Chapter 2
Inventory and Projections of GHG Emissions

Introduction

This chapter presents a summary of Minnesota's greenhouse gas (GHG) emissions and sinks (carbon storage) from 1990 to 2025. The Center for Climate Strategies (CCS) prepared a draft of Minnesota's GHG emissions inventory and reference case projections for the Minnesota Climate Change Advisory Group (MCCAG) of the Office of the Governor of Minnesota.[1] The draft inventory and reference case projections, completed in July 2007, provided the MCCAG with an initial, comprehensive understanding of current and possible future GHG emissions. The draft report was provided to the MCCAG and its Technical Work Groups (TWGs) to assist the MCCAG in understanding past, current, and possible future GHG emissions in Minnesota and thereby inform the policy recommendation development process. The MCCAG and TWGs have reviewed, discussed, and evaluated the draft inventory and methodologies as well as alternative data and approaches for improving the draft GHG inventory and forecast. The inventory and forecast have since been revised to address the comments provided by the MCCAG. In addition, the forecast has been extended to the year 2025 to comport with the Next Generation Energy Act of 2007 recently adopted by the State legislature and signed into law by the Governor of Minnesota.[2] The information in this chapter reflects the information presented in the final inventory and reference case projections report (hereafter referred to as the Inventory and Projections).[3]

Historical GHG emissions estimates (1990 through 2005)[4] were developed using a set of generally accepted principles and guidelines for state GHG emissions inventories, relying to the extent possible on Minnesota-specific data and inputs. The Minnesota Pollution Control Agency's (MPCA's) GHG inventory for 1990 through 2004 provides state-specific estimates for all the source sectors located within Minnesota. Therefore, historical emissions are based on the MPCA inventory. The reference case projections (2006–2025) are based on a compilation of various existing projections of electricity generation, fuel use, and other GHG-emitting activities, along with a set of simple, transparent assumptions described in the final Inventory and Projections report.

The Inventory and Projections report covers the six types of gases included in the U.S. Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates

[1] *Draft Minnesota Greenhouse Gas Inventory and Reference Case Projections, 1990–2020*, prepared by the Center for Climate Strategies for the Minnesota Pollution Control Agency, July 2007.

[2] Minnesota Session Laws 2007, Chapter 136, S.F. No. 145, available at: https://www.revisor.leg.state.mn.us/laws/?id=136&year=2007&type=0

[3] *Final Minnesota Greenhouse Gas Inventory and Reference Case Projections, 1990–2025*, prepared by the Center for Climate Strategies for the Minnesota Pollution Control Agency, February 2008.

[4] The last year of available historical data for each sector varies between 2000 and 2005.

the relative contribution of each gas, per unit mass, to global average radiative forcing on a global warming potential– (GWP–)weighted basis.[5]

It is important to note that the emissions estimates reflect the GHG emissions associated with the electricity sources used to meet Minnesota's demands, corresponding to a consumption-based approach to emissions accounting. Another way to look at electricity emissions is to consider the GHG emissions produced by electricity generation facilities in the State —a production-based method. The study covers both methods of accounting for emissions, but for consistency, all total results are reported as consumption-based.

Minnesota GHG Emissions: Sources and Trends

Table 2-1 provides a summary of GHG emissions estimated for Minnesota by sector for the years 1990, 2000, 2005, 2010, 2020, and 2025. As shown in this table, Minnesota is estimated to be a net source of GHG emissions (positive, or gross, emissions). No sinks of GHG emissions (removal of emissions, or negative emissions) were identified for Minnesota. As a result, Minnesota's gross GHG emissions are the same as the net emissions. The following sections discuss GHG emission sources, trends, projections, and uncertainties.

