

Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion

Overview

Activities in the RCI¹ sectors produce carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) emissions when fuels are combusted to provide space heating, water heating, process heating, cooking, and other energy end-uses. Carbon dioxide accounts for about 99% of RCI emissions in Minnesota on a million metric tons (MMt) of CO₂ equivalent (CO₂e) basis. In addition, since these sectors consume electricity, one can also attribute emissions associated with electricity generation to these sectors in proportion to their electricity use.² Direct use of oil, natural gas, coal, and wood in the RCI sectors accounted for an estimated 32 MMtCO₂e of gross greenhouse gas (GHG) emissions in 2005.³

Emissions and Reference Case Projections

The Minnesota Pollution Control Agency (MPCA) has prepared a detailed inventory of GHG emissions from 1970 through 2004 for CH₄ and N₂O, and through 2005 for CO₂. The MPCA inventory follows the United States Environmental Protection Agency's (US EPA) methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for RCI fossil fuel combustion.⁴ The MPCA emission estimates for 1990 through 2004 were used for the historical inventory presented in this appendix. Emissions were projected starting from 2004 through 2020 since 2004 is the last year for which MPCA estimated emissions for all three pollutants. Table B1 provides the references that MPCA used to compile information on fuel use activity data that informed the historical inventory.

Note that the EIIP methods for the industrial sector exclude from CO₂ emission estimates the amount of carbon that is stored in products produced from fossil fuels for non-energy uses. For example, the methods account for carbon stored in petrochemical feedstocks, and in liquefied petroleum gases (LPG) and natural gas used as feedstocks by chemical manufacturing plants (i.e., not used as fuel), as well as carbon stored in asphalt and road oil produced from petroleum. The carbon storage assumptions for these products are explained in Volume III, Chapter 1 of the EIIP guidance document.

¹ The industrial sector includes emissions associated with agricultural energy use. Emissions associated with the direct use of fuel by the natural gas transmission and distribution (T&D) industry are included in Appendix E.

² Emissions associated with the electricity supply sector (presented in Appendix A) have been allocated to each of the RCI sectors for comparison of those emissions to the fuel-consumption-based emissions presented in Appendix B. Note that this comparison is provided for information purposes and that emissions estimated for the electricity supply sector are not double-counted in the total emissions for the state. One could similarly allocate GHG emissions from natural gas T&D, other fuels production, and transport-related GHG sources to the RCI sectors based on their direct use of gas and other fuels, but we have not done so here due to the difficulty of ascribing these emissions to particular end-users. Estimates of emissions associated with the transportation sector are provided in Appendix C, and estimates of emissions associated with natural gas T&D are provided in Appendix E.

³ Emissions estimates from wood combustion include only N₂O and CH₄. Carbon dioxide emissions from biomass combustion are assumed to be "net zero", consistent with US EPA and Intergovernmental Panel on Climate Change (IPCC) methodologies, and any net loss of carbon stocks due to biomass fuel use should be accounted for in the land use and forestry analysis.

⁴ Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004, and Chapter 2 "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion", August 2004.

Table B1. References for RCI Activity Data for 1990 - 2004**Residential Sector:**

Natural gas and propane-air - United States Department of Energy (US DOE), Energy Information Administration (EIA), *Natural Gas Annual*,

http://tonto.eia.doe.gov/dnav/ng/ng_sum_snd_dcu_SMN_a.htm

LPG and coal - EIA, *State Energy Data (SED)*,

http://www.eia.doe.gov/emeu/states/state.html?q_state_a=mn&q_state=MINNESOTA

Distillate fuel oil and kerosene - EIA, *Fuel Oil Kerosene Sales*,

http://www.eia.doe.gov/oil_gas/petroleum/data_publications/fuel_oil_and_kerosene_sales/foks.html

Wood - Minnesota Department of Natural Resources (DNR) Fuelwood Surveys

Commercial Sector:

Natural gas and propane-air - EIA, *Natural Gas Annual* and Minnesota Pollution Control Agency (MPCA) Emission Inventory System (EIS) data

