2001) Climate Change 2001: A Scientific Basis, Intergovernmental Panel on Climate Change, Organization for Economic Cooperation and Development, International Energy Agency. Houghton, et al. Cambridge University Press. Cambridge, U.K. Retrieved from: http://www.ipcc.ch/present/graphics/2001syr/large/05.16.jpg

[ii] Union of Concerned Scientists (2003) *Confronting Climate Change in the Great Lakes Region*. Retrieved from: http://www.ucsusa.org/greatlakes/pdf/confronting_climate_change_in_the_great_lakes.pdf

Methodology

This inventory report provides estimates of anthropogenic greenhouse gas emission sources and sinks in the State of Michigan in the years 1990 and 2002. It considers the most important anthropogenic greenhouse gases, which include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs). These gases have a wide range of relative radiative forcing effects[iii] once they are emitted to the earth's atmosphere. Using CO_2 as the standard unit, the other greenhouse gases measured in this inventory have relative radiative forcing coefficients ranging from twenty-one for CH_4 to over three hundred for N_2O to as high as twenty-four thousand for SF_6 when compared to an equivalent amount of carbon dioxide. For accounting purposes, all gases were converted to the common metric known as the carbon equivalent.

Data were acquired in accordance with methodologies outlined by the U.S. EPA's State and Local Capacity Building Branch and the Emission Inventory Improvement Program (EIIP). The inventory research team employed the use of a Microsoft Excel spreadsheet-based emissions calculation tool, the State Greenhouse Gas Inventory Tool (SIT),[iv] as a means to organize collected data and thoroughly check the accuracy of the data. The SIT is divided into ten source-specific modules and includes a "synthesis module", which is used to compile emissions estimates from the individual modules.

The State of Michigan Greenhouse Gas Inventory report is organized around the basic format identified by the IPCC.[v] This framework groups source and sink categories into the following five sectors:

- **Energy** (Chapter 3): Total emissions from stationary and mobile energy activities.
- **Industrial Processes** (Chapter 4): Emissions from industrial processes, which are not associated with fuel combustion for energy.
- **Agriculture** (Chapter 5): Emissions from agricultural activities.
- **Land-Use Change** (Chapter 6): Emissions and sequestration of CO_2 resulting from land-use change, excluding forestry (addressed in Appendix I).
- **Waste** (Chapter 7): Emissions from solid waste and wastewater management activities.

[iii] Radiative forcing can be thought of as 'heat-trapping ability' of a particular greenhouse gas.
[iv] U.S. EPA, ICF Consulting (2004) State Greenhouse Gas Inventory Tool (8/3/2004 Version) [Computer software]. Washington, DC: U.S. EPA State and Local Climate Change Program
[v] IPCC (1997) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reporting Instructions.* Intergovernmental Panel on Climate Change, Organization for Economic Cooperation and Development, International Energy Agency.

Key Limitations

- **The majority of emissions calculations** relied on a combination of data specific to Michigan and data approximated from national data and trends. Key assumptions are defined in the report text and discussed in further detail in the Appendices. The accuracy of future greenhouse gas inventories could be improved by developing Michigan-specific data sources instead of relying on national data and trends.

- **Since 1999, Michigan has imported roughly 10 percent** of the electricity it consumes annually. It was not possible to calculate with certainty the emissions from imported electricity for 2002 because an accurate figure was not yet available. An estimate was made, however, but was not included in the baseline inventory due to its uncertainty.

- **Carbon sequestration** by land use activities is included in this report; however, forest activities were not included in the inventory results due to large uncertainties. A discussion of this issue is provided in Appendix I.

Key Findings

- **Total Michigan greenhouse gas emissions** amounted to 62.59 million metric tons carbon equivalent (MMTCE) in 2002 (Table ES-1). This represented an increase of 9.0 percent over the 1990 emissions baseline of 57.42 MMTCE.

- **The largest contributor to total emissions** in 2002 and 1990 was the electricity generation sector. Electricity generation accounted for 33 percent of total emissions in 2002 and 1990 (Figure ES-1). The second largest contributor for both years was the transportation sector. In 2002, industry contributed 17 percent to total emissions, a slight decline from a 19 percent contribution in 1990.

- **Michigan greenhouse gas emissions** were dominated by CO_2 in both 2002 and 1990 (Figure ES-2). Emissions of high global warming potential gases (SF_6, HFCs, and PFCs) were two percent of total emissions in 2002, an increase from the 1990 value of 0.5 percent. The contribution of these gases is expected to continuously increase in the coming decade.

Table ES-1: Summary of Michigan Greenhouse Gas Emissions and Sinks (excluding forestry) (MMTCE)

Gas / Activity	1990	2002
CO_2	**49.58**	**54.15**
Fossil Fuel Combustion	48.33	52.06
Iron and Steel Production	0.68	1.10
Cement Manufacture	0.62	0.58
Lime Manufacture	0.12	0.18
Waste Combustion	0.05	0.17
Limestone and Dolomite Use	0.04	0.03
Soda Ash Consumption	0.02	0.03
Landfilled Yard Trimmings	*(0.35)*	*(0.11)*
CH_4	**5.16**	**5.18**
Landfills	3.22	3.06
Natural Gas Systems	0.98	1.30
Enteric Fermentation	0.41	0.36
Wastewater Treatment	0.19	0.18
Manure Management	0.15	0.15
Stationary Sources [vi]	0.09	0.06
Mobile Sources	0.05	0.04
Petroleum Systems	0.04	0.02
Iron and Steel Production	0.02	0.02
Agricultural Residue Burning	0.00	0.00
N_2O	**2.12**	**2.13**
Agricultural Soil Management	1.24	1.27
Mobile Sources	0.50	0.48
Human Sewage	0.14	0.16
Stationary Sources	0.13	0.12
Manure Management	0.10	0.08
Agricultural Residue Burning	0.00	0.00
Waste Combustion	0.00	0.00
HFCs, PFCs, and SF_6	**0.30**	**1.13**
Electrical Transmission and Distribution	0.24	0.12
Magnesium Processing	0.05	0.14
Substitution of Ozone Depleting Substances	0.00	0.87
Semiconductor Manufacture	0.00	0.00
TOTAL	**57.42**	**62.59**
NET EMISSIONS (Sources and Sinks)	**57.07**	**62.48**

[vi] This category represents CH_4 emissions from fuel combustion activities.

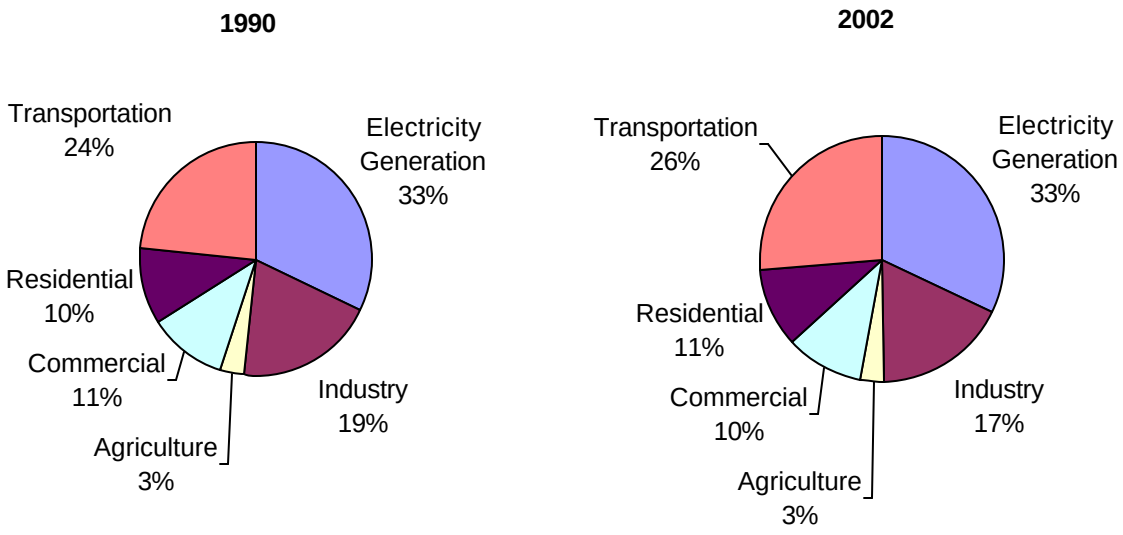


Figure ES-1: Distribution of Michigan Greenhouse Gas Emissions by Economic Sector

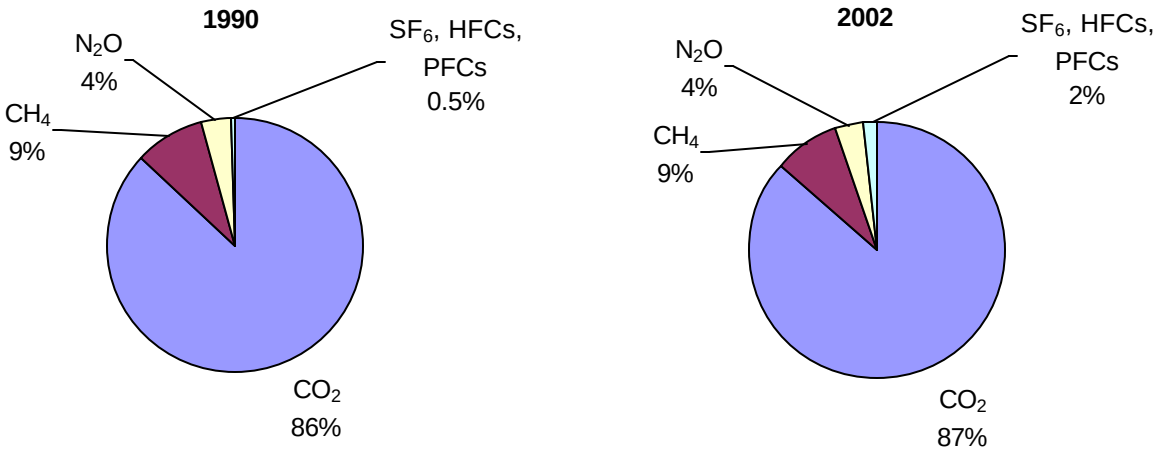


Figure ES-2: Distribution of Michigan Greenhouse Gas Emissions by Gas Type

- **Michigan greenhouse gas emissions per capita** increased from 6.17 MTCE in 1990 to 6.23 MTCE in 2002. As a point of reference, the national average was 6.57 MTCE per capita in 2002; however, this figure represents a more comprehensive inventory of emissions than estimates on the state level (please refer to Key Limitations).

- **Michigan greenhouse gas emissions intensity** was nearly equal to the national greenhouse gas emissions intensity of 0.19 kg carbon equivalent per dollar gross state product in 2002. Overall, Michigan emissions intensity has decreased 24.5 percent from 1990 to 2002. In 1990 the emissions intensity of Michigan was 0.24 kg carbon equivalent per dollar gross state product.

- **Michigan greenhouse gas emissions accounted** for 3.3 percent of total U.S. greenhouse gas emissions in 2002 and 3.4 percent of total U.S. greenhouse gas emissions in 1990.

Conclusions

This inventory was developed as a resource for government, the public, and businesses in the state to assist in developing policies and implementing strategies to reduce greenhouse gas emissions. Our results show that Michigan had a 9.0 percent increase in greenhouse gas emissions between 1990 and 2002 (Table ES-1). Understanding the differences in emissions between these two years is complex due to simultaneous changes in economic activity and the technology mix that affects carbon intensity. A major portion of this report disaggregates emissions into economic-delineated categories to allow for more in-depth analysis of emission trends over this twelve-year period.

Table ES-1 shows that emissions of CO_2 from fossil fuel combustion dominated all other categories, responsible for over 85 percent of the state's total. Within the category of CO_2 emissions from fossil fuel combustion, electricity production made up the largest percentage for both 1990 and 2002. Mobile combustion of fossil fuels made up the largest absolute gain in emissions over this period. The growing prevalence of lower fuel-efficient vehicles such as sport-utility vehicles and light-duty trucks along with an increasing rate of vehicle miles traveled per capita likely explains much of the rise in emissions from mobile combustion. Industry showed the largest absolute decline in emissions, which likely reflects energy efficiency and carbon intensity improvements in some industries.

The category that exhibited the largest percentage gain in emissions was from industrial manufacture of substitute chemicals of Ozone Depleting Substances (ODS). Even though emissions from industrial output accounted for less than

two percent of the state's total emissions, these ODS substitutes have very high individual global warming potentials. Unless a set of non-ODS substitutes are found with benign global warming potentials, then it is expected that emissions from ODS substitutes will continue to rise.

CH_4 emissions from landfill solid waste was the highest non-CO_2, non-fossil fuel based emission category. Despite a 40 percent increase in landfill waste from 1990 to 2002, the emissions of CH_4 from Michigan solid waste actually showed a slight decrease over this time period. Viewed as a win-win action toward mitigating Michigan solid waste emissions, the increase in landfill gas flaring and landfill gas-to-energy projects (recognized as a source of green power) have proven to be an economically profitable method to reduce the environmental burden associated with the release of landfill CH_4.

Land use activities and forestry practices also have significant potential as an offset of carbon emissions in the state. Results from the forestry sector were not included in this inventory due to uncertainty surrounding accounting methods and estimates of carbon sequestration rates by forestry activities.

Despite the lack of national policy to address greenhouse gas emissions and climate change to this point, state and local governments have stepped up efforts to take action to reduce emissions. It is important to consider that most climate scientists think that the emissions reductions called for by the Kyoto Protocol will not be enough to prevent a significant rise in global temperature. The Protocol calls for a reduction of 7 percent reduction of U.S. greenhouse gas emissions by 2012, yet climate models show that a 50 percent reduction in global emissions from current levels is required to stabilize the global CO_2 concentration in the atmosphere.[vii] Results from this report should foster the logical next step to formulate a state-level greenhouse gas reduction plan. As of May 2004, 29 states had developed State Action Plans specifically targeting greenhouse gas emissions reductions.[viii] Such a plan could simultaneously move Michigan toward a cleaner, more secure energy infrastructure and contribute towards mitigating greenhouse gas emissions on a global scale. Additionally, a strong economic argument can be made for the state to confront greenhouse gas emissions today as a hedge against the likelihood of future national and international policies that could impact some of Michigan's most vital industries.

[vii] IPCC (2001) *Climate Change 2001: Mitigation,* Intergovernmental Panel on Climate Change, Organization for Economic Cooperation and Development, International Energy Agency. Edited by Bob Metz *et al*. Cambridge University Press. Cambridge, U.K.

[viii] U.S. EPA (2004) *State Action Plans* Retrieved Jan. 2005 from http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ActionsStateActionPlans.html

1. Introduction

This inventory report provides estimates of anthropogenic greenhouse gas emission sources and sinks in the State of Michigan from the years 1990 and 2002. The inventory was conducted in accordance with methods and reporting standards established by the U.S. Environmental Protection Agency. The U.S. EPA has adopted the guidelines set forth by the internationally recognized Intergovernmental Panel on Climate Change (IPCC) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, as well as the *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*.

State of Michigan greenhouse gas emissions estimates are reported in the following ways:

Statewide: Estimates of total emissions for the entire State of Michigan

IPCC-Delineated Sectors: Emission estimates from five sectors – energy, industrial processes, agriculture, forestry, and waste. Each of these sectors is further categorized into smaller source categories that served as organizing units for data collection purposes.

Economic-Delineated Sectors: Emissions estimates categorized by electricity generation, agriculture, commercial, industry, residential, transportation, and land-use change and forestry.

By Greenhouse Gas Type: Six major greenhouse gas emissions are required by the 1992 United Nations Framework on Climate Change (NFCCC) Agreement to be included in national emissions inventories: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6).

Temporal Scale: The report presents emission estimates from 1990 and 2002.

1.1 Global Climate Change and the Role of Greenhouse Gases

According to the National Academy of Sciences, climate can be described as:

> …the average state of the atmosphere and the underlying land or water, on time scales of seasons or longer. Climate is typically described by the statistics of a set of atmospheric and surface variables such as temperature, precipitation, wind, humidity, cloudiness, soil moisture, sea surface temperature, and the concentration and thickness of sea ice.[1]

Naturally occurring greenhouse gases include water vapor, CO_2, CH_4, and N_2O. Excluding water vapor, the combined greenhouse gases make up less than one percent of the chemical composition of the Earth's atmosphere. These gases are vital for life systems on Earth because they absorb and re-emit the infrared radiation (felt as heat) that the Earth emits as a result of radiative heating by the sun. Without greenhouse gases in the atmosphere, the Earth's temperatures during nighttime hours would drop below a level that would allow for survival of terrestrial life[2] (Figure 1-1).

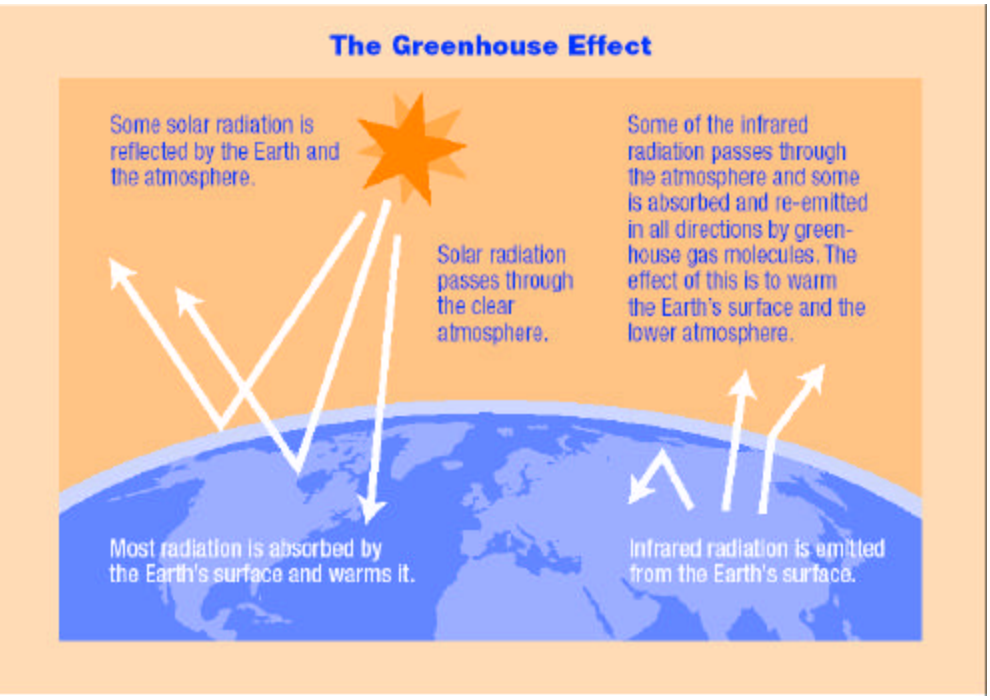


Figure 1-1: Radiation and heat flows of the greenhouse gas effect.[3]

The current problem involving global climate change and greenhouse gases can be described as the "enhanced greenhouse gas effect" where due to the increased concentrations of CO_2, N_2O, CH_4, and other greenhouse gases, more heat is retained in the atmosphere. With greater heat energy in the atmosphere, dramatic changes are likely in the coming decades concerning the earth's global climate and oceanic circulation system. According to the IPCC, "we have clear evidence that human activities have affected concentrations, distributions and life cycles of these gases".[4] Figure 1-2 links CO_2 concentration in the atmosphere to projected changes in global average temperature and sea level rise along with corresponding time horizons involved with each event. Despite potentially long feedback times of global temperature and sea level rise, the magnitude of these environmental responses at a planetary scale will likely be enormous.

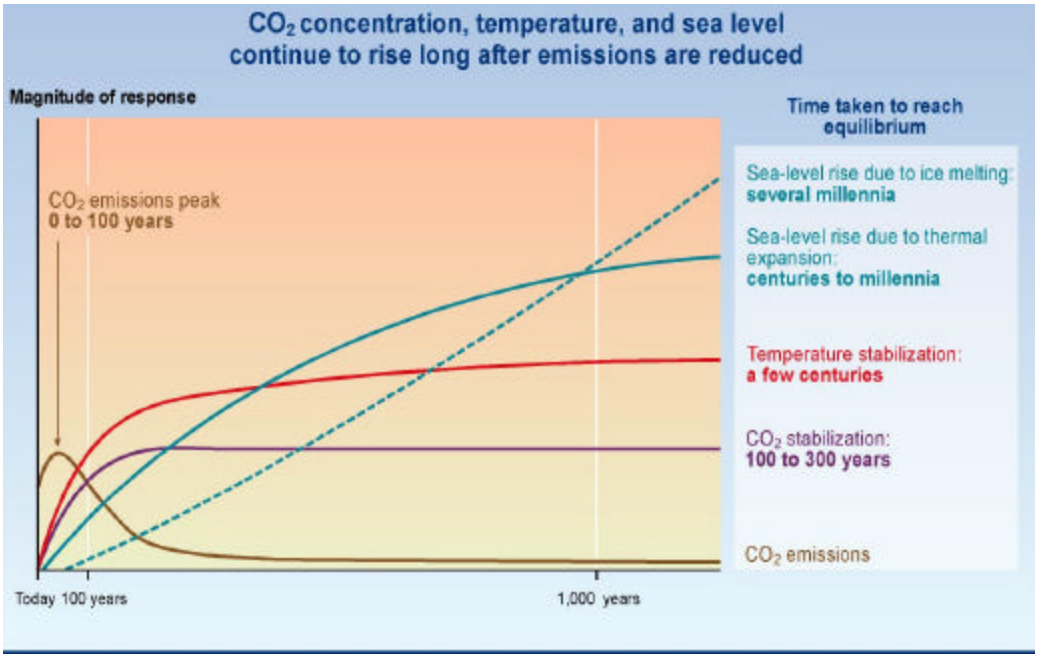


Figure 1-2: Future Time Horizons Associated with IPCC Projected Changes in Climate Temperature, Sea-level Rise, and CO_2 Stabilization.[5]

Expected climate changes in Michigan over the next century will likely show warmer average temperatures with longer periods of drought, most notably during the summer. The growing season is likely to extend by as much as ten weeks. Of significant cultural and economic concern to Michigan are the Great Lakes. It is estimated that the water levels of the Lakes will continue to decline, which could potentially be very costly to Michigan's fishing, tourism, and shipping industries.[6]

1.2 Greenhouse Gases Inventoried

For accounting purposes, all gases were converted to the common metric known as the carbon equivalent. The second column of Table 1-1, "100-year GWP" shows the coefficient values used to convert non-CO_2 gases to a carbon equivalent.[i] This report uses the international metric scale and commonly refers to carbon equivalents as million metric tons of carbon equivalent (MMTCE).

For this report, the carbon equivalent weights factored into each type of greenhouse gas were acquired from the IPCC Second Assessment Report (SAR). In 2001, the IPCC released an updated version of carbon equivalent weights in its Third Assessment Report (TAR) that adjusted for the radiative forcing of a number of greenhouse gases including carbon dioxide, which was lowered by twelve percent from SAR values. Using the SAR values is consistent with the U.S. EPA greenhouse gas reporting measures.

Each of the gases listed below are accounted for in this report.

Carbon dioxide (CO_2): Atmospheric CO_2 is part of the global carbon cycle and its concentration represents a steady state of dynamic flows that occur from natural biogeochemical processes. Since the industrial revolution of the 19th Century, global concentration of carbon dioxide has increased from 280 parts per million (ppm) in pre-industrial times to 372.3 ppm in 2001, representing a 33 percent increase. The IPCC has attributed this increase almost entirely to anthropogenic emissions as a result of combustion of fossil fuels and other sources including forest clearing, burning of biomass, and production of cement.

Methane (CH_4): Naturally occurring CH_4 emissions to the atmosphere result from the anaerobic decomposition of organic matter in biological systems. Agricultural processes in Michigan that contribute to CH_4 emissions include enteric fermentation in domesticated animals, manure management, decomposition of municipal solid wastes, fugitive emissions from natural gas and petroleum production and distribution, and a small amount from incomplete combustion of fossil fuels. IPCC estimates that over half the amount of total current CH_4 in the atmosphere is from human activities. Pre-industrial atmospheric concentration of CH_4 was at 0.722 ppm and has increased nearly 150 percent to 1.786 ppm.

[i] Referred to as the "global warming potential" (GWP), non-CO_2 gases are assigned a coefficient multiplier value to reflect the differences in radiative forcing of each type of greenhouse gas over a 100-year period. Radiative forcing refers to the magnitude of heat energy capture specific to each of the atmospheric greenhouse gases.

Nitrous oxide (N_2O): Nitrous oxide emissions from anthropogenic activities in Michigan include agricultural soils (which encompasses production of nitrogen-fixing crops and forages, the use of synthetic and manure fertilizers, and manure deposition of livestock), fossil fuel combustion (namely mobile combustion sources), wastewater treatment, waste combustion, and burning of biomass. Atmospheric concentration of N_2O has increased 17.8 percent from 0.27 ppm pre-industrial time to 0.318 ppm in 2002.

Halocarbons (HFCs), Perfluorocarbons (PFCs), and Sulfur hexafluoride (SF_6): Each of these potent greenhouse gases is man-made and emitted directly to the atmosphere from various anthropogenic activities chiefly from industrial processes. HFCs are used to replace the ozone-depleting CFCs and HCFCs phased out under the 1992 Montreal Protocol. PFCs and SF_6 currently contribute only a small portion of the total greenhouse gases emitted; however, the emissions growth rate of these compounds continues to accelerate. These gases are emitted in Michigan through the substitution of ozone depleting substances and through industrial processes that include semiconductor manufacturing, electric power transmission and distribution, and magnesium casting.

Table 1-1: Global Warming Potentials and Atmospheric Concentrations of Inventoried Greenhouse Gases (SAR Equivalents).[7]

Gas	100-Year GWP	Atmospheric Concentration (ppm)		Percent Change
		Pre-Industrial	Current	
CO_2	1	280	372.3	33.0%
CH_4	21	0.722	1.786	147.4%
N_2O	310	0.27	0.318	17.8%
HFC-23	11,700			
HFC-32	650			
HFC-125	2,800			
HFC-134a	1,300			
HFC-143a	3,800			
HFC-152a	140			
HFC-227ea	2,900			
HFC-236fa	6,300			
HFC-4310mee	1,300			
CF_4	6,500	40	80	100.0%
C_2F_6	9,200			
C_4F_{10}	7,000			
C_6F_{14}	7,400			
SF_6	23,900	0	4.75	

1.3 State-level Greenhouse Gas Inventories

In 1997 the international community assembled in Kyoto, Japan and formed the Kyoto Protocol as a policy mechanism aimed at reducing projected greenhouse gas emissions from developed nations. The international proposal set a target goal for the U.S. to reduce national greenhouse gas emissions by 7 percent of 1990 levels by year 2012.[8] Despite the United States' formal participation during the Protocol's negotiation and writing phase, in 2001 the Bush Administration made the decision to nullify congressional consideration regarding U.S. ratification of the Protocol by denying Congress the ability to carry out a formal voting procedure on the matter. Despite the lack of national policy confronting greenhouse gas emissions and climate change, state and local governments have stepped up efforts to take action to reduce emissions. As of May 2004, 29 states also have State Action Plans specifically targeting greenhouse gas emissions reductions.[9]

To date, 40 states and Puerto Rico have completed greenhouse gas inventories using the guidance and resources provided by the U.S. EPA (Figure 1-3). (Note that West Virginia has since completed a state-level inventory in 2004). State-level inventories identify major emissions sources and provide a baseline for states to create greenhouse gas reduction action plans. Most recent guidance for state-level inventory data collection and assessment procedures can be referenced in *Volume VIII of the Emission Inventory Improvement Program (EIIP) Guidelines.* This guidance served as the framework from which this inventory was carried out.

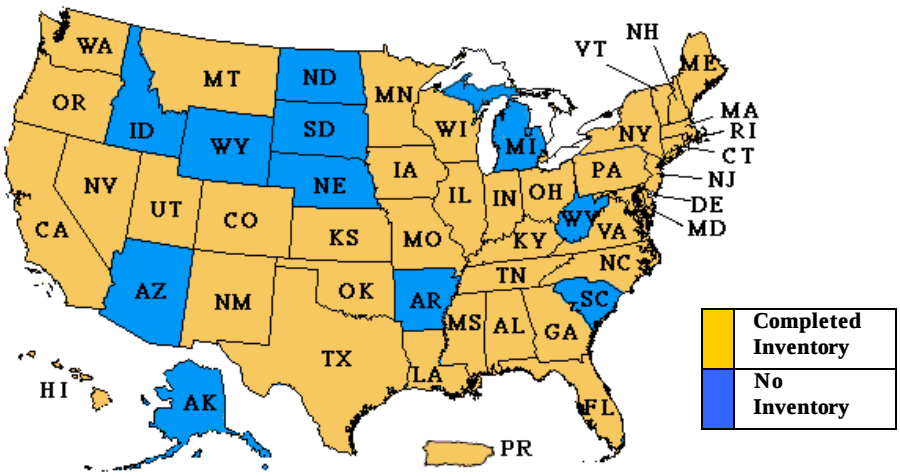


Figure 1-3: U.S. States with and without greenhouse gas inventories completed as of 2003.[10]

1.4 Report Organization

The State of Michigan Greenhouse Gas Inventory report is organized around the basic format identified by the IPCC.[11] This framework groups source and sink categories into the following five sectors: energy, industrial processes, agriculture, land-use change and forestry, and waste. The five IPCC sectors, four of which correspond to chapters contained in the Michigan inventory, are defined in Table 1-2.

It was decided that the methodology for calculating carbon sequestration from forestry activities was fraught with an unacceptable magnitude of uncertainty. For this reason, only "landfilled yard trimmings" were included in the main body of this report under the "Land Use Change and Forestry" section. Discussion of forestry carbon sequestration can be viewed in Appendix I.

Table 1-2: Description of IPCC Source/Sink Categories

IPCC Category	Description of Sector Activities	Corresponding MI Inventory Report Chapter
Energy	Total emissions of all GHGs resulting from stationary and mobile energy activities (fuel combustion as well as fugitive fuel emissions).	Chapter 3
Industrial Processes	By-product or fugitive emissions of greenhouse gases from industrial processes not directly related to energy activities such as fossil fuel combustion.	Chapter 4
Agriculture	Describes all anthropogenic emissions from agricultural activities except fuel combustion and sewage emissions, which are covered in Energy and Waste, respectively.	Chapter 5
Land Use Change and Forestry	Total emissions and removals of carbon dioxide from land-use change activities (excluding forestry).	Chapter 6
Waste	Total emissions from waste management activities.	Chapter 7

In addition to the chapters corresponding to four IPCC categories, Chapter 2 addresses the calculation methodology used to develop the inventory and

Chapter 7 contains inventory summary and conclusions. Lastly, the report appendices include additional details on calculation methodology, as well as the quality assurance/quality control plan and list of acronyms and chemical formulas.

2. Methodology

2.1 Emission Inventory Improvement Program

The State of Michigan's greenhouse gas inventory employed a set of methodologies outlined by the U.S. EPA's State and Local Capacity Building Branch and the Emission Inventory Improvement Program (EIIP). Known as *Volume VIII: Estimating Greenhouse Gas Emissions*, the purpose of the guidance document is to "present estimation techniques for greenhouse gas (GHG) sources and sinks in a clear and unambiguous manner and to provide concise calculations to aid in the preparation of emission inventories."[12]

The methodologies contained in the EIIP guidance were adapted from Volumes 1-3 of the *Revised 1996 IPCC Guidelines for National Greenhouse gas Inventories*, the IPPC *Good Practice Guidance*, and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2000*. Many of the methodologies in the EIIP guidance document are consistent with IPCC methodology and, where possible, default IPCC methodologies have been expanded into more comprehensive, U.S.-specific methods. Where EIIP methodologies do differ from the U.S. inventory and the IPCC, it is because "the data needed to follow the U.S. or IPCC methods are unavailable at the state level."[13] In this inventory report, detailed descriptions of the calculation methodologies used, as well as presentations of activity data and emissions factors, are contained in the Appendices.

2.2 State Greenhouse Gas Inventory Tool

Accompanying the EIIP guidance document is a Microsoft Excel spreadsheet-based emissions calculation tool, the State Greenhouse Gas Inventory Tool (SIT).[14] Meant to improve the ease and accuracy of estimating state GHG emissions, the SIT calculates annual emissions based on imbedded, default data or user-imputed, state-specific data. Wherever possible, the GHG emissions inventory for the State of Michigan attempted to maximize the use of state-specific data.

The SIT is divided into ten source-specific modules and includes a "synthesis module", which is used to compile emissions estimates from the individual modules. Since neither coal mining, nor rice cultivation activities occur in Michigan, the Methane Emissions from Coal Mining and Methane Emissions

from Rice Cultivation SIT modules were not utilized. Lastly, the SIT does not address GHG emissions from the iron and steel industry. It was believed that emissions from this source would represent a significant portion of industry-related emissions. Separate calculation methodologies were adapted from the U.S. EPA and the IPCC.

2.3 Quality Assurance / Quality Control Procedures

Quality assurance (QA) activities are essential to the development of comprehensive, high-quality emissions inventories of any purpose. The QA program for the State of Michigan greenhouse gas inventory is comprised of two components: quality control (QC) and external quality assurance. The complete QA / QC plan is provided as Appendix A.

The first component is that of QC, which is "a system of routine technical activities implemented by inventory development personnel to measure and control the quality of the inventory as it is being developed."[15] The QC system is designed to:

- Provide routine and consistent checks and documentation points in the inventory development process to verify data integrity, correctness, and completeness;
- Identify and reduce errors and omissions;
- Maximize consistency within the inventory preparation and documentation process; and
- Facilitate internal and external inventory review processes.[16]

QC activities include technical reviews, accuracy checks, and the use of approved standardized procedures for emission calculations. These activities should be included in inventory development planning, data collection and analysis, emission calculations, and reporting.

The second component of a QA program consists of external QA activities, which include a planned system of review and audit procedures conducted by personnel not actively involved in the inventory development process. The key concept of this component is independent, objective review by a third party to assess the effectiveness of the internal QC program and the quality of the inventory, and to reduce or eliminate any inherent bias in the inventory processes. In addition to promoting the objectives of the QC system, a comprehensive QA review program provides the best available indication of the inventory's overall quality completeness, accuracy, precision, representativeness, and comparability of data gathered.

For the purposes of this inventory, specific QC procedures were implemented for the following project stages: data collection and handling; emission calculations; and final report writing. The majority of these procedures

address documentation and data verification practices. Of particular importance to the project were documentation procedures. One of the major goals of this project was that after completing the initial inventory, archived documentation would be of sufficient detail to allow outside parties to fully recreate the inventory.

3. Energy

Energy-related activities were the largest sources of the state's anthropogenic greenhouse gas emissions, accounting for more than 85 percent of total emissions on a carbon equivalent basis in 1990 and 2002 (Table 3-1). This included more than 95 percent of the state's carbon dioxide (CO_2), 22-27 percent of methane (CH_4) and 28-30 percent of nitrous oxide (N_2O) emissions. Energy-related CO_2 emissions alone constituted more than 80 percent of the state's emissions from all sources, while the non-CO_2 emissions from energy related activities represented a much smaller portion of total state emissions (approximately three percent collectively). Table 3-1 summarizes emissions from energy-related activities in units of MMTCE. Overall emissions from these activities increased 7.9 percent from 50.11 MMTCE in 1990 to 54.07 MMTCE in 2002.

Emissions from fossil fuel combustion comprised the vast majority of energy-related emissions. As the Figure 3-1 shows, CO_2 was the primary gas emitted, while CH_4 and N_2O accounted for less than five percent collectively of the total greenhouse gas emissions from this source category. Due to the relative importance of fossil fuel combustion-related CO_2 emissions, they are considered separately from other energy-related emissions in Section 3.1. Fossil fuel combustion also emits CH_4 and N_2O, which are to be addressed in Section 3.2 for mobile combustion (emissions of these gases from the transportation sector) and Section 3.4 for stationary combustion (those from all the other end-use sectors). Energy-related activities other than fuel combustion, such as the production, transmission, storage, and distribution of fossil fuels, also emit greenhouse gases. These emissions consist primarily of fugitive CH_4 from natural gas systems and petroleum systems, which is to be discussed in Section 3.3, Natural Gas and Oil Systems.

Table 3-1: Greenhouse Gas Emissions from Energy in Michigan for 1990 and 2002 (MMTCE)[i]

Gas/Activity Type	1990	2002	Percent Change
CO_2	**48.33**	**52.06**	**7.7%**
Fossil Fuel Combustion	48.33	52.06	
Stationary Combustion	-	-	
Mobile Combustion	-	-	
Natural Gas and Oil Systems	-	-	
CH_4	**1.153**	**1.410**	**22.3%**
Fossil Fuel Combustion	-	-	
Stationary Combustion	0.092	0.061	
Mobile Combustion	0.047	0.036	
Natural Gas and Oil Systems	1.014	1.313	
N_2O	**0.630**	**0.604**	**-4.1%**
Fossil Fuel Combustion	-	-	
Stationary Combustion	0.126	0.120	
Mobile Combustion	0.504	0.484	
Natural Gas and Oil Systems	-	-	
Total	**50.11**	**54.07**	**7.9%**
Percent Share of State Total	**87.3%**	**85.4%**	

[i] This summary table does not include emissions from waste combustion caused by energy-related activities, which is included in Waste section in this inventory.

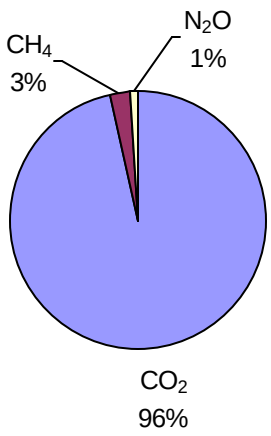


Figure 3-1: Energy Emissions by Gas (Carbon-Equivalent Adjusted) in 2002

3.1 Carbon Dioxide Emissions from the Combustion of Fossil Fuels

Fossil fuel is combusted to heat residential and commercial buildings, to generate electricity, to produce energy for industrial processes, and to power automobiles and other non-road vehicles. CO_2 is emitted as a result of oxidization of the carbon in the fuel from combustion. According to the EPA, other gases such as carbon monoxide and non-methane volatile organic compounds, which are first emitted as by-products of incomplete combustion, are eventually oxidized to CO_2 over periods ranging from a few days to decades.[17] For most greenhouse gas inventories, all carbon emitted to the atmosphere in the form of gases mentioned above is reported as CO_2 emissions. Those emitted as CH_4 is to be addressed in Section 3.4: CH_4 and N_2O Emissions from Stationary Combustion.

The amount of CO_2 emitted from fossil fuel is a function of the type and amount of fuel consumed, the carbon content of the fuel, and the fraction of the fuel that is oxidized. Carbon contents vary across fossil fuel types. For example, coal contains the highest amount of carbon per unit of energy (also referred to as 'carbon intensity'). For petroleum the amount of carbon per unit of energy (carbon intensity) is about 75 percent of that for coal; for natural gas, it is about 55 percent.[18] The fraction of oxidized fuel also varies for two main reasons. First, a small fraction of the carbon remains unburned as soot or ash because of

inefficiencies in combustion. Second, fossil fuels are also used for non-energy purposes, primarily as a feedstock for such products as petrochemicals, plastics fertilizer, lubricants, and asphalt. In some cases, as in fertilizer production, the carbon from the fuels is oxidized immediately to CO_2. In other cases, as in asphalt production, the carbon is sequestered in the product for centuries.[19]

Required Data

CO_2 emissions from fossil fuel combustion are influenced by the type and amount of fuel consumed, the carbon content of the fuel, and the fraction of the fuel that is oxidized. Therefore, less accuracy and precision in these parameters increases uncertainty in the overall estimate of CO_2. The EPA indicates, however, that the uncertainties associated with carbon contents and oxidation efficiencies are lower than those associated with fuel consumption data.[20]

To calculate CO_2 emissions from fossil fuel combustion for 1990, state-level fuel consumption for five end-use categories (residential, commercial, industrial, transportation and electric utilities) were collected from the Department of Energy, Energy Information Administration (EIA)'s consumption data.[21] Due to the timing of the research for this project, no comprehensive energy data for Michigan in 2002 had been compiled by EIA. Therefore, the *Annual Coal Report 2002*[22] and *Annual Natural Gas Report 2002* [23]were referred to as data sources for coal and natural gas consumption figures. For petroleum-based fuels and wood, the EIA's historical consumption data for 1990-2001 were used to estimate values for 2002. Although we could obtain a very likely figure for 2002 CO_2 emission from the estimation process, it should be corrected in a future research when more accurate data are published by the EIA.

According to the EPA, there is more uncertainty within data on total fossil fuel and other energy consumption at the state level, than those at the national level, which are considered relatively accurate. In particular, "the allocation of this consumption to individual end-use sectors (i.e., residential, commercial, industrial, and transportation)" introduces more uncertainty at the state level than at the national level.[24]

The absence of emission estimates from international bunker fuels may also have some impacts on the emission estimation from this source category. International inventory practices recommend that emissions from international bunkers may be calculated and reported separately from the state's total emission by the state of origin, if state-level data are available. However, due to practical difficulty in doing this calculation at the state level, this inventory does not include a report on emissions from international bunker fuel, which could overestimate or underestimate emissions of these fuels.[25]

In addition, we have not incorporated emissions from net electricity import/export, which should be another contributor to uncertainty. According

to the EPA's eGRID database, Michigan has turned to be a net electricity importer since 1997, importing constantly around 10 percent of total consumption from 1999 to 2000. Although 2001 and 2002 data are not available, the trend presumably continued also in 2002. If the net imported amount were accurately known, that would increase the state's CO_2 emissions from the electricity sector.

Methodology

Carbon emissions from fossil fuels for 1990 and 2002 were calculated using the EIIP guidelines and the State Inventory Tool (SIT). Consumption data that were originally provided in physical units such as barrels and short tons were converted to British thermal units (Btu) by factors supplied by the EIIP guidelines and EIA.

After converting the state-level fuel consumption data to Btu, the total carbon content for each fuel was calculated by multiplying the consumption of each fuel type (in Btu) by a carbon content coefficient (C/Btu) provided by the EIIP guidelines and the EIA's *Documentation for Emissions of Greenhouse Gases in the United States 2002*.[26] It should be noted that these coefficients were national averages and may not accurately represent the energy content of fuels combusted in Michigan.

Some fuel types were used in part for non-fuel purposes (i.e. asphalt and road oil) that would sequester the carbon for 20 years or more. To obtain the net carbon available for immediate release, the percentage of stored carbon for the specific non-fuel use was calculated for each fuel type. For the purpose of this inventory, the non-fuel use amount was subtracted from total consumption (for fuel use and non-fuel use) data to obtain a CO_2 amount immediately released to the atmosphere.

Fuel use for non-energy purposes is another cause of uncertainty in emission estimation. We used national figures as default values for the amount of non-energy fuel use and percentage of carbon stored by fuel types. State-specific data, if available, can reduce these uncertainties.

To account for fraction of carbon that did not oxidize immediately during fossil fuel combustion, the EIIP guidelines as well as *U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, provided fraction estimate factors for each given fuel type. The resulting fraction oxidized was multiplied by the tons of carbon available and resulted in total oxidized carbon or CO_2.

Results

CO_2 emissions from fossil fuel combustion in the State of Michigan were 52.05 MMTCE in 2002, a 7.7 percent increase from 48.32 MMTCE in 1990 (Table 3-2). This increase is quite modest since it is less than half of the national increase observed for the same period of time, 16.5 percent.[27] A likely explanation for the lower rate of emissions increase in Michigan compared to the national emissions rate may be the difference in population growth. Michigan's population increased 7.9 percent over these 12 years while the national population increased 15.4 percent during the same period of time.[ii] Another factor contributing to the state's smaller increase in emissions from fossil fuel combustion compared to the national rate is the ongoing shift from coal to natural gas use in Michigan, which has reduced the carbon intensity of Michigan energy production. It is also noteworthy for Michigan that emissions from coal use decreased slightly (three percent) over these 12 years, while that for the United States increased substantially by 19 percent.

Trends in CO_2 emissions from fossil fuel combustion are influenced by many long-term and short-term factors. According to the EPA, while the overall demand for fossil fuels in the short term is subject to "changes in economic conditions, energy prices, weather and the availability of non-fossil alternatives", longer-term changes tend to be more influenced by "aggregate societal trends that affect the scale of consumption (e.g. population, number of cars, and size of houses), the efficiency with which energy is used in equipment (e.g., cars, power plants, steel mills, and light bulbs), and social planning and consumer behavior."[28]

The emission reduction of CO_2 from energy use can be achieved by not only lowering total energy consumption, but also by lowering the carbon intensity of fuels through fuel switching from coal to natural gas. This is because the amount of carbon emitted from the combustion of fossil fuels is dependent upon the carbon content of the fuel and the fraction of that carbon that is oxidized. Fossil fuels vary in their average carbon content, ranging from about 31.90 lbs C/MMBtu for natural gas at the low end to high carbon intensities of 61.40 lbs C/MMBtu for coal and petroleum coke.[29] In general, the amount of carbon per unit of energy (carbon intensity) is the highest for coal products, followed by petroleum, and then natural gas. Even within fuel types, carbon contents will vary: lower quality coal (such as lignite and sub-bituminous coal) has a higher carbon coefficient with more carbon intensity. Producing a unit of heat or electricity using natural gas instead of coal can reduce the CO_2 emissions associated with energy consumption.

[ii] The calculation was based on population figures embedded in the SIT module: 9,310,462 for 1990 and 10,043,221 for 2002 in Michigan, and 294,464,396 for 1990 and 287,973,924 for 2002 in the U.S.

It is noteworthy for Michigan that its CO_2 emissions from natural gas had a higher share in the state's total CO_2 emissions from fossil fuel combustion (27 percent) compared with that for the United States (21 percent) in both 1990 and 2002.[30] At 921 billion cubic feet in 2002, Michigan was the sixth largest natural gas consuming state, accounting for 4.3 percent of U.S. consumption.[31] Approximately 40 percent of the natural gas consumed in Michigan was used by the residential sector, mainly for home heating purposes. In Michigan, over 78 percent of homes are heated with natural gas, which trails only Utah and Illinois in terms of the percentage of households with natural gas as the primary heating fuel.[32] According to Michigan Public Service Commission, Department of Consumer & Industry Services, Michigan also ranks among the top 10 states in total natural gas consumption by the commercial, industrial and electric generation sectors.[33]

Tables 3-2, 3-3, and 3-4 are the summaries of the CO_2 emissions and emission intensity from the State of Michigan for 1990 and 2002.

