Montana Greenhouse Gas Inventory and Reference Case Projections 1990-2020

Center for Climate Strategies
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Executive Summary

The Center for Climate Strategies (CCS) prepared this report under contract to the Montana Department of Environment Quality (MDEQ). The report contains an inventory and forecast of the state's greenhouse gas (GHG) emissions from 1990 to 2020.

Montana's anthropogenic GHG emissions and sinks (carbon storage) were estimated for the period from 1990 to 2020. Historical GHG emission estimates (1990 through 2005) were developed using a set of generally accepted principles and guidelines for state GHG emissions estimates (both historical and forecasted), with adjustments by CCS as needed to provide Montana-specific data and inputs as possible. The initial reference case projections (2006-2020) are based on a compilation of various existing projections of electricity generation, fuel use, and other GHG emitting activities, along with a set of transparent assumptions. A second projection case was also developed to explore the potential impact on GHG emissions of higher growth projections for fossil fuel production and consumption in the State. Although uncertainties exist for future growth in many activities, the High Fossil Fuel Production case focuses only on higher levels of electricity generation (mostly coal-based), coal bed methane and conventional natural gas production, oil refinery production and coal-to-liquids plants. These activities produce large amounts of GHG emissions and projections for future growth show wide variation.

Table ES-1 provides a summary of Montana historical (1990 and 2005) and reference case projection (2010 and 2020) GHG emissions. Activities in Montana accounted for approximately 37 million metric tons (MMt) of *gross consumption-based*[1] carbon dioxide equivalent (CO_2e) emissions in 2005, an amount equal to 0.6% of total U.S. gross GHG emissions. Montana's gross GHG emissions are rising at about the same rate as the nation as a whole. Montana's gross GHG emissions were up 14% from 1990 to 2005, while national emissions rose by 16% during this period.

Figure ES-1 illustrates the state's emissions per capita and per unit of economic output. On a per capita basis, Montanans emit about 40 metric tons (Mt) of CO_2e, which is about twice the national average of 25 $MtCO_2e$. The reasons for the higher per capita intensity in Montana are varied but include the State's strong fossil fuel production industry, large agricultural industry, large distances for transportation, and low population base. Like the nation as a whole, per capita emissions have remained fairly flat, while economic growth exceeded emissions growth throughout the 1990-2004 period. During the 1990s, emissions per unit of gross product dropped by 25% nationally, and by 18% in Montana.

The principal sources of Montana's GHG emissions are electricity use (excluding electricity exports) and agriculture, each accounting for about 27% of Montana's gross GHG emissions. The next largest contributor to emissions is the transportation sector.

[1] Excluding GHG emissions removed due to forestry and agricultural soils and excluding GHG emissions associated with exported electricity. Net emissions include the CO_2 sinks.

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projections, Montana's gross GHG emissions continue to grow, projected to climb to 42 $MMtCO_2e$ by 2020, 30% above 1990 levels. As shown in Figure ES-3, transportation is projected to be the largest contributor to future emissions growth, followed by emissions associated with fossil fuel production and electricity use in the State. Net GHG emissions, which included net sinks from forestry activities and agricultural soils, are estimated to increase from about 7 $MMtCO_2e$ in 1990 to 16 $MMtCO_2e$ in 2020.

Some data gaps exist in this analysis, particularly for the reference case projections. Key tasks include developing a better understanding of the electricity generation sources currently used to meet Montana loads (in collaboration with state utilities), and review and revision of key emissions drivers (such as electricity, fossil fuel production, and transportation fuel use growth rates) that will be major determinants of Montana's future GHG emissions.

Emissions of aerosols, particularly "black carbon" (BC) from fossil fuel combustion, could have significant climate impacts through their effects on radiative forcing. Estimates of these aerosol emissions on a CO_2e basis were developed for Montana based on 2002 data. The results were a total of 2.6 $MMtCO_2e$, which is the mid-point of a range of estimated emissions (1.7 – 3.5 $MMtCO_2e$). Estimates for 2018 indicate that BC emissions from important contributing sectors, onroad and nonroad diesel engines, are expected to decline due to new federal emissions standards for engines and fuels. Details of this analysis are presented in Appendix I to this report. These estimates are not incorporated into the totals shown in Table ES-1 below to reflect the additional uncertainty in these estimates (based on the lack of a global warming potential for BC assigned by the IPCC). By including black carbon emission estimates in the inventory, however, additional opportunities for reducing climate impacts can be identified.

Table ES-1. Montana Historical and Reference Case GHG Emissions, Consumption-based, by Sector

(Million Metric Tons CO_2e)	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Electric Sector	**8.9**	**9.5**	**10.0**	**10.0**	**11.0**	
Coal	15.8	16.2	18.5	20.2	22.5	See electric sector assumptions in appendix A
Natural Gas	0.0	0.0	0.0	0.4	0.4	
Petroleum Coke	0.0	0.8	0.8	0.8	0.8	
Net Exported Electricity	-7.0	-7.6	-9.4	-11.3	-12.8	
Res/Comm/Non-Fossil Ind (RCI)	**4.5**	**4.5**	**4.8**	**5.2**	**5.3**	
Coal	0.5	0.3	0.3	0.3	0.3	Based on USDOE regional projections from the *Annual Energy Outlook 2006.*
Natural Gas	2.1	3.1	2.9	3.2	3.3	
Oil	1.9	1.1	1.6	1.7	1.7	
Wood (CH_4 and N_2O)	0.0	0.0	0.0	0.0	0.0	Assumes no change after 2003
Transportation	**5.9**	**7.3**	**8.0**	**8.8**	**10.4**	
Motor Gasoline	3.8	4.4	4.4	4.8	5.7	Based on VMT growth provided by MDT and USDOE regional projections from the *Annual Energy Outlook 2006* for fuel efficiency changes.
Diesel[b]	1.7	2.5	3.1	3.4	3.9	
Natural Gas, LPG, other	0.1	0.1	0.1	0.1	0.1	
Jet Fuel, Aviation Gasoline	0.3	0.3	0.5	0.5	0.6	
Fossil Fuel Industry	**3.5**	**4.1**	**5.0**	**5.2**	**5.3**	
Natural Gas Industry	1.4	1.7	2.0	2.3	2.4	See Fossil Fuel Sector Appendix for Assumptions
Oil Industry	2.0	2.2	2.7	2.8	2.8	
Coal Mining (Methane)	0.2	0.2	0.2	0.2	0.2	Assumes no change after 2004
Coal to Liquids	n/a	n/a	n/a	n/a	n/a	Reference case assumes that no coal-to-liquids plants will be developed by 2020
Industrial Processes	**1.2**	**1.0**	**0.9**	**1.1**	**1.5**	
ODS Substitutes	0.0	0.2	0.4	0.5	0.9	Based on national projections (State Dept.)
SF_6 from Electric Utilities	0.1	0.1	0.0	0.0	0.0	Based on national projections (USEPA)
Cement & Other Industry	0.4	0.4	0.5	0.5	0.5	Increases with state population
Aluminum Industry	0.7	0.3	0.1	0.1	0.1	Projections constant at 2005 levels
Waste Management	**0.2**	**0.2**	**0.3**	**0.3**	**0.4**	
Solid Waste Management	0.1	0.2	0.2	0.2	0.2	Projections based on population.
Wastewater Management	0.1	0.1	0.1	0.1	0.1	Projections based on population.
Agriculture	**7.9**	**9.5**	**7.9**	**7.9**	**7.9**	
Livestock Management	3.2	3.7	3.6	3.6	3.6	Projections constant at 2005 levels
Ag. Soils and Residue Burning	4.7	5.8	4.2	4.2	4.2	Projections constant at 2005 levels
Total Gross Emissions	**32.2**	**36.1**	**36.8**	**38.5**	**41.7**	
Increase relative to 1990		*12%*	*14%*	*19%*	*30%*	
Forestry and Land Use	**-23.1**	**-23.1**	**-23.1**	**-23.1**	**-23.1**	Historical and projected emissions held at 2004 levels.
Agricultural Soils Sink	**-2.3**	**-2.3**	**-2.3**	**-2.3**	**-2.3**	Historical and projected emissions held at 1997 levels.
Net Emissions (including sinks)	**6.8**	**10.7**	**11.4**	**13.1**	**16.3**	

[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding; n/a = not applicable.
[b] Diesel fuel consumption in transportation includes locomotives.

Figure ES-1. Historical Montana and U.S. GHG emissions, per capita and per unit gross product

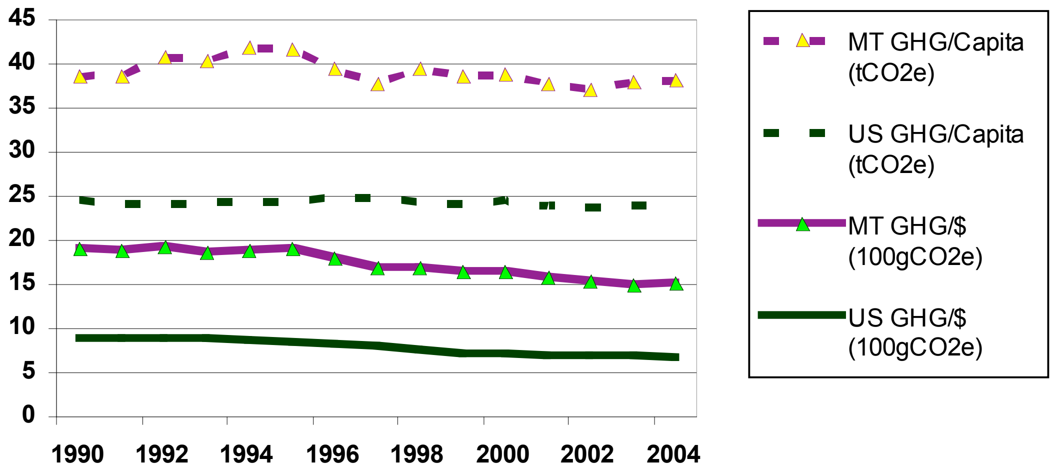


Figure ES-2. Montana gross GHG emissions by sector, 1990-2020: historical and reference case projection

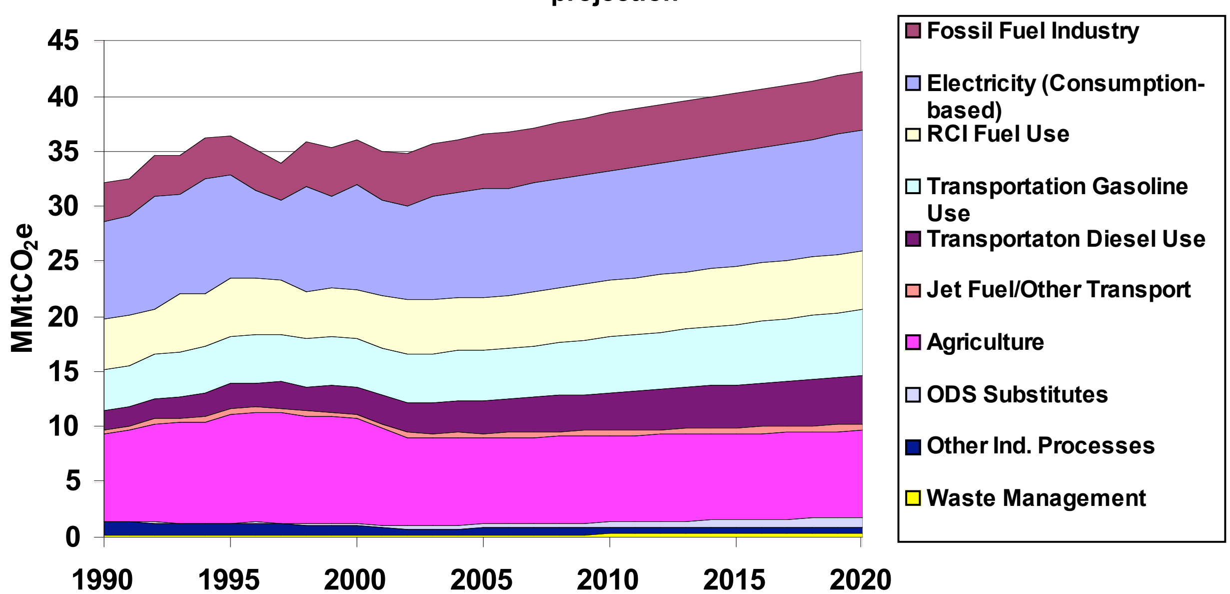


Figure ES-3. Sector contributions to emissions growth in Montana, 1990-2020: reference case projections

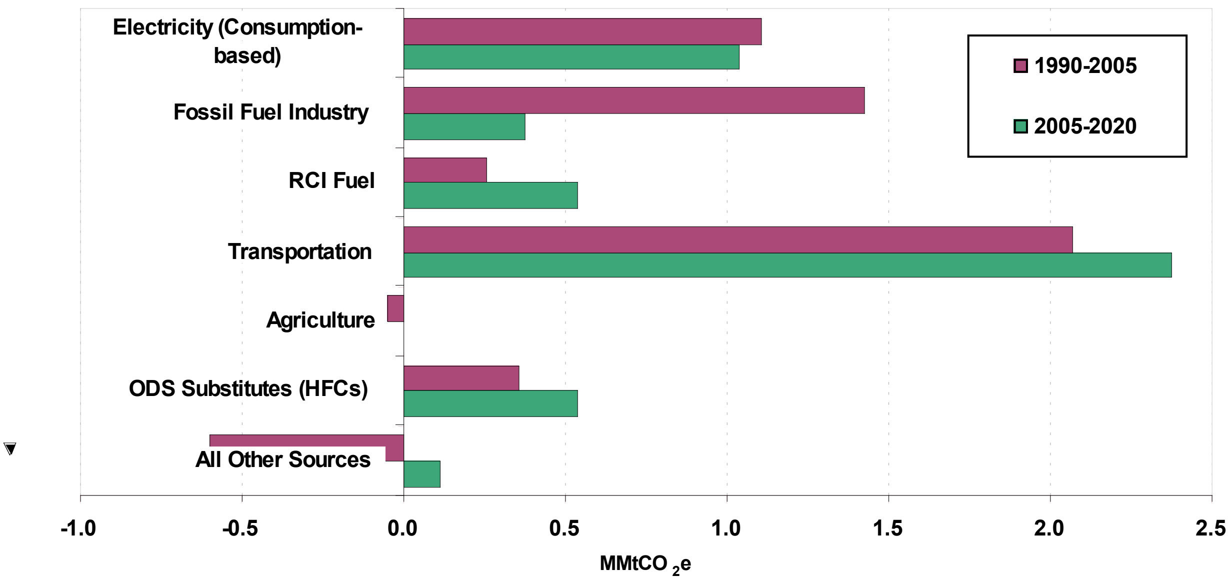
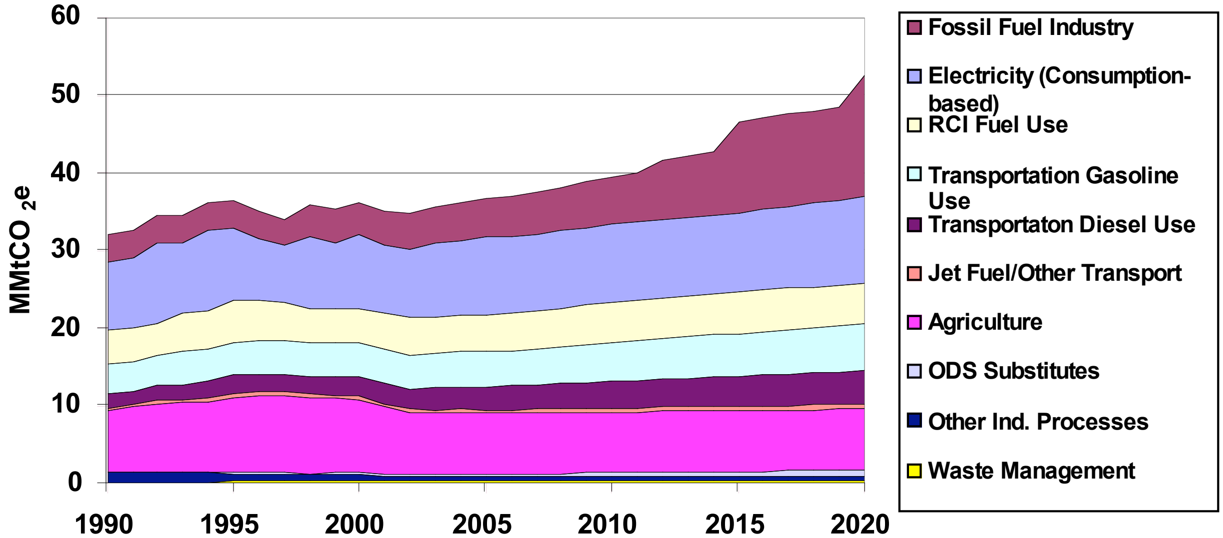


Figure ES-4 illustrates the growth in Montana's gross GHG emissions, under the alternative set of growth projections. Using the projection assumptions for the High Fossil Fuel case, Montana gross GHG emissions are estimated to grow to 52 $MMtCO_2e$ in 2020 (compared with 42 MMtCO2e in the Reference Case in 2020). Of the 10 $MMtCO_2e$ increase, 7 $MMtCO_2e$ is due to Coal-to-Liquids (CTL) plant development (the Reference Case assumes that no CTL development occurs before 2020, while the High Fossil Fuel Case assumes 2 plants are developed). The remaining 3 $MMtCO_2e$ difference in GHG emissions between the cases is due to higher assumed growth in oil refinery output and natural gas production (including coal bed methane). The High Fossil Fuel case also assumes that additional electricity transmission lines are developed between Montana and southern United States and, subsequently new coal-based power plants are built in Montana. These assumptions account for an additional 10 $MMtCO_2e$ in 2020, but since these are production-based emissions, rather than consumption-based emissions, the difference is not included in the summary tables.

Figure ES-4. Montana gross GHG emissions by sector, 1990-2020: historical and high fossil fuel case projection



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Acronyms and Key Terms

AEO2006 – EIA's Annual Energy Outlook 2006

BOC – Bureau of Census

CAIT – Climate Analysis Indicators Tool

CCAC – Climate Change Advisory Committee

CCS – Center for Climate Strategies

CFCs – Chlorofluorocarbons

CH_4 – Methane*

CO_2 – Carbon Dioxide*

CO_2e – Carbon Dioxide equivalent*

EIA – U.S. DOE Energy Information Administration

EIIP – Emissions Inventory Improvement Project (US EPA)

GHG – Greenhouse Gases*

GSP – Gross State Product

GWh – Gigawatt-hours

GWP - Global Warming Potential*

HFCs – Hydrofluorocarbons*

HPMS – Highway Performance Monitoring System

IPCC – Intergovernmental Panel on Climate Change*

IPPs – Independent Power Producers

LFGTE – landfill gas collection system and landfill-gas-to-energy

LMOP – Landfill Methane Outreach Program

LNG – Liquefied natural gas

LPG – Liquefied petroleum gas

Mt - Metric ton (equivalent to 1.102 short tons)

MMt – Million Metric tons

MTBE – Methyl Tertiary Butyl Ether

MDEQ – Montana Department of Environment Quality

N_2O – Nitrous Oxide*

NASS – National Agricultural Statistics Service

ODS – Ozone-Depleting Substances

OPS – United States Office of Pipeline Safety

PFCs – Perfluorocarbons*

RCI – Residential, Commercial, and Industrial

SED – State Energy Data

SF_6 – Sulfur Hexafluoride*

SGIT – State Greenhouse Gas Inventory Tool

Sinks – Removals of carbon from the atmosphere, with the carbon stored in forests, soils, landfills, wood structures, or other biomass-related products.

TWh – terawatt-hours

U.S. EPA – United States Environmental Protection Agency

U.S. DOE – United States Department of Energy

USFS – United States Forest Service

VMT – Vehicle-miles traveled

* - See Appendix J for more information.

Acknowledgements

We appreciate all of the time and assistance provided by numerous contacts throughout Montana, as well as in neighboring states, and at federal agencies. Thanks go to in particular the many staff at several Montana state agencies for their inputs, and in particular to Richard Opper, Jim Boyer, Lisa Peterson, Jeff Blend, Lou Moore, and Cyra Cain of the Montana Department of Environment Quality who provided key guidance for this analytical effort.

Summary of Preliminary Findings

Introduction

The Center for Climate Strategies prepared this report under contract to the Montana Department of Environmental Quality. This report presents initial estimates of base year and projected Montana anthropogenic greenhouse gas (GHG) emissions and sinks for the period from 1990 to 2020. These estimates are intended to assist the state, the Climate Change Advisory Committee (CCAC), the Scientific Advisory Panel, and technical work groups (TWGs) with an initial, comprehensive understanding of current and possible future GHG emissions for Montana, and, thereby, to inform the upcoming analysis and design of GHG mitigation strategies.

Historical GHG emissions estimates (1990 through 2005)[2] were developed using a set of generally accepted principles and guidelines for state GHG emissions inventories, as described in the *Approach* section, relying to the extent possible on Montana-specific data and inputs. The initial reference case projections (2006-2020) are based on a compilation of various existing projections of electricity generation, fuel use, and other GHG-emitting activities, along with a set of simple, transparent assumptions described in the appendices of this report. These estimates should be viewed as preliminary input to the CCAC process and are subject to revisions as better data are identified.

This report covers the six types of gases included in the U.S. Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates the relative contribution of each gas to global average radiative forcing on a Global Warming Potential- (GWP-) weighted basis. The final appendix to this report provides a more complete discussion of GHGs and GWPs. As stated in the Executive Summary, CCS also added current emission estimates for black carbon (BC) based on 2002 data from the Western Region Air Partnership (WRAP). Future year (2018) estimates for important contributing sectors were also incorporated (see Appendix I). Black carbon is an aerosol species with a positive climate forcing potential (that is, the potential to warm the atmosphere, as GHGs do).

It is important to note that the preliminary emissions estimates reflect the *GHG emissions associated with the electricity sources used to meet Montana's demands,* corresponding to a consumption-based approach to emissions accounting (see Approach Section below). Another way to look at electricity emissions is to consider the *GHG emissions produced by electricity generation facilities in the State.* For many years, Montana power plants have tended to produce considerably more electricity than is consumed in the State – emissions associated with exported electricity are excluded from the consumption-based emissions. This report covers both methods of accounting for emissions, but for consistency, all total results are reported as *consumption-based.*

[2] The last year of available historical data varies by sector; ranging from 2000 to 2005.

Montana Greenhouse Gas Emissions: Sources and Trends

Table 1 provides a summary of GHG emissions estimated for Montana by sector for the years 1990, 2000, 2005, 2010, and 2020. A key conclusion from the values reported in Table 1 is that Montana's historic net GHG emissions were negative (see 1990) – in other words, the GHG emissions removed from the atmosphere due to forestry (increases in forest biomass stocks) and other land uses were greater than the GHG emissions generated in the state from fossil fuel combustion and other activities. However, due to the growth in GHG emissions since 1990, the state's net emissions have turned positive and Montana is now estimated to be a net source of GHG emissions. We note that there are significant uncertainties associated with estimating forest carbon sink estimates. Details on the methods and data sources used to construct the forestry estimates are provided in Appendix H**.** In the sections below, we discuss GHG emission sources (positive, or *gross*, emissions) and sinks (negative emissions) separately in order to identify trends, projections and uncertainties clearly.

This next section of the report provides a summary of the historical emissions (1990 through 2005) followed by a summary of the forecasted reference case projection year emissions (2006 through 2020), and key uncertainties and next steps. We also provide an overview of the general methodology, principals, and guidelines followed for preparing the inventories. Appendices A through H provide the detailed methods, data sources, and assumptions for each GHG sector.

Appendix I provides information on 2002 BC estimates for Montana. CCS estimated that BC emissions ranged from 1.7 – 3.5 $MMtCO_2e$ with a mid-point of 2.6 $MMtCO_2e$. A range is estimated based on the uncertainty in the global modeling analyses that serve as the basis for converting BC mass emissions into their carbon dioxide equivalents (see Appendix I for more details). Since the IPCC has not yet assigned a global warming potential for BC, CCS has excluded these estimates from the GHG summary shown in Table 1 below. Future year estimates (based on 2018 data from the WRAP) for important contributing sectors (onroad and nonroad engines) were also assessed. These assessments indicate that the contributions from onroad and nonroad engines are expected to decline by 2020 due to new national standards for engines and fuels.

Table 1. Montana historical and reference case GHG emissions, consumption-based by sector[a]

(Million Metric Tons CO_2e)	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Electric Sector	**8.9**	**9.5**	**10.0**	**10.0**	**11.0**	
Coal	15.8	16.2	18.5	20.2	22.5	See electric sector assumptions in appendix A
Natural Gas	0.0	0.0	0.0	0.4	0.4	
Oil	0.0	0.8	0.8	0.8	0.8	
Net Exported Electricity	-7.0	-7.6	-9.4	-11.3	-12.6	
Res/Comm/Non-Fossil Ind (RCI)	**4.5**	**4.5**	**4.8**	**5.2**	**5.3**	
Coal	0.5	0.3	0.3	0.3	0.3	Based on USDOE regional projections from the *Annual Energy Outlook 2006.*
Natural Gas	2.1	3.1	2.9	3.2	3.3	
Oil	1.9	1.1	1.6	1.7	1.7	
Wood (CH_4 and N_2O)	0.0	0.0	0.0	0.0	0.0	Assumes no change after 2003
Transportation	**5.9**	**7.3**	**8.0**	**8.8**	**10.4**	
Motor Gasoline	3.8	4.4	4.4	5.2	5.7	Based on VMT growth provided by MDT and USDOE regional projections from the *Annual Energy Outlook 2006* for fuel efficiency changes.
Diesel[b]	1.7	2.5	3.1	3.4	3.9	
Natural Gas, LPG, other	0.1	0.1	0.1	0.1	0.1	
Jet Fuel, Aviation Gasoline	0.3	0.3	0.5	0.5	0.6	
Fossil Fuel Industry	**3.5**	**4.1**	**5.0**	**5.2**	**5.3**	
Natural Gas Industry	1.4	1.7	2.0	2.3	2.4	See Fossil Fuel Sector Appendix for Assumptions
Oil Industry	2.0	2.2	2.7	2.8	2.8	
Coal Mining (Methane)	0.2	0.2	0.2	0.2	0.2	Assumes no change after 2004
Coal to Liquids	n/a	n/a	n/a	n/a	n/a	Reference case assumes that no coal-to-liquids plants will be developed by 2020
Industrial Processes	**1.2**	**1.0**	**0.9**	**1.1**	**1.5**	
ODS Substitutes	0.0	0.2	0.4	0.5	0.9	Based on national projections (State Dept.)
SF_6 from Electric Utilities	0.1	0.1	0.0	0.0	0.0	Based on national projections (USEPA)
Cement & Other Industry	0.4	0.4	0.5	0.5	0.5	Increases with state population
Aluminum Industry	0.7	0.3	0.1	0.1	0.1	Projections constant at 2005 levels
Waste Management	**0.2**	**0.2**	**0.3**	**0.3**	**0.4**	
Solid Waste Management	0.1	0.2	0.2	0.2	0.2	Projections based on population.
Wastewater Management	0.1	0.1	0.1	0.1	0.1	Projections based on population.
Agriculture	**7.9**	**9.5**	**7.9**	**7.9**	**7.9**	
Livestock Management	3.2	3.7	3.6	3.6	3.6	Projections constant at 2005 levels
Ag. Soils and Residue Burning	4.7	5.8	4.2	4.2	4.2	Projections constant at 2005 levels
Total Gross Emissions	**32.2**	**36.1**	**36.8**	**38.5**	**41.7**	
Increase relative to 1990		*12%*	*14%*	*19%*	*30%*	
Forestry and Land Use	**-23.1**	**-23.1**	**-23.1**	**-23.1**	**-23.1**	Historical and projected emissions held at 2004 levels.
Agricultural Soils Sink	**-2.3**	**-2.3**	**-2.3**	**-2.3**	**-2.3**	Historical and projected emissions held at 1997 levels.
Net Emissions (including sinks)	**6.8**	**10.7**	**11.4**	**13.1**	**16.3**	

[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding. n/a = not applicable.
[b] Diesel fuel consumption in transportation includes locomotives, see appendix C for more information.

