Greenhouse Gas Emissions in Minnesota: 1970-2006

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Executive Summary

Under Minnesota statute (Minn. Stat. § 216H.07, subd. 3), the Minnesota Pollution Control Agency (MPCA) is obligated to report on statewide progress toward the greenhouse gas (GHG) reduction goals enumerated in the *Next Generation Energy Act* (Minn. Stat. § 216H.02). Greenhouse gases are gases that, upon emission to the atmosphere, warm the atmosphere and surface of the planet, and alter the climate. The *Next Generation Energy Act* established the following GHG reduction goals: 15 percent reduction from 2005 levels by 2015; 30 percent reduction by 2025; and 80 percent reduction by 2050.

To comply with this requirement, the MPCA estimated the emission of GHGs statewide for Minnesota for 2005, the baseline year designated by the Legislature, and 2006, the most recent year for which data are available to support an estimate. To facilitate the work of the Legislature, the MPCA also assembled a record of statewide GHGs going back to 1970. This inventory system has been in development for a number of years.

In compiling these estimates, the MPCA drew upon its GHG Emission Inventory, which tracks GHG emissions by gas, economic sector and emission source type. Emissions are grouped in the agricultural, commercial, electric generation, industrial, residential, transportation, and waste sectors, and into major activity groups by energy use and fuel production, agricultural process, industrial process, and waste management emissions.

We report only emissions of those GHGs named in the *Next Generation Energy Act:* carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), sulfur hexafluoride (SF_6), and two classes of compounds known collectively as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). We report emissions of all GHGs in both nominal and CO_2-equivalent tons. A CO_2-equivalent ton is a standardized and useful metric to compare and summarize emissions of different greenhouse gases. A CO_2-equivalent ton is the equivalent emission of any GHG that results in a 100-year integrated effect on the climate equal to the emission of one ton of CO_2 from fossil fuel combustion. This measure is calculated by multiplying the nominal tons of greenhouse gases by their global warming potential.

Only emissions that occur within the geographical borders of the state are estimated, with two exceptions – net imports of electricity into the state and emissions from the combustion of aviation fuel purchased in Minnesota, but not necessarily combusted within Minnesota air space.

The *Next Generation Energy Act* requires that evaluation of state-level GHG emissions take into account photosynthetically-removed CO_2 sequestered in biomass in forests, soils, landfills and structures. However, it has proven difficult or impossible to express some observed removals of CO_2 from the atmosphere in standard CO_2-equivalent terms. These removals, mostly involving forestry carbon, are tracked but are reported separately. Removals of CO_2 from the atmosphere and long-term storage in residential structures and demolition and construction landfills are included in statewide GHG emission totals.

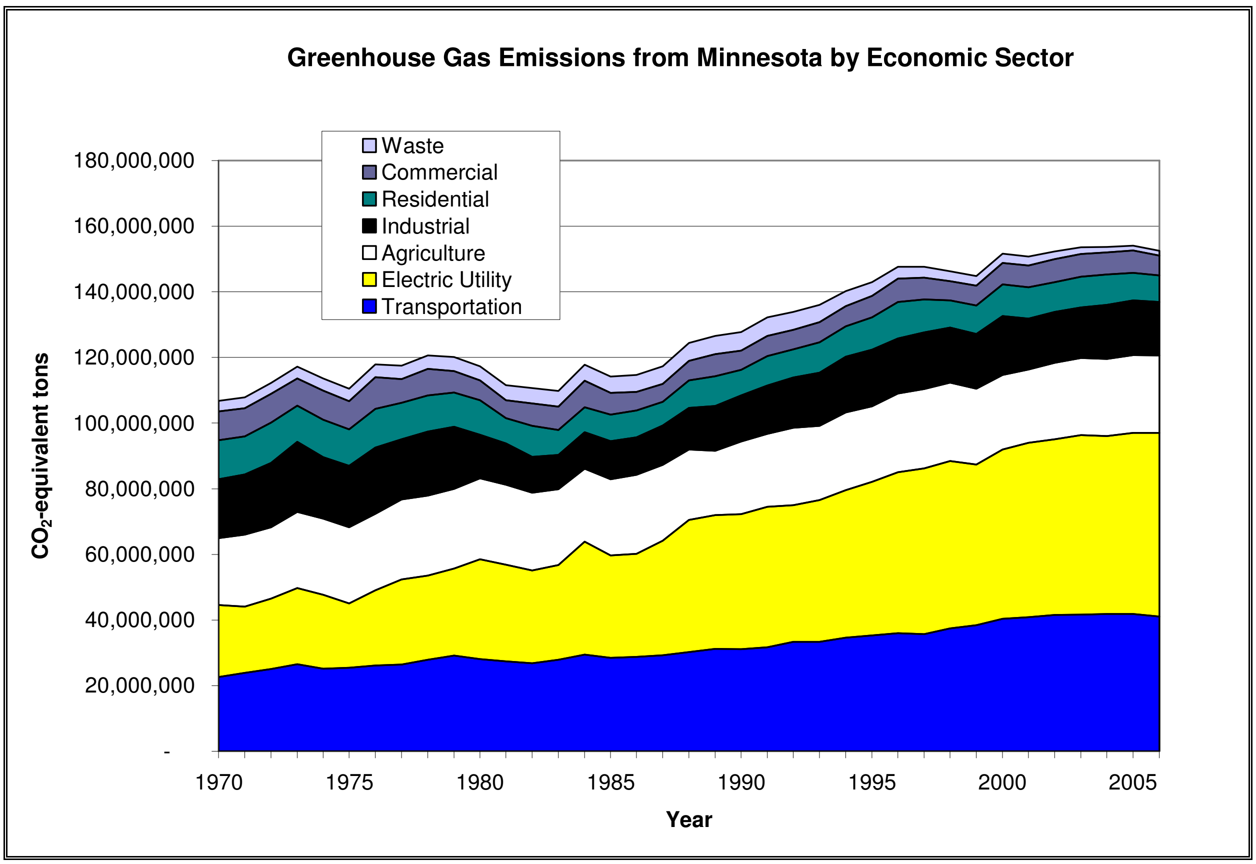
Emissions are estimated for all years from 1970 to 2006. With a few exceptions, the methods used to develop these estimates are derived from the following sources:

- Intergovernmental Panel on Climate Change, *2006 Guidelines for National Greenhouse Gas Inventories* (2006);
- Environmental Protection Agency, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2006* (2008a);
- The Climate Registry, *General Reporting Protocol* (2008);
- Environmental Protection Agency, *Climate Leaders Inventory Guidance* (2008b); and
- World Business Council for Sustainable Development/World Resources Institute, *GHG Protocol* (2004).

The methods used to develop GHG inventories have undergone substantial change in the last two years. Emissions for all years prior to 2006 were re-calculated to reflect methodological changes.

Not all emissions are included in statewide emission totals. In some cases, methods have not been developed or data do not exist to support an estimate. Important emissions sources not currently included in the GHG inventory include lake eutrophication, tiling and mineral wetland drainage, magnesium casting, and industrial and commercial refrigeration and space cooling.

Figure 1: Greenhouse Gas Emissions from Minnesota by Economic Sector



Statewide GHG emissions totaled 154.1 million CO_2-equivalent tons in the baseline year, 2005, falling to 152.5 million CO_2-equivalent tons in 2006 (Figure 1). Roughly 85 percent of all GHG emission in Minnesota are associated with energy consumption or the production and transportation of finished fuels in and through Minnesota. Most of the remainder derives from agricultural activities, chiefly soil nutrient management, manure management and ruminant livestock populations (e.g., cattle). Waste management and non-combustion industrial processes contribute a few percent to statewide emissions.

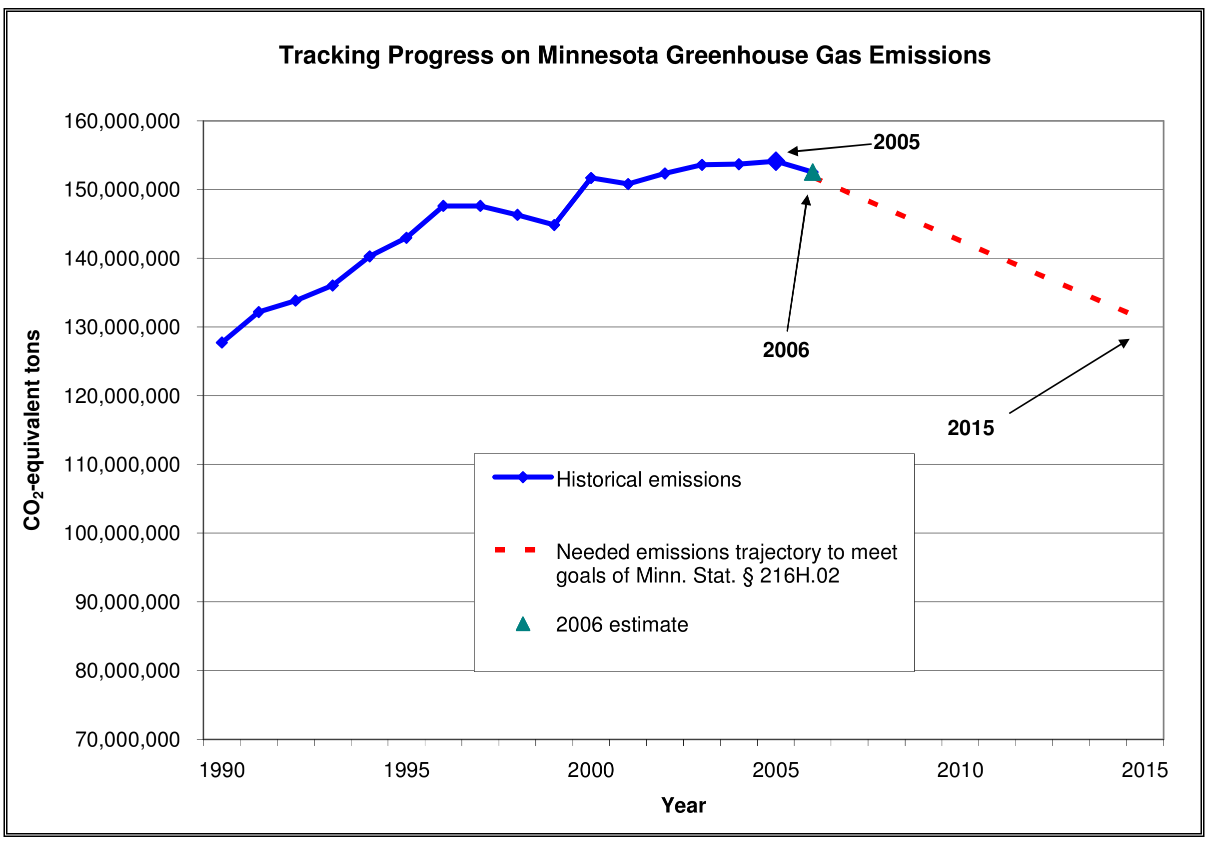
Prior to 2006, emissions had been rising at a 10-year average annual rate of 0.8 percent per year. Most of the historical growth in emissions occurred between 1985 and 1995, a period of rapidly declining real energy prices. During that period, GHG emissions increased 25 percent, stabilizing rapidly thereafter.

Under the *Next Generation Energy Act* goals, given a 2005 baseline of 154.1 million CO_2-equivalent tons, statewide emissions in 2015 would have to decline to about 131.0 million CO_2-equivalent tons, or a rate of about two million tons per year, from 2006 to 2015. These target levels are presented in Table 1 and in Figure 2, along with the pattern of statewide GHG emission since 1990. After one year of reporting, Minnesota is roughly on track to meet these objectives.

Table 1: Progress Toward Meeting Greenhouse Gas Reduction Goals

Progress Toward Meeting Greenhouse Gas Reduction Goals							
	2000	**2003**	**2004**	**2005**	**2006**	**2007**	**2015**
Historical emissions	151.7	153.6	153.7	154.1	152.5		
Needed emissions trajectory to meet goals of Minn. Stat. § 216H.02					151.8	149.5	131.0

Figure 2: Tracking Progress on Minnesota Greenhouse Gas Emissions



Section 1: Introduction

Like most climates, Minnesota's climate is warming. Since 1895, the mean annual temperature over Minnesota has increased about 1.5° Fahrenheit. This is similar to the roughly 1.4° Fahrenheit average warming of the surface of the earth. The consensus opinion in the atmospheric sciences is that this warming is due to the emission of greenhouse gases (GHGs) and their accumulation in the atmosphere.[1,2,3,4]

Greenhouse gases absorb energy at the same wavelengths that the earth radiates heat to space. Once emitted, GHGs absorb a part of that escaping longwave radiation and reradiate it back down to the surface of the earth, causing surface temperatures to rise and climate to change. At substantially elevated concentrations, anthropogenic GHG emissions can trap enough extra radiation in the lower atmosphere to change the climate at a rate previously only observed over geochronological epochs.

The greenhouse gases of most concern include carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3), sulfur hexafluoride (SF_6), and synthesized gases collectively known as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). While emissions of these gases are regulated in Europe, Canada and Japan under the Kyoto Protocol to the UN Framework Convention on Climate Change, with the exception of ozone, none of these gases are subject to federal regulation in the United States.[5]

In 2007, the Minnesota Legislature passed and the Governor signed into law the *Next Generation Energy Act* (Minn. Stat. § 216H.02) that, among other things, set GHG emission reduction goals of 15 percent, 30 percent and 80 percent for 2015, 2025, and 2050, respectively, from a 2005 baseline. In 2008 the legislature enacted a requirement that the Minnesota Pollution Control Agency (MPCA) track progress toward meeting these goals and report biennially to the Legislature (Minn. Stat. § 216H.07, subd. 3). The *Next Generation Energy Act* required CO_2, N_2O, CH_4, SF_6, HFCs and PFCs be tracked.

In addition, the statute required that, in establishing and tracking emissions, the MPCA account for GHG emissions associated with electricity that was consumed in Minnesota but was generated outside of the borders of the state. The law also required that, to the degree possible, removals of CO_2 from the atmosphere and its sequestration in living biomass and soils through forest regrowth or agricultural activities should be considered.

This MPCA GHG Emission Inventory technical report was prepared in compliance with these statutory obligations. It includes a statewide emission estimate for the 2005 baseline year, for 2006, which is the most recent year for which GHG emissions can be evaluated, and prior years

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[1] US National Academy of Sciences. (2001) *Climate Change Science: An Analysis of Some Key Questions.*
[2] Intergovernmental Panel on Climate Change. (2007) *Climate Change 2007: The Physical Science Basis.*
[3] Joint Academies of Science. (2005) *Global Response to Climate Change*. http://royalsociety.org/
[4] American Geophysical Union. (2007) *Human Effects on Climate*. http://www.agu.org/
[5] A number of regional initiatives have been or are being developed to regulate the emission of GHGs, including, in the Northeast and Middle Atlantic states, the Regional Greenhouse Gas Initiative, in the Western states, the Western Climate Initiative, and in Midwest, the Midwest Accord.

going back to 1970. The MPCA GHG Emission Inventory has been under development for a number of years.

In developing these estimates, the MPCA relied upon its GHG Emission Inventory, which tracks emissions within the geographical boundaries of the state. While in no sense in final form, it arguably represents one of the more advanced state-level GHG inventory and tracking systems in the country. Like most GHG inventories, it is in a state of continuous revisions as methods improve and new emission sources are incorporated. This has been especially true over the last two years, as a result of the revisions made to the underlying methods at the international level by the UN Intergovernmental Panel on Climate Change and, at the national level by the EPA.

The MPCA developed its GHG Emission Inventory System with the following in mind:

- the long record of emissions covering periods of years to decades;
- a consistent time series of estimates;
- best international and US practices;
- high level of data disaggregation; and
- timeliness.

The long record of emissions provides insight into the causes of rising emissions and describes the long-term dynamics of emissions in relation to population growth, technological change, and structural change in the economy. The long-term record sheds light on the time constants or useful lifetimes of systems, and also tells us something about the ease and timetable according to which emissions might be reduced from any one source or economic sector.

Most state-level emission reduction goals are expressed as percentage reductions from estimated emissions in a historical baseline year. To assure that progress is being measured, it is imperative to develop a consistent time series of emissions estimates. Given a set of methods applied consistently across all years, decision-makers can be reasonably sure that, even in situations where the absolute level of emissions is uncertain, they understand the general trend in emissions relative to the baseline. Since estimation methods and historical data are updated regularly, in practice this results in the frequent re-calculation of emissions from prior years to bring the historical baseline into methodological conformity with current year estimates.

If re-calculation ensures a consistent time series, the use of best available science and methods assures that, to the degree possible, emission inventory estimates reflect actual emissions from the state. In actuality, no objective or true inventory total exists, only truer or less true approximations of the actual emission total. The goal is the development of a progressively truer answer, given the limits of available data, methods and models.

Without quality, highly disaggregated emissions data, good policy design is difficult. The same is true for emission forecasting and policy analysis; both require detailed data on emissions extended down to the facility, end-use, and technology level to shed light on the determinants of emissions. Highly aggregated data are rarely useful in this regard. The MPCA GHG Emission Inventory has been developed with a view to acquiring and housing data at such a high level of disaggregation.

There is about a two- to three-year lag in the availability of the data used to estimate total GHG emissions from Minnesota, limiting the most recent estimate in this report to 2006. Thought will be given as to how this time lag might be rectified in future iterations of the biennial progress report, possibly using modeling techniques and indirect measures of emissions to approximate emissions in years for which data are not yet available.

Within the MPCA GHG Emission Inventory, emissions are reported in nominal and CO_2-equivalent tons. A CO_2-equivalent ton is the equivalent emission of any GHG that results in a 100-year integrated effect on the climate equal to the emission of one ton of CO_2 from fossil fuel combustion. It is a standardized and useful metric to compare and summarize emissions of different greenhouse gases. It is customary to use an index developed by the Intergovernmental Panel on Climate Change (IPCC) to convert nominal emissions of GHGs to a CO_2-equivalent basis. This is known as the Global Warming Potential Index. All of the emission estimates reported here use the most recent version of the IPCC GWP index (Appendix D).[6]

Not all greenhouse gas emissions to or removals from the atmosphere can be expressed in CO_2-equivalent terms. The calculation of CO_2-equivalence requires prior knowledge of, in the case of an emission, how long that emission will persist in the atmosphere and, in the case of a removal, whether what is removed remains in terrestrial storage and for how long. Because CO_2-equivalence is defined in terms of 100-years of integrated impact, the necessary foresight is measured in decades rather than years.

This is particularly a problem with respect to atmospheric removals of CO_2 during photosynthesis. During photosynthesis, CO_2 is removed from the atmosphere and incorporated into plant biomass. This places carbon in terrestrial storage. However, depending on how land is managed, stored carbon may remain sequestered for decades or, with more intensive use of the land, be reemitted quickly after initial storage. It depends on present and future land management decisions, and those cannot be known with any certainty (or perhaps at all) in the present.

This introduces irreducible uncertainties to the quantification of offsets or removals using the IPCC CO_2-equivalence framework. To offset one ton of CO_2 emissions from fossil fuel combustion, CO_2 removed from the atmosphere and placed into terrestrial carbon storage must remain there for at least 50 years. Without knowing how the future will unfold, there is no way that we can know if, for any single observed removal of CO_2 from the atmosphere, those conditions will be met.

In light of these irreducible uncertainties, CO_2 removals from the atmosphere (and CO_2 emission sources) that cannot properly be expressed in CO_2-equivalent terms are tracked separately, but not added to statewide totals. Forestry CO_2 offsets and emissions both fall into this category in the MPCA GHG Emission Inventory.

With two notable exceptions, only those emissions that occur within the geographical borders of the state are estimated. The exceptions are emissions from net imports of electricity consumed in

[6] In *the Next Generation Energy Act*, in provisions governing the reporting of emissions of so-called high GWP GHGs, the Minnesota legislature specifically required that the MPCA to use the most recently published GWP index by the IPCC. In this report, we follow that practice.

the state; and emissions from the combustion of aviation fuel purchased in Minnesota but not necessarily combusted in Minnesota airspace.

With a few notable exceptions, the methods used to develop these estimates derived from the following sources: Intergovernmental Panel on Climate Change, *2006 Guidelines for National Greenhouse Gas Inventories* (2006); EPA, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2006* (2008a); The Climate Registry, *General Reporting Protocol* (2008); EPA, *Climate Leaders Inventory Guidance* (2008b); and World Business Council for Sustainable Development/World Resources Institute, *Greenhouse Gas Protocol* (2004). The MPCA also relied on an extensive collection of emission factors that has been under development for a number of years.

Emissions are reported by greenhouse gas, by economic sector and by major activity. The major categories of activities into which emissions are organized are energy use and fuel production, agriculture, waste management, and industrial processes or other activities. The economic sectors around which reporting is organized are commercial, industrial, residential, agricultural, transportation, electric power generation, and waste management sectors.

Statewide GHG emissions totaled 154.1 million CO_2-equivalent tons in the baseline year, 2005, falling to 152.5 million CO_2-equivalent tons in 2006 (Figure 1). Roughly 85 percent of all GHG emissions in Minnesota are associated with energy consumption or the production and transportation of finished fuels in and through Minnesota. Most of the remainder derives from agricultural activities, chiefly soil nutrient management, manure management and ruminant livestock populations (e.g., cattle). Waste management and non-combustion industrial processes contribute a few percent to statewide emissions. After one year of reporting, Minnesota is roughly on track to meet the objectives of the *Next Generation Energy Act*.

Section 2: Sources and Sinks of Greenhouse Gases

The principal unregulated greenhouse gases, known as the six Kyoto gases, are carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), sulfur hexafluoride (SF_6) and two families of gases known as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). In addition, there are other GHGs and precursors of GHGs, including the chlorofluorocarbons (CFCs), the hydrchlorofluorocarbons (HCFCs), nitrogen trifluoride (NF_3), sulfuryl fluoride (SO_2F_2), ozone, and various idiocarbons and chlorocarbons like methylchloroform, methylene chloride and chloroform. Many of the non-Kyoto greenhouse gases are regulated under the Clean Air Act. In this report, we restrict our discussion to CO_2, N_2O, CH_4, SF_6, PFCs and HFCs.

The principal sources of these gases are listed in Table 2. A sink is a site of biological removal of GHG from the atmosphere and their terrestrial storage.

Table 2: Sources and Sinks of Greenhouse Gas Emissions in Minnesota

Sources of Greenhouse Gas Emissions in Minnesota		
Fossil CO_2	• Coal combustion • Oil combustion • Natural gas combustion • SO_2 pollution control • Waste burning • Peatland cultivation • Liming of agricultural fields • Urea fertilizer use • Taconite production • Steel production	• Glass manufacture • Solvent use • Soap and detergent use • Food additives • Lubrication • Peat mining and use • Tire abrasion • Industrial wax use • Industrial limestone consumption
CH_4	• Fossil fuel combustion • Biomass combustion • Hydroelectric reservoirs • Natural gas pipelines • Coal piles • Solid waste landfills • Solid waste composting	• Solid waste burning • Wastewater treatment • Ruminant flatulence • Manure storage • Lake eutrophication • Wild rice cultivation • Wildfire
N_2O	• Fossil fuel combustion • Biomass combustion • Mobile source catalytic converters • Sludge land application • Human sewage • Waste burning	• Cultivated peatlands • Fertilizer use • Nitrogen run-off and leaching • Crop residues • Manure storage and land application • Atmospheric nitrogen deposition
SF_6	• Electric transmission and distribution • Semiconductor manufacture	• Magnesium casting
HFCs	• Commercial refrigeration • Industrial refrigeration • Space cooling • Mobile air conditioning • Insulating foams	• Solvents • Aerosol propellants • Fire extinguishing equipment • Semiconductor manufacture
PFCs	• Semiconductor manufacture	• Fire extinguishing equipment
Biogenic CO_2	• Biomass combustion • Solid waste landfills	• Wastewater treatment plants • Forestland clearing

(continued on next page)

Table 2 (continued): Sources and Sinks of Greenhouse Gas Emissions in Minnesota

Sinks of Greenhouse Gas Emissions in Minnesota		
Biogenic carbon sequestration	• Forest growth or regrowth • Demolition/construction landfills	• Structures

Carbon dioxide

CO_2 is the most significant GHG in terms of total emissions. CO_2 primarily results from the combustion of fossil fuels and plant biomass. Upon combustion, most or all of the fuel or biomass carbon is oxidized to CO_2 and is emitted to the atmosphere. In instances where combustion is incomplete, carbon is emitted to the atmosphere as carbon monoxide and various volatile organic compounds, but these oxidize rapidly in the atmosphere to CO_2.

A small amount of CO_2 is found in natural gas. Natural gas can leak to the atmosphere from natural gas pipelines and compressor stations, resulting in a small amount of CO_2 emissions.

Refined petroleum products include carbon-based volatile compounds. Given the appropriate temperature and other environmental conditions, these volatilize and are released to the atmosphere in a gaseous form. After a short residence in the atmosphere, they oxidize to CO_2. Many nonfuel products are petroleum-based. Upon use, the petrochemical part of these products may be oxidized to form CO_2. Examples of nonfuel products include lubricating oils, industrial waxes, deicers, antifreeze, solvents, varnishes, paints, soaps and detergents.

CO_2 is also produced during industrial processes involving limestone or dolomite, which contain carbon in the form of carbonate. When heated, some of this carbon is oxidized and emitted to the atmosphere as CO_2. Limestone is used in the manufacture of cement, lime, glass, steel, abrasives and other products. In the taconite industry, limestone is incorporated into marketed taconite pellets. During induration, or manufacture, these pellets are exposed to high temperatures in indurating furnaces and some carbon is oxidized and emitted to the atmosphere as CO_2.

Limestone is also used in crop production to raise the pH levels of agricultural soils, rendering them less acidic. In this process, CO_2 is produced and emitted to the atmosphere. The use of urea-based fertilizer, which contains petrochemical carbon, also results in the production of CO_2.

Other potential sources of CO_2 are soils, decomposing biomass on the forest floor or standing dead wood, manure holding basins, wetlands, lake sediments and landfills. CO_2 also results from the oxidation in the atmosphere of emitted CH_4, albeit a decade after emission, given methane's roughly 10-year atmospheric lifetime.

Methane

Methane is the second most significant GHG in Minnesota, and is a potent GHG, having 25 times the global warming potential of CO_2. A large amount of methane is produced anaerobically in landfills and manure storage ponds, tanks and basins, and emitted to the atmosphere. In these oxygen-poor, or anaerobic, environments, organic matter is converted from complex carbon molecules to simpler forms by bacteria through biochemical processes that result in the production of CH_4.

A large amount of CH_4 is produced anaerobically in the rumen, or forestomachs, of cattle and the intestines of cattle, sheep, swine, horses, and other large animals. By employing bacteria in their rumen to break down low-grade cellulose materials into usable nutrition, cattle are able to digest food that cannot be digested by nonruminant animals. However, methane, the end product of ruminant digestion, is emitted through flatulence and belching. Cattle are the principal source of flatulence-based livestock emissions; other ruminants and nonruminant animals, like swine, contribute only marginally.

CH_4 is the principal gaseous constituent of natural gas. Each year a small amount of natural gas leaks to the atmosphere, resulting in the emission of CH_4. Some natural gas that is co-produced with oil is intentionally vented to the atmosphere during oil production.

CH_4 is also produced in the seams of coal mines and is emitted during coal mining and storage. A smaller amount is emitted during the refining and storage of petroleum products. A small amount of methane is also formed as a result of incomplete combustion of petroleum in vehicles and incomplete combustion of coal and biomass in boilers, furnaces, kilns, and other external combustion devices.

Methane is formed during the burning of solid waste and in wildfires and during prescribed burning for land management purposes. CH_4 is produced anaerobically in rice paddies, lake sediments and wetlands, and during domestic and industrial wastewater treatment.

Nitrous oxide

Nitrous oxide is released in small quantities, but is nearly 300 times as potent a GHG as CO_2. Nitrous oxide is produced principally in soils and surface waters by bacteria that, to derive energy for basic metabolic processes, oxidize ammonium to nitrate or reduce nitrate to nitrite or simpler forms of nitrogen. During crop production, large amounts of nitrogen are added to soils as a soil nutrient. The soil bacteria convert a part of that added nitrogen to N_2O, which is emitted to the atmosphere. Sources of nitrogen that are available to these soil bacteria, resulting in the production of N_2O, include synthetic fertilizers, crop residues, nitrogen deposited from the atmosphere, manure, wastewater sludge, compost and other organic amendments. Some N_2O is also a result of denitrification during the cultivation of organic soils.

Manure storage, particularly in a solid or dry form, is an important source of N_2O. In stored manure, N_2O production results from the same set of microbial nitrification and denitrification processes that occur in soils. N_2O is produced in surface waters after nitrogen discharge from domestic and industrial wastewater treatment plants. A small amount of N_2O is produced during wastewater treatment and the composting of solid waste.

Small amounts of N_2O also are formed during the combustion of fossil fuels and biomass in boilers, furnaces, and other stationary combustion sources. A smaller amount is formed during waste incineration, rural open burning and prescribed burning and in wildfires. In a post-combustion process, N_2O is formed in the catalytic converters of gasoline-driven light-duty and heavy-duty vehicles in normal operations. In catalytic converters, nitrogen oxides (NO_x) are reduced to dinitrogen (N_2). However, N_2O is produced as a byproduct and is subsequently emitted to the atmosphere.

A small amount of N_2O is emitted each year as a result of dentistry use of N_2O as an anesthetic and analgesic. N_2O is also used as an aerosol propellant in consumer products such as whipped cream and various cooling sprays. N_2O is used as an inert gas in food packaging to inhibit bacterial growth.

Finally, N_2O is also emitted during the industrial production of adipic acid and nitric acid; no adipic acid or nitric acid production is located in Minnesota.

Sulfur hexafluoride, HFCs, and PFCs

Sulfur hexafluoride is a synthetic gas that is produced for specific, mostly industrial, applications. SF_6 is used as a dialectic insulating gas in electricity transmission and distribution switchgear and high voltage circuit breakers. Upon servicing or disposal, some SF_6 is inadvertently released to the atmosphere. SF_6 is also used as an etchant in semiconductor manufacture and as a cover gas for casting magnesium parts. Fugitive releases from these industrial processes result in emissions to the atmosphere. Primary aluminum refining is the largest US source of SF_6 emissions; however no primary aluminum processing is based in Minnesota.

Hydrofluorocarbons are a family of synthesized compounds used primarily in refrigeration, space cooling, foam manufacture, semiconductor manufacture, and fire suppression. HFCs are used as aerosol propellants and as solvents in the manufacture of electronic components, biomedical apparatus and precision instruments. Leakage from refrigeration and space cooling equipment is the largest source of emissions to the atmosphere. As refrigerants, the HFCs are used in most mobile air conditioning units, residential refrigeration, and refrigerated transport. Cold grocery food cases rely on the HFCs as a refrigerant. Some commercial space cooling uses HFCs as a refrigerant.

HFCs leak to the atmosphere during industrial manufacturing processes. Besides their use as a solvent, HFCs are used as casting release agents. HFCs are used as insulating gases in foam insulation used in building construction. In this application, most of the HFC gas is retained in the foam for decades.

Consumer products that contain HFCs include pressurized dusters for computer cleaning, medical dose inhalants, tire inflators, air signaling horns, hairsprays, deodorants, antiperspirants, spray paints and automotive products. HFCs are released to the atmosphere upon use of these products.

Perfluorocarbons are a class of synthetic compounds used mainly in manufacturing. The principal use of PFCs in Minnesota is in semiconductor manufacturing, where PFCs are used as plasma etchants in the manufacture of computer chips. Other uses of PFCs include refrigeration and fire suppression. Small amounts of PFCs are also used in eye surgery and in ultrasound and MRI imaging equipment. They are also used in high-end ski waxes and as tracers in scientific work. The largest sources of US PFC emissions are PFC-14 and PFC-116 formed during primary aluminum refining. No primary aluminum refining is based in Minnesota.

Section 3: Inventory Boundaries and Organization

In developing the estimates included in this report, the MPCA relied on its GHG Emission Inventory, in which GHG emissions are organized by gas, economic sector, major activity and emission source type. The GHG emissions that are tracked are CO_2, N_2O, CH_4, SF_6, HFCs and PFCs, as established in the *Next Generation Energy Act* (Minn. Stat. § 216H.02).

The MPCA GHG Emission Inventory is organized on a spatial or geographical basis; GHG emissions that physically occur within the boundaries of the state of Minnesota are tracked, with exceptions for emissions associated with net electricity imports and with aviation.

In the *Next Generation Energy Act*, 2005 was designated as the baseline year against which progress on emission reduction was to be evaluated. The most recent available data are for 2006. In addition, in order to provide insight into the causes of rising emissions and shed light on the long-term dynamics of emissions in relation to population growth, technological change, and structural change in the economy, we report on emissions for prior years going back to 1970.

Only those emissions of GHGs that result directly from human activities and indirectly from disturbed ecosystems are tracked. GHG emissions produced naturally in undisturbed ecosystems are not tracked in the MPCA GHG Emission Inventory. To the degree that methods allow, we track both GHG emissions to the atmosphere and GHG removals from the atmosphere. CO_2 can be removed from the atmosphere photosynthetically and stored terrestrially in living and dead biomass.

While ideally, all sources of GHG emissions from Minnesota would be inventoried and tracked, in practice, only those sources are inventoried for which there exists a well developed scientific understanding of the physical and biological processes involved in the production and emission of GHGs. Protocols or methods must exist for sources to be treated, and data must be available to support the estimation effort.

Since this report tracks progress against a historical baseline, only those sources treated in the baseline year are evaluated. As methods are updated, the historical baseline may be adjusted.

The Legislature specifically directed the MPCA to include in its estimates of statewide GHG emissions those emissions that result from out of state electricity generation that is consumed within Minnesota. Total electricity consumption in Minnesota, net electricity generation in the state and all associated transmission and distribution (T&D) line losses are estimated. Total net generation needed to service Minnesota demand is set equal to total consumption less T&D line losses. Out-of-state net generation is estimated as the difference between total net generation needed to service Minnesota electrical demand and in-state net generation. The MPCA includes these emissions in the GHG Emission Inventory, using a nine-state and province average emission rate per megawatt-hour (MWh) of electricity generated. Electric transmission and distribution losses are factored into the estimate of emissions for imported power.

We also count emissions associated with jet fuel loaded onto to aircraft at Minnesota airports in Minnesota totals. A major international airline hub is located in Minnesota. It is reasonable to argue that the presence of a major airline hub and the headquarters of a major national air carrier in Minnesota contribute substantially to the economy of Minnesota, and as such, the emissions associated with operation of the international airport should be included in the GHG totals for Minnesota. Additionally, data are not available to estimate the number of miles flown by commercial aircraft in Minnesota airspace.

Only a part of these emissions might properly be said to occur within the geographical boundaries of the states; it also could be reasonably argued that the set of aviation emissions included in Minnesota totals should be limited to those that occur upon take-off and landing, i.e., those that physically occur in the state, consistent with the rest of the inventory. The MPCA is open to the possibility that future legislative reporting may treat only GHG emissions that result from aircraft take-offs and landings.

Most state-level GHG inventories adopt a geography-based approach, if only due to its relative simplicity. Lacking a compelling reason to depart from this practice, we follow this convention. With the exception of net electricity imports and aviation, all emissions that physically occur within the geographical boundaries are counted toward Minnesota's emission totals. Within that framework, those emissions can be said in some sense to result from economic activities that occur within those geographical boundaries, e.g., the production of goods and services.

There are at least two alternatives to this formulation of appropriate inventory boundaries. Starting with state-level economic accounts that measure the output of good and services within the state, we could estimate all GHG emissions associated with the production of good and services. Since those accounts include services provided by transportation firms based in Minnesota but operating at least in part outside of the state, by using this approach we would pick-up out-of-state emissions associated with the firms based in and contributing to the production of goods and services in Minnesota. However, under this approach, GHG emissions that occur on Minnesota highways from the operation of vehicles based out-of-state would not be counted.

We also could track GHG emissions associated with the production of goods and services that, upon purchase, are consumed by Minnesotans. In this formulation, it is the consumer demand for goods and services, not the production of goods and services, that determines what emissions are counted and where they might occur. This usefully relates emissions to purchases, but it also ignores the role played by goods and services-producing activities in Minnesota.

A distinction is often drawn between top-down approaches to emission inventories and bottom-up approaches and bottom-up emission sources. A bottom-up approach is a facility-level approach in which total emissions are the sum of all facility-level emissions. A bottom-up emissions source is a facility emission source. Under a top-down approach, emissions are calculated using highly aggregated sectoral data that is typically collected through surveys or is developed from sales data or tax receipts. As will be discussed in Section 4 below, the MPCA employs a combination of the two approaches. Facility data are utilized where available; where these are not available or are not sufficient to characterize emissions, sectoral data are used.

Reference is also often made to four distinct emission categories: upstream emissions, downstream emissions, direct emissions and indirect emissions. Upstream emissions are GHG emissions that are associated with the production of finished fossil fuels. Downstream emissions are emissions that are associated with the combustion or the process use of finished fossil fuels. They may also include all other noncombustion emissions of GHGs. Facility-level emissions are classed as either direct or indirect. Direct emissions are emissions that physically occur at a facility. Indirect emissions are emissions that occur off-site as a result of the production of purchased electricity or steam.

The MPCA GHG Emission Inventory is mostly concerned with downstream emissions. Upstream emissions are treated only to the degree that the refined petroleum products that are combusted in Minnesota are also refined in the state. The MPCA GHG Emission Inventory includes some facility-level information. In tracking facility-level emissions, the MPCA Emission Inventory treats only direct GHG emissions.

Within the MPCA GHG Emission Inventory, emissions are reported in nominal and CO_2-equivalent tons. A CO_2-equivalent ton is a standardized and useful metric to compare and summarize emissions of different greenhouse gases. A CO_2-equivalent ton is the equivalent emission of any GHG that results in a 100-year integrated effect on the climate equal to the emission of one ton of CO_2 from fossil fuel combustion. This measure is calculated by multiplying the nominal tons of greenhouse gases by their global warming potential.

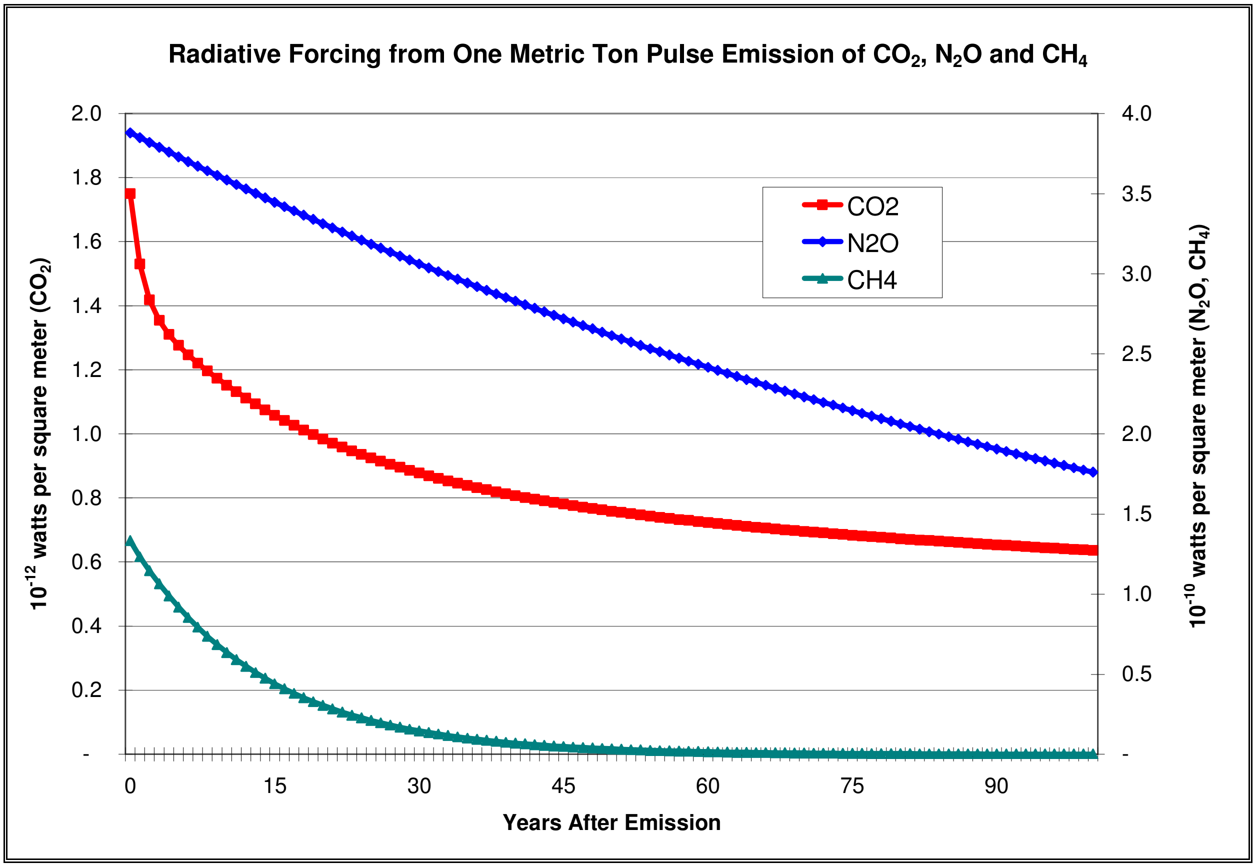
Only GHG emissions to and removals from the atmosphere that can be expressed quantitatively in CO_2-equivalent terms are counted against Minnesota statewide GHG emission totals. Those that cannot be properly expressed in CO_2-equivalent terms are tracked, but not added to statewide totals.

The IPCC did the basic work in developing the CO_2-equivalence framework. Upon emission, CO_2 absorbs a certain amount of radiation, described in extra watts for each square meter (W/m^2) of atmospheric absorption. For a one metric ton emission of CO_2, this equals about 1.75×10^{-12} W/m^2. The integrated 100 years absorption equals the annual amount of extra absorption summed over all 100-years. For fossil fuel CO_2, this is equal to about 85×10^{-12} W/m^2-years, which is essentially the amount of atmospheric absorption needed for the emission of any GHG to be said to be equal over a 100-year period to one CO_2-equivalent ton.

In terms of nominal tons of emissions, one CO_2-equivalent ton of emissions translates to 0.04 tons of CH_4 and 0.0034 tons of N_2O. This means that, on a per ton basis, an emission of CH_4 is 25 times as effective over a one-hundred-year period in absorbing infrared radiation as is fossil CO_2, and N_2O is 298 times more effective.

This concept of CO_2-equivalency is shown graphically in Figure 3, which shows the amount of extra radiation trapped in the atmosphere with a one metric ton pulse emission of CO_2, N_2O and CH_4 at various times after emission. The area under each of the curves gives the 100-year integrated forcing, which for CH_4 is about 21×10^{-10} W/m^2-years and, for N_2O is about 253×10^{-10} W/m^2-years. We have already seen that, for a one metric ton emission of CO_2, the integrated 100-year extra absorption is about 85×10^{-12} W/m^2-years.

Figure 3: Radiative Forcing from One Metric Ton of CO_2, N_2O, and CH_4



This integrated 100-year extra absorption for CO_2 of 85 x 10^{-12} W/m^2-years also is the amount of extra absorption that, over a one-hundred year period, would be avoided as a result of a one ton CO_2-equivalent removal from the atmosphere. Since a reduction -1.75 x 10^{-12} W/m^2 is associated with the removal of one ton of CO_2 for a single year, any one ton removed from the atmosphere would have to stay in storage roughly 50 years to offset the 100-year absorption of one emitted ton of CO_2.

These values can be calculated due to the very predictable schedule of retention of fossil CO_2, N_2O, CH_4 and the other GHGs in the atmosphere after emission. Retention depends only on the background state of the atmosphere at the time of emission. Nothing more needs to be known.

Not all emissions to or removals of greenhouse gases from the atmosphere can be expressed in CO_2-equivalent terms. The calculation of CO_2-equivalence requires knowledge of how long that emission will persist in the atmospheric and whether removals remain in terrestrial storage and for how long. Because CO_2-equivalence is defined in terms of 100-years of integrated impact, the necessary foresight is measured in decades rather than years.

This is particularly a concern with CO_2 emitted upon the combustion of biomass. If, after combustion, no new plant biomass grows back to replace what has been combusted, CO_2 is retained in the atmosphere at the same rate that fossil CO_2 is retained in the atmosphere. Under those conditions, one ton of emitted biomass CO_2 is equal to one CO_2-equivalent ton of emission. But, if after combustion, plant biomass is allowed to regrow on cleared land, eventually part or all of the emitted CO_2 may be photosynthetically removed from the atmosphere and returned to terrestrial storage, offsetting part or all of the effects of combustion emissions.

Biomass carbon accounting depends on uncertain land management practices, such as forest regrowth on cleared acres, which influence whether or not enough carbon will accumulate and be terrestrially stored over enough time, and if 85 x 10^{-12} W/m^2-years of integrated warming will be offset. We simply cannot know this answer because it depends on the unfolding of what is, in essence, an indeterminate future.

Including biomass CO_2 introduces irreducible uncertainties to the quantification of offsets or removals using the IPCC CO_2-equivalence framework. To offset one ton of CO_2 emissions from fossil fuel combustion, CO_2 removed from the atmosphere and placed into terrestrial carbon storage must remain there for at least 50 years. Without knowing how the future will unfold, there is no way that we can know if, for any single observed removal of CO_2 from the atmosphere, those conditions will be met. In light of these irreducible uncertainties, CO_2 removals from or to the atmosphere that cannot properly be expressed in CO_2-equivalent terms are tracked, but not added to statewide totals.

In terms of specific pools of carbon, we track changes in forest carbon stocks, but since we cannot express these mathematically in terms of CO_2 equivalence, these are kept separate from statewide GHG emission totals. Annual emissions or removals are recorded in nominal tons.

With the exception of CO_2 emissions from cultivated or pastured peatland (histosols), emissions of CO_2 or removal of CO_2 from the atmosphere as a result of the cultivation of agricultural soils also are not treated as no adequate method was identified for doing so.[7]

No adequate method was identified for state-level estimation of CO_2 emissions to or removals from the atmosphere from the cultivation of agricultural mineral soils. The underlying science appears to be far from mature on this topic. What a few years ago was thought to be settled science—the effect of different tillage practices on soil organic carbon gain and loss—now seems to be an open scientific question.[8,9] It seems possible that these soils could be a net emitter or a net sink of CO_2.

Until the science is clarified, the MPCA will not address CO_2 emissions or removals from mineral soils in agriculture and forestry.[10] This represents the single largest departure of the MPCA Inventory from the national inventory. Some of the issues that must be settled before any judgments can be drawn include:

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[7] A small placeholder emission from wind blown soils is included.

[8] J. Baker, *et al.*, "Tillage and Soil Carbon Sequestration-What Do We Really Know?" *Agriculture, Ecosystems, Environment, 118* (2007): 1-5.

[9] J. Manley, *et a*l., "Creating Carbon Benefits Through No-till Cultivation: A Meta-analysis of Costs and Carbon Benefits," *Climatic Change, 68* (2005): 41-65.

[10] These soils should be distinguished from highly organic soils or histosols, which have been determined unambiguously to be CO_2 emitting sources when under cultivation or pasture.

- the effect of tillage practice on soil organic carbon across the entire soil horizon;
- nutrient effects on soil respiration;
- the fate of eroded soils;
- the ongoing effects of climate change;
- the effect of drain tile in wet soils; and
- the strength of legacy emissions, if any, resulting from decades old wetlands drainage.

We do track carbon storage in residential housing and in demolition and construction landfills. These are removals from the atmosphere that unambiguously can be said to have persistent effects on climate for at least 50 years and perhaps as long as 100 years. We do not track carbon stocks in landfills receiving MMSW. This may potentially be added to the inventory in the next reporting cycle.

Table 3 summarizes the boundaries used by the MPCA to develop its statewide GHG emission totals. These can be roughly construed as the rules that determine what sources and sinks are counted against statewide totals, which are not, and why.

Table 3: Inventory Boundaries and Organization

Inventory Boundaries	
Inventory basis	• Physical emission within the geographical boundaries of Minnesota, plus electricity imports and aviation
Gases	• Six Kyoto Gases: CO_2 (from fossil fuels), N_2O, CH_4, SF_6, PFCs, HFCs
Sources	• Human-managed systems plus disturbed ecosystems
Other criteria for sources counted against statewide totals	• Well developed scientific basis emissions estimation • Preexisting protocol • Preexisting 2005 baseline emission estimate • Potential to be expressed in CO_2-equivalent terms
Reported separately	• Biomass CO_2, forestry carbon stock changes
Inventory Organization	
Inventory years	• 1970-2006
Baseline year	• 2005
Emission units reported	• Nominal short tons • CO_2-equivalent short tons
Reporting basis	• 7 economic sectors • 4 major emitting activities • 6 gases • 33 source categories
Data acquisition and organization	• Facility-level bottom up: electric power generation, industrial, and waste management sectors • Sectoral top-down: residential, commercial, agricultural, and transportation sectors
Principal methods	• IPCC 2006, EPA 2008, EPA 2005, EPA 2003, EPA 1995, CCAR *et al.*, 2008, TCR 2008
Methodological change	• Re-calculation of emissions to ensure consistent series

Table 3 also lists some of the more salient organizational characteristics of the inventory. Emissions are reported by gas, economic sector, major activity, and source category. The major activities around which emissions are organized are energy, agricultural processes, industrial processes, and waste management. Energy activities include all combustion leading to the production of useful energy, the generation of imported electricity, and the production and transport of finished fossil fuels. Energy-related activities were intentionally separated off from all other activities leading to the emission of GHGs to highlight the predominant role of the energy system in emissions.

Emissions are reported by economic sector to reveal relationships between the production of specific types of good and services and GHG emissions. Important services and goods production that can be organized by economic sector include: transportation services, waste disposal services, housing, electricity, and food.

The economic sectors around which GHG emissions are organized are the commercial, industrial, residential, agricultural, electric power generation and waste management sectors. The industrial sector includes the mining, construction and manufacturing industries. The agricultural sector includes the production of field crops and livestock. The electric power sector includes firms in the SIC codes 4911, 4931, 4953 and 4961, plus independent power producers selling power onto the Minnesota electrical grid. The electric power sector also includes waste-to-energy facilities that generate and sell electricity and steam off-site, which in terms of the inventory's sectoral organization also might have been be located in either the electric power sector or the waste management sector.