Table 3-2: CO_2 Emissions from Fossil Fuel Combustion from Michigan by Fuel Type and Sector for 1990 and 2002

		1990 Emissions (MMTCE)	2002 Emissions (MMTCE)	Percent Change
Residential	Coal	0.03	0.02	-33.3%
	Petroleum	0.99	1.14	15.2%
	Natural Gas	4.92	5.47	11.2%
	Total	**5.94**	**6.63**	**11.6%**
Commercial	Coal	0.13	0.15	15.4%
	Petroleum	0.39	0.32	-17.9%
	Natural Gas	2.40	2.60	8.3%
	Total	**2.92**	**3.07**	**5.1%**
Industrial	Coal	2.24	1.15	-48.7%
	Petroleum	1.99	1.83	-8.0%
	Natural Gas	4.25	3.60	-15.3%
	Total	**8.48**	**6.58**	**-22.4%**
Transportation	Coal	0.00	0.00	0.0%
	Petroleum	12.56	15.55	23.8%
	Natural Gas	0.27	0.40	48.1%
	Total	**12.83**	**15.95**	**24.3%**
Electric Utility	Coal	16.96	17.48	3.1%
	Petroleum	0.19	0.26	36.8%
	Natural Gas	1.00	2.08	108.0%
	Total	**18.15**	**19.82**	**9.2%**
All End-Use Sectors	**Coal**	**19.36**	**18.80**	**-2.9%**
	Petroleum	**16.12**	**19.10**	**18.5%**
	Natural Gas	**12.84**	**14.15**	**10.2%**
Grand Total		**48.32**	**52.05**	**7.7%**

Table 3-3: CO_2 Emissions from Fossil Fuel Combustion from Michigan by Fuel Type and Sector for 1990 and 2002 (MMTCE)

		1990		2002		
Fuel Type	**Sector**	**Emissions (MMTCE)**	**Sectoral Percentage**	**Emissions (MMTCE)**	**Sectoral Percentage**	**Change from 1990**
Coal	Residential	0.03	0.2%	0.02	0.1%	-33.3%
	Commercial	0.13	0.7%	0.15	0.8%	15.4%
	Industrial	2.24	11.6%	1.15	6.1%	-48.7%
	Transportation	0.00	0.0%	0.00	0.0%	0.0%
	Utility	16.96	87.6%	17.48	93.0%	3.1%
	Total	**19.36**	**100.0%**	**18.80**	**100.0%**	**-2.9%**
Petroleum	Residential	0.99	6.1%	1.14	6.0%	15.2%
	Commercial	0.39	2.4%	0.32	1.7%	-17.9%
	Industrial	1.99	12.3%	1.83	9.6%	-8.0%
	Transportation	12.56	77.9%	15.55	81.4%	23.8%
	Utility	0.19	1.2%	0.26	1.4%	36.8%
	Total	**16.12**	**100.0%**	**19.10**	**100.0%**	**18.5%**
Natural Gas	Residential	4.92	38.3%	5.47	38.7%	11.2%
	Commercial	2.40	18.7%	2.60	18.4%	8.3%
	Industrial	4.25	33.1%	3.60	25.4%	-15.3%
	Transportation	0.27	2.1%	0.40	2.8%	48.1%
	Utility	1.00	7.8%	2.08	14.7%	108.0%
	Total	**12.84**	**100.0%**	**14.15**	**100.0%**	**10.2%**

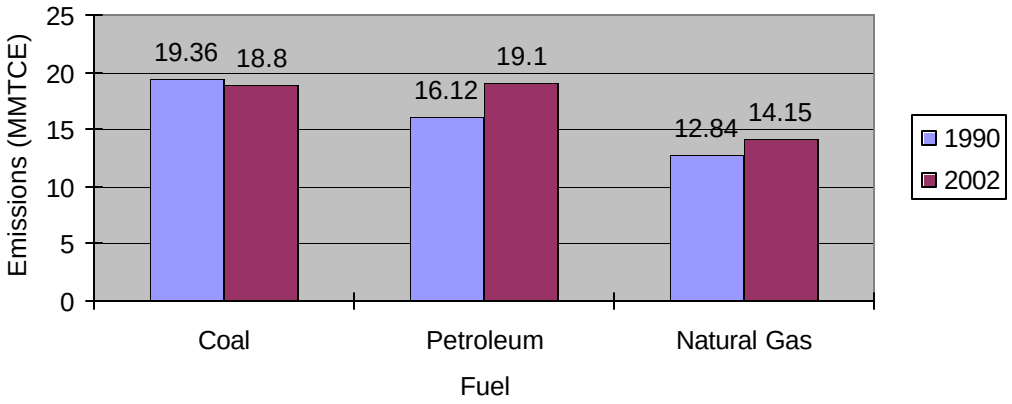


Figure 3-2: CO_2 Emissions from Fossil Fuel Combustion by Fuel Type for 1990 and 2002 (MMTCE)

Table 3-4: CO_2 Emission Intensity for Michigan by End-use Sector

Sector	1990		2002		Percent Change in Emission Intensity
	Energy (Bbtu)	MTCE/Bbtu	Energy (Bbtu)	MTCE/Bbtu	
Residential	396,384	14.99	444,739	14.91	-0.5%
Commercial	192,304	15.18	203,615	15.08	-0.7%
Industrial	486,683	17.42	388,407	16.94	-2.8%
Transportation	666,320	19.26	835,211	19.10	-0.8%
Electric Utility	741,845	24.47	836,167	23.70	-3.1%
Total	**2,483,536**	**19.46**	**2,708,139**	**19.22**	**-1.2%**

End-Use Sector Consumption

It can also be useful to view CO_2 emissions from economic sectors with emissions related to electricity generation distributed into four end-use categories: residential, commercial, industrial, and transportation. This allows for allocation of emissions associated with electricity generation to economic sectors based upon the sector's share of state electricity consumption.[34] This method of distributing emissions, which is also employed in *the Inventory of U.S. Greenhouse Gas Emissions and Sinks*, assumes that each sector consumes electricity generated from an equally carbon-intensive mix of fuels and other energy sources. In reality, however, sources of electricity vary widely in carbon intensity. By giving equal carbon-intensity weight to each sector's electricity consumption, emissions attributed to one end-use sector may be somewhat overestimated or underestimated.[35] Table 3-5 and Figures 3-3 to 3-6 summarize CO_2 emissions from direct fossil fuel combustion and prorated electricity generation emissions from electricity consumption by end-use sector.

The allocation of CO_2 emission from the electric utility sector to each of the other end-use sectors may introduce another uncertainty. As was mentioned above, distributing emissions based on the sector's share of state electricity consumption assumes that each sector consumes electricity generated from an equally carbon-intensive mix of fuels and other energy sources. In reality, however, sources of electricity vary widely in carbon intensity. By giving equal carbon-intensity weight to each sector's electricity consumption, emissions attributed to one end-use sector may be somewhat overestimated or underestimated.[36] In addition, the unknown breakdown of "Other", which is assumed to be added to the commercial sector, increases uncertainty as well, although the fraction is fairly small.

Table 3-5: CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector

End-Use Sector	1990				2002			
Sectoral Breakdown	Emissions (MMTCE)	% Share within Sector	Share by Sector w/ Electricity Use	Sectoral Share of Electricity Use	Emissions (MMTCE)	% Share within Sector	Share by Sector w/ Electricity Use	Sectoral Share of Electricity Use
Transportation	**12.83**	**100.0%**	**26.6%**		**15.95**	**100.0%**	**30.6%**	
Combustion	12.83	100.0%			15.95	100.0%		
Electricity	0.00	0.0%		**0.0%**	0.00	0.0%		**0.0%**
Industrial	**16.21**	**100.0%**	**33.5%**		**12.87**	**100.0%**	**24.7%**	
Combustion	8.48	52.3%			6.58	51.1%		
Electricity	7.73	47.7%		**42.6%**	6.29	48.9%		**31.7%**
Residential	**11.52**	**100.0%**	**23.8%**		**12.97**	**100.0%**	**24.9%**	
Combustion	5.94	51.6%			6.63	51.1%		
Electricity	5.58	48.4%		**30.7%**	6.34	48.9%		**32.0%**
Commercial	**7.46**	**100.0%**	**15.4%**		**10.08**	**100.0%**	**19.4%**	
Combustion	2.92	39.1%			3.07	30.4%		
Electricity	4.54	60.9%		**25.0%**	7.01	69.6%		**35.4%**
Others	**0.30**	**100.0%**	**0.6%**		**0.18**	**100.0%**	**0.3%**	
Electricity	0.30	100.0%		**1.7%**	0.18	100.0%		**0.9%**
Total	**48.32**		**100.0%**	**100.0%**	**52.05**		**100.0%**	**100.0%**

Note: The "Others" category in the Table includes various uses to be attributed to different sectors. According to EIA personnel[37], five percent of the "Others", in general, is to be allocated for the transportation sector and the remaining is to be for the commercial sector. However, the fraction to be allocated for transportation is quite negligible for the State of Michigan (0.3 percent for 2002). In addition, the "Others" category in the 1990 data seems to include the agricultural use of electricity[iii], but the fraction is unknown. Taking account of the above, it would be reasonable to consider that this portion can be added to the commercial sector. This approach is taken in Chapter 8.

[iii] The agricultural use of electricity is currently counted under the "industrial" category

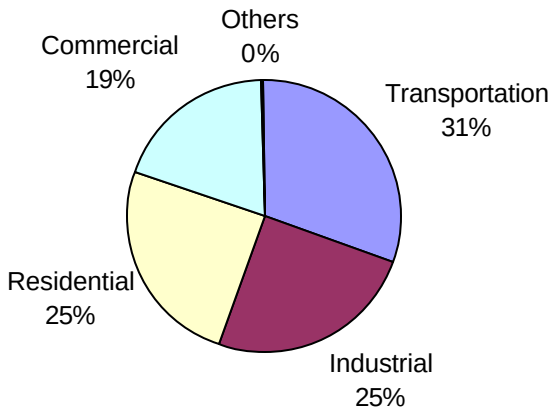


Figure 3-3: CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector for 2002

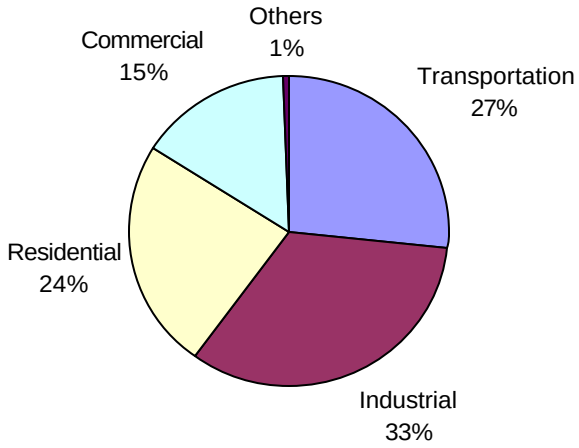


Figure 3-4: Breakdown of CO_2 Emissions from Combustion by End-Use Sector for 1990

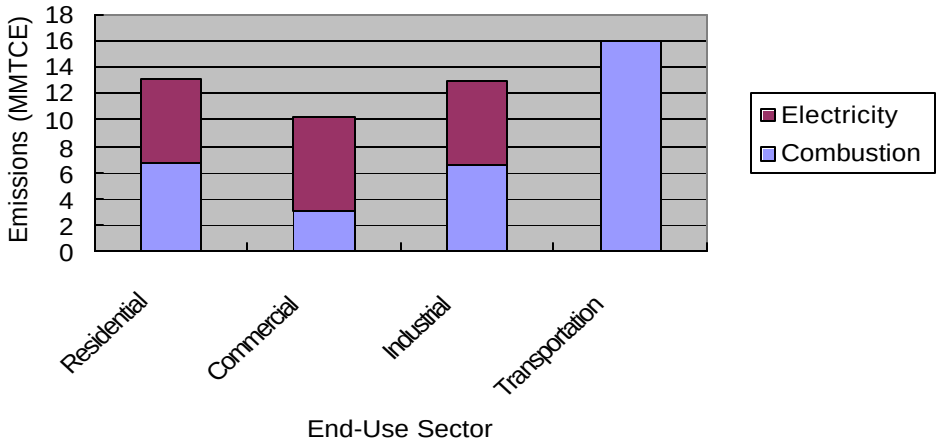


Figure 3-5: Breakdown of CO_2 Emissions from Combustion and Electricity Use by End-Use Sector for 2002

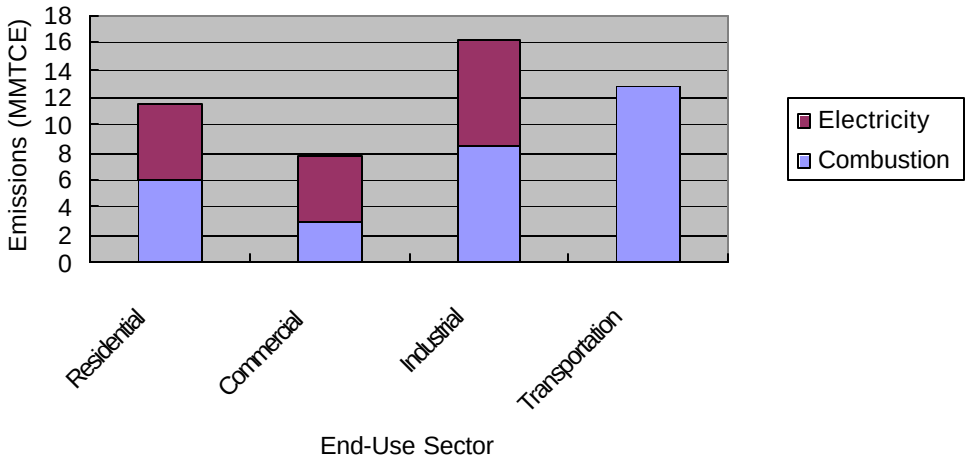


Figure 3-6: Breakdown of CO_2 Emissions from Combustion and Electricity Use by End-Use Sector for 1990

Residential and Commercial End-Use Sectors

In 2002, CO_2 emissions from fossil fuel combustion and electricity use within the residential and commercial end-use sectors were 12.97 MMTCE and 10.08 MMTCE, accounting for 25 percent and 19 percent respectively of the state total (Table 3-5). While, in 1990, they were 11.52 MMTCE and 7.46 MMTCE respectively, accounting for 24 percent and 15 percent of the state total. As presented in Table 3-5 and Figures 3-5 and 3-6, both sectors were heavily reliant on electricity for meeting energy needs. The electricity consumption for lighting, heating, air conditioning, and operating appliances accounted for 49 percent of emissions from the residential and 70 percent from the commercial sectors in 2002.

The remaining emissions were largely due to the direct consumption of natural gas and petroleum products, primarily for heating and cooking needs. It is noteworthy that the emissions from combustion were higher than that from electricity for the residential sector for both 1990 and 2002 in Michigan, whereas emissions from electricity have always taken a larger share in the residential sector for the whole United States.[iv] This might be due to the climate conditions of Michigan[v,38], where there is higher natural gas combustion occurring in winter for heating purposes. Emissions from natural gas consumption represent over 80 percent of the direct (not including electricity) fossil fuel emissions from the residential and commercial sectors for both years. In terms of the U.S., the value is consistently around 70 percent. In Michigan and throughout the Midwest, a much higher percentage of natural gas is used as a winter heating fuel, compared with warmer climates in the U.S., where natural gas is used primarily as a year-round industrial and electric generation fuel.[39] Compared to natural gas, coal consumption was a minor component of energy use in both of these end-use sectors.

According to the EPA, it seems to be a national trend that emissions from these two end-use sectors have "increased steadily since 1990, unlike those from the industrial sector, which experienced substantial reductions during the economic downturns of 1991 and 2002."[40] The EPA suggests that, in a shorter term, the residential and commercial sectors are more subjective to weather than to economic conditions. Considering this 12-year time period, however, it is also possible that these sectors might be affected by other longer-term factors suggested by the EPA in *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, such as population growth, regional migration trends, and changes in housing and building attributes (e.g., size and insulation).[41]

[iv] According to *the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*, the share of emissions from electricity use in the residential sector was 63 percent in 1990 and 68 percent in 2002 for the whole United States.

[v] Average winter temperature (Dec-Feb) in Michigan from 1990 to 2002 was 23.48 deg F, while the average for the United States for the same period of time was 34.63 deg F.

However, as noted by the EIA, given that commercial activity is a factor of the larger economy, emissions from the commercial sector in the long run are more influenced by economic trends and less influenced by population growth than are emissions from the residential sector.[42]

From 1990 to 2002, electricity sales (in megawatt hours) to the residential and commercial end-use sectors increased by 36 and 84 percent, respectively.[43] Compared with such a big increase in electricity consumption from both sectors, electricity-related emissions show a relatively lower increase for both sectors (14 and 54 percent, respectively) as the decline in carbon intensity of electricity generation outweighed the increase in electricity demand.

Industrial End-Use Sector

The industrial end-use sector is the only sector that showed a decrease in greenhouse gas emissions from fossil fuel combustion for 1990 and 2002 in the State of Michigan, unlike the federal trend for the sector that showed a slight increase.[vi, 44] Emissions from this sector were 12.87 MMTCE in 2002, accounting for 25 percent of the state's CO_2 emissions from fossil fuel combustion. This represents a decrease by 21 percent from 16.21 in 1990. The industrial end-use sector accounted for 34 percent share of the state's CO_2 emissions in 1990 (Table 3-5).

According to the definition by the EPA, the industrial end-use sector includes manufacturing, construction, and agriculture, of which the largest activity in terms of energy consumption is manufacturing.[45] For Michigan, the largest manufacturing industries, as measured by output, are transportation equipment (auto parts, and auto and truck production), machinery, especially metalworking machinery, and fabricated metal.[46] For both years, slightly over 50 percent of these emissions resulted from the direct consumption of fossil fuels for steam and process heat production. The remaining was associated with the consumption of electricity for uses such as motors, electric furnaces, ovens, and lighting.

As stated by the EPA, "in theory, emissions from the industrial end-use sector should be highly correlated with economic growth and industrial output."[47] The reasons for the disparity between substantial growth in Gross State Product (GSP)[vii,48] and the significant decrease in industrial emissions are not clear. The EPA indicates on a national scale that possible factors that may have influenced industrial emission trends are as follows: "1) more rapid

[vi] The emissions from the industrial sector (both from fossil fuel combustion and electricity use) for the whole United States increased approximately by 2 percent from 446.86 MMTCE in 1990 to 457.39 MMTCE.

[vii] According to the Bureau of Economic Analysis in U.S. DOC, the Total Gross State Product in Michigan was 234,181 millions dollars in 1990 and 337,708 million dollars in 2002 (both in 2000 dollars). In Quality Indexes for Real GSP with GSP in Year 2000 as 100.0, 1990 GSP was 71.8 and 2002 GSP was 99.9.

growth in less energy-intensive industries than in traditional manufacturing industries; 2) improvements in energy efficiency; and 3) a lowering of the carbon intensity of fossil fuel consumption by fuel switching from coal and coke to natural gas, etc."[49] In addition, a nation-wide concern over outsourcing jobs has been developed. It is suspected that the movement of Michigan's manufacturing facilities to foreign countries contributed to lower CO_2 emissions from this sector in 2002.[viii, 50]

It should be noted that industry is the largest user of fossil fuels for non-energy applications. Fossil fuels can be used for producing products such as fertilizers, plastics, asphalt, or lubricants that can sequester or store carbon for long periods of time. Asphalt used in road construction, for example, stores carbon essentially indefinitely. Similarly, fossil fuels used in the manufacture of materials like plastics can also store carbon, if the material is not burned.

Transportation End-Use Sector

CO_2 emissions from fossil fuel combustion for transportation in 2002 were 15.95 MMTCE, representing the largest share of CO_2 emissions from fossil fuel combustion (Figures 3-3 and 3-5). In 1990, emissions from this sector were 12.83 MMTCE, accounting for the second largest share of 27 percent (Figures 3-4 and 3-6). This trend is quite similar to the national trend (32 percent for 2002 and 31 percent for 1990).[51] Over these 12 years, the emissions from this sector increased by 24 percent (Table 3-5). Like overall energy demand, transportation fuel demand is a function of many short and long-term factors. In the short term only minor adjustments can generally be made through consumer behavior (e.g., not driving as far for summer vacations). However, long-term adjustments such as vehicle purchase choices, transport mode choice and access (i.e., trains versus planes), and urban planning can have a significant impact on fuel demand.[52]

Since 1990, travel activity in the United States has grown more rapidly than the population, with a 16 percent increase in vehicle miles traveled per capita.[53] For Michigan, the increase is 14.5 percent[54], slightly lower than the national average. This increase is partly due to an increase in the number of motor vehicles, which is significant for all vehicle types except automobiles. It is noteworthy that the number of automobiles registered decreased during these 12 years by 4.7 percent, but that the number for trucks (including passenger vans/minivans and utility-type vehicles) increased by 75.6 percent.[55] An increase in the number of cars per person is also another contributor of an increase in vehicle miles traveled (VMT) per capita. This

[viii] According to *Detroit New Business* (June 4, 2004), the study by Center for Automotive Research in Ann Arbor shows "the state has lost 168,200 manufacturing jobs due largely to rising productivity" and " that one in eight manufacturing jobs lost since 2001 were due to outsourcing or competition from fast-growing countries like China and India.

increased from 0.77 for 1990 to 0.85 for 2002 for the State of Michigan.[ix, 56] Furthermore, an increase in driving hours per capita could be another possible factor to increase the state VMT, although we have not yet collected data that could support this hypothesis. In addition to an increase in VMT, longer commute times due to traffic congestion could be another factor to increase fuel consumption. According to Michigan's Transportation System by the Road Information Program, the typical commuter in Michigan in 2002 spent on average an additional 24 hours a year on the road than 10 years before. [57]

Not only an increase in VMT, but the composition of vehicle types could also be another factor that increased the state's emissions from transportation. As mentioned above, the sales of trucks, vans and utility-type vehicles significantly increased over these 12 years, despite a slight decrease in the sales of automobiles. The increasing dominance of vehicles with less fuel efficiency can contribute higher emissions from this sector.

Electric Utility End-Use Sector

According to the EPA's new definition, the electric power industry includes all power producers, both regulated utilities and nonutilities (e.g. independent power producers, qualifying cogenerators, and other small power producers). The EPA includes the following definitions: "utilities primarily generate power for the U.S. electric grid for sale to retail customers, while nonutilites produce electricity for their own use to sell to large consumers, or to sell on the wholesale electric market (e.g., to utilities for distribution and resale customers)."[58]

The process of generating electricity is the single largest source of CO_2 emissions in the State of Michigan as well as in the United States. As we have seen, electricity is consumed primarily in the residential, commercial, and industrial end-use sectors for lighting, heating, electric motors, appliances, electronics, and air conditioning. Electricity generation also accounted for the largest share of CO_2 emissions from fossil fuel combustion, 38 percent in both 1990 and 2002.

The inventory does not incorporate emissions from net electricity import/export, which should contribute to calculation uncertainty. According to the EPA's eGRID database, Michigan has become a net electricity importer since 1997, importing consistently around 10 percent of total consumption from 1999 to 2000. Although 2001 and 2002 data are not available, if the trend continued for 2002 it would increase the state's CO_2 emissions from the electricity sector by 10 percent.

[ix] Per capita VMT was calculated by dividing all motor vehicles total by the State population.

Electricity sales in the State of Michigan were 107,311 thousand megawatt-hours (Mwh) in 2002, an increase of 30 percent from 82,367 thousand Mwh in 1990.[59] However, CO_2 emissions from this sector increased only nine percent during the same period of time (Table 3-2). This lower rate of emission increase compared with electricity consumption is partly due to the increased shares of petroleum and natural gas in the fuel mix. Although coal is consumed primarily by the electric power sector in Michigan (93 and 88 percent of total coal consumption in 2002 and 1990) as well as the whole United States (Table 3-3) coal consumption for electricity generation increased only by three percent over these 12 years (Table 3-2). On the other hand, natural gas consumption for electricity generation, which accounted for only 1 MMTCE in 1990, grew at a higher rate to 2.08 MMTCE in 2002 (Table 3-2).

3.2 Methane and Nitrous Oxide Emissions from Mobile Combustion

Although there is virtually no CH_4 in either gasoline or diesel fuel, CH_4 is emitted as a combustion by-product. The production of CH_4 is influenced by fuel composition, combustion conditions and efficiency, and any post-combustion control of hydrocarbon emissions, such as catalytic converters. According to the EPA, CH_4 emissions would be higher especially in aggressive driving, low speed operation, and cold start operation. Poorly tuned highway vehicle engines may also increase CH_4 emissions. For modern highway vehicles equipped with a three-way closed loop catalyst, emissions would be lowest when the right combination of hydrogen, carbon, and oxygen is achieved for complete combustion. On the other hand, the formation of N_2O in internal combustion engines is not yet fully understood, due to a limited amount of data on these emissions.[60] It is believed that N_2O emissions come from two distinct processes: first, during combustion in the cylinder, and second, during catalytic aftertreatment of exhaust gases.[61]

Based on the EPA's methodology, emissions from mobile combustion were estimated by transport mode (e.g., highway and non-highway (air, rail, marine), fuel type (e.g., motor gasoline, diesel fuel, jet fuel), and vehicle type (e.g., passenger cars, light-duty trucks, motorcycles).[62] Road transport accounted for more than 90 percent of mobile source fuel consumption, and thus, the majority of mobile combustion emissions.

Required Data

CH_4 and N_2O emission estimates for highway vehicles are calculated from two primary inputs: activity data (i.e., vehicle miles traveled (VMT)) and emission factors. Although other factors (e.g., the breakdown of vehicle

control technology, vehicle age, etc.) affect emission estimates, the uncertainty associated with them has a much smaller impact on estimates than the uncertainty related to the activity data and emission factors.[63]

Data for the road category were collected from Federal Highway Administration's *Highway Statistics Summary to 1995*[64] and *Highway Statistics 2002*.[65] Data for the non-road category were collected from various sources including *EIA Fuel Oil and Kerosene.*[66] Given that most of non-road data are not compiled at the state level, estimates were derived from the national consumption and sales data.

Emission estimates for non-highway sources are also driven by fuel consumption data and emission factors. Given that state-specific fuel consumption data for this category are not available, the data gathered at the national level were apportioned to states based on state-specific sales data or on a historical ratio, etc. This apportionment introduces some uncertainty.

Emission factors recommended by the EIIP were also taken from the IPCC[67], and with significant uncertainties, since research has not been conducted fully for emissions from these modes.[68] The EIIP also cautions that technologies and vehicle characteristics have changed since the factors were initially developed, which may introduce additional uncertainties.[69]

The uncertainty related to emission factors is relatively high for mobile combustion. According to the EIIP guidelines, most CH_4 emission factors they use were taken from IPCC[70], and were developed using EPA's MOBILE5a, which computes these factors based on inputs such as ambient temperature, vehicle speeds, gasoline volatility, and other variables.[71] The values for these factors can change significantly, depending on driving conditions and vehicle characteristics, etc. Emission factors for N_2O were developed by the EPA, using a variety of sources (described in *U.S. Greenhouse Gas Emissions and Sinks 1990-2002*[72]), through a scaling process based on ratios of fuel economy. This process also increases the level of uncertainty.[73]

Methodology

Emissions of CH_4 and N_2O from mobile sources were calculated for 1990 and 2002 from both road and non-road categories by using the EIIP guidelines and the State Inventory Tool (SIT). Road sources were vehicles that travel primarily on highways. Non-road sources included gasoline-fueled aircraft, jet aircraft, farm, industrial and construction equipment, boats, and ships. Except for gasoline-fueled aircraft, all of these non-road sources were typically equipped with diesel engines.

A methodology recommended by the EIIP guidelines apportions state VMT totals among different vehicle types based on national averages instead of state-specific data. As the guidelines point out, these percentages have relatively low uncertainty at the national level, but the uncertainty increases when applied at the state level because state-specific differences in consumer preferences for vehicle types and a variety of social, legal, and economic factors cannot be well captured.[74]

Results

From 1990 to 2002, mobile combustion had been responsible for less than one percent of the state's CH_4 emissions, but had been the second largest source of N_2O (23-24 percent) in the State of Michigan. Over these 12 years, CH_4 emissions declined by 24 percent, from 47,087 MTCE to 35,575 MTCE (Table 3-6), due largely to control technologies employed on highway vehicles nationwide that reduce CO, NOx, non-methane volatile organic compounds (NMVOC), and CH_4 emissions. The same technologies, however, resulted in higher N_2O emissions, with only a four percent decrease from 503,738 MTCE to 483,549 MTCE in N_2O emissions from mobile sources for the same period of time (Table 3-7). Overall, CH_4 and N_2O emissions were predominantly from gasoline-fueled passenger cars and light-duty gasoline trucks (Figures 3-7 and 3-8).

Table 3-6: CH_4 Emissions from Mobile Sources for 1990 and 2002

	1990			2002			
Fuel Type/Vehicle Type	**Emissions (MTCE)**	**% Share by vehicle**	**% Share by road category**	**Emissions (MTCE)**	**% Share by vehicle**	**% Share by road category**	**Change in Emissions from 1990**
Gasoline Highway	**42,509**		**100.0%**	**31,075**		**100.0%**	**-26.9%**
Passenger Cars	27,544	58.5%	64.8%	20,950	58.9%	67.4%	-23.9%
Light-Duty Trucks	12,375	26.3%	29.1%	8,722	24.5%	28.1%	-29.5%
Heavy-Duty Vehicles	1,694	3.6%	4.0%	1,206	3.4%	3.9%	-28.8%
Motorcycles	896	1.9%	2.1%	196	0.6%	0.6%	-78.1%
Diesel Highway	**2,306**		**100.0%**	**2,468**		**100.0%**	**7.0%**
Passenger Cars	52	0.1%	2.3%	63	0.2%	2.5%	20.6%
Light-Duty Trucks	42	0.1%	1.8%	56	0.2%	2.3%	32.8%
Heavy-Duty Vehicles	2,212	4.7%	95.9%	2,349	6.6%	95.2%	6.2%
Non-Highway	**2,271**		**100.0%**	**2,032**		**100.0%**	**-10.5%**
Boats	273	0.6%	12.0%	296	0.8%	14.6%	8.4%
Locomotives	207	0.4%	9.1%	123	0.3%	6.0%	-40.5%
Farm Equipment	589	1.3%	25.9%	507	1.4%	24.9%	-14.0%
Construction Equipment	155	0.3%	6.8%	168	0.5%	8.3%	8.4%
Aircraft	982	2.1%	43.2%	736	2.1%	36.2%	-25.0%
Other*	66	0.1%	2.9%	203	0.6%	10.0%	207.4%
Alternative Fuel Vehicles	-	-	-	-	-	-	-
Light Duty Vehicles	-	-	-	-	-	-	-
Heavy Duty Vehicles	-	-	-	-	-	-	-
Buses	-	-	-	-	-	-	-
Total	**47,087**	**100.0%**		**35,575**	**100.0%**		**-24.4%**

* "Other" includes snowmobiles, small gasoline powered utility equipment, heavy-duty gasoline powered utility equipment and heavy-duty diesel powered utility equipment

Table 3-7: N_2O Emissions from Mobile Combustion for 1990 and 2002

	1990			2002			
Fuel Type/Vehicle Type	**Emissions (MTCE)**	**% Share by vehicle**	**% Share by road category**	**Emissions (MTCE)**	**% Share by vehicle**	**% Share by road category**	**Change in Emissions from 1990**
Gasoline Highway	**467,022**		**100.0%**	**444,618**		**100.0%**	**-4.8%**
Passenger Cars	351,161		75.2%	316,829	65.5%	71.3%	-9.8%
Light-Duty Trucks	109,214	21.7%	23.4%	111,379	23.0%	25.1%	2.0%
Heavy-Duty Vehicles	6,417	1.3%	1.4%	16,320	3.4%	3.7%	154.3%
Motorcycles	231	0.0%	0.0%	90	0.0%	0.0%	-61.0%
Diesel Highway	**20,544**		**100.0%**	**26,362**		**100.0%**	**28.3%**
Passenger Cars	766	0.2%	3.7%	924	0.2%	3.5%	20.6%
Light-Duty Trucks	1,255	0.2%	6.1%	1,665	0.3%	6.3%	32.8%
Heavy-Duty Vehicles	18,524	3.7%	90.2%	23,773	4.9%	90.2%	28.3%
Non-Highway	**16,172**		**100.0%**	**12,569**		**100.0%**	**-22.3%**
Boats	1,401	0.3%	8.7%	1,520	0.3%	12.1%	8.5%
Locomotives	976	0.2%	6.0%	580	0.1%	4.6%	-40.5%
Farm Equipment	1,546	0.3%	9.6%	1,330	0.3%	10.6%	-14.0%
Construction Equipment	1,016	0.2%	6.3%	1,101	0.2%	8.8%	8.4%
Aircraft	10,800	2.1%	66.8%	6,708	1.4%	53.4%	-37.9%
Other*	433	0.1%	2.7%	1,330	0.3%	10.6%	207.4%
Alternative Fuel Vehicles	-	-	-	-	-	-	-
Light Duty Vehicles	-	-	-	-	-	-	-
Heavy Duty Vehicles	-	-	-	-	-	-	-
Buses	-	-	-	-	-	-	-
Total	**503,738**	**30.3%**		**483,549**	**100.0%**		**-4.0%**

* "Other" includes snowmobiles, small gasoline powered utility equipment, heavy-duty gasoline powered utility equipment and heavy-duty diesel powered utility equipment

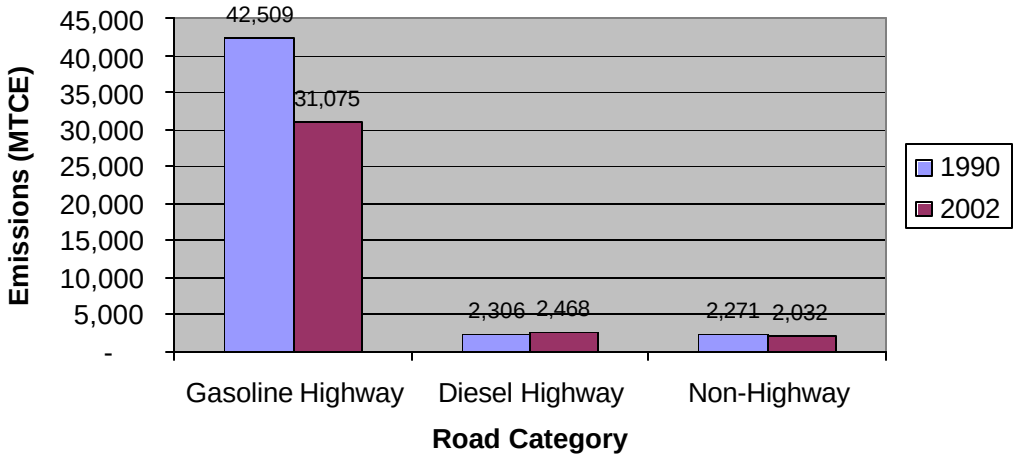


Figure 3-7: CH_4 Emissions from Mobile Combustion for 1990 and 2002

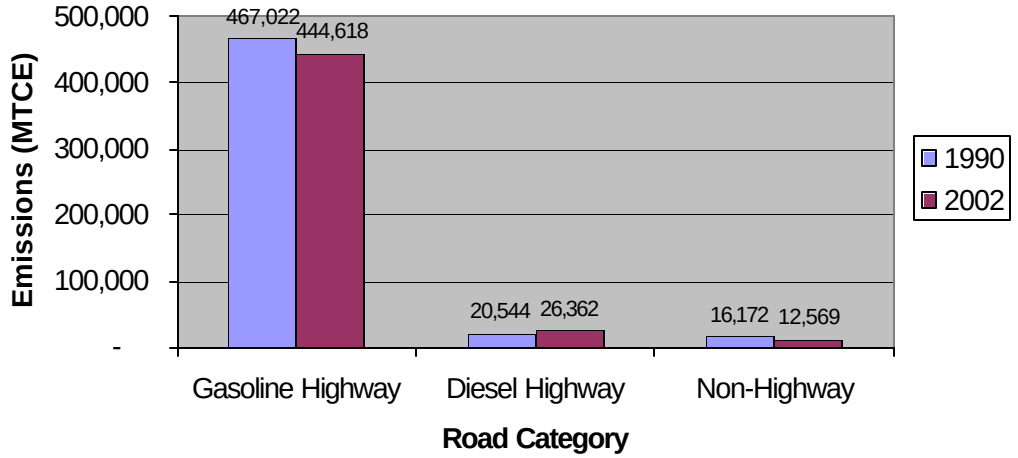


Figure 3-8: N_2O Emissions from Mobile Combustion for 1990 and 2002

Emissions from non-highway vehicles are a small portion of total emissions from mobile sources, representing less than 10 percent of both CH_4 emissions and N_2O emissions from mobile sources during 2002 and 1990. Given that they comprise a small share of mobile source emissions, even large uncertainties in these estimates will have a relatively small impact on the total emission estimate for mobile sources.

3.3 Natural Gas and Oil Systems

Natural gas and oil systems are the second largest source of CH_4 emissions in the United States.[75] As previously mentioned, CH_4 has a global warming potential of 21, which indicates that the gas' ability to trap heat in the atmosphere is 21 times greater than that of CO_2.[76] As a part of both natural gas and oil systems, CH_4 is emitted throughout the processes of production, storage, transportation, and distribution. Fugitive emissions occur during normal production and maintenance processes and as a result of leaks in distribution pipelines.

CH_4 emissions from natural gas systems occur during the following three activities: processing, transmission, and distribution. During processing, liquid constituents and condensate are removed before the natural gas is introduced into transmission pipelines. Major sources of CH_4 emissions include compressor equipment and venting practices.

The natural gas transmission infrastructure is composed of large diameter, high pressure pipelines that transport natural gas from production wells to processing plants, storage facilities, and, eventually, to distribution companies or large consumers. Along the length of transmission pipelines, compressor stations maintain the pipeline pressure. The major sources of CH_4 emissions include pipeline leaks, system vents, and compressor station equipment.

Compared to the transmission infrastructure, natural gas distribution pipelines are much smaller and are not as pressurized. As natural gas is transferred from the transmission system to the distribution system, the pressure is reduced before delivery to individual customers. The major sources of CH_4 emissions include leaks from pipeline, meters, and regulators.

The majority of CH_4 emissions from oil systems occur during crude oil extraction, transportation, and storage. The geologic formations that contain crude oil are often accompanied by natural gas. As oil is extracted from the subsurface, the associated natural gas is separated and transferred via

gathering pipelines to storage facilities. CH_4 emissions result from leaks in gathering pipeline, as well as venting and flaring activities. When crude oil is stored before transport to refineries, the natural gas left in solution vaporizes and is either vented directly to the atmosphere or collected in vapor recovery units. In general, emissions from crude oil storage represent the major source of CH_4 from oil systems.[77]

Required Data

Required activity data include various characteristics of the natural gas production, transportation, and distribution infrastructure. These types of activity data are described in Table 3-8.

Table 3-8: Required Activity Data for Natural Gas Systems

Production and Processing	Transmission	Distribution
Number of wells	Number of miles of transmission pipeline	Number of miles of pipeline (cast iron, unprotected steel, protected steel, and plastic)
Number of processing plants	Number of compressor stations and storage compressor stations	Total number of services (customer connections)
	Number of liquefied petroleum gas storage stations	Number of steel services (unprotected and protected)
	Number of miles of gathering pipeline	

Data on the number of miles of gathering, transmission, and distribution pipeline, as well as the number of services were obtained from the U.S. Department of Transportation, Office of Pipeline Safety. The number of natural gas processing plants was obtained from *Oil and Gas Journal.*[78,79] Since it was not possible to locate any sources for the number of compressor stations and storage compressor stations, these data were estimated following EIIP guidelines. For both 1990 and 2002, the number of compressor stations and the number of storage compressor stations were estimated by multiplying the transmission pipeline mileage by 0.005975 and by 0.001357, respectively. The Michigan Department of Environmental Quality indicated that the there are no liquefied petroleum gas storage stations in the state.[80]

The required activity data for oil systems include the amount of crude oil produced, refined, and transported. Oil production data were obtained from the EIA. The amount of oil refined was estimated using EIIP guidance and the amount of oil transported was assumed to equal the amount refined. A

detailed discussion covering the calculation of oil refined activity data is presented in Appendix F.

Methodology

The emissions calculation methodology for natural gas systems is straightforward. Once the required activity data were obtained, they were multiplied by the appropriate CH_4 emission factor. These emission factors are included in Appendix F. Finally, the CH_4 emissions are converted to million metric tons carbon equivalent.

Calculating CH_4 emissions from oil systems was slightly more involved than the natural gas system methodology. The default EIIP emission factors for production, refining, and transportation were not developed from the same source data. In order to match the default 2002 emission factors derived from U.S. EPA data, emission factors were calculated separately for 1990 using similar data from the U.S. EPA. Additional explanation of theses calculations is included in Appendix F.

Results

In 2002, activities associated with extraction, storage, transmission, and distribution of natural gas and oil emitted an estimated 1.31 MMTCE. This represented an increase of 30 percent from 1990 emissions. Emissions in 1990 were 1.01 million MMTCE. The growth in emissions was primarily driven by production and distribution activities in the natural gas sector. The number of natural gas wells and the number of miles of distribution pipeline grew substantially between 1990 and 2002, increasing CH_4 emissions. Emissions are summarized in Table 3-9.

Table 3-9: Summary of Natural Gas and Oil System Emissions (MMTCE)

Activity	1990	2002
Natural Gas	0.976	1.296
Production	0.03	0.11
Transmission	0.53	0.51
Distribution	0.42	0.67
Oil	0.0373	0.0177
Production	0.036	0.017
Refining	0.001	0.0007
Transportation	0.0003	0.0001
TOTAL	**1.014**	**1.313**

3.4 Methane and Nitrous Oxide Emissions from Stationary Combustion

The EPA defines stationary combustion as "all fuel combustion activities except those related to transportation (i.e. mobile combustion)."[81] Other than CO_2, emissions from stationary combustion include the greenhouse gases such as CH_4 and N_2O and various other air pollutants, carbon monoxide (CO), nitrogen oxides (NOx), and non-methane volatile organic compounds (NMVOC), as the result of incomplete combustion.[82] Emissions of these gases from this source category are influenced by fuel characteristics, size and vintage of equipment, combustion technology, pollution control equipment, operation and maintenance practices, and surrounding environmental conditions.[83]

N_2O emissions from stationary combustion are "closely related to air-fuel mixes and combustion temperatures, as well as the characteristics of any pollution control equipment that is employed".[84] CH_4 emissions from this source category are more a function of CH_4 content of the fuel and combustion efficiency. Emissions of these gases may range several orders of magnitude, much higher for facilities under poor maintenance and operation, as well as for those during start-up periods, when combustion efficiency is lowest.[85]

Required Data

The emissions of CH_4 and N_2O from stationary combustion depend on the amount and type of fuel used, combustion technologies, and the type of emission control. As the EIIP indicates, uncertainties exist in both the emission factors and activity data used to calculate emission estimates. Therefore, the more detailed information available on these factors related to combustion activity will lower uncertainty in emission estimation.[86]

To calculate CH_4 and N_2O emissions from stationary combustion for 1990, state-level fuel consumption data for five end-use categories (residential, commercial, industrial, transportation and electric utilities) were collected from the Department of Energy, Energy Information Administration (EIA)'s consumption data[87]. For uncertainties related to activity data, the EPA identifies difficulties in calculating emissions from wood combustion and the EIIP guidelines also state that the EIA *State Energy Data* does not fully capture the amount of wood used in fireplaces, wood stoves, and campfires.[88, 89]

Due to the timing of the research for this project, no comprehensive energy data for Michigan in 2002 had been compiled by EIA. Therefore, the *Annual Coal Report 2002*[90] and *Annual Natural Gas Report 2002*[91] were referred to as data sources for coal and natural gas consumption figures. For petroleum-based fuels and wood, the EIA's historical consumption data for 1990-2001 were used to estimate values for 2002. Although we could obtain a very likely figure for 2002 CH_4 and N_2O emissions from the estimation process, it should be corrected in a future research when more accurate data are published by the EIA.

The EPA states that "the uncertainties associated with the emission estimates of CH_4 and N_2O are greater than those associated with estimates of CO_2 from fossil fuel combustion, which mainly rely on the carbon content of fuel combusted."[92] Inherent uncertainties for the emission factors of these gases are mainly derived from the fact that they cover only a limited subset of combustion conditions. In this inventory, the estimates of CH_4 and N_2O emissions are based on fuel use multiplied by an aggregate emission factor for different sectors, rather than taking account of combustion technology and type of emission control.[93] However, because of "the combined difficulty in obtaining specific combustion technology information and the relatively low contribution of this source to a state's total emissions", the EIIP guidelines support the IPCC Tier 1 approach (the methodology employed here) as a recommended approach for a state's inventory purpose.[94]

Methodology

Emissions of CH_4 and N_2O from stationary combustion for 1990 and 2002 were calculated using the EIIP guidelines and the State Inventory Tool (SIT). Consumption data that were originally provided in physical units such as barrels and short tons were converted to British thermal units (Btu) by factors supplied by the EIIP guidelines and EIA.

For some fuel types used in part for non-fuel purposes (i.e. asphalt and road oil), the percentage of stored carbon for that non-fuel use was calculated for each fuel type to obtain use the net carbon available for immediate release. We subtracted the non-fuel amount from consumption data to obtain the CH_4 and N_2O amounts immediately released to the atmosphere.

Results

Overall, stationary combustion is a small source of CH_4 and N_2O in the State of Michigan as well as in the United States. However, there have been some interesting changes over the last 12 years. The economic sector that contributed most to CH_4 emissions was the residential sector, accounting for more than half, or 51 percent for 2002 and 64 percent for 1990 (Table 3-10). The second biggest contributor was the industrial sector, accounting for 29

and 21 percent, respectively, for 2002 and 1990. The industrial sector was followed by minor contributions from the commercial and electric utility sectors. The higher CH_4 emission from the residential sector is mainly due to this sectors' relative dependency on wood (Table 3-10), which has a higher emission factor for CH_4 compared with other fuels.[x] Higher dependency on wood made the emission intensity of this sector the highest among all economic sectors despite its relatively small energy consumption (Table 3-11).

On the contrary, the emission shares by sector were different for N_2O emissions. For both years, the electric utility sector was by far the largest emitter with over 60 percent of the state's total N_2O emissions from stationary combustion, followed by the industrial, residential and commercial sectors (Table 3-12). This is because the utility sector depends heavily on coal for electricity generation, and coal has a higher emission factor for N_2O compared with other fuels (Table 3-13).