Table 2-1. Minnesota historical and reference case GHG emissions, by sector*

MMtCO_2e	1990	2000	2005	2010	2020	2025
Energy Use (CO_2, CH_4, N_2O)	**90.3**	**112.5**	**125.5**	**131.2**	**152.1**	**163.7**
Electricity Use (Consumption)	**34.7**	**43.6**	**54.1**	**57.0**	**71.2**	**79.3**
Electricity production (in-state)	29.6	35.2	37.2	38.4	43.5	43.4
Coal	28.1	33.0	34.5	34.5	39.3	39.2
Natural gas	0.48	0.65	1.59	2.77	2.93	3.03
Oil	0.50	0.86	0.63	0.63	0.63	0.63
MSW/landfill gas	0.52	0.69	0.53	0.54	0.57	0.59
Biomass, nuclear (CH_4 and N_2O)	0.003	0.008	0.000	0.001	0.001	0.001
Net imported electricity	5.03	8.41	16.8	18.6	27.7	35.9
Residential/Commercial/Industrial (RCI) Fuel Use	**25.6**	**31.32**	**32.0**	**35.0**	**38.6**	**40.5**
Coal	1.97	3.34	2.54	2.71	2.87	3.00
Natural gas	14.3	17.6	17.5	19.9	22.7	23.8
Petroleum	9.17	10.2	11.7	12.2	12.9	13.4
Wood (CH_4 and N_2O)	0.21	0.18	0.20	0.21	0.23	0.24
Transportation	**28.7**	**35.4**	**37.2**	**36.6**	**38.8**	**39.8**
On-road gasoline	17.3	21.7	22.7	22.3	22.7	22.7
On-road diesel	4.46	5.85	6.67	7.11	8.49	9.18
Marine vessels	2.69	1.97	1.86	1.79	1.76	1.74

[5] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC, 1996). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth), http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm

MMtCO_2e	1990	2000	2005	2010	2020	2025
Jet fuel and aviation gasoline	3.45	5.03	4.95	4.61	5.19	5.49
Rail, natural gas, other	0.77	0.85	0.99	0.75	0.67	0.63
Fossil Fuel Industry	**1.37**	**2.12**	**2.25**	**2.60**	**3.50**	**4.07**
Natural gas industry	1.37	2.12	2.25	2.60	3.50	4.07
Industrial Non-Fuel Use Processes	**0.61**	**1.37**	**1.56**	**1.80**	**2.46**	**2.95**
Lime manufacture (CO_2)	0.000	0.04	0.02	0.02	0.02	0.02
Limestone use (CO_2)	0.01	0.02	0.02	0.02	0.02	0.02
Taconite production (CO_2)	0.31	0.58	0.58	0.61	0.67	0.70
Peat mining and use (CO_2)	0.04	0.07	0.06	0.06	0.06	0.06
Ammonia manufacture (CO_2)	0.03	0.000	0.000	0.000	0.000	0.000
ODS substitutes (HFC, PFC, and SF_6)	0.000	0.41	0.65	0.93	1.60	2.06
Semiconductor manufacturing (HFC, PFC)	0.000	0.032	0.021	0.015	0.008	0.007
Electric power T&D (SF_6)	0.21	0.21	0.20	0.14	0.08	0.07
Medical (N_2O)	0.008	0.008	0.008	0.009	0.009	0.010
Agriculture	**19.2**	**21.7**	**21.7**	**22.7**	**24.9**	**26.0**
Enteric fermentation	3.49	3.39	3.25	3.08	2.80	2.68
Manure management	1.96	2.80	2.91	2.96	3.09	3.16
Agricultural soils	9.15	10.7	10.7	11.7	13.8	14.9
Rice cultivation	0.10	0.09	0.11	0.14	0.20	0.24
Residential fertilizer	0.09	0.10	0.12	0.13	0.15	0.16
Agricultural burning	0.00	0.00	0.00	0.00	0.00	0.00
Urea application and liming	0.33	0.50	0.59	0.63	0.73	0.77
Changes in cultivation practices[†]	4.06	4.06	4.06	4.06	4.06	4.06
Waste Management	**5.55**	**4.97**	**4.96**	**4.85**	**4.66**	**4.58**
Solid waste management	5.27	4.64	4.62	4.48	4.23	4.11
Wastewater management	0.28	0.33	0.35	0.37	0.43	0.47
Forestry and Land Use	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**
Total Gross (and Net) Emissions (Consumption Basis)[†]	**119.0**	**143.8**	**157.1**	**163.8**	**187.4**	**200.5**
Increase relative to 1990		21%	32%	38%	57%	68%

MMtCO_2e = million metric tons of carbon dioxide equivalent; CH_4 = methane; N_2O = nitrous oxide; MSW = municipal solid waste; ODS = ozone-depleting substance; HFC = hydrofluorocarbon; PFC = perfluorocarbon; SF_6 = sulfur hexafluoride; T&D = transmission and distribution

* Totals may not equal exact sum of subtotals shown in this table due to independent rounding.