Distillate fuel oil and kerosene - EIA, *Fuel Oil Kerosene Sales* and MPCA-EIS data

Coal - MPCA-EIS data

Residual fuel oil and waste oil - MPCA-EIS data

Wood - EIA, SED

Industrial and Agricultural Sectors:

Bituminous, subbituminous, anthracite, and lignite coal - MPCA-EIS data

Refinery petroleum coke, residual fuel oil, heavy oil; solid resins; waste solvent; and other industrial - MPCA-EIS data

Refinery gas - 1990-1995, MPCA-EIS data; 1996-2004, calculated from refinery capacity, utilization rates, assumed energy input to refinery production, and assumed percentage of refinery gas contribution to total refinery fuel inputs

Coking coal and LPG - EIA, SED

Natural gas and propane-air - EIA, *Natural Gas Annual*

Distillate fuel oil and kerosene - EIA, *Fuel Oil Kerosene Sales*

Wood and wood waste, sawdust, bark, mixed wood, bark and sawdust, wet wood, wood sludge, black liquor - MPCA-EIS data

Waste oil - MPCA-EIS data and EIA, SED

Motor gasoline for agricultural sector - Federal Highway Administration's *Highway Statistics*

Reference case emissions from direct fuel combustion were estimated based on fuel consumption forecasts from EIA's *Annual Energy Outlook 2006 (AEO2006)*,⁵ with adjustments for Minnesota's projected population⁶ and employment growth. Minnesota employment data for the manufacturing (goods-producing) and non-manufacturing (commercial or services-providing) sectors were obtained from the Minnesota Department of Employment and Economic

⁵ EIA AEO2006 with Projections to 2030, (<http://www.eia.doe.gov/oiaf/aeo/index.html>).

⁶ Minnesota Department of Administration, Office of Geographic and Demographic Analysis, <http://www.mnplan.state.mn.us/resource.html?Id=3124>.

Development.⁷ Regional employment data for the same sectors were obtained from EIA for the EIA’s West North Central region.⁸

Table B2 shows historic and projected growth rates for electricity sales by sector. Table B3 shows historic and projected growth rates for non-electric energy use by sector and fuel type. For the residential sector, the rate of population growth is expected to average about 0.8% annually between 2005 and 2020; this demographic trend is reflected in the growth rates for residential fuel consumption. Based on the Minnesota Department of Employment and Economic Development’s industry projections (2004 to 2014), commercial and industrial employment are projected to increase at compound annual rates averaging about 1.5% and 0.4%, respectively, and these growth rates are reflected in the growth rates in energy use shown in Table B3 for the two sectors. The 2004-to-2014 commercial and industrial employment growth rates were carried forward to 2020 for the purpose of estimating emissions for the reference case projections. These estimates of growth relative to population and employment reflect expected responses of the economy — as simulated by the EIA’s National Energy Modeling System — to changing fuel and electricity prices and changing technologies, as well as to structural changes within each sector (such as shifts in subsectoral shares and in energy use patterns).

Table B2. Electricity Sales Annual Growth Rates, Historical and Projected

Sector	1990-2000^a	2000-2005^a	2005-2020^b
Residential	2.3%	2.6%	1.8%
Commercial	3.4%	6.3%	2.3%
Industrial	2.1%	-0.4%	1.2%
Total	2.4%	2.3%	1.7%

^a 1990-2000 and 2000-2005 compound annual growth rates calculated from Minnesota electricity sales by year from EIA state electricity profiles (Table 8), http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html. According to the EIA, starting in 2001 some facilities that previously reported their retail electricity purchases as industrial began reporting their retail purchases as commercial. Thus, between 2000 and 2001, there was a significant decline in retail sales reported for the industrial sector and a significant increase in retail sales reported for the commercial sector. The EIA was unable to identify the facilities that changed the sector for which they reported retail sales.

^b 2005-2020 compound annual growth rates based on average annual Mid-Continent Area Power Pool (MAPP) region annual growth rates by sector.