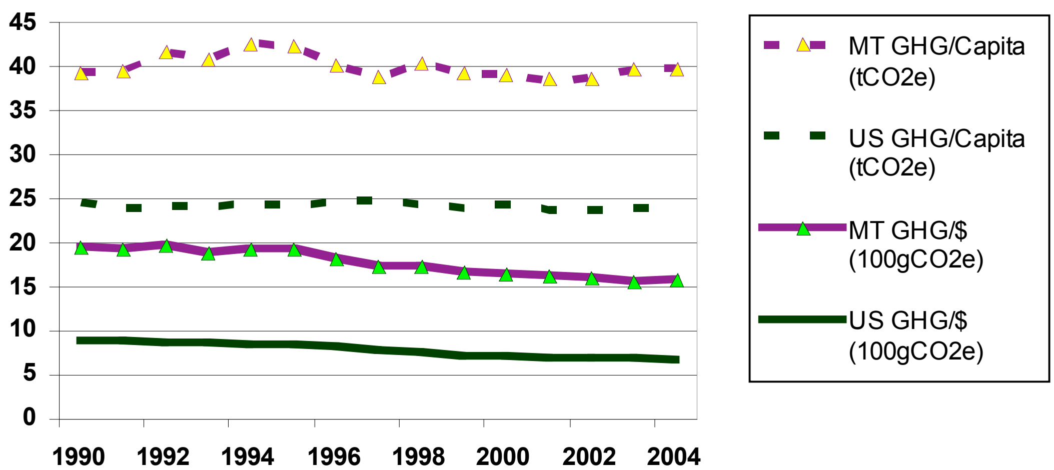
Historical Emissions

Overview

Preliminary analyses suggest that in 2005, activities in Montana accounted for approximately 37 million metric tons (MMt) of carbon dioxide equivalent (CO_2e) emissions, an amount equal to 0.6% of total U.S. GHG emissions.[3] Montana's *gross* GHG emissions are rising at about the same rate as the nation as a whole.[4] Montana's gross GHG emissions were up 14% from 1990 to 2005, while national emissions rose by 16% during this period.

Although Montana's GHG emissions are low on an absolute scale compared to the total national output, on a per capita basis, Montanans emit about 40 metric tons (Mt) of CO_2e, much higher than the national average of 25 $MtCO_2e$. Figure 1 illustrates the state's emissions per capita and per unit of economic output. The reasons for the higher per capita intensity in Montana are varied but include the State's strong fossil fuel production industry, large agricultural industry, large distances for transportation, and low population base. Figure 1 also shows that like the nation as a whole, per capita emissions have remained fairly flat, while economic growth exceeded emissions growth throughout the 1990-2004 period. From 1990 to 2004, emissions per unit of gross product dropped by 25% nationally, and by 18% in Montana.

Figure 1. Montana and US gross GHG emissions, per capita and per unit gross product

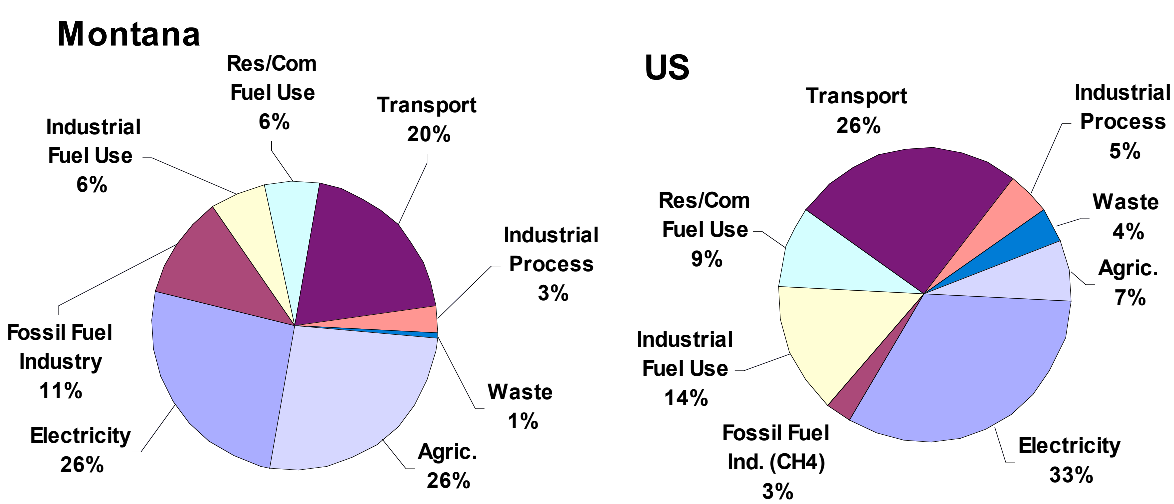


[3] United States emissions estimates are drawn from US EPA 2006. *Inventory of US Greenhouse gas Emissions and Sinks:1990-2004*.

[4] *Gross* emissions estimates only include those sources with positive emissions. Carbon sequestration in soils and vegetation is included in *net* emissions estimates. All emissions reported in this section for Montana reflect consumption-based accounting (excluding emissions from electricity exports). On a national basis, little difference exists between *production-based* and *consumption-based* accounting for GHG emissions because net electricity imports are less than 1% of national electricity generation.

Electricity use, transportation and agriculture are the State's principal GHG emissions sources. Together, the combustion of fossil fuels for electricity generation used in-state and in the transportation sector account for about 46% of Montana's *gross* GHG emissions, as shown in Figure 2. The relative contribution of agricultural emissions (methane and N_2O emissions from manure management, fertilizer use, and livestock) is much higher in Montana (26%) than in the nation as a whole (7%) This is a result of more agricultural activity per capita in Montana compared to the US. The remaining use of fossil fuels – natural gas, oil products, and coal -- in the residential, commercial, and industrial (RCI) sectors and the emissions from fossil fuel production constitute another 23% of state emissions.

Figure 2. Gross GHG emissions by sector, 2000, Montana and U.S.



Note: Totals might not add up to 100% due to independent rounding.

Industrial process emissions comprise almost 3% of state GHG emissions in 2000, but these emissions are rising rapidly due to the increasing use of HFC as substitutes for ozone-depleting chlorofluorocarbons.[5] Other industrial process emissions result from CO_2 released during aluminum and cement production, soda ash, limestone, and dolomite use. Landfills and wastewater management facilities produce CH_4 and N_2O emissions accounting for the remaining 1% of the state's emissions in 2000.

Forestry activities in Montana are estimated to be net sinks for GHG emissions (-23.1 $MMtCO_2$; see Appendix H). Also, agricultural soils are estimated to sequester an additional -2.3 $MMtCO_2$ (see Appendix F). For the 1990 to 2005 historic emission estimates, the annual forest carbon fluxes of forestlands were assumed to be at the same levels as those calculated for 2004. Montana's total net GHG emissions in 1990 are estimated at 7 $MMtCO_2e$/yr, increasing to 11 $MMtCO_2e$/yr in 2005.

[5] Chlorofluorocarbons (CFCs) are also potent GHGs; however they are not included in GHG estimates because of concerns related to implementation of the Montreal Protocol. See final Appendix (Appendix J).

A Closer Look at the Three Major Sources: Electricity, Agriculture and Transportation

As shown in Figure 2, the electric, agriculture and transportation sectors are the largest contributors to Montana's gross consumption-based emissions. These sectors accounted for 26%, 26% and 20%, respectively, of total GHG emissions in 2000.

It is important to note that the electricity emissions estimates reflect the *GHG emissions associated with the electricity sources used to meet Montana demands,* corresponding to a consumption-based approach to emissions accounting (see Section 2). Another way to look at electricity emissions is to consider the *GHG emissions produced by electricity generation facilities in the state.* For many years, Montana power plants have produced almost twice the electricity that is consumed in the state – in the year 2000, for example, Montana exported 41% of the electricity produced in the state. As a result, in 2000, emissions associated with electricity consumption (9.5 $MMtCO_2e$) were much lower than those associated with electricity production (17.1 $MMtCO_2e$).[6]

While we estimate both the emissions from electricity production and consumption, unless otherwise indicated, tables, figures, and totals in this report reflect electricity consumption emissions. The consumption-based approach can better reflect the emissions (and emissions reductions) associated with activities occurring in the state, particularly with respect to electricity use (and efficiency improvements), and is particularly useful for policy-making. Under this approach, emissions associated with electricity exported to other states would need to be covered in those states' accounts in order to avoid double counting or exclusions. (Indeed, Arizona, California, Oregon, New Mexico, and Washington are currently considering such an approach.)

Emissions from agricultural sources, CH_4 and N_2O emissions from enteric fermentation, manure management, agricultural soils and crop residue burning, ranged from about 8 to 10 $MMtCO_2e$ during the period 1990 to 2005. Total GHG emissions increased from 8 $MMTCO_2e$ in 1990 to a high of 10 $MMTCO_2e$ in 1996 before dropping back to 8 $MMTCO_2e$ in 2002 and remaining at this level. Except for emissions from agricultural soils, emissions in each subsector were fairly static. For agricultural soils, emissions grew through the mid-1990's, but then have begun to fall since the late 1990's. Emissions from agricultural soils are N_2O emissions from the use of synthetic fertilizers, crop residue, nitrogen fixing crops, and manure application. Manure application is the largest contributor to the emissions from agricultural soils.

Like electricity emissions, GHG emissions from transportation fuel use have risen steadily since 1990 at an average rate of slightly over 2% annually. In 2005, gasoline-powered vehicles accounted for about 54% of transportation GHG emissions. Diesel consumption accounted for another 39%; air travel for roughly 6%, and the remainder of transportation emissions came from natural gas and liquefied petroleum gas (LPG) vehicles and lubricants (See appendix C for details on these calculations). As the result of Montana's population and economic expansion

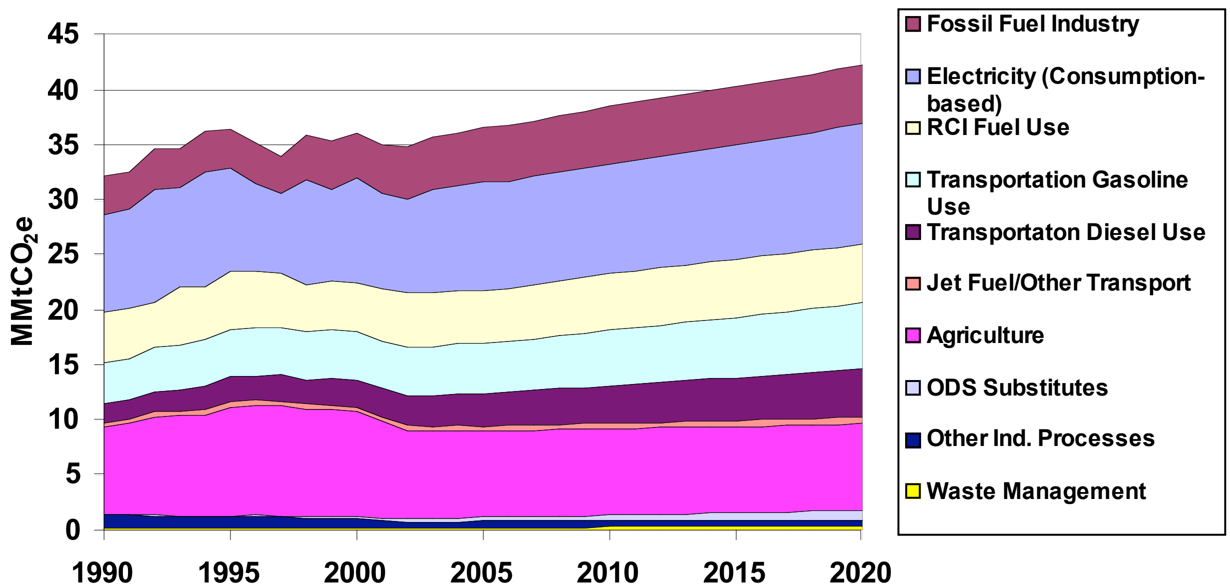
[6] Estimating the emissions associated with electricity use requires an understanding of the electricity sources (both in-state and out-of-state) used by utilities to meet consumer demand. The current estimate reflects some very simple assumptions described in Appendix A.

and an increase in miles traveled during the 1990s through 2005, gasoline use has grown at rate of 0.9% annually. Meanwhile, diesel use has risen 4% annually, suggesting an even more rapid growth in rail and truck freight movement within the State.

Reference Case Projections

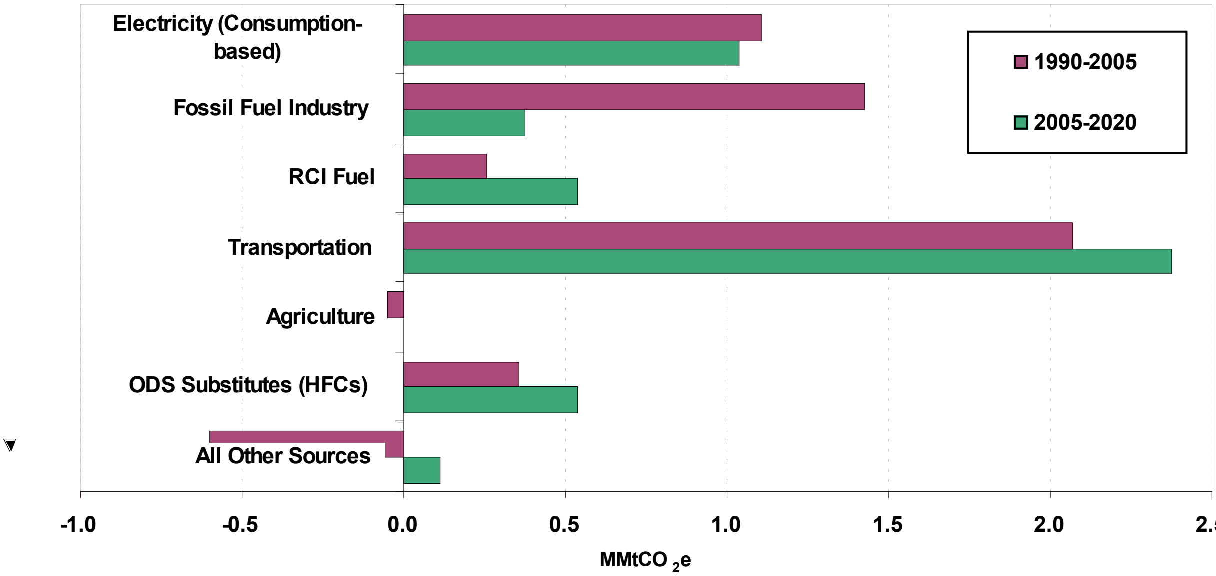
Relying on a variety of sources for projections of electricity and fuel use, as noted below and in the appendices, we developed a simple reference case projection of GHG emissions through 2020. As illustrated in Figure 3 and shown numerically in Table 1, under the reference case projections, Montana gross GHG emissions continue to grow steadily, climbing to 42 $MMtCO_2e$ by 2020, 30% above 1990 levels. Transportation is projected to be the largest contributor to future emission growth, followed by the electric sector, as shown in Figure 4. Other major sources of emissions growth include the fossil fuel industry, and fuel use in buildings and non-fossil fuel industry (RCI). The decrease in GHG emissions from *All Other Sources* in Figure 4 is driven by the drop in aluminum production from 1990 to 2005.

Figure 3. Montana gross GHG emissions by sector, 1990-2020: historical and projected under reference case assumptions



*RCI – direct fuel use in residential, commercial and industrial sectors (excluding the fossil fuel production industry) ODS Substitutes – Ozone Depleting Substances Substitutes. Other Ind. Processes includes process-related GHG emissions from aluminum production, soda ash, cement, limestone and dolomite use.

Figure 4. Sector contributions to emissions growth in Montana, 1990-2020: historic and reference case projections



*RCI – direct fuel use in residential, commercial and industrial sectors (excluding the fossil fuel production industry)
ODS Substitutes – Ozone Depleting Substances Substitutes, HFC - Hydrofluorocarbons.

High Fossil Fuel Production Scenario

Given the many factors impacting energy production-related emissions and a diversity of assumptions by stakeholders within the energy sector, developing a "reference case" projection for the most likely development of Montana's electricity and fossil fuel production sectors is particularly challenging. The principal uncertainty of interest is on the high side, given the many plans and initiatives to increase coal utilization locally and nationally. As a result, we explore an alternative scenario of future energy supply development – the high fossil fuel production scenario. The high fossil fuel scenario assumes:

- Additional new transmission lines will be built to export power from Montana. The total additional transmission lines in this case would have a capacity of 2,500 additional MW over the reference case addition of 500 MW, or 3,000 total additional MW capacity, relative to current levels. The new power plants built in Montana to use the capacity of the additional transmission lines are assumed to be a mix of 67% fluidized bed coal and 33% wind.
- Total natural gas production triples between 2005 and 2010, and increases an additional 74% above 2010 levels by 2020. Much of this increase is driven by increased coal bed methane development. To support this production, the scenario assumes two new natural gas transmission lines cross the State.
- Montana refining capacity increases, both through expansion of existing refineries and the addition of a new refinery, for refining of Athabasca crude from Alberta's oil sands.
- Two commercial coal-to-liquids plants are assumed to begin operation in Montana and coal mining increases modestly to support these plants.

The above assumptions reflect the high end of estimates for future fossil fuel development, under favorable conditions.

Table 4 presents a summary of GHG emissions from the electric sector in Montana on a production basis for both the reference case and the high fossil fuel scenario and on a consumption basis, which has the same estimated emissions for each case. Though the GHG emissions are significantly different from each other, each set of estimates is valid depending on circumstances. The difference between the emissions in the reference case and the high fossil fuel scenario estimates reflect the uncertainty in future energy development in Montana. From 2005 to 2020, using production-based accounting, GHG emissions from Montana's electric sector grow by 4.5 MMtCO2e in the reference case and 14.9 MMtCO2e in the high fossil fuel scenario. The consumption-based emissions represent a focus on the emissions associated with electricity consumption in Montana – this focus is important when evaluating the effects of actions directed at in-state electricity conservation. See Appendix A for more details on these GHG emission estimates.

Table 4. Summary GHG emissions for Montana electric sector

(Million Metric Tons CO2e)	1990	2000	2005	2010	2020
Production-based					
Reference case	**15.8**	**17.1**	**19.3**	**21.5**	**23.8**
High Fossil Fuel Scenario	**15.8**	**17.1**	**19.3**	**21.5**	**34.2**
Consumption-based	**8.9**	**9.5**	**10.0**	**10.0**	**11.0**

Note: Consumption-based emissions are the same for both the reference case and the high fossil fuel scenario because electricity consumption in Montana is the same for both cases.

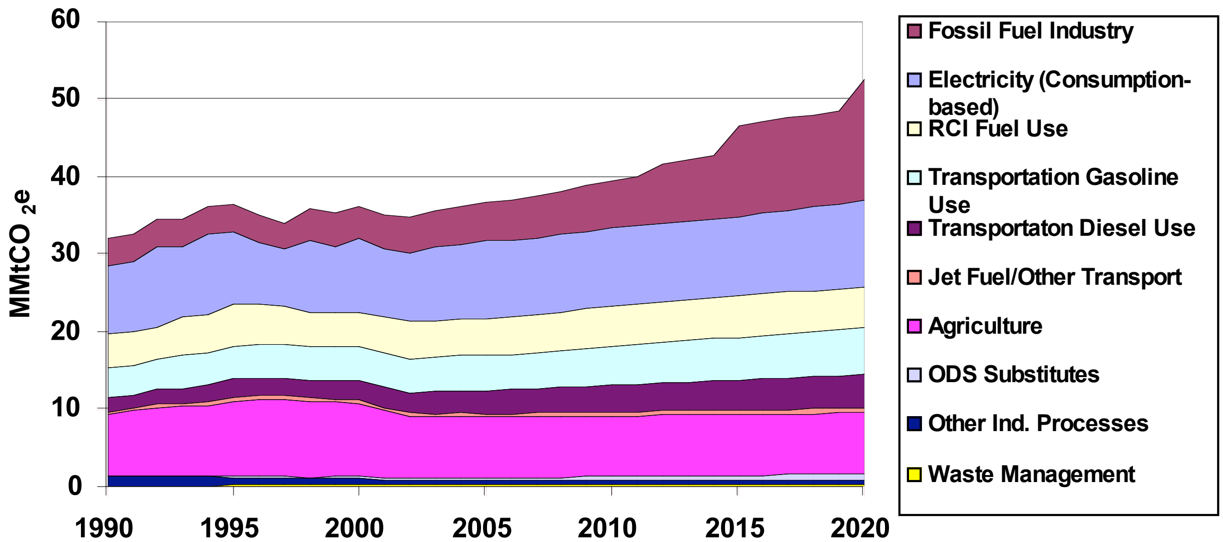
Table 5 presents a summary of GHG emissions from the Montana fossil fuel sector for both the reference case and the high fossil fuel scenario. The projected growth between 2005 and 2020 is only 7% in the reference case and 216% in the high fossil fuel case, in which a number of unconventional technologies reach commercial scale production.

Table 5. Comparison of total fossil fuel industry GHG emission for reference and high fossil fuel scenario

(Million Metric Tons CO2e)	1990	2000	2005	2010	2015	2020
Reference Case	**3.5**	**4.1**	**5.0**	**5.2**	**5.3**	**5.3**
Natural Gas Industry	1.4	1.7	2.0	2.3	2.3	2.4
Oil Industry	2.0	2.2	2.7	2.8	2.8	2.8
Coal-to-Liquids	n/a	n/a	n/a	n/a	n/a	n/a
Coal Mining	0.2	0.2	0.2	0.2	0.2	0.2
High Fossil Fuel Scenario	**3.5**	**4.1**	**5.0**	**6.2**	**11.7**	**15.7**
Natural Gas Industry	1.4	1.7	2.0	2.9	3.4	3.6
Oil Industry	2.0	2.2	2.7	3.1	4.4	4.4
Coal-to-Liquids	0.0	0.0	0.0	0.0	3.7	7.3
Coal Mining	0.2	0.2	0.2	0.2	0.2	0.3

Figure 5 illustrates the Montana gross GHG emissions under the high fossil fuel scenario assumptions. In this case, gross GHG emissions are projected to grow to 52 $MMtCO_2e$ by 2020, 61% above 1990 levels.

Figure 5. Montana gross GHG emissions by sector, 1990-2020: historical and projected under high fossil fuel scenario assumptions



Key Uncertainties

Some data uncertainties exist in this inventory, and particularly in the reference case projections. Potential improvements to this work include developing a better understanding of the electricity generation sources currently used to meet Montana loads (in collaboration with state utilities), and review and revision of key drivers such as the electricity and transportation fuel use growth rates that will be major determinants of Montana's future GHG emissions (See Table 6). These growth rates are driven by uncertain economic, demographic, and land use trends (including growth patterns and transportation system impacts), all of which could be refined further.

Perhaps the variable with the most important implications for GHG emissions is the type and number of power plants built in Montana between now and 2020. The assumptions on VMT and air travel growth also have large impacts on the GHG emission growth in the state. Finally uncertainty remains on estimates for historic GHG sinks from forestry and agriculture, and projections for these emissions will greatly impact the net GHG emissions attributed to Montana.

Table 6. Key annual growth rates for Montana, historical and projected

	1990-2005	2005-2020	Sources
Population	1.0%	0.6%	U.S. Bureau of Census
Employment			Montana Department of Labor website, based on analysis by the U.S. Bureau of labor and Statistics
Goods	2.5%	0.9%	
Services	2.3%	1.7%	
Electricity Sales	0.0%	1.6%	EIA data for 1990-2004 (0% growth is mix of increased residential and commercial electricity sales countered by large decrease in industrial sales), projections based on plans from Montana utilities (all sectors projected to have increased sales)
Vehicle Miles Traveled	1.7%	1.9%	Federal Highway Administration, Highway Statistic; projections from Montana Department of Transportation

* Population and employment projections for Montana were used together with US DOE's Annual Energy Outlook 2006 projections of changes in fuel use on a per capita and per employee, as relevant for each sector. For instance, growth in Montana's residential natural gas use is calculated as the Montana population growth times the change in per capita natural gas use for the Mountain region. Montana population growth is also used as the driver of growth in cement production, soda ash consumption, dolomite and limestone use.

Emissions of aerosols, particularly black carbon from fossil fuel combustion, could have significant impacts in terms of radiative forcing (i.e., climate impacts). Methodologies for conversion of black carbon mass estimates and projections to their global warming potential on a CO_2e basis involve significant uncertainty at present, but CCS has developed and used a recommended approach for estimating black carbon emissions based on methods used in other States. The current (2002) estimate is 2.6 $MMtCO_2e$/yr. Future year emissions for important sectors (onroad and nonroad diesel engines) are expected to decline due to new federal engine and fuel standards. As the scientific knowledge of the climate forcing effects of aerosols advances, the estimates presented here could be refined.

Approach

The principal goal of the inventories and reference case projections is to provide the state, CCAC, and TWGs with a general understanding of Montana's historical, current, and projected (expected) GHG emissions. The following explains the general methodology and the general principals and guidelines followed during development of these GHG inventories for Montana.

General Methodology

We prepared this analysis in close consultation with Montana agencies, in particular, the MDEQ staff. The overall goal of this effort is to provide simple and straightforward estimates, with an emphasis on robustness, consistency and transparency. As a result, we rely on reference forecasts from best available state and regional sources where possible. Where this is lacking, we use straightforward spreadsheet analysis and constant extrapolations of historical trends rather than complex modeling.

In most cases, we follow the same approach to emissions accounting for historical inventories used by the US EPA in its national GHG emissions inventory[7] and its guidelines for states.[8] These inventory guidelines were developed based on the guidelines from the Intergovernmental Panel on Climate Change, the international organization responsible for developing coordinated methods for national GHG inventories.[9] The inventory methods provide flexibility to account for local conditions. The electricity sector is one area in which we expand the US EPA inventory approach by evaluating consumption-based and production-based emissions, as described above. The key sources of activity and projection data are shown in Table 7. Table 7 also provides the descriptions of the data provided by each source and the uses of each data set in this analysis.

General Principles and Guidelines

A key part of this effort involves the establishment and use of a set of generally accepted accounting principles for evaluation of historical and projected GHG emissions, as follows:

[7] US EPA, Feb 2005. *Draft Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2003.* http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html .
[8] http://yosemite.epa.gov/oar/globalwarming.nsf/content/EmissionsStateInventoryGuidance.html.
[9] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm .

Table 7. Key sources for Montana data, inventory methods, and growth rates

Source	Information provided	Use of Information in this Analysis
US EPA State Greenhouse Gas Inventory Tool (SGIT)	US EPA SGIT is a collection of linked spreadsheets designed to help users develop State GHG inventories. US EPA SGIT contains default data for each State for most of the information required for an inventory. The SGIT methods are based on the methods provided in the Volume 8 document series published by the Emissions Inventory Improvement Program (http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html)	Where not indicated otherwise, SGIT is used to calculate emissions from residential/commercial/industrial fuel combustion, industrial processes, agriculture and forestry, and waste. We use SGIT emission factors (CO_2, CH_4 and N_2O per BTU consumed) to calculate energy use emissions.
US DOE Energy Information Administration (EIA) State Energy Data (SED)	EIA SED source provides energy use data in each State, annually to 2001.	EIA SED is the source for most energy use data. We also use the more recent data for electricity and natural gas consumption (including natural gas for vehicle fuel) from EIA website for years after 2001. Emission factors from US EPA SGIT are used to calculate energy-related emissions.
US DOE Energy Information Administration Annual Energy Outlook 2006 (AEO2006)	EIA AEO2006 projects energy supply and demand for the US from 2005 to 2030. Energy consumption is estimated on a regional basis. Montana is included in the Mountain Census region (AZ, CO, ID, MT, NM, NV, UT, and WY)	EIA AEO2006 is used to project changes in per capita (residential), per employee (commercial/industrial) energy consumption through 2020.
American Gas Association - Gas Facts	Natural gas transmission and distribution pipeline mileage.	Pipeline mileage from Gas Facts used with SGIT to estimate natural gas transmission and distribution emissions.
US EPA Landfill Methane Outreach Program (LMOP)	LMOP provides landfill waste-in-place data.	Waste-in-place data used to estimate annual disposal rate, which was used with SGIT to estimate emissions from solid waste. Additional data from MDEQ staff will be incorporated, when received.
US Forest Service	Data on forest carbon stocks for multiple years.	Data are used to calculate carbon dioxide flux over time (terrestrial CO2 sequestration in forested areas)
USDS National Agricultural Statistics Service (NASS)	USDA NASS provides data on crops and livestock.	Crop production data used to estimate agricultural. residue and soils emissions; livestock population data used to estimate manure and enteric fermentation emissions. Emission factors are from the EPA SGIT.