[†] Forest lands and changes in cultivation practices related to agricultural soils are net sources rather than sinks of emissions; therefore, gross and net emissions are the same.

Historical Emissions

Overview

In 2005, on a gross emissions consumption basis (i.e., excluding carbon sinks), Minnesota accounted for approximately 157 million metric tons (MMt) of CO_2e emissions, an amount equal

to 2.2% of total U.S. gross GHG emissions. On a net emissions basis (i.e., including carbon sinks), Minnesotans also accounted for approximately 157 MMtCO_2e of emissions in 2005 (the same as gross emissions since no emission sinks were identified in Minnesota), an amount equal to 2.4% of total U.S. net GHG emissions.[6] Minnesota's GHG emissions are rising more quickly than those of the nation as a whole. From 1990 to 2005, Minnesota's gross and net GHG emissions increased by 32% while national gross emissions rose by 16% during this period.[7]

On a per capita basis, Minnesotans emitted about 30 metric tons (t) of gross CO_2e in 2005, greater than the national average of about 24 tCO_2e. Figure 2-1 illustrates the State's emissions per capita and per unit of economic output. It also shows that in Minnesota per capita emissions have increased from 1990 to 2005, while per capita emissions remained fairly flat for the nation as a whole. In both Minnesota and the nation as a whole, economic growth exceeded emissions growth throughout the 1990–2005 period. From 1990 to 2005, emissions per unit of gross product dropped by 26% nationally, and by 23% in Minnesota.[8]

The principal sources of Minnesota's GHG emissions in 2005 are electricity use (including electricity imports) and transportation, accounting for 34% and 24% of Minnesota's gross GHG emissions, respectively, as shown in Figure 2-2. The use of fossil fuels—natural gas, oil products, coal, and wood—in the residential, commercial, and industrial (RCI) sectors accounts for another 20% of the state's emissions in 2005.

Agricultural activities, such as manure management, fertilizer use, livestock (enteric fermentation), and changes in soil carbon due to cultivation practices, result in CH_4 and N_2O emissions that account for another 14% of state GHG emissions. This is greater than the U.S. portion of emissions attributable to agriculture (8%). Landfills and wastewater management facilities produce CH_4 and N_2O emissions that accounted for 3% of total gross GHG emissions in Minnesota in 2005. Emissions associated with the transmission and distribution of natural gas accounted for 1% of the gross GHG emissions in 2005. Industrial process emissions accounted for about 1% of the state's GHG emissions in 2005, and these emissions are rising due to the increasing use of hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) as substitutes for ozone-depleting chlorofluorocarbons (CFCs).[9] Other industrial processes emissions result from taconite, lime, and peat manufacturing; PFC use in semiconductor manufacture; CO_2 released during limestone, dolomite, and peat use; SF_6 released from transformers used in electricity transmission and distribution systems; and N_2O from medical uses.