Emissions from the electric power sector, the industrial sector and waste management are, for the most part, estimated using facility-specific fuel use and related data. GHG emissions from the other four sectors are estimated using a top-down sectoral approach. Most data are available only at a sectoral level.

As discussed in the Section 1, the MPCA developed its GHG Emission Inventory with the importance of the following in mind:

- the long record of emissions covering periods of years to decades;
- a consistent time series of estimates;
- best international and US practices;
- high level of data disaggregation; and
- timeliness.

The long record of emissions provides insight into the causes of rising emissions and sheds light on the long-term dynamics of emissions. Most state-level emission reduction goals are percentage reductions from emissions for some historical baseline year. Because estimation methods and historical data are updated regularly, in practice this results in the frequent back-calculation of emissions from prior years to bring the historical baseline into methodological conformity with current year estimates. Without good, highly disaggregated emissions data, the design of good policy is difficult.

The methods that we use represent what is now considered to be best national and international practice. Timeliness ensures that decision-makers have the most recent data possible to develop state policy.

There is about a two- to three-year lag in the availability of the data used to estimate total GHG emissions from Minnesota. In instances where data for the most recent reported year are not yet available, to ensure that progress reports are timely, the most recent available data are used. As it becomes available, the data for the missing year are rolled into the inventory, which is then revised to reflect the changes.

The MPCA Emission Inventory is assembled on a biennial basis. All the data that are used to generate the estimates are archived. Where possible, multiple databases are maintained. These allow us to assess the quality and statistical characteristics of our input data in relation to other available data sets. A record is maintained of all methods, equations and conversion and emissions factors that are used. To support the inventory, a detailed database of emission and conversion factors and methods going back to the early 1990s has been developed. This allows us to follow the evolution of emission estimation practices in relation to the developing science and to trace the lineage of specific methods and factors.

As a general rule, the methods used are based on simplified equations that are easily applied and allow our results to be replicated. Methods that are chosen are selected based on the following criteria: best international practice; conformity with EPA practice; data availability; and resource requirements. Methods are sometimes selected based on resource requirements in relation to what might be gained by way of accuracy and precision in the estimation of emissions.

Data are acquired at the most local level possible. Facility-level data are preferable to sector-based survey data. As a part of the inventory, we maintain a detailed facility-level inventory of fuel use and emissions going back to the early and mid-1980s. Fuel use and emissions are tracked across ownership changes and product and production changes. New facilities are added as they are permitted and commence operation. Information is available down to the unit level.

Where data disaggregation is necessary to the work of decision-makers and the reported data are not available at this level of detail, the data are modeled to the end-use level. Vehicle emissions and fuel use are an example; these are modeled by vehicle type, fuel use and model year. It is possible that end-use modeling will play an ever larger role in the inventory in future years.

Finally, it bears repeating that the MPCA GHG Emission Inventory is a work in progress. Like the US national GHG inventory, it is in a state of continuous revision as methods improve and as new emission sources are incorporated. This has been particularly true over the last several years, as a result of the revisions introduced in the underlying methods at the international level by the IPCC and, at the national level, the EPA. This will continue to be true and perhaps intensify if GHGs become subject to regulation under the federal Clean Air Act. It should be expected that the emission totals given in this report will continue to shift for the foreseeable future.

Section 4: Methods and Data Sources

With a few exceptions, the methods used to develop these estimates derived from the following sources:

- Intergovernmental Panel on Climate Change, *2006 Guidelines for National Greenhouse Gas Inventories* (2006);
- Environmental Protection Agency, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2006* (2008a);
- The Climate Registry, *General Reporting Protocol* (2008);
- US Environmental Protection Agency, *Climate Leaders Inventory Guidance* (2008b); and
- World Business Council for Sustainable Development/World Resources Institute, *GHG Protocol* (2004).

The MPCA also relied on an extensive collection of emission factors that have been under development for a number of years.

Methods and sources are most easily discussed if grouped in the following categories: energy use and finished fossil fuel production; agriculture; waste management; and industrial processes and other sources.

Energy Use and Finished Fossil Fuel Production

Emissions from energy use and finished fossil fuel production and transportation constitute the largest single subset of emissions in Minnesota. Of these, CO_2 emissions from fossil fuel combustion are the largest source, about four-fifths of all GHG emissions from Minnesota. In the MPCA GHG Emission Inventory, CO_2 emissions from fossil fuel combustion are calculated for all in-state combustion sources and the generation out-of-state of electricity imported into Minnesota to serve Minnesota consumers.

CO_2 emissions from fossil fuel combustion for any single fossil fuel are calculated using the following basic expression, where MMBtu (million Btu) is a standard unit of energy and 3.66428 converts emissions of carbon to emissions of CO_2:

Total CO_2 = physical quantity of fuel **x** MMBtu/unit of fuel **x** lb of carbon/MMBtu **x** 3.66428

Most fossil fuels are commercially produced to meet specific fuel standards. As a result, the heat or energy content of these fuels and their carbon content are well known and are standardized across the country.

Coal is an exception to this rule of standardization. The energy content and carbon content of coal varies by coal rank, as well as by producing state. Bituminous coal has a higher heating value (higher Btu/ton) than subbituminous coal; the combustion of a ton of subbituminous coal typically releases five percent more CO_2 to the atmosphere per unit of useful energy than does the combustion of bituminous coal. Bituminous coal produced in West Virginia has a higher heat content than does Illinois bituminous coal, and a lower rate of CO_2 emissions per unit of useful energy produced upon combustion.

To account for this variability, in the MPCA GHG Emission Inventory most coal receipts are traced back to the state of origin and to the producing mine. The federal data on coal shipments include specific information of the heat content of coal on a mine-by-mine basis. Using these estimates, total coal consumption and its energy content in any given year can be apportioned back to the state of coal origin by coal rank. The US Department of Energy has developed information on the carbon content of the coal mined in each state by coal rank. Combining this information, and summing across all coal shipments, we calculate a mean rate of CO_2 emission per MMBtu of coal consumed by coal rank for each inventory year, and use this to estimate CO_2 emissions in that inventory year.[11]

Natural gas is another exception. The heat content of natural gas varies from year to year. Over the period since 1970, it has been as low as 950 Btu per standard cubic foot of gas (Btu/scf) and as high as 1050 Btu/scf. More CO_2 is emitted per unit of energy realized upon combustion from high Btu natural gas than from lower Btu natural gas. The average energy content of the natural gas that is combusted in Minnesota is tracked on an annual basis in the MPCA GHG Emission Inventory. CO_2 emissions are calculated using these estimates and EPA estimates of the amount of CO_2 emitted at differing natural gas energy or heat contents.

With the exception of natural gas and coal, CO_2 emissions from the combustion of commercial fossil fuels are calculated using standardized measures of fuel energy or heat content and standardized emission rates or emissions factors per MMBtu of energy produced during combustion.[12] These measures are from the US Energy Information Administration, State Energy Data database and the EPA annual national GHG inventory report.

In the MPCA GHG Emission Inventory, commercial fossil fuels include distillate fuel oil, diesel fuel oil, motor gasoline, residual fuel oil, liquefied petroleum gas (LPG), propane gas, kerosene, kerosene-based jet fuel, naphtha-based jet fuel, aviation gasoline, special naphtha, other oils, petroleum coke, coal coke, bituminous coal, subbituminous coal, lignite, anthracite, coking coal, natural gas, still gas, lubricating oils, and industrial waxes. Heavy oil used in the electric power sector and at oil refineries is assumed to have the same fuel characteristics as residual fuel oil.

Besides commercial fuels, a number of noncommercial waste fuels that are also combusted in Minnesota release CO_2 to the atmosphere, including unprocessed mixed municipal solid waste (MMSW), refused-derived fuel (RDF), tire-derived fuel (TDF), waste oil, waste solvent, and various other organic chemicals. A part of the carbon in MMSW and RDF is fossil carbon in the form of plastics and related petrochemicals. The rest is nonfossil and takes the form of wood, paper and food wastes. CO_2 emissions are calculated separately for each part of the waste. As discussed in the prior section, CO_2 emissions associated with the petrochemical part of the waste are included in statewide totals. CO_2 emissions from the combustion of the biomass portion are tracked separately. Emissions are calculated per ton of waste combusted.

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[11] In the MPCA GHG Emission Inventory, this is done for all coal consumed in all inventory years for the electric power sector, which accounts for about 95 percent of all coal consumption. CO_2 emissions from coal combustion in the industrial, commercial and residential sectors are estimated using average US rates of emission per MMBtu of coal consumption irrespective of the state of coal origin.

[12] In the fuel data used by the MPCA, the heat or energy content does vary year to year for petroleum coke combusted in the electric power sector and LPG combusted in all sectors. CO_2 emissions per unit of energy, however, are calculated using a uniform emission rate across all years and fuel heat contents.

The composition of unprocessed solid waste is estimated from various state-level waste classification studies dating back to the 1990s. Using this as a basis, unprocessed MMSW is estimated to be about 12 percent fossil carbon by weight. The composition of RDF used to calculate fossil CO_2 from combustion is developed from published literature.

Regarding CO_2 emissions from liquid waste fuels, emissions from the combustion of waste oil, the most important, are calculated using emission factors or rates of emission per MMBtu of energy for virgin lubricating oil. CO_2 emissions from the combustion of TDF and waste solvent are calculated using emission factors developed by the World Business Council for Sustainable Development and US Energy Information Administration, *Renewable Energy Annual.* A small amount of organic chemicals are combusted in Minnesota each year to produce energy. Combustion amounts are reported in the Toxic Release Inventory (TRI). CO_2 emissions from this source are calculated using the method that EPA uses to calculate emissions from TRI sources.

To estimate CO_2 emissions, annual fuel combustion must be known. In the MPCA GHG Emission Inventory, a variety of fuel use data are used to estimate emissions, including reported bottom-up facility level fuel use data, top-down data developed from federal surveys directed at fuel producers and transporters, and top-down data from state-level tax receipts. The sources of these data are listed in Table 4 for the most important fuels for 1980, 1986, 1988, and 1990-2006. Facility-level information is available for these years through the MPCA Criteria Pollutant Emission Inventory database.

Table 4: Data Sources for Fuel Use: 1980, 1986, 1988, 1990-2006

Electric Power Generation:	
Coal, lignite, petroleum coke, natural gas, fuel oil, LPG, waste oil, waste solvent, solid waste, landfill gas	MPCA Criteria Pollutant Emission Inventory
All Other Sectors:	
Coal[†], lignite, coal coke, petroleum coke, residual fuel oil, heavy refinery oil[‡], refinery gas[‡], waste oil, waste solvent, industrial wood, other biomass, biogas	MPCA Criteria Pollutant Emission Inventory
Natural gas, propane-air mixture	EIA, *Natural Gas Annual*
Motor gasoline, ethanol	FHA, *Highway Statistics*
Distillate fuel oil, kerosene	EIA, *Fuel Oil and Kerosene Sales*
On-highway diesel fuel oil	Calculated from VMTs and vehicle fuel economies
LPG, special naphthas, industrial oils, industrial waxes, lubricants, naphtha-type jet fuel, commercial wood	EIA, *State Energy Data Report* and database
Kerosene-type jet fuel	Minn. Dept. of Revenue, *Minnesota Petroleum Taxes*
Black liquor	EIA, Forms 900, 906, 920, 923
Residential wood	Minn. Dept. of Natural Resources, wood use surveys
Organic chemicals	EPA *Toxic Release Inventory*

[†] A small amount of residential coal use is calculated from decennial US Census estimates of the number of total residences relying on coal to satisfy for principal space heating needs.

[‡] 1980, 1986, 1990-5; after 1995 fuel use data are available only from the Marathon-Ashland refinery. After 1995, total refinery heavy oil and refinery gas combustion are estimated on the basis of statewide refinery distillation capacity, capacity utilization in the Minnesota-Wisconsin-Dakota refining district, and fuel use inputs to refining set at constant 1995 levels.

Table 5 lists data sources for fuel use for all other years. With the exception of federal data on fuel uses at power generation plants, all of this is top-down nonfacility sectoral information. In general, we have less confidence in it than the facility-specific information.

Table 5: Data Sources for Fuel Use: 1970-1979, 1981-1985, 1987, and 1989

Electric Power Sector	
All fuels	EIA, *Electric Power Annual* and EIA Forms 757, 900, 906, 920, 923
All Other Sectors	
Coal, lignite, coal coke	EIA, *State Energy Data Report*
Natural gas, propane-air mixture	EIA, *Natural Gas Annual*
Motor gasoline, ethanol	FHA, *Highway Statistics*
Residual fuel oil, LPG, special naphthas, industrial oils, industrial waxes, lubricants, naphtha-type jet fuel, commercial wood, industrial wood	EIA, *State Energy Data Report*
Distillate fuel oil, kerosene	EIA, *Fuel Oil and Kerosene Sales 1985, 1987, 1989,* EIA, *State Energy Data Report* 1970-79, 1981-84
On highway diesel fuel oil	Calculated from VMTs and vehicle fuel economies
Kerosene-type jet fuel	Minn. Dept. of Revenue, *Minnesota Petroleum Taxes 1974-79, 1981-5, 1987, 1989,* EIA, *State Energy Data Report*, 1970-73
Residential wood	Minn. Dept. of Natural Resources, wood use surveys
Refinery fuels	Calculated[†]

[†] Total refinery heavy oil and refinery gas combustion is estimated on the basis of statewide refinery distillation capacity, capacity utilization in the Minnesota-Wisconsin-North Dakota refining district, and fuel use inputs to refining calculated backward from 1995 using the national rate of improvement in energy inputs per barrel of refined petroleum productions at US refineries given in Office of Technology Assessment (1990).

Special note should be taken of our treatment of refinery fuels. Through 1995, fuel throughput data for Minnesota refineries was available through the MPCA Criteria Pollutant Emission Inventory database. Beginning in 1996, with Koch/Flint Hills Refinery's CAP permit, the receipt of this fuel use data was partially discontinued. While it continues to be received from the Marathon refinery, fuel use data is no longer received from the Flint Hills Refinery. To complete the record of fuel use after 1995, total refinery energy inputs are estimated annually based on refinery distillation capacity, reported refinery utilization rates in the Minnesota-Wisconsin-Dakota refining district, and nonelectric energy inputs per barrel of crude oil input held constant at 1995 levels. CO_2 emissions are calculated on the assumption that the distribution of refinery fuel uses on an MMBtu basis between refinery gas, natural gas, heavy refinery oil and distillate fuel oil also remained constant at 1995 levels.

This is an unsatisfactory situation that we hope to rectify over the next few years through new refinery fuel use reporting requirements. It is not known how the absence of direct facility reporting of fuel use might influence the emissions estimates reported in this document.

Transportation Energy Use

Emissions for on-highway fuel uses do not necessarily respect state borders. Fuel purchased in one state can be combusted in another. This is particularly a problem with respect to large commercial trucks with long multi-state hauls and large fuel tanks. As noted in Tables 4 and 5, the fuel use totals utilized to calculate CO_2 emissions from the combustion of on-highway diesel fuel are calculated totals, not reported fuel use totals.

Diesel fuel use in large commercial trucks is calculated in the MPCA GHG Emission Inventory on the basis of reported vehicle miles traveled (VMT) on Minnesota highways by heavy-duty commercial trucks and their reported average fuel economy. Annual data from the Minnesota Department of Transportation for heavy-duty commercial trucks (five-axles or more) is used, supplemented by periodic survey data from the Census Bureau *Vehicle Inventory and Use Survey* (VIUS) and *Truck Inventory and Use Survey* (TIUS) for diesel-driven trucks of fewer than five axles. Using the periodic VIUS/TIUS data, total VMTs on Minnesota highways for large commercial trucks (five axles and more) are split between Minnesota-based trucks and trucks based in other states.

Average fuel economy for all Minnesota-based commercial diesel-driven heavy-duty trucks (less than five axles and five axles and more) is from TIUS/VIUS Census reports for Minnesota and accompanying microdata. Average fuel economy for US-based heavy-duty combination trucks is from TIUS/VIUS reports for the US. Total fuel use is calculated by dividing total VMTs for each category by their respective fuel economies and summing across categories.

Diesel fuel is also combusted in light-duty trucks, diesel-driven passenger cars, recreational vehicles, transit buses and school buses. Since diesel fuel use is not broken down in the federal state-level fuel use survey data, fuel use data are not available for any of these categories by vehicle type. Fuel use in each of these classes of vehicle must be calculated.

Fuel consumption in transit buses and school buses is calculated in the MPCA GHG Emission Inventory from reported VMTs for each mode and estimated vehicle fuel economy. Fuel economy of school buses is assumed to be the same as school bus fuel economy nationally. The Minnesota Department of Education reports school bus miles annually. The average fuel economy of transit buses in Minnesota is estimated annually based on the mix of buses and bus VMTs reported in Minnesota Department of Transportation, *Annual Transit Report*. Five miles per gallon is a typical value for transit buses in Minnesota.

Diesel fuel use in light-duty trucks is calculated from the number of vehicles registered in the state, their age distribution, annual VMT accumulation each year by model year, and on-road fuel economy. Working backward, fuel economy is calculated from a schedule of fuel economy in any given inventory year by vehicle model year for gasoline-powered light-duty trucks. Diesel-powered light-duty trucks are roughly 15 percent more efficient per gallon than are gasoline-powered light trucks. Diesel fuel economy in light trucks is estimated by inflating the estimated fuel economy of gasoline-powered light trucks for any given inventory and model year by 15 percent. On-road fuel economy of gasoline-powered light trucks is calculated from new light truck fuel economy ratings, adjusted to account for the effects of vehicle age, annual average temperature (departure from optimal temperature conditions), and average highway speed. A generic 12.5 percent adjustment factor is first applied to the EPA-estimated fuel economies of new light trucks to account for the reported difference between EPA-rated new vehicle performance and actual on-road performance.

The rate of annual VMT accumulation per vehicle by age of vehicle for all light trucks registered in Minnesota is reported in the US Census Bureau TIUS/VIUS surveys. Following the procedure given in EPA (2008a), the average annual rate of VMT accumulation for diesel-powered light trucks is assumed to be the same as that for gasoline-powered light trucks. The rate of VMT accumulation rates for years between periodic TIUS/VIUS surveys is interpolated.

These same surveys also provide information on the age distribution of the light truck fleet in Minnesota on a periodic basis. Again data for years between surveys is interpolated. The total number of light-duty trucks registered in Minnesota is the difference between total trucks from Minnesota given in *Highway Statistics* and total heavy-duty trucks registered in Minnesota given in Minnesota Department of Public Safety, *Crash Facts*. It is assumed that, for any given new truck year, the penetration of diesel-powered light trucks in Minnesota fleet is the same as the penetration of diesels into the US light truck fleet.

For any inventory and model year, light truck VMTs are calculated by multiplying the number of vehicles registered in Minnesota by the average annual rate of VMT accumulation for these vehicles. Total statewide light truck VMTs in any year are calculated by summing across the calculated VMTs for vehicles of all model years in that year. Light-duty truck fuel use is calculated by dividing total state VMTs by average light truck fuel economy.

The procedure for calculating diesel fuel use in passenger cars is identical to that for light trucks. However, since state-level rates of VMT accumulation are not available, periodically available data on rates of VMT accumulation at a national level are used. These are from the US Department of Transportation, *National Personal Transportation Survey,* US Department of Transportation, *National Household Travel Survey,* and US Energy Information Administration, *Residential Transportation Energy Consumption Survey*. The age distribution of passenger cars is from R.L. Polk (1970-1994), Motor Vehicle Manufacturers Association (1996-2000), and EPA (2008a). The R.L. Polk data are Minnesota-specific estimates; the MVMA and EPA estimates are US-level estimates. The total number of passenger cars registered in Minnesota is from *Highway Statistics* and adjusted to account for definitional changes.

Data on the national rate of diesel penetration into the fleet is from Oak Ridge National Laboratory (1988-2008).

Sources of the fuel use totals used for the calculation of highway CO_2 emissions are shown in Table 6 for vehicle types and highway transportation fuels. In addition to diesel fuel oil and motor gasoline, small amounts of compressed natural gas (CNG) and liquefied petroleum gas (LPG) are combusted in heavy-duty trucks. In the case of LPG, this is estimated using the same methods described for heavy-duty diesel trucks. CNG used in heavy-duty trucks is from EIA, *Natural Gas Annual*.

Table 6: Data Sources for Vehicle Types and Transportation Fuels

Vehicle Type	Fuel	Source for Fuel Use Totals
Passenger cars, light-duty trucks, heavy-duty trucks, motorcycles, recreational vehicles, school buses, off- road vehicles	Motor gasoline	Federal Highway Admin., *Highway Statistics*
Passenger cars, light-duty trucks, recreational vehicles	Diesel	vehicle numbers, annual VMT/vehicle, and vehicle fuel economy
Heavy-duty trucks	CNG	EIA, *Natural Gas Annual*
Heavy-duty trucks	LPG, diesel	reported VMTs and vehicle fuel economy
Transit buses	Diesel	reported VMTs and est. fuel econ. from bus size
School buses	Diesel	reported VMTs and national est. of fuel economy

CO_2 emissions from light-duty vehicles, motorcycles, and heavy-duty gasoline trucks are estimated on the basis of reported state-level fuel use data. Based on the TIUS/VIUS Census data, most VMTs driven by Minnesota-based heavy-duty gasoline-powered trucks occur on Minnesota highways. It is also likely that most VMTs by light-duty vehicles are recorded on Minnesota highways. Because 10 percent of all motor gasoline blends must be fuel ethanol, before estimating fossil CO_2 emissions from highway vehicles using E10 blends of motor gasoline and ethanol, these biofuel fuel components are removed, and CO_2 emissions are calculated separately.

An effort is made to apportion VMT, fuel use and CO_2 emissions to specific vehicle types. Decision-makers require this type of information to make effective policy. In addition, emissions of N_2O and CH_4 from highway vehicles are calculated on the basis of the number of miles driven by each type of vehicle by vehicle age. Using the basic approach outlined above, VMT and fuel are both apportioned to specific vehicle types and fuels.

Figure 4 shows the result of this modeling effort with respect to statewide vehicle miles traveled on Minnesota highways. Passenger cars and light trucks account for roughly 90 percent of all VMTs statewide. Total modeled VMTs in the state largely agree with observed totals.

Figure 5 shows the modeled distribution of motor gasoline use between different vehicle types. Also shown is the observed trend in statewide motor gasoline use from tax receipts. In Minnesota, 97 to 98 percent of motor gasoline is consumed in passenger cars and light trucks. In its basic shape, the modeled trend generally replicates the trend in the observed data.

Figure 4: Vehicles Miles Traveled on Minnesota Roadways Pre-True-up

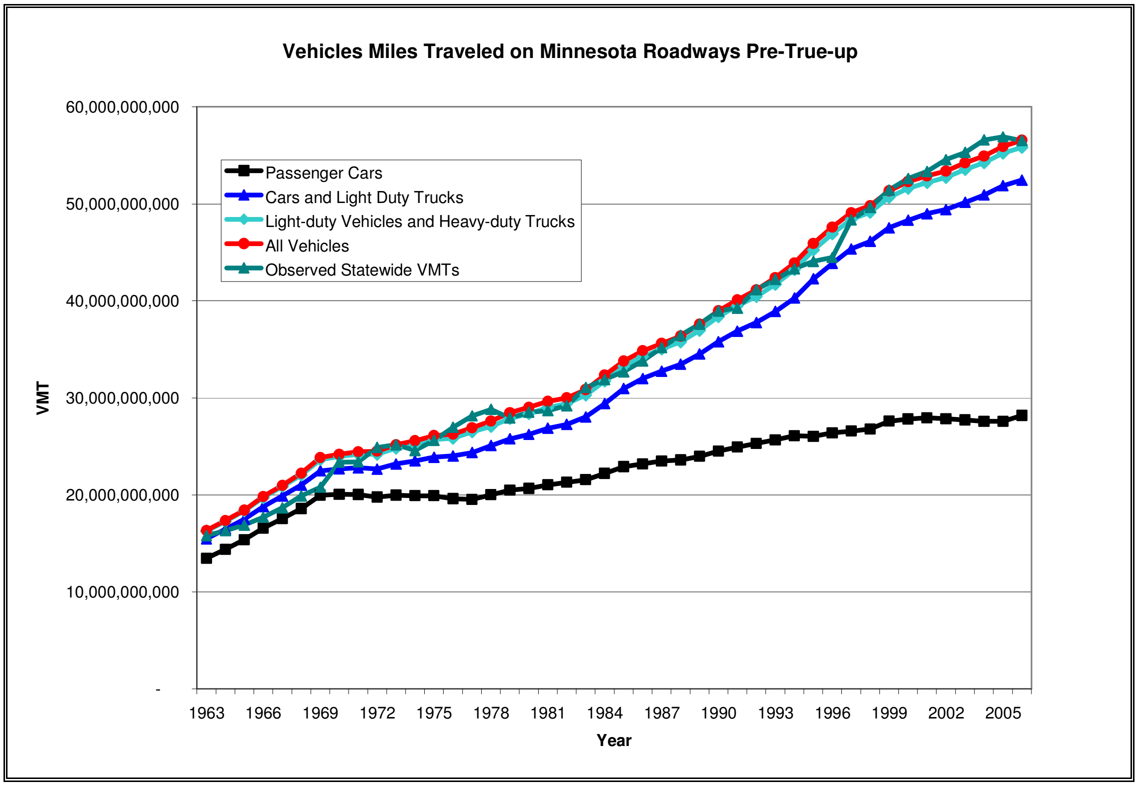
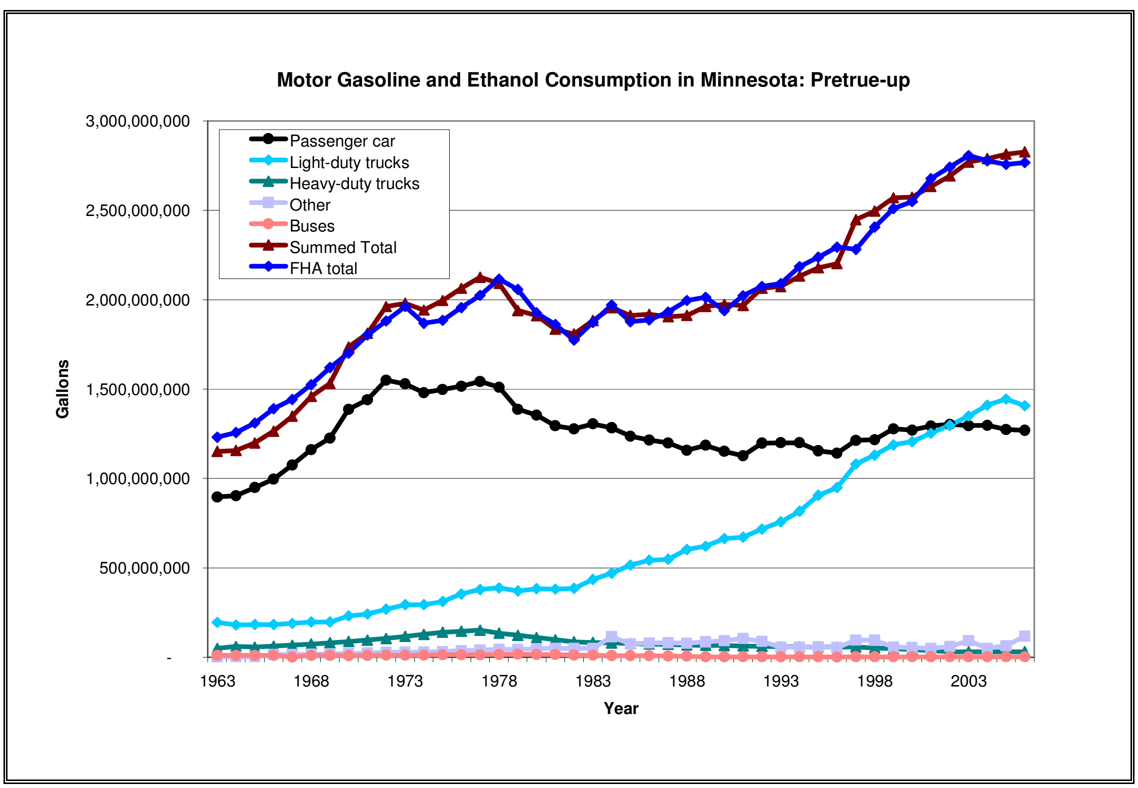


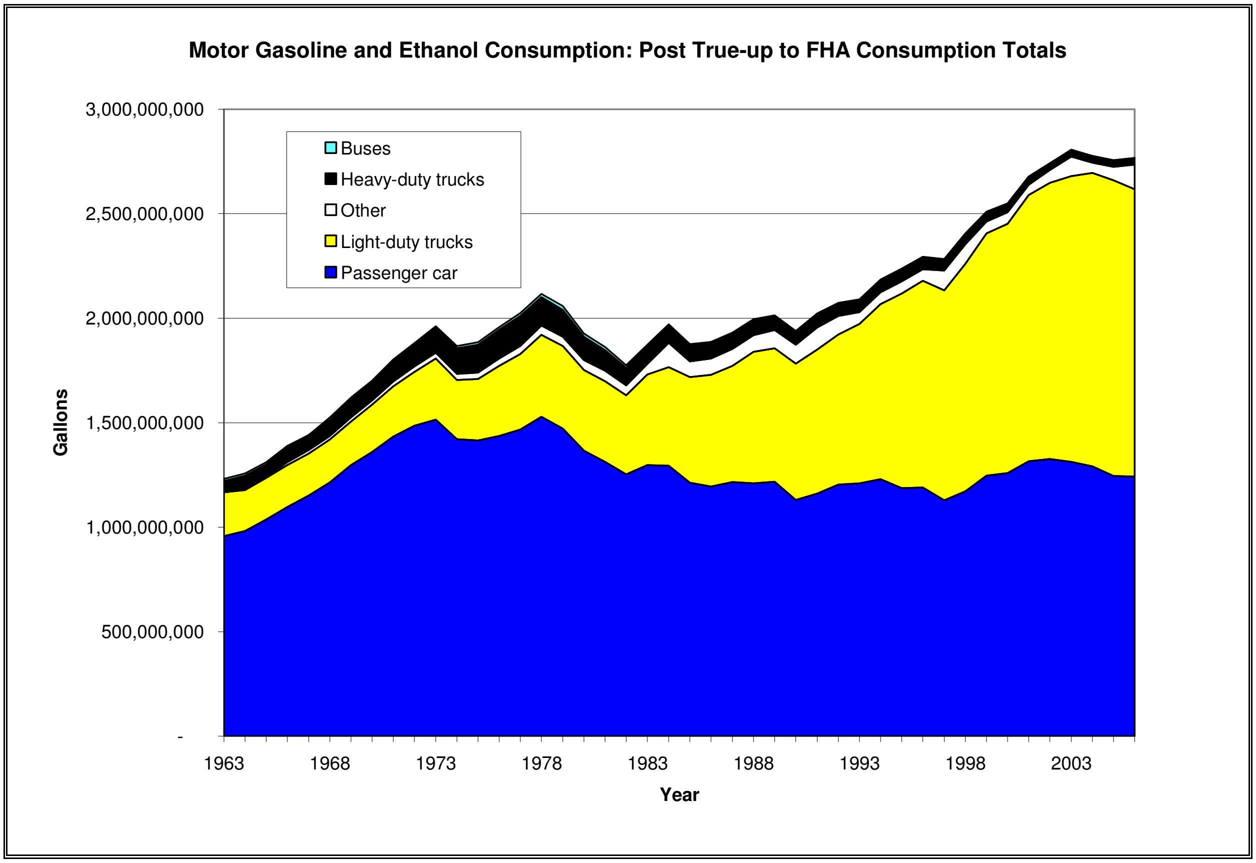
Figure 5: Motor Gasoline and Ethanol Consumption in Minnesota



In reporting CO_2 emissions from motor gasoline consumption, total CO_2 emissions are estimated for all highway combustion sources. Emissions are also reported by vehicle type. By applying the modeled percentage distribution of motor gasoline fuel use shown in Figure 5 to the fuel use total developed from tax receipts, 'trued-up' totals for vehicle fuel use for each vehicle type are developed. Total fuel use 'trued-up' to reported fuel use from tax receipts is shown in Figure 6.

Almost 95 percent of CO_2 emissions from Minnesota highway sources derive from the combustion of diesel fuel in heavy-duty commercial trucks and the combustion of motor gasoline in vehicles of all types. Most of the rest results from the combustion of diesel fuel in school buses and transit buses.[13] These are estimates that are closely tied to observed quantities like VMTs from traffic counts or fuel tax receipts. Only a relatively small percentage of emissions are modeled with no anchor in either observed VMTs on Minnesota highways or fuel sales.

Figure 6: Motor Gasoline and Ethanol Consumption: Post True-up to FHA Consumption Totals



[13] About one percent of highway emissions results from the combustion of diesel fuel in passenger cars, light-duty trucks and recreational vehicles and another 0.5 percent results from the combustion of LPG and compressed natural gas (CNG) in heavy-duty trucks.

Electricity Imports

A good deal of discussion has been devoted to the problem of out-of-state emissions. In the *Next Generation Energy Act*, the Legislature directed the MPCA to include in its estimation of state-wide emissions all GHG emissions associated with the import of electricity needed to service in-state electrical demand. This is done in this report using a nine-state/province[14] exporting region average for the amount of CO_2 emitted for each megawatt-hour (MWh) generated. Total needed net generation for any given year is calculated as the sum of total consumption in Minnesota plus transmission line losses. Line losses are estimated for Minnesota and the exporting region using data in EIA Form 860, which tracks line loss at a state level.

Needed net electricity imports are calculated as the difference between total needed generation and net generation in-state at Minnesota power plants. CO_2 emissions from imported power are calculated by multiplying the number of megawatt-hours of imported power by the calculated rate of emission per MWh for the exporting region.

In calculating the nine-state/province average emission rate for CO_2 per MWh-generated for 1990-2006, the Electric Power Annual database is used for CO_2 and net electric generation for the US states, and the data for Manitoba is from the Environment Canada, *National Inventory Report* and Canadian Energy Board. For years before 1990, CO_2 emissions are calculated on a state-by-state basis using the reported fuel use in electric power generation in EIA, *State Energy Data Report*. State-level electricity generation is from the EIA Form 757, and subsequent forms.

Biomass Combustion and Nonfuel Uses

Emissions of CO_2 from biomass combustion are calculated using the same methods described for CO_2 emissions from the combustion of fossil fuels. Biomass fuels include: wood, sawdust, bark, black liquor, dried sludge, grease, dried distillers grains with solubles, ethanol, biodiesel, landfill gas, digester gas, and other biogas. The biogenic part of MMSW and RDF is also biomass. Most of the biomass emission factors are from EPA (2003), EPA (1992), and EIA, *Electric Power Annual*. Fuel heat content is estimated using a variety of sources, especially EIA, *Renewable Energy Annual*, EIA, *Electric Power Annual*, EIA, *State Energy Data Report*, and ORNL, *Transportation Energy Databook*.

It is common practice in the development of GHG emission inventories to evaluate nonfuel uses of fossil fuel as sources of CO_2 emission. In the MPCA GHG Emission Inventory, emissions from nonfuel uses are estimated solely for lubricating oils, assuming that upon use or disposal, 91 percent of the carbon in these oils is oxidized. The data are based on state-levels sales and are from EIA, *State Energy Data System*.

A small amount of CO_2 is emitted to the atmosphere through the use of flue gas desulfurization equipment at power plants. These emissions are estimated using IPCC *2006 Guidance* methods. Limestone use data for these facilities is from the MPCA Criteria Pollutant Emission Inventory.

[14] Wisconsin, Iowa, South Dakota, North Dakota, Nebraska, Kansas, Missouri, Wyoming and Manitoba.

Nitrous Oxide and Methane from Energy Use

It is customary to calculate stationary sources of N_2O and CH_4 combustion emissions using published emission factors. Calculation typically takes the form of:

Total N_2O = physical quantity of fuel **x** MMBtu/unit of fuel **x** lb of N_2O/MMBtu

Total CH_4 = physical quantity of fuel **x** MMBtu/unit of fuel **x** lb of CH_4/MMBtu

Emissions from stationary combustion in the electric power sector and waste sector are calculated at a unit level, matching specific combustion technologies (e.g., specific boiler or engine types) to emission factors tailored to each combustion technology and fuel. While not well developed compared to other sectors, the literature is sufficiently well developed with regard to stationary combustion in electric generation and waste disposal to support the evaluation of emissions at a facility and a unit level. Emission factors for N_2O and CH_4 in electric generation and waste incineration are principally from Climate Registry (2008), EEA (2007), IPCC (2006), EPA (1995), and EPA (1992).

By contrast, N_2O and CH_4 emissions from stationary combustion in the residential, commercial and industrial sectors are calculated using fuel-based emissions factors developed by the IPCC at the sector level. In either instance, combustion activities leading to emissions of CH_4 and N_2O involve fossil fuels, biomass, bioliquids and biogas. The data sources that are used are discussed in relation to the estimation of CO_2 emissions from combustion and are listed in Tables 4 and 5.

CH_4 and N_2O emissions from off-road mobile combustion sources are calculated in a similar fashion to stationary source emissions. Nonroad combustion sources include: railroads, marine vessels, construction and mining equipment, farm equipment, off-road recreational vehicles, and aircraft. Emissions are calculated using emission factors given in EPA, *Climate Leaders Inventory Guidance* (2008b) and EPA (2004). Fuel use for each of these categories of nonroad combustion is given in FHA, *Highway Statistics* and EIA, *Fuel Oil and Kerosene Sales.*

Emissions of CH_4 and N_2O from highway vehicles are calculated based on the number of miles traveled by each vehicle type. This follows the approach of EPA (2008a), which for seven different classes of vehicles – gasoline-powered passenger cars, gasoline-powered light-duty trucks, motorcycles, heavy-duty gasoline powered trucks, diesel-powered passenger cars, diesel-powered light-duty trucks, and diesel-powered heavy-duty trucks—specifies average rates of emission of N_2O and CH_4 per mile driven for different groupings of model years for each vehicle type. To calculate on-road N_2O and CH_4 emission, we use these emission factors, as well as per mile driven estimates for different alternative fuel vehicles. VMTs for each vehicle type for each year by model year come from the model of highway vehicles, highway vehicle travel and fuel use described above.

CH_4 leakage from natural gas pipelines, services and compressor stations is evaluated using the methods described in Radian Corporation (1996). Although a decade old, this remains the authoritative source on emissions from natural gas transmission and distribution. Required data inputs include: numbers of compressor stations and operating compressors by type; compressor fuel use; amount of gas withdrawn annually into underground storage; numbers of pipeline interconnects, farm taps, industrial direct connections, and regulating and metering stations (city gates); number of miles of transmission and distribution pipelines by material type; miles of services by material type; and numbers of customer meters.

Data on these inputs are from: MPCA Criteria Pollutant Emission Inventory database; EPA Region 5 Criteria Pollutant Emission Inventory database; Federal Energy Regulatory Commission Form 2 database; US Pipeline and Hazardous Material Safety Administration pipeline database; American Gas Association, *Gas Facts*; and EIA, *Natural Gas Annual*. Information was also developed through personal communication with representatives of the major pipeline companies operating in Minnesota and from system information posted on company web sites.

CH_4 emissions during oil refining are estimated using the methods given in EPA (2008a). Data to support these calculations are from US EIA, *Petroleum Supply Annual*.

Estimates of CH_4 emissions from coal piles in Minnesota are developed using the emission factors given in EPA (2008a) for post-mining emissions during transportation and storage. The coal receipts data described above with reference to CO_2 emissions were used to calculate CH_4 losses.

A small amount of CH_4 is emitted from hydroelectric reservoirs located in Minnesota. In these reservoirs, organic matter decays anaerobically to form CH_4. Emissions are estimated using the estimates of emitted CH_4 per acre of surface water from northern Wisconsin reservoirs given in St. Louis, *et al*. (2000).

Sulfur Hexafluoride, HFCs and PFCs

SF_6 emissions from the switch gear and circuit breakers used in electricity transmission and distribution are estimated using the general approach taken in EPA (2003), which uses national emissions totals to calculate a rate of emission per MWh of electricity consumed in the US. They apply this rate at the state level to estimate emissions. We modify this approach by calculating an emission rate per mile of transmission line from the US data, and applying it to the Minnesota grid. US emissions are from EPA (2008). The total number of miles of transmission in the US and in Minnesota are from Edison Electric Institute, *Statistical Handbook* (1971-2008).

The number of miles of transmission line in Minnesota in 2000-2006 is from Edison Electric Institute, *Statistical Handbook* and covers investor owned utilities, cooperatives and power authorities. Prior to 2000, data were available only for that part of the transmission system owned by investor owned utilities. To estimate emissions before 2000, the ratio of total transmission miles in-state to total transmission miles owned by investor owned utilities was assumed to remain fixed at 2000 levels.

The MPCA recently instituted a mandatory reporting program for emissions of SF_6 from switch gear and circuit breakers used in electricity transmission and distribution, as well as other sources. Use will be made of that data as it becomes available.

We treat HFC-134a used as a working fluid in space cooling and refrigeration equipment as a part of the energy system. Only two sources of HFC-134a emissions during refrigerant use are treated in this report: emissions from mobile air conditioning and emissions from residential refrigeration. At the national level, emissions from mobile air conditioning are the single largest emission source of HFCs, in 2006 comprising almost two-thirds of all US HFC emissions.

In the MPCA GHG Emission Inventory, mobile air conditioning emissions are estimated using the methods and rates of emissions specified in EPA, *Regulatory Impact Analysis* (1988). Emissions are estimated during normal operations, at servicing and at retirement. The stock model of light-duty vehicles and heavy-duty trucks described above is used to track the total number of vehicles in each vehicle class by age, along with vehicle retirements. The average size of the refrigerant charge is specified for each model year based on values given in the published literature. The penetration of mobile air conditioning in new vehicles is from Motor Vehicle Manufacturers Association; since 2001, the penetration rate in Minnesota is assumed to be 100 percent.

The total quantity of refrigerant available for emission in any year is equal to the total number vehicles in the state multiplied by the average refrigerant charge per vehicle. HFC-134a use in new vehicles was assumed to have begun in 1994. It was assumed that in 1995 15% of existing vehicles were retrofit to use HFC-134a, increasing to 90% by 2001.

In 2006 the typical vehicle contained a charge of about 1.5 lb of refrigerant. An estimated 4.4 million light-duty vehicles traveled Minnesota's highways in 2006. Using the EPA method, nine percent of the vehicle charge is assumed to escape during normal operations. One percent is assumed to escape during servicing, while ten percent is assumed to remain in the vehicle at retirement, and is vented to the atmosphere.

A small amount of HFC-134a is vented to the atmosphere from refrigerators in the residential sector. This is estimated using the midpoint of the IPCC (2006) recommended range of annual emissions. The typical residential refrigerator contains about 0.3 lb of HFC-134a. It is assumed that HFC-134a use in residential refrigerators began in 1994. The stock of refrigerators purchased since 1994 is based on the total number of occupied housing units in Minnesota and the age distribution of refrigerators and freezers in the North Central region in 1993, 1997, 2001, and 2005 given in EIA, *Residential Energy Consumption Survey*.

Agriculture

The methodologies given in IPCC (2006) are used to calculate the CH_4 emissions from manure management. Potential methane emissions from manure are first calculated, assuming that conditions are in place for maximum potential emissions from stored manure. These are then adjusted to account for specific manure storage practices in use.

Maximum potential CH_4 emissions are estimated using the IPCC-recommended rates of gas production per unit of excreted livestock manure volatile solids (VS). Total livestock volatile solids production is calculated using total animal liveweight by animal type and production of volatile solids per lb of animal liveweight, again by animal type. Total livestock liveweight is evaluated from animal numbers on Minnesota farms and feedlots[15] and the average weight of each livestock type in the inventory.

Manure stored in a liquid form in outdoor lagoons for nine months or more has the highest rate of conversion of potential emissions to actual emissions, about 70 percent. Emissions from manure stored as a solid are about one to two percent of maximum potential emissions. Based on the IPCC methodology, methane emissions from manure stored in a liquid or slurry form below barn, in basins, or outdoor tanks are about 25 percent of maximum potential emissions.

The process for estimating CH_4 emissions from manure management can be expressed as:

> **Maximum potential. emissions** = number of livestock **x** average liveweight per head **x** lb VS/lb liveweight **x** cubic feet CH_4/lb VS **x** 0.04117 lb CH_4/cubic foot of CH_4
>
> **Actual emissions** = maximum potential emissions **x** % of maximum potential emissions actually realized for each storage type

The data used to calculate CH_4 emissions from stored and spread manure are listed in Table 7. The percentage distribution of manure management types by manure weight for the Minnesota livestock industry is developed for 1998, 2002 and 2006 from the MPCA Feedlot Inventory. Estimates for 1999-2001 and 2003-2005 are interpolated. Estimates for earlier years are developed based on information in the published literature.

Following the IPCC 2006 methodology, N_2O emissions from feedlot manure storage are calculated on the basis of excreted nitrogen and the percent of available nitrogen that, in each type of manure storage, is emitted to the atmosphere as N_2O. Little or no N_2O is produced in manure stored in a liquid or slurry form; most manure N_2O is emitted from manure that is stored in a solid form. The percentage of manure that, for each type of storage, is assumed to be emitted to the atmosphere in the form of N_2O is from the IPCC (2006). The distribution of manure storage by animal liveweight for 1998-present is from the MPCA Feedlot Inventory database; earlier values were developed from the published literature. Total manure nitrogen is calculated on a lb of nitrogen per lb liveweight basis. Total livestock liveweight is calculated using average liveweight per head of livestock for each livestock type and on-farm livestock populations.

CH_4 emissions from livestock flatulence are calculated per head of livestock on Minnesota farms and feedlots, using the methodology given in EPA (2003). Total emissions are estimated by summing across emissions from all animals in each livestock category and across livestock categories. Most flatulence emissions derive from cattle. Since cattle liveweights have persistently increased over the inventory period (e.g., 1970-2006), the rate of CH_4 production per head of cattle going backward in time has been calculated downward to reflect the generally smaller stature and lower energy requirements of cattle of earlier decades.

[15] In the case of most livestock populations, January 1 estimates for on-farm populations are used to estimate total average annual livestock liveweight on Minnesota farms and feedlots. Where quarterly and monthly data are available, they are used. Monthly data are available for milk cows and milk heifers that have calved. Quarterly estimates are available for swine.

Table 7: Principal Data Sources for Calculating GHG Emissions from Livestock Sources

Manure CH_4	
Head of livestock on MN farms and feedlots	USDA, *MN Agricultural Statistics*, USDA, *Census of Agriculture*
Liveweight per head	USDA, *Livestock Slaughter*, USDA, *Poultry Slaughter*, USDA *MN Agricultural Statistics*, EPA, *Inventory of US GHG Emissions and Sinks*
lb VS/lb liveweight	EPA, *Inventory of US GHG Emissions and Sinks, 2008 and 2003,* EPA, *State Workbook*, NRCS, *Agricultural Waste Management Field Handbook*
scf CH_4/lb VS	IPCC, *2006 Guidelines*
Actual emissions as % of max. potential emissions	IPCC, *2006 Guidelines*
% manure managed in each storage type in Minnesota	MPCA Feedlot Inventory database, other published sources
Manure N_2O	
Livestock numbers, Liveweight per head	See above
lb nitrogen per lb of liveweight	IPCC, *2006 Guidelines*, EPA, *Inventory of US GHG Emissions and Sinks*
lb N_2O-N per lb nitrogen excreted by storage type	IPCC, *2006 Guidelines*
% manure managed in each storage type in Minnesota	See above
Flatulence CH_4	
Head of livestock on MN farms and feedlots	See above
lb CH_4/head of livestock by animal type	IPCC, *2006 Guidelines*, EPA, *Inventory of US GHG Emissions and Sinks, 2003*

It should be noted that in calculating flatulence emissions we are using an older method. Under the current EPA method, emissions are estimated on the basis of the total digestible energy needed to grow beef cows, milk cows, and bulls to maturity or, in the case of steers and heifers for slaughter, to final target weights, and to sustain productivity during mature years. A stock model to support this calculation is under development at the MPCA, but is not yet available. Flatulence emissions from cattle will be calculated in future progress reports using this stock model approach.

N_2O emissions resulting nutrient management are calculated using the approach specified in IPCC (2006). Emissions are calculated on the basis of total available nitrogen for nitrification and denitrification by bacteria in soils and lake, river and wetland sediments. For soils, total nitrogen available in any year for nitrification and denitrification includes nitrogen in synthetic fertilizers, crop residues, land-applied manure, and other organic soil amendments. It also includes nitrogen that is atmospherically deposited in the form of particulate ammonium and oxides of nitrogen. In developing this total, 10 percent of all nitrogen in synthetic fertilizers is assumed to be lost to the atmosphere through volatilization and 20 percent of all manure nitrogen is assumed to be volatilized. An additional 30 percent of the nitrogen content of synthetic fertilizers and land applied manure is assumed to run-off or be leached to surface waters, where it available for denitrification to N_2O.

While in the past it has been conventional to include N_2O emissions from nitrogen biologically fixed by legumes (e.g. soybeans and alfalfa), the most recent IPCC guidance does not include biologically fixed nitrogen as a source of N_2O.

Emissions of N_2O from nutrient management are estimated by:

N_2O emissions from soils = total nitrogen (after losses) **x** 0.01 **x** 1.5711

N_2O emissions from surface water = total nitrogen **x** 0.0075 **x** 1.5711

where 0.01 and 0.0075 are the emissions rates of nitrogen in the form of N_2O from soil and surface water, respectively, and 1.5711 converts nitrogen to N_2O. Annual fertilizer usage estimates are from Minnesota Department of Agriculture (1970-2006), and annual atmospheric deposition estimates are from NAPAP (1977-2006). The amount of total nitrogen in annual crop residues is calculated on the basis of annual crop production and the equations that relate grain yield to total above and below ground biomass that are provided in EPA (2008).