As shown in Table B2, the growth rates for electricity sales for the commercial and industrial sectors changed significantly from 2000 through 2005 as a result of an accounting change-- facilities changing the sector under which they reported their electricity sales.⁹ From 1990 through 2000, the commercial and industrial sectors accounted for about 30% and 70%, respectively, of total retail electricity sales for these two sectors combined. Thus, these proportions were used to attribute emissions associated with the electricity supply sector presented in Appendix A to the commercial and industrial sectors for 2000 through 2020.

⁷ Minnesota Department of Employment and Economic Development, Industry Projections 2004-2014, <http://www.deed.state.mn.us/lmi/tools/projections/default.aspx>.

⁸ AEO2006 employment projections for EIA’s West North Central region obtained through special request from EIA (dated September 27, 2006).

⁹ Personal communication between Randy Strait, CCS, and Thomas Lecky, DOE, EIA ((202) 586-3548), July 19, 2007.

Table B3. Historical and Projected Average Annual Growth in Non-Electric Energy Use in Minnesota, by Sector and Fuel, 1990-2020

	1990-2005 ^a	2005-2010 ^b	2010-2015 ^b	2015-2020 ^b
Residential				
natural gas	1.2%	1.4%	0.8%	0.5%
petroleum	1.3%	0.3%	0.6%	0.3%
wood	-2.6%	1.8%	0.3%	0.6%
coal ^c	-7.1%	1.9%	-0.3%	-0.3%
Commercial				
natural gas	1.4%	1.3%	2.5%	1.7%
petroleum	2.4%	0.0%	1.3%	0.7%
wood	1.3%	0.4%	0.9%	0.6%
coal ^d	-7.5%	0.3%	0.9%	0.6%
Industrial				
natural gas	0.5%	5.8%	2.7%	0.6%
petroleum	3.6%	0.9%	0.4%	0.5%
wood	0.5%	2.0%	1.5%	1.3%
coal	3.4%	1.6%	0.6%	0.4%

^a Compound annual growth rates calculated from historical fuel consumption by sector and fuel type for Minnesota. Petroleum includes distillate fuel, kerosene, and liquefied petroleum gases (LPG) for all sectors plus residual oil and motor gasoline for the commercial and industrial sectors.

^b Figures for growth periods starting after 2005 are calculated from AEO2006 projections for EIA’s US West North Central region, adjusted for Minnesota’s projected population for the residential sector, projections for non-manufacturing employment for the commercial sector, and projections for manufacturing employment for the industrial sector.

^c In 1990, on a Btu basis, residential coal consumption accounted for only 0.04% of total residential energy consumption (based on the use of all fossil fuels and wood combined) and declined to about 0.01% of total energy consumption by 2005.

^d In 1990, on a Btu basis, commercial coal consumption accounted for only 1.5% of total commercial energy consumption (based on the use of all fossil fuels and wood combined) and declined to about 0.3% of total energy consumption by 2005.

