Appendix C. Transportation Energy Use

Overview

Transportation is one the largest greenhouse gas (GHG) source sectors in Minnesota. The transportation sector includes light and heavy-duty (onroad) vehicles, aircraft, rail engines, and marine engines. Emissions from this sector include carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) from combustion of fuels.

Emissions Inventory and Reference Case Projection Methods

Historical Emissions

GHG emissions for 1990 through 2004 were estimated by Minnesota Pollution Control Agency (MPCA) using United States Environmental Protection Agency (US EPA) methods and emission factors as provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector and the national greenhouse gas inventory.[1,2,3] For CO_2, emission factors are in units of lb/MMBtu, and the activity data are fuel consumption. Key sources of fuel consumption data are listed in Table C1.

Table C1. Sources for Historical Minnesota Fuel Consumption Estimates

Fuel Type	Fuel Consumption Data Source
Gasoline (highway, marine[a])	*Highway Statistics*, Federal Highway Administration (FHWA)
Diesel (highway, rail, military)	Fuel Oil and Kerosene Sales, Energy Information Administration (EIA)
Ethanol	*Highway Statistics*, Federal Highway Administration (FHWA)
Jet Fuel	Petroleum Tax Division, Minnesota Department of Revenue
Aviation Gasoline	*Highway Statistics*, Federal Highway Administration (FHWA)
Liquified Petroleum Gas (LPG)	Calculated from Vehicle Inventory and Use Survey (VIUS) vehicles, VMT/vehicle, and approximate fuel economy
Natural Gas	*Natural Gas Annual*, Energy Information Administration (EIA)
Waste Oil	Calculated at a rate of 1 quart of motor oil/2000 miles traveled

[a] Estimation of marine diesel and residual fuel consumption discussed under commercial marine section.

For CH_4 and N_2O, nonroad engine emissions are estimated using fuel consumption data, shown in Table C1. CH_4 and N_2O emissions from onroad vehicles are estimated from vehicle miles traveled (VMT), which were obtained from Minnesota Department of Transportation (MNDOT) by MPCA.[4] Onroad emissions are also dependent on the distribution of model years that are

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[1] Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2004, US Environmental Protection Agency, April 2006, http://epa.gov/climatechange/emissions/usinventoryreport.html.

[2] CO_2 emissions were calculated using EPA's State Greenhouse Gas Inventory Tool (SGIT) software, with reference to the EIIP guidance provided in Volume VIII: Chapter. 1. "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004.

[3] CH_4 and N_2O emissions were calculated using SGIT, with reference to the EIIP guidance provided in Volume VIII: Chapter. 3. "Methods for Estimating Methane and Nitrous Oxide Emissions from Mobile Combustion", August 2004.

[4] Minnesota Department of Transportation

operating in each year. Vehicle vintage data were obtained from the Vehicle Inventory and Use Survey (VIUS) and the National Household Travel Survey.[5,6]

State-total VMT were allocated to specific vehicle types using data from MNDOT (i.e. VMT for passenger cars and heavy duty trucks).[7] Vehicle-type specific VMT and estimated fuel economy obtained by MPCA were used to estimate vehicle-specific fuel consumption. Vehicle-type specific fuel consumption was then allocated to gasoline and diesel categories based on the following:

- Light-duty vehicles – MPCA data;
- Heavy-duty vehicles – MPCA data;
- Recreational vehicles – assumed national value of 85% gasoline for 1990-1993, 67% for 1999-2004, interpolated for 1994-1998;[8]
- School buses – 90% diesel;[9]
- Transit buses – fuel consumption data from National Transit Database;[10]
- Other buses – assumed 100% diesel.

Commercial Marine Vessels
For the commercial marine sector (marine diesel and residual fuel), 1990-2004 emission estimates are based on EPA emission factors applied to estimates of Minnesota marine vessel diesel and residual fuel consumption. The MPCA inventory estimated marine diesel and residual fuel emissions based on fuel consumption data from EIA. Because EIA estimates of marine vessel fuel consumption represent the State in which fuel is sold rather than consumed, an alternative method was used to estimate Minnesota marine vessel fuel consumption.