Land applied manure nitrogen is the nitrogen remaining in manure storage after volatilization and run-off losses from the barn, the feedlot floor, and storage. Losses are estimated using the methodology given in EPA (2008a). Under this methodology, depending on the manner of management and the how long manure is stored, between 10 and 50 percent of all manure nitrogen is assumed to be lost through run-off and volatilization before the manure is land applied.

Other sources of GHG emissions from soil nutrient management include CO_2 from urea-type fertilizer application and agricultural liming. Emissions from these sources are estimated using the methods given in EPA (2008a). Minnesota Department of Agriculture (1970-2006) provides data on total urea-type fertilizer use. Agricultural limestone uses are estimated using the data provided in USGS, *Minerals Yearbook* (1970-2006).

Data do not exist to support an interannual estimate of CO_2 emissions from the cultivation of organic or peatlands soils or their use as pasture. To estimate emissions on an annual basis, we would need to know both the number of peatland acres pastured and cultivated annually, and the residual effect on emissions of prior agriculture-related peatland disturbances.

In 2001, the USDA estimated that, in 1997, the cultivation of peatlands and their use as pastures resulted in an emission of 5.2 million tons of CO_2 to the atmosphere, using data from the Natural Resources Inventory. In 2008, the EPA developed a 2006 estimate for Minnesota peatlands of 7.2 million tons. In lieu of a means of estimating emissions on an interannual basis, in this report we conservatively apply the lower USDA estimate to all inventory years.

Backing out an estimate of the number of peatland acres that are tilled or pastured from the USDA estimate, we calculate that 0.8 million acres of peatland in Minnesota are in agricultural use. Farnham (1978) estimates that about three-quarters of this is pasture and one-quarter is field crops, including sod, carrots, clover seed, and wild rice. N_2O emissions from these are calculated assuming that 0.6 million acres are in pasture and 0.2 million acres of peatland are in cultivation. To calculate emissions, we use the IPCC (2006) recommended emission rate per acre of pastured and cultivated histosols or peatland.

Minor sources of GHG emissions include wild rice cultivation, wildfire and wind-blown soils. Emissions from the cultivation of wild rice in constructed paddies are calculated on a per acre-day basis, using Minnesota-specific emission factors and a 125-day growing season. Annual data on total acres in cultivation are from USDA, *Minn. Agricultural Statistics* (1970-2006).

The inventory includes a nominal placeholder for CO_2 emissions from wind-eroded soils. The amount of wind-blown soil that annually is removed from Minnesota agricultural lands is from periodic Natural Resources Inventory reports. Wind-blown soils are assumed to be two percent organic carbon by weight; a nominal one percent of the carbon content of these soils is assumed to be oxidized.

Finally, wildfire emissions of CH_4 and N_2O are calculated using the approach given in EPA (2008a). A carbon density of 16 tons of carbon per acre of burnt forestland is assumed. The historical record of wildfire is from Lewis (2002), Minnesota DNR, *Acres Burned,* and the National Interagency Fire Center

Waste

The methods used to estimate GHG emissions from waste disposal and processing derive from four principal sources:

- California Air Resources Board, *et al*., *LGO Protocol* (2008);
- EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* (2008);
- IPCC, *2006 IPCC Guidelines* (2006); and
- EPA, *AP-42* (with supplements (1995).

Methane emissions from landfills receiving mixed municipal solid waste are calculated using one of two methods, depending on whether or not landfill gas is actively captured and flared or used for energy production.

It is common practice at open and closed landfills to install piping throughout the landfill, to capture landfill gas by creating negative pressure in the landfill by pumping, to collect it, and to combust it in a flare, an engine or a turbine. For landfills at which landfill gas is actively captured, CH_4 emissions are estimated based on amount of gas that is collected. Starting from the twin assumptions that 75 percent of all gas that is generated in the landfill is captured and that, of the rest, 10 percent is oxidized in aerobic landfill cover soils, CH_4 emissions are calculated by:

Emissions (in scf) = volume of gas collected/0.75 **x** 0.25 **x** 0.9

For landfills containing MMSW that do not actively capture landfill gas, emissions are estimated using LandGEM (3.0), a first-order kinetic model of gas production. Upon placement in a land-fill, MMSW generates CH_4 at an exponentially decreasing rate with time. Given a schedule of waste placements, LandGEM simulates CH_4 generation in the landfill, all of which, less the 10 percent that is oxidized in the surface soils of the landfill, is assumed to be emitted to the atmos-phere. LandGEM can simulate emissions from both traditional 'dry tomb' nonrecirculating land-fills and landfills that practice leachate recirculation. The model includes default settings for a wide variety of landfill conditions. For purposes of estimating emissions from Minnesota landfills, model settings are selected that, for landfills that now actively capture landfill gas, yield LFG capture rates of 65 to 80 percent.

As of 2006, twenty-six landfills, which account for about half of gas generation at Minnesota landfills, were actively capturing landfill gas. Of these, six were active landfills still receiving waste; the rest were closed landfills owned and operated by the State. Ninety-seven landfills in Minnesota with MMSW did not actively capture landfill gas.

The data sources for MMSW include, for 1991-present, MPCA SCORE data and, for 1970-1990, the MPCA *Annual Solid Waste Report*, various MPCA staff compilations based on the MPCA *Annual Solid Waste Report* and landfill waste receipt data after 1980. Prior to 1980, large gaps appear in the receipts data and, before 1970, no data on receipts are available at all. Prior to 1970, solid waste was disposed of in city dumps, which eventually were closed and covered, effectively converting them into landfills.

To develop a complete record of MMSW receipts before 1980, the observed trend in per capita waste receipts was backcast to 1950. Using Minnesota population estimates, 1950-1980, a schedule of Minnesota MMSW generation was developed. Any waste that, over this period, could not be accounted for in landfill records is assumed to have been disposed of in a city dump. Of waste received at city dumps, 40 percent is assumed to have been combusted; the rest is assumed to have been available to generate CH_4.

Of industrial landfills, only paper pulp sludge landfills are evaluated with respect to CH_4 emissions. Emissions from paper pulp sludge landfills that actively capture landfill gas are evaluated using the method described above for landfills receiving MMSW. LandGEM is used for paper pulp sludge landfills not actively capturing LFG using LandGEM model settings recommended in NCASI (2005). Data on paper pulp sludge receipts are from MPCA *Annual Solid Waste Report*.

Taken together, emissions from landfills receiving MMSW and paper pulp sludge comprise most emissions from solid waste management. A small amount of CH_4 and N_2O is emitted during MMSW composting and a smaller amount of CH_4 is emitted during yard waste composting. Emissions from these sources are estimated using emission factors per unit of waste managed given in IPCC (2006) and EPA (2008a).

CO_2 emissions from rural open burning and solid waste mass burn facilities are estimated on the basis of waste carbon content. Waste carbon content is calculated from information in the 1992 and 1999 MPCA waste composition studies. N_2O and CH_4 emissions are calculated using emissions factors from IPCC (2006). Each year, a small amount of general medical waste is also combusted. CO_2 emissions from the combustion of general medical waste are estimated based on waste carbon content, which is taken from MPCA (1993). Finally, CO_2 emissions result from the incineration of hazardous waste. These emissions are estimated using an older emission factor (Ciborowski 1995).

Data sources for rural open burning and waste incineration include the MPCA *SCORE Report* and MPCA Criteria Pollutant Emission Inventory.

CH_4 emissions from domestic wastewater treatment are estimated using the methods given in EPA (2008a). The total biochemical oxygen demand (BOD) of wastewater is calculated for each inventory year using Minnesota population estimates and per capita BOD generation rates. The percentage of wastewater that, in any given year, is managed aerobically, anaerobically in a digester or anaerobically in a pond open to the atmosphere is estimated based on data from the EPA, *Clean Watersheds Needs Survey*. CH_4 emissions are calculated based on the amount of total BOD passing through each of these types of systems, using EPA estimates of CH_4 production per unit of managed BOD. For wastewater treatment plants managing wastewater in anaerobic digesters, it is assumed that, in any given year, 10 percent operated without an active flare and emitted CH_4 directly to the atmosphere.

CH_4 emissions from privately owned septic systems are estimated using a similar method. The percent of total wastewater managed in privately owned septic systems is assumed to be the same as the percent of privately owned residences that, for any given year, are serviced by septic systems.

N_2O emissions from wastewater treatment plant discharges are estimated using the methods specified in EPA (2006) and IPCC (2006). Most N_2O emissions from sewage result from nitrogen discharges to surface water. Based on the IPCC Guidelines, once released to surface water, 0.5 percent of discharged nitrogen is emitted to the atmosphere in the form of N_2O. Total wastewater treatment plant nitrogen discharges are calculated as the difference between total wastewater entering the facilities and the amount of nitrogen removed in the form of wastewater sludge. Total domestic wastewater nitrogen is estimated based on per capita protein consumption and total Minnesota population. This is augmented to account for commercial and industrial sector co-discharge of nitrogen.

The IPCC does not recommend a method to use in estimating N_2O emissions from septic systems. Consequently, no estimate is given in this report for N_2O emissions from this source.

Lastly, N_2O emissions result from the land application of sewage sludge and septage. These are calculated using the methods described for emissions from organic soil amendments in the discussion of agricultural sources. Total sludge applications are from a database maintained by the MPCA biosolids program. Emissions of N_2O and CH_4 from sludge combustion are estimated using emission factors given in EPA (1995) and EEA (2007).

Industrial Process and Other

CO_2 is emitted during the processing of taconite, in addition to CO_2 emitted as a result of fuel combustion at taconite facilities. CO_2 emissions from taconite production are calculated for fully-fluxed taconite pellets and partially-fluxed pellets using emission factors developed by the MPCA mining staff from data submitted by the taconite industry. On the basis of preliminary analysis, it is assumed that, for each long ton (2240 lb) of processed fully-fluxed pellets, 120 lb of CO_2 are emitted to the atmosphere. A lower value, 60 lb per long ton, is used for partially fluxed and acid pellets.

These emission factors, it should be noted, are tentative values that probably will be revised as more test data are analyzed. Annual taconite production data are from Minnesota Department of Revenue (1970-2008).

CO_2 process emissions from taconite production result largely from high temperature calcining of limestone and dolomite in indurating furnaces. Limestone and dolomite are added to taconite as a fluxing agent. Steelmaking and glass manufacture result in CO_2 emissions from similar processes involving limestone and dolomite. These are calculated using the methods given in IPCC (2006) and EPA (2008a) and historical data on limestone use in these industries from the MPCA Criteria Pollutant Emission Inventory database.

In other industrial processes, CO_2 results from the oxidation of emitted noncombustion carbon in the form of carbon monoxide (CO) and volatile organic compounds (VOCs). Historical data on noncombustion CO emissions are from the EPA, *National Emission Inventory* (NEI). Data on VOC emissions from Minnesota are from the EPA NEI and the EPA, *Toxic Release Inventory*. VOC emissions from the EPA NEI data are of two forms: solvent-related VOCs and other industrial VOCs. Solvent-related VOCs and other industrial VOCs are converted to CO_2 using an assumed carbon content of 56 percent and 85 percent, respectively, after EPA (2008).

CO_2 also results from the mining and horticultural use of peat; post-harvest emissions of CH_4 also result. GHG emissions from peat mining and use are estimated using emission factors given in Cleary, *et al*. (2003). Annual peat production in Minnesota in dry tons is from USGS, *Minerals Yearbook* (1970-2006).

Emissions of PFCs and HFCs from semiconductor manufacture are estimated on the basis of the value of semiconductor sales in Minnesota and the US rate of emission per dollar of US semiconductor sales, following the method presented in EPA (2003). Emissions of HFCs during the manufacture of electronics component are estimated on a per capita basis, using total resident Minnesota population and the US per capita emission rate for solvent uses in electronic manufacture, following the method given in EPA (2003).

CH_4 emissions from industrial wastewater treatment in Minnesota are estimated using the methods given in EPA (2008), which provides default values for wastewater production per unit of industrial production in different industries, BOD production per gallon of wastewater for each industry, CH_4 generation per lb of BOD for anaerobic treatment systems, and the percent nationally of BOD in each industry that is managed anaerobically. The industries include paper/pulp, red meat and poultry processing, vegetable processing, ethanol production and petroleum refining. Using these default values, we calculate CH_4 emissions from annual production data for paper pulp, red meat, poultry meat, vegetables, ethanol and refined petroleum products. These annual production data come from: USDA, *Minnesota Agricultural Statistics* (1970-2006), MPCA Criteria Pollutant Inventory database, and EIA, *Petroleum Supply Annual* (1983-2006).

Annual data for paper pulp production are not available for Minnesota. In lieu of these, to calculate emissions we use annual available paper pulp production capacity from NCFES, *Pulpwood Production in the North Central Region* (1991-2006),

Commercial and residential process emission sources include soaps, detergents, food additives, and dentistry. Emissions from each are calculated on a per capita basis using national rates of emission per capita from EPA (2008a) and resident Minnesota population.

Finally, removals of CO_2 from the atmosphere and its incorporation as wood-based carbon in the structural components, siding and flooring of residential housing are reported in this multi-year inventory. Removals are calculated using a stock model of Minnesota housing that tracks total residential units by type (single family, multifamily and mobile homes), age, and average floor space per residence. The stock model reports total square feet of residential housing floor space on an annual basis back to 1970. Given an estimate of total square feet of residential floor space by year of construction, it is possible to evaluate total wood stored in the housing stock using published estimates of wood use per residence per square foot of floor space.

Data inputs to the stock model include decennial census estimates of total Minnesota housing stock by housing type and year of construction, annual estimates developed since 2002 of total Minnesota housing stock by housing type and year of construction from the American Community Survey, and new home starts and new mobile home placements. The stock model conserves the observed total of residential units. The housing stock turns over as new construction is added. To bring total stock in any given model year into balance with observed housing totals, the oldest units in the model are retired.

Estimates of the amount of wood used in residential housing per square foot of housing floor space of going back to 1970 are developed from the published literature. Important sources of historical data include McKeever and Phelps (1994), Marcin (1995), Gray *et al*. (1986), and USFS (1982)

Forestry

Carbon stocks in Minnesota forests are estimated using USDA Forest Service data from the Forest Inventory and Analysis database. Under the most recent survey protocol, each site is surveyed once every five years.

For each forest type, belowground living biomass is derived from estimates of aboveground living biomass, using the equations given in Smith and Heath (2002b). Dead biomass and understory biomass are estimated similarly using the equations given in Smith and Heath (2002b) and EPA (2003b). Forest floor carbon is estimated based on acres of each age class by forest type, using carbon accumulation and decay models, derived from Smith and Heath (2002a).

Section 5: Greenhouse Gas Emissions in Minnesota: 1970-2006

Good policy depends on good data. As noted above, if we are to control GHG emissions, we must understand how emissions have changed historically, how they are changing now, and the factors that govern the rate at which we can reduce or eliminate GHG emissions. Using the methods discussed in Section 4, the MPCA has developed emission estimates for GHGs statewide for 2006 and prior years reaching back to 1970. To the maximum extent possible, the same set of methods was applied in each year over this period.

Estimated statewide emission totals are shown in Table 8, for 1990 and selected years (extended data available in Appendices B and C). Emissions in 2005 were an estimated 154.1 million CO_2-equivalent tons (Appendix A). Statewide emissions of GHGs were an estimated 127.7 million CO_2-equivalent tons in 1990, rising to about 151.7 million CO_2-equivalent tons in 2000. Emissions rose from 2000 to 2005 by about 2.4 million tons. In 2006, statewide emission totals fell by about 1.6 million CO_2-equivalent tons.

Table 8: Greenhouse Gas Emissions in Minnesota by Economic Sector and Gas

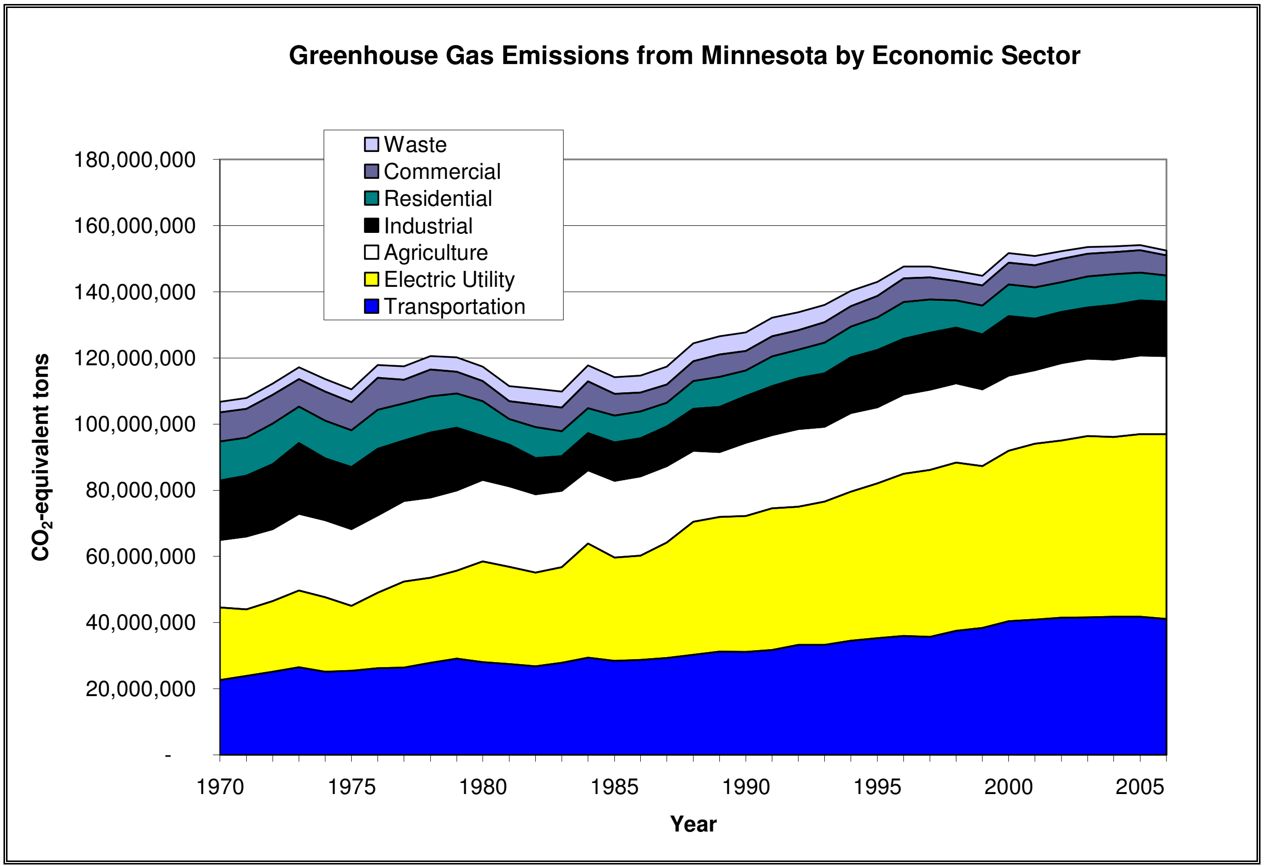
Greenhouse Gas Emissions in Minnesota by Economic Sector and Gas (Million CO_2-equivalent Tons)						
	1990	**2000**	**2003**	**2004**	**2005**	**2006**
Agriculture	22.2	22.8	23.4	23.5	23.8	23.5
Commercial	5.9	6.5	6.9	6.7	6.8	6.1
Electric Utility	41.1	51.6	54.8	54.3	55.2	56.0
Residential	7.8	9.6	9.4	9.2	8.4	8.0
Transportation	31.1	40.4	41.6	41.8	41.8	41.0
Industrial	14.1	18.0	15.5	16.5	16.6	16.4
Waste	5.6	2.9	2.0	1.7	1.6	1.4
Total*	**127.7**	**151.7**	**153.6**	**153.7**	**154.1**	**152.5**
N_2O	9.0	9.6	10.0	9.6	9.8	9.4
CH_4	14.2	12.6	12.0	11.6	11.5	11.5
CO_2	103.8	128.2	130.2	131.1	131.3	130.1
SF_6	0.7	0.4	0.4	0.4	0.4	0.5
HFC-134a/HFC-152a	-	0.2	0.2	0.2	0.2	0.2
HFC-134a	-	0.5	0.7	0.7	0.7	0.7
PFCs	-	0.1	0.1	0.1	0.1	0.1
Total*	**127.7**	**151.7**	**153.6**	**153.7**	**154.1**	**152.5**

*Totals may not add due to rounding.

Statewide emissions are presented in Figure 7 by economic sector for all years between 1970 and 2006. Between 1970 and 2006, statewide GHG emissions increased by an estimated 45.8 million CO_2-equivalent tons. By 2006, GHG emissions were roughly 40 percent higher than in 1970.

From Figure 7 it can be seen that, between 1970 and 2006, the majority of the growth in estimated statewide GHG emissions occurred in just two sectors: the electric power sector and the transportation sector. Emissions from transportation and electric power generation comprised roughly 42 percent of all Minnesota GHG emissions in 1970, and by 2006 they accounted for 64 percent, more than doubling in absolute terms. Emissions from the other sectors of the economy in aggregate declined by 6.6 million CO_2-equivalent tons between 1970 and 2006 (Table 9).

Figure 7: Greenhouse Gas Emissions from Minnesota by Economic Sector



Three distinctive phases of emission growth are evident in the record: a period of no or very slow growth in emissions from 1970 to the mid-1980s; a second period of rapid growth in emissions beginning in the mid-1980s and stretching the mid- to late-1990s; finally a return to slow growth dating from the late 1990s to 2006. During the two periods of slower growth, average GHG emissions increased less than 0.5 percent per year. Most of the growth in emissions occurred between 1985 and 1999, when statewide GHG emissions rose more than 25%.

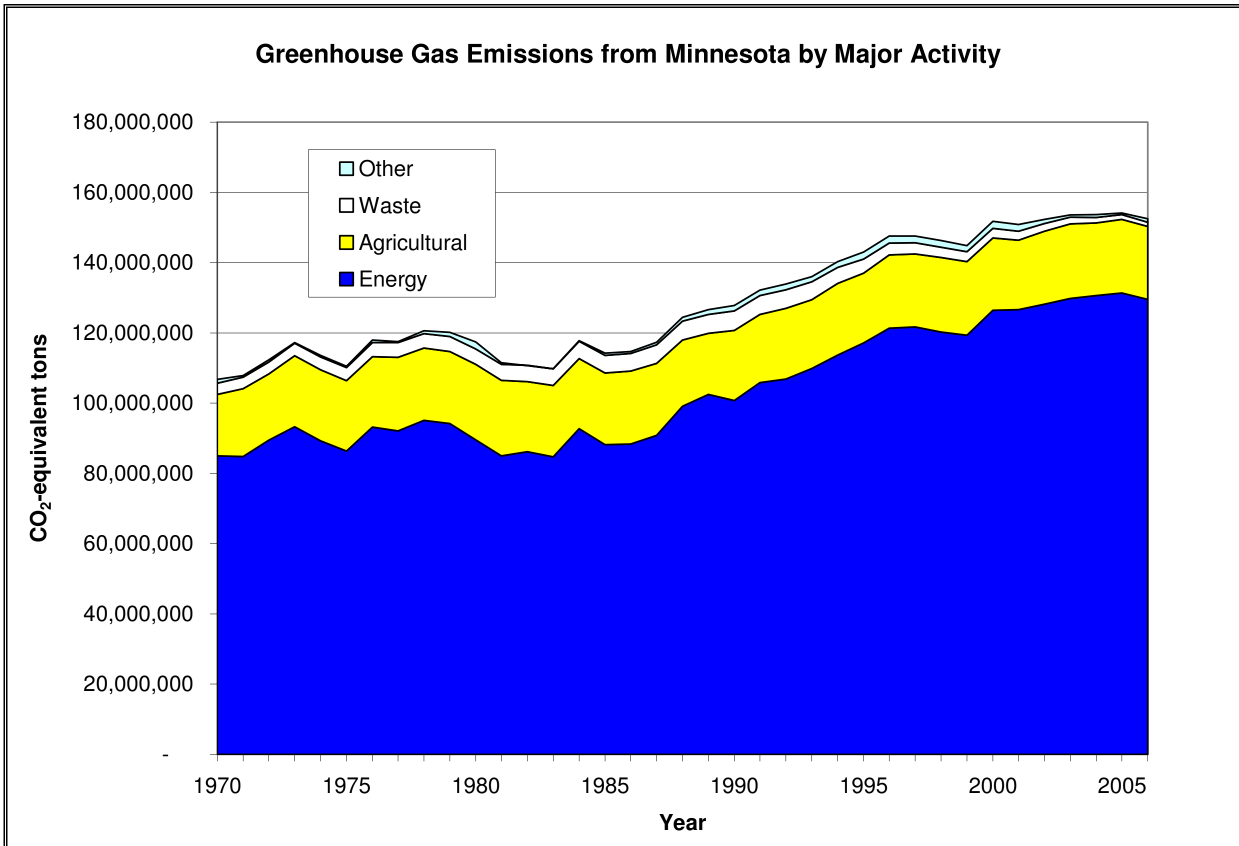
The same data can be organized by major activity. These are shown in Figure 8. Major activities include energy, waste disposal, industrial process, agriculture, and other activities. This grouping of activity is based on assumptions discussed in Section 3.

Table 9: Changes in Emissions Between 1970 and 2006 by Sector

Changes in Emissions Between 1970 and 2006 by Sector (Million CO_2-equivalent Tons)	
Electric Power Sector	+34.1
Transportation	+18.4
Agriculture	+3.2
Industrial	-1.6
Waste Management	-1.7
Commercial	-2.7
Residential	-3.8
Total*	**+45.8**

*Totals may not add due to rounding.

Figure 8: Greenhouse Gas Emissions from Minnesota by Major Activity



Included in emissions from energy-related activities are emissions from energy use and the emissions from production and transportation of finished fuels. Energy is the dominant activity in Minnesota leading to release of GHG emissions to the atmosphere, consistently accounting for about 85 percent of all statewide emissions. The emission of GHGs from energy use and production follows the same basic pattern described for all emissions statewide: a period of slow or no growth, 1970-1985; a period of rapid growth from 1985 to the late 1990s; then a flattening of emissions, 1998-2006. By contrast, in aggregate, nonenergy activity emissions varied little over the period of record, comprising about 20 million tons of emissions.

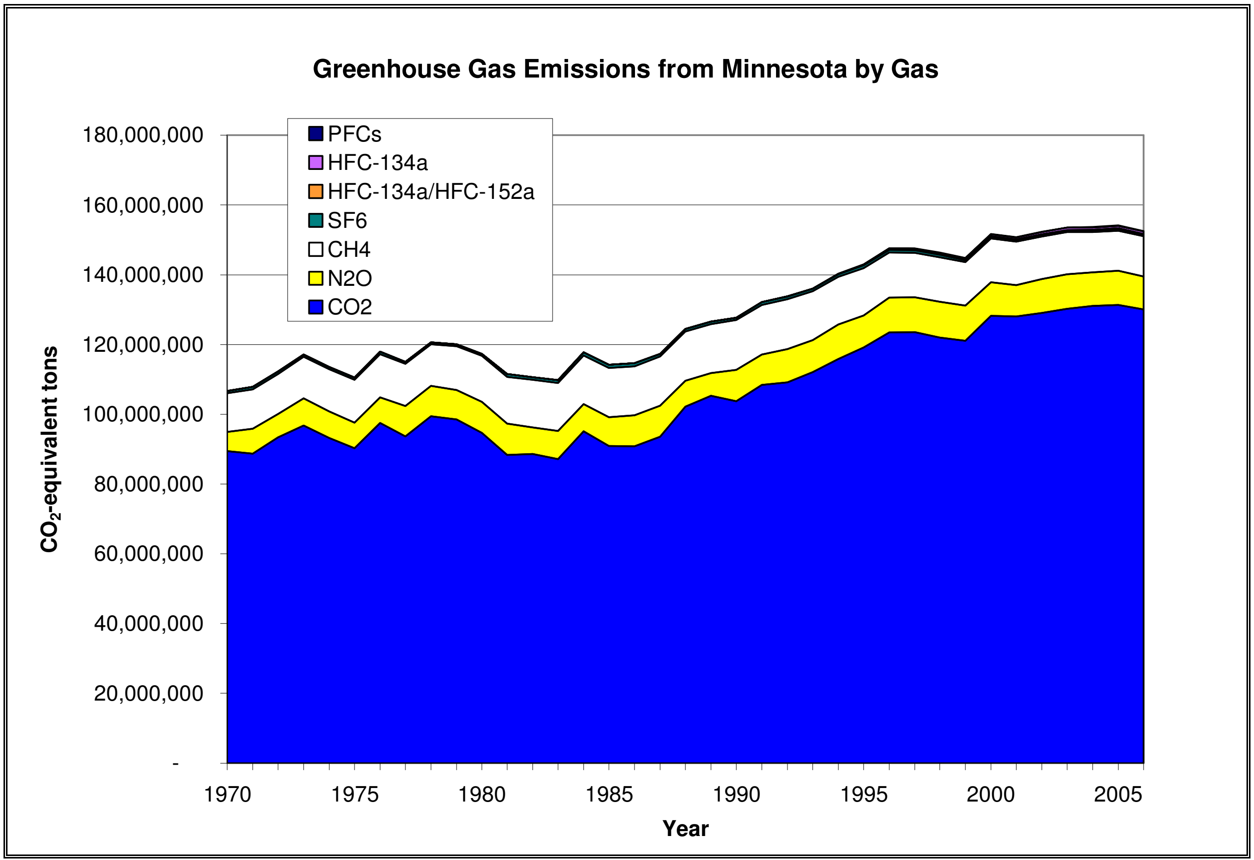
Table 10: Changes in Emissions Between 1970 and 2006 by Activity

Changes in Emissions Between 1970 and 2006 by Activity (Million CO_2-equivalent Tons)	
Energy	+44.5
Agriculture	+3.2
Waste	-1.9
Other	-0.1
Total*	**+45.8**

*Totals may not add due to rounding.

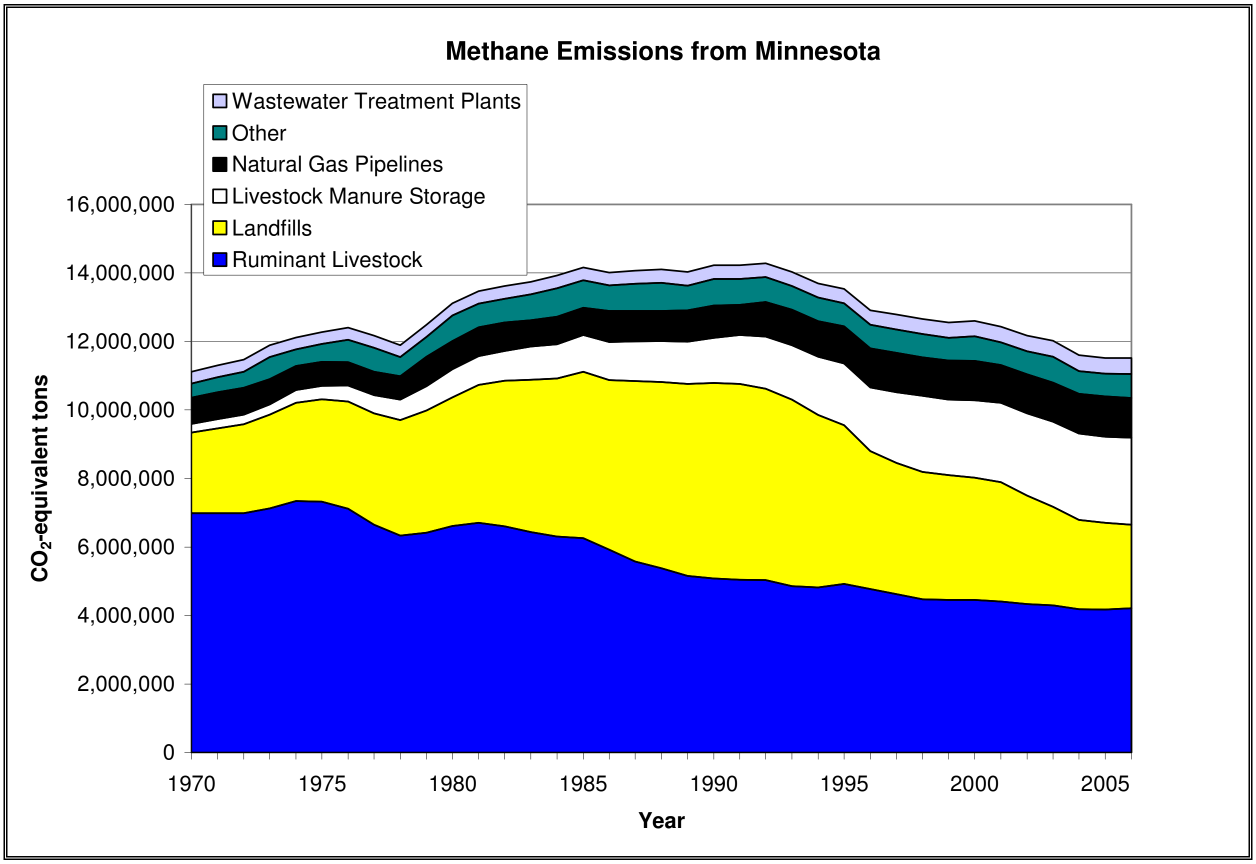
The trend in emissions by gas is shown in Figure 9. CO_2 emissions account for 85 percent of all statewide emissions across most years of the record. CH_4 is the second most important GHG in terms of total emissions, followed closely by emissions of N_2O. Far smaller, emissions of the HFCs, PFCs and SF_6 add about one percent for most years from 1970 to the present.

Figure 9: Greenhouse Gas Emissions from Minnesota by Gas



Figures 10-12 show the trend in statewide GHG emissions for each of the three principal greenhouse gases. The trend in the emissions of CH_4 is shown in Figure 10. Methane emissions peaked in the early 1990s and have been declining since. Much of the reduction in estimated CH_4 emissions can be tracked to a decline in emissions from ruminant cattle and reduced CH_4 emissions from landfills receiving mixed municipal solid waste (MMSW). CH_4 emissions are now about 20 percent lower than their 1990 peak.

Figure 10: Methane Emissions from Minnesota



The 36-year trend in N_2O emissions is shown in Figure 11. Fully three-quarters of all N_2O emissions in Minnesota result from agricultural soil nutrient management. Feedlot emissions and emissions from transportation sources account for most of the rest. N_2O emissions peaked in the record in 1997, also the peak year of N_2O emissions from mobile transportation sources. Transportation N_2O is produced principally in the catalytic converters used to control air pollutants. The vintages of catalytic converters typically in use in the middle 1990s acted to maximize N_2O emissions. More recent vintages of catalytic converters have more than halved the amount of N_2O produced per vehicle mile traveled.

As might be expected from the role played by fossil fuels in state energy use, CO_2 emissions have closely tracked total GHG emissions from energy use and fuels production (Figure 12). With the exception of the five to eight million tons of CO_2 that, depending on the year in question, were emitted from industrial and agricultural sources, most CO_2 results from fossil fuel combustion. More than 40 percent of all CO_2 emissions in 2006 resulted from the generation of electricity, both in-state and out-of-state, to service Minnesota electrical demand. Of the remainder, transportation sources were responsible for 30 percent of all statewide emissions. Over the 36-year period of record, statewide CO_2 emissions have followed the general pattern of total emissions: a period of rapidly rising emissions, 1985-1998, between periods of slow or no growth in emissions.

Figure 11: Nitrous Oxide Emissions from Minnesota

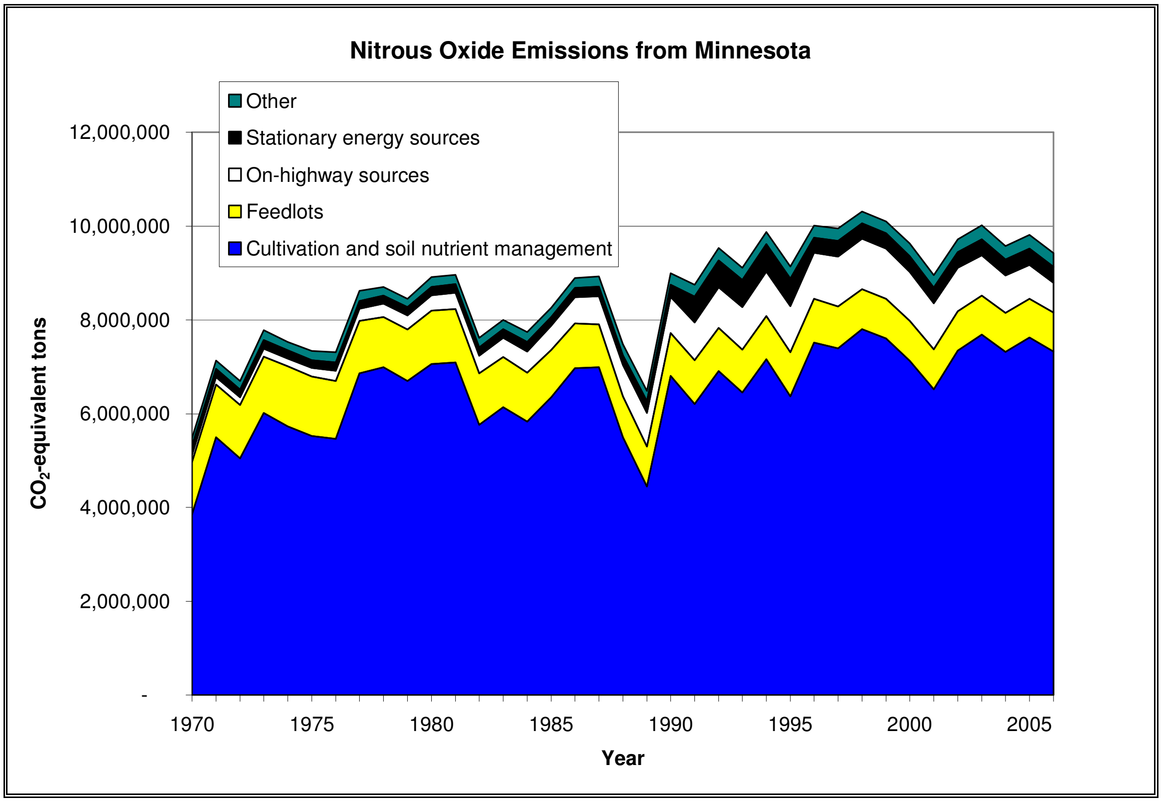
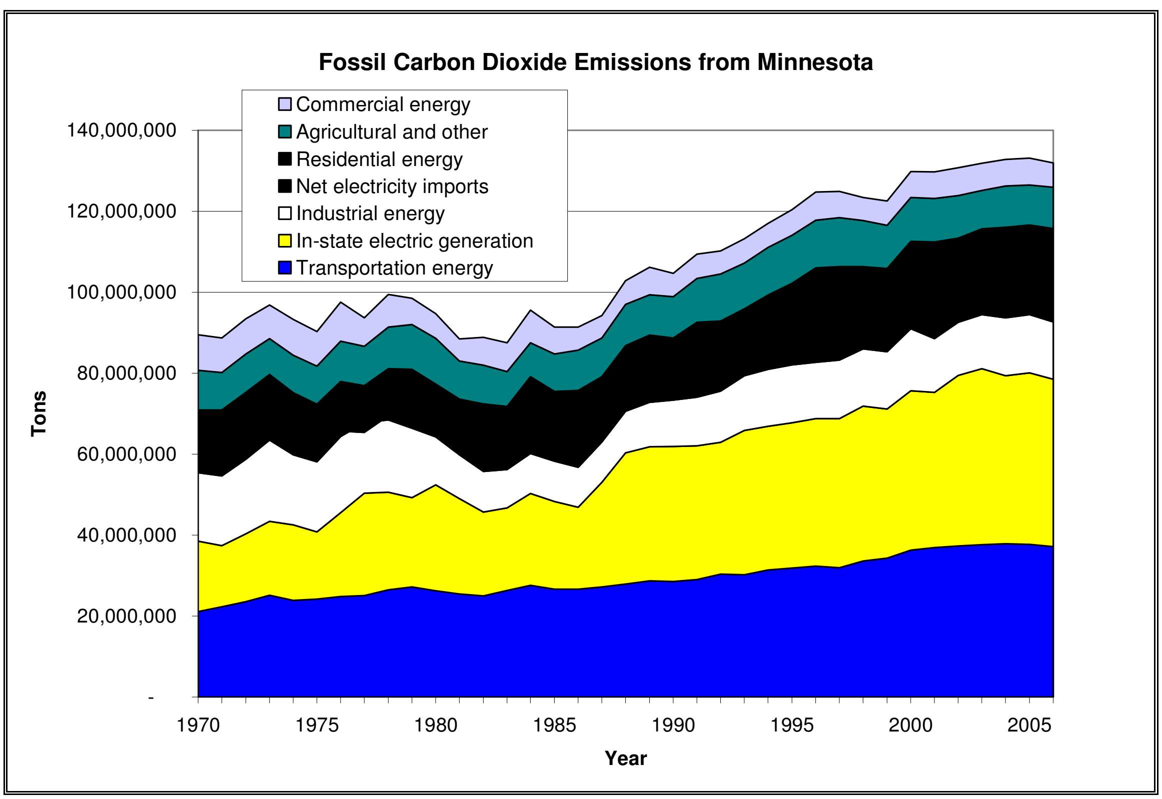


Figure 12: Fossil Carbon Dioxide Emissions from Minnesota



Section 6: Greenhouse Gas Emissions by Economic Sector: 1970-2006

Greenhouse gas emissions organized by economic sector can be further broken down by fuel and, if combustion is not involved, by noncombustion source. In the MPCA GHG Emission Inventory, the economic sectors within which emissions are treated are agriculture, the commercial sector, electric power generation, the industrial sector, residences, transportation, and waste management.

Agriculture

GHG emissions from the agricultural sector are shown in Figure 13 for 1970-2006 and in Table 11 for selected years. These estimates include all emissions from agricultural production, including emissions associated with farm energy use. Indirect emissions associated with electricity imports are not included; emissions associated with electricity consumption are estimated separately as electric power sector emissions. The methods used to develop these estimates are discussed in Section 4.

Table 11: Greenhouse Gas Emissions from Agriculture in Minnesota by Source and Gas

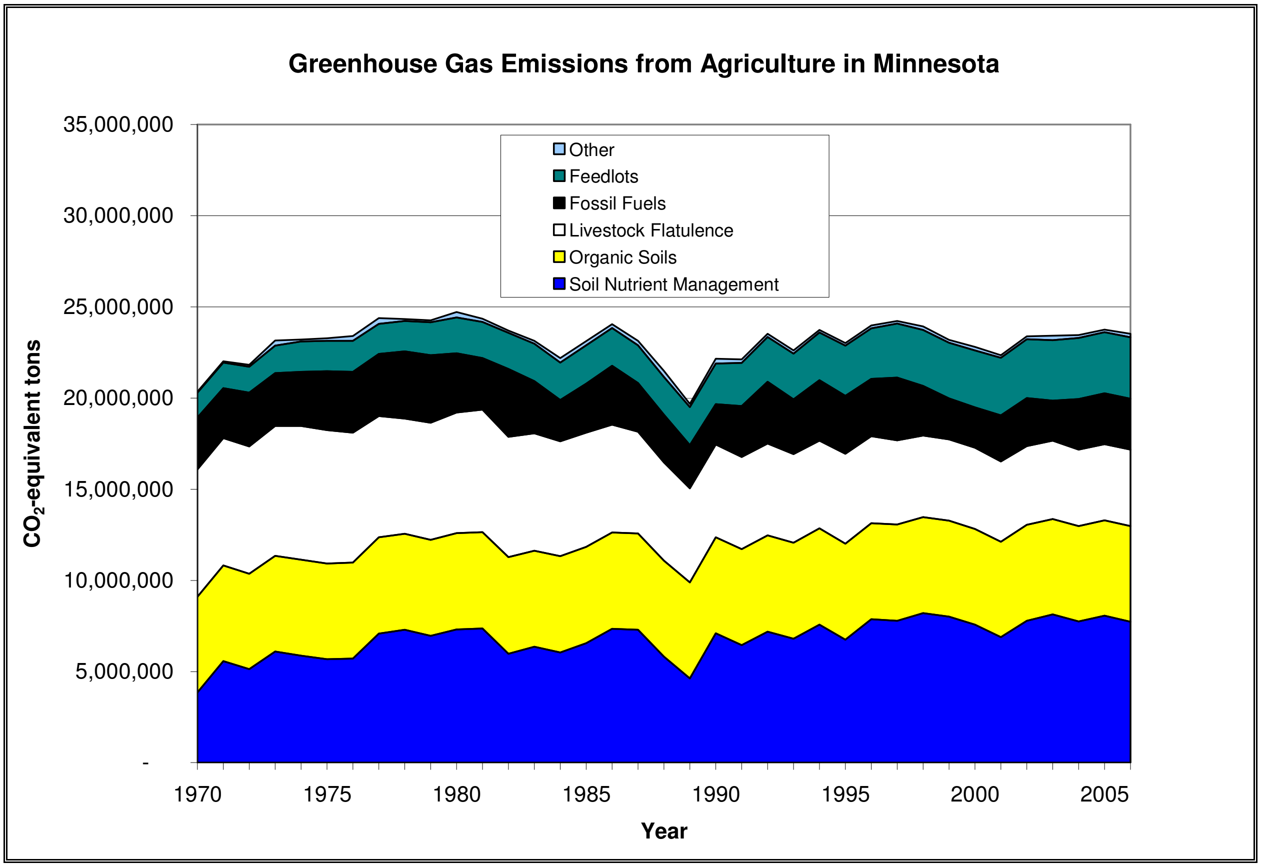
Agriculture Greenhouse Gas Emissions (Million CO_2 - Equivalent Tons)					
	2000	**2003**	**2004**	**2005**	**2006**
Fossil Fuels	2.2	2.2	2.8	2.8	2.8
Soil Nutrient Management	7.6	8.1	7.7	8.0	7.7
Feedlots	3.1	3.3	3.4	3.3	3.4
Livestock Flatulence	4.5	4.3	4.2	4.2	4.2
Organic Soils	5.2	5.2	5.2	5.2	5.2
Other Sources	0.3	0.3	0.2	0.2	0.3
Total	**22.8**	**23.4**	**23.5**	**23.8**	**23.5**
CH_4	6.9	7.0	6.9	6.8	6.9
CO_2	7.9	7.9	8.4	8.5	8.4
N_2O	8.0	8.6	8.2	8.5	8.2
Total	**22.8**	**23.4**	**23.5**	**23.8**	**23.5**

†Includes: crop residues, cultivated histosol N_2O, atmospheric deposition, fertilizer, liming of fields, manure, runoff, and urea application.
‡Includes: wild rice cultivation, wind erosion of soils, and wildfire.
*Totals may not add due to rounding.

Emissions are organized by major activity or source - soil nutrient management, organic soils, livestock flatulence, fossil fuel use, feedlots, and other activities. As discussed in Sections 3 and 4, included in soil nutrient management are N_2O emissions from soil bacteria that result from the application of or atmospheric deposition of nitrogen to agricultural fields. Also included in emissions from soil nutrients management are CO_2 emissions from the liming of agricultural fields and the use of urea-based fertilizers. Sources of agricultural nitrogen include synthetic fertilizer, livestock manure, crop residues, other organic amendments, and nitrogen atmospherically deposited on fields. Some nitrogen is also made available through mineralization with tillage. As noted in Section 4, no N_2O emissions are assumed to result from nitrogen biologically fixed by legumes.

Organic soils are commonly known as histosols or peat. The category of other activities includes emissions from wild rice cultivation, wildfire, and the wind erosion of soils. Because emissions from erosion are poorly understood, only a small nominal value is included.

Figure 13: Greenhouse Gas Emissions from Agriculture in Minnesota



In 2006, emissions from the agricultural sector were an estimated 23.5 million CO_2-equivalent tons, down slightly from 2005 levels. Since 1990, emissions from the Minnesota agricultural sector have been fairly constant, varying between 22 and 24 million CO_2-equivalent tons. Over this period, livestock flatulence emissions and emissions from soil nutrient management and manure management have moved in generally opposite directions. Flatulence emissions from livestock have contracted from an estimated seven million CO_2-equivalent tons in 1970 to about four million CO_2-equivalent tons in 2006. These reductions have been largely offset by increasing emissions from soil nutrient management and manure management, which have increased from about 8 million CO_2-equivalent tons in the early 1970s to 11.1 million CO_2-equivalent tons in 2006.

Emissions from other sources, including wildfire, erosion, and the cultivation of wild rice, are small and have varied little as a percent of total emissions. The emission estimate for organic soils was developed from a single point estimate for 1997 by the US Department of Agriculture. Data to support a more refined estimate are not now available. Emissions from the cultivation and pasturing of organic soils are assumed to be constant at 1997 levels throughout the reporting period.

Due to uncertainties in the underlying science, the emission estimates shown in Figure 13 and Table 11 are, of all of the estimates reported in this study, the most poorly defined. Because of this, in developing these agricultural estimates we have made an effort to err on the conservative side. In its national GHG inventory, the EPA has adopted a much more aggressive approach. Using a newly applied process model to evaluate N_2O emissions from soil nutrient management – the single largest source of agricultural emissions – the EPA estimates this emission from Minnesota in 2006 at nearly 17 million CO_2-equivalent tons, or more than double what was estimated using the simple method recommended in the IPCC guidelines and employed by the MPCA.[16]

The EPA is only several years into the use of formal process models to evaluate emissions from this source, so it is possible that the 2006 EPA estimate for Minnesota will prove anomalous and require substantial revision. If, after review, the state-level EPA estimates in fact are found to be the best representation of emissions at the state-level from soil management practices, the estimates given in this report for agricultural sources may require upward revision, possibly by as much as 10 million CO_2-equivalent tons.

Commercial Sector

Emissions from the commercial sector of the economy are shown in Figure 14 for 1970-2006 and in Table 12 for selected years. These include only direct emissions of GHGs to the atmosphere; indirect emissions from electricity consumption are not included. The methods used to develop these emissions estimates are discussed in Section 4.