Results

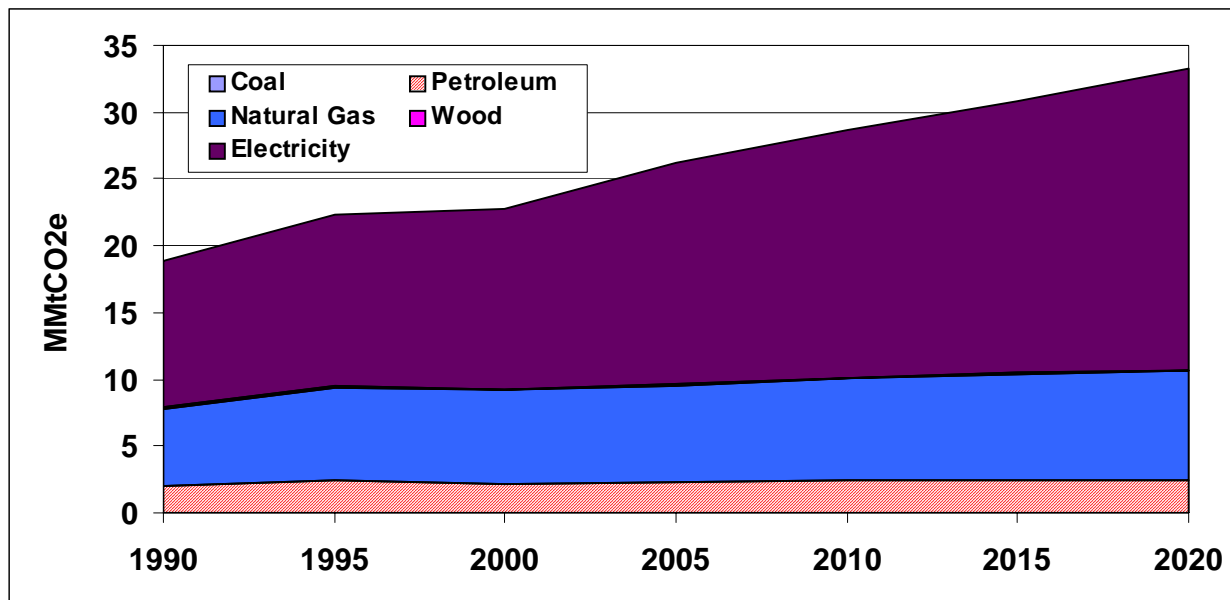
Figures B1, B2, and B3 show historical and projected emissions for the RCI sectors in Minnesota from 1990 through 2020. These figures show the emissions associated with the direct consumption of fossil fuels and, for comparison purposes, show the share of emissions associated with the generation of electricity consumed by each sector. During the period from 1990 through 2020, the residential sector’s share of total RCI emissions from direct fuel use and electricity ranged from 31% in 1990 to 32% in 2020. The commercial sector’s share of total RCI emissions from direct fuel use and electricity use ranged from 19% in 1990 to 21% in 2020. The industrial sector’s share of total RCI emissions from direct fuel use and electricity use ranged from 50% in 1990 to 47% in 2020. Emissions associated with the generation of electricity to meet RCI demand accounts for about 62% of the emissions for the residential sector, 61% of the emissions for the commercial sector, and 58% of the emissions for the industrial sector, on average, over the 1990 to 2020 time period. From 1990 to 2020, natural gas consumption is the next highest source of emissions for the residential and commercial sectors, accounting, on average, for about 28% and 33% of total emissions, respectively. For the industrial sector, emissions associated with the combustion of petroleum, natural gas, and coal account for about 20%, 15%, and 6% respectively, on average, of total industrial emissions from 1990 to 2020.

Residential Sector

Figure B1 presents the emission inventory and reference case projections for the residential sector. Figure B1 was developed from the emissions data in Table B4a. Table B4b shows the relative contributions of emissions associated with each fuel type to total residential sector emissions.

For the residential sector, emissions from electricity and direct fossil fuel use in 1990 were about 19 MMtCO_{2e}, and are estimated to increase to about 33 MMtCO_{2e} by 2020. Emissions associated with the generation of electricity to meet residential energy consumption demand accounted for about 58% of total residential emissions in 1990, and are estimated to increase to 68% of total residential emissions by 2020. In 1990, natural gas consumption accounted for about 30% of total residential emissions, and is estimated to account for about 24% of total residential emissions by 2020. Residential-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 2.2 MMtCO_{2e} combined, and accounted for about 12% of total residential emissions. By 2020, emissions associated with the consumption of these three fuels are estimated to be about 2.6 MMtCO_{2e}, accounting for 8% of total residential sector emissions by that year.

Figure B1. Residential Sector GHG Emissions from Fuel Consumption



Source: CCS calculations based on approach described in text.

Note: Emissions associated with coal and wood combustion are too small to be seen on this graph.

For the 15-year period 2005 to 2020, residential-sector GHG emissions associated with the use of electricity and natural gas are projected to increase at average annual rates of about 2% and 0.8% respectively. Emissions associated with the use of wood, petroleum, and coal are projected to increase annually by about 0.8%, 0.4%, and 0.3%, respectively. Total GHG emissions for the residential sector are projected to increase by an average of about 1.6% annually over the 15-year period.