- **Transparency:** We report data sources, methods, and key assumptions to provide open review and opportunities for additional revisions later based on stakeholder and technical work group input.

- **Consistency:** To the extent possible, the inventory and projections are designed to be externally consistent with current or likely future systems for state and national GHG emission reporting. We have used US EPA tools for state inventories and projections as a starting point. These initial estimates were then augmented to conform to local data and conditions, as informed by Montana-specific sources and experts.

- **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods.** This analysis aims to comprehensively cover GHG emissions associated with activities in Montana. It covers all six GHGs covered by U.S. and other national inventories: CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs.

- **Priority of Significant Emissions Sources:** In general, activities with relatively small emissions levels may not be reported with the same level of detail as other activities.

- **Priority of Existing State and Local Data Sources:** In gathering data and in cases where data sources conflicted, we placed highest priority on local and state data and analyses, followed by regional sources, with national data used as defaults where necessary or simplified assumptions such as constant extrapolation of trends.

- **Use of Consumption-Based Emissions Estimates:** To the extent possible, we estimated emissions that are caused by activities that occur in Montana. For example, we reported emissions associated with the electricity consumed in Montana. The rationale for this method of reporting is that it can more accurately reflect the impact of state based policy strategies such as energy efficiency on overall GHG emissions, and it resolves double counting and exclusion problems with multi emissions issues. This approach can differ from how inventories are compiled, for example, on an in-state production basis, in particular for electricity.

For electricity, we estimate, in addition to the emissions due to fuels combusted at electricity plants in the State, the emissions related to electricity *consumed* in Montana. This entails accounting for the electricity sources used by Montana utilities to meet consumer demands. As we refine this analysis, we may also attempt to estimate other sectoral emissions on a consumption basis, such as accounting for transportation fuel used in Montana, but purchased out-of-state. In some cases this can require venturing into the relatively complex terrain of life cycle analysis. In general, we recommend considering a consumption-based approach where it will significantly improve the estimation of the emissions impact of potential mitigation strategies.[10]

[10] For example re-use, recycling, and source reduction can lead to emission reductions resulting from lower energy requirements for material production (such as paper, cardboard, and aluminum), even though production of those materials, and emissions associated with materials production, may not occur within the state.

Some data gaps exist in this analysis, particularly for the reference case projections. Key tasks include developing a better understanding of the electricity generation sources currently used to meet Montana loads (in collaboration with state utilities), and review and revision of key emissions drivers (such as electricity and transportation fuel use growth rates) that will be major determinants of Montana's future GHG emissions.

Emissions of aerosols, particularly "black carbon" from fossil fuel combustion, could have significant climate impacts through their effects on radiative forcing. No estimates of these aerosol emissions have been developed for Montana as of yet. By including black carbon emission estimates in the inventory, however, additional opportunities for reducing climate impacts could be identified. CCS is currently conducting inventory and forecast work for a number states in coordination with the Western Governors' Association. Black carbon estimates produced as part of that process will be added to Montana's inventory when they are available.

Appendix A. Electricity Use and Supply

For at least the last 15 years, electricity generation has been a major export industry for Montana. The state exported 41% of the electricity it produced in 2000, and the inventory analysis indicates that exports in 2005 were about 40%. Export levels have varied between 37% and 47% since 1990,[11] depending on many factors including water levels for hydro-electric generation, economics and availability of power in neighboring regions, and Montana's own electricity demand. Montana electricity generation has been primarily a mix of coal and hydroelectricity. Generation from these two sources has been almost equal in some years, but recently coal sources have dominated. In 2004, coal accounted for 65% of generation, hydro for 33%, fuel oil for 2%, with the remaining sources (natural gas, biomass, and wind) contributing less than 0.5%. Coal-fired power plants produce as much as twice the CO_2 emissions per Megawatt-hour of electricity as natural gas-fired power plants, which dominate other states' production. In 2004, Montana emitted approximately 0.69 MtCO2e/MWh from electricity generation, compared to a national average of 0.65 MtCO2e/MWh.[12]

As noted earlier, one of the key questions for the state to consider is how to treat GHG emissions that result from consumption of electricity that is produced outside the state. In other words, should the state consider the GHG emissions associated with the state's electricity consumption or its electricity production, or some combination of the two? Since this question still needs to be resolved, this section examines electricity-related emissions from both a production and consumption basis.

This appendix describes Montana's electricity sector in terms of net consumption and production, including the assumptions used to develop the reference case projections. It then describes Montana's electricity trade and potential approaches for allocating GHG emissions for the purpose of determining the state's inventory and reference case forecasts. Finally, key assumptions and results are summarized.

We considered two sources of data in developing the inventory of CO_2 emissions from Montana power plants – 1) EIA's State Energy Data (SED) provides data on energy consumption, which then need to by multiplied by emission factors (i.e., tons of CO2, N2O and CH4 per unit of energy consumed) to calculate total GHG emissions and 2) U.S. EPA's Clean Air Markets Data[13] provides data on GHG emissions from larger plants (greater than 25 MW capacity) based on data from emissions monitors at the plants. We used the EIA's State Energy Data (SED) rather than EPA data because of its coverage of all power plants and because of inconsistencies that we found in the EPA data. Although the two sources provided similar estimates for CO_2 emissions in recent years, the EPA database shows the sum of emissions from individual power plants to be up to 10% greater than SED estimates for the entire state in earlier years (1997 and 1999). We discussed this with EPA and learned that EPA data tend to be conservative (i.e., overestimate emissions) because the data are reported as part of a regulatory program, and that during early years of the data collection program, missing data points were sometimes assigned a large value

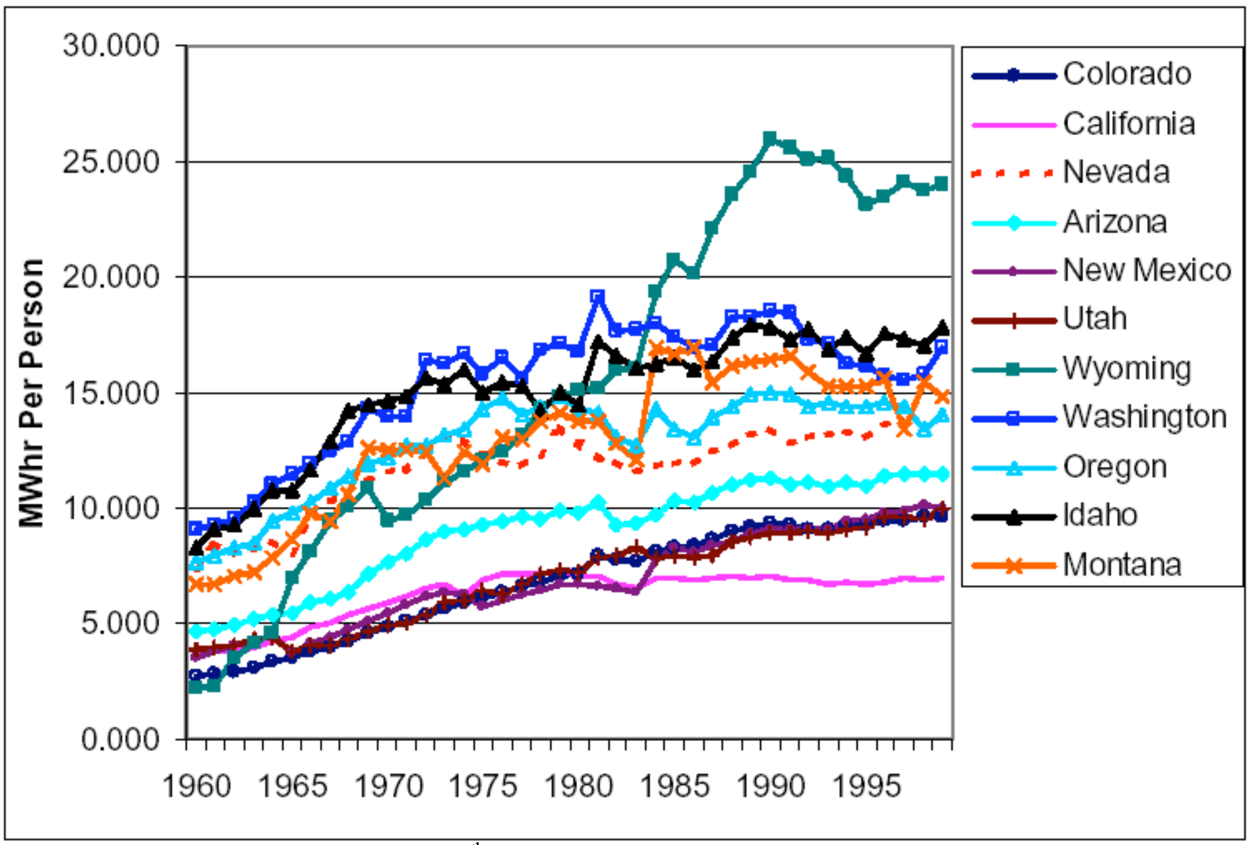
[11] eGRID2002 software (US EPA, http://www.epa.gov/cleanenergy/egrid/whatis.htm).
[12] EPA GHG Inventory.
[13] http://camddataandmaps.epa.gov/gdm/ .

as a placeholder. We applied SGIT emission factors to EIA's SED to develop the historic inventory of GHG emissions in the electricity sector.

Electricity Consumption

At about 14,000 kWh/capita (2004 data), Montana has relatively high electricity consumption per capita. By way of comparison, the per capita consumption for the U.S. was about 12,000 kWh per year.[14] Figure A1 shows Montana's rank compared to other western states from 1960-1999; while showing greater variation than most states, Montana's per capita consumption has been relatively high (4th out of 11).

Figure A1. Electricity consumption per capita in Western States, 1960-1999



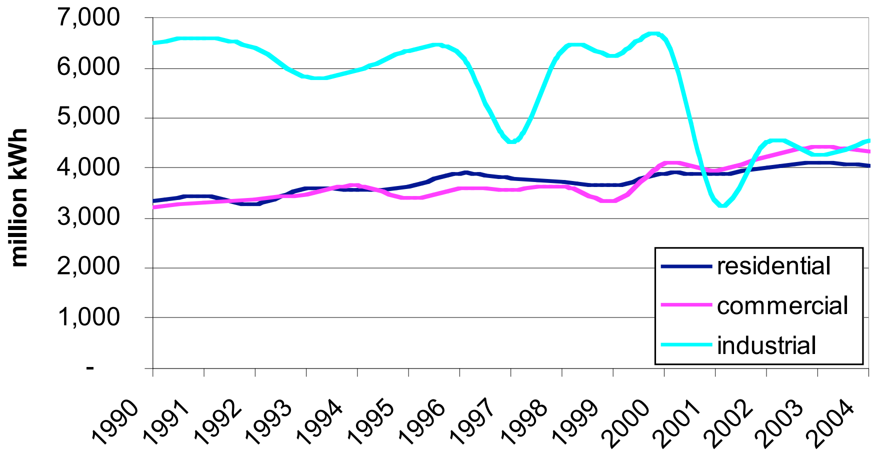
Source: Northwest Power Council, 5th Power Plan, Appendix A

As shown in Figure A2, electricity sales in the industrial sector of Montana have varied significantly over time, with a large decrease in 2001 due to the high prices and uncertainty of the electricity crisis.[15] Industrial sector sales have slowly increased since that year. The

[14] Census bureau for U.S. population, Energy Information Administration for electricity sales.
[15] MT DEQ 2004. *Understanding Energy in Montana*. http://leg.mt.gov/css/publications/lepo/2005_deq_energy_report/2005deqenergytoc.asp .

commercial and residential sectors have seen a more consistent trend of increases since 1990, with some variation year to year.[16]

Figure A2. Electricity consumption by sector in Montana, 1990-2004



In 2004, Montana had 44 entities involved in providing electricity to state customers. The state's two largest investor-owned utilities, MDU Resources and NorthWestern Energy, serve approximately 63% of the customers, and 43% of the electricity sales, as illustrated in Table A1. The two smaller investor-owned utilities, Avista and Black Hills Power, served about 50 customers in 2004, accounting for about 0.1% of sales in Montana. The state's 30 electric cooperatives serve 33% of the customers and 26% of sales. Five power marketers (Conoco Inc, Energy West Resources, Granite Power Energy, Hinson Power Company and PPL Energy Plus) provided electricity to less than 0.05% of retail customers, but accounted for over 22% of sales. Power marketers either produce energy or deliver electricity to customers so that the electricity produced is not sold directly to retail customers, but instead is sold to delivery companies. Three federal entities (Bonneville Power Administration, U.S. Bureau of Indian Affairs – Mission Valley Power, and Western Area Power Administrator) plus the city of Troy municipal utility account for the remaining 8% of sales and 4% of customers.

Table A1. Retail Electricity Sales by Montana Utilities (2004)

	Ownership Type	2004 MWh
Top 5 providers of Retail Electricity, ranked by retail sales		
NorthWestern Energy LLC	Investor-Owned	5,318,700
PPL EnergyPlus LLC	Power Marketer	2,362,601
Flathead Electric Coop Inc	Cooperative	1,274,131
MDU Resources Group Inc	Investor-Owned	610,855
Bonneville Power Admin	Power Marketer	570,960
Total Sales, Top Five Providers		10,137,247
Total, all Montana		12,956,782

Source: EIA state electricity profiles

[16] Electricity consumption figures here only include purchased electricity, and do not include electricity generated and consumed internally by specific industries, such as mining.

Overall, total electricity consumption decreased at an average annual rate of 0.1% from 1990 to 2004, but this value masks the many trends shown in Figure A2. During this period, the residential sector grew by an average of 1.4% per year, the commercial sector by 2.1% per year, and the industrial sector dropped by 2.5% per year.

A variety of sources were considered for initial projections of growth in electricity sales. Northwestern Energy provided projected retail sales in the Montana Energy Forum report.[17] The projections from the Montana-Dakota Utility (MDU) were provided by the Montana Public Service staff report from load forecasts in MDU's 2005 Integrated Resource Plan.[18] The 5th Power Plan from the Northwest Power and Conservation Council (NWPPC) also provided projected electricity growth for its share of Montana. The AEO2006 provides projections of electricity consumption for the Mountain census region. Since this census region includes states such as Arizona and New Mexico, which have much higher projected population and economic growth than Montana, these projections were adjusted to account for Montana's projected population and employment growth. These projections are summarized in Table A2 below.

Table A2. Electricity growth rates, projections

	Sample Projections					
	Northwestern Energy		MDU	NWPPC	AEO2006*	
	2004-2010	2010-2020	2004-2024	2000-2025	2004-2010	2010-2020
Residential	0.02%	0.2%	0.2%	n/a	1.5%	1.0%
Commercial	2.2%	1.2%	1.0%	n/a	2.9%	1.0%
Industrial	1.5%	0.0%	2.8%	n/a	0.8%	0.2%
Total	*1.3%*	*0.5%*	*0.90%*	*0.63%*	*1.7%*	*0.7%*

*AEO2006 projections have been adjusted for Montana's projected population and employment growth
Note that the sources do not report their projections based on consistent future time periods, also MDU and NWPPC only provided one average growth rate over the time period indicated, rather than annual variations.

To develop the projections for the reference case, the growth rates for NorthWestern Energy and MDU were applied to each utilities electricity sales in 2005. These utilities accounted for 41% and 5% of Montana's electricity sales respectively. Electricity growth for the remaining electricity sales (provided by electricity co-operatives and public utilities) was based on the average rate from the two utilities, NorthWestern Energy and MDU (0.2% per year for residential, 1.1% for commercial and 1.4% for industrial). The resulting projections for Montana are shown in Table A3.

[17] http://www.montanaenergyforum.com/
[18] Email to CCS from Bob Raney, December 4, 2006.

Table A3. Electricity growth rates, historic and reference case projections

	Historic		Projections	
	1990-2005	2002-2005	2005-2010	2010-2020
Residential	1.5%	1.6%	0.1%	0.2%
Commercial	2.2%	1.7%	1.8%	1.1%
Industrial	-2.1%	1.7%	1.5%	1.3%
Total	*0.2%*	*1.7%*	*1.2%*	*0.9%*

Source: Historic from EIA data, Projections based on growth rates from NorthWestern Energy and MDU.

For comparison, Montana's average annual growth rates by sector are also included in Table A3, for both 1990 to 2005 and also for the more recent time period, 2002 to 2005. Although industrial sector electricity sales have declined on average in the last fifteen years, both Table A3 and the previous Figure A2 show that much of that decrease occurred between 2000 and 2002. The projected growth rates for electric sales in this sector are similar to the more recent trends.

Electricity Generation – Montana's Power Plants

As mentioned above and displayed in Figure A3, coal figures prominently in electricity generation and accounts for almost all the GHG emissions from power plants in Montana. Table A4 reports the emissions from the four largest plants in Montana. The largest plant, Colstrip, accounts for 82% of Montana's GHG emissions. Colstrip is a large facility with 4 generator units built between 1976 and 1984, having a combined capacity of over 2,100 MW. It runs primarily on coal but also consumes propane, distillate oil, and petroleum coke. Ownership of the plant is shared by PPL Montana (36%), Puget Sound Energy (33%), Portland General Electric (14%), Avista (10%) and PacifiCorp West (7%).[19] PPL Montana is a subsidiary of PPL Corporation (Pennsylvania Power and Light) and the company is based in Billings. However, the other companies owning shares of Colstrip, and most of their customers, are based outside of Montana.

[19] EPA's Emission & Generation Resource Integrated database (EGRID), http://www.epa.gov/cleanenergy/egrid/index.htm .

Figure A3. Electricity generation and CO2 emissions from Montana power plants, 2004

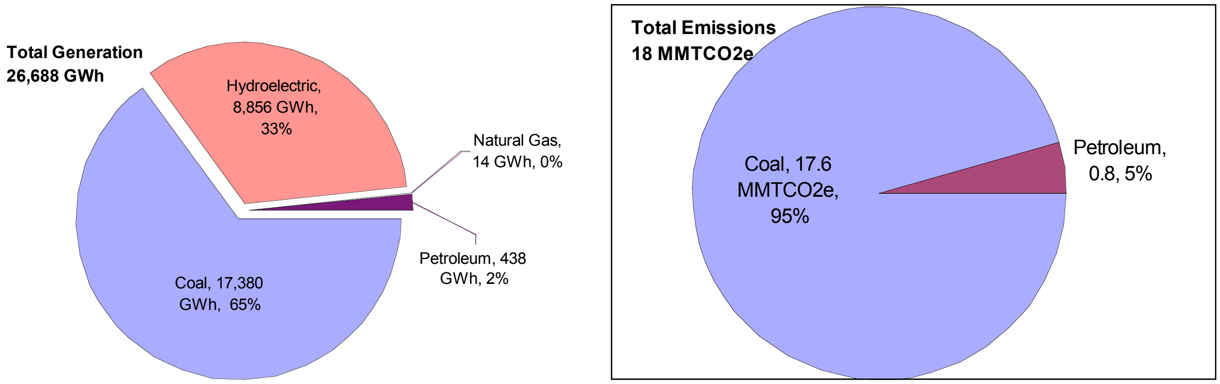


Table A4. CO2 emissions from individual Montana power plants, 1995-2004

(Million Metric Tons CO2e)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Colstrip	*13.8*	*11.4*	*15.3*	*16.9*	*16.9*	*15.0*	*16.8*	*14.8*	*15.9*	*16.0*
Glendive Generating Station	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*0.01*	*0.04*
J E Corette	*1.2*	*1.1*	*0.8*	*0.7*	*1.1*	*1.3*	*1.1*	*1.2*	*1.4*	*1.4*
Lewis & Clark	*0.4*	*0.3*	*0.3*	*0.4*	*0.3*	*0.5*	*0.5*	*0.4*	*0.5*	*0.5*
Other units	*1*	*1*	*0*	*0*	*0.0*	*0*	*0.0*	*0.0*	*0*	*1*
Total	**17**	**14**	**16**	**18**	**18**	**17**	**18**	**16**	**18**	**18**

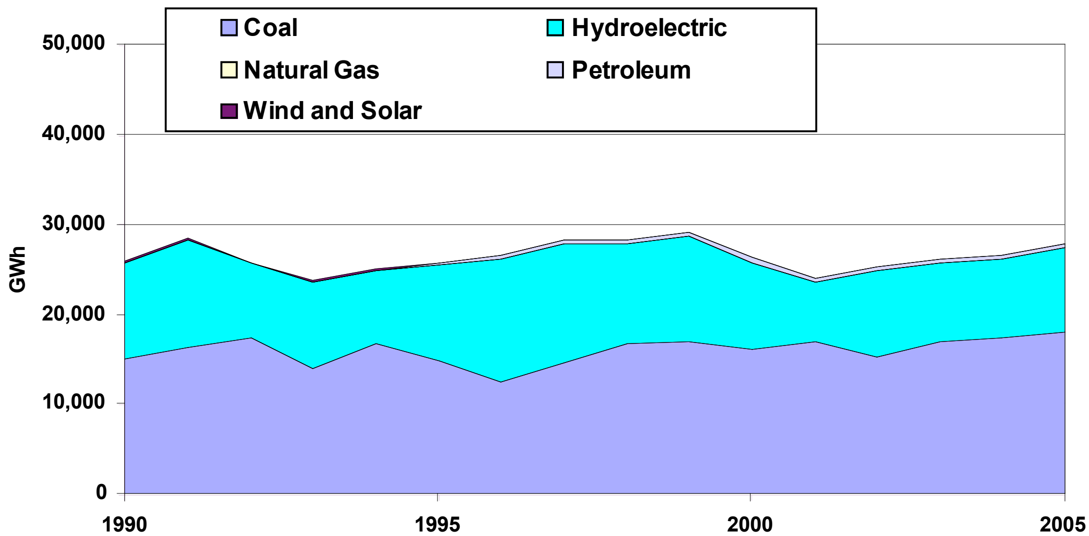
Source: U.S. EPA Clean Air Markets database for named plants (http://camddataandmaps.epa.gov/gdm/). Total emissions calculated from fuel use data provided by U.S. DOE EIA. Only CO_2 emissions are reported by Clean Air Markets database.

Figure A4 shows historical sources of electricity generation in the state by fuel source from 1990 through 2005. Table A5 shows the growth in generation by fuel type between 1990 and 2004. Overall generation grew by 3 percent between these two years, but as shown in Figure A4, generation levels vary greatly year to year. Coal generation shows the greatest increase in absolute terms over the 14-year period. Petroleum coke grew by the greatest percentage due to the BGI power plant starting up in 1995, but consumption of this fuel started at an extremely low level in 1990.

Table A5. Growth in Electricity Generation in Montana 1990-2004.

	Generation (GWh)		Growth
	1990	2004	
Coal	15,120	17,380	15%
Hydroelectric	10,717	8,856	-17%
Natural Gas	41	14	-67%
Biomass and waste	75	0	-100%
Petroleum Coke	27	438	1500%
Total	25,980	26,688	3%

Figure A4. Electricity generation in Montana 1990 - 2005



Source: EIA data, note that natural gas, wind and solar generation are less than 100 GWh in most years and are not visible in the figure.

Future Generation and Emissions

Estimating future generation and GHG emissions from Montana power plants requires estimation of new power plant additions and production levels from new and existing power plants. There are, of course, large uncertainties, especially related to the timing and nature of new power plant construction.

The future mix of plants in Montana remains uncertain as the trends in type of new builds are influenced by many factors. The most recent fossil-fuel plants have been natural gas-fired; however, there are concerns that natural gas prices may increase over the next decade, which could cause a trend towards a more coal-dominated mix. Recent announcements by several utilities indicate that coal will dominate new builds; Rocky Mountain Power, Inc.'s Hardin Generating Station is the first coal-fired power plant to be built in the state in the last 20 years (Thompson River Co-Gen, built in Thompson Falls in 2004, is currently not operating due to permit violations). Montana has also recently announced a renewable portfolio standard (RPS), requiring investor-owned utilities to generate (or purchase) a minimum amount of electricity from renewable sources. The RPS will likely spur additional new wind projects in the state. Table A6 presents data on new and proposed plants in Montana.

Table A6. New and proposed power plants in Montana

	Plant Name	Fuel	Status	Capacity MW	Expected Annu Generation GWh	Notes
Wind Plants	Judith Gap	wind	On-line 2006	135	355	The project will generate about 150 megawatts of power from 90 turbines.
	McCormick Ranch	wind	Proposed	120	315	
	Valley County Wind Energy Project	wind	Proposed	50 (2008) 100 (2010) 150 (2013) 200 (2016)	130 (2008) 260 (2010) 390 (2013) 520 (2016)	Proposal by Wind Hunter LLC for a project in north-central Valley County.
New plants	Rocky Mountain Hardin	Sub-bituminous coal	On-line 2006	135	1,005	3-year contract to sell 100% of electricity to British Columbia.
	Tiber Dam	water	On-line 2004	7	39	
	Thomson River Co-Gen	Sub-bituminous coal	On-line (but not operating)	16		
	Basin Creek, Equity Partner, LLC	Natural gas	On-line 2006	54.9	433	Offsets purchased so that power plant will meet the Oregon Standard for CO2 emissions
Proposed plants	SME Highwood Generating Station	lignite coal	Air quality permit issueded.	270	2,010	
	Silver Bow	Natural gas	Permitted	500	3,942	Permit application Jan-2001. Major permits secured Mar-2002.
	Roundup Bull Mountain, Broadview	lignite coal IGCC	Proposed	300		Proposed coal to liquids plant permitting proposed to be supplemental to MT DEQ air permits issued Feb 2003 for

Given the many factors impacting electricity related emissions and a diversity of assumptions by stakeholders within the electricity sector, developing a "reference case" projection for the most likely development of Montana's electricity sector is particularly challenging. The principal uncertainty of interest is on the high side, given the many plans and initiatives to increase coal utilization locally and nationally. As a result, we explore two cases of future electric sector development – the reference case and the high fossil fuel production scenario (these two cases were also developed for the fossil fuel production sector). For each case, simple assumptions were made to develop projections for electric generation, relying to the extent possible on existing proposals for future changes to Montana's transmission infrastructure.

The reference case projections assume:

- Existing transmission lines are upgraded in Montana but no new lines are built. These upgrades will allow an additional 500 MW of additional capacity to be built in the state, over the period 2008 - 2020.

- New fossil fuel plants will be coal plants, which are assumed to be pulverized coal with heatrates at on average 9000 BTU/kWh.

The high fossil fuel production case projections assume:

- Additional new transmission lines will be built to export power from Montana. The total additional transmission lines in this case would have a capacity of 2,500 additional MW over the reference case addition of 500 MW, or 3,000 total additional MW capacity, relative to current levels. This scenario assumes the following transmission lines are available, or lines of similar capacity:
  - A transmission line capable of carrying 300 MW of power from Montana to Alberta-British Columbia is approved and functioning by 2009. An example of such a project is the Montana Alberta Tie Line.[20] This is a privately funded transmission line proposed between Alberta and Montana capable of transferring 300 MW of power South North (and 300 MW of power North South, with capability of transfer to California).[21]
  - A transmission line capable of carrying 2,200 MW of power from Montana to Las Vegas (or that general area) will be approved and functioning by 2012. The proposed Northern Lights transmission line, to be operated by Transcanada, is an example of such a project.[22] According to MDEQ staff, it is very possible that such a line would initially carry up to 1,500 MW and eventually enough generation could be built in Montana to fill the 3,000 MW line.[23] An estimate of 2, 200 MW is an approximate mid-point between these potential capacity levels.
- The high fossil fuel scenario assumes that new power plants will be built in Montana to use the full capacity of these two assumed lines by 2020. The new plants are assumed to be a mix of 65% fluidized bed coal and 35% wind. These new power plants are in addition to the new plants described in the reference case.