In 2006, GHG emissions from the commercial sector of Minnesota's economy were an estimated 6.1 million CO_2-equivalent tons. Prior to 2006, emissions had been stable for about 15 years, oscillating between 5.5 and 7.5 million CO_2-equivalent tons per year. Emissions early in the record were much higher but fell by 1990 to approximately current levels. About 85 percent of all GHG emissions from commercial sector activity results from natural gas combustion, and most of the rest is the result of the combustion of petroleum products like distillate fuel oil. Coal use and minor noncombustion sources of emissions, including medical uses of N_2O, limestone use in fuel gas desulfurization, and commercial solvent uses, contribute only slightly to total emissions.

The change in total commercial GHG emissions between 2005 and 2006 was an estimated 0.7 million CO_2-equivalent tons, or about 10 percent.

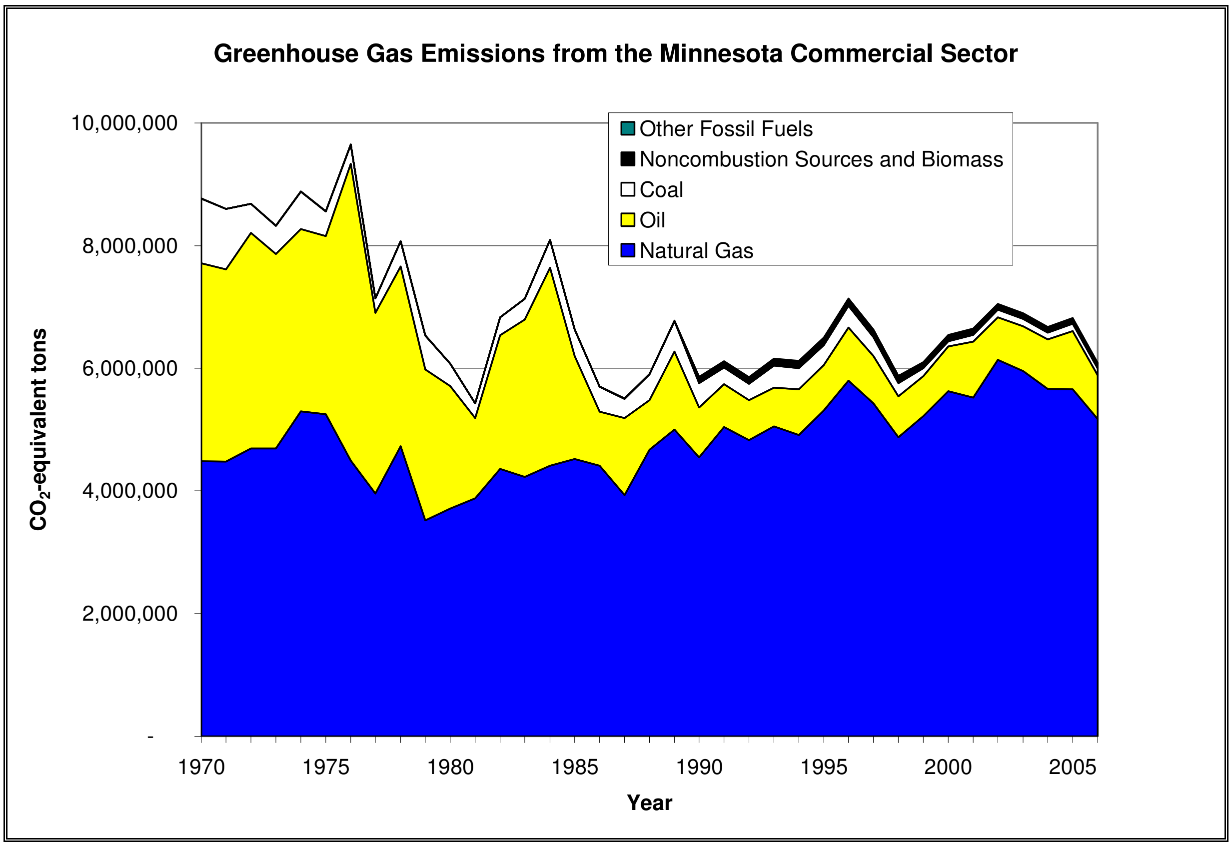
[16] The EPA also presented an estimate for CO_2 emissions from Minnesota organic soils of eight million CO_2-equivalent tons, roughly one-third higher than the more conservative value used in this report.

Table 12: Greenhouse Gas Emissions from the Minnesota Commercial Sector

Commercial Sector Greenhouse Gas Emissions (Million CO_2 - Equivalent Tons)					
	2000	**2003**	**2004**	**2005**	**2006**
Coal	0.1	0.1	0.1	0.1	0.1
Natural Gas	5.6	6.0	5.7	5.7	5.2
Petroleum	0.7	0.7	0.8	0.9	0.7
Other Sources†	0.1	0.1	0.1	0.1	0.1
Total*	**6.5**	**6.9**	**6.7**	**6.8**	**6.1**
CH_4	<0.1	<0.1	<0.1	<0.1	<0.1
CO_2	6.5	6.9	6.6	6.8	6.0
N_2O	<0.1	<0.1	<0.1	<0.1	<0.1
Total*	**6.5**	**6.9**	**6.7**	**6.8**	**6.1**

†Includes: Other fossil fuels (primarily the petrochemical components of resources derived fuel), biomass combustion, limestone use, medical use, and solvents.
*Totals may not add due to rounding.

Figure 14: Greenhouse Gas Emissions from the Minnesota Commercial Sector



Electric Generation

Emissions from electrical generation are shown in Figure 15 for 1970-2006 and in Table 13 for selected years. The estimates shown in Figure 15 and Table 13 include emissions associated with power generated out-of-state but consumed in-state. Again, the methods used to develop these estimates are described in Section 4. Unlike other economic sectors, emissions from electric generation have risen consistently since 1970, rising at an average annual rate of 3.4 percent between 1970 and 1988, and 1.8 percent per year between 1988 and 2006. Since 2000, emissions from electricity generation have increased about nine percent, rising at an average annual rate of 1.4 percent per year.

GHG emissions are shown in Figure 15 and Table 13 by fuel type. Emissions from electricity and noncombustion sources of emissions are shown as separate categories. Emissions from coal combustion and electricity imports account for most emissions in most years of the record, about 94 percent of emissions in 2006, and about 95 percent in 1990 and 2000. Based on the record shown in Figure 15, emissions from in-state coal combustion peaked in 2003 at about 40.7 million CO_2-equivalent tons and since have been falling, albeit slowly. Emissions associated with imported power have increased from an average annual rate in the early 1990s of about 7.9 million CO_2-equivalent tons per year to about 12.8 million CO_2-equivalent tons per year, the average for years 2004-2006.

Table 13: Greenhouse Gas Emissions from the Electric Generation Sector in Minnesota

Electric Generation Greenhouse Gas Emissions (Million CO_2 - Equivalent Tons)					
	2000	**2003**	**2004**	**2005**	**2006**
Coal	37.2	40.7	39.0	39.1	38.3
Natural Gas	0.7	1.3	1.1	1.8	2.0
Petroleum†	1.0	1.1	1.0	0.9	0.6
Electricity Imports	11.6	10.7	12.1	12.3	14.1
Other Sources‡	1.0	1.1	1.0	1.1	1.0
Total*	**51.6**	**54.8**	**54.3**	**55.2**	**56.0**
CH_4	<0.1	0.1	<0.1	<0.1	0.1
CO_2	50.9	54.0	53.5	54.5	55.2
N_2O	0.2	0.3	0.3	0.3	0.3
SF_6	0.4	0.4	0.4	0.4	0.5
Total*	**51.6**	**54.8**	**54.3**	**55.2**	**56.0**

†Includes: distillate fuel oil, residual fuel oil, petroleum coke, waste oil, and waste solvents.
‡Includes: Other fossil fuels (primarily petrochemical components of RDF and MMSW combusted for energy generation), biomass combustion, coal storage, FGD, methane from hydroelectric reservoirs, electricity transmission and distribution.
*Totals may not add due to rounding.

Emissions from the in-state combustion of oil, natural gas and other fossil fuels, principally the petrochemical portion of mixed municipal solid waste, are a few million CO_2-equivalent tons per year. Biomass combustion[17] and noncombustion sources account for about half a million CO_2-equivalent tons of emissions annually. Noncombustion sources include: electricity transmission

[17] Emissions of N_2O and CH_4 only

and distribution (SF_6), coal piles (CH_4), hydroelectric reservoirs (CH_4), and flue gas desulfurization (CO_2).

Between 2005 and 2006, GHG emissions from the electric sector increased 0.8 million CO_2-equivalent tons, despite a 0.8 million CO_2-equivalent ton drop in emissions from in-state coal combustion. An increase in emission associated with net electricity imports of more than 1.8 million CO_2-equivalent tons offset this reduction, leading to an overall net increase in emissions from electricity generation.

Figure 15: Greenhouse Gas Emissions from the Electric Generation Sector in Minnesota

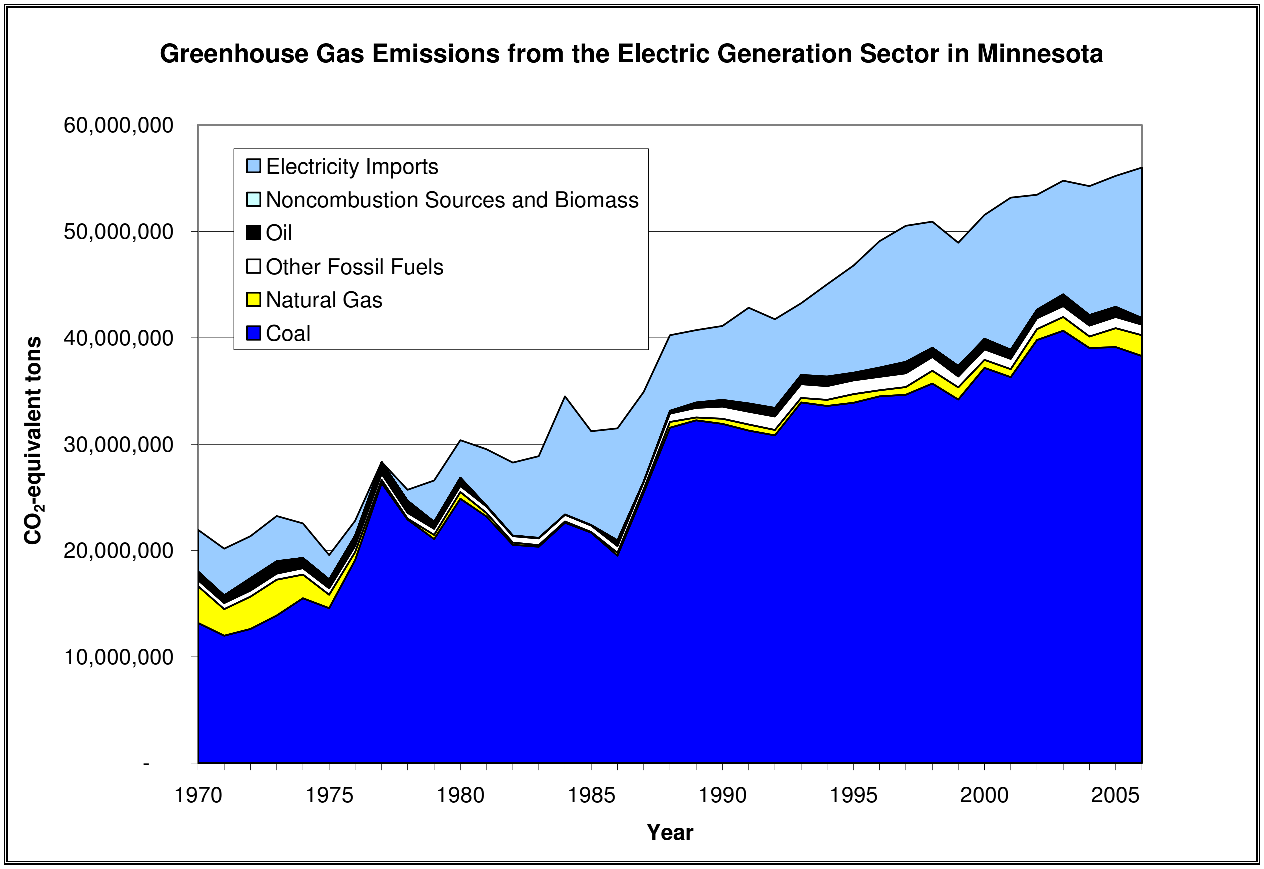


Table 14: Changes in Electric Generation Emissions by Fuel Between 1970 and 2006

Changes in Electric Generation Emissions by Fuel Between 1970 and 2006 (Million CO_2-equivalent Tons)	
Coal	+25.1
Natural Gas	-1.5
Oil	-0.2
Electricity Imports	+10.2
Other Fossil Fuels	+0.6
Noncombustion Sources and Biomass	-0.2
Total*	**+34.1**

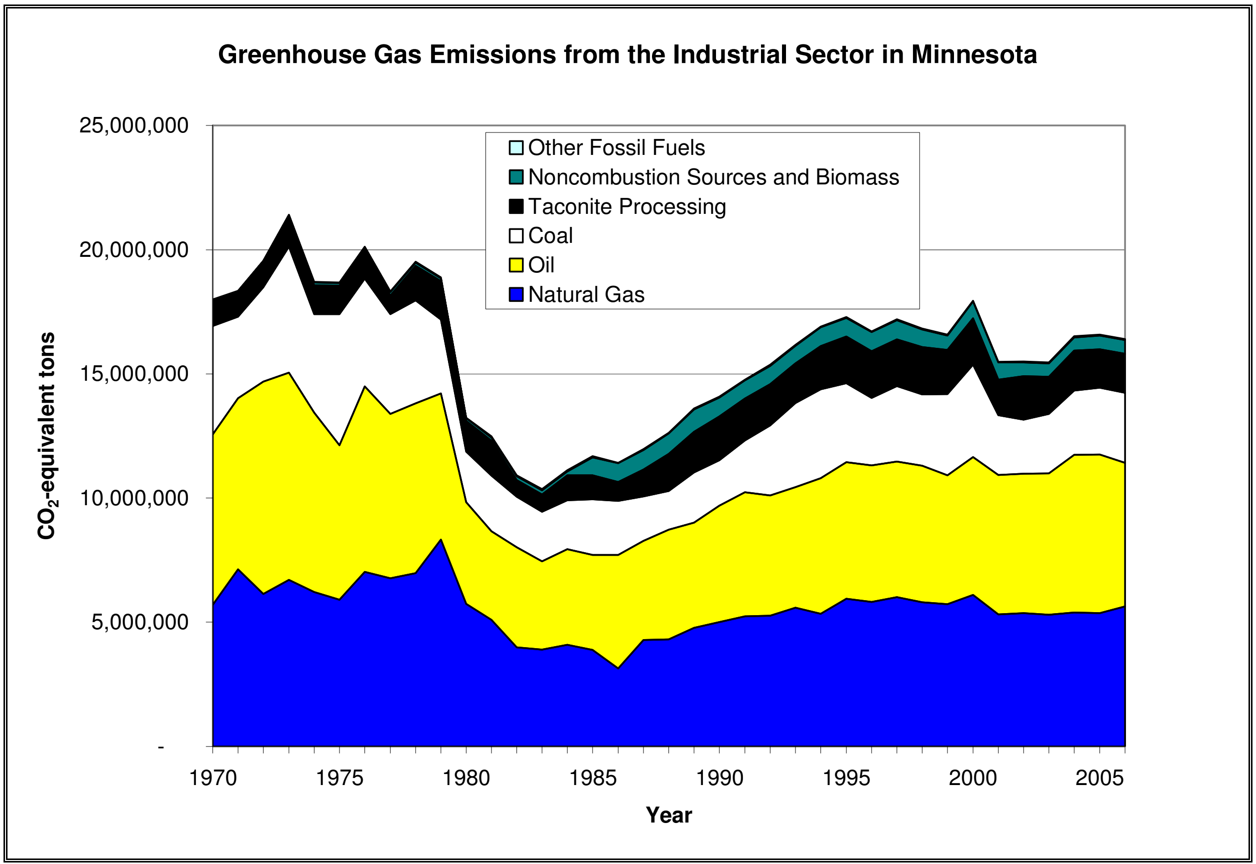
*Totals may not add due to rounding.

Industrial Sector

Emissions from the industrial sector are shown in Figure 16 for 1970-2006 and in Table 15 for selected years. In the MPCA GHG Emission Inventory, the industrial sector includes manufacturing, mining, and construction. The estimates shown in Figure 16 and Table 15 include only direct emissions of GHGs to the atmosphere; indirect emissions associated with the consumption of electricity are evaluated as electric power sector emissions. The methods used to develop the estimates shown in Figure 16 and Table 15 are discussed in Section 4.

Most industrial GHG emissions result from fossil fuel combustion. Emissions are presented in Figure 16 and Table 15 by fossil fuel type or by nonfuel use category. GHG industrial sources include fossil fuel use, biomass combustion, taconite processing, steel production, glass manufacture, ammonia production, oil refining, industrial wastewater treatment, coal piles, solvent uses, emissions of other volatile organic chemicals to the atmosphere, peat mining and use, semiconductor manufacture, and the fabrication of other electronics components, biomedical and other precision instruments. In the case of some nonfuel emission sources, data to support an emission estimate became available only in the early- to mid-1980s.

Figure 16: Greenhouse Gas Emissions from the Industrial Sector in Minnesota



The processing of taconite in indurating furnaces contributes one to two million tons of CO_2 annually. It is common practice in the taconite industry to incorporate limestone and dolomite with various binders into shipped taconite pellets. During induration, some of the carbon in the limestone, dolomite and binder is driven off and is emitted to the atmosphere.

Industrial GHG emissions have been quite variable since 1970, falling to half of earlier estimates during the deep recession of the early 1980s, rapidly recovering during the early 1990s, then stabilizing or slightly declining in the ten years after 1995. Industrial GHG emissions declined by 0.2 million CO_2-equivalent tons between 2005 and 2006. Currently, about 70 percent of industrial GHG emissions result from the combustion of petroleum and natural gas.

Table 15: Greenhouse Gas Emissions from the Industrial Sector in Minnesota

Industrial Greenhouse Gas Emissions (Million CO_2 - Equivalent Tons)					
	2000	**2003**	**2004**	**2005**	**2006**
Coal	3.7	2.4	2.6	2.7	2.8
Natural Gas	6.1	5.3	5.4	5.4	5.6
Petroleum	5.6	5.7	6.3	6.4	5.8
Taconite Processing	1.9	1.5	1.6	1.6	1.6
Other Sources†	0.7	0.6	0.6	0.6	0.6
Total*	**18.0**	**15.5**	**16.5**	**16.6**	**16.4**
CH_4	0.2	0.2	0.2	0.2	0.2
CO_2	17.6	15.1	16.2	16.2	16.0
N_2O	0.1	0.1	0.1	0.1	0.1
HFCs	0.1	0.1	0.1	0.1	0.1
Total*	**18.0**	**15.5**	**16.5**	**16.6**	**16.4**

†Includes: Biomass combustion, ammonia manufacturing, glass manufacturing, steel manufacturing, coal storage, industrial wastewater treatment, oil refining, other industrial processes, solvent, VOC, and TRI releases, peat mining and use, semiconductor manufacturing, and manufacture of electronic equipment and precision instruments.
*Totals may not add due to rounding.

Residential Sector

GHG emissions from the residential sector are shown in Figures 17 and 18 for 1970-2006 and in Table 16 for selected years. The methods used to develop the estimates are discussed in Section 4. The estimates of emissions include only direct emissions to or removals of GHGs from the atmosphere; indirect emissions from electricity consumption are not included. Most emissions in the residential sector result from fossil fuel combustion. Emissions are shown in Figure 17 and Table 16 by fuel type by nonfuel use category.

We have also estimated the amount of CO_2 annually removed from the atmosphere and semi-permanently stored as wood in new residential structures. The removal of CO_2 from the atmosphere acts to offset emissions of GHGs elsewhere in the economy. This annual removal of CO_2 is shown in Table 16 and in Figure 18.

Figure 17: Direct GHG Emissions from the Residential Sector in Minnesota (Excluding Sequestration)

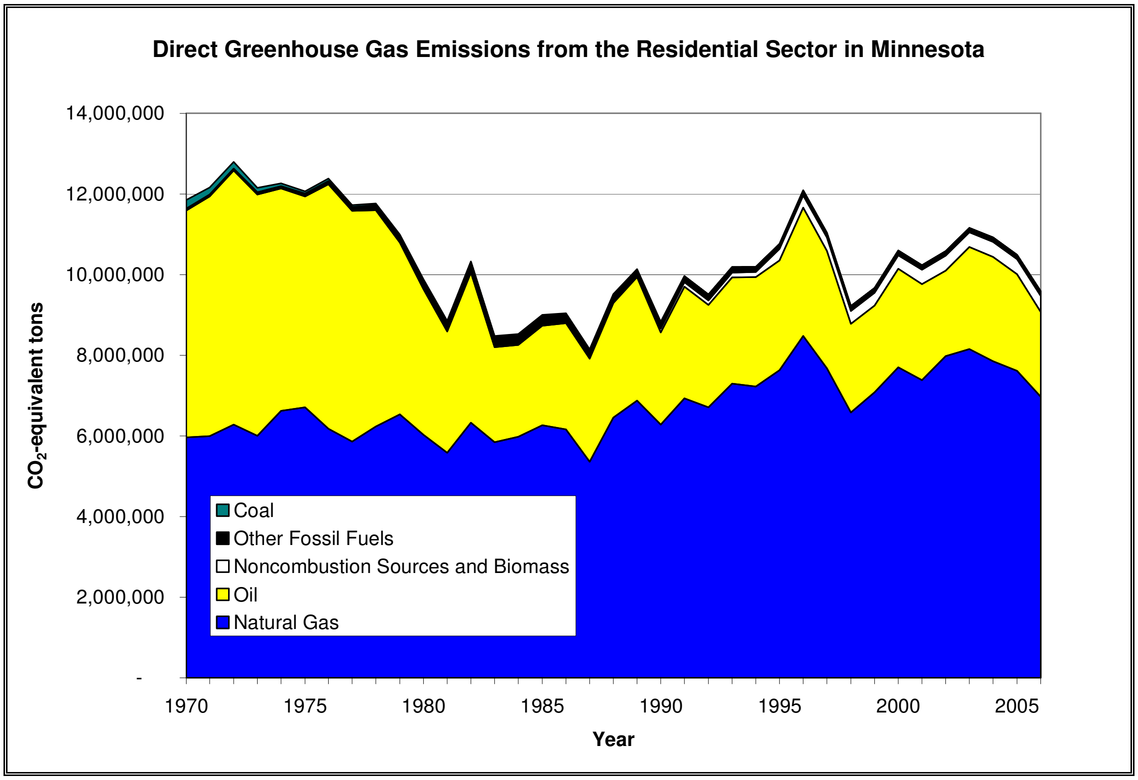


Figure 18: Direct GHG Emissions from the Residential Sector in Minnesota (Including Sequestration)

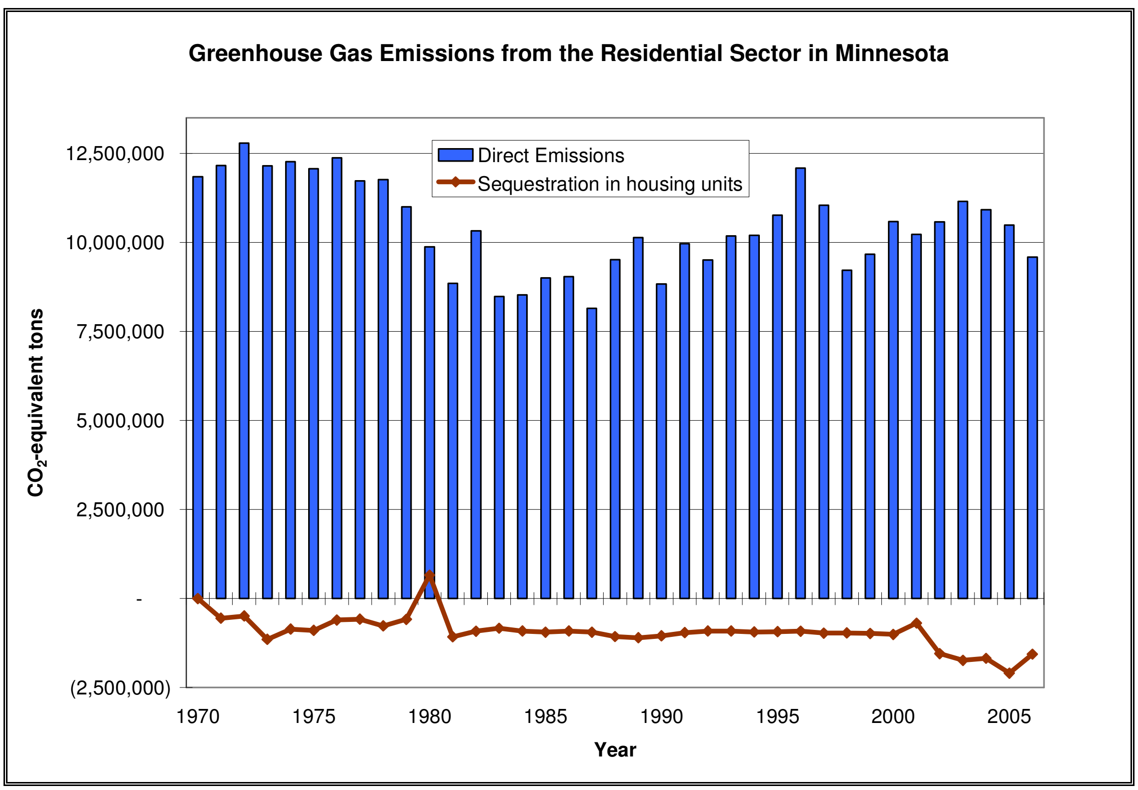


Table 16: Greenhouse Gas Emissions from the Residential Sector in Minnesota

Residential Greenhouse Gas Emissions (Million CO_2 - Equivalent Tons)					
	2000	**2003**	**2004**	**2005**	**2006**
Natural Gas	7.7	8.1	7.8	7.6	7.0
Petroleum†	2.4	2.5	2.6	2.4	2.1
Other Sources‡	0.4	0.5	0.5	0.5	0.5
Total*	**10.6**	**11.2**	**10.9**	**10.5**	**9.6**
Sequestration in Housing	(1.0)	(1.7)	(1.7)	(2.1)	(1.6)
Total*	**9.6**	**9.4**	**9.2**	**8.4**	**8.0**
CH_4	0.1	0.1	0.1	0.1	0.1
CO_2	9.2	9.0	8.8	8.0	7.6
N_2O	<0.1	0.1	0.1	0.1	0.1
HFCs	0.2	0.2	0.2	0.2	0.2
Total*	**9.6**	**9.4**	**9.2**	**8.4**	**8.0**

†Includes: Distillate fuel oil, liquid petroleum gas, and kerosene.
‡Includes: Wood combustion, coal, biomass, aerosols, food additives, soaps, detergents, shampoos, lawn fertilizers, and refrigeration.
*Totals may not add due to rounding.

In 2006, direct emissions from Minnesota residences, including sequestration of carbon in housing, were an estimated 9.6 million CO_2-equivalent tons, up from a low of 8.1 million tons in 1987, but down from peak emissions of about 12 million CO_2-equivalent tons in the early 1970s. Emissions rose between 1983 and 1996, but since have demonstrated no clear trend. About 73 percent of direct emissions of GHGs from Minnesota residences results from natural gas combustion. Most of the rest results from the combustion of heating fuels like distillate fuel oil and LPG. The combustion of coal and noncombustion emissions contribute only slightly to total sector emissions. Sources of noncombustion emissions include propellant aerosols, food additives, soaps, detergents, shampoos, lawn fertilizers and refrigeration.

Total emissions from Minnesota residences are the difference between direct emissions and carbon stored in the form of structural timbers, flooring and sheathing in residences. Total emissions in 2006 were about 8.0 million CO_2-equivalent tons, down from 2004 levels of 9.2 million CO_2-equivalent tons and 2000 levels of 9.6 million CO_2-equivalent tons.

Historically carbon storage in residential housing units has offset about one million tons of CO_2 emissions. During the housing boom, however, this peaked in 2005 at 2.1 million tons per year (Figure 18).

Transportation

The trend in estimated emissions from transportation in Minnesota is shown in Figure 19 by vehicle type or transportation mode and in Table 18 by vehicle type or mode, fuel used and greenhouse gas. The methods used to develop the estimates are discussed in Section 4.

Figure 19: Greenhouse Gas Emissions from Transportation in Minnesota

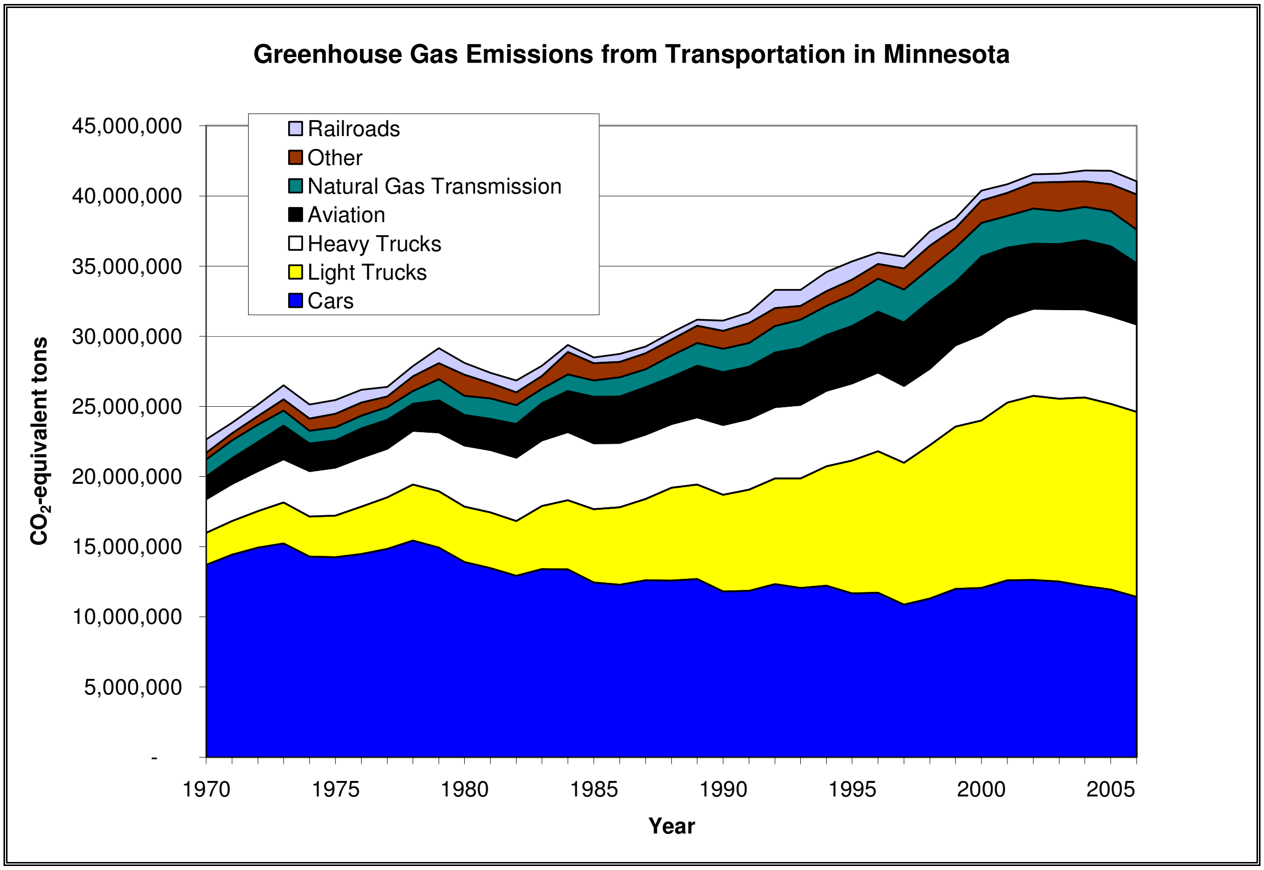


Table 17: Changes in Transportation Emissions by Mode Between 1970 and 2006

Changes in Transportation Emissions by Mode Between 1970 and 2006 (Million CO_2-equivalent Tons)	
Cars	-2.3
Light Trucks	+10.9
Heavy Trucks	+3.8
Aviation	+2.7
Natural Gas Transmission	+1.2
Other	+2.0
Railroads	-0.0
Total*	**+18.4**

*Totals may not add due to rounding.

In the MPCA GHG Emission Inventory, most transportation-related emissions result from the combustion of petroleum-based fuel or natural gas. Additionally, a small amount of N_2O forms after combustion in the catalytic converters of light-duty passenger vehicles and a similarly small amount of HFC-13 4a leaks from the mobile air conditioning units of light-duty passenger vehicles and heavy-duty vehicles. Natural gas transmission and distribution pipelines, services and compressor stations also leak CH_4 to the atmosphere. Because of its role in transporting natural gas, it is conventional to include natural gas transmission in the transportation sector. Nonfuel consumption of lubricants and tire abrasion also contribute small amounts to total transportation sector emissions.

In 2006, GHG emissions from transportation were an estimated 41.0 million CO_2-equivalent tons, not quite double emissions in 1970, which were about 22.6 million CO_2-equivalent tons. Transportation emissions rose consistently until 1999 or 2000, growing at an annual average rate of about 1.9 percent per year. Beginning in 1999, the rate of increase in transportation emissions slowed dramatically, peaking in 2003-5, and declining in 2006. About three-quarters of all transportation emissions are from highway sources and, of these, about 80 percent are produced during the operation of light-duty passenger vehicles. Of nonhighway transportation modes, aviation contributes about 4.4 million CO_2-equivalent tons of emissions. Natural gas pipelines are another significant source, adding annually about 2.4 million CO_2-equivalent tons to the atmosphere, mostly in the form of CO_2 and CH_4.

Table 18: Greenhouse Gas Emissions from Transportation in Minnesota

Transportation Greenhouse Gas Emissions (Million CO_2 - Equivalent Tons)					
	2000	**2003**	**2004**	**2005**	**2006**
Railroads	0.7	0.6	0.8	1.0	0.9
Natural Gas Transmission	2.4	2.4	2.4	2.5	2.4
Aviation	5.6	4.6	4.9	5.0	4.4
Other[◊]	1.6	2.1	1.8	1.9	2.5
Heavy Trucks	6.1	6.4	6.3	6.3	6.2
Light Trucks	11.9	13.0	13.4	13.2	13.2
Cars	12.1	12.5	12.2	11.9	11.4
Total[*]	**40.4**	**41.6**	**41.8**	**41.8**	**41.0**
Natural Gas	2.4	2.4	2.4	2.5	2.4
Petroleum	37.4	38.5	38.7	38.5	37.9
Other Energy from Fossil Fuel[†]	0.1	0.1	0.1	<0.1	<0.1
Other Sources[‡]	0.5	0.7	0.7	0.7	0.7
Total[*]	**40.4**	**41.6**	**41.8**	**41.8**	**41.0**
CH_4	1.2	1.2	1.2	1.2	1.2
CO_2	37.5	38.8	39.0	39.1	38.4
N_2O	1.1	0.9	0.9	0.8	0.7
HFCs	0.5	0.7	0.7	0.7	0.7
Total[*]	**40.4**	**41.6**	**41.8**	**41.8**	**41.0**

[◊]Includes: Military vehicles/equipment, off-highway, buses, marine, motorcycles, recreational vehicles, other on-highway, and mobile air conditioning.
†Includes: Abraded tires, lubricants, and coal.
‡Includes: Mobile air conditioner leakage, and natural gas transmission.
[*]Totals may not add due to rounding.

Between 1990 and 2006, transportation emissions increased by about 9.9 million CO_2-equivalent tons. This increase was divided among light-duty trucks (6.3 million CO_2-equivalent tons), heavy-duty trucks (1.3 million CO_2-equivalent tons), other sources (1.2 million CO_2-equivalent tons), and aviation (0.6 million CO_2-equivalent tons). Emissions from passenger cars decreased 0.4 million CO_2-equivalent tons.

During the period of stabilizing transportation emissions (2000-2006), total emissions increased only 0.7 million CO_2-equivalent tons. Emissions from aviation declined about 1.2 million CO_2-equivalent tons and emissions from passenger cars declined about 0.7 million CO_2-equivalent tons, offset by increases from light-duty trucks (1.3 million CO_2-equivalent tons), heavy-duty trucks (0.1 million CO_2-equivalent tons), railroads (0.2 million CO_2-equivalent tons), and other sources (0.9 million CO_2-equivalent tons). Between 2005 and 2006, total transportation emissions decreased by 0.8 million CO_2-equivalent tons.

Waste Management

Emissions from waste management are shown in Figures 20, 21, and Table 19. In the MPCA GHG Emission Inventory, waste management includes solid waste management and publicly owned domestic wastewater treatment, but does not include industrial wastewater treatment, which is included in the industrial sector. The methods used to develop the estimates are discussed in Section 4.

Most emissions from waste management in Minnesota are from landfills receiving mixed municipal solid waste (MMSW). Most of the remainder is from municipal wastewater treatment. Minor sources of GHGs from waste management include, in order of importance, industrial landfills, rural open burning, other solid waste incineration, solid waste composting, yard waste composting, landfills gas flares and landfill operations and recycling. MMSW combusted to produce energy is mainly treated in the electric power sector.

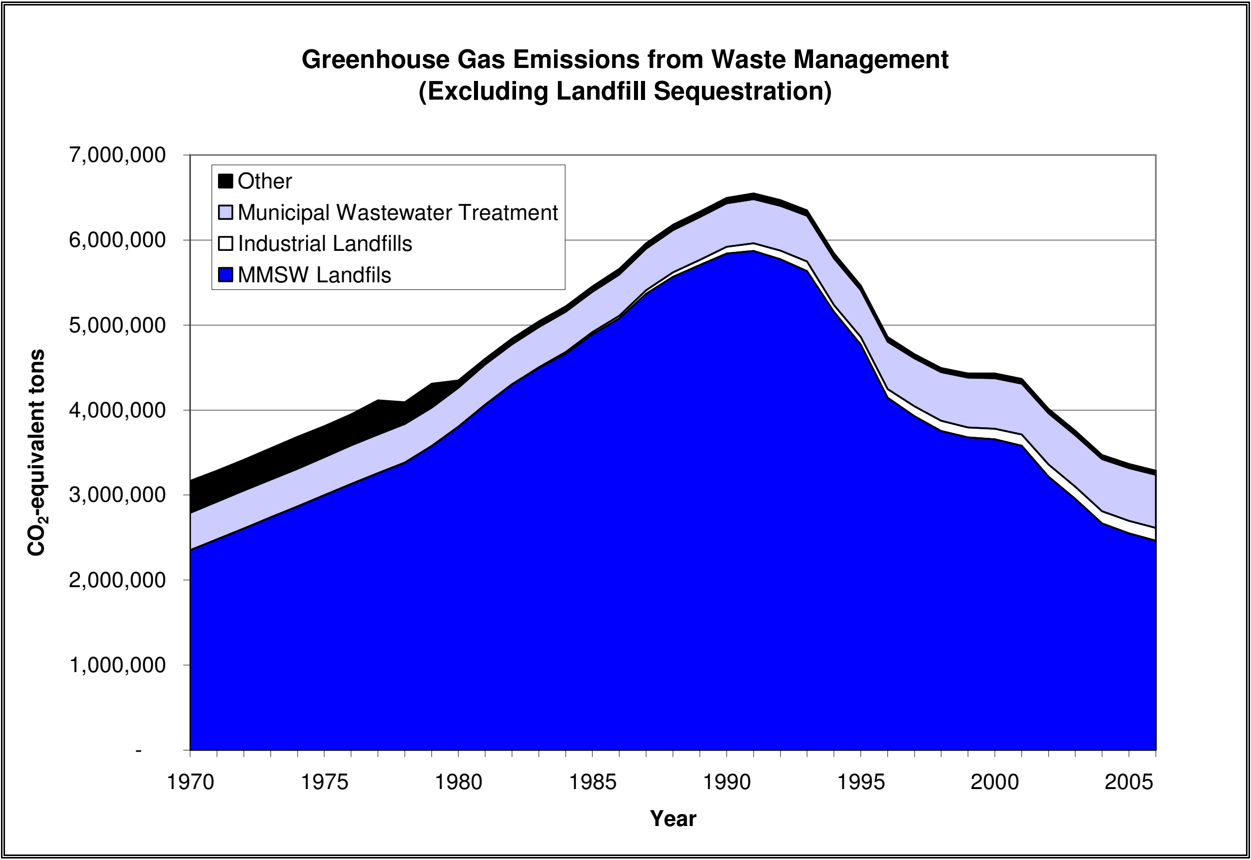
Table 19: Greenhouse Gas Emissions from Waste Management in Minnesota

Waste Greenhouse Gas Emissions (Million CO_2 - Equivalent Tons)					
	2000	**2003**	**2004**	**2005**	**2006**
Fossil Fuels	0.2	0.2	0.2	0.1	0.1
Other Sources and Biomass†	0.1	0.1	0.1	0.1	0.1
MMSW Landfills	3.4	2.7	2.5	2.4	2.3
Industrial Landfills	0.1	0.1	0.1	0.1	0.2
Municipal Wastewater Treatment‡	0.6	0.6	0.6	0.6	0.6
Total*	**4.4**	**3.8**	**3.5**	**3.4**	**3.3**
Sequestration in D/C Landfills	(1.6)	(1.7)	(1.8)	(1.8)	(1.9)
Total*	**2.9**	**2.0**	**1.7**	**1.6**	**1.4**
CH_4	4.1	3.4	3.1	3.0	2.9
CO_2	(1.3)	(1.5)	(1.6)	(1.6)	(1.7)
N_2O	0.2	0.2	0.2	0.2	0.2
Total*	**2.9**	**2.0**	**1.7**	**1.6**	**1.4**

†Includes: Landfill gas combustion and flaring, incineration of medical, industrial, commercial, and other waste, composting mixed municipal waste and yard waste, and rural open burning,
‡ Includes: municipal wastewater treatment, sewage, and land application of biosolids.
*Totals may not add due to rounding.

Direct GHG emissions from waste management rose consistently from 1970, more than doubling to peak in 1991, at an estimated 6.5 million CO_2-equivalent tons. Since 1991, emissions have declined by about 50 percent. Of the 3.3 million tons emitted in 2006, about 2.9 million CO_2-equivalent tons, or about 90 percent, was in the form of CH_4. At the peak of emissions in 1991, landfill CH_4 comprised about 85 percent of all estimated emissions from waste management. Since 2000, direct emissions from waste management have declined by about one-quarter, at an average annual rate of 4.9 percent per year.

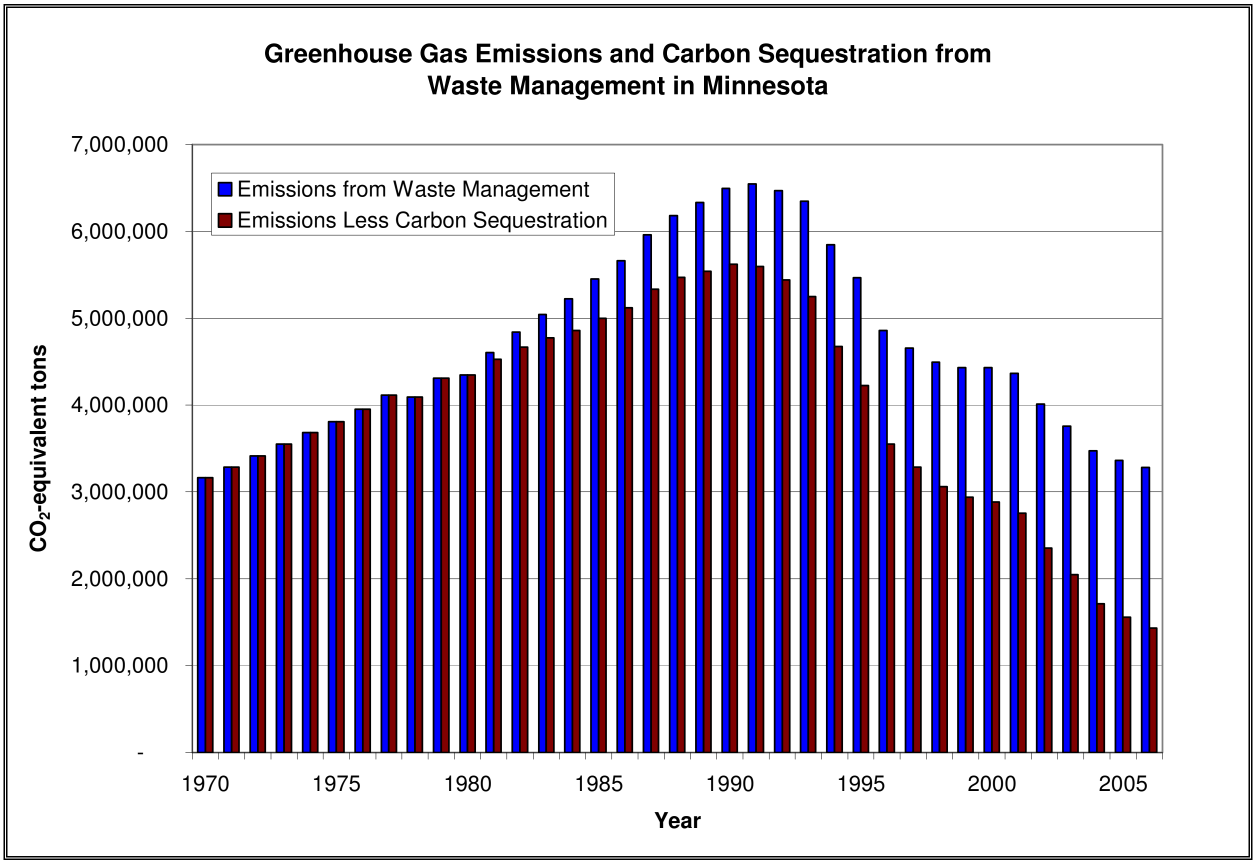
Figure 20: Greenhouse Gas Emissions from Waste Management (Excluding Landfill Sequestration)



An estimated 0.5 million tons of carbon is now sequestered annually in wood-based products in Minnesota demolition and construction landfills, offsetting about 1.9 million tons of emitted CO_2 from other sources. This is up from about 0.9 million tons of carbon in 1990 and 1.6 million tons in 2000 (Figure 21).

Net emissions are the difference between direct emissions of GHGs less any CO_2 that is removed from the atmosphere and is permanently stored as wood in demolition and construction landfills. Net emissions from waste management in 2006 were an estimated 1.4 million CO_2-equivalent tons, down from 1.6 million CO_2-equivalent tons in 2005, 2.9 million tons in 2000, and 5.6 million CO_2-equivalent tons at the peak of emissions from solid waste management in 1990.

Figure 21 Greenhouse Gas Emissions and Carbon Sequestration from Waste Management in Minnesota



Section 7: Greenhouse Gas Emissions by Activity: 1970-2006

Greenhouse gases also can be organized by major activity. Within the MPCA GHG Emission Inventory, major activities are energy use and fuel production; waste management; industrial processes, and agriculture and other activities. Substantial amounts of energy are used in agriculture, waste management and industrial processes. To avoid double counting, energy use in waste management, and in agricultural and industrial production is treated as part of the energy system. Only nonenergy process emissions are included in the waste management, agriculture and industrial process totals shown below.

Energy Use and Fuel Production

Energy use and fuel production comprises all activities that result in the production and use of useful energy. This includes the combustion of solid waste to produce useful energy for commercial sale and all energy use in agriculture, waste management and in industrial processes. Also included are finished fuels production and transportation and, by legislative requirement, out-of-state electricity generation to service Minnesota electricity demand. In the MPCA GHG Emission Inventory, the energy sector also encompasses electricity and natural gas transmission and distribution and the working fluids of transportation and heating and cooling equipment.

Specific energy-related activities include fossil fuel combustion, biomass combustion,[18] the combustion of solid waste[19] and organic chemicals, flue gas desulfurization, electricity transmission and distribution, net electricity imports, hydroelectric reservoirs, natural gas pipelines and compressor stations, industrial and transportation lubricants, and refrigerants.

In 2006, total GHG emissions from energy-related activities in Minnesota, including imported electricity, were an estimated 129.5 million CO_2-equivalent tons, down from an estimated 131.3 million CO_2-equivalent tons in 2005 but up from about 126.5 million CO_2-equivalent tons in 2000. Since 1970, energy sector GHGs have been increasing at an average rate of 1.2 percent per year.

The trend in emissions from energy use and fuel production is shown in Table 20 for selected years since 2000 by fuel type and, where noncombustion emissions are involved, other noncombustion sources. The 36-year trend, stretching back to 1970, is shown in Figure 22 using the same categories. The historical trend breaks down into roughly the three periods noted in Section 5 for all statewide emissions: 1970-1985, a period of no or slow growth in emissions; 1985-1998, a period of rapid growth in emissions; and 1998-2006, in which emissions growth plateaued and then began to decline.