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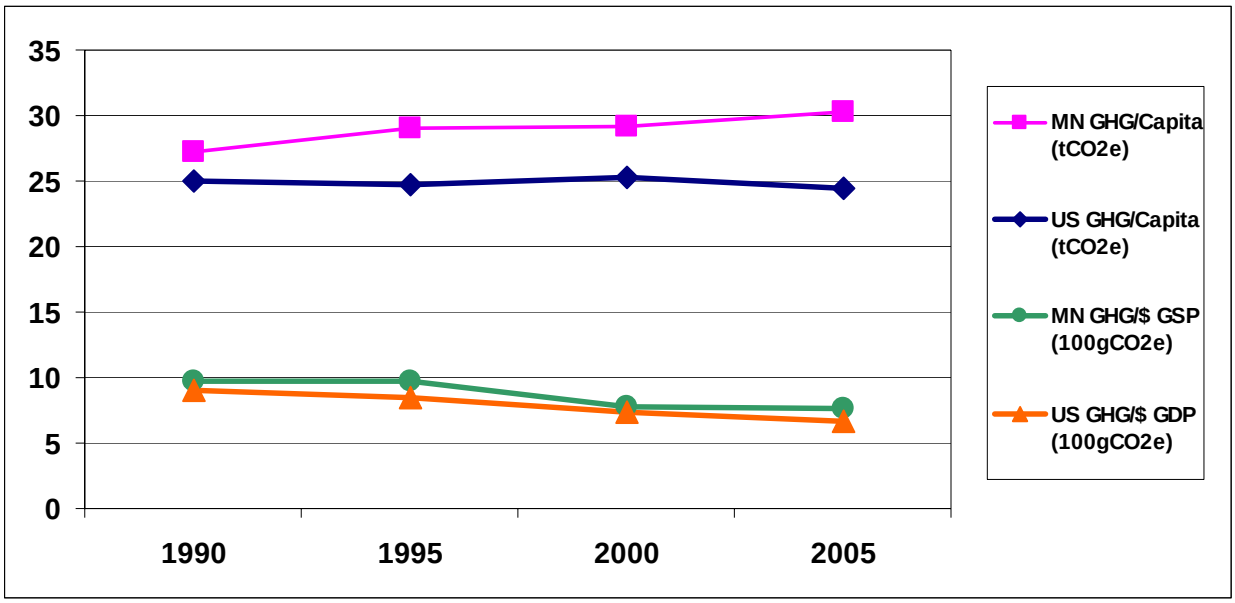
[6] National emissions from *Inventory of US Greenhouse Gas Emissions and Sinks:1990–2005*, April 2007, US EPA #430-R-07-002, http://www.epa.gov/climatechange/emissions/usinventoryreport.html

[7] During this period, population grew by 19% in Minnesota, which is the same as the national increase in population. However, Minnesota's economy grew at a faster rate on a per capita basis (up 71% vs. 57% nationally).

[8] Based on real gross domestic product (millions of chained 2000 dollars), that excludes the effects of inflation, available from the US Bureau of Economic Analysis, http://www.bea.gov/regional/gsp/

[9] CFCs are also potent GHGs; however, they are not included in GHG estimates because of concerns related to implementation of the Montreal Protocol. See Appendix I in the *Inventory and Projections* report for Minnesota, http://www.mnclimatechange.us/ewebeditpro/items/O3F16231.pdf

Figure 2-1. Minnesota and U.S. gross GHG emissions, per capita and per unit gross product



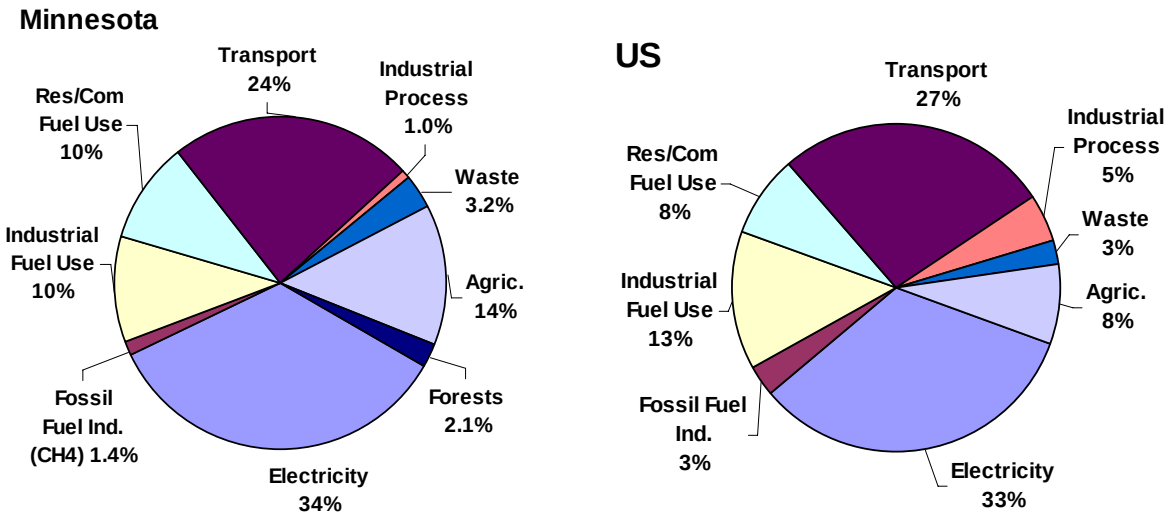
GSP = gross state product; GDP = gross domestic product; g = grams: tCO2e = tons carbon dioxide equivalent

