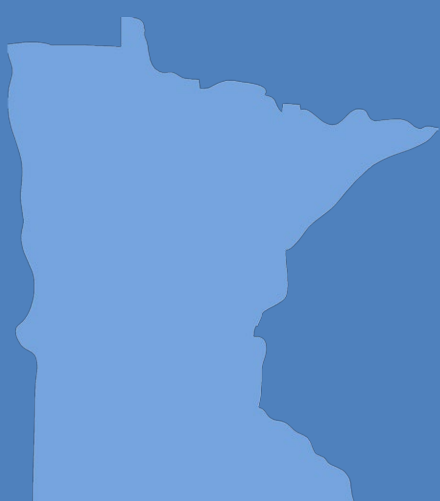
Minnesota "Business-as-Usual" Greenhouse Gas Forecast Technical Support Document

Prepared March 2015



Minnesota Pollution Control Agency

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Contributors/acknowledgements

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Electric power sector

Sector boundaries

The electric power sector includes in-state facilities that generate electric power for sale to the grid, as well as a limited number of facilities that produce steam for off-site commercial sale, and net imports of electricity into Minnesota. In-state sector boundaries largely are defined by Standard Industrial Classification (SIC) Code. The SIC codes included are: SIC 4911, 4931, and 4961. A number of facilities with the 4953 SIC designation also are included in the power sector.[1] As noted, a handful of facilities that are included in the electric power sector—by virtue of SIC classification—produce steam for off-site commercial sale. The rest generate power for sale unto the grid. Power generated and sold onto the grid by firms that are more properly commercial sector and industrial sector firms is included in electric power sector totals, as are attendant emissions.

The electric power sector does not include the self-generation of electric power for internal use at industrial facilities without an intervening sale of power to the grid.

Net imports and associated emissions are included within the boundaries to conform to MPCA reporting requirements under the Next Generation Energy Act (NGEA). Under NGEA, in its reporting on progress toward Next Generation Energy Act emission reduction goals, the MPCA must include in its emission totals emissions from the net import of electricity into the state and emissions associated with transmission and distribution losses.

In-state greenhouse gas (GHG) emissions from electric power sector firms are typically on-site combustion emissions associated with energy use, but may also include some non-combustion 'process emissions.' Fossil carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are emitted during the combustion of fossil fuels. CH_4 and N_2O are produced and emitted during the combustion of biomass. Noncombustion process emissions emitted in-state include CH_4 from coal piles and hydroelectric reservoirs, CO_2 from flue gas desulfurization (FGD), and sulfur hexafluoride (SF_6) from electric transmission and distribution (T&D). Emissions associated with net imports include fossil CO_2, CH_4 and N_2O emitted out-of-state during the generation of electricity and SF_6 from out of state transmission and distribution.

Present-day and historical emissions

Below are historical estimates for emissions from the electric power sector for selected years in million CO_2-equivalent tons. The estimates for emissions from in-state combustion are based on fuel throughput and conventional fuel-based emission factors. With few exceptions, fuel throughput data derives from the MPCA emission inventory database. Fuel use is reported annually to the MPCA by the operators of permitted facilities on a unit-by-unit basis. 138 electric power sector facilities report fuel use annually to the MPCA. Facility owners include utilities, municipal power agencies, and independent power producers (IPPs). The reporting goes back to 1980.

[1] In terms of the North American Industrial Classification Code, included are all establishments within NAICS code 22, plus a handful with NAICS classification 562212, 562213, 322122 and 622110.

Table E-1. Historical Emissions from Minnesota's Electric Power Sector (million CO_2-equivalent short tons)

	1990	2000	2005	2010	2011
In-state Emissions					
Combustion-based					
coal	31.90	37.22	39.29	32.31	32.08
oil	0.58	0.99	0.94	0.07	0.04
natural gas	0.49	0.97	1.81	2.45	2.10
other	0.52	0.63	0.69	0.65	0.71
subtotal	33.50	39.81	42.72	35.48	34.93
FGD	-	0.00	0.01	0.01	0.01
Hydroelectric reservoirs	0.00	0.01	0.01	0.01	0.01
Coal piles	0.06	0.06	0.06	0.06	0.06
Electric transmission and distributic	0.55	0.32	0.35	0.37	0.37
subtotal	34.10	40.20	43.15	35.92	35.37
Net Imports	8.40	13.89	13.60	13.68	14.40
Total Emissions	42.50	54.10	56.74	49.60	49.77

Emission factors are from the MPCA GHG emission inventory and are generally taken from one of a number of sources: Environmental Protection Agency (EPA), *Inventory of US Greenhouse Gases and Sinks*; EPA, *AP 42, Compilation of Air Pollution Emission Factors*; EPA, *Mandatory Reporting Rule;* EPA, *Technical Support Document for the Pulp and Paper Sector: Proposed Rule for Mandatory Reporting of Greenhouse Gases;* EPA, *Greenhouse Gas Emissions from the Management of Selected Materials in Municipal Solid Waste;* Energy Information Administration (EIA), *Electric Power Annual*; European Environmental Agency, *EMEP Corinair Emissions Inventory Guidebook*; Argonne National Laboratory, *GREET Lifecycle Model, version 1.7*; Intergovernmental Panel on Climate Change (IPCC), *2006 IPCC Guidelines for National Inventories*; The Climate Registry, *General Reporting Protocol*; World Business Council for Sustainable Development/World Resources Institute, *Stationary Source Tool*; and Miles *et al*., "Alkili Deposits Found in Biomass Power Plants." Combustion emissions of CO_2 are calculated on a fuel throughput basis regardless of boiler type, turbine type, or other technology consideration. By contrast, emission factors for both N_2O and CH_4 are fuel-based and technology-based, varying by type of combustion (internal, external) and also by boiler type and by fuel.

CO_2 emission factors for coal are calculated annually based on annual coal receipts at Minnesota coal-burning facilities and their state or origin, both reported in EIA *Form-923/423*, and the CO_2 emission rates reported by USEPA by state of coal origin. Separate values are calculated for bituminous and subbituminous coal.

With the exception of those for solid waste, the emission factors that are used to calculate emission are based on fuel energy content. Before emissions are calculated for any one fuel or inventory year, fuel is converted to standard units of energy (MMBtu). Emissions of CO_2 from the combustion of MMSW are calculated on a mass basis, using data from Minnesota-specific waste composition studies and the fossil and biogenic carbon content of different types of waste.

In most instances, fuel throughput is converted to units of energy using standard national-level conversion factors from EIA, *Annual Energy Review* and EIA, *Renewable Energy Annual*. Exceptions include bituminous and subbituminous coal, petroleum coke, wood, other solid biomass, LPG and natural gas. The energy content of bituminous and subbituminous coal is calculated using data on in-state fuel throughput and monthly data from EIA *Form-923/423* for facility-level fuel receipts and fuel energy content. The same approach is taken in calculating the energy content of petroleum coke. For solid biomass, total energy is a calculated value derived from fuel throughput and facility-level estimates of the per ton energy contents or heats of combustion of wood and wood sludge, black liquor, agricultural byproducts, RDF and MMSW from EIA *Form-906/923*. For turkey litter, total energy is calculated annually using fuel throughput and facility-reported estimates of fuel energy content.

For LPG and natural gas, total energy is calculated from reported fuel throughput and Minnesota-specific estimates of fuel heat of combustion from EIA, *State energy Data System* (SEDS). In the Minnesota SEDS data, estimates for Minnesota for natural gas for heat of combustion vary between 1,005 and 1,035 MMBtu per million cubic feet of gas.

Northshore Mining, an industrial sector firm, and Franklin Heating Station, a commercial sector facility, both generate electricity for sale to the electric grid. Energy use at these facilities for power generation, for ultimate sale to the grid, is calculated from annual electric sales and, in the case of the Northshore facility, average heat rates at Minnesota coal-fired electric generating units and, in the case of Franklin Heating Station, a heat rate of 11,373 btu/kwh. Information on annual sales is taken from EIA, *Form-906/923*, FERC *Form-1* and *Minnesota Annual Electric Report*. An 11,373 btu/kwh heat rate is characteristic of older natural-gas-fired and residual-oil-fired boilers.

Reported totals for annual energy use and fuel throughput to provide steam for Sappi-Cloquet unit 5 are from Minnesota Department of Commerce (MDOC), *Minnesota Utility Data Book*. Unit 5 is owned by Minnesota Power but operated by Sappi, and supplies power to the grid.

Energy use in farm-based anaerobic digesters for electric generation is not reported to the MPCA. Energy use in these systems is calculated from reported sales to the electric grid for these facilities, as given in *Minnesota Annual Electric Report* and an assumed heat rate of 13,648 btu/kwh.

By state law, all diesel fuel oil sold in the state must be blended with biodiesel at a current annual rate of 5 percent by volume, increasing to 7.5 percent by 2015. Biodiesel throughput is calculated based on total reported diesel fuel oil consumed in reciprocating engines and gas turbines and mandate blend levels. Biodiesel energy content is from Oak Ridge National Laboratory, *Transportation Energy Data Book*.

In-state process emissions include emissions from coal piles, FGD, hydroelectric reservoirs, and electric T&D. Emissions from coal storage, FGD and hydroelectric reservoirs are based on annual coal throughput, annual limestone throughput and reservoir surface area, respectively. Emission factors are from: EPA*, Inventory of US Greenhouse Gases and Sinks* and St. Louis, *et al*., "Reservoir Surfaces as Sources of Greenhouse Gases to the Atmosphere: A Global Estimate." Emissions from electric T&D are calculated on a per transmission mile (35 kV or greater) basis, using national per mile estimates from EPA, *Inventory of US Greenhouse Gases and Sinks* and in-state data on the transmission system from *Minnesota Electric Transmission Planning Biennial Report*.

GHG emissions from net imports are based on total MWH of need for net imports and emission factors for imported power from Minnesota's source region for imports. In estimating emissions from net imports, an 11-state/province exporting region is currently used, and includes the following states and provinces: Wisconsin, Iowa, South Dakota, North Dakota, Nebraska, Missouri, Kansas, Wyoming, Illinois, Indiana, and Manitoba. Average emissions per MWH for the exporting region are estimated on an annual basis using the state-level data given in EIA, *Electric Power Annual Database*.

The states and provinces in the exporting region were selected after a review, in 2005-2007, of the sources of purchased power for Minnesota electric utilities, as given in FERC *Form-1* and *Minnesota Annual Electric Report*. Since then, Midwest independent Service Operator (MISO) began operations. To accommodate greater east-west power flows, Illinois and Indiana have since been added to the exporting region.

The need for imported power is equal to total in-state demand less in-state net generation plus total transmission and distribution (T&D) losses, both in-state and out-of-state. State-level estimates of retail sales (electric demand) for this calculation are from EIA, *Electric Power Annual Database*. In-state generation is from the MPCA GHG inventory database, itself assembled on a facility-by-facility basis from: EIA, *Form-906/923*, FERC *Form-1*, *Minnesota Utility Data Book*, and *Minnesota Annual Electric Report*. Out of state T&D losses are US averages reported in EIA, *Monthly Energy Review*. In-state T&D losses are from EIA *Form-861*. Total T&D losses in 2011 were an estimated 5.4 percent. The methodology for estimating emissions from imported power is from The Climate Registry, *Electric Power Sector Protocol* and EPA, *Emission Inventory Improvement Program.*

The historic trend in net electric generation needed to meet Minnesota's electric load is shown in Table E-2 for selected years by fuel type and net imports. Total net generation to meet load was some 71.56 million MWH in 2011. Of this, an estimated 73 percent was generated in-state, and 27 percent was imported power. Of 2011 in-state net generation, 53 percent was coal-fired generation, 23 percent was nuclear-based, and 18 percent was renewable generation. In-state net generation to meet load peaked in 2005, declining about 3 percent between 2005 and 2011. Net imports increased an estimated 16 percent between 2005 and 2011, and, going back to 1990, more than doubled.

By fuel, in-state coal-fired generation declined by an estimated 7.31 million MWH between 2005 and 2011, or 21 percent. In-state nuclear generation declined 0.88 million MWH or 6 percent over the same period. Total demand for power to service Minnesota electric load increased some 0.96 million MWH between 2005 and 2011. Of the 9.16 million MWH of potential shortfall caused by declining coal-fired and nuclear generation and increased demand, 5.95 million MWH or 64.9 percent was made-up through an increase in renewable generation between 2005 and 2011, 0.6 million MWH or 6.6 percent through increased natural gas-fired generation, and 2.62 million MWH or 28.6 percent through an increase in net imports. For each MWH of coal-fired generation avoided, 0.65 MWH of renewable generation were added to the system between 2005 and 2011, along with 0.06 MWH of natural gas-fired generation and 0.29 MWH of imports.

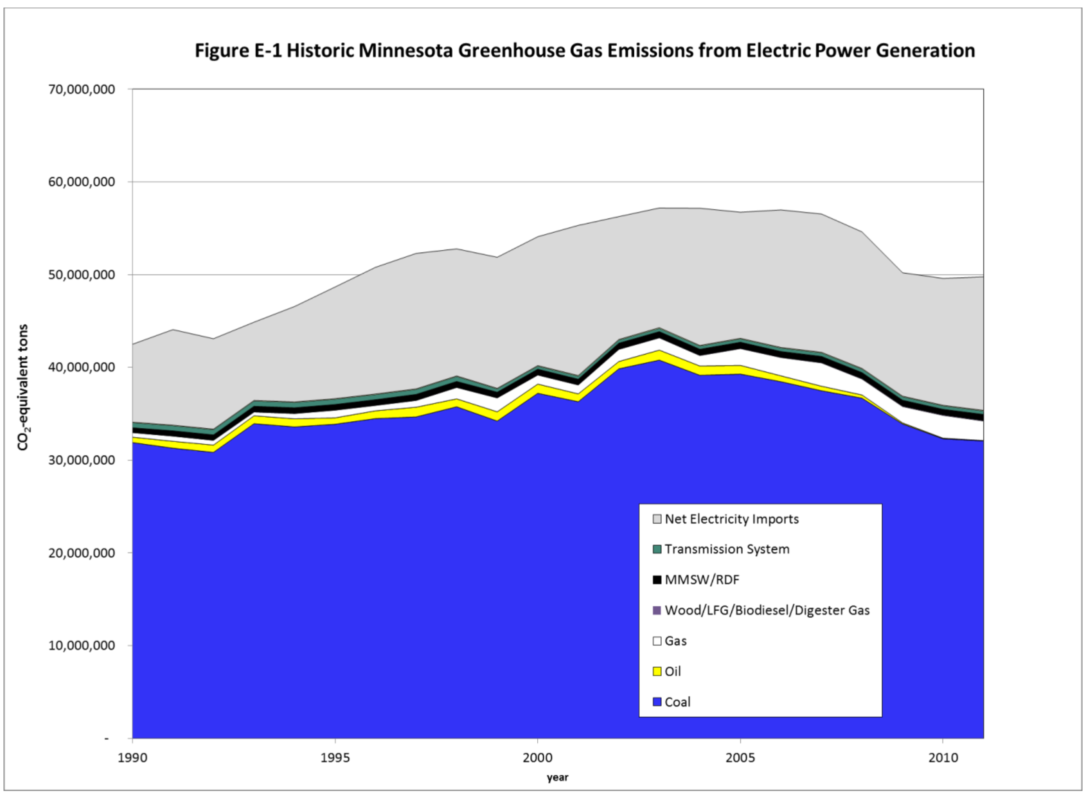
Between 2005 and 2011, emissions from the electric power sector declined about 12 percent or 6.97 million CO_2-equivalent tons. Over this period, emissions from in-state net generation declined 7.73 million CO_2-equivlalent tons, or 18 percent, offset by an increase in emissions from imported power of 0.8 million CO_2-equivalent tons or 5.9 percent. Most of the decline in in-state emissions resulted from the 21 percent decline in in-state coal-fired generation between 2005 and 2011 in favor of renewable energy-based generation and a smaller amount of increased in-state natural gas-fired generation and imports. As just noted, between 2005 and 2011 in-state renewable energy-based generation increased by 5.94 million MWH, accounting for about two-thirds of the decline in coal-fired generation over this period. Total CO_2-equivalent emissions in 2011 were some 49.8 million tons, of which 35.4 million were from in-state sources. The historical trend in emissions since 1990 is shown graphically in Figure E-1.

Table E-2. Historical Generation to Meet Minnesota's Electric Load (million MWH)

	1990	2000	2005	2010	2011
In-state generation					
coal	28.03	32.42	34.91	27.54	27.60
oil	0.03	0.08	0.15	0.03	0.03
natural gas	0.33	1.01	2.60	4.28	3.28
other	0.19	0.23	0.22	0.20	0.25
subtotal	28.59	33.74	37.89	32.05	31.16
nuclear	12.14	12.96	12.84	13.48	11.96
renewable	1.18	2.07	3.32	7.44	9.27
subtotal	41.90	48.77	54.04	52.97	52.39
Net Imports	9.53	15.74	16.55	17.87	19.17
Total	51.44	64.52	70.59	70.84	71.56

Continuous Emission Monitoring and facility-provided estimates of emissions under EPA's Mandatory Reporting Rule offer two independent checks on the emissions totals given above in Table E-1. For 2011, these two sources give state-level emission estimates for fossil CO_2 of 33.97 and 34.2 million tons, respectively, which, adjusted for the same fleet of facilities, agrees well with the 34.7 reported in the MPCA emission inventory.[2]

Full documentation of the sources and methods used to develop the electric power sector inventory is included in Appendix E of P. Ciborowski and A. Claflin, "Greenhouse Gas Emissions in Minnesota: 1970-2008: Second Biennial Progress Report – Technical Support Document" (2012).



[2] For instance, for 2011, continuous emission monitors report a state-level emission of 33.97 million tons. Adjusted for the same fleet of facilities, the MPCA GHG emission inventory reports 33.56 million tons, a value quite close to the CEM total. CEMs installed under Title 4 of the Clean Air Act monitor for CO_2 only.

Forecast methods

The forecast was developed using the same sector boundaries as underlie the sector inventory. The electric power sector includes in-state facilities that generate electric power for sale to the grid, as well as a limited number of facilities that produce steam for off-site commercial sale, and net imports of electricity into Minnesota. In-state emissions are comprised of combustion-based emissions from electric generating units, mainly fossil fuel-fired units, plus process emissions. In-state process emissions include: emissions from flue gas desulphurization, coal piles, hydroelectric reservoirs, and electric transmission and distribution. Emissions from net imports include GHGs emitted at generation from combustion-based units, and emissions associated with electric T&D.

The emissions forecast is shown below in Table E-3 for selected years in millions of CO_2-equivalent tons. Emissions decline slightly in the forecast from 2011 levels, by 6 percent by 2030. Emissions from net imports decline in the forecast slightly less than 40 percent, while by 2030 in-state emissions rise about 7 percent above 2011 levels. Nearly all of the projected increase in in-state emissions, 2011-2030, derives from increased natural gas use. Emissions from in-state coal combustion decline about 1 percent over the forecast period, while emissions from in-state solid waste combustion decline about 17 percent.

Table E-3. Forecasted Emissions from Minnesota's Electric Power Sector (million CO_2- equivalent short tons)

	2012	2015	2020	2025	2030
In-state Emissions					
Combustion-based					
coal	33.90	34.08	35.12	32.11	31.83
oil	0.05	0.06	0.06	0.05	0.04
natural gas	2.33	2.86	3.86	4.28	4.95
other	0.83	0.98	0.69	0.70	0.61
subtotal	37.12	37.98	39.74	37.14	37.44
FGD	0.01	0.01	0.00	0.00	0.00
Hydroelectric reservoirs	0.01	0.01	0.01	0.01	0.01
Coal piles	0.06	0.06	0.06	0.06	0.06
Electric transmission and distributio	0.39	0.41	0.44	0.48	0.52
subtotal	37.58	38.46	40.25	37.69	38.02
Net Imports	10.83	9.36	8.86	9.30	8.95
Total Emissions	48.41	47.82	49.11	46.99	46.97

The forecast of in-state emissions from in-combustion sources is based principally on the forecast information prepared by the largest utilities in the state and submitted as one piece of the *Minnesota Annual Electric Report* to the Minnesota Public Utilities Commission. For the electric power sector forecast shown above (Table E-3), we used the 2012 edition of the *Minnesota Annual Electric Report*, which provides forecast information on MWH generated by fuel type, fuel use by fuel type, planned unit retirements and additions, and retail sales out through 2026. Reporting annually under Minnesota Annual Electric Report process are: XCEL Energy, Minnesota Power, Otter Tail Power, Interstate Power, Great River Energy, Dairyland Power Cooperative, Minnkota Power Cooperative, Minnesota River Energy Services, and Southern Minnesota Municipal Power Agency.

Developed for the most part on the basis of the least-cost modeling of dispatch, the forecast information provided in the *Minnesota Annual Electric Report* provides an internally consistent representation of the future operation of generating units in the state, given unit age, nonfuel costs, forecast fuel costs, the costs of purchased power, any planned capacity additions and their costs, and forecast electric demand. The forecast information is publicly available, both as part of an ongoing Minnesota Public Utility Commission (MPUC) docket and triennially in utility integrated resource planning reporting.

Forecast information from the *Minnesota Annual Electric Report* covers roughly 97 percent of all in-state nonrenewable generation. Generation at facilities that account for the residual 3 percent of in-state generation is about 1.5 million MWH annually. Generation at these facilities is assumed to remain constant throughout the forecast period at 3-year, 2009-2011, average levels.

As noted above, in addition to electric generating units, a small number of facilities that produce steam for off-site commercial sale are also included as part of the Minnesota electric power sector. To account for emissions from these sources a 3-year, 2009-2011, average is used for energy input to these facilities.

Emissions are forecast based on MMBtu input to generation or steam production at in-state facilities and emission rates for recent years (3-year, 2009-2011 average) developed fuel-by-fuel for each utility or utility grouping. For utilities that report under the *Minnesota Annual Electric Report*, fuel use is reported in either physical units or MMBtu of energy input. Where forecast fuel throughput is reported in physical units, e.g., tons of coal, fuel use are transformed to energy using, again, a 3-year average, 2009-2011, for average fuel energy content. Emissions are estimated for fossil fuel-fired facilities and biomass-fired facilities. The fossil component of mixed fuels like refuse derived fuel (RDF) and mixed municipal solid waste (MMSW) is calculated based on 2011 values taken from the MPCA inventory.

The forecast accounts for all known additions and retirements of combustion-based generation capacity placed appropriately throughout the forecast period. Forecast coal plant retirements include: Black Dog units 3-4, Hoot Lake units 2-3, Taconite Harbor unit 3, and Silver Lake units 1-4. Forecast coal-to-gas conversions include Syl Laskin, units 1-2 and Austin NE. Forecast RDF plant retirements include: Wilmarth and Red Wing. Natural gas/biomass-fired Sappi unit 5 reverts to industrial sector status in 2016. Roughly 1,800 MW of new combined cycle natural gas turbine capacity is added by 2025 in the forecast, along with about 225 MW of simple cycle gas turbine capacity.

Heat rate improvements are implicit in the forecast for those utilities that provide forecast information in MMBtu input to generation. This is true for existing units and for planned units (in terms of percent improvement above existing average practice). Otherwise, heat rates for existing facilities are assumed to remain constant over the forecast period.

For the most part, emissions of fossil CO_2 from coal-based in-state power generation are calculated using utility-specific emission rates. For each utility that combusts bituminous or subbituminous coal, a three-year, 2009-2011, average emission rate, developed by coal grade, is used. The historic data for 2009-2011 are taken from MPCA Greenhouse Gas Emission Inventory database. For calculating fossil CO_2 emissions from coal combustion at district heating facilities, these facilities are grouped into two separate classes, each with a unique emission rate, again based on 2009-2011 data. Classes include district heating facilities that produce both steam for sale and electricity for sale to the grid and district heating facilities that, combusting coal, produce only steam for off-site sale.

Fossil CO_2 emissions from the combustion of all other fuels are calculated using standard fuel-based emission rates drawn from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* and, for TDF, EIA, *Electric Power Annual*. Emissions of fossil CO_2 from the combustion of MMSW and RDF are calculated using 2010 estimates of emissions per MMBtu of energy input derived from the data in the MPCA Greenhouse Gas Emission Inventory database.

Emissions of N_2O and CH_4 also are calculated using, for the most part, utility-or IPP-specific emission rates developed by prime mover, fuel and load type from MPCA Greenhouse Gas Emission Inventory data. Where forecast information contained in the *Minnesota Annual Electric Report* includes generation and fuel use at facilities under contract but not owned by the utility in question, emission rates are adjusted to accommodate facilities under contract. For some classes of small municipally-owned and operated facilities, a single emission factor is used for all facilities. Examples are municipally owned and operated reciprocating engines (natural gas and distillate-fired), simple cycle distillate-fired gas turbines and small (< 20 MW) natural gas-fired steam turbines. For waste oil, residual fuel oil, LFG and digester gas, a single state-level emission factor is used. A three-year average rate of emissions, using data for 2009 to 2011, is used in the calculations.

To develop a schedule of forecasted emissions from net imports, total statewide need for net imports is estimated for each forecast year in MWH. Forecasted emissions of CO_2 are calculated using this schedule of net imports and a forecast emission rate for CO_2 per MWH for the exporting region for each year of the forecast period developed from information given in EIA *Annual Energy Outlook 2013* for emissions and net generation by electricity market module region. Emissions of N_2O and CH_4 from out of state combustion are assumed to be proportional to the emission of N_2O and CH_4 in-state (as a percent of total GHGs from in-state combustion). [3]

The need for imported power is equal to total in-state demand less in-state net generation plus total T&D losses, both in-state and out-of-state. In-state generation equals in-state nonrenewable generation (fossil plus nuclear), plus in-state renewable generation. Forecast in-state nonrenewable generation was discussed above. With few exceptions, forecasted in-state generation from nonrenewable sources is from the *Minnesota Annual Electric Report*. As noted above, a small amount of electricity is generated at facilities that do not come under the *Minnesota Annual Electric Report* umbrella. For these facilities, a three-year, 2009-2011, average is used for forecast generation. Forecast net generation at renewable energy facilities comes from a detailed simulation, conducted utility-by-utility, of in-state renewable development under Minnesota's Renewable Energy Standard (RES) and Solar Energy Standard (SES). T&D losses are set at constant 2011 levels

Forecast retail sales for those utilities that submit forecast information in the *Minnesota Annual Electric Report* are from that report. For all other utilities or utility groups, retail sales are forecast using linear trends in retail sales, 2001-2011.

Under state rule, 15 electric utilities or utility groups have renewable energy obligations. Each year, to be in compliance with Minnesota's Renewable Energy Standard, these utilities must hold ownership right to and retire a predetermined number of renewable energy credits (RECs), each equal to one MWH of renewable energy generation. The number of credits that, for any one utility or utility group, must be retired is equal to an increasing percentage of retail sales, starting at fairly low levels currently and reaching, in the case of XCEL Energy, 30 percent by 2020 and, for all other utilities, 25 percent by 2025.

In addition, four utilities have separate renewable energy obligations under the state's Solar Energy Standard. These also are expressed as a percent of retail sales. REC retirement obligations under Minnesota's solar energy standard are, for the four utilities, equal to 1.5 percent of retail sales by 2020 and constant thereafter, with exclusions for industrial load that effectively lower this to a weighted statewide rate of 0.8 percent of retail sales.

[3] Total emissions of CH_4 and N_2O from in-state combustion sources are small, in aggregate less than 1 percent of total in-state emissions.

Compliance with the RES and SES is modeled using the existing fleet of renewable energy facilities, located both in-state and out-of-state, that are owned or under contract by one of the Minnesota utilities with RECs obligations under Minnesota state law, plus planned expansions. Performance is based on actual historical practice of the facilities in question or, in the case of planned expansions, projected average performance for new facilities. RECs generation, in-state and out-of-state, is the sum of all eligible renewable energy generation from existing and planned facilities. Compliance is determined on a utility-by-utility basis. Obligations are calculated from the schedule in statute for RECs retirements (as a percent of retail sales) and utility forecasted retail sales. Utilities are in compliance when sufficient RECs are available (through generation under contract or by purchase) to meet retirement obligations. Out of compliance utilities come back into compliance in the simulations by adding renewable generation.

Total renewable generation under Minnesota's RES and SES is tracked annually, by prime mover, fuel, and location. In term of location, generation additions that are not now planned but forced by unmet REC obligations are apportioned to states on the basis of past apportionment. The locations of existing facilities are, of course known, as are the locations of many planned facilities. Renewable generation capacity is also tracked, by prime mover, fuel and location.

The roster of existing RECs-earning facilities is taken from M-RETs reporting for 2012-2014 and utility compliance filings with the Minnesota Public Utilities Commission. Forecast generation for certain classes of renewable energy facilities like resource recovery facilities is given by utility in *Minnesota Annual Electric Report*. In those instances, those forecast data are used. Otherwise, performance data for renewable facilities are from EIA Form-923 and FERC Form-1. Announced facility retirement dates are honored, as are announced dates for future additions. These are variously included in the *Minnesota Annual Electric Report*, recent Integrated Resource Plans, other PUC filings or, in the case of a rapidly evolving technology like solar PV, public announcements.

A certain number of renewable energy facilities located in Minnesota generate RECs (and renewably-based electricity) but are not contractually required to provide RECs to any of the 15 utilities or utility groupings regulated under Minnesota's RES. Generation at these facilities is tracked as Minnesota renewable generation, but no RECs are retired.

Under the rules that govern compliance with the RES and SES, RECs may be banked for use in meeting REC obligations up to four years into the future. To maximize the use of the total pool of available RECs, in the MPCA simulations REC retirement proceeds from the oldest to the newest. RECs are retired without preference for renewable energy type or location by state. RECs are retired until all obligations are met. RECs that, due to age, are not eligible for use in Minnesota are removed from system. By Public Utility Commission rule, RECs used to satisfy Minnesota RPS obligations must be generated within the 7-state, 1-province M-RETs region.

In adding generation, we do so in increments of 5 MW. All capacity added under the RES is assumed to be wind power with a capacity factor of 40 percent. To maximize the effects of the REC banking rules, generation is added two years before the onset of any RECs deficit.

The simulation of RECs generation and retirement to meet Minnesota's RES requirements explicitly excludes the trading of RECS, with the sole exception of SMMPA. It is the announced intention of SMMPA to rely on purchased RECS to fulfill its Minnesota RES obligations. It is assumed in the RES simulations that, through 2020, any RECs deficits incurred by SMMPA are made-good through purchases of RECs from outside of the pool of utilities subject to the Minnesota RES. After 2020, any deficits incurred by SMMPA are resolved in the simulations through the construction of additional renewable energy capacity.

Five utilities have mandatory renewable portfolio standard (RPS) obligations that span several states: XCEL Energy (Minnesota, Wisconsin), Interstate Power (Minnesota, Iowa), Dairyland Power Cooperative (Minnesota, Wisconsin), Great River Energy (Minnesota, Wisconsin), and Basin Electric Power Cooperative (Minnesota, Montana). In the MPCA simulations, both set of obligations are addressed. A single REC requirement spanning requirements for both states is calculated for each forecast year. Compliance is modeled using all renewable generation available to these utilities within the M-RETs region, irrespective of state lines. Any renewable generation that must be added beyond what already exists or is planned is apportioned to states based on historical practice. Provisions that govern the vintage of RECs that might be used to meet a state's RPS obligations that are unique to any of the states in question are honored.

Table E-4 lists the RPS obligations of utilities that serve Minnesota customers for selected years. Total obligations under Minnesota's RES and SES come to 21.7 million MWH-equivalent RECs by 2030, equal to 27.3 percent of retail sales. Obligations at 2030 under the Iowa, Montana and Wisconsin RPSs come to an additional 1.25 million MWH-equivalent RECs, raising total 2030 obligations to 22.95 million MWH-equivalent of RECs.

Table E-4. Forecasted RPS Obligations of Electric Utilities Serving Minnesota Customers

	2012	2015	2020	2025	2030
Minnesota					
Retail sales (million MWH)	**68.00**	**69.61**	**72.93**	**76.23**	**79.46**
RES REC obligations (million MWH-eq.)	9.81	10.00	17.38	20.21	21.09
RES S-REC obligations (million MWH-eq.)	-	-	0.58	0.59	0.61
total Minnesota obligations	**9.81**	**10.00**	**17.95**	**20.80**	**21.70**
obligations as a % of retail sales	14.4%	14.4%	24.6%	27.3%	27.3%
RPS obligations for other states (million MWH-eq)					
Wisconsin	0.63	0.92	0.95	0.97	1.00
Montana	0.04	0.08	0.09	0.11	0.13
Iowa	0.12	0.12	0.12	0.12	0.12
Total REC Obligations	10.60	11.12	19.11	22.00	22.95

Simulated RECs balances as shown in Table E-5, again for selected years out to 2030. Total REC retirements equal total REC obligations, as noted above. In the simulations, most REC obligations are met in the early years of the forecast period using RECs that are 2 years old or older, following the rule that RECs are retired by age, oldest first. Early in the simulation period, the utilities bank large numbers of RECs for future use. By forecast year 2030, three-quarters of retired RECs are generated in the simulations in the same year that they are retired. In the simulations, by forecast year 2030, annual REC generation is about 30 percent larger than annual obligations, although a good deal of this surplus is held by utilities with large renewable generation resources but small Minnesota customer bases. In the simulations, by 2030, in aggregate the utilities that service Minnesota customers hold 6.7 million more RECs than are needed in forecast year 2030 to satisfy their RPS obligations.

Simulated renewable energy generation under the RPS is shown in Figure E-6. This includes all renewable generation that occurs in Minnesota, as well as generation outside of Minnesota that is assigned to the utilities that serve Minnesota customers by virtue of RECs ownership. As discussed above, the RPS simulations have been developed principally as a window into future renewable generation within the borders of Minnesota. In the simulations, by forecast year 2030, 7.24 million MWH of renewable generation that does not now exist is added in-state, equal to about 70 percent of present-day in-state renewable net generation.

Table E-5. Forecast REC Obligations, Retirements by REC Age, and REC Generation (million MWH-equivalent)

	2012	2015	2020	2025	2030
RPS obligations	**10.60**	**11.12**	**19.11**	**22.00**	**22.95**
REC retirements by REC age					
0-1 years old	1.21	1.04	2.61	15.25	16.91
1-2 years old	0.11	0.21	6.86	1.27	0.34
> 2 years old	9.28	9.86	9.64	5.48	5.69
total	**10.60**	**11.12**	**19.11**	**22.00**	**22.95**
REC generation					
in-state	10.76	11.98	13.01	17.58	18.59
out-of-state	9.50	9.42	9.82	10.73	11.07
total	**20.26**	**21.40**	**22.82**	**28.31**	**29.67**
Simple annual surplus or deficit	**9.66**	**10.28**	**3.71**	**6.31**	**6.72**

Table E-6. Forecast Renewable Energy Generation under Minnesota's RES and SES by Generation Status (million MWH)

	2012	2015	2020	2025	2030
In-state	10.54	11.72	12.85	17.43	18.44
existing RE generation	10.42	11.33	11.08	11.21	11.20
planned or forced new RE generation	0.12	0.39	1.77	6.22	7.24
Out-of-state	9.50	9.29	9.46	9.49	9.51
existing RE generation	9.49	9.27	9.43	9.22	9.22
planned or forced new RE generation	0.01	0.02	0.04	0.27	0.29
In-state plus Out of State	20.04	21.01	22.32	26.92	27.95
existing RE generation	19.91	20.59	20.51	20.43	20.42
planned or forced RE generation	0.13	0.41	1.81	6.49	7.53

The dispatch modelling around which the electric power sector forecast is constructed terminates in forecast year 2026. To extend the forecast to 2030, a 7-year, 2019-2026, average was calculated for annual in-state nuclear generation, a 3-year, 2004-2006, average for T&D losses, and a 5-year, 2002-2006, average for the fraction of in-state fossil generation as a percent of in-state fossil generation plus imports. In addition, the retail sales forecast was linearly extended to 2030 using 2020-2026 forecast data. Renewable energy generation by type, 2027-2030, was taken from the RPS analyses discussed above. For each year, 2027-2030:

- fossil generation = (retail sales + T&D losses – renewable generation – nuclear generation) * 0.75
- net imports = (retail sales + T&D losses – renewable generation – nuclear generation) * 0.25

Fossil generation was distributed among fuels using the trended percentage distribution, 2020-2026.

Forecast generation to meet Minnesota load is shown in Table E-7 for selected years by generation type. Total generation to meet Minnesota load increases in the forecast by 12.5 million MWH or 17.5 percent above 2011 levels; net imports decline 6.03 million MWH from 2011 levels. This results in the need in the forecast for roughly 18.53 million MWH of new in-state generation at 2030, of which renewable generation, increasing some 9.2 million MWH, contributes about 50 percent and new natural gas-fired generation, increasing in the forecast by 7.51 million MWH, contributes about 40 percent. Over the forecast period, nuclear generation increases 1.04 million MWH or 9 percent above 2011 levels, while net generation at in-state coal-fired units is for the most part unchanged in the forecast.

Generation to service Minnesota load increases over the forecast period 0.85 percent per year, or slightly less than 1 percent per year. The mean heat rate at in-state generating units, or the average amount of energy needed to generate one kWh of electricity, declines about 11 percent statewide over the forecast period.

Forecast noncombustion process emission sources include: coal piles (CH_4) flue gas desulphurization (CO_2), hydroelectric reservoirs (CH_4), and electric transmission and distribution (SF_6). Emissions from coal piles are forecast from forecasted annual coal throughput and emission factors given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Emissions from flue gas desulphurization are forecast on the basis of planned facility retirements; most present-day limestone use in FGD is at facilities that are slated to close half-way through the forecast period. Emissions from hydroelectric reservoirs are assumed to remain constant, with total reservoir surface area unchanged over the forecast period.

Table E-7. Forecasted Generation to Meet Minnesota's Electric Load (million MWH)

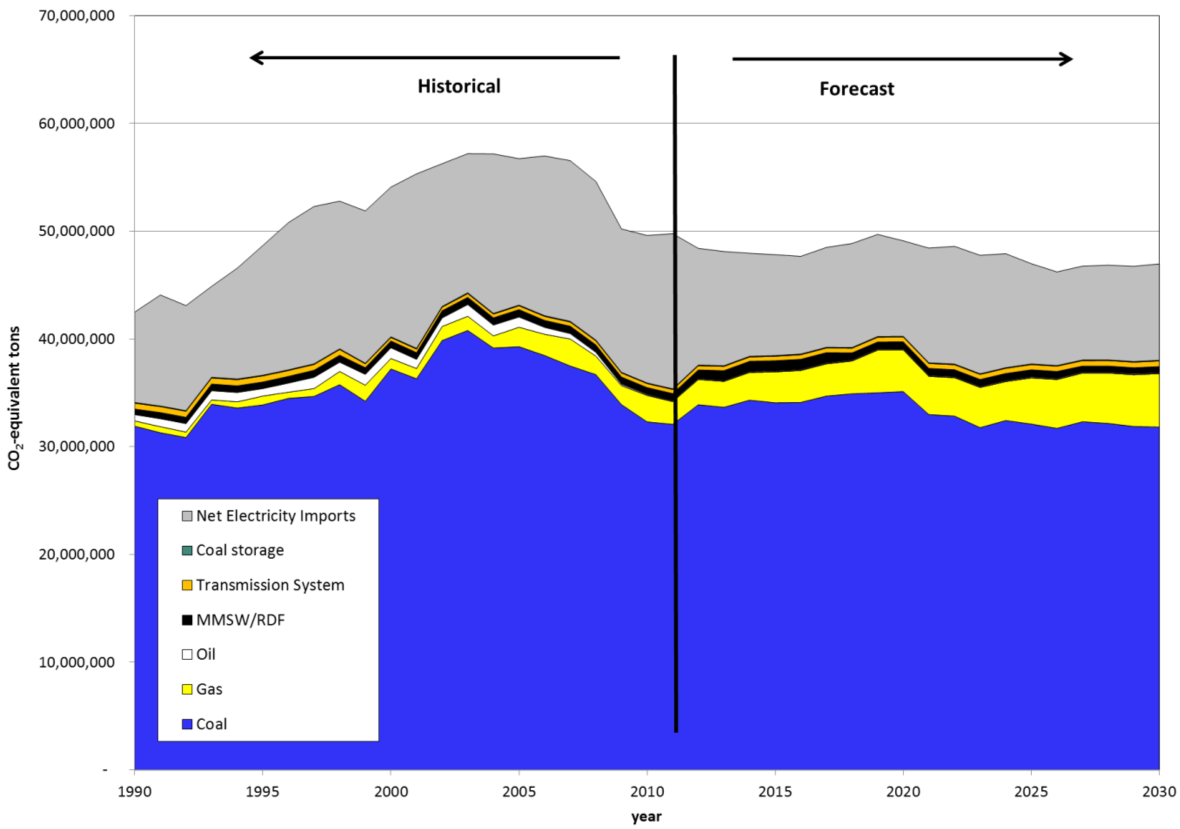
	2012	**2015**	**2020**	**2025**	**2030**
In-state generation					
coal	29.35	30.03	30.91	28.47	28.42
oil	0.03	0.03	0.03	0.02	0.02
natural gas	4.26	5.39	7.09	8.68	10.79
other	0	0	0	0	0
subtotal	33.93	35.77	38.25	37.40	39.45
nuclear	12.86	13.11	13.31	12.46	13.00
renewable	10.55	11.73	12.86	17.44	18.46
subtotal	**57.34**	**60.61**	**64.43**	**67.29**	**70.91**
Net Imports	14.63	13.04	12.72	13.35	13.13
Total	**71.98**	**73.65**	**77.15**	**80.64**	**84.05**
in-state heat rate (btu/kwh)	9,579	9,392	9,254	8,706	8,527

About 4,000 miles of transmission lines >34 kV are forecast to be added in Minnesota by 2022. (MISO, *MTEP12*) Forecasted emissions from T&D assume such an expansion to 2022 and present-day per transmission mile emission rates from EPA, *Inventory of US Greenhouse Gas Emissions and SInks*. Beyond 2022, the transmission system is assumed to continue to expand at 2012-2022 average annual rates.

The results shown above in Table E-1 for GHG emissions are summarized graphically below in Figure E-2. Electric power sector emissions decrease in the forecast by 5.6 percent, 2011-2030. Forecasted emissions from net imports decline 37.8 percent. Offsetting this are increased emissions from in-state combustion, which increases about 7 percent. In-state noncombustion process emissions increase about 30 percent from 2010 levels, but these are small, comprising about 1 percent of total sector emissions.

By fuel, emissions from the combustion of coal are essentially unchanged, declining in the forecast less than 1 percent from 2011 levels or 0.25 million CO_2-equivlent tons. Since emissions from coal combustion are the largest source of electric power sector emissions, the general flatness of the trend in emissions from coal over the forecast period translates to general flatness or no growth (or no substantial decline) in emissions in overall state-level electric power sector emissions. Emissions from net imports decline by 5.45 million CO_2-equivalent tons in the forecast, but are partially offset by a forecasted in-state emissions increase at 2030 from 2011 levels of 2.65 million CO_2-equivalent tons, leading to a forecasted 2.8 million CO_2-equivalent ton reduction in emissions at 2030 from 2011 levels.

Figure E-2 Historic and Forecasted Greenhouse Gas Emissions from Electric Power



The forecast was assembled in Winter/Spring 2013 and therefore does not reflect recent developments, including the 950 MW of new wind and 560 MW of new natural gas combined cycle ordered in October 2013 and December 2014, respectively, by the Minnesota Public Utilities Commission, the recent explosion of interest in community solar gardens, and the new 2015 XCEL Energy *Integrated resource Plan*. It is likely that, were these developments considered, the electric power sector forecast would include substantially lower forecast emission totals for 2030 than are shown in Table E-3 and Figure E-2. The forecast data for coal use for 2020-2028 forecast years given in the 2014 *Minnesota Annual Electric Report* suggests 2030 emissions levels at least 10 to 20 percent lower than shown in Table E-3 and Figure E-2. The forecast results shown in Table E-3, Figure E-2 and below in the following section, probably should be viewed in that light.

The principal sources for the data and methods used in the forecast include:

- MPCA, *Greenhouse Gas Emission Inventory database*
- EIA, *Form-906/923*
- FERC *Form-1*
- EIA *Form-861*
- EIA-*Form-923/423*
- EIA, *Electric Power Annual Database*
- 2012 *Minnesota Annual Electric Report*
- Minnesota Department of Commerce, *Minnesota Utility Data Book*
- M-RETs facility roster by RECs ownership
- EIA, *Annual Energy Outlook 2014*
- annual utility RES and SES compliance reports to the Minnesota Public Utilities Commission
- annual utility RPS compliance reports to the Wisconsin Public Service Commission
- electric utility integrated resource plans filed with the MNPUC, 2009-2013
- MNPUC orders setting protocols for compliance and reporting under Minnesota RES and SES
- USEPA, *Inventory of US Greenhouse Gas Emissions and Sinks*
- MISO, *Midwest Transmission Expansion Plan 2012*

Detailed forecast results

The results shown above in Table E-3 for forecasted emissions are shown are shown below in Table E-8 using a more detailed breakdown by fuel. Electric power sector emissions decline 6 percent over the forecast period or 2.80 million CO_2-equivalent tons. Emissions from the combustion of bituminous and subbituminous coal decline 0.25 million CO_2-equivalent tons or 1 percent. Forecast emissions from natural gas combustion are 2.85 million CO_2-equivalent tons higher in the forecast in 2030 than in 2011, for a 1.36-fold increase. Forecast emissions from net imports decline 5.45 million CO_2-equivalent tons or 38 percent.

Table E-8. Forecasted Emissions from Minnesota's Electric Power Sector (million CO_2- equivalent short tons)

	2012	2015	2020	2025	2030
In-state Emissions					
Combustion-based					
bituminous coal	0.14	0.13	0.04	0.04	0.04
subbituminous coal	33.76	33.95	35.08	32.07	31.79
RDF, MMSW, TDF	0.78	0.92	0.64	0.64	0.55
natural gas	2.33	2.86	3.86	4.28	4.95
distillate fuel oil	0.03	0.03	0.04	0.03	0.02
residual fuel oil	0.02	0.02	0.02	0.02	0.02
waste oil	0.00	0.00	0.00	0.00	0.00
wood	0.03	0.03	0.03	0.04	0.04
turkey litter/wood mix	0.01	0.01	0.01	0.01	0.01
LFG, digester gas	0.01	0.01	0.01	0.01	0.01
subtotal	**37.12**	**37.98**	**39.74**	**37.14**	**37.44**
FGD	0.01	0.01	0.00	0.00	0.00
Hydroelectric reservoirs	0.01	0.01	0.01	0.01	0.01
Coal piles	0.06	0.06	0.06	0.06	0.06
Electric transmission and distributio	0.39	0.41	0.44	0.48	0.52
subtotal	**0.46**	**0.48**	**0.51**	**0.55**	**0.58**
Net Imports	**10.83**	**9.36**	**8.86**	**9.30**	**8.95**
Total Emissions	48.41	47.82	49.11	46.99	46.97

Emissions from all other sources increase an aggregate 0.05 million CO_2-equivalent tons over the forecast period. Forecast emissions from electric transmission and distribution increase a projected 0.15 million CO_2-equivalent tons, or 42 percent, from 2011 levels, while emissions from the combustion of solid waste decline 0.11 million CO_2-equivalent tons in the forecast, or 17 percent. Forecast emissions of distillate fuel oil and residual fuel oil increase 0.01 million CO_2-equivalent tons, while emissions from wood combustion increase in the forecast a similar amount by 2030.

The emissions trend is generally flat to 2020, declining thereafter at an average annual rate of about 0.4 percent per year. The decline beginning in 2020 corresponds with the resumption in the forecast of large-scale construction of new renewable energy projects under the Renewable Energy Standard. Between forecast years 2020 and 2025, roughly 4.5 million MWH of renewable generation is added to in-state generation in the RES simulations. This is in contrast to the 1.1 million MWH added in the prior 5-year period, 2015-2020. In the power sector forecast, each MWH of in-state renewable generation that is added to electric power supply results in reduced need for net imports by an equal 1 MWH, with emissions from net imports correspondingly reduced.

Table E-9 shows the trend in forecasted emissions for selected years by greenhouse gas. Forecast emissions of fossil CO_2, the principal GHG, decline 5.9 percent from 2011 levels by 2030, by 2.89 million CO_2-equivalent tons. Projected emissions of N_2O increase by 11.1 percent between 2011 and forecast year 2030, by 0.03 million CO_2-equivalent tons, while projected emissions of CH_4 decline 0.01 million CO_2-equivalent tons or 9.5 percent. At 2030, forecast emissions of biogenic CO_2 are about 50 percent above 2011 levels, albeit from quite low initial levels. Nearly all of the projected increase is from the combustion of solid biomass fuels.

Table E-9. Forecasted Emissions from Minnesota's Electric Power Sector by Gas (million CO_2- equivalent short tons)

	2012	2015	2020	2025	2030
fossil CO_2	47.53	46.92	48.19	45.99	45.93
N_2O	0.26	0.28	0.26	0.28	0.29
CH_4	0.12	0.11	0.12	0.11	0.11
SF_6	0.50	0.51	0.54	0.60	0.63
subtotal	48.41	47.82	49.11	46.99	46.97
biogenic CO2	3.12	3.38	2.90	3.37	NA
solid biomass	3.01	3.28	2.79	3.27	NA
bioliquids	0.00	0.00	0.00	0.00	NA
biogas	0.11	0.11	0.11	0.11	NA

It bears repeating that the forecast, assembled in Winter/Spring 2013, does not reflect recent developments. It is likely that, were these developments considered, the forecast emission totals shown in Tables E-5 and E-6 for 2030 would be substantially lower than 47 million CO_2-equivalent tons.

Forecast generation to meet Minnesota load, shown above in Table E-7, is shown again below in Table E-10 using a more detailed breakdown by fuel type and load-type. Over the forecast period total in-state generation increases a projected 18.53 million MWH, offsetting a 6.03 million MWH decline in net imports. Of fossil sources, natural gas-fired generation in-state increases a projected 7.51 million MWH over the forecast period, while coal-fired generation increases 0.82 million MWH. Projected oil-fired net generation declines in the forecast by 0.02 million MWH, 2011-2030, split about equally between residual fuel oil- and distillate fuel oil-fired generation. Total fossil generation increases by 8.3 million MWH, but again, dominated by increased generation using natural gas, the least emitting of the fossil fuel. Projected nuclear-based generation is 1.04 million MWH higher in 2030 than in 2011.

By percent, projected fossil fuel-fired generation increases 27 percent over the forecast period, nuclear 9 percent, and renewably-based generation 99 percent. Within the individual groupings, natural gas-fired generation increases 2.29-fold, coal-fired generation 3 percent, and nuclear-based generation by 9 percent, 2011-2030.

Table E-10. Forecasted Generation to Meet Minnesota's Electric Load (million MWH)

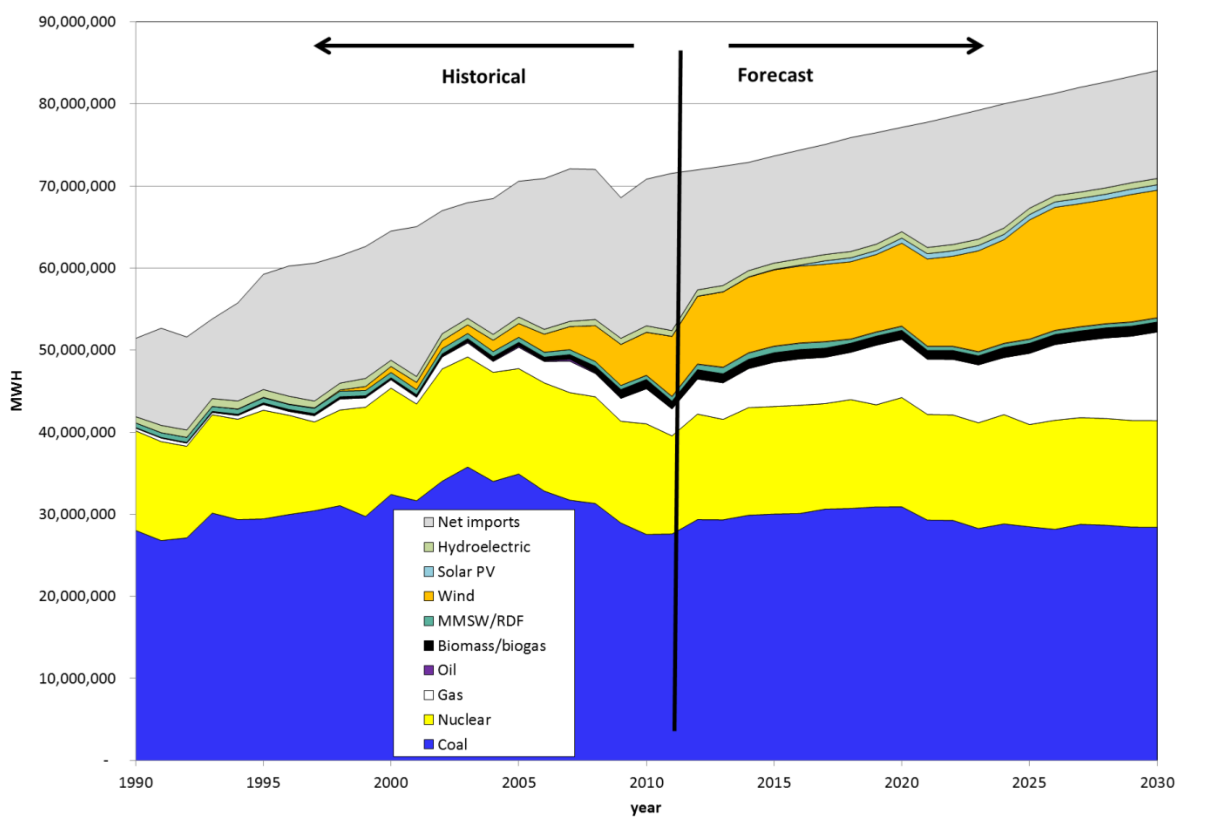
	2012	2015	2020	2025	2030
In-state Generation					
bituminous coal	0.02	0.02	-	-	-
subbituminous coal	29.33	30.01	30.91	28.47	28.42
solid waste	0.64	0.75	0.46	0.46	0.46
natural gas	4.26	5.39	7.09	8.68	10.79
distillate fuel oil	0.02	0.02	0.03	0.02	0.01
residual fuel oil	0.01	0.01	0.01	0.01	0.01
waste heat	0.06	0.06	0.06	0.06	0.06
nuclear	12.86	13.11	13.31	12.46	13.00
wood	0.52	0.54	0.48	0.61	0.61
turkey litter/wood mix	0.41	0.41	0.41	0.41	0.41
LFG, digester gas	0.19	0.19	0.19	0.19	0.19
wind	8.24	9.28	10.10	14.51	15.53
solar PV	0.02	0.06	0.63	0.65	0.66
hydroelectric	0.77	0.77	0.77	0.77	0.77
subtotal	**57.34**	**60.61**	**64.43**	**67.29**	**70.91**
Net Imports	14.63	13.04	12.72	13.35	13.13
Total Generation	**71.98**	**73.65**	**77.15**	**80.64**	**84.05**
Baseload	52.72	55.00	57.06	58.42	59.91
Intermediate load	3.93	4.93	5.96	8.12	9.99
Intermediate load-net imports	14.63	13.04	12.72	13.35	13.13
Peaking load	0.70	0.69	1.41	0.76	1.01
In-state renewable generation as % of total generation	14.66%	15.93%	16.67%	21.62%	21.97%
* solid waste includes MMSW and RDF, plus minute amounts of TDF					

Renewable generation increases over the forecast period by 9.2 million MWH (99 percent). Of this, most, 8.23 million MWH (113 percent), is from increased wind generation. Forecast solar PV-based generation increases 0.65 million MWH above 2011 levels in the forecast. Solid biomass-based generation increases 0.19 million MWH (19 percent). Renewable energy-based generation increases over the forecast period from about 14 percent in 2011 to a projected 22 percent in 2030.

By load-type, forecast baseload generation increases in the forecast by 11.12 million MWH or 23 percent and in-state intermediate load generation by 8.44 million MWH or 5.4-fold, while in-state peaking load generation declines over the forecast period by 1.03 million MWH or 50 percent. It is conventional to put imported power into the intermediate load category. As noted above, forecasted net imports decline in the forecast by 6.03 million MWH by 2030 or 31 percent. Generation is categorized by load type, assuming that generating units with capacity factors of 15 to 45 percent are intermediate load units, and that those with capacity factors below or above this range are peaking load and baseload units, respectively.

These same forecast data are shown graphically in Figure E-3, along with historic data from 1990 through 2011. Total generation to service Minnesota demand increases linearly over the forecast period by about 0.66 million MWH per year. By forecast year 2030, coal-fired and nuclear generation together comprise a projected 49 percent of all generation needed to service Minnesota demand, down from 55 percent in 2011. In absolute terms, generation from coal and nuclear units is projected to be about 2 million MWH higher in 2030 than in 2011. By forecast year 2030, natural gas-fired generation and wind generation together comprise a projected 31 percent of all generation needed to service Minnesota demand, up from 15 percent in 2011. In absolute terms, net generation at natural gas-fired units and in-state wind turbines increases 2.5-fold over the forecast period. By 2030, net imports comprise a forecasted 16 percent of total generation needed to service Minnesota demand, down from a 2011 estimate of 27 percent.

Figure E-3.Historic and Forecasted Electric Generation to Service Minnesota Demand



Projected in-state generation is shown in Table E-11 by prime mover. In the forecast, the percent of electricity generated in-state in traditional steam turbines declines from about 79 percent of total in-state generation in 2011 to a projected 61 percent in forecast year 2030. This continues a decline that has been evident for at least a decade and a half. Over the same period, generation in gas turbines, again expressed as a percent of total in-state net generation, increases from a 2011 level of about 6 percent to a projected 15 percent in 2030 forecast year. Most of this is from increased generation using combined cycle gas turbines technology. In-state electric generation in wind turbines increases in the forecast from a 2011 level of about 14 percent of total in-state net generation to a projected 2030 level of 23 percent.

Table E-11. Forecasted In-state Net Generation by Prime Mover (million MWH)

	2012	2015	2020	2025	2030
Steam turbine					
coal	29.35	30.03	30.91	28.47	28.42
nuclear	12.86	13.11	13.31	12.46	13.00
solid waste	0.64	0.75	0.46	0.46	0.46
biomass	0.93	0.95	0.89	1.02	1.02
other steam	0.21	0.23	0.14	0.13	0.13
Gas turbine					
natural gas	4.06	5.17	6.97	8.56	10.67
other	0.06	0.06	0.06	0.06	0.06
Reciprocating engines	0.14	0.14	0.14	0.14	0.14
Organic rankine cycle--waste heat	0.06	0.06	0.06	0.06	0.06
Wind turbine	8.24	9.28	10.10	14.51	15.53
Solar PV	0.02	0.06	0.63	0.65	0.66
Hydroelectric turbine	0.77	0.77	0.77	0.77	0.77
subtotal	**57.34**	**60.61**	**64.43**	**67.29**	**70.91**

The sector energy balance is shown in Table E-12 for selected years. In each forecast year, total requirement for power equals total power supply. Total requirements equal retail sales in Minnesota plus total transmission and distribution losses, including losses out-of-state associated with net imported power. Over the forecast period, retail sales in Minnesota grow at an average annual rate of 0.83 percent. By comparison, in the *Annual Energy Outlook 2013* and *Annual Energy Outlook* 2014 simulations, retail sales for the West North Central region increase at average annual rates, 2011-2030, of 1.0 and 0.7 percent. Line losses are 5.8 to 5.9 percent of retail sales throughout the forecast period.

Net imports equal total requirement less Minnesota in-state net generation. Forecasted 2030 imports are 16 percent of projected total requirements at 2030, down from a present level of 27 percent. The distribution of retail sales remains reasonably constant over the forecast period, with residential sector use increasing slightly from 29.3 percent in 2011 to a forecasted 31.3 percent in 2030 and commercial sector use declining from 31.2 percent of the market in 2011 to 35.4 percent in 2030. Agriculture's projected share also declines, from a present level of 4.1 percent to a forecasted 3.4 percent share in 2030.

Table E-12. Forecasted electric Power Sector Energy Balance (million MWH)

	2012	2015	2020	2025	2030
Requirement					
Retail sales	68.00	69.61	72.93	76.23	79.46
Line losses	3.98	4.04	4.22	4.41	4.59
in-state	2.99	3.16	3.36	3.51	3.70
out-of-state	0.99	0.88	0.86	0.90	0.89
total requirement	**71.98**	**73.65**	**77.15**	**80.64**	**84.05**
line losses as % of retail sales	5.9%	5.8%	5.8%	5.8%	5.8%
Supply					
Net in-state generation	57.34	60.61	64.43	67.29	70.91
Net imports including generation to make-up line loss	14.63	13.04	12.72	13.35	13.14
total supply	**71.98**	**73.65**	**77.15**	**80.64**	**84.05**
Retail sales					
residential	20.62	21.22	22.43	23.79	NA
commercial	21.21	21.53	22.25	22.87	NA
industrial	23.87	24.50	25.78	26.95	NA
mining	4.96	4.74	4.80	4.88	NA
other industrial	18.91	19.75	20.97	22.07	NA
agricultural	2.30	2.36	2.47	2.61	NA
total sales	**68.00**	**69.61**	**72.93**	**76.23**	**79.46**

Table E-13 shows projected trends in energy input to in-state generation by fuel or prime mover. In the calculation, no losses in generation are attributed to wind, solar PV or hydroelectric power, which harvest natural flows and require no prior input of energy in the form of heat. Over the forecast period, energy input to in-state generation increases about 10 percent or 93 million MMBtu, 2011-2030. Of this, about half is from increased natural gas use, or about 48 million MMBtu, 12 percent or 11 million MMBtu from expanded energy inputs to nuclear generation, and 30 percent or 28 million MMBtu from expanded wind power generation. Forecast energy inputs to biomass-fired generation increase 5.9 million MMBtu between 2011 and forecast year 2030, or about 20 percent.

By contrast, forecast energy inputs to coal-fired generation are almost unchanged from 2011 levels. Forecast 2030 energy inputs to coal-fired generation are smaller than 2011 inputs by but 1 percent, or 2.3 million MMBtu. As noted above, forecast net generation at coal-fired generation capacity increases about 3 percent, 2011-2030, while forecast heat rates at coal-fired generation capacity decline in the forecast by about the same amount, about 3 percent, 2011-2030.

Table E-13. Energy Input to In-state Generation (million MMBtu)

	2012	2015	2020	2025	2030
bituminous coal	1.35	1.31	0.40	0.40	0.40
subbituminous coal	313.37	315.07	325.59	297.63	295.08
solid waste	14.82	17.68	11.67	11.68	11.74
natural gas	39.48	48.40	65.38	72.38	83.63
distillate fuel oil	0.37	0.41	0.45	0.34	0.27
residual fuel oil, waste oil	0.26	0.26	0.26	0.26	0.26
waste heat	0.52	0.52	0.52	0.52	0.52
nuclear	134.69	137.34	139.43	130.51	136.16
wood	12.33	12.86	12.44	16.88	17.89
turkey litter/wood mix	5.97	5.97	5.97	5.97	5.97
biodiesel	0.01	0.01	0.01	0.01	0.00
LFG	1.39	1.39	1.39	1.39	1.39
digester gas	0.47	0.47	0.47	0.47	0.47
wind	28.10	31.67	34.45	49.52	53.00
solar PV	0.07	0.21	2.14	2.23	2.25
hydroelectric	2.62	2.63	2.63	2.63	2.63
total	**555.83**	**576.22**	**603.20**	**592.81**	**611.66**
District heating part only	6.56	6.96	6.96	6.96	6.96

* for wind, solar PV and hydroelectric, energy input to generation equals the energy content of the generated electricity

Over the forecast period, total energy inputs to generation increase at a rate of 0.9 percent per year. For comparison, from 2000 to 2011, energy use in-state in electric generation declined at an average annual rate of 0.2 percent and, from 1990 to 2000, energy use in-state in electric generation increased at an average annual rate of 1.5 percent. The decline in total energy inputs to generation in the 2000-2011 time frame resulted from, among other things, a 14 percent decline in energy and fuel inputs to coal-fired generation.

Predicted levels of installed electric generation capacity in-state are shown in Table E-14 for selected years by prime mover. Total generation capacity in state increases by 3,687 MW in the forecast, 2012-2025. Of this, a little less than one-half is from forecasted additions in wind turbine capacity, and a little less than one-half is from forecasted additions in fossil fuel-fired gas turbine capacity. Fossil steam turbine capacity declines in the forecast by 400 MW, or 8 percent, while forecast in-state solar PV capacity increases 383 MW by 2030. Of the forecasted increase in fossil fuel-fired gas turbine capacity, most is in the form of combined cycle capacity.

Unlike the projections for generation or emissions, the electric power sector projections for installed generation capacity in-state were not linearly extended beyond 2026.

Table E-14. Forecasted In-state Generation Capacity

	2012	2015	2020	2025	2026
Fossil-steam	4,965	4,978	4,566	4,566	4,566
Renewable-steam	347	347	309	309	309
Nuclear-steam	1,594	1,594	1,594	1,594	1,594
Other-steam	5	5	5	5	5
Fossil-gas turbine	5,058	5,181	5,771	6,993	6,993
simple cycle	3,053	3,176	3,089	3,089	3,089
combined cycle	2,004	2,004	2,681	3,903	3,903
Renewable-gas turbine	14	14	14	14	14
Fossil-reciprocating engine	433	433	433	433	433
Renewable-reciprocating engine	19	19	19	19	19
Wind turbine	2,846	3,157	3,390	4,651	4,784
Solar PV	18	53	381	401	401
Hydroelectrical turbine	181	182	182	182	182
Total	**15,479**	**15,963**	**16,663**	**19,166**	**19,299**

Figure E-4 shows the same forecast information graphically, along with historical information from 1990 to 2011. Between 1997 and 2009, gas turbine capacity in the state almost quintupled. The forecast continues this historic expansion in gas turbine capacity, albeit at a substantially more muted rate, about 2.5 percent per year. Between 1997 and 2011, wind turbine capacity in Minnesota increased 76-fold. Again, the forecast continues this expansion, with wind capacity in the state expanding over the forecast period, here 2012-2026, at an average annual rate of 4 .1 percent. Steam turbine capacity contracts in the forecast at a rate of about 0.2 percent per year, 2011-2026. Projected capacity of reciprocating engines and hydroelectric turbines is stable over the forecast period. Installed solar PV capacity increases 60-fold over the forecast period, albeit from quite low 2011 initial levels (6.5 MW).

Table E-15 shows forecasted in-state capacity factors for selected forecast years by prime mover. Over the forecast period, capacity factors at fossil steam units increase, compensating somewhat for the projected decline in generating capacity at in-state steam turbine units. The same is true for projected capacity factors for renewable steam turbines. Forecasted capacity factors for nuclear are fairly constant, generally bouncing around in the range of 92 to 95 percent. Capacity factors for wind turbines and solar PV increase over the forecast period, due to continuous technology development throughout the forecast period and increased penetration of new, better performing units into the fleet.

Projected capacity factors for gas turbines increase in the forecast as new combined cycle capacity, as a percentage of total gas turbine capacity, begins to exceed 50 percent. Combined cycle gas turbines operate at substantially higher capacity factors than simple cycle gas turbines.