Table B4a. Residential Sector Emissions Inventory and Reference Case Projections (MMtCO₂e)

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	0.007	0.005	0.002	0.002	0.003	0.003	0.002
Petroleum	2.06	2.47	2.21	2.36	2.40	2.47	2.51
Natural Gas	5.66	6.87	6.94	7.15	7.63	7.91	8.09
Wood	0.16	0.12	0.11	0.11	0.11	0.12	0.12
Electricity Consumption	11.0	12.9	13.5	16.6	18.5	20.3	22.5
Total	18.9	22.3	22.8	26.3	28.7	30.8	33.2

Source: CCS calculations based on approach described in text.

Table B4b. Residential Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Petroleum	11	11	10	9	8	8	8
Natural Gas	30	31	30	27	27	26	24
Wood	0.8	0.5	0.5	0.4	0.4	0.4	0.4
Electricity Consumption	58	58	59	63	65	66	68

Source: CCS calculations based on approach described in text.

Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B4a.

Commercial Sector

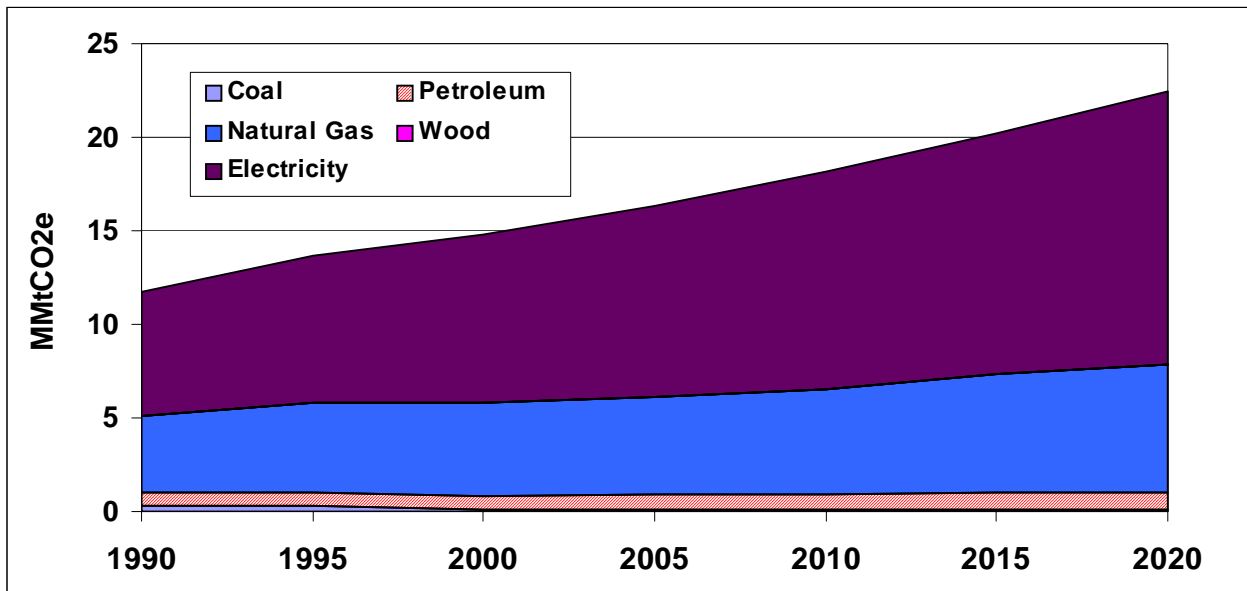
Figure B2 presents the emission inventory and reference case projections for the commercial sector. Figure B2 was developed from the emissions data in Table B5a. Table B5b shows the relative contributions of emissions associated with each fuel type to total commercial sector emissions.

For the commercial sector, emissions from electricity and direct fossil fuel use in 1990 were about 12 MMtCO₂e, and are estimated to increase to about 22 MMtCO₂e by 2020. Emissions associated with the generation of electricity to meet commercial energy consumption demand accounted for about 56% of total commercial emissions in 1990, and are estimated to increase to 65% of total commercial emissions by 2020. In 1990, natural gas consumption accounted for about 35% of total commercial emissions and is estimated to account for about 30% of total commercial emissions by 2020. Commercial-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 1.0 MMtCO₂e combined, and accounted for about 9% of total commercial emissions. By 2020, emissions associated with the consumption of these three fuels are estimated to be 1.1 MMtCO₂e and to account for about 5% of total commercial sector emissions.