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[18] N_2O and CH_4 emissions only
[19] N_2O, CH_4 plus CO_2 emissions from the petrochemical part of the waste

Table 20: Greenhouse Gas Emissions from Energy Use in Minnesota

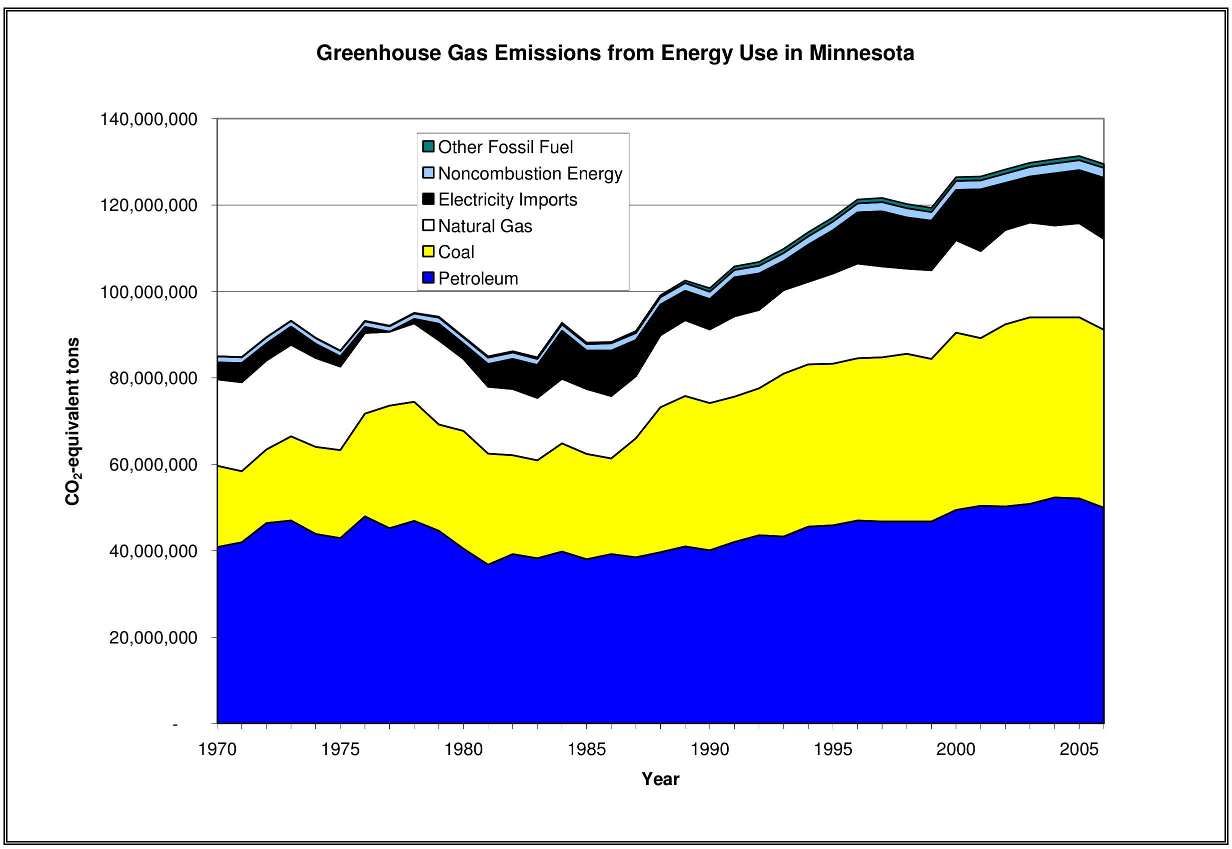
Greenhouse Gas Emissions from Energy Use in Minnesota (Million CO_2-equvalent tons)					
	2000	**2003**	**2004**	**2005**	**2006**
Agriculture	2.2	2.2	2.8	2.8	2.8
Commercial	6.5	6.8	6.6	6.7	6.0
Electric Generation	51.6	54.8	54.3	55.2	56.0
Industrial	15.4	13.5	14.4	14.5	14.3
Residential	10.3	10.8	10.5	10.1	9.2
Transportation	40.4	41.6	41.8	41.8	41.0
Waste	0.2	0.2	0.2	0.1	0.1
Total*	**126.5**	**129.8**	**130.6**	**131.3**	**129.5**
Coal	41.0	43.2	41.7	41.9	41.2
Natural Gas	22.6	23.1	22.4	23.0	22.1
Petroleum	49.4	50.9	52.3	52.1	50.0
Electricity Imports	11.6	10.7	12.1	12.3	14.1
Biomass CH_4 and N_2O†	0.9	0.9	0.9	0.9	0.9
Other Energy Process‡	0.9	1.1	1.1	1.1	1.1
Total*	**126.5**	**129.8**	**130.6**	**131.3**	**129.5**

†Includes: Only N_2O and CH_4 emissions associated with biomass combustion, such as ethanol, biodiesel, wood and wood wastes, black liquor, and DDGS syrup.

‡Includes: electricity transmission, coal storage, limestone use, flue gas desulfurization, hydroelectric reservoirs, oil refining, refrigeration, mobile air conditioning, and natural gas transmission.

*Totals may not add due to rounding

Figure 22: Greenhouse Gas Emissions from Energy Use, Fuel Production and Transportation in Minnesota



The in-state combustion of petroleum and petroleum products is the largest emission source from the energy sector, accounting in 2006 for about 39 percent of emissions, down from almost 50 percent in the early- to mid-1980s. The in-state combustion of coal is the second largest source of emissions. Unlike petroleum, its share of total emissions has approximately doubled since the mid-1980s; much of the growth in energy sector emissions since 1985 has come from an expansion in coal combustion. While the emission of GHGs from the combustion of natural gas has increased by about one-third since 1985, compared to 1970 emissions are unchanged. Emissions from electricity imported into Minnesota in 2006 were an estimated 14.1 million CO_2-equivalent tons, up from 11.6 million CO_2-equivalent tons in 2000. In aggregate, emissions from the combustion of other fossil fuels and from noncombustion sources were an estimated two million CO_2-equivalent tons, or less than two percent of total energy sector emissions, and were largely unchanged from earlier years.

Figure 23: Greenhouse Gas Emissions from Energy Use in Minnesota

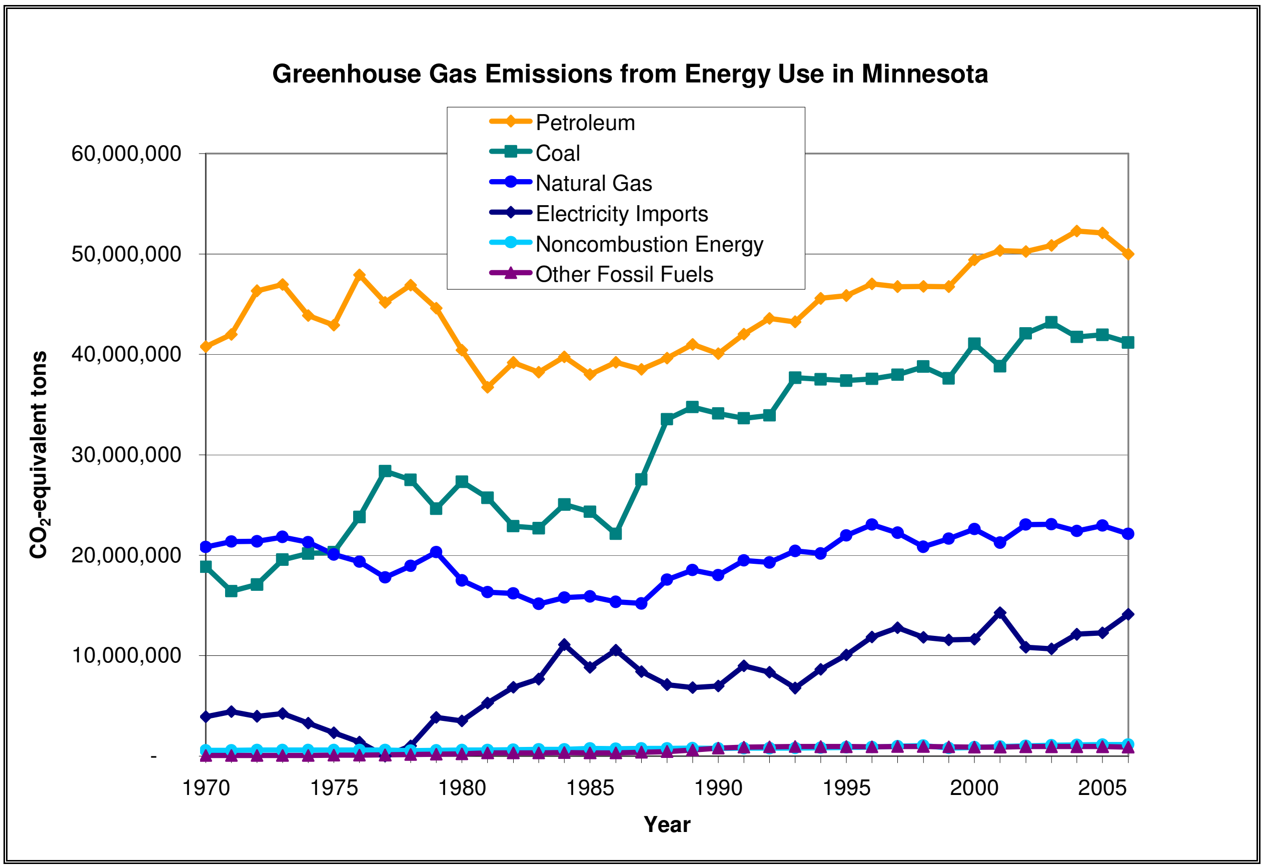


Figure 23 shows the same information using linear plots rather than stacked areas to represent the data. Since the early- to mid-1980s, emissions from most fuels and sources have been rising, generally peaking between 2002 and 2005. Emissions from in-state coal use peaked in 2003, those from petroleum use in 2004, and those from natural gas combustion in 2002. By contrast, GHG emissions associated with the generation of out-of-state of power imported into Minnesota peaked a first time in 2001 and a second time in 2006, reaching 14 million CO_2-equivalent tons in 2006. Prior to the early- to mid-1980s, in the case of natural gas and refined petroleum products GHG emissions had been generally falling or flat and, in the case of coal, prior to 1986, emissions showed an increase and reduction (Table 21).

Table 21: Average Annual Rate of Change in Energy Sector GHG Emissions

Average Annual Rate of Change	
Coal	
1970-1977	+5.8%/yr
1977-1986	-2.8%/yr
1986-2006	+3.3%/yr
Petroleum	
1970-1981	- 0.9%/yr
1981-2004	+1.5%/yr
2004-2006	-2.2%/yr
Natural Gas	
1970-1987	-2.0%/yr
1987-1996	+4.7%/yr
1996-2006	-0.4%/yr

Most of the reduction in emissions that occurred between 2005 and 2006 resulted from a reduction in petroleum use. Of the total 1.8 million CO_2-equivalent ton reduction in emissions between 2005 and 2006, reduced use of petroleum contributed 2.1 million CO_2-equivalent tons, reduced coal use 0.7 million CO_2-equivalent tons, and natural gas 0.9 million CO_2-equivalent tons, together offsetting the 1.8 million CO_2-equivalent ton increase in emissions associated with net electricity imports into Minnesota.

The trend in emissions from energy use, fuel production, and fuel transportation is shown by economic sector in Figure 24. In Figure 24, electric power sector emissions include GHGs emissions associated with net electricity import. Emissions are dominated by releases from the electric power sector and transportation. By 2006, emissions from transportation and electric power generation together had come to comprise three-quarters of all energy sector emissions. In 1970, those two sectors accounted for about half of all GHG emissions from energy. Between 1970 and 2006, GHG emissions from power generation and transportation more than doubled, increasing by about 53 million CO_2-equivalent tons. Over this same period, GHG emissions from all other sectors taken together declined by about 8 million CO_2-equivalent tons.

Emissions depend on and are calculated from fossil fuel throughput through the economy. The trend in energy consumption in Minnesota for 1970-2006 is shown in Figure 25, along with the calculated percent of fossil fuel energy of the total. As of 2006, about 85 percent of the energy used in Minnesota was produced through the combustion of fossil fuels. In 2006, an estimated 1.8 quadrillion BTUs (1,800,000,000 million BTUs or 1.8 Quads) were consumed in Minnesota. This includes both commercial and noncommercial energy sources and the energy used to generate imported power. Of this, an estimated 1.5 Quads were fossil fuel-based and about 0.3 Quads were nonfossil. Between 1970 and 2006, total energy use in Minnesota increased from about 1.1 Quads to about 1.8 Quads, or by about two-thirds. Over this same period, nonfossil fuels as a percent of total energy use increased from about five percent to about 15 percent.

Figure 24: Greenhouse Gas Emissions from Energy Use in Minnesota

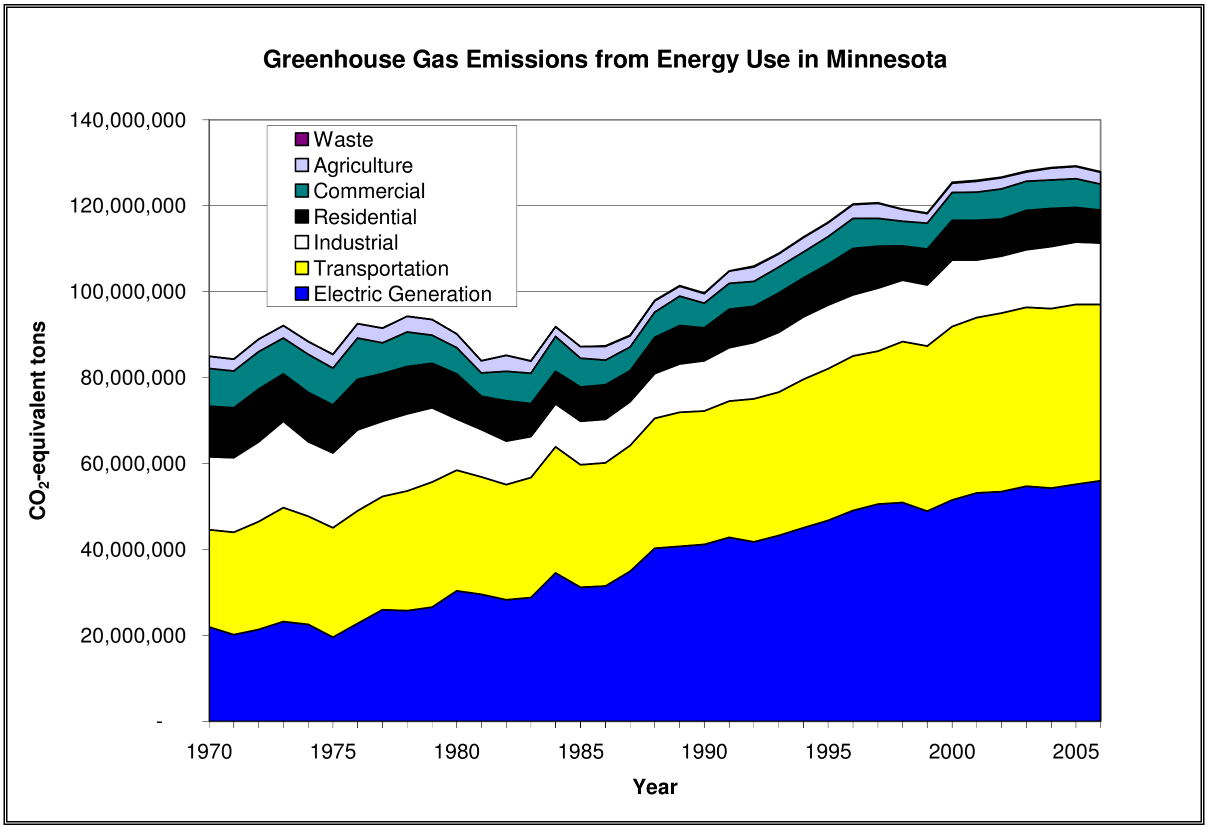


Table 22: Changes in Emissions from Energy Use by Sector Between 1970 and 2006

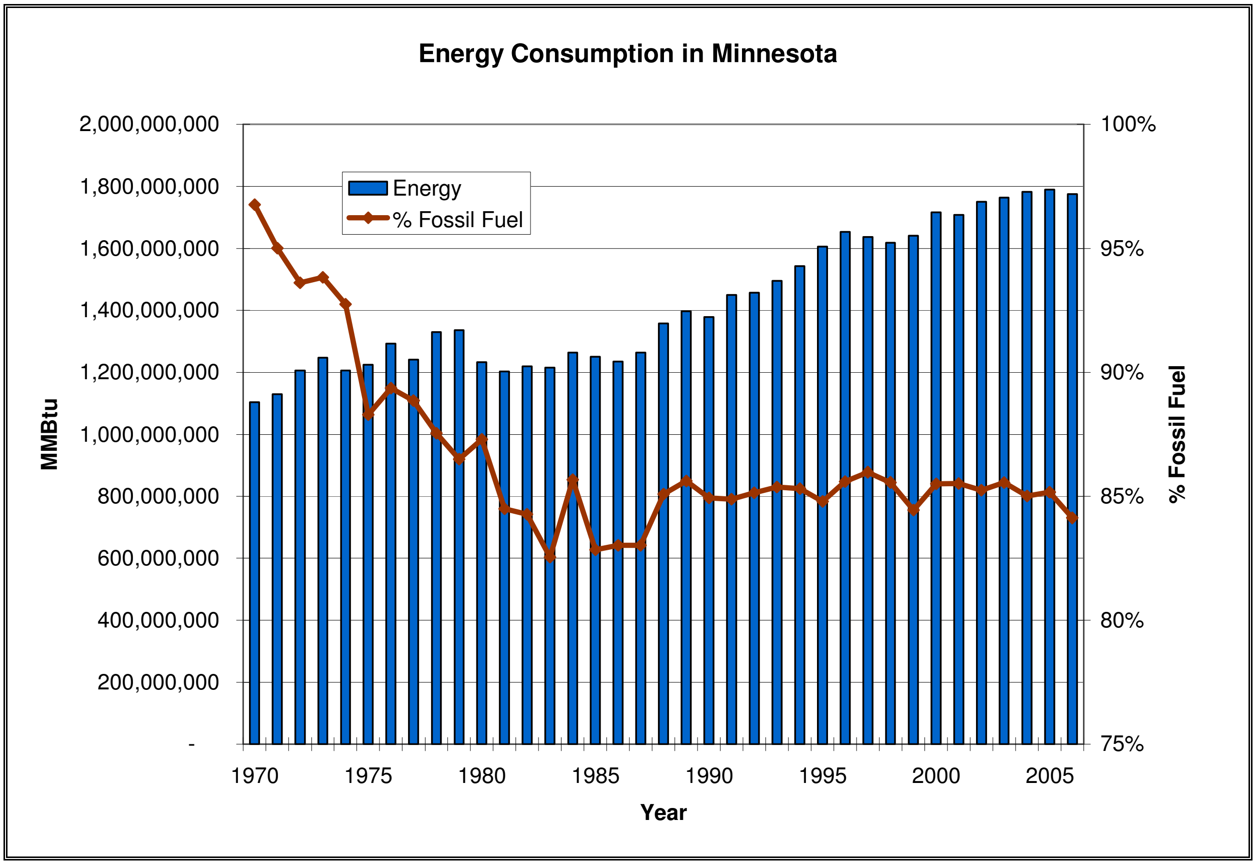
Changes in Emissions from Energy Use by Sector Between 1970 and 2006 (Million CO_2-equivalent Tons)	
Electric Generation	+34.1
Transportation	+18.4
Agriculture	-0.1
Industrial	-2.6
Waste Management	+0.1
Commercial	-2.8
Residential	-2.6
Total*	**+44.5**

*Totals may not add due to rounding.

As just noted, the data shown in Figures 24 and 25 account for the fuel used to generate electricity out-of-state that services in-state Minnesota demand. To develop the estimates shown in Figure 24, a nine-state/province[20] average heat rate for electricity generation was used.[21] The fossil energy component of electricity imports was estimated from the calculated 9-state rate of CO_2 emissions per MWh generated in relation to the rate of CO_2 emission per MWh in Minnesota and Minnesota electric power sector fuel use over the 36-year period of record.

The long-term trend in the fossil fuel component of total Minnesota energy use has been flat since at least 1988, at about 85 percent. Some slight improvement is evident in the record over the last few years.

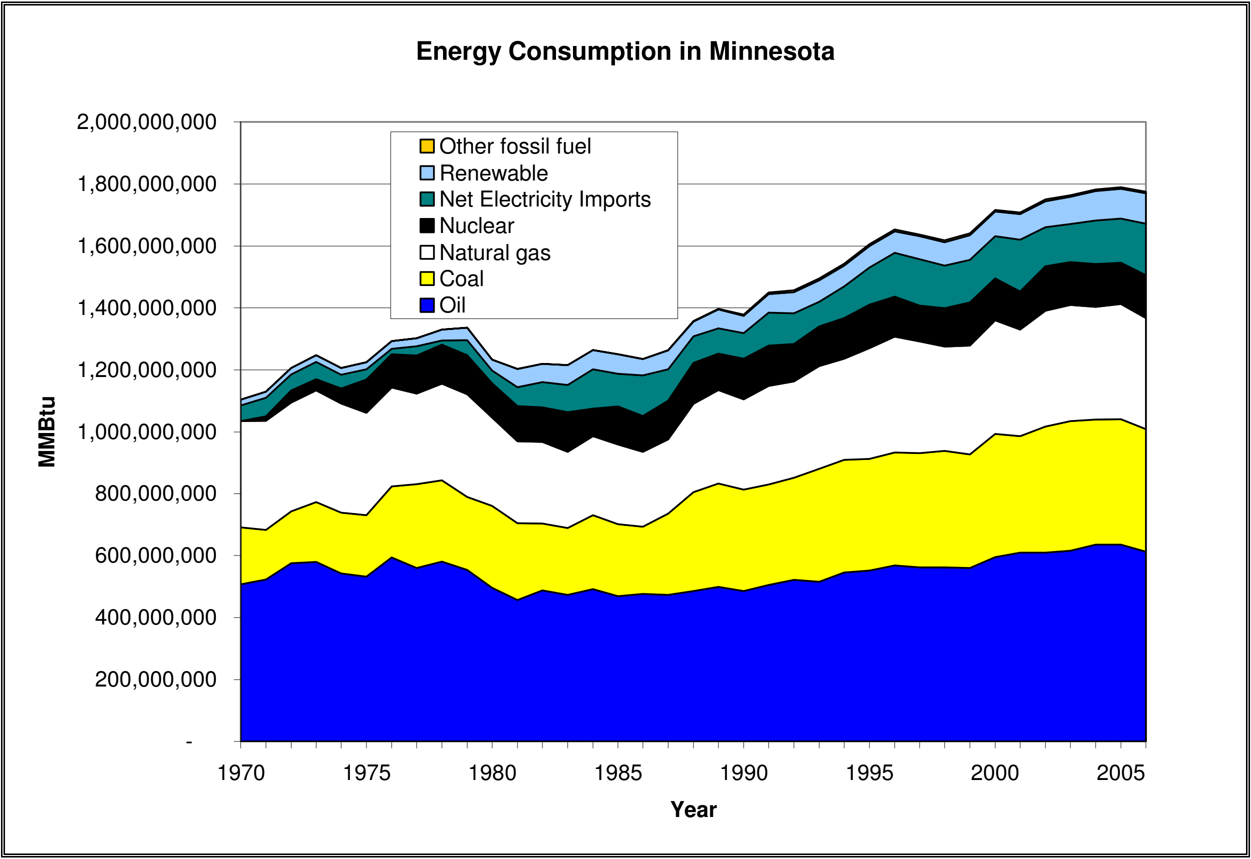
Figure 25: Energy Consumption in Minnesota



Total energy use in 2006 is estimated as 1.8 Quads, down about two percent from 2005 levels. This is shown in Figure 26. Of the roughly 1.8 Quads of consumption in 2006, an estimated 77 percent was associated with the in-state combustion of fossil fuels. Another roughly eight percent was associated with in-state nuclear generation and about six percent with in-state renewable energy. An estimated nine percent was used to generate electricity imported from out-of-state.

[20] Wisconsin, Iowa, South Dakota, North Dakota, Manitoba, Nebraska, Missouri, Kansas and Wyoming.
[21] Heat rate is the amount of energy in Btu's needed to generate one kWh of electricity

Figure 26: Energy Consumption in Minnesota



Finally, the long-term trend favors continued growth in statewide energy use. From 1970 to 2006, statewide energy use grew about 60 percent. More recent evidence suggests a plateauing of energy use at or near present-day levels, or at least a substantial slowing of the rate of growth. Since 2000, total statewide energy use has increased only three percent or at an average annual rate of less than 0.6 percent per year. Total energy use declined between 2005 and 2006. This situation will bear watching in future GHG progress reports, as it impacts how we understand the natural evolution of the energy system and the actions that might be needed to reduce GHG emissions. A detailed modeling approach may be called for to resolve the question.

Agriculture Processes

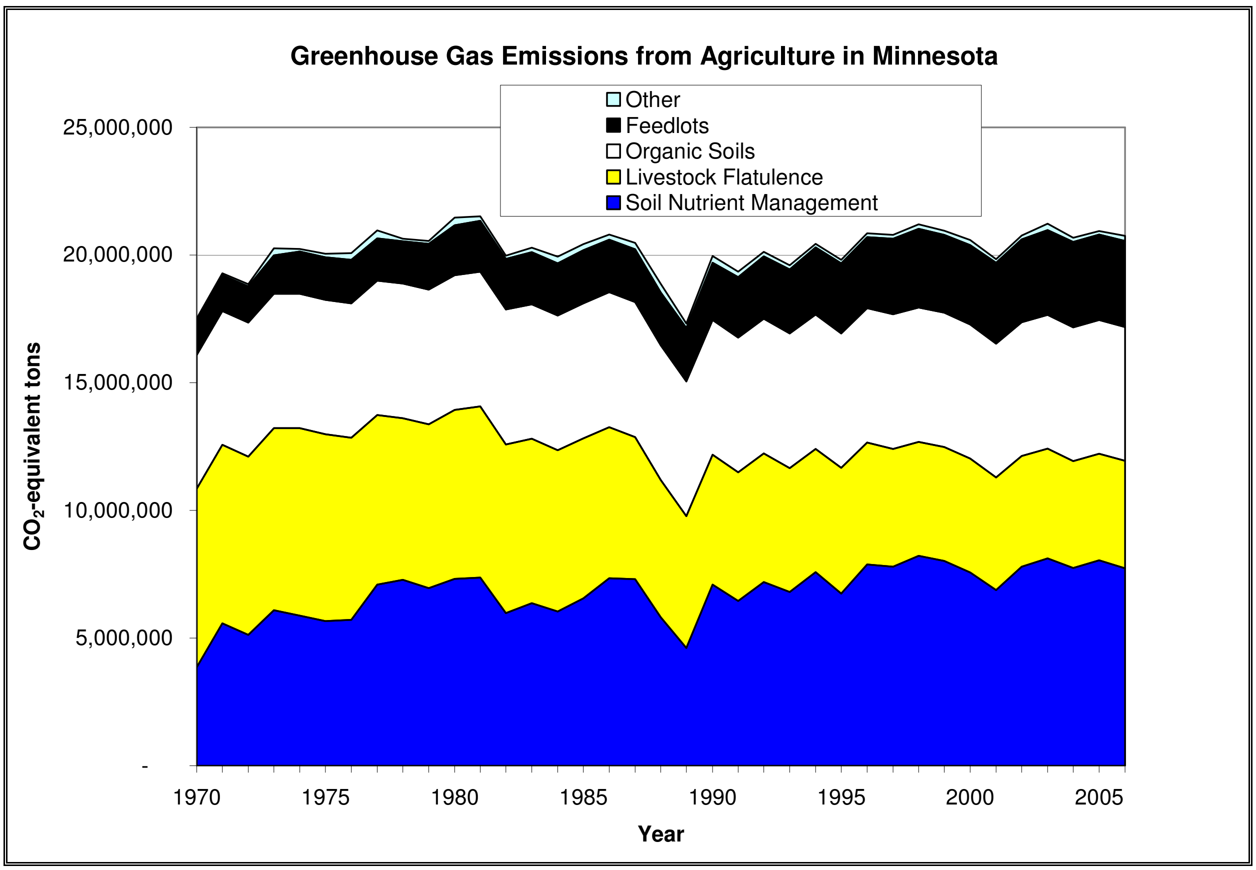
Agricultural process GHG emissions result primarily from soil nutrient management, the cultivation of histosol or peaty soils, the management and storage, and livestock flatulence. Small amounts of GHGs are emitted to the atmosphere as a result of the cultivation of wild rice and from wildfire.[22] A small placeholder emission of CO_2 from wind-eroded soils is also included. To avoid double counting, agricultural fuel use is treated as part of the energy system.

[22] Wildfire is included as part of emissions from agroforestry.

The trend in emissions from nonfuel agricultural activities is shown in Figure 27. Because agricultural fuel use is a relatively small contributor to emissions, the trend in emissions that is shown in Figures 13 and 27 is similar to total emissions from all agricultural sources, including those from agricultural fuel uses (Figure 13). GHG emissions from nonfuel agricultural activities have been relatively constant at 20 to 21 million CO_2-equivalent tons over much of the period of record.

As described in Section 6, soil nutrient management is the single largest contributor to emissions. Since roughly 1995, estimated emissions from soil nutrient management have been constant at about eight million CO_2-equivalent tons per year. Prior to 1995, emissions from soil nutrient management were at a slightly lower level, about six to seven million CO_2-equivalent tons per year. By contrast, estimated emissions from livestock flatulence have fallen consistently since 1970, from about seven million CO_2-equivalent tons in 1970 to an estimated 4.2 million CO_2-equivalent tons in 2006.

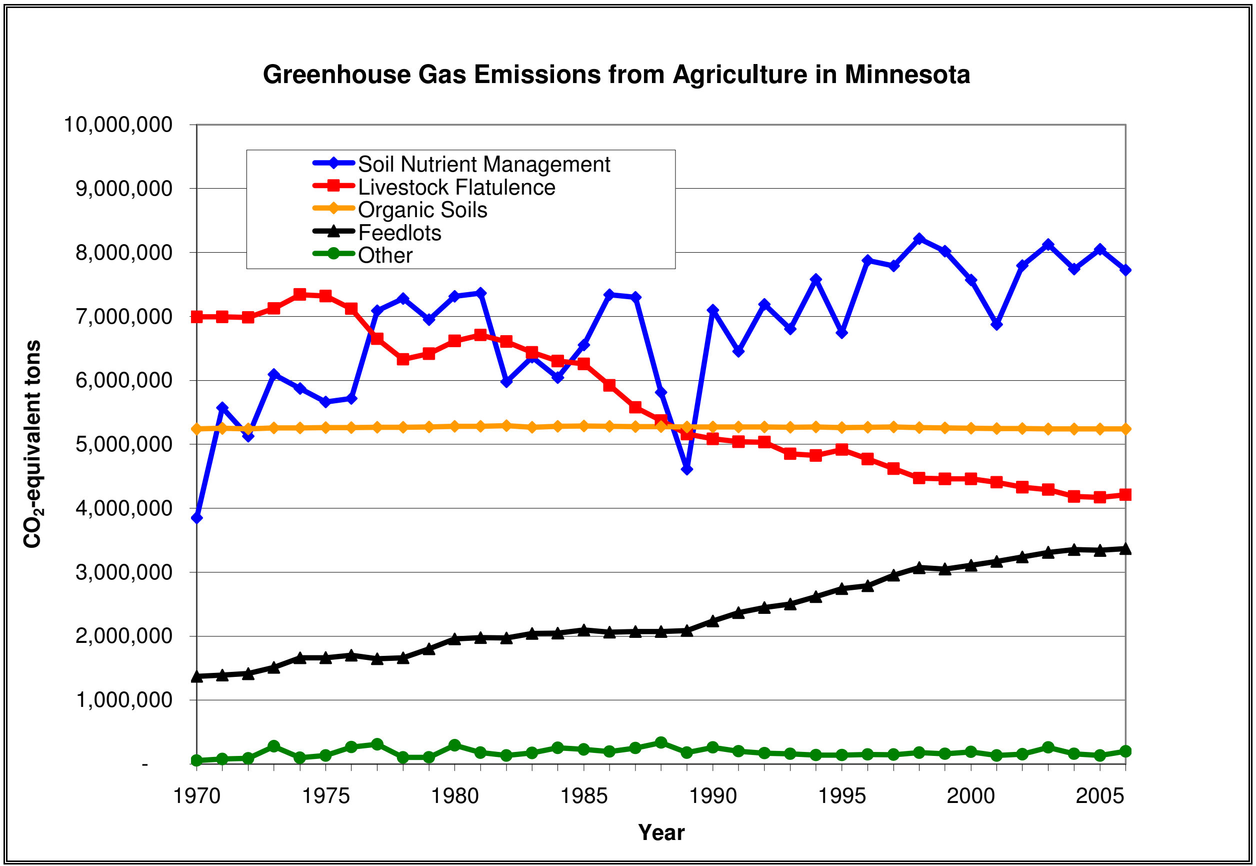
Figure 27: Greenhouse Gas Emissions from Agriculture in Minnesota



The trend in emissions, source by source, is shown in Figure 28. Particularly striking is the inverse relationship of livestock flatulence emissions and emissions from manure management. This reflects both the persistent contraction in Minnesota's dairy industry and the expansion of swine production. Cattle flatulence accounts for about 90 percent of all livestock flatulence emissions. By contrast, about half of all manure management emissions are from swine manure storage and half from cattle manure management.

Figure 28 also shows the estimated trend in other agricultural sources of GHGs. Emissions from the cultivation of histosols are estimated to be constant over time, but, as discussed in Section 4, this is less a reflection of actual trends than an artifact of limited data. Emissions of GHGs from minor sources have been stable or slightly rising at about 0.3 million CO_2-equivalent tons.

Figure 28: Greenhouse Gas Emissions from Agriculture in Minnesota



Trends in the underlying activities leading to the emission of GHGs from Minnesota agriculture are presented in Figures 29 and 30. The long-term trend in nitrogen inputs to Minnesota soils are shown in Figure 29. Nitrogen availability is the controlling factor in soil nutrient management emissions. With the exception of nitrogen fixed in the soils by legumes, nitrogen availability and input are the same. Nitrogen inputs to soils (and to surface waters through runoff and leaching) have been generally increasing throughout the period of record, from an estimated 0.8 million tons of nitrogen in 1970 to 1.6 million tons of nitrogen in 2006.

Figure 29: Agricultural Inputs of Nitrogen to Soils and Waters in Minnesota

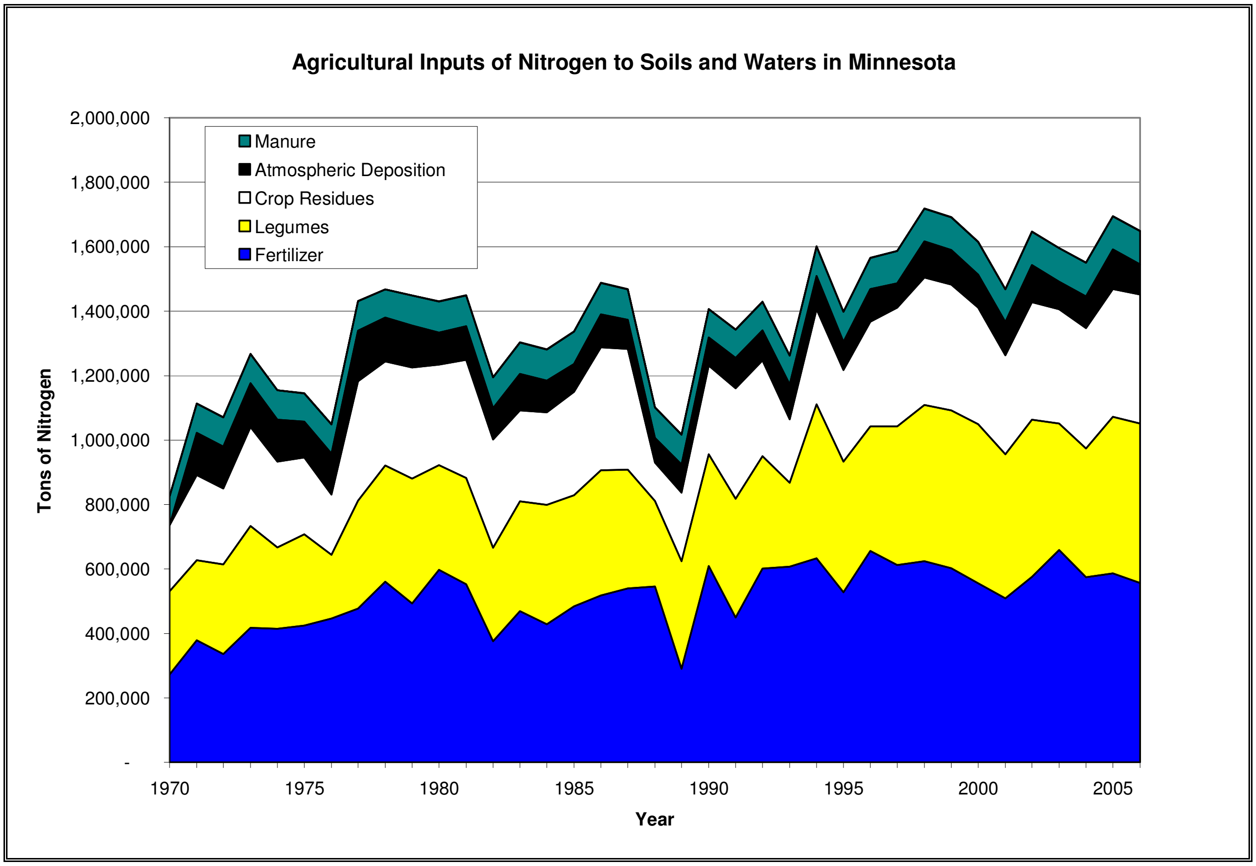
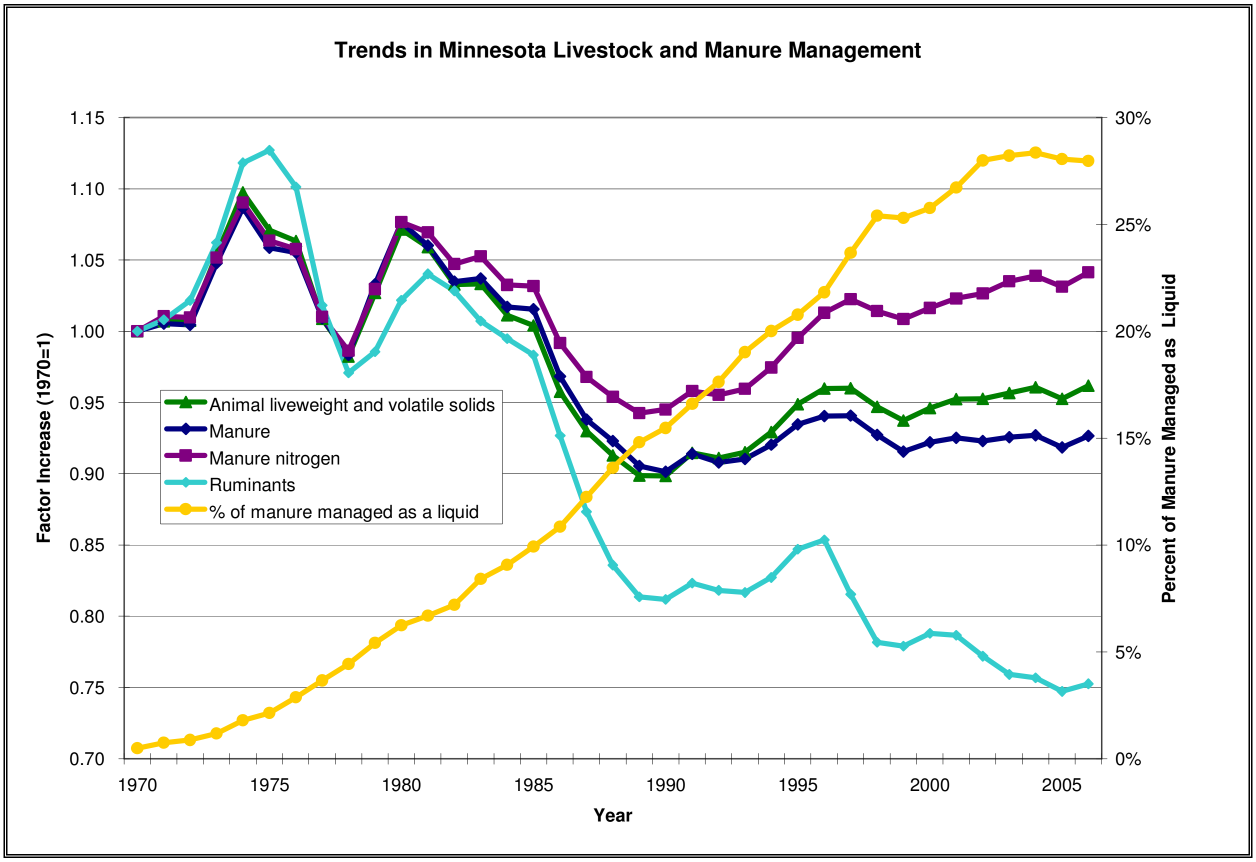


Figure 30 shows long-term trends in livestock liveweight on Minnesota farms and feedlots, manure production, and manure nitrogen and volatile solids production. To facilitate comparison, these are shown as a factor increase above 1970 levels. Figure 30 also shows the trend in the form in which manure is managed. Most methane generated from stored manure is produced from manure stored in a liquid or slurry form. The rate of methane generation also depends on the amount of volatile solids that is available for anaerobic decomposition. Both total manure volatile solids and the percent of manure that is managed as a liquid or slurry have been increasing since the late 1980s, leading to the increasing emission of CH_4 from manure storage ponds, tanks and pits.

Prior to the late 1980s, total manure volatile solids production was in decline, almost 10 percent from 1970 levels, while the percent of manure managed as a liquid rose rapidly from one to almost 15 percent. Total manure volatile solids tracks closely with both total animal liveweight on farms and feedlots and, to a slightly lesser degree, with total manure production.

CH_4 emissions from livestock flatulence correlate closely with the size of the ruminant livestock or cattle herd in the state. In animal unit equivalents (1,000 lb-equivalents), total head of ruminant cattle declined about 35 percent from their peak in 1974 to 2006, roughly mirroring the 40 percent decline in estimated livestock flatulence emissions over this period.

Figure 30: Trends in Minnesota Livestock and Manure Management



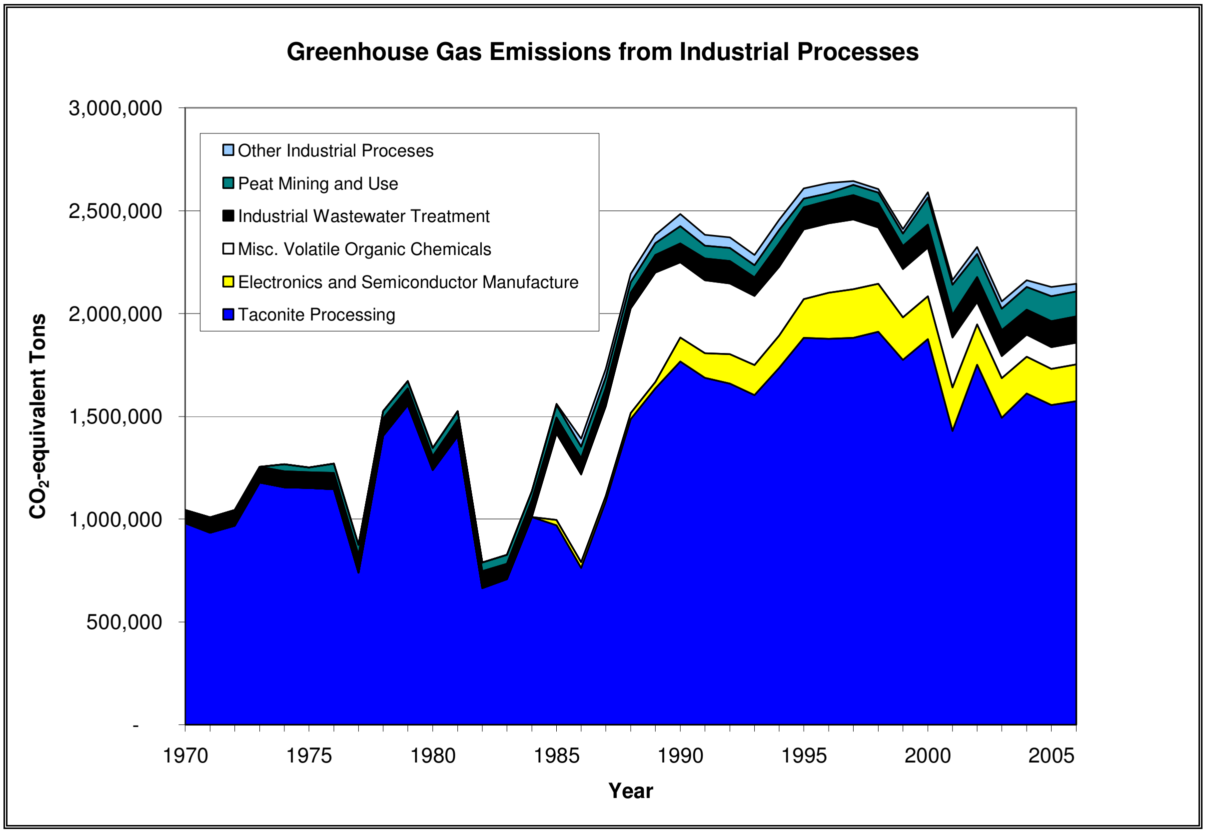
Finally, N_2O emissions from stored manure vary directly with nitrogen availability and inversely with manure wetness. Since 1990, total manure nitrogen has increased about 10 percent, while liquid/slurry management of manure, as a percent of total manure management, has increased 10 percent. Prior to 1990, the trend favored decreasing total manure nitrogen and enhanced used of liquid/slurry manure storage, leading to generally declining manure N_2O emissions.

Industrial Processes

Industrial processes include all noncombustion activities in the industrial sector. Industrial activities that involve combustion for energy production are included as energy sector activities. The industrial processes included are taconite production, the manufacture of semiconductors, electronic components and precision equipment, steel production, glass production, the manufacture of organic chemicals and ammonia, and industrial wastewater treatment.[23]

[23] A small number of minor emission sources that are not properly industrial sources, but do not easily fit into the other categories are included here: soaps, detergents, shampoos, food additives, medical N_2O, and propellant use of HFC-134 and HFC-152a.

Figure 31: Greenhouse Gas Emissions from Industrial Processes



The trend in estimated industrial process emissions is shown in Figure 31 by source. CO_2 emission from taconite production is the single largest emission source, accounting for about 70 percent of process emissions over much of the record. The emission factor that is used to estimate noncombustion emissions from taconite processing is a provisional emission factor developed during recent MPCA environmental review processes. If additional test data shows that a change in this provisional emission factor is needed, the emission factor will be revised.

Total industrial process emissions in 2006, excluding fuel use, were about 2.1 million CO_2-equivalent tons, essentially unchanged from 2005. Industrial process emissions peaked in the mid-1990s. Emissions in earlier years are low, an artifact of limited data availability for industrial process sources emitting GHGs to the atmosphere. Data needed for the estimation of some industrial process emissions are available only from the mid-1980s onward. The use and subsequent emission of chlorinated and organic solvents is the most obvious example of this.

Our confidence in the trend in industrial process emissions, particularly for recent years, since 1995 or 2000, is low, due largely to the absence of information on most industrial and commercial processes using HFCs, PFCs and SF_6. Emissions from industrial and commercial refrigeration and space cooling, magnesium casting, industrial foam blowing, and fire suppression are yet to be adequately treated. Use of HFCs, PFCs and SF_6 in these applications began in earnest only in the late 1990s. It is plausible that total emissions from these could add additional one million CO_2-equivalent tons to the inventory.

Waste Management

Waste management includes all solid waste disposal and treatment activities and domestic wastewater treatment. To avoid double counting, waste disposal activities that involve the combustion of solid waste or landfill gas for purposeful energy production are not included. These activities are treated in the discussion of emissions from energy use and fuel production. Energy used in waste processing also is not included, again to avoid double counting.

Total emissions from waste management include GHG emissions from domestic wastewater treatment, solid waste disposal or treatment through landfilling, composting, or burning, and biogenic carbon stored permanently in demolition and construction landfills. Emission sources include landfills receiving mixed municipal waste (MMSW), industrial landfills, landfill flares, MMSW and yard waste composting, rural open burning, the incineration of general medical waste and pathological waste, hazardous waste incineration, wastewater sludge incineration, private septic systems, centralized domestic wastewater treatment plants and discharges, and land application of wastewater sludge. Demolition and construction landfills act as carbon storage.

Table 23 shows the trend in total emissions from waste activities for selected years. With the exception of the roughly 0.1 million CO_2-equivalent tons of energy-related emissions inventoried in the energy system, the values in Table 23 are identical to those reported in Table 19. Total emissions in 2006 were an estimated 1.4 million CO_2-equivalent tons, down from 1.6 million CO_2-equivalent tons in 2005 and 2.9 million CO_2-equivalent tons in 2000.