Both cases assume:

- Generation from existing non-hydro plants is based on 2004 levels. Generation from existing hydro-electric plants is assumed to be 10,356 GWh per year, the average generation from the last ten years (EIA electric power annual data, 1995-2004). New plants and changes to existing plants due to plant renovations and overhauls that result in higher capacity factors are counted as new generation.

- The Renewable Portfolio Standard requirements are assumed to be met by in-state wind generation. Renewable generation must meet a minimum of 10% of sales from investor-owned utilities in 2010 and 15% in 2015 and every year thereafter.

- Electricity sales grow at 1.2% per year from 2006-2010 and 0.9% per year from 2011-2020, as described previously.

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[20] http://www.matl.ca/

[21] ABB Engineering. 2006. System Feasibility Report: Montana Alberta Tie Line (MATL) project. Executive summary. http://www.matl.ca/documents/ABB_Executive.pdf

[22] http://www.transcanada.com/pdf/company/projects/NorthernLights_LR.pdf

[23] Email from Jeff Blend, MDEQ to Alison Bailie, CCS, November 13, 2006.

Electricity Trade and Allocation of GHG Emissions

Montana is part of the interconnected Western Electricity Coordinating Council (WECC) region - a vast and diverse area covering 1.8 million square miles and extending from Canada through Mexico, including all or portions of 14 western states. The inter-connected region allows electricity generators and consumers to buy and sell electricity across regions, taking advantage of the range of resources and markets. Electricity generated by any single plant enters the interconnected grid and may contribute to meeting demand throughout much of the region, depending on sufficient transmission capacity. Thus, it is challenging to define which emissions should be allocated to Montana, and secondly in estimating these emissions both historically and into the future. Some utilities track and report electricity sales to meet consumer demand by fuel source and plant type; however, tracing sales to individual power plants may not be possible.

In 2004, electricity consumption in Montana was 13 terawatt-hours (TWh), while electricity generation was 27 TWh. Also as mentioned above, Montana utilities own less than half of the largest generating plant in the state. Thus, a significant portion of the electricity generated and economic benefits may serve consumers and investors in other states.

Since almost all states are part of regional trading grids, many states that have developed GHG inventories have grappled with the problem of how to account for emissions. Several approaches have been developed to allocate GHG emissions from the electricity sector to individual states for inventories.

In many ways the simplest approach is *production-based* – emissions from power plants within the state are included in the state's inventory. The data for this estimate are publicly available and unambiguous. However, this approach is problematic for states that import or export significant amounts of electricity. Because of the state's small imports and the uncertainty of the magnitude of future net imports, the question of consumption- versus production-based emissions may not be as important in Montana as in other states with greater percentages of net imports or exports. Under a production-based approach, characteristics of Montana electricity consumption would not be captured since only emissions from in-state generation would be considered.

An alternative is to estimate *consumption-based* or *load-based* GHG emissions, corresponding to the emissions associated with electricity consumed in the state. The load-based approach is currently being considered by states that import significant amounts of electricity, such as California, Oregon, and Washington.[24] By accounting for emissions from imported electricity, states can account for increases or decreases in fossil fuel consumed in power plants outside of the State, due to demand growth, efficiency programs, and other actions in the state. The difficulty with this approach is properly accounting for the emissions from imports and exports.

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[24] See for example, the reports of the Puget Sound Climate Protection Advisory Committee http://www.pscleanair.org/specprog/globclim/, the Oregon Governor's Advisory Group On Global Warming http://egov.oregon.gov/ENERGY/GBLWRM/Strategy.shtml, and the California Climate Change Advisory Committee, Policy Options for Reducing Greenhouse Gas Emissions From Power Imports - Draft Consultant Report http://www.energy.ca.gov/2005publications/CEC-600-2005-010/CEC-600-2005-010-D.PDF.

Since the electricity flowing into or out of Montana is a mix of all plants generating on the inter-connected grid, it is impossible to physically track the electrons.

The approach taken in this initial inventory is a simplification of the consumption-based approach. This approach, which one could term "*Net-Consumption-based,*" estimates consumption-based emissions as in-state (production-based) emissions times the ratio of total in-state electricity consumption to in-state generation (net of losses).

This method does not account for differences in the type of electricity that is imported or exported from the state, and as such, it provides a simple method for reflecting the emissions impacts of electricity consumption in the state. More sophisticated methods – e.g., based on individual utility information on resources used to meet loads – can be considered for further improvements to this approach.

Summary of Assumptions and Reference Case Projections

As noted, projecting generation sources, sales, and emissions for the electric sector out to 2020 requires a number of key assumptions, including economic and demographic activity, changes in electricity-using technologies, regional markets for electricity (and competitiveness of various technologies and locations), access to transmission and distribution, the retirement of existing generation plants, the response to changing fuel prices, and the fuel/technology mix of new generation plants. The key assumptions described above are summarized in Table A7.

Table A7. Key assumptions and methods for electricity projections for Montana

Assumptions for Both Scenarios

Electricity sales	Average annual growth of 1.2% from 2006 to 2010 and 0.9% per year from 2010 to 2020, based on growth rates from Northwestern Energy and MDU.
Transmission and Distribution losses	10% losses are assumed, based on average statewide losses, 1994-2000, (data from the US EPA Emission & Generation Resource Integrated Database[25])
Renewable Portfolio Standard	Montana's Renewable Portfolio Standard will be met by Northwestern Energy and MDU, 10% of State sales met by renewable generation by 2010, 15% by 2015 and in subsequent years. New renewables are assumed to be wind.
Heat Rates	The assumed heat rates for new gas and coal generation are 7000 Btu/kWh and 9000 Btu/kWh, respectively, based on estimates used in similar analyses.[26]
Operation of Existing Facilities	Existing facilities are assumed to continue to operate as they were in 2004. Changes in existing facilities that result in energy efficiency changes are captured under the new non-renewable generation sources.

Assumptions for Reference Case

New Electric Transmission Capacity	Transmission lines capable of carrying an additional 500 MW of new capacity will be on-line by 2020
New Generation Sources	All of the new generation capacity will be fluidized bed coal plants.

Assumptions for High Fossil Fuel Scenario

New Electric Transmission Capacity	Transmission lines capable of carrying an additional 3,000 MW of new capacity will be on-line by 2020
New Generation Sources	65% of new generation capacity will be fluidized bed coal plants, with wind generation accounting for the remaining 35%.

Results – Reference Case

Figure A5 shows historical sources of electricity generation in the state by fuel source, along with projections to the year 2020 based on the assumptions described above for the reference case. Based on the above assumptions for new generation, total generation increases by an average rate of 1.5%ercent from 2005 to 2020 and coal continues to dominate new generation.

[25] http://www.epa.gov/cleanenergy/egrid/index.htm.
[26] See, for instance, the Oregon Governor's Advisory Group on Global Warming http://egov.oregon.gov/ENERGY/GBLWRM/Strategy.shtml.

Figure A5. Electricity generated by Montana power plants, 1990-2020, reference case

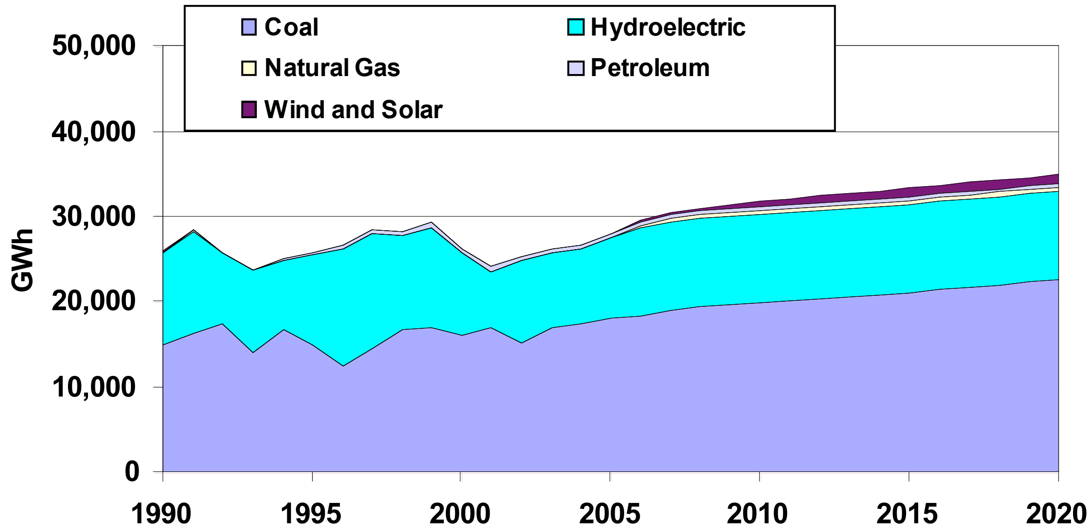


Figure A6 illustrates the GHG emissions associated with the mix of electricity generation shown in Figure A5. From 2005 to 2020, the emissions from Montana electricity generation are projected to grow at 1.3% per year, similar to the growth in electricity generation. The emission intensity (emissions per MWh) of Montana electricity is projected to decrease slightly, by about 2.4% (from 0.69 $MtCO_2$/MWh in 2005 to 0.67 $MtCO_2$/MWh in 2020).

Figure A6. Montana GHG emissions associated with electricity production (production-basis), includes exports, reference case

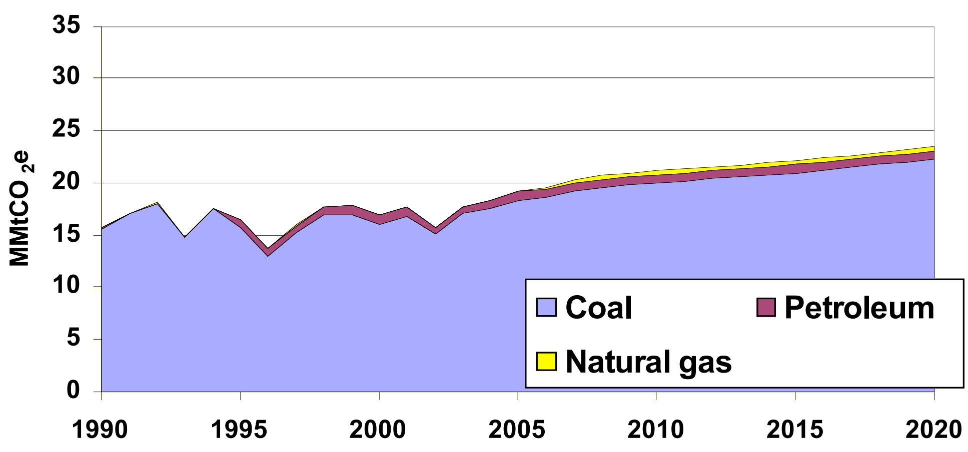
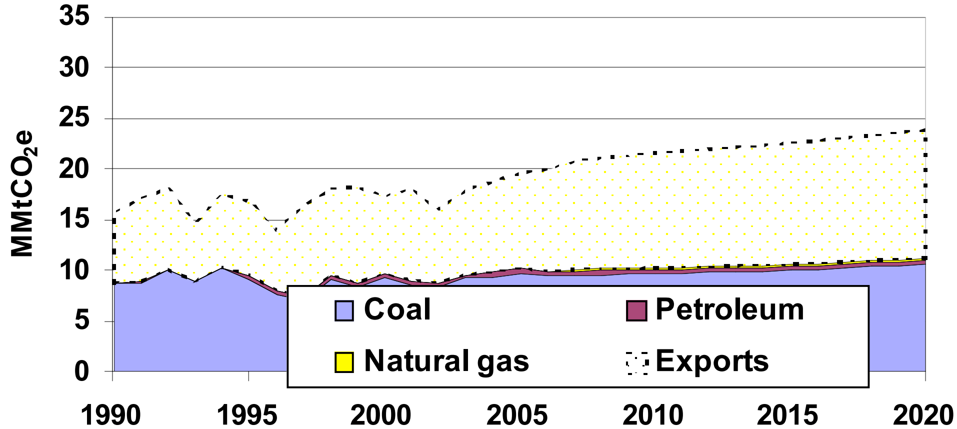


Figure A7 shows the "net-consumption-basis" emissions from 1990 to 2020. Total emissions match those shown in the previous "production-basis" chart; here, however, a significant fraction is attributed to net electricity exports as shown in the top area. Net-consumption based emissions grow at an average 0.6% per year from 2005 to 2020. This growth is lower than the average growth in total electricity sales for this period (1.0% per year) as the State RPS causes renewable generation to meet a larger fraction of in-state electricity sales.

Figure A7. Montana GHG emissions associated with electricity use (consumption-basis) and exports



Results – High Fossil Fuel Scenario

Figure A8 shows historical sources of electricity generation in the state by fuel source, along with projections to the year 2020 based on the assumptions described above for the high fossil fuel scenario. Based on the above assumptions for new generation, coal continues to dominate new generation throughout the forecast period but wind generation also grows strongly. Total generation increases by 3.9 percent per year from 2005 to 2020.

Figure A8. Electricity generated by Montana power plants, 1990-2020, high fossil fuel scenario

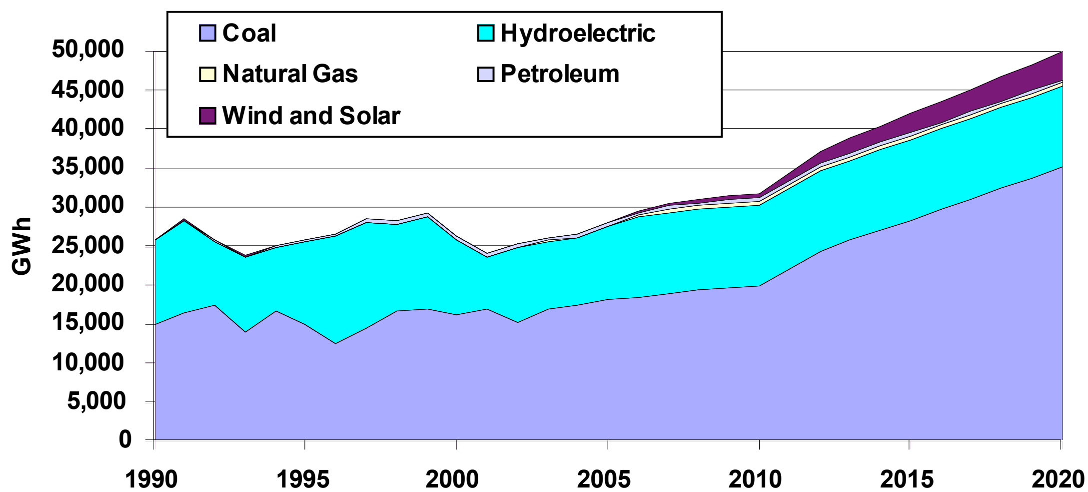
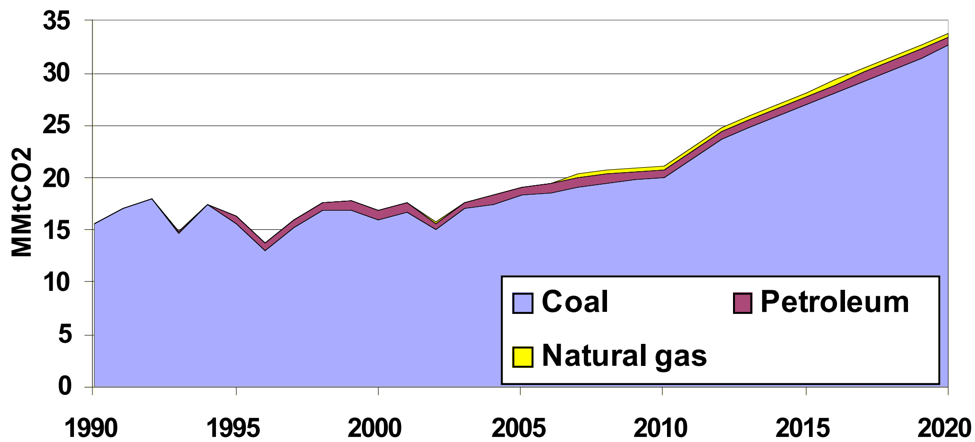


Figure A9 illustrates the GHG emissions associated with the mix of electricity generation shown in Figure A8. From 2005 to 2020, the emissions from Montana electricity generation are projected to grow at 3.8% per year, similar to the growth in electricity generation. The emission intensity (emissions per MWh) of Montana electricity is projected to decrease slightly, by about 2% (from 0.69 $MtCO_2$/MWh in 2005 to 0.68 $MtCO_2$/MWh in 2020). Although wind generation accounts for 35% of new electricity capacity, wind has lower capacity factors than coal generation and no new hydro-electric plants are assumed to be built so coal continues to dominate electricity production.

Figure A9. Montana CO2 emissions associated with electricity production (production-basis), includes exports, high fossil fuel scenario



The "net-consumption-basis" emissions for the high fossil fuel case are the same as for the reference case because the additional generation that is built under the high fossil fuel scenario is assumed to be used for export to other states.

Table A8 presents a summary of GHG emissions from the electric sector in Montana on a production basis for both the reference case and the high fossil fuel scenario and on a consumption basis, which has the same estimated emissions for each case. Though the GHG emissions are significantly different from each other, each set of estimates is valid depending on circumstances. From 2005 to 2020, using production-based accounting, GHG emissions from Montana's electric sector grow by 4.5 MMtCO2e in the reference case and 14.9 MMtCO2e in the High Fossil Fuel Scenario. The difference between the emissions in the reference case and the high fossil fuel scenario estimates reflect the uncertainty in future energy development in Montana. The consumption-based emissions represent a focus on the emissions associated with electricity consumption in Montana – this focus is important when evaluating the effects of actions directed at in-state electricity conservation.

Table A8. Summary GHG emissions for Montana electric sector

(Million Metric Tons CO2e)	1990	2000	2005	2010	2020
Production-based					
Reference case	**15.8**	**17.1**	**19.3**	**21.5**	**23.8**
High Fossil Fuel Scenario	**15.8**	**17.1**	**19.3**	**21.5**	**34.2**
Consumption-based	**8.9**	**9.5**	**10.0**	**10.0**	**11.0**

Note: Consumption-based emissions are the same for both the reference case and the high fossil fuel scenario because electricity consumption in Montana is the same for both cases.

Appendix B. Residential, Commercial, Industrial and Institutional Fossil Fuel Combustion (excluding fuel used by fossil fuel production industry)

The RCII[27] sectors produce CO_2, CH_4, and N_2O emissions when fuels are combusted for space heating, process heating, and other applications. Carbon dioxide accounts for over 99% of these emissions on an $MMtCO_2e$ basis. In addition, since these sectors consume electricity, one can also attribute electricity use emissions to these sectors.[28] This is particularly important to consider as the CCAC begins to explore options to improve energy efficiency (see Figures B1-B3), because the emissions associated with electricity use exceed those from direct fuel use in each sector, especially in residential and commercial buildings.

Direct use of coal, oil, natural gas, and wood[29] in the RCII sectors accounted for an estimated 12% of gross GHG emissions in 2005. However, if emissions associated with RCII electricity use are included, RCII energy use then accounts for 42% of gross GHG emissions.

Emissions for direct fuel use were estimated using the U.S. EPA's SGIT. Two changes were made to the default data provided in SGIT. First, the 2000 consumption estimates were updated using more recent data from EIA's website. The default data in the SGIT workbook are from EIA's *State Energy Data 2000*; however, the 2000 consumption estimates were revised in the 2001 edition of State Energy Data[30] and new data were provided for 2001. Secondly, EIA provides electricity consumption and natural gas consumption estimates for 2002, 2003 and 2004 as part of the *Electricity Production Annual*[31] and the *Natural Gas Navigator*.[32] These data were included in the Montana inventory.

Reference case emissions for direct fuel combustion were estimated based on fuel consumption forecasts from EIA *Annual Energy Outlook 2006,* with adjustments for Montana's projected population and employment growth. Table B1 and Table B2 report the historic and projected growth rates for electricity and fuels respectively.

[27] The industrial sector includes agricultural energy use as well but this section excludes fuel used by the fossil fuel production industry. Emissions from energy used in that industry are reported in Appendix F.
[28] One could similarly allocate GHG emissions due to natural gas transmission and distribution and other sources, but we have not done so here due to the relatively small level of emissions.
[29] Emissions from wood combustion include only N2O and CH4. Carbon dioxide emissions from biomass are assumed to be "net zero" consistent with U.S. EPA and IPCC methodologies, and any net loss of carbon stocks due to biomass fuel use should be picked up in the land use and forestry analysis.
[30] *State Energy Data 2001,* Energy Information Administration, Department of Energy
[31] http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html
[32] http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_SMT_a.htm

Table B1. Electricity sales annual growth rates, historical and projected

Sector	1990-2004	2004-2020
Residential	1.4%	1.5%
Commercial	2.1%	2.9%
Industrial	-2.5%	0.1%
Total	**-0.1%**	**1.6%**

Table B2. Historic and projected average annual growth in energy use, by sector and fuel, 1990-2020

	1990-2004	2004-2010	2010-2015	2015-2020
Residential				
Natural gas	1.2%	1.6%	1.2%	0.8%
Petroleum	-0.5%	0.2%	0.4%	-0.1%
Commercial				
Natural gas	0.7%	1.3%	2.5%	1.9%
Petroleum	-0.8%	-1.5%	0.8%	0.4%
Industrial				
Natural gas	5.7%	2.3%	-1.1%	-1.4%
Petroleum	-1.8%	1.9%	0.2%	-0.4%
Coal	-2.9%	0.5%	-1.5%	-1.6%

Figures B1, B2, and B3 illustrate historic and projected emissions for the RCII sectors from 1990 to 2020. Electricity consumption accounts for the largest component of each sector's emissions. The commercial sector shows the highest emissions growth, due to assumed strong growth in both electricity and natural gas consumption. Commercial electricity use grows faster than employment, while per-employee direct fuel use decreases. Residential sector emissions show strong growth with electricity and natural gas use growing faster than population. The historical industrial sector emissions show significant variation. Industrial energy consumption in Montana has been dominated by a relatively small number of large operations and the variation reflects market variation plus plant adjustments to energy prices.[33] The assumed growth rate for industrial sector fuel and electricity consumption is also higher than the growth in employment. For both the commercial and industrial sectors, energy consumption and resulting GHG

[33] While information on energy consumption by plant or industry were not available, general information was provided by MT DEQ 2004. *Understanding Energy in Montana*. http://leg.mt.gov/css/publications/lepo/2005_deq_energy_report/2005deqenergytoc.asp

emissions are projected to grow at a slower pace than GSP indicating an overall decrease in GHG intensity.[34]

Figure B1. Residential sector GHG emissions from fuel consumption

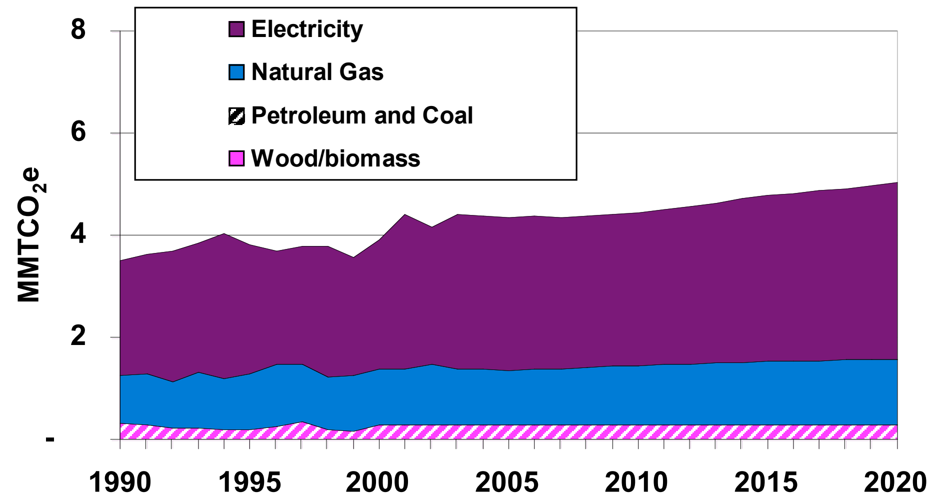
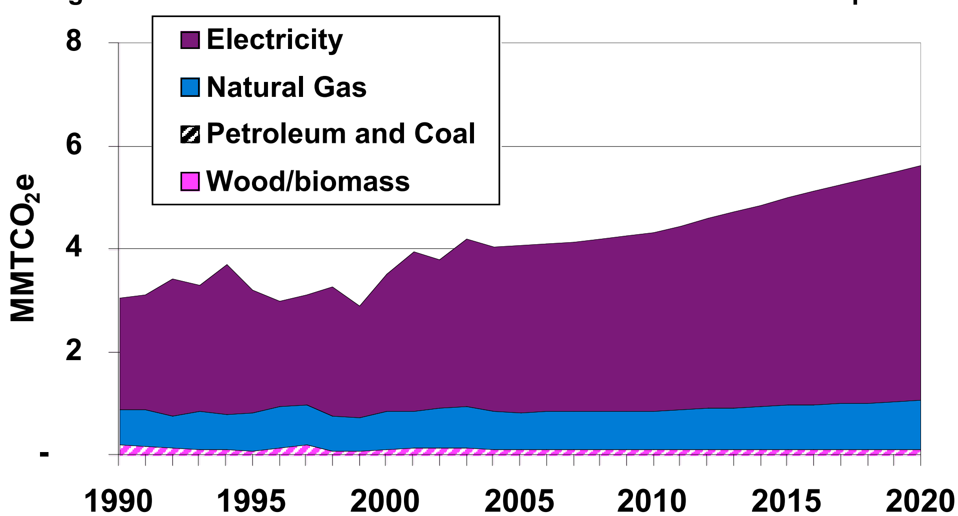
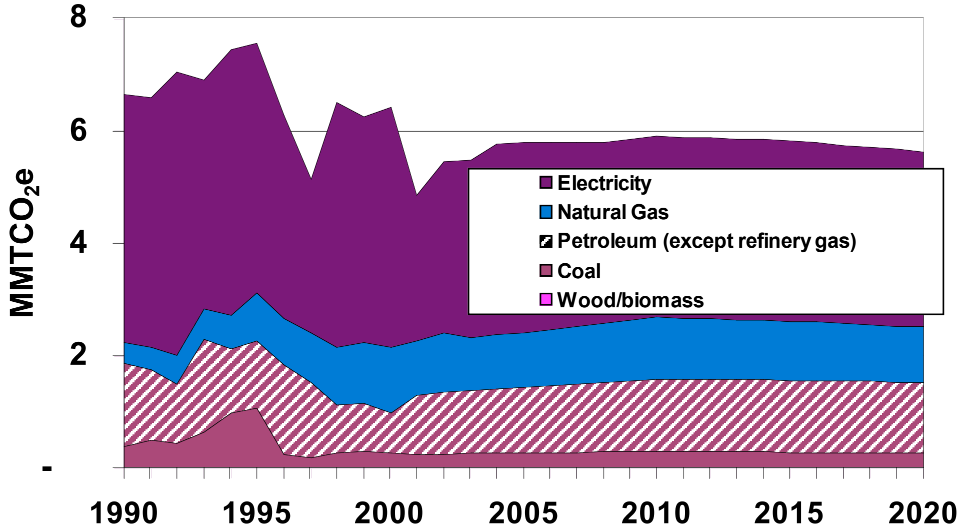


Figure B2. Commercial sctor GHG emissions from fuel consumption



[34] These estimates of growth relative to population and employment reflect expected responses – as modeled by the EIA NEMS model -- to changing fuel and electricity prices and technologies, as well as structural changes within each sector (subsectoral shares, energy use patterns, etc.).