Minnesota fuel consumption estimates were developed by allocating 1990-2004 national diesel and residual oil vessel bunkering fuel consumption estimates obtained from EIA.[11] Marine vessel fuel consumption was allocated to Minnesota using the marine vessel activity allocation methods/data compiled to support the development of EPA's National Emissions Inventory (NEI).[12] In keeping with the NEI, 75 percent of each year's distillate fuel and 25 percent of each year's residual fuel were assumed to be consumed within the port area (remaining consumption assumed to occur while ships are underway). National port area fuel consumption was allocated to Minnesota based on year-specific freight tonnage data as reported in "Waterborne Commerce

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[5] Vehicle Inventory and Use Survey, US Census Bureau, http://www.census.gov/svsd/www/vius/products.html.
[6] National Household Travel Survey, Federal Highway Administration, http://nhts.ornl.gov/.
[7] MPCA
[8] MOVES2004 Highway Vehicle Population and Activity Data, US Environmental Protection Agency, EPA420-P-04-020, Dec 2004.
[9] MPCA
[10] National Transit Database, US Federal Transit Administration, http://www.ntdprogram.com/ntdprogram/.
[11] US Department of Energy, Energy Information Administration, "Petroleum Navigator" (diesel data obtained from http://tonto.eia.doe.gov/dnav/pet/hist/kd0vabnus1a.htm; residual data obtained from http://tonto.eia.doe.gov/dnav/pet/hist/kprvatnus1a.htm).
[12] See methods described in ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_nonroad_methods.pdf

of the United States, Part 5 – Waterways and Harbors National Summaries."[13] Offshore CO_2 and hydrocarbon (HC) emissions for Minnesota's Exclusive Economic Zone (EEZ) were taken from a study by Corbett et al for the Commission for Environmental Cooperation in North America (CEC).[14] Offshore CH_4 emissions were estimated by speciating the HC emissions using the California Air Resources Board (CARB) total organic gases (TOG) profile #818.[15] Offshore N_2O emissions were estimated by applying the ratio of N_2O to CH_4 emission factors for residual fuel to the CH_4 emission estimate. The 2002 offshore emissions from the CEC inventory were scaled to other historic years based on the estimated port fuel consumption.

2005 Emission Estimates

Fuel consumption for 2005 was available from the sources listed in Table C1. Therefore, 2005 CO_2 emissions (except for marine diesel and residual fuel) were estimated based on historical fuel consumption estimates. Emissions of CH_4 and N_2O for all sources, except marine diesel and residual and onroad vehicles, was also estimated based on 2005 fuel consumption data. 2005 CH_4 and N_2O emissions from onroad vehicles were based on 2005 VMT projections (described in the Onroad Vehicle Projections section). Marine diesel and residual fuel consumption was projected from 2004 to 2005 using methods described in the Commercial Marine Projections section below. Table C2 provides a summary of key inventory projection issues.

Table C2. Key Assumptions and Methods for the Transportation Projections

Vehicle Type and Pollutants	Methods
Onroad gasoline, diesel, natural gas, and LPG vehicles – CO_2	Gasoline and diesel fuel projected using VMT projections provided by MNDOT adjusted by fuel efficiency improvement projections from AEO2006. Other onroad fuels projected using West North Central Region fuel consumption projections from EIA AEO2006.
Onroad gasoline and diesel vehicles – CH_4 and N_2O	VMT projections from MNDOT allocated to vehicle types using vehicle specific growth rates from AEO2006.
Non-highway fuel consumption (jet aircraft, aviation gasoline, boats, locomotives) – CO_2, CH_4 and N_2O	Aircraft projected using aircraft operations projections from FAA. Rail and marine gasoline projected based on historical fuel consumption. Commercial marine projected based on historical trend in freight tonnage at Minnesota ports.

[13] Waterborne Commerce Statistics Center, US Army Corps of Engineers, http://www.iwr.usace.army.mil/ndc/wcsc/wcsc.htm.
[14] Estimate, Validation, and Forecasts of Regional Commercial Marine Vessel Inventories, submitted by J. Corbett, prepared for the California Air Resources Board, California Environmental Protection Agency, and Commission for Environmental Cooperation in North America, http://coast.cms.udel.edu/NorthAmericanSTEEM/.
[15] California Air Resources Board, Speciation Profiles, http://www.arb.ca.gov/ei/speciate/speciate.htm.