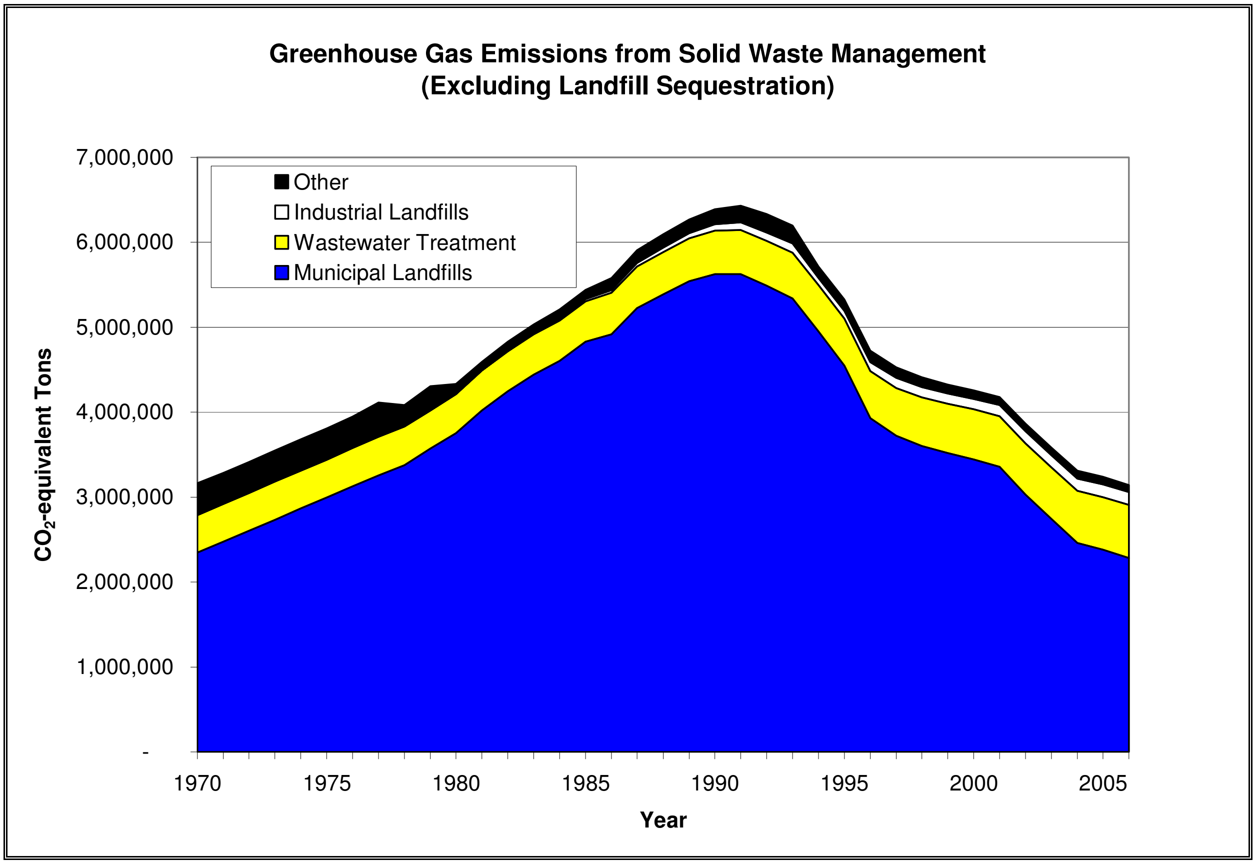
Table 23: Greenhouse Gas Emissions from Solid Waste Management

Greenhouse Gas Emissions from Solid Waste Management					
	2000	**2003**	**2004**	**2005**	**2006**
Municipal Landfills	3.4	2.7	2.5	2.4	2.3
Industrial Landfills	0.1	0.1	0.1	0.1	0.2
Wastewater Treatment	0.6	0.6	0.6	0.6	0.6
Other	0.1	0.1	0.1	0.1	0.1
Total*	**4.3**	**3.6**	**3.3**	**3.2**	**3.1**
Sequestration in D/C Landfills	(1.6)	(1.7)	(1.8)	(1.8)	(1.9)
Total*	**2.9**	**2.0**	**1.7**	**1.6**	**1.4**

*Totals may not add due to rounding.

The trend in direct emissions from waste management activities (again without of the energy system components of the waste management system), is shown in Figure 32. Emissions peaked in 1990 and have been declining since. Three-quarters of emissions are in the form of CH_4 from landfills receiving MMSW; most of the rest is from domestic wastewater and its treatment in centralized, publicly-owned wastewater treatment plants or in private septic systems.

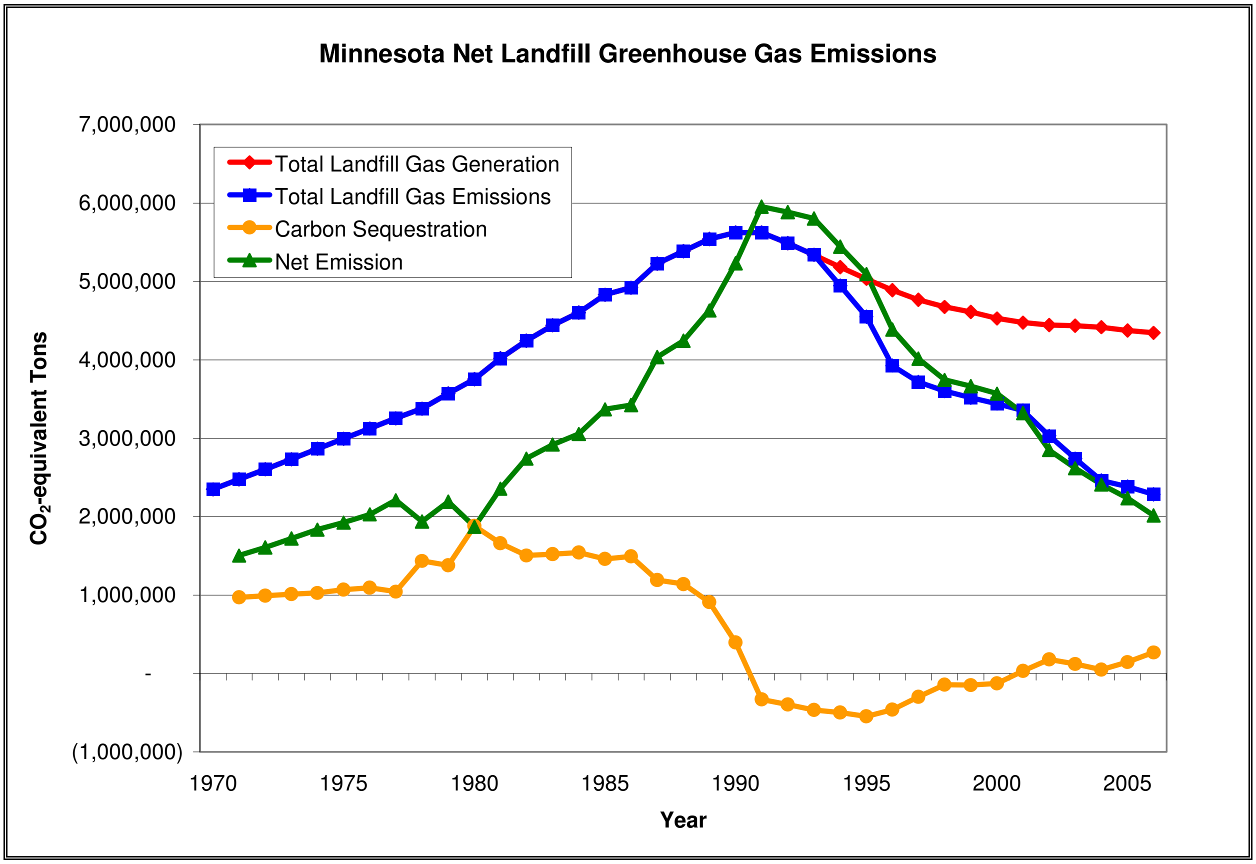
Figure 32: Greenhouse Gas Emissions from Solid Waste Management



The methods used to estimate CH_4 generation and emissions from landfills receiving MMSW are discussed in Section 4. Emissions from landfills that actively capture landfill gas are calculated from gas collection records and an assumed 75 percent gas collection efficiency. Total gas production from these landfills is the sum of gas captured to produce energy or for flaring and landfill gas that is escapes to the atmosphere or is oxidized in landfill cover soils. Emissions from landfills that do not actively capture landfill gas are estimated using LandGEM, an EPA landfill gas generation model.

Figure 33 shows total emissions from both classes of landfills (squares), plus total landfill gas generation prior to capture (diamonds), net biogenic carbon stored in the landfill (circles), and net landfill emissions (triangles). Net landfill emission is the difference between CH_4 emitted to the atmosphere and landfill biogenic carbon storage. Total landfill gas generation in 2006 was an estimated eight billion cubic feet, which if emitted to the atmosphere, would have totaled roughly 4.3 million CO_2-equivalent tons. Total emissions in 2006 were an estimated 2.2 million CO_2-equivalent tons. The difference, some 2.1 million CO_2-equivalent tons, was the landfill gas that was captured and destroyed at the landfill in flares, engines or gas turbines. This is equal to about half of all CH_4 generated in Minnesota landfills that still receive MMSW or that in the past have received MMSW and are now closed.

Figure 33: Minnesota Net Landfill Greenhouse Gas Emissions

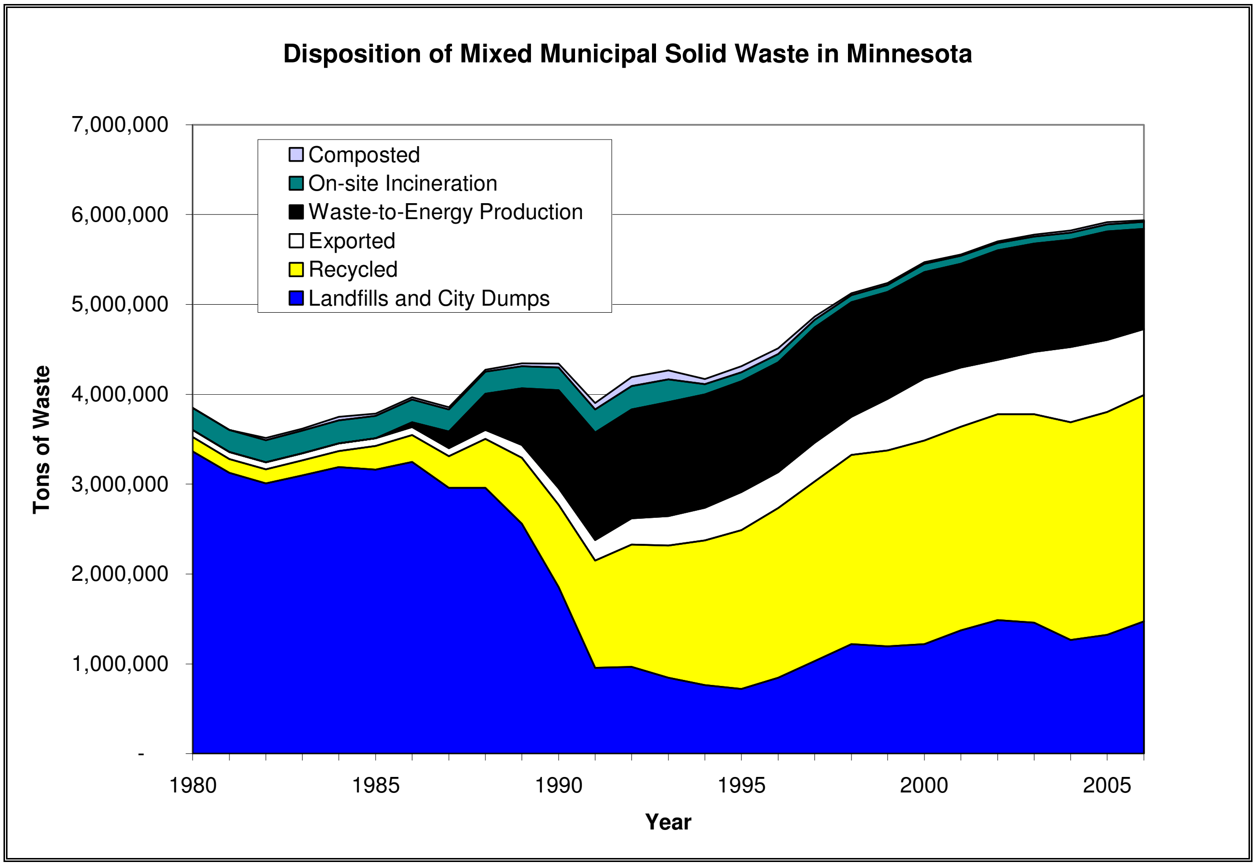


Active landfill gas capture began in the mid-1990s. By 2000, 11 landfills were actively capturing landfill gas, leading to the destruction of an estimated 1.2 million CO_2-equivalent tons of CH_4, or about one-quarter of all landfill gas generated in these landfills. In 2005, 4.4 million CO_2-equivalent tons of CH_4 were generated in these landfills, 2.0 million CO_2-equivalent tons were emitted[24], and 2.4 million CO_2-equivalent tons of CH_4 were captured and destroyed.

Even without active gas capture, landfill emission of CH_4 would have declined. Based on the modeling, in absence of active gas capture, CH_4 emissions from landfills receiving MMSW would have declined from a peak of about 5.7 million CO_2-equivalent tons in 1990 to about 4.3 million CO_2-equivalent tons in 2006 (diamonds, Figure 33). Beginning in the late 1980s, the amount of MMSW received at Minnesota landfills declined precipitously. By 1991, total receipts had declined to less than one-quarter of earlier totals. In general, without new decomposable waste, high rates of landfill CH_4 production cannot be sustained. In the MPCA GHG Emission Inventory, by 2006, total landfill gas generation was about 25 percent below its 1990 peak.

[24]Accounting for 10% oxidation in the cover soil.

Figure 34: Disposition of Mixed Municipal Solid Waste in Minnesota



The reconstructed history of waste generation in Minnesota and waste receipts at disposal or recycling facilities by receipt type is shown in Figure 34. By 2006, total estimated MMSW generation in Minnesota had reached almost six million tons per year. These data are from the MPCA, *SCORE Report* for 1991-present and, for prior years, from MPCA, *Annual Solid Waste Report*, MPCA, *Annual Solid Waste Policy Report*, and other estimates. In 2006, an estimated 40 percent of Minnesota's MMSW was recycled, 20 percent was combusted in waste-to-energy facilities, another one-quarter was landfilled in-state, and the remaining 15 percent was exported, to landfills outside of Minnesota. GHG emissions produced at waste-to-energy facilities are treated as energy sector emissions. Emissions from exported landfilled solid waste are not inventoried.

To return to Figure 33, the estimates shown do not account for the effect of leachate recirculation of landfill CH_4 production or emissions. A number of landfill operators practice, or will begin, leachate recirculation, but it is not yet clear how this will impact active landfill emissions of CH_4.

The modeled variability of biogenic carbon storage in landfills receiving MMSW is shown in Figure 33 (circles). Landfill storage is the difference between the carbon received in the form of paper, wood and food waste, and the carbon lost to the atmosphere in the form of CH_4 and CO_2. Between 1970 and about 1985, Minnesota landfills receiving MMSW had a net positive biogenic carbon balance, and after 1990 became net carbon emitters. In recent years, these landfills have begun to store biogenic carbon again, but, based on the modeling, they are only barely doing so.

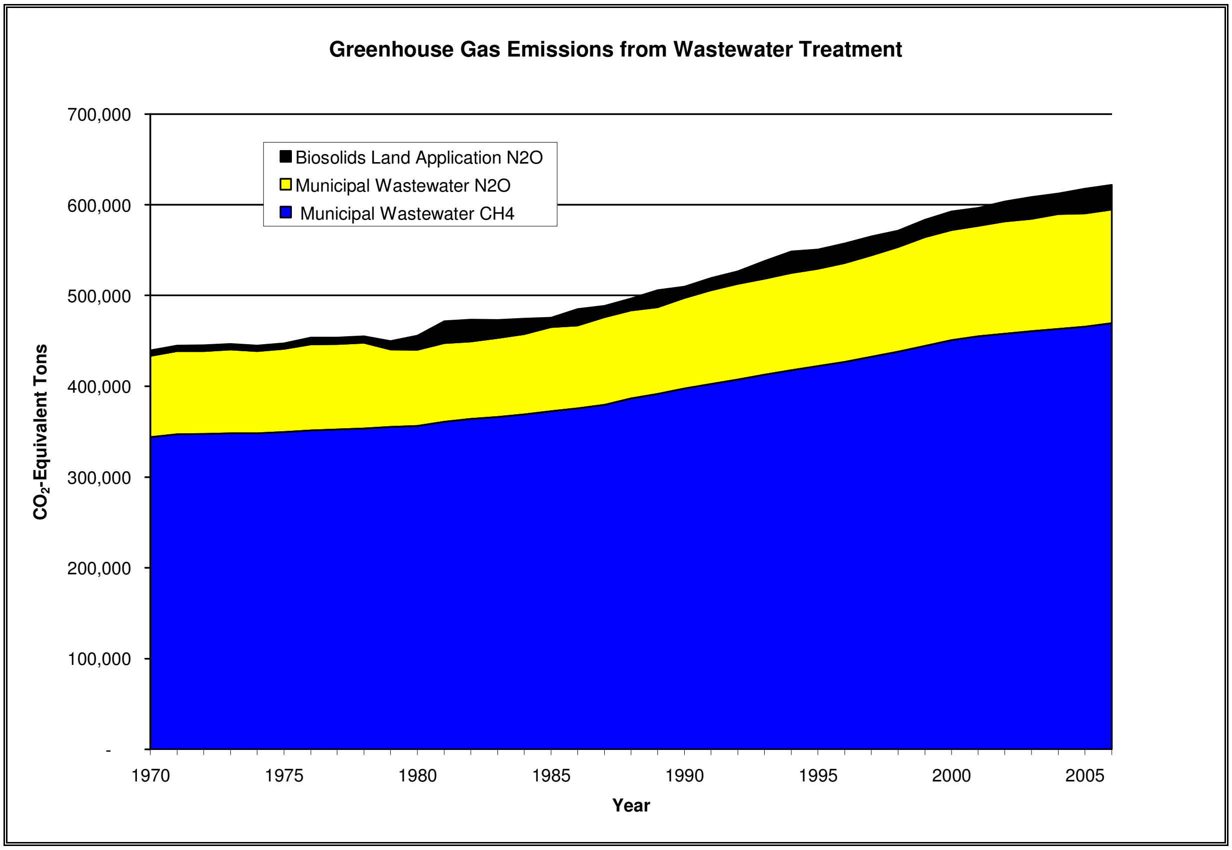
Within the standard framework, we say that one CO_2-equivalent ton of carbon stored terrestrially offsets a ton of emitted CO_2 if all of it remains in storage for roughly 50 years or half remains in storage for 100-years. We calculate carbon storage in a single year as the incremental gain or loss of carbon storage in the system. Combining these ideas, we say that the observed incremental gain of carbon in the system offsets an equivalent amount of emitted fossil CO_2 to the degree and only to the degree that that gain can be shown likely to persist for the requisite 50 to 100 years into the future. Figure 33 gives us no basis to conclude that persistence is either likely or necessary. For this reason, interannual changes in carbon storage in landfills receiving MMSW are not included in MPCA Emission Inventory totals.

To demonstrate the relative insensitivity of the calculation to what is assumed about landfill carbon sequestration, in Figure 33 we have calculated net landfill emissions as if landfill carbon sequestration could be valued at nominal rates (circles). As can be seen, net emissions follow landfill CH_4 emissions closely since 1990, suggesting that at least for the period since 1990, the calculation is relatively insensitive to how or whether landfill carbon storage is treated.

The same is not true about biogenic carbon stored in demolition and construction landfills. Much or most of the biogenic carbon buried in these landfills is in the form of wood, which is quite resistant to microbial degradation. Most carbon that is stored in these landfills in the form of wood today will remain in place in these landfills 100 years from now. The amount of carbon stored in this class of landfill has been increasing at an average annual rate of three percent per year since 2000, offsetting by 2006 almost 1.9 million CO_2-equivalent tons of GHG emissions. Since biogenic carbon storage in demolition and construction landfills results from the natural turn-over of the housing and commercial building stock, a continuation of this trend should be expected.

Finally, emissions from domestic wastewater treatment are shown in Figure 35 by gas. These are driven mostly by population growth. Estimated emission amounts, however, are small. Most estimated emissions from domestic wastewater treatment are in the form of methane produced in anaerobic treatment facilities lacking biogas capture.

Figure 35: Greenhouse Gas Emissions from Wastewater Treatment



Section 8: Forestry

It is a convention to track net CO_2 emissions from forests through changes in forest stocks. If in any one year the stock of forest carbon is concluded to have declined, a net emission of carbon in the form of CO_2 is said to have occurred. Living forest biomass is about 30 percent carbon.

The trend in carbon stocks on Minnesota forestland[25] is shown in Figure 36 and Table 24. As discussed in Section 4, in the case of the living part of the forest, these data were calculated from estimates of total forest biomass developed by the US Forest Service in their Forest Inventory Assessments. Carbon stocks in the forest floor were estimated from modeled rates of carbon accumulation and decay by stand age and forest type. The carbon stored in the mineral horizons of forest soils is not included in these estimates.

Table 24: Carbon Storage in Forests

Carbon Storage in Forests (Million Tons)					
	1990	**2003**	**2004**	**2005**	**2006**
Total Green Biomass	886.0	876.0	874.5	880.6	883.6
Total Oven Dry Biomass	467.6	465.2	464.8	468.4	470.4
Carbon in Biomass	503.4	495.3	494.1	497.7	500.7
CO_2 equivalent in Biomass	1,845.8	1,816.2	1,811.9	1,824.8	1,835.8
Rate of Change in Carbon Storage		-0.1	-0.2	0.7	0.6
Million Acres of Forestland	16.7	16.2	16.2	16.3	16.4
Tons of Carbon/Acre	30.2	30.5	30.5	30.5	30.5

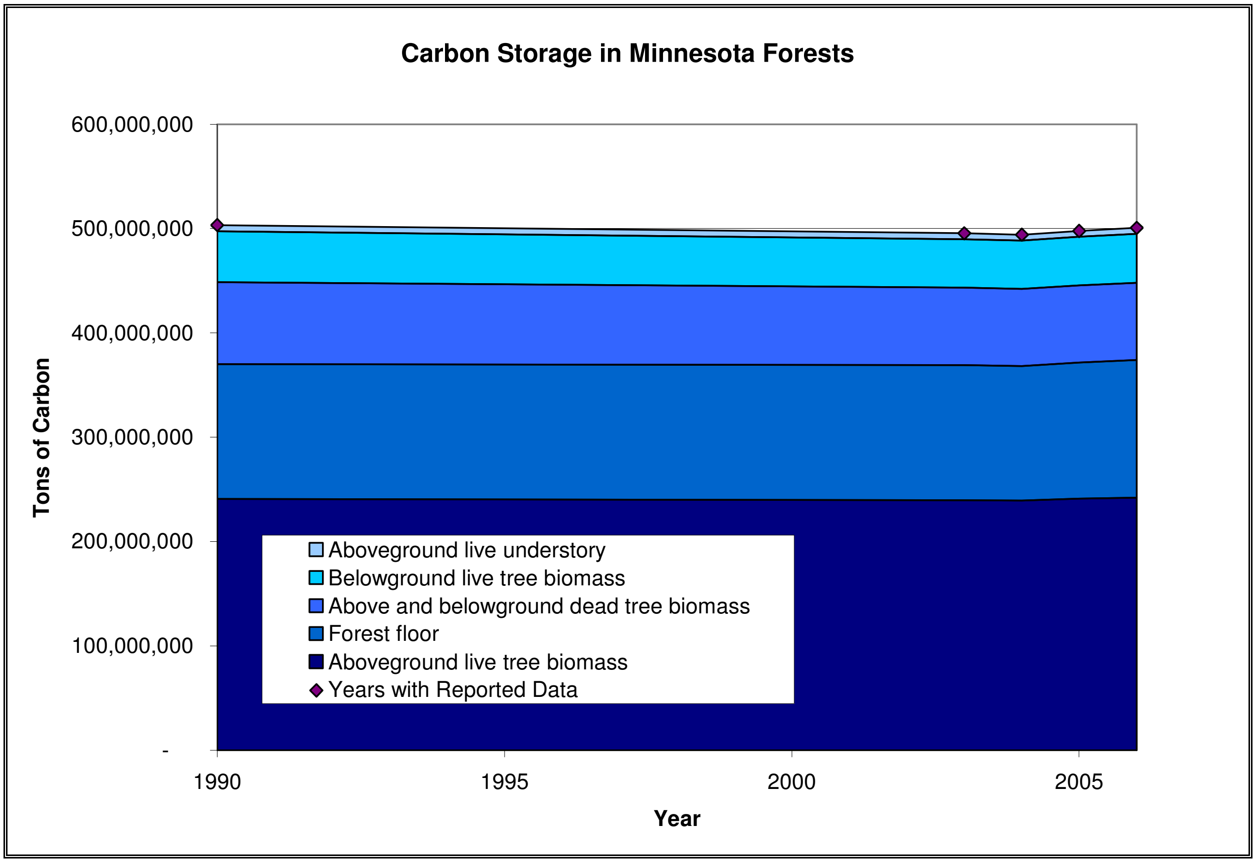
The US Forest Service Forest Inventory Assessments (FIA) for Minnesota stretch back to 1936. However, until 1990, they treated only the merchantable part of the tree and only trees found on timberland. Timberland is defined as forestland that is capable of producing crops of industrial wood in excess of 20 cubic feet per acre per year. Since 1990, the FIA has been expanded to include publicly-owned reserved forestland such as is found in the Boundary Waters Canoe Area and unproductive forestland. Beginning in 2003, the published estimates of total oven dried tons of live forest biomass are from surveys of one sample plot for every 6,000 acres of forest, cycling over five years.

The amount of carbon stored on Minnesota forestland in 2006 was an estimated 500 million tons. This includes above and below ground living and dead biomass and the litter on the forest floor. Carbon storage has been generally constant over the period of record, decreasing slightly from 1990 to 2004, followed by a slight increase between 2004 and 2006. Net emissions are the difference between total carbon tied up in forest stocks at any two points in time. Respecting the limits of the data, between 2005 and 2006 Minnesota forests may have acted as a sink or removal

[25] Forestland is defined as a minimum of one acre, with growing trees of any size with a 16.7 total stocking value or higher, or former undeveloped forest capable of becoming forest land. Roadside or shelterbelt forests must have a crown width of at least 120 feet. Forestland is divided into two categories (timberland and other forestland), and may be further classified as reserved if harvesting is prohibited.

mechanism for atmospheric CO_2, removing roughly 11 million tons from the atmosphere. Between 2003 and 2004, Minnesota forests may have been a net source of 4.3 million tons of CO_2 emissions.

Figure 36: Carbon Storage in Forests



The record of forest carbon storage is relatively short. As a result, whether the 2004-2006 trend is real or an artifact of sampling and reporting methods will have to wait until more data are assembled. Because of the shortness of the historical record, it may take years to determine if a trend exists in the data.

In addition, the short period of record leaves open the question of whether any increase or loss of carbon stored in forests will persist. As noted in Section 3, if forest carbon stocks show an upward trajectory lasting decades, it reasonably can be assumed that observed near-term changes in carbon storage will persist for decades. If forest carbon stocks show a downward trajectory lasting decades, an observed near-term loss of carbon reasonably can be assumed to be permanent.

As it currently stands, the record of forest carbon storage is too short to support a conclusion in either direction. It is possible that the observed increase in forest carbon storage from 2005 to 2006 will persist long enough to offset an equivalent amount of CO_2 emitted from fossil fuel combustion. It is also possible that the observed increase will prove transient and not represent permanent growth of the forest carbon pool. In the MPCA GHG Emission Inventory, we include in state-wide emissions totals only those emissions to or removals from the atmosphere that unambiguously can be said to have persistent effects on climate for at least 50 years and perhaps as long as 100 years. Removals of atmospheric CO_2 through forest growth and regrowth do not appear to meet this criterion.

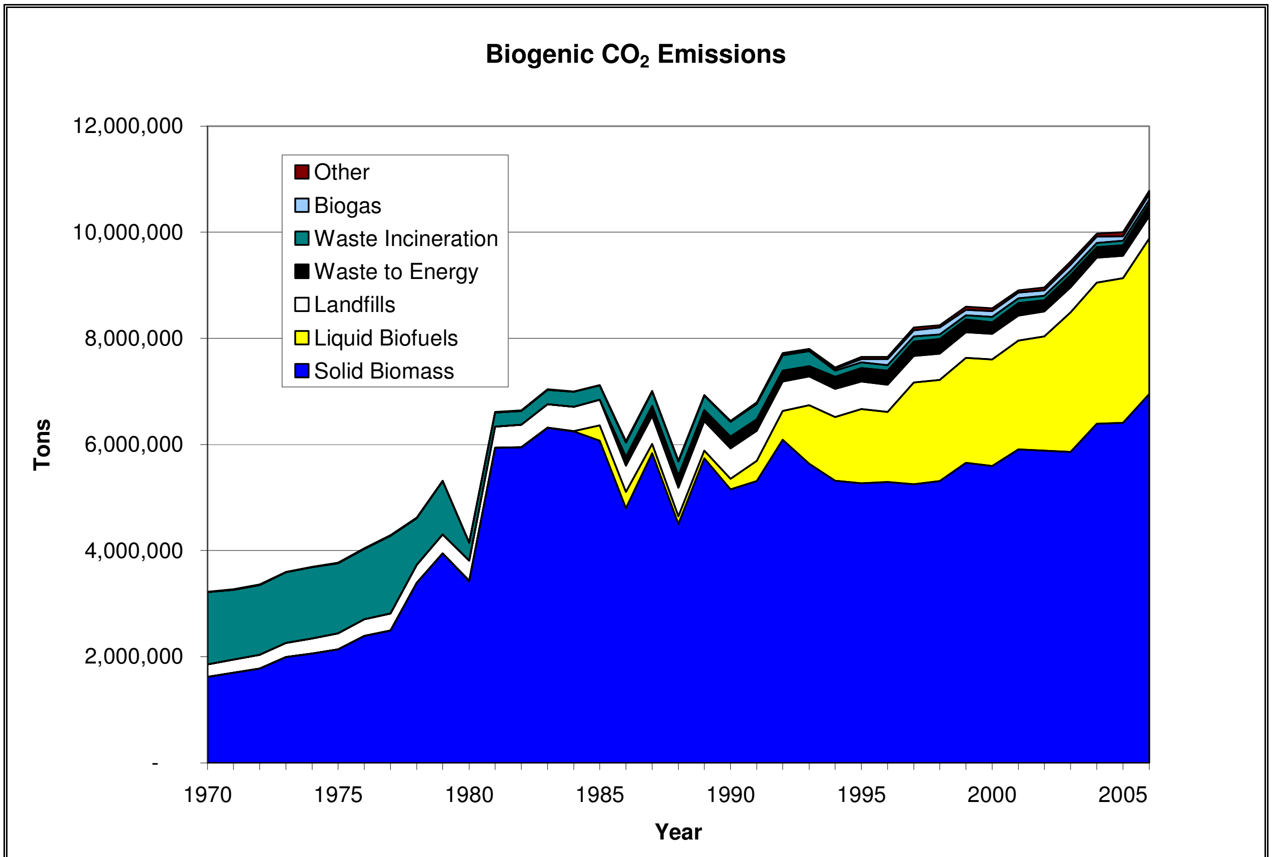
For this reason, as noted in Section 3, we track observed changes in forest carbon, but they are kept separate from the other emission and removal totals. Presumably, as more data are assembled, this situation will be clarified.

Section 9: Biogenic CO_2

As discussed in Section 3, emissions of biogenic CO_2 result from the combustion of solid biomass, liquid biofuels or biogas used as fuels. Solid biomass includes fuels like wood, sawdust, bark and the biomass component of solid waste. Liquid biofuels include ethanol and biodiesel. Landfill gas and digester gas are examples of biogas. Biogenic emissions of CO_2 also result from structural fires, wild fires, prescribed burning, agricultural residue burning, agricultural tillage, landfills and normal ecosystem respiration.

It is customary not to include emissions of CO_2 from biomass burning in state-level GHG emission totals. In GHG inventories, these are tracked indirectly through net changes in the level of carbon stocks in forests, soils, landfills, etc. (Sections 3 and 8). It is, however, customary to inventory the emission of biomass CO_2 and report these totals separately.

Figure 37: Biogenic CO_2 Emissions



In the MPCA GHG emission inventory, nonfossil, or biogenic, emissions of CO_2 are tracked only for combustion sources and landfills. The trend in emissions is shown in Figure 37 and Table 25 by fuel type and source. Biogenic emissions of CO_2 totaled 10.8 million tons in 2006, up from 10 million tons in 2005. Since 1990, emissions have been increasing about three percent per year.

Table 25: Biomass CO_2

Biomass CO_2 (Million Tons)					
	2000	**2003**	**2004**	**2005**	**2006**
Liquid Biofuels	2.0	2.6	2.7	2.7	2.9
Biogas	0.1	0.1	0.1	0.1	0.1
Waste to Energy	0.2	0.2	0.2	0.2	0.2
Other Solid Biomass	5.6	5.9	6.4	6.4	7.0
Waste Incineration	0.1	0.1	0.1	0.1	0.1
Landfills	0.5	0.5	0.5	0.4	0.4
Other	0.1	0.1	0.1	0.1	0.1
Total*	**8.6**	**9.5**	**10.1**	**10.0**	**10.8**

*Totals may not add due to rounding.

Section 10: Indicators of Trends

Measures of emission intensity are useful in understanding what has and has not happened and why. It is common to express emissions in relation to total population, household numbers, economic output, total energy consumption and other social and economic indicators of interest. The trend in emissions in relation to each of these indicators is shown in Table 26 for selected years. The data used in the development of these estimates are shown in the lower lines of Table 26. Total gross state product is expressed in constant 2000 dollars using a chain weighting index commonly utilized for these purposes.

In 2006, an estimated 1.5 CO_2-equivalent lb of GHGs were emitted from within the borders of Minnesota for every dollar of economic output from Minnesota. Per capita emissions in 2006 were an estimated 29.6 tons per Minnesotan, and per household an estimated 74.0 tons.[26] Emissions in 2006 per MMBtu of total energy consumption were an estimated 0.1 CO_2-equivalent tons.

Table 26: Indicators of Greenhouse Gas Emissions

Energy, Economic, and Socioeconomic Indicators					
	1990	**2000**	**2004**	**2005**	**2006**
Greenhouse Gases (million tons CO_2-eq)	127.7	151.7	153.7	154.1	152.5
lb GHGs/ $ real Gross State Product (chained 2000 dollars)	2.1	1.8	1.6	1.6	1.5
Tons GHGs/Capita	29.1	30.7	30.2	30.1	29.6
Tons GHGs/Household	77.5	80.0	74.0	75.6	74.0
Tons GHGs/MMBtu	0.09	0.09	0.09	0.09	0.09
$ Real GSP (million chained 2000 dollars)	122,967	172,874	190,183	197,688	198,841
Population (million)	4.4	4.9	5.1	5.1	5.2
Households (million)	1.6	1.9	2.1	2.0	2.1
MMBtu (million)	1,379	1,716	1,783	1,790	1,777

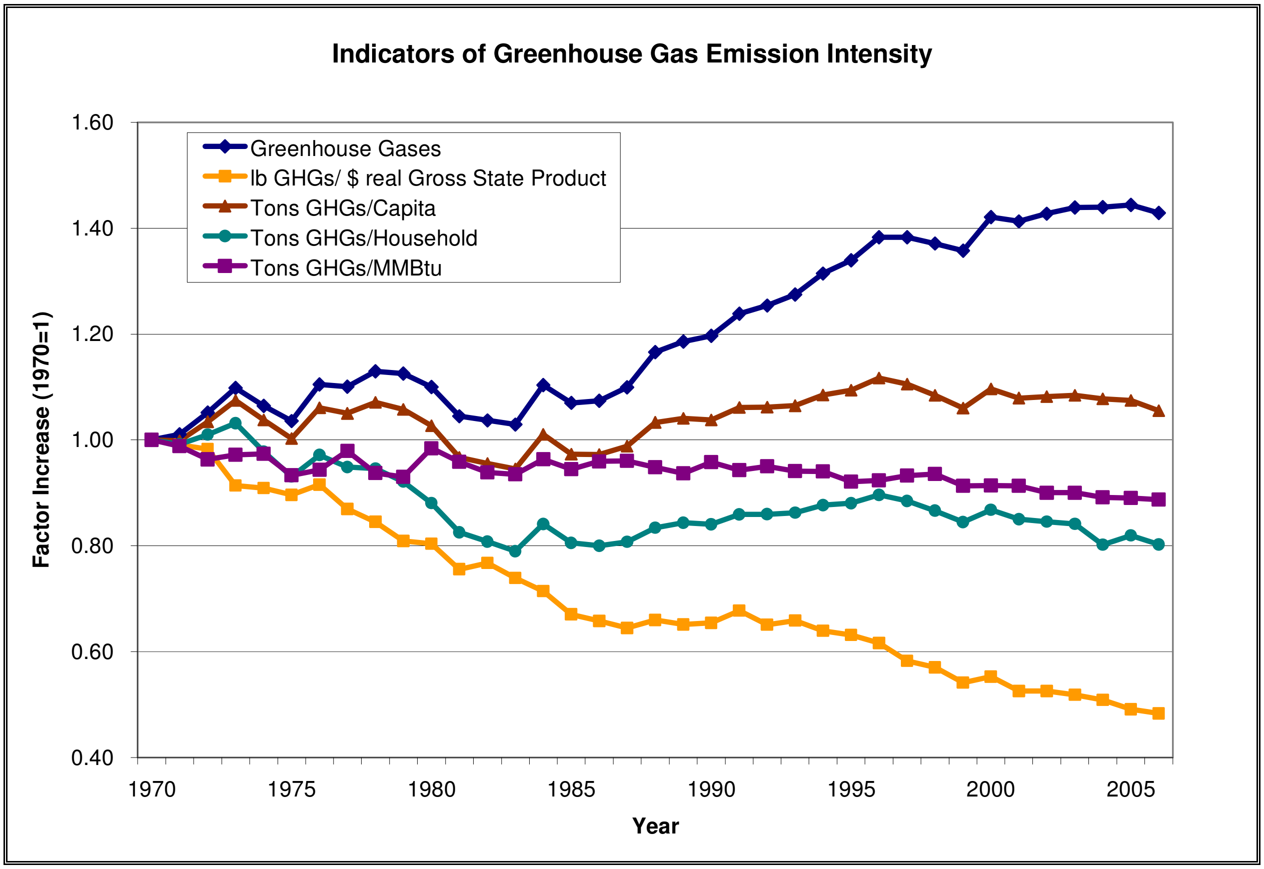
*Totals may not add due to rounding

The same data, for years 1970-2006, are shown in Figure 38 as a factor increase above 1970 levels of emission intensity. Over most of this period, emissions of GHGs per MMBtu of total energy use were flat or slightly falling, a reflection of the fact that, as we have seen in Figure 25 in Section 7, relatively little progress has been made since 1970 in decarbonizing energy use in Minnesota. Emissions per capita have been more or less constant since 1990, requiring that any population increase in the state would be reflected in a proportional increase in statewide GHG emissions. Between 1990 and 2006, statewide population increased about 19 percent, and so too did GHG emissions.

[26] This is not to be confused with emissions per household applied solely to residential sector emissions, which are estimated at a little less than two CO_2-equivalent tons per year (Table 28).

Emissions per household followed roughly the same pattern as per capita emissions with the exception of the steep decline associated with the rapid contraction of household size that occurred between 1970 and 1980.

Figure 38: Indicators of Greenhouse Gas Emission Intensity



By contrast, emissions of GHGs per real dollar of economic output (real dollars of gross state production (GSP)) declined rapidly between 1970 and 2006, at a rate of about two percent per year. The decline occurred in three distinct phases: a rapid decline 1970-1985; a subsequent flattening until the middle to late 1990s; and then a resumption of the earlier rapid rate of decline to the present. Emission per dollar of economic output is a measure of the efficiency of the economic system in generating economic activity at different levels of GHG emissions.

As can be seen in Figure 38, it was at least in part the inability between 1985 and 1995 to sustain the high rates of improvement in emissions per unit of economic output that has left us with statewide emissions of 150 million CO_2-equivalent tons rather than 120 million tons. With the rate of emission per unit of economic output constant or only slightly falling, the rate of emissions growth necessarily followed the rate of growth in economic output, which averaged about three percent per year in real terms. Most of the growth in emissions occurred from 1985 to 1995.

By contrast, had emissions remained constant per real dollar of GSP, by 2006 statewide GHG emissions would have doubled to about 370 million CO_2-equivalent tons, which points to the sensitivity of emissions to the rate of improvement in the intensity of emissions per dollar of economic output.

Electric Power Sector Indicators

It is common in the electric power sector to measure progress in reducing GHG emissions using various measures of GHG emission intensity. Frequently used measures of GHG emission intensity for this sector include lb GHG per kilowatt-hour (kWh) consumed, lb CO_2 per kWh consumed, lb GHG per kWh generated and lb GHG per MMBtu of energy input to the generation of electricity. Electric power sector indicators for Minnesota are shown in Table 27 using these units for selected years with supporting information. Also included is a metric relating emissions to the installed baseload generation capacity in-state.

Table 27: Electric Generation Greenhouse Gas Indicators

Electric Generation Indicators					
	1990	**2000**	**2004**	**2005**	**2006**
lb GHG/kWh Generated In-state	1.63	1.63	1.63	1.59	1.61
lb GHG/kWh Consumed	1.74	1.72	1.71	1.67	1.68
lb CO_2/kwh Consumed	1.70	1.70	1.69	1.65	1.65
lb GHG/Baseload kW-Installed	11,427	11,279	11,312	11,554	NA
lb GHG/MMBtu Energy Input	152.3	155.6	155.3	155.8	153.8
GHGs from In-State Electric Generation (million CO_2-eq. tons)	34.2	39.9	42.2	42.9	41.9
GHGs from In-State Electric Generation Plus Net Imports (million CO_2-eq. tons)	41.1	51.6	54.3	55.2	56.0
CO_2 from In-State Electric Generation Plus Net Imports (million CO_2-eq. tons)	40.2	50.9	53.5	54.5	55.2
Electrical Consumption (million MWh)	47.2	59.8	63.3	66.0	66.8
In-state Electrical Generation (million MWh)	41.9	48.8	51.8	53.9	52.0
Net Generation Out-of-State to Service Unmet Demand (million MWh)	8.0	13.4	13.8	14.1	16.7
Line Loss (million MWh)	2.8	2.4	2.2	2.0	1.9
Installed Generation Capacity (MW)†	8,777	9,577	11,138	11,532	12,064
Installed Baseload Gen. Capacity (MW)†	5,976	7,079	7,453	7,430	NA
Energy Input, In-State Generation Plus Net Imports (million MMBtu)	540	663	699	709	728
Heat Rate (Btu/kWh-consumed)	11,447	11,086	11,034	10,734	10,906
Total Energy Input: % Fossil Fuel	69.6%	71.6%	71.8%	72.6%	71.4%
Total Energy Input: % Nuclear	24.2%	20.4%	19.9%	18.9%	18.9%
Total Energy Input: % Renewable	6.2%	8.1%	8.3%	8.5%	9.7%

†Wind capacity adjusted to an average 28% capacity factor.
*Totals may not add due to rounding

As can be seen in Table 27, while the intensity of emissions has declined since 1990, progress has been slow. Since 1990, the intensity of GHGs emissions per megawatt-hour (MWh) has declined one to three percent, for both electricity generated within the state and total electricity generated to meet Minnesota electric demand. Based on the information in Table 27, GHG emissions per unit of energy input to the generation of electricity have actually increased as the fuel mix supporting electricity generation has changed.[27] The same is true for emissions per kilowatt (kW) of installed baseload capacity in the state, which were about two percent higher in 2005 than in 2004.

In Minnesota, roughly 1.61 CO_2-equivalent lb of GHGs were emitted per kWh generated in the state, while an estimated 1.68 and 1.65 CO_2-equivalent lb of GHGs and CO_2, respectively, are produced and emitted to the atmosphere for each kWh of electricity consumed. An estimated 153.8 CO_2-equivalent lb of GHGs are produced for each MMBtu of energy input to electricity generation to service Minnesota electrical demand.

The background information provided in Table 27 includes total emissions, total generation and total energy input to generation at power plants servicing Minnesota electric demands; heat rate of plants servicing Minnesota electric demand; and installed generation capacity in Minnesota. Total net generation serving Minnesota customers and businesses is also broken out in Table 27 by location. Line losses and sales in Minnesota are also shown.

Since 1990, total emissions have increased 36 percent and total energy input to electricity generation has increased 35 percent. Total generation needed to service electric demand in Minnesota has increased only slightly more, about 38 percent. The long-term records for net generation needed to service Minnesota demand by source are shown in Figure 39 and trends in total energy inputs are shown in Figure 40. These trends, more than anything else, explain the lack of substantial improvement in the rate of emission per MWh of electricity consumed in Minnesota that is evident in Table 27.

Power plant heat rates, or the amount of energy input needed to generate one kWh of electricity, fell between 1990 and 2006 by an estimated five percent. This seems to have been responsible for much of the limited improvement seen in the emission intensity of power generation between 1990 and 2006.

Regarding the estimated electricity balance shown in Table 27, in 2006 total generation needed to service Minnesota demand was an estimated 68.7 million MWh. Of this, 66.8 MWh were consumed in Minnesota by Minnesota consumers and businesses. An estimated 1.9 million MWh were lost during transmission and distribution. The number of megawatt-hours needed to service Minnesota demand, it might be noted, has been increasing a consistent 1.1 million MWh per year. To service this rising demand, out-of-state generation needed to service Minnesota demand has increased from about 17 percent of total generation in 1990 to an estimated 24 percent in 2006 (Figure 41). Half of the increase in power sector emissions between 1990 and 2006 was associated with imported power.

[27] The improving power plant heat rate accounts for the apparent discrepancy between falling emissions per unit of electricity generated in state and rising emission per unit of energy input to electricity generation. Power plant heat rate is a measure of the efficiency with which the energy in combusted fuel is converted to electricity.

Figure 39: Net Electrical Generation to Service Minnesota Demand

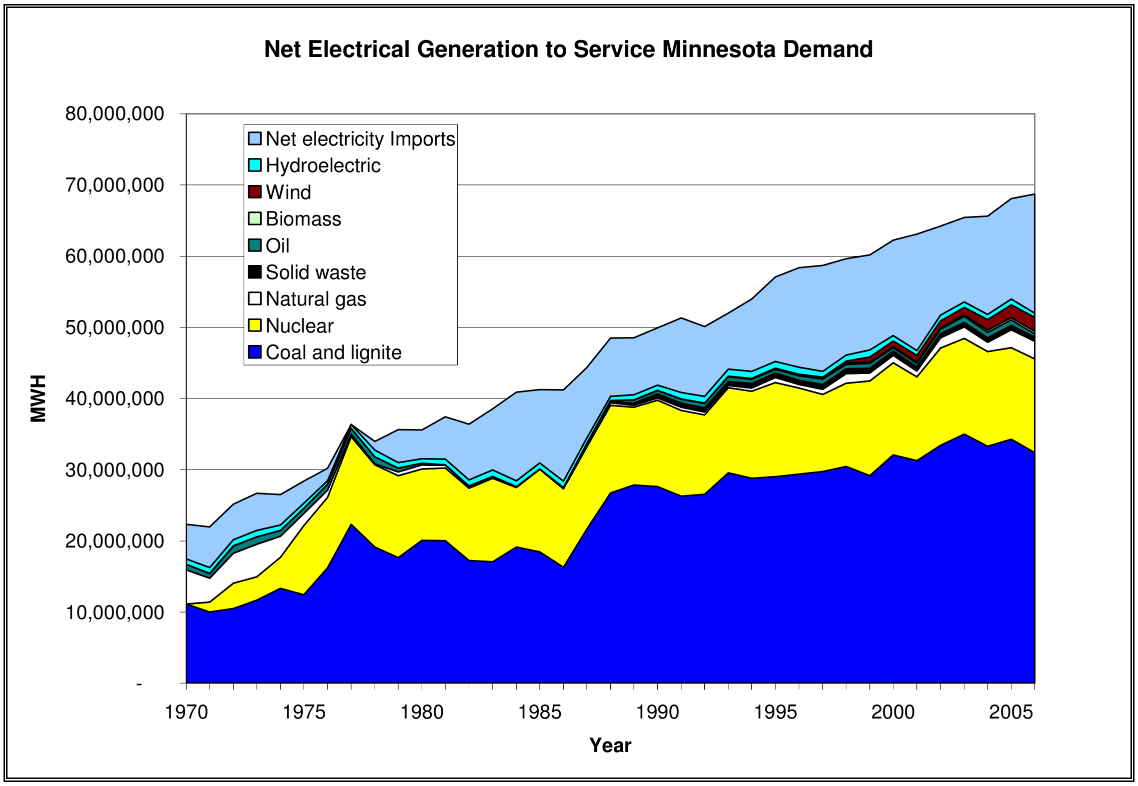


Figure 40: Energy Input to Electricity Generation to Service Minnesota Demand

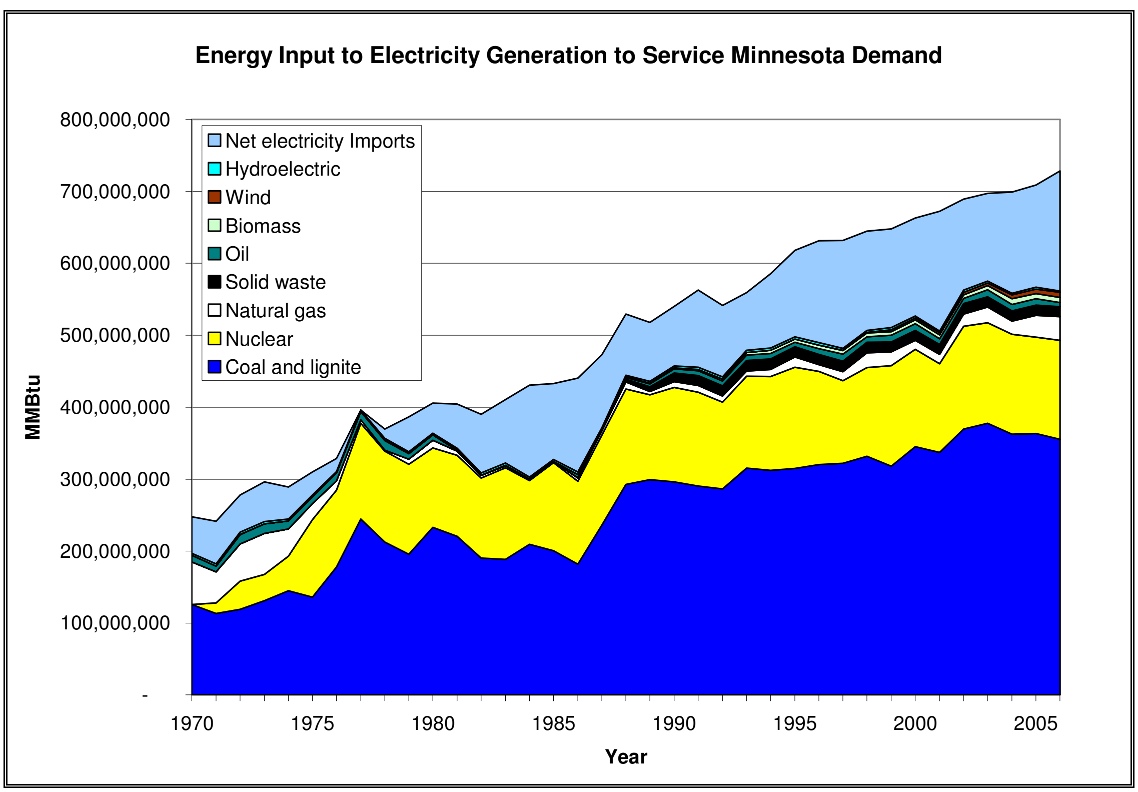
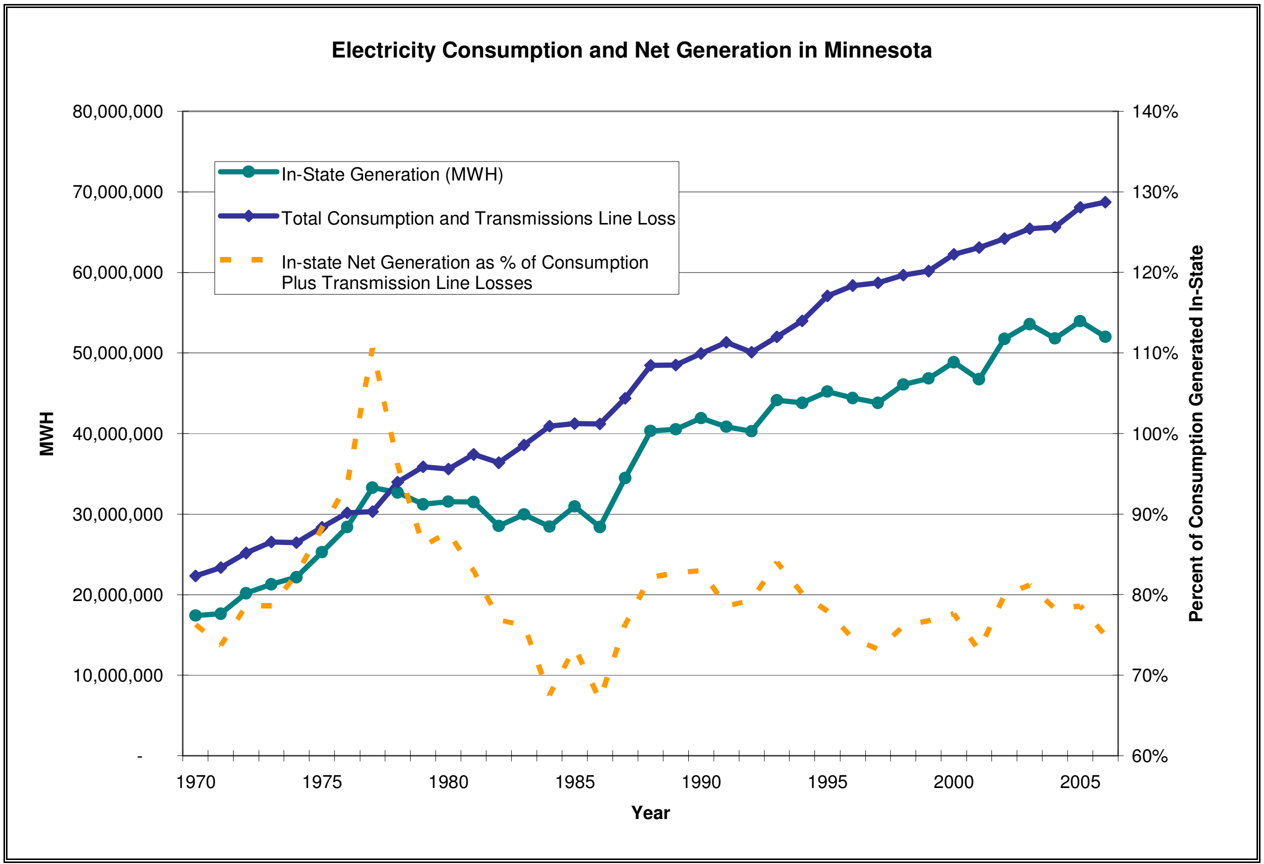


Figure 41: Electricity Consumption and Net Generation in Minnesota



With regard to in-state generation. fossil fuels remained the dominant in-state energy source for power production. Over the period from 1990 to 2006, the share of fossil fuels of all in-state power sector fuel sources increased from 69.6 to 71.4 percent (Table 27). As a percent of total energy input to in-state electricity generation, renewable energy went from 6.2 percent to 9.7 percent, but did so largely at the expense of nuclear power, whose share of total in-state energy inputs to power generation fell from 24.2 to 18.9 percent (Table 27). Total installed generation capacity increased in Minnesota by 3,300 megawatts (MW), or 37 percent, and installed baseload capacity increased by about 1,450 MW or 24 percent, but with little effect on intensity of GHG emissions per MWh (Table 27).