Emissions of CH_4 were 0.061 MMTCE in 2002, showing a decrease of 34 percent from 0.0924 MMTCE in 1990 (Table 3-10) despite growing energy consumption over these twelve years (Table 3-11). This decrease in CH_4 emissions was primarily due to less wood consumption in the residential sector. N_2O emissions decreased slightly, by four percent from 0.1256 MMTCE in 1990 to 0.1204 MMTCE in 2002 (Table 3-12). The largest source of N_2O emissions was coal combustion by electricity generators, which alone accounted for over 60 percent of total N_2O emissions from stationary combustion in both years.

[x] For CH_4 Emission Factors, see Appendix E.

Table 3-10: CH_4 Emissions from Stationary Combustion in Michigan for 1990 and 2002

		1990		2002		
		Emissions (MTCE)	Percent Share	Emissions (MTCE)	Percent Share	% Change in Emissions
Residential	Coal	2,300	*3.9%*	1,300	*4.2%*	-43.5%
Residential	Petroleum	3,100	*5.2%*	3,700	*12.0%*	19.4%
Residential	Natural Gas	9,300	*15.6%*	10,300	*33.3%*	10.8%
Residential	Wood	44,800	*75.3%*	15,600	*50.5%*	-65.2%
Residential	**Total**	**59,500**	**64.4%**	**30,900**	**50.7%**	**-48.1%**
Commercial	Coal	300	*3.4%*	300	*3.9%*	0.0%
Commercial	Petroleum	1,200	*13.6%*	1,000	*13.2%*	-16.7%
Commercial	Natural Gas	4,500	*51.1%*	4,900	*64.5%*	8.9%
Commercial	Wood	2,800	*31.8%*	1,400	*18.4%*	-50.0%
Commercial	**Total**	**8,800**	**9.5%**	**7,600**	**12.5%**	**-13.6%**
Industrial	Coal	5,100	*25.9%*	2,600	*14.8%*	-49.0%
Industrial	Petroleum	700	*3.6%*	600	*3.4%*	-14.3%
Industrial	Natural Gas	7,900	*40.1%*	6,700	*38.1%*	-15.2%
Industrial	Wood	6,000	*30.5%*	7,700	*43.8%*	28.3%
Industrial	**Total**	**19,700**	**21.3%**	**17,600**	**28.9%**	**-10.7%**
Utility	Coal	3,800	*86.4%*	3,900	*79.6%*	2.6%
Utility	Petroleum	200	*4.5%*	200	*4.1%*	0.0%
Utility	Natural Gas	400	*9.1%*	800	*16.3%*	100.0%
Utility	Wood	0	*0.0%*	0	*0.0%*	0.0%
Utility	**Total**	**4,400**	**4.8%**	**4,900**	**8.0%**	**11.4%**
Total	**Coal**	**11,500**	**12.4%**	**8,100**	**13.3%**	**-29.6%**
Total	**Petroleum**	**5,200**	**5.6%**	**5,500**	**9.0%**	**5.8%**
Total	**Natural Gas**	**22,100**	**23.9%**	**22,700**	**37.2%**	**2.7%**
Total	**Wood**	**53,600**	**58.0%**	**24,700**	**40.5%**	**-53.9%**
Total	**Total**	**92,400**	**100.0%**	**61,000**	**100.0%**	**-34.0%**

Note: Percentage shares in block letters are sectoral shares, while those in italics are shares within each end-use sector by fuel type.

Table 3-11: CH_4 Emission Intensity from Stationary Combustion in Michigan for 1990 and 2002

	1990		2002		
	Consumption (Bbtu)	Emission Intensity (MTCE/Bbtu)	Consumption (Bbtu)	Emission Intensity (MTCE/Bbtu)	% Change in Emission Intensity
Residential	423,848	0.1404	454,300	0.0680	-51.5%
Commercial	194,050	0.0453	204,495	0.0372	-18.0%
Industrial	480,647	0.0410	392,801	0.0448	9.3%
Utility	741,845	0.0059	836,167	0.0059	-1.2%
Total	**1,840,390**	**0.0502**	**1,887,762**	**0.0323**	**-35.6%**

Table 3-12: N_2O Emissions from Stationary Combustion in Michigan for 1990 and 2002

		1990		2002		
		Emissions (MTCE)	Percent Share	Emissions (MTCE)	Percent Share	% Change in Emissions
Residential	Coal	200	*1.4%*	100	*1.1%*	-50.0%
Residential	Petroleum	2,700	*18.8%*	3,200	*33.7%*	18.5%
Residential	Natural Gas	2,700	*18.8%*	3,100	*32.6%*	14.8%
Residential	Wood	8,800	*61.1%*	3,100	*32.6%*	-64.8%
Residential	**Total**	**14,400**	**11.5%**	**9,500**	**7.9%**	**-34.0%**
Commercial	Coal	600	*17.1%*	700	*21.2%*	16.7%
Commercial	Petroleum	1,000	*28.6%*	900	*27.3%*	-10.0%
Commercial	Natural Gas	1,300	*37.1%*	1,400	*42.4%*	7.7%
Commercial	Wood	600	*17.1%*	300	*9.1%*	-50.0%
Commercial	**Total**	**3,500**	**2.8%**	**3,300**	**2.7%**	**-5.7%**
Industrial	Coal	10,600	*38.0%*	5,400	*21.4%*	-49.1%
Industrial	Petroleum	3,300	*11.8%*	2,700	*10.7%*	-18.2%
Industrial	Natural Gas	2,300	*8.2%*	2,000	*7.9%*	-13.0%
Industrial	Wood	11,700	*41.9%*	15,100	*59.9%*	29.1%
Industrial	**Total**	**27,900**	**22.2%**	**25,200**	**20.9%**	**-9.7%**
Utility	Coal	78,700	*98.6%*	80,600	*97.8%*	2.4%
Utility	Petroleum	500	*0.6%*	600	*0.7%*	20.0%
Utility	Natural Gas	600	*0.8%*	1,200	*1.5%*	100.0%
Utility	Wood	0	*0.0%*	0	*0.0%*	0.0%
Utility	**Total**	**79,800**	**63.5%**	**82,400**	**68.4%**	**3.3%**
Total	**Coal**	**90,100**	**71.7%**	**86,800**	**72.1%**	**-3.7%**
Total	**Petroleum**	**7,500**	**6.0%**	**7,400**	**6.1%**	**-1.3%**
Total	**Natural Gas**	**6,900**	**5.5%**	**7,700**	**6.4%**	**11.6%**
Total	**Wood**	**21,100**	**16.8%**	**18,500**	**15.4%**	**-12.3%**
Total	**Total**	**125,600**	**100.0%**	**120,400**	**100.0%**	**-4.1%**

Note: Percentage shares in block letters are sectoral shares, while those in italics are shares within each end-use sector by fuel type.

Table 3-13: N_2O Emission Intensity from Stationary Combustion in Michigan for 1990 and 2002

	1990		2002		
	Consumption (Bbtu)	Emission Intensity (MTCE/Bbtu)	Consumption (Bbtu)	Emission Intensity (MTCE/Bbtu)	% Change in Emission Intensity
Residential	423,848	0.0340	454,300	0.0209	-38.4%
Commercial	194,050	0.0180	204,495	0.0161	-10.5%
Industrial	480,647	0.0580	392,801	0.0642	10.5%
Utility	741,845	0.1076	836,167	0.0985	-8.4%
Total	**1,840,390**	**0.0682**	**1,887,762**	**0.0638**	**-6.5%**

Residential Methane and Nitrous Oxide Emissions

CH_4 emissions from the residential sector in 2002 were 0.0309 MMTCE, decreasing 48 percent from 0.0595 MMTCE in 1990, despite a seven percent increase in overall energy consumption in this sector over these 12 years (Tables 3-10 and 3-11). This was mainly due to a 65 percent decrease in emissions from wood consumption in this sector. Even with such a sharp decrease in consumption, emissions from wood still accounted for the largest share (51 percent) of the total emissions from this sector. In contrast, the shares of emissions from petroleum and natural gas, which were 5 and 16 percent, respectively in 1990, increased to 12 and 33 percent. It is also noteworthy that emissions from coal consumption decreased by 44 percent during these 12 years. However, given the initial share of the emission had already been small (four percent), this 44 percent decrease did not have a major impact on the total CH_4 emission from this sector. The trend for Michigan was similar to that for the United States, where emissions from coal and wood consumption also showed a large decrease during the same period of time, 50 and 41 percent, respectively.[95] Although Michigan's residential sector showed slight increases in emissions from petroleum and natural gas consumption, while those for the United States remained nearly unchanged[96], the sector achieved a much larger reduction in total emissions, compared with the national trend, due to a large decrease in wood consumption.

The trend for N_2O for this same period of time was similar to that for CH_4, indicating a sharp decrease in emissions from wood consumption (Table 3-12). Emissions from coal consumption also decreased by 50 percent, but had a much smaller impact on the total emissions, given the even smaller share of the emissions from coal consumption compared with CH_4. The N_2O trend in Michigan also resembled the national trend, but achieved a higher, almost double, reduction.

Commercial Methane and Nitrous Oxide Emissions

Despite a five percent increase in energy consumption (Table 3-11), CH_4 emission from this sector decreased 14 percent from 0.0088 MMTCE in 1990 to 0.0076 MMTCE in 2002. This is because of emission reductions from petroleum and wood consumption (Table 3-10). The same trend could be observed for N_2O emissions, where the sharp decrease in emissions from wood consumption by 50 percent contributed to a six percent reduction in this sector (Table 3-12). However, the change in absolute amounts was very small, from 0.0035 MMTCE in 1990 to 0.0033 MMTCE in 2002.

Industrial Methane and Nitrous Oxide Emissions

Unlike the residential and commercial sectors, CH_4 emissions from wood consumption in the industrial sector slightly increased by 0.0017 MMTCE from 1990 to 2002. However, the sector as a whole achieved a total emission reduction of 11 percent, largely due to a 49 percent emission reduction from coal consumption as well as reductions from other types of fuel consumption (Table 3-10). A similar scenario took place for N_2O emissions from wood consumption increased by 0.0034 MMTCE from 1990 to 2002, but the reduced emissions from the other types of fuel consumption, notably from coal, contributed to a total reduction of 10 percent for this sector in these 12 years (Table 3-12).

Electric Utility Methane and Nitrous Oxide Emissions

The share of CH_4 emissions from the electric utility sector was small, eight percent for 2002 and five percent for 1990 (Table 3-10). This was because the sector did not depend on wood. On the other hand, the utility sector was the largest contributor for N_2O emissions, responsible for 68 percent for 2002 and 64 percent for 1990 – due to its higher coal dependency for power generation (Table 3-12). The N_2O emission from coal consumption in this sector was 98 and 99 percent in 2002 and 1990, respectively.

4. Industrial Processes

Industry emits greenhouse gases in two basic ways: through the combustion of fossil fuels for energy production and through a variety of raw material transformation and production processes. The emissions associated with fossil fuel combustion have already been accounted for and discussed in the previous energy section, Chapter 3.1: Carbon Dioxide Emissions from Fossil Fuel Combustion. This section of the report will focus on the various industrial processes that are major contributors of greenhouse gas emissions. The specific sources of emissions are as follows:

- Iron and Steel Production
- Cement Manufacture
- Lime Manufacture
- Limestone and Dolomite Use
- Nitric Acid Production
- Adipic Acid Production
- Ozone Depleting Substances Substitution
- Semiconductor Manufacture
- Magnesium Production
- Electric Power Transmission and Distribution Systems
- HCFC-22 Production
- Aluminum Production

In addition to contributing to carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions, certain industrial processes are major sources of emissions of GHGs with high global warming potentials. These gasses include sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs).

Research revealed that a number of industrial processes that have the potential for contributing significant amounts of greenhouse gases do not actually occur in Michigan and emissions calculations were not needed. These industries are: nitric acid production, adipic acid production, HCFC-22 production, and aluminum production.

The general methodology to estimate industrial process greenhouse gas emissions involves multiplying production data for each process by an emission factor per unit production. The emission factors used were either derived using calculations that assume precise and efficient chemical reactions or were based upon empirical data in published references.

4.1 Emissions Summary

Over the period of 1990 to 2002, Michigan's industrial process greenhouse emissions increased to 3.04 million metric tons carbon equivalent (MMTCE) in 2002 from 1.77 MMTCE in 1990, an increase of approximately 72 percent. A summary of all industrial process emissions is presented as Table 4-1. The iron and steel sector was the largest emitter in both 1990 and 2002. In 2002, CO_2 emissions increased to 1.08 MMTCE, nearly a 66 percent increase over 1990 emissions. Iron and steel CH_4 emissions decreased to 0.022 MMTCE, a decrease of 6.8 percent from 1990 levels. In 1990, this sector contributed emissions of CO_2 on the order of 0.65 MMTCE and CH_4 emissions totaling 0.024 MMTCE. Figure 4-1 presents industrial process CO_2 and CH_4 emissions.

Table 41: Summary of Industrial Process Greenhouse Gas Emissions: 1990 and 2002 (MTCE)

Gas/Activity Type	1990	2002	Percent Change
CO_2	**1,450,706**	**1,892,908**	**30.5%**
Cement Manufacture	620,007	577,489	-6.9%
Lime Manufacture	116,752	178,529	52.9%
Limestone and Dolomite Use	42,631	28,216	-33.8%
Soda Ash	19,349	27,336	41.3%
Iron and Steel	651,967	1,081,338	65.9%
Pig Iron Production	492,561	975,782	98.1%
Raw Steel Production	133,379	84,450	-36.7%
Electric Arc Furnace	4,124	4,705	14.1%
Steel Scrap Reuse	21,903	16,400	-25.1%
CH_4	**23,739**	**22,134**	**-6.8%**
Iron and Steel	23,739	22,134	-6.8%
Coking Operations	2,762	8,043	191.3%
Pig Iron Production	20,978	14,091	-32.8%
N_2O	--	--	**--**
Nitric Acid Production	--	--	--
Adipic Acid Production	--	--	--
HFC and PFC	**3,393**	**866,937**	**25,450.3%**
ODS Substitutes	3,393	866,937	25,450.3%
SF_6	**292,210**	**260,711**	**-10.8%**
Semiconductor Manufacturing	312	575	84.3%
Magnesium Casting	50,082	137,721	175.0%
Electric Power Transmission and Distribution Systems	241,816	122,415	-49.4%
HCFC-22 Production	--	--	--
Aluminum Production	--	--	--
Total	**1,770,048**	**3,042,690**	**71.9%**
Percent Share of State Total	**3.1%**	**4.9%**	

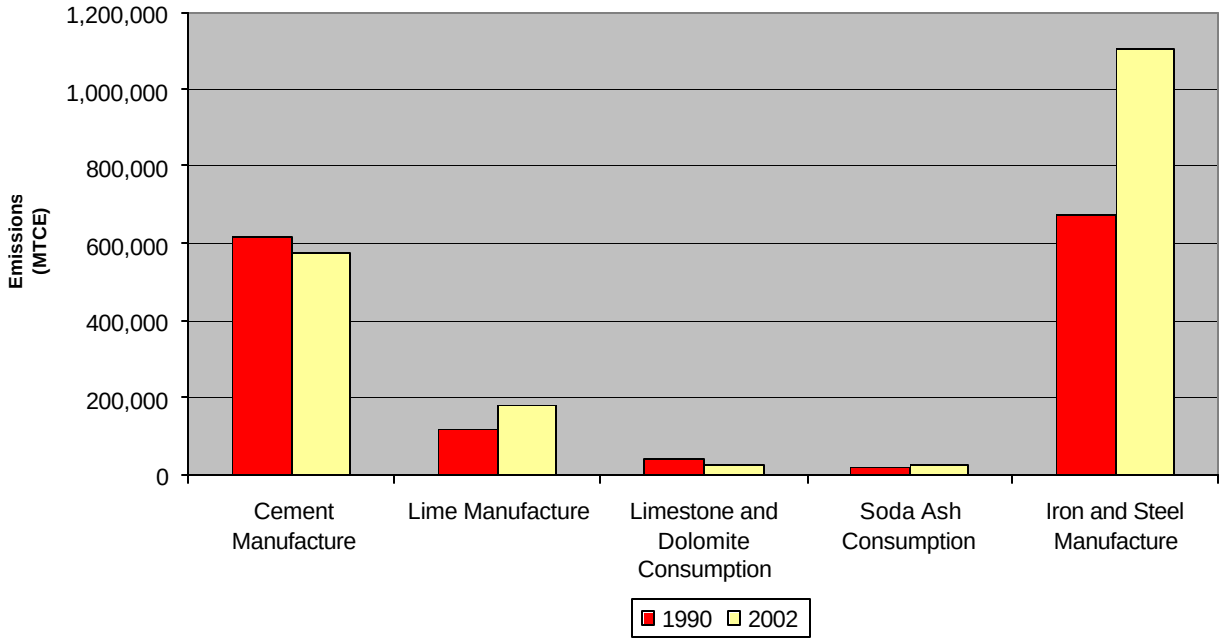


Figure 4-1: Michigan Industrial Process CO_2 and CH_4 Emissions: 1990 and 2002

In regards to SF_6, PFC, and HFC emissions, the magnesium casting sector witnessed a large emissions increase from 1990 and 2002. Specifically, emissions grew to 0.138 MMTCE in 200 from 0.050 MMTCE in 1990, a 175 percent increase. In the mid-1990s, a new major magnesium processing and casting facility began operations. The new facility significantly increased the amount of magnesium being processed and cast in Michigan, which is reflected in the large growth of emissions. All of Michigan's major magnesium facilities are partners in the U.S. EPA's voluntary SF_6 reduction program, which has been successful in reducing the greenhouse gas intensity of the industry.

A large increase of emissions was also noted due to the substitution of ozone depleting substances (ODS). In 2002, emissions from ODS substitutes had increased to 0.867 MMTCE, an increase of over 25,000 percent from 1990 emissions of 0.003 MMTCE. These values are not based on data specific to Michigan, but are instead estimated from national trends. Even though these emission estimates are based on national data, they still reflect the increasingly widespread use of HFCs and PFCs in refrigeration, cooling, and other industrial applications. Additionally, it is important to note the large increase in emissions from ODS substitution because HFCs and PFCs are powerful GHGs, with large global warming potentials. A summary of the industrial processes contributing to SF_6, PFC, and HFC emissions is presented as Figure 4-2.

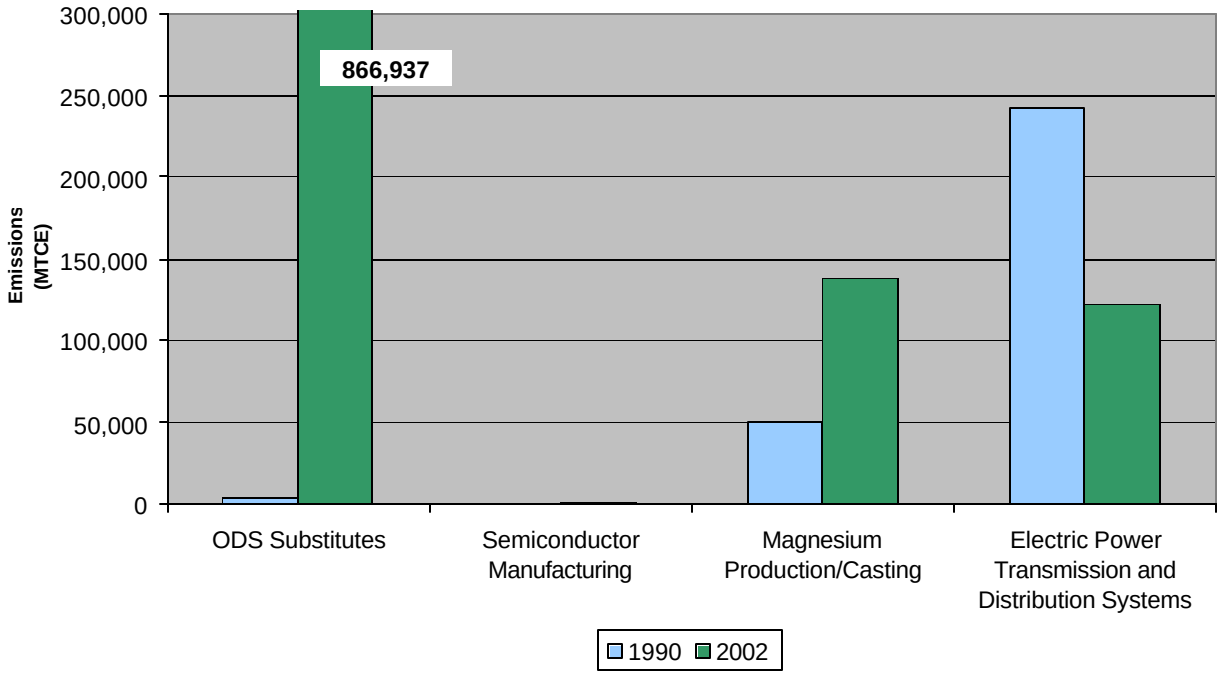


Figure 4-2: Michigan Industrial Process SF_6, HFC, and PFC Emissions: 1990 and 2002

CO_2 represents the largest contributor to Michigan's non-fuel greenhouse gas from industrial processes. Although this was especially true in 1990, the distribution of relative contribution underwent change by 2002. As shown by Figures 4-3 and 4-4, the relative contribution of CO_2 in 2002 was 62 percent, a substantial decrease from the contribution of 82 percent in 1990. The main factor influencing this change was the tremendous increase in use of HFCs and PFCs for replacement of ODS. The contribution of HFCs and PFCs increased to 28 percent in 2002, up from just slightly over 0.19 percent in 1990.

The contribution of SF_6 decreased from 1990 to 2002. In 2002, SF_6 contributed to 9 percent of industrial emissions, down by 17 percent from 1990. Due in large part to increases in CO_2, HFC, and PFC emissions, the contraction of the emissions share of SF_6 was also influenced by the voluntary reduction programs in the magnesium casting and electric power distribution and transmission sectors. As previously mentioned, SF_6 emissions from the electric power transmission and distribution sector may be larger than the calculations indicate for 2002. If this were the case, SF_6 emissions would represent a larger share of the overall emissions.

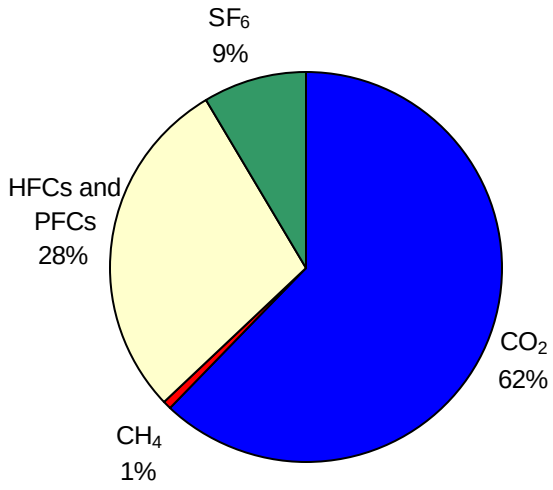


Figure 4-3: Industrial Process Emissions Distribution by Greenhouse Gas: 2002

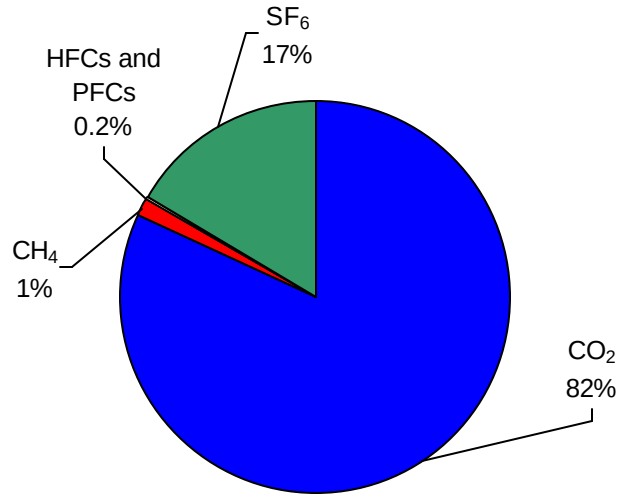


Figure 4-4: Industrial Process Emissions Distribution by Greenhouse Gas: 1990

4.2 Greenhouse Gas Intensity Analysis

Greenhouse gas intensity values remained relatively constant between 1990 and 2002 and are summarized in Table 4-2. The only exceptions were the sectors of pig iron production, magnesium production, and electric power transmission and distribution. In the case of pig iron production, the greenhouse gas intensity value in 2002 of 0.365 MTCE/metric ton of pig iron produced is more than double that of the 1990 value, 0.127 MTCE/metric ton pig iron produced. The reason for this is that in 2002 production of pig iron had declined, while the consumption of coal at coke plants had nearly doubled since 1990. Since the amount of coking coal consumed at coke plants was used to calculate emissions from pig iron production, the rise in emissions was reflected in the intensity value for 2002.

Conversely, the greenhouse gas intensity values for the magnesium casting, and electric power transmission and distribution sectors have declined over the same period. The U.S. EPA has created voluntary SF_6 emission reduction programs for both sectors and the effects of these programs are evident in the decrease of intensity values. The reduction program for the electricity transmission and distribution sector aims to replace SF_6 with other electrical insulators, while the magnesium sector reduction program focuses on finding substitute cover gases to replace SF_6.

The effects of voluntary emission reduction programs are significant. By 2002, the annual amount of magnesium cast had increased to 26,411metric tons, up from 1,874 metric tons in 1990. In the same time period, SF_6 emissions increased only to 137,721 MTCE from 50,082 MTCE. Consequently, the GHG intensity values decrease from 26.72 MTCE/metric ton Mg cast in 1990 to 5.21 MTCE/metric ton Mg cast in 2002. It should be noted that all of the Michigan firms contacted for magnesium casting data are members of the magnesium industry SF_6 reduction program.

In the case of the electric power transmission and distribution sector, calculated SF_6 emissions totaled 122,415 MTCE in 2002, compared to 241,816 MTCE in 1990. At the same time, electricity consumption increased to 107,311 million kilowatt-hours (kWh) from 82,367 million kWh in 2002 and 1990, respectively. As previously mentioned, there is one caveat: it may or may not be the case that Michigan's electricity generators have made the efforts to reduce SF_6 emissions from their transmission and distribution infrastructure. Michigan's emissions in this category were calculated based on the ratio of state and national population and national SF_6 emissions. The reduction of Michigan's SF_6 emissions and GHG intensity were expected to follow the national trend.

Table 4-2: Summary of Industrial Process Greenhouse Gas Intensity Values

Emissions Sector	1990 GHG Intensity	2002 GHG Intensity	Unit	Notes
CO_2 and CH_4 Emissions				
Cement Manufacture	0.134	0.132	MTCE/metric ton cement produced	Includes the production of both clinker and masonry cement.
Lime Manufacture	0.210	0.210	MTCE/metric ton lime produced	Includes high-calcium, dolomitic, and hyrdated lime
Limestone and Dolomite Consumption	0.122	0.124	MTCE/metric ton limestone and dolomite consumed	
Soda Ash Consumption	0.113	0.113	MTCE/metric ton soda ash consumed	
Iron and Steel Manufacture				
Coking Operations	0.682	0.701	MTCE/metric ton coal consumed at coke plants	
Pig Iron Production	0.127	0.365	MTCE/metric ton pig iron produced	Methodology is based on coal consumed at coke plants.
Raw Steel Production	0.019	0.014	MTCE/metric ton raw steel produced	
HFC, PFC, and SF_6 Emissions				
Semiconductor Manufacturing	0.010	0.016	MTCE/ $1,000 of shipments	
Magnesium Casting	26.72	5.21	MTCE/metric ton Mg cast	
Electric Power Transmission and Distribution Systems	2.94	1.14	MTCE/million kWh consumed	

4.3 Industrial Process Emissions Description

Iron and Steel

The production of raw steel begins with heating iron ore in the presence of a reducing agent, usually metallurgical coal coke, to produce pig iron. The majority of CO_2 emissions from iron and steel production occur when metallurgical coke is oxidized during the production of pig iron. Metallurgical coke is produced by carbonizing coking coal. During this process, coal is heated in the absence of air, which removes moisture and volatile organic constituents. Coking operations also produce carbon byproducts of coke oven gas, which is burned as fuel by the coking plant, and coal tar.

Steel is produced by heating pig iron, scrap steel or iron, and alloying elements in a furnace. This process removes much of the carbon contained in pig iron, which results in CO_2 emissions.

Required Data

The activity data required to calculate iron and steel emissions include the amount of coal consumed for coal coke production at Michigan coking plants and the amount of raw steel, pig iron, and electric arc furnace steel produced in Michigan. The amounts of pig iron and electric arc furnace steel produced were not available for Michigan. Therefore, these data were estimated based on national data. A more detailed description of the estimation methods is presented in Appendix G. Additionally, the amounts of scrap pig iron and scrap steel consumed were required for emissions calculations.

Except for the emission factors for coking coal, which were back calculated based on EIA data, all emission factors were obtained from the U.S. EPA.

Methodology

Since the SIT modules do not include calculations for emissions from the iron and steel industry, a separate methodology had to be pursued. Calculation methodologies from both the U.S. EPA and the IPCC were evaluated for applicability to Michigan. It was discovered that although the U.S. EPA methodology provides a more complete accounting of emissions, the Intergovernmental Panel on Climate Change (IPCC) methodology was a better fit for the available data. Use of the U.S. EPA methodology would have necessitated

numerous estimations of Michigan data, based only on national trends. For example, the amount of metallurgical coke imported and exported from Michigan was not available.

However, when possible, certain portions of the U.S. EPA methodology were incorporated into the approach used for Michigan. For instance, the U.S. EPA's practice of accounting for the release of CO_2 from scrap steel and scrap pig iron consumption was used in the emissions calculations. This practice included the assumption that the entire carbon content of the scrap steel and scrap pig iron is released on combustion. Also, the U.S. EPA methodology includes CH_4 emission factors for coking operations and pig iron production, whereas the IPCC methodology does not.

Results

The increase in total greenhouse emissions from the iron and steel sector was driven by the significant increase in coal consumed at coking plants. Although the production of both pig iron and steel decreased between 1990 and 2002, coking plants consumed nearly twice the amount of coal in 2002, which is reflected in the near doubling of emissions from the sector. Greenhouse gas emissions from the iron and steel sector totaled 1.10 MMTCE in 2002 and 0.676 MMTCE in 1990.

Cement Manufacture

Cement manufacture, an energy and raw material intensive process, is one of the largest sources of industrial CO_2 emissions in the U.S. Cement is produced by combining clinker with gypsum. Clinker production begins in a cement kiln, where limestone (calcium carbonate, $CaCO_3$) is heated at a temperature of about 2,400° F to form lime (calcium oxide, CaO) and CO_2. This process, known as calcination, is responsible for CO_2 emissions. Calcination is represented by the following equation:

$$CaCO_3 + heat \rightarrow CaO + CO_2$$

After calcining, the lime is mixed with silica-containing materials to produce clinker. After cooling, clinker is mixed with a small amount of gypsum and is used to make Portland cement. The production of masonry cement requires mixing Portland cement with additional lime, which results in additional CO_2 emissions.

Required Data

In order to calculate CO_2 emissions from cement manufacture, activity data for annual clinker and masonry cement production are required. Both types of data were obtained from USGS sources, including the 1990 and 2002 *Minerals Yearbook*.[97]

Methodology

In order to calculate the CO_2 emissions from clinker production, the emission factor for clinker was multiplied by the total annual clinker production. After the calcination process is complete, the cement kiln typically contains remnants of non-, partially, and fully-calcinated material, known as cement kiln dust (CKD). The calcinated portions of CKD are not accounted for in the clinker emissions calculations. Accordingly, the IPCC recommended methodology states that the CO_2 emissions due to CKD are approximately 2 percent of the total clinker production emissions.[98]

Since additional lime is required for the production of masonry cement, an emission factor for masonry cement was multiplied by the total annual masonry cement production. The sum of emissions from the clinker, CKD, and masonry cement categories represents the total CO_2 emissions for the cement industry.

Results

In 2002, CO_2 emissions from cement manufacture were 0.577 MMTCE, a 7 percent decrease from 1990 emissions. In 1990, CO_2 emissions totaled 0.620 MMTCE. The emissions decrease is a result of a modest drop in clinker production from 4.39 million metric tons in 1990 to 4.08 million metric tons in 2002.

Lime Manufacture

The term “lime” refers to six types of chemicals produced by calcining calcinic or dolomitic limestone. These include quicklime (CaO), hydrated quicklime ($Ca(OH)_2$), dolomitic quicklime (CaOMgO), and dolomitic hydrate ($Ca(OH)_2MgO$ and $Ca(OH)_2(MgO)_2$), and dead-burned dolomite. Lime is used in a variety of applications, including steel making, flue gas desulfurization, water purification, construction, and pulp and paper manufacturing.

The production of lime involves three main steps: stone preparation, calcination, and hydration. Like the initial step of cement production, calcining limestone, or a mixture of limestone and magnesium carbonate in a

kiln produces lime. This process produces quicklime (CaO), and CO_2. The CaO can either remain as is or undergo the process of slaking, which produces hydrated lime.

Required Data

In order to calculate the greenhouse gas emissions from lime manufacture it was necessary to collect annual production data for the following: high-calcium quicklime and hydrated lime; dolomitic quicklime and hydrated lime; and dead-burned dolomite. When available, production data were obtained from the USGS' *Minerals Yearbook*.[99]

Methodology

The basic calculation methodology for lime manufacture involves multiplying the amounts of high-calcium and dolomitic produced by their respective emission factors. Since the USGS only reports total quicklime and hydrated lime production for individual states, to account for the high calcium and dolomitic lime production it was necessary to disaggregate the Michigan lime data based on the distribution of national production.

Additionally, Michigan's total lime production for 2002 was not available. Instead, the value was estimated from a linear trend analysis of 1988 – 1999 production data.

Since water comprises a portion of hydrated lime it is necessary to correct for this fraction, which does not produce any CO_2. In order to correct for the water portion of hydrated lime, a water content percentage is applied to the annual hydrated lime production. The SIT uses water contents of 27 percent and 24 percent for high-calcium quicklime and dolomitic quicklime, respectively.[100]

Results

CO_2 emissions from lime manufacture increased from 1990 and 2002. In 2002, emissions were 0.179 MMTCE, while 1990 emissions were 0.117 MMTCE. This represents an increase of approximately 53 percent, which was driven by a rise in quicklime production. Conversely, the amount of hydrated lime produced in the state decreased between 1990 and 2002. Since hydrated lime production is a small fraction of the state's overall lime manufacture, the drop in production did not significantly affect CO_2 emissions.

Limestone and Dolomite Use

In addition to use as feedstocks for lime production, limestone and dolomite are used in a wide range of industries. These include construction, agriculture, metallurgy, pollution control, glass manufacturing, and chemical manufacturing. CO_2 emissions occur once either limestone or dolomite is heated sufficiently, as in the case of flue gas desulfurization and use as a flux in metallurgical furnaces.

Required Data

The required data include limestone and dolomite consumed for flux stone, chemical stone, glass making, and flue gas desulfurization. These data were obtained from the USGS' *Minerals Yearbook*.

Methodology

The basic method for calculating emissions involves multiplying the amount of limestone and dolomite consumed by the average carbon content for each type of stone. Assuming that all of this carbon is oxidized and released into the atmosphere as CO_2, the appropriate emission factor was then multiplied by the total annual amount of flux stone, chemical stone, glass making, and flue gas desulfurization consumed to calculate emissions.

Unfortunately, state-level data are not disaggregated into the required industrial sectors of limestone and dolomite use. It became necessary to apply national consumption patterns to the total amounts of limestone and dolomite used in Michigan.

Results

In 2002, the amount of CO_2 emitted from the use of limestone and dolomite had decreased to 0.028 MMTCE, a decrease of approximately 34 percent from 1990 emissions of 0.043 MMTCE. Although the total use of limestone and dolomite did not decrease in Michigan, the fraction of national consumption for industrial uses did decline from 1990 to 2002. The decrease in Michigan emissions reflected this national trend.

Soda Ash Consumption

Soda ash (sodium carbonate, Na_2CO_3) is consumed primarily in glass, alkali chemical, and soap and detergent production and is used for water treatment and flue gas desulphurization. CO_2 emissions can occur from soda ash

consumption and production of natural soda ash. Since soda ash is not produced in Michigan, only soda ash consumption is considered to be a source of emissions. For every mole of soda ash consumed in these uses, one mole of CO_2 is evolved.

Required Data

In order to calculate CO_2 emissions from soda ash consumption, state level soda ash consumption data are required. When these data are not available, national soda ash consumption data and national and Michigan population estimates are needed. National soda ash consumption data were obtained from the U.S.G.S.' *Minerals Yearbook*.[101]

Methodology

Since consumption data are not available on a state-level basis, the SIT calculation methodology uses a ratio of Michigan and national population multiplied by national consumption as an estimate. Instead of following this approach, value of shipments economic data for the soap and detergent, chemical, and glass manufacturing segments were collected for both Michigan and the U.S. from the U.S. Census Bureau. Specifically, value of shipments data were obtained for year 1992 for SIC codes 32, 284, and 2819.[i, 102] Value of shipments data for 1997 were obtained for NAICS codes 3272, 3256, 32518, and 325188. These data were used to calculate value of shipment ratios, which were multiplied by national soda ash consumption data to arrive at Michigan consumption estimates. Lastly, Michigan's total soda ash consumption was multiplied by the emission factor and converted to MMTCE.

Results

In 2002, CO_2 emissions from soda ash consumption were 0.027 MMTCE. This represents an increase of 41 percent over 1990 emissions of 0.019 MMTCE. The rise in emissions was due to an increase in estimated soda ash consumption.

Semiconductor Manufacture

The plasma etching and chemical vapor deposition processes of semiconductor manufacturing utilize a number of fluorinated gases, including

[i] "'Value of Shipments' refers to the value of all primary products produced by an industry; the value of secondary products, which are primary to other industries; … and the value of products purchased and resold without further processing" (U.S. Department of Commerce (2000)).

SF_6, HFCs, and PFCs. Continued industry growth and the introduction of increasingly complex semiconductor products have driven rapid emissions increases. Recently, however, the industry has begun implementing PFC emission reduction methods, including process optimization.

Required Data

In order to calculate emissions, value of shipments data for the semiconductor industries of Michigan and the U.S. were obtained from the U.S. Census Bureau. National SF6, PFC, and HFC emissions from semiconductor manufacture were obtained from the U.S. EPA.

Methods

As with the consumption of soda ash, state level SF_6 consumption data were not available and economic data were collected as surrogates. Specifically, the value of semiconductor shipments data (SIC 3674 and NAICS 334413) for both the U.S. and Michigan were used to calculate a ratio, which was then multiplied by the total U.S. SF_6 emissions for 1990 and 2002. The SIT methodology applied the same 1997 Economic Census data for 1990 and 2002. Instead of using the 1990 emissions estimates from the SIT module, a separate calculation was made using Economic Census data from 1992.

Results

Emissions from Michigan's semiconductor industry totaled 575 MTCE in 2002 and 312 MTCE in 1990. Although this represents an increase from 1990 emissions of over 84 percent, Michigan's semiconductor industry changed very little between the 1992 and 1997 Economic Census. Compared to national data, the increase in value of shipments for Michigan was slight.

Substitution of Ozone Depleting Substances (ODS)

As certain classes of ozone depleting substances (ODS) are phased out by requirements in the Montreal Protocol and the Clean Air Act Amendments of 1990, HFCs have been chosen as replacements. Although these categories of chemicals do not add to the destruction of the ozone layer, they are potent greenhouse gases.

The principle applications for ODS substitutes include refrigeration and air conditioning, solvent cleaning, fire extinguishing agents, and foam production. The U.S. EPA has developed a tool for estimating the rise in

consumption and emissions of HFCs and the decline of ODS consumption and emissions.

Required Data

The calculation of emissions from ODS substitution requires national emissions data from ODS substitution, as well as population estimates for Michigan and the United States. National emissions data from ODS substitution were obtained from the U.S. EPA. The SIT module contained default population data from the U.S. Census Bureau.

Methodology

Michigan-specific data do not exist for the consumption of HFCs for substitution of ODS. Consequently, emissions were calculated on a per-capita basis, by multiplying the national HFC emissions from ODS substitution by the ratio of Michigan population to United States population.

Results

In 2002, emissions from ODS substitution had increased from to 0.867 MMTCE, up from 0.003 MMTCE in 1990. This dramatic jump in emissions mirrors the national trend of greatly increased use of HFC-containing ODS substitutes. Until these interim substitutes are eventually phased out, the emissions trend is expected to continue and will likely accelerate in the coming decade.

Magnesium Production and Casting

Three types of emission sources are addressed in this category: primary magnesium production (i.e. producing metal from either magnesium oxide or magnesium chloride); secondary magnesium production (i.e. production using recycled material); and casting. In all three types of emission sources, a cover gas containing a small concentration of SF_6 is spread over molten magnesium in order to prevent violent oxidation. Since primary magnesium production does not occur in Michigan, and data sources indicated that all secondary magnesium processed is made into castings, emissions from casting operations are the primary focus of this sector.

Required Data

Calculating SF_6 emissions from magnesium casting requires the annual tonnage of magnesium cast. These data were obtained via personal communication with Michigan's two major magnesium processing facilities.

Methodology

Once annual magnesium casting data were obtained, they were multiplied by the appropriate SF_6 emission factor. These values were then converted to MMTCE.

Results

By 2002, emissions from magnesium casting had increased to 0.138 MMTCE from 0.050 MMTCE in 1990. Although this represented an increase of approximately 175 percent, emissions would have been much larger in 2002 without the involvement of Michigan's facilities in the U.S. EPA voluntary SF_6 reduction program. In 1995 a new magnesium processing facility began operations, greatly increasing the statewide casting capacity; however, reductions in the casting emission factor helped to offset the increased production.

The combination of improvements in technology and voluntary emission reduction programs has reduced emission factors for the primary production, secondary production, and casting sectors. These improvements are reflected in the dramatic reduction in emission factors, as shown in Table 4-3

Table 4-3: Magnesium Casting Emission Factors (tons SF_6/ton magnesium cast)

Year	Emission Factor
1990	0.0041
2002	0.0008

Electric Power Transmission and Distribution

The electric transmission and distribution sector is the largest user of SF_6, both domestically and internationally.[103] Since the 1950s, SF_6 has been used as an insulator in transmission and distribution equipment because of its properties of dielectric strength and arc-quenching ability.

Equipment seals are sources of fugitive SF_6 emissions. As equipment ages, the rate of these fugitive emissions is increased. Emissions also occur during normal installation, maintenance, and disposal operations.

Required Data

The calculation of SF_6 emissions requires the total national emissions of SF_6 from the electric utility sector, as well as the consumption of electricity in Michigan and the United States. National electric utility SF_6 emissions data were obtained from the U.S. EPA. Electricity consumption data were obtained from the EIA.

Methodology

Electric utility SF_6 emissions were obtained by first calculating the ratio of Michigan electricity consumption to national electricity consumption. These ratios were then multiplied by the total national emissions of SF_6 from the electric utility sector. Electricity consumption data were gathered from the EIA.

Results

Sulfur hexafluoride emissions from electric power transmission and distribution decreased from 1990 to 2002. In 2002, emissions totaled 0.122 MMTCE, compared to 0.242 MMTCE in 1990. It is expected that the emissions reduction is a result of the U.S. EPA's voluntary SF_6 reduction program. This program involves many major electricity producers across the U.S. Since the lack of Michigan-specific data forced the use of national SF_6 data, Michigan's calculated emissions reflect only national trends. It is unclear whether or not Michigan's electricity providers have taken steps to reduce their SF_6 emissions and not a single electricity provider is listed as a partner in the SF_6 reduction program.[104] Electricity consumption did increase between 1990 and 2002 and, consequently, it is questionable whether or not GHG emissions from this sector actually decreased during the same time period.

Other Industrial Processes

Greenhouse gas emissions from the following industries are addressed by the SIT, but were found not to occur in Michigan: adipic acid production, primary aluminum production, and HCFC-22 production. Additionally, research did not yield definitive evidence as to whether or not nitric acid was produced in

Michigan in 1990.[ii] One source indicated that nitric acid production facilities were not located in Michigan by 2002.[105]

[ii] As a surrogate for data, point source and fugitive nitric acid emissions obtained from the U.S. EPA's Toxic Release Inventory (TRI) data were analyzed. The total nitric acid releases in 1990 are less than in 1998, a year which a source indicates that nitric acid was not produced in Michigan, which lead to the conclusion that nitric acid was not produced in Michigan in 1990 and 2002.

5. Agriculture

Greenhouse gas emissions from agriculture are subdivided into the following sources: methane (CH_4) emissions from domesticated animals, livestock manure management, and agricultural residue burning; and nitrous oxide (N_2O) emissions from agricultural soil management practices, livestock manure management, and agricultural residue burning. Table 5-1 and Figure 5-2 show that emissions from agricultural soil management practices, which include addition of manure and fertilizers, made up the largest portion of agricultural emissions for 1990 and 2002. Nitrous oxide contributed nearly three-quarters of the total emissions (carbon-equivalent adjusted) from agriculture with methane contributing the other quarter in 2002 (Figure 5-1).

Agriculture in Michigan accounted for 3 percent (1.867 MMTCE) of the state's total greenhouse gas emissions in 2002. From 1990 to 2002, agricultural emissions fell by 2.7 percent from 1.92 MMTCE to 1.87 MMTCE. Nationally, agricultural emissions accounted for 6.7 percent of U.S. emissions. Two reasons help explain why Michigan's agricultural emissions are only 3 percent to the state's total, which is less than half of the 6.7 percent that agriculture contributed to the national greenhouse gas emission total in 2002. One reason is that Michigan does not produce rice, which is a major contributor of CH_4 for much of the agricultural activity in the Southeastern U.S. region. Second, Michigan lies along the northern border of the continental U.S., where climate north of 44 degrees latitude (dividing the state roughly where the City of Saginaw lies) does not have a long enough growing season, on average, to allow for nutrient-intensive row crops such as corn and soybeans.[106] Nutrient-intensive crops emit the largest portion of N_2O from application of nitrogen into the soil (see Part 5.3, "Agricultural Soil Management").