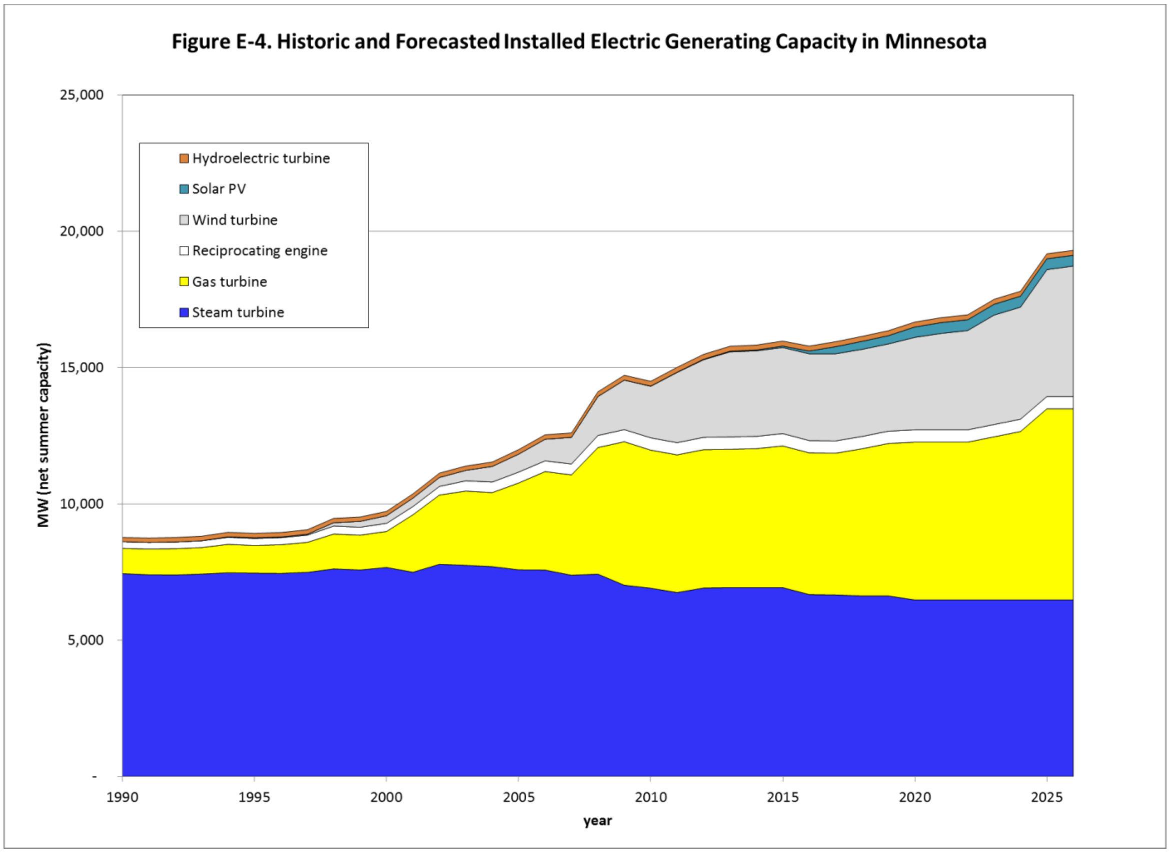
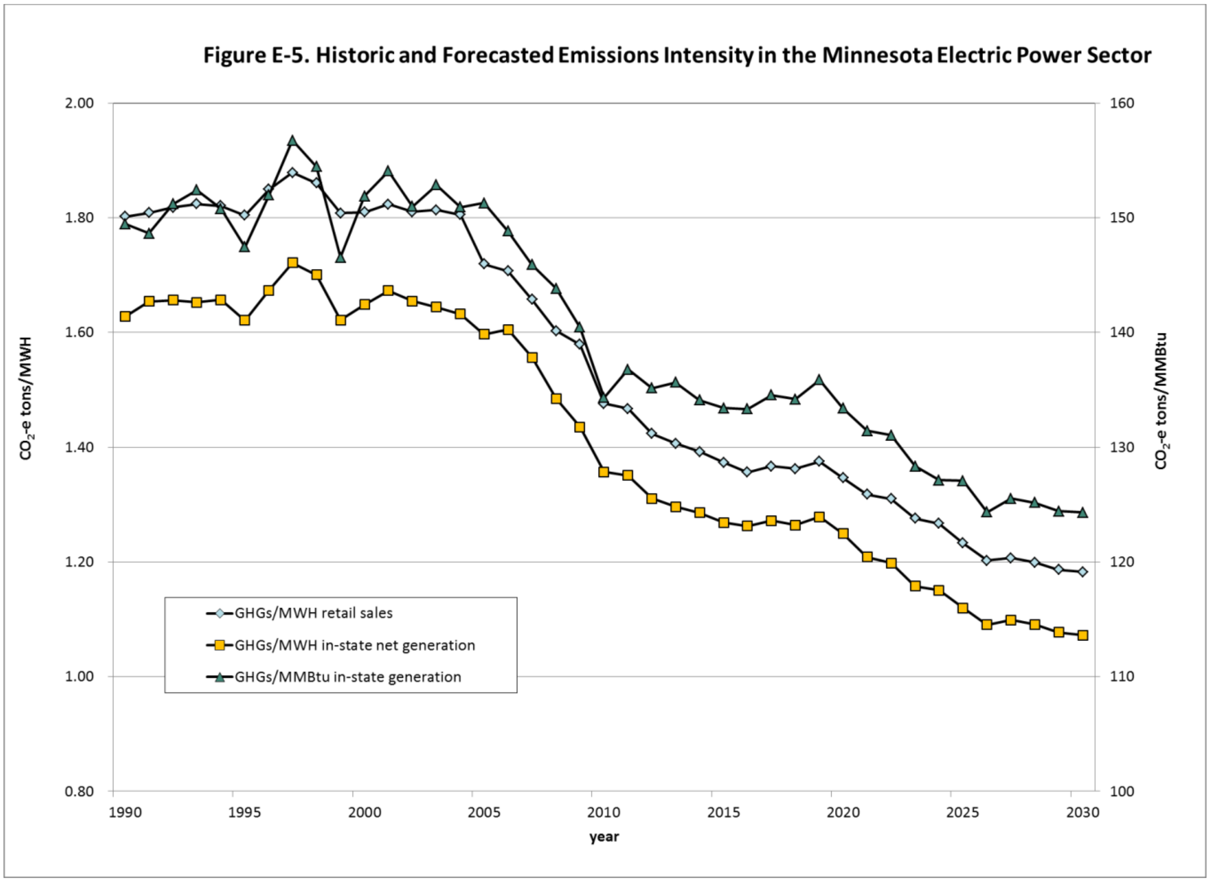


Table E-15. Forecasted Capacity Factors at In-state Electric Generating Units

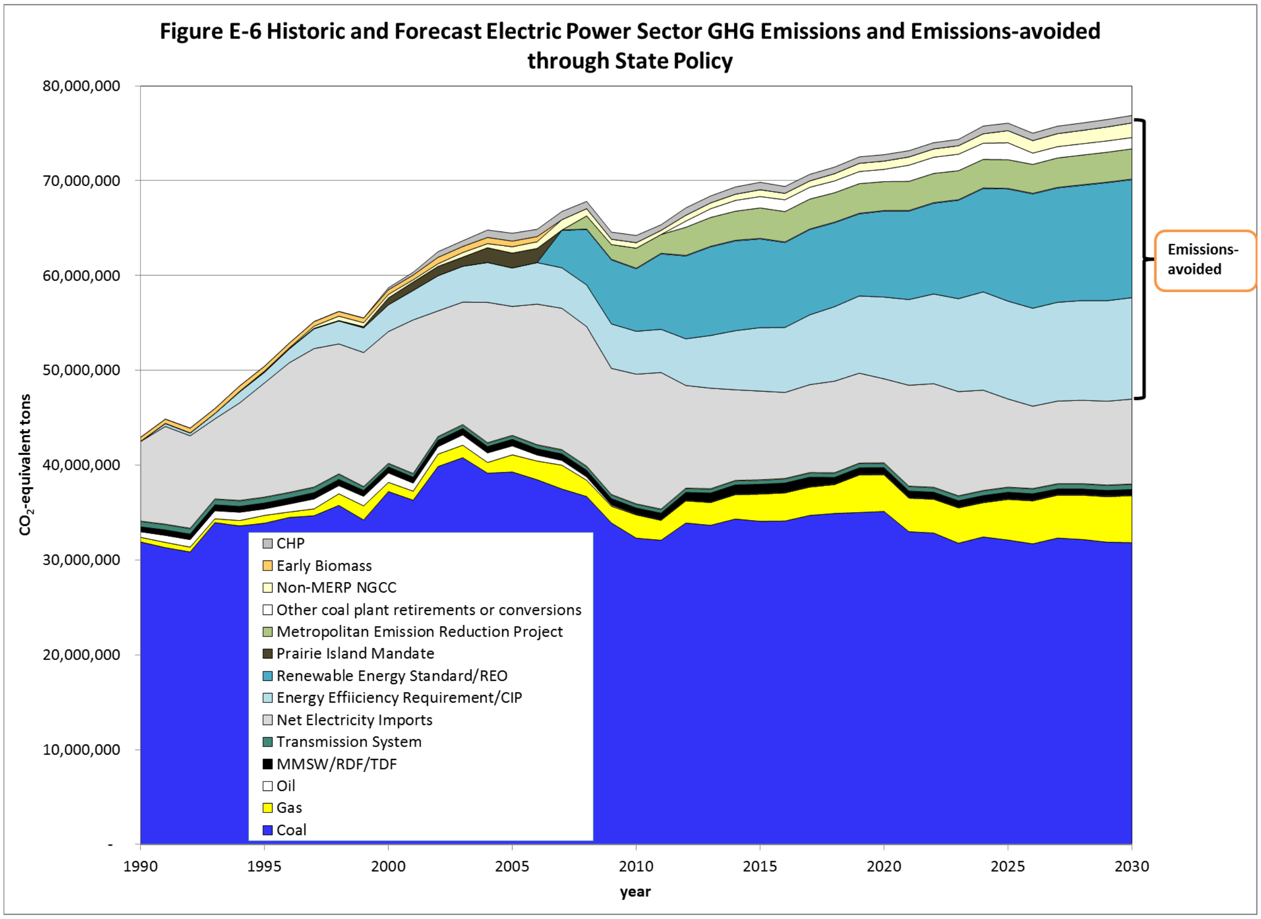
	2012	2015	2020	2025	2026
Fossil-steam	68.5%	70.0%	78.0%	71.9%	71.1%
Renewable-steam	44.1%	47.0%	43.7%	48.5%	48.5%
Nuclear-steam	92.1%	93.9%	95.3%	89.2%	95.2%
Fossil-gas turbine	9.2%	11.4%	13.8%	14.0%	14.9%
Renewable-gas turbine	44.2%	44.2%	44.2%	44.2%	44.2%
Fossil-reciprocating engine	0.1%	0.1%	0.1%	0.1%	0.1%
Wind turbine	33.0%	33.6%	34.0%	35.6%	35.7%
Solar PV	0.0%	13.2%	18.8%	18.6%	18.6%
Hydroelectrical turbine	48.4%	48.4%	48.4%	48.4%	48.4%

The historical trend in total electric power sector emissions (including emissions from net imports) per MWH of retail sales is shown in Figure E-5, along with the projected future trend in emissions per MWH of retail sales. Also shown are projected trends in emissions per MWH of power generated in-state and emissions per MMBtu of energy input in-state to generation. Until about 2004, emissions per MWH of retail sales were fairly constant near about 1.8 CO_2-equivalent tons per MWH. Beginning in 2005, emissions per MWH of retail sales began to fall, about 18 percent, to 2011 levels of about 1.5 tons per MWH. Emissions per MWH-generated in Minnesota declined a similar 17 percent over this period, while emissions per MMBtu of energy input to generation in Minnesota declined 9 percent, from 151 CO_2-equivalent tons per MMBtu to about 137 tons per MMBtu.



The projected trend in emissions per MWH of retail sales continues the decline seen in the historic data, as does the projected trend in emissions per MWH of in-state generation and MMBtu input to in-state generation. Over the forecast period, emissions per MWH of retail sales decline 19.7 percent, from 1.47 CO_2-equivalent tons per MWH to 1.18 CO_2-equivalent tons per MWH. Forecast emissions per MWH of in-state generation decline 20.7 percent, from 1.35 to 1.07 CO_2-equivalent tons per MWH. The decline in the forecast in emissions per MMBtu input to in-state generation is about 9 percent, 2011 to 2030, similar to what occurred between 2004 and 2011.

Lastly, an effort was made to evaluate the emission-avoidance effects of past and current policies on Minnesota electric power sector emissions, both historic and forecast. Policies include: renewable energy standard, EERS, Prairie Island renewable energy mandate, and the Metropolitan Emission Reduction Project (MERP). Also evaluated were the effects, past or future, of nonMERP coal plant retirements and nonMERP natural gas combined cycle additions to the generating fleet, plus existing combined heat and power (CHP) capacity and early biomass development. The results of this analysis are shown in Figure E-6, for both the historical period and the forecast period. For the forecast period, shown in Figure E-6 are the emissions reductions that we anticipate as a result of a continuation of current policies.



In 2030, we anticipate that a continuation of current policies will result in an emission reduction of about 30 million CO_2-equivalent tons, equal to about 40 percent of what we estimate emissions would otherwise be in absence of a continuation of current policy. We estimate the same value, at 2011, to be 15.6 million CO_2-equivalent tons.

In developing these estimates, a schedule of marginal emission factors was used, derived from the spatial data on marginal emission rates given in K. Siler-Evans, *et al*., "Marginal Emission Factors for the US Electricity System." Total MWH of conventional generation avoided were estimated for each policy. In some instances, in addition to direct effects on emissions, the policies in question also resulted in some new demands for power. Using the marginal emission factors developed from the data in Siler-Evans, *et al*., the competing effects of current policies on emissions were evaluated to produce what is seen in Figure E-6. Where the policies resulted in a one MWH for one MWH fuel switch, these effects were treated directly.

A caveat is in order: the effects of the RES are counted solely for generation installed in-state. Within the predetermined boundaries of MPCA GHG emission inventory, actions taken outside the state to reduce emissions can impact Minnesota power sector emissions only to the degree that those actions influence the average emission rate of the 10-state, one-province exporting region, which is to say, little at all. With a different emission inventory with different boundaries, results other than those shown in Figure E-6 are possible.

Transportation sector

Sector boundaries

The transportation sector consists of on-road vehicles, rail locomotives, vessels, boats, aircraft, and pipelines that are used to transport people and goods. Included are: light-duty vehicles like passenger cars and light-duty trucks, motorcycles, medium and heavy-duty trucks, transit buses, school buses, river barges, recreational marine craft, Great Lakes and ocean-going ships, rail locomotives and, in the case of pipelines, the compressor stations and the pipelines themselves.

Not included in the transportation sector are warehouses, barge terminals, airport terminals, airport and highway traffic control, and docks. In the MPCA GHG emission inventory, these are assigned to the commercial sector. Also not included are agricultural equipment and off-highway equipment and vehicles used in construction and mining. These are assigned to the agricultural and industrial sectors, respectively. The transportation sector does include some miscellaneous off-highway vehicles and equipment that, for convenience, in statistical summaries of activities, historically have been included in transportation sector totals.

Greenhouse gas (GHG) emissions from transportation sources typically are on-site combustion emissions associated with energy use, but may also include some non-combustion 'process emissions.' With one notable exception, aviation, emissions occur exclusively within the boundaries of the state. Aviation emissions include all emissions associated with fuel purchased in Minnesota.

Due to time and resource constraints, it was decided not to treat most noncombustion sources of transportation emissions in this emissions forecast. Noncombustion process emission sources from transportation not treated in this forecast include mobile air conditioning, on-road refrigerated trucks, and natural gas transmission and distribution pipelines. Pipeline combustion emissions also were not treated.

The generation off-site of grid-based electricity for end-use in transportation results in GHG emissions. Off-site emissions from the generation of grid-based electric power, regardless of end-use, are treated as electric power sector emissions. Light-rail transit cars are powered by electricity drawn from the grid, as are plug-in electric vehicles and the electric drive compressors used in oil pipelines.

Present-day and historical emissions

Greenhouse gases are emitted during combustion from highway vehicles and off-highway aircraft, boats, barges, ships, and rail locomotives. Noncombustion process emissions result from the oxidation of lubricating oil during use and frictional wear on tires. Most emissions are in the form of fossil CO_2. A sizable amount of N_2O on a CO_2-equivalent basis is produced in the catalytic converters of gasoline-driven highway vehicles and emitted to the atmosphere. CH_4 is formed during incomplete combustion of fuels and also is emitted during travel.

Estimates are shown below for historical emissions from the transportation sector for selected years in million CO_2-equivalent tons.[4] About two-thirds of emissions statewide derive from light-duty highway vehicles, about one-fifth from heavy-duty highway vehicles, and about 10 percent from aviation.

[4] Unlike the other seven emitting sectors, at the time this baseline forecast was being developed emission inventory estimates were available only through 2010.

Emissions of transportation sector emissions peaked in 2005 at 38.3 million CO_2-equivalent tons and by 2010 had declined about 10 percent from peak 2005 levels. Noncombustion process emissions from mobile air conditioning and combustion and noncombustion emissions from natural transmission and distribution were not included in these estimates for the reasons discussed above.

Table T-1. Historical Emissions from Minnesota's Transportation Sector (million CO_2-equivalent short tons)

	1990	1995	2000	2005	2010
Coal	-	-	-	-	-
Oil	29.47	33.08	37.41	38.22	34.43
Natural gas	-	0.00	0.00	0.00	0.00
Other	0.08	0.11	0.10	0.08	0.05
subtotal	29.55	33.18	37.51	38.30	34.48
Tires	0.01	0.01	0.01	0.02	0.01
Total	29.56	33.20	37.52	38.32	34.49
by vehicle type or mode:					
Light-duty highway vehicles	18.54	20.99	23.77	24.11	22.28
Heavy-duty highway vehicles	5.64	6.19	6.68	7.33	6.64
Tires and lubricants	0.12	0.14	0.16	0.17	0.17
Rail	0.72	1.31	0.71	0.96	0.80
Lake shipping and barge	0.04	0.06	0.17	0.18	0.26
Recreational marine	0.66	0.34	0.32	0.45	0.39
Military	0.01	0.00	0.01	0.00	0.00
Miscellaneous off-highway	-	-	0.05	0.04	0.39
Aviation	3.83	4.17	5.66	5.07	3.57
Total	29.56	33.20	37.52	38.32	34.49

Estimated emissions of CO_2 from combustion from highway sources are based on fuel throughput and conventional fuel-based emission factors. Emission factors for CO_2 are from Environmental Protection Agency (EPA), *Inventory of US Greenhouse Gas Emissions and Sinks* and Intergovernmental Panel on Climate Change, *2006 IPCC Guidelines for National Inventories*. For motor gasoline, E85, and compressed natural gas, data on fuel throughput derives from: Federal Highway Administration (FHA), *Highway Statistics*, Minnesota Department of Commerce, *E85 Fuel-use Data*, and Energy Information Administration (EIA) *Natural Gas Annual*. E10 is the dominant form in which motor gasoline is sold in Minnesota. By statute, all motor gasoline sold in Minnesota must be blended with at least 10 percent ethanol by volume, giving E10 its name. Total E10 motor gasoline use and ethanol use are calculated from reported E10 fuel totals and mandated blend levels. Total motor gasoline use in all fuel blends is a calculated value based on reported statewide E10 and E85 consumption and fuel volumetric mixes.

Annual fuel totals for diesel fuel oil are calculated totals developed from, in the case of light-duty vehicles (LDVs), vehicle totals by age and type, annual rates of VMT accumulation by vehicle age and type, and estimates of average on-road fuel economy, again by vehicle type and age. In the case of heavy-duty trucks, fuel totals for diesel fuel oil are calculated from observed total VMTs for heavy commercial trucks, the percentage distribution of annual vehicle miles traveled (VMT) by vehicle age, and on-road fuel economy by vehicle age. Total fuel use equals total VMT divided by average fuel economy.

Observed state-level VMTs on trunk highways for heavy-duty commercial trucks are from Minnesota Department of Transportation (MDOT), *Roadway Data-Vehicle Miles Traveled*. To these are added an additional increment of VMT to account for local travel. Total vehicle numbers by vehicle type are from

FHA, *Highway Statistics*. Total light-duty trucks is the difference between the total number of trucks reported in *Highway Statistics* as registered in Minnesota and total for all heavy-duty trucks registered in Minnesota that is given in Minnesota Department of Public Safety (MDPS), *Minnesota Motor Vehicle Crash Facts*.

The percentage of passenger cars or light duty trucks that, in any given year, are diesel driven is based on information on US new vehicle sales by fuel type given in Oak Ridge National Laboratory, *Transportation Energy Data Book*. Rates of annual VMT accumulation for light-duty vehicles are from periodic survey data given in FHA, *National Household Transportation Survey/National Personal Transportation Survey*. On-road fuel economy for any model year is based on average new LDV fuel economy for that model year by vehicle type, adjusted to account for the effects of vehicle age and average highway speed. For model years 2007 and before, a generic 10 percent adjustment factor is first applied to the EPA-estimated LDV fuel economies to account for the reported difference between EPA-reported new vehicle performance and actual on-road performance.[5] Fuel economy for diesel LDVs for each model year is inflated by 20 percent to account for the roughly 20 percent fuel economy advantage enjoyed by diesel LDVs over that of gasoline-powered LDVs.

The percent distribution of observed VMT by year of manufacture for heavy duty diesel trucks (HDDTs) is from Census Bureau, *Vehicle Inventory and Use Survey (VIUS)*. HDDT on-road fuel economy by vehicle age is from *VIUS*. 2002 is the last survey year for which data are available from *VIUS*. For any given year, total HDDT VMT on Minnesota highways equals total commercial truck VMT less calculated VMT from motor gasoline- and LPG-powered heavy duty trucks. Total statewide VMT by LPG-powered heavy-duty trucks were held constant at the last year for which *VIUS* state-based estimates are available. Total 2010 statewide VMT by motor gasoline-powered heavy were allowed to decline by half of 2002 levels, consistent with the approximate 50 percent registered between 1997 and 2002.

Transit buses and school buses also consume diesel fuel oil. Total fuel use in buses equals total VMT divided by average fuel economy. Annual VMT for transit buses is taken from MDOT, *Annual Transit Report*. State-level VMT are reported annually in Minnesota Department of Education, *Statewide Statistics Report*. Fuel economy for the transit bus fleet is a calculated total developed from the reported percentage distribution of the state-wide fleet by size. As of 2010, the fuel economy of the statewide fleet was an estimated 5.63 mpg (diesel-equivalent), up from 4.5 mpg in 2000. School bus fuel economy is set at 12 mpg-diesel-equivalent. Ten percent of school buses are assumed to be motor-gasoline powered, and the remainder diesel.

By statute, as of 2010, all diesel fuel sold in Minnesota is required to be 5 percent biodiesel by volume. Earlier requirements were, for 2006-2008, 2 percent and, for 2009, 4 percent. Emissions of fossil CO_2 emissions from highway fuels combustion are calculated only for the nonbiodiesel part of the fuel. Under a 5 percent mandate, on an energy content basis, a gallon of B5 is about 95.5 percent diesel and 4.5 percent biodiesel.

As noted above, LPG is used in Minnesota in heavy-duty trucks, but in very small amounts equal on an energy content basis to about 2 percent of annual HDDT diesel consumption. Annual emissions of fossil CO_2 are about 100,000 tons. Total fuel use is left at 2002 levels, the last year that is was possible, using VIUS-reported VMT, to estimate emissions on a quantitative basis.

Emissions of N_2O and CH_4 from light-duty vehicles and heavy-duty trucks are calculated based on total estimated vehicle miles traveled each inventory year by vehicle type and size and by year of

[5] Beginning with model year 2008, EPA instituted new fuel economy test that makes the use of this generic new vehicle adjustment factor unnecessary.

manufacture. Emission rates are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. For purposes of estimating emissions, gasoline-powered light-duty and heavy-duty vehicles are grouped by EPA into 6 vintages or age classes of vehicles, and diesel-powered LDVs and HDVs into 3 age classes. For buses, EPA provides a single emission factor irrespective of year of manufacture. VMT for diesel-driven vehicles were discussed above. The same methods that are used to develop those VMT estimates are used to estimate VMT for motor-gasoline driven vehicles and LPG-powered vehicles on Minnesota roads.

The percent distribution of observed VMT by year of manufacture for heavy duty gasoline driven trucks (HDGTs) and LPG-powered heavy trucks is from *VIUS*, and for the last year for which estimates were available. The data sources used to estimate light-duty vehicle VMT were discussed above. For inventory years for which data on vehicle distributions by age are lacking, the data for nearby years are interpolated. Minnesota-specific data are used for vehicle distributions by age, from Census Bureau, *National Household Transportation Survey/National Personal Transportation Survey*. All E85 use is ascribed to light-duty vehicles. For any year between 2002 and 2010, E85 consumption is equal to the incremental increase in E85 in that year over the preceding year. Use of E85 for all prior years is passed forward. VMT in flex fuel vehicles (FFVs) combusting E85 equal total fuel use divided by fuel economy. Estimated FFV fuel economy includes an assumed 2 percent engine efficiency improvement over conventional motor gasoline-powered internal combustion engines (ICEs).

All motorcycles are gasoline-powered. For these, a single rate of annual VMT accumulation is used irrespective of motorcycle age. This is taken from Bureau of Transportation Statistics, *National Transportation Statistics*.

Finally, in the MPCA GHG Emission Inventory, all calculated LDV VMT totals are 'trued' back to observed totals. Calculated totals for VMT for all categories of light-duty vehicles and motorcycles are summed and re-expressed as a percent of the total. Within categories, calculated VMT by model year (or vehicle age) are similarly summed and re-expressed as a percent of the total. From observations, total VMT for light-duty vehicles and motorcycles equal total observed statewide VMT less observed VMT for HDVs from MDOT reporting. Using the percentage distributions of modeled LDV VMT by vehicle category and, within categories, by vehicle age, observed LDV VMT totals are distributed back to light-duty vehicles by vehicle type, fuel and model year or vehicle age. All emission estimates are generated using these 'trued' distributions.

Off-highway sources of emissions sources include: lake freighters, barges, marine craft, railroad locomotives, aircraft, off-highway military equipment and various miscellaneous off-highway sources.

Off-highway emissions from combustion are based on fuel throughput and conventional fuel-based emission factors. Emission factors for are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Data on fuel throughput derives from: FHA, *Highway Statistics*, Minnesota Department of Revenue, *Petroleum Annual Reports*, and EIA, *Fuel Oil and Kerosene Sales*.

E10 is used in recreational marine craft and in miscellaneous off-highway equipment. Motor gasoline use in recreational marine craft and miscellaneous off-highway equipment is a calculated value based on reported off-highway E10 consumption and fuel volumetric mixes. Diesel fuel oil uses in rail, barge and freighter applications are assumed to be pure diesel fuel oil. All jet fuel is kerosene-based jet fuel.

Noncombustion process emissions sources include: lubricants and tire wear. Emissions for lubricant use are based on an average consumption of lubricants per light duty vehicle of 0.25 quarts per 1,000 VMT. Emissions are in the form of CO_2, as is the case in tire wear. Emissions from tire wear are based on the average annual emission per tire given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* and the estimated number of tires on vehicles traversing Minnesota's roadways annually. Data on the light-duty and bus fleet based in Minnesota are from: FHA, *Highway Statistics*, MDPS, *Minnesota Motor Vehicle Crash Facts*, and Minnesota DOT, *Annual Transit Report*. The number of HDDTs operating in Minnesota is equal, on an HDDT-equivalent basis, to total HDDT VMT divided by the average annual rate of VMT accumulation. Annual VMT accumulation is from *VIUS*, the most recent year available, as is the estimated number of HDGTs operating in Minnesota.

The following number of tires is assumed for each vehicle type: passenger car and light-duty truck – 4; motorcycle – 2; HDGT – 6; LPG-powered heavy-duty truck – 6; HDDT – 10; school bus – 6; and transit bus – 8.

Attribution of Emissions to Vehicle type

As noted above, CO_2 emissions from motor gasoline use in highway vehicles are calculated from statewide fuel use totals annually reported in FHA, *Highway Statistics*. In those totals, fuel use is not disaggregated by vehicle type, with the result that, using only this approach, historic and present-day CO_2 emissions are not broken down by vehicle type.

In the MPCA GHG Emission Inventory, a modeling approach is taken to the attribution of motor gasoline consumption and emissions to vehicles by vehicle type. For any vehicle type, fuel use equals VMT divided by fuel economy. Schedules of VMT accumulation, by vehicle type, fuel type and age are available from the effort to inventory CH_4 and N_2O emissions from light-duty vehicles and HDVs. The same is true of on-road fuel economy. Combining the two, schedules of motor gasoline use are developed by vehicle type and vehicle age for each gasoline-powered vehicle type (passenger cars, light-duty trucks, motorcycles, heavy-duty gasoline trucks, school buses) and totaled across model years and vehicle types. Converted to a percentage basis, these modeling data are applied to FHA motor gasoline totals to generate a bottom-up distribution of motor gasoline use by vehicle type, engine type and vehicle age.

Fossil CO_2 emissions are the product of fuel throughput, adjusted for biofuels content, and fuel specific emission factors. Using the fuel apportionment, end use totals are developed for CO_2 emissions. Total emissions by end use or vehicle type equal total fossil CO_2 emissions by vehicle type plus emissions of CH_4 and N_2O by vehicle type.

The fuel use totals reported in *Highway Statistics* are based on annually reported gasoline tax receipts. Use of these data, essentially as a second stable reference point (after state-level VMT totals), prevents the disaggregated fuel totals in the inventory from wandering from true totals. FHA-reported VMT of heavy-duty commercial trucks performs a similar function in firmly tying inventory totals for vehicle miles traveled for HDVs and LDVs (total VMT less HDV VMTs) to observations.

Historic Emissions and Energy Use

Table T-1 above showed transportation sector emissions for selected years back to 1990 by end-use. Figure T-1 shows the same data, along with that for intervening years, graphically. Light-duty highway vehicles account for about two-thirds of emissions, heavy-duty highway vehicles (HDVs) about one-fifth, and aviation, about 10 percent. Emissions from transportation peaked in 2005 at about 38.3 million CO_2-equivalent tons and as of 2010 had declined about 10 percent from peak levels. Between 2005 and 2010, emissions from light-duty vehicles declined 1.8 million CO_2-equivalent tons, accounting for about half of the 10 percent reduction in overall sector emissions evident in Figure T-1. Of the rest, about two-thirds resulted from declining emissions in aviation, the rest from declining emissions from heavy-duty vehicles.

Between 2005 and 2010, light-duty vehicles highway VMT declined about 1 percent. By contrast, On-road fuel economy by light-duty vehicles increased about 5 percent, making fuel improvements the largest single factor behind declining emissions, 2005-2010. LDV emissions declined about 8 percent, 2005-2010. Over the same period, aviation emissions declined about 30 percent, largely as a result of declining enplanements at Minnesota airports (-15 percent) and declining energy intensity of passenger travel (-10 percent).

Transportation sector on-site fuel use is shown in Table T-2 for selected years by fuel and by vehicle type and transport mode. Transportation fuel is overwhelmingly petroleum-based. As of 2010, only about 6 percent of transportation fuel was renewable fuel. Transportation fuel use declined about 9 percent between 2005 and 2010, having in the prior time segment, 1990-2005, increased by more than one-third. Between 2005 and 2010, fuel use in transportation fell at an average annual rate of about 1.7 percent.

By vehicle type and mode, fuel use in light-duty vehicles declined about 6 percent between 2005 and 2010, as did fuel use in heavy-duty vehicles. The corresponding reduction in aviation was 30 percent. The use of renewable fuels increased 13 percent, growing at an average annual rate of 2.5 percent per year, 2005-2010. This is, however, substantially down from the 5 percent per year rate increase realized between 2000 and 2005.

Figure T-1. Minnesota Transportation Sector Greenhouse Gases

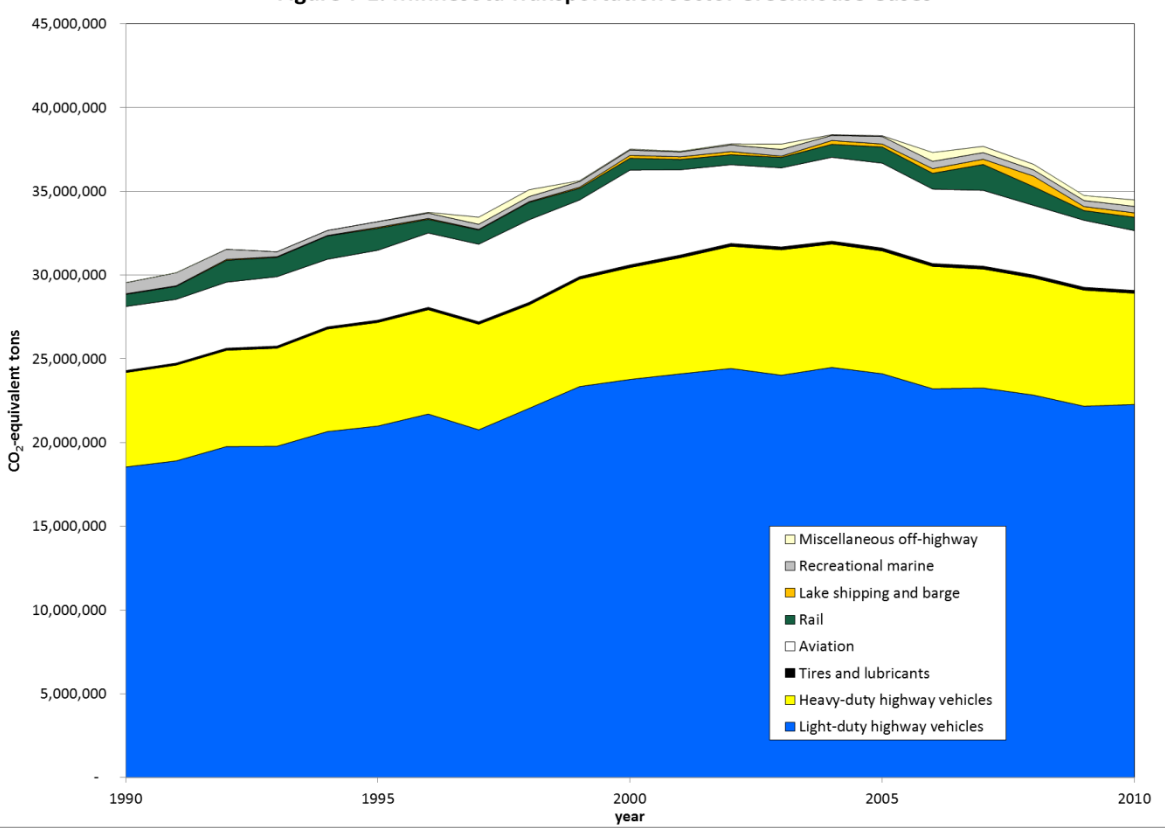


Table T-2. Minnesota Transportation Fuel Use (million MMBtu)

	1990	1995	2000	2005	2010
Coal	-	-	-	-	-
Oil	361.72	404.01	458.64	472.54	429.44
Natural gas	-	0.03	0.06	0.02	0.01
Other	1.76	12.05	17.36	22.34	25.31
subtotal	363.48	416.08	476.06	494.90	454.77
by vehicle type or mode:					
Light-duty highway vehicles	227.24	264.71	305.47	318.52	299.40
Heavy-duty highway vehicles	69.55	76.75	82.72	90.87	85.62
Lubricants	1.29	1.52	1.74	1.91	1.88
Rail	8.75	15.91	8.61	11.72	9.69
Lake shipping and barge	0.49	0.74	2.05	2.17	3.18
Recreational marine	8.37	4.47	4.23	6.03	5.23
Military	0.17	0.04	0.07	0.02	0.04
Miscellaneous off-highway	-	-	0.69	0.60	5.31
Aviation	47.62	51.95	70.47	63.06	44.43
Total	363.48	416.08	476.06	494.90	454.77
LDV mpg (gasoline-equivalent)	19.61	19.88	19.69	20.84	21.84

On-road LDV fuel economy increased from 19.88 mpg in 1995 to 20.84 mpg in 2005 and 21.84 mpg in 2010, values that agree well with estimates for on-road mpg reported at the national level by Bureau of Transportation Statistics, *National Transportation Statistics* (19.58, 20.18 and 21.57 mpg in 1995, 2005 and 2010, respectively). Modeled new on-road light-duty vehicle fuel economy for 2010 was 26.24 mpg.

Finally, it might be reiterated that, due to time and resource constraints, it was decided not to treat emissions from mobile air conditioning, on-road refrigerated trucks, and natural gas transmission and distribution pipelines. Between 2000 and 2010, annual emissions from these sources fell into a range of about 2.75 to 3.25 million CO_2-equivalents, peaking in 2005 and declining about 10 percent between 2005 and 2010.

Documentation

Full documentation of the sources and methods used to develop the transportation sector inventory is included in Appendix E of P. Ciborowski and A. Claflin, "Greenhouse Gas Emissions in Minnesota: 1970-2008: Second Biennial Progress Report – Technical Support Document" (2012).

Forecast methods

The forecast was developed using the same sector boundaries that underlie the sector inventory. The transportation sector consists of on-road vehicles, rail locomotives, vessels, boats, aircraft, and pipelines that are used to transport people and goods. Greenhouse gas emissions from transportation sources typically are on-site combustion emissions associated with energy use, but may also include some non-combustion 'process emissions.' Due to time and resource constraints, it was decided not to treat most noncombustion sources like mobile air conditioning, on-road refrigerated trucks, and natural gas transmission and distribution pipelines. Pipeline combustion emissions also were not treated in the forecast period.

With one notable exception, emissions occur exclusively within the boundaries of the state. Aviation emissions include all emissions associated with fuel purchased in Minnesota. Off-site emissions resulting from the generation of grid-based electric power, regardless of end-use, are treated as electric power sector emissions. Light-rail transit cars are powered by electricity drawn from the grid, as are plug-in electric vehicles.

The transportation sector emissions forecast is shown in Table T-3 for selected years by fuel type and noncombustion process emission type in CO_2-equivalent short tons. Emissions in the forecast decline by 3.33 million CO_2-equivalent tons or 10 percent, 2010-2030. Over the forecast period, 2010-2030, emissions from light-duty vehicles decline by 5.96 million CO_2-equivalent tons, or 27 percent. Partially offsetting this are increased emissions from heavy-duty vehicles and aviation. Emissions from heavy-duty trucks and buses increase in the forecast by 1.54 million CO_2-equivalent tons or 23 percent between 2010 and forecast year 2030. Emissions from aviation increase 1.25 million CO_2-equivalent tons or 35 percent from 2010 levels. Emissions from all other sources decline 0.15 million CO_2-equivalent tons over the forecast period.

Table T-3. Forecasted Emissions from Minnesota's Transportation Sector (million CO_2-equivalent short tons)

	2011	2015	2020	2025	2030
Coal	-	-	-	-	-
Oil	34.04	33.38	32.75	31.92	30.99
Natural gas	0.03	0.05	0.05	0.07	0.14
Other	0.05	0.02	0.02	0.02	0.02
subtotal	34.12	33.45	32.82	32.01	31.15
Tires	0.01	0.01	0.01	0.01	0.02
Total	34.14	33.47	32.84	32.02	31.17
by vehicle type or mode:					
Light-duty highway vehicles	22.08	20.31	18.94	17.51	16.32
Heavy- and medium-duty highway vehicles	6.85	7.40	7.79	8.12	8.18
Tires and lubricants	0.17	0.17	0.18	0.19	0.19
Rail	0.79	0.84	0.84	0.86	0.84
Lake shipping and barge	0.13	0.28	0.26	0.25	0.23
Recreational marine	0.33	0.38	0.38	0.38	0.38
Military	0.00	0.00	0.00	0.00	0.00
Miscellaneous off-highway	0.22	0.21	0.21	0.21	0.21
Aviation	3.58	3.88	4.23	4.52	4.82
Total	34.14	33.47	32.84	32.02	31.17

Emissions from highway and off-highway sources were forecast separately. Emissions of CO_2 from highway sources were forecast from a schedule of statewide VMT growing 0.85 percent per year annually and forecast trends in per mile energy intensity of travel out to 2030 taken from EIA, *Annual Energy Outlook 2014* (*AEO 2014*). For each forecast year, total VMT was forecast. VMT was distributed to vehicles by vehicle type and fuel-type or energy source using forecast information given in *EIA AEO 2014*. Energy use equals VMT divided by btu per VMT. Using forecast per mile energy intensity of travel, again from *AEO 2014* and again by vehicle type and fuel-type or energy source, forecast on-road energy use was calculated. This was distributed among fuel components, in the case of vehicles using E10, E85, B5 or B7.5, and by fuel in the case of bi-fuel vehicles. Emissions of CO_2 from fossil fuel sources were calculated from fuel totals using conventional fuel-based emission factors from EPA*, Inventory of US Greenhouse Gas Emissions and Sinks*.

Highway or on-road emissions of N_2O and CH_4 were forecast from forecast statewide VMT, by vehicle type, and per mile emission rates, again by vehicle type, developed from data in the MPCA GHG Emission Inventory database.

The average annual rate of increase in future statewide VMT was selected by experts representing the Minnesota Department of Transportation, the Metropolitan Council and the Minnesota Pollution Control Agency. The rate in fact is the weighted composite of two separate rates for light-duty vehicles (0.8 percent per year) and for heavy-duty commercial trucks (1.5 percent per year). The rate was chosen to reflect a low VMT growth future. Between 2004 and 2013 state-level VMT flattened or slightly declined, by 0.3 percent, after a decade and a half (1990-2003) of statewide VMT growth of 2.75 percent per year. The rate is somewhat higher than the rate used in the 2007/2008 MCCAG process (0.8 percent per year), but lower than EIA average annual rate of increase given in *Annual Energy Outlook 2014* (1.1 percent per year). The rate was first applied in the forecast in forecast year 2014. Since statewide VMT were known for 2011-2013, observed levels of statewide VMT were used for these forecast years.

Statewide VMT was distributed to light-duty vehicles and to medium- and heavy-duty vehicles using present-day percentage distributions of VMT in Minnesota by vehicle class and the expected change in these distributions, as developed at the national level by EIA. Using the percentage distributions of LDV VMT in *AEO 2014*, LDV VMT was then distributed to specific classes of light-duty vehicles by engine type and fuel. Medium-duty vehicle (MDV) and HDV VMT were similarly distributed by size (MDV, HDV) and fuel, using the same approach. A single manual adjustment was introduced to resulting VMT distribution; after consultation with experts at the Minnesota Department of Agriculture, it was decided to freeze forecast light-duty flex fuel vehicle (FFV) VMT at present levels. It was felt that, absent such a freeze, ethanol consumption in FFVs in the forecast grew too rapidly to levels possibly unsustainable in the market.

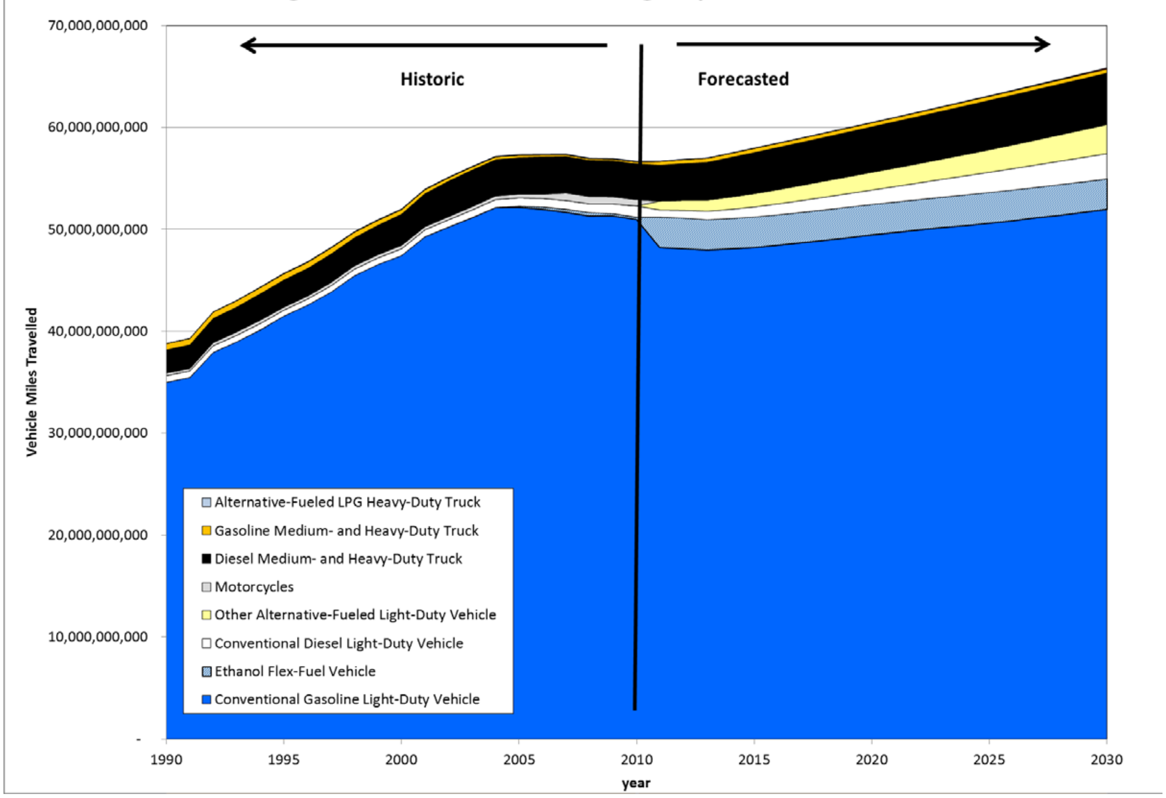
In Table T-4 are listed the classes of LDVs, MDVs and HDVs to which in the forecast statewide forecast VMT were distributed, including many alternative fuel vehicles (AFVs). The capture of a growing segment of the LDV markets by alternative fuel vehicles, including FFVs, is one of the more significant developments in transportation in recent years. Among the FFVs listed in Table T-4 are plug-in electric vehicles (PHEV). As noted above, for reasons of sector boundaries, grid-based emissions from PHEVs are not treated in the transportation forecast. PHEVs are treated to the degree that PHEV VMT is included in sector totals.

Figure T-2 shows graphically the forecasted trend in statewide VMT by vehicle type, as well as historical trends. Several things are of note. The trend in LDV VMT is discontinuous around 2010. With the exception of FFVs, the MPCA GHG emission inventory does not break the LDV fleet into conventional internal combustion engine-based vehicles (ICE) and AFVs parts and, to the degree that it does treat FFVs, it inventories only the E85 part of FFV VMT. Most fuel consumption in FFVs is in the form of E10, despite the dual fuel capability of the vehicles. Also of note in Figure T-2 is the increase, from 2011 levels, of VMT for all classes of vehicles other than FFVs. VMT for conventional diesel ICEs increase 2.6-fold in the forecast, those for medium- and heavy-duty diesel vehicles 43 percent. Medium- and heavy-duty diesel vehicles are mainly commercial trucks, but also include buses.

Table T-4. Vehicle Types Included in the Emissions Forecast

Light-duty vehicles	**Light-duty vehicles (cont)**
Conventional gasoline ICE	LPG bi-fuel
Conventional diesel ICE	Hydrogen fuel cell
Ethanol flex fuel ICE	**Medium-duty vehicles**
Gasoline-electric hybrid	Diesel
Diesel-electric hybrid	Gasoline
Electric vehicle 100 mile	LPG
Electric vehicle 200 mile	CNG
Plug-in hybrid PHEV10	**Heavy-duty vehicles**
Plug-in hybrid PHEV40	diesel
Natural gas ICE	gasoline
LPG ICE	LPG
Natural gas bi-fuel	CNG

Figure T-2. Historic and Forecasted Highway Vehicle Miles Travelled



Conventional gasoline ICE VMT increase in the forecast by about 8 percent, 2011-2030. Forecast VMT that would otherwise have accrued to FFVs were, with the decision to cap FFV VMT at current levels, diverted to gasoline ICEs, explaining some of the growth over the forecast period.

LDV energy use intensity, expressed in btu/VMT, was taken directly from *AEO 2014* with no modification. This is across all engine types and fuels and forecast years. A single schedule of energy intensity was developed for the forecast period for diesel-powered MDVs and HDVs. Present-day average fuel use intensity was calculated from the data in MPCA's GHG Emission Inventory, and using the percent decline in fuel intensity from 2011 levels given in *AEO 2014* for this class of vehicle by forecast year, a schedule of expected average on-road HDV fuel economy was developed out to 2030 for Minnesota heavy-duty vehicles. A similar procedure was followed in the case of gasoline-powered MDTs and HDTs and LPG-powered MDTs and HDTs.

The vehicle energy intensity estimates given in *AEO 2014* are estimates, at the national level, of the average on-road energy intensity of highway vehicles. Built into these estimates are the effects of the 2010 and 2011 CAFÉ standards for light-duty vehicles and medium- and heavy-duty trucks. Also built into these estimates is a roughly 15 percent gap between CAFÉ-rated fuel economy and actual on-road performance of new vehicles. Since, under CAFÉ, the energy intensity of light-duty vehicles is expected by 2030 to decline by one-third, the 2011 and 2012 CAFÉ standards are the single most important determinant of emissions from highway vehicles.

Under Minnesota state statute, each gallon of motor fuel sold in the state must be blended with a certain percentage of biofuels, either ethanol, in the case of gasoline blends, or biodiesel, in the case of diesel blends. Currently, motor gasoline sold in the state is by volume a mix of 90 percent gasoline and 10 percent ethanol. For diesel fuel oil, the prevailing blend is 95 percent diesel and 5 percent biodiesel, increasing to 7.5 percent in 2015. It was jointly decided by staff of the Minnesota Pollution Control Agency, the Minnesota Department of Agriculture and the Minnesota Department of Transportation to leave mandate levels for ethanol unchanged from present levels throughout the forecast period and biodiesel levels, once they attain 7.5 percent, at 2015 7.5 percent levels. In apportioning energy use to fuels, in the case of motor gasoline mixed with 10 percent ethanol (E10), 93 percent of the energy content of E10 was apportioned to gasoline and 7 percent to ethanol. For diesel fuel mixed with 7.5 percent biodiesel 93.1 percent of the energy content of B7.5 was apportioned to diesel and 6.9 percent to biodiesel.

AEO 2014 provides forecasts at the national level of total E85 use and total fuel use in FFVs, both in MMBtu-equivalents. Total energy use in FFVs in forecast years 2017-2030 was apportioned to E85 and E10 using the *AEO 2014* forecast ratio at the national level of total E85 use, expressed in units of energy, to total FFV fuel use, again expressed as energy. For 2012 and 2013 ethanol use in FFVs, historic data was used. For 2014-2016, a 3-year, 2011-2013, average was used for E85 consumption in FFVs. Using the AEO apportionment method described above, until 2017 or 2018, forecast E85 usage in FFVs is at levels that are well below historic levels of E85 consumption in the state back to 2006 or so, almost certainly an unreasonable result for these forecast years.

In apportioning energy use to fuels, in the case of motor gasoline mixed with 85 percent ethanol (E85), 20.9 percent of the energy content of E85 was apportioned to gasoline and 79.2 percent to ethanol.

Natural gas bi-fuel light vehicles can run on compressed natural gas or E10. LPG bi-fuel light-duty vehicles are designed to run on either LPG or E10. As in the case of FFVs, *AEO 2014* provides forecasts at the national level of, in the case of natural gas bi-fuel vehicles, total compressed natural gas (CNG) use and total fuel use in natural gas bi-fuel vehicles, and, in the case of LPG bi-fuel vehicles, total LPG use and total fuel use in LPG bi-fuel vehicles. Total energy use in bi-fuel vehicles was apportioned to CNG and E10, in the case of natural gas bi-fuel vehicles, and to LPG and E10, in the case of LPG bi-fuel vehicles, using these ratios. Electricity use in PHEVs was taken from Argonne National Laboratory, *Wells to Wheels of Energy Use and Greenhouse Gas Emission of Plug-in Hybrid Electric Vehicles*.

As noted above, forecast emissions of CO_2 were calculated from forecasted fuel totals using conventional fuel-based emission factors from EPA, *Inventory of US Greenhouse Gas Emissions and* Sinks and IPCC, 2006 *IPCC Guidelines for National Inventorie*s. Emissions of CH_4 and N_2O were calculated from forecast VMT by vehicle type and emission factors unique to vehicle types and fuel types. Emissions from alternative fuel light-duty vehicles were calculated using point estimates for emissions per VMT taken from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Based on the data in the MPCA GHG Emission Inventory database, between 2000 and 2010, emissions per mile of N_2O and CH_4 from conventional gasoline ICE LDVs declined at an average annual rate of 11.5 and 9 percent, respectively. Average per mile emission rates are assumed in the forecast to continue to decline, in the case of N_2O, asymptoting by 2025 to a level of 0.005 CO_2-equivalent lbs. per mile and, in the case of CH_4, asymptoting by 2025 to a level of 0.0005 CO_2-equivalent lbs. per mile

For conventional diesel ICE LDVs, no systematic trend is evident in the emission rate data in the MPCA GHG emission inventory database. The same is true for emission rates for heavy-duty diesel trucks Emission factors for these vehicle types were set at 10-year, 2000-2010 average per mile rates. Little trend is evident in the emission rate data for CH_4 from LPG-powered heavy trucks. A linear trend downward in emissions per mile traveled is, however, evident in the emission rate data for N_2O from LPG-powered heavy trucks. Emission factors for CH_4 for LPG-powered heavy trucks were set at the 10-year, 2000-2010, average per mile rates. N_2O Emission rates for LPG were allowed to decline linearly throughout the forecast period, using the 10-year 2000-2010 average rate of decline in the data. Lastly, based on the data in the MPCA GHG Emission Inventory database, between 2000 and 2010, emissions per mile of N_2O and CH_4 from gasoline-powered heavy-duty trucks declined at annual rates of 2.5 and 8.5 percent per year, respectively. Average per mile emission rates for gasoline HDVs are assumed in the forecast to continue to decline, in the case of N_2O, asymptoting by 2020 to a level of 0.04 CO_2-equivalent lbs. per mile and, in the case of CH_4, asymptoting by 2020 to a level of 0.004 CO_2-equivalent lbs. per mile

Off-highway emission sources include: aircraft, rail locomotives, lake freighters, barges, recreational marine craft, off-highway military vehicles, and miscellaneous off-highway equipment and vehicles not treated elsewhere. Emissions from rail locomotives and river barges and lake freighters were projected from projected fuel use in rail and marine applications. Present fuel use in Minnesota in rail and maritime uses was represented by a five-year, 2006-2010, average. Using the average annual rates of change in fuel use in rail and marine applications given in *AEO 2014* for the West North Central region, present levels of fuel use were grown out to 2030, and in the case of fuel used in barge and lake freighters, fuel use was apportioned to fuels using the historical 2003-2011 apportionment. Forecast emissions were calculated using fuel-based emission factors from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*.

Most emissions from aviation (90 percent or greater) are from commercial aviation. Emissions from commercial aviation were projected from forecast enplanements at airports located in Minnesota, given in Federal Aviation Administration (FAA), *Terminal Area Forecast (TAF)*, forecast average trip length on commercial flights, from FAA, *Aerospace Forecast, FY 2014-2034*, and forecast per passenger-mile energy intensity of commercial air travel. Forecast average trip lengths are given in FAA, *Aerospace Forecasts* at the national level by type of air carrier (domestic, international, and regional). FAA *TAF* gives enplanement forecasts for regional airlines and domestic and international air carriers. Enplanements were apportioned to international and domestic flights using the historic data from FAA *Form T-100*.

Per passenger-mile energy intensity is a calculated value developed from forecast data for seat miles of air travel per gallon of jet fuel and load factor, both by air carrier type, from *AEO 2014*. Using these data, average annual rates of decline in per passenger-mile energy use were calculated for the forecast period and applied to observed base year per passenger-mile rates of energy intensity from Bureau of Transportation Statistics, *National Transportation Statistics*. Data for 2010 from BTS were used for the base year.

Forecasted fuel use in commercial aviation is the product of enplanements, average trip length, and the energy intensity of air travel in commercial aviation per passenger mile, in each case by air carrier type. All fuel use is assumed to be kerosene-based jet fuel. Forecast emissions are calculated on the basis of annual fuel throughput.

Over the forecast period, enplanements increase about 40 percent, trip lengths increase 5 to 10 percent, while the intensity of air travel per passenger mile declines about 8 percent, leading to a 38 percent overall increase in energy use by air carriers. Of the forecasted decline in energy intensity of air travel, most is the result of declining energy use per seat-mile, and only a small part the result of an increased load factor.

Forecast emissions from general aviation at Minnesota airports were also calculated from forecast fuel throughput. FAA provides forecast information statewide to 2030 and beyond on the number of general aviation take-offs from and landings at Minnesota airports. From these forecast estimates can be developed for the number of flights of general aviation aircraft originating at airports in Minnesota. Present-day average fuel use per flight is given in FAA, *General Aviation and Part 135 Activity Surveys*, albeit at a national level. Total fuel use was calculated as the product of forecasted total annual number of flight and present-day fuel use per flight. Emissions were calculated as the product of fuel throughput and fuel-based emission factors from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*.

Emissions and fuel use in military flights were similarly calculated, although, in the case of military flights, using older data on fuel use, for 1988-1992, to calculate average per flight fuel consumption rates[6]. Annual emissions in Minnesota from military operations are small, an estimated 0.05 million CO_2-equivalent tons.

No secular trend is evident in the emissions data, stretching back more than a decade, for recreational marine craft, off-highway military vehicles, or miscellaneous off-highway vehicles and equipment. Fuel consumption in these vehicles, craft and equipment was set at constant 10-year, 2002-2011 average rates throughout the forecast period. As elsewhere, emissions were calculated as the product of fuel throughput and fuel-based emission factors from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*.

Forecasted fuel use in Minnesota's transportation sector is summarized in Figure T-5 by fuel and vehicle type or transportation mode for selected years. Total on-site fuel use declines in the forecast by 39.7 million MMBtu or about 9 percent from 2010 levels by forecast year 2030. By vehicle type or transportation mode, fuel use in light-duty vehicles declines by 75.6 million MMBtu, only partially offset in the forecast by increased fuel use in heavy-duty vehicles (22.6 million MMBtu) and aviation (15.5 million MMBtu). In percentage terms, forecast fuel use in LDVs in 2030 is about 25 percent lower than in 2011. Forecast 2030 fuel use in HDTs and aviation is larger than fuel use in 2011 by 26 and 35 percent, respectively. By fuel, total biofuels use is stationary over the forecast period. By contrast, use of oil declines in the forecast by 10 percent from 2010 levels by forecast year 2030 and accounts for the entire overall decline in fuel use plus some. Overall, over the forecast period, fuel use in transportation declines at an average annual rate of 0.5 percent.

[6] These are the last years that military fuel uses could be separated from civilian uses in the Minnesota EIA fuel use data.

Table T-5. Forecasted Fuel Use in Minnesota's Transportation Sector (million MMBtu)

	2011	2015	2020	2025	2030
Coal	-	-	-	-	-
Oil	424.75	417.12	409.17	398.57	386.52
Natural gas	0.55	0.80	0.79	1.07	2.27
Other	26.55	28.64	26.98	27.11	26.29
subtotal	451.85	446.57	436.94	426.75	415.08
by vehicle type or mode:					
Light-duty highway vehicles	298.56	277.15	258.07	239.93	223.81
Heavy- and medium-duty highway vehicles	88.26	97.64	102.81	107.12	108.17
Lubricants	1.90	1.93	2.01	2.09	2.18
Rail	9.63	10.16	10.21	10.46	10.23
Lake shipping and barge	1.51	3.35	3.17	2.94	2.75
Recreational marine	4.46	5.14	5.14	5.14	5.14
Military	0.06	0.06	0.06	0.06	0.06
Miscellaneous off-highway	2.95	2.80	2.80	2.80	2.80
Aviation	44.52	48.35	52.67	56.21	59.95
Total	451.85	446.57	436.94	426.75	415.08

Process emissions include emissions from lubricating oils oxidized during engine operation and wear from tires. Emissions from tire wear are calculated on a per tire basis. Emissions were calculated assuming the same number of tires per vehicle by vehicle type as was used in assembling the historic emissions estimate for this source. For any vehicle type, the number of vehicles operating in the state in any year equals total forecast VMT for that vehicle type divided by the forecast annual rate of VMT accumulation, again for that vehicle type. Total forecast VMT were discussed above. Forecast annual VMT accumulation rates are from *AEO 2014*.

As in the historical estimates of emissions, forecast emissions from the consumption of lubricating oil were developed only for LDV oil use. A rate of consumption of 0.25 gallon of oil per 1000 VMT was assumed.

Sources for the data used in the forecast include:

- Argonne National Laboratory, *Wells to Wheels of Energy Use and Greenhouse Gas Emission of Plug-in Hybrid Electric Vehicles*
- Bureau of Transportation Statistics, *National Transportation Statistics*
- EIA, *Annual Energy Outlook 2014*
- EIA, *Annual Energy Outlook 2013*
- EIA, *Annual Energy Outlook 2012*
- EIA, *Fuel Oil and Kerosene Sales*
- EIA, *State Energy Data System*
- EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*
- FAA, *Terminal Area Forecast, Fiscal years 2013-2040*
- FAA, *Aerospace Forecasts FY 2014-2034*
- FAA, *General Aviation and Part 135 Survey*
- FHA, *National Household Transportation Survey*
- Minnesota Department of Transportation, *Roadway Data, Vehicle Miles Traveled*
- MPCA, *GHG Emission Inventory database*
- Oak Ridge National Laboratory, *Transportation Energy Data Book*

Detailed forecast results

The results shown above in Table T-3 for forecasted emissions are shown below in Table T-6 using a more detailed breakdown by fuel. In the forecast, transportation sector emissions decline 10 percent from 2010 levels or 3.33 million CO_2-equivalent tons. Emissions from light-duty vehicles decline 27 percent or 5.96 million CO_2-equivalent tons over the forecast period. By contrast, by 2030 forecast emissions from heavy-duty vehicles increase 23 percent from 2010 levels, by some 1.54 million CO_2-equivalent tons, and aviation emissions by 35 percent, or 1.25 million CO_2-equivalent tons. Emissions from all other sources decline 0.15 million CO_2-equivalent tons over the forecast period. Over the forecast period emissions from transportation decline at an average annual rate of 0.5 percent.

By fuel, emissions from vehicles and off-highway equipment that use E10 and E85 blends of motor gasoline decline sharply over the forecast period, by more than one-quarter. By contrast, emissions increase from vehicles and off-highway equipment that use biodiesel blends or pure diesel fuel, as in the case of rail locomotives, by about one-quarter. By forecast year 2030, forecast emissions from the use of jet fuel in aviation are one-third higher than they were in 2010. Emissions from the use of all other fuels increase in absolute terms about 0.2 million CO_2-equivalent tons over the forecast period.

The distribution of emissions changes in the forecast. In 2010, an estimated two-thirds of emissions were attributable to light-duty vehicles, one-fifth attributable to HDVs, and about one-tenth to aviation. In the forecast, by 2030, only about half of emissions are attributable to light-duty vehicles, while roughly one quarter are attributable to heavy-duty vehicles, mostly trucks, 15 percent to aviation, and 2 percent to rail.

Table T-7 shows the trend in forecasted emissions for selected years by greenhouse gas. In the forecast, emissions of fossil CO_2, the principal gas, decline 9 percent from 2010 levels by 2030, by 3.15 million CO_2-equivalent tons. Emissions of CH_4 and N_2O decline by comparatively larger percentages, 32 and 40 percent, respectively, but by small absolute amounts (0.18 million CO_2-equivalent tons). Emissions of biogenic CO_2 increase slightly over the forecast period, about 4 percent. The combustion of biofuels results in emissions of biogenic CO_2. However, since, through crop regrowth, these are rapidly removed from the atmosphere, usually within a year or two of emission, these emissions are not counted against transportation sector totals.

Table T-6. Forecasted Emissions from Minnesota's Transportation Sector (million CO_2-equivalent short tons)

	2011	2015	2020	2025	2030
Light-duty vehicles					
motor gasoline ICEs	20.14	18.37	16.87	15.46	14.24
diesel ICEs	0.40	0.49	0.61	0.76	0.86
flex fuel vehicles	1.27	1.10	1.05	0.84	0.71
other alternative fuels vehicles	0.27	0.34	0.41	0.45	0.50
Heavy-and medium-duty diesel vehicles	6.40	6.88	7.29	7.59	7.57
Other heavy- and medium-duty vehicles	0.45	0.52	0.50	0.53	0.60
Tires and lubricants	0.17	0.17	0.18	0.19	0.19
Rail	0.79	0.84	0.84	0.86	0.84
Lake shipping and barge	0.13	0.28	0.26	0.25	0.23
Recreational marine	0.33	0.38	0.38	0.38	0.38
Military	0.00	0.00	0.00	0.00	0.00
Miscellaneous off-highway	0.22	0.21	0.21	0.21	0.21
Aviation	3.58	3.88	4.23	4.52	4.82
Total	**34.14**	**33.47**	**32.84**	**32.02**	**31.17**
by fuel:					
E10	22.52	20.74	19.25	17.65	16.34
E85	0.04	0.06	0.04	0.08	0.09
B5/B7.5	6.81	7.37	7.91	8.35	8.45
B0 (diesel fuel oil, no biodiesel)	0.84	0.96	0.95	0.97	0.84
LPG	0.07	0.07	0.06	0.07	0.08
CNG	0.03	0.05	0.05	0.07	0.14
Residual fuel oil	0.08	0.16	0.15	0.14	0.23
Jet fuel	3.53	3.84	4.19	4.47	4.77
Aviation gasoline	0.05	0.04	0.04	0.05	0.05
Lubricants and tires	0.17	0.17	0.18	0.19	0.19
Total	**34.14**	**33.47**	**32.84**	**32.02**	**31.17**

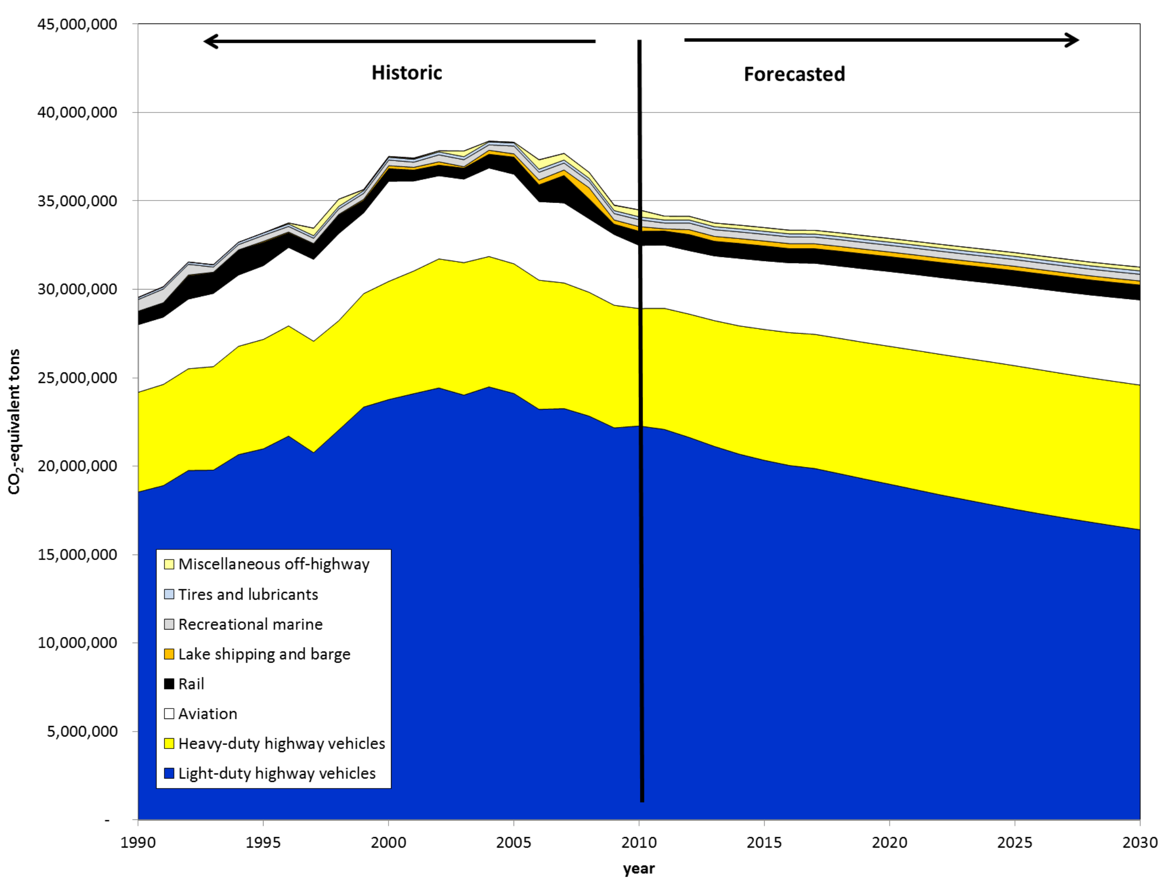
Table T-7. Forecasted Emissions from Minnesota's Transportation Sector by Gas (million CO_2-equivalent short tons)

	2011	2015	2020	2025	2030
CO_2	33.71	33.16	32.56	31.76	30.89
CH_4	0.04	0.03	0.03	0.03	0.03
N_2O	0.39	0.28	0.25	0.23	0.25
Total	34.14	33.47	32.84	32.02	31.17
Biogenic CO_2	2.01	2.18	2.05	2.06	2.00
Ethanol	1.70	1.66	1.49	1.47	1.40
Biodiesel	0.31	0.52	0.56	0.59	0.60

Figure T-3 shows the forecasted trend in emissions graphically. Emissions, which had peaked in 2004, decline linearly throughout the forecast period. As noted above, in the forecast, emissions from light-duty vehicles fall by 27 percent from 2010 levels by forecast year 2030, continuing a pattern of decline that began in 2004. The decline in emissions from light-duty vehicles results principally from the penetration into the light-duty highway vehicle fleet of substantial fuel efficiency improvements. Over the forecast period, the average energy intensity of light-duty vehicles, expressed on a btu/mile basis, declines more than 50 percent. This more than offsets the effects of the forecasted 15 percent increase in light-duty vehicle travel, 2010-2030.

Increased emissions from heavy-duty trucks and aviation offset about half of the reductions forecasted for light-duty vehicles at 2030. As noted above, and is evident in Figure T-3, by 2030 nearly half of all forecast emissions from the transportation sector are HDV and aviation emissions, up from about one-third presently. Of the increase in HDV emissions in the forecast, most can be traced to a large forecasted increase in heavy-duty vehicle VMT, about 40 percent by 2030, that is only partially offset in the forecast by a 15 percent improvement in vehicle fuel economy. A large projected increase in enplanements explains most of the forecasted increase in aviation emissions.

Figure T-3. Historic and Forecasted Greenhouse Gas Emissions from Transportation



Projected fuel use is shown in Table T-8 for selected years by vehicle type and by fuel type and fuel blend. In the forecast, total fuel use in transportation declines 9 percent, 2010-2030. Fuel use in light-duty vehicles declines in the forecast by 25 percent, some 75.6 million MMBtu, offset by a 26 percent increase in fuel use in heavy-duty trucks (22.6 million MMBtu) and a forecast 35 percent increase in aviation (15.5 million MMBtu).

Table T-8. Forecasted Fuel Use in Minnesota's Transportation Sector (million MMBtu)

	2011	2015	2020	2025	2030
Light-duty vehicles					
motor gasoline ICEs	271.34	248.90	228.75	209.90	193.14
diesel ICEs	5.18	6.43	8.09	9.97	11.33
flex fuel vehicles	18.40	17.11	15.66	13.94	12.48
other alternative fuels vehicles	3.64	4.71	5.57	6.12	6.87
Heavy-and medium-duty diesel vehicles	82.24	90.61	96.01	99.87	99.71
Other heavy- and medium-duty vehicles	6.02	7.03	6.80	7.25	8.46
Lubricants	1.90	1.93	2.01	2.09	2.18
Rail	9.63	10.16	10.21	10.46	10.23
Lake shipping and barge	1.51	3.35	3.17	2.94	2.75
Recreational marine	4.46	5.14	5.14	5.14	5.14
Military	0.06	0.06	0.06	0.06	0.06
Miscellaneous off-highway	2.95	2.80	2.80	2.80	2.80
Aviation	44.52	48.35	52.67	56.21	59.95
Total	**451.85**	**446.57**	**436.94**	**426.75**	**415.08**
by fuel:					
Motor gasoline	282.74	261.98	243.21	223.51	206.83
Ethanol	22.56	21.96	19.80	19.51	18.59
gasoline plus ethanol total by blend:					
E10	303.50	280.91	260.96	239.44	221.42
E85	1.79	3.03	2.05	3.58	4.00
Diesel fuel oil	93.75	102.06	108.61	114.14	114.98
Biodiesel	4.00	6.67	7.16	7.55	7.64
diesel plus biodiesel total by blend:					
B5/B7.5	87.48	97.09	104.16	109.93	111.18
diesel fuel, no biodiesel	10.27	11.63	11.61	11.76	11.44
LPG	0.97	0.94	0.91	0.98	1.05
Natural gas	0.55	0.80	0.79	1.07	2.27
Hydrogen	-	0.01	0.03	0.04	0.06
Residual fuel oil	0.87	1.87	1.77	1.64	1.54
Jet fuel	43.94	47.79	52.09	55.63	59.35
Aviation gasoline	0.58	0.56	0.57	0.58	0.60
Lubricants	1.90	1.93	2.01	2.09	2.18
subtotal	**451.85**	**446.57**	**436.94**	**426.75**	**415.08**

By fuel, the consumption of motor gasoline is forecast to decline by 2030 by 28 percent from present levels, ethanol use 13 percent. By contrast, the consumption of diesel fuel oil in transportation is projected by 2030 to increase 22 percent from present levels and biodiesel use by 93 percent. Jet fuel increases 35 percent in the forecast. By blend, use of E85 in the forecast more than doubles, while E10 use declines 27 percent by 2030. Forecast use of biodiesel blends at 2030 is about one-quarter higher than use in 2010.