Residential Sector Indicators

Common measures of GHG emission intensity in the residential sector include emissions per capita, emissions per household and emissions per housing unit. The rate of emission per square foot of floor space is another useful measure of emissions intensity. These measures are shown in Table 28 for the residential sector in Minnesota for selected years. To maintain consistency with the rest of this report, with one exception, these estimates do not account for indirect emissions associated with purchased electricity. In this report, all emissions associated with the production of electricity are treated as electric power sector emissions. These intensity indicators are based on estimates of direct emissions from fuel use in Minnesota residences, nonfuel emissions associated with the consumption of nondurable consumer goods, and CO_2 removals from the atmosphere in the form of carbon stored as wood in the residential structures.

Table 28: Residential Sector Greenhouse Gas Indicators

Residential Sector Indicators					
	1990	**2000**	**2004**	**2005**	**2006**
lb GHG/Housing Unit (CO_2-eq./unit)†	8,321	9,151	8,354	7,452	7,028
lb GHG/Occupied Housing Unit (CO_2-eq./unit) †	9,348	10,116	8,996	8,309	7,857
lb GHG/Household (CO_2-eq./household) †	9,445	10,116	8,897	8,227	7,782
lb GHG/Capita (CO_2-eq./person) †	3,546	3,885	3,635	3,282	3,112
lb Direct GHG/sq ft Housing Floor Space (CO_2-eq./sq. ft.)†	5.6	5.9	5.2	4.6	4.4
lb Direct and Indirect GHG/sq ft Housing Floor Space (CO_2-eq./sq. ft.)‡	14.9	15.8	15.1	14.7	14.3
Direct GHGs (million CO_2-eq. tons) †	7.8	9.6	9.2	8.4	8.0
Direct and Indirect GHGs (million CO_2-eq. tons)‡	20.7	25.7	26.8	26.6	26.4
Housing Units (million)	1.9	2.1	2.2	2.3	2.3
Occupied Housing Units (million)	1.7	1.9	2.1	2.0	2.0
Households (million)	1.6	1.9	2.1	2.0	2.1
Population (million)	4.4	4.9	5.1	5.1	5.2
Housing Floor Space (million sq. ft.)	2,786	3,251	3,542	3,619	3,684
Carbon in Housing (million tons)	15.9	18.4	20.0	20.6	21.0
Tons Carbon/Housing Unit	8.5	8.8	9.0	9.1	9.2

†Direct emissions and sequestration; no indirect emissions from electricity consumption
‡Indirect emissions were estimated using the percentage breakdown of Minnesota residential electricity consumption given in the US EIA Electric Power Annual and Minnesota State Energy Data report, and total electric power sector emissions given in Table 27 and Appendix B.
*Totals may not add due to rounding

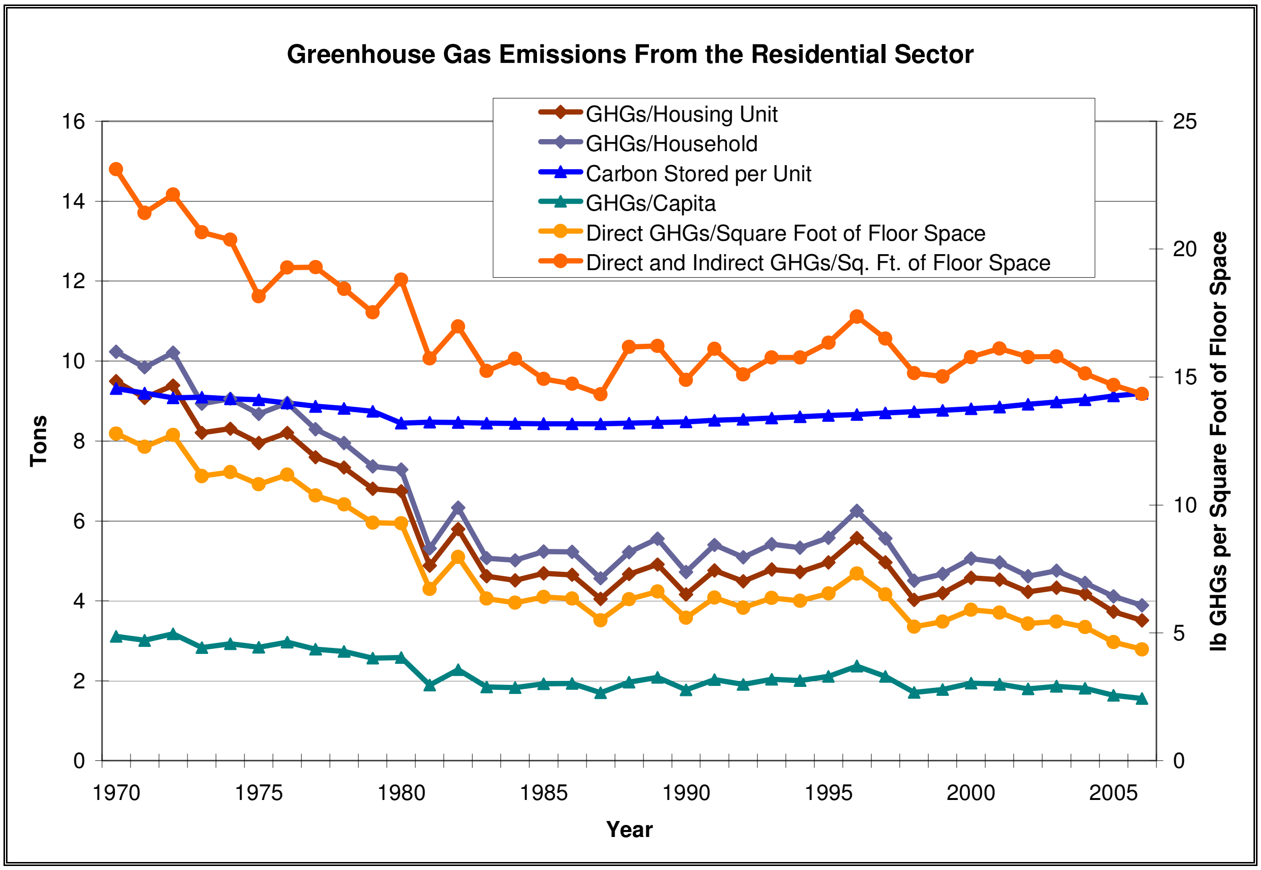
Emissions per occupied housing unit, excluding indirect emissions associated with electricity consumption, are currently about four CO_2-equivalent tons (7,857 CO_2-equivalent lb) annually. Emissions per household, again excluding electricity, are also currently about four tons per year (7,782 CO_2-equivalent lb). Given Minnesota's average household size of about 2.5 persons, per capita emissions are about 1.6 CO_2-equivalent tons per year (3,112 CO_2-equivalent lb). The slight discrepancy in emission estimates for households and total housing units results from the use of a different data source for each calculation.

Emissions per square foot of floor space, again excluding emissions from electricity generation, are estimated at about 4.4 CO_2-equivalent lb of GHGs per year, based on an estimated 3.7 billion square feet of residential floor space in Minnesota. This estimate was developed using a stock model of housing in Minnesota and estimates compiled at the national level of floor space for new single family, multifamily and mobile home housing units. If emissions associated with the generation of purchased electricity are considered, total emissions per square foot of residential floor space increase to about 14.3 CO_2-equivalent lb of GHGs per year, or over triple the estimate for direct emissions only.

The intensity of GHG emissions from residential structures is declining. Since 1990, the per-housing-unit and per-household intensity of direct GHG emissions has declined about 16 percent, and per capita, direct GHG emissions decreased 12 percent. Accounting for the indirect emissions associated with the generation of purchased electricity, the decline in emission intensity since 1990 is smaller, five to eight percent.

The long-term trend in each of these measures is shown graphically in Figure 42. The reduction in emission intensity was particularly intense from 1970 to 1980. From roughly 1985 to 1995, GHG emission intensity flattened across nearly all measures. Starting in the late 1990s, the intensity of GHG emissions from the residential sector began again to decline, albeit at much slower rates than a few decades earlier.

Figure 42: Greenhouse Gas Emissions from the Residential Sector



A note was made in Section 6 about the role of carbon storage in residential structures in total emissions. Historically, depending on the year in question, carbon storage in residential structures has offset between 8 to 15 percent of emissions associated with direct fuel use in the residential sector. During the housing boom of 2002-2006, this offset increased to 15 to 20 percent on an annual basis, contributing to the downward movement in residential GHG emission intensity. In light of the housing bust, it would be unwise to expect housing carbon storage to continue to contribute in this fashion. Some leveling of the trend in GHG emission intensity seems inevitable in coming years.

Finally, none of these estimates have been normalized for weather. Weather normalization assumes that weather is stochastic in nature, whereas we have every reason to believe that the warming of recent years is not random but represents a persistent trend toward warmer temperatures, both winter and annual.

Commercial Sector and Industrial Sector Indicators

The intensity of emissions is typically measured in lb of GHG per unit of economic output. This is due to the wide range of productive activities that are involved, allowing for only the broadest measures of output in the treatment of emissions intensity. Commercial and industrial sector indicators are shown in Table 29. Two different estimates are presented for each economic sector: GHG emission per dollar of economic output, accounting only for direct emissions; and GHG emissions per dollar of output accounting for both direct and indirect emissions. As in the residential sector, indirect emissions are off-site emissions associated with the generation of purchased electricity.

The estimates shown in Table 29 also include a second indicator of emissions intensity: CO_2-equivalent tons per employee per year. Supporting information is shown in the lower lines of Table 29. Economic output is expressed in constant 2000 dollars. The employment data and the data on economic output are from the Bureau of Labor Statistics (BLS) and the Bureau of Economic Analysis (BEA), respectively.

On an output basis, and accounting for direct and indirect emissions, for every dollar of economic output from the commercial sector in Minnesota, about 0.3 CO_2-equivalent lb of GHGs are emitted to the atmosphere. If indirect emissions are excluded, this falls to about 0.1 CO_2-equivalent lb per dollar of output. For the industrial sector, direct emissions per dollar of real output are about 15-fold larger than in the commercial sector, about 1.2 CO_2-equivalent lb per dollar of output. If emissions associated with purchased are included, these double to about 2.5 CO_2-equivalent lb per dollar of output, or a rate nearly eight-fold higher than found in the commercial sector

Per commercial sector employee, about 2.8 CO_2-equivalent tons of GHGs are emitted per year in the form of direct emissions; including indirect emissions associated with electricity purchases brings this to about 11.3 CO_2-equivalent tons per year. The corresponding values for the industrial sector would be 34.2 and 73.4 CO_2-equivalent tons per year, respectively.

Care should be taken in comparing the estimates for 1990 and for the other years given in Table 31 across years. Between 1997 and 1998 the BEA altered its method for compiling its estimates of economic output by economic sector. As a result, the BEA estimates for economic output for 1990 for the commercial and industrial sectors may not be strictly comparable with those after 1998. It appears, that since 2000 the intensity of industrial sector GHG emissions has been declining. A decline in intensity between about 10 percent and 20 percent is evident across all measures of emissions intensity shown in Table 29, from 2000 to 2006.

By contrast, the situation in the commercial sector is more muddled, with commercial sector emissions per employee and direct plus indirect emissions per unit of output rising by about one-third since 2000, but direct emissions per unit of output falling about 20 percent. This may be an artifact of rapidly rising commercial sector electrification and productivity during these years.

Table 29: Commercial and Industrial Sector Greenhouse Gas Indicators

Commercial and Industrial Sectors Indicators					
	1990[†]	**2000**	**2004**	**2005**	**2006**
lb Direct GHGs/$ of Commercial Sector Economic Activity (CO_2-eq. lb/$)	0.12	0.10	0.09	0.09	0.08
lb Direct and Indirect GHGs/$ of Commercial Sector Economic Activity (CO_2-eq. lb/$)	0.29	0.25	0.32	0.33	0.32
lb Direct GHGs/$ of Industrial Economic Activity (CO_2-eq. lb/$)	0.87	1.25	1.16	1.16	1.16
lb Direct and Indirect GHGs/$ of Industrial Economic Activity (CO_2-eq. lb/$)	2.10	2.97	2.49	2.44	2.49
Tons Direct and Indirect GHGs/Commercial Sector Employee (tons CO_2-eq./employee)	8.35	8.34	11.45	11.75	11.30
Tons Direct and Indirect GHGs/Industrial Sector Employee (tons CO_2-eq./employee)	79.70	81.16	74.28	72.43	73.38
Direct GHGs from Commercial Sector (million CO_2-eq. tons)	5.9	6.5	6.7	6.8	6.1
Direct and Indirect GHGs from Commercial Sector (million CO_2-eq. tons)[‡]	13.5	17.2	24.2	25.2	24.7
Direct GHGs from Industrial Sector (million CO_2-eq. tons)	14.1	18.0	16.5	16.6	16.4
Direct and Indirect GHGs from Industrial Sector (million CO_2-eq. tons)[‡]	34.1	42.5	35.5	35.0	35.2
Commercial Sector Product (million chained 2000 dollars)	94,315	135,327	152,159	153,139	156,381
Industrial Sector Product (million chained 2000 Dollars)	32,541	28,653	28,430	28,639	28,275
Commercial Sector Employment (million)	1.62	2.06	2.11	2.15	2.19
Industrial Sector Employment (million)	0.43	0.52	0.48	0.48	0.48

[†]US Bureau of Economic Analysis 1990 commercial and industrial sector GSP estimates may not be compatible with estimates made since 1990 due to changes in estimation methodology.
[‡]Indirect emissions were estimated using the percentage breakdown of Minnesota electricity consumption given in US EIA Electric Power Annual and total electric power sector emissions given in Table 27 and Appendix B.
[*]Totals may not add due to rounding.

Agricultural Indicators

Several indicators suggest themselves for Minnesota agriculture: for field crops, lb GHGs per acre of harvested cropland, and for livestock, lb GHGs per lb of livestock liveweight on farms and feedlots. These are shown in Table 30 for selected years. Emissions data for both crop production and livestock production are shown in the lower lines, along with historical estimates of harvested acres of cropland in the state and total livestock liveweight. Since GHG emissions from agricultural activities are calculated on a source specific basis (Section 4), with the exception of emissions from fuel use, it was a relatively easy matter to separate out emissions associated with crop production from those associated with livestock production. Emissions associated with fuel use were modeled using characteristic fuel inputs per acre for different crops and the fractional amount of fuel-related agricultural GHGs associated with crop and livestock production. A fractional 85/15 split between crop productions and livestock production was derived and applied to all years.

Table 30: Agricultural Sector Greenhouse Gas Indicators

Agricultural Sector Indicators					
	1990	**2000**	**2004**	**2005**	**2006**
lb GHGs/Acres Harvested (CO_2-eq./acre)	1,467	1,440	1,554	1,611	1,557
lb GHGs/lb Liveweight on Farms and Feedlots (CO_2-eq./lb)	4.5	4.5	4.4	4.5	4.4
GHGs from Crop Production (million CO_2-eq. tons)	14.5	14.9	15.5	15.8	15.5
GHGs from Livestock (million CO_2-eq. tons)	7.7	8.0	8.0	8.0	8.1
Harvested Acres (million)	19.8	20.7	19.9	19.6	19.9
Liveweight on Farms and Feedlots (million lb)	3,391	3,571	3,627	3,596	3,630

*Totals may not add due to rounding

As shown in Table 30, about three-quarters of a CO_2-equivalent ton (1,557 CO_2-equivalent lb) of GHGs is emitted annually per acre of harvested cropland in Minnesota and about 4.5 CO_2-equivalent lb is emitted annually per lb of liveweight on Minnesota farms and feedlots. No trend is evident in the GHG emission intensity measure for livestock on farms; the estimates are constant at about 4.5 CO_2-equivalent lb of livestock liveweight on Minnesota farms and feed-lots.

By contrast, emissions per acre of harvested cropland do appear to be on the rise, coincident with increasing emissions from soil nutrient management (Section 6) and a constant land base. Between 1990 and 2006, estimated emissions per acre increased about seven percent.

Caution should be exercised in using these estimates. As noted in Section 6, the EPA has developed emissions estimates for Minnesota soil nutrient management using a soil process model that are more than twice the emission estimates for soil nutrient management given in this report. It is possible that the per acre estimates of emissions shown in Table 30 may substantially understate actual emissions from cropland in Minnesota, as discussed in Section 4. The MPCA will closely observe the EPA estimates for Minnesota cropland as they evolve and will make any changes as needed.

Transportation Indicators

Transportation indicators and supporting data are shown in Table 31 for light-duty vehicles, heavy-duty trucks, transit buses, aircraft and natural gas pipelines for selected years. In aggregate, light-duty vehicles, heavy-duty trucks and transit buses account for 98 percent of all highway vehicle miles traveled (VMTs). Light-duty vehicles, heavy-duty trucks, transit buses, aircraft and natural gas pipelines together account for between 90 and 95 percent of transportation sector GHG emissions, depending on the year in question.

Light-duty vehicles include passenger cars, wagons, and light-duty trucks, including sport utility vehicles and minivans. The typical light-duty vehicle emits about 5.7 CO_2-equivalent tons of GHGs to the atmosphere annually. The typical household emits roughly twice this, about 12.3 tons per year. Per capita light-duty vehicle emissions are an estimated 4.9 CO_2-equivalent tons per year.

Per mile traveled, the typical light-duty vehicle emits about one CO_2-equivalent lb of GHGs. On a passenger-mile basis, the typical light-duty vehicle emits about 0.6 CO2-equivalent lb of GHGs. This was calculated using national data on average vehicle occupancy on roadways. Adequate state-level statistics on average vehicle occupancy (other than trip-to-work occupancy) are not available.

Since 1990, even while overall GHG emissions from light-duty vehicles have increased by about one-third, the intensity of GHG emissions have declined six to eight percent. This is true for emissions per VMT and emissions per passenger-mile. Annual emissions per vehicle have remained constant, while emissions per capita and per household have increased. The fossil fuel intensity of travel (in Btu of fossil fuel energy per VMT) declined over this period from about 6,350 to 5,800 Btu per VMT. Much or most of this was the result of the Minnesota state ethanol mandate, which requires that 10 percent of motor gasoline sold in the state by volume be blended with ethanol. As discussed in Sections 3 and 9, CO_2 emissions from the combustion of ethanol are not counted against statewide GHG emission totals.

Trends in the factors that underlie these estimates are shown graphically in Figure 43. These are shown as relative factor increases compared to 1970 levels. Since 1970, total VMT for light-duty vehicles have increased more than two-fold. Over this same period, fossil fuel economy, as measured in Btu of fossil fuel energy consumed per mile traveled, has improved by about one-third. By 2006, greenhouse gas emissions were 1.6-fold higher than in 1970.

Light-duty vehicles account for about 90 percent of all highway vehicle miles traveled. Most of the rest are driven by heavy-duty trucks and buses, as shown in Figure 44. GHG emissions per mile traveled for heavy-duty trucks are estimated at about 3.7 CO_2-equivalent lb of GHGs per VMT, and emissions per mile-traveled for transit buses about 4.1 CO_2-equivalent lb of GHGs per VMT. Since 1990, emissions per vehicle mile traveled have declined an estimated four percent for heavy duty trucks and 25 percent for transit buses. In the case of bus transit, a measurable part of this reduction can be traced back to enhanced biodiesel fuel use in Metropolitan Transit Commission buses beginning in 2004.

Table 31: Transportation Sector Greenhouse Gas Indicators

Transportation Sector Indicators					
	1990	2000	2004	2005	2006
Passenger Cars and Light-Duty Trucks					
lb GHG/Vehicle Mile Traveled	1.05	1.01	1.00	0.98	0.97
lb GHGs/Passenger-mile	0.63	0.63	0.61	0.59	0.59
Tons GHGs/Vehicle	5.6	6.1	6.1	5.9	5.7
Tons GHG/Household	11.4	12.9	12.7	12.7	12.3
Tons GHG/Capita	4.3	5.0	5.2	5.1	4.9
Btu/Mile Traveled	6,411	6,342	6,436	6,317	6,279
Btu/Mile Traveled (fossil fuel only)	6,348	5,981	5,997	5,876	5,828
GHGs from Passenger Cars and Light-Duty Trucks (million CO_2-eq. tons)[†]	18.7	24.5	26.3	25.9	25.3
Vehicle Miles Traveled (million)	35,754	48,593	52,486	52,738	52,122
Passenger Cars and Light-Duty Trucks (million)	3.3	4.0	4.3	4.4	4.4
Households (million)	1.6	1.9	2.1	2.0	2.1
Population (million)	4.4	4.9	5.1	5.1	5.2
Million MMBtu of Fuel Used in Passenger Cars and Light-Duty Trucks	229.2	308.2	337.8	333.2	327.3
Million MMBtu of Fossil Fuel Used in Passenger Cars and Light-Duty Trucks	227.0	290.6	314.8	309.9	303.8
Miles per Gallon	19.27	19.46	19.17	19.23	19.37
Vehicle Occupancy Rate (US Average, Passenger Cars and Light Trucks)	1.66	1.59	1.65	1.65	1.65
Heavy-Duty Trucks					
lb GHG/Vehicle Mile Traveled	3.87	3.72	3.78	3.76	3.72
lb GHGs/Passenger-mile	3.87	3.72	3.78	3.76	3.72
Btu/Mile Traveled	23,938	22,764	23,126	23,026	22,785
GHGs from Heavy-Duty Trucks (million CO_2-eq. Tons)	5.0	6.1	6.3	6.3	6.2
Vehicle Miles Traveled (million)	2,570	3,285	3,330	3,329	3,354
Million MMBtu of Fuel Used in Heavy-Duty Trucks	61.5	74.8	77.0	76.7	76.4
Miles per Gallon	5.68	5.88	5.82	5.85	5.92
Vehicle Occupancy Rate (US Average)	1.00	1.00	1.00	1.00	1.00
Bus Transit					
lb GHG/Vehicle Mile Traveled	5.41	4.97	4.33	4.36	4.07
lb GHG/Passenger-mile	NA	0.60	0.54	0.53	0.48
GHGs from Bus Transit (CO_2-eq. Tons)	108,320	146,106	137,035	147,628	139,771
Vehicle Miles Traveled (million)	40.0	58.8	63.3	67.7	68.7
Passengers-miles (million)	NA	484.9	505.6	552.3	581.3
Aviation					
lb GHG/Passenger-mile	0.76	0.61	0.51	0.50	0.48
Btu/Passenger-Mile (US Average, Domestic Flights)	4,890	3,883	3,296	3,182	3,070
Natural Gas Pipelines					
Leakage Rate (%)	0.66%	0.65%	0.66%	0.65%	0.67%
Natural Gas Entering MN (million MMcf)	1.25	2.05	2.48	2.53	2.45
Natural Gas Transshipped Through MN (million MMcf)	0.95	1.69	2.11	2.16	2.10
Natural Gas Consumed or Stored in MN (million MMcf)	0.30	0.37	0.36	0.37	0.36

[*]Totals may not add due to rounding
[†]Includes mobile air conditioning

Figure 43: Trends in Light-Duty Vehicle Numbers, Operation, and Emissions

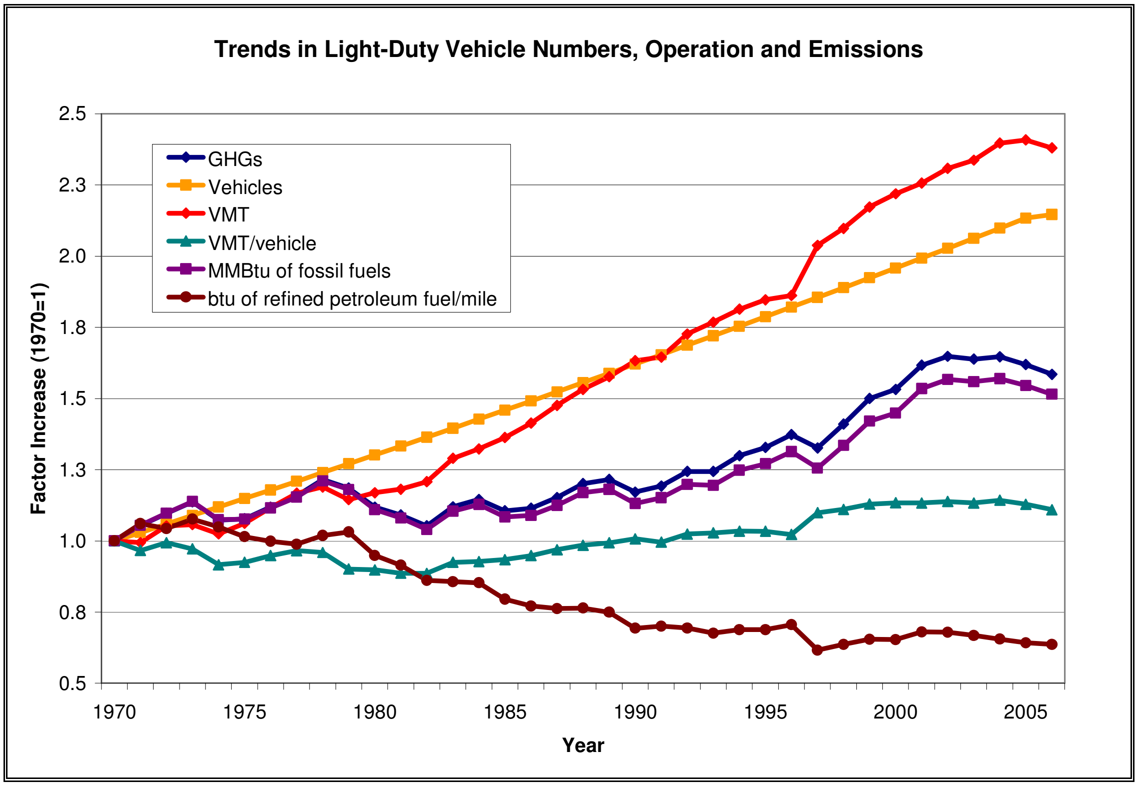
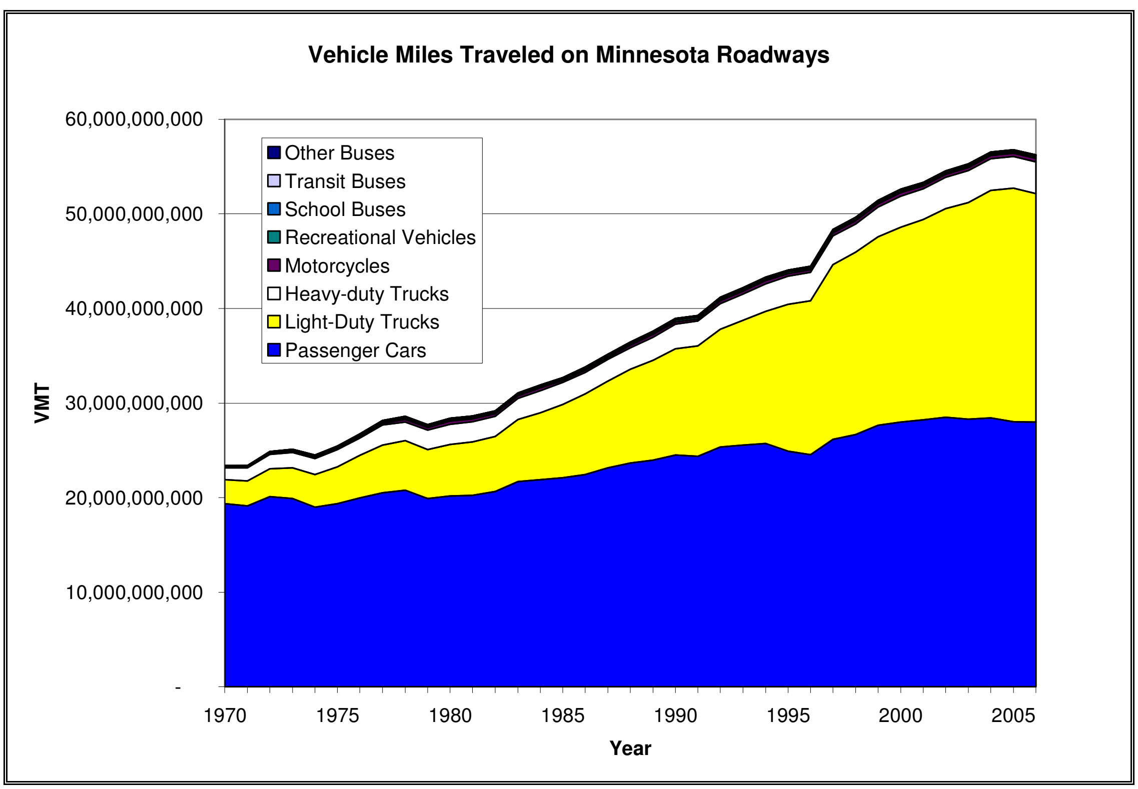


Figure 44: Vehicle Miles Traveled on Minnesota Roadways



Since occupancy rates vary substantially between light-duty vehicles, heavy-duty trucks and bus transit, emissions per passenger-mile traveled constitute a better measure of emissions that do emissions per VMT (Table 32).

Table 32: 2006 Estimated Emissions per Passenger-mile

2006 Estimated Emissions per Passenger-mile (CO_2-equivalent lb per passenger-mile)	
Light-duty Vehicles	0.59
Heavy-duty Trucks	3.72
Bus Transit	0.48
Aviation	0.48

On a passenger-mile basis, bus transit is about 20 percent less emitting than light-duty vehicles. Emissions per passenger-mile traveled for aviation and bus transit are remarkably similar. Trip length, of course, differs substantially between bus transit and commercial aviation. With an assumed vehicle occupancy of one, emissions per passenger mile for heavy-duty trucks are identical to emissions per VMT for this class of vehicles. In the case of each vehicle type or transportation mode, the trend favors generally decreased emissions per passenger-mile traveled.

It should be noted that emissions per passenger-mile for bus transit were calculated using data only for the largest three bus transit systems in Minnesota; data on fuel use and passenger-miles traveled were not available for other Minnesota-based bus transit systems. Emissions per aviation passenger-mile were calculated from reported fuel use per passenger-mile traveled at a national level. Data were not available at a state level to support an estimate for passengers and aircraft leaving Minnesota airfields.

Finally, Table 31 includes information on leakage rates from natural gas transmission and distribution in Minnesota. An estimated 0.67 percent of total natural gas that is consumed in Minnesota leaks from Minnesota pipelines, services and compressor stations to the atmosphere in the form of CH_4. Gas transshipment through Minnesota accounts for about 85 percent of all natural gas in the system. As a result, a significant part of this leakage emission would be associated with shipments of natural gas through the state to non-Minnesota destinations.

Section 11: Explaining the Trends

Since 1970, greenhouse gas emissions from Minnesota have increased by about 43 percent. As noted in Section 5, most of this increase occurred between the mid-1980s and the late-1990s. Prior to this, emissions were roughly stable or slowly increasing. After 1998, emissions again stabilized and, in 2006, declined slightly.

Real energy prices explain at least part of this trend. The rate at which energy is used depends on price, among other things. At high prices, it is more economical for businesses and individuals to buy less fuel and electricity, and to use the money saved to purchase energy efficient devices, vehicles, equipment and structures. The same energy services are procured, but with higher front-end expenditures on efficient equipment, rather than on high cost fuel. At lower energy prices, individuals and businesses forego the high front-end costs of energy efficiency improvements, because at a certain point energy expenses become too minor to matter.

Between 1973 and 1985, the rate of improvement in energy efficiency averaged about 2.3 percent per year, primarily in response to high and rising real energy prices. Over this same period, the rate of real growth in the economy was 2.4 percent per year, implying a stabilization in energy use over this period, which, in fact, is what occurred. Energy use and GHG emissions are closely related - about 85 percent of GHGs are from energy use. Over the period from 1973 to 1985, GHG emissions intensity declined substantially, at a rate of 2.6 percent per year. About three million less CO_2-equivalent tons of GHGs were emitted in 1985 than 1973.

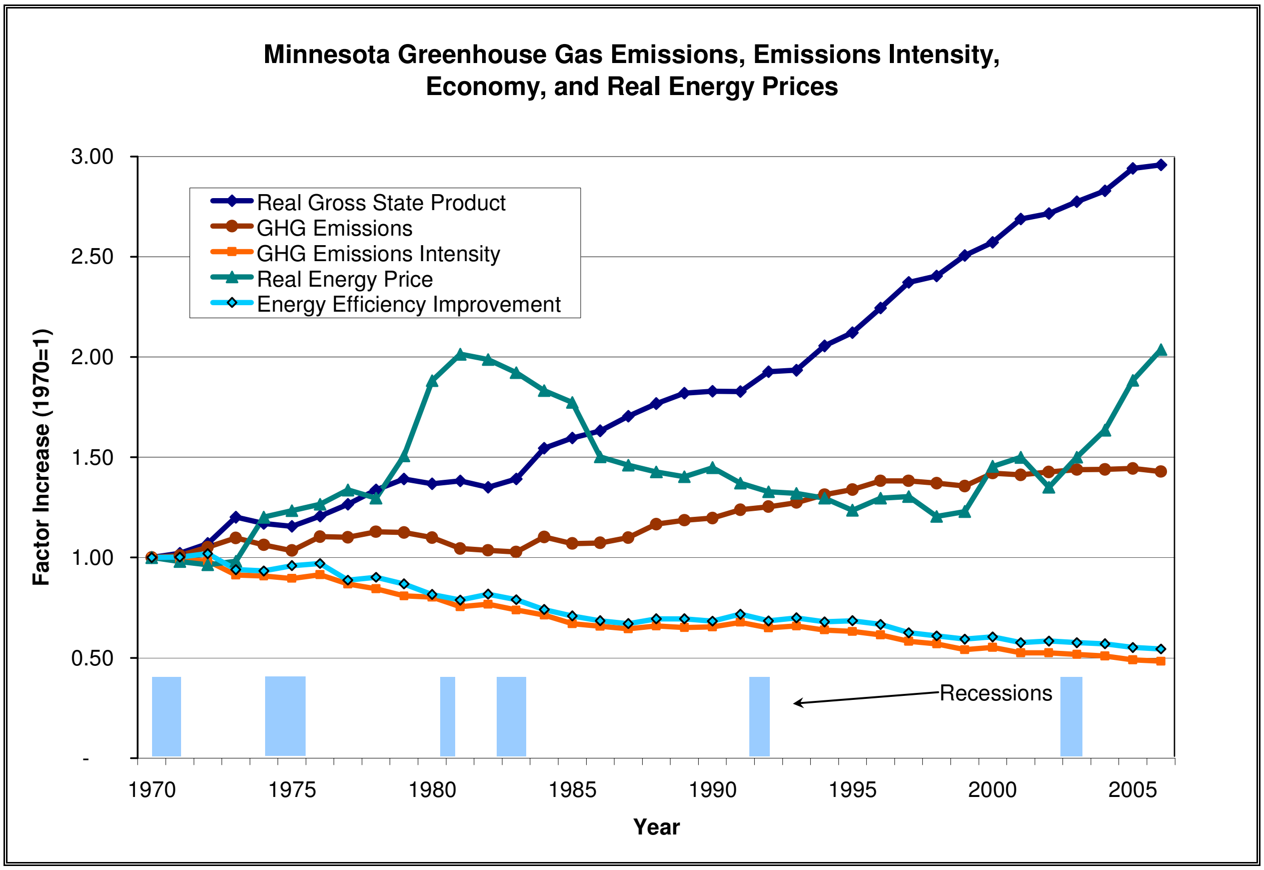
By contrast, with the collapse in real energy prices between 1985 and 1986, the rate of energy efficiency improvement in Minnesota slowed to an average annual rate of 1.2 percent per year, a rate roughly paralleled by the decline in GHG emission intensity. Between 1985 and 1998, the GHG intensity of Minnesota's economic output decreased by 1.25 percent per year, or about 18 percent overall. Economic output, however, increased by 50 percent in real terms between 1985 and 1998, at an average annual rate of 3.2 percent per year and swamping any gains resulting from improved efficiency. With the recovery of real energy prices after 1998, and particularly after 2002, the average annual rate of energy efficiency improvement returned to a higher rate, about 1.9 percent per year, 2002-6. The emission intensity of GHGs declined about 15 percent between 1998 and 2006, offsetting about two-thirds of the real increase in economic output.

None of this is particularly startling or innovative, but it bears repeating: at lower prices, the quantity demand for any economic good increases. If that good is fossil fuel, and if GHGs are emitted as a result of fossil fuel combustion, with lower real energy prices, emissions will invariably rise, at least as long as regulations limiting emissions are not in place.

One caveat is in order: in the period 1985-1998, stagnation in energy conservation was not the only factor contributing to rapidly increasing GHG emissions; rapid increase in economic output also contributed. GHG emissions are the product of some measure of economic output and the rate of emissions for every unit of economic output. Real economic output in Minnesota increased rapidly between 1985 and 1998, about 50 percent.

Figure 45 and Table 33 summarize the trend from 1970 to 2006 in GHG emissions as a factor increase compared to 1970 levels, along with parallel trends for state economic output (real Gross State Output), GHG emission intensity, energy efficiency, and real energy prices. Real energy prices peaked in 1981, remained at high levels through 1985, and then declined to the late 1990s. After 1998, real energy prices began a slow climb. Energy use efficiency declined rapidly, 1970-1985, stabilized from 1985-1998, then resumed its earlier pattern of decline. GHG emission intensity followed a similar pattern. Real economic output showed an inverse pattern, growing slowly through 1983, accelerating from 1983 to 1997, and then slowing after 1997.

Figure 45: Minnesota Greenhouse Gas Emissions, Emissions Intensity, Economy, and Real Energy Prices



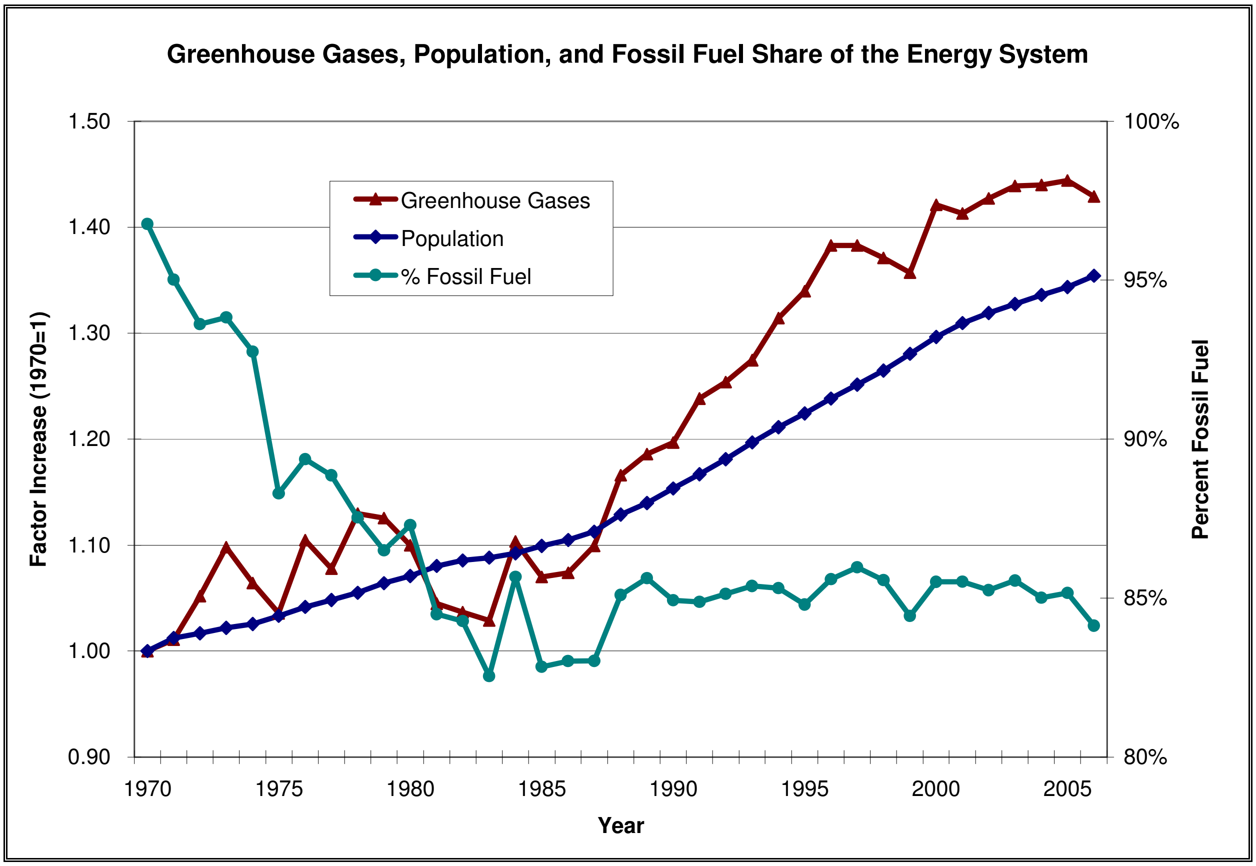
GHG emissions also can be related to population. Per capita GHG emissions have been constant since the early 1990s. The state's population increased substantially from 1985 to 2006, particularly from 1985 to 1995. This is another essential descriptor of the trend of GHG emissions in the record; without pollution control regulations and widespread improvement in emissions per capita, population growth requires that emissions rise.[28] The relationship between population and GHG emissions is shown in Figure 46.

[28] Upward trends in statewide economic output and population are mutually reinforcing. A rapidly rising population contributes to a growing gross state product; rapid economic growth encourages migration into the state. In this sense, the upward trend in both state GSP and population indicate roughly the same thing: generally rising productive capacity leading to increasing GHG emissions.

Table 33: Trends in Real Energy Prices, GHG Emissions, and Decarbonization

Trends in Real Energy Prices, GHG Emissions and Decarbonization					
	Factor Increase in GHG Emissions	Avg. Ann. Rate of Decline of Energy Use Intensity	Avg. Ann. Rate of Decline of GHG Emission Intensity	Change in Non-Fossil Fuel part of Energy System	Factor Increase in Real Energy Prices
1970-1985	1.07	-2.3	-2.3	14%	1.77
1985-1998	1.28	-1.2	-1.3	3%	0.68
1998-2006	1.04	-1.5	-2.1	2%	1.69

Figure 46: Greenhouse Gases, Population, and Fossil Fuel Share of the Energy System



Finally, it might be noted that the rate of efficiency improvement in energy use does not always determine of GHG emissions. If energy supply is being diversified to include large amounts of nonfossil fuel energy, the background rate of growth in energy efficiency can remain constant and GHG emissions could still decline. However, little diversification away from fossil fuels is evident in the record. The rate of efficiency improvement is plotted against GHG emissions in Figure 45. Absent significant diversification, the combination of the annual rate of improvement in energy efficiency and the annual rate of growth in economic output remains the best indicator of trends in statewide GHG emissions.

Section 12: Greenhouse Gas Emissions in Minnesota: 2006

In 2006, greenhouse gas emissions from Minnesota totaled an estimated 152.5 million CO_2-equivalent tons. These are listed in Table 34 in CO_2-equivalent tons by sector, activity and gas and in Table 35 in CO_2-equivalent tons by major emission source. In 2006, an estimated 130.1 million tons of fossil CO_2 were emitted to the atmosphere. In the same year, 31,600 tons of N_2O were emitted, equivalent to 9.4 million CO_2-equivalent tons, and 460,700 tons of CH_4 were emitted, which translates to 11.5 million CO_2-equivalent tons of emissions. In aggregate, about 800 tons of SF_6, PFCs and HFCs were emitted in 2006, or about 1.5 million CO_2-equivalent tons.

Table 34: 2006 Greenhouse Gas Emissions by Economic Sector, Major Activity, and Gas

2006 Greenhouse Gas Emissions by Economic Sector, Major Activity, and Gas		
	CO_2-equivalent Tons (Million)	**Percentage of Total**
Agriculture	23.5	15.4%
Commercial	6.1	4.0%
Electric Generation	56.0	36.7%
Industrial	16.4	10.8%
Residential	8.0	5.3%
Transportation	41.0	26.9%
Waste	1.4	0.9%
Total*	**152.5**	
Energy	129.5	84.9%
Agricultural	20.8	13.6%
Waste	1.3	0.8%
Other	1.0	0.6%
Total*	**152.5**	
N_2O	9.4	6.2%
CH_4	11.5	7.6%
CO_2	130.1	85.3%
SF_6	0.5	0.3%
HFC-134a/HFC-152a	0.2	0.2%
HFC-134a	0.7	0.5%
PFCs	0.1	0.1%
Total*	**152.5**	

*Totals may not add due to rounding.

In-state fossil fuel combustion was the principal source of CO_2 emissions in 2006, comprising 86 percent of total CO_2 emissions, equaling an estimated 111.8 million tons CO_2 in 2006. CO_2 emissions associated with the net import of electricity added an extra 13.9 million tons, bringing total emissions associated with fossil fuel combustion, in-state and out-of-state, to an estimated 125.7 million tons. Taken together, these constitute the single largest emission source in the 2006 GHG emission inventory, accounting for an estimated 82 percent of total greenhouse gas emissions.

Of the remaining sources of CO_2, only taconite induration and agricultural peatland uses contribute measurably to the totals, roughly 6.8 million tons. Carbon storage in residential structures and demolition and construction landfills was an estimated 3.5 million CO_2-equivalent tons, offsetting an equivalent amount of emissions from fossil CO_2 sources.

Nutrient soil management was the largest source of N_2O emissions to the atmosphere in 2006, comprising 78 percent of total estimated N_2O emissions. An estimated 24,700 tons of N_2O were emitted from soil nutrient management, equal to 7.4 million CO_2-equivalent tons. N_2O is produced in soils by soil bacteria using the nitrogen found in synthetic fertilizer, livestock manure, and crop residues or atmospherically-deposited nitrogen as an energy source.