Figure B3. Industrial sector GHG emissions from fuel consumption



Key sources of uncertainty underlying the estimates are as follows:

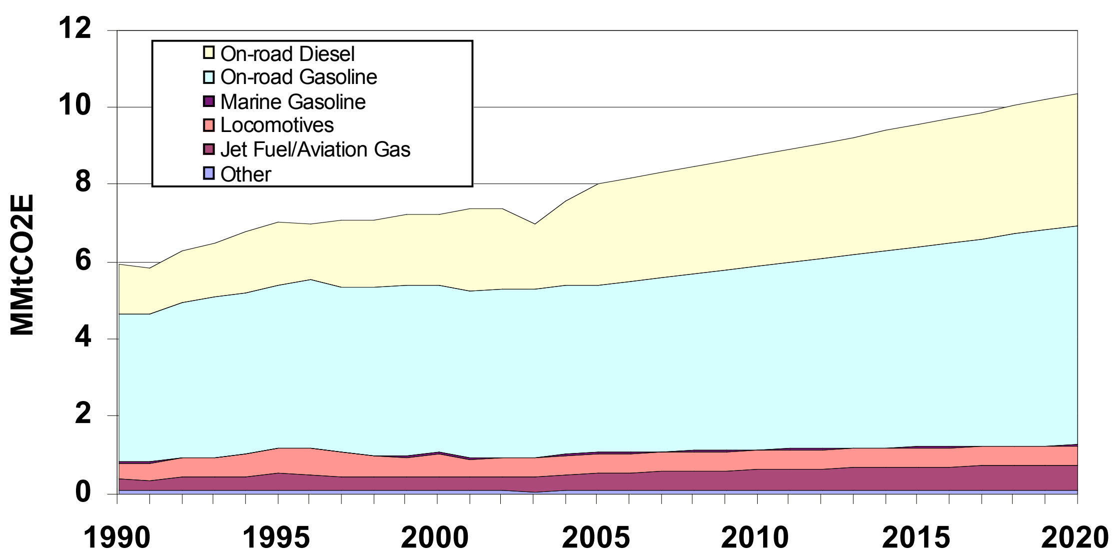
- Population and economic growth are the principal drivers for electricity and fuel use and are subject to significant uncertainties.
- The projections assume no large long-term changes in relative fuel and electricity prices, as compared with current levels and U.S. DOE projections. Price changes would influence consumption levels and encourage switching among fuels.
- It is assumed that energy consumed at military bases and national laboratories are included in the energy statistics from the EIA. However, under-reporting may have occurred, and estimating that impact is beyond the scope of this effort.
- Growth of major industries – the energy consumption projections assume no new large energy-consuming facilities and no major changes in mining activity. A few large new facilities – or the decline of major industries – could significantly impact energy consumption and subsequent emissions.

Appendix C. Transportation Energy Use

The transportation sector is a major source of GHG emissions in Montana – accounting for about 21% of Montana's gross GHG emissions in 2005. Carbon dioxide accounted for about 95% of transportation GHG emissions from fuel use in 1990 and increases to about 97% of transportation GHG emissions from fuel use by 2020. The proportion of CO_2 increases from 1990 to 2020 because of the increasing number of vehicles with advanced control technologies that reduce CH_4 and N_2O. Most of the remaining GHG emissions from the transportation sector are due to N_2O emissions from gasoline engines.

As shown in Figure C1, gasoline consumption accounts for the largest share of transportation GHG emissions. This category includes both onroad and marine gasoline; although, only a small fraction (less than 1%) of the total is marine gasoline. Emissions from gasoline vehicles increased by about 13% from 1990 – 2005 to cover 54% of total transportation emissions in 2005. GHG emissions from diesel fuel consumption increased significantly more than gasoline emissions – an overall increase of 84% from 1990 to 2005, with a couple dips such as in 2003 when emissions dropped by 15%, compared to the previous year, followed by a 21% increase from 2003 to 2004. By 2005 diesel consumption accounted for nearly 39% of GHG emissions from the transportation sector. Air travel fuel consumption and emissions grew by 44% between 1990 and 2005, with much of the increase occurring between 2001 and 2005. Combustion of natural gas and LPG and oxidation of lubricants accounted for only about 1% of transportation emissions in 2005.

Figure C1. Transportation GHG emissions by fuel, 1990-2020



GHG emissions from transportation are expected continue these growth trends over the next 15 years due to increased demand for current modes of transportation and alternative fuels such as natural gas. Vehicle miles traveled (VMT) projections supplied by the Montana Department of Transportation (MDT) suggest that VMT for road vehicles will grow at a rate of 1.92% per year between 2005 and 2020.[35] These VMT projections combined with vehicle fuel efficiency projections from EIA's *Annual Energy Outlook* (AEO), which account for technology changes, fuel prices, and legislation, yield an average growth rate of about 1.8% per year in gasoline consumption and 1.9% for diesel between 2006 and 2020.

These assumptions combine to project a 75% increase in GHG emissions from the transportation sector from 1990 to 2020. GHG emissions from diesel consumption are expected to increase from 1.7 $MMtCO_2e$ in 1990 to 3.9 $MMtCO_2e$ in 2020, while GHG emissions associated with air travel are expected to double during this time period. There is strong historical and projected growth in natural gas vehicle fuel consumption; however, the overall consumption of this fuel is small compared to other fuels. While gasoline emissions still account for the greatest share of the transportation emissions in 2020, the share of these emissions shrinks from 65% in 1990 to 55% in 2020, with the increased rate of diesel emissions accounting for the decreased share of onroad gasoline emissions. The high overall growth in transportation sector emissions suggests many opportunities and challenges for reducing Montana's GHG emissions.

The EPA SGIT was used to prepare the inventory and reference case projections. For onroad vehicles, the CO_2 emission factor is in units of lb/MMBtu and the CH_4 and N_2O emission factors are both in units of grams/VMT. Key assumptions in this analysis are listed in Table C1. The default data within SGIT were used (with the exception of natural gas) to estimate emissions, with the most recently available fuel consumption data (2005) from EIA SED, 2002 VMT estimates from FHWA's Highway Statistics, and estimates of 2002-2004 natural gas consumption from EIA's Natural Gas Navigator added.[36,37,38] For natural gas, the default data includes pipeline fuel. For this inventory, pipeline fuel is included in the natural gas transmission category; therefore, this data was replaced by the consumption for vehicle fuel only.

Fuel consumption data from EIA includes nonroad gasoline and diesel fuel consumption with commercial and industrial sectors. Therefore, nonroad emissions were included in the RCII emissions in this inventory (see Appendix B). Table C2 shows how EIA divides gasoline and diesel fuel consumption between the transportation, commercial, and industrial sectors.

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[35] Personal Communication. Lewison Lem, Strategic Consulting, reporting information provided by Bill Cloud, MDT.
[36] Energy Information Administration, State Energy Consumption, Price, and Expenditure Estimates (SEDS), http://www.eia.doe.gov/emeu/states/_seds.html
[37] Federal Highway Administration, Highway Statistics 2002, http://www.fhwa.dot.gov/policy/ohim/hs02/index.htm
[38] Energy Information Administration, http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_SMT_a.htm .

Table C1. Key assumptions and methods for the transportation inventory and projections

Vehicle Type and Pollutants	Methods
On-road gasoline, diesel, natural gas, and LPG vehicles – CO_2	**Inventory (1990 – 2005)** EPA SGIT and fuel consumption from EIA SED and EIA Natural Gas Navigator. **Reference Case Projections (2006 – 2020)** Transportation fuel consumption projections for the Mountain Region from EIA Annual Energy Outlook 2006.
On-road gasoline and diesel vehicles – CH_4 and N_2O	**Inventory (1990 – 2005)** The onroad vehicle CH_4 and N_2O emission factors by vehicle type and technology type were updated to the latest factors used in the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003.* VMT taken from FHWA's *Highway Statistics* was added for 2002. **Reference Case Projections (2006 – 2020)** The average annual growth rate for VMT is assumed to be 1.92% per year from 2002 to 2020, based on projections provided by the MDT to the Transportation Sector Technical Working Group of the Montana CCAC.
Non-highway fuel consumption (jet aircraft, gasoline-fueled piston aircraft, gasoline-fueled boats) – CO_2, CH_4 and N_2O	**Inventory (1990 – 2005)** EPA SGIT and fuel consumption from EIA SEDS. **Reference Case Projections (2006 – 2020)** Transportation fuel consumption projections for the Mountain Region from EIA Annual Energy Outlook 2006.

Table C2. EIA classification of gasoline and diesel consumption

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

Key uncertainties

One uncertainty is the consumption of international bunker fuels included in jet fuel consumption from EIA. This fuel consumption associated with international air flights should not be included in the state inventory; however, data were not available to subtract this consumption from total jet fuel estimates. Another source of uncertainty is the lack of VMT data for alternative fuel vehicles. VMT for these vehicles are assumed to be included in the gasoline and diesel VMT estimates; therefore, CH_4 and N_2O emissions from these vehicles are included in the gasoline and diesel emission estimates. The CH_4 and N_2O emissions for these vehicles are small compared to the total emissions. Also, CH_4 and N_2O emission factors for these vehicles are similar to those of gasoline and diesel vehicles; therefore, the effect on the total emissions estimate is assumed to be small.

Another uncertainty is the contribution of out-of-state travel and non-residents to the estimates of Montana's transportation GHG emissions. Following guidelines from US EPA SGIT for state GHG emissions, the GHG emission estimates for Montana are based on energy consumption data from the US EIA. The EIA data reflect fuel sales in the state, rather than fuel consumption.

It is possible for vehicles to purchase fuel in Montana that is then consumed in a different state. Also out-of-state drivers will consume fuel while traveling in Montana. While the non-resident contribution is an uncertainty for any state GHG estimate, the affect may be relatively larger in Montana due to the large fraction of out-of-state travelers. For example, in the *2002 Nonresident All Year and Four Season Comparison: Visitor Profile*[39], the Institute for Travel and Recreational Research reports that nonresidents accounted for up to 46% of the traffic on one section of I-90. Data are not available to reliably determine the contribution of nonresident travelers to Montana's GHG emissions but future analysis could provide some rough estimates.

[39] http://www.itrr.umt.edu/research/NonresSeason02.pdf

Appendix D. Industrial Processes

Emissions in this category span a wide range of activities, and reflect non-combustion sources of CO_2 from industrial manufacturing (cement, lime, and soda ash production plus emissions from limestone and dolomite use), the release of hydrofluorocarbons (HFCs) from cooling and refrigeration equipment, perfluorocarbons (PFCs) from aluminum production, and the release of sulfur hexafluoride (SF6) from electricity transformers.

Overall, industrial processes and related emissions, as shown in Figure D1, showed an overall decrease from 1990 though 2003 but are expected to continue to grow strongly through 2020. Note, that the total contribution to Montana's GHG emissions from this category remains quite small, less than 3% of total gross emissions. The contributions of each sub-category are shown in Figure D2 and explained below.

Figure D1. GHG emissions from industrial processes, 1990-2020

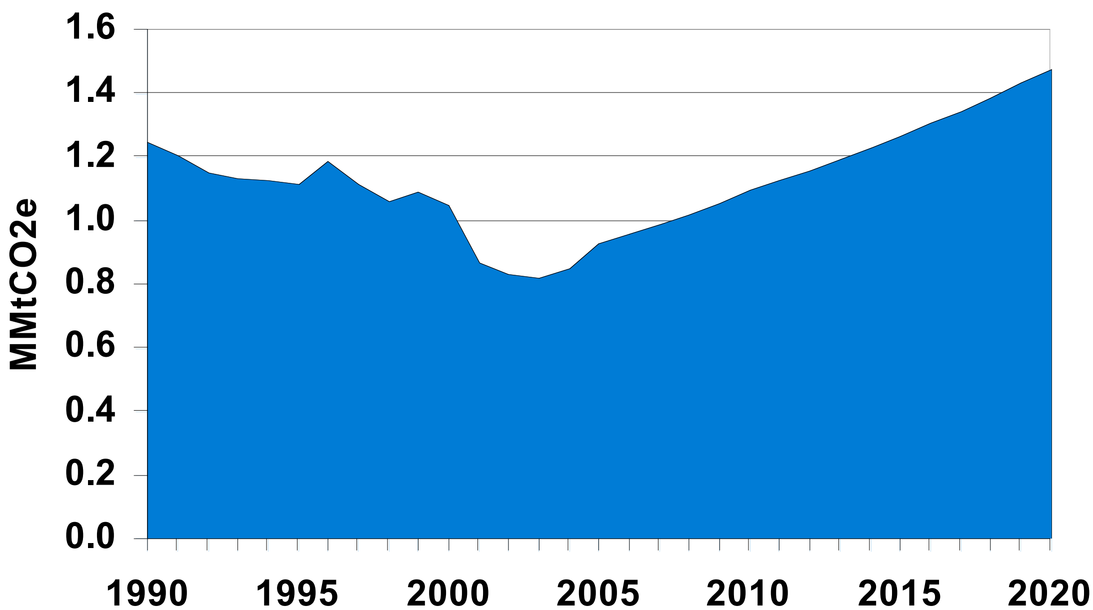
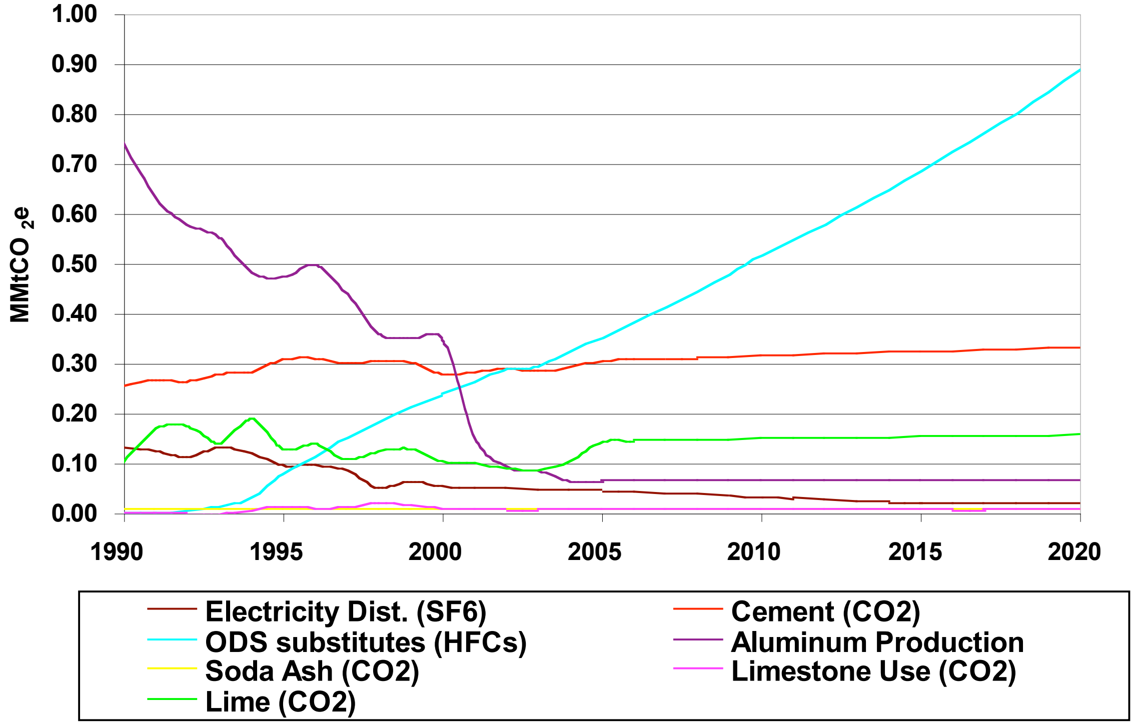


Figure D2. GHG emissions from industrial processes, 1990-2020, by source



Aluminum production generates two types of perfluorocarbons – tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6) – which are highly potent greenhouse gases. As shown in Figure D2, estimated GHG emissions from this source in Montana have shown significant ups and downs in the past, based partly on the variation in aluminum production and partly on changes to the manufacturing process that have led to lower GHG emissions.[40] High uncertainty exists with this data since the industry in Montana did not provide data on production or on GHG emissions per unit of production. Based on data from MDEQ and default values from SGIT, estimated GHG emissions from aluminum production decreased from about 0.75 MMtCO2e in 1990 to less than 0.1 MMtCO2e in 2005. The reference case projections assume that GHG emissions from this source will remain near 2005 levels through 2020.

Cement production emits CO_2 during the calcination process, whereby calcium carbonate ($CaCO_3$) is converted to calcium oxide (CaO). This process also requires significant energy consumption. Emissions related to fuel use at cement plants are reported in the RCI section above. The process emissions are directly related to the amount of clinker and masonry cement produced. For 1990-2005, GHG emissions are calculated as the production from this plant by a standard emission factor of 0.507 tons CO_2/ton clinker.[41] Cement production is projected to increase at the same rate as population.

[40] Data on aluminum production was provided by MDEQ for 2002, 2003, 2004 and 2005. Production for other years and the GHG emissions rate per aluminum production are based on SGIT defaults.
[41] Annual production from the cement plants came from Eric Merchant, MDEQ based on information provided by cement manufacturers (Montana City and Holcim).

After 2005, emissions from HFCs in refrigeration and air conditioning equipment dominate the category and show strong growth through 2020. HFCs are being used to substitute for ozone-depleting substances (ODS), most notably CFCs (also potent warming gases) in compliance with the *Montreal Protocol*.[42] Even low amounts of HFC emissions, from leaks and other releases under normal use of the products, can lead to high GHG emissions. Emissions from the ODS substitutes in Montana are estimated to have increased from 0.0002 $MMtCO_2e$ in 1990 to 0.08 $MMtCO_2e$ in 2002, with further increases of 8% per year expected from 2005 to 2020. The estimates for the emissions in Montana are based on the state's population and estimates of emissions per capita from the U.S. EPA national GHG inventory.[43]

Emissions of SF_6 from electrical equipment have experienced declines since the early-nineties (see Figure D2), mostly due to voluntary action by industry. SF_6 is used as an electrical insulator and interrupter in the electricity transmission and distribution system. Emissions for Montana from 1990 to 2003 were estimated based on the estimates of emissions per kWh from the U.S. EPA GHG inventory (U.S. EPA 2005 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*) and Montana's electricity consumption. The U.S. Climate Action Report[44] shows expected decreases in these emissions at the national level, and the same rate of decline is assumed for emissions in Montana. The decline in emissions in the future reflects expectations of future actions by the electric industry to reduce these emissions.

Emissions from lime manufacture production are based on the amounts of these products produced in Montana[45] multiplied by emissions factors from SGIT. Emissions from soda ash, limestone and dolomite use are estimated by the state consumption of the products for various uses – uses such as sorbants for flue gas desulphurization processes for electric power plants or industry and material for glass making will heat limestone to a sufficiently high temperature to cause release of CO_2 emissions.[46] The assumed trend is for these emissions to remain at 2002 levels through 2020.

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[42] ODS substitutes are primarily associated with refrigeration and air conditioning, but also many other uses such as fire extinguishers, solvent cleaning, aerosols, foam production ns for ODS substitutes depend on technology characteristics in a range of equipment. For the US national inventory, a detailed stock vintaging model was used, but such analysis has not been completed at the state level. This report uses the EPA SGIT procedure of estimating state-level emissions based on the state's fraction of US population and the US emissions. Growth rates are based on growth in projected national emissions from recent EPA report, US EPA 2004, *Analysis of Costs to Abate International ODS Substitute Emissions,* EPA 430-R-04-006.
http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/RAMR62AS98/$File/IMAC%20Appendices%206-24.pdf

[44] U.S. Department of State, *U.S. Climate Action Report 2002*, Washington, D.C., May 2002.
http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/SHSU5BNQ76/$File/ch5.pdf
[45] Lime production from Eric Merchant, MTDEQ based on information provided by Graymont Lime.
[46] Consumption data is from the United States Geological Survey (USGS).

Key Uncertainties

Since emissions from industrial processes are determined by the level of production and the production processes of a few key industries, there is relatively high uncertainty regarding future emissions. Future emissions depend on the competitiveness of Montana manufacturers, and the specific nature of their production processes.

The projected largest source of future industrial emissions, HFCs used in cooling applications, is subject to a number of uncertainties as well. First, historical emissions are based on national estimates for emission factors; Montana-specific estimates are currently unavailable. Second, emissions will be driven by future choices regarding air conditioning technologies and coolants used, for which a number of options currently exist.

Appendix E. Fossil Fuel Production Industry[47]

Greenhouse gas (GHG) emissions are released during the production, processing, transmission, distribution, and consumption of fossil fuels. This appendix reports GHGs emitted as a result of these activities, both combustion emissions from fuel consumption in the production, processing, and transport of fossil fuels,[48] as well as fugitive emissions from coal mining and oil and gas systems. Fugitive emissions are releases of methane (CH_4) and carbon dioxide (CO_2) gases released via leakage and venting at coal mines, oil and gas fields, processing facilities, and pipelines. Nationally, fugitive emissions from natural gas systems, petroleum systems, and coal mines accounted for 2.8% of total US GHG emissions in 2004 on a CO_2 equivalent basis.[49]

Industry Overview

Oil production in Montana peaked in 1968 at 49million barrels annually.[50] Montana currently ranks 10th in oil production among US states, accounting for about 1% of US crude oil production. Montana's proved crude oil reserves sit at 364 million barrels (bbls), 1% of US proved reserves. Montana has 4 petroleum refineries, with a combined crude oil distillation capacity of 66 million barrels annually.[51] Alberta crude oil is the primary crude oil source for these refineries: in recent years, Alberta has provided 75% for the crude oil processed by Montana refineries, with 4% coming from Montana and 21% from Wyoming.[52]

Montana currently produces more natural gas than it consumes. For example, in 2002, Montana produced 86 billion cubic feet (Bcf) and consumed 70 Bcf . Natural gas price increases since 2000 have resulted in increased Montana gas production. Coal bed methane has not yet become a significant source of natural gas production in the state, but is expected to play a larger role in the near future.[53] There is interest in coal-to-liquids development in Montana, as indicated by Governor Brian Schweitzer's October 2, 2006 announcement of plans for a coal-to-liquids plant near Roundup.[54] Still, any commercial scale coal-to-liquids production appears to be a number of years away.[55]

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[47] This category includes emissions from the production, processing and transmission of natural gas, oil and coal. Emissions are released due to energy consumption (mostly CO2) and methane release (venting or leaks) during processing and transmission.
[48] Note that any GHG emissions resulting from energy consumed in the mining of coal are excluded from this sector, due to lack of disaggregated data for this activity. Instead, these GHG emissions are aggregated within the emissions reported for the industrial sector (see Appendix B).
[49] "The US Inventory of Greenhouse Gas Emissions and Sinks", US EPA, 2005.
[50] "Understanding Energy in Montana", MDEQ Report for the EQC, October 2004, Accessed at http://www.leg.mt.gov/css/publications/lepo/2005_deq_energy_report/2005deqenergytoc.asp
[51] US DOE Energy Information Administration website.
[52] "Understanding Energy in Montana", DEQ Report for the EQC, October 2004.
[53] Understanding Energy in Montana", DEQ Report for the EQC, October 2004, Accessed at http://www.leg.mt.gov/css/publications/lepo/2005_deq_energy_report/2005deqenergytoc.asp
[54] On-line news sources – CBS, Reuters, Billings Gazette, etc. Accessed December 15, 2006.
[55] Montana Governor Brian Schweitzer Hot Topics Accessed at http://governor.mt.gov/hottopics/faqsynthetic.asp Accessed January 15, 2007.

Montana has six operational coal mines which produced 40 million short tons of coal in 2005.[56] Of Montana's six coal mines, one is underground, while five are surface mines.

Oil and Gas Industry Emissions

Emissions of carbon dioxide (CO_2) and methane (CH_4) occur at many stages of production, processing, transmission, and distribution of fossil fuels. With over 4,000 oil wells and over 5,000 gas wells in the state, 3 operational gas processing plants, 4 oil refineries, and over 10,000 miles of gas pipelines[57], there are significant uncertainties associated with estimates of the state's GHG emissions from the fossil fuels sector. This is compounded by the fact that there are no regulatory requirements to track CO_2 or methane emissions. As a result, greenhouse gas emissions can only be estimated based on industry-wide averages reported at the state level.

Fortunately, the State Greenhouse Gas Inventory Tool (SGIT) developed by the US EPA facilitates development of an estimate of state-level fugitive greenhouse gas emissions from gas and oil systems.[58] Methane emission estimates are calculated by multiplying emissions-related activity levels (e.g. miles of pipeline, number of compressor stations) by aggregate emission factors. Key information sources for the activity data are the EIA, Gas Facts, and Energize Montana. Methane emissions were estimated using SGIT, with reference to the EIIP guidance document.

Table E1 provides an overview of the required data and data sources used to calculate inventory estimates.

Coal Production Emissions

Methane occurs naturally in coal seams, and is typically vented during mining operations for safety reasons. Coal mine methane emissions are usually considerably higher, per unit of coal produced, from underground mining than from surface mining.

Methane emissions from coal mines in this inventory are as reported by the EPA, and include emissions from underground coal mines, surface mines, and post-mining activities.[59] As Montana currently has only one underground mine, coal mine methane emissions are a small contribution to total fossil fuel emissions. Note that any GHG emissions resulting from energy consumed in the mining of coal are excluded from this sector, due to lack of disaggregated data. Instead, these GHG emissions are aggregated within the emissions reported from the industrial sector (see Appendix B).

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[56] Energy Information Administration data.
[57] Data from the Energy Information Administration and the American Gas Association's annual publication "Gas Facts".
[58] Methane emissions were calculated using SGIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems", March 2005.
[59] Emissions from EPA *Inventory of Greenhouse Gas Emissions and Sinks: 1990-2004* (April 2006) http://yosemite.epa.gov/OAR/globalwarming.nsf/UniqueKeyLookup/RAMR6MBLPF/$File/06upfront.pdf

Table E1. Approach to estimating historical carbon dioxide and methane emissions from natural gas and oil systems

	Approach to Estimating Historical Emissions	
Activity	***Required Data for SGIT***	***Data Source***
Natural Gas Drilling and Field Production	Number of wells	EIA
	Miles of gathering pipeline	Gas Facts[60]
Natural Gas Processing	Number of gas processing plants	EIA[61]
Natural Gas Transmission	Miles of transmission pipeline	Gas Facts[60]
	Number of gas transmission compressor stations	EIIP[62]
	Number of gas storage compressor stations	EIIP[63]
	Number of LNG storage compressor stations	Unavailable, assumed negligible.
Natural Gas Distribution	Miles of distribution pipeline	Gas Facts[60]
	Total number of services	Gas Facts
	Number of unprotected steel services	Ratio estimated from 2002 data[64]
	Number of protected steel services	Ratio estimated from 2002 data[64]
Natural Gas Industry (fuel use)	Annual amount of energy consumed	EIA[65]
Coal Bed Methane – Entrained CO_2	Average % CO_2	Industry and Government Contacts
Oil Production	Annual production	EIA[66]
Oil Refining (fuel use)	Annual amount of energy consumed	EIA[67]
Oil Refining	Annual amount refined	EIA[68]
Oil Transport	Annual oil transported	Unavailable, assumed oil refined = oil transported

[60] No Gas Facts available for 1991 and 1993, so a linear relationship was assumed to extrapolate from the previous and subsequent year.
[61] EIA reported data for 1995 and 2004.
[62] Number of gas transmission compressor stations = miles of transmission pipeline x 0.006 EIIP. Volume VIII: Chapter 5. March 2005.
[63] Number of gas storage compressor stations = miles of transmission pipeline x 0.0015 EIIP. Volume VIII: Chapter 5. March 2005.
[64] Gas Facts reported unprotected and protected steel services for 2002, but only total services for other years. Therefore the ratio of unprotected and protected steel services in 2002 was assumed to be the ratio for all other years (0.4891 for protected services and 0.0045 for unprotected services). This yields more congruent results than the EIIP guidance of using multipliers of 0.2841 total services for protected steel services, and 0.0879 for unprotected steel services.
[65] Energy Information Administration reports natural gas lease fuel, plant fuel, pipeline and distribution use, and refinery gas.
[66] Data extracted from the Petroleum Supply Annual for each year.
[67] Data on refinery gas consumption from EIA's State Energy Data.
[68] Refining assumed to be equal to the total input of crude oil into PADD IV times the ratio of Montana's refining capacity to PADD IV's total refining capacity. No data for 1995 and 1997, so linear relationship assumed from previous and subsequent years.

Future Fossil Fuel Industry Emissions

Estimating potential future GHG emissions from oil and gas systems and coal mining requires estimation of production, processing, and transport of these fossil fuels. Future projections of methane emissions from oil and gas systems are calculated based on two key drivers:

- Consumption – projections of natural gas consumption in Montana.
- Production – projected production of coal, natural gas, and oil, including unconventional sources, are included in the fossil fuel scenarios below.