As might be inferred from the above discussion, much of the forecasted change in fuel use results from a combination of fuel economy improvements and VMT growth. The use of alternative fuels plays a lesser role. In the case of ethanol use, enhanced use of E85 in the forecast acts to temper somewhat the effects of forecast declining ethanol use, as a blend component of E10, in conventional gasoline ICEs.

Figure T-4 shows the forecasted trend in transportation sector energy use graphically. The forecast trend in fuel use closely mirrors the forecast trend in GHG emissions. As noted above, the MPCA GHG emission inventory does not distinguish between conventional ICEs and alternative fuel light duty vehicles in its inventory of LDV fuel use (and emissions). Fuel use in AFVs is shown first in Figure T-4 only beginning in 2011, the first forecast year.

Figure T-4. Historic and Forecasted Energy Input to Transportation

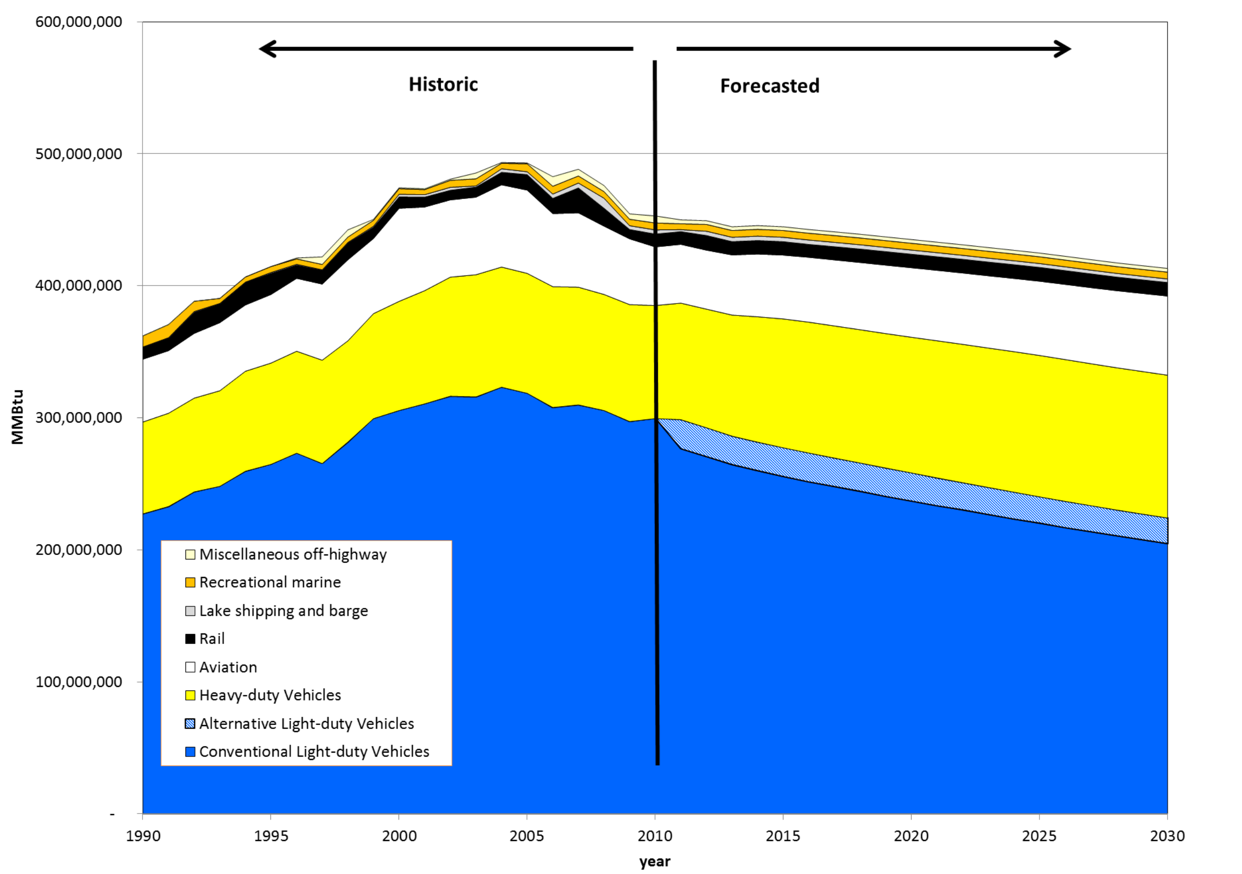


Table T-9 shows forecast trends in highway vehicle miles traveled by vehicle type and fuel. Forecast highway vehicle miles traveled at 2030 are 16 percent higher than observed 2010 levels, rising in the forecast at a rate of 0.7 percent per year, 2010-2030.[7] VMT from conventional gasoline ICEs increase in the forecast by 8 percent by forecast year 2030, while VMT from diesel ICEs and from gasoline-electric hybrids increase 2.6-fold and 2.1-fold, respectively, in the forecast, from 2010/2011 levels. Again, after consultation with experts at the Minnesota Department of Agriculture, it was decided to freeze forecast light-duty flex fuel vehicle (FFV) VMT at present levels. VMT from conventional gasoline ICEs, diesel ICEs, FFVs and gasoline-electric hybrids comprise 99 percent of total LDV vehicle-miles traveled regardless of forecast year.

VMT of other classes of LDVs grow quite impressively in percentage terms in the forecast, but, since VMT for these vehicle types is generally at very low initial levels, total VMT for these vehicles remains miniscule in the forecast out to 2030. In the forecast, VMT for electric vehicles and plug-in hybrids increase 9.3-fold and 24.4-fold, respectively from present levels by 2030. Forecast VMT for natural gas

[7] The selected average annual rate of increase for the forecast period was first applied in forecast year 2014. VMT estimates for 2011-2013 are observed totals. Between 2010 and 2013, VMT growth is an anemic 0.2 percent per year.

ICEs and bi-fuel vehicles increase 59 percent and 43 percent, respectively over the forecast period. VMT for natural gas ICEs and bi-fuel vehicles increase 98 percent and 22 percent, respectively, over the forecast period. With no 2011 VMT, hydrogen fuel cells experience essentially infinite growth over the forecast period.

Table T-9. Forecasted Highway Vehicle Miles Traveled (million)

	2011	2015	2020	2025	2030
Light-duty vehicles					
Conventional gasoline ICE	48,186.21	48,191.58	49,411.96	50,593.53	51,921.40
Conventional diesel ICE	693.58	984.70	1,427.69	1,989.77	2,482.29
Ethanol flex fuel ICE	3,011.44	3,011.44	3,011.44	3,011.44	3,011.44
Gasoline-electric hybrid	641.93	952.39	1,258.07	1,582.30	1,995.45
Diesel-electric hybrid	-	-	0.85	14.35	41.29
Electric vehicle	12.62	35.61	49.40	71.49	129.67
Plug-in hybrid	14.83	86.50	165.57	247.82	377.24
Natural gas ICE	26.16	31.70	36.32	39.40	41.65
LPG ICE	30.11	38.46	46.97	53.87	59.54
Natural gas bi-fuel	43.45	50.11	55.82	59.42	61.93
LPG bi-fuel	106.59	115.43	122.23	126.95	130.53
Hydrogen fuel cell	-	1.61	8.08	14.27	19.56
Medium-duty vehicles					
Diesel	691.09	875.37	984.49	1,077.25	1,128.19
Gasoline	279.59	341.91	339.41	344.35	340.83
LPG	6.68	9.42	13.03	17.91	22.73
CNG	7.55	7.05	6.12	7.88	9.99
Heavy-duty vehicles					
Diesel	2,835.88	3,147.15	3,466.20	3,757.05	3,911.61
Gasoline	75.43	67.93	59.99	63.59	64.79
LPG	10.35	7.69	5.82	6.09	7.00
CNG	1.53	12.97	13.30	26.82	84.91
Total	**56,675.00**	**57,969.00**	**60,482.77**	**63,105.53**	**65,842.03**

By percent, at forecast year 2030, light-duty vehicle VMTs comprise 91.5 percent of projected statewide VMT. Of these, 90 percent are in vehicles powered by conventional internal combustion engines, and of these, 95 percent are motor gasoline-powered. Of the remaining 10 percent of projected light-duty VMT, about half are forecast ethanol FFV VMT and one-third forecast gasoline-electric hybrid VMT.

About 90 percent of all forecast HDV VMT are diesel-driven VMT, again irrespective of forecast year. By 2030, VMT of diesel-powered medium-duty and heavy-duty vehicles are projected to be about 45 percent higher than the values given in the MPCA GHG emission inventory for inventory year 2010 for this class of vehicle. About three-quarters of the forecasted growth in VMTs for diesel- powered medium-duty and heavy-duty vehicles is from increasing HDV VMT.

Projected vehicle per mile-traveled energy intensity is shown is shown in Table T-10 for selected forecast years and by vehicle and engine or fuel type. Energy intensity of conventional gasoline ICEs, diesel ICEs, flex fuel vehicles, and gasoline-electric hybrids declines in the forecast 34 percent, 27 percent, 32 percent and 30 percent, respectively, between 2011 and 2030. The 2030 forecasted intensity of energy use per mile traveled for all light-duty vehicles is 34 percent lower than 2010 levels. In terms of the more familiar miles per gallon measure, average on-road fuel economy increases in the forecast from 21.8 mpg in 2010 to a projected 33.6 mpg in 2030. Due to a more rapid rate of decline in per mile energy intensity, by 2030 gasoline ICEs are a projected 13 percent more energy efficient than diesel ICEs, erasing the fuel economy advantage long enjoyed by diesel ICEs. Of the four LDV vehicle types that in the forecast dominate total vehicle miles driven—gasoline ICEs, diesel ICEs, FFVs, and gasoline-electric hybrids-- gasoline-electric hybrids are the most energy efficient, across all forecast years.

Table T-10. Forecasted On-highway Vehicle Fuel Efficiency (btu/mile)

	2011	2015	2020	2025	2030
Light-duty vehicles					
conventional gasoline ICE	5,588	5,119	4,587	4,111	3,684
conventional diesel ICE	5,386	5,104	4,772	4,462	4,172
ethanol flex fuel ICE	6,110	5,683	5,202	4,628	4,143
gasoline-electric hybrid	3,491	3,257	3,037	2,721	2,455
diesel-electric hybrid	-	-	2,518	2,135	2,074
100 mile EV	1,034	1,127	1,140	1,136	1,129
plug-in hybrid (PHEV10)	-	2,544	2,441	2,221	2,022
plug-in hybrid (PHEV40)	2,047	2,075	2,026	1,916	1,819
natural gas ICE	5,762	5,382	4,892	4,291	3,815
natural gas bi-fuel	6,505	6,031	5,444	4,771	4,227
LPG ICE	6,486	5,839	5,188	4,505	4,056
LPG bi-fuel	7,067	6,415	5,678	4,949	4,427
hydrogen fuel cell	-	3,451	3,115	3,012	2,974
commercial light-duty vehicles	8,420	7,811	6,974	6,158	5,562
Medium- and Heavy duty vehicles					
diesel	23,319	22,526	21,572	20,659	19,785
gasoline	15,299	15,172	15,013	14,857	14,702
LPG	24,765	23,556	22,127	20,785	19,525
CNG-medium	17,496	17,325	17,033	15,612	14,600
CNG-heavy-duty	22,519	21,744	21,391	21,016	20,835

The energy intensity of heavy-duty vehicles also declines in the forecast, though proportionally less. Forecast energy intensities of diesel-driven HDVs decline about 15 percent over the projection period, those for HDGTs, about 4 percent.

The forecast trend in average on-road fuel economy for LDVs and HDVs is shown in Figure T-5. Fuel economy, measured in miles per gallon, grows in the forecast at a projected average annual rate of 2.2 and 0.8 percent for light-duty vehicles and HDVs, respectively. For light-duty vehicles the increase continues unabated beyond 2030, to 2040 at least. In *AEO 2014*, by 2040, on-road mpg for light-duty vehicles increases to 37.2 mpg. The on-road performance of new LDVs, as distinct from the on-road performance of all light-duty vehicles on the road, at 2030 is a forecast 38.6 mpg, up from an estimated 25.24 mpg in 2011.[8]

[8] CAFÉ standards over the forecast period increase from 27.6 mpg at present to 46.6 mpg in 2030.

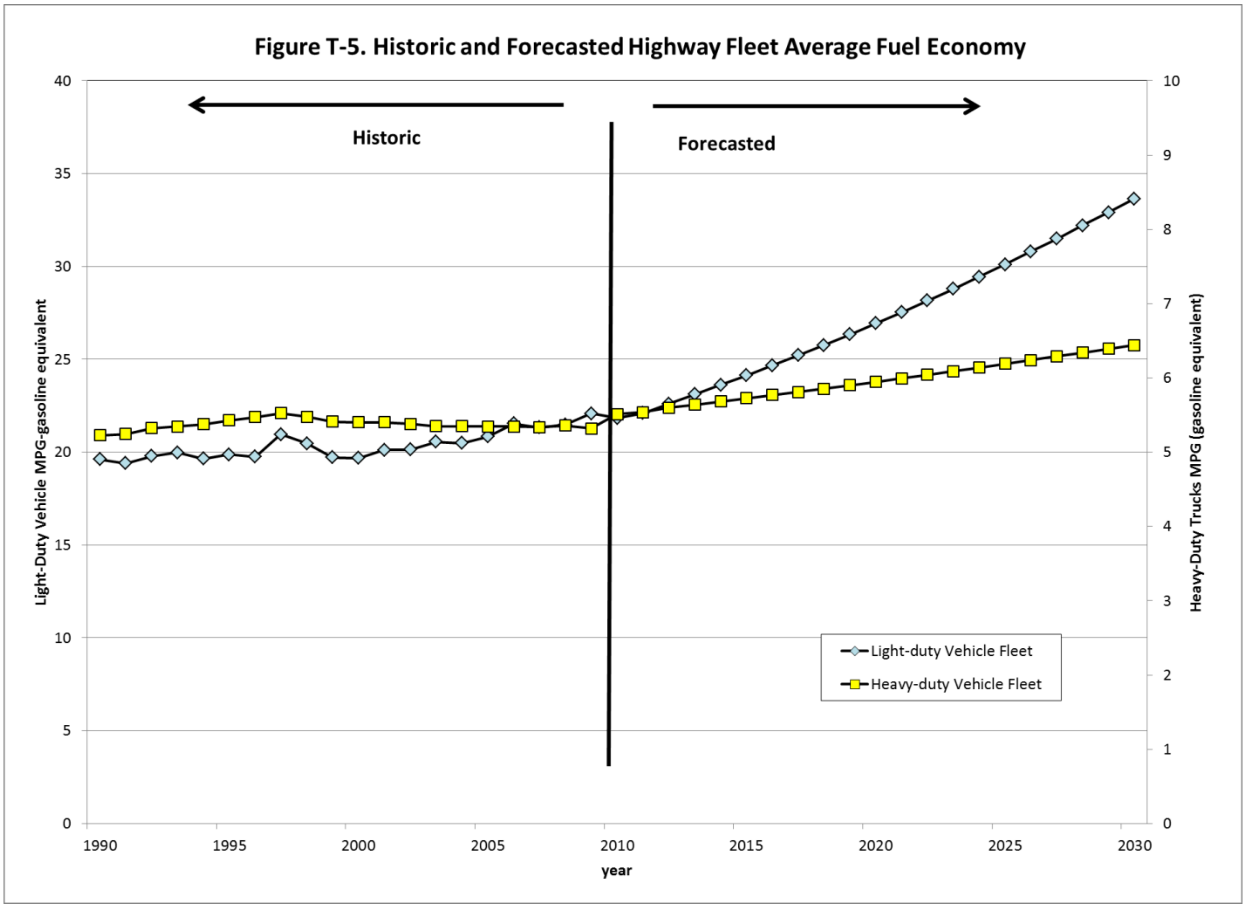
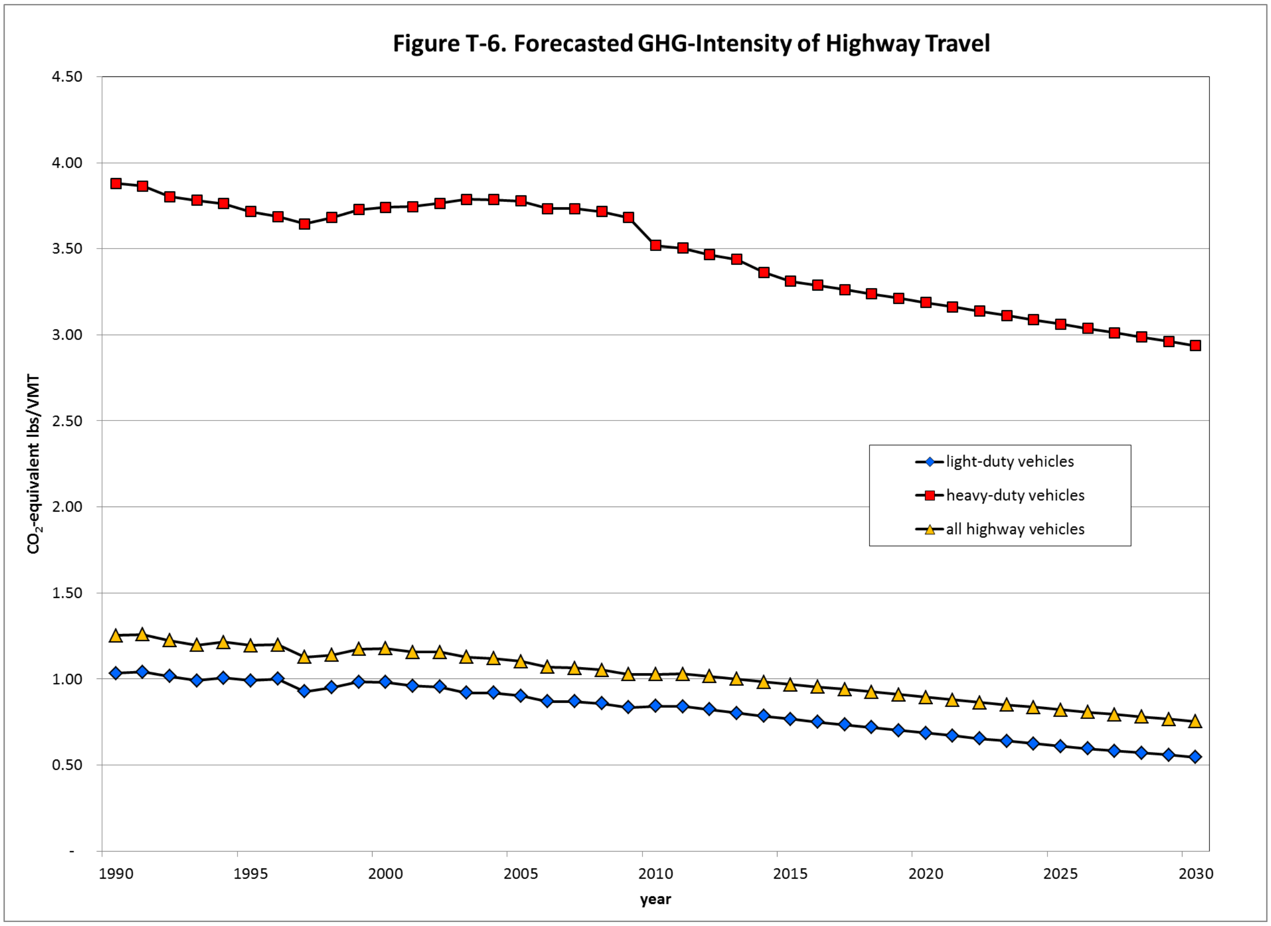


Figure T-6 shows graphically the forecast per mile rate of GHG emissions from highway transportation over the projection period. The forecasted average emission rate, in CO_2-equivalent lbs. per mile, declines linearly from about 1 lbs. per mile at present to 0.75 lbs. per mile in 2030, or 27 percent. For LDVs, the projected percentage decline is larger, about 35 percent, from about 0.85 CO_2-equivalent lbs. per mile in 2010 to about 0.58 CO_2-equivalent lbs. per mile in 2030. For HDVs the reduction is about 17 percent. Since measures designed to control GHG emissions by reducing aggregate VMT are less effective at lower levels of per mile emissions, the trends shown in Figure T-6 may be of significance for policymaking.



Forecast values for selected years for many of the essential parameters used to project aviation emissions are shown in Table T-11. As discussed above enplanements increase 40 percent in the forecast from present levels and trip lengths by 1 to 8 percent, depending on air carrier type. For domestic air carriers, energy use per passenger-mile of air travel increases in the forecast 0.5 percent per year throughout the projection period: 0.4 percent per year for regional carriers, and 0.6 percent per year for international carriers. General aviation and military operations are mostly flat over the forecast period.

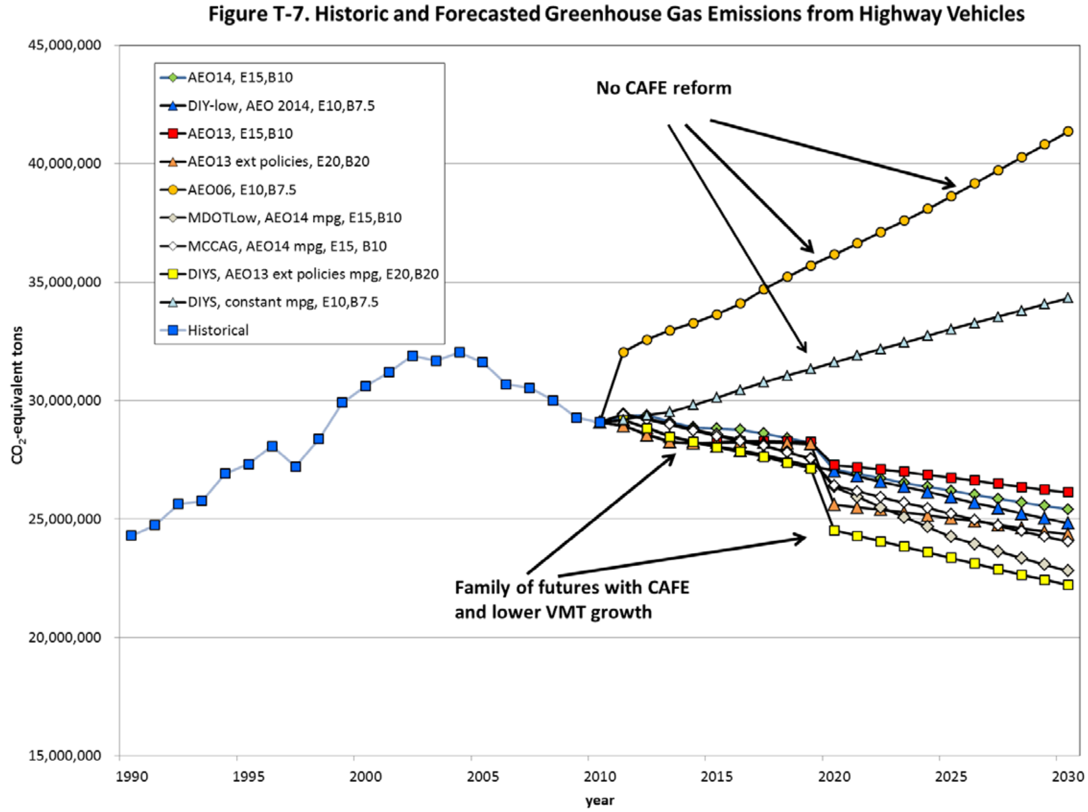
Table T-11. Aviation Indicators

	2011	2015	2020	2025	2030
Enplanements (millions)	16.17	17.54	19.42	20.99	22.69
Trip length (miles)					
domestic carrier	880	894	903	915	928
regional carrier	467	473	483	493	503
international carrier	2,993	2,949	2,976	3,004	3,013
btu/passenger-mile					
domestic carrier	2,541	2,511	2,458	2,398	2,319
regional carrier	3,609	3,570	3,517	3,446	3,359
international carrier	2,730	2,682	2,606	2,524	2,423
Generation aviation operations (millions)	1.52	1.47	1.50	1.54	1.57
Military operations	0.03	0.04	0.04	0.04	0.04
MMbtu/generation operation	2.21	2.21	2.21	2.21	2.21
MMbtu/military operation	20.55	20.55	20.55	20.55	20.55

An analysis was undertaken of the sensitivity of the forecast results to a wider array of published estimated for VMT growth, vehicle energy intensity improvement and biofuels use from *AEO 2006*, *AEO 2012*, *AEO 2013*, the Minnesota Climate Change Advisory Group (MCCAG) study, and MDOT, *Statewide Transportation Plan Update, TAC/MIC 2008*. The results of that analysis are shown in Figure T-7. DIY, an abbreviation for 'do it yourself,' identifies the base case or business-as-usual (BAU) 0.85 percent per year VMT scenario discussed above. The resulting emissions forecasts separate into two distinct families of forecasts, depending on how fuel economy improvements are treated: a family with rising emissions and a family with emissions declining at rates of 0.5 to 1 percent per year. That parameter aside, the results tightly cluster along a set of pathways of declining emissions with terminal 2030 values of 22 to 26.5 million CO_2-equivalent tons. The downward ratchet in emissions around 2020 is the effect of enhanced biofuels use, either with E15 or E20, in the case of ethanol, and B10 or B20, in the case of biodiesel. At 2030 the impact of enhanced biofuels use can be as much as 3 million CO_2-equivalent tons.

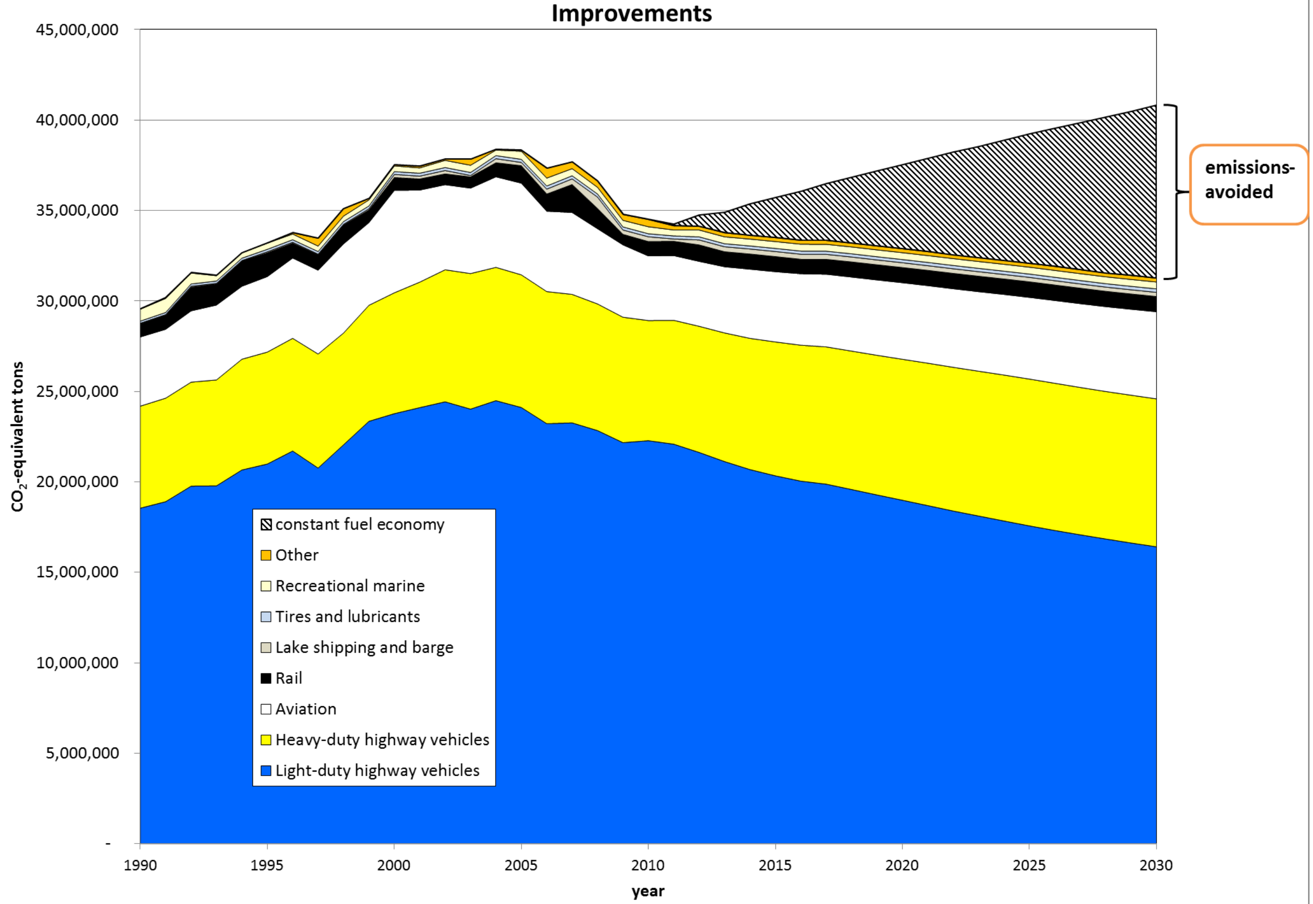
Finally, as in the case of the residential, commercial and industrial sectors, as attempt was made to assess the emission-avoidance effects of select current policies on forecasted emissions. The results of this analysis are shown in Figure T-8 with respect to the required 2010 and 2011 fuel economy improvements under CAFÉ. By 2030, modeled emissions-avoided come to about 10 million CO_2-equivlaent tons, equal to about one-third of forecasted emissions from transportation.

Figure T-7. Historic and Forecasted Greenhouse Gas Emissions from Highway Vehicles



*The initial study listed is the source of the VMT and fuel economy forecast. Where VMT growth and fuel economy improvement are taken separately from 2 different studies, a second study is listed. E10, E15, E20, B5, B7.5, B10 or B20 identifies the biofuels scenario.

Figure T-8. Forecasted GHG Emissions and Emissions-avoided from Projected Fuel Economy Improvements



Industrial sector

Sector boundaries

The industrial sector encompasses all private establishments that are engaged in mining and manufacturing activities. By Standard Industrial Classification (SIC) code or North American Industrial Classification (NAICS) code, this includes all establishments in SIC codes 10 through 30 or NAICS codes 21, 23, 31, 32 and 33. Important industrial groupings in Minnesota include iron ore mining, construction, food products, forest products, paper and pulp, ethanol, oil refining, fabricated metals, and electronic equipment and computers

Greenhouse gas (GHG) emissions from these firms are typically on-site combustion emissions associated with energy use, but may also include some non-combustion 'process emissions.' In the MPCA GHG emission inventory, on-site combustion includes both stationary combustion and, for mining and construction, off-highway mobile equipment and trucks. Also included in the industrial sector is on-site industrial wastewater treatment.

Off-site emissions result from the consumption by commercial establishments of electricity purchased from the electric grid, but in the MPCA GHG inventory, these are treated in the electric power sector. Emissions from self-generation of electric power for on-site use, with no sales to the grid, are included in industrial sector emission totals.

Minnesota is an important producer of biofuels which, when consumed out-of-state, may displace refined petroleum fuels and lead to GHG emissions reductions beyond the borders of Minnesota. In tracking present-day emissions (or forecasting future emissions), no effort is made to track emission reductions outside of Minnesota that may or may not have occurred. Some analysis is performed of the effects on in-state emissions of policies intended to reduce emissions within Minnesota. We report on the results of these analyses.

Present-day and historical emissions

Below are estimates for historical emissions from the industrial sector for selected years in million CO_2-equivalent tons. The estimates for on-site combustion-based emissions are based on fuel throughput and conventional fuel-based emission factors. Fuel throughput data derives from a number of sources, including: Energy Information Administration (EIA), *Natural Gas Annual*, EIA, *Fuel Oil and Kerosene Sales*, EIA, *State Energy Data System*, EIA *Form-906/923*, Federal Highway Administration, *Highway Statistics* and, for large industrial facilities burning bituminous or subbituminous coal, anthracite, coal coke, petroleum coke, solid resins, TDF, refinery gas, other industrial process gas, residual fuel and other heavy oil, waste oil, waste solvent, solid biomass (wood and wood waste, sawdust, bark, black liquor, wood sludge), grease, syrup, digester gas and pulp mill gas, the MPCA emission inventory. Fuel use is reported annually to the MPCA by the operators of permitted facilities on a unit-by-unit basis.

Northshore Mining generates electricity for sale to the grid. Emissions from the generation of electricity sold to the grid are reported as electric power sector emissions and are subtracted from industrial sector totals. Energy inputs to the generation of marketed electricity are calculated from annual electric sales and, in the case of the Northshore facility, average heat rates at Minnesota coal-fired generating units. Fuel use in the generation of electricity for sale to the grid is distributed to fuels proportionally to overall fuel use at the Northshore power boilers. Annual electricity sales from Northshore are reported in FERC *Form*-1 and *Minnesota Annual Electric Report*.

Table I-1. Historical Emissions from Minnesota's Industrial Sector (million CO_2-equivalent short tons)

	1990	2000	2005	2010	2011
Combustion-based Emissions					
coal	1.82	3.72	2.58	2.62	2.69
oil	3.75	4.20	5.31	4.36	4.25
natural gas	5.17	6.27	5.55	9.32	9.29
other	0.03	0.03	0.05	0.05	0.05
subtotal	**10.77**	**14.22**	**13.49**	**16.35**	**16.28**
Taconite induration (flux pellets)	2.10	2.29	1.82	1.96	2.10
DRI pellet production (reductant)	0.00	0.00	0.00	0.11	0.22
Copper production (autoclave limestone)	0.00	0.00	0.00	0.00	0.00
Oil refining (hydrogen and sulfur production, FCC)	0.91	2.12	2.07	2.50	2.59
Steelmaking	0.00	0.04	0.03	0.03	0.03
Wastewater treatment	0.12	0.15	0.17	0.18	0.18
Semiconductor manufacture	0.00	0.23	0.25	0.19	0.14
HFC/PFC solvent uses	0.00	0.05	0.03	0.03	0.03
Foam insulation manufacture	0.00	0.00	0.00	0.04	0.05
Magnesium casting	0.15	0.28	0.39	0.18	0.15
Miscellaneous process	0.53	0.45	0.32	0.32	0.30
Total	**14.58**	**19.82**	**18.57**	**21.89**	**22.06**

By statute, all diesel fuel oil sold in the state must be blended with biodiesel at a current annual rate of 5 percent by volume, rising to 7.5 percent in 2015. Annual biodiesel use by Minnesota industry is calculated from total diesel fuel oil consumption by industrial sector firms in Minnesota, as reported in EIA, *Fuel oil and Kerosene Sales*, and mandated blend levels. The same method is used to calculate annual ethanol throughput in the industrial sector. By state law, all motor gasoline sold in Minnesota must be blended with 10 percent ethanol by volume. Reported motor gasoline fuel use in the commercial sector is from FHA, *Highway Statistics*.

Emission factors are from the MPCA GHG emission inventory and are generally taken from a number of sources. For fossil CO_2, sources include: Environmental Protection Agency (EPA), *Inventory of US Greenhouse Gas Emissions and Sinks* (various editions) and EIA, *Electric Power Annual*. The emission factor for motor gasoline is from EIA, *Emissions of Greenhouse Gases in the US*. Emissions of CO_2 from the combustion of bituminous and subbituminous coal are calculated using the long-term rate of emissions per MMBtu from the Minnesota electric power sector by coal grade.

For heavy refinery oil, an emission factor for fossil CO_2 from EIA, *Electric Power Annual* is used, while emissions per MMBtu for pressure swing absorption tailgas (PSA), a low btu gas produced in and combusted at oil refineries, is a calculated value based on fuel composition. Fossil CO_2 emissions from the combustion of refinery gas equal total facility reported fossil CO_2 produced by combustion at Minnesota oil refineries, as reported to the EPA Mandatory GHG Reporting Program (MMR)[9], less calculated fossil CO_2 emissions from Minnesota refineries from the combustion of all other fuels. Fuel use at Minnesota refineries is reported annually to the MPCA by fuel. Refinery fuels combusted in Minnesota include: PSA, refinery gas, heavy oil, natural gas, residual fuel oil, distillate fuel oil, and LPG.

[9] Beginning in 2010, large industrial facilities emitting more than 25,000 metric tons annually of greenhouse gases were required to report their emissions by gas, fuel type and noncombustion industrial process.

Emission factors for these fuels are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* and EIA, *Electric Power Annual* (or, as in the case of PSA, calculated).

CO_2 emissions from the combustion of biomass are calculated using emission factors for solid biomass, biogas and various bioliquids from EIA, *Renewable Energy Annual*; EIA, *Electric Power Annual* (various editions); EPA *AP-42, Compilation of Air Pollution Emission Factors*; EPA, *Mandatory Reporting Rule;* EPA*, Technical Support Document for the Pulp and Paper Sector: Proposed Rule for Mandatory Reporting of Greenhouse Gases;* Intergovernmental Panel on Climate Change (IPCC), *2006 IPCC Guidelines for National Inventories;* The Climate Registry*, General Reporting Protocol; T.* Miles *et al*., "Alkili Deposits Found in Biomass Power Plants"; R. Morey, *et al*., "Characterization of Feed Streams and Emissions from Biomass Gasification/Combustion at Fuel Ethanol Plants"; and R. Patzer*,*"Combustion of Crude Glycerin and Yellow Grease in a Fire Tube Boiler." While tracked in the MPCA GHG emission inventory, emissions of CO_2 from the combustion of biomass do not count toward the state's greenhouse gas emission totals under the Next Generation Energy Act.

CH_4 and N_2O emission factors for stationary combustion are fuel-based factors from IPCC, *2006 IPCC Guidelines for National Inventories*. CH_4 and N_2O emission factors for mining and construction vehicles and equipment are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.*

Before emissions are calculated for any one fuel or inventory year, fuel is converted to standard units of energy (MMBtu), in most instances using standard national level conversion factors from EIA, *Annual Energy Review* and EIA, *Renewable Energy Annual*. For natural gas and LPG, total fuel energy is calculated from reported fuel use and Minnesota-specific estimates of fuel heats of combustion or fuel energy content from EIA, *State Energy Data System*. In the Minnesota SEDS data, the heat content of natural gas tends to vary between 1,005 and 1,035 MMBtu per million cubic feet of gas and those for LPG between 88 and 90 MMBtu per thousand gallons.

Bituminous and subbituminous coal throughput is converted to units of energy using the long-term average for the Minnesota electric power sector for fuel energy content of these grades of coal. Facility-specific conversions factors are used for wood, wood sludge, and pulp mill gas from facility reports to MPCA. For ethanol, fuel energy content is from EIA, *Annual Energy Review* and that for biodiesel is from Oak Ridge National Laboratory (ORNL), *Transportation Energy Data Book*.

Noncombustion-based 'process' emissions from the industrial sector include noncombustion emissions from: oil refinery operations; industrial limestone use in ferrous and nonferrous mining and metals production and glassmaking; nonfuel feedstock and lubricant use of commercial fossil fuels; solvent, etchant and cover gas uses of HFCs, PFCs and SF_6; other industrial solvent use; and various miscellaneous activities like wastewater treatment, peat mining, and coal storage.

CO_2 is emitted at oil refineries during hydrogen production, typically using natural gas as a feedstock, sour gas clean-up during sulfur production, and coke burn-off from catalyst particles in fluid catalytic cracking units (FCCUs). Emissions from FCCU petroleum coke burn-off are calculated from EIA-reported refinery combustion of petroleum coke, reported in EIA, *State Energy Data System*, and an emission rate per MMBtu of petroleum coke from Minnesota refineries derived from facility emissions reporting under EPA's mandatory greenhouse gas reporting rule.

Emissions from refinery hydrogen and sulfur production are calculated using reported sulfur and hydrogen production capacity at Minnesota refineries and 2010 fossil CO_2 emission rates for refinery hydrogen and sulfur production per unit of refinery capacity. As in the case of refinery FCCU emission rates, 2010 fossil CO_2 emission rates were derived from facility reporting under the EPA MRR. In either instance --FCCU petroleum coke burn-off or hydrogen and sulfur production – reported MRR facility emissions totals are conserved or retained unchanged in MPCA totals for oil refining for reporting years, 2010 to 2013. As can be inferred from the discussion above, the same is true for total reported emissions from combustion.

CH_4 is also emitted from noncombustion refinery processes, albeit in quite small amounts. These include fugitive emissions and emissions from intentional venting. These are estimated using the methods and emission factors given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* and reported refinery distillation capacity, approximate refinery utilization rates, and reported daily asphalt production capacity.

Limestone is incorporated as a flux in taconite green balls that, when fired in high temperature indurating furnaces, emit CO_2. Pellets can be fully fluxed (2 percent by weight or greater) or only partially fluxed. Upon firing, acid pellets also emit a small amount of CO_2 from natural geological sources. Annual production of taconite pellets is reported in *Minnesota Mining Tax Guide* by pellet type. Annual emissions from the production of these pellets are calculated using annual production statistics and process emission rates per ton of pellets by pellet type derived from 2010 facility reporting under EPA's MRR.[10]

Limestone is also used in Minnesota in steelmaking, secondary lead processing, and glass manufacture. Process emissions from these sources are calculated from limestone throughput. Annual limestone throughput is reported to MPCA.

Besides, taconite pellets, Direct Reduced Iron (DRI) pellets also are produced in Minnesota. In the production of these pellets, coal is used as a reductant and CO_2 is emitted as a process byproduct. Reductant emissions are estimated from annual facility reports under the MRR and known fuel throughput for purposeful energy production.

Emissions from nonfuel uses include emissions from nonfuel paraffinic wax and lubricant uses. Annual throughput for estimating emissions from these sources is from EIA, *State Energy Data System*. Emission factors for waxes and lubricants are from EPA*, Inventory of US Greenhouse Gas Emissions and SInks*. Storage factors for waxes and lubricants derive from the same source. Emissions of volatile organic compounds from solvent and nonsolvent uses are from EPA, *National Emission Inventory*; the assumed average fossil carbon content by weight of these compounds is from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*.

HFCs, PFCs and SF_6 are used in semiconductor manufacture as etchants and in electronic and instrument manufacturing as solvents. SF_6 is also used as a cover gas in magnesium die casting. HFCs are used as insulating gases in refrigeration equipment, with some emitted during manufacture. Solvent emissions uses are estimated based on nationally-based *per capita* emission rates given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* and Minnesota population estimates. All other emissions are from facility-reporting of uses under the MPCA's mandatory high GWP reporting requirement. [11]

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[10] Facility-level reporting includes emissions of CO_2 from all sources. Fuel use is reported to the MPCA annually and, on the basis of this, emissions associated with fuel use can be calculated. Process emissions equal total CO_2 emissions less emissions from the combustion of fossil fuels for energy production.

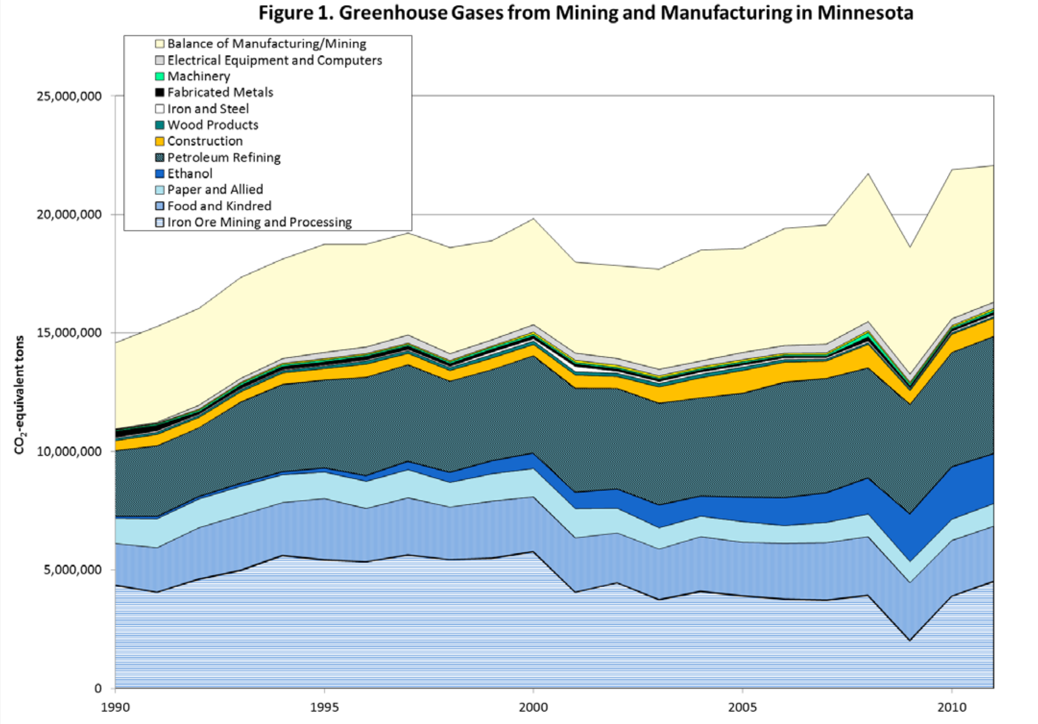
[11] Facility reports comprise the basis for 2010-2012 emission estimates for magnesium die casting, 2011-2012 estimates for semiconductor manufacture, and 2007-2012 estimates for appliance manufacture. For inventory years prior to 2011, emissions from semiconductor manufacture were calculated on the basis of the reported value of Minnesota shipments of semiconductors and the 2007 reported rate of Minnesota emission per dollar of shipments or, in cases of earlier years in the sequence, US emissions per dollar of US shipments. 2007 emissions were from facility reporting to the MPCA under its mandatory high GWP emission reporting requirement. For Inventory years prior to 2010, emissions from magnesium die casting were estimated on the basis of the reported

Small amounts of process emissions also derive from industrial wastewater treatment, coal storage and peat mining. Most peat that is mined in Minnesota is used for horticultural purposes. Emissions of CO_2 from peat mining are assumed to be equal to the carbon content of the mined peat. Emission factors for CH_4 for peat mining are from J. Cleary, *et al*., "Greenhouse Gas Emissions from Canadian Peat Extraction, 1990-2000: A Lifecycle Analysis." Annual peat production is reported in USGS, *Minerals Yearbook*. Emission rates from coal storage are taken from EPA, *Inventory of US Greenhouse Gas Emissions and SInks* and annual coal use is from MPCA greenhouse gas emission inventory database. Emissions from industrial wastewater treatment are estimated using the methods given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* and annually reported data for red meat and poultry meat production, the production of vegetables and fruits for processing, and refinery finished fuel output. For wastewater treatment at paper/pulp mills, statewide wood pulping capacity was used.

Historically, most GHG emissions from Minnesota industry have been combustion-based emissions. About one quarter of industrial sector emissions are noncombustion industrial process emissions. Historically, between 75 and 85 percent of Minnesota industrial process emissions have derived from iron ore mining and processing and oil refining.

Industrial sector greenhouse gas emissions are shown graphically in Figure 1 for 1990-2011. Industrial sector emissions increased rapidly from 1990 through 1995, about 5 percent per year, but since 1995 at a much slower rate of about 1 percent per year. The step increase in emissions about 2008 was probably the result of the change, about 2008, to generally lower natural gas prices. Over the period 1995-2011, emissions from ethanol production, oil refining, construction, and balance of mining and manufacturing increased about 4.7 million CO_2-equivalent tons. Offsetting this was a decline of about 1.3 million CO_2-equivalent tons in aggregate from iron ore mining, food processing and pulp and paper production.

Figure 1. Greenhouse Gases from Mining and Manufacturing in Minnesota



Value of Minnesota shipments of nonferrous die-casts (NAICS 3315522, SIC 3364) and the 2007 reported rate of Minnesota emission per dollar of shipments. No manufacturing emissions for refrigeration equipment are reported for inventory years prior to 2007.

Industrial sector on-site fuel use is shown in Table I-2 for selected years by fuel and by major industrial group. In aggregate, between 2000 and 2011 on-site fuel use in Minnesota industry increased 24 percent. Coal use declined 28 percent over this period, while the use of natural gas increased 48 percent. The use of renewable energy increased 23 percent.

About two-thirds of industrial on-site fuel use occurs in five industrial groups: iron ore mining, food processing, paper and pulp production, ethanol production and oil refining. Between 2000 and 2011, fuel use in iron ore mining declined 32 percent, while on-site fuel use in ethanol production and oil refining increased 229 percent and 36 percent, respectively. Over the same period, on-site energy use in food processing and paper and pulp production increased 7 and 8 percent, respectively. Roughly one-quarter of energy use in mining and manufacturing in Minnesota cannot be assigned to any particular industrial group on the basis of fuel use reported under air permitting programs. Energy use in this category of industrial energy use increased 48 percent between 2000 and 2011, possibly signaling the shift of energy use increasingly to small, unpermitted facilities.

Full documentation of the sources and methods used to develop the industrial sector inventory is included in Appendix E of P. Ciborowski and A. Claflin, “Greenhouse Gas Emissions in Minnesota: 1970-2008: Second Biennial Progress Report – Technical Support Document” (2012).

Table I-2. On-site Fuel Use in Minnesota Mining and Manufacturing (million MMBtu)

	1990	2000	2005	2010	2011
by fuel type:					
Coal	17.36	34.70	24.12	24.44	25.11
Oil	56.58	65.46	83.78	74.33	73.92
Natural gas	88.69	107.40	95.13	159.80	159.28
Other [a]	18.07	23.91	26.33	28.96	29.46
total	180.70	231.46	229.37	287.52	287.78
by major industrial group:					
Iron Ore Mining and Processing	36.90	43.89	28.68	25.01	29.90
Copper Mining and Processing	0.00	0.00	0.00	0.00	0.00
Construction	5.15	5.75	11.73	9.79	9.85
Food and Kindred	19.61	27.49	26.80	29.39	29.53
Wood Products	4.69	7.22	7.79	2.70	2.65
Paper and Allied	28.24	33.79	29.11	35.05	36.34
Ethanol	0.78	10.90	17.24	37.19	35.89
Petroleum Refining	33.03	38.22	47.25	50.39	52.16
Iron and Steel	0.83	0.95	0.80	0.70	0.83
Fabricated Metals	3.88	2.05	1.42	1.54	1.74
Machinery	0.75	1.25	1.09	1.19	1.37
Electrical Equipment and Computers	0.52	0.59	0.41	0.48	0.66
Transportation Equipment	0.45	1.51	1.35	1.22	1.41
Balance of Manufacturing/Mining	45.86	57.87	55.70	92.88	85.45
Total	180.70	231.46	229.37	287.52	287.78

[a] mostly solid biomass, bioliquids and biogas

Forecast methods

The forecast was developed using the same sector boundaries that underlie the sector inventory. The industrial sector includes all private firms that are engaged in mining and manufacturing. Emissions are comprised of emissions from on-site combustion for energy production and noncombustion process emissions. Noncombustion emissions are from a wide variety of sources, including oil refinery production of sulfur and hydrogen and petroleum coke burn-off in fluid catalytic cracking (FCC) operations, taconite and DRI pellet production, limestone use in glass, steel and copper production, magnesium die casting, semiconductor manufacture and industrial solvent use.

The industrial sector emissions forecast is shown in Table I-3 by fuel type and noncombustion process emission type in CO_2-equivalent short tons. Emissions rise in the forecast by 4 percent from 2011 levels by forecast year 2030. Most of the increase is from increased process emissions, which in the forecast rise 10 percent from 2011 levels by 2030. Emissions from on-site combustion increase only slightly, by 2 percent by 2030. Most of the increase in noncombustion process emissions derives from an increase in emissions from iron pellet production and oil refining.

Table I-3. Forecasted Emissions from Minnesota's Industrial Sector (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Combustion-based Emissions					
coal	2.42	2.38	2.42	2.46	2.50
oil	4.35	4.57	4.84	4.92	5.02
natural gas	9.26	9.07	9.11	9.11	9.11
other	0.03	0.03	0.03	0.04	0.04
subtotal	**16.06**	**16.06**	**16.41**	**16.52**	**16.67**
Taconite induration (flux pellets)	2.05	2.12	2.17	2.21	2.26
DRI pellet production (reductant)	0.28	0.25	0.25	0.25	0.25
Copper production (autoclave limestone)	0.00	0.00	0.10	0.10	0.10
Oil refining (hydrogen and sulfur production, FCC)	2.64	2.93	3.09	3.03	2.99
Steelmaking	0.03	0.03	0.03	0.03	0.03
Wastewater treatment	0.18	0.18	0.19	0.20	0.21
Semiconductor manufacture	0.16	0.16	0.16	0.16	0.16
HFC/PFC solvent uses	0.03	0.03	0.03	0.04	0.04
Foam insulation manufacture	0.05	0.05	0.00	0.00	0.00
Magnesium casting	0.02	0.05	0.05	0.05	0.05
Miscellaneous process	0.30	0.30	0.30	0.30	0.30
Total	**21.79**	**22.15**	**22.76**	**22.88**	**23.04**

The forecast was developed on an SIC-by-SIC code basis using regional forecast information from the EIA, *Annual Energy Outlook 2014*. EIA forecasts regional and national industrial sector energy use on a fuel-by-fuel basis for major industrial groups. Beginning with the reference case forecast for the West North Central region, a 19-year, 2011-2030, average annual rate of increase in total on-site fuel use plus on-site hydroelectric generation was calculated from the EIA base forecast for each major industrial group. On-site fuel use at large permitted industrial facilities in Minnesota is known from annual fuel use reports to the Minnesota Pollution Control Agency. A three-year, 2009-2011, average was calculated for total fuel use for each major industrial groups from reports to MPCA and, using the 19-year average annual rates of increase given in the regional *AEO 2014* forecast, were grown out to 2030.

A three-year average was used for the base level of on-site fuel use to remove from the forecast the effects of shorter-term variability introduced by the intense 2009 recession. On an MMBtu basis, on-site hydroelectric generation in the *AEO 2014* forecasts is typically less than 0.1 percent of total on-site fuel use, and so is safely ignored in the analysis.

Forecast fuel use, converted to an MMBtu-basis, was distributed among fuels using a normalized distribution of fuels developed for each major industrial grouping. A three-year, 2009-2011, average was calculated for fuel use for each fuel for each major industrial groups from MPCA data and, using the average rates of increase given in the regional *AEO 2014* forecast for each fuel in each major industrial grouping for the forecast period (2012-2030), each was grown out to 2030. The resulting distribution of fuel use was converted in each forecast year and within each major industrial grouping to a percentage basis. Total energy use within major industrial groupings was apportioned to individual fuels using this percentage distribution. Natural gas usage in turn was adjusted to reflect energy savings required under Minnesota statute.

Emissions of fossil CO_2, CH_4 and N_2O, the principal greenhouse gases associated with combustion, were estimated for each forecast year using fuel-based emission factors. Emission factors for CH_4 and N_2O were taken from from IPCC, *2006 IPCC Guidelines for National Inventories*. Given the large number of combustion–based emission sources, emissions of CH_4 and N_2O in the industrial forecast are calculated on a fuel type-basis, rather by combustion technology and fuel. Emissions of fossil CO_2 were calculated using fuel-based emission factors principally from EPA*, Inventory of US Greenhouse Gas Emissions and Sinks*. Exceptions include: bituminous and subbituminous coal, heavy refinery oil, tire-derived fuel, pressure swing absorption tailgas (PSA) and refinery gas. CO_2 emissions from bituminous coal and subbituminous coal were calculated using a 39-year, 1972-2010, average for emissions per MMBtu from bituminous and subbituminous coal combustion at Minnesota electric power plants.

The emission rate for heavy refinery oil is from EIA, *Electric Power Annual*, while emissions per MMBtu from PSA combustion are a calculated value from fuel composition. [12] The emission factor for CO_2 from Minnesota refinery gas is a calculated average value developed from data available for 2010-2012 for: total reported CO_2 emissions from Minnesota oil refineries, calculated emissions from refinery combustion of fuels other than refinery gas (distillate fuel oil, residual fuel oil, refinery heavy oil, LPG, natural gas and PSA), total Minnesota refinery nonelectric energy input and the percentage distribution of fuel use. Total nonelectric energy use at Minnesota refineries is reported in *State Energy Data System*. State-level EIA data on total refinery energy use is available back to 1970. The percentage distribution of refinery fuel use was developed from information on fuel use provided to the MPCA in annual facility reporting. Annual estimates for 2010-2012 for combustion based fossil CO_2 emissions from Minnesota refineries are from facility reporting to EPA.

Emission factors generally take the form of CO_2-equivalent lbs. per MMBtu of energy input to combustion using higher heating values for fuel energy content.

Forecasts were developed for the following major industrial groups: iron mining and processing, copper mining and processing, construction, food processing, wood products manufacture, paper/pulp production, ethanol production, oil refining, steel production, fabricated metals manufacture, electronics and computer manufacture, machinery, and transportation equipment. In addition, a forecast was developed for the balance of mining and manufacturing. *AEO 2014* provides a forecast at a regional level for the balance of mining and manufacturing not represented in the results for the major

[12] PSA by volume is assumed to be 44% CO_2, 28% hydrogen, 17% CH_4, 10% carbon monoxide and 1% nitrogen, after the estimate given in C. Baukal, ed., *John Zink Combustion Handbook: Industrial Combustion*, 2001.

industrial groups that EIA assesses. As in the case of each named major industrial group, a 19-year, 2011-2030, average annual rate of increase in nonelectric energy use was calculated from the West North Central AEO reference case for the balance of mining and manufacturing. Using a three-year average for fuel use that, in the MPCA inventory, does not fall into the major industrial groups named above, a schedule of fuel use for the balance of mining and manufacturing was developed and expressed as emissions of CO_2, CH_4 and N_2O.

Total forecasted on-site fuel use in each major industrial group was distributed among fuels (fossil and biomass) using a distribution of fuel use calculated using present-day fuel use in Minnesota in each industrial grouping and *AEO 2014* forecast average annual growth rates for each fuel to 2030. For each forecast year a schedule of fuel use was developed for each major industrial group on a fuel-by-fuel basis. This was converted to a percentage distribution and applied to total on-site energy production forecast for each major industrial group to yield a Minnesota specific schedule of fuel use on a fuel-by-fuel basis for each major industrial group.

For minor fuels that are consumed by Minnesota industry but for which forecast values are not reported out in *AEO 2014*, a 3-year, 2009-2011, average was used for fuel use across all forecast years. Minor fuels include: motor gasoline, waste oil, waste solvent, tire-derived fuel, kerosene, manufacturing residues and biodiesel.

Fuel use for a single year, 2012 was used as the base period against which fuel use in the paper/pulp production was grown. Fuel use in the prior two-years, 2010 and 2011, was anomalously high with respect to historic levels of fuel use. The 2012 base-level fuel use itself was adjusted to reflect facility retirements, announced in 2012, at Sartell and Brainerd. To accommodate the change, the average annual rate of increase in on-site energy production in the paper/pulp group was calculated from *AEO 2014* using forecast data for 2012-2030. No adjustment to the base values were made for the late 2013 announced retirement of two of four paper machines announced at the Boise-White facility in International Falls.

For ethanol production, a single year, 2012, was likewise used for the base period to capture in the base level of fuel use facility modifications introduced first in 2012, notably the Heron Lake conversion from subbituminous coal to natural gas.

The Polymet copper mining and processing facility is slated to open in 2017. Forecasted annual fuel use at the facility was derived from forecast average annual emissions (83,760 CO_2-equivalent tons) reported in the facility Supplemental Environmental Impact Statement (SEIS). 45 percent of Polymet SEIS-projected emissions are combustion-based greenhouse gases emitted during the on-site production of energy. Of these, 33 percent is assumed to derive from natural gas combustion, 57 percent from distillate fuel oil combustion and 10 percent from LPG combustion, based on information from the SEIS. On-site fuel use was calculated backwards using conventional rates of CO_2 emissions per MMBtu of fuel throughput.

The operators of Flint Hills Refinery, the state's largest oil refinery, have announced plans to modify the facility in 2014 and again in 2016. Under its settlement agreement with Minnesota Center for Environmental Advocacy (MCEA) in 2014 the refinery will expand operations at the refinery, increasing the facility's annual emissions of CO_2 by 235,000 tons. The operators announced a further refinery expansion in March 2014 involving in 2016 the addition of 49.9 MW of natural gas turbine CHP capacity and enhanced sulfur and nitrogen removal capacity at the refinery.

As of August 2014, the time that this forecast was developed, information on emissions and fuel use at Minnesota oil refineries was available through the end of 2012. To forecast emissions through 2016, the year of the final announced refinery modification, the change in refinery fuel throughput resulting from these planned modifications was calculated assuming, for the 49.9 MW CHP addition, a heat rate of 7,317 btu/kwh and an 85 percent capacity factor and, for the expansion under Flint Hills/MCEA settlement agreement, average 2010-2012 rates of refinery energy use per ton of emitted CO_2 from combustion processes. Beginning in 2017, total on-site energy production at Minnesota refineries was calculated using the forecast *AEO 2014* 2017-2030 average annual rate of increase in on-site energy production for refineries in the West North Central region and 2016 fuel throughput based on the description just given. The observed 2010-2012 percent distribution of fuel use by fuel at Minnesota refineries was used to distribute forecast on-site refinery fuel use among fuels.

The AEO mining forecast is principally a coal mining and oil and gas extraction forecast. Because of this, an alternative approach to fuel use forecasting for iron ore mining and processing was developed. Separate calculations were performed for DRI and taconite pellet production. Forecast nonelectric fuel input to DRI pellet production was estimated using average 2011-2012 pellet production and 2012 per ton rates of nonelectric fuel input to DRI pellet production. DRI pellet production is relatively new to Minnesota, with but a few years of data on energy use and production levels available. For taconite production, linear trends were calculated for annual pellet production and nonelectric fuel input to production per ton of pellets using 2001-2011 data; over the period, a slight positive linear trends is evident in the state-level production data, accompanied by a slight negative linear trend in per ton nonelectric energy inputs. Linear trends in taconite production and nonelectric fuel use per pellet were extended to 2030 and, in combination, were used to forecast fuel use in taconite production. Total on-site nonelectric energy use for both pellet types was then distributed among fuels using the historic percentage distributions drawn from 2010-2012 data for the sector.

In 2010, Minnesota began implementing its energy efficiency resource standard (EERS). Under Minnesota state statute, regulated natural gas distribution utilities are required to demonstrate for each year beginning in 2010 annual energy savings on the part of their customers equal to one percent of average retail sales for the prior three years. In the case of the industrial sector, the needed savings rate is effectively 0.8 percent, due to exemptions granted to certain natural gas end-users. [13] EERS savings for any forecast year were calculated using modeled demand for the prior three years. Energy savings were then subtracted from what demand for natural gas in any forecast year would have been in absence of statutory requirements. What in any forecast year demand would have been absent an EERS was calculated from the modeled schedule of demand for natural gas pre-EERS, 2011-2030. Implicit in this schedule is, for each forecast year, an increase in demand to which markets in natural gas are assumed to return once the prior year's EERS requirements have been satisfied. Demand prior to EERS is this growth plus the modeled post-EERS estimates of natural gas use for the prior year.

In as much as the *AEO 2014* forecast was developed at a regional level, without reference to energy savings under a state-level EERS, it affords little basis in itself for any adjustments for embedded energy savings from early investments in energy conservation, from 1999 to 2011. Simply, no EERS savings were assumed in the *AEO 2014* regional forecasts. It might be possible to adjust upward the base 2011 natural gas use estimates that in the MPCA forecast, major industrial group by major industrial group, were grown using the average annual rate of increase given in AEO 2014 for natural gas consumption. In doing so, DSM investment lifetimes need to be considered. Investments in energy conservation have a 12 or 13-year lifetime. By 2020, most investments dating from 2007 and before will be retired. Manipulating the mathematics, it appears that over the forecast period 2012-2020, consideration of

[13] Estimated by Minnesota Department of Commerce staff

embedded effects can have impact on the shape of the natural gas demand curve pre-EERS, but the effect all but disappears by 2025.

At a more practical level, the data do not exist to assess present-day levels of embedded energy savings on a sector or SIC code level. The program data for the Minnesota Conservation Improvement Program give a single value only for all savings in the commercial and industrial sectors. By contrast, the MPCA forecast was developed at an SIC code level, and one gets quite different results for the exercise described in the immediately preceding paragraph depending on how embedded savings are distributed through the industrial sector.[14] Mindful that the effects of embedded savings go to zero in the 2020 to 2025 time frame, no effort was made to adjust the background pre-EERS demand schedule for embedded energy savings, in part due to these limited effects at 2020 or 2025, but also due to unknowns which abound in this topical area.

Forecast retail sales of natural gas to Minnesota mining and manufacturing firms in absence of and prior to any statutory requirement (governing energy savings) and after those same requirements are shown in Table I-4. The use of roughly 25 million MMBtu of natural gas is expected to be avoided in 2030 as a result of statutory provisions that govern energy savings. As just noted, absent those provisions, retail sales of natural gas will grow at an average annual rate of about 0.8 percent. With those provisions in play, growth in retail sales is expected to be near zero throughout much of the forecast period.

Table I-4. Forecast On-site Fuel Use in Minnesota Mining and Manufacturing (million MMBtu)

	2012	2015	2020	2025	2030
million MMBtu					
Coal	24.44	22.04	22.40	22.76	23.12
Oil	74.33	80.54	84.90	85.21	86.08
Natural gas	159.80	155.52	156.13	156.11	156.16
Other	28.96	28.55	30.93	33.52	36.34
total	282.84	286.64	294.36	297.60	301.69
total before energy savings law	284.04	291.66	305.87	315.86	326.99
annnual rate of increase in natural gas use:					
before energy savings law	0.38%	0.80%	0.80%	0.79%	0.82%
after energy savings law	-0.37%	0.00%	0.00%	-0.01%	0.02%

From table I-4, total sector fuel use increases less than 5 percent over the forecast period, principally the result of savings under the natural gas energy savings law. Of the forecasted increase in oil consumption shown in Table I-4, about half results from increased combustion of refinery gas and PSA at the state's oil refineries, much of the rest from increased distillate fuel oil consumption throughout industry. Much of the growth in oil consumption occurs early in the forecast period, in the 2012-2020 timeframe, largely following upon the planned refinery expansion at Flint Hills.

Noncombustion process emissions were forecast to 2030 for oil refining, taconite and DRI pellet production, copper mining and processing, industrial wastewater treatment, steel production, magnesium die casting, semiconductor manufacture, HFC-based solvent uses in precision cleaning and the manufacture of insulating foams used in appliances. In addition, emissions were forecast for a miscellaneous category of sources that includes glass and secondary lead production, paraffinic wax

[14] Within the framework described, with embedded savings accumulating in industries with low or zero background rates of growth in natural gas demand, the effects of embedded savings on pre-EERS demand tend to be more muted than the case with embedded savings concentrating in industries with high rates of increase in gas use.

consumption, peat mining, coal storage, non HFC solvent uses and other industrial VOC emission. In aggregate, emissions from this miscellaneous category of emissions show no discernible trend over the period 2002-2011. Emissions for these sources out to 2030 were set at average 10-year, 2002-2011, levels.

The same is true of emissions from semiconductor manufacture, which likewise show little discernible trend, 2002-2011. Future emissions from this source were set at average 2009-2011 levels. Emissions from semiconductor manufacture include various HFCs, PFCs and SF_6. Forecast emissions of HFC-based solvent use were calculated on a *per capita* basis, using population forecasts prepared by the Minnesota State Demographer and average 2009-2011 *per capita* emission rates. Emissions from the manufacture of insulating foams are assumed to go to zero in 2017 under pending EPA rules governing allowable uses of HFCs. As noted above with respect to the use of HFCs in commercial refrigeration, in August 2014 the EPA issued a draft rule that beginning in 2016, would prohibit certain uses of HFCs. Under the proposed rule, as of January 1, 2017 use of HFCs in foam blowing applications in refrigeration manufacture would be prohibited in the US. Emissions of HFCs in foam blowing applications were set for forecast years 2012-2016 at average 2009-2011 levels.

Emissions from magnesium die casting are forecast to decline by 90 percent from 2011 levels to 45,000 CO_2-equivalent tons. This reflects a commitment by Consolidated Precision Products, the largest magnesium die caster in Minnesota, to reduce emissions to 30,000 CO_2-equivalent tons annually by 2013.

Emissions from wastewater in ethanol production were set at average 2009-2011 levels; emissions from ethanol production are small and the historical data on emissions shows little secular trend. Recent facility retirements have led to a contraction in total state wood pulping capacity. Emissions from wastewater treatment in paper/pulp production were set proportional to the change from 2011 levels in state-level pulping capacity resulting from these retirements. By contrast, emissions from industrial wastewater treatment in food processing are grown over the forecast period at an average annual rate equal to the rate of increase in nonelectric energy use in SIC 20 (food and kindred products production), using average 2009-2011 levels as base levels. The basic equations that are used to estimate emissions annually from wastewater treatment at paper/pulp facilities are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*; all equation parameters other than state-level pulping capacity are assumed to remain constant at 2011 levels.[15] .

Forecast process emissions from taconite pellet production were calculated from 12-year, 2001-2012, trends in pellet production. Forecast flux emissions of CO_2 per pellet were set at 3-year, 2010-2012, levels. As noted in the discussion of forecasted on-site combustion emissions, trends in pellet production since 2001 are slightly positive, leading by 2030 in the forecast to a 7 percent increase in pellet production No systematic trend in CO_2 process emissions per ton of pellets is evident in the data.

Noncombustion process emissions associated with DRI pellet production were calculated from 2011-2012 production levels and the 2010-2012 average rate of emission per ton of DRI pellets produced. As noted above, little empirical information exists on which to ground a better developed estimate of future emissions. Process emissions from copper processing were taken from the Polymet Supplemental Environmental Impact Statement. 55 percent of total facility emissions reported in the Polymet SEIS was assumed to be noncombustion emissions, after the information presented in the SEIS appendices. Industrial process emissions from Minnesota steel production are small. These are grown at the forecast rate of increase in nonelectric energy use in Minnesota steel production, using the historic 2009-2011 emissions level as base level.

[15] Parameters include: gallons of wastewater per ton of pulp produced, BOD per gallon of wastewater, ratio of COD:BOD, percent of wastewater that is treated anaerobically, production rate of CH_4 per unit of wastewater COD.