Feedlots and mobile source fuel combustion account for most of the remaining N_2O emission. In 2006 feedlots emitted an estimated 2,800 tons of N_2O (800,000 CO_2-equivalent tons) and mobile sources released an estimated 2,400 tons of N_2O (700,000 CO_2-equivalent tons) to the atmosphere. Mobile sources include passenger cars, light-duty trucks, heavy-duty trucks, buses, motorcycles, railroad engines, aircraft, marine craft, and agricultural and construction equipment

Of the 460,700 tons of methane that were emitted in 2006, manure storage, ruminants, and MMSW landfills accounted for an estimated 367,700 tons, or about 80 percent of the total methane emitted. An estimated 101,700 tons of methane were emitted from manure storage facilities in 2006, or 2.5 million CO_2-equivalent tons. Emissions from ruminant livestock were somewhat larger, an estimated 168,500 tons of CH_4 in 2006 (4.2 million CO_2-equivalent tons), while those from landfills were somewhat smaller, 97,500 tons of CH_4 (2.4 million CO_2-equivalent tons).

Of remaining methane sources, only stationary combustion contributed substantially, resulting in the emission of an estimated 53,700 tons of CH_4, or 1.4 million CO_2-equivalent tons.

Emissions of HFCs, PFCs and SF_6 contribute only weakly to total emission in the 2006 inventory. This part of the inventory is incomplete. Most emissions of this class of gases result from leakage from mobile air conditioning.

By gas, the 2006 emission inventory is dominated by CO_2 emissions, which in 2006 comprised an estimated 85 percent of all inventoried GHG emissions. Emissions of CH_4 accounted for an additional 7.5 percent of emissions, and N_2O another 6.2 percent of emissions. In aggregate, emission of the PFCs, HFCs and SF_6 accounted for one percent of all GHG emissions.

By major emitting activity, energy system emissions dominate the 2006 GHG emissions total. Included in emissions from the energy system are emissions from combustion, net electricity imports, flue gas desulfurization, coal piles, natural gas transmission and distribution, oil refining, and various working fluids of transportation or space heating and cooling equipment like oil lubricants. In 2006 the energy system accounted for an estimated 129.5 million CO_2-equivalent tons of GHG emissions to the atmosphere, or about 83 percent of gross emissions.

Nonenergy-related agricultural activities in aggregate accounted for about 20.8 million CO_2-equivalent tons, or roughly 13 percent of gross emissions. Emissions from the waste sector comprised about one percent of all weighted emissions; emissions from industrial processes and all other sources comprised three percent of gross statewide emissions. Carbon sequestration in residential structures and demolition and construction landfills offset 3.5 million tons of GHGs.

Table 35: 2006 Greenhouse Gas Emissions in Minnesota

2006 Greenhouse Gas Emissions in Minnesota		
	Nominal Tons *(Thousands)*	**CO_2-eqivalent Tons *(Millions)***
CO_2		
Fossil Fuel Combustion	110,500	110.5
Electricity Imports	13,900	13.9
Other Energy Related[1]	1,200	1.2
Histosol Cultivation	5,200	5.2
Liming, Urea Fertilizer, Erosion, Peat Mining	600	0.6
Solvents[2]	200	0.2
Taconite Processing	1,600	1.6
Other Industrial Limestone Use[3]	<100	<0.1
Non-energy Industrial CO emissions	<100	<0.1
Carbon Sequestration in Housing	(1,600)	(1.6)
Other Residential[4]	100	0.1
Sequestration in D/C Landfills	(1,900)	(1.9)
Other Waste[5]	100	0.1
Subtotal*	**130,100**	**130.1**
N_2O		
Stationary Combustion	0.9	0.3
Mobile Source Combustion	2.4	0.7
Electricity Imports	0.2	0.1
Nutrient Soil Management[6]	24.7	7.4
Feedlots	2.8	0.8
Waste[7]	0.5	0.2
Other[8]	<0.1	<0.1
Subtotal*	**31.6**	**9.4**
CH_4		
Stationary Source Combustion	53.7	1.4
Mobile Source Combustion	2.5	<0.1
Electricity Imports	0.5	<0.1
Other Electricity[9]	0.9	<0.1
Manure Storage	101.7	2.5
Ruminants	168.5	4.2
Other Agriculture[10]	7.4	0.2
Other Industrial[11]	7.7	0.2
Municipal & Industrial Landfills	97.5	2.4
Municipal Wastewater	18.8	0.5
Other Waste[12]	1.5	<0.1
Subtotal*	**460.7**	**11.5**
HFCs and PFCs		
Mobile AC, Industrial Processes	0.7	1.0
SF_6		
Electricity Transmission & Distribution	<0.1	0.5
Total*		**152.5**

[1]Flue gas desulfurization, natural gas pipelines; [2]Industrial and commercial solvents and other industrial VOC and TRI releases; [3]Glass manufacture, steel production; [4]Food additives, soaps, and detergents; [5]Medical waste incineration, rural open burning, other landfill operations; [6]Agricultural and residential fertilizer, manure field applications, atmospheric nitrogen deposition, cultivated histosols, crop residues, and runoff; [7]Biosolids application, municipal wastewater, rural open burning, municipal solid waste composting, medical waste incineration, and other landfill operations; [8]Wildfires, medical use; [9]Coal storage and hydroelectric reservoirs; [10]Wild rice and wildfire; [11]Industrial coal storage, industrial wastewater treatment, oil refining, and peat mining; [12]Municipal waste composting, rural open burning, landfill gas flaring, other landfill operations.

* Totals may not add due to rounding

Section 13: Progress Toward GHG Reduction Goals

In the *Next Generation Energy Act* (Minn. Stat. § 216H.02), the State Legislature established goals for statewide GHG emissions reductions for Minnesota. These include the following percentage emission reductions from a 2005 baseline level:

- 2015: 15 percent
- 2025: 30 percent
- 2050: 80 percent

Baseline 2005 emissions were estimated at 154.1 million CO_2-equivalent tons, which implies that a 2015 target level under the Next Generation Energy Act goals of 131.0 million CO_2-equivalent tons and a 2025 target of 107.9 million CO_2-equivalent tons. Assuming a linear approach or trajectory to these target levels, Minnesota state-level GHG emissions would need to decline about two million CO_2-equivalent tons per year to meet these goals.

In 2006 state-level GHG emissions from Minnesota were an estimated 152.5 million CO_2-equivalent tons, or roughly two million tons lower than 2005 levels. This appears to place Minnesota state-level emissions roughly on the needed trajectory of reductions to meet the 2015 *Next Generation Energy Act* target.

The 2006, 2007 and 2015 target levels under the *Next Generation Energy Act* are shown on Table 36, along with estimated emissions for 2000 and 2003-2006. Figure 47 shows the same data graphically, along with emission estimates for all prior years stretching back to 1990.

Table 36: Progress Toward Meeting Greenhouse Gas Reduction Goals

Progress Towards Meeting Greenhouse Gas Reduction Goals							
	2000	**2003**	**2004**	**2005**	**2006**	**2007**	**2015**
Historical emissions	151.7	153.6	153.7	154.1	152.5		
Emission trajectory for Minn. Stat. § 216H.02 goals					151.8	149.5	131.0

The distribution of the emission reductions estimated to have occurred between 2005 and 2006 is shown in Table 37 by economic sector. Much of the reduction in estimated state-level GHG emissions occurred in the commercial, residential and transportation sectors. By gas, most of the reduction in emissions was in the form of reduced CO_2 emissions. By major activity, reduced emissions from energy use accounted for most of the reduction in statewide emissions between 2005 and 2006.

Figure 47: Tracking Progress on Minnesota Greenhouse Gas Emissions Reduction Goal

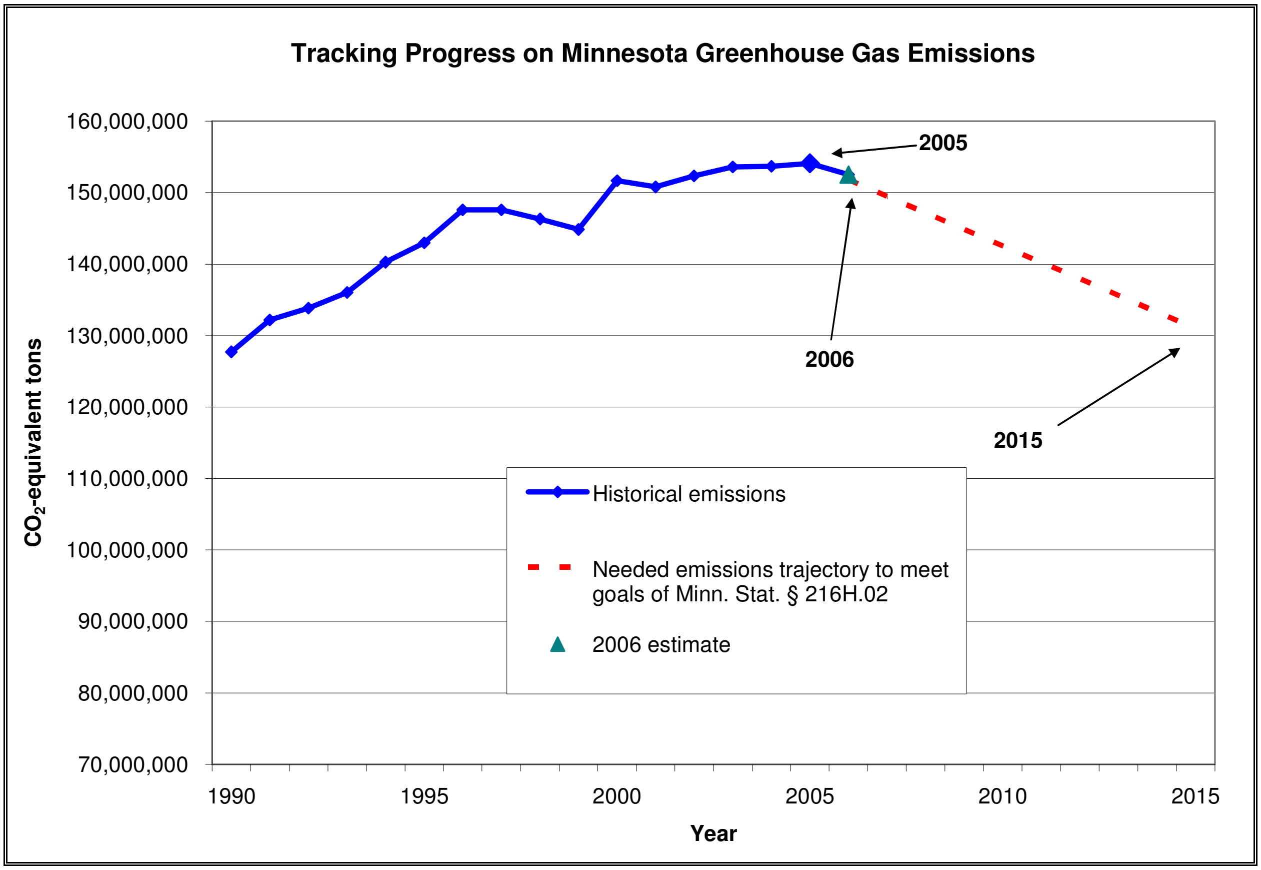


Table 37: Changes in Greenhouse Gas Emissions by Economic Sector

Greenhouse Gas Emissions by Economic Sector				
	2005	**2006**	**Net Change**	**Principal Source of the Sector Change in Emissions**
Agriculture	23.8	23.5	(0.2)	Reduced emissions from soil nutrient management
Commercial	6.8	6.1	(0.7)	Reduced energy use
Electric Utility	55.2	56.0	0.8	Increasing energy use
Residential	8.4	8.0	(0.4)	Reduced energy use
Transportation	41.8	41.0	(0.7)	Reduced fuel use by passenger cars and aviation
Industrial	16.6	16.4	(0.2)	Reduced energy use
Waste	1.6	1.4	(0.1)	Reduced emissions from landfills
Total	**154.1**	**152.5**	**(1.6)**	

Section 14: Omitted Sources

A number of potentially significant emission sources are not treated in the MPCA GHG emission inventory. In the case of most of these sources, delineated in Table 38, either the data needed to support emissions estimates are not available or estimation methods have not yet been developed. While quantitative estimates will have to await the development of these data sources and methods, it is a reasonable conjecture that, in aggregate, the emitted sources listed in the table might add an additional one to 10 million CO_2-equivalent tons to the MPCA GHG emission inventory. Emissions from cultivated agricultural lands or disturbed wetlands and lakes may be especially important.

Table 38: Sources and Sinks of Greenhouse Gas Emissions Not Included in Inventory

Sources of Greenhouse Gas Emissions Not Included in Inventory		
Fossil CO_2	• Water erosion of soils • Miscellaneous industrial limestone use • Tiling of other wet soils	• Mineral wetlands drainage • Out-of-state finished fossil fuels production
N_2O	• Stationary source pollution control • Prescribed burning • Agricultural burning	• Agricultural tiling • Sediment run-off to lakes and streams
CH_4	• Lake eutrophication • Prescribed burning • Agricultural burning • Out-of-state landfills	• House fires • Non-paper/pulp industrial landfills
SF_6	• Magnesium casting	
HFCs	• Commercial and industrial refrigeration • Space cooling	• Insulating foams • Fire extinguishing equipment
PFCs	• Fire extinguishing equipment	
Sinks of Greenhouse Gas Emissions Not Included in Inventory		
Biogenic carbon sequestration or stock loss	• Agricultural soils • Urban soils • Forest soils • Non-residential structures	• Urban forest • Wood products • Lake sediments • Wetlands

Besides the omitted sources and sinks listed in Table 38, other potential sources of GHG emissions, albeit of lesser significance exist. These include artificially-flooded reservoirs (CH_4), landfilled plastics and waste oil (fossil CO_2), landfill refrigerant emissions (HFCs), paints and other fossil-based liquid coverings and cleaners (fossil CO_2), pharmaceuticals, pesticides and other agricultural chemicals (fossil CO_2), flotation foams (HFCs), insulated windows (SF_6), and miscellaneous consumer products (N_2O, HFCs, CO_2). However, total GHG emissions from these sources are unlikely to be substantial.

Section 15: Next Steps

The MPCA GHG Emission Inventory is a work in progress, and is likely to remain so until the science matures, particularly regarding our ability to model and track emissions from perturbed natural systems and highly managed agroforestry systems. Frequent re-calculation of emissions estimates is a common feature of GHG inventory development at both the state and national level. This need for continual revision is a measure of the degree to which our understanding of the processes leading to GHG emissions is still developing.

Planned improvements for the next biennial report, covering 1970-2008, include:

- an improved HFC/PFC inventory based on the full implementation of the mandatory high GWP reporting rule;
- new fuel use and feedstock reporting requirements for in-state petroleum refineries;
- greater disaggregation of state-level energy use data to the end-use level;
- a new stock model for monthly estimation of livestock populations on farms and feedlots;
- development of an emission forecasting capability.

As noted in Section 4, using a process model, the EPA has published state-level emission estimates for emissions from nutrient management that, in the case of Minnesota for 2006, are roughly twice what are estimated by the MPCA using a simpler method. This is the first time in developing its national inventory that the EPA has reported estimates for emissions from soil nutrient management at the state level. The EPA is only several years into the use of formal process models to evaluate emissions from this source; the 2006 EPA estimate for Minnesota may prove anomalous and require substantial revision. However, the situation bears watching. If, after review, the state-level EPA estimates in fact are found to be the best representation of emissions at the state-level from soil management practices, a entirely new inventory approach to N_2O emissions from soil nutrient management may become necessary for Minnesota.

A full listing of priority improvements to the inventory for the next two to five years is shown in Table 39. It is likely that some of this will have to await developments in the underlying science. As we develop the inventory and prepare the next biennial report, we welcome comments.

Table 39: Priority Inventory Improvements

Priority Inventory Improvements	
Source Development	High GWP emissions from commercial space cooling, refrigeration, magnesium refining
	CH_4 from lake eutrophication
	Industrial limestone use
	Carbon in wood products
Data development	Cultivated and disturbed peatlands
	Oil refining
Improved methods	Nutrient soil management
	Livestock flow model
New departures	GHG emission forecasting
	GHG fuel cycle emission tracking
	Energy end-use breakdown
	Ecosystem carbon fluxes

Section 16: Conclusion

Prior to 2005, statewide greenhouse gas emissions had been rising in Minnesota at a ten-year annual average rate of 0.8 percent per year. In the decade from 1985 to 1995, emissions increased by about one quarter, rising at a ten-year average annual rate of 2.2 percent per year. The period between 1985 and 1995 was characterized by dramatically falling real energy prices. Between 2005 and 2006, statewide GHG emissions declined by about two million CO_2-equivalent tons, from about 154.1 million CO_2-equivalent tons to 152.5 million CO_2-equivalent tons. After one year of reporting, statewide GHG emissions are generally on the trajectory of reduction delineated in the Next Generation Energy Act.

The MPCA GHG emission inventory is a work in progress. As more is learned and new tools are developed, new emission sources are rolled into the inventory. To accommodate improvements in estimation methodologies, GHG emission estimates are frequently re-calculated. This adds a certain fluidity to the estimates. This situation is unlikely to end soon, particularly as the science that underlies the treatment of GHG emissions from biological and other natural sources is far from mature. The MPCA GHG emission inventory should be viewed as a work in progress rather than a final completed statement about statewide emissions from Minnesota.

Given a set of methods that are applied consistently across all years, decision-makers can be reasonably sure that, even in situations where the absolute level of emissions is uncertain, they understand the general trend in emissions relative to the baseline. The MPCA GHG Emission Inventory was developed with this insight in mind. The intent is to provide information on how emissions are changing, how fast, and why, not necessarily an exact total.

Finally, the development of detailed breakdowns of emissions by energy end-use will be given a high priority in the coming year, as absent that breakdown, emission forecasting and policy analysis are difficult or impossible. Other high priority areas for inventory improvement include emissions from: in-state petroleum refinery operations, cultivated and disturbed peatlands, lake eutrophication, soil nutrient management, tiling and mineral wetland drainage, commercial and industrial refrigeration and space cooling, magnesium casting, and industrial limestone use.

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Appendix A: Greenhouse Gas Emissions in Minnesota: 2005

Table 40: 2005 Greenhouse Gas Emissions in Minnesota

2005 Greenhouse Gas Emissions in Minnesota		
CO_2	**Nominal Tons *(Thousands)***	**CO_2-equivalent Tons *(Millions)***
Fossil Fuel Combustion	114,000	114.0
Electricity Imports	12,100	12.1
Other Energy Related	1,300	1.3
Histosol Cultivation	5,200	5.2
Liming, Urea Fertilizer, Erosion, Peat Mining	600	0.6
Solvents	200	0.2
Taconite Induration	1,600	1.6
Other Industrial Limestone Use	<100	<0.1
Non-energy Industrial CO emissions	<100	<0.1
Carbon Sequestration in Housing	(2,100)	(2.1)
Other Residential	100	0.1
Sequestration in D/C Landfills	(1,800)	(1.8)
Other Waste	<100	<0.1
Subtotal	**131,300**	**131.3**
N_2O		
Energy (Stationary and Mobile)	3.7	1.1
Electricity Imports	0.2	0.1
Nutrient Soil Management	25.7	7.7
Feedlots	2.8	0.8
Waste	0.5	0.2
Other	<0.1	<0.1
Subtotal	**32.9**	**9.8**
CH_4		
Energy (Stationary and Mobile)	57.1	1.4
Electricity Imports	0.4	<0.1
Other Electricity	1.0	<0.1
Manure Storage	100.9	2.5
Ruminants	166.9	4.2
Other Agriculture	5.2	0.1
Other Industrial	7.8	0.2
Municipal & Industrial Landfills	101.2	2.5
Municipal Wastewater	18.6	0.5
Other Waste	1.7	<0.1
Subtotal	**460.9**	**11.5**
HFCs and PFCs		
Mobile AC, Industrial Processes	0.7	1.0
SF_6		
Electricity Transmission & Distribution	<0.1	0.4
Total		**154.1**

[1]Flue gas desulfurization, nat. gas pipelines; [2]Ind./comm. solvents, VOC and TRI releases; [3]Glass manufacture, steel production; [4]Food additives, soaps, detergents; [5]Med. waste incineration, rural open burning, landfill operations; [6]Ag. and residential fertilizer, manure field applications, atmospheric nitrogen deposition, cultivated histosols, crop residues, runoff; [7]Biosolids application, mun. wastewater, rural open burning, MMSW composting, med. waste incineration, landfill operations; [8]Wildfire, medical use; [9]Coal storage, hydroelectric reservoirs; [10]Wild rice, wildfire; [11]Industrial coal storage, industrial wastewater treatment, oil refining, peat mining; [12]MMSW composting, rural open burning, landfill gas flaring, landfill operations.

Appendix B: Extended Data Tables

Greenhouse Gas Emissions in Minnesota

Table 41: Greenhouse Gas Emissions by Sector

Greenhouse Gas Emissions by Sector (million tons CO_2-equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Agriculture	20.4	24.7	22.2	22.8	22.3	23.4	23.4	23.5	23.8	23.5
Commercial	8.8	6.1	5.9	6.5	6.6	7.1	6.9	6.7	6.8	6.1
Electric Utility	21.9	30.4	41.1	51.6	53.2	53.5	54.8	54.3	55.2	56.0
Residential	11.8	10.5	7.8	9.6	9.5	9.0	9.4	9.2	8.4	8.0
Transportation	22.6	28.1	31.1	40.4	40.8	41.5	41.6	41.8	41.8	41.0
Industrial	18.0	13.2	14.1	18.0	15.5	15.5	15.5	16.5	16.6	16.4
Waste	3.2	4.3	5.6	2.9	2.8	2.4	2.0	1.7	1.6	1.4
Total	**106.7**	**117.4**	**127.7**	**151.7**	**150.8**	**152.3**	**153.6**	**153.7**	**154.1**	**152.5**

Table 42: Greenhouse Gas Emissions by Major Activity

Greenhouse Gas Emissions by Major Activity (million tons CO_2-equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Energy	85.0	89.5	100.7	126.4	126.5	128.1	129.7	130.5	131.2	129.4
Agriculture	17.5	21.5	20.0	20.6	19.8	20.8	21.2	20.7	20.9	20.8
Waste	3.2	4.3	5.6	2.8	2.7	2.3	2.0	1.6	1.5	1.4
Industrial Process	1.0	1.3	2.5	2.6	2.2	2.3	2.1	2.2	2.1	2.1
Other	<0.1	0.7	(0.9)	(0.7)	(0.3)	(1.2)	(1.4)	(1.3)	(1.7)	(1.2)
Total	**106.7**	**117.4**	**127.7**	**151.7**	**150.8**	**152.3**	**153.6**	**153.7**	**154.1**	**152.5**

Table 43: Greenhouse Gas Emissions by Gas

Greenhouse Gas Emissions by Gas (million tons CO_2-equivalent)										
	1970	1980	1990	2000	2001	2002	2003	2004	2005	2006
N_2O	5.5	8.9	9.0	9.6	9.0	9.7	10.0	9.6	9.8	9.4
CH_4	11.1	13.1	14.2	12.6	12.4	12.2	12.0	11.6	11.5	11.5
CO_2	89.5	94.7	103.8	128.2	128.1	129.1	130.2	131.1	131.3	130.1
SF_6	0.7	0.7	0.7	0.4	0.4	0.4	0.4	0.4	0.4	0.5
HFC-134a/ HFC-152a	-	-	-	0.2	0.2	0.2	0.2	0.2	0.2	0.2
HFC-134a	-	-	-	0.5	0.6	0.6	0.7	0.7	0.7	0.7
PFCs	-	-	-	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**106.7**	**117.4**	**127.7**	**151.7**	**150.8**	**152.3**	**153.6**	**153.7**	**154.1**	**152.5**

Greenhouse Gas Emissions by Sector

Table 44: Agriculture Greenhouse Gas Emissions

Agriculture Greenhouse Gas Emissions (million tons CO_2 - equivalent)										
	1970	1980	1990	2000	2001	2002	2003	2004	2005	2006
Fossil Fuels	2.8	3.3	2.2	2.2	2.5	2.6	2.2	2.8	2.8	2.8
Soil Nutrient Management†	3.9	7.3	7.1	7.6	6.9	7.8	8.1	7.7	8.0	7.7
Feedlots	1.4	2.0	2.2	3.1	3.2	3.2	3.3	3.4	3.3	3.4
Livestock Flatulence	7.0	6.6	5.1	4.5	4.4	4.3	4.3	4.2	4.2	4.2
Organic Soils	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Other Sources‡	0.1	0.4	0.4	0.3	0.2	0.2	0.3	0.2	0.2	0.3
Total	**20.4**	**24.7**	**22.2**	**22.8**	**22.3**	**23.4**	**23.4**	**23.5**	**23.8**	**23.5**
CH_4	7.3	7.7	6.7	6.9	6.9	6.9	7.0	6.9	6.8	6.9
CO_2	8.1	8.8	7.8	7.9	8.1	8.3	7.9	8.4	8.5	8.4
N_2O	5.0	8.2	7.8	8.0	7.4	8.2	8.6	8.2	8.5	8.2
Total	**20.4**	**24.7**	**22.2**	**22.8**	**22.3**	**23.4**	**23.4**	**23.5**	**23.8**	**23.5**

†Includes: crop residues, cultivated histosol N_2O, atmospheric deposition, fertilizer, liming of fields, manure, runoff, and urea application.
‡Includes: wild rice cultivation, wind erosion of soils, and wildfire.

Table 45: Commercial Greenhouse Gas Emissions

Commercial Greenhouse Gas Emissions (million tons CO_2 - equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Coal	1.1	0.4	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Natural Gas	4.5	3.7	4.5	5.6	5.5	6.1	6.0	5.7	5.7	5.2
Oil	3.2	2.0	0.8	0.7	0.9	0.7	0.7	0.8	0.9	0.7
Noncombustion Sources, Biomass and Other Fossil Fuels	<0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**8.8**	**6.1**	**5.9**	**6.5**	**6.6**	**7.1**	**6.9**	**6.7**	**6.8**	**6.1**
CH_4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CO_2	8.7	6.0	5.8	6.5	6.6	7.0	6.9	6.6	6.8	6.0
N_2O	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total	**8.8**	**6.1**	**5.9**	**6.5**	**6.6**	**7.1**	**6.9**	**6.7**	**6.8**	**6.1**

†Includes: Other fossil fuels, limestone use, medical use, and solvents.

Table 46: Electric Generation Greenhouse Gas Emissions

Electric Generation Greenhouse Gas Emissions (million tons CO_2 - equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Coal	13.2	24.9	31.9	37.2	36.3	39.8	40.7	39.0	39.1	38.3
Natural Gas	3.5	0.6	0.5	0.7	0.8	1.0	1.3	1.1	1.8	2.0
Petroleum	0.8	0.8	0.6	1.0	0.8	0.8	1.1	1.0	0.9	0.6
Electricity Imports	3.9	3.5	7.0	11.6	14.3	10.8	10.7	12.1	12.3	14.1
Noncombustion Sources, Biomass and Other Fossil Fuels	0.6	0.6	1.2	1.0	1.0	1.0	1.1	1.0	1.1	1.0
Total	**21.9**	**30.4**	**41.1**	**51.6**	**53.2**	**53.5**	**54.8**	**54.3**	**55.2**	**56.0**
CH_4	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	0.1	<0.1	<0.1	0.1
CO_2	21.2	29.6	40.2	50.9	52.5	52.8	54.0	53.5	54.5	55.2
N_2O	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
SF_6	0.7	0.7	0.7	0.4	0.4	0.4	0.4	0.4	0.4	0.5
Total	**21.9**	**30.4**	**41.1**	**51.6**	**53.2**	**53.5**	**54.8**	**54.3**	**55.2**	**56.0**

†Includes: Other fossil fuels, coal storage, FGD, and methane from hydroelectric reservoirs.

Table 47: Industrial Greenhouse Gas Emissions

Industrial Greenhouse Gas Emissions (million tons CO_2 - equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Coal	4.4	2.0	1.8	3.7	2.4	2.2	2.4	2.6	2.7	2.8
Natural Gas	5.7	5.7	5.0	6.1	5.3	5.4	5.3	5.4	5.4	5.6
Petroleum	6.9	4.1	4.7	5.6	5.6	5.6	5.7	6.3	6.4	5.8
Taconite Processing	1.0	1.2	1.8	1.9	1.4	1.8	1.5	1.6	1.6	1.6
Noncombustion Sources, Biomass and Other Fossil Fuels	0.1	0.1	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.6
Total	**18.0**	**13.2**	**14.1**	**18.0**	**15.5**	**15.5**	**15.5**	**16.5**	**16.6**	**16.4**
CH_4	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CO_2	17.9	13.1	13.9	17.6	15.1	15.1	15.1	16.2	16.2	16.0
N_2O	0.1	<0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
HFCs	-	-	-	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**18.0**	**13.2**	**14.1**	**18.0**	**15.5**	**15.5**	**15.5**	**16.5**	**16.6**	**16.4**

†Includes: Other fossil. fuel, semiconductor, ammonia and glass manufacture, coal storage, solvent, ind. wastewater, oil refining, ind. process, VOC/TRI releases, peat mining.

Table 48: Residential Greenhouse Gas Emissions

Residential Greenhouse Gas Emissions (million tons CO_2 - equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Coal	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Natural Gas	6.0	6.0	6.3	7.7	7.4	8.0	8.1	7.8	7.6	7.0
Petroleum	5.6	3.6	2.3	2.4	2.4	2.1	2.5	2.6	2.4	2.1
Noncombustion Sources, Biomass and Other Fossil Fuels	<0.1	0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Total	**11.8**	**9.9**	**8.8**	**10.6**	**10.2**	**10.6**	**11.2**	**10.9**	**10.5**	**9.6**
Sequestration in housing units	-	0.7	(1.0)	(1.0)	(0.7)	(1.5)	(1.7)	(1.7)	(2.1)	(1.6)
Total	**11.8**	**10.5**	**7.8**	**9.6**	**9.5**	**9.0**	**9.4**	**9.2**	**8.4**	**8.0**
CH_4	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CO_2	11.7	10.3	7.6	9.2	9.2	8.6	9.0	8.8	8.0	7.6
N_2O	<0.1	0.1	<0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.1
HFCs	-	-	-	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	**11.8**	**10.5**	**7.8**	**9.6**	**9.5**	**9.0**	**9.4**	**9.2**	**8.4**	**8.0**

†Includes: Aerosols, food additives, soaps, detergents, shampoos, lawn fertilizers, refrigeration, and sequestration in housing.

Table 49: Transportation Greenhouse Gas Emissions

Transportation Greenhouse Gas Emissions (million tons CO_2 - equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Other (military, off highway, other on-highway, buses, marine)	0.5	1.5	1.3	1.6	1.6	1.8	2.1	1.8	1.9	2.5
Railroads	0.9	0.8	0.7	0.7	0.6	0.6	0.6	0.8	1.0	0.9
Natural Gas Transmission	1.2	1.4	1.7	2.4	2.2	2.5	2.4	2.4	2.5	2.4
Aviation	1.6	2.2	3.8	5.6	5.0	4.6	4.6	4.9	5.0	4.4
Heavy Trucks	2.4	4.3	5.0	6.1	6.1	6.2	6.4	6.3	6.3	6.2
Light Trucks	2.3	4.0	6.9	11.9	12.7	13.1	13.0	13.4	13.2	13.2
Cars	13.7	13.9	11.8	12.1	12.6	12.6	12.5	12.2	11.9	11.4
Total	**22.6**	**28.1**	**31.1**	**40.4**	**40.8**	**41.5**	**41.6**	**41.8**	**41.8**	**41.0**
Natural Gas	1.2	1.4	1.7	2.4	2.2	2.5	2.4	2.4	2.5	2.4
Petroleum	21.4	26.7	29.4	37.4	38.0	38.3	38.5	38.7	38.5	37.9
Other Energy from Fossil Fuel	<0.1	<0.1	<0.1	0.1	0.1	0.1	0.1	0.1	<0.1	<0.1
Other Sources	-	-	-	0.5	0.6	0.6	0.7	0.7	0.7	0.7
Total	**22.6**	**28.1**	**31.1**	**40.4**	**40.8**	**41.5**	**41.6**	**41.8**	**41.8**	**41.0**
CH_4	0.9	1.0	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
CO_2	21.6	26.8	29.2	37.5	38.0	38.7	38.8	39.0	39.1	38.4
N_2O	0.2	0.4	0.8	1.1	1.0	1.0	0.9	0.9	0.8	0.7
HFCs	-	-	-	0.5	0.6	0.6	0.7	0.7	0.7	0.7
Total	**22.6**	**28.1**	**31.1**	**40.4**	**40.8**	**41.5**	**41.6**	**41.8**	**41.8**	**41.0**

†Includes: Mobile air conditioner leakage, and natural gas transmission.

Table 50: Waste Greenhouse Gas Emissions

Waste Greenhouse Gas Emissions (million tons CO_2 - equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Fossil Fuels	<0.1	<0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1
Noncombustion Sources and Biomass	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
MMSW Landfills	2.7	3.8	5.6	3.4	3.4	3.0	2.7	2.5	2.4	2.3
Industrial Landfills	-	-	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Municipal Wastewater Treatment	0.4	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Total	**3.2**	**4.3**	**6.5**	**4.4**	**4.4**	**4.0**	**3.8**	**3.5**	**3.4**	**3.3**
D/C sequestration	-	-	(0.9)	(1.6)	(1.6)	(1.7)	(1.7)	(1.8)	(1.8)	(1.9)
Total	**3.2**	**4.3**	**5.6**	**2.9**	**2.8**	**2.4**	**2.0**	**1.7**	**1.6**	**1.4**
CH_4	2.7	4.1	6.1	4.1	4.0	3.7	3.4	3.1	3.0	2.9
CO_2	0.3	0.1	(0.6)	(1.3)	(1.4)	(1.5)	(1.5)	(1.6)	(1.6)	(1.7)
N_2O	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Total	**3.2**	**4.3**	**5.6**	**2.9**	**2.8**	**2.4**	**2.0**	**1.7**	**1.6**	**1.4**

Biogenic Greenhouse Gases

Table 51: Biomass CO_2

Biomass CO_2 (million tons)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Liquid Biofuels	-	<0.1	0.2	2.0	2.0	2.2	2.6	2.7	2.7	2.9
Solid Biomass	1.6	3.4	5.2	5.6	5.9	5.9	5.9	6.4	6.4	7.0
Biogas	-	-	<0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Waste to Energy	-	-	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Waste Incineration	1.4	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Landfills	0.2	0.4	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4
Other	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.1	0.1	0.1	0.1
Total	**3.2**	**4.2**	**6.4**	**8.6**	**8.9**	**9.0**	**9.5**	**10.0**	**10.0**	**10.8**

Appendix C: Extended Data Tables (Metric Tons)

Greenhouse Gas Emissions in Minnesota

Table 52; Greenhouse Gas Emissions by Economic Sector

Greenhouse Gas Emissions by Economic Sector (million metric tons CO_2-equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Agriculture	18.5	22.4	20.1	20.7	20.3	21.2	21.3	21.3	21.5	21.3
Commercial	8.0	5.5	5.3	5.9	6.0	6.4	6.3	6.1	6.2	5.5
Electric Utility	19.9	27.5	37.3	46.8	48.2	48.5	49.7	49.2	50.1	50.8
Residential	10.7	9.6	7.1	8.7	8.7	8.2	8.5	8.4	7.6	7.3
Transportation	20.5	25.5	28.2	36.6	37.0	37.7	37.7	37.9	37.9	37.2
Industrial	16.3	12.0	12.8	16.3	14.1	14.1	14.0	15.0	15.0	14.9
Waste	2.9	3.9	5.1	2.6	2.5	2.1	1.9	1.6	1.4	1.3
Total	**96.8**	**106.5**	**115.9**	**137.6**	**136.8**	**138.2**	**139.3**	**139.4**	**139.8**	**138.4**

Table 53: Greenhouse Gas Emissions by Major Activity

Greenhouse Gas Emissions by Major Activity (million metric tons CO_2-equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Energy	77.1	81.2	91.3	114.7	114.7	116.2	117.7	118.4	119.1	117.4
Agriculture	15.9	19.5	18.1	18.7	18.0	18.8	19.3	18.8	19.0	18.8
Waste	2.9	3.9	5.1	2.5	2.4	2.1	1.8	1.5	1.4	1.3
Industrial Processes	0.9	1.2	2.3	2.3	2.0	2.1	1.9	2.0	1.9	1.9
Other	<0.1	0.6	(0.8)	(0.6)	(0.3)	(1.1)	(1.2)	(1.2)	(1.6)	(1.0)
Total	**96.8**	**106.5**	**115.9**	**137.6**	**136.8**	**138.2**	**139.3**	**139.4**	**139.8**	**138.4**

Table 54: Greenhouse Gas Emissions by Gas

Greenhouse Gas Emissions by Gas (million metric tons CO_2-equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
N_2O	5.0	8.1	8.2	8.7	8.1	8.8	9.1	8.7	8.9	8.6
CH_4	10.1	11.9	12.9	11.4	11.3	11.0	10.9	10.5	10.5	10.4
CO_2	81.1	85.9	94.1	116.3	116.2	117.1	118.1	118.9	119.1	118.0
SF_6	0.6	0.6	0.7	0.4	0.4	0.4	0.4	0.4	0.4	0.4
HFC-134a/HFC-152a	-	-	-	0.2	0.2	0.2	0.2	0.2	0.2	0.2
HFC-134a	-	-	-	0.4	0.5	0.6	0.6	0.6	0.6	0.7
PFCs	-	-	-	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**96.8**	**106.5**	**115.9**	**137.6**	**136.8**	**138.2**	**139.3**	**139.4**	**139.8**	**138.4**

Greenhouse Gas Emissions by Economic Sector

Table 55: Agriculture Greenhouse Gas Emissions

Agriculture Greenhouse Gas Emissions (million metric tons CO_2-equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Fossil Fuels	2.6	3.0	2.0	2.0	2.3	2.4	2.0	2.5	2.6	2.5
Soil Nutrient Management†	3.5	6.6	6.4	6.9	6.2	7.1	7.4	7.0	7.3	7.0
Feedlots	1.2	1.8	2.0	2.8	2.9	2.9	3.0	3.0	3.0	3.1
Livestock Flatulence	6.3	6.0	4.6	4.0	4.0	3.9	3.9	3.8	3.8	3.8
Organic Soils	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Other Sources‡	0.1	0.4	0.3	0.3	0.2	0.2	0.3	0.2	0.2	0.3
Total	**18.5**	**22.4**	**20.1**	**20.7**	**20.3**	**21.2**	**21.3**	**21.3**	**21.5**	**21.3**
CH_4	6.6	7.0	6.0	6.3	6.2	6.2	6.4	6.2	6.2	6.3
CO_2	7.3	7.9	7.0	7.2	7.3	7.5	7.1	7.6	7.7	7.6
N_2O	4.5	7.5	7.0	7.3	6.7	7.4	7.8	7.4	7.7	7.4
Total	**18.5**	**22.4**	**20.1**	**20.7**	**20.3**	**21.2**	**21.3**	**21.3**	**21.5**	**21.3**

†Includes: crop residues, cultivated histosol N_2O, atmospheric deposition, fertilizer, liming of fields, manure, runoff, and urea application.
‡Includes: wild rice cultivation, wind erosion of soils, and wildfire.

Table 56: Commercial Greenhouse Gas Emissions

Commercial Greenhouse Gas Emissions (million metric tons CO_2-equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Coal	1.0	0.3	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Natural Gas	4.1	3.4	4.1	5.1	5.0	5.6	5.4	5.1	5.1	4.7
Oil	2.9	1.8	0.7	0.7	0.8	0.6	0.7	0.7	0.9	0.7
Noncombustion Sources, Biomass and Other Fossil Fuels	<0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**8.0**	**5.5**	**5.3**	**5.9**	**6.0**	**6.4**	**6.3**	**6.1**	**6.2**	**5.5**
CH4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
CO_2	7.9	5.5	5.3	5.9	6.0	6.4	6.2	6.0	6.1	5.5
N_2O	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total	**8.0**	**5.5**	**5.3**	**5.9**	**6.0**	**6.4**	**6.3**	**6.1**	**6.2**	**5.5**

†Includes: Other fossil fuels, limestone use, medical use, and solvents.

Table 57: Electric Generation Greenhouse Gas Emissions

Electric Generation Greenhouse Gas Emissions (million metric tons CO_2-equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Coal	12.0	22.5	28.9	33.7	32.9	36.1	36.9	35.4	35.5	34.7
Natural Gas	3.1	0.6	0.4	0.7	0.7	0.9	1.2	1.0	1.6	1.8
Petroleum	0.7	0.7	0.5	0.9	0.8	0.7	1.0	0.9	0.9	0.6
Electricity Imports	3.5	3.2	6.3	10.6	13.0	9.8	9.7	11.0	11.1	12.8
Noncombustion Sources, Biomass and Other Fossil Fuels	0.5	0.5	1.1	0.9	0.9	0.9	1.0	1.0	1.0	0.9
Total	**19.9**	**27.5**	**37.3**	**46.8**	**48.2**	**48.5**	**49.7**	**49.2**	**50.1**	**50.8**
CH_4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
CO_2	19.2	26.8	36.5	46.1	47.6	47.9	49.0	48.6	49.4	50.1
N_2O	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SF_6	0.6	0.6	0.7	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total	**19.9**	**27.5**	**37.3**	**46.8**	**48.2**	**48.5**	**49.7**	**49.2**	**50.1**	**50.8**

†Includes: Other fossil fuels, coal storage, FGD, and methane from hydroelectric reservoirs.

Table 58: Industrial Greenhouse Gas Emissions

Industrial Greenhouse Gas Emissions (million metric tons CO_2-equivalent)										
	1970	1980	1990	2000	2001	2002	2003	2004	2005	2006
Coal	4.0	1.8	1.6	3.4	2.2	2.0	2.2	2.4	2.4	2.6
Natural Gas	5.2	5.2	4.5	5.5	4.8	4.9	4.8	4.9	4.9	5.1
Petroleum	6.2	3.7	4.3	5.0	5.1	5.1	5.2	5.7	5.8	5.3
Taconite Processing	0.9	1.1	1.6	1.7	1.3	1.6	1.4	1.5	1.4	1.4
Noncombustion Sources, Biomass and Other Fossil Fuels	0.1	0.1	0.7	0.6	0.7	0.5	0.5	0.5	0.5	0.5
Total	16.3	12.0	12.8	16.3	14.1	14.1	14.0	15.0	15.0	14.9
CH_4	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CO_2	16.2	11.9	12.6	16.0	13.7	13.7	13.7	14.7	14.7	14.6
N_2O	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.1	0.1	0.1
HFCs	<0.1	<0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	16.3	12.0	12.8	16.3	14.1	14.1	14.0	15.0	15.0	14.9

†Includes: Other fossil fuels, ammonia manufacturing, glass manufacturing, coal storage, solvents, industrial wastewater treatment, oil refining, other industrial processes, VOC and TRI releases, peat mining, and semiconductor manufacturing.

Table 59: Residential Greenhouse Gas Emissions

Residential Greenhouse Gas Emissions (million metric tons CO_2-equivalent)										
	1970	1980	1990	2000	2001	2002	2003	2004	2005	2006
Coal	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Natural Gas	5.4	5.5	5.7	7.0	6.7	7.2	7.4	7.1	6.9	6.3
Petroleum	5.1	3.3	2.1	2.2	2.2	1.9	2.3	2.4	2.2	1.9
Other Sources	<0.1	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.5
Sequestration in Housing Units	-	0.6	(0.9)	(0.9)	(0.6)	(1.4)	(1.6)	(1.5)	(1.9)	(1.4)
Total	10.7	9.6	7.1	8.7	8.7	8.2	8.5	8.4	7.6	7.3
CH_4	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CO_2	10.6	9.3	6.9	8.4	8.3	7.8	8.2	8.0	7.2	6.9
N_2O	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	0.1	<0.1	<0.1
HFCs	-	-	-	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	10.7	9.6	7.1	8.7	8.7	8.2	8.5	8.4	7.6	7.3

†Includes: Aerosols, food additives, soaps, detergents, shampoos, lawn fertilizers, refrigeration, and sequestration in housing.

Table 60: Transportation Greenhouse Gas Emissions

Transportation Greenhouse Gas Emissions (million metric tons CO_2-equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Other[‡]	0.4	1.4	1.2	1.4	1.5	1.7	1.9	1.7	1.7	2.3
Railroads	0.9	0.8	0.6	0.6	0.6	0.5	0.6	0.7	0.9	0.8
Natural Gas Transmission	1.1	1.2	1.5	2.2	2.0	2.3	2.1	2.2	2.3	2.2
Aviation	1.5	2.0	3.4	5.0	4.5	4.2	4.2	4.5	4.5	4.0
Heavy Trucks	2.2	3.9	4.5	5.5	5.5	5.7	5.8	5.7	5.7	5.7
Light Trucks	2.1	3.6	6.3	10.8	11.5	11.9	11.8	12.2	12.0	12.0
Cars	12.4	12.6	10.7	10.9	11.4	11.5	11.3	11.1	10.8	10.3
Total	**20.5**	**25.5**	**28.2**	**36.6**	**37.0**	**37.7**	**37.7**	**37.9**	**37.9**	**37.2**
Natural Gas	1.1	1.2	1.5	2.2	2.0	2.3	2.1	2.2	2.3	2.2
Petroleum	19.4	24.2	26.7	33.9	34.4	34.8	35.0	35.1	35.0	34.4
Other Energy from Fossil Fuel	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Other Sources	-	-	-	0.4	0.5	0.6	0.6	0.6	0.6	0.7
Total	**20.5**	**25.5**	**28.2**	**36.6**	**37.0**	**37.7**	**37.7**	**37.9**	**37.9**	**37.2**
CH_4	0.8	0.9	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.1
CO_2	19.6	24.3	26.5	34.1	34.5	35.1	35.2	35.4	35.4	34.8
N_2O	0.2	0.3	0.7	1.0	0.9	0.9	0.8	0.8	0.7	0.6
HFCs	-	-	-	0.4	0.5	0.6	0.6	0.6	0.6	0.7
Total	**20.5**	**25.5**	**28.2**	**36.6**	**37.0**	**37.7**	**37.7**	**37.9**	**37.9**	**37.2**

†Includes: Mobile air conditioner leakage, and natural gas transmission.

‡Includes: Military, off highway, other on-highway, buses, and marine

Table 61: Waste Greenhouse Gas Emissions

Waste Greenhouse Gas Emissions (million metric tons CO_2-equivalent)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Fossil Fuels	<0.1	<0.1	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.1
Noncombustion Sources and Biomass	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
MMSW Landfills	2.4	3.4	5.1	3.1	3.0	2.7	2.5	2.2	2.2	2.1
Industrial Landfills	-	-	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Municipal Wastewater Treatment	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6
Total	**2.9**	**3.9**	**5.9**	**4.0**	**4.0**	**3.6**	**3.4**	**3.2**	**3.1**	**3.0**
D/C sequestration	-	-	(0.8)	(1.4)	(1.5)	(1.5)	(1.6)	(1.6)	(1.6)	(1.7)
Total	**2.9**	**3.9**	**5.1**	**2.6**	**2.5**	**2.1**	**1.9**	**1.6**	**1.4**	**1.3**
CH_4	2.5	3.8	5.6	3.7	3.6	3.3	3.1	2.8	2.8	2.7
CO_2	0.3	0.1	(0.6)	(1.2)	(1.3)	(1.3)	(1.4)	(1.4)	(1.5)	(1.5)
N_2O	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**2.9**	**3.9**	**5.1**	**2.6**	**2.5**	**2.1**	**1.9**	**1.6**	**1.4**	**1.3**

Biogenic Greenhouse Gases

Table 62 Biomass CO_2

Biomass CO_2 (million metric tons)										
	1970	**1980**	**1990**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Liquid Biofuels	-	<0.1	0.2	1.8	1.9	2.0	2.4	2.4	2.5	2.7
Solid Biomass	1.5	3.1	4.7	5.1	5.4	5.3	5.3	5.8	5.8	6.3
Biogas	-	-	<0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Waste to Energy	-	-	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Waste Incineration	1.2	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Landfills	0.2	0.3	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Other	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.1	0.1	0.1	0.1
Total	**2.9**	**3.8**	**5.8**	**7.8**	**8.1**	**8.1**	**8.6**	**9.1**	**9.1**	**9.8**

Appendix D: Global Warming Potentials

Table 63 Global Warming Potentials of Common Greenhouse Gases

Global Warming Potentials†		
Name	**Chemical Formula**	**100-year Integration Time**
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
Hydrofluorocarbons (HFCs)		
HFC-23	CHF_3	14,800
HFC-32	CH_2F_2	675
HFC-41	CH_3F	97
HFC-125	CHF_2CF_3	3,500
HFD-134	CHF_2CHF_2	1,100
HFC-134a	CH_2FCF_3	1,430
HFC-143	CHF_2CH_2F	330
HFC-143a	CH_3CF_3	4,470
HFC-152	CH_2FCH_2F	43
HFC-152a	CH_3CHF_2	124
HFC-161	CH_3CH_2F	12
HFC-227ea	CF_3CHFCF_3	3,220
HFC-236cb	CH_2FCF_2CF3	1,300
HFC-236ea	CHF_2CHFCF_3	1,200
HFC-236fa	$CF_3CH_2CF_3$	9,810
HFC-245ca	$CH_2FCF_2CHF_2$	640
HFC-245fa	$CHF_2CH_2CF_3$	1,030
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1,640
Perfluorocarbons (PFCs)		
PFC-14	CF_4	7,390
PFC-116	C_2F_6	12,200
PFC-218	C_3F_8	8,830
PFC-318	$c-C_4F_8$	10,300
PFC-3-1-10	C_4F_{10}	8,860
PFC-4-1-12	C_5F_{12}	9,160
PFC-5-1-14	C_6F_{14}	9,300
PFC-9-1-18	$C_{10}F_{18}$	>7500
Other Perfluorinated Compounds		
Sulfur hexafluoride	SF_6	22,800
Trifluoromethyl sulfur pentafluoride	SF_5CF_3	17,700
Nitrogen trifluoride	NF_3	17,200

†All values are from the IPCC Fourth Annual Report, unless the most recent value is only published in Third Annual Report.