Table 5-1: Agriculture Emissions by Gas and Activity 1990 and 2002 (MMTCE)

Gas/Source	1990	2002	Percent Change
CH_4	**0.570**	**0.506**	**-11.3%**
Enteric Fermentation	0.415	0.357	-14.0%
Manure Management	0.151	0.145	-4.0%
Agricultural Residue Burning	0.004	0.004	0.0%
N_2O	**1.348**	**1.361**	**1.0%**
Agricultural Soil Management	1.244	1.273	2.3%
Manure Management	0.102	0.085	-16.7%
Agricultural Residue Burning	0.002	0.003	50.0%
Total	**1.918**	**1.867**	**-2.7%**
Percent Share of State Total	**3.3%**	**3.0%**	

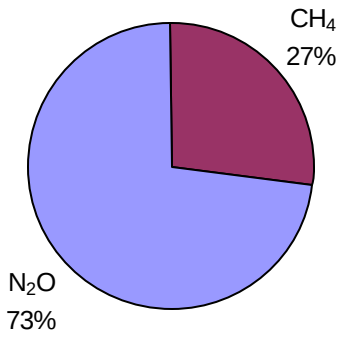


Figure 5-1: Agriculture Emissions by Gas (Carbon-Equivalent Adjusted) in 2002

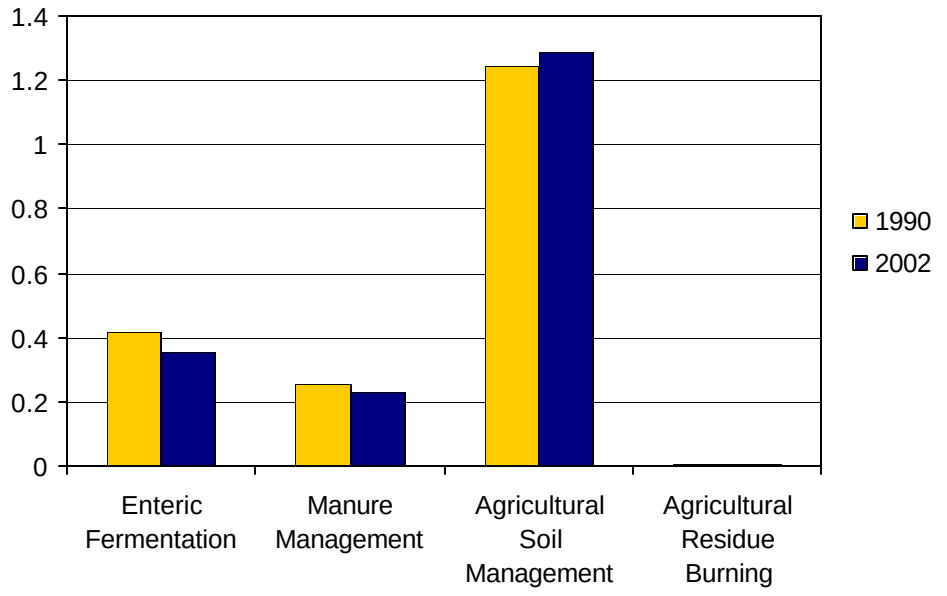


Figure 5-2: Agriculture Emissions Categories in 1990 and 2002 (MMTCE)

5.1 Methane Emissions from Domesticated Animals

Microbes that reside in the rumen or "fore stomach" of ruminants such as cattle, sheep, and goats give off a significant amount CH_4 during digestion in a process known as enteric fermentation. The CH_4 produced in the enteric fermentation process is then exhaled or eructated by the animal. Non-ruminants such as horses and swine produce much less CH_4 due to limited fermentation that takes place in the large intestine. Wild ruminants are not considered because only domesticated animals are a result of human activity.[107]

Factors that influence CH_4 emissions from domesticated animals include the type of animal, age and weight of the animal, and the quantity and quality of feed consumed. The quality component of feed largely depends on the physical and chemical properties of the feed as well as feed additives. Less significant factors influencing CH_4 emissions include animal feeding schedule and the general activity level and health of the animal. Some genetic factors may also affect CH_4 production.

Required Data

Given the distribution and number of domesticated animals throughout the state it was not practical to take direct measurements. Instead, specific categorical emission factors were coupled with state animal population estimates to provide a reasonably accurate measure of CH_4 emissions from enteric fermentation.

Data on animal population were obtained from the National Agricultural Statistics Service (NASS), USDA Internet database.[108] Cattle, sheep, and swine population estimates for years 1990 and 2002 were used from the NASS database using Michigan-specific data. Due to the fluctuation of animal populations within a given year, the average animal population across each animal type for the year was used.

Methodology

The estimated population of each animal type was multiplied by the given emission factor provided by the EIIP Inventory Guidance, which was based on estimated annual CH_4 emissions per animal type from the Midwest region. See Appendix H for greater detail on specific factors and calculations used to estimate emissions data.

Results

Table 5-2 shows that in 2002, total CH_4 emitted from domestic animals was 0.357 MMTCE, which represented a 14 percent decrease from 1990 emissions. The magnitude of emissions change from this category dropped from 1990 to 2002 by 0.058 MMTCE. Within this category, milk cows made up the largest portion of CH_4 emissions in both 1990 (0.207 MMTCE) and 2002 (0.197 MMTCE). Sheep represented the greatest percent decrease in emissions from 1990 to 2002 dropping 41 percent and goats had the greatest percent increase of 76 percent.

Table 5-2: CH_4 Emissions from Domesticated Animals 1990 and 2002 (MMTCE)

Animal Type	1990	2002	Percent Change
Dairy Cows			
Milk Cows	0.207	0.197	-5.1%
Milk Replacements	0.046	0.039	-14.6%
Beef Cattle			
Beef Cows	0.050	0.031	-36.9%
Beef Replacements	0.009	0.009	-6.0%
Heifer Stockers	0.002	0.003	33.2%
Steer Stockers	0.014	0.013	-4.1%
Feedlot Heifers	0.006	0.006	-8.6%
Feedlot Steer	0.041	0.027	-33.9%
Bulls (500+)	0.010	0.009	-4.1%
Other			
Sheep	0.006	0.003	-40.5%
Goats	0.000	0.001	75.8%
Swine	0.011	0.008	-26.8%
Horses	0.013	0.011	-19.3%
Total	**0.415**	**0.357**	**-14.0%**

5.2 Manure Management

Both CH_4 and N_2O emissions can occur from livestock manure management. When manure is allowed to decompose anaerobically, CH_4 is produced. N_2O is emitted as an intermediate when organic nitrogen in manure and urine undergo nitrification and denitrification. The biological processes of nitrification and denitrification are illustrated in the following equations:

Nitrification:

$$NH_4^+ + O_2 \rightarrow H^+ + H_2O + NO_2^-$$

$$NO_2^- + O_2 \rightarrow NO_3^-$$

Denitrification:

$$NO_3^- \rightarrow N_2O \rightarrow N_2$$

Livestock manure that is managed as a liquid in lagoons, ponds, tanks, or pits, undergoes decomposition under anaerobic conditions, producing CH_4. Manure

that is managed as a solid and is deposited on fields or stored in stacks or pits is decomposed aerobically and produces little if no CH_4. Although manure is still primarily managed in solid form, there is a growing trend of liquid management, particularly among large swine and dairy producers. Concurrently, land application of manure is decreasing on smaller farms due to new nutrient regulations.[109]

A variety of factors can influence the amount of CH_4 produced from manure management. These factors include environmental conditions like ambient temperature, pH, and moisture. Other factors include the characteristics of the manure management system, such as residency time of the manure. The amount of CH_4 produced is also dependent on the composition of the manure itself. The digestive systems and diets of livestock vary and these differences are expressed in the amount of volatile solids produced and the CH_4 producing potential of volatile solids for each animal type. For example, cattle with diets of high-energy grain produce manure with a larger CH_4 producing capacity than cattle with low energy forage material diets.

In addition to the composition of manure, the amount of N_2O produced from manure management is also dependent on the composition of urine. N_2O production also depends on the amounts of oxygen and moisture in the manure system. Emissions are most likely to occur from a manure management system where dry, aerobic conditions are found with moist, anaerobic conditions.

The methodologies for calculating N_2O emissions from manure management and agricultural soils encompass similar sources of emissions. The distinction between the two categories is that manure management includes manure that is systematically managed in liquid or solid form, while agricultural soil management addresses manure applied directly to soil. Figure 5-2 further clarifies the distinctions between these categories.

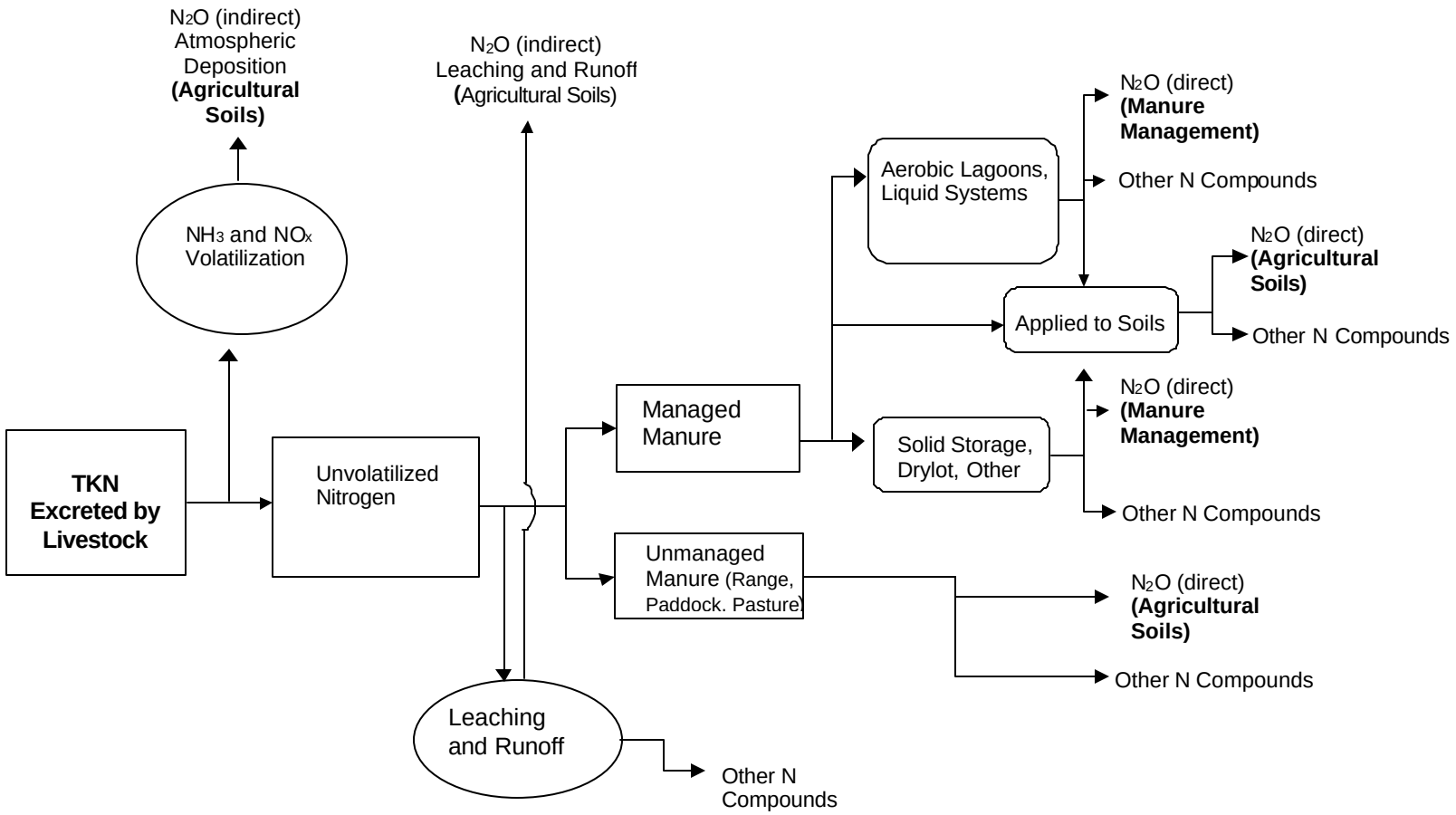


Figure 5-2: Nitrogen Flows Related to Livestock (adapted from EPA (2003) *Volume VIII: Estimating Greenhouse Gas Emissions,* Figure 8.3-1, p.8.3-3)

Required Data

The types of animals included in the emissions analysis for manure management are limited to cattle, swine, poultry, sheep, goats, and horses. In order to calculate the greenhouse gas emissions for manure management, it was necessary to collect the following data:

- Animal population;
- Rate of volatile solids produced per animal type;
- CH_4-producing potential of volatile solids for each animal type;
- Rate of nitrogen produced per animal type;
- Portion of manure managed in each type of manure management system; and
- Portion of manure deposited on land or used in daily spread systems.

The average annual populations for all appropriate animals were obtained from a variety of documents published by the U.S. Department of Agriculture and the Michigan Department of Agriculture's Michigan Agricultural Statistics Service. Values for maximum CH_4 producing capacity of manure, volatile solids production, rate of total Kjeldahl nitrogen[i] emitted, and types of manure management systems utilized were all obtained from the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2002*.

Methodology

Once the activity data were collected, the calculation of CH_4 emissions began with calculating the total amount of volatile solids produced annually for each animal type. The amount of volatile solids was then multiplied by the maximum CH_4 production potential and CH_4 conversion factor for each type of manure management system to arrive at the amount of CH_4 emitted. The amount of CH_4 is then summed across all animal types and converted to million metric tons carbon equivalent. A more detailed description of the methodology used to calculate CH_4 emissions is presented in Appendix H.

The calculation of N_2O emissions began with multiplying the typical animal mass for each animal type by the appropriate rate of Kjeldahl nitrogen excreted. It was then necessary to determine the amount of Kjeldahl nitrogen managed in liquid and solid manure management systems. Once these values were calculated for each animal type, they were multiplied by the N_2O emission factors for each type of manure management system. Lastly, these values were summed and converted to MMTCE. A more detailed description

[i] Total Kjeldahl nitrogen is defined as the measure of organically bound nitrogen and nitrogen as ammonia.

of the methodology used to calculate N_2O emissions is presented in Appendix H.

Results

In 2002, greenhouse gas emissions from manure management were 0.230 MMTCE. This represents a decrease of approximately 9.1 percent from 1990 emissions. In 1990, emissions from manure management were 0.253 MMTCE. As shown in Table 5-3, emissions decreases were observed for both CH_4 and N_2O. Total N_2O decreased most significantly, dropping by approximately 17 percent from 1990 to 2002.

Table 5-3: Summary of Manure Management Emissions (MMTCE)

Gas/Animal Type	1990	2002	Percent Change
CH_4	**0.151**	**0.145**	**-4.0%**
Dairy Cattle	0.071	0.083	16.9%
Beef Cattle	0.005	0.003	-40.0%
Swine	0.068	0.054	-20.6%
Poultry	0.004	0.003	-25.0%
Sheep	0	0	0.0%
Goats	0	0	0.0%
Horses	0.002	0.002	0.0%
N_2O	**0.102**	**0.085**	**-16.7%**
Dairy Cattle	0.063	0.052	-17.5%
Beef Cattle	0.025	0.021	-16.0%
Swine	0.002	0.002	0.0%
Poultry	0.011	0.01	-9.1%
Total	**0.253**	**0.230**	**-9.1%**

5.3 Agricultural Soil Management

N_2O is naturally created through soil microbial activity through the processes of nitrification and denitrification. Several common practices in agricultural soil management, however, add additional sources of nitrogen to the soil, therefore increasing the amount of atmospheric N_2O from anthropogenic activity. Common practices include, application of synthetic and organic fertilizers, irrigation, tillage practices, and fallowing of land.[110]

N_2O emissions are divided into three categories: (1) direct emissions from agricultural soils due to cropping practices; (2) direct emissions from agricultural soils due to animal production; (3) emissions from soils indirectly induced by agricultural applications of nitrogen.

Required Data

Following EIIP guidance, N_2O emissions sources within agricultural soil management were divided into direct and indirect emissions of N_2O. Direct sources were further subdivided into fertilizer use, crop residues, n-fixing crops, manure applied to soils, and pasture, range, and paddock. Likewise indirect emission sources were subdivided into animal waste and leaching and runoff.

Methodology

Note: see Appendix H for greater detail on specific factors and calculations used to estimate emissions data.

Direct Emissions

Fertilizer Use (Synthetic and Organic)

Synthetic Fertilizers: Data on synthetic and organic fertilizer consumed in 1990 and 2002 were obtained from the Fertilizer Institute.[ii] Data were confirmed with the Michigan Department of Agriculture.[111,112] According to EIIP, 10 percent of the total nitrogen content of fertilizers upon application volatilizes as various forms of nitrogen oxide (NOx) and ammonia (NH_3). This 10 percent is accounted for as indirect emissions. The remaining 90 percent of nitrogen applied to soils not taken up by plants is emitted to the atmosphere in the direct form as N_2O.

Organic Fertilizers: This category consisted of dried blood, compost, and peat applied to soils. Organic manure is not counted in this category to avoid double counting as stated in the IPCC Good Practice Guidelines. Instead, it is listed in the category below titled "Manure Applied to Soils".[113] According to EIIP, on the average, the bulk content of nitrogen in organic fertilizers is 4.1 percent. Similar to calculating N_2O in synthetic fertilizers, there were calculations involved in estimating both direct and indirect emissions. For organic fertilizers, 80 percent of the nitrogen remained unvolatilized and emitted directly as N_2O. The other 20 percent volatilized as NH_3 and NO_x and were accounted through indirect emissions.

[ii] Organic fertilizer data were obtained from the Fertilizer Institute and subsequent interview with April Hunt of the Michigan Department of Agriculture, June 2004.

Crop Residues

Crop residue that is not harvested for food nor burned contains some nitrogen that is eventually emitted as N_2O. The crops in Michigan for 1990 and 2002 that contributed to these emissions included corn, wheat, barley, oats, rye, soybeans, and dry edible beans. Production estimates were obtained from the Michigan Department of Agriculture annual agriculture reports. To estimate the amount of N_2O emitted, crop production values were multiplied by the N_2O crop residue constants specific for each type of crop.

Nitrogen-Fixing Crops

Three N-fixing crops were included in the inventory. These were alfalfa, soybeans, and dry edible beans. Production data were obtained from the Michigan Agricultural Statistics Service annual reports. These reports listed crop production data in tons, bushels, and hundredweight, respectively, and were all converted to metric tons. EIIP Guidance provided necessary constants for each crop including the residue to product mass ratio, fraction of dry matter in above ground biomass, and the fraction of nitrogen in the crops.

Manure Applied to Soils

Animal types that were included in the analysis were dairy cows, dairy heifers, feedlot heifers, feedlot steers, swine, and poultry. To obtain the amount of nitrogen from this category, referred to as Kjedahl nitrogen, four data figures were required. 1) annual average population of each animal type, 2) percentage of each animal type's manure used as daily spread, 3) each animal type's Typical Animal Mass (TAM), and 4) amount of Kjedahl nitrogen produced each year per animal. Similar to organic fertilizer, 20 percent of the nitrogen volatilized as NH_3 and NO_x and calculated as indirect emissions. 80 percent of the nitrogen content in the manure volatilized as direct emissions of N_2O.

Pasture, Range, and Paddock

This category included all types of dairy and beef cattle (excluding feedlots), swine, turkeys, sheep, goats, and horses. It required an identical calculation as the "manure applied to soils" category, except it included EIIP Guidance-provided factors on the percentage of manure deposited on pasture, range, and paddock systems from each animal type.

Indirect Emissions

Volatilized nitrogen from fertilizers (leaching and runoff) and animal wastes were included in this category. Indirect emissions include the nitrogen that volatilized into the atmosphere as NH_3 and NO_x in which a small portion subsequently became chemically altered in the atmosphere and equilibrated as N_2O.

Animal Waste
This includes the volatilized fraction of nitrogen in both manure applied to soils and pasture, range, and paddock systems. The calculation includes the same four data figures and steps that were used to calculate Kjedahl nitrogen, except in this category it is multiplied by 0.20 to reflect the 20 percent volatilized N.

Leaching and Runoff
This category includes all categories listed in direct N_2O emissions, accounting for the volatilized N_2O fraction from synthetic fertilizers, organic fertilizers, and animal waste that leached into streams and waterways. EIIP Guidance provided an estimate that 30 percent of all applied fertilizers and animal wastes leached out of the soil.

Results

This category accounted for largest portion of agricultural emissions making up 67 percent of the total emissions from agriculture. Table 5-4 and Figure 5-3 show that total emissions of N_2O emissions from agricultural soil management showed an increase of 2 percent from 1990 to 2002.

Direct Emissions

Fertilizer Use (Synthetic and Organic)
Fertilizer use contributed 17 percent toward the total agricultural soil emissions in 2002 and was 4 percent lower in 2002 from 1990. Synthetic fertilizers contributed around 85 percent of the N_2O emissions for 1990 and 2002.

Crop Residues
Crop residue emissions increased the most from 1990 to 2002 with a 38 percent increase. On the whole, emissions from this category rose from a 12 percent share in 1990 of agricultural soil emissions to a 16 percent share in 2002.

Nitrogen-Fixing Crops
N-fixing crops saw a substantial increase of 15 percent from 1990 to 2002. This category also contributes the largest share of total agricultural N_2O emissions in Michigan with a 34 percent share in 2002.

Manure Applied to Soils
Manure applied to soils contributed 10 percent of agricultural soil emissions in 2002. This category decreased by 19 percent from 1990 to 2002.

Pasture, Range, and Paddock

Pasture, range, and paddock emission made up 5 percent of the total share of agricultural soil emissions in 2002 and had a 24 percent decline in emissions from 1990 to 2002.

Indirect Emissions

Animal Waste

This was the smallest contributor toward soil emissions with 2 percent of the total share in 1990 and 2002. Emissions also declined by 17 percent from animal waste from 1990 to 2002.

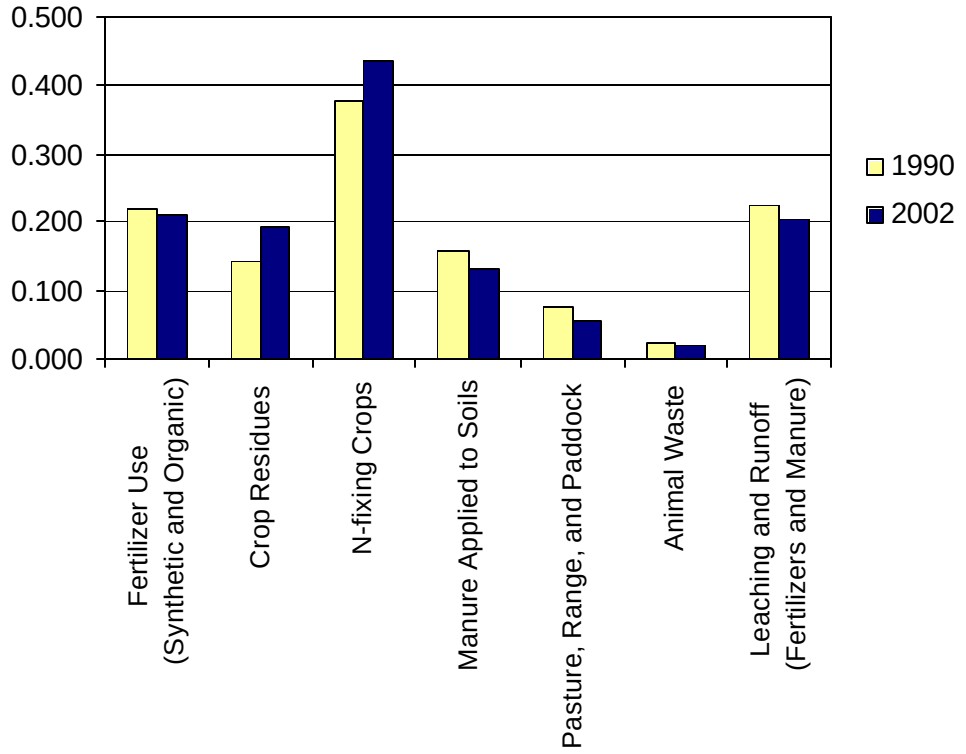
Leaching and Runoff

Leaching and runoff was responsible for 16 percent of the share of agricultural soil emissions in 2002. This category source was 9 percent lower in 2002 than in 1990.

Table 5-4: N_2O Emissions from Agricultural Soil Management (MMTCE)

Category	1990	2002	Percent Change
Direct N_20 Emissions			
Fertilizer Use (Synthetic and Organic)	0.221	0.212	-4.1%
Crop Residues	0.142	0.195	37.5%
N-fixing Crops	0.379	0.436	15.3%
Manure Applied to Soils	0.159	0.130	-18.5%
Pasture, Range, and Paddock	0.075	0.057	-23.7%
Indirect N_20 Emissions			
Animal Waste	0.024	0.020	-16.9%
Leaching and Runoff	0.224	0.203	-9.3%
Total	**1.225**	**1.255**	**2.4%**

Figure 5-3: Comparison of 1990 and 2002 Emissions from Agricultural Soil Management (MMTCE)



5.4 Field Burning of Agricultural Residues

Agricultural production results in large quantities of crop wastes. Some residues of crops are burned in the field to clear remaining stubble after harvest. Greenhouse gases released as a result of crop residue burning include CO_2, CH_4, and N_2O. Only emissions of CH_4 and N_2O are accounted for. CO_2 emissions are not accounted for because CO_2 released during residue burning had originally been sequestered from the atmosphere through photosynthesis, resulting in zero net emissions of CO_2.[114]

Required Data and Methodology

The EIIP guidance document was used to calculate CH_4 and N_2O emissions from burning of agriculture residues for 1990 and 2002. Four crops in

Michigan were assessed from the EIIP guidance and EPA SIT software: barley, corn, soybeans, and wheat. Emissions estimates were based on three criteria: (1) the amounts of carbon and nitrogen in crop residue combusted; (2) the emission ratio of CH_4 to carbon released in combustion; (3) the emission ratio of N_2O to nitrogen released in combustion.

State production values of each of the four crops from 1990 and 2002 were obtained from the Michigan Agricultural Statistics Service.[115, 116] See Appendix H for greater detail on specific factors and calculations used to estimate emissions data.

Results

Table 5-5 shows that total emissions from burning of agricultural residues yielded 0.007 MMTCE, which was less than 1 percent to the total emissions from agriculture in 2002. Soybeans had the largest change in emissions from 1990 to 2002, increasing by 80 percent.

Table 5-5: Summary of Emissions from Field Burning of Agricultural Residues (MMTCE)

Crop Type	1990	2002	Percent Change
Barley	0.000	0.000	-61.8%
Corn	0.003	0.003	-2.4%
Soybeans	0.002	0.004	80.4%
Wheat	0.001	0.001	-20.4%
Total	**0.006**	**0.007**	**23.7%**

6. Land-Use Change

Note: Carbon sequestration from forestry activities was not included in the inventory results due to large uncertainties. A discussion of this issue is provided as an appendix to the inventory report.

6.1 Liming of Agricultural Soils

Agricultural row crops in Michigan are grown upon rich calcareous soils in the lower half of the state's Lower Peninsula. Soil liming is done in very small quantities in the state and therefore has negligible effects on emissions. Soil liming data in Michigan can be obtained from the National Fertilizer Institute.

6.2 Yard Trimmings

Landfilled yard trimmings are considered an emission sink category because CO_2 is fixed in the cellulose fibers of the grass, leaves, and small tree branches through photosynthesis. Once discarded, the carbon is stored indefinitely within municipal landfill waste sites.

Required Data and Methodology

Yard trimmings emissions estimates were calculated using total Michigan solid waste data for 1990 and 2002 (see Appendix J, Table J-2 for *Biocycle* citations) and multiplying the annual waste amounts by the estimated fraction of yard trimmings taken from national level estimates for each respective year (listed in EIIP Guidance). See Appendix J, Table J-1 for further details on data and calculations used.

Results

As shown in Table 6-1, landfilled yard trimmings sequestered 0.111 MMTCE in 2002, which was 67 percent less than in 1990 with 0.351 MMTCE. Despite the fact that total solid waste disposal increased from 1990 to 2002 (see Section 7.1, "Municipal Solid Waste"), the overall amount of yard trimmings has continually decreased over the same period. The decrease in national level disposal rate of

yard trimmings is likely a result of numerous local programs around the country that either ban yard trimmings disposal and/or encourage composting the waste.

Table 6-1: Landfilled Yard Trimmings Sequestration Amounts (MMTCE)

Yard Trimmings	1990	2002	Percent Change
MMTCE	(0.351)	(0.111)	-66.7%

7. Waste

Waste accounted for slightly less than 6 percent of the total greenhouse gas emissions in Michigan in 2002. Waste is broken down into two main categories: (1) emissions from solid waste (both land filled and incinerated) and (2) emissions from wastewater treatment. Figure 7-1 displays the distribution of emissions by greenhouse gas type, while Figure 7-2 displays the relative size of emissions contribution from wastewater treatment and solid waste. Municipal solid waste made up the majority of emissions within the waste category, accounting for 91 percent of emissions in 2002. The total emissions from waste decreased by less than 1 percent from 3.593 MMTCE in 1990 to 3.581 MMTCE in 2002. This difference from 1990 to 2002 is likely insignificant given the range of uncertainty from the acquired state-level data of municipal solid waste and wastewater amounts.

Table 7-1: Waste Emissions by Gas and Activity 1990 and 2002 (MMTCE)

Activity	1990	2002	Percent Change
CH_4	**3.413**	**3.244**	**-5.0%**
Municipal Solid Waste	3.219	3.061	-4.9%
Wastewater Treatment	0.194	0.183	-5.7%
CO_2	**0.040**	**0.174**	**335.0%**
Municipal Solid Waste	0.040	0.174	335.0%
Wastewater Treatment	--	--	--
N_20	**0.140**	**0.163**	**16.8%**
Municipal Solid Waste	0.002	0.004	150.2%
Wastewater Treatment	0.138	0.159	15.2%
Total	**3.593**	**3.581**	**-0.3%**
Percent Share of State Total	**6.2%**	**5.7%**	

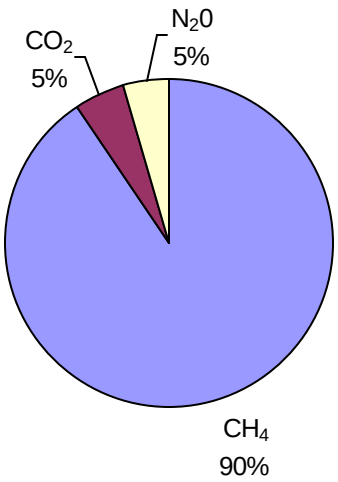


Figure 7-1: Waste Emissions by Gas (Carbon-Equivalent Adjusted) in 2002

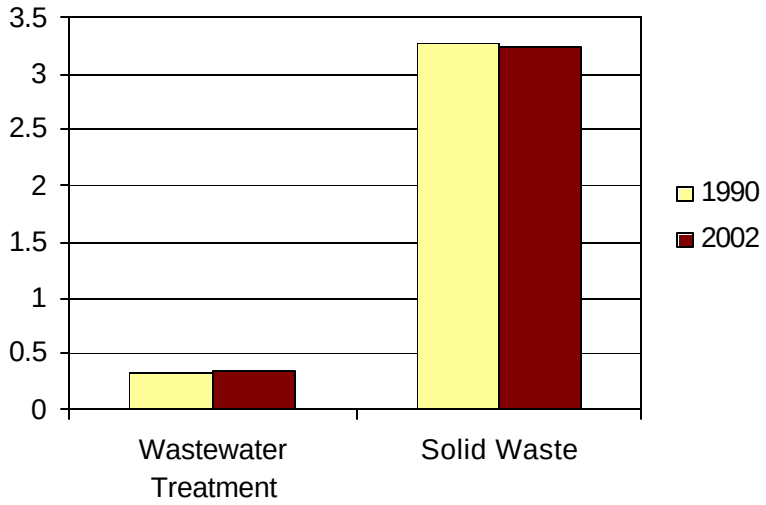


Figure 7-2: Summary of Emissions from Waste in 1990 and 2002 (MMTCE)

7.1 Municipal Solid Waste

In landfills, methane (CH_4) and carbon dioxide (CO_2) are produced from anaerobic decomposition of organic matter by methanogenic bacteria. Organic waste first decomposes aerobically (in the presence of oxygen) and is then decomposed by anaerobic non-methanogenic bacteria, which convert organic material to simpler forms like cellulose, amino acids, sugars, and fats. These simple substances are further broken down to gases and short-chain organic compounds (H_2, CO_2, CH_3COOH, HCOOH, and CH_3OH), which support the growth of methanogenic bacteria. The bacteria further metabolize these fermentation products into stabilized organic materials and "biogas," which consists of approximately 50 percent CO_2 and 50 percent CH_4 by volume. Additionally, some landfills flare recovered landfill gas, which converts the CH_4 portion of the gas to CO_2.

Neither the CO_2 emitted directly as biogas nor the CO_2 emitted from combusting CH_4 is counted as an anthropogenic greenhouse gas emission. The source of the CO_2 is primarily the decomposition of organic materials derived from biomass sources (e.g., crops, forests). Much of the carbon in landfills that is not converted to CO_2 or CH_4 is stored indefinitely and removed from the pool of carbon available to cycle to the atmosphere, i.e., it is sequestered (Note: landfilled yard trimmings are not accounted for in this sector, see "Land-Use Change"). In accordance with the Intergovernmental panel on Climate Change (IPCC) guidelines on greenhouse gas accounting only biogenic carbon (i.e., carbon from plant or animal matter) is counted as sequestered. Plastics that are landfilled represent a transfer of carbon from one long-term carbon pool (oil or natural gas reserves) to another (landfills), and thus are not counted as incremental carbon sequestered.

Waste combustion emits both CO_2 and nitrous oxide (N_2O). CO_2 is produced from oxidation of organic materials in waste, such as paper, food scraps, yard trimmings, and plastic. As with CO_2 from biogas and oxidation of CH_4, CO_2 emissions from biogenic sources (e.g., paper and food scraps) are not counted as greenhouse gas emissions because they simply return CO_2 that plants previously absorbed through photosynthesis to the atmosphere. However, some CO_2 is from nonbiogenic sources (e.g., plastic and rubber made from petroleum), and is thus counted as a greenhouse gas emission. N_2O is produced at the high temperature found in waste combustors by the combination of nitrogen (both nitrogen contained in the waste and nitrogen gas in the air) and oxygen gas in the air.[117]

Required Data

(1) The total amount of MSW in landfills. While the duration that landfilled waste generates CH_4 varies by landfill, it is generally accepted that this period is approximately 30 years. In other words,

waste that was deposited up to 30 years ago is assumed to still generate CH_4 today.

(2) The composition of the waste entering landfills. Municipal solid waste supplies the necessary starting material for CH_4 generation in landfills by providing degradable organic carbon (DOC), which is metabolized by methanogenic bacteria to produce landfill gas. Food waste has a high DOC content, as do some grades of paper (e.g., office paper). Wastes such as metal and glass have no DOC.

(3) The characteristics of landfills receiving waste. In particular, a landfill's size, moisture content, pH level, and temperature can all influence the amount of CH_4 that is generated.

(4) The amount of CH_4 that is recovered and either flared or used for energy. Due to a 1996 U.S. EPA rule that requires gas recovery at large municipal solid waste landfills, the number of landfill gas recovery systems is increasing and the CH_4 generated from landfills is being captured and flared or used as an energy source. (The rule requires a well-designed and well-operated landfill gas collection system at landfills that (1) have a design capacity of at least 2.5 million metric tons and 2.5 million cubic meters, and (2) emit more than 50 metric tons of nonmethane organic compounds per year.)

(5) The amount of CH_4 oxidized instead of being released into the atmosphere. While the extent to which CH_4 is oxidized at the landfill surface varies by landfill, an assumption of 10 percent oxidation is currently being used for the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.[118]

Methodology

Emissions of CH_4, CO_2, and N_2O from municipal solid waste, industrial waste, and waste combustion were calculated for years 1990 and 2002 using EIIP guidance. EIIP guidance used the method of acquiring state-level landfill data and applying U.S. EPA region-specific field measurements and statistical models to estimate CH_4 emissions. For more details on the calculations and factors used see Appendix J.

The following data sources were required to estimate CH_4 emissions:

(1) 30-year Waste-in-Place data using:
   a. State population estimates from 1961 to 1989.
   b. Annual amount of landfilled waste from 1989 to 2002.
(2) Number of landfills, large and small, operating in 1990 and 2002.
(3) Rainfall amount in the state. According to EIIP Guidance, Michigan is considered non-arid.
(4) Amount of CH_4 flared or recovered from landfills.

Waste-in-place data is necessary to estimate the amount and age of waste across Michigan landfills. Size and age of garbage, along with its composition are the three main factors that determine how much landfill CH_4 is produced. Due to lack of information regarding state waste estimates prior to 1990, state population data and annual waste per capita were used to estimate the amount of waste landfilled in Michigan from 1961 to 1989. This assumed that net imports and exports of waste in Michigan were zero and that national averages of annual waste amounts per capita best represented the municipal solid waste stream in the state during that time period. Michigan DEQ Solid Waste Program has tracked waste imports since 1996. 1990 through 2002 landfill estimates were obtained from *Biocycle* and Michigan DEQ Annual Reports of Solid Waste in Michigan.[i]

Large and small landfill estimates were acquired from EIIP Guidance, which assumed the EPA Upper Midwest region had 81 percent of state waste in large landfills and 19 percent in small landfills. This ratio was used for both 1990 and 2002.[ii] Industrial and commercial construction wastes were assumed to be 7 percent of the total solid waste stream.[119]

The amount of CH_4 flared or recovered from landfills was obtained from the U.S. EPA Landfill Methane Outreach Program, which tracks when and how much methane is flared or recovered for heat and/or energy from specific landfills that are catalogued on a statewide basis. [120]

Municipal Small Landfills

Taking the total waste-in-place in Michigan for 1990 and 2002 and multiplying by 0.19 to reflect that 19 percent of Michigan waste went to small landfills. A CH_4 conversion factor provided by EIIP guidance for small landfills was used to obtain CH_4 emissions estimates.

Municipal Large Landfills

Similar to calculating solid waste CH_4 emissions from small landfills, the total waste-in-place for 1990 and 2002 were multiplied by 0.81 to reflect that 81 percent of waste disposed went to large landfills. A CH_4 conversion factor provided by EIIP guidance for large landfills was used to obtain CH_4 emissions estimates.

Industrial Landfills

According to EIIP, the U.S. EPA estimates that 7 percent of solid waste in municipal landfills comes from industrial and construction waste. Therefore, to account for industrial waste, solid waste-in-place figures for both 1990 and

[i] 1990-2002 data were obtained from MDEQ Solid Waste and Biocycle. See Appendix I, Table I-2 for all cited references used in this category.

[ii] Provided by EIIP guidance from U.S. EPA region-specific estimates of the ratio of landfill waste in small versus large landfills for 1990 and 2002

2002 were multiplied by 0.07. A CH_4 conversion factor provided by EIIP guidance for industrial landfills was used to obtain CH_4 emissions estimates.

Flared and Recovered CH_4

In both 1990 and 2002, a number of landfills flared excess CH_4 that reduced emissions. In addition, some landfills recovered CH_4 for energy use and sale. The amount of CH_4 that is flared or recovered represents a reduction in greenhouse gas emissions because the avoided emissions of CH_4 through CH_4 combustion causing subsequent emissions of CO_2 represents a 1/21 reduction ratio since CH_4 has a global warming potential that is 21 times more potent than CO_2.

Oxidized CH_4

Oxidation of CH_4 naturally occurs when some CH_4 from within a landfill rises to the surface and comes in contact with atmospheric oxygen. Oxidation of CH_4 forms H_2O and CO_2. Since CO_2 is a factor 1/21 less potent of a greenhouse gas than CH_4, oxidation of CH_4 represents a reduction in emissions. According to EIIP guidance, approximately 10 percent of CH_4 produced in landfills oxidizes from this process. 10 percent of total waste-in-place not flared or recovered for 1990 and 2002 was subtracted from the total CH_4 landfill emissions.

Combustion CO_2 Emissions

Plastics, Synthetic Rubber and Synthetic Fibers

This source category was calculated using EIIP guidance from national estimations of percent of solid waste that was combusted in 1990 and 2002. Plastics, synthetic rubber, and synthetic fibers were each multiplied by CO_2 emission factors provided by EIIP guidance per given amount combusted. In 1990, 4 percent of municipal solid waste was combusted. In 2002 this factor increased to an average of 7 percent solid waste combusted.

Combustion N_2O Emissions

The estimation of N_2O emissions only accounted for emissions resulting from combustion of plastics, synthetic rubber and synthetic fibers. The same amounts of combusted waste that were calculated in CO_2 emissions were used to estimate N_2O emissions. N_2O emission factors for combusted plastics, synthetic rubber, and synthetic fibers were obtained from EIIP Guidance.

Results

Table 7-2 and Figure 7-3 show that in 2002 Michigan municipal solid waste emitted 3.418 MMTCE, which represented 6 percent of the state's total emissions. Despite an increase of 40 percent of solid waste-in-place over this twelve year period, emissions from solid waste actually decreased a slightly. The rapid increase in flared and recovered CH_4 projects at Michigan landfills is the main reason that landfill emissions did not increase proportionately with the increase of waste-in-place over this time period.

Briefly noting Michigan waste imports and exports – in 1996, annual municipal solid waste imports were just above 13 percent and have steadily increased to 20 percent in 2002. The make-up of the imported waste is assumed to be the same non-hazardous and non-industrial waste that constitutes the municipal solid waste produced within the state. Therefore it was inferred that the portion of municipal solid waste emissions from imports is identical to the bulk percentage of imports that make up the total amount of waste in the state. Using 2002 municipal solid waste data, 20 percent of Michigan solid waste was imported, so it can be assumed that emissions from imported solid waste constituted 20 percent of the total greenhouse gas emissions from landfilled municipal solid waste in the state.

Municipal Small Landfills

In 2002 municipal small landfills contributed 0.841 MMTCE, an increase of 13 percent from 1990 of 0.745 MMTCE.

Municipal Large Landfills

Municipal large landfills represented the largest portion of solid waste emissions; contributing 72 percent of the total solid waste emissions (see Figure 7-3) of 3.368 MMTCE in 2002. This was an increase of 18 percent from 1990 emissions of 2.859 MMTCE.

Industrial Landfills

2002 industrial landfills contributed 0.295 MMTCE, an increase of 17 percent from 1990 emissions of 0.252 MMTCE.

Flared and Recovered CH_4

Flared and recovered CH_4 showed an increase of over 200 percent from 1990 to 2002. In 2002, flared and recovered CH_4 substantially reduced emissions of landfill CH_4, offsetting landfill CH_4 emissions by 25 percent.

Oxidized CH_4

Oxidized CH_4 was calculated as a proportional factor of all emissions from municipal and industrial landfills for both 1990 and 2002 (10 percent was used for both years). In 2002, solid waste emissions were offset by 0.344 MMTCE emissions from oxidized CH_4.

Combustion CO_2 Emissions and N_2O Emissions

Plastics, Synthetic Rubber and Synthetic Fibers

CO_2 and N_2O emissions from combustion of plastics, synthetic rubber, and synthetic fibers also saw large increases from 1990 to 2002 (Table 7-2 and Figure 7-3).

Table 7-2: Summary of Greenhouse Gas Emissions from Municipal Solid Waste 1990 and 2002 (MMTCE)

Activity	1990	2002	Percent Change
CH_4	**3.219**	**3.061**	**-4.9%**
Municipal Small Landfills	0.745	0.841	13.0%
Municipal Large Landfills	2.859	3.368	17.8%
Industrial Landfills	0.252	0.295	16.9%
Flared/Recovered	(0.358)	(1.103)	208.3%
Oxidized	(0.280)	(0.340)	21.6%
CO_2	**0.040**	**0.174**	**333.7%**
Plastics Combusted	0.032	0.119	274.6%
Synthetic Rubber Combusted	0.007	0.019	169.1%
Synthetic Fibers Combusted	0.002	0.037	2242.0%
N_20	**0.002**	**0.004**	**150.2%**
Waste Combustion	0.002	0.004	150.2%
Total	**3.261**	**3.418**	**4.8%**

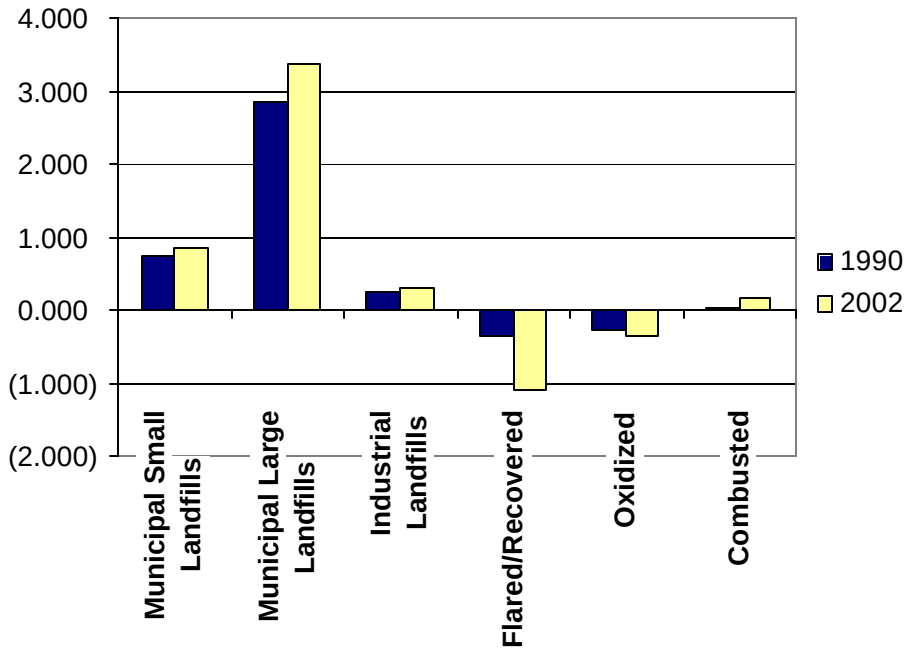


Figure 7-3: Sources of Emissions from Solid Waste in 1999 and 2002 (MMTCE)

7.2 Wastewater Treatment

The treatment and disposal of domestic and industrial wastewater can result in CH_4 emissions. Whether or not CH_4 is emitted depends on the presence of oxygen. Wastewater can be treated under aerobic or anaerobic conditions. When wastewater does not undergo treatment, it may degrade naturally through aerobic and anaerobic processes. With anaerobic treatment processes, CH_4 is produced as a byproduct of microbial degradation of organic material. Industrial wastewater streams containing high amounts of organics, such as the effluents from the pulp and paper industry, fruit and vegetable processing, and red meat and poultry slaughter, are the main focus of industrial wastewater treatment emissions accounting.

In addition to CH_4, N_2O is emitted from municipal and industrial wastewater treatment. For wastewater containing nitrogen-rich organic material, the microbial processes of nitrification and denitrification convert ammonia to N_2O. During the two stages of nitrification, ammonia is aerobically converted to nitrite then nitrate. In the subsequent process of denitrification, nitrate is anaerobically converted to N_2O. It is believed that human sewage is responsible for a significant portion of the N_2O emissions from wastewater treatment.[121] Currently, industrial wastewater streams and the other portions of domestic wastewater are not considered in the estimation of N_2O emissions from wastewater treatment.