Onroad Vehicle Projections
Onroad vehicle gasoline and diesel emissions were projected from 2005-2030 based on VMT forecasts from MNDOT[4] and growth rates developed from national vehicle type VMT forecasts reported in EIA's *Annual Energy Outlook* 2006 (AEO2006). The AEO2006 data were incorporated because they indicate significantly different VMT growth rates for certain vehicle types (e.g., 34 percent growth between 2002 and 2020 in heavy-duty gasoline vehicle VMT versus 284 percent growth in light-duty diesel truck VMT over this period). The procedure first applied the AEO2006 vehicle type-based national growth rates to 2004 Minnesota estimates of VMT by vehicle type. LPG vehicle VMT were assumed to grow at the regional transportation LPG fuel consumption growth rate from AEO2006. These data were then used to calculate the estimated proportion of total VMT by vehicle type in each year. Next, these proportions were applied to the MNDOT estimates for total VMT in the State for each year to yield the vehicle type annual average growth rates displayed in Table C3.

Table C3. Minnesota Vehicle Miles Traveled Annual Growth Rates

Vehicle Type	2004-2005	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030
Light-duty gas	-0.4%	2.2%	1.6%	1.4%	1.1%	0.9%
Heavy-duty gas	-0.7%	-0.3%	1.1%	1.7%	2.1%	2.3%
Light-duty diesel	3.1%	6.5%	6.6%	6.6%	7.2%	6.8%
Heavy-duty diesel	2.6%	3.1%	2.8%	2.6%	2.3%	2.3%
LPG	0%	4.9%	2.1%	1.7%	1.9%	1.6%
Total VMT	**0%**	**2.4%**	**1.9%**	**1.7%**	**1.6%**	**1.5%**

For forecasting GHG emissions, growth in fuel consumption is also needed along with VMT. Onroad gasoline and diesel fuel consumption were forecasted by developing a set of growth factors that adjusted the VMT projections to account for improvements in fuel efficiency. Fuel efficiency projections were taken from AEO2006.

The 2005-2006 growth factors for onroad diesel were also adjusted to account for increased consumption of biodiesel. The recent biodiesel mandate, which requires that 2% of diesel fuel sold at filling stations is blended with biodiesel, took effect in late September of 2005. Since the 2% mandate was in effect for approximately one quarter of the year, 2005 consumption of biodiesel was assumed to be 0.5% of diesel consumption. Biodiesel consumption was assumed to increase to 2% in 2006 and to remain at this level through 2030.

The Minnesota Legislature also recently passed an ethanol mandate that would require the state's gasoline supplies to contain 20% ethanol (E-20). This standard, which is to take effect in 2013, would double the current ethanol consumption. Since Minnesota must obtain federal approval to use E-20 blends, and this approval has not yet been granted, increased ethanol consumption was not included in the business as usual projection. If, following further review of these draft emission estimates, the standards are determined to be likely to take effect, the resulting emission reductions should be incorporated into the BAU projection.

The effects of increased fuel efficiency and increased consumption of biodiesel yield the fuel consumption annual growth rates shown in Table C4.

Table C4. Minnesota Onroad Fuel Consumption Annual Growth Rates

Vehicle Type	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030
Passenger car gas	0.9%	1.2%	1.1%	0.7%	0.8%
Light-duty truck gas	1.2%	1.0%	0.8%	0.5%	0.6%
Heavy-duty gas	-0.6%	0.9%	1.5%	2.1%	2.2%
Passenger car diesel	6.4%	6.4%	6.6%	7.0%	6.8%
Light-duty truck diesel	5.7%	6.2%	6.3%	6.7%	6.6%
Heavy-duty diesel	2.7%	2.2%	1.6%	1.6%	1.7%

Emissions from transportation LPG, natural gas, and lubricants were projected using West North Central Regional fuel consumption projections from AEO2006.