For the 15-year period 2005 to 2020, commercial-sector GHG emissions associated with the use of electricity and natural gas are projected to increase at average annual rates of about 2.4% and 1.8% respectively. Emissions associated with the use of wood, petroleum, and coal are projected to increase annually by about 0.6%, 0.7%, and 0.6%, respectively. Total GHG emissions for the

commercial sector are projected to increase by an average of about 2.1% annually over the 15-year period.

Figure B2. Commercial Sector GHG Emissions from Fuel Consumption



Source: CCS calculations based on approach described in text.

Note: Emissions associated with coal combustion are too small to be seen on this graph.

Table B5a. Commercial Sector Emissions Inventory and Reference Case Projections (MMtCO₂e)

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	0.35	0.29	0.09	0.12	0.12	0.12	0.13
Petroleum	0.68	0.69	0.69	0.83	0.84	0.89	0.92
Natural Gas	4.11	4.80	5.08	5.19	5.60	6.28	6.83
Wood	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Electricity Consumption	6.54	7.88	8.94	10.2	11.5	12.9	14.5
Total	11.7	13.7	14.8	16.3	18.1	20.2	22.4

Source: CCS calculations based on approach described in text.

Table B5b. Commercial Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	3.0	2.1	0.6	0.7	0.7	0.6	0.6
Petroleum	5.8	5.0	4.6	5.1	4.6	4.4	4.1
Natural Gas	35	35	34	32	31	31	30
Wood	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Electricity Consumption	56	58	60	62	64	64	65

Source: CCS calculations based on approach described in text.

Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B5a.

