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
[2] Intergovernmental Panel on Climate Change (IPCC) (2000) *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC National Greenhouse Gas Inventories Programme Technical Support Unit, Kanagawa, Japan. http://www.ipcc-nggip.iges.or.jp/public/gp/english/8_QA-QC.pdf

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-energy use of fuel (MMBtu) x C Content Coefficient (lbs C/MMBtu) ÷ 2000 lbs/ton x 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 2-Axle, 6-Ti	Single Unit Trucks 3-Axle	Single Unit Trucks 4 or more Axle	Single Trailer Trucks 4 or Less Axle	Single Trailer Trucks 5-Axle	Single Trailer Trucks 6 or More Axle	Multi Trailer 5 or Less Axle	Multi Trailer 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 Principapl 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 2-Axle, 6-Ti	Single Unit Trucks 3-Axle	Single Unit Trucks 4 or more Axle	Single Trailer Trucks 4 or Less Axle	Single Trailer Trucks 5-Axle	Single Trailer Trucks 6 or More Axle	Multi Trailer 5 or Less Axle	Multi Trailer 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 Principapl 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 Principapl 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 Principapl 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 Survey (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

<table>
<tr><th rowspan="2">Animal</th><th rowspan="2">Typical Animal Mass (TAM) (kg)</th><th colspan="2">Volatile Solids (VS) (kg VS/1000 kg animal mass/day)</th><th rowspan="2">Max Potential Emissions (BO) (m3 CH4/ kg VS)</th></tr>
<tr><th>1990</th><th>2002</th></tr>
<tr><td>Dairy Cattle</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Dairy Cows</td><td>604</td><td>8.67</td><td>8.38</td><td>0.24</td></tr>
<tr><td>Dairy Replacement Heifers</td><td>476</td><td>6.82</td><td>6.82</td><td>0.17</td></tr>
<tr><td>Beef Cattle</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Feedlot Heifers</td><td>420</td><td>5.16</td><td>3.35</td><td>0.33</td></tr>
<tr><td>Feedlot Steer</td><td>420</td><td>5.00</td><td>3.28</td><td>0.33</td></tr>
<tr><td>Bulls</td><td>750</td><td>6.04</td><td></td><td>0.17</td></tr>
<tr><td>Calves</td><td>118</td><td>6.41</td><td></td><td>0.17</td></tr>
<tr><td>Beef Cows</td><td>533</td><td>6.63</td><td>6.63</td><td>0.17</td></tr>
<tr><td>Beef Replacement Heifers</td><td>420</td><td>7.05</td><td>7.05</td><td>0.17</td></tr>
<tr><td>Steer Stockers</td><td>318</td><td>7.44</td><td>7.46</td><td>0.17</td></tr>
<tr><td>Heifer Stockers</td><td>420</td><td>7.09</td><td>7.04</td><td>0.17</td></tr>
<tr><td>Swine</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Breeding Swine</td><td>198</td><td colspan="2">2.6</td><td>0.48</td></tr>
<tr><td>Market Under 60 lbs</td><td>15.88</td><td colspan="2">8.8</td><td>0.48</td></tr>
<tr><td>Market 60-119 lbs</td><td>40.6</td><td colspan="2">5.4</td><td>0.48</td></tr>
<tr><td>Market 120-179 lbs</td><td>67.82</td><td colspan="2">5.4</td><td>0.48</td></tr>
<tr><td>Market over 180 lbs</td><td>90.75</td><td colspan="2">5.4</td><td>0.48</td></tr>
<tr><td>Poultry</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Layers</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hens > 1 yr</td><td>1.8</td><td colspan="2">10.8</td><td>0.39</td></tr>
<tr><td>Pullets</td><td>1.8</td><td colspan="2">9.7</td><td>0.39</td></tr>
<tr><td>Chickens</td><td>1.8</td><td colspan="2">10.8</td><td>0.39</td></tr>
<tr><td>Broilers</td><td>0.9</td><td colspan="2">15</td><td>0.36</td></tr>
<tr><td>Turkeys</td><td>6.8</td><td colspan="2">9.7</td><td>0.36</td></tr>
<tr><td>Other</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sheep on Feed</td><td>27</td><td colspan="2">9.21</td><td>0.36</td></tr>
<tr><td>Sheep Not on Feed</td><td>27</td><td colspan="2">9.21</td><td>0.19</td></tr>
<tr><td>Goats</td><td>64</td><td colspan="2">9.53</td><td>0.17</td></tr>
<tr><td>Horses</td><td>450</td><td colspan="2">10</td><td>0.33</td></tr>
</table>

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

Crop Type	1990		2002	
	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** **Agricultural Soil Management (Animal Waste Portion)**	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
	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)

	Total Carbon Stocks (million metric tons carbon)			
Category	**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 Sectors70

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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