Aviation Projections
Emissions from jet fuel and aviation gasoline consumption were projected from 2005 to 2006 using prime supplier sales volume of these fuels in Minnesota from EIA.[16] Emissions were projected from 2006-2030 using general aviation and commercial aircraft operations from the Federal Aviation Administration's Terminal Area Forecast System[17,18] and national aircraft fuel efficiency forecasts. To estimate changes in jet fuel consumption, itinerant aircraft operations from air carrier, air taxi/commuter, and military aircraft were first summed for each year of interest. The post-2006 estimates were adjusted to reflect the projected increase in national aircraft fuel efficiency (indicated by increased number of seat miles per gallon), as reported in AEO2006. Because AEO2006 does not estimate fuel efficiency changes for general aviation aircraft, forecast changes in aviation gasoline consumption were based solely on the projected number of itinerant general aviation aircraft operations in Minnesota, which was obtained from the FAA source noted above. The resulting compound annual growth rates are displayed in Table C5.

Table C5. Minnesota Aviation Fuels Annual Growth Rates

Fuel	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030
Aviation Gasoline	-1.06%	1.04%	0.90%	0.95%	0.95%
Jet Fuel	-1.41%	1.23%	1.16%	1.12%	1.12%

[16] US Department of Energy, Energy Information Administration, "Petroleum Navigator", http://tonto.eia.doe.gov/dnav/pet/hist/c400013451a.htm.
[17] Terminal Area Forecast, Federal Aviation Administration, http://www.apo.data.faa.gov/main/taf.asp.
[18] 2005 aircraft operations in the FAA projections were estimated using a different modeling scenario and were not consistent with the 2006-2030 projections; therefore, 2005 to 2006 growth was estimated using the historical prime supplier data from EIA.

Rail and Marine Vehicles Projections
Marine gasoline consumption was projected to 2020 using historical data, which shows an average annual growth rate of 3.2%. The historic data for rail shows no significant positive or negative trend; therefore, no growth was assumed for this sector. Port and offshore commercial marine emissions were projected based on linear projection of the 1990-2004 freight tonnage data, resulting in an annual average growth rate of -0.8% for 2005-2030.

Nonroad Engines
It should be noted that fuel consumption data from EIA includes nonroad gasoline and diesel fuel consumption in the commercial and industrial sectors. Emissions from these nonroad engines are included in the inventory and forecast for the residential, commercial, and industrial (RCI) sectors. Table C6 shows how EIA divides gasoline and diesel fuel consumption between the transportation, commercial, and industrial sectors.

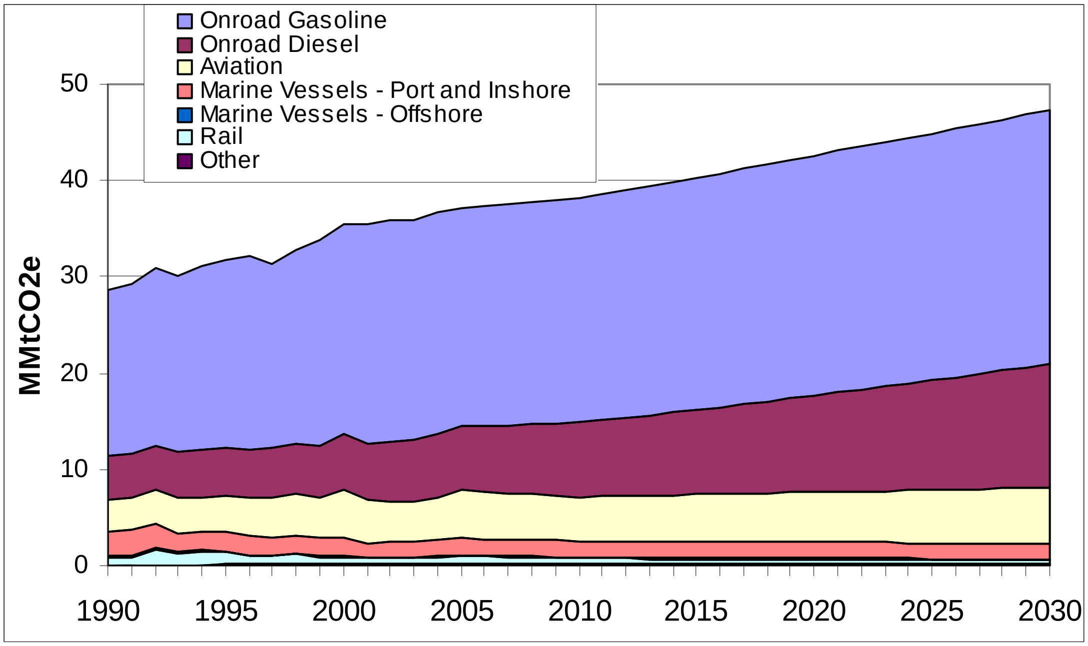
Table C6. EIA Classification of Gasoline and Diesel Consumption