Industrial process emissions from oil refining were forecast as a linear function of refinery inputs of crude oil and natural gas liquids and emission rates. Crude oil and natural gas liquid Inputs to refining were assumed to increase proportionally to total energy inputs to refining. Over the forecast period, total energy inputs to refining are projected to increase about 10 percent. The rate of noncombustion process CO_2 emissions per MMBtu of crude oil and natural gas liquid inputs to refining is assumed to increase slightly from 2011 levels, from 0.0032 tons/MMBtu input in 2012 to 0.0034 tons/MMbtu refinery input in 2017, associated with a projected increase in tar sands use statewide at Minnesota refineries from about 60 percent in 2012 to a projected 72 percent in 2017. A rate of change in emissions per percent change in tar sands input to Minnesota refineries was calculated from historic data and applied to the forecasted percentage increase in tar sands inputs to refining.

Tar sands are deficient in hydrogen, which, to improve product quality, must be added. During hydrogen production, CO_2 is emitted to the atmosphere. In Minnesota, in 2012, 1.6 million tons of CO_2 were emitted during refinery hydrogen production, equal to about two-thirds of all refinery combustion emissions.

With a few exceptions, empirical data upon which to construct a forecast of refinery process emissions are lacking. Canadian production of tar sands is projected to increase by 2017 by about two-thirds from 2011 levels, providing impetus to further penetration of tar sands into Midwest refining markets. But more than this probably cannot be said. In general terms, refinery process emissions should increase, but more study may be needed to say how much and how rapidly.

An abbreviated summary of the forecast methods and/or sources is provided in Table I-5 by major industrial group. Forecast average annual rates of forecasted increase in on-site fuel use before energy savings are also summarized in Table I-5, as an essential point of reference in any forecast evaluation.

Lastly, sources for the data and methods used in the forecast include:

- Canadian Association of Oil Producers, *CAPP Crude Oil Forecast, Markets, Transportation*
- EIA, *Annual Energy Outlook 2014*
- EIA, *Refinery Capacity Report*
- EIA, *Petroleum Marketing Annual*
- EIA, *State Energy Data System*
- EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*
- EPA, *Mandatory GHG Reporting database*
- EPA, Significant New Alternatives Program (SNAP) proposed rule
- IPCC, *2006 IPCC Guidelines for National Inventories*
- MCEA/Flint Hills Settlement Agreement
- Minnesota House of Representatives, *Petroleum Infrastructure: Pipelines, Refineries, Terminals*
- Minnesota State Demographer, *State Population and Household Estimates*
- MNDNR, *Polymet Supplemental Environmental Impact Statement (SEIS)*
- MNDOR, *Mining Tax Guide*
- MPCA, *GHG Emission Inventory database*
- MPCA, High GWP Reporting database
- MPCA, *Technical Support Document for Flint Hills Clean Fuels and CHP Proposals*
- Oil Change International, *Refinery Report: Tar Sands Refining in the US and Canada, 2010-2012*
- US Forest Service, *National Pulpwood Production*

Table I-5. Summary of Methods Used in Industrial Sector Forecast

Major Industrial Grouping	average annual rate of increase, energy use before natural gas adjustment, 2011-2030	Source or Method	notes on energy calculation or process emission calculation
Iron ore mining and processing	0.1	linear trend, taconite pellet production, 2001-2012 (0.4%/yr av growth); 2-yr av, 2011-2012, DRI pellet production	constant current CO2 emission rate for fluxes and reductant per ton of taconite pellets (0.05) and tons of DRI pellets (1.35); linear trend in MMBtu/ tons taconite pellets, 2001-2012; current energy input per ton of DRI pellets
Copper mining and processing	constant at EIS-estimated annual actuals	Polymet SEIS	% actual autoclave process (neutralization) emissions of all assumed at same % as PTEs
Construction	1.89	EIA, Annual Energy Outlook 2014 (AEO 2014)	
Food and kindred products	1.35	AEO 2014	same assumed rate of increase for WWTP process emissions
Wood products	2.08	AEO 2014	biomass-dominated fuel supply
Paper and allied products	1.57	AEO 2014	biomass-dominated fuel supply; WWTP emissions calculated at pulping capacities adjusted for facility retirements
Ethanol production	0.7	AEO 2014	
Oil refining	0.6	Flint Hills Refinery expansion plans, AEO 2014	Flint Hills expansion through 2016, thereafter AEO 2014 av annual rates of increase in energy use, 2017-2030; process CO2 emissions rate (tons per barrel crude input) constant near present levels (6% increase)
Steel production	0.1	AEO 2014	
Durable metal products	0.8	AEO 2014	
Machinery	1.07	AEO 2014	
Electrical equipment and computers	1.74	AEO 2014	process emissions show no evident 10-year trend and assumed to remain constant at 2009-2011 levels
Transportation equipment	1.83	AEO 2014	
Balance of manufacturing/mining	0.6	AEO 2014	emissions from magnesium casting decline 90% based on announced facility commitments; other, miscellaneous process emissions show no evident 10-year trend and assumed to remain constant at 2002-2011 levels
Total	**0.7**	**see above**	
Total after natural gas adjustment	**0.2**	natural gas use adjusted for energy savings equal to 0.8% of av retail sales for prior 3-yrs; all other fuel use unchanged from forecast by major industrial group	it is assumed that in any forecast year, demand before savings will revert to its percentage pre-savings growth rate; adjusted demand equals demand before savings less energy savings

Detailed forecast results

The results shown above in Table I-3 for emissions are shown are shown below in Table I-6 using a more detailed breakdown of emissions by fuel. In the forecast, industrial sector emissions increase 4 percent above 2011 levels by forecast year 2030, or 0.98 million CO_2-equivalent tons. Combustion emissions increase 0.4 million CO_2-equivalent tons, or 2 percent above 2011 levels. More than offsetting a part of this decline is an increase in noncombustion process emission of 0.58 million CO_2-equivalent tons, from 5.8 million CO_2-equivalent tons in 2011 to 6.4 million CO_2-equivalent tons in forecast year 2030. Over the forecast period, industrial process emissions increase at an average annual rate of 0.5 percent, while combustion emissions increase at a rate of 0.1 percent per year over the same period.

Table I-6. Forecasted Emissions from Minnesota's Industrial Sector: detailed results (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Combustion-based Emissions					
bituminous, subbituminous coal	2.29	2.24	2.27	2.29	2.31
other coal, coke	0.13	0.14	0.15	0.17	0.19
natural gas	9.26	9.07	9.11	9.11	9.11
refinery gas and PSA	2.18	2.36	2.46	2.40	2.37
distillate fuel oil	1.18	1.24	1.39	1.50	1.61
residual fuel oil	0.17	0.19	0.20	0.22	0.24
LPG	0.14	0.15	0.16	0.16	0.16
petroleum coke	0.15	0.10	0.10	0.10	0.10
other oil (gasoline, heavy refinery oil, solvent)	0.13	0.14	0.14	0.14	0.14
waste oil and lubricants	0.39	0.40	0.40	0.40	0.40
solid biomass	0.03	0.03	0.03	0.04	0.04
solid waste fuels (TDF, solid waste)	0.01	0.00	0.00	0.00	0.00
subtotal	**16.06**	**16.06**	**16.41**	**16.52**	**16.67**
Iron ore mining and processing	2.33	2.37	2.41	2.46	2.50
Copper production (autoclave limestone)	0.00	0.00	0.10	0.10	0.10
Oil refining (hydrogen and sulfur production, FCC)	2.64	2.93	3.09	3.03	2.99
Steelmaking	0.03	0.03	0.03	0.03	0.03
Wastewater treatment	0.18	0.18	0.19	0.20	0.21
Semiconductor manufacture	0.16	0.16	0.16	0.16	0.16
HFC/PFC solvent uses	0.03	0.03	0.03	0.04	0.04
Foam insulation manufacture	0.05	0.05	0.00	0.00	0.00
Magnesium casting	0.02	0.05	0.05	0.05	0.05
Miscellaneous process	0.30	0.30	0.30	0.30	0.30
Total	**21.79**	**22.15**	**22.76**	**22.88**	**23.04**

GHG emissions from the combustion of natural gas and coal decline in the forecast, by 2030 by 0.37 million CO_2-equivalent tons or 3 percent. The decline is about equally shared by the two emission sources. By contrast, emissions from the combustion of petroleum-based fuels increase in the forecast by 0.77 million CO_2-equivalent tons or 18 percent from 2011 levels. About three-quarters of the forecasted increase in emissions from oil result from increased combustion of refinery gas, PSA and distillate fuel oil. Forecast emissions from the combustion of solid biomass or waste fuels are unchanged over the forecast period.

With decreased reliance on coal, the industrial sector emission rate per MMBtu declines slightly over the forecast period, about 3 percent between 2011 and 2030.

Noncombustion process emissions from mining activities increase in the forecast by 0.27 million CO_2-equivalent tons, from 2.33 million CO_2-equivalent tons in 2011 to 2.6 million CO_2-equivalent tons in forecast year 2030. Noncombustion refinery emissions increase a forecasted 0.4 million CO_2-equivalent tons. Offsetting these increases is a forecasted 0.15 million CO_2-equivalent ton reduction from magnesium die casting and appliance foam manufacture.

Table I-7 shows forecasted emissions from mining and manufacturing by gas. 97 percent of all GHG emissions from the industrial sector are in the form of fossil CO_2. Emissions of fossil CO_2 increase over the forecast period at an average annual rate of about 0.3 percent, similar to the average annual rate of growth for GHGs as a whole. Of the rest, emissions of HFCs, PFCs and SF_6 in aggregate decline about 40 percent over the forecast period, driven principally by reductions in SF_6 emissions from magnesium die casting. Emissions of CH_4 and N_2O increase in the forecast 15 to 20 percent, but from generally low initial levels.

Biogenic emissions of CO_2 increase about 28 percent over the forecast period, at an average annual rate of 1.2 percent. Most results from the combustion of solid biomass, principally wood, wood wastes, bark and black liquor. In Minnesota, at present about 30 percent of biogenic emissions of CO_2 derive from the industrial sector.

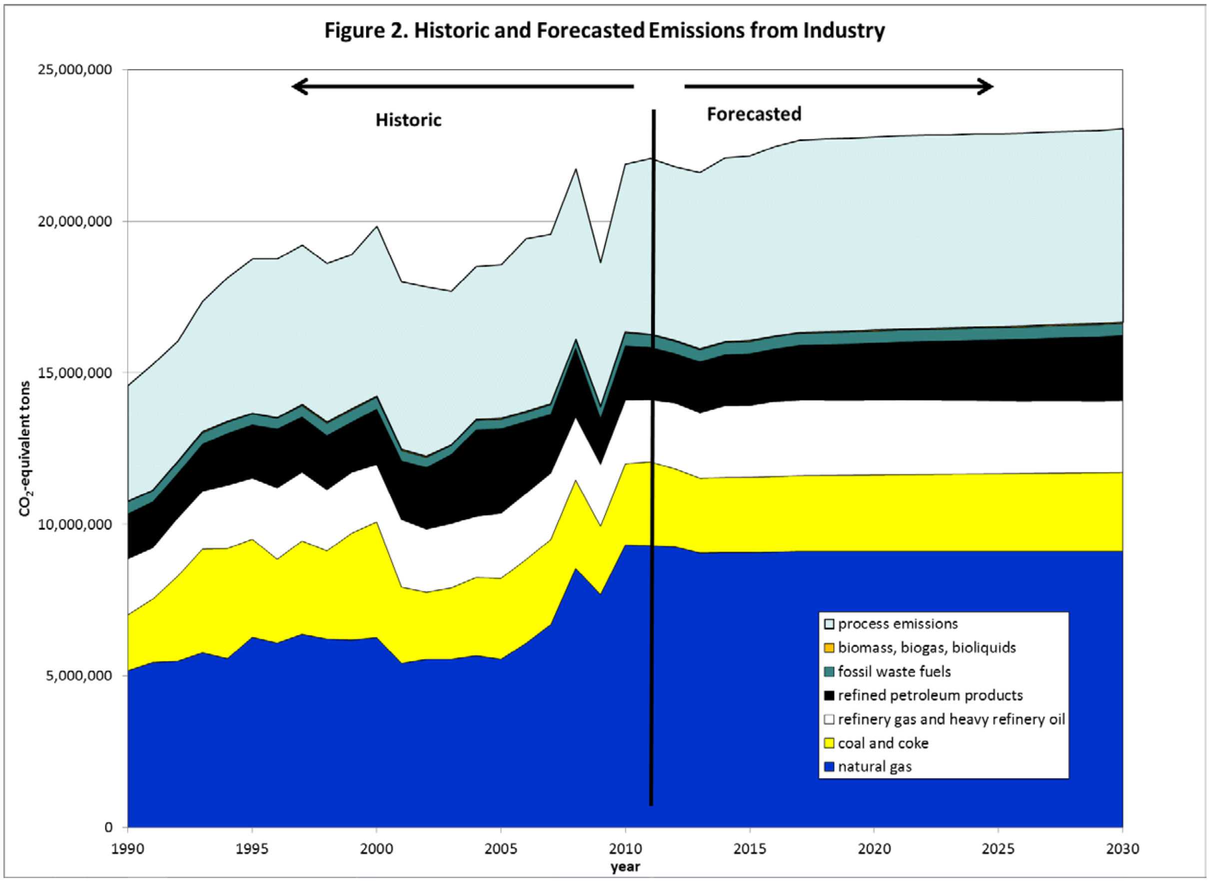
Table I-7. Forecasted Emissions from Minnesota's Industrial Sector by Gas (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
fossil CO_2	21.24	21.56	22.20	22.30	22.45
CH_4	0.25	0.26	0.27	0.28	0.29
N_2O	0.04	0.05	0.05	0.05	0.06
HFCs, PFCs	0.24	0.24	0.20	0.20	0.20
SF_6	0.02	0.05	0.05	0.05	0.05
Total	**21.79**	**22.15**	**22.76**	**22.88**	**23.04**
Biogenic CO_2*	2.66	2.99	3.24	3.50	3.78
Solid biomass	2.48	2.65	2.87	3.11	3.37
Liquid biofuels	0.13	0.29	0.31	0.33	0.34
Biogas	0.04	0.05	0.06	0.06	0.07

*Does not include CO_2 emitted from wastewater treatment

Biogenic emissions are not now counted in industrial sector totals. Upon combustion, CO_2 from biomass is emitted to the atmosphere, where it remains for periods of a few years to decades. At some point in time it is removed from the atmosphere and photosynthetically reincorporated into the living biomass of plants, resulting over periods of decades to centuries in no net change long-term change in atmospheric CO_2 levels.

Figure I-2 shows the forecasted trend in emissions graphically. Over the forecast period, the trend in Industrial sector emissions, which through 2011 had been increasing at a 15-year, 1996-2011, average annual rate of 1 percent, flattens. From 2011 to 2030, emission increase at an average annual rate of increase of just 0.2 percent. Between 2005 and 2011, emissions from the industrial sector increased about 20 percent. All of this plus some was the result of increased use of natural gas. In the forecast, natural gas use initially declines, and then use stabilizes, with essentially no growth to 2030.



As noted above, increased emissions from use of petroleum-based fuels and from industrial processes account for the little growth in emissions, 2011-2030, that is evident in Figure I-2. Emissions from the use of petroleum-based fuels increase in the forecast by 0.77 million CO_2-equivalent tons, 2011-2030. Industrial process emissions increase 0.58 million CO_2-equivalent tons over the same forecast period.

Figure I-3 shows pictorially forecasted emissions by major industrial grouping absent the modeled effects of the EERS. Also shown are historic emissions back to 1990. With no EERS, industrial emissions are forecast to increase 11 percent or 0.6 percent per year. Increased emissions from oil refining and food and kind food products account for about half of the increase in emissions between 2011 and 2030, again absent the modeled effects of the EERS. Increased emissions from iron and copper mining and ethanol production account for about one-quarter of the forecasted increase.

The difference between Figures I-2 and I-3 in the rate of growth in emissions is the modeled effect of the EERS in bending the curve of emissions to a condition of near-zero growth. This is possible only because of the predominant role of natural gas use in overall industrial sector fuel use. As noted above, the EERS is directed solely to natural gas. Forecasted fuel use in the industrial sector is presented in Table I-8 by fuel and selected years out to 2030. More than half of all fuel use in the industrial sector, on an MMBtu-basis, is the form of natural gas.

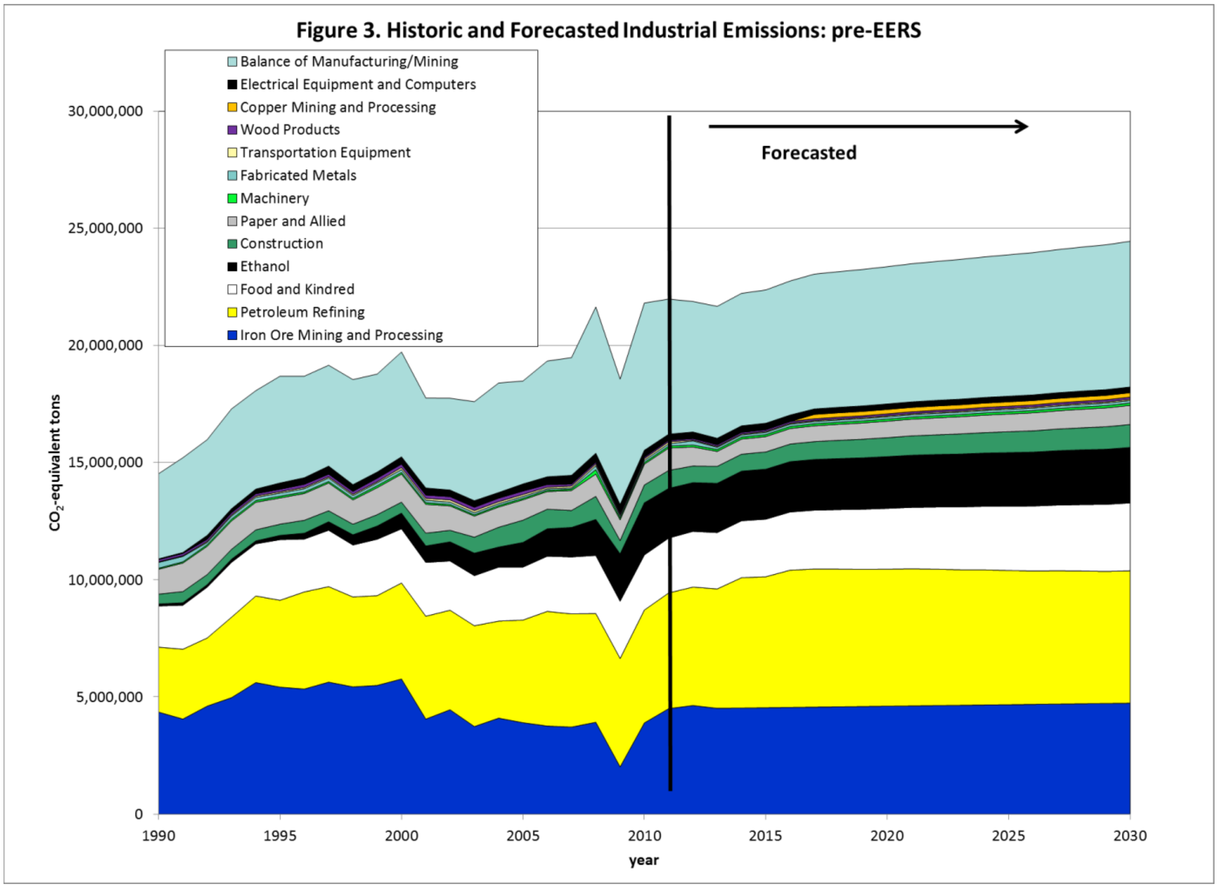


Table I-8 shows numerically the modelled effect of the EERS. By 2030, as a result of the EERS, energy savings equal to about 8 percent of total sector fuel use, are realized in the forecast. At 2020, total energy savings, again as a percent of sector fuel use, are 4 percent.

Also shown in Table I-8 is the projected distribution of fuel use by fuel for selected forecast years. From Table I-8, in 2030, the forecasted share of the industrial fuels market held by natural is 52 percent, that for refinery gas and PSA 18 percent. In 2030, the market share of wood and black liquor is a forecast 11 percent, coal 8 percent and distillate fuel oil 7 percent. This is quite close to the present-day percent distribution of fuel use in the industrial sector (by energy content): natural gas 55 percent; refinery gas and PSA 16 percent; coal 8 percent; wood and black liquor 9 percent; and distillate fuel oil 6 percent. In the forecast, the renewable share of industrial fuel use increases from 10 to 12 percent.

Figure I-4 shows pictorially the forecasted trend in industrial sector fuel use by fuel. Also shown is the historic trend in fuel use back to 1990. In most dimensions, the pattern of forecasted fuel use follows the pattern of forecasted emissions. Over the forecast period, total sector fuel use increases about 5 percent. As noted above, due to the way that the data are collected, it was not possible to determine what effects embedded industrial energy savings might have on the demand for fuels, particularly at the SIC code level. It is possible that, accounting for savings, background levels of growth prior to EERS effects might be higher than estimated here, at least through 2020, and future emissions, again through 2020, correspondingly higher.

Table I-8. Forecast On-site Fuel Use in Minnesota Mining and Manufacturing (million MMBtu)

	2012	2015	2020	2025	2030
Fossil Fuels					
bituminous coal	2.25	1.01	1.02	1.03	1.04
subbituminous coal	19.10	19.79	20.02	20.23	20.41
other coal (coal coke, anthracite)	1.17	1.24	1.36	1.51	1.67
natural gas	158.69	155.52	156.13	156.11	156.16
refinery gas and PSA	49.24	53.59	55.72	54.46	53.62
distillate fuel oil	14.40	15.12	16.98	18.27	19.68
residual fuel oil	2.09	2.29	2.46	2.67	2.91
LPG	2.12	2.15	2.29	2.32	2.34
petroleum coke	1.31	0.87	0.88	0.88	0.89
other oil (gasoline, heavy refinery oil, solvent)	1.64	1.70	1.70	1.70	1.70
waste oil and lubricants	4.81	4.83	4.86	4.90	4.94
solid waste fuels	0.07	0.00	0.00	0.00	0.00
subtotal	**256.89**	**258.09**	**263.43**	**264.08**	**265.36**
Renewable Energy					
wood and wood waste	8.67	10.68	11.58	12.56	13.64
black liquor	15.05	14.67	15.87	17.17	18.58
other solid biomass	0.29	0.31	0.33	0.36	0.39
biogas	0.78	0.85	0.97	1.11	1.26
yellow grease and syrup	0.36	0.83	0.88	0.93	0.99
biofuels	0.80	1.20	1.29	1.38	1.49
subtotal	**25.95**	**28.55**	**30.93**	**33.52**	**36.34**
Total	**282.84**	**286.64**	**294.36**	**297.60**	**301.69**
Renewable Energy as % of total	9%	10%	11%	11%	12%
Total prior to EERS	**284.04**	**291.66**	**305.87**	**315.86**	**326.99**
Energy use avoided due to EERS	**27.15**	**33.57**	**42.43**	**51.78**	**25.30**

From the data shown in Table I-8, it is possible to determine the effects into the forecast period of the implementation of the EERS for natural gas in the industrial sector. The results of that assessment, discussed above as the difference in total emissions between Figures 2 and 3, are shown below in Figure I-5. From Figure 4, by 2030, in absence of Minnesota's conservation programs for natural gas, emissions from on-site combustion in the industrial sector would be some 24.5 million CO_2-equivalent tons, up from a forecast 22 million CO_2-equivalent tons in 2012, growing at a rate of 0.6 percent per year. By 2015, roughly 0.3 million CO_2-equivalent tons of emissions might be expected to be avoided as a result of the natural gas EERS, rising to about 1.07 million CO_2-equivalent tons by 2025 and 1.45 million CO_2-equivalent tons by 2030.

Again, mindful that background emissions prior to the EERS might be higher than are estimated here, at least through 2020 (see earlier discussion of the effects of embedded energy savings through 2020), the estimates given here for avoided emissions are best interpreted as a lower limit to likely levels of emissions-avoided between 2015 and 2020 at 80 percent compliance.

Figure 4. Historic and Forecasted Industrial Fuel Use

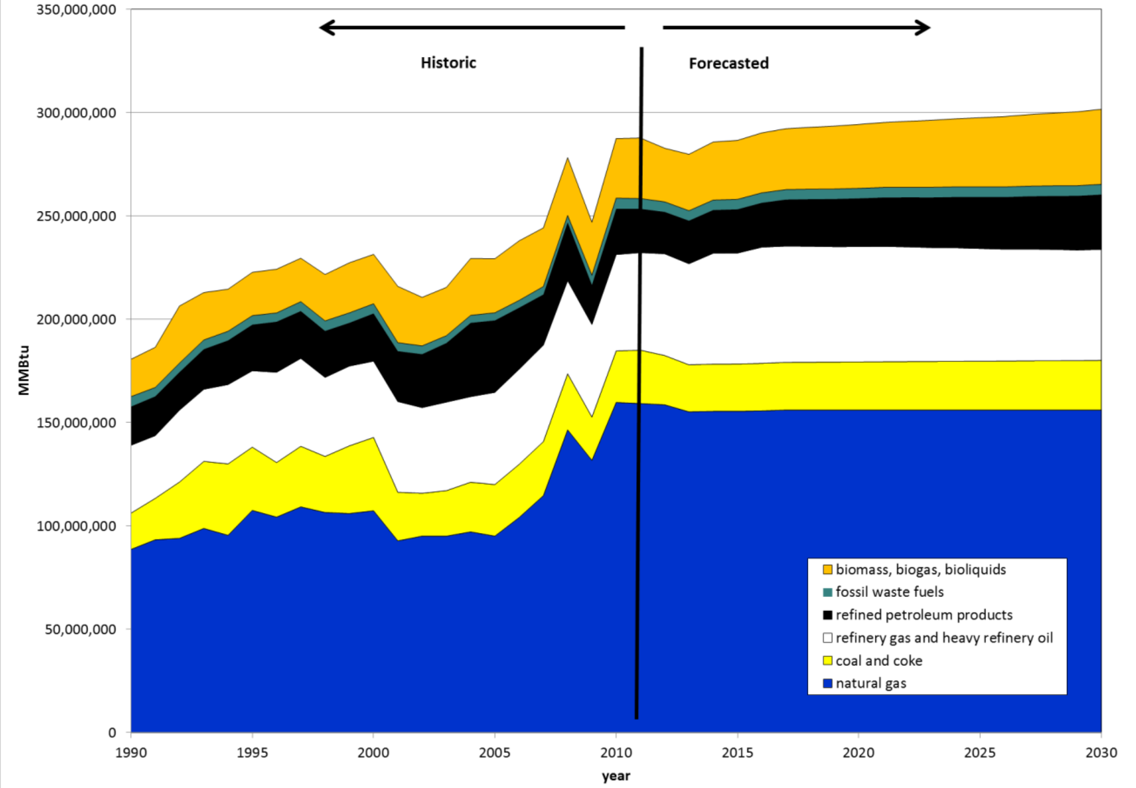
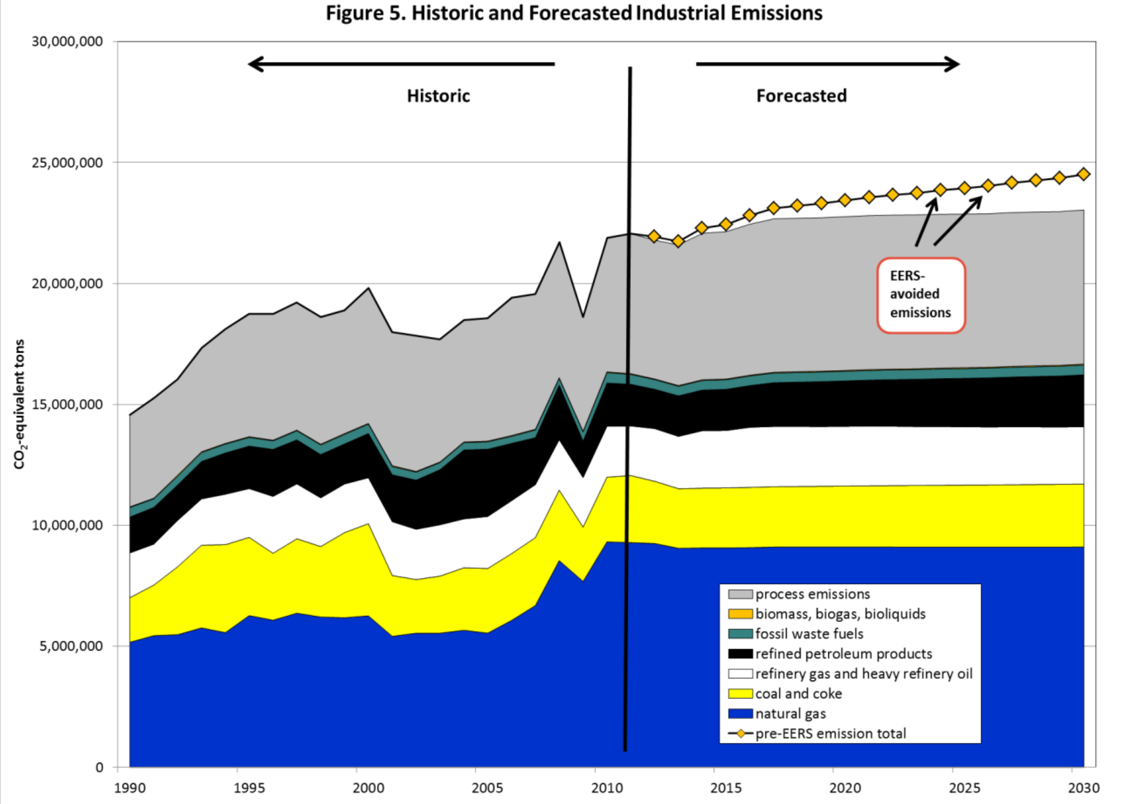


Figure 5. Historic and Forecasted Industrial Emissions



Residential sector

Sector boundaries

The residential sector encompasses all occupied and vacant personal residences in Minnesota, excluding institutional housing like hostels, military barracks, and school dormitories. Included are both owner-occupied units and renter occupied units. By type, included are all detached single family houses, townhouses, mobile homes, and multi-family housing units. The sector includes the structures themselves, space and water heating equipment, other nonelectric energy end-use, and the on-site consumption of nonenergy consumer goods.

Greenhouse gas emissions from Minnesota residences are mostly on-site combustion emissions associated with energy use, principally during space heating and water heating but also cooking, clothes drying and miscellaneous activities. A small statewide emission also results from the household use of medical devices like metered dose-inhalers and the household consumption of consumer products like soaps, detergents, shampoos and food additives. As in the case of other electricity end-use sectors, no electric gird emissions are included in residential sector emission totals. These are included in electric power sector totals. However, fugitive emissions of refrigerants used as the working fluids in certain household electric appliances, like refrigerators, freezers and air conditioners, are treated as residential sector emissions.

Most housing in Minnesota is wood-framed, wood-sheathed housing that, once constructed, remains in-place and in-use for as long as a century. Carbon stored in the structural parts and sheathing of housing was once atmospheric carbon that, upon plant photosynthesis, was withdrawn from the atmosphere and incorporated into the living biomass of trees. In the Minnesota emission inventory, net additions to very long-lived wood storage in the structural parts and sheathing of housing are treated as negative emissions or 'sinks', offsetting a part of emissions from other sources.

Emissions from the Minnesota do not include emissions from personal vehicles. These are included in the Minnesota greenhouse gas emission inventory as transportation sector emissions. Emissions from recreational vehicles, boats and other recreational watercraft, other miscellaneous off-highway activities are likewise included in the transportation sector.

Present-day and historical emissions

Below are estimates for historical emissions from the residential sector for selected years in million CO_2-equivalent tons. The estimates for on-site combustion-based emissions are based on fuel throughput and conventional fuel-based emission factors. Fuel throughput data derives from a number of sources, including: Energy Information Administration (EIA), *Natural Gas Annual*, EIA, *Fuel Oil and Kerosene Sales*, EIA, *State Energy Data System* and, for wood combustion, periodic wood use surveys developed by the Minnesota Pollution Control Agency and Minnesota Department of Natural Resources. Residential coal use in space and water heating is small. Estimated annual coal throughput is based on annual survey data on the number of residences that burn coal for space heating from the *American Community Survey* and an estimated 70 MMBtu of annual use per residence combusting coal.

Emission factors are from the MPCA GHG emission inventory and are generally taken from one of two sources: EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* and Intergovernmental Panel on Climate Change, *2006 IPCC Guidelines for National Inventories*. The emission factor for CO_2 for bituminous coal is a calculated long-term average rate of emission for bituminous coal combusted in the Minnesota electric power sector. The emission factors are based on fuel energy content. Before emissions are calculated for any one fuel or inventory year, fuel is converted to standard units of energy (MMBtu), typically drawn from EIA, *Annual Energy Review*. Physical units of natural gas (MMcf) and LPG (thousand gallons) are converted to MMBtu using the Minnesota-specific heats of combustion given in EIA, *State Energy Data System*. In converting tons of bituminous coal to MMBtu, a long-term average for bituminous coal from the Minnesota electric power sector is used.

Table R-1. Historical Emissions from Minnesota's Residential Sector (million CO_2- equivalent short tons)

	1990	2000	2005	2010	2011
Combustion emissions					
coal	0.01	0.00	0.00	0.00	0.00
oil	2.32	2.51	2.45	1.96	1.85
natural gas	6.28	7.70	7.61	7.26	7.39
other	0.16	0.11	0.13	0.16	0.16
subtotal	**8.77**	**10.32**	**10.20**	**9.38**	**9.40**
Food additives	0.07	0.09	0.13	0.14	0.14
Soaps, shampoos, detergents	0.01	0.01	0.02	0.02	0.02
Urban lawn fertilizer	0.02	0.02	0.03	0.03	0.03
Wood-in-structures	(1.08)	(0.89)	(2.03)	0.51	(0.66)
Refrigerator refrigerant	-	0.00	0.00	0.00	0.00
Air conditioner refrigerant	-	-	0.01	0.08	0.10
HFC-aerosol use	-	0.21	0.15	0.19	0.20
Total	**7.79**	**9.76**	**8.50**	**10.35**	**9.23**

The EPA develops annual estimates of US emissions from the use of soaps, detergents, shampoos, food additives and HFC-based metered dose inhalers from which US *per capita* emissions levels year by year can be determined. Minnesota emissions are calculated from Minnesota state-level population estimates and US *per capita* rates of emission for these sources.

Emissions from the use of lawn fertilizer are calculated using the average rate of US emission per single family housing unit (with mobile homes) and the estimated number of total occupied single family houses and mobile homes in Minnesota. US estimates of emissions from the use of lawn fertilizer are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*.

Refrigerators and freezers manufactured after 1994 are designed to use HFC-based refrigerants. These units emit HFCs, mostly HFC-134a, at a slow, average annual rate equal to about 0.3 percent of their initial refrigerant charge. Emissions of HFC-134a from units in Minnesota are calculated using this rate, an average charge rate per unit of 3.1 lbs., and the estimated statewide stock of post-1994 vintage residential refrigerators and freezers. The statewide stock of post-1994 vintage refrigerators and freezers is derived for each inventory year from regional survey data for 1997, 2001, 2005 and 2009 given in EIA, *Residential Energy Consumption Survey*. By 2009 virtually all occupied residences in the West North Central region of the US had a primary refrigerator, while 30 percent had a second refrigerator, 47 percent had a single stand-alone freezer, and about 5 percent had two stand-alone freezers. By vintage, by 2009 in the West North Central region roughly 70 percent of refrigerators and 48 percent of stand-alone freezers were of 1995 vintage or younger.

The number of total occupied housing units in Minnesota is taken from Census Bureau, *American Community Survey*. Applying the regional rates described above, the stock of post-1994 vintage residential refrigerators and freezers comes to roughly 2.8 million units in 2011. Emissions, however, are small, 0.002 million CO_2-equivalent tons.

Historically, central air conditioning units have used HFC-22 as a refrigerant. Under the Clean Air Act the production of HCFC-22 is scheduled to be completely phased out by 2020; as a prelude, in 2011, allowable domestic US consumption was reduced by two-thirds from average 1994-1997 levels and in 2015 by regulation will fall to just 7 percent of 1994-1997 levels. The principal substitute identified by EPA for this this application is R-410A, a mixture of HFC-32 and HFC-125.

Estimated annual emissions in Minnesota of HFC-32 and HFC-125 from residential central air conditioning are about 0.1 million CO_2-equivalent tons. These estimates, and estimates for earlier years, are based on total refrigerant use, average annual leakage rates from central or unitary air conditioners and the schedule of market penetration, back to 2001 and reaching to 2011, for R-410A in new central AC units (unitary units) developed by EPA for use in its ODS vintaging model. Based on model simulations, the market share of R-410A in new units is probably now greater than 50 percent, up from about 5 percent in 2005. EPA-estimated market share can be found in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Leakage rates also are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. The number of central AC units installed and operating in Minnesota is calculated using regional survey data for 1997, 2001, 2005 and 2009 for central AC penetration from EIA, *Residential Energy Consumption Survey* and state-level estimates of occupied housing in Minnesota.

Household room air conditioners in Minnesota leak a small amount of HFCs to the atmosphere, but total estimates emissions are miniscule, a few hundred CO_2-equivalent tons per year. The methods used to estimate emissions from room air conditioners are similar to those used for household central air conditioning.

Annual removals of CO_2 from the atmosphere are calculated from the incremental change in statewide biogenic carbon storage in residential structures. The US Forest Service develops annual estimates of the per square foot floor space intensity of wood use in new residential structures by housing type. These wood-based intensity measures are readily convertible to measures of biogenic carbon intensity. Using these, an inventory of stored carbon is developed for each housing type for each inventory year. Housing types include: single family homes, multifamily units and mobile home. Total carbon stored is estimated by year of construction. Total carbon storage is summed across all construction years and converted to CO_2-equivalent units.

These estimates are developed bottom-up from modeled residential floor space by housing type, year of construction and inventory year. For any year of construction and housing type, residential floor space equals the number of housing units in that category and the mean size of housing units in that class in the Midwest region. The latter are given in Census Bureau, *Construction Reports*. Total housing units in Minnesota, occupied and vacant, are given by housing type in *American Community Survey* and, for years prior to 2003, Census Bureau, *Decennial Census of Housing*. Census Bureau also provides annual estimates of the total housing stock by year of construction. For any given inventory year, single family units by year of construction equals the total housing supply, again by year of construction, less the stock of multifamily units and mobile homes, again developed by year of construction. The stock of multifamily units and mobile homes is developed from the record of multifamily unit completions, and for mobile homes, manufactured housing placements. These are given in Census Bureau, *Construction Reports*. Totals units are trued to the reported totals given in *American Community Survey* for multifamily unit and mobile homes through orderly unit retirements, starting with the very oldest units.

Table R-2 provides summary statistics for housing units, floor space, and per square foot biogenic carbon intensity of the housing stock. Between 2000 and 2011, the housing stock in Minnesota increased 12 percent between 2000 and 2011, at an average annual rate of 1 percent year. The increase in total floor space has been somewhat larger over the same period, about 18 percent. Average annual carbon storage over this period was some 0.86 million CO_2-equivalent tons.

Table R-2. Long-lived Biogenic Carbon Storage in Minnesota Housing (million CO_2-equivalent short tons)

	1990	2000	2005	2010	2011
Housing units (million)	1.87	2.09	2.25	2.35	2.35
single family (SF)	1.34	1.53	1.69	1.75	1.76
multi-family (MF)	0.45	0.46	0.47	0.52	0.51
mobile homes (MH)	0.08	0.10	0.09	0.09	0.09
net annual additions to stock	0.03	0.02	0.04	0.02	0.01
Floor space (billion sq ft)	2.79	3.25	3.61	3.82	3.85
single family	2.28	2.69	3.02	3.20	3.23
multi-family	0.44	0.46	0.47	0.52	0.51
mobile homes	0.07	0.10	0.11	0.10	0.10
Mean floor space, existing SF home (sq ft)	1,696	1,759	1,794	1,835	1,838
Mean floor space, new SF home (sq ft)	2,005	2,170	2,310	2,265	2,287
lbs of wood-based carbon per sq ft floor space	11.46	11.25	11.22	10.82	10.84
existing single family	12.74	12.33	12.14	11.73	11.72
existing multi-family	5.89	6.25	6.34	5.96	6.04
existing mobile homes	4.53	5.48	6.76	7.04	7.06
new single family	11.13	10.29	9.45	9.12	9.12
Yearly gain or loss of long-lived biogenic carbon in structures (million CO_2-e tons)	1.08	0.89	2.03	(0.51)	0.66

Attribution of Emissions to End-Use Activities

In the residential sector, most fuel use is for space heating, water heating, cooking and clothes drying. Of the fuel used in Minnesota housing, about 80 percent, is in space heating. Of the remainder, about 18 percent of fuel use is for water heating and about 1 percent is used for cooking and clothes drying each. Natural gas, LPG, distillate fuel oil, bituminous coal, and wood are combusted to provide space heat in Minnesota residences, as is a small amount of kerosene. In Minnesota housing, water is heated using natural gas and LPG, with small amounts of distillate fuel oil and bituminous coal also utilized. Natural gas and LPG are used for cooking, while natural gas is the only fuel directly combusted in Minnesota residences in clothes drying.

On-site fuel use in Minnesota's residential is shown in Table R-3 for selected years by end use and fuel type. Also shown are data for the state housing stock, estimated occupied square feet of floor space in the state, and average total fuel use levels per housing unit and per square foot of occupied floor space, again by selected year. Fuel use in water heating, cooking and clothes drying is generally higher now than in 1990, about 25 percent higher for water heat and 40 to 80 percent for clothes drying and cooking, respectively. The record of fuel use in space heating is noisier, the result of substantial interannual variability in weather. Between 1990, total on-site fuel use in space heating increased about 5 percent. Average on-site fuel use per household declined about 15 percent between 1990 and 2011, and fuel use levels per square foot of occupied floor space declined about 20 percent. Total occupied square feet of residential floor space increased about 35 percent.

Table R-3. Minnesota Residential On-site Fuel Use

	1990	2000	2005	2010	2011
On-site fuel use (million MMBtu)					
Coal	0.07	0.02	0.03	0.01	0.02
Oil	30.33	34.21	33.35	27.14	25.87
Natural gas	107.32	131.64	130.05	124.21	126.40
Renewable	19.60	13.93	15.70	19.58	19.58
Total	**157.32**	**179.81**	**179.13**	**170.94**	**171.87**
% Renewable	12.5%	7.7%	8.8%	11.5%	11.4%
Space heating	130.92	148.64	143.62	136.88	137.86
Water heating	22.75	25.69	29.16	28.72	28.77
Cooking	2.34	3.82	4.20	4.29	4.28
Clothes drying	1.79	2.20	2.75	2.47	2.46
Total	**157.81**	**180.35**	**179.73**	**172.35**	**173.38**
Households (millions)	1.65	1.90	2.04	2.09	2.10
Occupied floor space (billion sq ft)	2.48	2.94	3.23	3.41	3.42
MMBtu/household	95.47	94.88	87.82	81.90	81.79
btu/sq foot floor space	0.063	0.061	0.055	0.050	0.050

By fuel, from Table R-3, natural gas is overwhelmingly the principal fuel used in Minnesota residences, accounting for about three-quarters of on-site fuel use. Wood use accounts for about 12 percent of direct fuel use in Minnesota residences, a value largely unchanged since 1990.

Fuel use was attributed to specific end-uses using the data shown in Table R-4 for historic use levels by end-use and fuel type. Total fossil fuel use in space heating equals total fossil fuel use (MMBtu-basis) less fossil fuel used in water heating, cooking and clothes drying, again on an MMBtu-basis. Wood use in space heating equals total wood use for primary and secondary space heating plus recreational uses of wood. Fossil space heating intensity equals total fossil fuel input to space heating (MMBtu-basis) divided by total square feet of occupied floor space heated through on-site combustion of natural gas, LPG, distillate or coal, and normalized for heating degree days.

The values given in Table R-4 for fuel use per household for water heating are regional values (West North Central region) for 1990 through 2011 from EIA, *Residential Energy Consumption Survey*. The values given for cooking and clothes drying are, for 1998-2011, regional values, from EIA, *Annual Energy Outlook (1999-2014)*, and for 1990 and for 1990 and 1997, regional values from AGA, *Patterns in Residential Natural Gas Consumption*. The values shown for market mix for water heating, cooking and clothes drying are reconstructed values derived from the periodic *American Housing Survey for Minneapolis-St. Paul SMA*. For 2011, for water heating, natural gas had an approximate 57 percent market share and LPG 5 percent; electric water heat accounted for the remainder of the market (32 percent). An estimated 7 percent of housing units had no water heating. For cooking, natural gas, LPG and electricity had market shares in 2011 of 34, 3 and 63 percent, respectively. For clothes drying, natural gas had an approximate 39 percent market share, and electricity the remainder. In 2011, 14 percent of occupied housing units had no clothes drying.

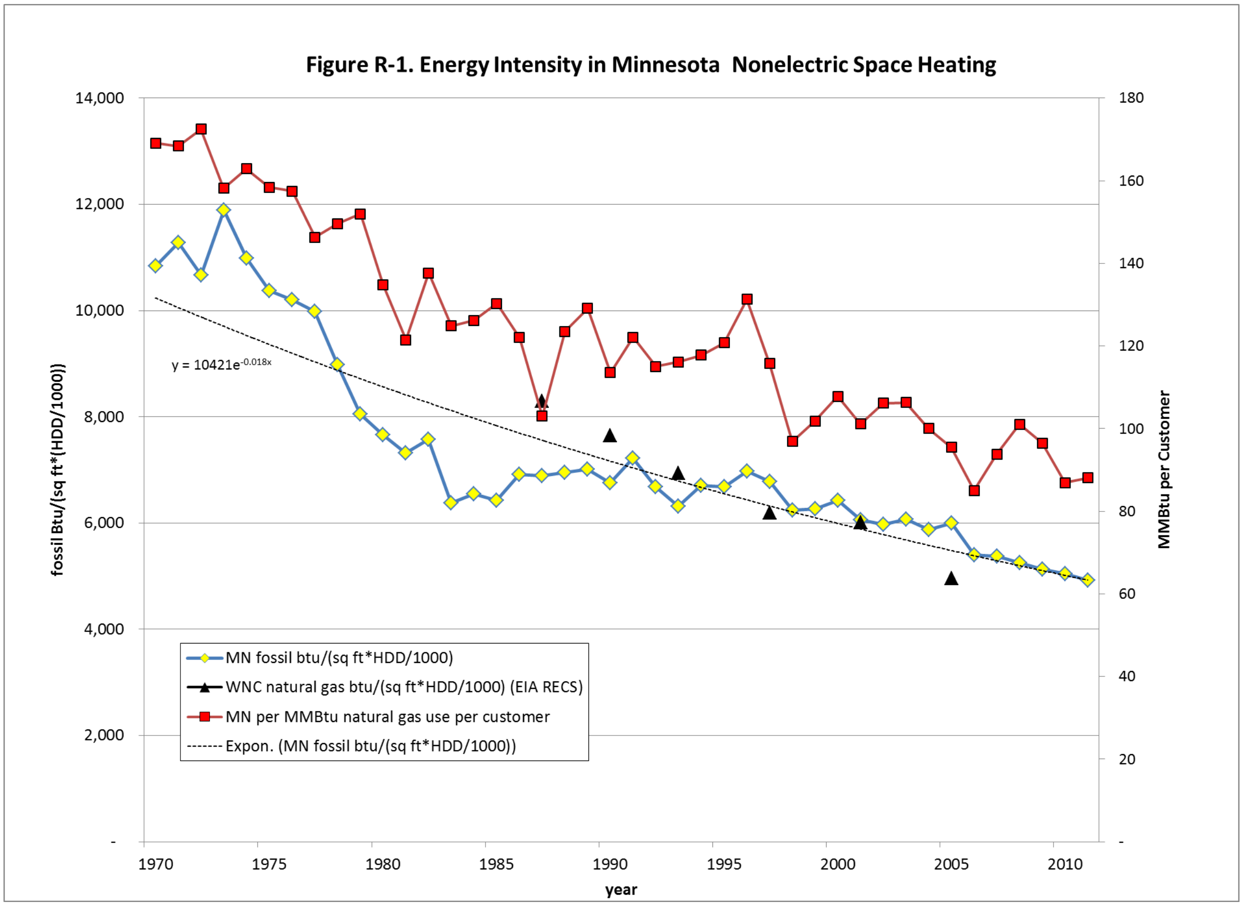
Table R-4. Average Fuel Use by Fuel Type and End-Use in Minnesota for Selected Years

	1990	2000	2005	2010	2011
Space Heating Energy Intensity					
fossil btu/(sq ft*HDD/1000)	6,752	6,421	5,998	5,048	4,921
occupied floor space, fossil fuel-heated (million sq ft)	2,112	2,544	2,756	2,834	2,825
Unit energy Use (UEC) (MMBtu/housing unit)					
Water heating					
natural gas	21.95	21.03	22.60	22.58	22.58
LPG	20.20	17.29	25.40	18.72	18.72
distillate fuel oil	20.20	17.29	25.40	18.72	18.72
coal	25.25	24.18	25.99	NA	NA
Cooking					
natural gas	4.13	5.52	5.69	5.60	5.58
LPG	4.42	6.90	5.34	5.43	5.43
Clothes drying					
natural gas	3.93	3.59	3.61	3.00	2.97
Market share for on-site fossil fuel use (%)					
Space heating	83%	84%	83%	81%	80%
Water heating	60%	64%	63%	62%	62%
Cooking	34%	36%	37%	37%	37%
Clothes drying	27%	32%	38%	39%	39%
* principal alternatives include electricity, w ood, solar and none					

In 2011, space heating at 80 percent of occupied units in Minnesota was with on-site fossil fuel use, the rest was electric heat (16 percent), or wood-based space heat (3 percent). Approximately 1 percent of units had no space heat. These data are from Census Bureau, *American Community Survey* and reach back to 2001. Earlier data on space heating market fix are from the *Decennial Census of Housing*. By fuel, in 2011, natural gas was used in 67 percent of occupied Minnesota housing units, LPG in 11 percent, and distillate fuel oil in 3 percent.

The historic data on occupied residential floor space were developed from the information shown in Table R-2 and state-level information on vacancy rates from Census Bureau, *American Community Survey* and *Decennial Census of Housing*. Occupied residential floor space was apportioned to on-site fossil heating systems, electric systems, and wood-based systems using the percentage distribution of space heating by energy source given in Census Bureau, *American Community Survey* and the *Decennial Census of Housing*. Heating degree days (HDDs) are taken from NOAA, *Heating Degree Data, Monthly Summaries*. Population-weighted HDDs were used.

From Table R-4, space heating intensity for fossil fuels in Minnesota declined an estimated 27 percent. Going back to 1970, the calculated decline is closer to 55 percent. This is shown in Figure R-2, along with the trend in space heating intensity in the West North Central region for 1990 through 2005 from the EIA *Residential Energy Consumption Survey*. The measure of space heating intensity that is employed–btu/(sq ft * HDD/1000)—is from EIA *Residential Energy Consumption Survey.* The more familiar trend in residential natural gas use per customer in Minnesota is also shown. About 85 percent of occupied units that heat using fossil fuels do so with natural gas. Roughly three-quarters of natural gas use in Minnesota is in space heating, requiring that the per customer trend in natural gas use necessarily reflects long-term trends in natural gas space heating efficiency.[16] Between 1970 and 2011, space heat intensity for fossil fuels, adjusted for climate, declined at an average annual rate of 1.8 percent per year.



Emissions, apportioned to end-uses, are shown in Table R-5 for selected years. Space heating accounts for about 80 percent of emissions on an annual basis. Most of the rest results from fuel use in water heating. Emissions associated with space heating increased perhaps 1 percent between 1990 and 2011, though the record exhibits substantial interannual variability due to weather. Emissions from water heating, cooking and clothes drying are generally higher now than in 1990, about 30 percent higher for water heat and 40 to 80 percent for clothes drying and cooking, respectively.

These same data are shown graphically in Figure R-2 by end-use. Evident from Figure 2 is the singular importance of space heating and water heating to sector totals. In general, and against leaving aside 1990, emissions associated with space heating and water heating generally decline over the historical period, albeit at a slow rate. The growth that there is in emissions comes from increased emissions of HFCs used as refrigerants in air conditioners. Total sector emissions are the sum of emissions plus sinks. Long-term carbon storage in residences, particularly strong between 2002 and 2007, and then weak from 2008-2010, generally acts to push up net emissions over the historical period. Using 1990 and 2011 end-points, net residential sector emissions rise over the forecast period 18 percent. Regressing the net emissions data, 1990-2011, against time gives a more muted 8 percent increase in emissions over the historical period.

[16] Between 1970 and 2011, floor space in the typical occupied housing unit in Minnesota increased about 13 percent. Declining average natural gas use per household, 1970-2011, did not result from declining home size.

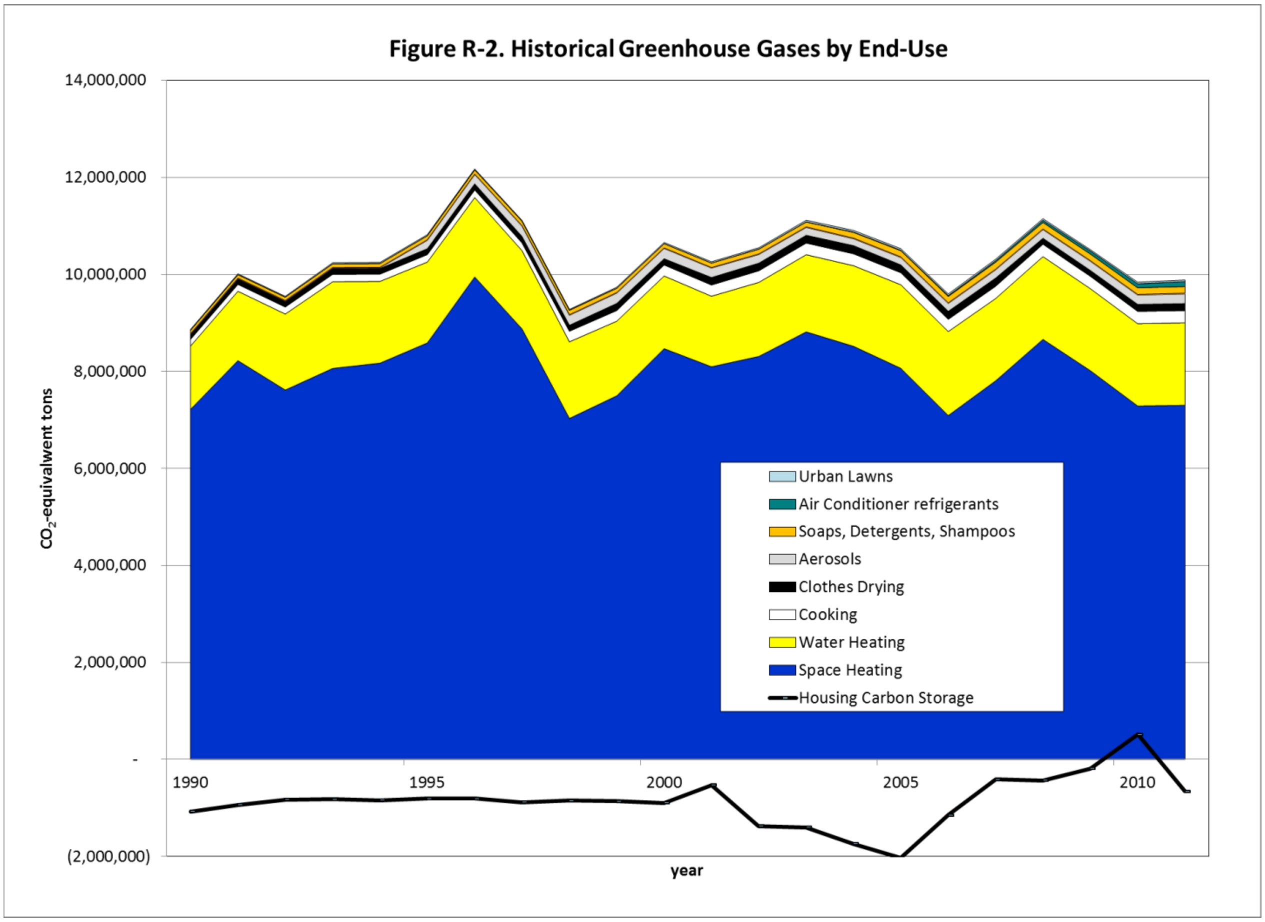
Full documentation of the sources and methods used to develop the residential sector inventory is included in Appendix E of P. Ciborowski and A. Claflin, "Greenhouse Gas Emissions in Minnesota: 1970-2008: Second Biennial Progress Report – Technical Support Document" (2012).

Table R-5. Historical Emissions from Minnesota's Residential Sector by End-Use (million CO_2- equivalent short tons)

	1990	2000	2005	2010	2011
Combustion emissions					
Space heating	7.22	8.47	8.06	7.29	7.30
Water heating	1.31	1.50	1.72	1.70	1.70
Cooking	0.14	0.23	0.25	0.25	0.25
Clothes drying	0.10	0.13	0.16	0.14	0.14
subtotal	8.77	10.32	10.20	9.38	9.40
Food additives	0.07	0.09	0.13	0.14	0.14
Soaps, shampoos, detergents	0.01	0.01	0.02	0.02	0.02
Urban lawn fertilizer	0.02	0.02	0.03	0.03	0.03
Wood-in-structures	(1.08)	(0.89)	(2.03)	0.51	(0.66)
Refrigerator refrigerant	-	0.00	0.00	0.00	0.00
Air conditioner refrigerant	-	-	0.01	0.08	0.10
HFC-aerosol use	-	0.21	0.15	0.19	0.20
Total	**7.79**	**9.76**	**8.50**	**10.35**	**9.23**

Forecast methods

The forecast was developed using the same sector boundaries as underlie the sector inventory. Emissions from energy use were limited to those from on-site combustion activities; emissions associated with electricity consumed at Minnesota residences but generated off-site were not included. Process emissions include: refrigerant HFCs from air conditioners and refrigeration equipment, medical devices like metered dose-inhalers and the household consumption of consumer products like soaps, detergents, shampoos and food additives. Long-term wood-based carbon storage in the structural parts and sheathing of housing is treated as an emission offset. The residential sector encompasses all occupied and vacant personal residences in Minnesota, excluding institutional housing like hostels, military barracks, and school dormitories.



The emissions forecast is shown below in Table R-6 for selected years in millions of CO_2-equivalent tons. In the forecast, emissions decline 13 percent from 2011 levels. Emissions from on-site combustion decrease 14 percent, from 9.4 million CO_2-equivalent tons in 2011 to 8.05 in forecast year 2030. Process emissions (with sinks) increase 0.18 million CO_2-equivalent tons, from -0.11 million CO_2-equivalent tons in 2011 to +0.01 million CO_2-equivalent tons in 2030.

In developing the forecast, combustion emissions and process emissions were projected separately. The forecast of combustion emissions was developed on an end-use basis. Using trended nonelectric fossil space heating intensity (see discussion above), and projected additions and retirements to the housing stock, total future fossil fuel inputs to space heating were estimated to 2030. This was distributed among natural gas, LPG, distillate fuel oil and coal using a distribution near the present percent distribution. To accommodate the energy savings provisions of Minnesota statute specific to natural gas, forecasted natural gas use in residential space heating was then adjusted downward to reflect full compliance with statutory goals. Minnesota statute requires annual energy savings in natural gas usage through demand-side management programs equal to 1% of average usage. Emissions from space heating were calculated from adjusted fuel totals using fuel-specific emission factors for CO_2, CH_4 and N_2O.

Table R-6. Forecasted Emissions from Minnesota's Residential Sector (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Combustion emissions					
coal	0.00	0.00	0.00	0.00	0.00
oil	1.53	1.66	1.56	1.48	1.39
natural gas	6.82	7.40	7.08	6.68	6.49
other	0.15	0.15	0.15	0.16	0.17
subtotal	**8.52**	**9.21**	**8.80**	**8.32**	**8.05**
space heating	6.49	7.16	6.75	6.27	6.04
water heating	1.62	1.63	1.60	1.57	1.52
cooking	0.26	0.27	0.28	0.30	0.31
clothes drying	0.16	0.16	0.17	0.18	0.19
subtotal	8.52	9.21	8.80	8.32	8.05
Food additives	0.15	0.16	0.19	0.21	0.23
Soaps, shampoos, detergents	0.02	0.02	0.02	0.02	0.02
Urban lawn fertilizer	0.03	0.03	0.03	0.04	0.04
Wood-in-structures	(0.66)	(1.00)	(0.92)	(0.83)	(0.88)
Refrigerator refrigerant	0.00	0.00	0.00	0.00	0.00
Air conditioner refrigerant	0.13	0.21	0.38	0.44	0.39
HFC-aerosol use	0.18	0.19	0.19	0.20	0.21
Total	**8.37**	**8.82**	**8.70**	**8.40**	**8.06**

To forecast emissions from water heating, an average per household rate of fuel use (unit energy consumption or UECs) for water heating was developed for each fuel type from the forecast data given in EIA, *Annual Energy Outlook 2014*. Estimates were developed out to 2030 for the total number of households likely to use natural gas and LPG for water heating, based on projected total Minnesota households from the Minnesota State Demographer's Office and an assumed future market share of the water heating for natural gas and LPG at or very near present levels. Fuel use, calculated for each fuel for all years of the forecast period, was, in the case of natural gas use, adjusted downward to reflect full compliance with statutory energy savings goals. Emissions were calculated from fuel totals using fuel-specific emission factors for CO_2, CH_4 and N_2O.

State-level use of natural gas and/or LPG in cooking and clothes drying was forecast using regional forecast UECs for these end-uses, again developed from *AEO 2014*, and projections of fuel market share and total households. Market share was assumed to remain at or very near present levels for LPG and natural gas. Emissions were calculated from forecast fuel totals again using fuel-specific emission factors for CO_2, CH_4 and N_2O.

Wood is used for primary and secondary space heating and in recreational burning. Methane is produced during the combustion of wood, as is a small amount of N_2O. State-level wood use for primary space heating was forecast using a calculated 2008 UEC from MPCA inventory data for this source and market share increasing from 2.6 percent in 2011 to 4 percent in 2030. Little is known about recreational uses of wood. Given the paucity of information here, recreational uses were held constant in the forecast at present levels. Uses of wood for secondary heating have declined dramatically since 1990, by probably more than half. The use of wood for secondary heating is assumed to continue to decline linearly throughout the forecast period at historic rates. Emissions were calculated from forecast fuel totals using fuel-specific emission factors for CH_4 and N_2O.

Table R-7 shows forecast UECs utilized in developing the residential forecast by end-use and by fuel for selected years. Also shown is the forecasted trend in space heating energy intensity and parameters used to calculate fuel inputs to space heating. By 2030 forecasted space heating intensity declines by 30 percent from 2011 levels. The energy intensity of space heating, measured on a square foot basis, is about 10 percent lower at forecast year 2030 than it would otherwise be in absence of Minnesota's energy saving requirement (energy efficiency resource standard or EERS). Occupied floor space increases about 20 percent over the forecast period. Population-weighted heating degree days decline about 8 percent from average 2009-2011 levels

The heating degree day forecast that was used is from EIA, *Annual Energy Outlook 2014*, West North Central region output. Population-weighted HDDs for Minnesota for 2009-2011 were used as the base condition. The percent change from 2011 levels in *AEO 2014* regional HDDs was calculated for each forecast year. Minnesota population-weighted HDDs were forecast using this schedule of change in HDDs at the regional level and 2011 Minnesota HDDs as the base level.

Table R-7. Measures of Energy Intensity in Minnesota Residences

	2012	2015	2020	2025	2030
Space Heating Energy Intensity					
fossil btu/(sq ft*HDD/1000) before EERS	5,003	4,823	4,524	4,224	3,925
fossil btu/(sq ft*HDD/1000) after EERS	4,963	4,652	4,169	3,712	3,461
occupied floor space, fossil fuel-heated (million sq ft)	3,001	3,117	3,307	3,477	3,628
populaton-weighted HDDs	8,599	7,949	7,883	7,812	7,739
Unit energy Use (UEC) (MMBtu/housing unit)					
Water heating					
natural gas	21.00	20.57	19.93	19.48	18.87
LPG	18.65	18.13	17.50	17.04	16.12
Cooking					
natural gas	5.49	5.43	5.34	5.26	5.21
LPG	5.52	5.46	5.38	5.29	5.23
Clothes drying					
natural gas	2.87	2.87	2.86	2.84	2.80

The forecast change in occupied residential floor space was developed from an extension of the existing inventory of total and occupied floor space by housing type and year of construction. Occupied floor space is the total floor space adjusted for vacancy rates, which in Minnesota characteristically run about 10 percent. To extend the existing inventory, total demand for housing was taken from projected total households from the Minnesota State Demographer. The inherited stock of housing less retirements was brought forward. Any new additions that might be needed are the difference between the demand for housing in any forecast year and inherited stock less retirement. New units were added in this amount each forecast year, bringing supply and demand into balance.

New additions were apportioned to single family units, multi-family units and mobile homes to support a predetermined distribution of total units by housing type. The present distribution of housing units by type is: single family 75.2 percent, multifamily 21.7 percent, and mobile home 3.2 percent. This is forecast to change only slightly by 2030, to 76.1 percent for single family, 22.7 percent for multifamily and the remainder to mobile homes. These forecast levels were calculated using the percent changes in the distribution of housing by housing type from 2011 levels given in *AEO 2014* for the West North Central region.

Regarding retirements, each year, about 0.5 percent of the housing stock is retired. By housing type, the percent of the existing stock that in the forecast is retired would be, for single family units, 0.3 percent per year, for multifamily units, 0.2 percent year and, for mobile homes 3.3 percent per year. Units are retired in order of oldest to newest. In the existing inventory, a mean housing size is assigned to housing by year of construction and housing type. These are taken from the historical series developed for the Midwest by the Census Bureau, *Characteristics of New Housing* and *Manufactured Homes Survey*. Best fit to these data for the most informative time segment, 2001-2011 gives an average annual rate of increase in the size of new constructions, all types, of 0.85 percent per year, the rate then used to inflate the size of future new construction.

Totals for occupied residential floor space were developed by summing across occupied floor space for all years of construction and housing types. In the forecast, occupied residential floor space increases from about 2.8 billion square feet in 2011 to 3.6 billon square feet in 2030. Total residential square feet increases from 3.9 billon square feet in 2011 to 5.0 billion square feet in 2030. The average housing unit size, summing across all housing types, is projected to increase to 1,699 square feet in 2020 and 1,731 square feet in 2025, which agrees well with *AEO 2014* estimates for the West North Central region (1,736 in 2020 and 1,771 in 2025). The average size of all existing units in 2011 was an estimated 1,630 square feet.

Forecast market shares for space heating, water heating, cooking and clothes drying for the forecast period are shown in Table R-8. For all types of spacing heating other than natural-gas fired space heating, ten-year linear tends were calculated and extended to 2030. The residual, 65 to 68 percent of the market, depending on forecast year, is the market share accruing to natural gas. For water heat, little change was envisaged, with the exception of a return to 3 percent levels for homes lacking any water heating. Prior to about 2004, it was rare for more than a few percent of home to lack water heat.

For cooking, linear trends in market share for natural gas and LPG were calculated using 2000-2011 data and extended to 2030, and the market share of electricity was adjusted to fit the result. In the forecast, in clothes drying, natural gas gains parity with electricity and the percent of homes with no clothes drier stabilizes at 10 percent.

In 2010, Minnesota began implementing its energy efficiency resource standard (EERS). Under Minnesota state statute, regulated natural gas distribution utilities are required to demonstrate for each year beginning in 2010 annual energy savings on the part of their customers equal to one percent of average retail sales for the prior three years. The effect of this was modeled for space heating and water heating, which together account for about 95 percent of natural gas use in Minnesota. EERS energy savings for any forecast year were calculated using modeled demand for the prior three forecast years. As discussed earlier, energy savings, expressed as MMBtu, were then subtracted from what demand for natural gas in any forecast year would have been in absence of statutory requirements. What in any forecast year demand would have been absent an EERS was calculated from the modeled schedule of demand for natural gas pre-EERS, 2011-2030. Implicit in this schedule is, for each forecast year, an increase in demand to which markets in natural gas are assumed to return once the prior year's EERS requirements have been satisfied. Demand prior to the EERS is this growth plus the modeled post-EERS estimates of natural gas use for the prior year.

Table R-8. Forecast Market Share for Space Heat, Water heat and Appliances

	2012	2015	2020	2025	2030
Space heating					
natural gas	68%	68%	67%	66%	65%
LPG	10%	10%	10%	10%	9%
distillate fuel oil	3%	2%	2%	1%	1%
wood	3%	3%	3%	4%	4%
electric	15%	15%	16%	17%	19%
other and none	2%	2%	2%	2%	2%
Water Heating					
natural gas	57%	58%	59%	59%	59%
LPG	5%	5%	5%	5%	5%
electric	32%	33%	33%	33%	33%
none	6%	4%	3%	3%	3%
Cooking					
natural gas	34%	34%	35%	35%	36%
LPG	3%	3%	3%	3%	4%
electric	63%	63%	62%	61%	61%
Clothes drying					
natural gas	43%	44%	45%	45%	45%
electric	43%	44%	45%	45%	45%
none	13%	12%	11%	10%	10%

For space heating the schedule of demand for natural gas prior to the EERS (or absent the EERS) was developed from trended historical data for the energy intensity of space heating (per unit of floor space) and total projected floor space for each forecast year. For water heating the schedule of demand for natural gas prior to EERS was developed from *AEO 2014* UECs, the projected fuel mix in water heating, and forecast numbers of households, again as discussed above.

In Minnesota, energy savings requirements have been in-place for a number of years under the Conservation Improvement Program. As a result, embedded energy savings are already implicit in the observed demand for natural gas. In the calculation of pre-EERS demand or demand prior to EERS, these were removed. All embedded savings were assumed to be savings in natural gas used in space heating. Data, developed by the Minnesota Department of Commerce (MDOC) for energy savings under the CIP, 1997-2011, were used in the calculation. The MDOC data do not disaggregate savings by end-use. The removal of these savings resulted in an adjusted trend in space heat energy intensity with intensity levels about 6 percent higher in 2011 than would be calculated without the removal of embedded savings. At 2030, with these savings removed, the trended intensities would be roughly 12 percent higher than the trend inclusive of these savings.[17]

An average 1 percent EERS savings requirement was used for the residential sector as a whole. This includes a 1 percent savings target for water heating and a 1.07 percent requirement for space heating. As just noted above, in the modeling, EERS requirements were applied only to natural gas use in space heating and water. The slightly higher 1.07 percent requirement was used for space heating to cover the

[17] For the larger demand schedule for natural gas prior-to-EERS, a data point was calculated for 2030, using the best linear fit to the most recent 25 years of adjusted data. . A straight-line linear relation was assumed between end-points at 2011 and 2030. The adjusted 2011 value is the 2011 estimate shown in Figure R-1 adjusted for known CIP savings.

residual uses of natural gas in cooking and clothes drying that were not otherwise treated in the analysis of the future effects of Minnesota's natural gas EERS.