In both municipal and industrial systems, the amount of CH_4 produced is dependent on a variety of factors, including temperature, biological oxygen demand (BOD) loading, retention time, and fraction of wastewater treated anaerobically. The amount of N_2O produced is related to similar factors, in addition to pH and nitrogen concentration.

Required Data

In order to calculate CH_4 from municipal wastewater treatment, the following activity data are required: state population, kilograms of BOD per capita per day, and the fraction of total wastewater that undergoes anaerobic treatment. With the exception of state population estimates, all data were obtained from the U.S. EPA.

The calculation of N_2O emissions from municipal wastewater treatment required the following data: annual per capita protein consumption and the fraction of nitrogen in protein. Both categories of data were obtained from the U.S. EPA.

Ideally, wastewater production data would be used to calculate CH_4 emissions from the pulp and paper, fruits and vegetables, and red meat and poultry industries. Since these data were not available, annual production and

wastewater intensity data (volume of wastewater produced per unit of product output) served as the basis for emissions calculations.

Methodology

The methodologies for calculating CH_4 and N_2O emissions from municipal wastewater treatment are described in detail in Appendix K.
Since complete wastewater discharge data for all three industrial sectors were difficult to obtain, production data were used as surrogates. These production data were then multiplied by default wastewater production factors (e.g. cubic meters of wastewater/metric ton product) to obtain estimates of the total wastewater discharge. In order to account for the portion of wastewater that was treated anaerobically, default SIT data were applied. Finally, the results were multiplied by CH_4 emission factors.

Results

In 2002, greenhouse gas emissions from wastewater treatment were approximately 0.342 MMTCE. This represented an increase of nearly 3 percent over 1990 emissions. In 1990, emissions from wastewater treatment were 0.333 MMTCE. Wastewater treatment emissions are summarized in Table 7-3.

Table 7-3: Summary of Wastewater Treatment Emissions (MMTCE)

Activity	1990	2002	Percent Change
Municipal Wastewater Treatment			
CH_4	**0.123**	**0.133**	**7.9%**
N_20	**0.138**	**0.159**	**15.2%**
Direct N_20	0.002	0.003	7.9%
Biosolid N_20	0.136	0.157	15.3%
Industrial Wastewater Treatment			
CH_4	**0.071**	**0.050**	**-30.0%**
Fruits & Vegetables	0.002	0.002	-11.8%
Red Meat & Poultry	0.044	0.016	-63.4%
Pulp & Paper	0.025	0.032	26.5%
Total	**0.333**	**0.342**	**2.8%**

CH_4 emissions from the industrial wastewater treatment sector declined from 0.071 MTCE to 0.050 MTCE, a decrease of 30 percent. This decrease was a direct result of a drop in the amount of livestock and poultry slaughtered in 2002 compared to 1990. In turn, CH_4 emissions from the sector dramatically

shrunk by 63 percent, from 0.044 MMTCE in 1990 to nearly 0.016 MMTCE in 2002. A slight decrease in emissions of 12 percent was noted for the pulp and paper sector, while the fruit and vegetable sector increased emissions on the order of 27 percent from 0.025 MMTCE in 1990 to 0.032 MMTCE in 2002.

8. Results and Conclusion

8.1 Michigan Greenhouse Gas Emissions

In 2002, the State of Michigan emitted an estimated 62.59 million metric tons carbon equivalent (MMTCE). This represented an increase of 9.0 percent over the 1990 emissions baseline of 57.42 MMTCE. Briefly consider that the Kyoto Protocol called for the U.S. to reduce greenhouse emissions by 7 percent over 1990 baseline levels. In just twelve years, Michigan's emissions are estimated to have grown by 9 percent over its 1990 baseline. Michigan's greenhouse gas emissions and sinks, summarized by Intergovernmental Panel on Climate Change (IPCC) Category, are presented as Table 8-1.

The IPCC methodology for calculating greenhouse gas emissions is divided into six categories: Energy, Industrial Processes, Solvent Use, Agriculture, Land-Use Change and Forestry, and Waste.[122] When emissions are viewed in terms of IPCC categories, the energy category was the largest contributor to overall emissions in both 1990 and 2002. In 2002, this category was responsible for 86.7 percent of total emissions, or 54.22 MMTCE. In 1990, energy-related emissions contributed 87 percent of total emissions, or 50.16 MMTCE. Overall, energy-related emissions increased by over 8 percent from 1990 to 2002. Carbon dioxide (CO_2) emissions from fossil fuel combustion are the major contributor to energy-related emissions, as well as the state's total emissions. Additional increases in emissions were the result of construction of new natural gas transmission and distribution pipelines and associated infrastructure. As described in Section 3.1 of the Energy Chapter, CO_2 emissions are influenced by a myriad of short- and long-term factors. On a year-to-year basis, seasonal temperatures, population and economic growth, and general economic conditions are among the dominant drivers for fossil fuel combustion and subsequent CO_2 emissions.

Second in contribution to total emissions was the IPCC category of waste. In 2002, emissions resulting from waste management activities totaled 3.40 MMTCE and were responsible for nearly 5.4 percent of total state emissions. Waste-related emissions decreased by 4.2 percent from 1990 to 2002. An explanation of this decrease is that although the amount of solid waste placed in landfills increased substantially in the mid- to late 1990s, the effect was offset by increased amount of methane (CH_4) flared at large landfills.

The largest increase between 1990 and 2002 levels was exhibited by industrial process emissions. In 2002, emissions from industrial processes contributed

3.06 MMTCE, or 4.9 percent of total state emissions. Overall, industrial process emissions increased nearly 71 percent between 1990 and 2002. The emissions growth was driven by an increase in the amount of coke produced at coke plants and the increased use of hydrofluorocarbons (HFCs) as substitutes for ozone depleting substances (ODS).

Between 1990 and 2002, emissions from agriculture decreased. In 2002 emissions from agriculture activities totaled 1.87 MMTCE, compared to 1.92 MMTCE in 1990. Both CH_4 and N_2O emissions from agriculture were reduced in 2002 as a result of lower domestic livestock populations. The decreased number of domestic livestock reduced emissions from enteric fermentation and manure management.

Table 8-1: Emissions Summary by IPCC Category (MMTCE)

	Emissions (MMTCE)		Percent Change (1990 to 2002)	Percent of Total Emissions	
IPCC Category	**1990**	**2002**		**1990**	**2002**
Energy	50.16	54.25	8.2%	87.4%	86.7%
Industrial Processes	1.79	3.06	70.9%	1.6%	2.5%
Agriculture	1.92	1.87	-2.7%	2.0%	1.6%
Waste	3.55	3.40	-4.2%	6.6%	5.8%
Total	**57.42**	**62.59**	**9.0%**	**100%**	**100%**

As identified in Chapter 3, it was not possible to account for emissions related to imported electricity consumption. Michigan became a net importer of electricity in 1997, but the amount imported in 2002 was not yet available when this inventory was conducted. It is estimated that accounting for emissions from importing 10 percent of electricity consumption would add an additional 2 MMTCE to Michigan's total emissions for 2002. This figure is uncertain, as the exact amount of imported electricity and the fuel mix used to generate this electricity are unknown.

8.2 Emissions by Greenhouse Gas Type

Another method of examining the State of Michigan's greenhouse gas emissions is to group sources by greenhouse gas type. Table 8-2 summarizes emissions and sinks by the six types of greenhouse gases and the various activities that contribute to emissions. A number of activities, such as iron and steel production, manure management, and agricultural residue burning, contribute to emissions of more than one type of greenhouse gas.

Table 8-2: Summary Greenhouse Gas Emissions and Sinks (excluding Forestry) Distribution by Gas Type- Weighted by Global Warming Potential (MMTCE)

Gas / Activity	1990	2002	Michigan-Specific, National, or Combined Activity Data[i]
CO_2	**49.85**	**54.15**	
Fossil Fuel Combustion	48.33	52.06	**C**
Iron and Steel Production	0.68	1.10	**C**
Cement Manufacture	0.62	0.58	**MI**
Lime Manufacture	0.12	0.18	**C**
Waste Combustion	0.05	0.17	**C**
Limestone and Dolomite Use	0.04	0.03	**C**
Soda Ash Consumption	0.02	0.03	**C**
Lanfilled Yard Trimmings	*(0.35)*	*(0.11)*	**C**
CH_4	**5.16**	**5.18**	
Landfills	3.22	3.06	**C**
Natural Gas Systems	0.98	1.30	**MI**
Enteric Fermentation	0.41	0.36	**MI**
Wastewater Treatment	0.19	0.18	**C**
Manure Management	0.15	0.15	**MI**
Stationary Sources	0.09	0.06	**C**
Mobile Sources	0.05	0.04	**C**
Petroleum Systems	0.04	0.02	**C**
Iron and Steel Production	0.02	0.02	**C**
Agricultural Residue Burning	0.00	0.00	**MI**
N_2O	**2.12**	**2.13**	
Agricultural Soil Management	1.24	1.27	**MI**
Mobile Sources	0.50	0.48	**C**
Human Sewage	0.14	0.16	**C**
Stationary Sources	0.13	0.12	**C**
Manure Management	0.10	0.08	**MI**
Agricultural Residue Burning	0.00	0.00	**MI**
Waste Combustion	0.00	0.00	**C**
HFCs, PFCs, and SF_6	**0.30**	**1.13**	
Electrical Transmission and Distribution	0.24	0.12	**C**
Magnesium Processing	0.05	0.14	**MI**
Substitution of Ozone Depleting Substances	0.00	0.87	**US**
Semiconductor Manufacture	0.00	0.00	**C**
TOTAL	**57.42**	**62.59**	
NET EMISSIONS (Sources and Sinks)	**57.07**	**62.48**	

[ii] This column indicates if the emissions calculations were based on activity data specific to Michigan (**MI**), an approximation using only national activity data and/or trends (**US**), or a combination of Michigan and national activity data (**C**).

The distribution of Michigan's greenhouse gas emissions by gas type did not change significantly between 1990 and 2002. For both years, CO_2 was the overwhelmingly largest contributor to emissions. As shown by Figure 8-1, CO_2 emissions contributed to approximately 87 percent of Michigan's overall emissions in 2002. CH_4 emissions were the second largest contributor in 2002, at approximately 9 percent of total emissions. Although emissions from sulfur hexafluoride (SF_6), HFCs, and perfluorocarbons (PFCs) represented only 2 percent of Michigan's overall greenhouse gas emissions in 2002 their contribution has grown rapidly since 1990. In particular, the use of HFCs as substitutes for ODS is expected to increase emissions of these gases well into the coming decade.

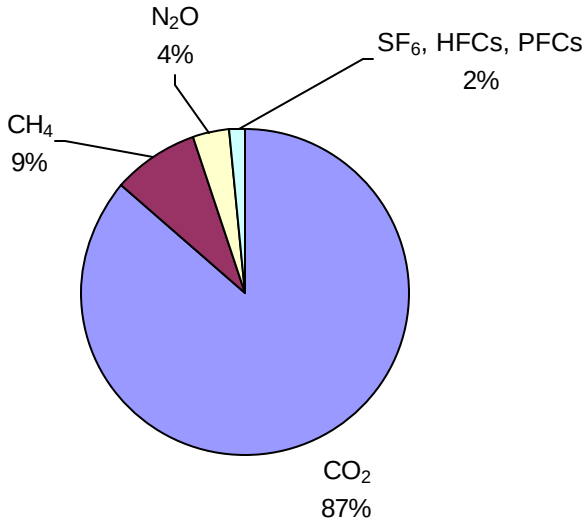


Figure 8-1: Greenhouse Gas Emissions Distribution by Gas Type: 2002 Emissions Weighted by Global Warming Potential

In 1990, the contribution of CO_2 emissions was slightly lower than in 2002. As shown by Figure 8-2, CO_2 emissions were responsible for 86 percent of total emissions. The contributions of CH_4 and N_2O emissions were also slightly lower in 1990 than in 2002. CH_4 and N_2O emissions accounted for 9 percent and 4 percent, respectively, of total emissions in 1990. Emissions of SF_6, HFCs, and PFCs were responsible for 0.5 percent of total greenhouse gas emissions.

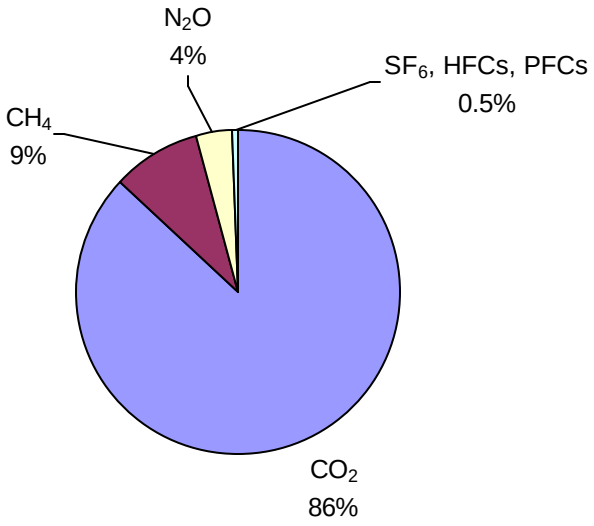


Figure 8-2: Greenhouse Gas Emissions Distribution by Gas Type: 1990 Emissions Weighted by Global Warming Potential

8.3 Emissions by Economic Sectors

Although the IPCC guidelines group greenhouse gas emissions into six separate categories, dividing emissions into economic sectors provides a more useful categorization. These economic sectors are considered to be more intuitive for analysis and include electricity-related, industry, agriculture, commercial, residential, and transportation. A summary of emissions allocated to economic sector is presented as Table 8-4. Please refer to Appendix L for the methodology used to allocate emissions by economic sector.

Before emissions from these economic sectors are discussed, an economic snapshot of Michigan's private industries in 1990 and 2002 is provided as Table 8-3. In both 1990 and 2002, the service industries contributed the largest portion of Gross State Product of private industries. Durable goods manufacturing was the second largest contributor in both years; however, growth was not as significant as witnessed by the service industries.

Table 8-3: Real Gross State Product of Michigan's Private Industries (millions of chained 2000 dollars)[ii,123]

1990		2002[iii]	
Services	$49,273	Services	$94,855
Durable goods	$41,619	Durable goods	$61,066
Finance, insurance, and real estate	$38,174	Finance, insurance, and real estate	$59,635
Nondurable goods	$17,514	Nondurable goods	$12,370
Retail trade	$17,474	Retail trade	$25,448
Transportation and public utilities	$15,055	Transportation and public utilities	$14,584
Wholesale trade	$12,006	Wholesale trade	$20,534
Construction	$10,920	Construction	$13,781
Agriculture, forestry, and fishing	$2,028	Agriculture, forestry, and fishing	$1,634
Mining	$1,287	Mining	$598

In terms of emissions from economic sectors, in 2002 electricity-related activities contributed the largest fraction to overall emissions. This sector emitted 20.22 MMTCE in 2002, a 9.0 percent increase over 1990 emissions. In 1990, emissions from electricity related activities predominated, contributing 18.54 MMTCE.

The transportation sector was responsible for the second largest share of emissions in both 1990 and 2002. In 2002, emissions from this sector totaled 16.47 MMTCE, an increase of over 23 percent from 1990. This increase was the largest observed in the six economic sectors and reflects the growing numbers of vehicle miles traveled, vehicles per capita, and light-duty trucks and sport-utility vehicles in operation.

The only economic sectors to decrease emissions between 1990 and 2002 were the industry, commercial, and agriculture sectors. Michigan's industries emitted 10.87 MMTCE in 2002, a 1.8 percent decrease from 1990 emissions. Emissions from the commercial sector remained nearly constant at 6.49 MMTCE in 1990 and 6.48 MMTCE in 2002. Agriculture emissions accounted for 1.87 MMTCE, a 2.6 percent decrease from 1990 emissions.

[ii] "In the past, the measures of change in real GSP were calculated by fixing valuations in a period (base year) and holding those valuations over all the years for which product estimates are produced. However, these "fixed-weighted" measures of real product tend to misstate growth as one moves further from the base period–usually understating growth before the base year and overstating it after the base year. This tendency, often referred to as the "substitution bias," reflects the fact that the commodities for which output grows rapidly tend to be those for which prices increase less than average or decline. To correct for this bias, BEA introduced chain-type measures." (U.S. Department of Commerce (2004)).

[iii] 2002 data were reported by North American Industry Classification System category, but were then adjusted to follow the Standard Industrial Classification categories used in 1990.

Table 8-4: Greenhouse Gas Emissions Allocated to Economic Sector (MMTCE)

Economic Sector	1990	2002	Percent Change
Electricity Generation	18.54	20.22	9.0%
Transportation	13.38	16.47	23.1%
Industry	11.07	10.87	-1.8%
Residential	6.02	6.67	10.8%
Commercial	6.49	6.48	-0.1%
Agriculture	1.92	1.87	-2.6%

A graphical presentation of the allocation of emissions by economic sector is shown below as Figure 8-3.

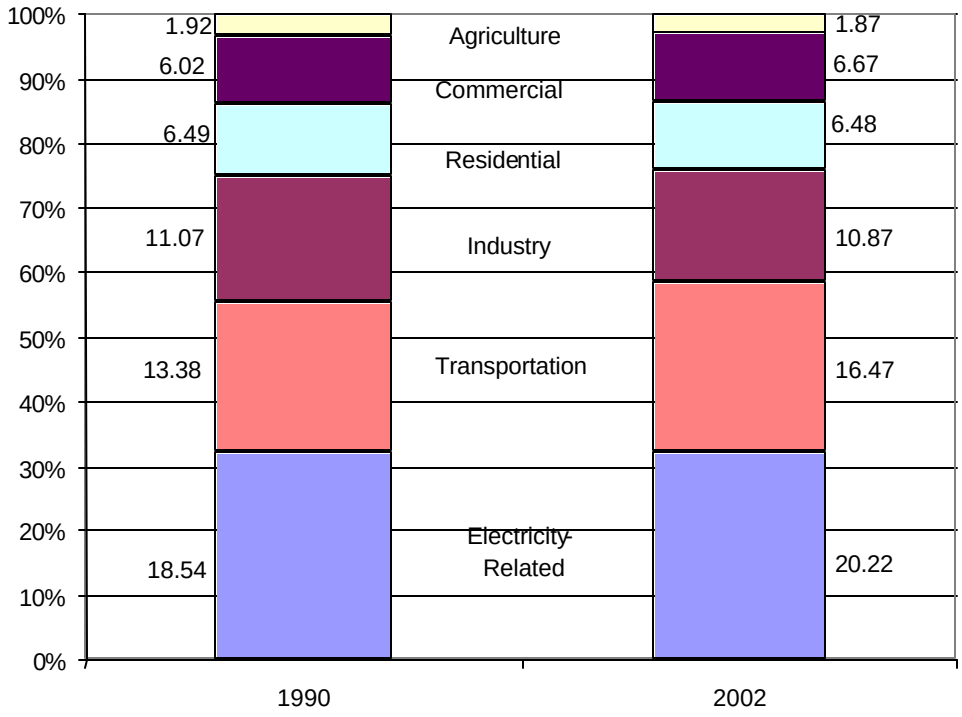


Figure 83: Distributions of Greenhouse Gas Emissions by Economic Sector-Electricity-Related as Separate Sector (MMTCE)

An additional method of viewing greenhouse gas emissions is to distribute emissions that result from electricity consumption. This method allocates all electricity-related emissions to the end user (i.e. industry, commercial, and residential sectors) based on individual electricity consumption. These

electricity-related emissions are summarized in Table 8-5. Generally, emissions would also be allocated to the agriculture and transportation sectors. However, emissions for agriculture and transportation remained unchanged due to a lack of data concerning electricity consumption for these sectors. According to the Energy Information Administration, Michigan's transportation electricity consumption is negligible, accounting for less than 1 percent of total state consumption.[124]

Table 8-5: Summary of Electricity-Related Greenhouse Gas Emissions (MMTCE)

Gas/Fuel Type or Source	1990	2002
CO_2	**18.2**	**20.0**
CO_2 from Fossil Fuel Combustion	18.1	19.8
Coal	17.0	17.5
Natural Gas	0.995	2.08
Petroleum	0.192	0.256
Waste Combustion	0.049	0.018
Limestone and Dolomite Use	0.021	0.014
CH_4	**0.004**	**0.005**
Stationary Combustion	0.004	0.005
N_2O	**0.080**	**0.082**
Stationary Combustion	0.080	0.082
SF_6	**0.242**	**0.122**
Electrical Transmission and Distribution	0.242	0.122
Total	**18.5**	**20.2**

With electricity-related emissions allocated by economic sector, industry was the largest contributor to Michigan's emissions in both 1990 and 2002. Emissions from industry have deceased over the years, however. In 2002 industry emitted 17.29 MMTCE, a decrease of 9.0 percent from the 1990 emissions of 18.97 MMTCE. Conversely, the commercial sector exhibited a large increase in emissions from 1990 to 2002. During these twelve years, emissions increased from 11.44 MMTCE in 1990 to 13.82 MMTCE in 2002, which represents an increase of greater than 20 percent. Emissions summaries are presented as Table 8-6 and graphically as Figure 8-4.

With the consideration of emissions resulting from electricity consumption, the importance of industry, commercial, and residential sectors is magnified. In particular, the amount of emissions from the commercial and residential sectors appears to be much less significant without including electricity-related emissions. The impact of these sectors on overall emissions is much

more apparent when emissions related to their electricity consumption are expressed.

Table 8-6: Greenhouse Gas Emissions with Electricity Distributed to Economic Sectors (MMTCE)

Economic Sector	1990	2002	Percent Change
Industry	18.97	17.29	-8.8%
Transportation	13.38	16.47	23.1%
Commercial	11.44	13.82	20.8%
Residential	11.72	13.14	12.1%
Agriculture	1.92	1.87	-2.6%

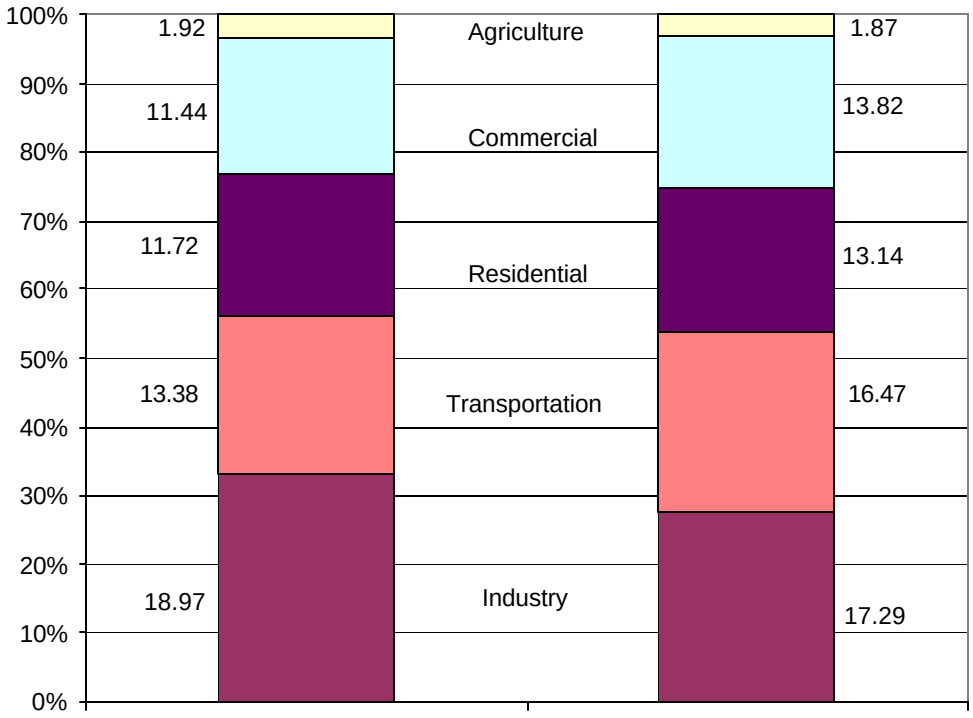


Figure 8-4: Greenhouse Gas Emissions with Electricity Distributed to Economic Sectors (MMTCE)

8.4 Comparisons with the United States

Greenhouse gas emissions from Michigan's economic sectors were compared to emissions from the same economic sectors of the U.S. From this comparison, the State of Michigan's contribution to overall U.S. economic sector emissions was determined. The contributions from these sectors, electricity generation, industry, agriculture, commercial, residential, and transportation, are shown in Table 8-7.

Overall, Michigan's contributions to gross national emissions remained nearly constant in 1990 and 2002 at 3.4 percent and 3.3 percent, respectively. The residential and commercial economic sectors contributed the largest portion of gross national emissions. Michigan's residential sector emissions accounted for 6.3 percent of national residential emissions in 2002 and 6.4 percent of emissions in 1990. Michigan's commercial sector emissions accounted for 4.8 percent of national commercial sector emissions in 2002 and 5.0 percent of emissions in 1990. Michigan's agriculture sector contributed the least to national emissions from agriculture for both 1990 and 2002. This sector accounted for 1.3 percent of national agriculture emissions in 2002 and 1.5 percent of emissions in 1990.

Table 8-7: State of Michigan Greenhouse Gas Emissions Contribution to National Greenhouse Gas Emissions

Economic Sector	1990	2002
Electricity Generation	3.7%	3.2%
Industry	2.8%	3.0%
Agriculture	1.5%	1.3%
Commercial	5.0%	4.8%
Residential	6.4%	6.3%
Transportation	3.2%	3.2%
Total	**3.4%**	**3.3%**

The distribution of greenhouse gas emissions among economic sectors also served as a means of comparing Michigan and the U.S. For 2002, notable differences occurred in the residential, commercial, and agriculture sectors. As Figure 8-5 shows, greenhouse gas emissions associated with the residential sector accounted for 11 percent of Michigan's overall emissions, but only six percent of the total U.S. emissions. Similarly, emissions from the commercial sector accounted for 10 percent of Michigan's emissions and only seven percent of U.S. Emissions. One explanation for the difference in this type of emissions indicator is that Michigan's residential and commercial sectors consume larger quantities of fossil fuels for winter heating than the national average.

Another notable difference in the economic distribution of emissions is the agriculture sector. In 2002, emissions from agriculture accounted for eight percent of U.S. emissions and only 3 percent of Michigan emissions. A number of factors are believed to be behind this difference. Unlike the national emissions data, it was not possible to allocate CO_2 emissions from agriculture fossil fuel combustion. This results in an understatement of Michigan's agriculture emissions. Also, Michigan's populations of certain types of cattle are less than national population averages. This observation, combined with lower than average cattle emission factors and volatile solids production for the Midwest could explain some of the differences in emissions from agriculture. As stated in the Agriculture Chapter, Michigan does not have a long enough growing season, on average, to allow for nutrient-intensive row crops such as corn and soybeans. Nutrient-intensive crops emit the largest portion of N_2O from application of nitrogen into the soil.

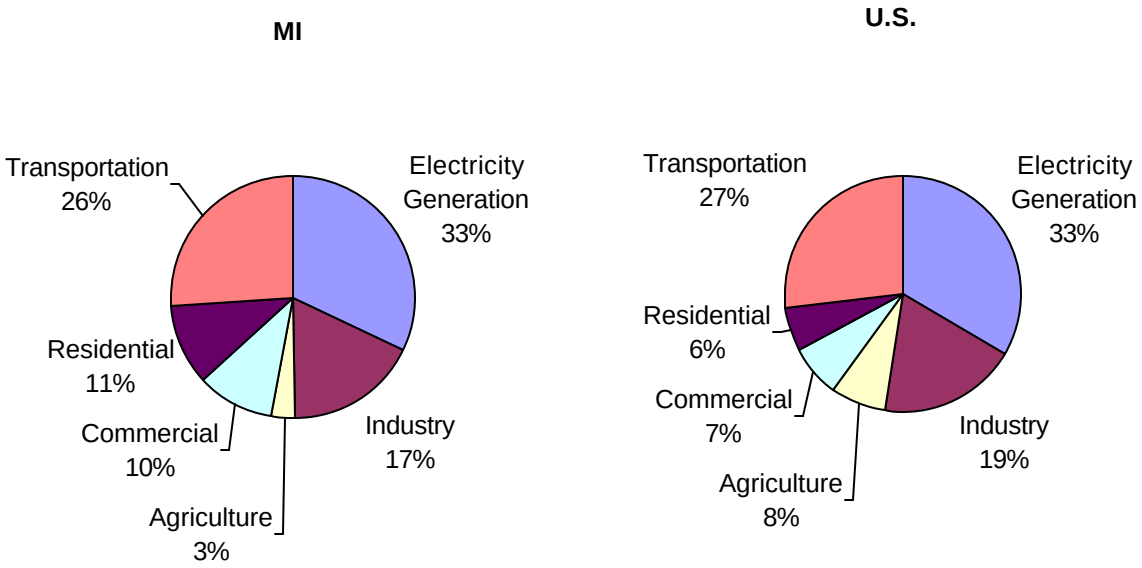


Figure 8-5: Comparison of Michigan and U.S. Economic Sector Emissions: 2002

In 1990, there were similar differences between the residential, commercial, and agriculture sector emissions as in 2002. Additionally, emissions from the U.S. industry sector comprised 24 percent of total national emissions, while Michigan's industry accounted for 19 percent of the state's total emissions. It is thought that the reason for this difference involves many of the industrial emissions sources that occur on the national level, but not in Michigan. Accounting for emissions from these industries (coal mining, aluminum production, HCFC-22 production, etc.) results in an increased share of total national emissions. A possible explanation of why this was not also true in

2002 is that these industries emitted much larger quantities of greenhouse gases in 1990 than in 2002. Also, national industry emissions experienced a larger decrease from 1990 to 2002 than Michigan industry emissions.

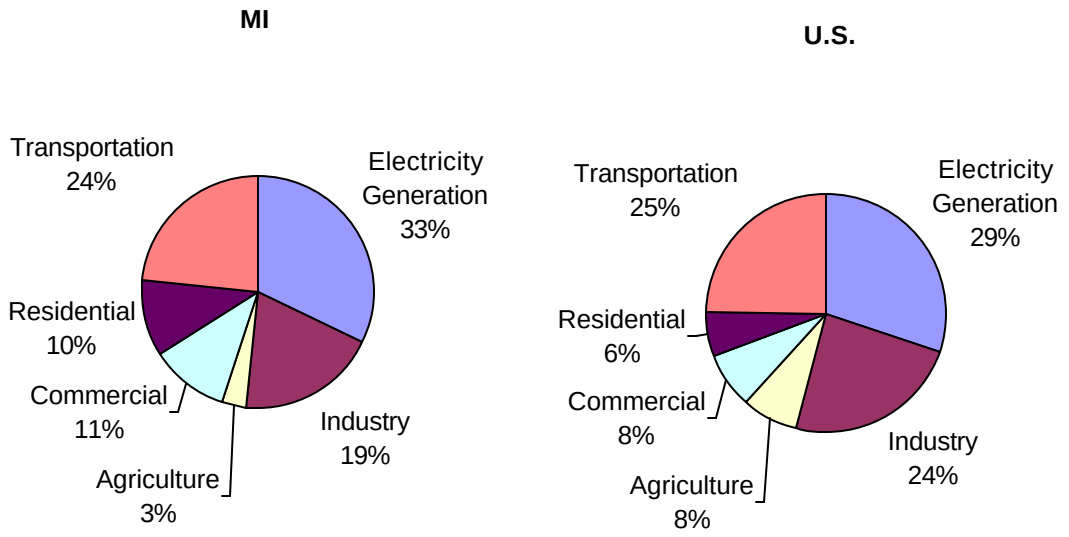


Figure 8-6: Comparison of Michigan and U.S. Economic Sector Emissions: 1990

In 1990 and 2002, Michigan was found to be less greenhouse gas intensive on a per capita basis than the national average. As shown in Table 8-8, Michigan's emissions in 2002 were 6.23 MTCE per capita compared to the U.S. value of 6.57 MTCE per capita. In 1990, Michigan emissions were 6.17 MTCE per capita compared to 6.70 MTCE per capita for the U.S.

Unlike the national per capita average, which decreased from 1990 to 2002, Michigan's per capita emissions increased over the same period. Both the U.S. and Michigan exhibited comparable percentage increases in emissions, but the U.S. population grew at a rate nearly double that of Michigan. This large difference in population growth explains why Michigan's per capita emissions increased and the U.S.'s per capita emissions decreased from 1990 to 2002.

It is important to note that Michigan's per capita emissions might only appear to be smaller than the national per capita emissions because of differences in data availability. Data for certain emissions sources, such as international bunker fuels, were simply not available at the state level. In this regard, the national inventory presents a more complete estimate of emissions.

Table 8-8: Comparison of Per Capita Greenhouse Gas Emissions for Michigan and the U.S. (MTCE/person)

	1990		2002	
	MI	U.S.	MI	U.S.
Total Emissions (MMTCE)	57.42	1,671.6[125]	62.59	1,891.3[103]
Population[126, 127]	9,310,462	248,709,873	10,043,221	287,973,924
Emissions per Capita	**6.17**	**6.70**	**6.23**	**6.57**

Michigan is certainly not the only state whose per capita greenhouse gas emissions were below the national per capita figure. Table 8-9 presents a comparison of per capita emissions for 13 other states, including all Midwestern states, for 1990.[i] With the exception of four states, all other states listed in the table exhibited per capita emissions below the national figure. It should be noted that the methodology for estimating emissions has been refined since these estimates were made.[128]

Table 8-9: Comparison of State Per Capita Greenhouse Gas Emissions in 1990 (MTCE/person)

Emissions per Capita (MTCE/person)[129]	1990
CA	3.9
KS	8.4
IA	6.1
IL	5.8
IN	11.0
MA	3.6
MN	5.1
MO	5.8
NY	4.2
OH	8.2
PA	6.4
TX	10.4
WI	5.5

Greenhouse gas emissions for Michigan and the U.S. were also compared on an economic basis. In this instance, a measure of the kilograms of carbon (kg

[i] As of March 2005, North Dakota, South Dakota, and Nebraska have not completed inventories of greenhouse gas emissions. Year 2002 inventories are not available for any of the states listed in Table 8-9.

C) emitted per dollar Gross State Product (GSP).[ii] As shown in Table 8-10, the kg C per dollar GSP for Michigan and the U.S. were approximately equal in both 2002 and 1990. In 2002, both Michigan and the U.S. emitted approximately 0.19 kg C for every dollar of GSP. In 1990, the kg C emitted per dollar GSP was 0.25 and 0.24 for Michigan and the U.S., respectively.

Calculating the growth of emissions and GSP from 1990 to 2002 reveals why the amount of carbon per dollar has decreased. The values for state and total GSP have increased by a much larger percentage from 1990 to 2002 than have greenhouse gas emissions. In 2002, both Michigan and the U.S. experienced GSP values that grew over 44 percent since 1990. Concurrently, emissions in 2002 had increased by less than 14 percent since 1990 for both.

Table 8-10: Comparison of Greenhouse Gas Emissions per Economic Output (Normalized to Year 2000 Chained Million Dollars)

	1990		2002		Change from 1990 to 2002	
	MI	U.S.	MI	U.S.	MI	U.S.
Total Emissions (MMTCE)	57.42	1671.6	62.59	1891.3	8.9%	13.1%
GSP (Year 2002 chained $million)[130]	234,181	6,939,733	337,708	10,014,936	44.2%	44.3%
Kg C per dollar GSP	**0.25**	**0.24**	**0.19**	**0.19**	**-24.5%**	**-21.6%**

8.5 Recommendations for Future Action

It is recommended that the State of Michigan institutionalize the process of annually reporting its greenhouse gas emissions. With the establishment of these inventory procedures, efforts should also be made to replace data based on national trends with data specific to Michigan.

This inventory has identified which portions of Michigan's economy are the largest contributors to the state's greenhouse gas emissions. It is recommended that the results of this inventory be used as an aid in the development of a State Action Plan to reduce greenhouse gas emissions. Over

[ii] In order to provide a consistent metric for comparison, this economic analysis utilizes the measurements of Michigan's Gross State Product (GSP) to the total U.S. GSP (Total GSP). According to the U.S. Department of Commerce Bureau of Economic Analysis, GSP is a measurement of the "value added in production by the labor and property located in a state". The GSP is considered to be the state counterpart of the gross domestic product (GDP). GSP for the U.S., or Total GSP, differs from GDP in that "[Total] GSP excludes and GDP includes the compensation of federal civilian and military personnel stationed abroad and government consumption of fixed capital for military structures located abroad and for military equipment, except office equipment" (U.S. Department of Commerce (2004)).

half of all states have developed such plans and California and many of the New England states could serve as excellent examples for Michigan. A detailed review and discussion of state initiatives is presented in *Statehouse And Greenhouse: The Emerging Politics Of American Climate Change Policy*.[131]

A variety of programs and strategies for reducing greenhouse gas emissions can be pursued. These include:

- **Renewable energy portfolio standards (RPS):** Mandates that a specific percentage of utility's plant capacity or generation come from renewable sources by a specific date. At least 18 states have passed RPS legislation. Additional information can be found at: http://www.pewclimate.org/docUploads/States%5FInBrief%2Epdf
- **Targets for reduction:** At least four states have developed climate action plans that include enforceable greenhouse gas reduction targets. For instance, in 1998 New Jersey committed to reducing greenhouse gas emissions by 3.5% below 1990 levels by 2005. Additional information can be found at: http://www.pewclimate.org/docUploads/States%5FInBrief%2Epdf
- **One-Tonne Challenge:** A Canadian program that encourages citizens to reduce their individual greenhouse gas emissions by one tonne (approximately 20% for the average Canadian) by using energy and resources more efficiently. More information can be found here: http://www.climatechange.gc.ca/onetonne/english/about.asp
- **U.S. EPA Partnerships**: A multitude of partnering opportunities relating to energy efficiency, methane capture, and decreased high-GWP use exist with the EPA. A complete list of partnerships can be found at: http://www.epa.gov/partners/programs/.

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Appendix A

Acronyms and Chemical Formulas

Acronyms

AFV	Alternative Fuel Vehicle
BEA	Bureau of Economic Analysis, U.S. Department of Commerce
BOC	Bureau of Census
BOD_5	Biochemical oxygen demand over a 5-day period
BTS	Bureau of Transportation Statistics, U.S. Department of Transportation
Btu	British thermal unit
CAAA	Clean Air Act Amendments of 1990
CFC	Chlorofluorocarbon
CNG	Compressed Natural Gas
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EAF	Electric Arc Furnace
EF	Emission Factor
EIA	Energy Information Administration, U.S. Department of Energy
EIIP	Emissions Inventory Improvement Program
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FAO	Food and Agricultural Organization
FCCC	Framework Convention on Climate Change
FHWA	Federal Highway Administration
GDP	Gross domestic product
GHG	Greenhouse gas
GWP	Global warming potential
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HDDV	Heavy duty diesel vehicle
HDGV	Heavy duty gas vehicle
HFC	Hydrofluorocarbon
HHV	Higher Heating Value
IEA	International Energy Association
IPCC	Intergovernmental Panel on Climate Change
LDDT	Light duty diesel truck
LDDV	Light duty diesel vehicle
LDGT	Light duty gas truck

LDGV	Light duty gas vehicle
LEV	Low emission vehicles
LFG	Landfill gas
LFGTE	Landfill gas-to-energy
LHV	Lower Heating Value
LMOP	EPA's Landfill Methane Outreach Program
LNG	Liquefied Natural Gas
LPG	Liquefied petroleum gas
LULUCF	Land use, land-use change, and forestry
MC	Motorcycle
MI	Michigan
MMCFD	Million Cubic Feet Per Day
MMTCE	Million metric tons carbon equivalent
MSW	Municipal solid waste
NASS	USDA's National Agriculture Statistics Service
NMVOC	Non-methane volatile organic compound
NOx	Nitrogen Oxides
NVFEL	National Vehicle Fuel Emissions Laboratory
OAP	EPA Office of Atmospheric Programs
ODS	Ozone depleting substances
OECD	Organization of Economic Co-operation and Development
OTAQ	EPA Office of Transportation and Air-Quality
POTW	Publicly Owned Treatment Works
Ppmv	Parts per million by volume
Pptv	Parts per trillion by volume
QA/QC	Quality Assurance and Quality Control
SNG	Synthetic natural gas
SOC	Soil Organic Carbon
TAR	IPCC Third Assessment Report
TBtu	Trillion Btu
TRI	Toxic Release Inventory
U.S.	United States
ULEV	Ultra Low Emission Vehicle
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
VMT	Vehicle miles traveled
VOCs	Volatile Organic Compounds
VS	Volatile Solids
WIP	Waste-in-Place

Chemical Formulas

C	Carbon
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
$CaCO_3$	Calcium carbonate, Limestone
$CaMg(CO_3)_2$	Dolomite
CaO	Calcium oxide, Lime
Fe_2O_3	Ferric oxide
H_2O	Water
N, N_2	Atomic Nitrogen, molecular Nitrogen
NH_3	Ammonia
NH_4^+	Ammonium ion
HNO_3	Nitric Acid
N_2O	Nitrous oxide
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_3	Nitrate radical
Na_2CO_3	Sodium carbonate, soda ash
O, O_2	Atomic Oxygen, molecular Oxygen
O_3	Ozone
SF_6	Sulfur hexafluoride

Appendix B

Quality Assurance/Quality Control Plan

Introduction

Please note that portions of this Quality Assurance/Quality Control Plan have been taken directly from the U.S. EPA[1] and the Intergovernmental Panel on Climate Change (IPCC).[2]

Quality assurance (QA) activities are essential to the development of comprehensive, high-quality emission inventories for any purpose. Furthermore, a well-developed and well-implemented QA program fosters confidence in the inventory and any resulting regulatory and/or control program.

An overall QA program comprises two distinct components. The first component is that of quality control (QC), which is a system of routine technical activities implemented by inventory development personnel to measure and control the quality of the inventory as it is being developed. The QC system is designed to:

- Provide routine and consistent checks and documentation points in the inventory development process to verify data integrity, correctness, and completeness;
- Identify and reduce errors and omissions;
- Maximize consistency within the inventory preparation and documentation process; and
- Facilitate internal and external inventory review processes.

QC activities include technical reviews, accuracy checks, and the use of approved standardized procedures for emission calculations. These activities should be included in inventory development planning, data collection and analysis, emission calculations, and reporting.

The second component of a QA program consists of external QA activities, which include a planned system of review and audit procedures conducted by personnel not actively involved in the inventory development process. The key concept of this

[1] U.S. EPA (2002) *Quality Assurance / Quality Control and Uncertainty Management Plan for the U.S. Greenhouse Gas Inventory: Procedures Manual for Quality Assurance / Quality Control and Uncertainty Analysis.* Office of Atmospheric Programs, Greenhouse Gas Inventory Program, Washington DC. http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/SLUZ5EBMKT/$File/procedures02.pdf

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component is independent, objective review by a third party to assess the effectiveness of the internal QC program and the quality of the inventory, and to reduce or eliminate any inherent bias in the inventory processes. In addition to promoting the objectives of the QC system, a comprehensive QA review program provides the best available indication of the inventory's overall quality completeness, accuracy, precision, representativeness, and comparability of data gathered.

Too often, QA activities are concentrated at the end of the inventory process. An effective QA program will include planning, numerous QC checks during inventory development, and QA audits at strategic points in the process. These strategic points need to be identified in the planning stage and will vary somewhat between agencies and inventories. However, the ideal QA program would include at least one audit conducted after the planning is completed and before the emissions calculations are more than 25 percent completed; another should occur near the end of the process. Other audits between these two points are desirable, but the exact scope, timing, and number of audits will depend on resources available as well as the procedures and methods being used to estimate emissions.

Quality Assurance Overview

According to the IPCC,

> [G]ood practice for QA procedures requires an objective review to assess the quality of the inventory, and also to identify areas where improvements could be made. The inventory may be reviewed as a whole or in parts. The objective in QA implementation is to involve reviewers that can conduct an unbiased review of the inventory. It is good practice to use QA reviewers that have not been involved in preparing the inventory.
>
> It is good practice for inventory agencies to conduct a basic expert peer review prior to inventory submission in order to identify potential problems and make corrections where possible. It is also good practice to apply this review to all source categories in the inventory. However, this will not always be practical due to timing and resource constraints.[3]

Activity Data Quality Control

Where possible, a comparison check of activity data from multiple reference sources should be undertaken. This is important for source categories that have a high level of uncertainty associated with their estimates. For example, many of the agricultural source-categories rely on government statistics for activity data such as livestock populations, areas under cultivation, and the extent of prescribed burning. Similar statistics may be prepared by industry, universities, or other organizations and can be used to compare with standard reference sources. As part of the QC check, the inventory agency should ascertain whether independent data have been used to derive alternative activity data sets.

[3] IPCC (2000)

Emissions Data Quality Control

According to the IPCC,

> Where IPCC default emission factors are used, it is good practice to assess the applicability of these factors. Another emission comparison may be used for source categories that rely on empirical formulas for the calculation of emissions. Where such formulas are used, final calculated emission levels should follow stochiometric ratios and conserve energy and mass. In a number of cases where emissions are calculated as the sum of sectoral activities based on the consumption of a specific commodity (e.g. fuels or products like HFCs, PFCs or SF_6), the emissions could alternatively be estimated using apparent consumption figures:
>
> National total production + import – export ± stock changes.
>
> For carbon dioxide from fossil fuel combustion, a reference calculation based on apparent fuel consumption per fuel type is mandatory according to the IPCC Guidelines. Another example is estimating emissions from manure management. The total quantity of methane produced should not exceed the quantity that could be expected based on the carbon content of the volatile solids in the manure. Discrepancies between inventory data and reference calculations do not necessarily imply that the inventory data are in error.[4]

Project Specific Quality Control Procedures

For the purposes of the State of Michigan greenhouse gas inventory, specific QC procedures will be implemented for the following project stages: **data collection and handling**; **emission calculations**; and **final report writing**. The majority of these procedures address documentation and data verification practices. Of particular importance to us are documentation procedures. A major goal of this project is that after completing the initial inventory, our archived documentation will be of sufficient detail to allow outside parties to fully recreate the inventory.

As part of QC procedures, it is good practice to document and archive all information required to produce the national emissions inventory estimates. Every primary data element (activity data, emission factor, carbon coefficient, etc.) must have a reference. Every reference citation on the spreadsheet should appear in the reference list of the inventory document, and the same format should be used in both places. Everything-supporting documentation, comments, and especially all printouts made from spreadsheets- should be dated.

The group responsible for conducting the inventory should maintain this documentation for every annual inventory produced and to provide it for review.