Due to the high levels of uncertainty surrounding future fossil fuel activity in Montana, particularly around the development of 'unconventional' sources and the GHG emissions associated with these, two scenarios were developed for future fossil fuel emissions – the reference case and the high fossil fuel production scenario (these two cases were also developed for the electric sector). For each case, simple assumptions were made to develop projections for fossil fuel activities, relying to the extent possible on existing proposals and announcements regarding oil, gas, and coal projects in Montana.

Reference Case
Projected emissions for the reference case are generally based on an assumption of a continuation of recent trends in production and processing trends in the state, or on an assumption of emission levels holding flat at current levels (where trends are hard to discern or no new facilities are planned). Simple assumptions were made for activities with minimal impact on the inventory, such as gas processing and coal mine methane. Assumptions for the reference case projections are outlined in Table E2.

Table E2. Key assumptions and methods for reference case projections for Montana

Activity	*Key Assumptions*
Natural Gas Drilling and Field Production	Emissions follow trend of natural gas production, which continues to grow at 4.5% annually until 2010, then holds flat until 2020.[69]
Natural Gas Processing	With only 3 gas processing plants in the state (declining from 8 in 1995), gas processing emissions projected to hold flat until 2020.[70]
Natural Gas Transmission	Emissions continue to grow at an average of 0.5% annually.[71]
Natural Gas Distribution	Distribution emissions projected to follow growth in natural gas consumption, based on AEO regional projections.[72]

[69] Assumption based on calculations from EIA data, supported by discussion in "Understanding Energy in Montana", DEQ Report for the EQC, October 2004, Accessed at http://www.leg.mt.gov/css/publications/lepo/2005_deq_energy_report/2005deqenergytoc.asp . Based on EIA data, marketed natural gas production averaged 4.5% growth annually between 1990 and 2005.
[70] Assumption based on EIA gas processing data. Historically, natural gas production, processing, and transmission have grown at differing rates; therefore, projected growth rates also differ.
[71] Natural gas transmission emissions grew at an average annual rate of 0.51% between 1990 and 2002.

Coal Bed Methane	Assumes very limited CBM activity (production system emissions accounted for in natural gas drilling and field production, above.) Entrained CO2 estimates assumed negligible given minimal CBM activity.
Oil Production	Emissions follow trend of state oil production, which is projected to grow at 5% annually until 2010, then hold flat until 2020.[73]
Oil Refining	Assumes little growth in state refining, emissions projected to hold flat at 2004 levels.
Oil Transport	Emissions follow trend of state oil refining, as above.
Coal Mining Methane	Emissions held flat at 2004 levels[74]
Coal-to-Liquids	Assumes no commercial production.

High Fossil Fuel Scenario

Unlike the reference case, the high fossil fuel scenario assumes that regional fossil fuel production and processing activities increase rapidly and that a number of unconventional oil, gas, and coal activities gain considerable traction over the next 15 years in the State. Renewed interest in a number of unconventional technologies is already apparent in response to concerns about energy security and high energy prices, along with increased activity in neighboring states and internationally.

This scenario assumes the following additional activities occur in Montana by 2020:

- Coal bed methane development begins in 2006 and proceeds fairly rapidly, based on estimates from the Montana Environmental Impact Statement.[75] In this scenario, total natural gas production triples between 2005 and 2010, and increases an additional 74% above 2010 levels by 2020.[76]
- Montana refining capacity increases, both through expansion of existing refineries and the addition of a new refinery, for refining of Athabasca crude from Alberta's oil sands.[77]
- Two new natural gas transmission lines cross the state.
- Two commercial coal-to-liquids plants are operating in Montana.

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[72] Assumption based on regional projections from the EIA's Annual Energy Outlook 2006 (AEO2006).
[73] Assumption based on "Understanding Energy in Montana", DEQ Report for the EQC, October 2004, Accessed at http://www.leg.mt.gov/css/publications/lepo/2005_deq_energy_report/2005deqenergytoc.asp and supported by Tom Richmond of the Montana Board of Oil and Gas.
[74] Note that coal mine methane emissions are a very small portion of total fossil fuel industry emissions.
[75] 'Final Statewide Oil and Gas Environmental Impact Statement and Proposed Amendment of the Powder River and Billings Resource Management Plans', January 2003, U.S Dept. of the Interior and the State of Montana. Assumes Year 1 in this document is 2005, as advised by Jeff Blend, MT DEQ, November 9, 2006.
[76] From 'Final Statewide Oil and Gas Environmental Impact Statement and Proposed Amendment of the Powder River and Billings Resource Management Plans'. CBM well projections (pg 4-117) and assumption that the average CBM production well in Montana produces 125,000 cubic feet per day, pg 4-111. Conventional natural gas projections outlined in Table E3.
[77] Additional oil production, beyond the growth projected in the reference case, was not included in the high fossil fuel scenario. It is possible that additional oil production could occur but the overall GHG emissions associated with the increased oil production in Montana are low compared with GHG emissions from increased oil refining, petroleum product consumption, or energy consumed in coal to liquids refining.

- Coal mining increases modestly with coal-to-liquids development in the State.

Table E3 outlines the key assumptions for the high fossil fuel case, both from conventional and unconventional sources.

Table E3. Key assumptions and methods for high fossil fuel scenario projections

Activity	***Key Assumptions and Methods***
Natural Gas Drilling and Field Production	Conventional natural gas increases at 6.5% annually until 2010, then holds flat (as in reference case) until 2020[78].
Natural Gas Processing	Emissions follow trend of conventional natural gas production, as above.[79]
Natural Gas Transmission	Assumes two new natural gas transmission lines cross the State, operational in 2012 and 2016.[80]
Natural Gas Distribution	*Same as reference case.*
Coal Bed Methane	Assumes CBM production growth as predicted in the Montana Environmental Impact Statement,[81] averaging almost 80% annual growth in the first five years, and slowing to about 6% average annual growth between 2012 and 2020. Note that levels of entrained CO_2 above pipeline specification in CBM wells has not been included[82]
Oil Production	*Same as reference case*[83]
Oil Refining	Assumes additional refining capacity of 50,000 bbl/day at existing refineries, and a new 100,000 bbl/day refinery,[84] for an average annual growth of 4.4% between 2005 and 2020.
Oil Transport	Emissions follow trend of state oil refining, as above.
Coal Mining Methane	Emissions hold flat at 2004 levels until startup of coal-to-liquids plants, as below.[85]

78 Personal communication with Paul Cartwright, MDEQ. January 8, 2007.
79 While natural gas processing has been declining in recent years, increased production of conventional gas and coal bed methane will likely result in some increased gas processing in the state.
80 E-mail communication with Jeff Blend, MDEQ, December 15th, 2006. Distance across Montana, north to south, estimated at 400 miles using google maps.
81 'Final Statewide Oil and Gas Environmental Impact Statement and Proposed Amendment of the Powder River and Billings Resource Management Plans', January 2003, U.S Dept. of the Interior and the State of Montana. Assumes Year 1 in this document is 2006, based on direction from Jeff Blend, MDEQ, November 9, 2006.
82 Depending on entrained CO2 levels in Montana CBM, this could be a significant source of CO2.
83 Personal communication with Paul Cartwright, MDEQ. January 8, 2007. Unless a new oil pipeline is projected for the State, there are no signals to indicate higher sustained oil production growth.
84 Personal communication, Paul Cartwright, MDEQ, January 9, 2007.
85 Based on coal-to-liquids data provided by Diane Kearney, EIA, using methodology described in D. Gray and G. Tomlinson, Coproduction: A Green Coal Technology, Technical Report MP 2000-28 (Mitretek, March 2001), a 22,000bbl/day CTL plant will require approximately 4 million short tons coal per year.

Coal-to-Liquids	Assumes first 22,000 bbl/day coal-to-liquids plant in 2015, second 22,000 bbl/day plant by 2020.[86]

Results – Reference Case

Table E4 displays the estimated methane emissions from the fossil fuel industry in Montana from 1990 to 2005, with reference case projections to 2020. Emissions from this sector grew by 40% from 1990 to 2005, and are projected to increase modestly, by a further 7%, between 2005 and 2020. The oil and natural gas industries are the largest contributors to fossil fuel greenhouse gas emissions in Montana currently. A trend that is further reflected in the reference case projections for Montana.

[86] Coal-to-liquids plant capacity estimates and assumption that CTL development will have to be paired with some level of carbon capture and storage (likely enhanced oil recovery) based on input from Paul Cartwright, MDEQ, Jan 09 2007. Assumed 30% of CO2 is sequestered due to losses underground from enhanced oil recovery (Paul C, MDEQ), backed by IEA. 2004. *Prospects for* CO2 *Capture and Storage*, p. 81, which reports the proportion retained in EOR varying between 20%–67%. Greenhouse gas emissions intensity estimate provided by Diane Kearney at EIA. Model plant based on methodology described in D. Gray and G. Tomlinson, Coproduction: A Green Coal Technology, Technical Report MP 2000-28 (Mitretek, March 2001). Assumes 40% of emissions attributed to co-gen plant, thus not included in Appendix E. Note that any potential fugitive emissions from CTL are not included due to a lack of data.

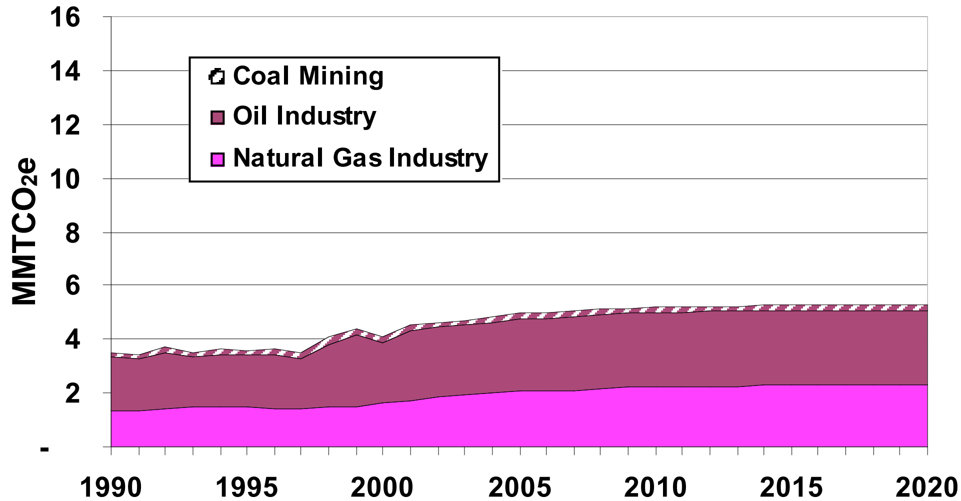
Table E4. GHG emissions and reference case projections for the fossil fuel industry in Montana

(Million Metric Tons CO_2e)	1990	2000	2005	2010	2015	2020
Fossil Fuel Industry	**3.5**	**4.1**	**5.0**	**5.2**	**5.3**	**5.3**
Natural Gas Industry	1.4	1.7	2.0	2.3	2.3	2.4
Total Fuel Use (CO_2)	0.2	0.6	0.7	0.8	0.8	0.8
Total Methane Emissions (CH_4)	1.1	1.1	1.3	1.5	1.5	1.6
Total Entrained (CO_2)	0.0	0.0	0.0	0.0	0.0	0.0
Production	0.3	0.4	0.7	0.8	0.8	0.8
Fuel Use (CO_2)	*0.1*	*0.1*	*0.2*	*0.3*	*0.3*	*0.3*
Methane Emissions (CH_4)	*0.2*	*0.3*	*0.4*	*0.5*	*0.5*	*0.5*
Processing	0.2	0.1	0.1	0.1	0.1	0.1
Fuel Use (CO_2)	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Methane Emissions (CH_4)	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
Entrained Gas (CO_2)	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Transmission	0.7	1.0	1.0	1.1	1.1	1.1
Fuel Use (CO_2)	*0.1*	*0.4*	*0.4*	*0.5*	*0.5*	*0.5*
Methane Emissions (CH_4)	*0.6*	*0.6*	*0.6*	*0.6*	*0.7*	*0.7*
Distribution	0.1	0.1	0.2	0.2	0.3	0.3
Methane Emissions (CH_4)	*0.1*	*0.1*	*0.2*	*0.2*	*0.3*	*0.3*
Oil Industry	2.0	2.2	2.7	2.8	2.8	2.8
Production	0.1	0.1	0.3	0.3	0.3	0.3
Methane Emissions (CH_4)	*0.1*	*0.1*	*0.3*	*0.3*	*0.3*	*0.3*
Refineries	1.8	2.1	2.4	2.4	2.4	2.4
Fuel Use (CO_2)	1.8	2.1	2.4	2.4	2.4	2.4
Methane Emissions (CH_4)	0.0	0.0	0.0	0.0	0.0	0.0
Coal-to-Liquids (CO_2)	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Coal Mining (CH_4)	0.2	0.2	0.2	0.2	0.2	0.2

Note that CH_4 in the above table refers to the type of emission e.g. fugitive methane emission. All values in the above table are reported as million metric tons carbon dioxide equivalent (CO_2e). Distribution fuel use is included with transmission fuel use. Oil production fuel use is included in industrial fuel use (Appendix B).

Figure E1 displays the reference case methane emissions from coal mining, and natural gas and oil production, processing, and transport in the state, on a CO_2 equivalency basis.

Figure E1. Fossil fuel industry reference case emission trends (Million metric tons CO2e)



Results – High Fossil Fuel Case

Table E5 displays the estimated greenhouse gas emissions for the high fossil fuel scenario for Montana. For the high fossil fuel scenario, representing fairly rapid fossil fuel development, GHG emissions are projected to increase by a further 216% from 2005 to 2020. In this scenario, increased refining production and coal-to-liquids development have the most dramatic impact on increasing GHG emissions for the state. Also significant are the projected GHG emissions from natural gas transmission and coal bed methane production.

Table E5. GHG emissions and high fossil fuel scenario projections for the Montana fossil fuel industry.

(Million Metric Tons CO_2e)	1990	2000	2005	2010	2015	2020
Fossil Fuel Industry	**3.5**	**4.1**	**5.0**	**6.1**	**11.7**	**15.7**
Natural Gas Industry	1.4	1.7	2.0	2.8	3.3	3.6
Total Fuel Use (CO_2)	0.2	0.6	0.7	0.8	0.8	0.9
Total Methane Emissions (CH_4)	1.1	1.1	1.3	2.0	2.5	2.7
Total Entrained (CO_2)	0.0	0.0	0.0	0.0	0.0	0.0
Production	0.3	0.4	0.7	1.4	1.8	1.9
Fuel Use (CO_2)	*0.1*	*0.1*	*0.2*	*0.3*	*0.3*	*0.3*
Methane Emissions (CH_4)	*0.2*	*0.3*	*0.4*	*1.1*	*1.5*	*1.6*
Processing	0.2	0.1	0.1	0.1	0.1	0.1
Fuel Use (CO_2)	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Methane Emissions (CH_4)	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
Entrained Gas (CO_2)	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Transmission	0.7	1.0	1.0	1.1	1.2	1.3
Fuel Use (CO_2)	*0.1*	*0.4*	*0.4*	*0.4*	*0.5*	*0.5*
Methane Emissions (CH_4)	*0.6*	*0.6*	*0.6*	*0.6*	*0.7*	*0.7*
Distribution	0.1	0.1	0.2	0.2	0.3	0.3
Methane Emissions (CH_4)	*0.1*	*0.1*	*0.2*	*0.2*	*0.3*	*0.3*
Oil Industry	2.0	2.2	2.7	3.1	4.4	4.4
Production	0.1	0.1	0.3	0.3	0.3	0.3
Methane Emissions (CH_4)	*0.1*	*0.1*	*0.3*	*0.3*	*0.3*	*0.3*
Refineries	1.8	2.1	2.4	2.8	4.1	4.1
Fuel Use (CO_2)	1.8	2.1	2.4	2.8	4.1	4.1
Methane Emissions (CH_4)	0.0	0.0	0.0	0.0	0.0	0.0
Coal-to-Liquids (CO_2)	0.0	0.0	0.0	0.0	3.7	7.3
Coal Mining (CH_4)	0.2	0.2	0.2	0.2	0.2	0.3

Note that CH_4 in the above table refers to the type of emission e.g. fugitive methane emission. All values in the above table are reported as million metric tons carbon dioxide equivalent (CO_2e). Distribution fuel use included with transmission fuel use. Oil production fuel use included in industrial fuel use (Appendix B).

Figure E2 displays the high fossil fuel case methane emissions from natural gas and oil production, processing, and transport, and coal mining in the state, on a CO_2 equivalency basis.

Figure E2. Fossil fuel industry high fossil fuel scenario emission trends (Million metric tons CO2e)

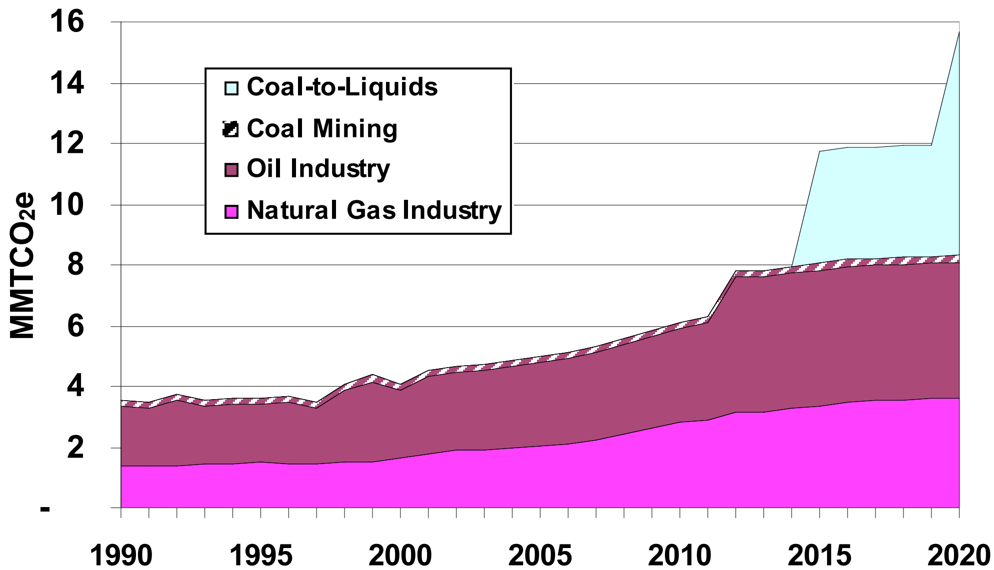


Table E6 presents a summary of GHG emissions from the Montana fossil fuel sector for both the reference case and the high fossil fuel scenario. The difference between the projected emissions in the reference case and the high fossil fuel scenario is a reflection of the uncertainty surrounding future energy developments in Montana. The projected growth between 2005 and 2020 is only 7% in the reference case and 216% in the high fossil fuel case, in which a number of unconventional technologies reach commercial scale production. Under the high fossil fuel scenario, GHG emissions in 2020 are 10 MMtCO2e higher than in the reference case, adding approximately 19% to the state's production-based emissions in that year.

Table E6. Comparison of total fossil fuel industry GHG emissions for reference and high fossil fuel scenario

(Million Metric Tons CO2e)	1990	2000	2005	2010	2015	2020
Reference Case	**3.5**	**4.1**	**5.0**	**5.2**	**5.3**	**5.3**
Natural Gas Industry	1.4	1.7	2.0	2.3	2.3	2.4
Oil Industry	2.0	2.2	2.7	2.8	2.8	2.8
Coal-to-Liquids	n/a	n/a	n/a	n/a	n/a	n/a
Coal Mining	0.2	0.2	0.2	0.2	0.2	0.2
High Fossil Fuel Scenario	**3.5**	**4.1**	**5.0**	**6.2**	**11.7**	**15.7**
Natural Gas Industry	1.4	1.7	2.0	2.9	3.4	3.6
Oil Industry	2.0	2.2	2.7	3.1	4.4	4.4
Coal-to-Liquids	0.0	0.0	0.0	0.0	3.7	7.3
Coal Mining	0.2	0.2	0.2	0.2	0.2	0.3

Key Uncertainties

Key sources of uncertainty underlying the estimates of historic emissions and both future scenarios are as follows:

- Projections of future production of fossil fuels. These industries are difficult to forecast with the mix of drivers: economics, resource supply, demand, and regulatory procedures. Large price swings, resource limitations, or changes in regulations could significantly affect technological innovation, future production levels, and the associated GHG emissions.
- Current levels of fugitive emissions. These are based on industry-wide averages, and until estimates are available for local facilities significant uncertainties remain.
- Other uncertainties include the fraction of entrained CO_2 in projected CBM production, the actual emissions intensity of any coal-to-liquids production, and potential emission reduction improvements to production, processing, and pipeline technologies.
- In addition, any oil pipeline constraints and/or potential oil pipeline projects which would impact oil transmission pipeline capacity have not been considered.

Appendix F. Agriculture

The emissions discussed in this appendix refer to non-energy emissions and sinks from agricultural practices. Energy emissions (fossil fuel combustion in agricultural equipment) are included in the RCI sector estimates. The agricultural emissions here include emissions from livestock, agricultural soil management and field burning.

Emissions Data and Methods
Agricultural emissions include CH_4 and N_2O emissions from enteric fermentation, manure management, agricultural soils and crop residue burning. Emissions were estimated with the use of EPA's SGIT. Data on crops and animals in the state from 1990 to 2002 from the USDA National Agriculture Statistical Service are incorporated as defaults within SGIT. Newer information from NASS on cattle populations (up to 2005) were incorporated into SGIT, as these are one of the primary drivers of GHG emissions in the agricultural sector. However, these newer data had little effect on the estimated emissions.

State-specific crop residue burning data were also investigated. In Montana, the only crop residue known to be burned is irrigated wheat. The default acreage burned in SGIT is 3%. Data from a WRAP-sponsored study suggest that only 1% of wheat residue is burned.[87] Other than cattle, activity data for all other crop and livestock sectors were held constant from 2002 – 2005.

Data and Methods for Soil Carbon Sinks
Carbon dioxide is either emitted or sequestered as a result of agricultural practices. Net carbon fluxes from agricultural soils have been estimated by researchers at the Natural Resources Ecology Laboratory at Colorado State University and are reported in the U.S. Inventory of Greenhouse Gas Emissions and Sinks[88] and the U.S. Agriculture and Forestry Greenhouse Gas Inventory. The estimates are based on the IPCC methodology for soil carbon adapted to conditions in the U.S. Preliminary state-level estimates of CO_2 fluxes from mineral soils and emissions from the cultivation of organic soils were reported in the U.S. Agriculture and Forestry Greenhouse Gas Inventory.[7] Currently, these are the best available data at the state-level for this category. The inventory did not report state-level estimates of CO_2 emissions from limestone and dolomite applications; hence, this source is not included in this inventory at present.

Carbon dioxide fluxes resulting from specific management practices were reported. These practices include: conversions of cropland resulting in either higher or lower soil carbon levels; additions of manure; participation in the Federal Conservation Reserve Program (CRP); and cultivation of organic soils (with high organic carbon levels). For Montana, Table F1 below shows a summary of the latest estimates available from the USDA.[89] The latest data available are

[87] *Non-Burning Management Alternatives on Agricultural Lands in the Western United States, Volume I: Agricultural Crop Production and Residue Burning in the Western United States*, Eastern Research Group, 2002.
[88] U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2004 (and earlier editions), U.S. Environmental Protection Agency, Report # 430-R-06-002, April 2006. Available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.
[89] U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001. Global Change Program Office, Office of the Chief Economist, U.S. Department of Agriculture. Technical Bulletin No. 1907. 164 pp. March 2004. http://www.usda.gov/oce/global_change/gg_inventory.htm; the data are in Appendix B table B-11. The table

for 1997 agricultural practices. These data show that changes in agricultural practices are estimated to result in a net sink of 2.3 $MMtCO_2e$/yr in Montana. Since data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing, the net sink of 2.3 $MMtCO_2e$/yr is assumed to remain constant.

Table F1. GHG emissions from soil carbon changes due to cultivation practices (MMtCO2e)

Changes in cropland			Changes in Hayland				Other			Total[4]
Plowout of grassland to annual cropland[1]	Cropland manage-ment	Other cropland[2]	Cropland converted to hayland[3]	Hayland manage-ment	Cropland converted to grazing land[3]	Grazing land manage-ment	CRP	Manure application	Cultivation of organic soils	Net soil carbon emissions
1.91	(0.59)	0.00	(1.28)	(0.07)	(0.48)	0.00	(1.80)	(0.08)	0.11	(2.30)

Based on USDA 1997 estimates. Parentheses indicate net sequestration.
[1] Losses from annual cropping systems due to plow-out of pastures, rangeland, hayland, set-aside lands, and perennial/horticultural cropland (annual cropping systems on mineral soils, e.g., corn, soybean, cotton, and wheat).
[2] Perennial/horticultural cropland and rice cultivation.
[3] Gains in soil carbon sequestration due to land conversions from annual cropland into hay or grazing land.
[4] Total does not include change in soil organic carbon storage on federal lands, including those that were previously under private ownership, and does not include carbon storage due to sewage sludge applications.

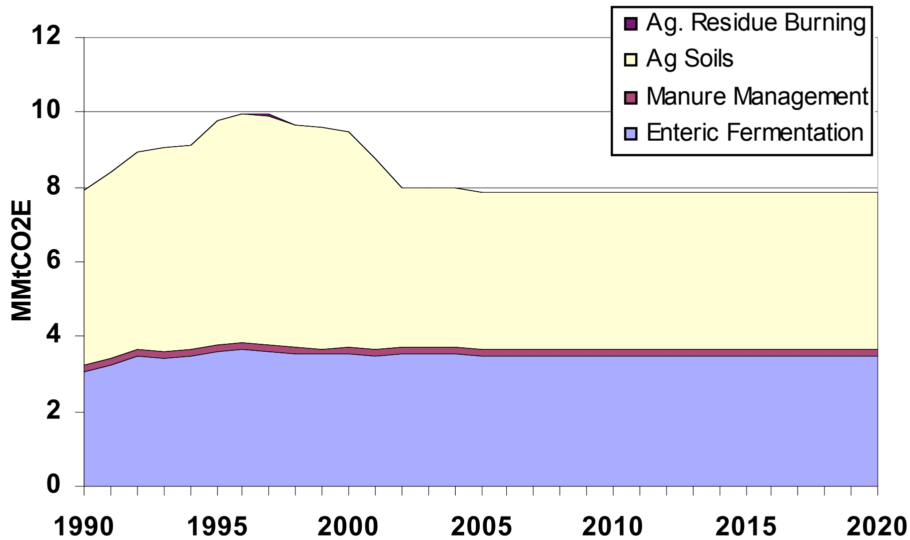
Historic Emissions and Projections

As shown in Figure F1, emissions from agricultural sources remain fairly stable from 1990 through 2020. Historically, total emissions for the sector have ranged from about 8 to 10 $MMtCO_2e$. Except for emissions from agricultural soils, emissions in each subsector were fairly static. For agricultural soils, emissions grew through the mid-1990's, but then have begun to fall since the late 1990's. Emissions from agricultural soils are N_2O emissions from the use of synthetic fertilizers, crop residue, nitrogen fixing crops, and manure application. Manure application is the largest contributor to the emissions from agricultural soils. There was no rice cultivation in Montana and therefore, no CH_4 and N_2O emissions from this sector.

No information was identified that suggested significant future changes in Montana agricultural practices or activity levels. Historical activity levels, based on USDA NASS data, do not show any significant positive or negative trends in Montana agricultural sectors. Therefore, emissions were held constant from 2005 – 2020.

contains two separate IPCC categories: "carbon stock fluxes in mineral soils" and "cultivation of organic soils." The latter is shown in the second to last column of Table F1. The sum of the first nine columns is equivalent to the mineral soils category.

Figure F1. Gross GHG emissions from agriculture



Note: From 2005 forward, agricultural activity (and emissions) are held constant. Gross emissions exclude soil carbon sinks.