Finally, in the MPCA analysis of the EERS it was implicitly assumed that, for each forecast year, the annual increase in natural gas demand prior to any energy savings returns to pre-EERS levels. This may or may not be a good assumption.

Forecasted on-site fossil fuel use in Minnesota's residential sector is summarized in Table R-9 by fuel and end-use for selected years. In the forecast, total on-site fuel use declines about 12 percent from 2011 levels by 2030. By end-use, on-site combustion associated with space heating declines in the forecast by about 14 percent, and water heating about 11 percent. By fuel, natural gas use declines in the forecast by 12 percent, 2011-2030, oil use by 22 percent. Wood use increases by 7 percent in the forecast. Projected total fuel use is roughly 10 percent lower in 2030 that it would otherwise be absent the EERS for natural gas. In the final five years of the forecast, natural gas use declines at an average annual rate of 0.7 percent, an average annual rate of decline matching that for the prior five year period (2020-2025).

Table R-9. Forecasted On-site Fuel Use in Minnesota's Residential Sector (million MMBtu)

	2012	2015	2020	2025	2030
On-site Energy Production (million MMBtu)					
Coal	0.02	0.02	0.02	0.02	0.01
Oil	26.13	23.61	22.43	21.31	20.17
Natural gas	136.22	126.39	121.01	114.12	111.05
Renewable	18.99	18.56	19.10	19.93	20.92
Total	181.37	168.58	162.56	155.39	152.15
Total before EERS	182.66	173.86	174.12	172.87	169.94
Average annual rate of increase in natural gas use:					
before EERS *	NR	1.0%	0.5%	0.3%	0.1%
after EERS *	NR	0.0%	-0.5%	-0.7%	-0.7%
On-site energy end-use (million MMBtu):					
Space heating	147.04	133.83	127.80	120.75	118.09
Water heating	27.34	27.47	27.02	26.51	25.58
Cooking	4.33	4.48	4.75	4.99	5.25
Clothes drying	2.66	2.79	2.99	3.13	3.23
Total	**181.37**	**168.58**	**162.56**	**155.39**	**152.15**

*Average annual rate of increase for the period beginning in 2001 and terminating in the year designated in the column

Noncombustion process emissions from the use of soaps, detergents, shampoos, food additives and HFC-based metered dose inhalers were forecast on a *per capita* basis using population projections developed by the Minnesota State Demographer and, for HFC-based aerosols, average 1998-2011 per *capita rates* and, for soaps, detergents, shampoos, and food additives, linearly trended *per capita* estimates developed from historical 1990-2011 data. For HFC-based aerosols, no discernible trend in *per capita* emission rate is evident in the data back to 1998. Emissions from the use of lawn fertilizer were projected based on forecast numbers of single family housing units (see discussion above) and prevailing rates of per household emissions (5-year, 2006-2011, average).

CO_2-offsets through housing inventory change were estimated using the same stock approach described above. For any forecast year, wood-based carbon storage by year of construction equals total residential floor space for that year of construction and average carbon stored per square foot of floor space for that housing type and year of construction. Average rates of carbon storage per unit of floor space were projected. Residential floor space, both occupied and vacant, was forecast on the basis of population projections of the State Demographer, vacancy rates, and other factors described above (see discussion above). Biogenic carbon storage was then calculated for each forecast year for each year of construction and each housing type and totaled. CO_2 offsets through housing inventory change were calculated from the year-to-year change in total carbon storage converted to tons of CO_2.

Regarding forecast rates of carbon storage, carbon storage in new mobile homes was assumed to stabilize at 0.005 tons per square foot, the prevailing level. For multi-family homes, average carbon storage per square foot of floor space likewise was assumed to stabilize, at average 1997-2011 values. Little discernible trend in rates of carbon storage in multifamily units is evident in the reconstructions housed in the MPCA GHG Emission Inventory database, at least back to 1997. Average carbon storage per square foot of single family floor space declines in the forecast about 25 percent, based on linearly trended data back to 1980.

Noncombustion emissions from air conditioning were forecast using present-day emissions rates (percent of charge) and total forecasted HFC refrigerant in use in Minnesota. Nearly all emissions from residential air conditioning (AC) derive from leakage from central AC. Forecast HFC refrigerant in use is given by the average refrigerant charge of central AC units (lbs. per unit) at full charge, the forecast number of occupied residential units in Minnesota, the forecast percentage of occupied housing units with central air conditioning and the percentage of those units that use HFC refrigerants. As of 2009, based on the regional penetration of air conditioning given in EIA, *Residential Energy Consumption Survey* (RECs), 75 percent of all housing units were equipped with central AC. In the forecast, the percent of Minnesota households with central air conditioning increases linearly at the average rate of gain, 2002-2009, until, at 2020, 90 percent of all households have central air conditioning.

For any forecast year, the number of units using HFCs was calculated from the 2009 age distribution of central AC units from the RECs, the percent penetration of HFCs in the inherited stock by age of unit, and the schedule of HFC penetration of new central air conditioners given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. The method used to forecast the number of occupied housing units in Minnesota out to 2030 was discussed above. The average per unit charge of refrigerant is assumed to remain unchanged from current levels.

In 2011, an estimated 12 percent of refrigerant used in central air conditioning in Minnesota was HFC-based. By 2030, this is projected to increase to 63 percent. Of this, about three quarters is assumed to be in the form of HFC-32, based on the schedule given in EPA, *Benefits of Addressing HFCs under the Montreal Protocol*. The remainder is R-410A, which is a mix of 50 percent HFC-32 and 50 percent HFC-125.

Emissions from residential refrigeration were projected from numbers of forecast occupied housing units, the percent of housing units with a primary and or a secondary refrigerator and a primary and or a secondary freezer, the average refrigerant change per unit, and the present-day emission rate (percent of initial charge). The method used to forecast the number of occupied housing units in Minnesota out to 2030 was discussed above. The present-day emission rate is 0.3 percent per year, and the average change about 0.3 lbs. As of 2009, 100 percent of all homes in the West North Central region had a refrigerator, 30 percent had a secondary refrigerator, 47 percent had a freezer, and 5 percent had a secondary freezer. These percentages, which were used to estimate emissions statewide for 2009, were assumed to persist throughout the forecast period.

By 2020, total refrigerant emissions are forecast to be some 4,200 lbs. in 2015 and 4,400 lbs. in 2020. Of these, about 85 percent were forecast to be HFC-based in 2015 and 95 percent in 2020. Since 1994, HFC-134a was been used as the refrigerant in new residential refrigerators and freezer. Natural turn-over of the stock has gradually increased the share of equipment using HFC-based refrigerants to about 80 percent today. Total forecast emissions from residential refrigeration are small, 0.003 million CO_2-equivalent tons.

Sources for the data used in the forecast include:

- AGA, *Patterns in Residential Natural Gas Consumption*
- Census Bureau, *American Housing Survey, Minneapolis-St. Paul SMA*
- Census Bureau, *American Community Survey*
- Census Bureau, *Decennial Census of Housing*
- Census Bureau, *Characteristics of New Housing*
- Census Bureau, *Manufactured Homes Survey*
- EIA, *Annual Energy Outlook 2014*
- EIA *Residential Energy Consumption Survey*
- EIA, State Energy Data System
- EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*
- EPA, *Benefits of Addressing HFCs under the Montreal Protocol*
- Intergovernmental Panel on Climate Change, *2006 IPCC Guidelines for National Inventories*
- Minnesota State Demographer, *State Population and Household Estimates*
- Minnesota Department of Commerce, *CIP Program Data*
- MPCA, *GHG Emission Inventory database*
- UNEP Technical and Economic Assessment Panel, *2002 Report of the Refrigeration, Air Conditioning and Heat Pump Technical Option Committee*
- USFS, *Solid Wood Timber Consumption in Major End Uses in the United States, 1950-2009*

Detailed forecast results

The results shown above in Table R-6 for emissions are shown are shown below in Table R-10 using a more detailed breakdown of emissions by fuel. In the forecast, residential sector emissions decline 13 percent over the forecast period, or 1.16 million CO_2-equivalent tons. Combustion emissions decline 1.35 million CO_2-equivalent tons, or 14 percent. Offsetting a part of this decline is an increase in the forecast in noncombustion process emission of 0.18 million CO_2-equivalent tons, from -0.11 million CO_2-equivalent tons in 2011 to +0.01 million CO_2-equivalent tons in forecast year 2030. Two-thirds of the forecast reduction in emissions from on-site fuel use result in the forecast from reduced natural gas use. Forecast residential emissions from the combustion of natural gas decline 12 percent between 2011 and 2030. The increase in process emissions results principally from an increase in emissions from air conditioning, only a part of which is offset by an increase in long-term wood-based carbon storage in residential structures.

Table R-10. Forecasted Emissions from Minnesota's Residential Sector (million CO_2- equivalent short tons)

	2012	2015	2020	2025	2030
Combustion emissions					
bituminous coal	0.00	0.00	0.00	0.00	0.00
LPG	1.22	1.37	1.36	1.33	1.29
distillate fuel oil	0.32	0.29	0.21	0.14	0.10
natural gas	6.82	7.40	7.08	6.68	6.49
wood	0.15	0.15	0.15	0.16	0.17
subtotal	8.52	9.21	8.80	8.32	8.05
space heating	6.49	7.16	6.75	6.27	6.04
water heating	1.62	1.63	1.60	1.57	1.52
cooking	0.26	0.27	0.28	0.30	0.31
clothes drying	0.16	0.16	0.17	0.18	0.19
subtotal	8.52	9.21	8.80	8.32	8.05
Food additives	0.02	0.02	0.02	0.02	0.02
Soaps, shampoos, detergents	0.15	0.16	0.19	0.21	0.23
Urban lawn fertilizer	0.03	0.03	0.03	0.04	0.04
Wood-in-structures	(0.66)	(1.00)	(0.92)	(0.83)	(0.88)
Refrigerator refrigerant	0.00	0.00	0.00	0.00	0.00
Air conditioner refrigerant	0.13	0.21	0.38	0.44	0.39
HFC-aerosol use	0.18	0.19	0.19	0.20	0.21
Total	**8.37**	**8.82**	**8.70**	**8.40**	**8.06**

In the forecast, emissions from the on-site combustion of distillate fuel oil and LPG decline from 2011 levels, while emissions from wood use slightly increase. As just noted, emissions from natural gas combustion decline 12 percent over the forecast period, emissions from LPG, the second most important residential fuel, about 3 percent.

Between 2011 and forecast year 2030, emissions from on-site fuel use in space heating and water heating decline 16 percent. Emissions from other end-uses increase, although only slightly in absolute terms. In the analysis of the EERS, it was assumed that utility demand-side management programs for natural gas under the EERS would focus exclusively on space heating and water heating end-uses.

Table R-11 shows the trend in forecasted emissions for selected years by greenhouse gas. In the forecast, net emissions of CO_2, the principal gas, decline 17 percent from 2011 levels by 2030. Net emissions of CO_2 include emissions of fossil the result from the on-site combustion of fossil fuels and CO_2 removals from the atmosphere resulting from long-term storage in the structural components and sheathing of housing of wood-based carbon. Emissions of HFCs are forecast to double between 2011 and 2030.

The combustion of wood results in emissions of biogenic CO_2. However, since, through tree regrowth, these are rapidly offset by new terrestrial carbon storage, these emissions do not count against sector totals. Emissions of biogenic CO_2 from wood combustion in the residential sector forecast increase about 7 percent from 2011 to 2030.

Table R-11. Forecasted Emissions from Minnesota's Residential Sector by Gas (million CO_2- equivalent short tons)

	2012	2015	2020	2025	2030
CO_2					
fossil CO_2 emissions	8.50	9.21	8.83	8.37	8.11
long-term biogenic CO_2 storage	(0.66)	(1.00)	(0.92)	(0.83)	(0.88)
subtotal	**7.85**	**8.21**	**7.91**	**7.54**	**7.24**
CH_4	0.15	0.15	0.15	0.16	0.16
N_2O	0.06	0.06	0.06	0.06	0.06
HFC-134a/HFC-152a	0	0	0	0	0
HFC-32	0.02	0.03	0.07	0.14	0.22
HFC-125	0.11	0.18	0.31	0.30	0.17
Total	**8.37**	**8.82**	**8.70**	**8.40**	**8.06**
Biogenic CO_2 emissions	**2.16**	**2.11**	**2.17**	**2.27**	**2.38**

Figure R-3 shows the same data graphically. To 2014, the effect of HFC refrigerant leakage—the principal source of HFC emissions from housing— in the forecast is muted. However, by 2020 the moderating effect of these emissions on what is otherwise a rapidly declining forecast emissions total becomes evident, which may recommend an HFC control strategy for this sector. It is possible that some future level of HFC control not envisioned in this forecast could result from yet now unknowable future federal regulatory action. As discussed with respect to commercial sector emissions, EPA recently issued draft rules that prohibit a number of nonresidential uses of HFCs.

Figure R-3. Historic and Forecasted Net GHG Emissions from Minnesota Residences

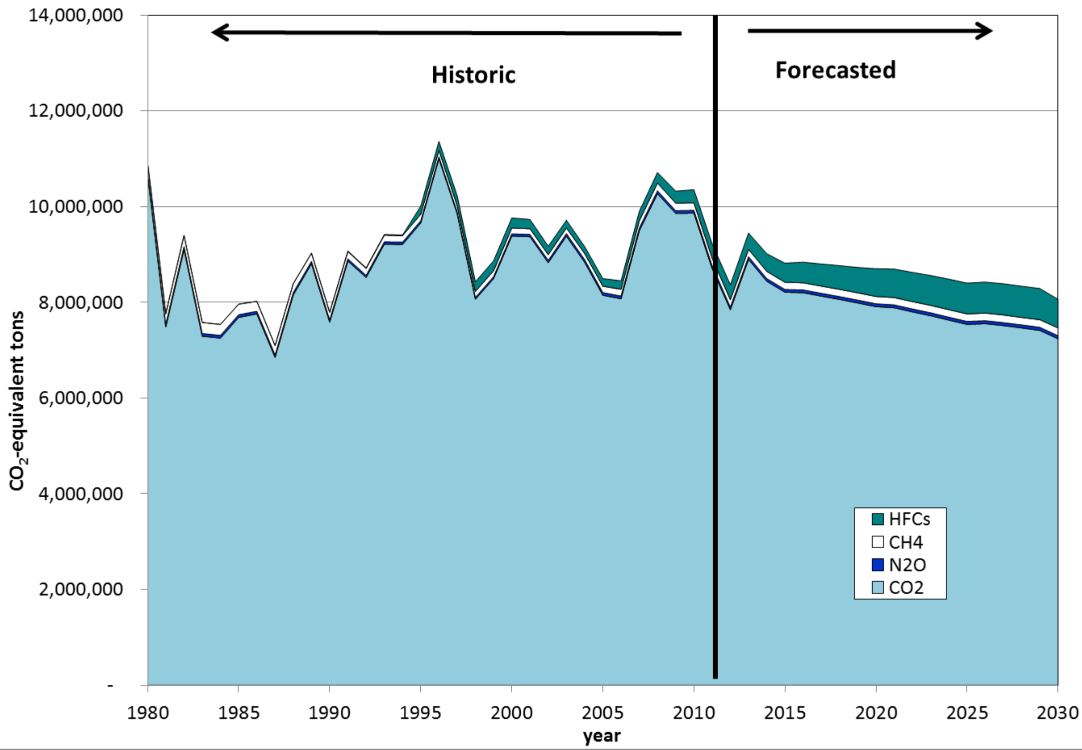


Figure R-4 shows the trend in forecast emissions across all forecast years by end-use and process emission type. Also shown is the offsetting effect in the forecast of the long-term storage of wood-based carbon in housing in Minnesota. Visually striking in Figure R-4 is the persistent downward linear trend over the forecast period in GHG emissions from space heating. A part of this is the effect in the forecast of a declining trend in forecasted heating degree days. Forecasted emissions at 2030 are some 8.04 million CO_2-equivalent tons. Emissions in 2011 from space heating were an estimated 7.3 million CO_2-equivalent tons. If we fix forecasted HDDs at average 1981-2011 levels (30-year climatological normal), forecasted space heating emissions at 2030 rise to 6.7 million CO_2-equivalent tons, which suggests that perhaps half of the forecast reductions in space heating emissions from 2011 levels that are reported in Table R-9 and shown graphically in Figure R-4 result from declining forecast HDDs.

Figure R-4 Historic and Forecasted GHG Emissions from Minnesota Housing

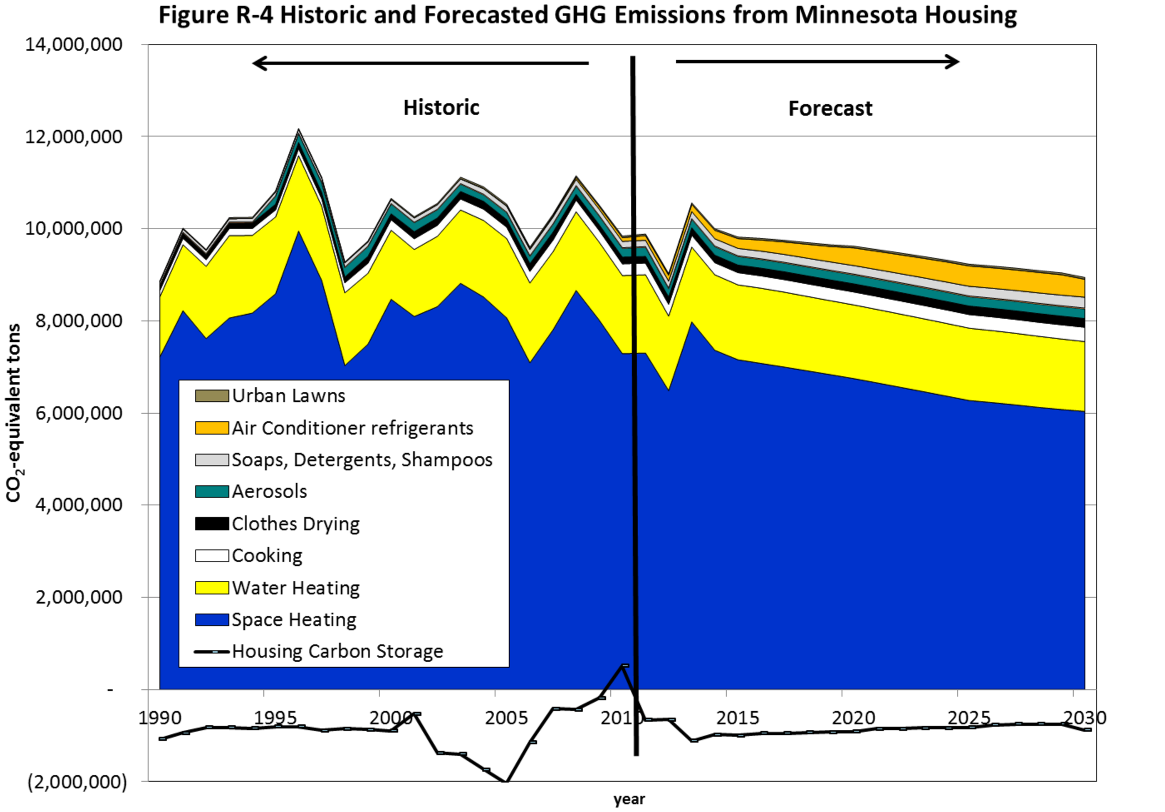


Table R-12 shows forecast trends in on-site fuel use by fuel type and end-use for selected forecast years. In the forecast, on-site natural gas use declines 12 percent between 2011 and 2030, LPG 3 percent and distillate fuel oil use 8 percent. On-site combustion of wood increases 7 percent from 2011 levels by forecast year2030. Total projected on-site fuel use declines in the forecast by 21 million MMBtu or 12 percent. By end-use, by 2030 projected on-site fuel use for space heating declines 14 percent from 2011 levels, and on-site fuel use for water heating declines by 11 percent.

In the forecast, total on-site fuel use declines to some 152 million MMBtu by forecast year 2030. Absent the EERS, modeled on-site fuel use for 2030 comes to some 170 million MMBtu. The difference, 18 million MMBtu, is the result of energy savings implemented under Minnesota's EERS.

The market share for fuels changes only marginally in the forecast. In the forecast, at 2030, natural gas commands about 73 percent of the market for total fuel use in the residential sector, down 1 percent from observed 2011 levels. The market share for oil is down several percent by forecast year 2030, all of this from declining distillate fuel use. As noted above, the use of fuel oil use in space heating declined more than 3-fold between 1990 and 2011. In the forecast, at 2030, wood has a 12 percent market share. Absent the EERS, this 2030 distribution would have been only slightly different, with natural gas commanding 73 percent of the market, wood 14 percent and oil, chiefly LPG, 13 percent.

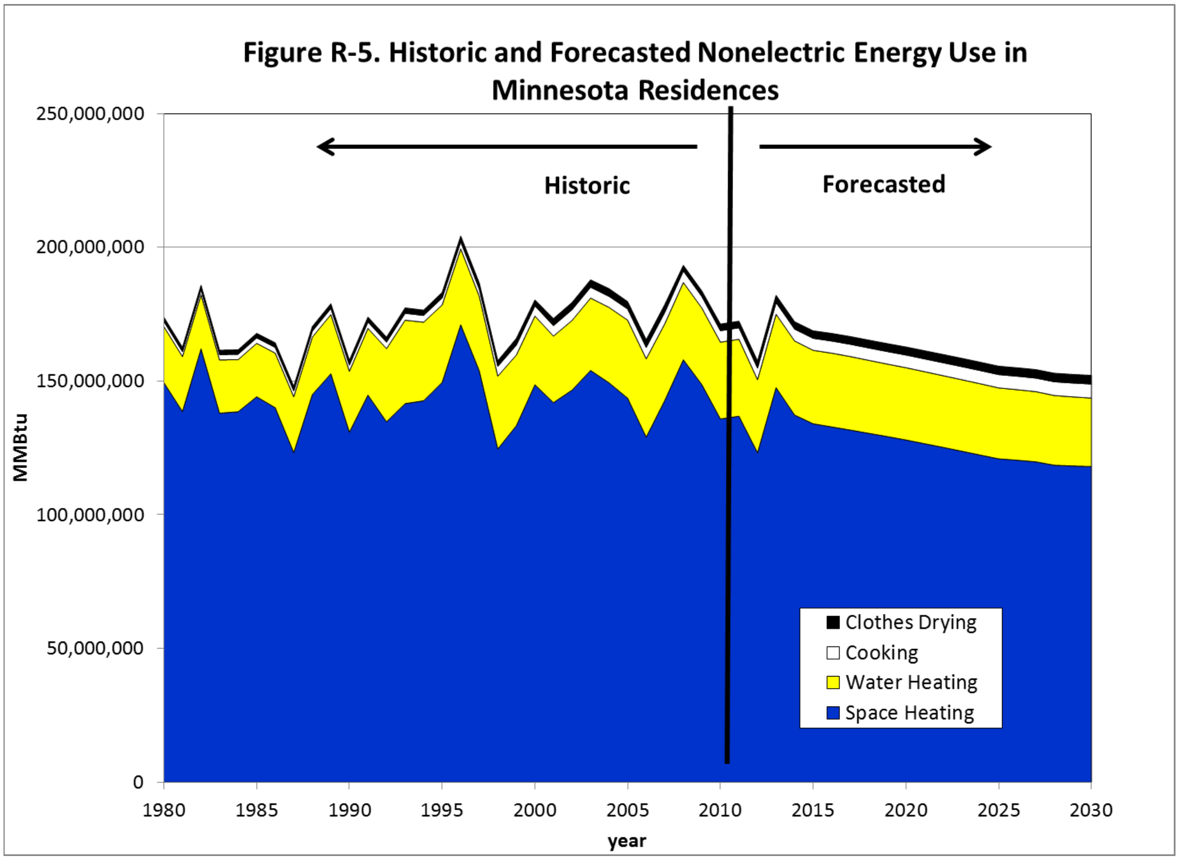
The forecasted long-term trend in energy use is shown graphically in Figure R-5. As noted above, fuel use in space heating declines throughout the forecast period at a rate of 0.8 percent per year. Perhaps as much as half of this is the result of declining numbers of total annual heating degree days in the forecast.

Table R-12. Forecasted On-site Fuel Use in Minnesota's Residential Sector (million MMBtu)

	2012	2015	2020	2025	2030
On-site Energy Production (million MMBtu)					
Bituminous coal	0.02	0.02	0.02	0.02	0.01
LPG	21.40	20.03	19.91	19.56	18.97
Distillate fuel ol	4.73	3.57	2.52	1.75	1.20
Natural gas	136.22	126.39	121.01	114.12	111.05
Renewable	18.99	18.56	19.10	19.93	20.92
Total	**181.37**	**168.58**	**162.56**	**155.39**	**152.15**
Total before EERS	182.66	173.86	174.12	172.87	169.94
Average annual rate of increase in natural gas use:					
before EERS *	NR	1.01%	0.53%	0.29%	0.10%
after EERS *	NR	-0.01%	-0.49%	-0.73%	-0.68%
On-site energy end-use (million MMBtu):					
Space heating	147.04	133.83	127.80	120.75	118.09
Water heating	27.34	27.47	27.02	26.51	25.58
Cooking	4.33	4.48	4.75	4.99	5.25
Clothes drying	2.66	2.79	2.99	3.13	3.23
subtotal	**181.37**	**168.58**	**162.56**	**155.39**	**152.15**
Market share before application of EERS (%)					
Coal	0%	0%	0%	0%	0%
Oil	14%	14%	13%	12%	12%
Natural gas	75%	76%	76%	76%	76%
Renewable	10%	11%	11%	12%	12%
Market share after application of EERS (%)					
Coal	0%	0%	0%	0%	0%
Oil	14%	14%	14%	14%	13%
Natural gas	75%	75%	74%	73%	73%
Renewable	10%	11%	12%	13%	14%

*Average annual rate of increase for the period beginning in 2001 and terminating in the year designated in the column

Table R-13 presents summary data for housing out to 2030. This includes, for selected years, forecasted numbers of households, housing units by housing type, net annual additions to the housing stock, total residential floor space (occupied and vacant), mean floor space per housing unit, and the intensity of carbon storage per square foot of floor space, again by housing type. Also shown, again for selected years, are the forecast results for total biogenic carbon stored in housing in Minnesota and the yearly gain or loss of biogenic carbon from housing, expressed as tons of CO_2 added to or removed from the atmosphere. By number of units, the housing stock increases in the forecast by 21 percent, 2011-2030; numbers of single family units increase slightly more, by 23 percent. By floor space, the increase in either case is larger. Total residential floor space increases about 30 percent in the forecast, 2011-2030, at a rate of about 1.4 percent per year. For single family homes, the increase is 32 percent. This results in the forecast from a projected increase in the average size of housing of about 8 percent over the forecast period.



In the forecast, by 2030, the amount of wood-based carbon stored per square foot of floor space declines by 6 percent from 2011 levels. For new single family homes this change is much larger, about 24 percent. Total biogenic carbon in-place increases over the forecast period by 4.5 million tons of carbon, or by 22 percent. Annual offsets, expressed as tons of CO_2, remain relatively constant over the forecast, with the 10-year, 2002-2011, average annual offsets equal to 0.89 million CO_2-equivalent tons, those for forecast year 2030 equal to 0.88 million CO_2-equivalent tons.

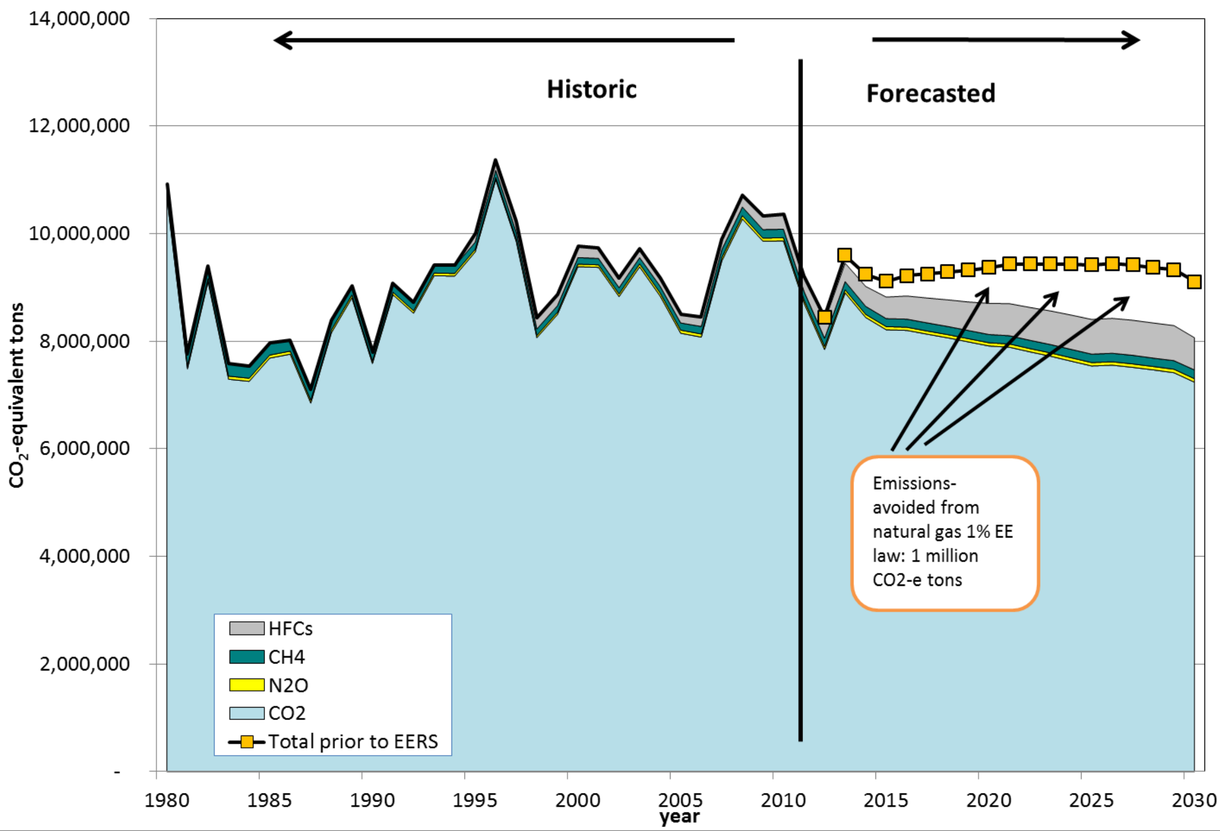
From the data shown in Table R-12, it is possible to determine the effects into the forecast period of the implementation of the EERS for natural gas. The results of that assessment are shown below in Figure R-6 below. By 2030, in absence of Minnesota's conservation programs for natural gas, emissions from on-site combustion are projected to be some 9.1 million CO_2-equivalent tons, up from a forecast 8.37 million CO_2-equivalent tons in 2012, and growing at a rate of 0.5 percent per year. With the EERS, by 2015, roughly 0.3 million CO_2-equivalent tons of emissions are forecast to be avoided, rising to about 1 million CO_2-equivalent tons by 2025.

This calculation includes all effects, including the effects of embedded savings from CIP program activities 1998-2011, on the calculated long-term trajectory of natural gas demand. By as early as 2005, avoided natural gas use as a result of Minnesota's conservation programs for natural gas were equal in the residential sector to 0.5 percent of gas use and, by 2011, to 1 percent. In evaluating how demand might have evolved in absence of any constraints to demand growth, these 'embedded savings' were added back into the trended data on gas use (see the discussion above). What is shown in Figure R-6 by the trend given by yellow squares is how emissions might have evolved absent any conservation programs for natural gas. It is possible that other counter-factuals might yield different results.

Table R-13. Forecast Long-lived Biogenic Carbon Storage in Minnesota Housing (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Households (million)	2.14	2.22	2.34	2.45	2.56
Housing units (million)	2.38	2.46	2.60	2.72	2.84
single family (SF)	1.79	1.86	1.97	2.07	2.16
multi-family (MF)	0.51	0.53	0.56	0.60	0.63
mobile homes (MH)	0.08	0.07	0.06	0.05	0.04
net annual additions to stock (million)	0.02	0.03	0.03	0.03	0.02
vacancy rate (%)	0.10	0.10	0.10	0.10	0.10
Floor space (billion sq ft)	3.91	4.10	4.41	4.71	5.00
single family	3.30	3.47	3.75	4.01	4.26
multi-family	0.51	0.54	0.58	0.62	0.67
mobile homes	0.10	0.09	0.08	0.07	0.07
Mean floor space, existing SF home	1,850	1,868	1,902	1,935	1,966
Mean floor space, new SF home	2,265	2,401	2,506	2,615	2,728
Mean floor space, existing all housing units	1,646	1,665	1,699	1,731	1,760
lbs of wood-based carbon per sq ft floor space, existing stock	10.76	10.69	10.50	10.32	10.15
single family	11.60	11.49	11.24	11.01	10.79
multi-family	6.03	6.10	6.18	6.26	6.33
mobile homes	6.98	6.97	7.11	7.29	8.21
lbs of wood-based carbon per sq ft floor space, new SF home	8.78	8.47	7.97	7.47	6.96
Total carbon in-place (million tons)	21.04	21.88	23.16	24.30	25.36
Yearly gain or loss of carbon in-place (million CO_2-e tons)	0.66	1.00	0.92	0.83	0.88

Figure R-6.Historic and Forecasted Residential Sector GHG Emissions



Commercial sector

Sector boundaries

The commercial sector encompasses firms or public institutions that are not engaged in mining, manufacturing, and transportation and are not treated separately in the electric power sector or waste management sector. Examples of facilities, firms or public institutions that fall within the commercial sector of the MPCA emission inventory include: hotels, restaurants, wholesale businesses, retail stores, warehouses, storage facilities, banks and investment houses, law firms, firms that provide other business and personal services, schools and higher education, hospitals and other health care facilities, corrections, and state and local government.

The commercial sector does include some facilities that might otherwise fall into the transportation sector, including warehouses, barge terminals, airport terminals, airport and highway traffic control, and docks. The transportation sector is generally limited to on-road and off-road vehicles, barges, boats, ships, rail locomotives, aircraft, and pipelines. Wastewater treatment, sewers and solid waste disposal are housed in the waste management sector. The commercial sector does include public water utilities and regulated telecommunications firms.

As noted below in the discussion of the electric power sector, facilities that produce steam for sale off-site are included in the electric power sector facilities. These would otherwise fall into the commercial sector.

Greenhouse gas emissions from these firms are typically on-site combustion emissions associated with energy use, but may also include some non-combustion 'process emissions.' Off-site emissions also result from the consumption by commercial establishments of electricity, but in the MPCA GHG inventory, these are treated in the electric power sector. A number of firms generate electricity for on-site use with no sales to the grid. Emissions from self-generation of electric power solely for on-site use are included in commercial sector emission totals, but self-generation in itself is not tracked.

Present-day and historical emissions

Below in Table C-1 are estimates for historical emissions from the commercial sector for selected years in million CO_2-equivalent tons. The estimates for on-site combustion-based emissions are based on fuel throughput and conventional fuel-based emission factors. Fuel throughput data derives from a number of sources, including: Energy Information Administration (EIA), *Natural Gas Annual*, EIA, *Fuel Oil and Kerosene Sales*, EIA, *State Energy Data System* (SEDS), Federal Highway Administration, *Highway Statistics* and, for large commercial facilities burning bituminous and subbituminous coal, residual fuel oil, waste oil, waste solvent or solid biomass, the MPCA Greenhouse Gas Emission Inventory database. Fuel use is reported annually to the MPCA by operators of permitted facilities on a unit-by-unit basis.

Franklin Heating Station generates electricity for sale to the electric grid. Emissions from the generation of electricity sold to the grid are reported as electric power sector emissions and are subtracted from commercial sector totals. Energy inputs to the generation of marketed electricity are calculated at a heat rate of 11,373 btu/kwh and distributed to fuels proportionally to overall fuel use at the facility. Annual electricity sales by the operators of Franklin Heating Station are given in EIA *Form-906/923*.

Table C-1. Historical Emissions from Minnesota's Commercial Sector (million CO_2- equivalent short tons)

	1990	2000	2005	2010	2011
Combustion-based emissions					
coal	0.39	0.09	0.12	0.10	0.06
oil	0.79	0.64	0.86	0.73	0.82
natural gas	4.38	5.26	5.48	5.04	5.17
other	0.01	0.01	0.02	0.02	0.02
subtotal	5.57	6.00	6.47	5.89	6.06
HFC refrigerants	-	0.15	0.28	0.66	0.78
Solvents	0.09	0.08	0.07	0.10	0.10
Medical uses of N_2O	0.08	0.09	0.08	0.08	0.08
Total	**5.74**	**6.33**	**6.90**	**6.73**	**7.02**

By state law, all diesel fuel oil sold in the state must be blended with biodiesel at a current annual rate of 5 percent by volume, rising to 7.5 percent in 2015. Annual biodiesel use in the commercial sector is calculated from total diesel fuel oil consumption by commercial sector firms in Minnesota, as reported in EIA, *Fuel oil and Kerosene Sales*, and mandated blend levels. The same method is used to calculate annual ethanol throughput in the commercial sector. By state law, all motor gasoline sold in Minnesota must be blended with 10 percent ethanol by volume. Reported motor gasoline fuel use in the commercial sector is from FHA, *Highway Statistics*.

Emission factors are from the MPCA GHG emission inventory database and are generally taken from one of two sources: EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* and IPCC, *2006 IPCC Guidelines for National Inventories*. Emissions of CO_2 from the combustion of coal are calculated using the long-term average rate of emissions from the Minnesota electric power sector for each coal grade. Emissions of CO_2 from the combustion of waste solvent are calculated using emission factors from EIA, *Electric Power Annual* and those for agricultural byproducts using emission factors from T. Miles, *et al*., "Alkili Deposits Found in Biomass Power Plants."

Before emissions are calculated for any one fuel and inventory year, fuel is converted to standard units of energy (MMBtu). In most instances, fuel throughput is converted to units of energy using standard national level conversion factors from EIA, *Annual Energy Review* and EIA, *Renewable Energy Annual*. For natural gas and LPG, total fuel energy is calculated from reported fuel use and Minnesota-specific estimates of fuel heats of combustion or fuel energy content from EIA, *State Energy Data System*. In the Minnesota SEDS data, the heat content of natural gas tends to vary between 1,005 and 1,035 MMBtu per million cubic feet of gas and those for LPG between 88 and 90 MMBtu per thousand gallons.

Bituminous and subbituminous coal throughput is converted to units of energy using the long-term average for the Minnesota electric power sector for fuel energy content of these grades of coal. For ethanol, fuel energy content is from EIA, *Annual Energy Review* and that for biodiesel is from Oak Ridge National Laboratory (ORNL), *Transportation Energy Data Book*.

Noncombustion-based emissions from the commercial sector are of three types: solvent-based emissions of various petroleum-based compounds that partially or wholly oxidize to CO_2 in the atmosphere, incidental releases of N_2O from dentistry and medical uses, and refrigerant-based emissions of hydrofluorocarbons (HFCs). Each three years, EPA's National Emission Inventory provides statewide estimates for Minnesota of total commercial sector volatile organic compound solvent emissions. These are converted to CO_2 using an emission factor taken from EPA, *Inventory of US Greenhouse Gases and Sinks*.

Medical releases of N_2O (laughing gas) are estimated on a *per capita* basis, using US *per capita* rates of emission and Minnesota population estimates as the basis of the calculation.

Commercial sector chillers and food and other refrigeration equipment use HFCs as a working fluid or refrigerant. HFCs that are commonly used in commercial food refrigeration and in commercial air space cooling include HFC-32, HFC-125, HFC-134a, and HFC-143a. In the MPCA GHG emission inventory, refrigerant emissions in Minnesota are set equal to the US *per capita* emission rate for nontransport sector HFCs multiplied by historic Minnesota population estimates. Commercial sector refrigerant-based HFC emissions are equal to total refrigerant emissions in Minnesota less estimated refrigerant emissions estimated for the residential sector.[18] Most nontransport sector HFC emissions nationally are from space cooling and refrigeration

Historically, most GHG emissions from the Minnesota commercial sector have been combustion-based emissions. Recently, refrigerant-based emissions have become a more important part of the inventory. HFC refrigerants are a replacement for hydrochlorofluorocarbon (HCFC) refrigerants, which up to a few years ago had been the refrigerants of choice in the commercial sector. Since 2010, the production of these HCFC refrigerants has been reduced in the US, in anticipation of a complete 2020 US ban on production. HFC refrigerant use is increasing as a result. HCFCs are ozone depleting compounds regulated under the Clean Air Act.

Commercial sector greenhouse gas emissions are shown graphically in Figure 1 for 1990-2011. Commercial sector emissions increased from 1990 to 2011 by about 1.3 million CO_2-equivalent tons, or at an average annual rate of about 1 percent per year. Noncombustion process emissions increased by 0.8 million CO_2-equivalent tons over this period, accounting for about 60 percent of the increase. Between 1990 and 2011, commercial sector noncombustion process emissions increased 4.7-fold, or at an average annual rate of about 8.7 percent. Over the same period, emissions associated with combustion increased about 9 percent or at an average rate of 0.4 percent per year. Combustion emissions peaked in 2002 and since have been flat or slightly declining.

[18] A small amount of refrigerant use also may occur within the industrial sector, but it is assumed to be minimal.

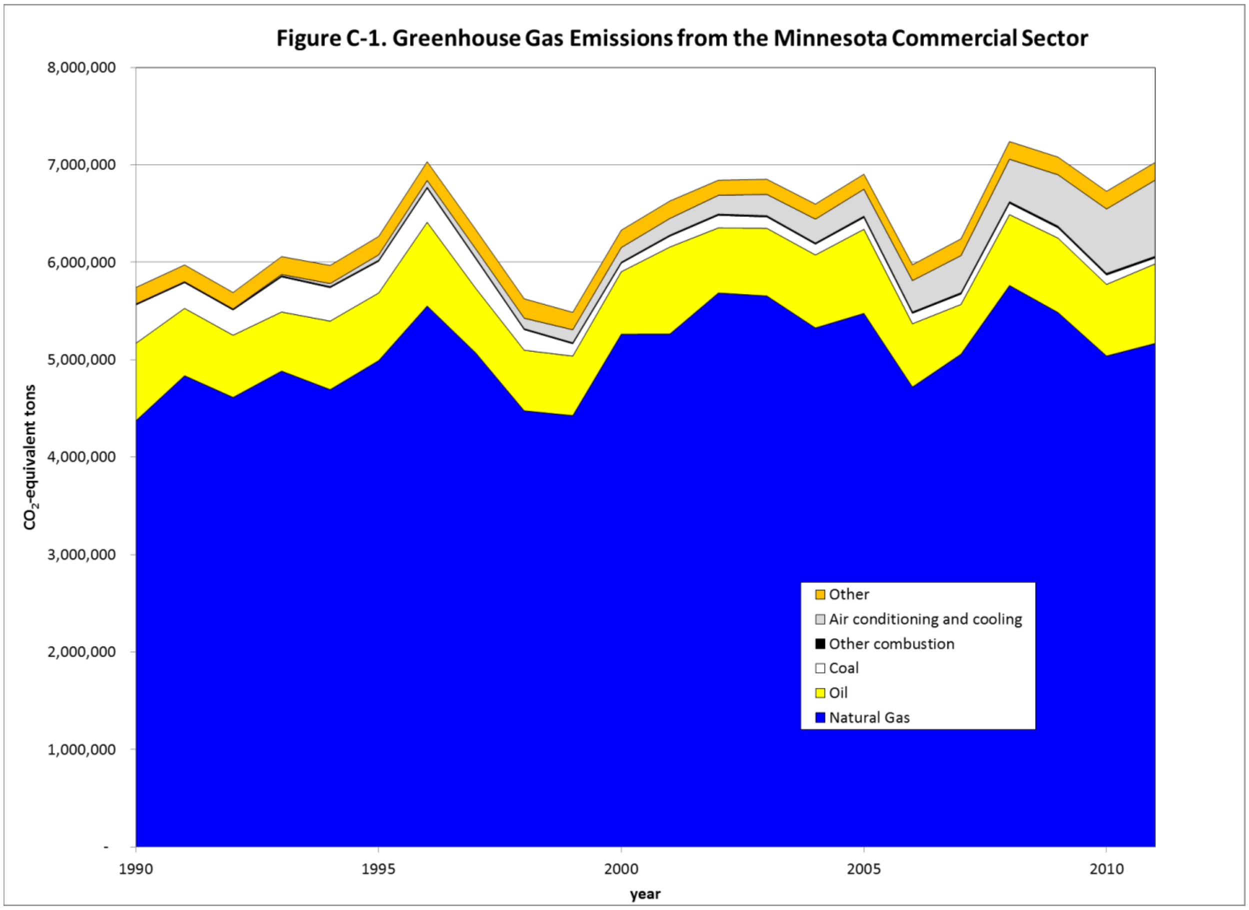


Table C-2 provides historical estimates of on-site fuel use for selected years through 2011. On-site energy use increased 13 percent between 1990 and 2011. Of this, most was from increased combustion of natural gas. The market share of natural gas increased in the commercial sector from about 83 percent in 1990 to 87 percent in 2011. Coal use declined by 85 percent over the same period. Overall on-site fuel use increased at an average annual rate of 0.6 percent per year, 1990-2011.

Table C-2. On-site Commercial Sector Fuel Use (million MMBtu)

	1990	2000	2005	2010	2011
coal	3.70	0.81	1.10	0.89	0.56
oil	10.02	8.33	10.98	9.42	10.50
natural gas	74.83	89.96	93.50	86.06	88.28
other	1.24	1.35	1.81	2.13	2.13
total	89.79	100.44	107.40	98.50	101.47

Full documentation of the sources and methods used to develop the commercial sector inventory is included in Appendix E of P. Ciborowski and A. Claflin, “Greenhouse Gas Emissions in Minnesota: 1970-2008: Second Biennial Progress Report – Technical Support Document” (2012).

Forecast methods

The forecast was developed using the same sector boundaries as underlie the sector inventory. Emissions from energy use were limited to those from on-site combustion activities; emissions associated with electricity consumed at commercial establishments but generated off-site were not included. Process emissions include: refrigerant HFCs from chillers and refrigeration equipment, medical uses of N_2O and fugitive solvent emissions. The establishments in question are firms and public institutions that provide educational, health, legal, financial, business, personal and wholesale and retail sales services.

The emissions forecast is shown below for selected years in millions of CO_2-equivalent tons. Emissions increase in the forecast by 18 percent from 2011 levels. Emissions from on-site combustion decrease 5 percent, while process emissions more than triple.

Table C-3. Forecasted Emissions from Minnesota's Commercial Sector (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Combustion-based emissions					
coal	0.05	0.04	0.05	0.05	0.05
oil	0.83	0.79	0.82	0.81	0.84
natural gas	4.99	4.96	4.84	4.73	4.83
other	0.02	0.02	0.02	0.02	0.02
subtotal	5.88	5.82	5.72	5.60	5.72
HFC refrigerants	1.01	0.67	1.14	1.87	2.34
Solvents	0.10	0.10	0.10	0.10	0.10
Medical uses of N_2O	0.09	0.09	0.09	0.09	0.09
Total	**7.08**	**6.67**	**7.04**	**7.66**	**8.25**

A number of methods were used to forecast emissions. To forecast combustion-related emissions, total sector nonelectric energy use was projected through 2030 and was distributed between fuels using the present distribution of energy use in Minnesota's commercial sector by fuel and the differential fuel growth rates for the West North Central region given in EIA, *Annual Energy Outlook 2014*. To account for the energy savings goals specific to natural gas usage under Minnesota Statute, total forecasted natural gas usage by commercial establishments was then adjusted downward to reflect 100 percent compliance with statutory goals. Minnesota statute requires annual energy savings in natural gas usage through demand-side management programs equal to 1 percent of average usage. Emissions were calculated from adjusted fuel totals using fuel-specific emission factors for CO_2, CH_4 and N_2O.

Nonelectric energy demand prior to the application of Minnesota's energy savings law for natural gas (energy efficiency resource standard or EERS) was forecast using the 14-year, 1997-2011, trend in commercial sector on-site fuel use per dollar of commercial sector gross state product (GSP) and forecasted commercial sector GSP to 2030. Between 1997 and 2011, on-site fuel use per dollar or real commercial sector GSP declined at an average annual rate of about 1.5 percent per year (and, going back to 1985, about 2.5 percent per year), an average annual rate of increase assumed to continue through 2030.[19] Commercial sector GSP was projected from forecast *per capita* commercial sector GSP growth and projected Minnesota population growth. Forecast Minnesota population out to 2030 is from the State Demographer's Office. Over the period 1997-2011, *per capita* commercial sector GSP grew at an average annual rate of 1.4 percent per year, a rate of increase that, based on available data, is presumed to persist through 2030.

[19] The initial year of the period 1997-2011 corresponds with the time period of availability for state-level Bureau of Economic Analysis chain-type quantity index-based estimates of state and state-level real commercial sector GSP. Between 1996 and 1997, the BEA data are discontinuous. Our analysis stops at 2011, the last year of available emission estimates at the time the forecast was developed.

On-site fuel use prior to the application of Minnesota's energy savings law for natural gas increases in the commercial sector forecast by about 9 percent over the forecast period, from about 98.5 million MMBtu to approximately 107.8 million MMBtu. On-site fuel use per dollar of real commercial sector GSP declines from about 540 btu per real dollar commercial sector GSP ($2005) in 2011 to about 393 btu/real dollar in 2030. Commercial sector real GSP increases from about $182.7 billion ($2005) in 2011 to about $274 billion ($2005) in 2030.

For the future percentage distribution of nonelectric fuel use among fuels, a distribution was created using the observed 2011 Minnesota commercial sector nonelectric fuel mix in percent and the percentage change *in AEO 2014* in market share, fuel-by-fuel, over the forecast period in the nonelectric fuel mix in *AEO 2014*. To insure that the total in any forecast year did not exceed or fall short of 100 percent, the distribution was normalized to total 100 percent. Gains or losses in market share out to 2030 in *AEO 2014*, West North Central commercial sector forecast, are minimal, at the one percent level or less.

Using this approach, the distribution of on-site fuel use in Minnesota in the commercial sector remains throughout the forecast essentially unchanged. The market share of natural gas use increases slightly in the forecast, from a current 86.5 percent to 87.37 percent in forecast year 2030, while that of distillate fuel oil declines from 6.3 percent at present to 5.7 percent in forecast year 2030. The forecast market share of LPG, the fuel with the third largest share of on-site commercial sector fuel use, declines slightly from a current 3.4 percent share to a forecast 3.3 percent share in forecast year 2030.

The one percent natural gas savings target was calculated using, as a base, average consumption for the prior three years, including in the case of any forecast year after 2012, forecasted levels of gas consumption that, due to the prior application of the state's energy savings law (in prior forecast years), already have moved to generally lower levels. Energy savings were subtracted from forecasted natural gas demand. The incremental change in natural gas demand, year to year (and prior to natural gas savings), was calculated using the annual change in demand from the original pre-savings demand schedule (see above) and final, savings-adjusted demand for the prior year.

Demand-side management programs for natural gas have been in place since the 1990s. As a result, it is possible, even probable, that implicit in the demand schedule for natural gas pre-EERS are embedded savings from earlier investments in energy conservation. No attempt was made to remove these effects. The program data for commercial/industrial conservation from the Minnesota Conservation Improvement Program are not broken out by commercial sector and industrial sector, making problematical any effort to do so. The effect of embedded savings is to lower by some unknown amount the forecasted level of demand for natural gas 'before EERS' from which savings in any forecast year are subtracted, leading potentially to an underestimate of future natural gas use. From the discussion above, forecasted natural gas use equals natural gas 'before EERS' minus EERS savings.

Table C-4 below provides summary statistics for on-site fuel use for the forecast period. Over the forecast period, total on-site fuel use declines about 5 percent from 2011 levels. In absence of the natural gas energy savings law, forecast on-site fuel use at 2030 is forecast to be about 6 percent higher than 2011 levels. Energy use per dollar of real commercial sector GSP is 35 percent lower in the forecast in 2030 than it was in 2011.

Regarding alternative forecasting approaches, with few exceptions, the data do not exist to support an end-use based forecast. Data on commercial sector floor space do not exist for Minnesota, either for total floor space or for floor space by the individual industries that comprise the commercial sector or by fuel. This is true both for recent years and across time. Detailed data on energy end-use in Minnesota in the commercial sector also do not exist, nor are data available at a state-level for the intensity of end-use, particularly with respect to trends over time. It is possible that, once the current EIA, *Commercial Building Energy Survey* (CBES) is finalized, some useful information might be extracted from the latest CBES. The last information available from the CBES dates back to 2003.

Regarding process emissions, the EPA provides to the states a GHG forecasting tool that gives state-by-state estimates of future HFC emissions by end-use. To project Minnesota commercial sector refrigerant emissions, 2011 inventory estimates were grown by the percentage change reported in the EPA forecast tool for Minnesota. HFCs are the overwhelmingly dominant source, comprising about 80 percent of present commercial sector process emissions and more than 90 percent of forecasted commercial sector process emissions. This forecast does not account for the effects of USEPA's proposed rules on the use of HFCs in commercial refrigeration.[20]

Of all other process emissions, the ten-year, 2001-2011, record of aggregate emissions from all these other sources of commercial sector process emissions--VOCs and N_2O from medical applications—shows little trend. For these sources, a simple ten-year average emission rate was used. Emissions from these emission sources comprise less than 3 percent of the inventory.

Table C-4. Forecasted Commercial Sector On-site Fuel Use

	2012	2015	2020	2025	2030
million MMBtu					
coal	0.44	0.41	0.42	0.42	0.43
oil	10.72	10.28	10.61	10.58	10.85
natural gas	85.39	84.92	82.86	80.89	82.56
other	2.31	2.24	2.34	2.37	2.39
total	98.85	97.86	96.23	94.26	96.22
total before EERS	99.75	101.34	103.95	106.10	107.79
btu/commercial sector $GSP ($2005)					
before EERS	553	507	466	428	393
after EERS	548	490	431	380	351

Finally, sources for the data and methods used in the forecast include:

- MPCA, *Greenhouse Gas Emission Inventory database*
- MPCA, *Minnesota Climate Change Action Plan: A framework for Climate Change Action*
- USEPA, *Inventory of US Greenhouse Gas Emissions and Sinks*
- Bureau of Economic Analysis, *Regional Accounts*
- Minnesota State Demographer, *Population and Household Estimates*
- EIA, *Annual Energy Outlook 2014*
- USEPA, *GHG Forecasting Tool*

Detailed forecast results

The results shown above in Table C-3 for GHG emissions are shown below in Table C-5 using a more detailed breakdown of emissions by fuel. Commercial sector emissions increase 23 percent during the forecast period. Forecasted emissions from fuel use decline slightly, about 3 percent. Offsetting this are

[20]On August 6, 2014, USEPA published proposed rules that, if finalized, would ban the use of certain HFC-based refrigerants (R-404A, R-407A, R-507A, and R-134a) in commercial refrigeration beginning in 2016. http://www.epa.gov/ozone/snap/download/SAN_5750_SNAP_Status_Change_Rule-FactSheet_080114.pdf

changes in process emissions, which in the forecast more than triple. As just noted, recently EPA issued draft rules, known as Significant New Alternatives Policy (SNAP) rules that would prohibit the use of certain HFC-based refrigerants in commercial refrigeration equipment beginning in January 2016. If that rule is finalized in its present form, it is likely that some part of the forecasted increase in HFC emissions shown in Table C-5 would be avoided. The proposed rule would not impact emissions from the operation of commercial chillers.

Table C-6 shows the trend in forecasted emissions for selected years by greenhouse gas. Emissions of fossil CO_2, the principal GHG, decline in the forecast by 3 percent, 2011-2030. Emissions of HFCs increase 1.56 million CO_2-equivalent tons, accounting for all of the increase in emissions and then some. Emissions of biogenic CO_2 from wood, ethanol and biodiesel remain constant over the forecast period.

Table C-5. Forecasted Emissions from Minnesota's Commercial Sector (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Combustion-based emissions					
subbituminous coal	0.05	0.04	0.05	0.05	0.05
natural gas	4.99	4.96	4.84	4.73	4.83
distillate fuel oil	0.51	0.47	0.50	0.49	0.51
LPG	0.23	0.24	0.24	0.24	0.24
kerosene	0.00	0.00	0.00	0.00	0.00
residual fuel oil	0.00	0.00	0.00	0.00	0.00
motor gasoline	0.08	0.08	0.08	0.08	0.08
ethanol	0.00	0.00	0.00	0.00	0.00
biodiesel	0.00	0.00	0.00	0.00	0.00
wood	0.02	0.02	0.02	0.02	0.02
subtotal	**5.88**	**5.82**	**5.72**	**5.60**	**5.72**
HFC refrigerants	1.01	0.67	1.14	1.87	2.34
Solvents	0.10	0.10	0.10	0.10	0.10
Medical uses of N2O	0.09	0.09	0.09	0.09	0.09
Total	**7.08**	**6.67**	**7.04**	**7.66**	**8.25**

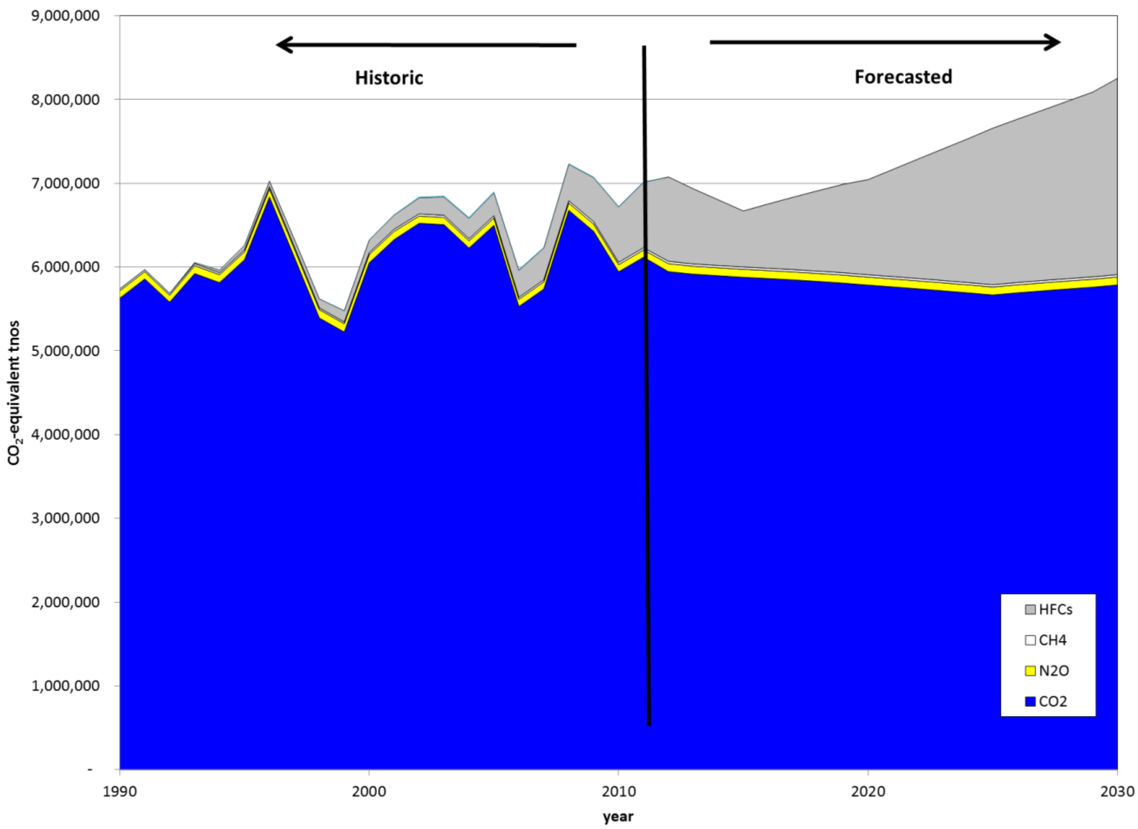
Table C-6. Forecasted Emissions from Minnesota's Commercial Sector by Gas (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Fossil CO_2	5.95	5.88	5.79	5.67	5.79
N_2O	0.10	0.10	0.10	0.10	0.10
CH_4	0.03	0.03	0.03	0.03	0.03
HFCs	1.01	0.67	1.14	1.87	2.34
Total	**7.08**	**6.67**	**7.04**	**7.66**	**8.25**
Biogenic CO_2	**0.26**	**0.25**	**0.26**	**0.26**	**0.26**
solid biofuels	0.24	0.23	0.23	0.23	0.24
ethanol	0.01	0.01	0.01	0.01	0.01
biodiesel	0.01	0.01	0.01	0.01	0.02

Figure C-2 shows the same data graphically. Particularly striking is the effect in the forecast of the HFCs in transforming what would otherwise be a declining emissions trend into a trend moving sharply upward with time. Again, to reiterate, it is possible that, with EPA SNAP rule changes, a part of this HFC-inspired increase might be avoided.

Table C-7 shows forecast trends in on-site fuel use by fuel type for the forecast period. Natural gas use declines in the forecast about 7 percent, 2011-2030, at an average annual rate of about 0.4 percent. This accounts for the effects of the natural gas EERS. Without the EERS, natural gas use is forecast to increase about 7 percent above 2011 levels, 2011-2030. Distillate fuel oil use declines in the forecast, while LPG uses increase somewhat. Fuel use for most other fuel types remains constant over the forecast period. Total on-site fuel use declines in the forecast by about 5 percent, declining between 2011 and forecast year 2030 at an average annual rate of about 0.3 percent. Without the EERS, on-site fuel use is forecast to increase about 6 percent above 2011 levels, 2011-2030.

Figure C-2. Historic and Forecasted Commercial Sector GHG Emissions



In terms of intensity of energy use, energy use per dollar of real commercial sector GSP is a forecast 35 percent lower in 2030 than in 2011. Forecast real commercial sector GSP increases about 50 percent, 2011-2030.

To evaluate the sensitivity of the forecast results to the chosen forecast method, emissions were modeled using:

- the observed trend, extrapolated forward, in emission intensity (in CO_2-e lbs.), all sources, per dollar of real commercial sector GSP;
- the observed trend, extrapolated forward, in energy intensity of the commercial sector per dollar of real commercial sector GSP, considering all energy consumption, nonelectric and electric;
- percentage change in energy use in the AEO *Annual Energy Outlook 2014* West North Central commercial sector forecast, fuel-by-fuel, applied to the base 2011 Minnesota condition

The results of this sensitivity analysis are shown below in Figure C-3 for forecast emissions before and after the application of the natural gas energy savings targets of Minnesota statute. The results of the alternative treatments are in good agreement with the results presented in Table C-3 and Figure C-1.

Finally, from the data given in Table C-7, it is a simple matter to estimate the prospective GHG emissions-avoided over the forecast period as a result of the implementation of the natural gas EERS. The results of that assessment are shown in Figure C-4 below. By 2015, roughly 0.2 million CO_2-equivalent tons of emissions might be expected to be avoided as a result of the natural gas EERS, rising to 0.7 million tons in 2025 and 2030. This is roughly comparable to the avoided emissions at the same forecast dates for the residential sector (1 million CO_2-equivalent tons at 2030).

Table C-7. Forecasted Commercial Sector On-site Fuel Use

	2012	2015	2020	2025	2030
million MMBtu					
subbituminous coal	0.44	0.41	0.42	0.42	0.43
natural gas	85.39	84.92	82.86	80.89	82.56
distillate fuel oil	6.26	5.78	6.06	5.96	6.19
LPG	3.35	3.45	3.50	3.55	3.58
kerosene	0.01	0.01	0.01	0.01	0.02
residual fuel oil	0.02	0.02	0.02	0.02	0.02
motor gasoline	1.07	1.02	1.01	1.03	1.04
ethanol	0.08	0.08	0.12	0.12	0.12
biodiesel	0.13	0.18	0.19	0.19	0.19
wood	2.10	1.99	2.03	2.06	2.07
total	**98.85**	**97.86**	**96.23**	**94.26**	**96.22**
total before EERS	**99.75**	**101.34**	**103.95**	**106.10**	**107.79**
annual rate of increase in natural gas use:					
before EERS*	NR	0.2%	0.5%	0.4%	0.0%
after EERS*	NR	-0.8%	-0.4%	-0.5%	-0.9%
btu/commercial sector $GSP ($2005)					
before EERS	553	507	466	428	393
after EERS	548	490	431	380	351
commercial sector real GSP (millions) ($2005)	180,300	199,876	223,195	248,014	274,318
-					
market share before application of EERS					
coal	0.9%	0.4%	0.4%	0.4%	0.4%
oil	9.5%	10.4%	10.5%	10.3%	10.4%
natural gas	87.4%	87.2%	87.1%	87.4%	87.3%
other	2.0%	2.0%	2.0%	1.9%	1.9%

*annual rate of increase in that forecast year

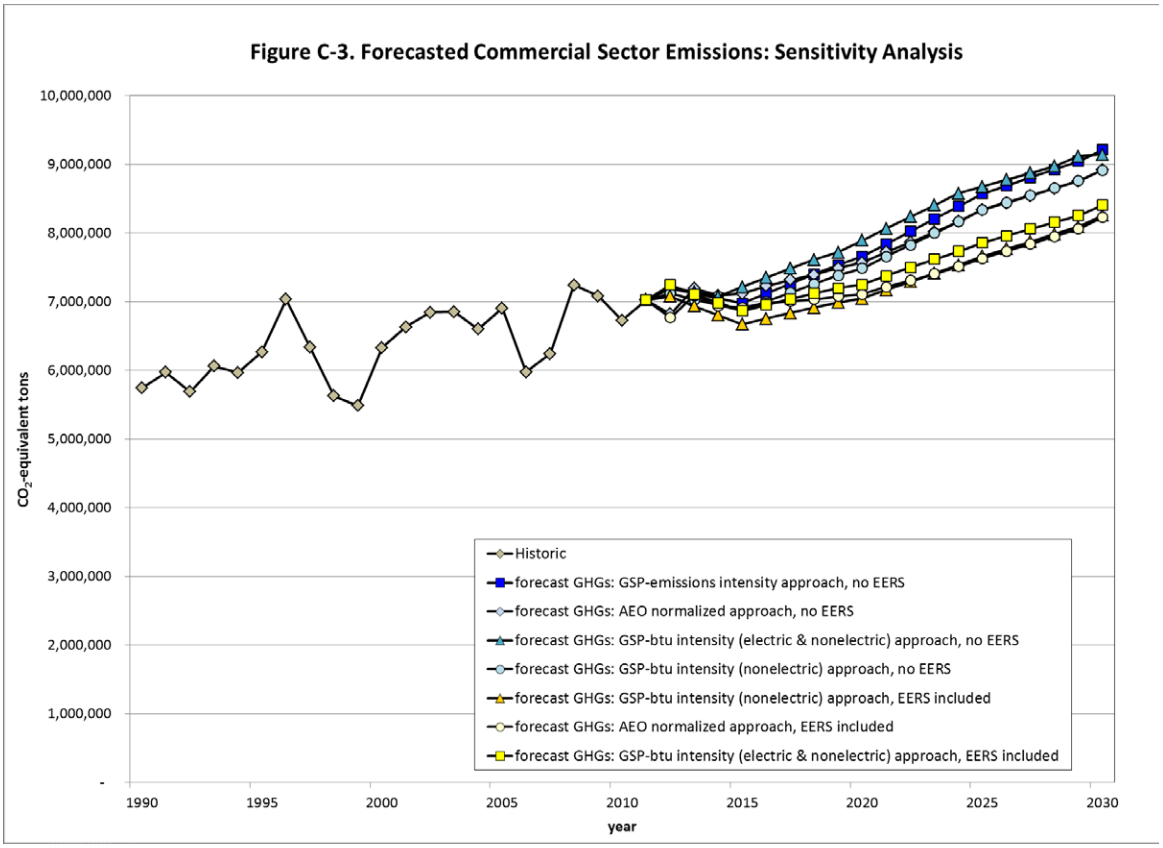


Figure C-3. Forecasted Commercial Sector Emissions: Sensitivity Analysis
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CO_2-equivalent tons
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Historic
forecast GHGs: GSP-emissions intensity approach, no EERS
forecast GHGs: AEO normalized approach, no EERS
forecast GHGs: GSP-btu intensity (electric & nonelectric) approach, no EERS
forecast GHGs: GSP-btu intensity (nonelectric) approach, no EERS
forecast GHGs: GSP-btu intensity (nonelectric) approach, EERS included
forecast GHGs: AEO normalized approach, EERS included
forecast GHGs: GSP-btu intensity (electric & nonelectric) approach, EERS included

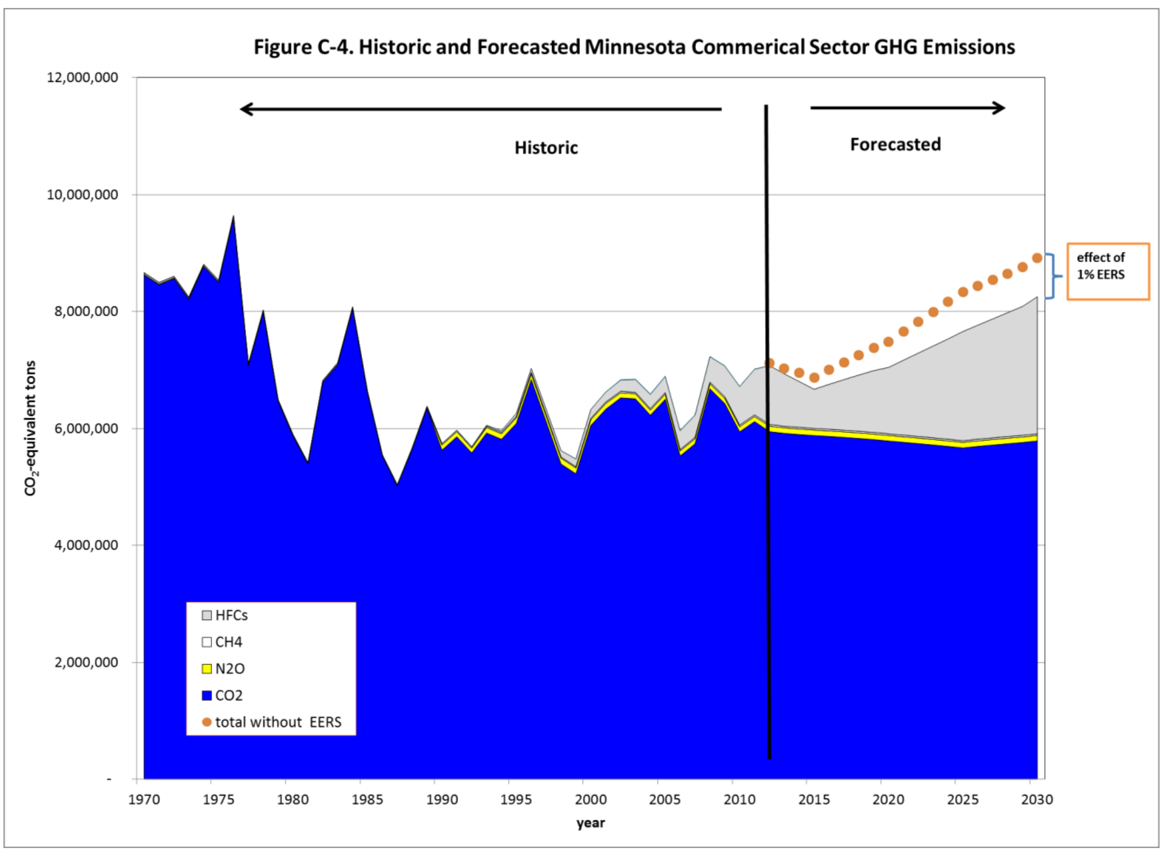
Figure C-4. Historic and Forecasted Minnesota Commerical Sector GHG Emissions
12,000,000
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-
CO_2-equivalent tons
Historic
Forecasted
effect of 1% EERS
HFCs
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N2O
CO2
total without EERS
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1990
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2000
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2030
year

Solid waste sector

Sector boundaries

The waste management sector includes firms and public institutions that, as their principal focus, are engaged in the management of solid and human waste. It also includes facilities that, while part of a large commercial sector of industrial sector firm, are dedicated solely to waste disposal. Activities in which these firms and public agencies engage or that occur at these dedicated facilities include: solid waste landfilling, incineration, waste preprocessing, waste recycling, composting, wastewater treatment, and biosolids land application. Dedicated facilities include incinerators at hospitals and industrial hazardous waste incinerators of large industrial firms.