[4] IPCC (2000)

As stated by the IPPC,

> It is good practice to maintain and archive this documentation in such a way that every inventory estimate can be fully documented and reproduced if necessary. Inventory agencies should ensure that records are unambiguous; for example, a reference to 'IPCC default factor' is not sufficient. A full reference to the particular document (e.g. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories) is necessary in order to identify the source of the emission factor because there may have been several updates of default factors as new information has become available.[5]

Data Collection and Handling

Each project team member should record and document data collection activities in a project logbook. Once activity data are collected, the project team member should record the following information:

- Date data were collected;
- Full data source reference;
- Full website reference;
- Name of electronic file saved on CSS P: drive;
- Explanation of any assumptions made in selecting activity data or emission factors;
- Explanation of any calculations performed; and
- Date when hard copies of data were placed in data folder

Note that hard copies of all collected activity data should be placed in the appropriate source category folders in the CSS office. These hard copies should contain the date that they were printed and a detailed reference documenting their source.

In addition to the logbook, team members should record data collection activities in the "Data Collection Tracking" tab of the Summary of Required Data spreadsheet, which is located in the GHG project folder on the CSS P: drive.

As an accuracy check when researching and collecting data, each project team member should compare the current year's data with previous and subsequent years' data and any historical trend. If estimates do not exhibit relatively consistent changes from year to year, it should be determined whether characteristics of the source category have changed, or if any errors in transcription may have occurred.

If data are calculated (*e.g.* by interpolating or extrapolating from available activity data) it is necessary that the documentation procedures presented in Table B-1 be followed.

[5] IPCC (2000)

Table B-1: Required Documentation for Calculations Outside of State Inventory Tool

Hand Calculations	Spreadsheet Calculations
The preparer's name	The preparer's name
Date created	Date created
Signature of reviewer	Spreadsheet version number
Date reviewed	Name of spreadsheet reviewer
Citations for all data used	Date reviewed
List of assumptions	Citations of all references from which data were obtained
Page number	All constants factors, or other data (i.e. no hidden data)
	All calculation documentation
	Page Number

Before the collected activity data are entered into a SIT module, the QC procedures outlined in Table B-2 are to be undertaken.

Table B-2: General Inventory Quality Control Procedures: Data Collection and Handling

QC Activity	Procedures
Check that assumptions and criteria for the selection of **activity data** and **emission factors** are documented.	• Cross-check descriptions of activity data and emission factors with information on source categories and ensure that these are properly recorded and archived.
Check for transcription errors in data input and reference	• Confirm that bibliographical data references are properly cited in the internal documentation. • Cross-check a sample of input data from each source category (either measurements or parameters used in calculations) for transcription errors.

In addition to the QC procedures followed by the project team member in charge of the source category (source category lead), a peer cross check will performed to verify accuracy, methodology, and documentation. Table B-3 identifies the source category leads and the team members responsible each peer cross check.

Table B-3: Source Category Lead and QC Peer Cross Check

Source Category	Lead	QC Peer Cross Check
CO_2 from Fossil Fuel Combustion	Asako Yamamoto	Pierre Bull
CH_4 and N_2O from Stationary Combustion	Asako Yamamoto	Colin McMillan
CH_4 and N_2O from Mobil Combustion	Asako Yamamoto	Colin McMillan
CH_4 from Natural Gas Systems	Colin McMillan	Asako Yamamoto
Non-Energy GHGs from Industrial Processes	Colin McMillan	Asako Yamamoto
CH_4 from Domestic Animals	Pierre Bull	Colin McMillan
GHGs from Livestock Manure Management	Colin McMillan	Pierre Bull
GHGs from Agricultural Soil Management	Pierre Bull	Asako Yamamoto
GHGs from Field Burning of Agricultural Residue	Pierre Bull	Asako Yamamoto
GHGs from Municipal Solid Waste	Pierre Bull	Colin McMillan
GHGs from Wastewater	Colin McMillan	Pierre Bull
Forest Management and Land Use Change	Asako Yamamoto	Pierre Bull

A checklist encompassing the requirements of the peer cross check is included as Attachment 1. This list is to be completed as part of the cross check QC process and placed in the source category data folder upon completion.

Emissions Calculations

These QC procedures address the calculation of emissions from the 12 source categories and the subsequent analysis of factors affecting the emissions estimates. The project team will perform the specific procedures, shown as Table B-4, collectively.

Table B-4: General Inventory Level QC Procedures: Emissions Calculations

QC Activity	Procedures
Check that emissions are calculated correctly.	• Reproduce a representative sample of emissions calculations. • Selectively mimic complex model calculations with abbreviated calculations to judge relative accuracy. • Verify emission factor used. If factor is default IPCC, verify appropriateness for United States.
Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used.	• Check that units are properly labeled in calculation sheets. • Check that units are correctly carried through from beginning to end of calculations. Check that conversion factors are correct. • Check that temporal and spatial adjustment • factors are used correctly.
Check for consistency in data between source categories.	• Identify parameters (e.g. activity data, constants) that are common to multiple source categories and confirm that there is consistency in the values used for these parameters in the emissions calculations.
Undertake review of internal documentation.	• Check that there is detailed internal documentation to support the estimates and enable duplication of the emission and uncertainty estimates. • Check that inventory data, supporting data, and inventory records are archived and stored to facilitate detailed review.

Final Report

This stage, in particular, should involve QA/QC by persons not directly involved with building the inventory. Specifically, Professor Keoleian and contacts at the Michigan Department of Environmental Quality (MDEQ) should review the completed inventory and the summary report with Table B-5 QC procedures in mind.

Table B-5: General Inventory Level QC Procedures: Final Report

QC Activity	Procedures
Check methodological and data changes resulting in re-calculations.	• Check for temporal consistency in time series input data for each source category. • Check for consistency in the algorithm/method used for calculations throughout the time series.
Undertake completeness checks.	• Confirm that estimates are reported for all source categories and for all years from the appropriate base year to the period of the current inventory. • Check that known data gaps that result in incomplete source category emissions estimates are documented.
Compare estimates to other state inventories with similar economies.	• For each source category, current inventory estimates should be compared estimates from other state inventories. If there are significant departures from expected trends, re-check estimates and explain any difference.

ATTACHMENT 1- PEER CROSS CHECK FORM

Source Category: _____

Signature (QC review) _____ Date 5/14/2004

Signature (QA review) _____ Date

	YES	NO	Could Not be Determined
Are all appropriate data sources referenced?			
Do collected data match referenced data (no transcription errors)?			
If additional calculations were made, is required documentation present?			
Are these calculations correct?			
If default emission factors are used, was their applicability assessed?			

.

The following corrections should be made: _____

Corrective action taken: _____

Appendix C

Carbon Dioxide Emissions from Fossil Fuel Combustion

Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels Methodology

The estimation methodology consists of seven steps presented in the EIIP guidelines: (1) obtain required energy data; (2) estimate total C content in fuels; (3) estimate C stored in products; (4) calculate net potential C emissions; (5) estimate C oxidized from energy uses; (6) convert units to million metric tons of C equivalent; and (7) calculate total emissions.

Step (1): Obtain Required Energy Data
Required Energy Data. The information necessary to calculate emissions estimates is annual state energy consumption by fuel types (e.g., coal, natural gas, and petroleum, and petrochemicals) by *sector* (e.g., Residential, Commercial, Industrial, Transportation, and Electric utilities).

Data Sources. As the State of Michigan does not compile its own energy consumption data, we consulted with EIA for most recent available data for the state energy consumption (1990-2001). These data are available on the Internet at http://www.eia.doe.gov/emeu/states/sep_fuel/notes/_fuelnotes_multistate.html#use_. Fossil fuel statistics should be provided on an energy basis (e.g., in units of Btu). State Energy Data is available both in physical units and in units of Btu. As 2002 data were not available at the time of data collection, *Annual Coal Report 2002* and *Natural Gas Annual 2002* were used for 2002 coal and natural gas consumption data. For wood and petroleum based fuels, 2002 figures were estimated from their historical 1990-2001 data by performing a trend calculation for each of these fuels, and extrapolating 2002 data if R^2 is more than 0.5. For those R^2 is less than 0.5, the average of the recent five years was calculated to estimate the 2002 figures. These consumption data given in physical units as shown in Table C-1 were then converted into million Btu by applying the heat contents listed in Table C-2.

For state energy data, the reported values for gasoline consumption include ethanol fuel consumption. As ethanol is a biofuel, carbon emissions from ethanol combustion should not be counted as greenhouse gas emissions. Therefore, the gasoline values must be adjusted by subtracting out the energy consumption (Btu) of ethanol fuel combustion. This energy is subtracted from motor gasoline energy consumption.

EIA's data also include industrial coal used to produce synthetic natural gas, which is accounted for in both industrial coal and natural gas consumption data. Therefore, the energy content of synthetic natural gas should be subtracted from the energy content of industrial coal to prevent double-counting of emissions. State-specific natural gas data can be obtained from Table 12 of EIA's *Historical Natural Gas Annual* (EIA 2001) and Table 8 of EIA's *Natural Gas Annual* (EIA 2004). For the State of Michigan, the value is zero for both 1990 and 2002.

Table C-1: Required Data Sources for Emissions from Fossil Fuel Combustion

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
Fossil Fuel Combustion / Stationary Combustion	Commercial Coal	214.16	236	T Short Tons	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, Annual Coal Report 2002 (http://www.eia.doe.gov/cneaf/coal/page/acr/table26.html)
Fossil Fuel Combustion / Stationary Combustion	Commercial Distillate Fuel	2,010.20689	1,448.36	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Commercial Kerosene	17.97638	45.2009	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Commercial LPG	1,153.71071	2,334.41	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Commercial Motor Gasoline	770.09566	209.27	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Commercial Natural Gas	159,429	175,055	M Cubic Feet	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, Natural Gas Annual 2002 (http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_annual/historical/2002/pdf/table_048.pdf)

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
Fossil Fuel Combustion / Stationary Combustion	Commercial Residual Fuel	71.32119	16.3157	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Stationary Combustion	Commercial Wood	1746.349	879.293	B Btu	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Electric Utilities Distillate Fuel	341.181	405.647	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Electric Utilities Petroleum Coke	0	35.634	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Electric Utilities Residual Fuel	1,149.206	1,522.98	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Electric Utilities Coal	29,829.564	33,378	T Short Tons	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, Annual Coal Report 2002 (http://www.eia.doe.gov/cneaf/coal/page/acr/table26.html)
Fossil Fuel Combustion / Stationary Combustion	Electric Utilities Natural Gas	85,035.606	146,133	M Cubic Feet	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, Natural Gas Annual 2002 (http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_annual/historical/2002/pdf/table_048.pdf)

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
Fossil Fuel Combustion / Stationary Combustion	Industrial Asphalt and Road Oil	3,950.03962	6,485.85	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Aviation Gasoline Blending Components	0.37264	6.96911	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Distillate Fuel	3,957.19315	4,113.49	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Feedstocks, Naphtha less than 401 F	1,630.31516	4,715.38	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Feedstocks, Other Oils greater than 401 F	3,183.95215	5,200.15	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Kerosene	34.47657	46.7585	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial LPG	6,926.01579	1,671.19	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
Fossil Fuel Combustion / Stationary Combustion	Industrial Lubricants	1,839.37582	1,835.54	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Misc. Petro Products	585.01237	881.079	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Motor Gasoline	976.38877	1,256.03	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Motor Gasoline Blending Components	81.04467	0	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Natural Gas	289,709	249,503	M Cubic Feet	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, Natural Gas Annual 2002 (http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_annual/historical/2002/pdf/table_048.pdf)
Fossil Fuel Combustion / Stationary Combustion	Industrial Other Coal	3,656.348	1,802	T Short Tons	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, Annual Coal Report 2002 (http://www.eia.doe.gov/cneaf/coal/page/acr/table26.html)

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
Fossil Fuel Combustion / Stationary Combustion	Industrial Pentanes Plus	1,332.85208	2,696.98	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Petroleum Coke	1,159.60768	1,330.87	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Residual Fuel	1,415.61367	424.139	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Special Naphthas	1,461.06265	1,120.7	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Still Gas	1,946.71336	1,410.3	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Unfinished Oils	-502.19631	-106.52	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Industrial Waxes	79.87106	284.004	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
Stationary Combustion	Industrial Wood and Wastes	36,495.32642	47,064.38	B Btu	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Residential Coal	53.54	30	T Short Tons	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, Annual Coal Report 2002 (http://www.eia.doe.gov/cneaf/coal/page/acr/table26.html)
Fossil Fuel Combustion / Stationary Combustion	Residential Distillate Fuel	4,841.50516	2,417.4	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Residential Kerosene	217.31185	342.249	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Residential LPG	6,537.69405	13,228.1	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Residential Natural Gas	327,396	368,720	M Cubic Feet	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, Natural Gas Annual 2002 (http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_annual/historical/2002/pdf/table_048.pdf)
Stationary Combustion	Residential Wood	27,463.55	9,560.734	B Btu	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion /	Transportation Aviation Gasoline	214.91401	186.637	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html).

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
Stationary Combustion					For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Transportation Distillate Fuel	13,206.69605	21,222.2	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Transportation Jet Fuel, Kerosene	8,629.8971	8,211.23	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Transportation Jet Fuel, Naphtha	1,426.69348	0.27015	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Transportation LPG	283.12707	355.4	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a five-year average from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Transportation Motor Gasoline	98,166.86323	121,587	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Transportation Natural Gas	17,930	27,236	M Cubic Feet	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, Natural Gas Annual 2002 (http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_annual/historical/2002/pdf/table_048.pdf)
Fossil Fuel Combustion / Stationary Combustion	Transportation Residual Fuel	91.83514	57.6582	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
Fossil Fuel Combustion / Stationary Combustion	Transportation Ethanol	1,205.278	1,223.97	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).
Fossil Fuel Combustion / Stationary Combustion	Transportation Lubricant	1,512.62043	1,509.47	T Barrels	For 1990 data, State Energy Data 2001 Consumption (http://www.eia.doe.gov/emeu/states/_use_multistate.html). For 2002 data, a regression from State Energy Data 2001 (1990-2001).

Table C-2: Heat Content by Fuel Type[1,2]

Fuel	Unit	Heat Content 1990	2002	
Asphalt	(MMBtu/Barrel)	6.636	6.636	
Aviation Gasoline		5.048	5.048	
Distillate Fuel Oil		5.825	5.825	
Ehtane		3.082	3.082	
Ehtane-Propane Mixture		3.308	3.308	
Jet Fuel (Kerosene)		5.67	5.67	
Fet Fuel (Naphtha)		5.355	5.355	
Kerosene		5.67	5.67	
Lubricants		6.065	6.065	
Motor Gasoline (Conventional)		5.253	5.253	
Moter Gasoline (Oxygenated)		5.15	5.15	
Fuel Ethanol		3.539	3.539	
Natural Gasoline		4.62	4.62	
Pentanes Plus		4.62	4.62	
Naphtha less than 401F		5.248	5.248	
Other Oils equal to or greater than 401F		5.825	5.825	
Petroleum Coke		6.024	6.024	
Plant Condensate		5.418	5.418	
Propane		3.836	3.836	
Residual Fuel Oil		6.287	6.287	
Road Oil		6.636	6.636	
Special Naphthas		5.248	5.248	
Still Gas		6	6	
Unfinished Oils		5.825	5.825	
Unfractionated Stream		5.418	5.418	
Waxes		5.537	5.537	
Miscellaneous		5.796	5.796	
LPG		3.625	3.614	
Natural Gas for Electricity	(TBtu/C-foot)	0.813	0.99	*
Natural Gas other than Electricity		1.04437	1.03102	*
Electricity Coal	(MMBtu/Ton)	22.243	20.353	*
Residential and Commercial Coal		24.81175	25.102	*
Coking Coal		26.8	27.42527	*
Industrial Coal		24.45063	25.07067	*

Note: Values with asterisks are 2001 values because 2002 values were not available.

Previously, emissions from non-utilities (e.g., independent power producers and industrial cogenerators) are accounted for in the industrial sector. However, the EIA has been working to combine fuel consumption by utilities with fuel consumption by non-utilities (currently captured in the industrial sector) to create an “electric power” sector, which is reflected in their Revised Historical Data we used for this inventory development.

Step (2): Estimate Total Carbon Content in Fuels

Carbon content is the total amount of carbon that could be emitted if 100 percent was released to the atmosphere. To estimate the total carbon that could be released from the fuels, energy consumption for each fuel type must be multiplied by the appropriate carbon content coefficients, which, in general, are determined based on the composition and heat contents of fuel samples. We used carbon content coefficients for a wide range of fuel types estimated by the EIA. These coefficients, which can also be found in *the Inventory of the US Greenhouse Gas Emissions and Sinks*[3], are similar to those recommended in the IPCC guidelines, with some modifications for U.S.-specific fuel characteristics. As with thermal conversion factors, these average carbon coefficients may not precisely reflect the carbon content of fuel used in a particular state, and the degree of geographical and temporal variation is generally quite small for natural gas and refined petroleum fuels, but coal coefficients vary for different mining places and different years.

The specific elements of this step are as follows:

To estimate the total carbon content of a particular fuel, the consumed energy in Btus must be multiplied by the appropriate carbon content coefficient, as presented in Table C-3. The resulting potential emissions calculated with the following equations will be in pounds of carbon:

Total C Contained in Fuel i (lbs C) = Fuel Consumption for Fuel i (BBtu) x C Content Coefficient for Fuel i (lbs C/MMBtu)

The resulting potential emission in pounds of carbon must be converted to tons of carbon for each fuel type. For each sector, sum the results of the fuel types to obtain the total carbon content.

Table C-3: Carbon Content Coefficients[4,5,6]

Fuel		1990 lbsC/MMbtu	2002 lbsC/MMbtu
Coal	Residential Coal (MI)	55.88	57.42
	Commercial Coal (MI)	55.88	57.42
	Industrial Coking Coal (MI)	56.29	56.51
	Other Coal (MI)	55.88	56.76
	Utility Coal (MI)	56.92	57.29
Natural Gas	Natural Gas	31.90	31.90
Petroleum	Asphalt and Road Oil	45.46	45.46
	Aviation Gasoline	41.60	41.60
	Distillate Fuel Oil	43.98	43.98
	Jet Fuel, Kerosene	42.77	42.62
	Jet Fuel, Naphta	43.50	43.50
	Kerosene	43.48	43.48
	LPG	37.95	38.01
	Lubricants	44.62	44.62
	Motor Gasoline	42.79	42.64
	Residual Fuel	47.38	47.38
Other Petroleum	AvGas Blen Components	41.60	41.60
	Crude Oil	44.44	44.60
	MoGas Blend Components	42.79	42.64
	Misc. Products	44.44	44.60
	Naphtha (<401F)	39.99	39.99
	Other Oil (>401F)	43.98	43.98
	Pentanes Plus	40.21	40.21
	Petroleum Coke	61.40	61.40
	Still Gas	38.60	38.60
	Special Naphtha	43.78	43.78
	Unfinished Oils	44.40	44.60
	Waxes	43.67	43.67

Step (3): Estimate Carbon Stored in Products

After estimating the total carbon contained in the fuels, the next step is to estimate the amount of carbon from these fuels that is sequestered in non-energy products for a significant period of time (e.g., more than decades). Most fossil fuels are used for non-energy purposes to some degree.

However, not all non-energy uses of fossil fuels result in carbon sequestration. The approach used to determine the portion of carbon sequestered in products is based on that used by the EIA and U.S. EPA, which are based on the IPCC guidelines. The default values for the storage factors in Table C-4 were developed based on this approach. As more detailed information on non-energy uses of fossil fuels becomes available, these figures may change.

Table C-4: Storage Factors[7]

Fuels	Storage Factor	
	1990	2002
Asphalt	1	1
Distillate Fuel Oil	0.5	0.5
Lubricants	0.09	0.09
Pentanes Plus	0.59	0.67
Naphtha less than 401F	0.59	0.67
Other Oils equal to or greater than 401F	0.59	0.67
Petroleum Coke	0.5	0.5
Residual Fuel Oil	0.5	0.5
Still Gas	0.8	0.8
Waxes	1	1
Miscellaneous	1	1
LPG	0.59	0.67
Natural Gas other than Electricity	0.59	0.67
Industrial Coal	0.75	0.75

The specific elements of this step are as follows:
For each fuel type that has non-energy uses (as listed in Table C-5 (1)), the fuel consumption (in Btus) in non-energy uses must be estimated, based on (1) the total fuel consumption and (2) the fraction consumed for non-energy uses. Given the absence of state-specific data, the national-level fraction of each fuel type used for non-energy uses is estimated based on the Inventory of U.S. Greenhouse Gas Emissions and Sinks:1990-2002, as seen in Table C-5 (2), although this method is less accurate.

To estimate carbon sequestered in products for each state, the fuel consumption in Btus for non-energy purposes must be multiplied by (1) the fuel-specific carbon content coefficients in Table C-3 and (2) the fuel-specific storage factor. National default values for storage factors are given in Table 4:

$$C\ Sequestered\ (tons\ C) = Non\text{-}energy\ use\ of\ fuel\ (MMBtu) \times C\ Content\ Coefficient\ (lbs\ C/MMBtu) \div 2000\ lbs/ton \times Storage\ Factor\ (\%)$$

The carbon sequestered for each fuel must be summed up to yield the total carbon sequestered. This carbon should then be subtracted from the estimates of the total carbon in fuels.

Table C-5 (1): U.S. Total Fossil Fuel Consumption and Non-Energy Consumption from the Industrial and Transportation Sectors

U.S. Industrial Sector fuel consumption (Tbtu)			
Fuel Type	**1990**	**2002**	**Data Sources**
Other Coal (corrected)	1,607.0	1,306.0	For 1990 data, Inventory of US Greenhouse Gas Emissions and Sinks 1990-2000 (Table2-13) and for 2002 data, Inventory of US Greenhouse Gas Emissions and Sinks 1990-2002 (Table 2-1)
Other Coal (uncorrected)			
Synthetic Natural Gas Correction			
Coke Imports	5.0	62.1	
Natural Gas	8,133.9	8,242.4	
Unmetered			
Natural Gas (uncorrected)			
Biogas added to pipeline			
Asphalt and Road Oil	1,170.2	1,240.0	
Aviation Gasoline			
Distillate Fuel	1,143.4	1,274.0	
Jet Fuel			
Kerosene	12.3	13.9	
LPG	1,607.8	2,172.3	
Lubricants	186.3	171.9	
Motor Gasoline	185.2	303.1	
Residual Fuel	411.4	222.2	
Other Petroleum			
AvGas Blend Components	0.2	7.3	
Crude Oil	50.9		
MoGas Blend Components	53.7		
Misc. Petro Products	137.9	131.1	
Feedstocks, Naphtha less than 401 F	347.9	569.3	
Feedstocks, Other Oils greater than 401 F	754.2	617.6	
Pentanes Plus	250.4	218.7	
Petroleum Coke	626.2	814.2	
Still Gas	1,473.7	1,427.7	
Special Naphthas	107.1	100.1	
Unfinished Oils	(369.1)	(132.6)	
Waxes	33.3	31.4	

U.S. Transportation Sector fuel consumption (TBtu)			
Fuel Type	**1990**	**2002**	**Data Sources**
Lubricants	176.00	162.40	For 1990 data, Inventory of US Greenhouse Gas Emissions and Sinks 1990-2000 (Table 2-13) and for 2002 data, Inventory of US Greenhouse Gas Emissions and Sinks 1990-2002 (Table 2-1)

U.S. Non-Energy Consumption Industrial Sector (Tbtu)			
Fuel Type	**1990**	**2002**	**Data Source**
Natural Gas	288.00	325.63	For 1990 data, Documentation for Emissions of Greenhouse Gases in the U.S. 2002 (Section 1.2). And for 2002 data, Inventory of US Grenhouse Gas Emissions and Sinks 1990-2002 (Table 3-11). The shaded cells are adjusted to account for exports. Based on the calculation in Inventory of US Greenhouse Gas Emissions and Sinks 1990-2000 and 1990-2002, the export factor is 8% for 1990 and 4% for 2002.
Asphalt and Road Oil	1,170.19	1,240.00	
LPG	1,105.32	1,622.98	
Lubricants	186.34	171.90	
Pentanes Plus	*76.51*	164.54	
Feedstocks, Naphtha less than 401 F	319.98	546.53	
Feedstocks, Other Oils greater than 401 F	693.61	592.90	
Still Gas	21.29	30.30	
Petroleum Coke	*178.74*	156.60	
Special Naphthas	107.09	100.10	
Distillate Fuel	7.04	11.70	
Residual Fuel	47.30	56.60	
Waxes	33.30	31.40	
Misc. Petro Products	137.83	131.10	

U.S. Non-Energy Consumption Transportation Sector (Tbtu)			
Fuel Type	**1990**	**2002**	**Data Sources**
Lubricants	176.00	162.40	For 1990 data, Documentation for Emissions of Greenhouse Gases in the U.S. 2002 (Section 1.2), and for 2002 data, Inventory of US Greenhouse Gas Emissions and Sinks 1990-2002 (Table 3-11)

Table C-5 (2): National Non-Energy Consumption Percentages[8,9]

Industrial Sector	1990	2002
Coking Coal		
Natural Gas	4%	4%
Asphalt and Road Oil	100%	100%
LPG	69%	75%
Lubricants	100%	100%
Pentanes Plus	31%	75%
Feedstocks, Naphtha less than 401 F	92%	96%
Feedstocks, Other Oils greater than 401 F	92%	96%
Still Gas	1%	2%
Petroleum Coke	29%	19%
Special Naphthas	100%	100%
Distillate Fuel	1%	1%
Residual Fuel	11%	25%
Waxes	100%	100%
Misc. Petro Products	100%	100%
Other Coal	0%	0%
Independent Power Coal	0%	0%
Aviation Gasoline Blending Components	0%	0%
Crude Oil	0%	0%
Kerosene	0%	0%
Motor Gasoline	0%	0%
Motor Gasoline Blending Components	0%	0%
Unfinished Oils	0%	0%
Transportation		
Lubricants	100%	100%

Step (4): Calculate Net Potential Carbon Emissions

The stored carbon calculated in Step 3 must be subtracted from the total carbon estimated for each fuel type (from Step 2). The resulting estimates represent the net potential carbon emissions.

Step (5): Estimate Carbon Oxidized from Energy Uses

The amount of carbon that does not oxidize during combustion and remains sequestered in soot or ash is usually a small fraction of total carbon, and of this amount a large portion oxidizes in the atmosphere immediately after combustion.

In order to calculate carbon oxidized, net potential carbon emissions (Step 4) must be multiplied by the fractions of fuel combusted recommended by the EIA (Table C-6).

Table C-6: Fraction of Fuel Combusted[10]

Fuels	Fraction of Fuel Combusted
Asphalt	0.99
Aviation Gasoline	0.99
Distillate Fuel Oil	0.99
Ehtane	0.99
Ehtane-Propane Mixture	0.99
Jet Fuel (Kerosene)	0.99
Fet Fuel (Naphtha)	0.99
Kerosene	0.99
Lubricants	0.99
Motor Gasoline (Conventional)	0.99
Moter Gasoline (Oxygenated)	0.99
Natural Gasoline	0.99
Pentanes Plus	0.99
Naphtha less than 401F	0.99
Other Oils equal to or greater than 401F	0.99
Petroleum Coke	0.99
Plant Condensate	0.99
Propane	0.99
Residual Fuel Oil	0.99
Road Oil	0.99
Special Naphthas	0.99
Still Gas	0.995
Unfinished Oils	0.99
Unfractionated Stream	0.99
Waxes	0.99
Miscellaneous	0.99
LPG	0.995
Natural Gas for Electricity	0.995
Natural Gas other than Electricity	0.995
Electricity Coal	0.99
Residential and Commercial Coal	0.99
Coking Coal	0.99
Industrial Coal	0.99

Step (6): Convert Units to Million Metric Tons of Carbon Equivalent (MMTCE)
The total carbon oxidized in tons (Step 5) for each fuel type and sector must be multiplied by the ratio of metric tons per ton (0.9072) to obtain metric tons of carbon equivalent emissions.

In order to find the total state emissions of CO_2 from energy consumption (again, measured in metric tons of carbon), emissions are summed over all fuel types and sectors, and then divided by 10^6 to express emissions in million metric tons of carbon (MMTCE).

Step (7): Calculate Total Emissions

The steps above provide estimates of total carbon in fossil fuels consumed, carbon sequestered in non-energy products, and amount of carbon oxidized to CO_2. With these estimates, total carbon emissions from fossil fuel combustion can be determined. Total carbon emissions are equal to the total carbon content in fuel, minus carbon sequestered in products, adjusted for the carbon unoxidized during combustion, and summed over all fuel types and sectors.

Appendix D

Mobile Combustion

Method for Estimating Methane and Nitrous Oxide Emissions from Mobile Combustion

The estimates of methane (CH_4) and nitrous oxide (N_2O) in this inventory were calculated based on guidance and instructions in the EIIP guidelines. To develop estimates of these gases, emissions from mobile sources, information is required on the level of activity leading to emissions, the combustion technologies used, and the type of emission control technologies employed during and after combustion. The basic approach for estimating emissions is presented in the following equation:

$$Emissions = \Sigma (EF_{abc} \times Activity_{abc})$$

where
- EF = emissions factor (e.g., grams/kilometer traveled);
- Activity = activity level measured in the units appropriate to the emission factor (e.g., miles);
- a = fuel type (e.g., diesel or gasoline);
- b = vehicle type (e.g., passenger car, light duty truck, etc.); and
- c = emission control type.

For required data sources for this process, see Table D-1.

Using the general equation above, the following steps are required to estimate motor vehicle emissions of CH_4 and N_2O: (1) obtain activity data on vehicle miles traveled (VMT); (2) calculate the VMT for each vehicle type; (3) convert the VMT data for use with existing emission factors; (4) distribute VMT by vehicle age; (5) determine emissions control systems for each vehicle type; (6) estimate emissions for each vehicle type; and (7) calculate total emissions in metric tons of carbon equivalent (MTCE).

Step (1): Obtain Activity Data on Vehicle Miles Traveled
Necessary data to calculate the number of vehicle miles traveled (VMT) for all vehicle types were taken from FHWA's *Highway Statistics* as seen in Table D-1, which provides annual estimates of VMT, based on traffic count data. These estimates are available from FHWA on the Internet at http://www.fhwa.dot.gov/ohim/ohimstat.htm, in the table entitled "Vehicle miles of travel, by functional system (Table VM-2)", which shows the number of miles traveled for each state.

Step (2): Calculate the Vehicle Miles Traveled for Each Vehicle Type

For each vehicle type shown in FHWA data, the VMT needs to be calculated. In order to do so, the total VMT must be multiplied by the national percentage of that mileage accounted for by each vehicle type. The national percentage can be calculated using Table VM-1 of the Highway Statistics report, which presents national VMT by vehicle type for each road type.

Step (3): Convert the VMT Data for Use with Existing Emission Factors
The VMT for each vehicle type must be converted into *VMT for the EPA vehicle types* for which emission factors have been developed—i.e., light duty gasoline vehicles (LDGV), light duty gasoline trucks (LDGT), heavy duty gasoline vehicles (HDGV), light duty diesel vehicles (LDDV), light duty diesel trucks (LDDT), heavy duty diesel vehicles (HDDV), and motorcycles (MC). The definitions for these vehicle types presented in the EIIP Guideline are as follows:

- LDGV consists of gasoline-powered passenger cars;
- LDGT consists of gasoline-powered single-unit 2-axle trucks weighing less than 8,500 pounds;
- HDGV consists of gasoline-powered single-unit 2-axle trucks with 6 or more tires, weighing more than 8,500 pounds, and gasoline-powered buses;
- LDDV consists of diesel-powered passenger cars;
- LDDT consists of diesel-powered single-unit 2-axle trucks;
- HDDV consists of diesel-powered single-unit 2-axle trucks with 6 or more tires, weighing more than 8,500 pounds, and most buses and combination trucks (with single or multiple trailers); and
- MC consists of motorcycles.

The distribution of FHWA VMT to EPA vehicle categories is shown in Table D-2 and D-3.

Table D-1: Required Data Sources for CH_4 and N_2O Emissions from Mobile Combustion

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
State Total VMT	Functional System Travel	See Table 2	See Table 3		For 1990 data, USDOT Highway Statistics Summary to 1995 (http://www.fhwa.dot.gov/ohim/summary95/vm202.xlw) and for 2002 data, USDOT Highway Statistics 2002 (VM-2) (http://www.fhwa.dot.gov/policy/ohim/hs02/pdf/vm2.pdf)
	Annual VMT by Vehicle Type	See Table 2	See Table 3		For 1990 data, USDOT Highway Statistics Summary to 1995 (http://www.fhwa.dot.gov/ohim/summary95/vm201.xlw) and for 2002 data, USDOT Highway Statistics 2002 (VM-1) (http://www.fhwa.dot.gov/policy/ohim/hs02/pdf/vm1.pdf)
Non-Highway Fuel Consumption	Fuel Consumption by Aircrafts (Jet Fuels (Kerosene)	48,931,517	35,262,820	Million BTU	State Energy Data 2001. For 2002 data, 2001 data was used as a proxy.
	Fuel Consumption by Aircrafts (Jet Fuels (Naptha)	7,639,944	0	Million BTU	State Energy Data 2001. For 2002 data, 2001 data was used as a proxy.
	Fuel Consumption by Aircrafts (Aviation Gasoline)	1,039,527	1,026,066	Million BTU	USDOT Highway Statistics (Summary to 1995 and 2002) MF-24 Aviation / 42 * 5.048
	Fuel Consumption by Boats (Residual Fuel Oil)	3,608,000	2,086,000	gallons	For 1990 data, a spreadsheet provided by D. Walzer at EIA. For 2002 data, Fuel Oil and Kerosene Sales 2002 (Table 23, Vessel Bunkering Residual)
	Fuel Consumption by Boats (Distillate Fuel Oil)	3,040,000	4,944,000	gallons	For 1990 data, a spreadsheet provided by D. Walzer at EIA. For 2002 data, Fuel Oil and Kerosene Sales 2002 (Table 23, Vessel Bunkering Distillate)
	Fuel Consumption by Boats (Gasoline)	65,909,000	71,945,000	gallons	USDOT Highway Statistics (Summary to 1995 and 2002), (MF-24)
	Fuel Consumption by Locomotives (Diesel)	40,353,000	24,004,000	gallons	For 1990 data, a spreadsheet provided by D. Walzer at EIA. For 2002 data, Fuel Oil and Kerosene Sales 2002 (Table 23)

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
	Fuel Consumption by Farm Equipment (Gasoline Tractor)	20,767,000	22,187,000	gallons	USDOT Highway Statistics (Summary to 1995 and 2002), (MF-24)
	Fuel Consumption by Farm Equipment (Diesel Tractor)	53,607,000	42,283,000	gallons	For 1990 data, a spreadsheet provided by D. Walzer at EIA. For 2002 data, Fuel Oil and Kerosene Sales 2002 (Table 22)
	Fuel Consumption by Construction (Gasoline)	12,048,000	16,240,000	gallons	USDOT Highway Statistics (Summary to 1995 and 2002), (MF-24)
	Fuel Consumption by Construction (Diesel)	36,629,000	36,912,000	gallons	For 1990 data, a spreadsheet provided by D. Walzer at EIA. For 2002 data, Fuel Oil and Kerosene Sales 2002 (Table 24, Diesel Construction)
	Fuel Consumption by Other Non-highway Vehicles (Gasoline HD utility)	9,058,000	43,437,000	gallons	USDOT Highway Statistics (Summary to 1995 and 2002) (MF-24 Industrial and Commercial)
	Fuel Consumption by Other Non-highway Vehicles (Gasoline Small utility)	11,347,038	22,483,607	gallons	For 1990 data, Michigan Industrial and Commercial gasoline use divided by US Total Industrial and Commercial gasoline use, then multiplied by 642200000. For 2002 data, Michigan Gasoline HD Utility divided by US Total Gasoline HD Utility multiplied by 595433333 (US Gasoline Small Utility Total – advised by EPA)
	Fuel Consumption by Other Non-highway Vehicles (Diesel HD utility)	2,432,000	4,274,000	gallons	For 1990 data, spreadsheets by D. Walzer at EIA. For 2002 data, Fuel Oil and Kerosene Sales 2002 (Table 24 Military Diesel plus Other Off-highway Diesel)

Table D-2: Functional System Travel and Annual VMT by Vehicle Type for 1990

Functional System Travel	Motor Cycle	Passenger Car	Other 2-Axle 4-Tire Vehicle	Buses	Single Unit Trucks			Single Trailer Trucks			Multi Trailer	
					2-Axle, 6-Ti	3-Axle	4 or more Axle	4 or Less Axle	5-Axle	6 or More Axle	5 or Less Axle	6-Axle
Rural Interstate	0.81%	67.23%	18.12%	1.37%	1.02%	1.28%	0.05%	2.09%	6.01%	0.51%	0.40%	0.06%
Rural Other Principal Arterial	0.52%	66.18%	24.22%	1.48%	0.98%	0.95%	0.05%	1.83%	2.32%	0.40%	0.19%	0.03%
Rural Minor Arterial	0.60%	68.61%	23.76%	1.73%	0.95%	0.69%	0.05%	1.35%	1.30%	0.26%	0.07%	0.01%
Rural Major Collector	0.45%	70.78%	22.99%	1.49%	0.74%	0.73%	0.03%	0.98%	1.06%	0.18%	0.08%	0.01%
Rural Minor Collector	0.45%	75.10%	19.18%	1.54%	0.78%	0.51%	0.08%	1.21%	0.55%	0.21%	0.10%	0.01%
Rural Local	0.00%	65.50%	30.10%	0.00%	3.70%	0.60%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
Urban Interstate	0.51%	69.25%	20.64%	1.34%	0.79%	1.13%	0.07%	2.14%	2.52%	0.54%	0.17%	0.04%
Urban Other Freeways and Expressways	0.43%	77.80%	12.20%	0.95%	0.63%	0.67%	0.07%	2.27%	3.54%	0.39%	0.25%	0.04%
Urban Other Principl Arterial	0.33%	74.73%	20.16%	1.09%	0.66%	0.59%	0.05%	1.04%	0.78%	0.19%	0.05%	0.01%
Urban Minor Arterial	0.53%	78.34%	16.66%	1.53%	0.56%	0.50%	0.04%	1.19%	0.14%	0.10%	0.03%	0.01%
Urban Collector	0.64%	76.30%	18.17%	1.43%	0.50%	2.06%	0.03%	0.62%	0.04%	0.06%	0.06%	0.00%
Urban Local	0.00%	75.80%	19.90%	1.00%	1.90%	0.80%	0.10%	0.20%	0.30%	0.00%	0.00%	0.00%

Source: Travel Activity Report for 1990, Highway Performance Monitoring System

Functional System Travel	VM2 Data	Motor Cycle	Passenger Car	Other 2-Axle 4-Tire Vehicle	Buses	Single Unit Trucks			Single Trailer Trucks			Multi Trailer	
						2-Axle, 6-Ti	3-Axle	4 or more Axle	4 or Less Axle	5-Axle	6 or More Axle	5 or Less Axle	6-Axle
Rural Interstate	5850	47.385	3932.955	1060.02	80.145	59.67	74.88	2.925	122.265	351.585	29.835	23.4	3.5
Rural Other Principal Arterial	6386	33.2072	4226.2548	1546.6892	94.5128	62.5828	60.667	3.193	116.8638	148.155	25.544	12.1334	1.915
Rural Minor Arterial	6060	36.36	4157.766	1439.856	104.838	57.57	41.814	3.03	81.81	78.78	15.756	4.242	0.60
Rural Major Collector	10176	45.792	7202.5728	2339.4624	151.6224	75.3024	74.2848	3.0528	99.7248	107.866	18.3168	8.1408	1.017
Rural Minor Collector	1524	6.858	1144.524	292.3032	23.4696	11.8872	7.7724	1.2192	18.4404	8.382	3.2004	1.524	0.152
Rural Local	2542	0	1665.01	765.142	0	94.054	15.252	2.542	0	0	0	0	
Urban Interstate	11114	56.6814	7696.445	2293.9296	148.9276	87.8006	125.5882	7.7798	237.8396	280.073	60.0156	18.8938	4.445
Urban Other Freeways and Expressways	3577	15.3811	2782.906	436.394	33.9815	22.5351	23.9659	2.5039	81.1979	126.626	13.9503	8.9425	1.430
Urban Other Principl Arterial	15010	49.533	11216.973	3026.016	163.609	99.066	88.559	7.505	156.104	117.078	28.519	7.505	1.50
Urban Minor Arterial	11156	59.1268	8739.6104	1858.5896	170.6868	62.4736	55.78	4.4624	132.7564	15.6184	11.156	3.3468	1.115
Urban Collector	3748	23.9872	2859.724	681.0116	53.5964	18.74	77.2088	1.1244	23.2376	1.4992	2.2488	2.2488	
Urban Local	3948	0	2992.584	785.652	39.48	75.012	31.584	3.948	7.896	11.844	0	0	
						726.6937	677.3561	43.2855	1078.1355	1247.51	208.5419	90.3771	15.694
Total	**81091**	374.3117	58617.325	16525.0656	1064.8691		1447.3353				3062.0933		

Source: Highway Statistics Summary to 1995

(Million Miles)

Table D-3: Functional System Travel and Annual VMT by Vehicle Type for 2002

VM2 Functional System Travel	Annual VTM by Vehicle Type	Motor Cycle	Passenger Car	Other 2-Axle 4-Tire Vehicle	Buses	Single-Unit Trucks	Combination Trucks	Total
Rural Interstate	Rural Interstate	0.10%	69.00%	16.40%	0.30%	2.80%	11.40%	100.00%
Rural Other Principal Arterial	Other Arterial	0.10%	65.40%	25.80%	0.20%	3.20%	5.30%	100.00%
Rural Minor Arterial	Other Arterial	0.10%	65.40%	25.80%	0.20%	3.20%	5.30%	100.00%
Rural Major Collector	Other Rural	0.20%	65.70%	28.30%	0.10%	4.10%	1.60%	100.00%
Rural Minor Collector	Other Rural	0.20%	65.70%	28.30%	0.10%	4.10%	1.60%	100.00%
Rural Local	Other Rural	0.20%	65.70%	28.30%	0.10%	4.10%	1.60%	100.00%
Urban Interstate	Urban Interstate	0.10%	76.40%	14.30%	0.20%	2.80%	6.20%	100.00%
Urban Other Freeways and Expressways	Other Urban	0.30%	71.00%	20.90%	1.30%	2.50%	4.00%	100.00%
Urban Other Principl Arterial	Other Arterial	0.10%	72.90%	22.30%	0.10%	1.70%	2.90%	100.00%
Urban Minor Arterial	Other Arterial	0.10%	72.90%	22.30%	0.10%	1.70%	2.90%	100.00%
Urban Collector	Other Urban	0.30%	71.00%	20.90%	1.30%	2.50%	4.00%	100.00%
Urban Local	Other Urban	0.30%	71.00%	20.90%	1.30%	2.50%	4.00%	100.00%

Source: Travel Activity Report for 2002, Highway Performance Monitoring System

Functional System Travel	VM2 Data	Motor Cycle	Passenger Car	Other 2-Axle 4-Tire Vehicle	Buses	Single-Unit Trucks	Combination Trucks	Total
Rural Interstate	7636	7.636	5268.84	1252.304	22.908	213.808	870.504	7636
Rural Other Principal Arterial	8831	8.831	5775.474	2278.398	17.662	282.592	468.043	8831
Rural Minor Arterial	6933	6.933	4534.182	1788.714	13.866	221.856	367.449	6933
Rural Major Collector	10588	21.176	6956.316	2996.404	10.588	434.108	169.408	10588
Rural Minor Collector	1383	2.766	908.631	391.389	1.383	56.703	22.128	1383
Rural Local	2671	5.342	1754.847	755.893	2.671	109.511	42.736	2671
Urban Interstate	14457	14.457	11045.148	2067.351	28.914	404.796	896.334	14457
Urban Other Freeways and Expressways	4676	14.028	3319.96	977.284	60.788	116.9	187.04	4676
Urban Other Principl Arterial	18111	18.111	13202.919	4038.753	18.111	307.887	525.219	18111
Urban Minor Arterial	13970	13.97	10184.13	3115.31	13.97	237.49	405.13	13970
Urban Collector	4340	13.02	3081.4	907.06	56.42	108.5	173.6	4340
Urban Local	6548	19.644	4649.08	1368.532	85.124	163.7	261.92	6548
Total	**100144**	145.914	70680.927	21937.392	332.405	2657.851	4389.511	100144

Source: Highway Statistics 2002 Table VM-2 (million miles)

Step (4): Distribute VMT by Vehicle Age

In order to account for changes over time in the control technologies used by vehicles, estimates of VMT by vehicle type must be distributed across vehicle age, or "vintage." To do this, it is necessary to incorporate (1) vehicle age distribution, and (2) annual age-specific vehicle mileage accumulation. Vehicle age distribution simply refers to the age distribution of the vehicle fleet. This distribution may vary by state due to climate, cultural reasons, and/or economic reasons. The average vehicle age distribution for the United States provided in Table D-4, and was used as a default because state-specific data were not available.

Table D-4: Age Distribution by Vehicle/Fuel Type[11]

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	5.3%	5.8%	4.9%	5.3%	5.9%	4.2%	14.4%
2	7.1%	7.6%	8.9%	7.1%	7.4%	7.8%	16.8%
3	7.1%	7.5%	8.1%	7.1%	6.9%	7.2%	13.5%
4	7.1%	7.3%	7.4%	7.1%	6.4%	6.7%	10.9%
5	7.0%	7.1%	6.8%	7.0%	6.0%	6.2%	8.8%
6	7.0%	6.8%	6.2%	7.0%	5.6%	5.8%	7.0%
7	6.9%	6.5%	5.6%	6.9%	5.2%	5.3%	5.6%
8	6.8%	6.1%	5.1%	6.8%	4.8%	5.0%	4.5%
9	6.6%	5.7%	4.7%	6.6%	4.5%	4.6%	3.6%
10	6.3%	5.2%	4.3%	6.3%	4.2%	4.3%	2.9%
11	5.9%	4.7%	3.9%	5.9%	3.9%	4.0%	2.3%
12	5.4%	4.2%	3.6%	5.4%	3.6%	3.7%	9.7%
13	4.6%	3.6%	3.3%	4.6%	3.4%	3.4%	0.0%
14	3.6%	3.1%	3.0%	3.6%	3.2%	3.2%	0.0%
15	2.9%	2.6%	2.7%	2.9%	2.9%	2.9%	0.0%
16	2.3%	2.2%	2.5%	2.3%	2.7%	2.7%	0.0%
17	1.8%	1.8%	2.3%	1.8%	2.5%	2.5%	0.0%
18	1.4%	1.4%	2.1%	1.4%	2.4%	2.4%	0.0%
19	1.1%	1.2%	1.9%	1.1%	2.2%	2.2%	0.0%
20	0.9%	1.1%	1.7%	0.9%	2.1%	2.0%	0.0%
21	0.7%	1.1%	1.6%	0.7%	1.9%	1.9%	0.0%
22	0.6%	1.0%	1.5%	0.6%	1.8%	1.8%	0.0%
23	0.4%	1.0%	1.3%	0.4%	1.7%	1.6%	0.0%
24	0.4%	0.9%	1.2%	0.4%	1.6%	1.5%	0.0%
25	1.0%	4.6%	5.4%	1.0%	7.3%	7.2%	0.0%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

LDGV (gasoline passenger cars, also referred to as light-duty gas vehicles)
LDGT (light-duty gas trucks)
HDGV (heavy-duty gas vehicles)
LDDV (diesel passenger cars, also referred to as light-duty diesel vehicles)
LDDT (light-duty diesel trucks)
HDDV (heavy-duty diesel vehicles)
MC (motorcycles)

Annual age-specific vehicle mileage accumulation refers to the relative distance that vehicles are driven annually. The U.S. average annual age-specific vehicle mileage accumulation is provided in Table D-5. Since state-specific data were unavailable for vehicle mileage accumulation, the U.S. values were used as defaults.