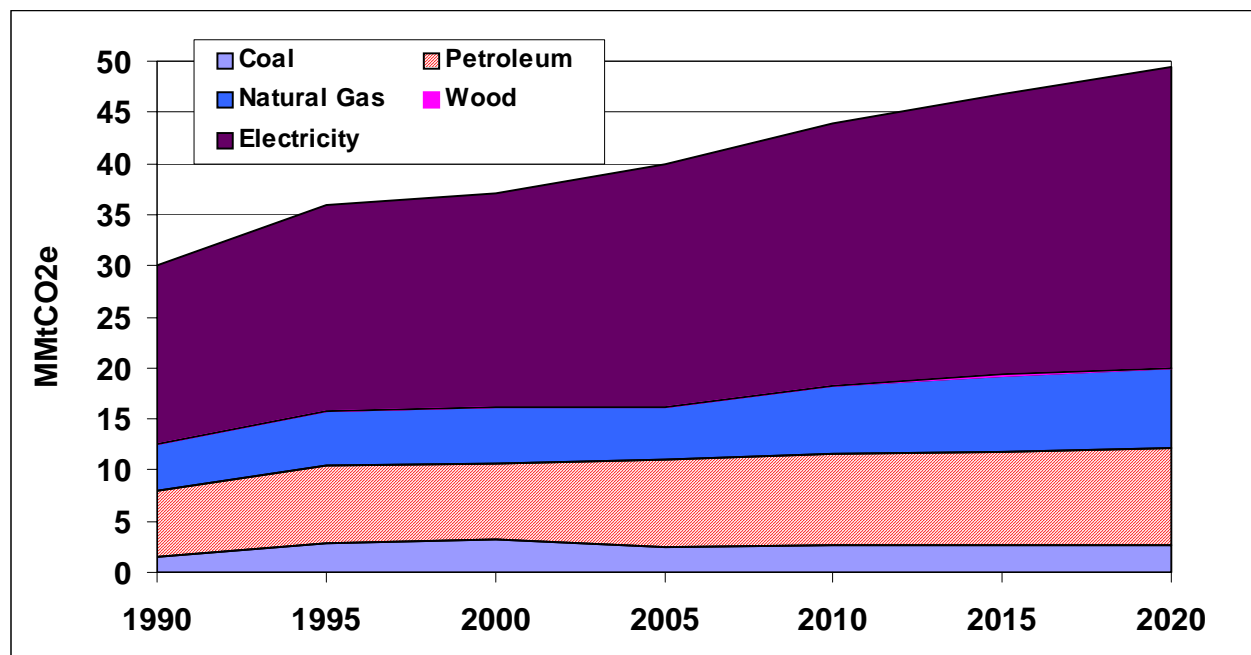
Industrial Sector

Figure B3 presents the emission inventory and reference case projections for the industrial sector. Figure B3 was developed from the emissions data in Table B6a. Table B6b shows the relative contributions of emissions associated with each fuel type to total industrial sector emissions.

For the industrial sector, emissions from electricity and direct fuel use in 1990 were about 30 MMtCO₂e and are estimated to increase to about 49 MMtCO₂e by 2020. Emissions associated with the generation of electricity to meet industrial energy consumption demand accounted for about 58% of total industrial emissions in 1990, and are estimated increase to about 59% of total industrial emissions by 2020. In 1990, petroleum consumption accounted for about 21% of total industrial emissions, and is estimated to account for about 19% of total industrial emissions by 2020. In 1990, natural gas consumption accounted for about 15% of total industrial emissions, and is estimated to account for about 16% of total industrial emissions by 2020. Industrial-sector emissions associated with the use of coal and wood in 1990 were about 1.6 MMtCO₂e combined, and accounted for about 6% of total industrial emissions. For 2020, emissions associated with the consumption of these two fuels are estimated to be 2.8 MMtCO₂e, and to continue to account for about 6% of total industrial sector emissions.

For the 15-year period 2005 to 2020, industrial-sector GHG emissions associated with the use of electricity, petroleum, and natural gas are projected to increase at average annual rates of about 1.4%, 0.6%, and 2.7% respectively. Emissions associated with the use of wood and coal are projected to increase annually by about 1.6% and 0.8%, respectively. Total GHG emissions for the industrial sector are projected to increase by an average of about 1.4% annually over the 15-year period.

Figure B3. Industrial Sector GHG Emissions from Fuel Consumption



Source: CCS calculations based on approach described in text.
 Note: Emissions associated with wood combustion are too small to be seen on this graph.

Table B6a. Industrial Sector Emissions Inventory and Reference Case Projections (MMtCO₂e)

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	1.61	2.80	3.25	2.42	2.59	2.67	2.74
Petroleum	6.43	7.60	7.33	8.56	8.92	9.12	9.42
Natural Gas	4.49	5.38	5.55	5.18	6.67	7.47	7.77
Wood	0.04	0.06	0.06	0.08	0.09	0.09	0.10
Electricity Consumption	17.4	20.1	20.9	23.7	25.7	27.3	29.4
Total	30.0	36.0	37.1	39.9	44.0	46.7	49.4

Source: CCS calculations based on approach described in text.

Table B6b. Industrial Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	5.4	7.8	8.8	6.1	5.9	5.7	5.5
Petroleum	21	21	20	21	20	20	19
Natural Gas	15	15	15	13	15	16	16
Wood	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Electricity Consumption	58	56	56	59	58	59	59

Source: CCS calculations based on approach described in text.
 Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B6a.

Key Uncertainties

Key sources of uncertainty underlying the estimates above are as follows:

- Population and economic growth are the principal drivers for electricity and fuel use. The reference case projections are based on regional fuel consumption projections for EIA’s West North Central modeling region, scaled for Minnesota population and employment growth projections. Consequently, there are significant uncertainties associated with the projections. Future work should attempt to base projections of GHG emissions on fuel consumption estimates specific to Minnesota, to the extent that such data become available.
- The AEO2006 projections assume no large long-term changes in relative fuel and electricity prices, relative to current price levels and to US DOE projections for fuel prices. Price changes would influence consumption levels and, to the extent that price trends for competing fuels differ, may encourage switching among fuels, thereby affecting emissions estimates.