Appendix G. Waste Management

Overview
GHG emissions from waste management include:

- Solid waste landfills – CH_4 emissions from landfills and waste combustion, accounting for identified CH_4 that is flared or captured for energy production;

- Solid waste combustion – emissions of CO_2, CH_4 and N_2O from controlled waste combustion (e.g. in waste to energy plants) or uncontrolled combustion (e.g. residential open burning of solid waste) and

- Wastewater management – CH_4 and N_2O from municipal and industrial wastewater treatment facilities.

Inventory & Forecast
Solid Waste Landfills
For solid waste management, we used the U.S. EPA SGIT, the U.S. EPA LMOP landfills database,[90] and additional landfill data from MDEQ to estimate emissions.[91] The data from MDEQ on additional landfill sites, their years of operation, waste in place, and use of landfill gas controls covered 30 sites. Data were sufficient from 25 of these sites to develop the inputs needed to SGIT to estimate emissions. To obtain the annual disposal for each landfill needed by SGIT, the waste-in-place was divided by the number of years of operation. This average annual disposal rate for each landfill was assumed for all years that the landfill was operating.

CCS used SGIT to model emissions for two different sets of landfills: (1) uncontrolled landfills; and (2) landfills with a landfill gas collection system and control (e.g. flare, leachate evaporation system, or other combustion device). The following three sites made up the controlled landfill group: Flathead County; Bozeman; and Missoula. For each of these landfills, we assumed that the overall collection and control efficiency is 75%.[92] The remaining sites were placed into the uncontrolled landfills category. No waste in place data were available for the following five uncontrolled sites, and these were excluded from the modeling: City of Hardin; Coral Creek; Lake County; Town of Chester; and Park County.

CCS used the SGIT default for industrial landfills. This default is based on national data indicating that industrial landfilled waste is emplaced at approximately 7% of the rate of MSW emplacement. No controls were assumed for industrial waste landfilling.

Growth rates for the 2005-2020 time-frame were developed from the growth in emissions during the period from 1995-2005. This period was selected due to the changes that occurred in the solid waste industry from the mid-1980s thru the early 1990s as a result of new regulations

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[90] LMOP database is available at: http://www.epa.gov/lmop/proj/index.htm. Database downloaded June 2006.
[91] Rick Thompson, MDEQ, personal communications with S. Roe, CCS, June and August, 2006.
[92] As per EPA's AP-42 Section on Municipal Solid Waste Landfills: http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf.

covering the solid waste industry. For uncontrolled landfills, the growth rate based on the historical emissions data was 2.4%/yr. For controlled sites, the growth rate is also 2.4%. For industrial waste landfilling, the growth was 3.2%/yr.

Solid Waste Combustion

The only municipal waste combustion facility in Montana was closed in 2005. SGIT defaults data were used to estimate emissions. These data included waste combustion tonnages from 1990-1998. No waste combustion data were provided for the post-1999 period. Projected emissions are assumed to remain at zero.

No data were identified to estimate emissions from open burning of solid waste (e.g. residential burn barrels).

Municipal Wastewater Treatment

GHG emissions from municipal wastewater treatment were also estimated. Emissions are calculated in EPA's SGIT based on state population, assumed biochemical oxygen demand (BOD) and protein consumption per capita, and emission factors for N_2O and CH_4. The key SGIT default values are shown in Table G1 below. The growth factor used to project emissions from 2005 to 2020 was 1.26%/yr (based on emissions growth from 1990-2005), which is slightly higher than the state's population growth rate over the 1990 to 2005 period.

Industrial Wastewater Treatment

For industrial wastewater emissions, SGIT provides default assumptions and emission factors for three industrial sectors: fruits & vegetables, red meat & poultry, and pulp & paper. Production rates or wastewater flows for each of these three sectors are needed to estimate CH_4 emissions. There are no known fruit/vegetable processing facilities in the state.[93] CCS did not identify any other data on wastewater flows for use in assessing emissions from the pulp & paper or meat & poultry industries.

Table G1. SGIT key default values for municipal wastewater treatment

Variable	Value
BOD	0.065 kg /day-person
Amount of BOD anaerobically treated	16.25%
CH_4 emission factor	0.6 kg/kg BOD
Montana residents not on septic	75%
Water Treatment N2O emission factor	4.0 g N_20/person-yr
Biosolids Emission Factor	0.01 kg N_2O-N/kg sewage-N

Source: US EPA. *State Greenhouse Gas Inventory Tool.* Draft Guidance http://www.epa.gov/ttn/chief/eiip/techreport/volume08/

[93] Bonnie Lovelace & Jeff May, MDEQ, personal communications with S. Roe, CCS, June 19-21, 2006.

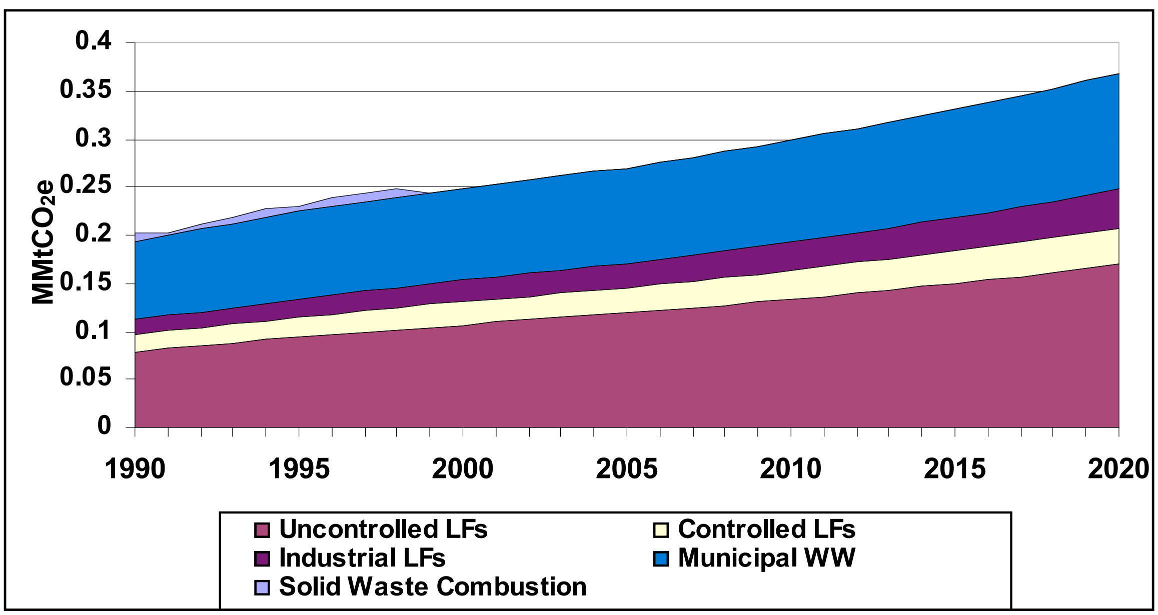
Results

Figure G1 shows the emission estimates for the waste management sector. Overall, the sector accounts for 0.27 $MMtCO_2e$ in 2005. Total sector emissions were estimated to be 0.20 $MMtCO_2e$ in 1990 and are estimated to grow to 0.37 $MMtCO_2e$ by 2020 under business as usual conditions.

For the reference case projections for MSW landfills, growth from the 2005 level was assumed to follow patterns in emissions growth at controlled and uncontrolled landfills between 1995 and 2005. Uncontrolled sites contributed 44% of the waste management sector emissions in 2005 (0.12 $MMtCO_2e$) and are projected to contribute 46% in 2020 (0.17 $MMtCO_2e$). Controlled sites contributed 10% of the waste management sector emissions in 2005 (0.03 $MMtCO_2e$), and the percent contributions are expected to remain the same in 2020 (0.04 $MMtCO_2e$). Industrial landfills contributed 9% in 2005 (0.03 $MMtCO_2e$), and this percentage contribution is expected to increase to 11% in 2020 (0.04 $MMtCO_2e$).

Emissions from municipal wastewater treatment were forecasted based on emissions growth from 1990-2005 (similar to population growth during this period). In 2005, municipal wastewater emissions were estimated to be 0.10 $MMtCO_2e$ (37% of waste management sector emissions) and are expected to grow to 0.12 $MMtCO_2e$ by 2020 (33% of waste management sector emissions). As mentioned above, no data were identified to estimate emissions from the industrial wastewater treatment sector.

Figure G1. Montana GHG emissions from waste management



Appendix H. Forestry

Overview

Forestland emissions refer to the net CO_2 flux[94] from forested lands in Montana, which account for about 24% of the state's land area.[95] The dominant forest type in Montana is Douglas Fir, which makes up about 32% of forested lands.[96] Other important forest types are Lodgepole Pine (22%), Fir-Spruce (21%), and Ponderosa Pine (13%).

Forestlands are net sinks of CO_2 in Montana. Through photosynthesis, carbon dioxide is taken up by trees and plants and converted to carbon in biomass within the forests. Carbon dioxide emissions occur from respiration in live trees and decay of dead biomass. In addition, carbon is stored for long time periods when forest biomass is harvested for use in durable wood products. CO_2 flux is the net balance of carbon dioxide removals from and emissions to the atmosphere from the processes described above.

Inventory and Reference Case Projections

For over a decade, the United State Forest Service (USFS) has been developing and refining a forest carbon modeling system for the purposes of estimating forest carbon inventories. The methodology is used to develop national forest CO_2 fluxes for the official US Inventory of Greenhouse Gas Emissions and Sinks.[97] The national estimates are compiled from state-level data. The Montana forest CO_2 flux data in this report come from the national analysis and are provided by the USFS.

The forest CO_2 flux methodology relies on input data in the form of plot level forest volume statistics from the Forest Inventory Analysis (FIA). FIA data on forest volumes are converted to values for ecosystem carbon stocks (i.e., the amount of carbon stored in forest carbon pools) using the FORCARB2 modeling system. Coefficients from FORCARB2 are applied to the plot level survey data to give estimates of C density (Mg per hectare) for a number of separate C pools.

CO_2 flux is estimated as the change in carbon mass for each carbon pool over a specified time frame. Forest volume data from at least two points in time are required. The change in carbon stocks between time intervals is estimated at the plot level for specific carbon pools (Live Tree, Standing Dead Wood, Under-story, Down & Dead Wood, Forest Floor, and Soil Organic Carbon) and divided by the number of years between inventory samples. Annual increases in carbon density reflect carbon sequestration in a specific pool; decreases in carbon density reveal

[94] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.
[95] Table 9 in "Montana's Forest Resources", USDA Forest Service, Resource Bulletin INT-81, September 1993, Conner, Roger C. and O'Brien, Renee A. There are a total of 22,400,000 acres of timberland and 91,000 acres of woodland in Montana. The same table shows Montana has a total land and water area of 94,109,000 acres.
[96] Based on data from the USFS: http://www.fs.fed.us/ne/global/pubs/books/epa/states/MT.htm.
[97] U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2004 (and earlier editions), US Environmental Protection Agency, Report # 430-R-06-002, April 2006. Available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

CO_2 emissions or carbon transfers out of that pool (e.g., death of a standing tree transfers carbon from the live tree to either the standing dead wood or down & dead pool). The amount of carbon in each pool is also influenced by changes in forest area (e.g. an increase in area could lead to an increase in the associated forest carbon pools and the estimated flux). The sum of carbon stock changes for all forest carbon pools yields a total net CO_2 flux for forest ecosystems.

In preparing these estimates, USFS estimates the amount of forest carbon in different forest types as well as different carbon pools. The different forests include those in the national forest system and those that are not federally-owned (private and other public forests). USFS also provides information on forests categorized as being either woodlands (forests with low productivity) and non-woodlands (e.g. timberlands or productive forest systems).

Carbon pool data for two periods are used to estimate CO_2 flux for each pool. The data shown in Table H1 are a summary of the FIA data used to derive the carbon pool and flux estimates that are summarized in Table H2. As shown in Table H1, the current forest carbon pool estimates are derived from 2004 FIA data. The previous inventory data came from a previous FIA cycle in 1989.

Table H1. Forestry data used to estimate forest CO2 flux

Forest	Current Inventory Source	Past Inventory Source	Avg. Year[1]	Interval[2] (yr)	Current Forest Area (10^3 hectares)	Previous Forest Area (10^3 hectares)
National Forests	FISDB21_MT_02_2005	FISDB21_MT_01_1989	2004.6	8.6	6,070	5,909
Non-Nat Forests	FISDB21_MT_02_2005	FISDB21_MT_01_1989	2004.6	15.6	4,053	3,488
				Totals	**10,123**	**9,397**

[1] Average year for the current FIA inventory data.
[2] The number of years between the current inventory source and the past inventory source (does not match database years).

The data in Table H1 show an increase of 726 kilo-hectares (1.8 million acres) in forested area during the period of analysis (1989-2004), which is approximately 115,000 acres per year. As mentioned under key uncertainties below, some of this difference is likely driven by methodological differences in survey methods between the two FIA cycles. Another forest grouping assessed by the USFS was the non-National Forests reserved forests (areas where no timber harvesting occurs). Because these areas were not well represented in the earlier FIA cycle, USFS suggested that CCS leave these out of the estimation of forest flux (essentially assuming that no net changes in carbon pools occurred in these areas). Hence, they are not shown in Table H1 and excluded from the flux estimates in Table H2. Additionally, discussions with USFS have indicated that the soil carbon pool estimates carry a high level of uncertainty and in many cases might not be statistically different than zero.[98] Although estimates are provided in Table H2 for organic soil carbon, these values are excluded from the totals in Table ES-1 and Table 1, at the start of the document.

[98] Rich Birdsey, USFS, personal communication with CCS, May 2007.

Table H2 provides a summary of the size of the forest carbon pools for the final survey period and the resultant flux estimates (in units of C and CO_2) developed by the USFS. A total of 21 $MMtCO_2$ is estimated to be sequestered in Montana forests each year with most of this accumulating in the live tree and forest floor carbon pools. Note that this analysis averages out annual fluctuations in carbon sequestration rates over an approximate 9 year time interval in National Forests and 16 years in non-National Forest areas.

In addition to the forest carbon pools, additional carbon stored as biomass is removed from the forest for the production of durable wood products; carbon remains stored in the products pool or is transferred to landfills where much of the carbon remains stored over a long period of time. An estimated 2.5 $MMtCO_2e$ is sequestered annually in wood products; these data are based on the latest estimates from USFS.[99] Additional details on all of the forest carbon inventory methods can be found in Annex 3 to EPA's 2006 GHG inventory for the U.S.[100]

Table H2. Forestry CO2 flux estimates for Montana

Forest	Carbon Pool (MMt Carbon)					
	Live Tree	Standing Dead	Under-story	Down & Dead	Forest Floor	Soil Organic
National Forests	464	56	14	34	202	239
Non-National Forests	190	26	12	14	117	159
Totals	**654**	**82**	**26**	**48**	**318**	**398**

Forest	Carbon Pool Flux (MMt C/yr)					
	Live Tree	Standing Dead	Under-story	Down & Dead	Forest Floor	Soil Organic
National Forests	-2.63	-0.42	-0.06	-0.21	-1.07	-0.83
Non-National Forests	-0.02	-0.14	-0.17	-0.01	-0.91	-1.53
Totals	**-2.6**	**-0.56**	**-0.23**	**-0.22**	**-2.0**	**-2.4**

Forest	Carbon Pool Flux (MMt CO_2/yr)					
	Live Tree	Standing Dead	Under-story	Down & Dead	Forest Floor	Soil Organic
National Forests	-9.66	-1.53	-0.21	-0.78	-3.93	-3.06
Non-National Forests	0.06	-0.51	-0.62	-0.03	-3.35	-5.63
Totals	**-9.6**	**-2.04**	**-0.83**	**-0.81**	**-7.3**	**-8.7**

Total Forest Flux =	**-29.3**
Total Forest Flux = (excluding soil organic carbon)	**-20.6**
Harvested Wood Products =	**-2.5**
Total Statewide Flux = (excluding soil organic carbon)	**-23.1**

NOTE: Totals may not add exactly due to rounding.
USFS have indicated that the soil carbon pool estimates carry a high level of uncertainty

[99] Data provided by Jim Smith, USFS, to CCS in December 2006.
[100] Annex 3 to EPA's 2006 report can be downloaded at: http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/RAMR6MBLNQ/$File/06_annex_Chapter3.pdf.

For the 1990 and 2000 historic emission estimates as well as the reference case projections, the annual forest carbon fluxes of forestlands were assumed to be at the same levels as those shown in Table H2. This assumes that the underlying increase in forest area continues into the future at a constant annual rate and that growth rates of existing forests also remain constant. This may overestimate the real future forestry sink, however there is no clear approach to adjusting the flux estimates. Also, it is unclear whether near term climate change (10-15 year) will impact the current flux estimates significantly. Hence, we have assumed no change in the estimated future sinks for 2010 and 2020.

In order to provide a more comprehensive understanding of GHG sources/sinks from the forestry sector, CCS also developed some rough estimates of state-wide emissions for methane and nitrous oxide from wildfires and prescribed burns. A study published earlier this year in *Science* indicated an increasing frequency of wildfire activity in the western U.S. driven by a longer fire season and higher temperatures.[101]

CCS used 2002 emissions data developed by the Western Regional Air Partnership (WRAP) to estimate CO_2e emissions for wildfires and prescribed burns.[102] The CO_2e from methane emissions from this study were added to an estimate of CO_2e for nitrous oxide to estimate a total CO_2e for fires (the carbon dioxide emissions from fires are captured within the carbon pool accounting methods described above). The nitrous oxide estimate was made assuming that N_2O was 1% of the emissions of nitrogen oxides (NO_x) from the WRAP study. The 1% estimate is a common rule of thumb for the N_2O content of NO_x from combustion sources.

The results for 2002 are that fires contributed about 0.21 $MMtCO_2e$ of methane and nitrous oxide from about 190,000 acres burned. Over 90% of the CO_2e was contributed by CH_4. Note that this level of activity compares to a similar area burned in Montana in 1996 (186,000).[103] A comparison 2002 estimate was made using emission factors from a 2001 global biomass burning study[104] and the total tons of biomass burned from the 2002 WRAP fires emissions inventory. This estimate is nearly 0.26 $MMtCO_2e$ with about equal contributions from methane and nitrous oxide on a CO_2e basis. Although not indicated by the estimates provided above for 1996 and 2002, there are large swings in fire activity from year to year. Because of this and the current lack of data for multiple years, CCS did not include these estimates in with the annual forestry flux estimates presented in the emissions summaries of this report. However, it appears that CH_4 and N_2O emissions from forest fires typically contribute less than 1 $MMtCO_2e$/yr in Montana.

Key Uncertainties

It is important to note that there were methodological differences in the two FIA cycles that can produce different estimates of forested area and carbon density. Recent FIA surveys are a result of an expanded focus in the FIA program, which historically was only concerned with timber

[101] Westerling, A.L. et al, "Warming and Earlier Spring Increases Western U.S. Forest Wildfire Activity", *Sciencexpress,* July 6, 2006.
[102] *2002 Fire Emission Inventory for the WRAP Region Phase I – Essential Documentation*, prepared by Air Sciences, Inc., June 2004.
[103] *1996 Fire Emission Inventory,* Draft Final Report, prepared by Air Sciences, Inc., December 2002.
[104] M. O. Andreae and P. Merlet, "Emission of trace gases and aerosols from biomass burning", *Global Biogeochemical Cycles*, Vol. 15, No. 4, pp. 955-966, December 2001.

resources, while more recent surveys have aimed at a more comprehensive gathering of forest biomass data. In addition the FIA program has moved from a periodic to annual sampling design. These changes are believed to have resulted in more forest being sampled in recent years than in the past and direct comparison of old and new FIA datasets can show larger than real changes in forest areas in certain places. In addition, surveys since 1999 include all dead trees on the plots, but data prior to that are variable in terms of these data.

The effect of these changes in survey methods has not been systematically addressed by the USFS. The decision to exclude carbon fluxes on non-NF reserved lands in Montana was done in consultation with the USFS to account in part for this potential systematic error.

As stated in the previous section, emission estimates for methane and nitrous oxide from fires were left out of the statewide flux estimates due to a lack of data for years other than 1996 and 2002 (emissions of carbon dioxide from fires are captured in the carbon flux accounting methods used by the USFS). Based on the level of activity in 2002, these additional emissions are on the order of 0.2 $MMtCO_2e$/yr and would not have a significant impact on the overall flux estimates shown in Table H2.

We expect that there will be additional revisions to the USFS forest carbon estimated in the near future as new FIA data are made available. For Montana, the latest FIA subcycle shows about a half a million fewer forested acres than the previous subcycle. Hence, this could result in slightly lower carbon sequestration estimates in future revisions by the USFS. The difference in acreage appears to be due to the recent implementation of a change in the definition of forested area.[105] The old definition was based on a minimum of 5% forest crown cover (in order for an area to be considered a forest). The new definition is based on a minimum of 10% crown cover.

As mentioned above, CCS included the forestry estimates without the soil carbon pool in the emissions summary tables (see Tables ES-1 and Table 1) for this report, since the USFS has indicated a high level of uncertainty for this carbon pool. These uncertainties are likely to remain until additional data from measurements and potentially improved modeling methods are developed.

[105] Larry Deblander, USFS, Ogden Research Station, personal communication with S. Roe, CCS, May 2007.

Appendix I. Inventory and Forecast for Black Carbon

This appendix summarizes the methods, data sources, and results of the development of an inventory and forecast for black carbon (BC) emissions in Montana. Black carbon is an aerosol (particulate matter) species with positive climate forcing potential but currently without a global warming potential defined by the IPCC (see Appendix J for more information on black carbon and other aerosol species). BC is synonymous with elemental carbon (EC), which is a term common to regional haze analysis. An inventory for 2002 was developed based on inventory data from the Western Regional Air Partnership (WRAP) regional planning organization[106] and other sources. This appendix describes these data and methods for transforming the mass emission estimates for BC into carbon dioxide equivalents (CO_2e) in order to present the emissions within a GHG context.

In addition to the particulate matter (PM) inventory data from WRAP, PM speciation data from EPA's SPECIATE database were also used: These data include PM fractions of elemental carbon (aka black carbon) and primary organic aerosols (aka organic material or OM). These data come from recent updates to EPA's SPECIATE database.[107] These new profiles have just recently been released by EPA. As will be further described below, both BC and OM emission estimates are needed to assess the CO_2e of black carbon emissions. While BC and OM emissions data are available from the WRAP regional haze inventories, CCS favored the newer speciation data available from EPA for the purposes of estimating BC and OM. In particular, better speciation data are now available from EPA for important BC emissions sources (e.g., fossil fuel combustion sources).

After assembling the BC and OM emission estimates, the mass emission rates were transformed into their CO_2e estimates using information from recent global climate modeling. This transformation is described in later sections below.

Development of BC and OM Mass Emission Estimates

The BC and OM mass emission estimates were derived by multiplying the particulate matter less than 2.5 microns ($PM_{2.5}$) emission estimates by the appropriate aerosol fraction for BC and OM. The aerosol fractions were taken from Pechan's ongoing work to update EPA's SPECIATE database.

After estimating both BC and OM emissions for each source category, we used the BC estimate as described below to estimate the CO_2e emissions. Also, as described further below, the OM emission estimate was used to determine whether the source was likely to have positive climate forcing potential. The mass emission results for 2002 are shown in Table 1 below.

[106] Tom Moore, Western Regional Air Partnership, data files provided to Steve Roe, CCS, December 2006.
[107] Version 4.0 of the SPECIATE database and report:
http://www.epa.gov/ttn/chief/software/speciate/index.html#related.

Development of CO_{2e} for BC+OM Emissions

We used similar methods to those applied previously in Connecticut for converting BC mass emissions to CO_2 equivalents.[108] These methods are based on the modeling of Jacobson (2002)[109] and his updates to this work (Jacobson, 2005a).[110] Jacobson (2005a) estimated a range of 90:1 to 190:1 for the climate response effects of BC+OM emissions as compared to CO_2 carbon emissions (depending on either a 30-year or 95-year atmospheric lifetime for CO_2). It is important to note that the BC+OM emissions used by Jacobson were based on a 2:1 ratio of OM:BC (his work in these papers focused on fossil fuel BC+OM; primarily diesel combustion, which has an OM:BC ratio of 2:1 or less).

For Maine and Connecticut, ENE (2004) applied climate response factors from the earlier Jacobson work (220 and 500) to the estimated BC mass to estimate the range of CO_2e associated with BC emissions. Note that the analysis in the northeast was limited to BC emissions from onroad diesel exhaust. An important oversight from this work is that the climate response factors developed by Jacobson (2002, 2005a) are on the basis of CO_2 carbon (not CO_2). Therefore, in order to express the BC emissions as CO_2e, the climate response factors should have been adjusted upward by a factor of 3.67 to account for the molecular weight of CO_2 to carbon (44/12).

For this inventory, we started with the 90 and 190 climate response factors adjusted to CO_2e factors of 330 and 697 to obtain a low and high estimate of CO_2e for each sector. An example calculation of the CO_2e emissions for 10 tons of $PM_{2.5}$ from onroad diesel exhaust follows:

BC mass = (10 tons $PM_{2.5}$) x (0.613 ton EC/ton $PM_{2.5}$) = 6.13 short tons BC

Low estimate CO_2e = (6.13 tons BC) (330 tons CO_2e/ton BC+OM) (3 tons BC+OM/ton BC) (0.907 metric ton/ton) = 5,504 metric tons CO_2e

High estimate CO_2e = (6.13 tons BC) (697 tons CO_2e/ton BC+OM) (3 tons BC+OM/ton BC) (0.907 metric ton/ton) = 11,626 metric tons CO_2e

NOTE: The factor 3 tons BC+OM/ton BC comes directly from the global modeling inputs used by Jacobson (2002, 2005a; i.e. 2 tons of OM/ton of BC).

For source categories that had an OM:BC mass emission ratio >4.0, we zeroed out these emission estimates from the CO_2e estimates. The reason for this is that the net heating effects of OM are not currently well understood (overall OM is thought to have a negative climate forcing effect or a net cooling effect). Therefore, for source categories where the PM is dominated by

[108] ENE, 2004. Memorandum: "Diesel Black Carbon Calculations – Reductions and Baseline" from Michael Stoddard, Environment Northeast, prepared for the Connecticut Stakeholder Dialog, Transportation Work Group, October 23, 2003.
[109] Jacobson, 2002. Jacobson, M.Z., "Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming", *Journal of Geophysical Physical Research*, volume 107, No. D19, 4410, 2002.
[110] Jacobson, 2005a. Jacobson, M.Z., "Updates to 'Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming", *Journal of Geophysical Research Atmospheres*, February 15, 2005.

OM (e.g. biomass burning), the net climate response associated with these emissions is highly uncertain and potentially have a negative climate forcing potential. Further, OM:BC ratios of 4 or more are well beyond the 2:1 ratio used by Jacobson in his work.

Results and Discussion

We estimate that BC mass emissions in Montana total about 2.6 $MMtCO_2e$ in 2002. This is the mid-point of the estimated range of emissions. The estimated range is 1.7 – 3.5 $MMtCO_2e$ (see Table I-1), which is roughly 5 to 10% of the estimated emissions for the six Kyoto gases. The primary contributing sectors in 2002 were nonroad diesel (31%), rail (29%), and onroad diesel (24%).

CCS expects that there will be a drop in the future BC emissions for the onroad and non-road diesel sectors due to new engine and fuels standards that will reduce particulate matter emissions. If data on projected emissions (2018) are available from the WRAP before this report is finalized, they will be incorporated for comparison to the 2002 emissions. Based on work conducted in other states, the onroad diesel will likely see the largest reductions. Another significant contributor to BC emissions in Montana is commercial/industrial wood-fired boilers, which make up a large fraction of the "non-electricity generating unit (EGU) other" emissions. Residential wood combustion is also included in this sector, however the OM:BC ratio is >4 so the emissions were not converted to CO_2e.

Wildfires and miscellaneous sources such as fugitive dust from paved and unpaved roads contributed a significant amount of particulate matter and subsequent BC and OM mass emissions (see Table I-1); however the OM:BC ratio is >4 for these sources, so the BC emissions were not converted to CO_2e.