Sector	Gasoline Consumption	Diesel Consumption
Transportation	Highway vehicles, marine	Vessel bunkering, military use, railroad, highway vehicles
Commercial	Public non-highway, miscellaneous use	Commercial use for space heating, water heating, and cooking
Industrial	Agricultural use, construction, industrial and commercial use	Industrial use, agricultural use, oil company use, off-highway vehicles

Results
As shown in Figure C1, onroad gasoline consumption accounts for the largest share of transportation GHG emissions. Emissions from onroad gasoline vehicles increased by about 31% from 1990-2005 and contributed 61% of total transportation emissions in 2005. GHG emissions from onroad diesel fuel consumption increased by 49% from 1990 to 2005, and by 2005 accounted for 18% of GHG emissions from the transportation sector. Emissions from aviation grew by 44% between 1990 and 2005 to cover 13% of transportation emissions in 2005, and emissions from boats and ships decreased by 31% from 1990-2005 to cover 5% of transportation emissions in 2005. Emissions from all other categories combined (locomotives, natural gas and LPG, and oxidation of lubricants) contributed less than 3% of total transportation emissions in 2005.

GHG emissions from all onroad vehicles combined are projected to increase by 32% between 2005 and 2030, due to a 56% increase in VMT during this period and projected fuel efficiency improvements. Historical growth for diesel fuel was stronger than for gasoline. This trend is expected to continue for the 2005-2030 period, with gasoline and diesel fuel consumption projected to increase by 15% and 93%, respectively. Jet fuel and aviation gasoline consumption is projected to increase by 17% between 2005 and 2030. The historical negative growth for marine vessels is projected to continue with a decline of 7% from 2005 to 2030.

Figure C1. Transportation GHG Emissions by Fuel, 1990-2030



Key Uncertainties

Projections of VMT

One source of uncertainty is the future year vehicle mix, which was calculated based on national growth rates for specific vehicle types. These growth rates may not reflect vehicle-type specific VMT growth rates for the state.

Uncertainties in Aviation Fuel Consumption and Projection

The jet fuel and aviation gasoline fuel consumption from EIA is actually fuel *purchased* in the state, and therefore includes fuel consumed during state-to-state flights and international flights. There is a question as to whether fuel consumption associated with state-to-state and international air flights should be included in Minnesota's inventory; however, data were not available to subtract fuel consumption occurring outside of Minnesota air space from total jet fuel estimates (also IPCC guidance directs countries to include all emissions associated with fuel sales in the totals for each country). Another uncertainty associated with aviation emissions is the use of general aviation forecasts to project aviation gasoline consumption. General aviation aircraft consume both jet fuel and aviation gasoline, but fuel specific data were not available.

Uncertainties in Marine Fuel Consumption

There are several assumptions that introduce uncertainty into the estimates of commercial marine fuel consumption. These assumptions include:

- 75% of marine diesel and 25% of residual fuel is consumed in port (based on EPA NEI assumptions);
- The state's fraction of national fuel consumption is proportional to the fraction of national freight tonnage moving through Minnesota ports; and

- Future emissions from marine vessels will follow the same trend as historical freight tonnage.

Our handling of commercial marine emissions differs from commercial aircraft in that we have attempted to account only for fuel consumption that occurs within the State's waters. Reviewers might decide to base the estimates on total fuel sales instead to maintain consistency with the methods used in the aircraft subsector.