The waste management sector does not include on-highway waste transport to or from disposal or processing facilities. On highway transportation is treated within the transportation sector. The waste management sector also does not include industrial wastewater treatment, which in the Minnesota Pollution Control Agency GHG emission inventory is housed in the industrial sector. Solid waste incinerators that produce electricity for sale to the grid or steam for off-site industrial use are included in the electric power sector as large energy facilities. This is to facilitate the analysis of emissions from large energy producing plant.

The state's borders set the geographical boundaries of the waste management sector. Activities that occur outside of Minnesota, even while involving waste that may have been exported across state borders, are not counted as a part of the Minnesota waste management sector.

Some greenhouse gas emissions from waste management are on-site combustion emissions, mostly incineration-related, but most are non-combustion 'process emissions.' Process emission sources from waste management include: landfills, solid waste and yard waste composting, wastewater treatment, wastewater discharge to surface waters, and land-applied wastewater sludge. The generation off-site of grid-based electricity results in GHG emissions. Electricity is used in wastewater treatment and waste processing. Emissions from grid-based generation of electricity are treated in this forecast as electric power sector emissions

Each year large amounts of wood-based waste are placed in demolition and construction (D/C) landfills where this waste, unless subsequently removed, is stored for very long periods of time, probably longer than a century. Carbon stored in the wood was once atmospheric carbon that, upon plant photosynthesis, was withdrawn from the atmosphere and incorporated into the living biomass of trees. In the Minnesota emission inventory, net additions to very long-lived wood storage in D/C landfills are treated as negative emissions or 'sinks', offsetting a part of emissions from other sources.

Present-day and historical emissions

Estimates are shown below in Table W-1 for historical emissions from the waste management sector for selected years in million CO_2-equivalent tons. Total emissions from waste management in 2011 were some 1.97 million CO_2-equivalent tons. In 2011, sanitary landfills (SLFs) emitted an estimated 1.84 million CO_2-equivalent tons, industrial landfills an estimated 0.13 million CO_2-equivalent tons, waste incineration an estimated 0.15 million CO_2-equivalent tons, and wastewater treatment an estimated 0.59 million CO_2-equivalent tons. Partially offsetting this was long-term storage of wood-based carbon in demolition/construction landfills, in 2011, estimated at about 0.87 million CO_2-equivalent tons. Between

1990 and 2011, total emissions from waste management declined by almost two-thirds, from 5.54 to 1.97 million CO_2-equivalent tons. Two-thirds of this reduction occurred between 1990 and 2000, and most of the rest occurred between 2000 and 2005.

In aggregate, between 1990 and 2011, waste sector emissions declined by 3.55 million CO_2-equivalent tons, driven principally by declining SFL emissions. Emissions from SLFs declined by 3.28 million CO_2-equivalent tons between 1990 and 2011, or by an estimated 64 percent from1990 levels. Emissions from wastewater treatment increased slightly, by 0.08 million CO_2- equivalent tons or by 15.6 percent, 1990-2011, while emissions from incineration declined by about 0.1 million CO_2-equivalent tons. Finally, annual carbon storage in D/C landfills increased by 0.37 million CO_2-equivalent tons or by 70 percent, 1990-2011.

Table W-1. Historical Emissions from Minnesota's Waste Management Sector (million CO_2-equivalent short tons)

	1990	2000	2005	2010	2011
Combustion-based Emissions					
Fuel use					
coal	-	0.07	-	-	-
oil	0.04	0.05	0.05	0.04	0.05
natural gas	0.03	0.03	0.01	0.02	0.02
other	0.00	-	-	-	-
subtotal	0.07	0.15	0.07	0.06	0.06
Incineration					
hazardous waste	0.09	0.09	0.11	0.11	0.07
medical waste	0.00	0.01	0.00	0.00	0.00
sludge	0.01	0.01	0.01	0.01	0.01
RDF/MMSW-mass burn	0.03	-	-	-	-
other incineration	0.05	-	-	-	-
rural open burning	0.07	0.06	0.05	0.05	0.05
landfill gas flaring/combustion	0.00	0.02	0.02	0.02	0.02
subtotal	0.25	0.18	0.19	0.19	0.15
subtotal	0.32	0.33	0.26	0.25	0.22
Sanitary landfills	5.12	3.18	2.25	1.83	1.84
Industrial landfills	0.07	0.11	0.12	0.13	0.13
Waste composting	0.02	0.04	0.05	0.04	0.04
Limestone use	-	0.00	-	-	-
Biosolids land application	0.01	0.01	0.02	0.01	0.02
Wastewater treatment	0.51	0.54	0.56	0.58	0.59
Demolition/Construction landfills	(0.51)	(1.04)	(0.99)	(0.70)	(0.87)
Total	**5.54**	**3.17**	**2.26**	**2.16**	**1.97**

Historically, landfills receiving mixed municipal solid waste (MMSW) or sanitary landfills have been the largest source of waste management emissions in Minnesota. Methane (CH_4) 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, by creating negative pressure in the landfill through pumping to capture landfill gas (LFG), and to combust it in a flare, engine or gas 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:

$$Emissions\ (in\ scf) = \frac{volume\ of\ gas\ collected}{0.75} \times 0.25\ \times 0.9$$

For landfills containing MMSW that do not actively capture landfill gas, emissions are estimated using LandGEM (3.2), a first-order kinetic model of landfill gas production. Upon placement in a landfill, MMSW generates CH_4 at a rate that declines exponentially 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 atmosphere. LandGEM can simulate emissions from both traditional 'dry tomb' nonrecirculating landfills and landfills that practice leachate recirculation. The model includes default settings for a 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.[21]

As of 2011, thirty landfills were actively capturing landfill gas. Of these, ten were active landfills still receiving waste; the rest were closed landfills owned and operated by the State of Minnesota. Ninety-one landfills in Minnesota with MMSW did not actively capture landfill gas. About two-thirds of landfill gas generation at Minnesota landfills occurs at the thirty SLFs that actively capture LFG.

The data sources for MMSW amounts received at Minnesota landfills include, for 1991-present, MPCA SCORE data and, for 1970-1990, the MPCA *Annual Solid Waste Report* and various MPCA staff compilations based on the MPCA *Annual Solid Waste Report* and other waste receipt data. Prior to 1980, large gaps appear in the MPCA 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.

In those instances where emissions are back-calculated from LFG gas collection, data on annual LFG throughput through landfill flares, reciprocating engines, sterling engines or gas turbines are taken, for landfills still receiving MMSW, from annual facility reporting to the MPCA and, for closed landfills, MPCA, *Closed Landfill Annual Report*. In a few instances over the historical period, MPCA facility reporting did not cover all landfills in the state that collected LFG. To supplement the record, historical data on LFG throughput were additionally drawn from Chicago Climate Exchange reporting.

In the MPCA GHG Emission Inventory database, CH_4 emissions from the landfills are tracked landfill-by-landfill. Biogenic emissions of carbon dioxide (CO_2) are also tracked, as are total waste receipts to each

[21] $k = 0.05$, $L_0 = 170$, CH_4 50% by volume

landfill in the state. Biogenic emissions of CO_2 from landfills are calculated assuming that, on a volumetric basis, LFG is 50 percent CH_4 and 50 percent biogenic CO_2.

As of 2011, total CH_4 emissions from SLFs and closed city dumps were an estimated 3,521 MMcf of CH_4 or 1.84 million CO_2-equivalent tons. Of this, CH_4 emissions from SLFs still actively receiving MMSW accounted for about 45 percent of all SLF CH_4 emissions, while closed landfills and closed city dumps accounted for the remainder. In 2011, emissions from landfills, both active and closed, that actively capture LFG comprised 30 percent of total statewide SLF emissions, while emissions from landfills without active gas capture and closed city dumps together constituted the remaining 70 percent. CH_4 emissions from SLFs that are actively receiving waste and actively collected LFG were, in 2011, an estimated 23 percent of 2011 estimated statewide SLF emissions.

In addition to emissions from the surface of the landfills, landfills also emit may a small amount of CH_4 while flaring landfill gas in landfill flares. These are tracked, as are N_2O emissions from flared gas. Emissions of CH_4 from incomplete combustion at landfill flares are calculated using estimated LFG throughput and a flare destruction efficiency of 99 percent. For N_2O, emissions are calculated using estimated LFG throughput, converted to an MMBtu-basis, and an emission factor taken from Intergovernmental Panel on Climate Change (IPCC), *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. As noted above, where LFG is combusted to produce electricity, emissions of N_2O or CH_4 are reported in the electric power sector inventory as electric power sector emissions.

GHG emissions from out-of-state SLFs are not tracked. As noted above, the geographical boundaries of the waste management sector are set to coincide with the state's borders. Within this framework, activities that occur outside of those borders belong to Minnesota's neighbors. In 2011 about 0.3 million tons of MMSW were exported from the state for processing and disposal. Earlier in the historic period, in 2004 and 2005, 0.8 to 0.84 million tons of MMWS were exported annually.

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, *Calculation Tools for Estimating Greenhouse Gas Emissions from Pulp and Paper Finals, Report Version 1.1*. Data on paper pulp sludge receipts are from MPCA Annual *Solid Waste Receipts Data Base*.

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. Emissions from this source are estimated using emission factors per unit of waste managed given in IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories* and Environmental Protection Agency (EPA), *Inventory of US Greenhouse Gas Emissions and Sinks 1990-2008*. Data on annual MMSW receipts at MMSW composting facilities are from the MPCA SCORE database.

Long-term biogenic carbon storage in demolition and construction (D/C) landfills is estimated using the waste receipts data from MPCA *Annual Solid Waste Reports* and *Solid Waste Receipts database* and the data on D/C waste biogenic carbon content in RTI International, *Carbon Footprint of Demolition and Construction Waste Management*. Based on the RTI work, on a mass basis, 12.7 percent of D/C waste is estimated to be wood-based. Reported D/C receipts are converted to a mass basis assuming 0.56 tons per cubic yard of waste. D/C landfills are assumed to be 100 percent inert. Estimated annual storage of biogenic carbon is calculated from year-to-year changes in biogenic carbon stocks in these landfills. Tons of carbon are converted to tons of CO_2 using a conventional conversion factor of 3.66.

As discussed above, each year large amounts of wood-based waste are placed in demolition and construction (D/C) landfills where this waste, unless subsequently removed, is stored for very long periods of time. In the Minnesota emission inventory, net additions to very long-lived wood storage in D/C landfills are treated as negative emissions or 'sinks', offsetting a part of emissions from other sources.

CO_2 emissions from rural open burning and solid waste mass burn are estimated on the basis of waste carbon content. The fossil carbon content of MMSW is calculated from waste composition, using periodic information given in MPCA, *Solid waste Composition Study 1990-1992*, Solid Waste Management Coordinating Board (SWMCB), *Minnesota Statewide MSW Composition Study* and MPCA, *Minnesota Statewide Waste Characterization Study*. MPCA data on the carbon content, both biogenic and fossil, of different waste materials also are used. Emissions of N_2O and CH_4 from rural open burning are calculated using emissions factors from IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* N_2O and CH_4 emissions from mass burn incinerators are calculated using emissions factors from EPA, *Greenhouse Gas Emissions from Management of Selected Materials in Municipal Solid Waste* and R.W. Beck and Ecobalance, *Municipal Solid Waste Management and Impact on Resource Conservation and Greenhouse Gas Emissions*.

Data on amounts of MMSW combusted are from the MPCA *SCORE Report* and MPCA facility-level fuel use reporting. Most mass burn of MMSW in the waste management sector ceased in the mid1990s. Mass-burn of MMSW at facilities that generate electricity or steam for sale off-site continues to the present day. As noted above, mass burn of MMSW at those facilities is treated in the electric power sector.

In the 1990s, 20,000 to 40,000 tons per year of refuse-derived fuel (RDF) was combusted in waste management sector facilities. Historical emissions from RDF combustion are calculated from fossil carbon content of RDF and historic data on waste throughput from MPCA facility-level fuel use reporting. RDF fossil carbon content is calculated from data on waste composition given in the 1999 MPCA, *Minnesota Statewide Waste Characterization Study*, adjusted to account for the precombustion removal of 60 percent of the metals, household appliances and bulk items, vehicle batteries and other inorganic materials from the waste.

Each year, a small amount of general medical waste is also combusted. Fossil CO_2 emissions from the combustion of general medical waste are estimated based on estimated waste carbon content, which is taken from MPCA, *Estimated Costs of Waste Disposal/Incineration Alternatives*. Emissions of N_2O from the combustion of general medical waste are estimated using an emission factor taken from IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Fossil CO_2 emissions result from the incineration of hazardous waste. These emissions are estimated using an emission factor for industrial wastes from IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. N_2O emissions from hazardous waste incineration are calculated using an emission factor from Global Environmental Facility, *Technical Report on Energy Efficiency and Production of Unintended POPs*. Estimates of waste throughput, for medical waste and hazardous waste incineration, are from MPCA facility-level fuel use reporting.

Emissions of N_2O and CH_4 from the incineration of wastewater treatment plant sludge are estimated using emission factors given in EPA *AP-42, Compilation of Air Pollution Emission Factors* and European Environmental Agency (EEA), *EMEP/CORINAIR Emission Inventory Guidebook 2007*. Estimated amounts of sludge that are incinerated are reported annually to the MPCA by WWTP owner/operators on a unit-by-unit basis.

Ancillary fuels are used in solid waste combustion. Most commonly, natural gas is combusted to support waste incineration, but ancillary incinerator fuels also include, for the historic period, 1990-2011: bituminous coal, wood, residual fuel oil, waste solvents, LPG, and distillate fuel oil. GHG emissions from the combustion of these ancillary fuels are calculated using reported fuel throughput and emissions factors drawn from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks,* IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories, and* The Climate Registry*, General Reporting Protocol.* Fuel use is reported annually to the MPCA by the operators of permitted facilities in the waste sector on a unit-by-unit basis. Before emissions are calculated, fuel throughput is converted to standard units of energy (MMBtu), in most instances using standard national-level conversion factors from Energy Information Administration (EIA), *Annual Energy Review* and EIA, *Renewable Energy Annual*.

Emissions of CO_2 from the combustion of bituminous coal are calculated using the long-term rate of emissions per MMBtu for bituminous coal use in the Minnesota electric power sector. Emissions from the combustion of waste solvent are calculated using an emission factor given in EIA, *Electric Power Annual*. Emissions of N_2O from combustion of natural gas and diesel fuel oil in reciprocating engines are estimated using emission factors given in EEA, *EMEP/CORINAIR Emission Inventory Guidebook 2007*, as are CH_4 emissions from the combustion of bituminous coal in industrial boilers.

Annually-varying Minnesota-specific estimates of fuel energy content, taken from EIA, *State Energy Data System*, are used in the case of natural gas, LPG and bituminous coal to convert fuel use to MMBtu.

Diesel fuel oil is used in waste preprocessing and in landfill operations. Fuel use in waste preprocessing and landfill operations is calculated using fuel use rates per unit of waste processed or landfilled from R.W. Beck and Ecobalance, *Municipal Solid Waste Management and Impact on Resource Conservation and Greenhouse Gas Emissions*. Waste recycling involves preprocessing and sorting, as does the production of RDF and the preparation of MMSW for use in mass-burn facilities and at waste composting facilities. Yard waste also must be preprocessed prior to composting. Using present-day and historical information on MMSW that annually is composted, burnt in resource recovery facilities or recycled, fuel use is calculated. GHG Emissions in turn are calculated using emission factors for diesel fuel oil for CO_2, N_2O and CH_4 given in EPA*, Inventory of US Greenhouse Gas Emissions and Sinks*. Before emissions are calculated, fuel throughput is apportioned to diesel fuel oil and biodiesel fuel oil, following the requirements of the state's biodiesel mandate, and converted to standard units of energy (MMBtu).

A similar calculation is done for yard waste composting. Data for MMSW that is recycled and composted is from MPCA SCORE database. For MMSW combusted in resource recovery facilities, annual facility-level reporting of waste throughput is used. Facilities with an air permit are required to report fuel or waste throughput to the MPCA on a unit-by-unit basis. For composted yard waste, an older estimate of 400,000 tons per year was used. [22]

CH_4 emissions from domestic wastewater treatment are estimated using the methods given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. 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

[22] 1994 is the last year that SCORE reporting is available for yard waste composting.

is assumed that, in any given year, 10 percent of WWTP digesters operated without an active flare and emitted CH_4 directly to the atmosphere.

In the calculation of total wastewater BOD, 0.19 lbs. of BOD are assumed to be produced per person per day, the rate given at an average national level in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.* In 2011, roughly two-thirds of BOD in Minnesota wastewater was managed aerobically in centrally-managed systems, about 5 percent was managed anaerobically in centrally-managed systems, and about 8 percent was managed with anaerobic digestion in centrally-managed systems.

All equations for calculating CH_4 emissions from BOD in wastewater are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.* National default values are used in the equations for the following terms: potential CH_4 production capacity for domestic wastewater per unit of BOD; percent of BOD that is removed during primary treatment (and is not available for the production of CH_4); and the percent of potential CH_4 generation that is realized in wastewater treatment by treatment type (well-managed aerobic treatment, poorly-managed aerobic treatment, anaerobic treatment). Ten percent of aerobic systems are assumed to be poorly managed, after EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.* For anaerobic digesters, emissions are calculated from estimated annual wastewater flows to the digester, a rate of production rate of CH_4 in the digester of 0.01 lbs. of CH_4 per gallon of wastewater, a 99 percent efficient flare, and, as noted above, an assumed 10 percent flare downtime.

CH_4 emissions from privately-owned septic systems are estimated from BOD using the equations and national defaults given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.*

Using the EPA equations, for septic systems the CH_4 emission rate per unit of BOD is about two-thirds that for centrally-managed anaerobic systems, but 16-fold larger than that of centrally-managed aerobic systems. In 2011, an estimated 20.6 percent of households were served by septic systems.

N_2O emissions from wastewater treatment plant discharges are estimated using the methods specified in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Most N_2O emissions from sewage result from nitrogen discharges to surface water. Based on IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, 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 (WWTP) nitrogen discharges are calculated as the difference between total wastewater entering the facilities and the total amount removed in the form of wastewater sludge plus WWTP nitrogen loses to the atmosphere. WWTP denitrification losses to the atmosphere are set at a constant 40 percent. Total domestic wastewater nitrogen is calculated from estimates of national *per capita* protein consumption and total Minnesota resident population. Total estimated nitrogen from domestic wastewater is augmented to account for commercial and industrial sector co-discharge of nitrogen, after the practice followed in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*.

Per capita protein consumption is calculated from data for the US for average protein in-take from FAO, *FAOSTAT Food Balances, Protein Supply Quantity* and a protein availability factor from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.* Protein nitrogen content is assumed to be 16 percent.

A small amount of N_2O is produced *in situ* in wastewater treatment plants, typically 5 percent of all direct wastewater N_2O emissions. These are calculated using emission factors from IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* The IPCC does not recommend a method to use in estimating N_2O emissions from septic systems. Consequently, no estimate is given for N_2O emissions from this source.

Lastly, N_2O emissions result from the land application of sewage sludge and septage. These are calculated assuming that 1 percent of nitrogen in land applied sludge and septage nitrogen that is not volatilized or leaches to groundwater or run-off to surface waters is emitted to the atmosphere in the form of N_2O, after *IPCC, 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Emissions from waters laden with sludge and septage nitrogen are estimated using an emission factor of 0.0075 lbs. of nitrogen emissions per lbs. of sludge and septage nitrogen in surface and groundwater. Total sludge applications are from a database maintained by the MPCA biosolids program.

Septage land application is calculated from total wastewater nitrogen produced in the state, the percentage of households served by septic systems, and septage nitrogen as a percent of total influent nitrogen. It is assumed that per household wastewater nitrogen production in households with septic systems is the same as that ofhouseholds served by centrally-managed wastewater treatment plants. From Centre Europeanne d'Etude des Polyphosphates, "Fate of Phosphorus in Septic Tanks," nitrogen in septage is set equal to 10 percent of influent nitrogen to septic systems. Nitrogen losses due to volatilization during land application of sludge and septage are assumed to be 20 percent, and those due to leaching and surface run-off are assumed to be 30 percent.

Table W-2 gives the historic record of solid waste generation and its disposition since 1990. In 2011, 5.45 million tons of mixed municipal solid waste were generated, 1.51 million tons of industrial waste, 1.87 million tons of demolition and construction waste, and 0.16 million dry tons of sewage sludge. MMSW generation in 2011 was 28 percent higher than in 1990, but only about 1 percent higher than in 2000. MMSW generation peaked in 2006 at levels about 8 percent higher than 2011 levels. Of generated MMSW, in 2011, 46 percent was recycled, 26 percent was landfilled, 20 percent was combusted to produce energy or steam for sale off-site and 6 percent was exported.

Table W-2. Historic Solid Waste Generation and Disposition (million short tons)

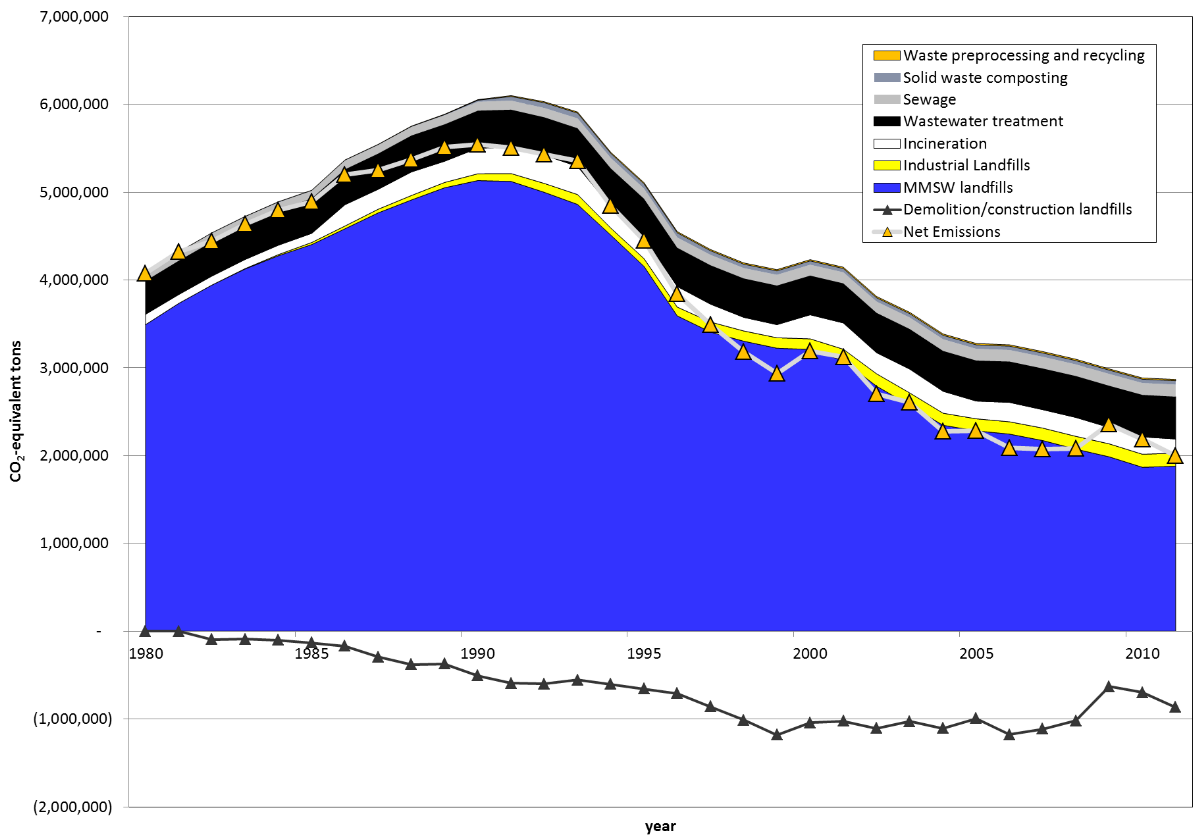
	1990	2000	2005	2010	2011
Mixed Municipal Solid Waste					
Sanitary landfills	1.85	1.22	1.32	1.58	1.45
Waste-to-energy production	1.09	1.18	1.21	1.01	1.12
On-site incineration	0.25	0.10	0.08	0.07	0.06
Composted	0.04	0.02	0.02	0.02	0.02
Exported	0.19	0.69	0.80	0.37	0.33
Recycled	0.92	2.27	2.48	2.43	2.56
subtotal	**4.34**	**5.47**	**5.92**	**5.49**	**5.54**
Industrial Waste					
Industrial landfills	0.50	1.43	1.89	2.17	1.51
Landfills receiving paper/pulp waste	0.31	0.28	0.15	0.11	0.10
Other	0.19	1.15	1.75	2.06	1.41
subtotal	**0.50**	**1.43**	**1.89**	**2.17**	**1.51**
Demolition/Construction Waste					
Demolition/construction landfills	1.09	2.24	2.14	1.50	1.87
subtotal	**1.09**	**2.24**	**2.14**	**1.50**	**1.87**
Medical Waste					
On-site incineration	0.00	0.01	0.00	0.00	0.00
subtotal	**0.00**	**0.01**	**0.00**	**0.00**	**0.00**
Sewage Sludge[a]					
On-site incineration	0.11	0.09	0.09	0.10	0.10
Land application	0.02	0.04	0.06	0.05	0.06
subtotal	**0.12**	**0.13**	**0.15**	**0.15**	**0.16**

[a] dry tons

Figure W-1 shows graphically the information on historic emissions that is contained in Table W-1. Net emissions in 2011 were an estimated 1.97 million CO_2-equivalent tons. Gross emissions from landfills, incineration, wastewater treatment and other sources were some 2.84 million CO_2-equivalent tons, offset by 0.87 million CO_2-equivalent tons of biogenic carbon storage in D/C landfills. Net emissions from waste management in Minnesota peaked in 1990, declining about 60 percent by 2006, after which net emissions stabilized near present levels. Gross emissions peaked in 1991, while net removals through sequestration in D/C landfills peaked in 1999. Between the time of peak gross emissions and 2011, gross emissions fell at an average rate of about 4.5 percent per year.

Full documentation of the sources and methods used to develop the waste sector inventory is included in Appendix E of P. Ciborowski and A. Claflin, "Greenhouse Gas Emissions in Minnesota: 1970-2008: Second Biennial Progress Report – Technical Support Document" (2012).

Figure W-1. Greenhouse Gas Emissions from Minnesota Waste Management



Forecast methods

The forecast was developed using the same sector boundaries that underlie the sector inventory. The waste management sector includes firms and public institutions that, as their principal focus, are engaged in the management of solid and human waste, including solid waste recycling, landfilling, incineration, composting, waste preprocessing, and wastewater treatment. It also includes facilities that, while owned or operated by large commercial or industrial sector firms, are dedicated solely to waste disposal. Dedicated facilities include incinerators at hospitals and industrial hazardous waste incinerators at large industrial firms.

Emission sources include: sanitary landfills and SLF flares; industrial landfills; solid waste composting; rural open burning; hazardous waste, medical waste and sewage sludge incineration; waste preprocessing; wastewater treatment; wastewater discharges; and sewage sludge land application. As in the inventory, very long-term biogenic carbon storage in demolition and construction landfills acts to remove CO_2 from the atmosphere, offsetting a part of emitted greenhouse gases.

The waste management sector emissions forecast is shown in Table W-3 by fuel type and noncombustion process emission type in CO_2-equivalent short tons. Emissions decline in the forecast by 0.34 million CO_2-equivalent tons or 7 percent from 2011 levels by forecast year 2030. Gross emissions in the forecast decline by 0.11 million CO_2-equivalent tons, while removals of CO_2 from the atmosphere in the form of biogenic landfill storage increase by 0.23 million CO_2-equivalent tons. Emissions from SLFs decline by almost 0.23 million CO_2-equivalent tons by 2030 from 2011 levels, partially offset by increases in emissions from other waste management sources of 0.12 million CO_2-equivalent tons.

Forecast emissions of CH_4 from SLFs are of two types: legacy emissions from MMSW placements in in-state landfills that date to 2011 or earlier; and emissions from MMSW that is projected to be placed in in-state SLFs 2012-2030. Forecast legacy emissions from landfills with no active gas capture are taken from the MPCA GHG Emission Inventory database. As described above, emissions from landfills and open dumps with no active gas capture are estimated for the historical period using EPA LandGEM landfill gas model and total waste placements, landfill-by-landfill, by year of placement and a 10 percent landfill oxidation factor. Using LandGEM, these have been extended to 2030, and with the information from the historic period, are stored in the MPCA GHG Emission Inventory database.

Legacy emissions from open landfills with active gas capture are forecast using the same LandGEM simulations, albeit, in the case of open landfills with active gas capture, adjusted by a constant factor to account for gas flaring. In the calculation, an adjustment factor of 0.82 was used across all years of the forecast period, based on the historic average ratio, 2007-2011, of modeled emissions at open landfills with no controls to observed emissions at open landfills with operating flares.

Table W-3. Forecasted Emissions from Minnesota's Waste Management Sector (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Combustion-based Emissions					
Fuel use					
coal	-	-	-	-	-
oil	0.05	0.05	0.05	0.05	0.06
natural gas	0.02	0.02	0.02	0.02	0.02
other	-	-	-	-	-
subtotal	0.07	0.07	0.07	0.07	0.07
Incineration					
hazardous waste	0.10	0.10	0.10	0.10	0.10
medical waste	0.00	0.00	0.00	0.00	0.00
sludge	0.01	0.01	0.01	0.01	0.01
rural open burning	0.05	0.05	0.05	0.05	0.05
landfill gas flaring/combustion	0.02	0.02	0.02	0.03	0.03
subtotal	0.19	0.19	0.19	0.19	0.19
subtotal	0.25	0.26	0.26	0.26	0.27
Sanitary landfills	1.75	1.74	1.73	1.67	1.61
Industrial landfills	0.13	0.14	0.14	0.14	0.14
Waste composting	0.04	0.04	0.04	0.04	0.04
Limestone use	-	-	-	-	-
Biosolids land application	0.01	0.01	0.01	0.01	0.01
Wastewater treatment	0.59	0.60	0.62	0.63	0.65
Demolition/Construction landfills	(1.08)	(1.08)	(1.09)	(1.09)	(1.10)
Total	1.71	1.71	1.71	1.67	1.64

For legacy emissions from closed landfills with gas capture, for 2012, a similar 0.8 adjustment factor was used. However, in addition, in estimating emissions, a 20 percent decline in flare operating hours, 2011-2020, also was assumed, following guidance of the MPCA staff that manages the state's closed landfill program. As landfilled waste ages, its CH_4 generation potential declines. Because of this, in Minnesota, in recent years it has become difficult at maintain around the clock operation of landfill flares at the state's oldest closed landfills, a condition that, the CLP staff projects, will intensify over the next decade.

With a 20 percent reduction in flare operating hours, at 2020, the adjustment factor of controlled to uncontrolled emissions at 2020 is 0.64. This is held constant at 0.64 for forecast years 2020-2030.

In forecasting emissions from SLFs from MMSW generated during the forecast period, it is assumed that 79 percent of all MMSW landfilled during each forecast year is disposed of in SLFs that actively capture LFG and 21 percent is landfilled at SLFs without any gas capture. This is based on the 2009-2011 average practice. Total landfill gas generation is forecast using LandGEM and total MMSW landfill amounts by forecast year. Emissions from SLFs with active gas capture are calculated using total landfill gas generation, a 75 percent LFG collection efficiency, and a 10 percent landfill cover oxidation rate. For SLFs without active gas capture, emissions are calculated from total landfill gas generation and a 10 percent landfill cover oxidation rate. Landfill gas is assumed to be 50 percent CH_4 by volume.

Future amounts of MMSW to be landfilled are forecast as the difference between total forecasted MMSW generation and the sum of MMSW that is recycled, combusted in resource recovery facilities, composted, burned in rural areas in burn barrels or piles, or exported from the state. The forecast statewide recycling rate is taken from MPCA, *Metropolitan Solid Waste Management Plan*. Under this plan, at 2025, 51.5 percent of MMSW generated in Minnesota is to be recycled, reaching 57 percent by 2030. Export totals are set at 3-year, 2009-2011, levels, as are annual MMSW composting and rural open burning totals. Export totals, which peaked in 2004/2005 at about 0.8 million tons have, in recent years, fallen to levels between 0.33 and 0.47 million tons, 2009-2011, with 2012 recording a 0.27-million-ton value. The amount of MMSW burned in barrels or piles has been stable for at least five years at levels of 65,000 to 70,000 tons per year. Composting totals have been stable at levels of 15,000 to 16,500 tons per year.

Annual resource recovery throughputs of MMSW are set in the forecast at average 2009-2011 levels plus an additional 70,000 tons to accommodate recent facility expansions at Polk County Solid Waste Resource Recovery Facility and Perham Resource Recovery Facility. Prior to these expansions, annual throughput of MMSW at resource recovery facilities had been stable at these facilities at about 1.1 million tons per year, going back at least 10 years.

MMSW generation is forecast from population growth and forecast *per capita* rates of waste generation. The state population forecast is taken from Minnesota State Demographer, *Population and Household Estimates*. A stream of *per capita* MMSW generation out to 2019 was developed, using the historic rate of *per capita* waste generation back to 1990 and a best polynomial fit to the data. Beginning in 2020, *per capita* MMSW generation is held constant at 2019 levels. Using the best polynomial fit to the observed data, after 2019, *per capita* rates of generation decline slightly from 2019 levels.

SLF flare emissions are calculated from forecast amounts of LFG combusted and 99 percent combustion efficiency. As noted above, only emissions associated with flaring are included in the waste sector forecast; fugitive emissions from the combustion of LFG in reciprocating engines or gas turbines to generate electricity are treated in the electric power sector forecast.

Emissions from the management of MMSW other than in SLFs are forecast using the methods and emission factors used to estimate present-day emissions. Fossil CO_2 emissions from rural open burning are forecast using year 2011 MMSW fossil carbon content. The CH_4 and N_2O emission factors that are used to estimate emissions are from IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. As discussed above, the amount of MMSW that is burnt in burn barrels or piles in areas with no central solid waste collection is in the forecast set for all forecast years at 3-year, 2009-2011, average levels.

For waste composting, as discussed above, a 3-year, 2009-2011, average rate was used for total waste composted annually for all years of the forecast period. Emissions are estimated using emission factors given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*.

Emissions from on-site fuel used in processing of solid waste are estimated using the per ton estimates of distillate oil fuel use in waste processing given in R.W. Beck and Ecobalance, *Municipal Solid Waste Management and Impact on Resource Conservation and Greenhouse Gas Emissions*. MMSW is preprocessed before it is combusted as RDF or in mass-burn facilities or composted. In the forecast, the amount of MMSW that is processed annually is assumed to be equal to the forecast amount of waste that is combusted in RDF-burning facilities and MMSW mass-burn facilities and is composted. Forecast emissions from distillate fuel oil combustion during waste processing are calculated using the emission factors given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*.

Distillate fuel oil is also used in landfill operations and at solid waste recycling centers. The consumption of distillate fuel oil during landfill operations or during solid waste recycling is forecast from estimates of recycled and landfilled solid waste for each year of the forecast period and present-day rates of on-site fuel use in recycling and landfilling operations from R.W. Beck and Ecobalance, *Municipal Solid Waste Management and Impact on Resource Conservation and Greenhouse Gas Emissions*. Forecast emissions from distillate fuel oil combustion during waste processing are calculated using the emission factors given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.*

Emissions from industrial landfills are forecast using the same methods and tools described above for present-day and historic emissions. As in the case of present-day and historical emissions, estimate of emissions from industrial landfills are restricted to those from industrial landfills receiving paper and pulp industry waste. Emissions are estimated using LandGEM and the recommended NCASI settings. Forecast waste inputs to industrial landfills are frozen at the 10-year, 2003-2012, average rate of waste input to the landfills. Historically, waste receipts at landfills receiving paper and pulp industry wastes varied between 80,000 and 150,000 tons per year, 2003-2012, higher earlier in the period and hovering near 100,000 tons, 2008-2012. Prior to 2003 waste receipts at these landfills were larger, up to 400,000 tons per year.

Emissions from the incineration of hazardous waste, medical waste and sewage sludge are forecast using the same emission factors that are used to estimate of present-day and historical emissions (see discussion above). Sources include: IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories,* Global Environmental Facility, *Technical Report on Energy Efficiency and Production of Unintended POPs,* EPA *AP-42, Compilation of Air Pollution Emission Factors* and European Environmental Agency (EEA), and *EMEP/CORINAIR Emission Inventory Guidebook 2007*. The carbon density of medical waste is derived from the data in MPCA, *Estimated Costs of Waste Disposal/Incineration Alternatives*.

Due to lack of any substantial trend in the historic record, 2003-2012, hazardous and sewage sludge waste inputs to incineration are held at constant at average 2007-2011 rates throughout the forecast period. Medical waste inputs to incineration are held at constant in the forecast at average 2009-2011 rates, for the same reason.

Emissions from associated incinerator fuels are calculated from forecast amounts of combusted hazardous waste, sewage sludge and medical waste and historic rates of GHG emission per unit of waste combusted by waste type. For historical rates of emission, a 3-year average rate of emission is used for fossil CO_2, N_2O and CH_4, calculated using data for 2009-2011 from the MPCA GHG Emission Inventory database.

As noted above, each year large amounts of wood-based waste are placed in demolition and construction landfills where this waste, unless subsequently removed, is stored for very long periods of time. Carbon stored in the wood was once atmospheric carbon that, upon plant photosynthesis, was withdrawn from the atmosphere and incorporated into the living biomass of trees. Atmospheric CO_2 removals to long-term storage are estimated, for demolition/ construction landfills, from projected annual inputs of D/C waste to these landfills and the biogenic content of D/C waste from RTI International, *Carbon Footprint of Demolition and Construction Waste Management*. Future generation of D/C waste is forecast using pre-recession data for 1998-2008, linearly trended and extended to the future. The trend in the generation of D/C waste over this period was slightly positive, increasing about 0.1 percent per year. With the Great Recession, waste receipts data gyrate wildly, making it unsuitable for use in forecasting rates of waste generation forward.

Emissions from operations at demolition/construction landfills are estimated using rates of forecast waste disposal at these landfills and rates of distillate fuel oil consumption per ton of disposed waste given in R.W. Beck and Ecobalance, *Municipal Solid Waste Management and Impact on Resource Conservation and Greenhouse Gas Emissions*. GHG emissions are calculated using emission factors given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Emissions from operations at industrial landfills are similarly estimated. The amount of industrial waste that is managed, including paper and pulp waste and all other industrial wastes, are assumed to increase 3 percent per year over the forecast period. [23]

Table W-4 provides forecast estimates for the generation of industrial solid waste and demolition and construction wastes by selected forecast year. Also shown are estimates for MMSW generation and disposition by means of disposal by selected forecast years. In the forecast, by 2030, total solid waste generation increases by 23 percent from 2011 levels. By 2030, forecasted MMSW generation increases about 15 percent from 2011 levels, projected industrial solid waste generation increases about 70 percent, solid waste generation in the paper/pulp industry is flat, and forecast demolition and construction waste generation increases by 1 percent from 2011 levels. As noted above, forecast levels of medical waste generation and sewage sludge generation are held constant at present levels throughout the forecast period. *Per capita* waste generation increases over the forecast period by 1 percent, while state-level population increases by 15 percent. By disposition, recycled MMSW amounts increase in the forecast by 44 percent from 2011 levels, while amounts of landfilled MMSW decline by 15 percent from 2011 levels.

As in the case of present-day and historical emissions, CH_4 emissions from domestic wastewater treatment are forecast using the calculative methods given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. The total biochemical oxygen demand (BOD) of wastewater is calculated for each inventory year using Minnesota population forecasts 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 specified. CH_4 emissions are calculated based on the forecasted 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 of WWTP digesters operate without an active flare and emit CH_4 directly to the atmosphere.

[23] This is the average annual rate of increase, 2000-2011, in the data for industrial waste receipts in the MPCA solid waste receipts database.

Table W-4. Forecasted Solid Waste Generation and Disposition (million short tons)

	2012	2015	2020	2025	2030
Mixed Municipal Solid Waste					
Sanitary landfills	1.70	1.71	1.71	1.67	1.44
Waste-to-energy production	1.17	1.17	1.17	1.17	1.17
On-site incineration	0.07	0.07	0.07	0.07	0.07
Composted	0.02	0.02	0.02	0.02	0.02
Exported	0.39	0.39	0.39	0.39	0.39
Recycled	2.71	2.89	3.17	3.46	3.91
subtotal	6.06	6.25	6.53	6.77	6.99
per capita generation rate (lbs./day)	6.14	6.18	6.19	6.19	6.19
forecast population (million)	5.40	5.54	5.77	5.99	6.18
Industrial Waste					
Industrial landfills receiving paper/pulp waste	2.15	2.35	2.73	3.17	3.69
pulp and paper landfills	0.10	0.10	0.10	0.10	0.10
Hazardous waste incineration (trillion btu)	0.64	0.64	0.64	0.64	0.64
Demolition/Construction Waste					
Demolition/construction landfills	2.32	2.33	2.34	2.35	2.36
Medical Waste					
On-site incineration	0.00	0.00	0.00	0.00	0.00
Sewage Sludge[a]					
On-site incineration	0.10	0.10	0.10	0.10	0.10
Land application	0.05	0.05	0.05	0.05	0.05
subtotal	0.15	0.15	0.15	0.15	0.15

In the calculation of total wastewater BOD, 0.19 lbs. of BOD are assumed to be produced per person per day, the assumed 2011 rate used in the calculation of present-day and historical emissions. Forecast estimates for future Minnesota population are from the Minnesota State Demographer's office. The percent of BOD that is managed in privately-owned septic systems is assumed in the forecast to decline slightly from 20.6 percent in 2011 to 18 percent in 2020, consistent with forecasts in which most Twin Cities metropolitan growth occurs in established urban and suburban areas (e.g., Metropolitan Council, *Thrive MSP 2040*). After forecast year 2020, it is assumed to stabilize. In the forecast, the remaining roughly 80 percent of BOD in human wastewater is managed at centrally located wastewater treatment plants. The percentage distribution of managed BOD at centrally managed WWTPs by aerobic and anaerobic treatment types is held at present levels throughout the forecast period. The percent of managed BOD that does and does not receive primary treatment is likewise frozen at present levels throughout the forecast period.

The percent of centrally managed BOD that is secondarily treated through anaerobic digestion is assumed to increase from 12 percent in 2011 to 15 percent by 2012, attendant to the 2012 anaerobic digester start-up at Blue Lake.

In the forecast, in forecast year 2030, 66 percent of BOD in Minnesota wastewater is managed aerobically in centrally-managed systems, 5 percent is managed anaerobically in centrally-managed systems, and a projected 11 percent is managed with anaerobic digestion in centrally-managed systems.

As is the case of the present-day and historic emissions estimates, all equations for calculating CH_4 emissions from BOD in wastewater are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Present-day national default values are used in the equations for the following terms: potential CH_4 production capacity for domestic wastewater per unit of BOD; percent of BOD that is removed during primary treatment (and is not available for the production of CH_4); and the percent of potential CH_4 generation that is realized in wastewater treatment by treatment type (well-managed aerobic treatment, poorly managed aerobic treatment, anaerobic treatment). As is the case of the present-day and historic emissions estimates, ten percent of aerobic systems are assumed to be poorly managed. Anaerobic digester emissions are calculated from forecast annual wastewater flows to the digester, a rate of production rate of CH_4 in the digester of 0.01 lbs. of CH_4 per gallon of wastewater, a 99 percent efficient flare, and an assumed 10 percent flare downtime.

CH_4 emissions from privately-owned septic systems are estimated from BOD using the equations and present-day national defaults given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*.

Forecast emissions of N_2O from wastewater treatment and WWTP discharges are estimated using the same equations and methods described above for present-day and historical emissions. Most N_2O emissions from sewage result from nitrogen discharges to surface water. Total wastewater treatment plant nitrogen discharges are calculated as the difference between total wastewater entering the facilities and the total amount removed in the form of wastewater sludge plus WWTP nitrogen loses to the atmosphere. As discussed above, in the forecast, the amount of sludge that is incinerated is held constant at present levels. The same is true for the amount of sludge that is land-applied. Between 1997 and 2011, no trend is evident in the data for amounts of annually incinerated sludge, which have varied within a fairly tight range of 90,000 to 100,000 tons. Similarly, little systematic *trend* is evident in the data for land-applied sludge, here using the 10-year, 2002-2011 record. As in the case of present-day emissions, forecast WWTP denitrification losses to the atmosphere are set at a constant 40 percent.

Total domestic wastewater nitrogen is forecast from present-day estimates of national *per capita* protein-take and forecast total Minnesota resident population. This is adjusted to account for protein availability, using present-day factors given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Total estimated nitrogen from domestic wastewater is augmented to account for commercial and industrial sector co-discharge of nitrogen, again using the present-day factors given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*.

Once released to surface water, 0.5 percent of discharged nitrogen is assumed in the forecast calculations to be emitted to the atmosphere in the form of N_2O, the same rate used in the estimate of historic and present-day emissions.

Emissions *in situ* from the wastewater treatment plants are calculated from forecast Minnesota resident population and present-day *per capita* emissions rates from IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. In *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, IPCC develops separate present-day emission factors for facilities that remove WWTP nitrogen using nitrification and denitrification and those that do not. Present-day national defaults from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* are used for the percent of wastewater flows that are treated in facilities that nitrify or denitrify wastewater.

Forecast emissions of N_2O from the land application of sewage sludge and septage are calculated from forecast levels of sewage sludge and septage land-applied. As discussed above, in the forecast, total amounts of land-applied sewage sludge are held constant at present levels. Forecast amounts of septage nitrogen are calculated from forecast influent nitrogen (see discussion above) and septage nitrogen as a percent of influent nitrogen.[24] Forecast emissions are estimated using emission factors taken from IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Emissions are estimated for that fraction of sludge and septage nitrogen that is not lost due to volatilization. Nitrogen losses due to volatilization during land application of sludge and septage are assumed to be 20 percent.

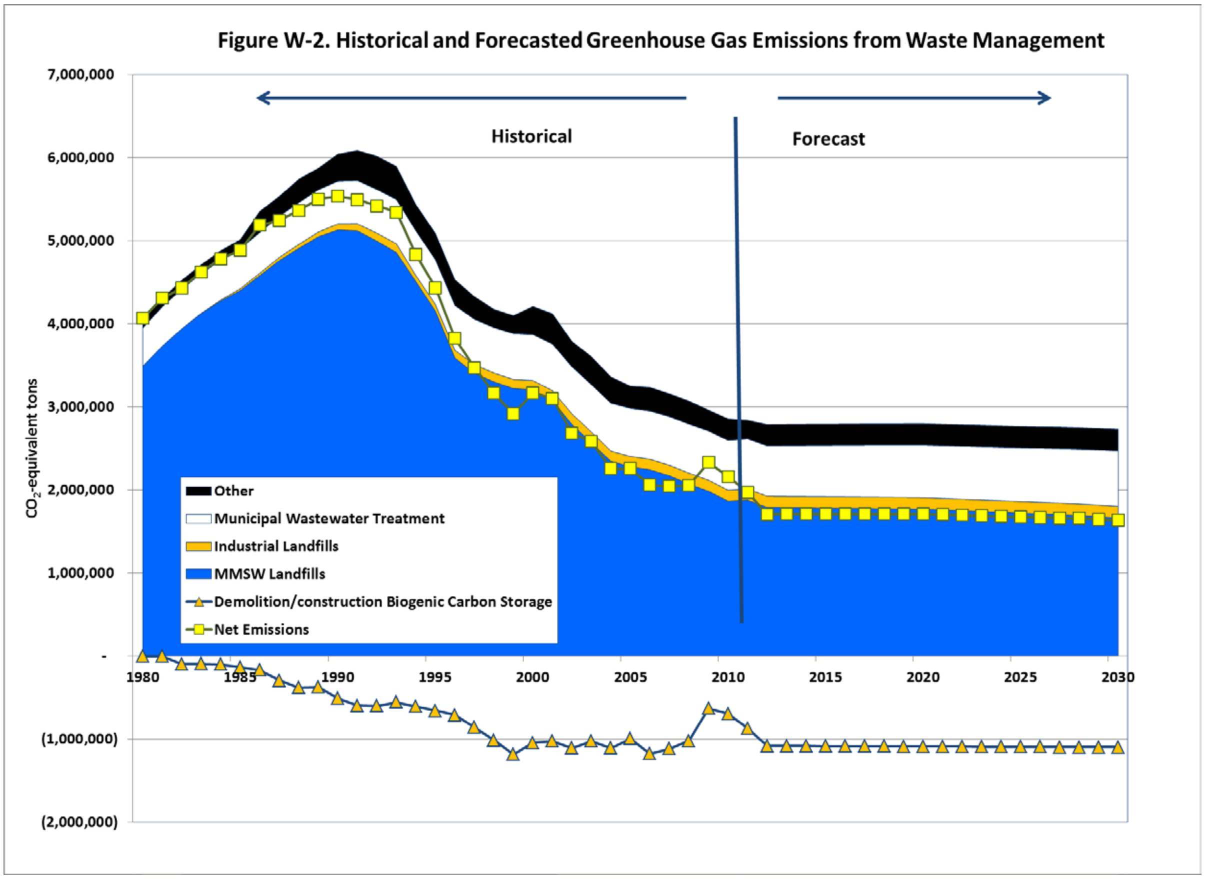
Finally, future emissions from energy use at WWTPs other than related to sludge incineration are set at average 2009-2011 levels. Emissions from this source come to a few hundred CO_2-equivalent tons for any year of the forecast period.

Figure W-2 shows the forecast trend in emissions from waste management, as well as the historic data for emissions from this sector. Net emissions are flat across the forecast period. Emissions in 2011 were an estimated 1.97 million CO_2-equivalent tons. At 2030, emissions from waste management are projected to be 1.64 million CO_2-equivalent tons, or 17 percent less than in 2011. Forecasted gross emissions at 2030 are 2.73 million CO_2-equivalent tons, or 4 percent lower than in 2011. Emissions from SLFs decline in the forecast by about 0.22 million CO_2-equivalent tons, 2011-2030; forecasted emissions from wastewater treatment increase by 0.06 million CO_2-equivalent tons, 2011-2030. Annual offsets through very long-lived biogenic carbon storage in demolition/construction landfills increase in the forecast by 0.23 million CO_2-equivalent tons from 2011 levels.

Lastly, sources for the data and methods used in the forecast include:

- EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*
- EPA, *LandGEM Landfill Gas Model*
- EPA, *Greenhouse Gas Emissions from Management of Selected Materials in Municipal Solid Waste*
- EPA AP-42, *Compilation of Air Pollution Emission Factors*
- European Environmental Agency (EEA), *EMEP/CORINAIR Emission Inventory Guidebook 2007*
- IPCC, *2006 IPCC Guidelines for National Inventories*
- Metropolitan Council, *Thrive MSP 2040*
- MPCA, *Greenhouse Gas Emission Inventory database*
- MPCA, *Metropolitan Solid Waste Management Plan*
- MPCA, *Minnesota Statewide Waste Characterization Study*
- NCASI, *Calculation Tools for Estimating Greenhouse Gas Emissions from Pulp and Paper Finals, Report Version 1.1.*
- RTI International, *Carbon Footprint of Demolition and Construction Waste Management*
- R.W. Beck and Ecobalance, *Municipal Solid Waste Management and Impact on Resource Conservation and Greenhouse Gas Emissions*
- State Demographer, *Population and Household Estimates*

[24] 10 percent



Detailed forecast results

The same forecast information that was shown in Table W-3 above is shown again below in Table W-5, albeit using a more detailed breakdown of emissions. In the forecast, greenhouse gas emissions from Minnesota waste management decrease by 0.34 million CO_2-equivalent tons or about 17 percent between 2011 and forecast year 2030. Between 2011 and forecast year 2030, emissions from landfills decline by 0.44 million CO_2-equivalent tons, offset by emission increases of 0.06 million CO_2-equivalent tons from wastewater treatment and 0.03 million CO_2-equivalent tons from waste incineration. Forecast emissions from composting increase slightly from 2011 levels, as do emissions from waste pre-processing.

From Table W-5, total forecast emissions from landfills in forecast year 2030 come to 0.71 million CO_2-equivalent tons, down from 1.15 million CO_2-equivalent tons in 2011. Of this forecasted reduction, about half is the result of forecasted declining emission reductions from SLFs and about half from forecasted increased biogenic carbon sequestration in demolition/construction landfills. As discussed above, in the MPCA GHG emission inventory, increased long-term biogenic carbon storage is treated as a negative emission. Emissions from industrial landfills are forecast to increase by 0.01 million CO_2-equivalent tons by forecast year 2030, as are forecast fugitive emissions from LFG flaring and emissions from all landfill operations. Total emissions from landfills of all categories decline a projected 38 percent over the forecast period. In the forecast, emissions from SLFs decline about 12 percent, 2011-2030, while by forecast year 2030 net removals or emission offsets from biogenic carbon storage increase by 26 percent above 2011 levels.

Forecast emissions from SLFs are comprised of emissions from legacy waste placed in landfills in 2011 and years before and emissions from new waste, in nearly equal increments. In forecast year 2030, emissions from new waste placed in the forecast in SLFs in forecast year 2012 and after comprise 54 percent of emissions, while emissions from legacy wastes comprise the remaining 46 percent of forecasted SLF emissions. In forecast year 2020, about 70 percent of total forecast emissions derive from old, legacy wastes. In the forecast, legacy emissions decline by 60 percent or 1.1 million CO_2-equivalent tons from 2011 levels, due mainly to the effects of waste age on waste CH_4 production potential. By forecast year 2030, about 80 percent of the reduction in legacy emissions in the forecast is offset by increased emissions from MMSW landfilled over the period 2012-2030.

In the forecast, at 2030, two-thirds of all emissions from SLFs derive from SLFs without active gas capture, down from about 70 percent in 2011. Landfills without active gas capture tend to be small, long-closed landfills with old waste with reduced CH_4 producing potential.

Forecast emissions from wastewater treatment at 2030 total some 0.67 million CO_2-equivalent tons, up 0.06 million CO_2-equivalent tons from 2011 levels, or about 11 percent. Of this, about 70 percent is from CH_4 emissions from wastewater treatment plants, the remaining coming from wastewater nitrogen discharges. In the forecast, between 2011 and forecast year 2030, emissions of CH_4 from wastewater treatment increase about 9 percent from 2011 levels, or 0.05 million CO_2-equivalent tons. In the forecast, emissions from wastewater nitrogen discharges in forecast year 2030 are about 20 percent above 2011 levels or 0.02 million CO_2-equivalent tons higher.

Table W-5. Forecasted Emissions from Minnesota's Waste Management Sector (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Landfills					
MMSW landfills (SLFs)					
legacy waste	1.75	1.53	1.23	0.96	0.74
new waste, 2012-2030	-	0.21	0.50	0.72	0.87
subtotal	1.75	1.74	1.73	1.67	1.61
SLFs with active gas	0.50	0.54	0.58	0.59	0.58
SLFs without active gas	1.26	1.21	1.14	1.09	1.03
Industrial landfills	0.13	0.14	0.14	0.14	0.14
Demolition/construction (D/C) landfills	(1.08)	(1.08)	(1.09)	(1.09)	(1.10)
LFG combustion/flaring	0.02	0.02	0.02	0.03	0.03
Landfill operations	0.02	0.02	0.02	0.02	0.02
subtotal	**0.85**	**0.84**	**0.82**	**0.77**	**0.71**
Incineration					
Rural open burning	0.05	0.05	0.05	0.05	0.05
Hazardous waste incineration	0.10	0.10	0.10	0.10	0.10
Medical waste incineration	0.00	0.00	0.00	0.00	0.00
Sludge incineration	0.01	0.01	0.01	0.01	0.01
Associated incinerator fuels	0.03	0.03	0.03	0.03	0.03
subtotal	**0.20**	**0.20**	**0.20**	**0.20**	**0.20**
Composting					
MMSW composting and compost land appli	0.00	0.00	0.00	0.00	0.00
Yard waste composting	0.04	0.04	0.04	0.04	0.04
subtotal	**0.04**	**0.04**	**0.04**	**0.04**	**0.04**
Waste Pre-processing					
Materials recovery facilities (MRF)	0.01	0.01	0.01	0.01	0.01
RDF processing	0.00	0.00	0.00	0.00	0.00
MMSW compost preprocessing	0.00	0.00	0.00	0.00	0.00
Yard waste preprocessing	0.00	0.00	0.00	0.00	0.00
subtotal	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Wastewater treatment					
Wastewater treatment	0.49	0.50	0.51	0.52	0.53
Wastewater discharge	0.10	0.10	0.11	0.11	0.12
Biosolids land application	0.01	0.01	0.01	0.01	0.01
subtotal	**0.61**	**0.62**	**0.63**	**0.65**	**0.67**
Total	**1.71**	**1.71**	**1.71**	**1.67**	**1.64**

Forecast emissions from incineration come to 0.2 million CO_2-equivalent tons in forecast year 2030, up from 0.17 million CO_2-equivalent tons in 2011 or 20 percent. Of this, nearly all is from increased emissions from hazardous waste incineration. Total waste management sector emissions from incineration comprise 10 percent of emissions across nearly all forecast years.

In 2011, emissions from landfills, wastewater treatment and waste incineration comprised an estimated 58 percent, 31 percent and 8 percent of Minnesota waste management emissions, respectively. In the forecast, the distribution changes to 43 percent, 41 percent and 12 percent for emissions from landfills, wastewater treatment and waste incineration, respectively, for forecast year 2030. As might be inferred from the discussion above, much of this change results from declining net emissions from SLFs and industrial and D/C landfills.

Table W-5 shows forecast estimates for emissions by gas for selected forecast years. Over the forecast period, emissions decline 0.34 million CO_2-equivalent tons from 2011 levels. Of this, about half is from declining net CO_2 emissions and half from declining CH_4 emissions. Between 2011 and 2030, emissions of fossil CO_2 plus sequestration decline by 0.19 million CO_2-equivalent tons or 27 percent, while emissions of CH_4 decline by 0.17 million CO_2-equivalent tons or 7 percent. In the forecast, N_2O emissions from waste management decline by 0.02 million CO_2-equivalent tons, 2011-2030.

Table W-5 also shows the forecast trend in emissions of biogenic CO_2. Over the forecast period, emissions of biogenic CO_2 increase by 0.06 million tons. Most of this is from increased emissions from SLFs. As discussed above, biogenic emissions are not now counted in waste sector totals.

Table W-5. Forecasted Emissions from Minnesota's Waste Management Sector by Gas (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Fossil CO_2 plus D/C sequestration	(0.87)	(0.87)	(0.87)	(0.88)	(0.88)
N_2O	0.13	0.14	0.14	0.15	0.15
CH_4	2.45	2.45	2.44	2.40	2.36
total	**1.71**	**1.71**	**1.71**	**1.67**	**1.64**
Biogenic CO_2					
SLFs	0.54	0.55	0.58	0.60	0.61
Industrial landfills	0.02	0.02	0.02	0.02	0.02
biodiesel fuel use	0.00	0.00	0.00	0.00	0.00
sludge incineration	0.13	0.13	0.13	0.13	0.13
rural open burning	0.04	0.04	0.04	0.04	0.04
medical waste incineration	0.00	0.00	0.00	0.00	0.00
MMSW composting	0.00	0.00	0.00	0.00	0.00
total	**0.74**	**0.75**	**0.78**	**0.80**	**0.81**

LandGEM model output for SLFs and industrial landfills includes forecasted emissions of biogenic CO_2 out to 2030. Forecast biogenic CO_2 emissions from sludge are estimated using emissions factors taken from World Resources institute/World Business Council for Sustainable Development, *Stationary Source Tool*. Biogenic CO_2 emissions from rural open burning are estimated using 2013 estimates of waste biogenic carbon content.

Table W-6 shows the forecasted SLF CH_4 balance out to 2030. This includes totals for modeled CH_4 *in-situ* generation, CH_4 oxidation in landfill covers, CH_4 combusted in flares and engines and CH_4 emitted to the atmosphere. Emitted CH_4 includes that small part of CH_4 that is fed to landfill flares but goes uncombusted. In the forecast, in forecast year 2012, roughly 60 percent of all CH_4 that, in the forecast, is generated *in situ* in Minnesota's SLFs is destroyed during flaring or in the landfill cover, rising to about 65 percent by forecast year 2030. As discussed above, in SLFs without active gas capture, 10 percent of landfill CH_4 is destroyed in landfill covers. For landfills with active gas capture, a combined 82 to 83 percent of landfill-generated CH_4 is in the forecast destroyed either during flaring or in landfill cover soils.

Table W-6. Forecast SLF Methane Balance (CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Legacy Waste					
existing closed SLFs and city dumps, no active gas capture					
CH_4 generated in-situ	0.86	0.74	0.57	0.45	0.35
CH_4 oxidized	0.09	0.07	0.06	0.04	0.03
CH_4 emitted	0.77	0.66	0.52	0.40	0.31
existing active SLFs, no active gas capture					
CH_4 generated in-situ	0.54	0.46	0.36	0.28	0.22
CH_4 oxidized	0.05	0.05	0.04	0.03	0.02
CH_4 emitted	0.48	0.42	0.32	0.25	0.20
existing closed SLFs, active gas capture					
CH_4 generated in-situ	0.62	0.54	0.42	0.33	0.25
CH_4 oxidized and combusted	0.50	0.41	0.28	0.22	0.17
CH_4 emitted	0.12	0.13	0.14	0.11	0.08
existing active SLFs, active gas capture					
CH_4 generated in-situ	2.31	1.99	1.55	1.21	0.94
CH_4 oxidized and combusted	1.94	1.67	1.30	1.01	0.79
CH_4 emitted	0.37	0.32	0.25	0.20	0.15
New Waste, 2012-2030					
Active SLFs without active gas					
CH_4 generated in-situ	-	0.14	0.33	0.48	0.58
CH_4 oxidized	-	0.01	0.03	0.05	0.06
CH_4 emitted	-	0.13	0.30	0.43	0.52
Active SLFs with active gas					
CH_4 generated in-situ	-	0.54	1.27	1.84	2.22
CH_4 oxidized and combusted	-	0.45	1.08	1.55	1.88
CH_4 emitted	-	0.08	0.20	0.28	0.34
Total Emissions	**1.75**	**1.74**	**1.73**	**1.67**	**1.61**
% of new waste to SLFs with active gas capture	79%	79%	79%	79%	79%

Over the forecast period, CH_4 generation *in situ* in the landfill from legacy wastes declines about 60 percent from 2011 levels. Of total landfill gas generation from legacy wastes, a constant 60 percent is, in the forecast, destroyed during flaring or in landfill cover soils, 2012-2030. Landfill gas production from new waste grows from 0 to 2.80 million CO_2-equivalent tons by forecast year 2030. As discussed above in the methods section, in the forecast, 79 percent of all forecasted new MMSW is landfilled in SLFs with active capture. A combined 70 percent of CH_4 generation in SLFs with and without active gas capture is estimated to be destroyed in landfill cover soils and during flaring, 2011-2030.

Figure W-3 presents the same information pictorially. In the forecast, the percent of SLF CH_4 that is destroyed through flaring (and oxidation in landfill cover soils) rises from an estimated 53 percent in 2011 to a projected 61 percent in forecast year 2030. Based on the modeling, in absence of LFG capture, total forecasted emissions from SLFs at 2030 would total some 4 million tons, rising about 0.3 percent per year. With CH_4 destruction, forecast CH_4 emissions from SLFs come to some 1.6 million CO_2-equivalent tons, falling 0.7 percent per year over the forecast period.

Figure W-3. Historic and Forecasted Emissions from SLFs

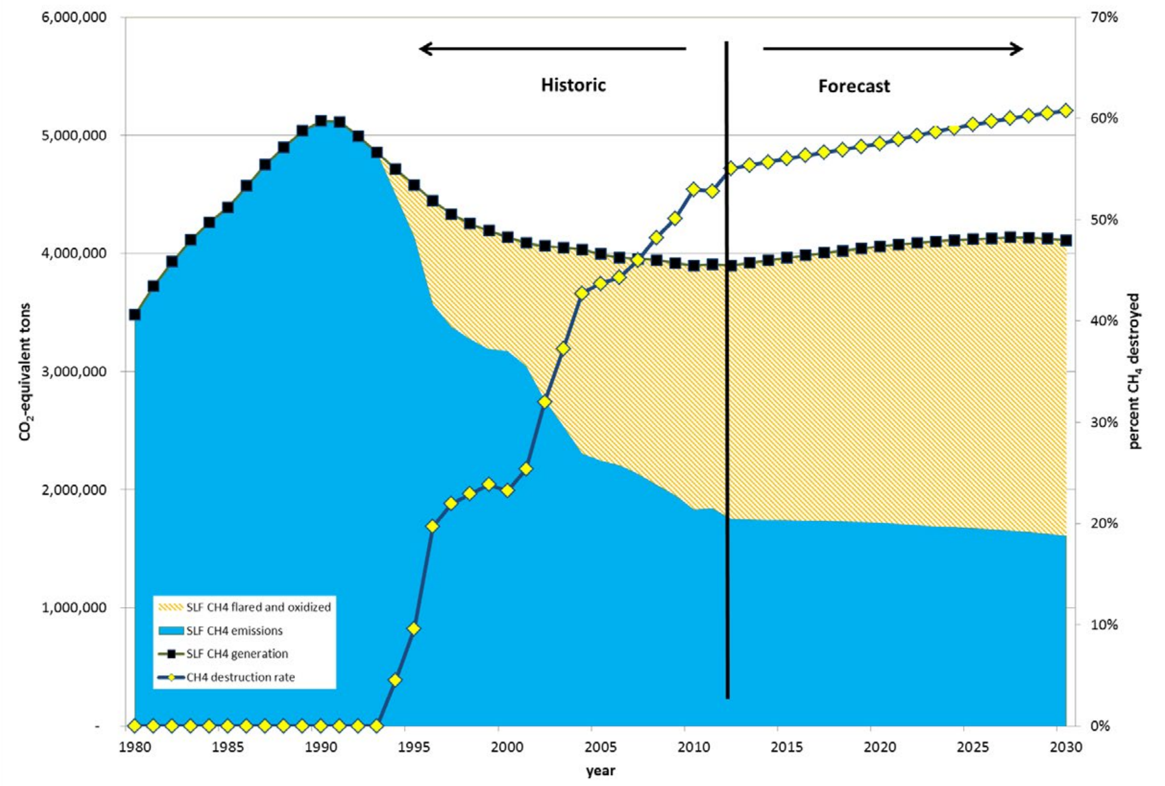


Table W-7 provides a detailed breakdown of forecasted emissions from wastewater management in Minnesota by gas. Roughly 80 percent of forecast wastewater emissions are in the form of CH_4 and, of these, about 60 percent are from private septic systems. Forecast emissions of N_2O are much smaller, 0.12 to 0.14 million CO_2-equivalent tons, and, as noted above, are dominated by emissions from effluent discharges. Emissions of methane from the management of human wastewater increase in the forecast by 0.04 million CO_2-equivalent tons between 2011 and 2030 or by about 9 percent. Three quarters of this increase is from increased emissions from centrally-managed wastewater treatment, particularly systems in which human waste is managed anaerobically.

Table W-7. Forecasted Emissions from Wastewater Management in Minnesota (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
CH_4					
centrally managed wastewater treatment					
aerobic treatment	0.04	0.05	0.05	0.05	0.05
anaerobic treatment	0.13	0.13	0.14	0.14	0.15
secondary treatment, anaerobic digestion	0.01	0.01	0.01	0.01	0.01
private septic systems	0.31	0.31	0.31	0.31	0.32
subtotal	**0.48**	**0.49**	**0.50**	**0.51**	**0.53**
N_2O					
in-situ WWTF	0.01	0.01	0.01	0.01	0.01
effluent discharges	0.10	0.10	0.11	0.11	0.12
sludge/septage land application	0.01	0.01	0.01	0.01	0.01
sludge/septage Nitrogen run-off/leakage	0.00	0.00	0.00	0.00	0.00
subtotal	**0.12**	**0.12**	**0.13**	**0.14**	**0.14**
Total	**0.61**	**0.62**	**0.63**	**0.65**	**0.67**

Emissions of N_2O from wastewater treatment increase 0.02 million CO_2-equivalent tons over the forecast period or 17 percent from 2011 levels. By individual source, emissions of CH_4 from septic systems, the largest individual wastewater management emission, increase in the forecast by 0.01 million CO_2-equivalent tons or 3 percent, 2011-2030. In the forecast, N_2O emissions from effluent discharge increase 0.02 million CO_2-equivalent tons, 2011-2030, or by 22 percent from 2011 levels. N_2O emissions from effluent discharge are the second largest emission source and, with emissions from septic systems, constitute about two-thirds of wastewater management emissions over the forecast period. Of smaller sources, emissions from centrally managed systems in which human waste is managed anaerobically increase 0.02 million CO_2-equivalent tons, or 19 percent, 2012-2030. Emissions from centrally managed systems in which human waste is managed aerobically increase 0.01 million CO_2-equivalent tons or 19 percent from 2011 base levels.