Table D-5: Annual Age-Specific Vehicle Mileage Accumulation of U.S. Vehicles (miles)[12]

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	14,910	19,906	20,218	14,910	26,371	28,787	4,786
2	14,174	18,707	18,935	14,174	24,137	26,304	4,475
3	13,475	17,559	17,100	13,475	22,095	24,038	4,164
4	12,810	16,462	16,611	12,810	20,228	21,968	3,853
5	12,178	15,413	15,560	12,178	18,521	20,078	3,543
6	11,577	14,411	14,576	11,577	16,960	18,351	3,232
7	11,006	13,454	13,655	11,006	15,533	16,775	2,921
8	10,463	12,541	12,793	10,463	14,227	15,334	2,611
9	9,947	11,671	11,987	9,947	13,032	14,019	2,300
10	9,456	10,843	11,231	9,456	11,939	12,817	1,989
11	8,989	10,055	10,524	8,989	10,939	11,719	1,678
12	8,546	9,306	9,863	8,546	10,024	10,716	1,368
13	8,124	8,597	9,243	8,124	9,186	9,799	1,368
14	7,723	7,925	8,662	7,723	8,420	8,962	1,368
15	7,342	7,290	8,028	7,342	7,718	8,196	1,368
16	6,980	6,690	7,610	6,980	7,075	7,497	1,368
17	6,636	6,127	7,133	6,636	6,487	6,857	1,368
18	6,308	5,598	6,687	6,308	5,948	6,273	1,368
19	5,997	5,103	6,269	5,997	5,454	5,739	1,368
20	5,701	4,642	5,877	5,701	5,002	5,250	1,368
21	5,420	4,214	5,510	5,420	4,588	4,804	1,368
22	5,152	3,818	5,166	5,152	4,209	4,396	1,368
23	4,898	3,455	4,844	4,898	3,861	4,023	1,368
24	4,656	3,123	4,542	4,656	3,542	3,681	1,368
25	4,427	2,822	4,259	4,427	3,250	3,369	1,368

To obtain estimates of VMT by vehicle age, the vehicle age distribution and annual age-specific vehicle mileage accumulation must be cross-multiplied. The result of this cross-multiplication for the U.S. defaults is shown in Table D-3.

Table D-6: VMT Distribution by Vehicle Age[13]

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	7.51%	9.41%	7.89%	7.51%	11.50%	8.27%	19.39%
2	9.52%	11.56%	13.48%	9.52%	13.07%	14.00%	21.15%
3	9.05%	10.62%	11.11%	9.05%	11.15%	11.86%	15.82%
4	8.59%	9.70%	9.85%	8.59%	9.51%	10.05%	11.82%
5	8.14%	8.80%	8.43%	8.14%	8.11%	8.52%	8.77%
6	7.68%	7.92%	7.21%	7.68%	6.92%	7.22%	6.37%
7	7.22%	7.04%	6.16%	7.22%	5.90%	6.13%	4.60%
8	6.72%	6.19%	5.27%	6.72%	5.04%	5.20%	3.31%
9	6.20%	5.36%	4.51%	6.20%	4.30%	4.41%	2.33%
10	5.64%	4.57%	3.86%	5.64%	3.67%	3.74%	1.62%
11	5.03%	3.82%	3.31%	5.03%	3.13%	3.18%	1.09%
12	4.38%	3.14%	2.83%	4.38%	2.67%	2.70%	3.73%
13	3.54%	2.52%	2.42%	3.54%	2.28%	2.29%	0.00%
14	2.67%	1.99%	2.07%	2.67%	1.95%	1.94%	0.00%
15	2.01%	1.54%	1.76%	2.01%	1.66%	1.65%	0.00%
16	1.52%	1.16%	1.52%	1.52%	1.42%	1.40%	0.00%
17	1.14%	0.87%	1.30%	1.14%	1.21%	1.19%	0.00%
18	0.86%	0.64%	1.12%	0.86%	1.04%	1.01%	0.00%
19	0.65%	0.50%	0.96%	0.65%	0.89%	0.86%	0.00%
20	0.49%	0.43%	0.82%	0.49%	0.76%	0.73%	0.00%
21	0.37%	0.37%	0.70%	0.37%	0.65%	0.62%	0.00%
22	0.28%	0.32%	0.60%	0.28%	0.55%	0.53%	0.00%
23	0.21%	0.27%	0.52%	0.21%	0.47%	0.45%	0.00%
24	0.16%	0.23%	0.44%	0.16%	0.40%	0.38%	0.00%
25	0.43%	1.04%	1.85%	0.43%	1.75%	1.65%	0.00%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Note: Estimated by weighting data in Table D-5 by data in D-6.

For each vehicle type, allocate the vehicle miles traveled to the relevant emission control technologies. Percentage breakdowns for each vehicle type are presented in Tables D-7 to D-10.

Table D-7: Control Technology Assignments for Gasoline Passenger Cars (percent of VMT)[14]

Model Years	Non-Catalyst	Oxidation	Tier 0	Tier 1	LEV
≤1974	100%	-	-	-	-
1975	20%	80%	-	-	-
1976-1977	15%	85%	-	-	-
1978-1979	10%	90%	-	-	-
1980	5%	88%	7%	-	-
1981	-	15%	85%	-	-
1982	-	14%	86%	-	-
1983	-	12%	88%	-	-
1984-1993	-	-	100%	-	-
1994	-	-	60%	40%	-
1995	-	-	20%	80%	-
1996	-	-	1%	97%	2%
1997	-	-	0.5%	96.5%	3%
1998	-	-	-	87%	13%
1999	-	-	-	67%	33%
2000	-	-	-	44%	56%
2001	-	-	-	3%	97%
2002	-	-	-	1%	99%

Table D-8: Control Technology Assignments for Gasoline Light-Duty Trucks (percent of VMT)[15]

Model Years	Non-Catalyst	Oxidation	Tier 0	Tier 1	LEV
≤1974	100%	-	-	-	-
1975	30%	70%	-	-	-
1976	20%	80%	-	-	-
1977-1978	25%	75%	-	-	-
1979-1980	20%	80%	-	-	-
1981	-	95%	5%	-	-
1982	-	90%	10%	-	-
1983	-	80%	20%	-	-
1984	-	70%	30%	-	-
1985	-	60%	40%	-	-
1986	-	50%	50%	-	-
1987-1993	-	5%	95%	-	-
1994	-	-	60%	40%	-
1995	-	-	20%	80%	-
1996-1997	-	-	-	100%	-
1998	-	-	-	80%	20%
1999	-	-	-	57%	43%
2000	-	-	-	65%	35%
2001	-	-	-	1%	99%
2002	-	-	-	10%	90%

Table D-9: Technology Assignments for Gasoline Heavy-Duty Vehicles (percent of VMT)[16]

Model Years	Uncontrolled	Non-Catalyst	Oxidation	Tier 0	Tier 1	LEV
≤1981	100%	-	-	-	-	-
1982-1984	95%	-	5%	-	-	-
1985-1986	-	95%	5%	-	-	-
1987	-	70%	15%	15%	-	-
1988-1989	-	60%	25%	15%	-	-
1990-1995	-	45%	30%	25%	-	-
1996	-	-	-	25%	10%	65%
1997	-	-	-	10%	5%	85%
1998	-	-	-	-	96%	4%
1999	-	-	-	-	78%	22%
2000	-	-	-	-	54%	46%
2001	-	-	-	-	64%	36%
2002	-	-	-	-	69%	31%

Table D-10: Control Technology Assignments for Diesel Highway and Motorcycle VMT[17]

Vehicle Type/Control Technology	Model Years
Diesel Passenger Cars and Light-Duty Trucks	
Uncontrolled	≤1982
Moderate control	1983-1995
Advanced control	1996-2002
Heavy-Duty Diesel Vehicles	
Uncontrolled	1966-1972
Moderate control	1983-1995
Advanced control	1996-2002
Motorcycles	
Uncontrolled	1966-1995
Non-catalyst controls	1996-2002

Step (6): Estimate Emissions for Each Vehicle Type

For each combination of vehicle type and emission control type, the VMT must be multiplied by the appropriate emission factor for CH_4, from Table D-11. The process must be repeated for N_2O, using data from Table D-12. This step estimates emissions in units of grams.

Table D-11: Methane Emission Factors for Highway Vehicles[18]

Emission Control Technology	Vehicle Type						
	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
Tier 1 Three-Way Catalyst	0.048	0.056	0.097				
Tier 0 Three-Way Catalyst	0.064	0.113	0.121				
Oxidation Catalyst	0.113	0.145	0.145				
Non-Catalyst Controls	0.193	0.225	0.201				0.209
LEV	0.040	0.048	0.071				
Advanced Control (Diesel)				0.016	0.016	0.064	
Moderate Control (Diesel)				0.016	0.016	0.080	
Uncontrolled	0.217	0.217	0.435	0.016	0.016	0.097	0.418

Table D-12: Nitrous Oxide Emission Factors for Highway Vehicles[19]

Emission Control Technology	Vehicle Type						
	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
Tier 1 Three-Way Catalyst	0.046	0.058	0.139				
Tier 0 Three-Way Catalyst	0.082	0.102	0.236				
Oxidation Catalyst	0.052	0.065	0.150				
Non-Catalyst Controls	0.017	0.021	0.048				0.007
LEV	0.028	0.035	0.113				
Advanced Control (Diesel)				0.016	0.032	0.048	
Moderate Control (Diesel)				0.016	0.032	0.048	
Uncontrolled	0.017	0.021	0.048	0.016	0.032	0.048	0.007

Step (7): Calculate Total Emissions in Metric Tons of Carbon Equivalent

To obtain total emissions from motor vehicles, CH_4 emissions estimates must be summed across all vehicle and emission control types. The same process is required for N_2O.

The values for both CH_4 and N_2O must be converted from units of grams to units of MTCE by first dividing the number of grams by one million to obtain the number of metric tons. Then, for CH_4, the number of metric tons must be multiplied by 12/44 (the ratio of the atomic weight of carbon to the molecular weight of CO_2) and by 21 (the Global Warming Potential (GWP) of CH_4) to obtain CH_4 emissions in MTCE. For N_2O, the number of metric tons must be multiplied by 12/44 and by 310 (the GWP of N_2O) to obtain N_2O emissions in MTCE.

Method for Estimating Methane and Nitrous Oxide Emissions from Non-Road Mobile Sources

Mobile sources other than road vehicles have received relatively little study compared to passenger cars and heavy-duty trucks. Major sources of pollutant emissions among non-road vehicles include jet aircraft, gasoline-fueled piston aircraft, agricultural and construction equipment, railway locomotives, boats, and ships.

Using the general equation presented at the beginning of this section, the following steps are required to estimate CH_4 and N_2O emissions from non-highway mobile sources: (1) obtain data on fuel consumption by each type of non-highway vehicle; (2) convert units to kilograms or megajoules; (3) estimate emissions for each type of non-highway vehicle; and (4) convert units to MTCE.

Step (1): Obtain Data on Fuel Consumption by Each Type of Non-Highway Vehicle
Currently, there are no recommended data sources for fuel consumption data for the non-highway vehicles required for this purpose. We, therefore, obtained the data following the way used for calculating default values in the SIT software and based on the guidance of the EIA personnel. The data source for each type of non-highway vehicles is listed in Table D-1.

Step (2): Convert Units to Kilograms or Megajoules
Units must be converted to kilograms (kg) or megajoules (MJ) of fuel consumed as appropriate. To convert Btus to MJ, the number of Btus must be multiplied by 1,054 joules per Btu. Then, the value in joules must be divided by 1,000,000 to convert to MJ.

Step (3): Estimate Emissions by Converting Kilograms or Megajoules to Grams of CH_4 and N_2O, for Each Type of Non-Highway Vehicle
The amount of fuel consumed must be multiplied by the appropriate emission factor for CH_4, and for N_2O. Data on emission factors from engines used in aircraft, boats and ships, railway locomotives, agricultural equipment (such as tractors and harvesters), and construction equipment (such as bulldozers and cranes) are shown in Table D-13.

Table D-13: Emission Factors for U.S. Non-Road Mobile Sources[20]

Source	Uncontrolled Emissions	
	CH_4	N_2O
Jet Turboprop Aircraft		
g/kg Fuel	0.087	0.100
g/MJ Fuel	0.002	0.023
Gasoline (Piston) Aircraft		
g/kg Fuel	2.640	0.040
g/MJ Fuel	0.060	0.0009
Boats and Ships		
g/kg Fuel	0.230	0.080
g/MJ Fuel	0.005	0.002
Locomotives		
g/kg Fuel	0.250	0.080
g/MJ Fuel	0.006	0.002
Agricultural Equipment		
g/kg Fuel	0.450	0.080
g/MJ Fuel	0.011	0.002
Construction and Industrial Equipment		
g/kg Fuel	0.180	0.080
g/MJ Fuel	0.004	0.002

Step (4): Convert Units to Metric Tons of Carbon Equivalent

The values for both CH_4 and N_2O should be converted from units of grams to units of MTCE by first dividing the number of grams by one million to obtain the number of metric tons. Then, for CH_4, the number of metric tons must be multiplied by 12/44 (the ratio of the atomic weight of carbon to the molecular weight of CO_2) and by 21 (the GWP of CH_4) to obtain CH_4 emissions in MTCE, and, for N_2O, the number of metric tons must be multiplied by 12/44 and by 310 (the GWP of N_2O) to obtain N_2O emissions in MTCE.

Appendix E

Stationary Combustion

Method for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion

The emissions of methane and nitrous oxide from this source category were calculated based on guidance and instructions in the EIIP guidelines. Estimation of emissions from this source category using the Intergovernmental Panel on Climate Change (IPCC) Tier 1 approach can be described as a following formula:

$$Emissions = \Sigma (Activity_{ab} \times EF_{ab})$$

where: Activity = Energy input (BBtu);
EF = Emission factor (mt/BBtu);
a = Primary fuel type; and
b = Sector.

As seen in this equation, emission estimation is based on (1) energy activities and (2) emission factors, each of which vary by primary fuel type (coal, oil, or gas), and sector.

The methodologies for estimating emissions of these two gases are identical. The methodology consists of five steps: (1) obtain required data; (2) make data adjustments; (3) estimate emissions using the IPCC Tier 1 approach; (4) sum across all fuel types and sectors to derive total emissions; and (5) convert units to metric tons of carbon equivalent (MTCE).

Step (1): Obtain Required Data
Required Data: The required data are the amount of coal, petroleum, natural gas, and wood combusted in the Residential, Commercial, Industrial, and Electric Utility sectors. (They are same as the data for fossil fuel combustion, although wood combustion was not counted in the fossil fuel category.)

Data Sources: As the State of Michigan does not compile its own energy consumption data, we consulted with EIA for most recent available data for the state energy consumption (1990-2001). These data are available on the Internet at http://www.eia.doe.gov/emeu/states/sep_fuel/notes/_fuelnotes_multistate.html#use_. Fossil fuel statistics should be provided on an energy basis (e.g., in units of Btu). State Energy Data is available both in physical units and in units of Btu. As 2002 data were not available at the time of data collection, Annual Coal Report 2002 and Natural Gas

Annual 2002 were used for 2002 coal and natural gas consumption data. For wood and petroleum based fuels, 2002 figures were estimated from their historical 1990-2001 data by performing a trend calculation for each of these fuels, and extrapolating 2002 data if R^2 is more than 0.5. For those R^2 is less than 0.5, the average of the recent five years was calculated to estimate the 2002 figures. These consumption data given in physical units as shown in Table C-1 in Method for Estimating Carbon Dioxide from Fossil Fuel Combustion were then be converted into million Btu by applying the heat contents listed in Table C-2 in the same section.

Step (2): Make Data Adjustments

Adjust for non-energy uses of fuels. Many fossil fuels are used for non-energy purposes to some degree. Since these fuels are not combusted when used for non-energy purposes, their consumption should be subtracted from statistics that include total fuel use.

For each fuel type that has non-energy uses (as listed in Table C-5 (1) and Table C-5 (2) in "Method for Estimating Carbon Dioxide from Fossil Fuel Combustion"), the quantity of fuel consumed in non-energy uses must be subtracted, based on (1) the total amount consumed and (2) the fraction consumed for non-energy uses. An example on how to carry out this adjustment is presented in Method for Estimating Carbon Dioxide from Fossil Fuel Combustion. For data on the fraction of each fuel type consumed for non-energy uses, given the absence of state-specific data, the national-level fraction of each fuel type used for non-energy uses is estimated using U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2002, although this method will be less accurate.

Synthetic natural gas production: EIA's coal data also include industrial coal used to make synthetic natural gas, which is also accounted for under natural gas consumption data. Therefore, the energy content of synthetic natural gas should be subtracted from the energy content of industrial coal to prevent double counting of emissions. State-specific natural gas data can be obtained from EIA's *Natural Gas Annual* (EIA 2004). For the State of Michigan, the value is zero for both 1990 and 2002.

Step (3): Estimate Emissions Using the IPCC Tier 1 Approach

To estimate emissions using this approach, fuel use in BBtu was multiplied by the appropriate emission factor in Table E-1.

Step (4): Sum Across All Fuel Types and Sectors to Derive Total Emissions

The estimates of CH_4 and N_2O emission were summed across all fuels and sectors to derive total emissions (in metric tons) of each gas.

Step (5): Convert Units to Metric Tons of Carbon Equivalent

To obtain emissions in metric tons of CO_2 equivalent ($MTCO_2E$), the emissions in metric tons for each of the gases were multiplied by the Global Warming Potential (GWP) for each gas. The GWPs of CH_4 and N_2O are 21 and 310, respectively.

The data from $MTCO_2E$ of gas was converted to MTCE by multiplying by 12/44, which is the ratio of the atomic weight of C to the molecular weight of CO_2.

Table E-1: CH_4 and N_2O Emission Factors by Fuel Type and Sector (metric tons/BBtu)[21]

Fuel/End-Use Sector	N_2O	CH_4
Coal		
Residential	0.00140	0.30069
Commercial	0.00140	0.01002
Industrial	0.00140	0.01002
Electric Utilities	0.00140	0.00100
Petroleum		
Residential	0.00060	0.01002
Commercial	0.00060	0.01002
Industrial	0.00060	0.00200
Electric Utilities	0.00060	0.00301
Natural Gas		
Residential	0.00009	0.00475
Commercial	0.00009	0.00475
Industrial	0.00009	0.00475
Electric Utilities	0.00009	0.00095
Wood		
Residential	0.00380	0.28487
Commercial	0.00380	0.28487
Industrial	0.00380	0.02849
Electric Utilities	0.00380	0.02849

Appendix F

Natural Gas and Oil Systems

Natural Gas and Oil Systems Methodology

The emissions calculation methodology for natural gas systems is straightforward. Once the required activity data were obtained, shown in Table F-1, they were multiplied by the appropriate methane emission factor, shown in Table F-2. Finally, the methane emissions are converted to million metric tons carbon equivalent.

Calculating CH_4 emissions from oil systems was slightly more involved than the natural gas system methodology. The default EIIP emission factors for production, refining, and transportation were not developed from the same source data. In order to match the default 2002 emission factors derived from U.S. EPA data, emission factors were calculated separately for 1990 using similar data from the U.S. EPA. The emission factors used in calculating emissions from oil systems are shown in Table F-3.

The original oil system emission factors included in the SIT module were calculated by ICF Consulting. These factors were based on a petroleum industry data model, which is not available to the general public. Since the original emission factors were only calculated up through year 2000, it was necessary to calculate new emission factors for year 2002 using similar data available from the U.S. EPA.

Rather than apply emission factors from two different sources, ICF and the U.S. EPA, new emission factors for 1990 were calculated using the same methodology and data from the U.S. EPA.

Since the data are not directly available, it was necessary to estimate the amount of oil refined in 1990 and 2002. The SIT natural gas and oil module contains a preset formula that estimates the amount of oil refined based on the amount of crude oil entering the crude atmospheric distillation unit by Petroleum Administration for Defense Districts (PADD) and the operating refining capacity of state and PADD.

Table F-1: Natural Gas and Oil Systems Activity Data

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Source
Methane from Natural Gas and Oil Systems	Number of natural gas wells	2,467	8,021	Number	U.S. Department of Energy, Energy Information Administration (EIA) (2002) "Distribution of Wells by Production Rate Bracket" http://www.eia.doe.gov/pub/oil_gas/petrosystem/mi_table.html (Accessed: 5/11/2004) EIA (1990) "Distribution of Oil Wells and Production by Rate Bracket" http://www.eia.doe.gov/pub/oil_gas/petrosystem/petroleum/mi-1b.xls (Accessed: 5/11/2004)
Methane from Natural Gas and Oil Systems	Number of natural gas processing plants	28	19	Number	Oil and Gas Journal (2003) June 30, 2003. Vol. 101, Iss. 25; p. 57. Oil & Gas Journal (1991) July 22, 1991. Vol. 89, Iss. 29; p. 54.
Methane from Natural Gas and Oil Systems	Number of miles of natural gas transmission pipeline	7,567 **(EST)**	8,618	Miles	U.S. Department of Transportation, Office of Pipeline Safety (U.S.DOT). "Distribution and Transmission Annuals Data: 1990 and 2002". http://ops.dot.gov/DT98.htm. (Accessed 5/21/2004)
Methane from Natural Gas and Oil Systems	Number of transmission compressor stations	45 **(EST)**	51 **(EST)**	Number	Estimated by multiplying the transmission pipeline mileage by 0.005975.
Methane from Natural Gas and Oil Systems	Number of transmission storage compressor stations	10 **(EST)**	12 **(EST)**	Number	Estimated by multiplying the transmission pipeline mileage by 0.001357.

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Source
Methane from Natural Gas and Oil Systems	Number of liquified natural gas storage stations	0	0	Number	Zajac, Andrea (2004) Email communication with Andrea Zajac, Storage Tank Division Chief, Michigan Department of Environmental Quality, 20 July.
Methane from Natural Gas and Oil Systems	Number of mile of natural gas gathering pipeline	207 **(EST)**	463	Miles	U.S.DOT, "Distribution and Transmission Annuals Data: 1990 and 2002". http://ops.dot.gov/DT98.htm. (Accessed 5/21/2004)
Methane from Natural Gas and Oil Systems	Number of miles of cast iron main natural gas pipeline	4,288	5,722	Miles	U.S.DOT, "Distribution and Transmission Annuals Data: 1990 and 2002". http://ops.dot.gov/DT98.htm. (Accessed 5/21/2004)
Methane from Natural Gas and Oil Systems	Number of miles of unprotected steel main natural gas pipeline	2,604	4,621	Miles	U.S.DOT, "Distribution and Transmission Annuals Data: 1990 and 2002". http://ops.dot.gov/DT98.htm. (Accessed 5/21/2004)
Methane from Natural Gas and Oil Systems	Number of miles of protected steel main natural gas pipeline	24,165	28,023	Miles	U.S.DOT, "Distribution and Transmission Annuals Data: 1990 and 2002". http://ops.dot.gov/DT98.htm. (Accessed 5/21/2004)
Methane from Natural Gas and Oil Systems	Number of miles of plastic main natural gas pipeline	10,409	32,075	Miles	U.S.DOT, "Distribution and Transmission Annuals Data: 1990 and 2002". http://ops.dot.gov/DT98.htm. (Accessed 5/21/2004)
Methane from Natural Gas and Oil Systems	Total number of services (customer connections)	2,641,960	4,221,437	Number	U.S.DOT, "Distribution and Transmission Annuals Data: 1990 and 2002". http://ops.dot.gov/DT98.htm. (Accessed 5/21/2004)

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Source
Methane from Natural Gas and Oil Systems	Number of unprotected steel services	70,691	134,826	Number	U.S.DOT, "Distribution and Transmission Annuals Data: 1990 and 2002". http://ops.dot.gov/DT98.htm. (Accessed 5/21/2004)
Methane from Natural Gas and Oil Systems	Number of protected steel services	1,015,646	1,046,057	Number	U.S.DOT, "Distribution and Transmission Annuals Data: 1990 and 2002". http://ops.dot.gov/DT98.htm. (Accessed 5/21/2004)
Methane from Natural Gas and Oil Systems	Oil produced	12,509,088	5,757,100	Barrels	U.S. Department of Energy, Energy Information Administration (EIA) (2002) "Distribution of Wells by Production Rate Bracket" http://www.eia.doe.gov/pub/oil_gas/petrosystem/mi_table.html (Accessed: 5/11/2004) EIA (1990) "Distribution of Oil Wells and Production by Rate Bracket" http://www.eia.doe.gov/pub/oil_gas/petrosystem/petroleum/mi-1b.xls (Accessed: 5/11/2004)
Methane from Natural Gas and Oil Systems	Oil refined	38,539,600 **(EST)**	24,212,000 **(EST)**	Barrels	Estimated based on EIA data and calculation tool provided in SIT Oil and Gas Systems module
Methane from Natural Gas and Oil Systems	Oil transported	38,539,600 **(EST)**	24,212,000 **(EST)**	Barrels	Estimated to equal oil refined

Note: (EST) Indicates that the value has been estimated

Table F-2: Natural Gas Systems Emission Factors

Activity and Emission Factor Unit		Emission Factor 1990 and 2002
Production		
	Metric tons of CH_4 per Well	2.34
	Metric tons of CH_4 per off-shore platforms in the Gulf of Mexico	25.10
	Metric tons of CH_4 per off-shore platforms not in the Gulf of Mexico	13.06
Transmission		
	Metric tons of CH_4 per mile of gathering pipeline	0.40
	Metric tons of CH_4 per gas processing plant	1218.03
	Metric tons of CH_4 per gas transmission compressor station	974.78
	Metric tons of CH_4 per gas storage compressor station	954.55
	Metric tons of CH_4 per mile of transmission pipeline	0.61
	Metric tons of CH_4 per LNG storage compressor station	1040.50
Distribution		
	Metric tons of CH_4 per mile of cast iron distribution pipeline	4.75
	Metric tons of CH_4 per mile of unprotected steel distribution pipeline	2.25
	Metric tons of CH_4 per mile of protected steel distribution pipeline	0.084
	Metric tons of CH_4 per mile of plastic distribution pipeline	0.54

Table F-3: Oil Systems Emission Factors

Activity and Emission Factor Unit	Emission Factor	
	1990	2002
Oil Production (kg CH_4 per 1000 barrels)	500.64	511.14
Oil Refining (kg CH_4 per 1000 barrels)	5.11	4.95
Oil Transported (kg CH_4 per 1000 barrels)	1.43	0.92

Appendix G

Industrial Processes

Industrial Processes Methodology

With the exception of the limestone and dolomite, and iron and steel sectors, all industrial process emissions were calculated based on methodology outlined in the EIIP guidance document. The methodology used to calculate emissions from limestone and dolomite use was described in Chapter 5 of this report. A detailed description of the methodology used to calculate emissions associated with iron and steel manufacture is presented in this appendix. Table G-1 summarizes all emission factors used to calculate industrial process greenhouse gas (GHG) emissions, while Table G-2 summarizes all activity data, including their sources.

Table G-1: Summary of Industrial Process Emission Factors

Industrial Process	1990	2002	Unit	Source
Iron and Steel Manufacture				
Coking Coal	25.56	25.56	Teragrams Carbon / Quadrillion BTU of Coking Coal Consumed	IPCC[22]
Coking Coal (Energy Intensity)	26.8	27.4	Million BTU / Short Ton Coking Coal	EIA[23]
Steel, Percent Carbon by Weight	0.4%	0.4%	Percent Carbon by Weight	EPA[24]
Pig Iron, Percent Carbon by Weight	4%	4%	Percent Carbon by Weight	EPA
Electric Arc Furnace Anode	0.0015	0.0015	Metric Ton Carbon / Metric Ton Arc Furnace Steel Produced	EPA
Coal Coke	0.5	0.5	Grams CH_4 / Kilogram Coal Coke	EPA
Pig Iron	0.9	0.9	Grams CH_4 / Kilogram Pig Iron	EPA
Cement Production				
Clinker	0.507	0.507	Metric Tons CO_2 / Metric Ton of Clinker Produced	EPA
Cement Kiln Dust (CKD)	0.020	0.020	Metric Tons CKD CO_2 / Metric Ton of Clinker CO_2 Emitted	EPA
Masonry Cement	0.022	0.022	Metric Tons CO_2 / Metric Ton of Masonry Produced	EPA
Lime Manufacture				
High-Calcium Lime	0.75	0.75	Metric Tons CO_2 / Metric Ton High-Calcium Lime Produced	EPA
Dolomitic Lime	0.86	0.86	Metric Tons CO_2 / Metric Ton Dolomitic Lime Produced	EPA

Industrial Process	1990	2002	Unit	Source
Limestone and Dolomite Use				
Limestone	0.440	0.440	Metric Tons CO_2 / Metric Ton Limestone (Calcite)	EPA
Dolomite	0.484	0.484	Metric Tons CO_2 / Metric Ton Limestone (Dolomite)	EPA
Soda Ash Consumption	0.415	0.415	Metric Tons CO_2 / Metric Ton Soda Ash	EPA
Magnesium Casting	0.0041	0.0008	Metric Tons SF_6 / Metric Ton Magnesium Cast	EPA
Electric Power Transmission and Distribution	1.0	1.0	Metric Tons SF_6 / Metric Ton SF6 Consumed (Sold)	EPA

Iron and Steel Sector Methodology

The SIT modules were applicable to most industrial process sectors. The notable exceptions were the iron and steel industry and soda ash consumption sectors. Since an iron and steel module does not exist, separate calculations were made. For the soda ash sector, instead of following the SIT methodology and basing calculations on the ratio of Michigan population to U.S. population, economic census data for the value of shipments in the soap and detergent, glass, and chemical industries were used.

However, when possible, certain portions of the U.S. EPA methodology were incorporated into the approach used for Michigan. For instance, the U.S. EPA's practice of accounting for the release of carbon dioxide from scrap steel and pig iron consumption was used in the emissions calculations, following the assumption that the entire carbon content of the materials is released on combustion. Also, the U.S. EPA methodology includes methane emission factors for coking operations and pig iron production, whereas the IPCC methodology does not. Both methodologies account for the additional emissions from electric arc furnace anodes, which are part of the production of steel from pig iron. Due to a lack of coke trade data for the state of Michigan, it was not possible to follow the U.S. EPA methodology and account for emissions from imported metallurgical coke consumed in pig iron production.

The following equations summarize the basic calculation methodologies for pig iron and raw steel CO_2 emissions
:

Equation 125

$$Emissions_{pig\ iron} = Emission\ Factor_{reducing\ agent} * Mass\ of\ Reducing\ Agent + (Mass\ of\ Carbon\ in\ Ore - Mass\ of\ Carbon\ Pig\ Iron) * 44 / 12$$

Equation 226

$$Emissions_{crude\ steel} = (Mass\ of\ Carbon\ in\ the\ Crude\ Iron\ used\ for\ Crude\ Steel\ Production - Mass\ of\ Carbon\ in\ the\ Crude\ Steel) * 44 / 12 + Emission\ Factor_{EAF} * Mass\ of\ Steel\ Produced\ in\ EAF$$

Since the amount of pig iron produced in Michigan was not available from either the AISI or the USGS, the data were estimated. The estimation was based on the ratio of Michigan:United States raw steel production and the total U.S. blast furnace pig iron production. The assumption was

made that the percentage of national steel output produced in Michigan is equal to the percentage of national pig iron output produced in Michigan. The reasoning behind this assumption was the statement by the USGS that 95% of all pig iron produced is transported molten to steel making furnaces at the same site27. Therefore, multiplying the ratio of Michigan:U.S. raw steel production by the U.S. total blast furnace pig iron production will result in the amount of pig iron produced in Michigan.

Other assumptions were made for calculating greenhouse gas emissions from iron and steel production. The fraction of coal carbonized during coking operations was assumed to be 0.928. The carbon contents of iron ore, pig iron, and raw steel were assumed to be 0%, 4%, and 0.4%, respectively.29 Lastly, the percentage of raw steel produced in the various furnace types for Michigan was assumed to be equal to the national distribution.

Table G-2: Summary of Industrial Process Activity Data

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
Iron and Steel Production	Pig iron production (national)	49.67	40.23	Million metric tons	American Iron and Steel Institute. (1990, 2002) *Annual Statistical Report.* American Iron and Steel Institute. Washington, DC
	Steel production	7.348	6.22	Million metric tons	United States Geological Survery (USGS). *Mineral Industry of Michigan*. (1990, 2002). USGS, Minerals Information Service. Reston, VA. http://minerals.usgs.gov/minerals/pubs/state/mi.html
	Scrap pig iron consumption	6,041,000	5,401,235	Short Tons	USGS *Iron and Steel Scrap: Minerals Yearbook: 1990, 2002.* USGS, Minerals Information Service. Reston, VA. http://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel_scrap/
	Scrap steel consumption	6,036,000	4,519,400	Short Tons	USGS *Iron and Steel Scrap: Minerals Yearbook: 1990, 2002.* USGS, Minerals Information Service. Reston, VA. http://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel_scrap/
	Coal consumed at coke plants	1,063	1,720.012 (EST)	1000 short tons	U.S. Department of Energy. *Coal and Coke Consumption.* U.S. Department of Energy, Energy Information Administration. Washington, DC. http://www.eia.doe.gov/emeu/states/sep_fuel/html/csv/use_cl_all.csv
Cement Production	Annual clinker production	4,385,331	4,082,000	Metric tons	USGS *Cement: Minerals Yearbook: 1990, 2002.* USGS, Minerals Information Service. Reston, VA. http://minerals.usgs.gov/minerals/pubs/commodity/cement/

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
	Annual masonry cement production	246,754	290,000	Metric tons	USGS *Cement: Minerals Yearbook: 1990, 2002.* USGS, Minerals Information Service. Reston, VA. http://minerals.usgs.gov/minerals/pubs/commodity/cement/
Lime Production	Annual high-calcium quicklime and hydrated lime production	Quicklime: 447,529 **(EST)** Hydrated Lime: 16,758 **(EST)**	Quicklime: 720,942 **(EST)** Hydrated Lime: 618 **(EST)**	Metric Tons	USGSLime*: Minerals Yearbook: 1990, 2002.* USGS, Minerals Information Service. Reston, VA. http://minerals.usgs.gov/minerals/pubs/commodity/lime/
	Annual dolomitic quicklime and hydrated lime production	Quicklime: 88,011 **(EST)** Hydrated Lime: 3,798 (**EST**)	Quicklime: 130,200 **(EST)** Hydrated Lime 185 **(EST)**	Metric Tons	USGSLime*: Minerals Yearbook: 1990, 2002.* USGS, Minerals Information Service. Reston, VA. http://minerals.usgs.gov/minerals/pubs/commodity/lime/
Limestone and Dolomite Use	Limestone used in industrial applications	293,000 **(EST)**	160,000 **(EST)**	Metric tons	USGS *Crushed Stone: Minerals Yearbook: 1990, 2002.* USGS, Minerals Information Service. Reston, VA. http://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/
	Dolomite used in industrial applications	56,600 **(EST)**	68,300 **(EST)**	Metric tons	USGS *Crushed Stone: Minerals Yearbook: 1990, 2002.* USGS, Minerals Information Service. Reston, VA. http://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/
Soda Ash Consumption	Amount of soda ash consumed (U.S.)	6,530,000	6,430,000	Metric tons	USGS *Soda Ash: Minerals Yearbook: 1990, 2002.* USGS, Minerals Information Service. Reston, VA. http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/
	Value of Shipments, 1997 (Michigan)		1,381,858 (NAICS 3272); 2,820,215 (NAICS 3256); 160,137 (NAICS 32518)	$1,000	U.S. Census Bureau, *Economic Census 1997.* U.S. Department of Commerce Economics and Statistics Administration http://www.census.gov/epcd/www/97EC_MI.HTM
	Value of Shipments, 1997 (U.S.)		22,762,525 (NAICS 3272); 57,507,318 (NAICS 3256);	$1,000	U.S. Census Bureau, *Economic Census 1997.* U.S. Department of Commerce Economics and Statistics Administration http://www.census.gov/epcd/www/97EC31.HTM

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
			17,260,787 (NAICS 325188)		
	Value of Shipments, 1992 (Michigan)	2,424,648 (SIC 32); 1,753,900 (SIC 284); 139,900 (SIC 2819)		$1,000	U.S. Census Bureau, *Census of Manufacturers 1992.* U.S. Department of Commerce Economics and Statistics Administration. http://www.census.gov/prod/1/manmin/92area/mca23f.pdf
	Value of Shipments, 1992 (U.S.)	62,520,611 (SIC 32); 42,875,402 (SIC 284); 18,128,853 (SIC 2819)		$1,000	U.S. Census Bureau, *Economic Census 1992.* U.S. Department of Commerce Economics and Statistics Administration http://www.census.gov/prod/1/manmin/92mmi/92manuff.html
ODS Substitution	National emissions of HFCs used as ODS subsitutes in MTCE	81,818.1818	25,009,090.909	MTCE	U.S. EPA. *U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2002*. U.S. EPA. Washington, DC. April 15, 2004.
Electric Power Distribution and Transmission	National emissions of SF6 from electric utility sector in MTCE	7,963,636	4,036,363	MTCE	U.S. EPA. *U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2002*. U.S. EPA. Washington, DC. April 15, 2004.
	State electricity consumption	82,366.869	107,311	Million kWh	Department of Energy, Energy Information Administration. *Electricity Consumption*. http://www.eia.doe.gov/emeu/states/sep_fuel/notes/_fuelnotes_multistate.html. *State Energy Profile: Michigan.* http://www.eia.doe.gov/cneaf/electricity/st_profiles/michigan.pdf
	National electricity consumption	2,712,554.665	3,504,521 **(EST)**	Million kWh	Department of Energy, Energy Information Administration. *Electricity Consumption*. http://www.eia.doe.gov/emeu/states/sep_fuel/notes/_fuelnotes_multistate.html
Semiconductor Manufacture	Value of MI semiconductor shipments	30,600 (1992)	35,905 (1997)	$1,000	U.S. Census Bureau. *Economic Census: 1992, 1997.U.S. Census Bureau. Washington, DC.* http://www.census.gov/econ/census02/
	Value of U.S. semiconductor shipments	32,191,352 (1992)	78,539,562 (1997)	$1,000	U.S. Census Bureau. *Economic Census: 1992, 1997.U.S. Census Bureau. Washington, DC.* http://www.census.gov/econ/census02/

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
Magnesium Casting	Magnesium metal cast	1,874	26,411	Metric tons	Personal communication with Michigan magnesium casting facilities

Note
(EST): Required activity data was not available and required estimation

Appendix H

Agriculture

Methane Emissions from Domestic Animals Methodology

Important to measuring emissions of methane from domestic animals and manure management are the data of population estimates of animal types. To ensure consistency, the data were obtained from the National Agricultural Statistics Service (NASS) as well as state publications that are listed in Table H-6. The steps from EIIP guidance used to acquire and calculate emissions estimates were as follows:

(1) Obtain required data

(2) Identify Geographic Region
Michigan is grouped into the Midwest region. Methane emissions from animal digestion varied across regions due to differences in feed and forage types.

(3) Estimate Methane Emissions
EIIP and the SIT factors provided emission factors for each animal type in terms of kg of methane per head per year (Table H-1).

(4) Convert to units of MTCE

Table H-1: Methane from Domestic Animals Calculation Values

Livestock Type	kg CH_4/ head	
	1990	2002
Dairy Cows		
Milk Cows	105.2	115.4
Milk Replacements	53.5	53.4
Beef Cattle		
Beef Cows	74.1	74.1
Beef Replacements	56.3	56.4
Heifer Stockers	48.2	48.7
Steer Stockers	54.5	54.4
Feedlot Heifers	37.4	31.8
Feedlot Steer	39.8	33.7
Bulls (500+)	100.0	100.0
Other		
Sheep	8.0	8.0
Goats	5.0	5.0
Swine	1.5	1.5
Horses	18.0	18.0

Methane and Nitrous Oxide Emissions from Livestock Manure Management Methodology

Table H-2 lists the factors used in estimating emissions from manure management. The steps from EIIP guidance used to acquire and calculate emissions estimates were as follows:

(1) Obtain required data
Data on fertilizer amounts were obtained from sources listed in Table H-6.

(2) Identify Geographic Region
Michigan is grouped into the Midwest region.

(3) Estimate Typical Animal Mass

(4) Obtain Volatile Solids Emission Factors (in EIIP Guidance) for each animal type

(5) Estimate methane and nitrous oxide emissions

(6) Convert to units of MTCE

Table H-2: Manure Management Animal Calculation Values

Animal	Typical Animal Mass (TAM) (kg)	Volatile Solids (VS) (kg VS/1000 kg animal mass/day) 1990	2002	Max Potential Emissions (BO) (m3 CH4/ kg VS)
Dairy Cattle				
Dairy Cows	604	8.67	8.38	0.24
Dairy Replacement Heifers	476	6.82	6.82	0.17
Beef Cattle				
Feedlot Heifers	420	5.16	3.35	0.33
Feedlot Steer	420	5.00	3.28	0.33
Bulls	750	6.04		0.17
Calves	118	6.41		0.17
Beef Cows	533	6.63	6.63	0.17
Beef Replacement Heifers	420	7.05	7.05	0.17
Steer Stockers	318	7.44	7.46	0.17
Heifer Stockers	420	7.09	7.04	0.17
Swine				
Breeding Swine	198		2.6	0.48
Market Under 60 lbs	15.88		8.8	0.48
Market 60-119 lbs	40.6		5.4	0.48
Market 120-179 lbs	67.82		5.4	0.48
Market over 180 lbs	90.75		5.4	0.48
Poultry				
Layers				
Hens > 1 yr	1.8		10.8	0.39
Pullets	1.8		9.7	0.39
Chickens	1.8		10.8	0.39
Broilers	0.9		15	0.36
Turkeys	6.8		9.7	0.36
Other				
Sheep on Feed	27		9.21	0.36
Sheep Not on Feed	27		9.21	0.19
Goats	64		9.53	0.17
Horses	450		10	0.33

Agricultural Soil Management Methodology

The steps from EIIP guidance used to acquire and calculate emissions estimates were as follows:

Direct Nitrous Oxide Emissions

Commercial Synthetic Fertilizers:

(1) Obtain required data
Data on fertilizer amounts were obtained from sources listed in Table H-6.

(2) Calculate unvolatilized applied nitrogen from synthetic fertilizer
EIIP suggests that 90% of applied nitrogen remains unvolatilized.

(3) Calculate direct emissions from synthetic fertilizer application
EIIP recommended emission factor of 1.25% was used as the unvolatilized nitrogen fertilizer portion that was emitted into the atmosphere directly. The result of step (3) was multiplied by 1.25%.

(4) Convert to MTCE

Commercial Organic Fertilizers:

(1) Obtain required data
Data on fertilizer amounts were obtained from sources listed in Table H-6.

(2) Subtract out manure from organics used as commercial fertilizer
"Manure applied to soils" (header below) is subtracted out of this category to avoid double counting.

(3) Calculate the amount of nitrogen from organics used as commercial fertilizer
The fraction of nitrogen in organics that is emitted as nitrous oxide is 80%

(4) Calculate direct emissions from organics
EIIP recommended emission factor of 1.25% was used as the unvolatilized nitrogen fertilizer portion that was emitted into the atmosphere directly. The result of step (3) was multiplied by 1.25% for each organic fertilizer category.

(5) Convert to MTCE

Crop Residues

(1) Obtain required data
Data on crop production were obtained from sources listed in Table H-6.

(2) Calculate the amount of nitrogen entering the crop residue pool
The production of each type of nitrogen-fixing crop is multiplied by (EIIP Guidance) factors relating residue to crop mass ratio, residue dry matter fraction, residue retention fraction, and nitrogen content of residue (Table H-3). Note that alfalfa and soybeans have much higher "N-content of residue" values due to the

nitrogen fixation associated with soil mycorrhizae bacteria that mutually associate with the roots of these crop types.

(3) Calculate direct emissions from crop residue in soils
EIIP recommended emission factor of 1.25% was used as the unvolatilized nitrogen from crop residue that was emitted into the atmosphere directly. The result of step (2) was multiplied by 1.25% for each crop type.

(4) Convert to MTCE

Manure Applied to Soils

(1) Obtain required data
Data on livestock animal production were obtained from sources listed in Table H-6.

(2) Calculate nitrogen from animal waste applied as daily spread
Table H-4 shows the factors of typical animals mass (TAM) and Kjeldahl nitrogen factors that were obtained from EIIP Guidance. The animal population estimates were multiplied by the TAM and Kjeldahl nitrogen factors from manure spread operations.

(3) Calculate nitrogen from animal waste from managed systems eventually applied to soils
This total adjusts for animal waste that came from livestock manure management systems (typically large livestock operations) that eventually were applied to soils. Note that "methane and nitrous oxide emissions from livestock manure management" does not account for waste applied to soils to avoid double counting.

(4) Sum the nitrogen from animal waste applied as daily spread and nitrogen from animal waste from managed systems

(5) Calculate direct emissions from manure systems
EIIP recommended emission factor of 1.25% was used as the unvolatilized nitrogen from animal waste that was emitted into the atmosphere directly. The result of step (3) was multiplied by 1.25% for each animal type.

(6) Convert to MTCE

Pasture, Range and Paddock

(1) Obtain required data
Data on livestock animal production were obtained from sources listed in Table H-6.

(2) Calculate nitrogen from animal waste deposited directly on pastures, ranges, and paddocks
Table H-4 shows the factors of typical animals mass (TAM) and Kjeldahl nitrogen factors that were obtained from EIIP Guidance. The animal population

estimates were multiplied by the TAM and Kjeldahl nitrogen factors from statewide estimates of pasture, range, and paddock operations.

(3) Calculate direct nitrous oxide emissions from animal production
The IPCC default emission factor for pasture, range, and paddock is 2.0%.