Forestry emissions refer to the net CO_2 flux[10] from forested lands in Minnesota, which account for about 32% of the state's land area.[11] Minnesota's forests are estimated to be net sources of CO_2 emissions in Minnesota, accounting for about 2% of total gross GHG emissions in 2005. Forestry emissions are estimated to be a net source in Minnesota primarily due to a decrease in forested area over the period used to estimate the CO_2 flux for Minnesota (1990 to 2003), based on U.S. Forest Service (USFS) Forest Inventory Analysis data.

[10] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.

[11] Total forested acreage is 16.2 million acres in 2003; J. Smith, USFS, personal communication with S. Roe, CCS, April 2007. Acreage by forest type is available from the USFS at: http://nrs.fs.fed.us/pubs/rb/rb_nrs006.pdf. The total land area in Minnesota is 51 million acres, http://www.50states.com/minnesot.htm

Figure 2-2. Gross GHG emissions by sector, 2005: Minnesota and U.S.



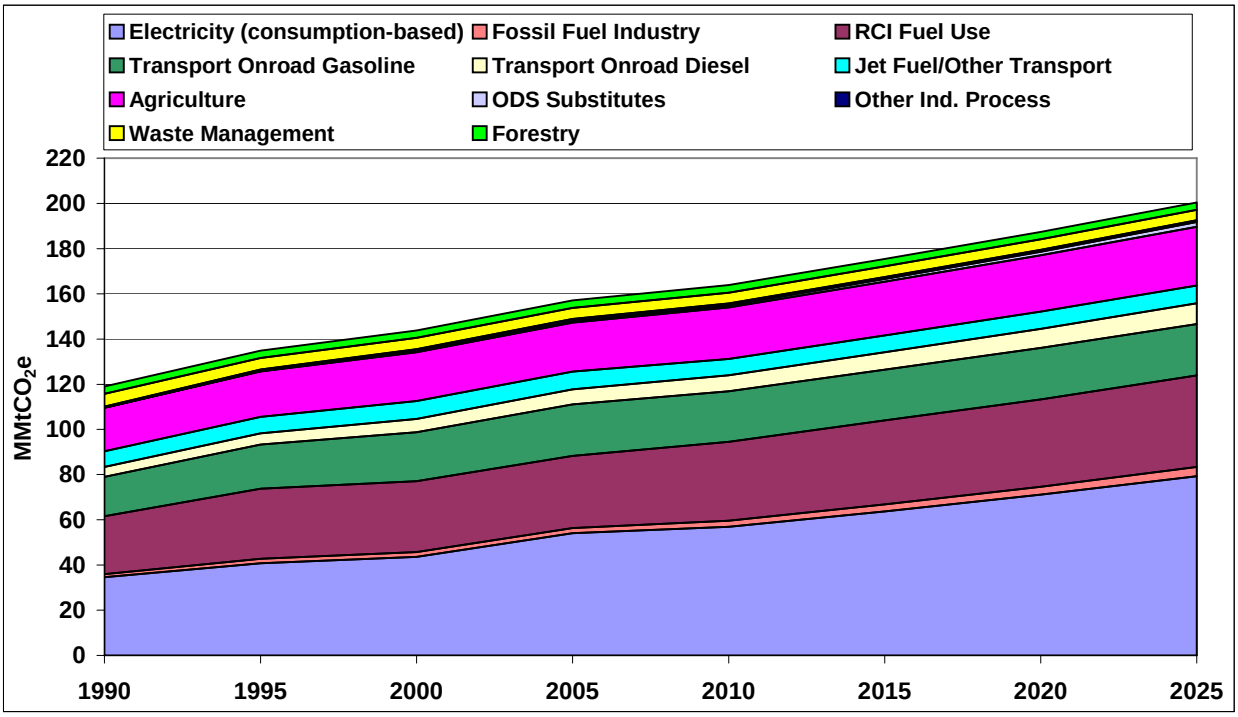
Note: At a national level, forests act as a net sink of CO_2; therefore, they do not show up in the above graph of gross US emissions sources.