In absolute terms, the change in emissions from all other wastewater management emission sources is negligible over the forecast period. Total forecast emissions from these sources are similarly small over the forecast period, 0.03 million CO_2-equivalent tons for all years of the forecast.

Table W-8 summarizes the forecast trends in some of the important underlying terms used to project future emissions of CH_4 from wastewater treatment in Minnesota. Total generated BOD increases in the forecast by 15 percent, coincident with the forecast rate of population increase in the state, 2011-2030. In the forecast, most of this occurs at centrally-managed facilities that manage wastewater aerobically. In the forecast, total wastewater flows increase about 18 percent, 2011-2030.

Table W-8. Forecast BOD Generation and Management

	2012	2015	2020	2025	2030
BOD generated (million lbs./day)	1.01	1.04	1.08	1.12	1.16
BOD per capita (lbs./capita/day)	0.19	0.19	0.19	0.19	0.19
state resident population (millions)	5.38	5.54	5.77	5.99	6.18
BOD managed (million lbs./day)					
Centrally managed					
aerobic with primary treatment	0.59	0.61	0.65	0.68	0.70
aerobic without primary treatment	0.14	0.14	0.15	0.16	0.16
anaerobic with primary treatment	0.00	0.00	0.00	0.00	0.00
anaerobic without primary treatment	0.06	0.06	0.06	0.07	0.07
secondary teatment, anaerobic	0.00	0.00	0.00	0.00	0.00
Private septic systems	0.22	0.23	0.23	0.22	0.23
% of BOD managed in septic systems	20%	19%	19%	18%	18%
Flows (million gallons per day)	56.17	58.17	61.24	64.15	66.24

Finally, to evaluate the sensitivity of the waste management forecast to assumptions about waste generation and LFG capture, emissions were modeled using:

- 90 percent diversion of new MMSW to SLFs with active gas capture
- constant 2011 *per capita* MMSW generation, 2011-2030
- constant 2011 *per capita* MMSW generation, 2011-2020, followed by *per capita* MMSW generation declining 1 percent per year, 2021-2025

The results of this sensitivity analysis are shown below in Figure W-4. Base forecast levels at 2030 are 1.61 million CO2-equivalent tons, or about 10 to 15 percent higher than estimated in the sensitivity runs. In absolute terms, forecast 2030 emissions under 90 percent diversion of new MMSW to SLFs with active gas capture are 0.21 million CO_2-equivalent tons lower than 2030 base forecast emissions, those for constant 2011 *per capita* MMSW generation, 2011-2030, about 0.1 million CO_2-equivalent tons lower than 2030 base forecast emissions. Emissions for constant 2011 *per capita* MMSW generation, 2011-2020, followed by declining *per capita* MMSW generation are 0.14 million CO_2-equivalent tons lower than base forecast emissions. In any of the three instances assessed, the departures of emissions from the base forecast emission trend are small in absolute terms.

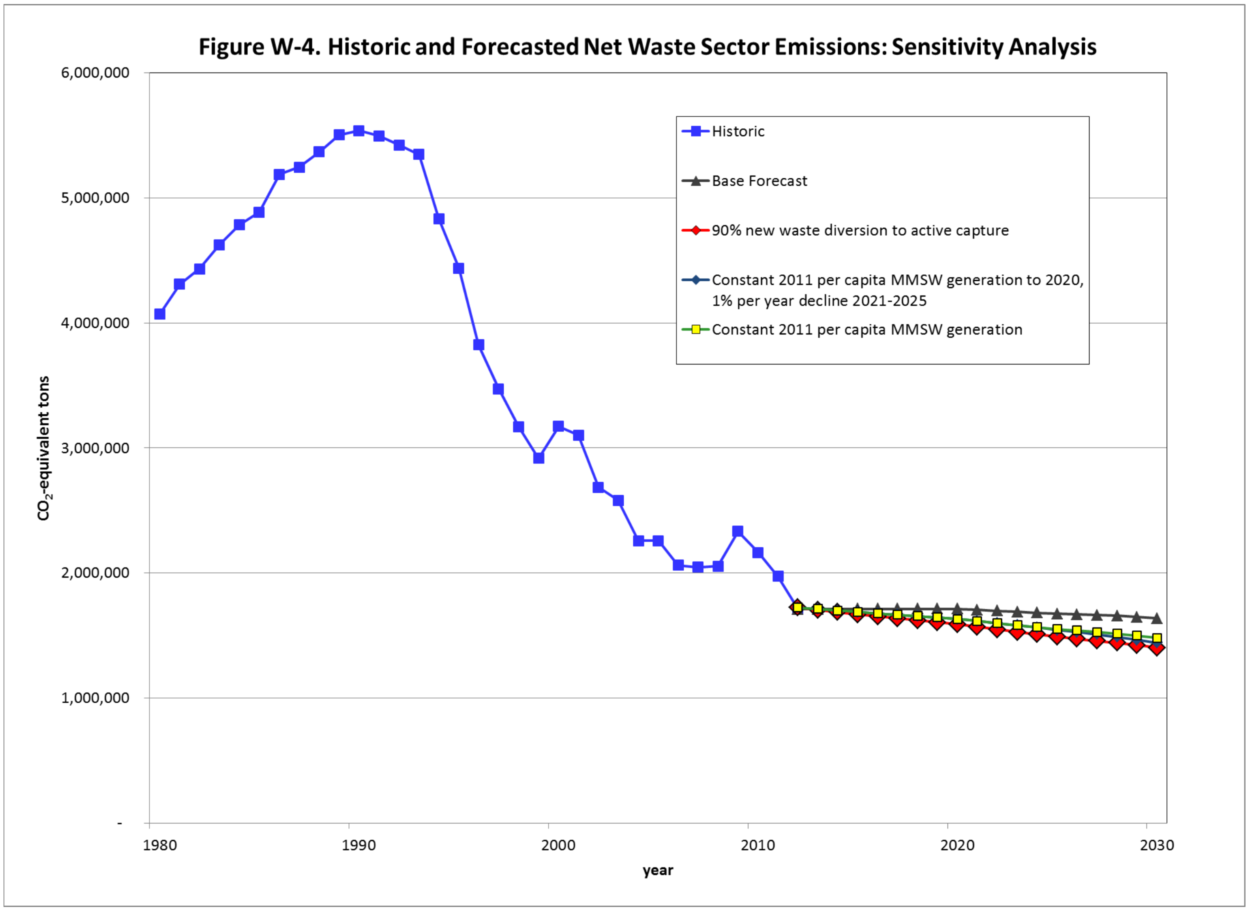


Figure W-4. Historic and Forecasted Net Waste Sector Emissions: Sensitivity Analysis
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
-
CO2-equivalent tons
1980
1990
2000
2010
2020
2030
year
Historic
Base Forecast
90% new waste diversion to active capture
Constant 2011 per capita MMSW generation to 2020, 1% per year decline 2021-2025
Constant 2011 per capita MMSW generation

Livestock sector

Sector boundaries

The feedlot/livestock sector includes commercial feedlots and that part of farms dedicated to the production of meat for slaughter and milk and egg products. It also includes pasture-based cow-calf and grass-fed stocker and backgrounder operations that supply young animals to feedlots for finishing prior to slaughter. It includes the animal production systems, including housing, feeding and grazing, breeding, manure management, and, in the case of milk production, the milking of the animals and milk storage, as well as the animals themselves.

The feedlot sector does not include the production of grain, grain-products or fodder for feed on Minnesota feedlots. The production of feed for livestock is included in the crop production subsector of the agricultural sector. The feedlot sector also does not include highway transport of animals to and from feedlots. The highway transport of animal is treated in the transport sector.

Most greenhouse gas emissions from feedlots and livestock are non-combustion 'process emissions,' although some are on-site emissions from fuel use. Feedlot process emission include emissions from ruminants, stored manure, manure land applied as a nutrient source, manure deposited in pastures and paddocks, and manure nitrogen deposited in streams, lakes and groundwater after run-off from feedlots and fields.

Electricity is used in milk production and storage, the feeding of livestock and other activities on feedlots. The generation off-site of grid-based electricity results in GHG emissions, but these are treated elsewhere in the inventory and forecast as electric power sector emissions

Present-day and historical emissions

Estimates are shown below for historical emissions from the feedlot/livestock sector for selected years in million CO_2-equivalent tons. Most emissions from feedlots and livestock derive from the animals themselves in the form of flatulence and from the storage and management of manure. CH_4 is emitted from livestock flatulence, mostly ruminant flatulence, in the case of Minnesota livestock, dairy and beef cattle. Both CH_4 and N_2O are emitted from stored manure and N_2O is emitted from land-applied manure or manure nitrogen run-off to streams, rivers, lakes, and groundwater.

Emissions of CH_4 from livestock flatulence are calculated on a per head basis by animal type and size, using emission factors given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Present-day and historical estimates for on-farm head of livestock are from USDA, *Minnesota Agricultural Statistics* and, for some minor livestock types like bison, horses, mules, asses and goats, periodic estimates from Census Bureau, *Census of Agriculture*. The emission factors used are nationally-based factors that, back to the estimates for 1991, vary annually with animal diet, mass and gross and net energy.

Table F-1. Historical Emissions from Minnesota's Livestock Sector (million CO_2-equivalent short tons)

	1990	2000	2005	2010	2011
Combustion emissions					
oil	0.77	0.76	0.77	0.82	0.82
other	0.00	0.00	0.00	0.00	0.00
subtotal	0.77	0.76	0.77	0.82	0.82
Flatulence	6.01	5.69	5.28	5.46	5.45
Feedlot manure	2.56	3.45	3.62	4.02	4.02
Land-Applied manure	0.33	0.37	0.39	0.40	0.40
Manure nitrogen run-off/leaching (field)	0.15	0.17	0.17	0.18	0.18
Total	9.82	10.44	10.23	10.88	10.86
by livestock type:					
Dairy cattle	4.55	3.95	3.55	3.97	3.92
Beef cattle	3.62	4.02	3.92	3.92	3.89
Swine	1.17	1.83	2.11	2.39	2.46
Poultry	0.34	0.44	0.44	0.41	0.41
Other	0.14	0.20	0.21	0.19	0.19
Total	9.82	10.44	10.23	10.88	10.86

Emissions of CH_4 from manure storage are a calculated total derived from annually estimated totals for volatile manure solids (VS) produced by Minnesota livestock and a conversion factor from VS to CH_4 that varies by manure storage type. Volatile solids production is calculated from average animal liveweight on-farm at any one moment during the inventory year, by animal type and size, and a rate of production per lbs. of animal liveweight, again by animal type and size. VS production rates are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Volatile solids production rates for dairy and beef cattle for 2009-2011 are Minnesota-specific estimates from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2011*. EPA introduced a change in methodology in 2009 that rendered the earlier state-specific data discontinuous with estimates for 2009-2011. The earlier estimates, also constructed at a state-level, were rescaled using a three-year, 2009-2011, average for VS production per lbs. of liveweight by animal type and size.

Annual estimates of VS production rates (per lbs. of liveweight) back to 1990 for sheep, horses, mules, turkeys, broilers and layers also are from EPA*, Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2011*. These are nationally-based annually varying estimates of per lbs. of liveweight VS generation. For swine, EPA*, Inventory of US Greenhouse Gas Emissions and Sinks* gives a single rate of VS production per lbs. of liveweight by animal size for all inventory years back to 1990 that we use. These also are nationally-based values. For minor animal types like bulls, pullets of varying ages, breeding hens, and bison, the rates given in earlier editions of EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* are used.

Livestock liveweight on-farm is a calculated total using the population estimates described above for livestock on Minnesota farms and feedlots and average per head liveweights for Minnesota livestock, again by animal type. In evaluating liveweight, for milk replacement heifers and beef replacement heifers we use the estimates given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* for average liveweight per animal. For dairy cows, beef cows, beef bulls and steers, the normalized change from year 2000 levels in US slaughter weights for these classes of animals from USDA, *Livestock Slaughter* is used, along with estimated year 2000 on-farm average liveweights of 1,332, 1,301, 1,653 and 701 lbs. for dairy cows, beef cows, beef bulls and steers, respectively. For feedlot heifers, the normalized change in slaughter weights from 1995 levels from USDA, *Livestock Slaughter* is used, along with a 1995 on-farm liveweight of 926 lbs. Calf liveweight is a calculated total using a constant 397 lbs. per calf across the inventory period.

The data for total market swine given in USDA, *Minnesota Agricultural Statistics* is organized by weight class. Total market swine liveweight is calculated using an average value for liveweight per weight class and the total head of swine reported for each weight class. For breeding swine, a constant 437 lbs. per sow is used, taken from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. This is a nationally-based estimate. US Slaughter weights are used to calculate total liveweight for mature sheep and replacement lambs, as is also the case for turkeys and broilers. Point estimates for animal liveweight are used for goats, horses, mules, bison, layers, pullets of laying age, breeding hens and pullet chicks, mostly drawn from EPA*, Inventory of US Greenhouse Gas Emissions and Sinks*. Again, these are nationally-based estimates. For pullets of laying age and breeding hens, an average liveweight of 2.9 and 3.5 lbs. is assumed.

In the calculation of emissions, total annual VS production is converted to CH_4 using Minnesota-specific factors by manure storage type, taken from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. The percent distribution in Minnesota of manure volatile solids by storage type is from the MPCA feedlot inventory. Manure storage types include: below barn pits; outdoor tanks or basins; outdoor anaerobic and aerobic lagoons; solid storage; stall and poultry barn accumulation of manure with periodic clean-out; and drylot accumulation with periodic clean-out. The most recent estimates that are available for the percent distribution of manure volatile solids by storage type are from 2006. The observed increase in anaerobic digestion of dairy manure, 2007-2011, is incorporated into the estimates given for dairy manure management.

CH_4 production in stored manure varies directly with stored manure water content and length of storage. Manures stored in a solid dry state generally have low emissions. Livestock manure stored for lengthy periods in outdoor tanks, basins, anaerobic lagoons and below barn in pits have much higher rates of emission. In addition to liquid and solid storage, manure also is managed in Minnesota through daily scrape and haul systems and the pasturing of animals, and can involve treatment prior to storage in the form of anaerobic digestion or manure composting. Emissions are estimated from each of these systems or pre-treatments, but these are generally small.

Emissions of CH_4 from mink manure are calculated on a per head basis, following the method given in Intergovernmental Panel on Climate Change, *2006 Guidelines for National Greenhouse Gas Inventories*. Historic on-farm populations of mink are from USDA, *Minnesota Agricultural Statistics*.

Emissions of N_2O from stored manure are calculated from estimates by animal type and size of total excreted manure nitrogen and emission rates developed at the national levels for N_2O from stored manure. Total excreted manure itself is calculated from manure nitrogen excretion rates, developed on a liveweight basis, and total animal liveweight, also by animal type and size. For dairy and beef cattle, Minnesota specific rates of manure nitrogen excretion are used, derived for 2009-2011 from estimates given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. For all other animal types, excretion rates developed at the national level are used. Estimated total liveweight on farms and feedlots by animal type is taken from the analysis described above.

In the calculation of emissions, total annual manure nitrogen is converted to emitted N_2O using factors by manure storage type, again taken from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. To carry out the calculation, excreted manure nitrogen is distributed to manure storage types using the historic information on manure management by animal number and animal type given in the MPCA feedlot inventory. Total manure nitrogen is first adjusted to account for nitrogen lost during the combustion of turkey litter at the Fibrominn solid biomass power plant.

Roughly half of all beef cattle and goats, 60 percent of sheep and a quarter of horses in the state are pastured. To estimate emissions from pastured animals, total pastured animal liveweight is estimated and converted to excreted manure nitrogen. Emissions are then calculated using the factors for pasture given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Prior to the calculation of emissions, total nitrogen excreted on pasturelands is adjusted for losses due to volatilization, leaching and surface runoff.

After varying periods of storage, livestock manure is land-applied as a soil nutrient. In addition, about 20 percent of manure from dairy cows and about 1 percent of swine manure are land-applied within days of excretion, with essentially no storage as part of daily scape and haul systems. Upon land application, roughly 50 percent of manure nitrogen volatilizes, runs off or leaches through the soil to ground water. Of the remainder, roughly one percent of all applied manure nitrogen is lost to the atmosphere in the form of N_2O.

Emissions from land application are calculated assuming that 0.5 percent of land applied manure nitrogen is directly lost to the atmosphere from soils as N_2O.

Of that part of land-applied manure nitrogen that runs off or is leached from the soil, roughly 0.75 percent is eventually emitted to the atmosphere. Of all nitrogen lost through volatilization, leaching and run-off, about 60 percent is associated with leaching and run-off. Emissions of N_2O from surface run-off and leaching are calculated from total applied nitrogen, assuming that, of this total, 0.23 percent is emitted indirectly in the form of N_2O from groundwater and surface waters.

On site fuel combustion results in the emission of CO_2, N_2O and CH_4 to the atmosphere. Emissions from on-site combustion are estimated using annual estimates of fuel use in the farm production of milk and meat animals and conventional fuel-based emission factors. The emission factors that are used are from USEPA, *Inventory of US Greenhouse Gas Emissions and Sinks* and The Climate Registry, *General Reporting Protocol*. The emission factors are based on fuel energy content. Before emissions are calculated for any one fuel or inventory year, fuel is converted to standard units of energy (MMBtu).

Fuel use is estimated using the data on fuel use per pig litter for swine farrowing and nurse systems, per finished hog for swine finishing, per calf for cow-calf operations, per finished steer for beef finishing, per turkey raised, and per hundred weight of milk produced, all given in B. Ryan and D. Tiffany, "Minnesota Agricultural Energy Use and the Incidence of a Carbon Tax." Data on the annual Minnesota production of turkeys, milk and litters of pigs is taken from USDA, *Minnesota Agricultural Statistics*. The total number of finishing hogs in any inventory year is estimated from the annual Minnesota swine slaughter and average hog liveweight at slaughter, both given in USDA, *Minnesota Agricultural Statistics*. The number of finishing steers is similarly estimated.

Table F-2 provides historical information on livestock liveweight on Minnesota farms and feedlots, total volatile solids and manure nitrogen production, and amounts of manure nitrogen land-applied. Also shown are historical estimates of total ruminant cattle on Minnesota farms and feedlots and the percent distribution of manure management by type in the state. Between 1990 and 2011, livestock liveweight on Minnesota farms and feedlots increased by about 10 percent. Over this period, total estimated on-farm liveweight of beef and dairy cattle declined by 8 percent. By contrast, total swine and poultry liveweight on-farm increased 50 percent and 95 percent, respectively, more than offsetting the estimated decline in beef and dairy liveweight on-farm. Between 1990 and 2011, the number of ruminant cattle in the state declined by about 12 percent.

Table F-2. Historical Activity on Minnesota's Livestock Sector

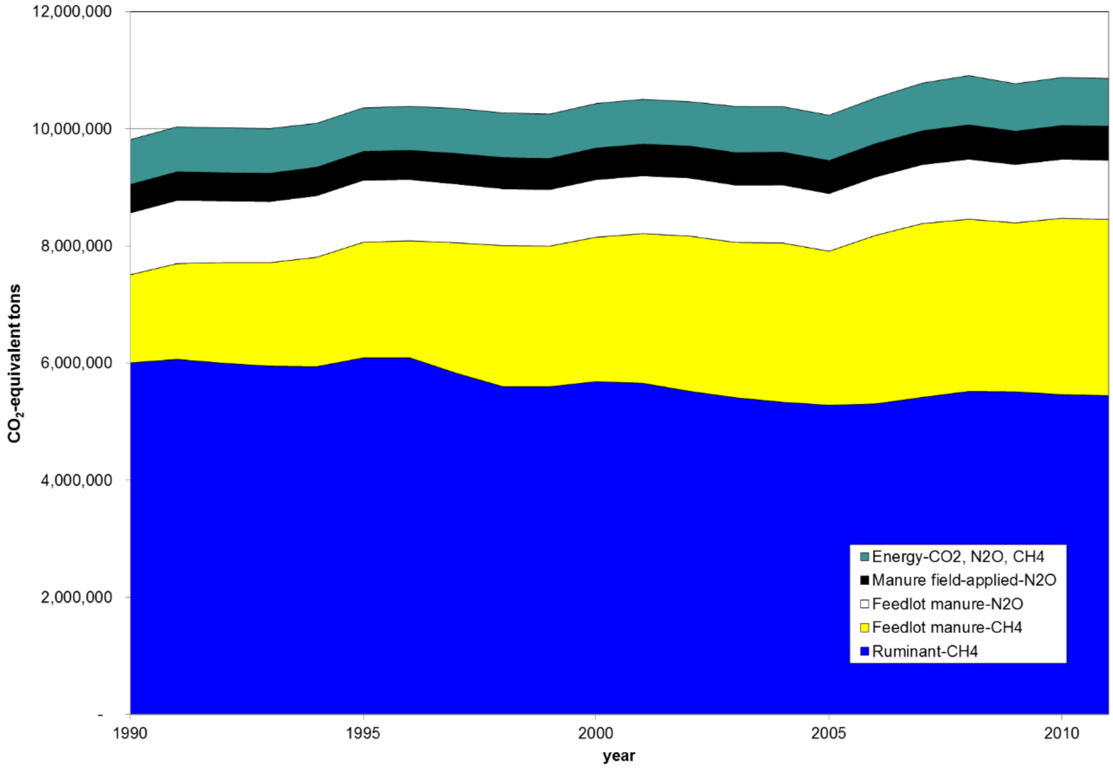
	1990	2000	2005	2010	2011
Liveweight on Feedlots (million lbs.)					
Dairy	1,178	971	886	919	899
Beef	1,280	1,407	1,404	1,361	1,357
Swine	660	773	879	969	995
Poultry	182	302	358	354	354
Other	83	104	125	119	121
Total	3,382	3,558	3,651	3,722	3,726
Manure volatile solids (tons)	4,848,580	4,808,431	4,944,517	4,964,135	4,949,954
Manure nitrogen (tons)	278,396	292,474	305,955	319,571	321,631
Manure nitrogen land-applied (tons)	142,735	158,367	165,542	169,409	170,139
Ruminant Cattle (thous head)					
Milk cows	710	534	453	470	468
Beef cows	357	396	384	361	353
Other non-calf cattle	1,075	1,082	1,034	1,059	1,082
Calves	565	540	505	497	473
	2,707				2,374
Manure management (% liveweight managed)					
liquid/slurry storage	0.28	0.41	0.45	0.46	0.46
solid storage	0.30	0.28	0.28	0.28	0.28
anaerobic digester	-	0.00	0.00	0.01	0.01
daily spread	0.14	0.06	0.04	0.04	0.04
pasture/paddock	0.27	0.24	0.23	0.22	0.22

liquid/slurry storage = below barn storage and outdoor basin, tank,pond, lagoon; solid storage = drylot, solid storage, poultry litter floor, stall accumulation with periodic scrape

Between 1990 and 2011, total volatile solids production by livestock on-farm increased 2 percent, while total manure nitrogen production on Minnesota farms and feedlots increased about 16 percent. Long-term storage of manure in a liquid or slurry form increased as a percent of total manure storage from an estimated 28 percent in 1990 to about 46 percent in 2011, while the use of daily scrape and haul and pasture systems declined, as a percent of the total, from an estimated 41 percent in 1990 to about 26 percent in 2011. Again, stored in for long periods of time in liquid, anaerobic conditions, manure is a large emitter of greenhouse gases. Increased liquid or slurry storage of manure was probably the single most important factor in the increase in total GHG emissions from feedlots and livestock over this period.

Figure F-1 shows graphically the emissions data that were presented in Table F-1 in tabular form. Between 1990 and 2011, greenhouse gas emissions from feedlots and feedlot and farm livestock increased 10.4 percent, rising at an average annual rate of about 0.5 percent. In absolute terms, emissions increased by about 1.02 million CO_2-equivalent tons. Emissions from stored livestock manure increased by an estimated 1.46 million CO_2-equivalent tons or 57 percent, offsetting an estimated decline in emissions from ruminant flatulence of 0.56 million CO_2-equivalent tons or 9 percent.

Figure F-1. Greenhouse Gas Emissions from Minnesota Feedlots and Farm Livestock



By livestock type (shown in Table F-1 but not in Figure F-1), most of the increase in emissions between 1990 and 2011 was the result a much larger swine herd in the state and, more significantly, heavier reliance on long-term storage of manure in more liquid forms. As noted above, storage of manure in liquid forms promotes the formation of CH_4. Emissions from the production of swine roughly doubled between 1990 and 2011, by 1.25 million CO_2-equivalent tons, offsetting an estimated 0.63 million tons (14 percent) reduction in direct emissions from milk production. Emissions from beef production rose by an estimated 0.27 million CO_2-equivalent tons between 1990 and 2011 or 7 percent, Emissions from all other livestock types increased by an estimated 0.12 million CO_2-equivalent tons, accounting for the remainder of the observed net increase, 1990-2011.

Full documentation of the sources and methods used to develop the feedlot/livestock sector inventory is included in Appendix E of P. Ciborowski and A. Claflin, "Greenhouse Gas Emissions in Minnesota: 1970-2008: Second Biennial Progress Report – Technical Support Document" (2012).

Forecast methods

The forecast was developed using the same sector boundaries as discussed above. The feedlots and livestock sector includes commercial feedlots and that part of farms dedicated to the production of meat for slaughter and milk and egg products. It includes the animals, as well as livestock manure management, grazing, breeding, housing, and, in the case of milk production, the milking of the animals and milk storage. It does not include the farm production of forages or feeds consumed by the animals, or, where grid-based, on-farm electricity consumption.

The emissions forecast is shown below in Table F-3 in million CO_2-equivalent tons. Emissions increase 1.43 million CO_2-equivalent tons or 13 percent over the forecast period, 2011-2030. Of this increase, most of it, 0.91 million CO_2-equivalent tons, is from feedlot manure storage and management. Emissions from livestock flatulence increase in the forecast by 0.357 million CO_2-equivalent tons or 6 percent. Emissions from land-applied manure increase 0.2 million CO_2-equivalent tons. By animal type, most of the increase results from an expanded forecasted swine herd in the state.

Emissions from manure management are projected from forecasted livestock liveweight on-farm and from a schedule of manure management by animal type and production system to 2025. Total liveweight on-farm determines the annual rate of production of livestock volatile solids, from which for any forecast year maximum potential CH_4 production from stored manure is estimated. Manure storage type and length of storage determines the rate of actual CH_4 production, expressed as a percentage of maximum potential CH_4 production. Out to 2025, forecast rates of actual CH_4 production per lbs. of manure stored or managed by manure storage type and storage length are assumed to remain unchanged from current values. These are taken from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. Rates of maximum CH_4 production from stored volatile solids by livestock type, age and feed ration also are assumed to remain unchanged from present-day rates. These are taken from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.*

For dairy cows, total liveweight is calculated from total forecast numbers of dairy cows for Minnesota through 2022 given in Food and Agricultural Policy Institute (FAPRI), *2012 US Baseline Briefing Book* and forecast average on-farm liveweights. FAPRI annually develops forecasts at the state-level of the US dairy herd. The forecast for Minnesota was extended to 2025, using the average annual rate of decline in herd size in the Minnesota FAPRI forecast data, 2019-2022, applied to FAPRI-forecast 2022 levels. For dairy cows, on-farm liveweights have been increasing for decades, at a long-term rate of about 80 lbs. per decade. This long-term linear rate of increase is assumed to continue to 2025. Total on-farm dairy cow liveweight is the product of the total number of forecasted dairy cows and, for any one forecast year, forecast average animal liveweight.

Table F-3. Forecasted Emissions from Minnesota's Livestock Sector (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Combustion emissions					
oil	0.81	0.80	0.84	0.86	0.88
other	0.00	0.00	0.00	0.00	0.00
subtotal	0.81	0.80	0.84	0.86	0.88
Flatulence	5.43	5.45	5.65	5.64	5.80
Feedlot manure	3.97	4.07	4.38	4.65	4.93
Land-Applied manure	0.40	0.41	0.43	0.45	0.47
Manure nitrogen run-off/leaching (field)	0.18	0.18	0.19	0.20	0.21
Total	10.79	10.91	11.49	11.81	12.29
by livestock type:					
Dairy cattle	3.89	3.89	3.94	3.99	NA
Beef cattle	3.88	3.95	4.20	4.14	NA
Swine	2.41	2.44	2.69	2.96	NA
Poultry	0.42	0.43	0.46	0.48	NA
Other	0.19	0.19	0.21	0.24	NA
Total	10.79	10.91	11.49	11.81	NA

The typical dairy cow produces milk for commercial sales for about 3 to 4 years, after which it is sold for slaughter. To replace aging milk cows, a herd of dairy replacement heifers is maintained in Minnesota, at a ratio of about 0.6 heifers in the state for each one mature dairy cow. This ratio has been increasing linearly for at least three decades, but was virtually flat between 2003 and 2012, a condition that is assumed to continue. For each forecast year, the total number of milk replacement heifers is the product of this ratio and the total forecast number of dairy cows from FAPRI. Total milk replacement heifer liveweight is the product of total heifers and forecast average on-farm milk replacement heifer liveweight. In the EPA data discussed above (in the section on present-day and historical emissions), average milk replacement heifer liveweight is fairly constant at about 990 lbs. per animal across all 20 inventory years reported (1991-2011) and is assumed to remain at that level.

To project VS production per lbs. of liveweight for dairy cows and milk replacement heifers, data for this parameter for 1990-2011 from the MPCA GHG Emissions Inventory database were linearly trended and extended to 2025. Total volatile solids production from dairy cows and milk replacement heifers is projected using forecast liveweight and forecast production of VS per lbs. of livestock liveweight.

For egg layers (layers and pullets of laying age), total liveweight is calculated from total forecast egg production in Minnesota to 2025, the ratio of layers to egg layed, and average liveweight per layer. Total forecast egg production in Minnesota is some 3.6 billion eggs in 2025. It assumes that Minnesota maintains its long-term 30-year average market share (3.6 percent) and that US egg production grows 0.6 percent per year, based on the national forecast given in FAPRI, *2012 US Baseline Briefing Book.* The FAPRI forecast, for years 2012 through 2022, is extended to 2025, using the average annual rate of increase in FAPRI forecast US egg production, 2019-2022 and forecast 2022 levels. Based on data housed in the MPCA GHG Emission Inventory database, the 10-year 2002-2011 average ratio of layers to egg layed was 0.0035, a rate that is assumed to persist through 2025. The 10-year, 2002-2011, average liveweight per layer, again from the MPCA GHG Emission Inventory database, was an estimated 3.4 lbs., an average weight also assumed to persist. No secular trend in evident in the data for either of these two parameters.

Layer volatile solids production is projected using forecast liveweight and constant 2006-2011 rates of VS production per lbs. of livestock liveweight. Based on EPA data, at the national level VS production per lbs. of layer liveweight was roughly constant over the historical period, with values of 3.69 lbs. per lbs. liveweight, 1990-2005 and 3.72 lbs. per lbs. liveweight, 2006-2011.

For pullet chicks, breeding hens and other chickens, total forecast liveweight is calculated from projected layer liveweight over the forecast period and historical estimates of layer liveweight as a fraction of all nonbroiler chicken liveweight. The historical data are from the MPCA GHG Emission Inventory database. Forecast VS production by breeding hens, pullet chicks and other chickens is calculated using forecast liveweight for these animals and VS production rates for 'other chickens' given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks, 1990-2008.*

For goats, horses, mules and bison, on-farm liveweight is projected from forecast numbers of livestock on-farm for each of these categories and present-day average animal liveweights, again by animal type. Data on on-farm livestock populations are from the periodic Census Bureau, *Census of Agriculture*. Using data for on-farm populations of goats, mules, horsed and bison from the 2002 and 2007 *Census of Agriculture*, an average annual rate of change was calculated for each and applied to the most recent inventory estimates available for on-farm animals for these livestock types. At the time this forecast was developed, the 2012 *Census of Agriculture* had not been published. Present-day average animal liveweights are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.*

Annual volatile solids production for mules, bison and goats is projected from forecast liveweight for each class of animals and points estimates for VS production per lbs. of liveweight, given at the national level, for these classes of livestock in EPA*, Inventory of US Greenhouse Gas Emissions and Sinks*. For horses, an average 2008-2011 VS production rate per lbs. of liveweight is used. In the data in the MPCA GHG Emissions Inventory, VS production per lbs. of equine liveweight, which had declined linearly, 1999-2008, appears to be stabilizing at 2008 levels. In absence of better information, constant 2008-2011 rates are employed in the Minnesota projections.

On-farm liveweight for sheep is estimated for all years of the forecast period using the average annual rate of decline in total sheep and lambs in Minnesota, 2007-2012, and linearly trended historic data on animal liveweights. The sheep and lamb herd has been in long-term decline for decades, although the rate of decline has been slowing in recent years. Between 1990 and 2012, the herd declined by roughly half. The average annual rate of decline in the size of the herd between 2007 and 2012 was 0.6 percent. Based on data housed in the MPCA GHG Emission Inventory database, average animal liveweights have increased from about 110 lbs. per animal in 1990 or 2000 to about 120 lbs. per animal in 2011 or 2012.

Sheep volatile solids production is projected using forecast sheep and lamb liveweight and constant 2011 rates of VS production per lbs. of liveweight for these livestock. In the data in the MPCA GHG Emissions Inventory database, VS production per lbs. of sheep and lamb liveweight, which had declined linearly, 1999-2008, appears to be stabilizing at 2008 levels. In absence of better information, constant 2008-2011 rates are employed in the Minnesota projections.

On-farm swine, beef, turkey and broiler liveweight is projected from annual animal liveweight production and historic ratios of on-farm liveweight to annual liveweight production. Values for both are taken from the MPCA GHG Emission Inventory database. For swine, the observed 2011 ratio of on-farm liveweight to annual liveweight production is used. The same is true for turkeys. For beef and broiler chickens, a 10-year, 2003-2012, average is employed. In the case of swine, the ratio of on-farm liveweight to annual liveweight production has been declining for decades, but more recently at a rapidly decelerating rate, with indications that the value may be stabilizing near 0.25. For beef and broiler chickens, this ratio has been constant for, in the case of beef, since the middle 1990s and, for boiler chickens, the early 2000s. For turkeys, the ratio of on-farm liveweight to annual liveweight production increased about 6 percent from 1998 to 2007, but has been unchanged since, through 2012.

Annual liveweight production is projected from forecast Minnesota poultry and meat production and slaughter yields. Historic slaughter yields from the US Department of Agriculture (USDA), *Agricultural Statistics* and USDA, *Livestock Slaughter* are used. A 10-year, 2003-2011, average is employed. Slaughter yield equals total meat production divided by liveweight production.

Minnesota meat production is projected using US-level Food and Agricultural Policy Research Institute forecasts for poultry and red meat production and, for each meat type, an assumed Minnesota market share for each year of the forecast period out to 2025. The FAPRI forecast is from FAPRI, *2012 US Baseline Briefing Book*.[25] For swine, a 12.8 percent share of the US market at 2025, up from 11.9 percent in 2011, is assumed. For turkey meat and chicken meat, market share constant at present levels is assumed across the forecast period. For beef, a 2.9 percent market share, up from 2.6 percent in 2011, is assumed. For beef, a 12-year, 2000-2012, average for percent share of the US beef market, is used. The Minnesota share of US beef markets has oscillated between 2.6 and 2.9 percent since about 1998. Minnesota share of the US turkey meat and chicken meat markets has been reasonably stable, in

[25] The FAPRI national-level forecasts for poultry and red meat production are for forecast years 2012-2022. To bring the forecast to 2025, US levels of poultry and red meat production were extended out to 2025, using the average annual rate of increase in FAPRI forecast for US pork, beef, chicken, and turkey meat production, 2019-2022, and 2022 forecast levels.

the case of turkey meat, since about 2007 at 16 percent, and in the case of chicken meat, since 1998 at about 0.5 percent.

For Minnesota pork, market share increased rapidly from the middle 1990s until about 2003, but since 2003 at a much slower linear rate of about 0.07 percent per year. The forecast Minnesota share of the US pork market is based on 2003-2012 data for the Minnesota percent share of US pork production, linearly trended and extended to 2025.

All historic data on Minnesota and US meat production are from USDA, *Minnesota Agricultural Statistics*, USDA, *Agricultural Statistics*, and USDA, *Livestock Slaughter*.

To project total VS production by swine, total swine liveweight is distributed between market swine and breeding swine, and, within the market swine class, to animals weighing less than 60 lbs. and those weighing more than 60 lbs. The rate of volatile solids production by swine varies by swine type (market swine, breeding swine) and size. Market swine produce volatile solids at a higher rate per lbs. of animal liveweight than do breeding swine (sows, boars), and piglets and market hogs smaller than 60 lbs. produce VS at higher rates, again per lbs. of liveweight, than do swine weighing more than 60 lbs. In the forecast, the distribution of swine liveweight is based on 1990-2012 data for the percent distribution of liveweight on Minnesota farms and feedlots across these livestock categories, linearly trended and extended to 2025. The historic data are from the MPCA GHG Emission Inventory database.

For beef cattle, VS production varies by feed regimen and by animal function, with VS production per lbs. of liveweight generally higher for beef cattle not-on-feed than those on-feed, and VS production by beef cows and beef steers not-on-feed generally higher per lbs. of animal liveweight than VS production by beef heifers. In the forecast, beef cattle liveweight is distributed among animal types using the ten-year, 2003-2012, average distribution. The data, drawn from the MPCA GHG Emission Inventory database, show little change in the distribution of beef cattle liveweight by beef cattle type going back to 2000.

Volatile solids production by swine, beef cattle, chicken broilers and turkeys is projected using total animal liveweight and projected rates of VS production per forecasted lbs. of liveweight by animal type. For turkeys and broiler chickens, constant 2011 rates of VS production per lbs. of liveweight are used. Based on the EPA data, VS production by turkeys and broilers per lbs. of liveweight was constant, 1990-1996, and then increased between 1996 and 2008, before stabilizing (seemingly), 2008-2011, at 2008 levels. For swine, conventional point estimates of VS production per lbs. of liveweight for breeding swine and market swine weighing less than and more than 60 lbs. from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* are employed.

For beef cattle on feed, beef cows, and steers and heifers not-on-feed, historical data for Minnesota from the MPCA GHG Emission Inventory database are linearly trended and extended to 2025. For cattle on feed, data for 1996-2011 are used, while data for 1990-2011 are used for beef cows, and steers and heifers not-on-feed. These data, adjusted for a change in methods around 2007/2008, are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.* For bulls, conventional point estimates for VS production per lbs. of liveweight are used, taken from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.* For calves, VS production per lbs. of liveweight is held constant at 2011 rates throughout the forecast period. 2011 rates for beef calves are taken from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.* Calf VS production per lbs. of liveweight was constant, 1990-1996, increased over period 1996-2008, and then stabilized at 2008 levels, 2008-2011.

As noted above, rates of maximum potential CH_4 production from stored volatile solids by livestock type, age and feed ration, are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks, as* are emission rates by manure storage type. In the conventional methodology, emissions are estimated as a percent of maximum potential emissions, with this percent varying by storage type or management system.

The projected future distribution of manure storage is shown below in Table F-4. Also shown is estimated present percentage distribution. With few exceptions, manure management remains unchanged in the forecast from the present. The management of swine manure below barn in long-term slurry storage increases by 1 percent over the forecast period. Storage of dairy manure in a liquid form out-doors increases in the forecast by 7 percent, while the percent of dairy manure that is assumed to be anaerobically digested roughly doubles to 10 percent by forecast year 2025. Between 2000 and 2010, the percentage of dairy manure that was anaerobically digested increased from 0.2 to 5 percent. The management of dairy manure through daily scrape and haul systems is assumed to decline 7 percent over the forecast, continuing a long-term decline that has been evident for at least three decades.

Table F-4. Forecast Change in the Distribution of Manure Management in Minnesota

	2011	2025
Dairy cows	62% outdoor slurry basin or tank (OSBT), 14% solid storage (SS), 19% daily spread (DS), 5% anaerobic digestion (AD)	69% OSBT, 11% SS, 10% DS, 10% AD
Replacement dairy heifers	42% OSBT, 17% SS, 41% drylot (DL)	49% OSBT, 22% SS, 30% (DL)
Beef cattle	20% OSBT, 25% SS, 55% pasture/range (P/R)	no change
Swine	20% OSBT, 3% SS, 1% DS, 1% DL, 72% below barn (BB), 3% stall floor accumulation (SFA)	73% BB, 3% SFA, otherwise no change
Turkeys	3% OSBT, 97% floor accumulation (FA)	no change
Broiler chickens	20% OSBT, 80% FA	no change
Laying Chickens	15% OSBT, 85% FA	no change
Sheep	15% OSBT, 25% SS, 60% PR	no change
Goats	5% OSBT, 45% SS, 50% PR	no change
Horses	10% OSBT, 25% PR, 25% paddock	no change

As noted above, the most recent data available for manure storage in Minnesota dates to 2006. Lacking more up-to-date data, most forecast values were left at 2006 levels. The forecast changes in the distribution of manure storage and management in dairy manure are to reflect the dramatic changes observed between 1999 and 2006 in the storage and management of dairy manure, changes that, in direction and to a lesser degree intensity, are assumed to continue.

Emissions of CH_4 from manure produced on-farm by commercial mink populations are estimated on a per head basis. On-farm mink populations are projected for 2012-2025 using the average annual rate of change in observed on-farm mink numbers for the period 2002-2007, the years for which data on on-farm mink populations were available at the time this forecast was developed. Constant emission rates, from IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, are used.

As noted in the discussion of present-day and historic emissions, N_2O is also produced in and emitted from stored manure. Emissions vary by manure storage type. For any one forecast year and storage technology, forecast emissions equal manure nitrogen managed using that storage technology or storage type and technology specific emissions factors, expressed in lbs. N_2O per ton of managed manure nitrogen. As in the case of the calculation of present-day N_2O emissions from stored manure, emission factors by manure storage type are from EPA, *Inventory of US Greenhouse Gas Emissions and*

Sinks. Forecast manure nitrogen amounts are calculated from projected liveweight amounts on-farm, discussed above, and rates of manure nitrogen production per lbs. of livestock liveweight on-farm. Rates of manure nitrogen production per lbs. of livestock liveweight on-farm are from EPA, *Inventory of US Greenhouse Gas Emissions and Sinks.* The future distribution of manure storage is the same as is used to projected CH_4 emissions from stored manure.

For dairy and beef cattle, only three years of Minnesota-specific data are available for manure nitrogen production rates per lbs. of livestock liveweight. For these animals, manure nitrogen production is calculated for all forecast years using a three-year, 2009-2011, average rate of manure nitrogen production per lbs. of livestock liveweight. For all other livestock types, a constant 2008 rate is employed. In the EPA data for all other livestock types, rates of manure nitrogen production per lbs. of livestock liveweight were constant, 1990-1996, increased between 1996 and 2006, then stabilized, 2008-2011.

After varying periods of storage, livestock manure is land-applied as a soil nutrient. In addition, in the forecast about 10 percent of manure from dairy cows and 1 percent of swine manure is in forecast year 2025 land-applied within days of excretion with essentially no storage as part of daily scape and haul systems. Upon land application, roughly 50 percent of manure nitrogen volatilizes, runs-off or leaches through the soil to ground water. Of the remainder, roughly one percent of all applied manure nitrogen is lost to the atmosphere in the form of N_2O. Forecast emissions from land-applied manure are calculated using this assumed one percent loss rate.

Of that part of land applied manure nitrogen that runs-off or is leached from the soil, roughly 0.75 percent is emitted to the atmosphere as N_2O. Of nitrogen lost through volatilization, leaching and run-off, 60 percent in the forecast is associated with leaching and run-off.

The forecast accounts for combustion-related the losses of manure nitrogen. As noted above, each year a small amount of livestock manure, in the form of turkey litter, is combusted at the Fibrominn power plant. Nitrogen lost during combustion is not available to produce N_2O in agricultural soils. The combustion of turkey litter at Fibrominn is assumed to continue at present levels throughout the forecast period.

The forecast also accounts for emissions from pastured livestock. In the forecast, roughly half of all beef cattle and goats, 60 percent of sheep and a quarter of horses in the state are pastured. To estimate emissions from pastured animals, total forecast liveweight is calculated for pastured animals and converted to excreted manure nitrogen. Emissions are calculated using the factors for pasture given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*. As in the case of the estimation of present-day emission, prior to the calculation of emissions, total nitrogen excreted on pasturelands is adjusted for losses due to volatilization, leaching and surface runoff.

Emissions from livestock flatulence are forecast from projected livestock populations and forecast rates of emission per head of livestock by livestock type. For any one animal type, total head of livestock equals total livestock liveweight on-farm divided by average livestock liveweight. The methods used to project livestock liveweight on-farm are discussed above. For market swine, average liveweights per head are forecast using historical data on average liveweights from 1983 to 2012, linearly trended and brought forward to 2025. While the record is noisy, over this period, average liveweight per head of market swine declined at an average rate of about 0.1 lbs. per year. For breeding swine, the point estimate given in EPA, *Inventory of US Greenhouse Gas Emissions and Sinks* is used. It is assumed that for each boar there are 20 sows, a continuation of the historic ratio. For beef cows, bulls, beef cattle on-feed, and calves not-on-feed, a 10-year average liveweight per head of livestock is used, based on 2003-2012 data.

For heifers and steers not-on-feed, forecast liveweights are based on historic data from 1980-2012, linearly trended and extended to 2025. Liveweights for this class of livestock have been increasing for decades, whereas liveweights for bulls and calves have been flat since the early 1990s and early 1980s, respectively. The record for beef cows since 2000 is quite noisy, with average liveweights at first increasing, to 2006, then decreasing to 2008, then stabilizing near 2008 levels to 2012. As noted above in the discussion of present-day emissions, the historic record for average liveweights on-farm for beef cattle was developed from reported slaughter weights nationally by beef cattle type.

Forecast numbers of dairy cows are from FAPRI, *2012 US Baseline Briefing Book*. The forecast population of dairy replacement heifers for any forecast year is based upon forecast numbers of dairy cows and the historic ratio of dairy replacement heifers, 2003-2012, linearly trended and extended to 2025. Again, the historic data for the calculation are taken from MPCA, GHG Emission Inventory database.

The derivation of forecasted goat, horse, bison, mules and sheep populations was discussed above. The number of layers on-farm in any forecast year is calculated from total layer liveweight and average 2002-2011 layer liveweight. Finally, the forecast population of beef replacement heifers is developed from the forecast population of beef cattle and ratio of beef replacement heifers to beef cows plus beef replacement heifers, averaged for years 2002 to 2011.

Per head emission rates from livestock flatulence are based on data, developed at a national level, by EPA in *Inventory of US Greenhouse Gas Emissions and Sinks.* For dairy cows and milk replacement heifers, emissions are based on national data from 1996-2011, linearly trended and extended to 2025. Over this period, emissions have been increasing linearly, at an average annual rate of about 0.9 percent per year. For beef steer and heifer stockers, 2002-2011 average US rates of emissions per head are used, based on essentially flat trends in emissions, 1998-2011 for stocker steers and 2000-2011 for stocker heifers. For beef cows and bulls, the long-term trend has been rolling over, with indications that levels may be stabilizing near 2011 levels. Forecast per head rates of emission for bulls and beef cows are set at or near 2011 rates.

Per head emission rates for beef on feedlots has been increasing at average annual rates of 0.4 percent per year since the early 1990s, a rate of increase that is assumed to persist over the forecast period. The trend in per head emissions has been flat for calves not-on-feed for the period since 1990. For calves, an average 1990-2012 emission rate is used for calves not-on-feed. For swine, the best fit to the historical data back to 1990 is a logarithmic fit, which in the forecast is extended forward to 2025. The same is true of the per head emission rates for horses.

For mules and goats, the historical record is quite noisy. In light of this, a constant present-day, 2011, emission rate is used to forecast future emissions.

Fuel use in livestock and milk production is projected using the data on fuel use per pig litter for swine farrowing and nurse systems, per finished hog for swine finishing, per calf for cow-calf operations, per finished steer for beef finishing, per turkey raised, and per hundred weight of milk produced, all given in B. Ryan and D. Tiffany, "Minnesota Agricultural Energy Use and the Incidence of a Carbon Tax." The forecast number of pig litters is calculated from the number of forecast sows, discussed above, divided by the number of litters per sow. The forecasted number of litters per sow is developed using historical data for 2003-2012, linearly trended and extended to 2025. The forecast number of swine finishers and turkeys raised annually are calculated totals, developed from forecast animal liveweights, again discussed above, and average liveweight at slaughter for swine and turkeys. For average liveweight at slaughter, in each case, a 10-year, 2002-2011, average liveweight at slaughter is used, taken or developed from data in USDA, *Minnesota Agricultural Statistics*.

The forecast number of beef finishers is calculated in the same fashion as swine finishers. 2011 liveweight at slaughter is used throughout the forecast period to calculate total beef finishers. The forecast number of beef calves is, for each forecast year, calculated from the total number of forecast beef cows and milk cows, and the historic 10-year, 2003-2012, average ratio of calves to total cows in Minnesota. Finally, forecast milk production for Minnesota for the forecast period is from FAPRI, *2012 US Baseline Briefing Book*.

Again, the historic data for all of the calculations are from MPCA, GHG Emission Inventory database.

The forecast was developed in fall 2013. It was designed with a 2025 terminal year. Later, in spring 2014, it was decided that the terminal year for all the forecast should be moved to 2030. To accommodate the change, using emissions forecast data for 2012-2025, a linear trend was calculated for emissions for each of the five principal emission sources associated with livestock production: CH_4 from flatulence, manure storage and fuel use; N_2O from manure storage, land-applied manure, and fuel use; and fossil CO_2 from fuel use. Using this linear trend, the 2012-2025 forecast was linearly extended to 2030.

Figure 5 provides summary information on forecast activity levels for the feedlot/livestock forecast. In the forecast, to 2025, total liveweight on-farm increases by 11.5 percent from 2011 levels. VS production in the forecast increases 13 percent, 2011-2025, while over the forecast period manure nitrogen production on-farm increases 13.2 percent. Total manure nitrogen that is land-applied increases by 13.6 percent over the forecast period. By contrast, the forecast number of ruminant cattle increases a scant 3.5 percent, 2011-2025. As noted above, ruminant cattle are the principal source of CH_4 emissions from livestock flatulence. With calves are removed, the forecast number of ruminant cattle in the forecast at 2025 is 1 percent below 2011 levels.

In the forecast, manure is managed roughly in the same fashion as in 2011. This is expressed in Table F-5 as the percent of forecast livestock liveweight served by one of the available systems of manure storage and disposal. In the forecast, in forecast year 2025 a slightly higher percentage of livestock liveweight is served using slurry forms of manure storage, but the change is quite minor, a few percent. The percent of animal liveweight served by traditional scrape and daily haul systems declines in the forecast by two percent, from four percent to two percent statewide by forecast year 2025.

Sources for the data used in the forecast include:

- Census Bureau, *Census of Agriculture* (2002, 2007)
- EPA, *Inventory of US Greenhouse Gas Emissions and Sinks*
- Food and Agricultural Policy Institute (MO), *2012 US Baseline Briefing Book*
- Food and Agricultural Policy Institute (IA), *2012 World Agricultural Outlook*
- Food and Agricultural Policy Institute (MO-IA), *2011 US and World Agricultural Outlook*
- IPCC, 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*
- MPCA, *GHG Emission Inventory database*
- B. Ryan and D. Tiffany, ‘Minnesota Agricultural Energy Use and the Incidence of a Carbon Tax’
- USDA, *USDA Agricultural Projections to 2022*
- USDA, *Agricultural Statistics*
- USDA, *Livestock Slaughter*
- USDA, *Minnesota Agricultural Statistics*
- USDA, *Poultry Slaughter*

Table F-5. Forecasted Activity on Minnesota's Livestock Sector (million CO_2-equivalent short tons)

	2012	2015	2020	2025
Liveweight on Feedlots (million lbs)				
Dairy	904	903	899	895
Beef	1,404	1,432	1,528	1,509
Swine	977	990	1,083	1,184
Poultry	368	381	400	416
Other	119	120	127	151
Total	3,773	3,826	4,037	4,156
Manure volatile solids (tons)	5,046,556	5,140,211	5,420,435	5,593,335
Manure nitrogen (tons)	324,154	330,289	349,794	364,165
Manure nitrogen land-applied (tons)	172,058	175,100	184,248	193,240
Ruminant Cattle (thous head)				
Milk cows	465	452	440	429
Beef cows	382	389	415	410
Other cattle not-on-feed	1,320	1,322	1,372	1,341
Other cattle on-feed	258	263	280	277
Manure management (% liveweight managed)				
liquid/slurry storage	0.46	0.46	0.47	0.48
solid storage	0.28	0.28	0.27	0.27
anaerobic digester	0.01	0.01	0.01	0.02
daily spread	0.04	0.03	0.02	0.02
pasture/paddock	0.22	0.22	0.22	0.22

Detailed forecast results

The same forecast information that was shown in Table F-3 above is shown again below in Table F-6, albeit using a more detailed breakdown of emissions. In the forecast, greenhouse gas emissions from Minnesota livestock and feedlots increase by 1.43 million CO_2-equivalent tons or about 13 percent. Of this, 0.91 million CO_2-equivalent tons or 64 percent are from increased forecast emissions from manure management, 0.35 million CO_2-equivalent tons or 24 percent are from increased projected emissions from livestock flatulence, 0.1 million CO_2-equivalent tons are from manure nitrogen land-application and leaching/run-off, and 0.06 million CO_2-equivalent tons are from increased projected fuel use on feedlots. In the forecast, aggregate emissions from feedlots and livestock increase at an average annual rate of about 0.7 percent, driven principally by a 1.1 percent per year average growth rate for emissions from manure management over the forecast period. Emissions from ruminant flatulence, the second largest emissions source, increase in the forecast at a low average annual rate of about 0.3 percent.

Table F-6. Forecasted Emissions from Minnesota's Livestock Sector (million CO_2-equivalent short tons)

	2012	2015	2020	2025	2030
Flatulence					
Dairy cattle	2.28	2.26	2.27	2.29	NA
Beef cattle	2.86	2.91	3.09	3.04	NA
Swine	0.15	0.14	0.14	0.15	NA
Other	0.13	0.13	0.14	0.17	NA
subtotal	**5.43**	**5.45**	**5.65**	**5.64**	**5.80**
Feedlot manure					
Below barn pit	1.28	1.31	1.47	1.65	NA
Outdoor basin or tank	1.75	1.80	1.91	2.00	NA
Anaerobic digestion with pond	0.01	0.01	0.02	0.02	NA
Solid storage	0.15	0.15	0.16	0.16	NA
Drylot	0.09	0.08	0.08	0.07	NA
Stall floor accumulation/periodic removal	0.08	0.07	0.07	0.07	NA
Poultry with litter/bedding	0.07	0.07	0.08	0.08	NA
Pasture, range and paddock	0.51	0.52	0.55	0.55	NA
Other	0.00	0.00	0.00	0.00	NA
Run-off and leaching from feedlot	0.04	0.04	0.04	0.04	NA
subtotal	**3.97**	**4.07**	**4.38**	**4.65**	**4.93**
CH_4	2.95	3.03	3.29	3.55	3.78
N_2O	1.02	1.03	1.09	1.10	1.15
subtotal	**3.97**	**4.07**	**4.38**	**4.65**	**4.93**
Dairy cattle	1.15	1.17	1.21	1.24	NA
Beef cattle	0.89	0.91	0.98	0.97	NA
Swine	1.74	1.79	2.00	2.23	NA
Poultry	0.13	0.14	0.15	0.15	NA
Other	0.05	0.05	0.05	0.06	NA
subtotal	**3.97**	**4.07**	**4.38**	**4.65**	**4.93**
Land-Applied manure	**0.40**	**0.41**	**0.43**	**0.45**	**0.47**
Manure nitrogen run-off/leaching (field)	**0.18**	**0.18**	**0.19**	**0.20**	**0.21**
Fuel use	**0.81**	**0.80**	**0.84**	**0.86**	**0.88**
Total	**10.79**	**10.91**	**11.49**	**11.81**	**12.29**

Of the forecasted increase in flatulence emissions, most of that increase derives from beef cattle. In the forecast, between 2011 and forecast year 2025, the total number of noncalf beef cattle increases by 4 percent. As noted above, detailed forecast values by animal type are available only through 2025.

Of the forecasted increase in emissions from livestock manure, 2011-2025, about two-thirds is from increased manure storage in deep below barn pits and about one-third is from increased storage of manure in outdoor basins or tanks. By livestock type, about three-quarters of the increase in emissions in the forecast is from swine, and the remainder is from cattle, split about evenly between dairy cattle and beef cattle. By gas, of the forecasted increase in emissions from livestock manure, 2011-2030, about 85 percent is in the form of CH_4, the rest in the form of increased N_2O emissions.

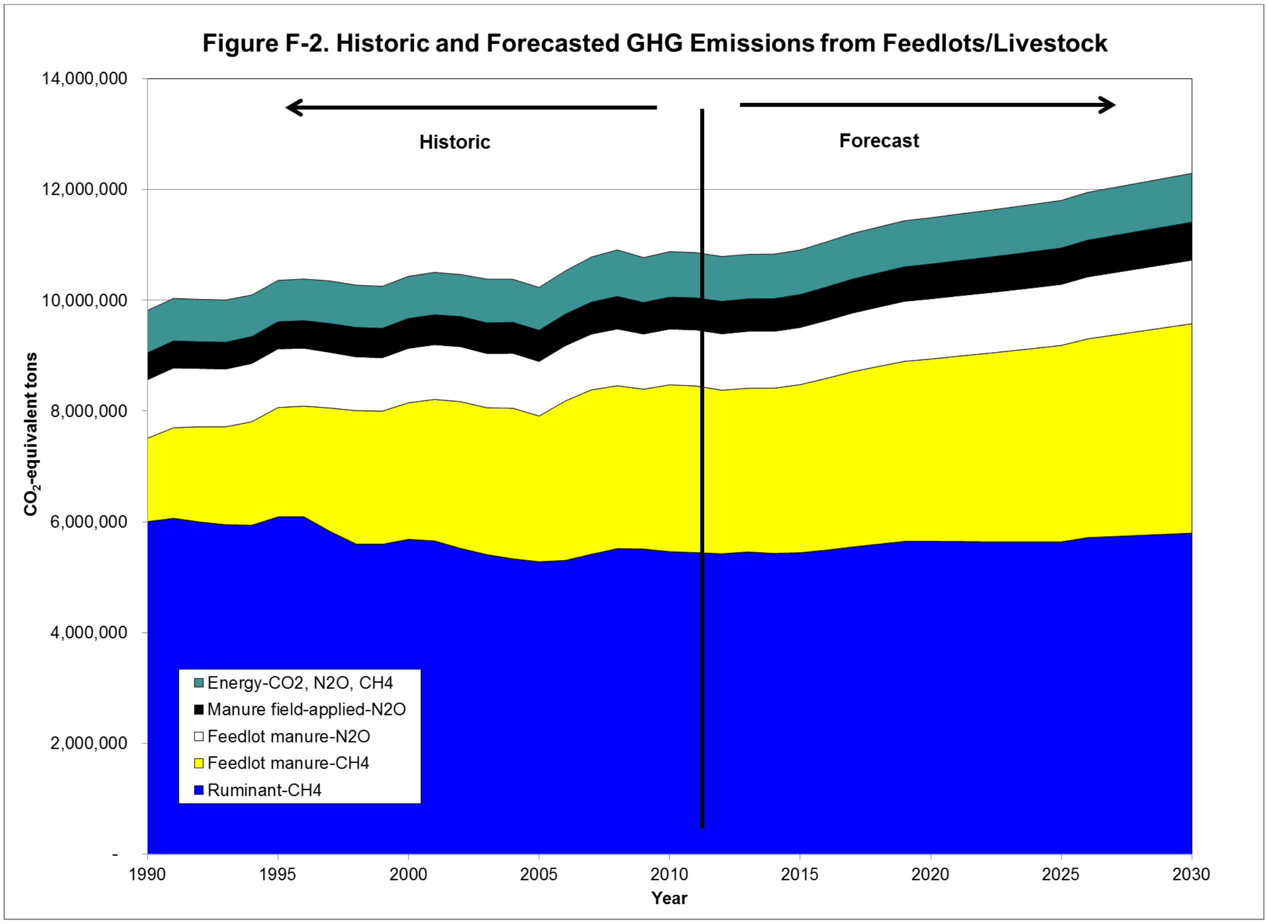
Table F-7 shows the trend in forecasted emissions for selected years by greenhouse gas. In the forecast, emissions of CH_4 and N_2O, the principal GHGs associated with feedlot/livestock emissions, increase by 13 and 15 percent, respectively from 2011 levels. Emissions of fossil CO_2 increase 8 percent over the forecast period, but from low initial levels.

At 2030, forecast emissions of CO_2 from the combustion of ethanol and biodiesel are about 25 percent above 2011 levels. Biogenic emissions of CO_2 are not counted against feedlot/livestock sector totals. Through crop regrowth, corn regrowth in the case of ethanol and soybeans regrowth in the case of biodiesel, biogenic emissions of CO_2 are rapidly removed from the atmosphere, usually within a year of emission. The totals shown in Table F-7 also do not include CO_2 emissions from manure storage facilities, land-applied manure, or animal respiration.

Figure F-2 shows graphically the historical and forecasted trend in GHG emissions out to 2030. Over the historical period, emissions from feedlots/livestock in Minnesota grew at an average annual rate of about 0.5 percent. Over the forecast period this rate is largely continued, increasing slightly to an average rate of 0.7 percent per year, 2011-2030. The percent distribution of emissions changes between 2011 and forecast year 2030, with the percent share of emissions from manure management increasing from 42 to 46 percent of the total. Emissions from livestock flatulence, which in 2011 accounted for 50 percent of emissions from Minnesota feedlots/livestock, decline to about 47 percent of emissions by forecast year 2030.

Table F-7. Forecasted Emissions from Minnesota's Livestock Sector by Gas (million CO_2-equivalent short tons)

	2012	**2015**	**2020**	**2025**	**2030**
CO_2	0.80	0.79	0.82	0.85	0.87
CH_4	8.38	8.48	8.94	9.19	9.58
N_2O	1.61	1.64	1.72	1.77	1.84
Total	10.79	10.91	11.49	11.81	12.29
Biogenic CO_2	0.03	0.04	0.04	0.04	0.04
ethanol	0.00	0.00	0.00	0.00	0.00
biodiesel	0.02	0.03	0.03	0.04	0.03



The historic and forecasted trend in emissions from manure storage and management is shown graphically in Figure F-3. As noted above, the average annual rate of increase in emissions from manure storage and management slows from about 2 percent per year, the average annual the rate of growth for the historic period 1990-2011, to 1.1 percent per year for the forecast period, 2011-2030. In the forecast, emissions increase about 0.7 million CO_2-equivalent tons, 2011-2030. Forecast emissions from the management of swine manure increase about 0.5 million CO_2-equivalent tons, accounting for about 70 percent of the increase. Emissions from the management of cattle manure increase about 0.15 million CO_2-equivalent tons from 2011 levels, accounting for most of the rest of the forecasted increase.

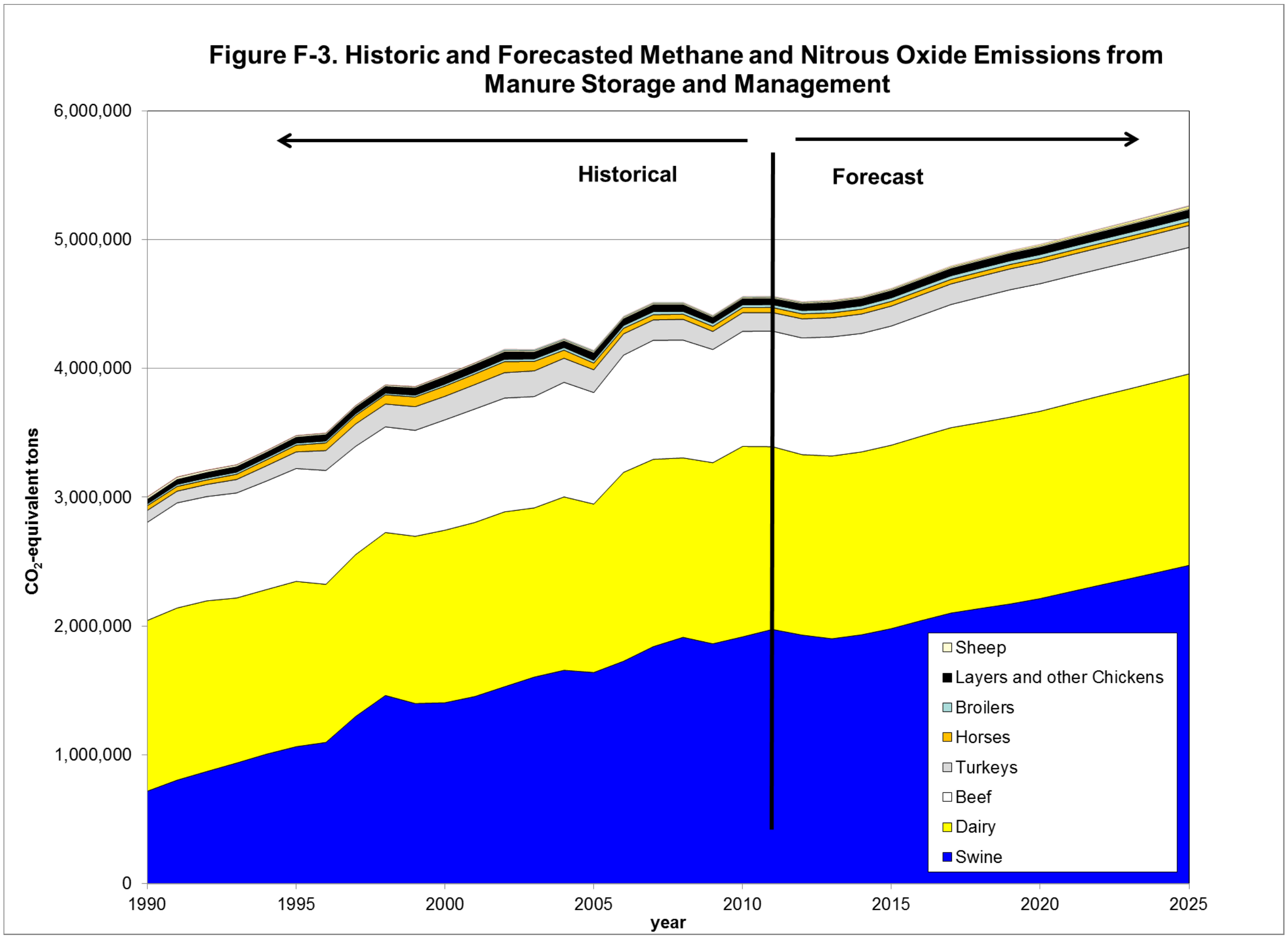


Table F-8 shows projected livestock liveweight on Minnesota farms and feedlots by livestock type for selected years. In the forecast, total livestock liveweight on Minnesota farms and feedlots increases 430 million lbs. between 2011 and forecast year 2025. Increased forecast swine liveweight accounts for about for about 45 percent of this; much of the remainder is accounted for by increased forecast beef liveweight and turkey liveweight. Over the forecast period, swine liveweight on Minnesota farms and feedlots grows at an average annual rate of 1.2 percent, while that for beef and turkeys grows over the forecast period at average annual rates 0.8 and 1 percent, respectively. In percentage terms, swine liveweight on-farm increases by about 20 percent, which is in line with a slightly increased market share of the US pork market and US pork production itself larger by 20 percent at forecast year 2030 levels. Beef liveweight on farm increases in the forecast by about 10 percent about 2011 levels, 2011-2025, and turkey liveweight increases by 16 percent, 2011-2025.

The trend in livestock liveweight on-farm is shown graphically in Figure F-4. Notable is the broad continuity of the forecast trend with the historic trend. Total liveweight grows in the forecast at an average annual rate of 0.8 percent, 2011-2025. This is in comparison to the 0.7 percent per year rate, 1990-2008, the last year before the Great Recession, and 0.5 percent per year inclusive of the Great Recession years. The marked increase in liveweight on-farm in forecast years 2014-2018 reflects the strong growth in forecast US pork production in the FAPRI forecast for these forecast years. Swine liveweight on-farm as a percentage of total liveweight on-farm increases over the forecast period from about 26.5 to 28.5 percent; dairy cattle liveweight declines as a percentage of total liveweight on-farm from about 24 percent to 21.5 percent, 2011-2030.

Table F-8. Forecast Animal Liveweight on Minnesota Farms and Feedlots (million lbs.)