(4) Convert to MTCE

Indirect Nitrous Oxide Emissions

Nitrogen-Containing Fertilizers and Animal Waste Volatilized Fraction

(1) Obtain required data
Data on commercial synthetic fertilizer, commercial organic fertilizer, and livestock animal production were obtained from sources listed in Table H-6.

(2) Calculate the amount of nitrogen applied to the soil as fertilizer that volatilized
According to EIIP Guidance, the volatilized potion of nitrogen included:

a. 10% of total state application of synthetic fertilizer

b. 20% of total state application of organic fertilizer

(3) Calculate the total nitrogen excretion by livestock that volatilizes
EIIP suggests 20% of N excretion by livestock volatilizes

(4) Calculate total indirect nitrous oxide emissions from volatilization of NH_3 and NO_x
According to IPCC estimates, 1% of volatilized nitrogen eventually converts to nitrous oxide. The volatilized emissions from steps (2) and (3) are summed together and then multiplied by 0.01 to reflect the 1% fraction that converts to nitrous oxide.

(5) Convert to MTCE

Leaching and Runoff of Nitrogen-Containing Fertilizers and Animal Waste

(1) Obtain required data
Data on commercial synthetic fertilizer, commercial organic fertilizer, and livestock animal production were obtained from sources listed in Table H-6.

(2) Calculate the amount of nitrogen applied to the soil as fertilizer that volatilizes
According to EIIP guidance, 30% of all applied nitrogen-containing fertilizers and manure applied to soils leached or became soil runoff. Unvolatilized N from synthetic fertilizer, organic fertilizer, and livestock manure were each multiplied by 0.3.

(3) Calculate direct emissions from leaching and runoff

EIIP recommended emission factor of 1.25% was used as the unvolatilized nitrogen from leaching and runoff that was emitted into the atmosphere. The result from of step (3) for each category was multiplied by 1.25%.

(4) Convert to MTCE

Table H-3: Agricultural Soil Management Crop Factors

Crop	Residue to Crop Mass Ratio	Residue Dry Matter Fraction	Residue Retention Fraction	N Content of Residue (kg N/kg dry biomass)
Alfalfa	0	0.85	0	0.03
Corn for Grain	1	0.91	0.9	0.0058
All Wheat	1.3	0.93	0.9	0.0062
Barley	1.2	0.93	0.9	0.0077
Oats	1.3	0.92	0.9	0.007
Rye	1.6	0.9	0.9	0.0048
Soybeans for Beans	2.1	0.87	0.9	0.023
Dry Edible Beans	1.55	0.87	0.9	0.0062

Table H-4: Agricultural Soil Management Animal Waste Factors

Animal	Typical Animal Mass (TAM) (kg)	Kjeldahl Nitrogen (kg/1000 kg animal mass/day)	Poultry-only animal waste as feed factor
Dairy Cattle			
Dairy Cows	604	0.00044	
Dairy Replacement Heifers	476	0.00031	
Beef Cattle			
Feedlot Heifers	420	0.00033	
Feedlot Steer	420	0.00031	
Bulls	750	0.0003	
Calves	118	0.00031	
Beef Cows	533	0.00031	
Beef Replacement Heifers	420	0.0003	
Steer Stockers	318	0.0003	
Heifer Stockers	420	0.00031	
Swine			
Breeding Swine	198	0.000235	
Market Under 60 lbs	15.88	0.0006	
Market 60-119 lbs	40.6	0.00042	
Market 120-179 lbs	67.82	0.00042	
Market over 180 lbs	90.75	0.00042	
Poultry			
Hens > 1 yr	1.8	0.00083	0.958
Pullets	1.8	0.00062	0.958
Chickens	1.8	0.00083	0.958
Broilers	0.9	0.0011	0.958
Turkeys	6.8	0.00074	0.958
Other			
Sheep on Feed	27	0.00042	
Sheep Not on Feed	27	0.00042	
Goats	64	0.00045	
Horses	450	0.0003	

Agricultural Residue Burning Methodology

The following steps were adopted from EIIP guidance for emissions estimates from agricultural residue burning:

(1) Obtain required data
Data were gathered from the sources listed in Table H-6 on crop production used to make emission estimates

(2) Calculate the amount of dry matter burned
EIIP Guidance provided national averages on estimates of the crops burned each year. For Michigan crops, this value was 3%. Residue/crop ratio, proportion of dry matter, burning efficiency and combustion efficiency were all factored into the final emissions calculation for each crop type.

(3) Estimate emissions of methane
Results of methane emissions for each crop type are in Table H-5.

(4) Estimate emissions of nitrous oxide
Results of nitrous oxide emissions for each crop type are in Table H-5.

(5) Convert to MTCE

Table H-5: Methane and Nitrous Oxide Emissions from Agriculture Residue Burning Values

	1990		2002	
Crop Type	**CH4 (metric tons)**	**N2O (metric tons)**	**CH4 (metric tons)**	**N2O (metric tons)**
Barley	5	<1	2	<1
Corn	403	9	394	8
Soybeans	159	13	286	24
Wheat	98	2	78	2
Total	**665**	**24**	**760**	**34**

Table H-6: Summary of Agriculture Activity Data

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Source
Methane from Domestic Animals **Livestock Manure Management**	Breeding swine annual average population	173,800	112,500	Population	MDA (1991a, 2003a) *Livestock, Dairy, & Poultry.* Michigan Agricultural Statistics Service, Michigan Department of Agriculture, http://www.nass.usda.gov/mi/stats03/livestock.pdf
Agricultural Soil Management (Animal Waste Portion)	Market swine <60 lbs annual average population (AAP)	405,000	305,000	Population	MDA (1991a, 2003a)
	Market swine 60-119lbs AAP	272,500	202,500	Population	MDA (1991a, 2003a)
	Market swine 120-179 lbs AAP	217,500	156,250	Population	MDA (1991a, 2003a)
	Market swine >180 lbs AAP	188,800	143,750	Population	MDA (1991a, 2003a)
	Poultry hens > 1 year AAP	1,950,000	5,149,000	Population	MDA (2003b) *Agricultural Statistics 2002-2003.* Michigan Agricultural Statistics Service, Michigan Department of Agriculture, http://www.nass.usda.gov/mi/stats03/livestock.pdf. MDA (1991b) *Agricultural Statistics 1991.* Michigan Agricultural Statistics Service, Michigan Department

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Source
					of Agriculture http://www.nass.usda.gov/mi/archive/1990/1990.pdf
	Poultry pullets AAP	4,365,000	1,270,000	Population	MDA (1991b, 2003b)
	Poultry chickens AAP	15,000	1,000	Population	MDA (1991b, 2003b)
	Poultry broilers AAP	141,800	120,640	Population	USDA (2002) *Census of Agriculture*. U.S. Department of Agriculture, National Agricultural Statistics Service http://www.nass.usda.gov/census/census02/volume1/mi/st26_1_027_029.pdf. MDA (1991b)
	Poultry turkeys AAP	1,791,700	1,483,402	Population	USDA (2004) *Poultry Production and Value: Final Estimates 1998 – 2002.* U.S. Department of Agriculture, National Agricultural Statistics Service http://usda.mannlib.cornell.edu/usda/reports/general/sb/sb994.pdf. MDA (1991b)
	Sheep on feed AAP	29,000	24,510 (EST)	Population	MDA (1991b, 2003b)

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Source
	Sheep not on feed AAP	92,000	47,490 (EST)	Population	MDA (1991b, 2003b)
	Goats AAP	12,000	21,094	Population	USDA (2002) http://www.nass.usda.gov/census/census02/volume1/mi/st26_1_030_032.pdf. MDA (1991b)
	Horses AAP	130,000	104,949	Population	USDA (2002) http://www.nass.usda.gov/census/census02/volume1/us/st99_2_015_015.pdf. MSU (1990) *Michigan Horse Industry Overview.* Michigan State University Agriculture Experiment Station Http://www.msue.msu.edu/msue/imp/modsr/sr489201.html
Agricultural Soil Management (Crop Portion)	Alfalfa	4,875	3,150	'000 short tons	MDA (1991b, 2003b)
Agricultural Residue Burning	Corn for Grain	238,050	232,300	'000 bushel	MDA (1991b, 2003b)
	Wheat	41,250	32,830	'000 bushel	MDA (1991b, 2003b)

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Source
	Barley	2,580	988	'000 bushel	MDA (1991b, 2003b)
	Oats	13,050	4,160	'000 bushel	MDA (1991b, 2003b)
	Rye	580,000	Not available	'000 bushel	MDA (1991b, 2003b)
	Soybeans	43,320	78,155	'000 bushel	MDA (1991b, 2003b)
	Dry Edible Beans	5,445	4,903	Cwt	MDA (1991b, 2003b)

Note
(EST): Required activity data was not available and required estimation

Appendix I

Land Use/Land Change and Forestry

Changes in Forest Carbon Stocks

Forests are complex ecosystems with several interrelated components. Trees, understory vegetation, the forest floor (fallen trees, branches, and leaves) and soils act as carbon storage pools. Through biological processes of trees and plants (growth and mortality) and human activities (harvesting and other removals), carbon is continuously cycled within these ecosystem components, and also between the forest ecosystem and the atmosphere. For example, as trees grow, they absorb carbon from the atmosphere. They continue to accumulate carbon until they reach maturity. When they die or drop branches and leaves, decay processes emit carbon to the atmosphere, while often increasing soil carbon at the same time. "The net change in forest carbon is the change in the amount of carbon stored in each of these pools (trees, understory vegetation, the forest floor and soil) over time."[30]

Harvesting can also change the amount of forest carbon, but harvests may not always result in an immediate flux of carbon to the atmosphere. Once in wood products, the carbon will be emitted over time as CO_2 through either combustion or decomposition, although the exact rate of emission varies substantially for different product pools.[31]

With this carbon storage function, forests are considered net sinks, and are expected to provide a low-cost approach to reduce net accumulations of atmospheric CO_2. "Determining the level of carbon stocks in forest ecosystems has become a concern of governments, businesses, and many organizations"[32], but a question of how much carbon is sequestered by forest ecosystem cannot be answered exactly, due to a tremendous amount of uncertainty related to biomass data and carbon conversion factors.[33]

While the forest ecosystem has substantial opportunities for storing carbon in trees and soils to help curb the threat from climate change, it is also subject to climate change. Global climate change will affect tree species, geographic extent, and health and productivity of forests.[34] According to the Union of Concerned Scientists, warmer temperatures will likely cause boreal forests to shrink and other forest species to move northward.[35] According to the EPA, drier conditions could reduce the current range and density of forests and replace them with grasslands and pasture.[36] A warmer and drier climate would accelerate other stresses to forests, such as fire, pests, and diseases. EPA also indicates that "with changes in climate, the extent of forested areas in Michigan could change little or decline by as much as 50-70 percent."[37] The uncertainties depend on whether or not soil becomes drier and by how much. If the change is significant

enough, it could not only affect the character of Michigan forests and the activities that depend on them, but also reduce the capacity of forests in Michigan as promising greenhouse gas sinks.

Methodology and the Data Requirement

A "Stock approach" is one of the methods recommended by the IPCC to calculate net annual CO_2 emissions and uptake resulting from forest management and land-use change activities.[38,39] This approach estimates the total stock of carbon at two points in time, taking the difference between the two estimates, and converting the difference to an annual rate of change. In order to measure the changes in total biomass and soil carbon stocks, these stocks can be divided into four subcategories: trees, understory, forest floor, and soil. Harvested carbon is treated separately. The change in carbon stocks of each subcategory must be summed to calculate the net carbon flux between the biosphere and the atmosphere. This is also the approach currently used for CO_2 emissions estimation from land-use change and forestry for the EPA's annual inventory of U.S. greenhouse gas emissions and sinks.[40]

Forest carbon inventories calculated based on this stock approach are available for each state from the U.S. Department of Agriculture (USDA) Forest Service for 1987, 1992, and 1997.[41] For 2002, the team conducted the estimation of carbon from forest ecosystem, based on the latest available USDA data[42], following the methodology recommended in the *State Workbook*[43] and the 1999 version of the EIIP guidelines.[44] The methodology presented in the above document is based on the state-by-state estimates complied by the USDA[45,46], which secures the best possible data continuity and consistency with the past USDA figures.

However, it is still difficult to develop an accurate estimation of forest carbon due to a number of uncertainties in forest statistics and carbon conversion factors. Although the most comprehensive and accurate regional estimates of carbon flux using inventory data are for above-ground biomass, there are sampling and measurements errors as well as estimation errors in forest statistics.[47] There are additional uncertainties associated with the estimation of soil carbon. For many long-term and suspected significant changes in quantities of soil carbon, assumptions employed by the methodology are logical, but remain untested. Also, the lack of harvested product data is another source of uncertainty. In the past inventories by Birdsey and Lewis, the model called HARVCARB was used to estimate forest harvest because a complete inventory of the volume or mass of carbon in wood products was not available.[48] To calculate 2002 data, because the HARVCARB model was not available, a regression analysis was performed with past data from 1987, 1992, and 1997. If such data on harvested wood products were available at the state level for Michigan, it would be helpful in reducing calculation uncertainties.

In addition, it is also difficult to completely secure data and methodological consistency. There is not always data consistency and continuity between statistics for different years as well as between federal and state statistics. For example, state-specific statistics have data for a forestland area per tree species, while federal statistics do not classify data in

that way. In another case, the classification of land use is different from year to year. As basic statistics change, the employed methodology must be different. Therefore, it is extremely difficult to keep data and methodological consistency in an estimation process.

Despite such data and methodological limitations, the team estimated the carbon stocks in the forest ecosystems of the State of Michigan for 2002. Here is a step-by-step explanation of how the team conducted the estimation.

1. Calculating Carbon Stocks in Trees

- State forest inventory data on the volume of merchantable timber for 2002 were obtained from *USDA Forest Service, 2002 RPA Draft Tables* (see Table I-1). [49]
- The volume of merchantable timber was multiplied by the appropriate expansion ratio (defined by region and by species type) to calculate the total volume of above- and belowground biomass for all live and dead trees. According to Birdsey, the default expansion ratio for softwood and hardwood in North Central were 2.514 and 2.418 respectively.[50]
- The total volume of tree biomass was multiplied by the biomass conversion ratio (= specific gravity times the weight of a cubic food of water (62.4lbs) times percent carbon) to calculate the mass of tree biomass on a dry-weight basis. Default factors are provided in Table I-2.
- As the carbon stocks were given in lbs, they were converted to metric ton by dividing the values by 2204.62 (lbs/metric ton).

Table I-1: Merchantable Timber and Factors to Convert Tree Volume to Carbon for 2002* [51]

Tree Species	Growing Stocks (million metric ton)	Conversion Factor	Applied Conversion Factor
Longleaf and Slash Pine	0	13.69	Pines (Softwood)
Loblolly and Shortleaf Pines	0	13.69	Pines (Softwood)
Other Yellow Pines	87	13.69	Pines (Softwood)
White and Red Pines	2498	13.69	Pines (Softwood)
Jack Pines	604	13.69	Pines (Softwood)
Spruce and Balsam fir	1682	11.41	Spruce-fir (Softwood)
Eastern Hemlock	662	11.41	Spruce-fir (Softwood)
Cypress	0	0	
Other Softwoods	2044	12.95	Average for North Central Softwoods
Select White Oaks	820	19.64	Oak-hickory (Hardwood)
Select Red Oaks	1606	19.64	Oak-hickory (Hardwood)
Other White Oaks	1	19.64	Oak-hickory (Hardwood)
Other Red Oaks	399	19.64	Oak-hickory (Hardwood)
Hickory	158	19.64	Oak-hickory (Hardwood)
Yellow Birch	498	14.45	Aspen-birch (Hardwood)
Hard Maple	4044	17.9	Maple-beech (Hardwood)
Soft Maple	3456	17.9	Maple-beech (Hardwood)
Beech	478	17.9	Maple-beech (Hardwood)
Sweetgum	0	0	
Tupelo	6	17.99	Bottomland hardwoods (Hardwood)
Ash	1153	17.99	Bottomland hardwoods (Hardwood)
Basswood	904	17.9	Maple-beech (Hardwood)
Yellow Popular	39	17.99	Bottomland hardwoods (Hardwood) for SE and SC
Cottonwood and Aspen	3687	14.45	Aspen-birch (Hardwood)
Black Walnut	54	19.64	Oak-hickory (Hardwood)
Black Cherry	496	16.9	Average for North Central Hardwoods
Other Hardwoods	1287	16.9	Average for North Central Hardwoods

*Note: Conversion factors applied for this inventory purpose were based on advice from David Ellsworth, Ph.D. at the University of Michigan. This inventory applies average factors for "Other Softwoods" and "Other Hardwoods". Considering the significant volumes of these categories, it would be better to apply specific factors though such carbon conversion factors are not currently available. However, applying the averaged factors was the best possible way to make a carbon calculation, given that the tree types of these categories was unspecified.

2. Calculating Carbon Stocks in Understory

- The total forest area in the state in 2002 was obtained from *USDA Forest Service, 2002 RPA Draft Tables.*[52]
- The total forest area was multiplied by the average understory biomass carbon content. The default value provided by Birdsey was 1117 lbs/acre and is based on an average from a small number of studies, subject to large variation.[53]
- The value was converted from lbs to metric ton.

3. Calculating Carbon Stocks in the Forest Floor

- The total forest area in the state, broken down by forest type year, was obtained from *USDA Forest Service, 2002 RPA Draft Tables.*[54]

- A percentage share of each forest type (which was not available from the above data source) was calculated based on data in *Michigan's Forest Resources in 2001*.[55] The ratio calculated above was applied to the 2002 total forest area to estimate the area of each forest type in 2002. In order to obtain the amount forest floor carbon, the area of each forest type was multiplied by a default conversion factor. The default values provided by Birdsey are presented in Table I-2.
- The values were converted from lbs to metric ton.

Table I-2: Estimates of Carbon on Forest Floor by Forest Type for North Central and Central[56]

Forest Type	Carbon (Lbs/ac)
Pines	23061
Spruce-fir	23122
Oak-hickory and bottomland hardwoods	12045
Maple-beech and Aspen-birch	16663
Average	18722.75

4. Calculating Carbon Stocks in the Soil

- The total forest area in the state was obtained from *USDA Forest Service, 2002 RPA Draft Tables.*[57]
- The total forest area was multiplied by the average soil carbon content. The default value provided by Birdsey was115262 lbs/acre and is based on a small number of studies subject to large uncertainties.[58]
- The value was converted from lbs to metric ton.

5. Calculating Carbon in Wood Products and Landfills

For 1987 and 1997 data, Birdsey used "a modification of the stock-change approach for wood products because a complete inventory of volume or mass of carbon in wood products and landfill was not available".[59] They calculated carbon retained in this subcategory by "compiling estimates of wood production periodically from 1952 to 1997, and applying to these estimates a model of carbon retention in various harvest carbon pools", which was called HARVCARB.[60]

For 2002, due to a lack of comprehensive removal data and information about methodology Birdsey, *et al*. employed for their data development, the team conducted a regression analysis to estimate carbon retained in wood products and landfills. As the past data calculated based on the model were plotted linearly on a trend line with R^2= 0.9987, it is quite reasonable to extrapolate the value for 2002 from the past data. However, it is likely that the State should have this kind of data, although the team could not locate them during this inventory making effort. Therefore, it is highly

recommended for future research that data on wood products and landfills based on actual performance should be included.

6. Calculating Average Annual Carbon Flux from Changes in All of the Above Stocks.

- The difference between total carbon stocks in the two inventory years was calculated for each of the above subcategories. A net decrease in given stocks represents carbon emissions, while a net increase represents carbon sequestration.
- The difference in the carbon stocks was divided by the number of years between forest inventories to calculate the apparent average annual carbon storage for the period between forest inventories.
- To be consistent with the IPCC sign conversion, net carbon emissions should be expressed as a positive value, and net carbon uptake as a negative value.

Results

Table I-3 presents the carbon stocks in the State of Michigan calculated by the USDA for the past inventory years as well as the team's estimates for 2002. Overall, the largest contributor to the carbon sequestration in the forest ecosystem is the soil, accounting for approximately 60 percent of total carbon sequestration. This is followed by the tree biomass, which sequesters about 25-30 percent of the total carbon, the forest floor (10 percent of total carbon) and wood products and landfills (less than five percent of total carbon).

Table I-3: Summary of Carbon Stocks: 1987 to 2002 (MMTC)

Category	Total Carbon Stocks (million metric tons carbon) 1987	1992	1997	2002
Biomass	382.22	436.03	489.92	483.07
Forest floor and coarse woody debris	160.03	165.43	170.46	151.72
Soils	952.53	961.12	969.39	1,008.05
Wood products and landfills	51.47	59.39	65.88	73.32
Total	**1,546.25**	**1,621.96**	**1,695.65**	**1,716.16**

Source: Embedded values in the 2003 version of the State Inventory Tool for 1987, 1992, and 1997 values[6]
Values for 2002 were estimated by the team.

[6] The default values in the EPA's State Inventory Tool (SIT) for Forest Management and Land-Use Change are based on estimates by Birdsey, et. al. (2003)

Due to difficulty determining exact methodological steps taken for the 1987-1997 inventories, it was impossible to completely ensure data and methodological consistency for the carbon inventories for the first three inventory year intervals and the latest inventory interval. The team tried several possible approaches to simulate Birdsey's estimates, but could not re-create the values of his calculations. For example, the team's calculation for the soil carbon stock in 1987 was almost equivalent to Birdsey's estimate, but the team's estimate of soil carbon for 1997 indicated a much higher value than the one stated in Table I-3. The team's value showed a 3.5 times higher growth rate in the soil carbon stocks, which is shown in Table I-4. It would have been possible to re-create the team's version of carbon inventories for the past 15 years if all the necessary data had been available for all of the past years. With such limitations, Table I-3 is the best possible result the team can currently achieve.

Table I-4: Difference in Percentage Growth Rate in the Soil Carbon Stock (1987-1997)

	% Growth in Carbon Stock by Birdsey's Estimation	% Growth in Carbon Stock by Team's Estimation
Soils	1.77%	6.11%

In order to obtain annual carbon storage by the forest ecosystem, a difference in carbon stocks in two point in time must be divided by the number of years as explained previously in the methodology. The SIT software, embedded with Birdsey's estimates from 1987 to 1997, calculates annual sequestration for 1990 as shown in Table I-5. The results indicate that 15.14 MMTC were sequestered in 1990. Using this estimate, the net carbon emissions in Michigan would be 41.93 MMTCE (57.07 MMTCE – 15.14 MMTC) in 1990. For 2002, it would be possible to calculate annual sequestration using the same method, but it requires a caution because inconsistency in data and methodology for 1997 and 2002 values would increase uncertainty in the annual storage value.

Table I-5: Annual Net Carbon Storage from the Forest Ecosystem (1990)

Category	Annual Net Carbon Storage (million metric tons carbon) 1990
Biomass	10.76
coarse woody debris	1.08
Soils	1.72
Wood products and landfills	1.58
Total	**15.14**

Table I-6 shows the percentage change in the carbon stocks from the first inventory year (1987) to the most recent (2002), indicating the total carbon stocks from the forestry ecosystem increased 11 percent over these 15 years. It is difficult to secure complete consistency in data and methodology as mentioned above, therefore large uncertainties in results are expected. Given the soil carbon stock, which is a simple function of a forest land area, accounts for the dominant part of the total sequestration, this percentage increase in the total carbon stocks can be considered reasonable, as the forest land area in Michigan increased approximately nine percent from 17,682 thousand acres in 1987[61] to 19,281 thousand acres in 2002.[62] However, as the accounting of soil carbon is one of the most controversial areas of accounting for terrestrial carbon storage and is subject to many uncertainties[63] which require future research on a more accurate accounting methodology. In addition to forestland area, tree ages are another factor that is responsible for changes in carbon stocks in the forest ecosystem. This is because tree age influences growing stock volume on timberland, which is used to estimate the amount of carbon stored in tree biomass, the second biggest contributor in the total sequestration.

Table I-6: Percentage Change in Carbon Stocks 1987-2002

	Percentage Change in 1987- 2002
Biomass	26.39%
Forest floor and coarse woody debris	-5.20%
Soils	5.83%
Wood products and landfills	42.46%
Total	**10.99%**

Although there are a number of problems with data and methodological continuity and consistency, one thing that should be mentioned is that Michigan is one of few states that showed a significant increase in carbon storage from the forest ecosystem over the past years (1997-2002). Based on the USDA's estimates (Table I-3), the forest carbon stocks in Michigan increased 10 percent from 1,546.25 MMTC in 1987 to 1,695.65 MMTC in 1997. Although Michigan was ranked as the 11th largest state in 1987 and the 9th largest state in 1997 for its forest carbon stocks, this 10 percent rise was the largest increase observed among the top 15 carbon stock states in the same period of time.[64] One of the possible contributors to this increase was a significant increase in a forestland area, up to more than 19 million acres as of 2002, covering more than 50 percent of the state area.[65] An increase in forestland during 1980s and early1990s was predominantly brought about by the reclassification of abandoned cropland and pasture as well as marginal forestland as timberland due to forest succession as well as a change in the definition. The definition of timberland accounts for 98 percent of total forestland. According to *Michigan's Forest Resources in 2001*, however, an increase in timberland continuing thereafter is noteworthy, "considering that suburban development and second homes continue to expand to rural areas" and that "resort communities or enclaves, including golf courses, continue to expand timberland areas".[66] The report further notes that "timberland that converted to other land use is apparently supplanted by land, some of it agricultural land, that reverted back to forest."

An increase in the growing stock volume is another contributor to increased forest carbon in Michigan over the past years. According to *Michigan Forest Profile 2001*, published by the USDA North Central Research Station, the growing stock volume in Michigan increased by 35 percent since 1980, rising to nearly 27 billion cubic feet.[67] In Michigan, hardwood accounts for more than 70 percent of the total growing stock, with maples as the predominant species. With a larger volume of hardwood growing stocks, in the type of hardwood that has a high carbon content, Michigan has a large potential to accumulate forest carbon. In order to maximize the potential and to make the best use of it, however, consistent statistics should be compiled to enable more precise and accurate estimates and such estimates should guide forest management. In addition, it is also expected that further research should be conducted to reduce scientific uncertainties related to the accounting methodology, particularly for forest floor and soil carbon storage.

Appendix J

Landfill Waste

Methane Emissions from Landfills Methodology

These steps were taken to acquire and compute the emissions estimates data for methane emissions from landfills. The steps listed are taken from the EIIP guidance and are described briefly below.

1) **Estimate waste-in-place (WIP) at Municipal Solid Waste (MSW) landfills**

   Waste in place is the total quantity of waste that has been landfilled over the past 30 years (by mass measured through short tons). 1990 WIP was estimated as the sum of annual amounts of solid waste landfilled in Michigan from 1961-1990 and 2002 WIP was estimated as the sum of annual amounts of solid waste landfilled in Michigan from 1973-2002.

   1990 to 2002 annual solid waste landfilled in Michigan estimates were obtained by *Biocycle* "State of Garbage in America" annual reports. Annual solid waste data were not available prior to 1989. A data extrapolation method going backward in time was used, where annual Michigan census population estimates were multiplied by one minus U.S. annual waste per capita estimate factors (provided by EIIP Guidance) to obtain estimates of waste-in-place from 1960 to 1988. Table J-1 displays the population and annual waste per capita factors used in estimating WIP for 1990 and 2002.

2) **Estimate fraction of waste in place in large versus small MSW landfills**

   Large landfills are defined as having more than 1.1 million tons of waste in place. The Midwest region estimate of waste-in-place in large-small landfills provided by EIIP Guidance was 81% large and 19% small landfills for both 1990 and 2002.

3) **Classify state as non-arid or arid**

4) **Estimate the landfill methane that is annually recovered or flared**

5) **Adjust municipal solid waste methane generation for oxidation**

   EPA estimates that 10% of landfill methane at the surface of landfills oxidizes into the potent carbon dioxide.

6) **Estimate methane generated from Industrial landfills**

7) **Convert to MTCE**

Carbon Dioxide and Nitrous Oxide Emissions from Waste Combustion Methodology

These steps were taken to acquire and compute the emissions estimates data for carbon dioxide and nitrous oxide emissions from combustion of waste. The steps listed are taken from the EIIP guidance document and are described briefly here.

1) **Estimate the quantity of MSW combusted**

   Biocycle estimates of annual waste combustion (also referred to as waste incineration) per state are estimated as a fraction of total MSW for a given year.

2) **Estimate carbon dioxide emissions from combustion of MSW**

   National estimates of the amount of fossil-derived materials (plastics, synthetic rubber, and synthetic fibers) in combusted MSW were used.

3) **Estimate nitrous oxide emissions from combusted MSW**

4) **Convert units to metric tons of carbon equivalent**

Table J-1: Factors Used for WIP Amounts for 1990 and 2002[7]

Year	MI Census Population estimate	US (PCTL) growth rate by decade	Annual waste/capita (short tons)	Landfill Amount (short tons)
2002	10,043,221	--	1.313	13,182,448
2001	10,005,218	--	1.380	13,803,230
2000	9,955,795	--	1.372	13,663,410
1999	9,863,775	--	1.384	13,650,000
1998	9,820,231	--	1.390	13,650,000
1997	9,785,450	--	0.897	8,775,000
1996	9,739,184	--	0.901	8,775,000
1995	9,659,871	--	0.908	8,775,000
1994	9,584,481	--	1.001	9,590,000
1993	9,529,240	--	0.822	7,830,000
1992	9,470,323	--	0.782	7,410,000
1991	9,395,022	--	0.697	6,552,000
1990	9,310,462	--	1.206	11,232,000
1989	9,253,298	--	1.214	11,232,000
1988	9,218,002	0.003	1.210	11,155,589
1987	9,187,484	0.003	1.207	11,085,300
1986	9,127,774	0.003	1.203	10,980,216
1985	9,076,287	0.003	1.199	10,885,525
1984	9,049,454	0.003	1.196	10,820,784
1983	9,047,764	0.003	1.192	10,786,307
1982	9,115,196	0.003	1.189	10,834,096
1981	9,209,287	0.003	1.185	10,913,092
1980	9,262,044	0.003	1.181	10,942,683
1979	9,249,000	0.020	1.158	10,708,726
1978	9,202,000	0.020	1.135	10,441,223
1977	9,157,000	0.020	1.112	10,182,359
1976	9,117,000	0.020	1.090	9,935,123
1975	9,108,000	0.020	1.068	9,726,809
1974	9,109,000	0.020	1.047	9,533,319
1973	9,072,000	0.020	1.026	9,304,704
1972	9,025,000	0.020	1.005	9,071,368
1971	8,972,000	0.020	0.985	8,837,734
1970	8,881,826	0.030	0.965	8,573,931
1969	8,775,963	0.030	0.936	8,217,586
1968	8,670,100	0.030	0.908	7,874,904
1967	8,564,236	0.030	0.881	7,545,388
1966	8,458,373	0.030	0.855	7,228,555
1965	8,352,510	0.030	0.829	6,923,942
1964	8,246,647	0.030	0.804	6,631,099
1963	8,140,784	0.030	0.780	6,349,596
1962	8,034,920	0.030	0.757	6,079,015
1961	7,929,057	0.030	0.734	5,818,954

[7] Note: No state-level specific landfill amounts were available prior to 1989. "Annual Waste per Capita" from 1989 to 2002 (data for these years were obtained from *Biocycle* reports in Table J-2) was calculated by dividing the "Landfill Amount" by the "MI Census Population Estimate" for each year. "Annual Waste per Capita" from 1960 to 1998 was extrapolated backwards in time by first taking the 1989 estimate and multiplying the "MI Census Population Estimate" by one minus the "US Per Capita Tons Landfilled (PCTL) growth rate" provided by EIIP guidance.

Table J-2: Solid Waste Emissions Activity Data

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
Municipal Solid Waste	Waste-in-Place (WiP)	226,680	256,248	'000 short tons	
	Waste-in-Place Data Sources				
	Michigan Department of Environmental Quality (1996, 1997, 1998, 1999, 2000, 2001, 2002) *Report of Solid Waste Landfilled in Michigan* [Online] http://www.michigan.gov/deq/0,1607,7-135-3312_4123-47581--,00.html. (Note: This data was not directly used in the inventory, but instead served as a secondary data check to the *Biocycle* annual data.)				
	Kaufman, S. et al. (2004) "The State of Garbage in America" *Biocycle*, 45:1, p 31.				
	Goldstein, et al. (2000) "The State of Garbage in America" *Biocycle*, 41:11, p 40.				
	Glenn, J. (1999) "The State of Garbage in America" *Biocycle*, 40:4, p 60.				
	Glenn, J. (1998) "The State of Garbage in America" *Biocycle*, 39:4, p 32.				
	Goldstein, N. (1997) "The State of Garbage in America" *Biocycle*, 38:4, p 60.				
	Steuteville, R. (1996) "The State of Garbage in America" *Biocycle*, 37:4, p 54.				
	Steuteville, R. (1995) "The State of Garbage in America" *Biocycle*, 36:4, p 54.				
	Steuteville, R. (1994) "The State of Garbage in America" *Biocycle*, 35:4, p 46.				
	Steuteville, R., et al. (1993) "The State of Garbage in America" *Biocycle*, 34:5, p 42.				
	Glenn, J. (1992) "The State of Garbage in America" *Biocycle*, 33:4, p 46.				
	Glenn, J. (1991) "The State of Garbage in America" *Biocycle*, 32:4, p 34.				

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
	Glenn, J. (1990) "The State of Garbage in America" *Biocycle*, 32, 4; pg 34 Glenn, J. (1989) "The State of Garbage in America" *Biocycle*, 31, 3; pg 48 U.S. Census Bureau, *Michigan Intercensal Estimates of the Resident Population, and Year-to-Year Components of Change 1980-1989.* U.S. Department of Commerce Economics and Statistics Administration. [Online] http://www.michigan.gov/documents/8090com_26024_7.pdf U.S. Census Bureau, *Michigan Intercensal Estimates of the Resident Population, and Year-to-Year Components of Change 1970-1979.* U.S. Department of Commerce Economics and Statistics Administration. [Online] http://www.michigan.gov/documents/8008_26021_7.500.1970.pdf U.S. Census Bureau, *Michigan Intercensal Estimates of the Resident Population, and Year-to-Year Components of Change 1960-1969.* U.S. Department of Commerce Economics and Statistics Administration. [Online] http://www.michigan.gov/documents/MCD1960-1990C_33608_7.pdf				
	Fraction of Waste-in-Place in Large versus Small Landfills	81% large / 19% small	81% large / 19% small		U.S. EPA (2003) *Volume VIII: Estimating Greenhouse Gas Emissions.* U.S.EPA State and Local Climate Change Program, Emission Inventory Improvement Program. Washington, DC. June 2003.
	State Average Annual Rainfall	MI is non-arid	MI is non-arid		U.S. EPA (2003) *Volume VIII: Estimating Greenhouse Gas Emissions.* U.S.EPA State and Local Climate Change Program, Emission Inventory Improvement Program. Washington, DC. June 2003.
	Landfill Methane Flared	35,844	6,968	Annual short tons of methane avoided	U.S. EPA (2004) *Landfill Methane Outreach Program: LMOP Landfill and Project Database* [Online] http://www.epa.gov/lmop/proj/index.htm
	Landfill Methane Recovered in Landfill Gas-to-Energy Projects (LFGTE)	17,990	212,200	Annual short tons of methane avoided	U.S. EPA (2004) *Landfill Methane Outreach Program: LMOP Landfill and Project Database* [Online] http://www.epa.gov/lmop/proj/index.htm
	Oxidized landfill methane	10%	10%	Annual percent of methane oxidized	U.S. EPA (2003) *Volume VIII: Estimating Greenhouse Gas Emissions.* U.S.EPA State and Local Climate Change Program, Emission Inventory Improvement Program. Washington, DC. June 2003.

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Data Source
	Methane from industrial landfills	7%	7%	Percent of total solid waste methane emissions from industrial landfills	U.S. EPA (2003) *Volume VIII: Estimating Greenhouse Gas Emissions.* U.S.EPA State and Local Climate Change Program, Emission Inventory Improvement Program. Washington, DC. June 2003.
	Amount of Solid Waste Combusted (Referred to as Waste-to-Energy data in *Biocycle*)	468,000	1,184,125	Short tons	Kaufman, S. et al. (2004) "The State of Garbage in America" *Biocycle*, 45:1, p 31. Glenn, J. (1991) "The State of Garbage in America" *Biocycle*, 32:4, p 34.

Appendix K

Wastewater Treatment

Methane Emissions from Municipal Wastewater Treatment Methodology

Once the required activity data are collected, there are four basic steps required to calculate methane emissions from municipal wastewater treatment. These four steps are taken from the EIIP guidance document68 and are described briefly here. The emission factors and other required conversion data are shown in Table K-1.

8) **Estimate Biochemical Oxygen Demand (BOD)**
   Multiply the total state population by the wastewater BOD_5 generation rate to obtain BOD generated per day.

   BOD_5 Generated (kg/day) = Population x BOD_5 Generation Rate (kg/capita/day)

9) **Estimate Annual Amount of BOD_5 Treated Anaerobically**
   Multiply the BOD_5 generated by the fraction of wastewater BOD_5 treated anaerobically and by 365 days per year to arrive at the amount of BOD_5 treated anaerobically.

   Annual BOD_5 Treated Anaerobically (kg/year) = BOD_5 Generated (kg/day) x Fraction of Wastewater BOD_5 Treated Anaerobically (%) x 365 (days/year)

10) **Estimate Gross Annual Methane Emissions From Wastewater Treatment**
    Multiply the amount of BOD_5 treated anaerobically by the CH_4 emission factor (in kg CH_4/kg BOD_5) to obtain the total CH_4 emissions.

    CH_4 Emissions (kg CH_4) = BOD_5 Treated Anaerobically (kg BOD_5/year) x CH_4 Emission Factor (kg CH_4/kg BOD_5)

11) **Convert Annual Methane Emissions from Wastewater to Metric Tons of Carbon Equivalent**
    Multiply the result from Step 3 by 0.001 (metric tons/kg), by the mass ratio of carbon to carbon dioxide (12/44), and by the Global Warming Potential for CH_4.

    CH_4 Emissions (MTCE) = CH_4 Emissions (kg CH_4) x 0.001 (metric tons/kg) x (12/44) x 21

Table K-1: Methane from Municipal Wastewater Treatment Emission Factors

Emission Source	Default Value	Unit
Municipal Wastewater CH4 Emissions		
Per capita 5-day Biochemical Oxygen Demand (BOD_5)	0.065	(kg/day)
Fraction of wastewater BOD_5 anaerobically digested	16.25%	
Emission Factor	0.6	(Gg CH_4/Gg BOD_5)

Nitrous Oxide Emissions from Municipal Wastewater Treatment Methodology

Like the previous section addressing methane emissions, the calculation of nitrous oxide emissions from municipal wastewater treatment requires four basic steps once the required activity data have been collected. The emission factors and associated conversion data used to calculate nitrous oxide emissions from municipal wastewater treatment are shown in Table K-2. The four steps are as follows:

1) **Estimate Annual Per Capita Consumption of Nitrogen in Protein**
   Multiply the annual per capita consumption of protein by the percentage of nitrogen in protein to arrive at the annual per capita of nitrogen in protein.

   Per Capita Consumption of Nitrogen in Protein (kg) = Per Capita Protein Consumption (kg) x Nitrogen in Protein (%)

2) **Estimate Annual Consumption of Nitrogen in Protein**

   Multiply the annual per capita consumption of nitrogen in protein by the state population to arrive at the annual consumption of nitrogen in protein.

   Annual Consumption of Nitrogen in Protein (kg N) = Consumption of Nitrogen in Protein (kg/capita) x State Population

3) **Estimate Annual Nitrous Oxide Emissions from Wastewater Treatment**

   Multiply the annual consumption of nitrogen in protein by the emission factor of 0.01 kg N_2O-N/kg N in protein) to arrive at the annual emissions of N_2O in terms of nitrogen. Next, multiply by the ratio of the molecular weight of N_2O to the atomic weight of the nitrogen contained in N_2O.

   Annual Emissions of N_2O from Wastewater (kg N_2O) = Annual Consumption of N in Protein (kg N) x Emission Factor (kg N_2O-N/kg N) x (44/28)

4) Convert Annual Nitrous Oxide Emissions to MTCE

Convert emissions from kilograms N_2O to MTCE by multiplying the result from Step 4 by 0.001, by the ratio of carbon to carbon dioxide, and by the global warming potential of N_2O (310).

N_2O Emissions (MTCE) = N_2O Emissions (kg N_2O) x 0.001 (metric tons/kg) x (12/44) x 310

Table K-2: Nitrous Oxide from Municipal Wastewater Treatment Emission Factors

Emission Source	Default Value	Unit
Municipal Wastewater Direct N2O Emissions		
Factor non-consumption nitrogen	1.75	
Fraction of population not on septic	75%	
Direct wastewater treatment plant emissions	4.0	(g N_2O/person/year)
Municipal Wastewater N2O Emissions from Biosolids		
Emission Factor (kg N_2O-N/kg sewage N-produced)	0.01	
Fraction of nitrogen in protein ($Frac_{NPR}$)	16%	

Methane Emissions from Industrial Wastewater Treatment Methodology

Although emissions estimates were developed for three separate industries (fruits and vegetables, red meat and poultry, and pulp and paper) the same calculation methodology used for each industry. The various emission factors and conversion values used for calculating methane emissions from industrial wastewater treatment are presented in Table K-3. This methodology is comprised of two basic steps, which are outlined below.

1) Calculate Annual Wastewater Production

Multiply annual industry production data by the amount of wastewater produced per metric ton of product.

Wastewater Production (L) = Production (metric tons/year) x Wastewater Produced per Metric Ton of Product (m^3/metric ton) x 1,000 (L/m^3)

2) Calculate Methane Emissions

To calculated methane emissions for each industry, multiply the annual wastewater production by the industry-specific COD, fraction of COD treated anaerobically, and the industry-specific emission factor.

CH_4 Emissions (g CH_4) = Wastewater Production (L) x COD (g COD/L) x Fraction of COD Treated Anaerobically (%) x Methane Emission Factor (g CH_4/g COD)

Table K-3: Methane Emissions from Industrial Wastewater Treatment Emission Factors

Emission Source	Default Value	Unit
Industrial Wastewater CH4 Emissions - Fruits and Vegetables		
Wastewater Outflow	5.6	(m^3/metric ton)
WW Organic Content – Chemical Oxygen Demand (COD)	5	(g/L)
Fraction of COD anaerobically degraded	5%	
Emission factor	0.25	(g CH_4/g COD)
Industrial Wastewater CH4 Emissions - Red Meat and Poultry		
Wastewater Outflow	13	(m^3/metric ton)
WW Organic Content - Chemical Oxygen Demand (COD)	4.1	(g/L)
Fraction of COD anaerobically degraded	77%	
Emission factor	0.25	(g CH_4/g COD)
Industrial Wastewater CH4 Emissions – Pulp and Paper		
Wastewater Outflow	85	(m^3/metric ton)
WW Organic Content - Chemical Oxygen Demand (COD)	0.4	(g/L)
Fraction of COD anaerobically degraded	10.3%	
Emission factor	0.6	(g CH_4/g COD)

A summary of all wastewater treatment activity data is shown as Table K-4.

Table K-4: Summary of Wastewater Treatment Activity Data

Emission Source Category	Required Activity Data	Activity Data: 1990	Activity Data: 2002	Unit	Source
Industrial Wastewater	Annual production for pulp and paper industry	176,276,875,624 **(EST)**	223,068,130,273 **(EST)**	Metric tons	Michigan Department of Environmental Quality. *Pulp & Paper Pollution Prevention Program: 2002 Annual Report*. http://www.deq.state.mi.us/documents/deq-ess-p2-p5-05p5annrpt.pdf
	Annual production for fruit and vegetables industry	6,708,010,523 **(EST)**	5,913,352,082 **(EST)**	Metric tons	Michigan Department of Agriculture (MDA). *Michigan Agricultural Statistics.* 1991, 2002-2003. http://www.nass.usda.gov/mi/stats03/statstext.html; http://www.nass.usda.gov/mi/archive/1990/1990.pdf
	Annual production for red meat and poultry industries	9,658,989,386 **(EST)**	3,539,354,078 **(EST)**	Metric tons	Michigan Department of Agriculture (MDA). *Michigan Agricultural Statistics. 1991, 2002-2003.* http://www.nass.usda.gov/mi/stats03/statstext.html; http://www.nass.usda.gov/mi/archive/1990/1990.pdf United States Department of Agriculture. *Livestock Slaughter Summary: 2002*. National Agricultural Statistics Service. March 2003. http://usda.mannlib.cornell.edu/reports/nassr/livestock/pls-bban/
Municipal Wastewater	State Population	9,310,462	10,043,221		U.S. Census Bureau. American FactFinder http://factfinder.census.gov/home/saff/main.html

Note
(EST): Required activity data was not available and required estimation

Appendix L
Conclusions

Methodology for Aggregating Emissions by Economic Sector

The methodology used to allocate total State emissions by economic sector was adapted from the U.S. EPA.69 Methane and nitrous oxide emissions from landfills and industrial and municipal wastewater treatment are included in the commercial sector. Waste combustion emissions are allocated to the electricity generation sector since nearly all combustion occurs at waste-to-energy facilities. Limestone and dolomite use emissions are allocated 50 percent to electricity generation and 50 percent to the industrial sectors. Half of all limestone and dolomite consumption is for flue gas desulfurization. The electricity generation sector also includes emissions from electric power transmission and distribution systems

Unlike the U.S. EPA methodology, all of the ODS substitution emissions are allocated to the industrial sector. Also, it was not possible to allocate carbon dioxide emissions from agriculture fossil fuel consumption. These emissions are represented in the transportation, commercial, and industrial sectors. Mobile source emissions of methane and nitrous oxide from farm equipment are allocated to the agriculture sector.

In order to allocate emissions associated with electricity, it was necessary to determine the percentage of electricity consumed by the residential, commercial, and industrial sectors. As described in the chapter addressing emissions from fossil fuel combustion, there was an additional category of electricity consumption, referred to as “others”. This “others” category was eventually allocated to the commercial sector. The following table, Table L-1, presents the percentage of electricity consumed by the residential, commercial, residential, and “other” sectors for 1990 and 2002.

These distributions were then multiplied by emissions from fossil fuel combustion (from electric utilities), stationary combustion (from electric utilities), electric power transmission and distribution, 50% of limestone and dolomite use, and waste combustion. The products were then allocated amongst the residential, commercial, and industrial sectors.

Table L-1: Distribution of Electricity Consumption among Economic Sectors[70]

Sector	1990 Percentage	2002 Percentage
Residential	30.74%	32.00%
Commercial	25.02%	35.38%
Industrial	42.57%	31.73%
Others	1.67%	0.89%

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