Reference Case Projections

Relying on a variety of sources for projections, as noted in the Inventory and Projections report, a simple reference case projection of GHG emissions through 2025 was developed. As illustrated in Figure 2-3 and shown numerically in Table 2-1, under the reference case projections, Minnesota's gross GHG emissions continue to grow steadily, climbing to about 200 $MMtCO_2e$ by 2025, 68% above 1990 levels. This equates to an annual rate of growth of 1.2% per year. By 2025, the share of emissions associated with electricity consumptions grows to 40% of total gross and net GHG emissions. The share of emissions from the RCI fuel use sector increase slightly to 21% of Minnesota's gross and net GHG emissions in 2025, while the share of emissions from the transportation sectors declines somewhat to 20% by 2025, with slightly lower emissions than the RCI fuel use sector.

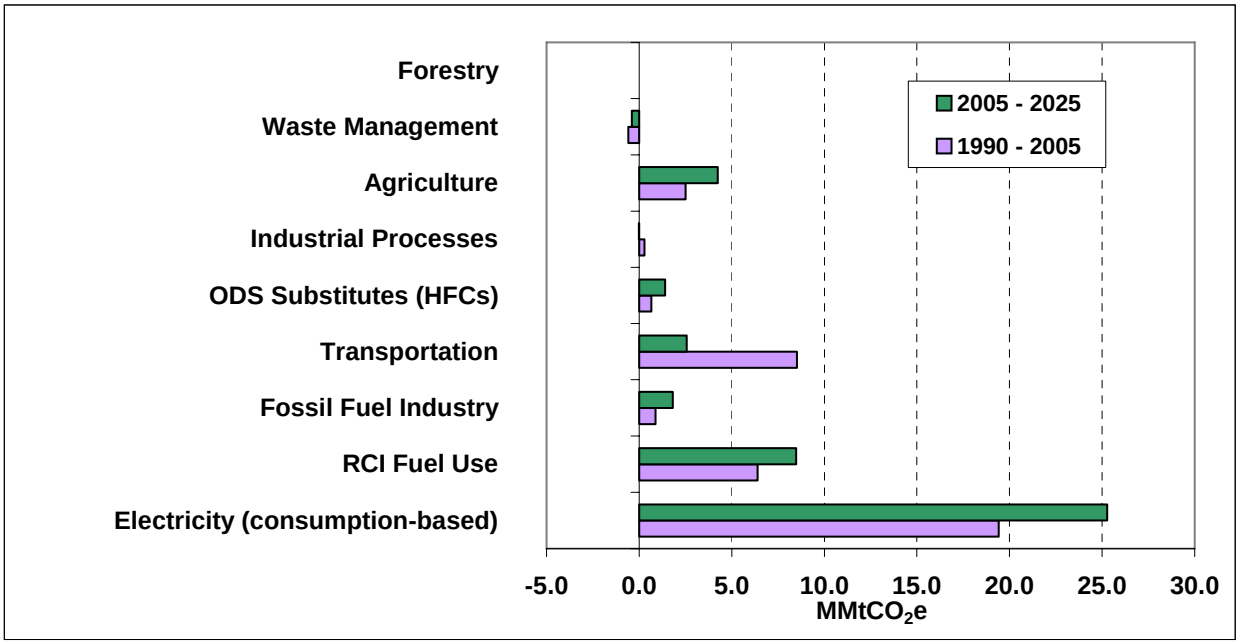
Emissions associated with electricity generation and imports to meet in-state demand is projected to be the largest contributor to future emissions growth, followed by emissions associated with the RCI fuel use, as shown in Figure 2-4. Other sources of emissions growth include agriculture, primarily from agricultural soils; transportation fuel use, primarily from on-road diesel; the transmission and distribution of natural gas; and the increasing use of HFCs and PFCs as substitutes for ozone-depleting substances (ODSs) in refrigeration, air conditioning, and other applications. Table 2-2 summarizes the growth rates that drive the growth in the Minnesota reference case projections as well as the sources of these data.