	2012	2015	2020	2025
Dairy cows and two-yr old heifers that have calved	650	657	659	662
Milk replacement heifers	254	246	240	233
Beef cows not-on-feed	523	533	569	562
Other beef cattle not-on-feed	662	675	720	711
Beef cattle on-feed	220	224	239	236
Market swine	733	763	872	994
Breeding swine	244	227	211	190
Sheep	16	17	17	17
Goats	6	9	16	30
Horses	89	87	85	83
Mules and asses	1	2	7	21
Bison	7	5	2	1
Turkeys	302	314	329	342
Broilers	15	16	17	19
Layers, pullets, hens, chicks	50	52	53	55
total	3,773	3,826	4,037	4,156

Figure F-4. Historic and Frecasted Livestock Liveweight on Minnesota Farms and Feedlots

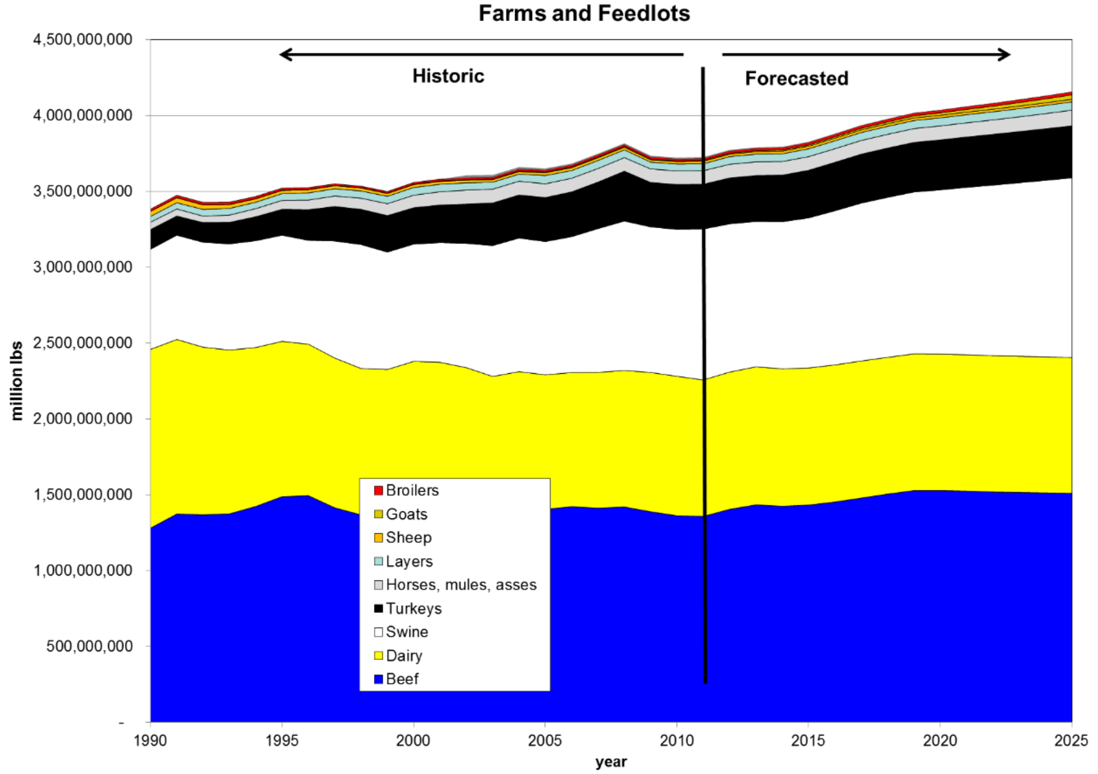


Table F-9 shows forecast data used to derive on-farm liveweight estimates for the forecast period for beef cattle, swine, turkeys and broiler chickens. As discussed in the 'Forecast Methods' section above, liveweight on-farm for these classes of livestock is derived from forecast total liveweight production on Minnesota farms and feedlots and observed ratios of liveweight on-farm to annual liveweight production, by livestock class. Forecast liveweight production is derived from forecast Minnesota meat production and historic slaughter yields, generally developed at the national level. Forecast Minnesota meat production is based on forecast US meat production, 2012-2023, and a schedule of Minnesota share of these markets out to 2025.

Table F-9. Forecast Minnesota Meat and Liveweight Production and Liveweight on-Farm

	2012	2015	2020	2025
Minnesota market share (% of US)				
Beef	2.9%	2.9%	2.9%	2.9%
Pork	12.1%	12.3%	12.5%	12.8%
Turkey	16.0%	16.0%	16.0%	16.0%
Chicken	0.5%	0.5%	0.5%	0.5%
Meat production (million lbs.)				
Beef	694	707	755	746
Pork	2,905	2,942	3,219	3,521
Turkey	945	980	1,029	1,070
Chicken	197	208	225	242
Liveweight production (million lbs.)				
Beef	1,100	1,122	1,197	1,183
Swine	3,900	3,950	4,323	4,727
Turkeys	1,219	1,264	1,327	1,380
Broiler chickens	270	285	308	331
lbs. liveweight on-farm (annual average) per lbs. liveweight production				
Beef	1.28	1.28	1.28	1.28
Swine	0.25	0.25	0.25	0.25
Turkeys	0.32	0.32	0.32	0.32
Broiler chickens	0.06	0.06	0.06	0.06
Animal liveweight on-farm (million lbs.)				
Beef cow	522.77	533.03	568.81	561.89
Beef steers, beef heifers (NOF)	601.20	613.01	654.15	646.20
Beef on feed	219.51	223.82	238.85	235.94
Bulls	60.73	61.92	66.08	65.28
Market swine	733.03	762.78	871.79	993.93
Breeding swine	244.07	226.85	211.13	190.30
Turkeys	302.42	313.64	329.16	342.36
Broiler chickens	15.27	16.13	17.42	18.76

Table F-9 gives the schedule of assumed market share of US meat production. As discussed above, with the exception of an increasing share of the US pork market, more or less constant market share is assumed for Minnesota red and poultry meat producers. Red and poultry meat production in the forecast increases in aggregate 25 percent, 2011-2025. About three quarters of the increase in the forecast is from increased forecast pork production and 14 percent from increased turkey meat production. In the forecast, Minnesota pork production increases by 30 percent from 2011 levels, and turkey meat production by 17 percent from 2011 levels.

Annual liveweight production in Minnesota increases in the forecast by an aggregate 24 percent or 1.45 billion lbs., 2011-2025. Of this, 1.04 billion lbs. are in the form of increased forecast swine liveweight production, and 0.2 billion lbs. are from increased turkey liveweight production. Increased beef cattle liveweight contributes in forecast year 2025 an additional 0.1 billion lbs. to the increase. From 2011 levels, swine liveweight production increases in the forecast by 28 percent, 2011-2025, that for beef cattle by 10 percent and that for turkeys by 18 percent. Forecast of liveweight on-farms was discussed above.

Forecast on-farm livestock populations are shown in Table F-10 by livestock type for selected forecast years. On-farm population is the average number of livestock on farms and feedlots at any one time during the year, averaging across all days of the year. As noted above, emissions of CH_4 from livestock flatulence are calculated on a per head basis. Roughly speaking, in Minnesota about 95 percent of flatulence CH_4 emissions are from ruminant cattle, both dairy and beef cattle. Most of the rest is from swine and sheep. In the forecast, the total number of dairy cattle on-farm declines by 65,000 head or about 9 percent from 2011 levels. The total number of beef cattle on-farm increases about 3 percent in the forecast, by 58,000 head, 2011-2025.

Table F-10. Forecast Head of Livestock on Minnesota Farms and Feedlots (thousand head)

	2012	2015	2020	2025
Dairy cows	465	452	440	429
Dairy replacement heifers	283	275	267	260
Beef cows not-on-feed	382	389	415	410
Other beef cattle not-on-feed	1,037	1,047	1,105	1,080
Beef cattle on-feed	258	263	280	277
Market swine	7,318	7,639	8,689	9,858
Breeding swine	580	524	493	447
Sheep	142	140	136	132
Goats	42	60	113	209
Horses	90	88	86	83
Mules and asses	5	9	25	73
Bison	5	4	2	1
Mink	130	126	120	115
Turkeys	18,807	19,504	20,470	21,290
Layers, pullets of laying age, pullet chicks, other chickens	15,065	15,450	15,937	16,431
Broilers	5,870	6,199	6,696	7,212

Total swine numbers on-farm increase in the forecast by 2.3 million, or 29 percent above 2011 levels by forecast year 2025. Of this, all plus some is the result of an expanding forecast market swine population in the state, continuing the focus of the state's swine industry on swine finishing, as opposed to farrowing or farrow-to-finish operations. The sheep herd declines in the forecast by about 3 percent from 2011 levels, 2011-2025, about 4,000 head.

Table F-11 shows forecast volatile solids production by livestock type for selected years. In the forecast, VS production increases by 0.64 million tons between 2011 and forecast year 2025, from 4.95 to 5.59

million tons. Between 2011 and forecast year 2025, swine production of VS increases in the forecast by 0.24 million tons, accounting for 38 percent of the overall increase. Over the same period, volatile solids production by beef cattle increases by 0.27 million tons, or 42 percent of the overall increase. Increased VS production by turkeys, some 0.07 million tons, accounts for much of the remainder. In the forecast, VS production by swine increases 26 percent between 2011 and forecast year 2025, and by 17 percent in the case of beef cattle. Forecast VS production by turkeys increases 16 percent from 2011 levels, 2011-2025.

In the forecast, total VS production increases at an average annual rate of about 0.9 percent. The forecast distribution of VS production changes, with VS production by dairy cattle, expressed as a percent of total VS production, falling from 34 to 29 percent over the forecast period. In the forecast, VS production by swine, again expressed as a percent of the total, increases from 18 to 21 percent, and that of beef cattle, from 32 to 34 percent.

Table F-11. Forecast Manure Volatile Solids Production (million tons)

	2012	2015	2020	2025
Dairy cows	1.29	1.30	1.30	1.31
Dairy replacement heifers	0.39	0.38	0.37	0.36
Beef cows not-on-feed	0.69	0.70	0.76	0.75
Other beef cattle not-on-feed	0.84	0.86	0.93	0.93
Beef cattle on-feed	0.19	0.19	0.21	0.21
Market swine	0.78	0.81	0.92	1.05
Breeding swine	0.12	0.11	0.10	0.09
Sheep	0.02	0.03	0.03	0.03
Goats	0.01	0.01	0.03	0.05
Horses and mules	0.10	0.10	0.10	0.12
Bison	0.01	0.01	0.00	0.00
Turkeys	0.47	0.49	0.51	0.53
Broilers	0.05	0.05	0.05	0.06
Layers, pullets, hens, chicks	0.09	0.10	0.10	0.10
total	5.05	5.14	5.42	5.59

Table F-12 shows the forecast manure nitrogen budget for selected forecast years. Over the forecast period, total manure nitrogen production increases by about 13 percent or 42,530 tons. The production of swine manure nitrogen increases in the forecast by 24,420 tons, accounting for about 57 percent of the overall increase in manure nitrogen production. The production of manure nitrogen by beef cattle increases in the forecast by 7,870 tons, accounting for 19 percent of the overall increase in the forecast in manure nitrogen production. Manure nitrogen production by turkeys increases by 5,470 tons over the forecast period, accounting for 13 percent of the overall increase in forecast manure nitrogen production.

Table F-12. Forecast Manure Nitrogen Budget and Sources (thousand tons)

	2012	2015	2020	2025
Manure Nitrogen Production	324.15	330.29	349.79	364.17
Manure Nitrogen Disposition				
Lost during combustion	5.24	5.24	5.24	5.24
Volatilized, leached or run-off from/at feedlot or pasture	144.76	147.82	158.06	163.41
Emitted from feedlot/pasture as N2O	2.10	2.13	2.24	2.27
Land applied	172.06	175.10	184.25	193.24
volatilized	34.41	35.02	36.85	38.65
leached or run-off	51.62	52.53	55.27	57.97
available to produce N2O in soils	86.03	87.55	92.12	96.62
Manure Nitrogen Production by animal type:				
Dairy cows	75.09	75.88	76.11	76.41
Dairy replacement heifers	21.50	20.85	20.28	19.76
Beef cows not-on-feed	31.03	31.64	33.77	33.35
Other beef cattle not-on-feed	42.32	43.15	46.05	45.49
Beef cattle on-feed	15.63	15.94	17.01	16.80
Market swine	78.52	81.60	93.08	105.92
Breeding swine	8.91	8.28	7.71	6.95
Sheep	1.31	1.40	1.39	1.38
Goats	0.48	0.70	1.30	2.43
Horses and mules	4.13	4.13	4.27	4.91
Bison	0.41	0.27	0.14	0.07
Turkeys	34.79	36.09	37.87	39.39
Broilers	2.68	2.83	3.05	3.29
Layers, pullets, hens, chicks	7.35	7.54	7.77	8.02
total	**324.15**	**330.29**	**349.79**	**364.17**

In terms of percentage change, manure nitrogen production by swine increases by 27 percent over the forecast period, 2011-2025, while that by beef cattle increases by a more modest 9 percent. Manure nitrogen production by turkeys increases by 16 percent over the forecast period, 2011-2025.

In terms of manure nitrogen disposition, in 2011, roughly 45 percent of manure nitrogen was lost from the feedlot or pasture/range through volatilization, leaching or run-off, 1.6 percent was lost during turkey litter combustion, 53 percent was land-applied, and 0.6 percent was emitted from the feedlot or pasture/range as N_2O. These percentages remain mostly unchanged over the forecast period. Over the forecast period, the total amount of manure nitrogen that is emitted from the feedlot or pasture/range increases by about 10 percent, while in the forecast, the total quantity of manure nitrogen that is available in soils and surface and groundwater for the formation of N_2O increases by about 13.5 percent. In the forecast, the amount of manure nitrogen that is land-applied increases by about 13.5 percent, 2011-2025.

Table F-13 shows the livestock flatulence emission rates used for the forecast period. The emission rates shown in Table F-13 for ruminant cattle are shown from largest to smallest. As noted above, about 95 percent of flatulence emissions statewide are from ruminant cattle. Most of the remainder of flatulence emissions is from swine. Dairy cows are far and away the largest emitters of CH_4, followed by beef bulls and beef cows. Generally speaking, on a per head basis, heifers and stock steers tend to emit at a rate of about one-third that of a mature dairy cow. With the exception of American bison, forecast emission rates for other livestock types are small. Forecast on-farm populations of American Bison are miniscule for Minnesota.

Forecast flatulence emissions from four livestock types are calculated using variable emission factors: dairy cows, beef cattle on-feed, swine, sheep and horses. Over the forecast period, 2011-2025, emissions per dairy cow increase about 10 percent, more than offsetting the predicted 8 percent decline in dairy cows in the state, 2011-2025. For beef cattle on-feed, emission rates increase in the forecast by about 6.5 percent, 2011-2025. Per head emission rates for swine decline over the forecast period, by about one-quarter. Per head emission rates for sheep increase over the forecast period and, for horses, decline over the forecast period, 2011-2025.

Table F-13. Forecast CH_4 Emission Rates from Livestock Flatulence (lbs. CH_4 per head per year)

	2012	2015	2020	2025
Dairy cows	316	323	336	349
Bulls NOF	216	216	216	216
Beef cows NOF	210	210	210	210
Heifer stockers (including calves) NOF	132	132	132	132
Steer stockers (including calves) NOF	128	128	128	128
Milk replacement heifers	127	127	127	127
Beef cattle on-feed	90	91	94	96
Swine	2	1	1	1
Sheep	33	36	42	48
Goats	11	11	11	11
Horses	49	48	45	43
Mules and asses	15	15	15	15
American bison	192	192	192	192

NOF = not-on-feed

Table F-14 shows emission rates for CH_4 and N_2O from manure by manure storage and management type. From Table F-6 above, at present, about three-quarters of emissions from feedlot manure are in the form of CH_4. As discussed above, emissions of CH_4 from manure increase as manure is stored in ever more liquid or slurry forms. From Table F-14, emission rates are roughly an order of magnitude higher for manures stored in a slurry form, either in outdoor tanks or basins or in deep pits below barn, than manure stored in a solid form on slabs or as dry poultry manure or excreted on pastureland, rangeland or in paddocks. As discussed above, in the forecast, manure is managed much as it is today, with the sole exception of a slight approximate 2 percent shift from more solid storage or daily scrape and haul systems to more slurry-based storage outdoor in basins or tanks or below barn storage in deep pits (see Table F-4 above).

For N_2O, emissions are much higher from manure stored in dry aerobic environments or land-applied within days or weeks or excretion.

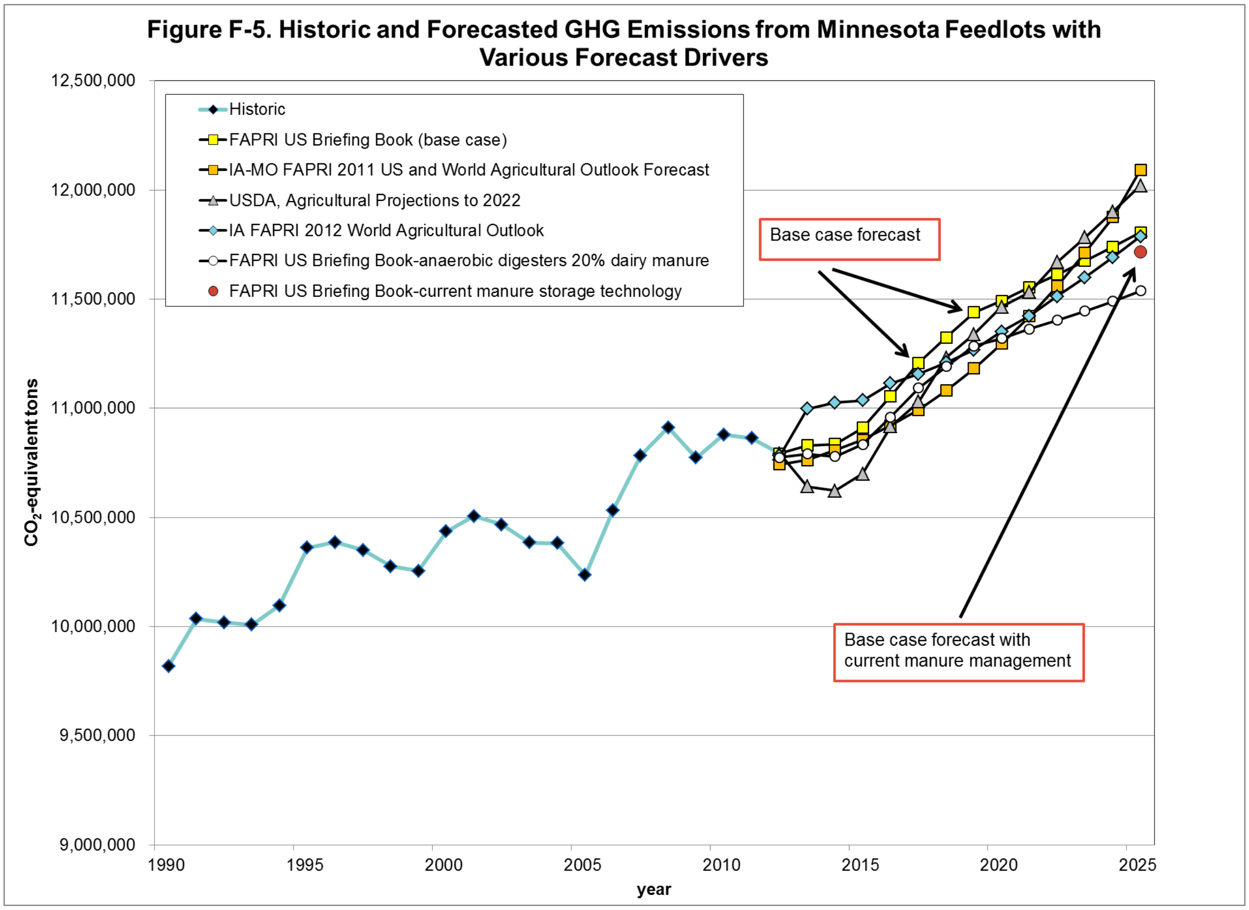
Table F-14. Emission Rates for GHGs from Stored Manure (lbs. per lbs. of manure nitrogen or of maximum potential CH_4 production)

	Nitrogen	CH_4
Outdoor liquid/slurry basin/tank	0.005	0.235
Long-term below barn pit storage	0.002	0.235
Stall floor accumulation/periodic remov	0.010	0.210
Drylot	0.020	0.010
Solid storage	0.005	0.020
Poultry with litter/bedding	0.001	0.015
Paddock	0.010	0.010
Pasture/range		
sheep, goats, horses, mules, asses	0.010	0.010
beef, bison	0.020	0.010
Daily scrape and haul	0.010	0.001
Anaerobic digester	0.005	0.010

Finally, to evaluate the sensitivity of the forecast results to the underlying dairy and meat commodities forecast, and also to different assumptions about future manure management, emissions were modeled using:

- FAPRI (MO), *2012 US Baseline Briefing Book* (base case described above)
- FAPRI (IA), *2012 World Agricultural Outlook*
- FAPRI (MO-IA), *2011 US and World Agricultural Outlook*
- USDA, *USDA Agricultural Projections to 2022*
- FAPRI (MO), *2012 US Baseline Briefing Book*, with present-day manure management
- FAPRI (MO), *2012 US Baseline Briefing Book*, with dairy manure 20% anaerobic digestion

The results of this sensitivity analysis are shown below in Figure F-5. In forecast year 2025, emissions range from 11.5 to 12.1 million CO_2-equivalent tons. With the USDA long-range projections or the FAPRI, *2011 US and World Agricultural Outlook* projections, forecast emissions are generally higher; with manure storage technology frozen at present levels or the enhanced use of anaerobic digestion, forecast emissions are generally lower. The base case emissions at forecast year 2025 tend to fall mid-way in the range of forecasts shown in Figure F-5. The effect of a freeze on manure storage technology at present levels is to lower forecast emissions at 2025 by 0.09 million CO_2-equivalent tons or about 0.8 percent, while enhanced used of anaerobic digestion lowers emissions at 2025 by 0.27 million CO_2-equivalent tons, or 2.2 percent.



In percentage terms, in the sensitivity analysis forecast emissions at 2025 are 8 to 11 percent above 2011 levels, depending on the scenario in question. Forecasts using alternative forecast data sources and alternative assumptions about manure storage technologies are in good agreement with the base case forecast presented above.

Statewide summary

Introduction

To support what has become the Climate Strategies and Economic Opportunities (CSEO) project, between October 2012 and September 2014 the Minnesota Pollution Control Agency (MPCA) developed a 19-year greenhouse gas (GHG) emission forecast, beginning in forecast year 2012 and terminating in forecast year 2030. The intent was and is to provide the analysts at the Center for Climate Strategies (CCS) with an internally consistent, highly detailed energy use and emissions forecast for use in quantifying the costs of policies to reduce statewide GHG emissions. The forecast was developed on a sector-by-sector basis and, given the need of the analysts for highly detailed projection information for energy use, industrial production, waste generation and disposition and other precursor forecast information, generally bottom-up. An effort was made in the forecasting to account for all policies now on the books. In August 2014, the forecast was frozen in place in the form of the forecast then current, based on the work completed at various times over the prior two years.

In the forecast, the economy is segmented into eight emitting sectors: electric power, transportation, industry (mining and manufacturing), commercial buildings, residential buildings, livestock production, crop production, and waste management. Of those, the MPCA developed emission forecasts for all but the crop producing sector. The staff of CCS developed its own forecast for the crop producing sector, the results of which are incorporated in the statewide totals reported below.

The forecast is accompanied by historical reconstructions of past emissions back to 1990. All systems have characteristic time constants which limit the rate at which they might change or be changed. It is reasonable to think that the historic record may shed some light on these rate constants, sector-by-sector.

The forecast begins in 2012 and extends to 2030. At the time the emission forecast was developed, present-day emissions estimates were available only through 2011. With two important exceptions, the boundaries of both the forecast of emissions and historical reconstruction of present-day and past emissions coincide with the geographical boundaries of the state. By statute, the MPCA is required to include in its emission estimates emissions that arise out-of-state as a result of electricity consumed within the borders of Minnesota. Emission totals for aviation include all emissions that result from aircraft departing from airports located in Minnesota regardless of destination.

Specific greenhouse gases (GHGs) that are treated in the forecast include fossil carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6) and two families of GHGs known as perfluorocarbons (PFCs) and hydrofluorocarbons (HFCs). The forecast also accounts for very long-term storage of wood-based biogenic carbon in residential housing and in demolition and construction landfills. Carbon stored in housing or in housing debris in D/C landfills was once atmospheric carbon that, upon plant photosynthesis, was withdrawn from the atmosphere and incorporated into the living biomass of trees. In the forecast, net additions to very long-lived wood storage in the structural parts and sheathing of housing are treated as negative emissions or 'sinks', offsetting a part of emissions from other sources.

In the forecast, GHGs from the residential, commercial, and industrial sectors and waste management are physically emitted on-site, often in association with combustion, but also in association with other noncombustion 'processes'. The emission totals for these sectors do not include emissions associated with the end-use consumption of electricity. It is conventional to treat emissions that are associated with the end-use consumption of electricity as electric power sector emissions. Emissions from feedlots and livestock include emissions from barns, drylots, manure storage structures and pastures plus emissions from the downstream disposal or land application of livestock manure, but not emissions associated with the generation of electricity used in livestock production or the production of milk and eggs. Most emissions from feedlots and livestock are noncombustion emissions from livestock flatulence and manure storage and disposal.

Emissions from transport include direct emissions, mostly from fuel combustion, from on-road vehicles, rail locomotives, vessels, boats, and aircraft, but not emissions from the generation of electricity used in plug-in electric vehicles or light rail transit. As elsewhere, these emissions are treated as electric power sector emissions.

To maintain internal consistency, the forecast uses the same sector boundaries that are used in the MPCA's biennial legislative reporting on progress toward the GHG emission reduction goals of the Next Generation Energy Act (NGEA).

Forecast methods are described and documented in detail in the following sector forecast summaries:

- MPCA, Minnesota Electric Power Sector Greenhouse Gas Forecast: Business as Usual GHG Projections, Technical Support Document, 1-20-2015
- MPCA, Minnesota Transportation Sector Greenhouse Gas Forecast: Business as Usual GHG Projections, Technical Support Document, 1-20-2015
- MPCA, Minnesota Industrial Sector Greenhouse Gas Forecast: Business as Usual GHG Projections, Technical Support Document, 1-20-2015
- MPCA, Minnesota Residential Sector Greenhouse Gas Forecast: Business as Usual GHG Projections, Technical Support Document, 1-20-2015
- MPCA, Minnesota Commercial Sector Greenhouse Gas Forecast: Business as Usual GHG Projections, Technical Support Document, 1-20-2015
- MPCA, Minnesota Feedlot/Livestock Sector Greenhouse Gas Forecast: Business as Usual GHG Projections, Technical Support Document, 2-4-2015
- MPCA, Minnesota Waste Management Sector Greenhouse Gas Forecast: Business as Usual GHG Projections, Technical Support Document, 3-17-2015

A number of different forecasting strategies were employed in the development of this forecast. In some sectors of the economy, policy is now the dominant control on future emissions. This seems to hold largely true for the electric power sector and transportation. For these sectors, the forecasting exercise was largely an effort to understand the future effects of policies now on the books on emissions. For other sectors, like the residential sector, a single dominant background trend reaching back decades seems largely to control the long-term trajectory of emissions. For residential buildings, emissions follow trends in energy intensity of on-site space heating intensity with a persistence that, due to the very long life of most residential structures, allows for the extrapolation of observed trends to the distant future.

In some sectors, emissions are sensitive to fuel pricing, such that forecasting strategies necessarily require the use of economic models tuned to specific sectors of the economy. Fuel use in Minnesota's industrial sector is a good example. In this forecast, industry-specific fuel use forecasts taken from the Energy Information Administration's *Annual Energy Outlook 2014* are used to develop a downscaled forecast of emissions for Minnesota's industrial sector.

Extensive analyses of the historic record were conducted to determine the most appropriate forecasting strategy to use for each emitting sector. In instances where the historic record might be understood only in light of policies that have been implemented in Minnesota, these effects were subjected to scrutiny to understand how their continued pursuit might impact future emissions. Where a predominantly empirical approach was taken to derive trends in important forecast parameters, given the wholesale changes of the last decade in the economy, the data used was generally drawn from the last 10 or 15 years. Underlying the forecast is the assumption that the flattening of the statewide emissions trajectory over the last decade is real and provides an important window to the future.

At the time of the drafting of this forecast summary, no written documentation was available for the crop production emissions forecast. As noted above, the crop production forecast was developed by the staff of the Center for Climate Strategies. The results of that forecast are included in the totals shown below.

Regarding present-day and historic emissions, the methods that were used to develop the present-day and historic emissions estimates are discussed in detail in Appendix E of P. Ciborowski and A. Claflin, "Greenhouse Gas Emissions in Minnesota: 1970-2008: Second Biennial Progress Report – Technical Support Document" (2012).

Finally, by definition, all forecasts are wrong or, with the fullness of time, will be shown to be wrong. The purpose of this forecast is less to provide an objectively correct estimate of future emissions levels than an internally consistent framework of future economic activity and emissions within which the effects of different policies and their costs might be evaluated. The forecast should be viewed in that light.

Results

Table S-1 shows historic and forecasted GHGs from Minnesota for selected years in millions of CO_2-equivalent tons. Using 2011, the last historical year for which emission estimates were available, in the forecast, total statewide emissions decline 5.1 million CO_2-equivalent tons or a 3 percent. Most of this occurs between 2011 and 2015, after which forecast emissions are relatively stable at about 150 million CO_2-equivalent tons per year. Over the forecast period, emissions from electric power decline by 2.77 million CO_2-equivalent tons or 6 percent from 2011 levels. Emissions from transportation decline by 2.97 million CO_2-equivalent tons or 9 percent from 2011 levels. Emissions from industry increase by 0.98 million CO_2-equivalent tons or 4 percent over the forecast period.

Table S-1. Historic and Forecasted Greenhouse Gas Emissions by Sector (Million CO_2-equivalent short tons)

	historical	historical	historical	historical	forecast	forecast	forecast
	1990	**2000**	**2005**	**2011**	**2015**	**2025**	**2030**
Residential	7.79	9.76	8.50	9.23	8.81	8.39	8.07
Commercial	5.74	6.32	6.89	7.01	6.67	7.66	8.25
Industrial	14.58	19.82	18.57	22.06	22.15	22.88	23.04
Electric Power	42.48	54.08	56.72	49.74	47.82	46.99	46.97
Transportation	29.56	37.52	38.32	34.14	33.47	32.02	31.17
Waste Management	5.54	3.17	2.26	1.97	1.71	1.67	1.64
Feedlots/Livestock	9.82	10.44	10.23	10.86	10.91	11.81	12.29
Crop Production	17.16	18.08	19.00	20.05	18.46	18.12	18.54
total	132.67	159.20	160.49	155.07	149.99	149.53	149.97
NGEE goals	-	-	-	-	136.41	112.34	96.29

Of the smaller emitting sectors, in the forecast, emissions from the residential sector decline by 1.16 million CO_2-equivalent tons or 13 percent from 2011 levels, while emissions from the commercial sector rise by 18 percent from 2011 levels or 1.24 million CO_2-equivalent tons. Forecast emissions from feedlots and livestock increase by 1.43 million CO_2-equivalent tons or 13 percent. These are more than fully offset by a forecast 1.51 million CO_2-equivalent tons emission reduction from crop production. In the forecast, emissions from waste management decline slightly, by 0.34 million CO_2-equivalent tons.

Between 2011 and forecast year 2030, statewide emissions decline at an average rate of about 0.2 percent per year. In terms of the percentage distribution of emissions, this is largely unchanged between 2011 and forecast year 2030, with electric power sector share of emission declining from 32 to 31 percent, and transportation from 22 to 21 percent. Over this same period, industrial emissions as a percent of total statewide emissions increase from 14 to 15 percent.

In the 2007 The Next Generation Energy Act, the State of Minnesota set statutory emission reductions goals of 15, 30 and 80 percent from 2005 levels by 2015, 2025 and 2050. Forecasted statewide emissions in 2005 were an estimated 160.49 million CO_2-equivalent tons, yielding 2015 and 2025 NGEA target levels of 136.41 and 112.34 million CO_2-equivalent tons in 2015 and 2025 respectively. In the forecast, 2015 and 2025 estimated statewide GHG emissions come to 149.99 and 149.53 million CO_2-equivalent tons, respectively, short of statutory reduction goals at 2015 and 2025 by a projected 13.58 and 37.19 million CO_2-equivalent tons, respectively.

In the forecast, 2030 emissions statewide come to 149.97 million CO_2-equivalent tons. Drawing a straight line between NGEA 2025 and 2050 percentage goals yields a 2030 NGEA target of 40 percent or, in absolute terms, 96.29 million CO_2-equivalent tons.

Historic emissions also are shown in Table S-1. Over the reported historical period, 1990-2011, total statewide GHG emissions from Minnesota increased by 17 percent or 22.4 million CO_2-equivalent tons. Most of this occurred between 1990 and 2000. Between 2000 and 2011, statewide emissions declined 4.13 million CO_2-equivalent tons or about 3 percent.

The same data that are shown in Table S-1 are shown pictorially in Figure S-1 below. Over the combined historical/forecast period, statewide emissions peak in 2008 at 161.86 million CO_2-equivalent tons, subsequently falling by 2011, the last year for which historical data are available, to 155.07 million CO_2-equivalent tons. Emissions throughout much of the forecast period settle near 150 million tons. By 2030, the gap between forecasted emissions and inferred NGEA target levels is equal to 36 percent of forecasted 2030 emissions or about 54 million tons.

Of the historical and forecast emission reductions, 1990-2030, most occur in the historical period and, of these, most occur in the electric power and transportation sectors.

Historical and forecasted emissions are shown in Figure S-2 by gas. Over the forecast period, fossil CO_2 remains the dominant GHGs emittant in Minnesota, comprising a little more than 80 percent of all statewide emissions. Emissions of PFCs, HFCs and SF_6 increase during the forecast period from about 1 percent of total statewide emissions in 2011 to about 3 percent in 2030. As was discussed in the documentation to the Commercial Sector forecast[26], federal rules are pending that, over the forecast period, might somewhat slow the growth of emissions of HFCs in Minnesota.

[26] MPCA, Minnesota Commercial Sector Greenhouse Gas Forecast: Business as Usual GHG Projections, Technical Support Document, 1-20-2015

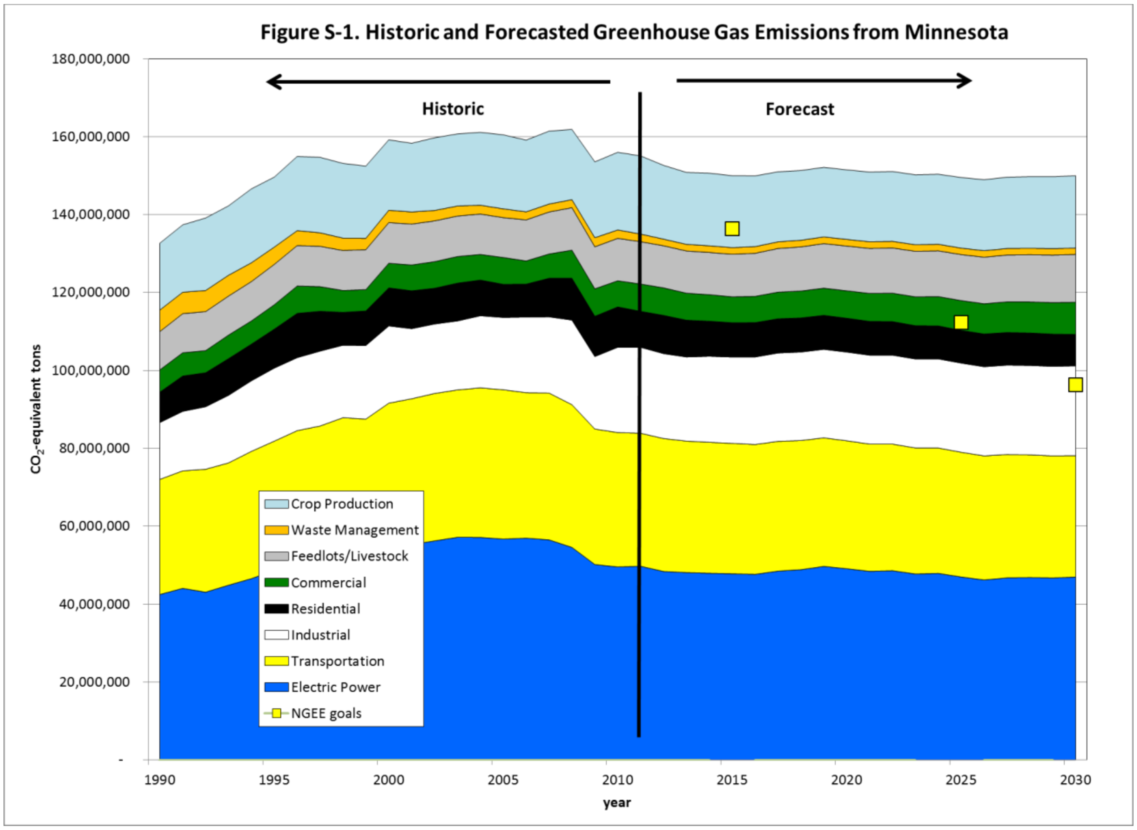


Figure S-1. Historic and Forecasted Greenhouse Gas Emissions from Minnesota
Historic
Forecast
CO2-equivalent tons
180,000,000
160,000,000
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
-
1990
1995
2000
2005
2010
2015
2020
2025
2030
year
Crop Production
Waste Management
Feedlots/Livestock
Commercial
Residential
Industrial
Transportation
Electric Power
NGEE goals

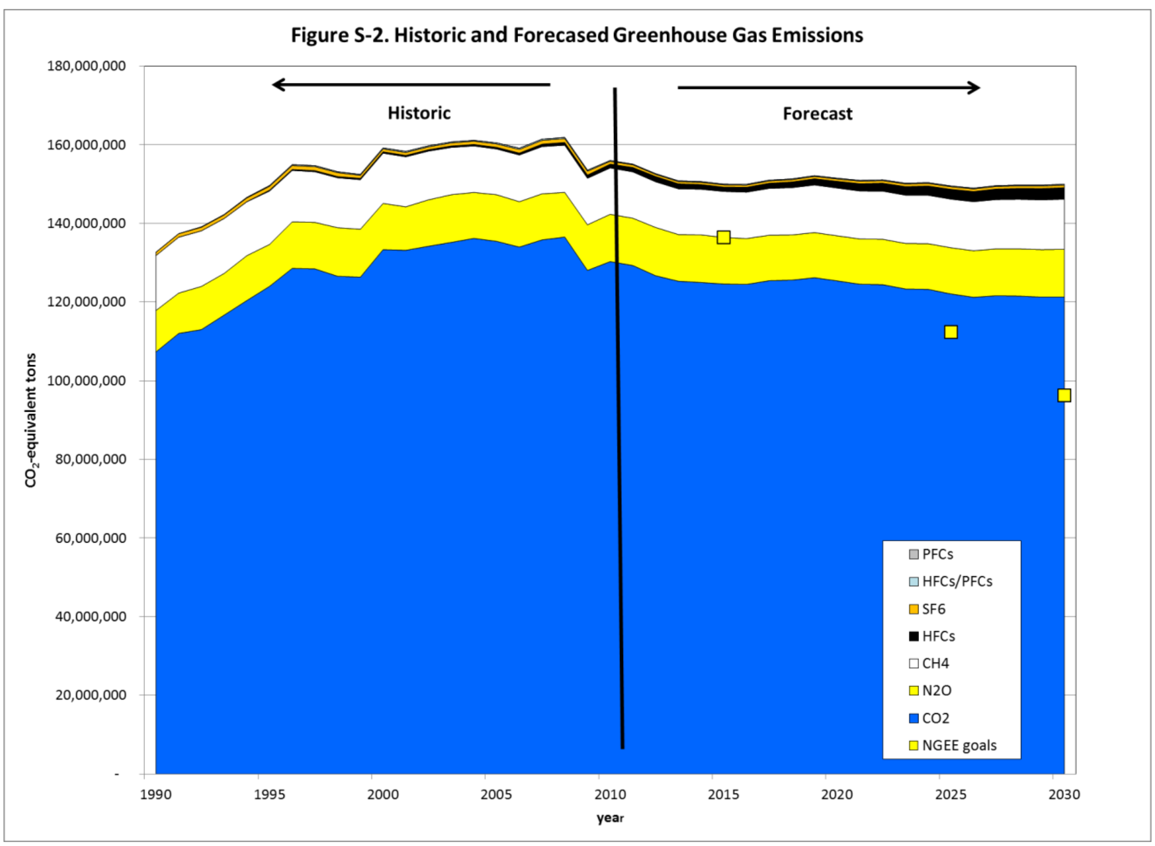


Figure S-2. Historic and Forecased Greenhouse Gas Emissions
Historic
Forecast
CO2-equivalent tons
180,000,000
160,000,000
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
-
1990
1995
2000
2005
2010
2015
2020
2025
2030
year
PFCs
HFCs/PFCs
SF6
HFCs
CH4
N2O
CO2
NGEE goals

Figure S-3 shows pictorially the trend in historic and forecasted emissions by major activity. Currently, about 80 percent of all GHG emissions from Minnesota are associated with the production or use of energy. Included in this are all emissions associated with combustion for the production of useful energy, plus noncombustion emissions associated with petroleum refining, electric transmission and distribution, air conditioning and refrigeration and nonfuel uses of lubricating oils. Of the remainder, most of this derives from agricultural activities. Waste management and miscellaneous industrial processes contribute a few percent to statewide totals.

In forecast, energy use and production remains the predominant source of emissions, consistently accounting for slightly less than 80 percent of all statewide emissions across all forecast years.

Figure S-3. Historic and Forecasted Emissions by Major Activity

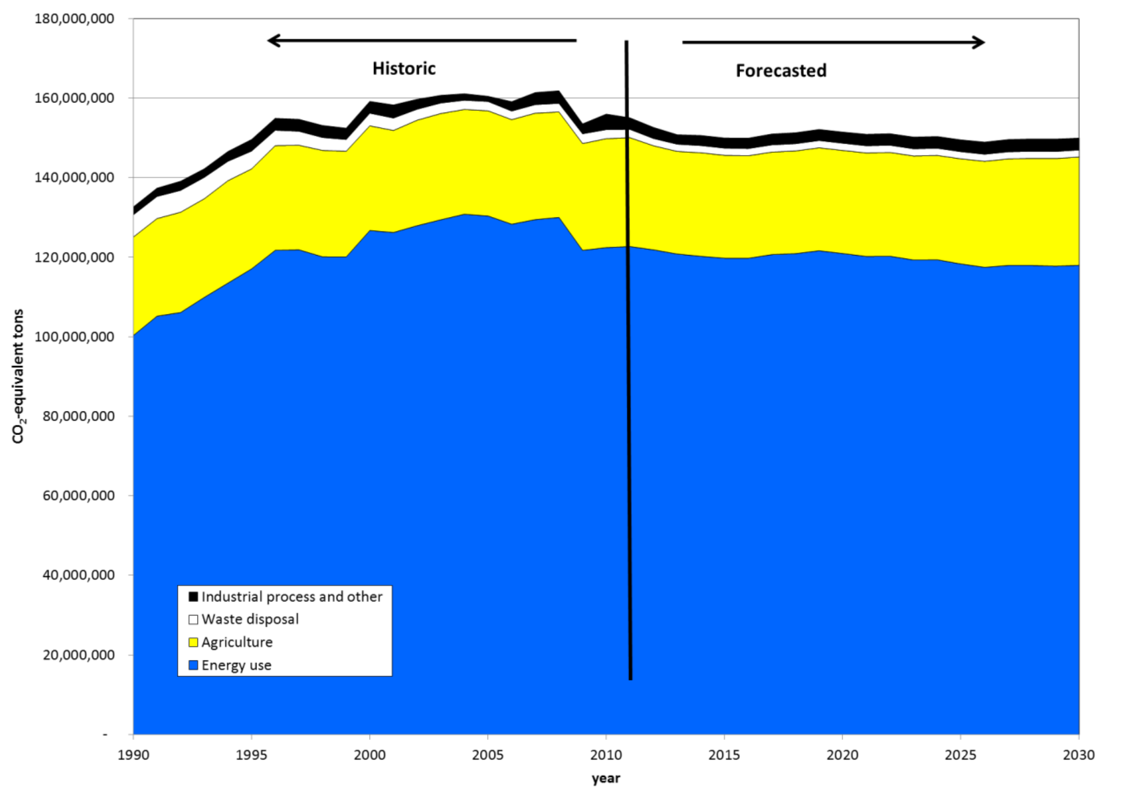


Table S-2 provides a detailed breakdown of historic and forecasted emissions for selected years by emissions source. In Minnesota, about three-quarters of GHG emissions are associated with combustion for the purposeful production of energy, and the rest are noncombustion emissions. This percentage breakdown of emissions persists throughout the forecast period. In the forecast, statewide emissions from combustion decline by 7.03 million CO_2-equivalent tons, 2011-2030, or about 6 percent. Over the forecast period, emissions associated with the combustion of oil decline by 2.6 million CO_2-equivalent tons, while emissions associated with the generation out-of-state of imported power decline by 5.41 million CO_2-equivalent tons, 2011-2030. These are partially offset in the forecast by increased emissions from the combustion of natural gas, some 1.54 million CO_2-equivalent tons. Emissions from the combustion of coal are almost unchanged in the forecast, declining 0.5 million CO_2-equivalent tons by forecast year 2030. Combustion emissions totaled an estimated 118.6 million CO_2-equivalent tons in 2011, declining in the forecast to 111.57 million tons by forecast year 2030.

Statewide noncombustion emissions in 2011 were some 36.46 million CO_2-equivalent tons. In the forecast, emissions from noncombustion sources increase from 36.46 million CO_2-equivalent tons in 2011 to 38.39

million CO_2-equivalent tons in forecast year 2030 or 1.93 million CO_2-equivalent tons. Most of this is from commercial buildings. In the forecast, emissions from commercial buildings increase by 1.75 million CO_2-equivalent tons, principally in the form of HFC emissions from commercial air conditioning and refrigeration. Over the forecast period, emissions from industrial noncombustion processes increase a smaller 0.58 million CO_2-equivalent tons, while agricultural and waste management noncombustion process emissions decline in the forecast by 0.17 and 0.35 million CO_2-equivalent tons, respectively, 2011-2030.

Table S-2. Historic and Forecasted Greenhouse Gas Emissions by Sector (Million CO_2-equivalent short tons)

	historical	historical	historical	historical	forecast	forecast	forecast
	1990	2000	2005	2011	2015	2025	2030
Combustion Emissions							
Coal	34.11	41.08	41.98	34.82	36.51	34.61	34.38
Oil	39.18	47.98	50.63	44.57	44.00	42.71	41.96
Natural gas	16.34	20.23	20.45	24.00	24.35	24.87	25.54
Other fuel	0.79	0.88	0.95	0.97	1.20	0.93	0.86
Net Electricity imports	8.26	13.78	13.48	14.24	9.26	9.18	8.83
Noncombustion Process Emissions							
Electric Power							
Electric transmission and distribution	0.68	0.43	0.46	0.52	0.51	0.60	0.63
Other electric power sector process	0.06	0.07	0.07	0.07	0.07	0.06	0.06
Industry							
Iron ore processing	2.10	2.29	1.82	2.33	2.37	2.46	2.50
Copper ore processing	-	-	-	-	-	0.10	0.10
Oil refining	0.91	2.12	2.07	2.59	2.93	3.03	2.99
Magnesium die casting	0.15	0.28	0.39	0.15	0.05	0.05	0.05
Semiconductor manufacture	-	0.23	0.25	0.14	0.16	0.16	0.16
Industrial wastewater treatment	0.12	0.15	0.17	0.18	0.18	0.20	0.21
Other industrial sector process	0.53	0.53	0.38	0.40	0.40	0.36	0.36
Transportation							
Tire abrasion	0.01	0.01	0.02	0.01	0.01	0.01	0.02
Agriculture							
Manure management	3.04	3.99	4.18	4.60	4.66	5.30	5.61
Ruminant flatulence	6.01	5.69	5.28	5.45	5.45	5.64	5.80
Soil nutrient management	7.20	8.06	8.30	9.06	8.97	8.83	9.20
Histosols	7.68	7.68	7.68	7.49	6.06	6.06	6.06
Other agricultural processes	0.82	0.91	1.00	0.79	0.73	0.60	0.55
Waste Management							
MMSW landfills	5.12	3.19	2.26	1.86	1.77	1.70	1.64
Industrial landfills	0.07	0.11	0.12	0.13	0.14	0.14	0.14
Solid waste incineration	0.16	0.07	0.06	0.06	0.06	0.06	0.06
Hazardous waste incineration	0.09	0.09	0.11	0.07	0.10	0.10	0.10
Wastewater treatment	0.51	0.54	0.56	0.59	0.60	0.63	0.65
Carbon sequestration in D/C landfills	(0.51)	(1.04)	(0.99)	(0.87)	(1.08)	(1.09)	(1.10)
Other waste management process emissions	0.02	0.05	0.06	0.06	0.06	0.06	0.06
Buildings							
Carbon sequestration in housing	(1.08)	(0.89)	(2.03)	(0.66)	(1.00)	(0.83)	(0.88)
Other housing sector process	0.10	0.34	0.33	0.49	0.61	0.91	0.89
Commercial air conditioning	-	0.15	0.28	0.78	0.67	1.87	2.34
Other Commercial sector process	0.17	0.18	0.15	0.18	0.19	0.19	0.19
Total	**132.67**	**159.20**	**160.49**	**155.07**	**149.99**	**149.53**	**149.97**

other agriculture processes: agricultural burning, atmospheric nitrogen deposition, wild rice cultivation, wind erosion of soils

As discussed with respect to Figure S-2, it is possible that, with pending federal rules on the allowable use of HFCs in commercial refrigeration, some of the forecasted increase in noncombustion emissions, 2011-203, may be avoided.

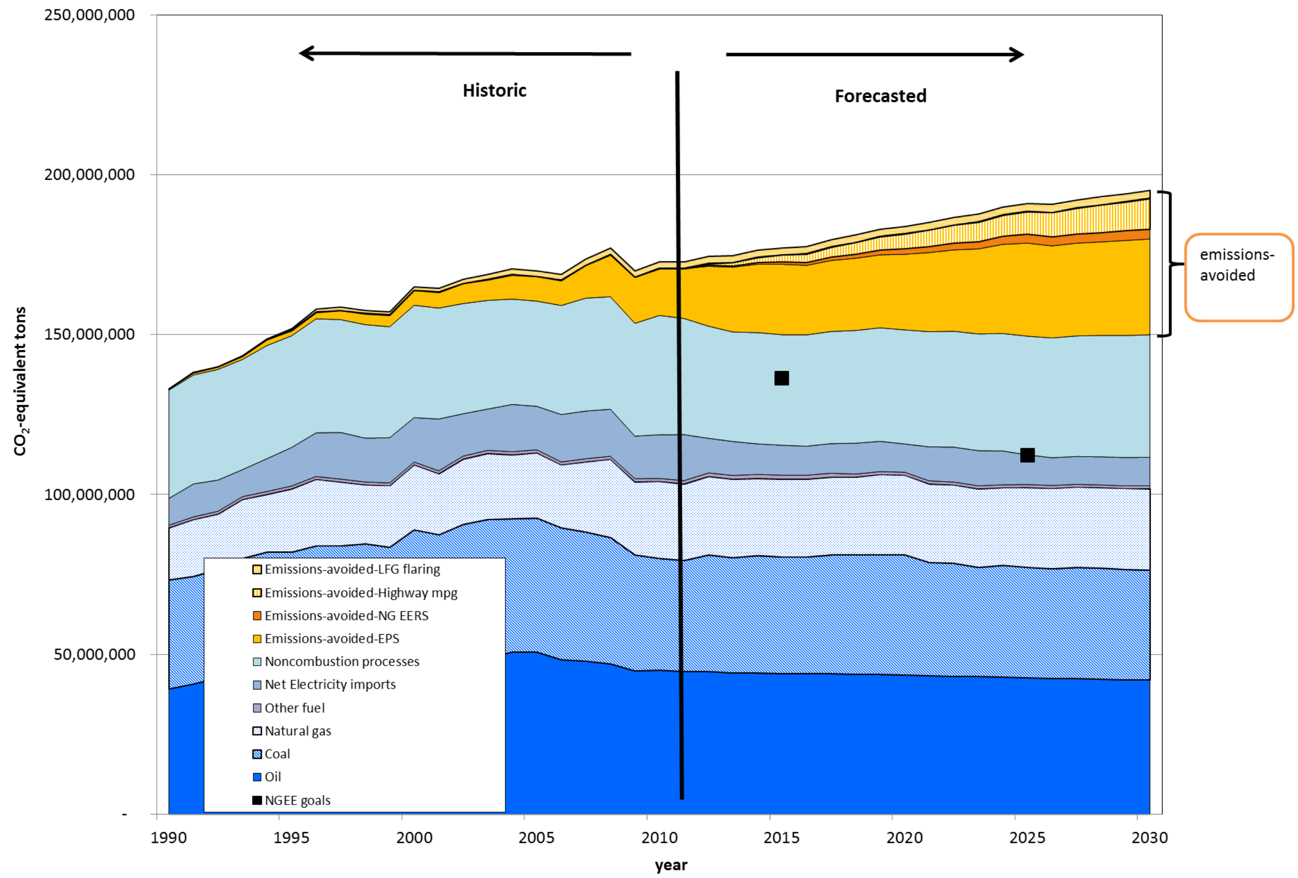
Regarding the distribution of emissions among sources, this remains largely unchanged over the forecast period. With regard to combustion emissions, at present about 29 percent derive from the combustion of coal, 38 percent from the combustion of refined petroleum products and 20 percent from the combustion of natural gas. As of 2011, about 12 percent of combustion-based emissions derived from out-of-state combustion leading to the generation of electricity that eventually is consumed in Minnesota by Minnesotans. In the forecast, by forecast year 2030, a projected 31 percent of combustion emissions are associated with coal combustion, 38 percent with the combustion of oil and 23 percent with the combustion of natural gas. The percent of total combustion emissions that are associated with net imported electricity declines to about 8 percent in the forecast by forecast year 2030.

About 75 percent of noncombustion emissions now are agricultural in origin and another roughly 16 percent are of an industrial provenance. Waste management accounts for an additional 5 percent and buildings 2 percent. In the forecast, by forecast year 2030, these distributions are only slightly different, with agricultural contribution at 71 percent, industry at 17 percent, buildings 6 percent and waste management 4 percent.

In developing the sector forecasts, substantial efforts were made to understand the impacts of policies that are already in-place on emissions over the historic period and forecast emissions. Figure S-4 shows the results of those efforts pictorially. The figure was assembled from the results shown in:

- Figure E-6. Minnesota Electric Power Sector Greenhouse Gas Forecast, Technical Support Document
- Figure T-8. Minnesota Transportation Sector Greenhouse Gas Forecast, Technical Support Document
- Figure I-5. Minnesota Industrial Sector Greenhouse Gas Forecast, Technical Support Document
- Figure R-6. Minnesota Residential Sector Greenhouse Gas Forecast, Technical Support Document
- Figure C-4. Minnesota Commercial Sector Greenhouse Gas Forecast, Technical Support Document
- Figure W-3. Minnesota Waste Management Sector Greenhouse Gas Forecast, Technical Support Document

Figure S-4. Historic and Forecasted Emissions and Emissions-avoided



The questions asked were:

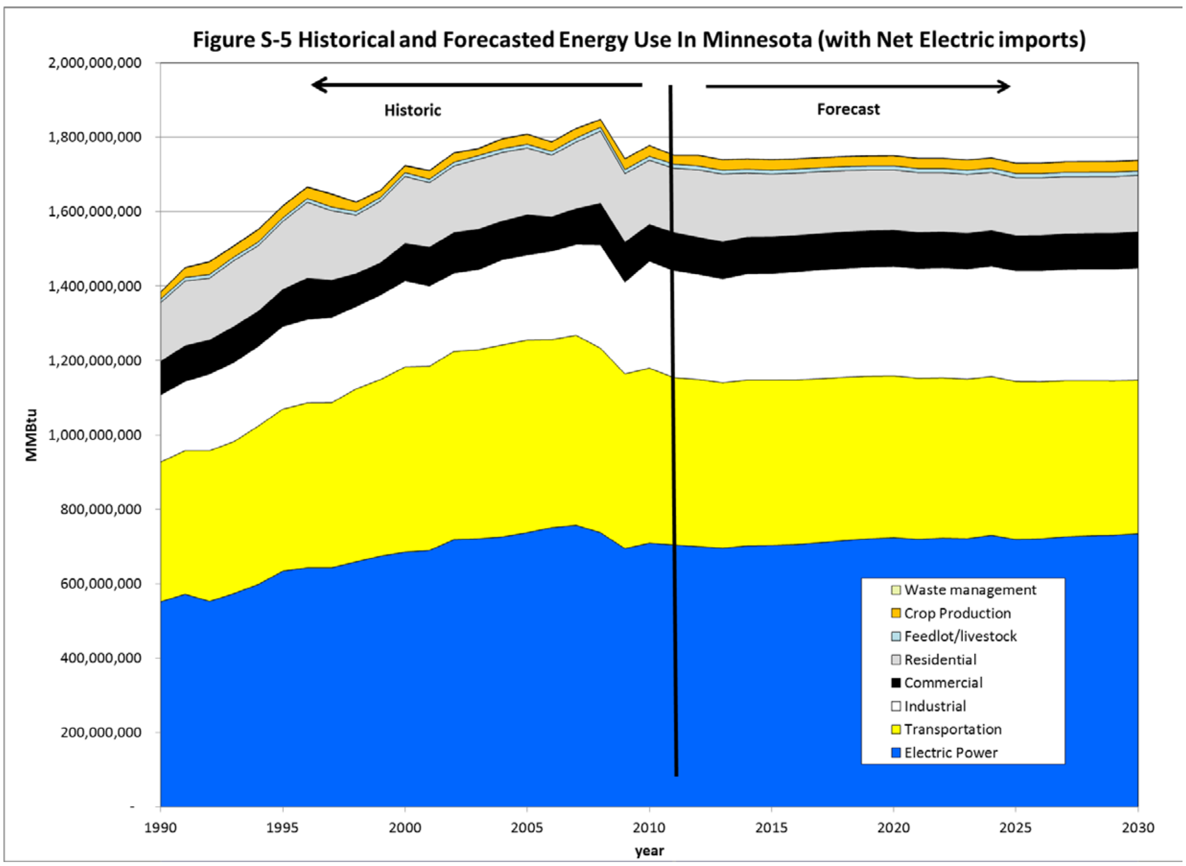
- In the case of forecast emissions, if emissions were modeled with no consideration given to the effects of policies now in-place and expected to continue in-place throughout the forecast period, how would the forecast trend in emissions differ from what otherwise is projected out to 2030?
- In the case of emissions during the historical period, how would have the known trajectory of emissions otherwise been different had the policies that in fact were implemented over that period not been implemented?

If modeled without consideration given to the effects of policies now in-place and expected to continue in-place throughout the forecast period, projected state-level GHG emissions would be roughly 45 million CO_2-equivalent tons higher in 2030 than are now projected. Based on the modeling, in absence of the policies that are now in place, historical emissions would have been higher in 2000 and 2011 than the historic data record by an estimated 5.6 and 17.6 million CO_2-equivalent tons, respectively or 4 and 11 percent. In the historical record, emissions peak in 2008 and decline about 4 percent through 2011. Forecast emissions are largely flat at levels only slightly lower than 2011 levels. Absent the policies that are now in place, emissions over the combined historical period and forecast period would have grown, 1995-2011, and otherwise would grow in the forecast, 2011-2030, at a sustained 30-year rate of about 0.6 percent per year out to 2025.

As noted above, the NGEA targets at 2025 are some 112.3 million CO_2-equivalent tons, while forecasted emissions in 2025 are 149.5 million CO_2 equivalent tons. Forecasted emissions-plus-emissions-avoided are some 192.5 million CO_2-equivalent tons. This suggests that, with the emissions reductions already baked into the forecast, the state is roughly halfway to its NGEA statutory goals. This is shown in Figure S-4 as the difference between total forecasted emissions plus emissions-avoided and the NGEA targets, on the one hand, and total forecasted emissions and the NGEA targets, on the other hand.

Figure S-5 shows the trend and breakdown of historic and forecasted future energy use in Minnesota. This includes the energy associated with the generation out-of-state of electricity that is consumed in Minnesota. Total energy use in Minnesota increased at an average annual rate of 1.1 percent over the historical period (1990-2011), peaking in 2008 and declining by about 5 percent to 2011. Of the 2008-2011 decline, about half of this occurred in transportation and one-third in the electric power sector. The rate of growth in energy use was rapid early in the historical period, 2 percent per year, 1990-2000, declining to 0.3 percent per year, 2000-2010.

In the forecast, total energy use in Minnesota declines by 14 million MMBtu from 2011 levels by forecast year 2030 or by 1 percent. In the forecast, total energy use in transportation and housing declines 37 and 21 million MMBtu, respectively, 2011-2030, partially offset by increased energy use in electric power and industry (mining and manufacturing), some 30 and 14 million MMBtu, respectively. Over the forecast period, total energy use declines at an average annual rate of 0.04 percent per year, continuing the flattening of growth in energy use evident in the historical record back to the early 2000s. Energy use in transportation declines in the forecast principally in response to federal fuel economy standards, and energy use in residential housing due to declining space heating energy intensity, the state's natural gas energy efficiency resource standard (EERS), and continued projected climatic warming. Energy use in electric power generation increases in the forecast principally in response to forecasted increased future electric demand.



Forecast energy use in mining and manufacturing increases mainly due to rising industrial production, particularly in oil refining, food processing, mining, and miscellaneous light manufacturing. By sector, total forecasted energy use in Minnesota increases by 0.2, 0.2 and 0.8 percent per year in the electric power sector, industry and agriculture, respectively. Energy use in transportation, residential housing, and the commercial sector declines in the forecast at an average annual rate of 0.5, 0.7 and 0.3 percent per year, respectively, 2011-2030.

By percent, the distribution of total Minnesota energy use by sector remains relatively unchanged over the forecast period, with electric power sector share of total energy use increasing from 40 to 42 percent, and transportation's share falling slightly from 26 to 24 percent of the total, 2011-2030. By forecast year 2030, total forecasted energy use in Minnesota is 6 percent below peak 2008 energy use levels.

Table S-3 shows historic and forecasted energy use in Minnesota by fuel type and energy carrier. Also shown is the energy consumed out-of-state to generate electricity that is imported into Minnesota. In the forecast, the in-state use of natural gas, nuclear energy, and renewable energy increases 26, 11 and 45 million MMBtu, respectively, offset by a reduction in the in-state use of refined petroleum products of 33 million MMBtu and a reduction of an estimated 64 million MMBtu in out-of-state energy used to generate electricity imported into Minnesota. In percentage terms, in-state use of natural gas increases 6 percent over the forecast period, 2011-2030, while the use of refined petroleum products decreases by 6 percent. In-state use of renewable energy increases in the forecast by about 36 percent, while out-of-state energy used to generate electricity imported into Minnesota declines a forecast 34 percent, 2011-2030. Energy inputs to nuclear power increase in the forecast about 9 percent from 2011 levels.

In-state coal use, the third largest source of energy for the Minnesota economy, declines in the forecast, but only slightly, by 4 million MMBtu or 1 percent, 2011-2030.

The percentage distribution of energy use by fuel changes slightly in the forecast. In the forecast, by forecast year 2030, natural gas and renewable energy account for a combined 35 percent of total energy use in Minnesota, up from a combined 30 percent in 2011. The forecasted share of net electric imports and refined petroleum products of total state energy use declines in the forecast from a combined 40 percent in 2011 to 35 percent in forecast year 2030.

Table S-3. Historic and Forecasted Total State Energy Use by Fuel (Million MMBtu)

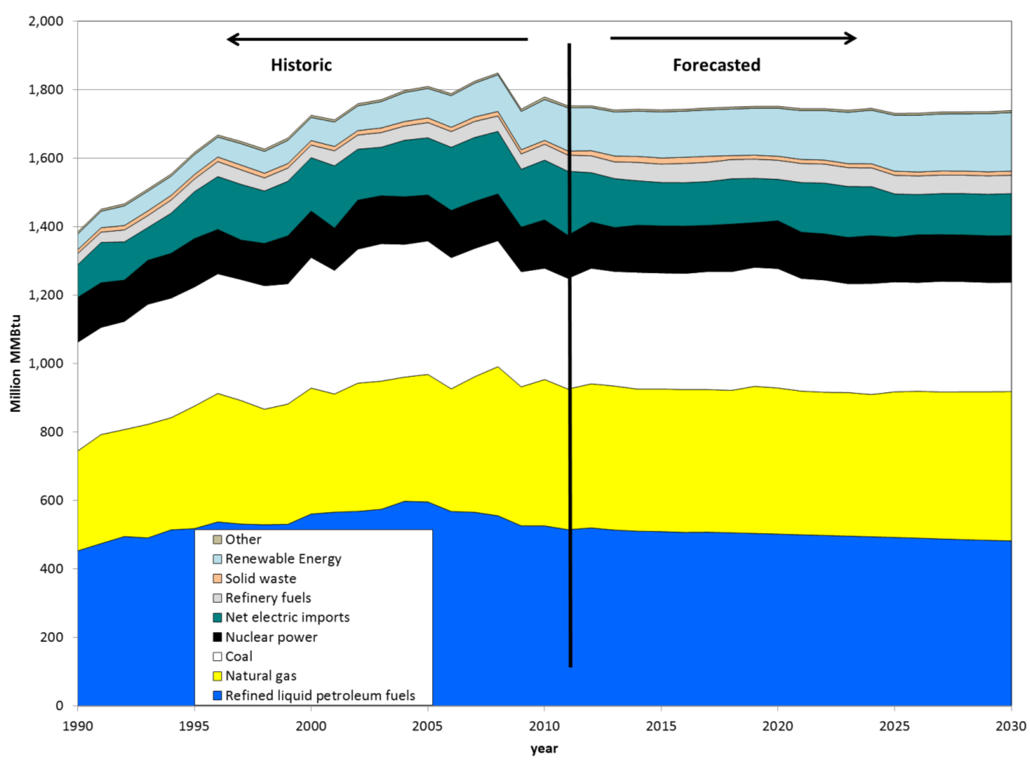
	1990	2000	2011	2020	2030
Refined liquid petroleum fuels	453	561	515	502	482
Natural gas	292	367	410	426	436
Coal	317	382	323	349	319
Nuclear power	131	135	125	139	136
Net electric imports	95	156	187	121	123
Renewable Energy	46	68	126	140	171
Refinery fuels	33	37	47	56	54
Solid waste	11	13	12	12	12
Other	6	6	6	6	6
total	**1,385**	**1,725**	**1,752**	**1,751**	**1,739**

Figure S-6 shows the same data pictorially. As noted above, the forecast largely continues trends in energy use that are evident in the historic data since the mid-2000s. Striking is the decline in the use of refined petroleum products between 2005 and 2011 and continuing throughout the forecast period. In-state coal use, which declined 17 percent between 2005 and 2011, continues near those reduced levels throughout the forecast period. In-state production of energy from renewable energy sources, mostly in the form of electricity, increases in the forecast, as does natural gas use, again mostly in electricity generation. Forecast energy inputs to net imported electricity decline about one-third over the forecast period. In the forecast, net electricity imports decline 31 percent between 2011 and forecast year 2030.

Finally, Figure S-7 shows the changing distribution of statewide energy use using the following categories: fossil fuels, nuclear power, renewable energy, and net electricity imports. In the forecast, in forecast year 2030, 75 percent of total energy use in Minnesota is from fossil fuels, unchanged from 2011 levels. In forecast year 2030, 10 percent of statewide energy use is from renewable energy sources, up from 8 percent in 2011, while the energy associated with the generation of power for import declines in the forecast from 11 percent in 2011 to 7 percent by forecast year 2030. Energy inputs to nuclear power generation increase over the forecast period from 7 to 8 percent, 2011-2030.

Using 1990 as a starting point, in the forecast, the system is decarbonizing, but at a slow long-term rate of 0.2 percent per year. Adding in the effects of increased out-of-state use of renewables in imported power would only slightly change this conclusion.[27]

Figure S-6. Historic and Forecasted Energy Use by Fuel



[27] Assuming in the extreme case that 50% of forecasted net imports in 2030 are fossil-based, and 100% of 1990 net imports were fossil based, the system would remain 78 percent fossil dependent as late as forecast year 2030, declining at a rate of 0.3 percent per year, 1990-2030.

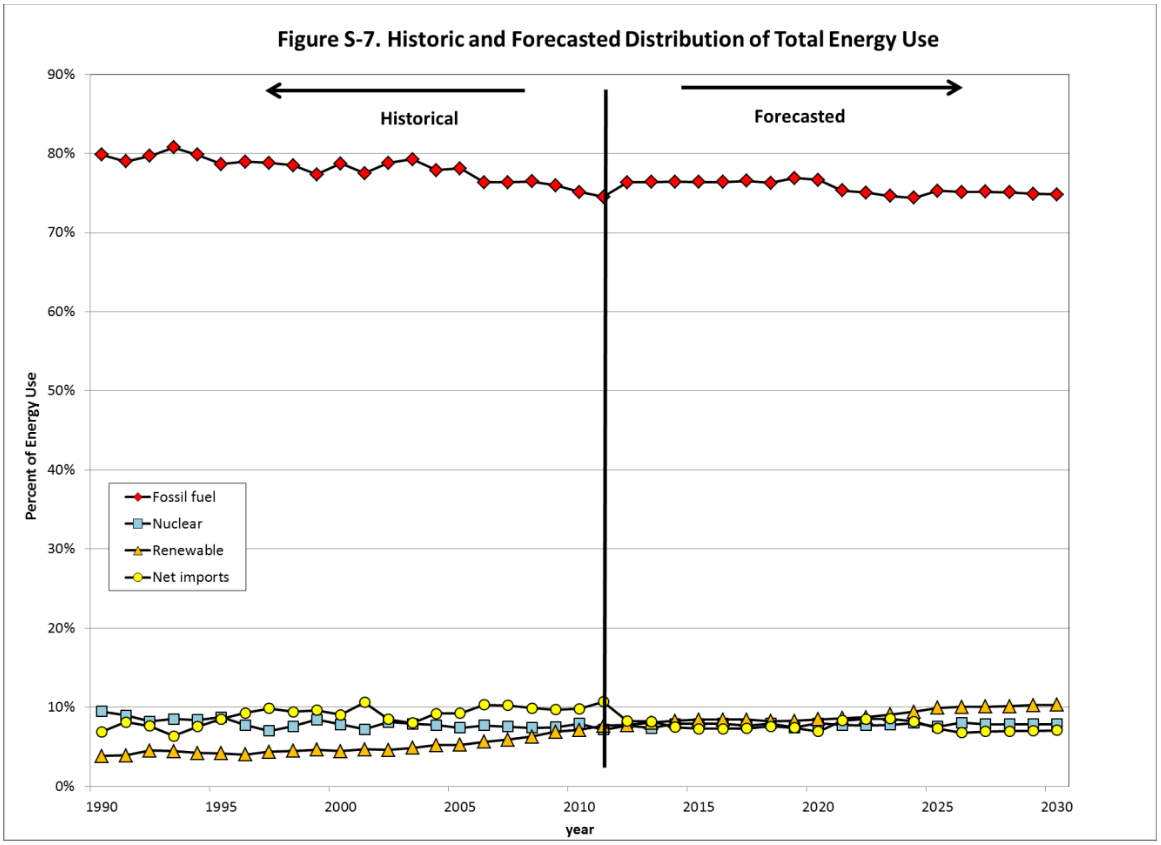


Figure S-7. Historic and Forecasted Distribution of Total Energy Use
Historical
Forecasted
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of Energy Use
Fossil fuel
Nuclear
Renewable
Net imports
1990
1995
2000
2005
2010
2015
2020
2025
2030
year