Figure 2-3. Minnesota gross GHG emissions by sector, 1990–2025: historical and projected



RCI = direct fuel use in residential, commercial, and industrial sectors; ODS = ozone depleting substance.

Figure 2-4. Sector contributions to gross emissions growth in Minnesota, 1990–2025: reference case projections ($MMtCO_2e$ basis)



ODS = ozone depleting substance; HFCs = hydrofluorocarbons; RCI = direct fuel use in residential, commercial, and industrial sectors.

Table 2-2. Key annual growth rates for Minnesota, historical and projected

	1990–2005	2005–2025	Sources
Population*	1.2%	0.8%	Minnesota Department of Administration, Office of Geographic and Demographic Analysis, State Demographic Center
Employment*			Minnesota Department of Employment and Economic Development
Goods	N/A†	0.4%	
Services	N/A	1.5%	
Electricity sales	2.3%	2.04%	Inventory: The US DOE Energy Information Administration's (EIA's) Electric Utility Sales data, available at: http://www.eia.doe.gov/cneaf/electricity/esr/esr_sum.html. As approved by the MCCAG, the average annual growth in electricity sales for 2005–2025 was assumed to be equal to the 2.04% per year, which corresponds to the average annual growth rate for the preceding 10-year period in Minnesota. This represents the business-as-usual forecast and does not include the effects of Minnesota's Conservation Improvement Program (CIP), which is addressed in Chapter 3 of this report.
Vehicle miles traveled	2.5%	0.8%	Minnesota Department of Transportation

* For the residential, commercial, and industrial (RCI) fuel consumption sectors, population and employment projections for Minnesota were used together with US DOE EIA's Annual Energy Outlook 2006 (AEO2006) projections of changes in fuel use for the EIA's U.S. West North Central region on a per capita basis for the residential sector, and on a per employee basis for the commercial and industrial sectors. For instance, growth in Minnesota's residential natural gas use is calculated as the Minnesota population growth times the change in per capita natural gas use for the West North Central region.

† N/A = not available; historical employment data for Minnesota for the goods producing and services providing sectors could not be identified during development of this report.

A Closer Look at the Two Major Sources: Electricity Supply and Transportation

As shown in Figure 2-2, electricity use in 2005 accounted for 34% of Minnesota's gross GHG emissions (about 54 $MMtCO_2e$), which is slightly higher than the national share of emissions from electricity production (33%). On a per capita basis, Minnesota's GHG emissions from electricity consumption are higher than the national average (in 2005, 10.4 $MMtCO_2e$ per capita in Minnesota vs. 8.1 $MMtCO_2e$ per capita nationally). From 1990 through 2005, electricity generated by coal-fired power plants in Minnesota accounted for 64% to 68% of total in-state generation. Nuclear power accounted for 25% to 30% of total in-state generation from 1990 through 2005. The remaining in-state generation came from a mix of natural gas, oil, refuse-derived fuel, and hydroelectric facilities. The consumption of imported electricity has increased from 12% of total Minnesota demand in 1990 to 27% of total Minnesota demand in 2005.[12]

As noted above, these electricity emissions estimates reflect the GHG emissions associated with the electricity sources used to meet Minnesota demands, corresponding to a consumption-based approach to emissions accounting. For many years, Minnesota power plants have tended to produce less electricity than is consumed in the State. In the year 2005, for example, emissions associated with Minnesota's electricity consumption (54 $MMtCO_2e$) were higher than those associated with electricity production (37 $MMtCO_2e$). The higher level for consumption-based emissions reflects GHG emissions associated with net imports of electricity to meet the State's

[12] Percentages are based on gross generation (including plant fuel use and line losses) associated with imports relative to total gross generation to meet Minnesota demand.

electricity demand.[13] Estimates of electricity sales for 2005 through 2025 indicate that Minnesota will remain a net importer of electricity. For the period covering 2005 through 2025, the reference case projection assumes that production-based emissions associated with electricity generated in-state will increase by about 6 $MMtCO_2e$, while emissions associated with imported electricity will increase by about 19 $MMtCO_2e$.

While estimates are provided for emissions from both electricity production and consumption, unless otherwise indicated, tables, figures, and totals in this report reflect electricity consumption emissions. The consumption-based approach can better reflect the emissions (and emissions reductions) associated with activities occurring in the state, particularly with respect to electricity use (and efficiency improvements), and is particularly useful for decision making. Under this approach, emissions associated with electricity exported to other states would need to be covered in those states' accounts in order to avoid double counting or exclusions.

Like electricity emissions, GHG emissions from transportation fuel use have risen steadily—from 1990 to 2005 transportation GHG emissions have increased at an average rate of 1.7% annually. Gasoline-powered on-road vehicles accounted for about 61% of transportation GHG emissions in 2005, on-road diesel vehicles accounted for another 18%, and aviation fuels for roughly 13%. Marine vessels accounted for 5% of transportation emissions in 2005. Rail and other sources (natural gas- and liquefied petroleum gas- [LPG-] fueled vehicles used in transport applications) accounted for the remaining 3% of transportation emissions. As a result of Minnesota's population and economic growth and an increase in total vehicle miles traveled (VMT), emissions from on-road gasoline use grew at a rate of 1.8% annually between 1990 and 2005. Meanwhile, emissions from on-road diesel use rose 2.7% per year during that period, suggesting an even more rapid growth in freight movement within or across the state. However, the Minnesota Department of Transportation projects a slowing in the VMT growth rate. Given this, emissions from on-road gasoline vehicles are projected to remain nearly the same in 2025 as in 2005, and emissions from on-road diesel vehicles are projected to increase at an annual rate of 1.6% per year from 2005 to 2025.

MCCAG Revisions

The following identifies the revisions that the MCCAG made to the inventory and reference case projections thus explaining the differences between this report and the initial assessment completed during July 2007:

- Forecast for all sectors: Extended the reference case projections for all sectors from 2020 to 2025 to align the forecast with Minnesota's GHG reduction goal for 2025.
- Energy Supply: Revised the electricity sales forecast for 2005 through 2025 for the business-as-usual reference case projections from 1.72% per year to 2.04% per year based on information compiled by the Energy Supply TWG. This revision increased emissions by 2.1$MMtCO_2e$ in 2015 and by 12.4 $MMtCO_2e$ in 2025 relative to the initial forecast presented in the July 2007 draft inventory and forecast report.

[13] Estimating the emissions associated with electricity use requires an understanding of the electricity sources (both in-state and out-of-state) used by utilities to meet consumer demand. The current estimates reflect some very simple assumptions, as described in Appendix A in the *Inventory and Projections* report.

- Transportation: Revised the VMT forecast for 2005 through 2025 for the business-as-usual reference case projections from 1.9% per year to 0.8% per year based on updated modeling results provided by the Minnesota Department of Transportation. This revision lowered emissions by 2.7 $MMtCO_2e$ in 2015 and by 4.9 $MMtCO_2e$ in 2025 relative to the initial forecast presented in the July 2007 draft inventory and forecast report.
- Agriculture: Revised the inventory and reference case projections for all agriculture sectors (except for enteric fermentation, manure management, and changes in soil cultivation practices).

Key Uncertainties

Some data uncertainties exist in this inventory, and particularly in the reference case projections. Key tasks for future refinement of this inventory and projection include review and revision of key drivers, such as the growth rate assumptions for electricity generation and consumption, transportation fuel use, and the use of renewable versus fossil fuels that will be major determinants of Minnesota's future GHG emissions (see Table 2-2). These growth rates are driven by uncertain economic, demographic, and land-use trends (including growth patterns and transportation system impacts), all of which deserve closer review and discussion. For the agriculture sector, significant uncertainty exists in the agricultural soil carbon levels, as these are based on a single year (1997) of data. Additionally, growth in many of the agriculture categories is assumed to follow historic emission trends. Significant uncertainties also exist in the forestry sector due to methodological changes in inventory methods over time. All of these issues warrant further investigation and considerable Minnesota-specific research.