CCS also performed an assessment of the primary BC contributing sectors from the 2018 WRAP forecast. A drop in the future BC emissions for the onroad and nonroad diesel sectors is expected due to new engine and fuels standards that will reduce particulate matter emissions. For the nonroad diesel sector the estimated 0.80 $MMtCO_2e$ in 2002 drops to 0.78 $MMtCO_2e$ in 2018. For the onroad diesel sector, 0.62 $MMtCO_2e$ was estimated for 2002 dropping to 0.15 $MMtCO_2e$ in 2018. Emissions from the rail sector rose only slightly in 2018 from the 2002 levels. No significant reductions are expected in the other emission sectors. The development of emission estimates for each of the smaller source sectors was beyond the scope of this analysis.

While the state of science in aerosol climate forcing is still developing, there is a good body of evidence supporting the net warming impacts of black carbon. Aerosols have a *direct* radiative forcing because they scatter and absorb solar and infrared radiation in the atmosphere. Aerosols also alter the formation and precipitation efficiency of liquid water, ice and mixed-phase clouds, thereby causing an *indirect* radiative forcing associated with these changes in cloud properties (IPCC, 2001).[111] There are also a number of other indirect radiative effects that have been modeled (e.g. Jacobson, 2002).

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[111] IPCC, 2001. Climate Change 2001: The Scientific Basis, Intergovernmental Panel on Climate Change, 2001.

The quantification of aerosol radiative forcing is more complex than the quantification of radiative forcing by greenhouse gases because of the direct and indirect radiative forcing, and the fact that aerosol mass and particle number concentrations are highly variable in space and time. This variability is largely due to the much shorter atmospheric lifetime of aerosols compared with the important greenhouse gases (i.e. CO_2). Spatially and temporally resolved information on the atmospheric burden and radiative properties of aerosols is needed to estimate radiative forcing.

The quantification of indirect radiative forcing by aerosols is especially difficult. In addition to the variability in aerosol concentrations, some quite complicated aerosol influences on cloud processes must be accurately modeled. For example, the warm (liquid water) cloud indirect forcing may be divided into two components. The first indirect forcing is associated with the change in droplet concentration caused by increases in aerosol cloud condensation nuclei. The second indirect forcing is associated with the change in precipitation efficiency that results from a change in droplet number concentration. Quantification of the latter forcing necessitates understanding of a change in cloud liquid-water content and cloud amount. In addition to warm clouds, ice clouds may also be affected by aerosols.

To put the radiative forcing potential of BC in context with CO_2, the Intergovernmental Panel on Climate Change estimated the radiative forcing for a doubling of the earth's CO_2 concentration to be 3.7 watts per square meter (W/m^2). For BC, various estimates of current radiative forcing have ranged from 0.16 to 0.42 W/m^2 (IPCC, 2001). These BC estimates are for direct radiative effects only. There is a higher level of uncertainty associated with the direct radiative forcing estimates of BC compared to those of CO_2 and other GHGs. There are even higher uncertainties associated with the assessment of the indirect radiative forcing of aerosols.

Table I-1. 2002 BC emission estimates

Sector	Subsector	Mass Emissions BC	Mass Emissions OM	Mass Emissions BC + OM	CO_2e Low	CO_2e High	Contribution to CO2e
		Metric Tons			Metric Tons		
Electric Generating Units (EGUs)							
	Coal	26	37	62	25,380	53,605	1.5%
	Oil	0	0	0	0	0	0.0%
	Gas	0	0	0	0	0	0.0%
	Other	0	4	4	0	0	0.0%
Non-EGU Fuel Combustion (Residential,Commercial, and Industrial)							
	Coal	24	35	59	24,230	51,176	1.5%
	Oil	12	10	22	12,098	25,552	0.7%
	Gas	0	117	117	0	0	0.0%
	Other[a]	557	2,254	2,812	146,366	309,142	8.8%
Onroad Gasoline (Exhaust, Brake Wear, & Tire Wear)		62	251	313	19,414	41,004	1.2%
Onroad Diesel (Exhaust, Brake Wear, & Tire Wear)		444	186	631	395,855	836,093	23.7%
Aircraft		20	52	71	19,547	41,286	1.2%
Railroad[b]		482	158	640	477,446	1,008,424	28.6%
Other Energy Use							
	Nonroad Gas	16	45	62	15,952	33,693	1.0%
	Nonroad Diesel	519	170	689	513,844	1,085,301	30.8%
	Other Combustion[c]	0	4	4	0	0	0.0%
Industrial Processes		73	841	914	18,913	39,946	1.1%
Agriculture[d]		305	5,230	5,534	0	0	0.0%
Waste Management							0.0%
	Landfills	0	4	4	0	0	0.0%
	Incineration	0	0	0	283	598	0.0%
	Open Burning	110	1,413	1,523	0	0	0.0%
	Other	0	0	0	0	0	0.0%
Wildfires/Prescribed Burns		1,561	11,550	13,111	0	0	0.0%
Miscellaneous[e]		2,164	35,104	37,268	0	0	0.0%
Total		**6,377**	**57,464**	**63,842**	**1,669,327**	**3,525,821**	**100%**

[a] Primarily wood-fired commercial/industrial boilers with some large diesel engines.
[b] Railroad includes Locomotives and Railroad Equipment Emissions.
[c] Other Combustion includes Motor Vehicle Fire, Structure Fire, and Aircraft/Rocket Engine Fire & Testing Emissions.
[d] Agriculture includes Agricultural Burning, Agriculture/Forestry and Agriculture, Food, & Kindred Spirits Emissions.
[e] Miscellaneous includes Paved/Unpaved Roads and Catastrophic/Accidental Release Emissions.

Appendix J. Greenhouse Gases and Global Warming Potential Values: Excerpts from the *Inventory of U.S. Greenhouse Emissions and Sinks: 1990-2000*

Original Reference: Material for this Appendix is taken from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2000*, U.S. Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-02-003, April 2002 (http://epa.gov/climatechange/emissions/usinventoryreport.html). Michael Gillenwater directed the preparation of this appendix.

Introduction

The *Inventory of U.S. Greenhouse Gas Emissions and Sinks* presents estimates by the United States government of U.S. anthropogenic greenhouse gas emissions and removals for the years 1990 through 2000. The estimates are presented on both a full molecular mass basis and on a Global Warming Potential (GWP) weighted basis in order to show the relative contribution of each gas to global average radiative forcing.

The Intergovernmental Panel on Climate Change (IPCC) has recently updated the specific global warming potentials for most greenhouse gases in their Third Assessment Report (TAR, IPCC 2001). Although the GWPs have been updated, estimates of emissions presented in the U.S. *Inventory* continue to use the GWPs from the Second Assessment Report (SAR). The guidelines under which the *Inventory* is developed, the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines for national inventories[112] were developed prior to the publication of the TAR. Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. This excerpt of the U.S. *Inventory* addresses in detail the differences between emission estimates using these two sets of GWPs. Overall, these revisions to GWP values do not have a significant effect on U.S. emission trends.

Additional discussion on emission trends for the United States can be found in the complete Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000.

What is Climate Change?

Climate change refers to long-term fluctuations in temperature, precipitation, wind, and other elements of the Earth's climate system. Natural processes such as solar-irradiance variations, variations in the Earth's orbital parameters, and volcanic activity can produce variations in climate. The climate system can also be influenced by changes in the concentration of various gases in the atmosphere, which affect the Earth's absorption of radiation.

The Earth naturally absorbs and reflects incoming solar radiation and emits longer wavelength terrestrial (thermal) radiation back into space. On average, the absorbed solar radiation is balanced by the outgoing terrestrial radiation emitted to space. A portion of this terrestrial radiation, though, is itself absorbed by gases in the atmosphere. The energy from this absorbed terrestrial radiation warms the Earth's surface and atmosphere, creating what is known as the "natural greenhouse effect." Without the natural heat-trapping properties of these atmospheric gases, the average surface temperature of the Earth would be about 33°C lower (IPCC 2001).

[112] See FCCC/CP/1999/7 at www.unfccc.de.

Under the UNFCCC, the definition of climate change is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." Given that definition, in its Second Assessment Report of the science of climate change, the IPCC concluded that:

> *Human activities are changing the atmospheric concentrations and distributions of greenhouse gases and aerosols. These changes can produce a radiative forcing by changing either the reflection or absorption of solar radiation, or the emission and absorption of terrestrial radiation (IPCC 1996).*

Building on that conclusion, the more recent IPCC Third Assessment Report asserts that "[c]oncentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities" (IPCC 2001).

The IPCC went on to report that the global average surface temperature of the Earth has increased by between 0.6 ± 0.2°C over the 20th century (IPCC 2001). This value is about 0.15°C larger than that estimated by the Second Assessment Report, which reported for the period up to 1994, "owing to the relatively high temperatures of the additional years (1995 to 2000) and improved methods of processing the data" (IPCC 2001).

While the Second Assessment Report concluded, "the balance of evidence suggests that there is a discernible human influence on global climate," the Third Assessment Report states the influence of human activities on climate in even starker terms. It concludes that, "[I]n light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations" (IPCC 2001).

Greenhouse Gases

Although the Earth's atmosphere consists mainly of oxygen and nitrogen, neither plays a significant role in enhancing the greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse effect is primarily a function of the concentration of water vapor, carbon dioxide, and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth (IPCC 1996). Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC 1996). Holding everything else constant, increases in greenhouse gas concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth).

Climate change can be driven by changes in the atmospheric concentrations of a number of radiatively active gases and aerosols. We have clear evidence that human activities have affected concentrations, distributions and life cycles of these gases (IPCC 1996).

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as bromofluorocarbons (i.e., halons). Because CFCs, HCFCs, and halons are stratospheric ozone depleting substances, they are covered under the Montreal Protocol on Substances that Deplete the Ozone Layer. The UNFCCC defers to this earlier international treaty; consequently these gases are not included in national greenhouse gas inventories. Some other fluorine containing halogenated substances—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—do not deplete stratospheric ozone but are potent greenhouse gases. These latter substances are addressed by the UNFCCC and accounted for in national greenhouse gas inventories.

There are also several gases that, although they do not have a commonly agreed upon direct radiative forcing effect, do influence the global radiation budget. These tropospheric gases—referred to as ambient air pollutants—include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and tropospheric (ground level) ozone (O_3). Tropospheric ozone is formed by two precursor pollutants, volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of ultraviolet light (sunlight). Aerosols—extremely small particles or liquid droplets—often composed of sulfur compounds, carbonaceous combustion products, crustal materials and other human induced pollutants—can affect the absorptive characteristics of the atmosphere. However, the level of scientific understanding of aerosols is still very low (IPCC 2001).

Carbon dioxide, methane, and nitrous oxide are continuously emitted to and removed from the atmosphere by natural processes on Earth. Anthropogenic activities, however, can cause additional quantities of these and other greenhouse gases to be emitted or sequestered, thereby changing their global average atmospheric concentrations. Natural activities such as respiration by plants or animals and seasonal cycles of plant growth and decay are examples of processes that only cycle carbon or nitrogen between the atmosphere and organic biomass. Such processes—except when directly or indirectly perturbed out of equilibrium by anthropogenic activities—generally do not alter average atmospheric greenhouse gas concentrations over decadal timeframes. Climatic changes resulting from anthropogenic activities, however, could have positive or negative feedback effects on these natural systems. Atmospheric concentrations of these gases, along with their rates of growth and atmospheric lifetimes, are presented in Table 10.

Table 10. Global atmospheric concentration (ppm unless otherwise specified), rate of concentration change (ppb/year) and atmospheric lifetime (years) of selected greenhouse gases

Atmospheric Variable	CO_2	CH_4	N_2O	SF_6[a]	CF_4[a]
Pre-industrial atmospheric concentration	278	0.700	0.270	0	40
Atmospheric concentration (1998)	365	1.745	0.314	4.2	80
Rate of concentration change[b]	1.5[c]	0.007[c]	0.0008	0.24	1.0
Atmospheric Lifetime	50-200[d]	12[e]	114[e]	3,200	>50,000

Source: IPCC (2001)

[a] Concentrations in parts per trillion (ppt) and rate of concentration change in ppt/year.
[b] Rate is calculated over the period 1990 to 1999.
[c] Rate has fluctuated between 0.9 and 2.8 ppm per year for CO_2 and between 0 and 0.013 ppm per year for CH4 over the period 1990 to 1999.
[d] No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.
[e] This lifetime has been defined as an "adjustment time" that takes into account the indirect effect of the gas on its own residence time.

A brief description of each greenhouse gas, its sources, and its role in the atmosphere is given below. The following section then explains the concept of Global Warming Potentials (GWPs), which are assigned to individual gases as a measure of their relative average global radiative forcing effect.

Water Vapor (H_2O). Overall, the most abundant and dominant greenhouse gas in the atmosphere is water vapor. Water vapor is neither long-lived nor well mixed in the atmosphere, varying spatially from 0 to 2 percent (IPCC 1996). In addition, atmospheric water can exist in several physical states including gaseous, liquid, and solid. Human activities are not believed to directly affect the average global concentration of water vapor; however, the radiative forcing produced by the increased concentrations of other greenhouse gases may indirectly affect the hydrologic cycle. A warmer atmosphere has an increased water holding capacity; yet, increased concentrations of water vapor affects the formation of clouds, which can both absorb and reflect solar and terrestrial radiation. Aircraft contrails, which consist of water vapor and other aircraft emittants, are similar to clouds in their radiative forcing effects (IPCC 1999).

Carbon Dioxide (CO_2). In nature, carbon is cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. The largest fluxes occur between the atmosphere and terrestrial biota, and between the atmosphere and surface water of the oceans. In the atmosphere, carbon predominantly exists in its oxidized form as CO_2. Atmospheric carbon dioxide is part of this global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. Carbon dioxide concentrations in the atmosphere increased from approximately 280 parts per million by volume (ppmv) in pre-industrial times to 367 ppmv in 1999, a 31 percent increase (IPCC 2001). The IPCC notes that "[t]his concentration has not been exceeded during the past 420,000 years, and likely not during the past 20 million years. The rate of increase over the past century is unprecedented, at least during the past 20,000 years." The IPCC definitively states that "the present atmospheric CO_2 increase is caused by anthropogenic emissions of CO_2" (IPCC 2001). Forest clearing, other biomass burning, and some non-energy production processes (e.g., cement production) also emit notable quantities of carbon dioxide.

In its second assessment, the IPCC also stated that "[t]he increased amount of carbon dioxide [in the atmosphere] is leading to climate change and will produce, on average, a global warming of the Earth's surface because of its enhanced greenhouse effect—although the magnitude and significance of the effects are not fully resolved" (IPCC 1996).

Methane (CH_4). Methane is primarily produced through anaerobic decomposition of organic matter in biological systems. Agricultural processes such as wetland rice cultivation, enteric fermentation in animals, and the decomposition of animal wastes emit CH_4, as does the decomposition of municipal solid wastes. Methane is also emitted during the production and distribution of natural gas and petroleum, and is released as a by-product of coal mining and incomplete fossil fuel combustion. Atmospheric concentrations of methane have increased by about 150 percent since pre-industrial times, although the rate of increase has been declining. The IPCC has estimated that slightly more than half of the current CH_4 flux to the atmosphere is anthropogenic, from human activities such as agriculture, fossil fuel use and waste disposal (IPCC 2001).

Methane is removed from the atmosphere by reacting with the hydroxyl radical (OH) and is ultimately converted to CO_2. Minor removal processes also include reaction with Cl in the marine boundary layer, a soil sink, and stratospheric reactions. Increasing emissions of methane reduce the concentration of OH, a feedback which may increase methane's atmospheric lifetime (IPCC 2001).

Nitrous Oxide (N_2O). Anthropogenic sources of N_2O emissions include agricultural soils, especially the use of synthetic and manure fertilizers; fossil fuel combustion, especially from mobile combustion; adipic (nylon) and nitric acid production; wastewater treatment and waste combustion; and biomass burning. The atmospheric concentration of nitrous oxide (N_2O) has increased by 16 percent since 1750, from a pre industrial value of about 270 ppb to 314 ppb in 1998, a concentration that has not been exceeded during the last thousand years. Nitrous oxide is primarily removed from the atmosphere by the photolytic action of sunlight in the stratosphere.

Ozone (O_3). Ozone is present in both the upper stratosphere, where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere, where it is the main component of anthropogenic photochemical "smog." During the last two decades, emissions of anthropogenic chlorine and bromine-containing halocarbons, such as chlorofluorocarbons (CFCs), have depleted stratospheric ozone concentrations. This loss of ozone in the stratosphere has resulted in negative radiative forcing, representing an indirect effect of anthropogenic emissions of chlorine and bromine compounds (IPCC 1996). The depletion of stratospheric ozone and its radiative forcing was expected to reach a maximum in about 2000 before starting to recover, with detection of such recovery not expected to occur much before 2010 (IPCC 2001).

The past increase in tropospheric ozone, which is also a greenhouse gas, is estimated to provide the third largest increase in direct radiative forcing since the pre-industrial era, behind CO_2 and CH_4. Tropospheric ozone is produced from complex chemical reactions of volatile organic compounds mixing with nitrogen oxides (NO_x) in the presence of sunlight. Ozone, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter are included in the category referred to as "criteria pollutants" in the United States under the Clean Air Act and its subsequent amendments. The tropospheric concentrations of ozone and these other pollutants are short-lived and, therefore, spatially variable.

Halocarbons, Perfluorocarbons, and Sulfur Hexafluoride (SF_6). Halocarbons are, for the most part, man-made chemicals that have both direct and indirect radiative forcing effects. Halocarbons that contain chlorine—chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl chloroform, and carbon tetrachloride—and bromine—halons, methyl bromide, and hydrobromofluorocarbons (HBFCs)—result in stratospheric ozone depletion and are therefore controlled under the Montreal Protocol on Substances that Deplete the Ozone Layer. Although CFCs and HCFCs include potent global warming gases, their net radiative forcing effect on the atmosphere is reduced because they cause stratospheric ozone depletion, which is itself an important greenhouse gas in addition to shielding the Earth from harmful levels of ultraviolet radiation. Under the Montreal Protocol, the United States phased out the production and importation of halons by 1994 and of CFCs by 1996. Under the Copenhagen Amendments to the Protocol, a cap was placed on the production and importation of HCFCs by non-Article 5 countries beginning in 1996, and then followed by a complete phase-out by the year 2030. The ozone depleting gases covered under the Montreal Protocol and its Amendments are not covered by the UNFCCC.

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) are not ozone depleting substances, and therefore are not covered under the Montreal Protocol. They are, however, powerful greenhouse gases. HFCs—primarily used as replacements for ozone depleting substances but also emitted as a by-product of the HCFC-22 manufacturing process—currently have a small aggregate radiative forcing impact; however, it is anticipated that their contribution to overall radiative forcing will increase (IPCC 2001). PFCs and SF_6 are predominantly emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. urrently, the radiative forcing impact of PFCs and SF_6 is also small; however, they have a significant growth rate, extremely long atmospheric lifetimes, and are strong absorbers of infrared radiation, and therefore have the potential to influence climate far into the future (IPCC 2001).

Carbon Monoxide (CO). Carbon monoxide has an indirect radiative forcing effect by elevating concentrations of CH_4 and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radical, OH) that would otherwise assist in destroying CH_4 and tropospheric ozone. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmosphere, it is eventually oxidized to CO_2. Carbon monoxide concentrations are both short-lived in the atmosphere and spatially variable.

Nitrogen Oxides (NO_x). The primary climate change effects of nitrogen oxides (i.e., NO and NO_2) are indirect and result from their role in promoting the formation of ozone in the troposphere and, to a lesser degree, lower stratosphere, where it has positive radiative forcing effects. Additionally, NO_x emissions from aircraft are also likely to decrease methane concentrations, thus having a negative radiative forcing effect (IPCC 1999). Nitrogen oxides are created from lightning, soil microbial activity, biomass burning – both natural and anthropogenic fires – fuel combustion, and, in the stratosphere, from the photo-degradation of nitrous oxide (N_2O). Concentrations of NO_x are both relatively short-lived in the atmosphere and spatially variable.

Nonmethane Volatile Organic Compounds (NMVOCs). Nonmethane volatile organic compounds include compounds such as propane, butane, and ethane. These compounds participate, along with NO_x, in the formation of tropospheric ozone and other photochemical oxidants. NMVOCs are emitted primarily from transportation and industrial processes, as well as biomass burning and non-industrial consumption of organic solvents. Concentrations of NMVOCs tend to be both short-lived in the atmosphere and spatially variable.

Aerosols. Aerosols are extremely small particles or liquid droplets found in the atmosphere. They can be produced by natural events such as dust storms and volcanic activity, or by anthropogenic processes such as fuel combustion and biomass burning. They affect radiative forcing in both direct and indirect ways: directly by scattering and absorbing solar and thermal infrared radiation; and indirectly by increasing droplet counts that modify the formation, precipitation efficiency, and radiative properties of clouds. Aerosols are removed from the atmosphere relatively rapidly by precipitation. Because aerosols generally have short atmospheric lifetimes, and have concentrations and compositions that vary regionally, spatially, and temporally, their contributions to radiative forcing are difficult to quantify (IPCC 2001).

The indirect radiative forcing from aerosols is typically divided into two effects. The first effect involves decreased droplet size and increased droplet concentration resulting from an increase in airborne aerosols. The second effect involves an increase in the water content and lifetime of clouds due to the effect of reduced droplet size on precipitation efficiency (IPCC 2001). Recent research has placed a greater focus on the second indirect radiative forcing effect of aerosols.

Various categories of aerosols exist, including naturally produced aerosols such as soil dust, sea salt, biogenic aerosols, sulphates, and volcanic aerosols, and anthropogenically manufactured aerosols such as industrial dust and carbonaceous aerosols (e.g., black carbon, organic carbon) from transportation, coal combustion, cement manufacturing, waste incineration, and biomass burning.

The net effect of aerosols is believed to produce a negative radiative forcing effect (i.e., net cooling effect on the climate), although because they are short-lived in the atmosphere—lasting days to weeks—their concentrations respond rapidly to changes in emissions. Locally, the negative radiative forcing effects of aerosols can offset the positive forcing of greenhouse gases (IPCC 1996). "However, the aerosol effects do not cancel the global-scale effects of the much longer-lived greenhouse gases, and significant climate changes can still result" (IPCC 1996).

The IPCC's Third Assessment Report notes that "the indirect radiative effect of aerosols is now understood to also encompass effects on ice and mixed-phase clouds, but the magnitude of any such indirect effect is not known, although it is likely to be positive" (IPCC 2001). Additionally, current research suggests that another constituent of aerosols, elemental carbon, may have a positive radiative forcing (Jacobson 2001). The primary anthropogenic emission sources of elemental carbon include diesel exhaust, coal combustion, and biomass burning.

Global Warming Potentials

Global Warming Potentials (GWPs) are intended as a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas. It is defined as the cumulative radiative forcing—both direct and indirect effects—integrated over a period of time from the emission of a unit mass of gas relative to some reference gas (IPCC 1996). Carbon dioxide (CO_2) was chosen as this reference gas. Direct effects occur when the gas itself is a greenhouse gas. Indirect radiative forcing occurs when chemical transformations involving the original gas produce a gas or gases that are greenhouse gases, or when a gas influences other radiatively important processes such as the atmospheric lifetimes of other gases. The relationship between gigagrams (Gg) of a gas and Tg CO_2 Eq. can be expressed as follows:

$$\text{Tg } CO_2 \text{ Eq} = (\text{Gg of gas}) \times (\text{GWP}) \times \left(\frac{\text{Tg}}{1{,}000 \text{ Gg}}\right) \text{where,}$$

Tg CO_2 Eq. = Teragrams of Carbon Dioxide Equivalents
Gg = Gigagrams (equivalent to a thousand metric tons)
GWP = Global Warming Potential
Tg = Teragrams

GWP values allow policy makers to compare the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of roughly ±35 percent, though some GWPs have larger uncertainty than others, especially those in which lifetimes have not yet been ascertained. n the following decision, the parties to the UNFCCC have agreed to use consistent GWPs from the IPCC Second Assessment Report (SAR), based upon a 100 year time horizon, although other time horizon values are available (see Table 11).

In addition to communicating emissions in units of mass, Parties may choose also to use global warming potentials (GWPs) to reflect their inventories and projections in carbon dioxide-equivalent terms, using information provided by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report. Any use of GWPs should be based on the effects of the greenhouse gases over a 100-year time horizon. In addition, Parties may also use other time horizons. (FCCC/CP/1996/15/Add.1)

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. The short-lived gases such as water vapor, carbon monoxide, tropospheric ozone, other ambient air pollutants (e.g., NO_x, and NMVOCs), and tropospheric aerosols (e.g., SO_2 products and black carbon), however, vary spatially, and consequently it is difficult to quantify their global radiative forcing impacts. GWP values are generally not attributed to these gases that are short-lived and spatially inhomogeneous in the atmosphere.

Table 11. Global warming potentials (GWP) and atmospheric lifetimes (years) used in the inventory

Gas	Atmospheric Lifetime	100-year GWP[a]	20-year GWP	500-year GWP
Carbon dioxide (CO_2)	50-200	1	1	1
Methane (CH_4)[b]	12±3	21	56	6.5
Nitrous oxide (N_2O)	120	310	280	170
HFC-23	264	11,700	9,100	9,800
HFC-125	32.6	2,800	4,600	920
HFC-134a	14.6	1,300	3,400	420
HFC-143a	48.3	3,800	5,000	1,400
HFC-152a	1.5	140	460	42
HFC-227ea	36.5	2,900	4,300	950
HFC-236fa	209	6,300	5,100	4,700
HFC-4310mee	17.1	1,300	3,000	400
CF_4	50,000	6,500	4,400	10,000
C_2F_6	10,000	9,200	6,200	14,000
C_4F_{10}	2,600	7,000	4,800	10,100
C_6F_{14}	3,200	7,400	5,000	10,700
SF_6	3,200	23,900	16,300	34,900

Source: IPCC (1996)
[a] GWPs used here are calculated over 100 year time horizon.
[b] The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

Table 12 presents direct and net (i.e., direct and indirect) GWPs for ozone-depleting substances (ODSs). Ozone-depleting substances directly absorb infrared radiation and contribute to positive radiative forcing; however, their effect as ozone-depleters also leads to a negative radiative forcing because ozone itself is a potent greenhouse gas. There is considerable uncertainty regarding this indirect effect; therefore, a range of net GWPs is provided for ozone depleting substances.

Table 12. Net 100-year global warming potentials for select ozone depleting substances*

Gas	Direct	Net_{min}	Net_{max}
CFC-11	4,600	(600)	3,600
CFC-12	10,600	7,300	9,900
CFC-113	6,000	2,200	5,200
HCFC-22	1,700	1,400	1,700
HCFC-123	120	20	100
HCFC-124	620	480	590
HCFC-141b	700	(5)	570
HCFC-142b	2,400	1,900	2,300
$CHCl_3$	140	(560)	0
CCl_4	1,800	(3,900)	660
CH_3Br	5	(2,600)	(500)
Halon-1211	1,300	(24,000)	(3,600)
Halon-1301	6,900	(76,000)	(9,300)

Source: IPCC (2001)

* Because these compounds have been shown to deplete stratospheric ozone, they are typically referred to as ozone depleting substances (ODSs). However, they are also potent greenhouse gases. Recognizing the harmful effects of these compounds on the ozone layer, in 1987 many governments signed the *Montreal Protocol on Substances that Deplete the Ozone Layer* to limit the production and importation of a number of CFCs and other halogenated compounds. The United States furthered its commitment to phase-out ODSs by signing and ratifying the Copenhagen Amendments to the *Montreal Protocol* in 1992. Under these amendments, the United States committed to ending the production and importation of halons by 1994, and CFCs by 1996. The IPCC Guidelines and the UNFCCC do not include reporting instructions for estimating emissions of ODSs because their use is being phased-out under the *Montreal Protocol*. The effects of these compounds on radiative forcing are not addressed here.

The IPCC recently published its Third Assessment Report (TAR), providing the most current and comprehensive scientific assessment of climate change (IPCC 2001). Within that report, the GWPs of several gases were revised relative to the IPCC's Second Assessment Report (SAR) (IPCC 1996), and new GWPs have been calculated for an expanded set of gases. Since the SAR, the IPCC has applied an improved calculation of CO_2 radiative forcing and an improved CO_2 response function (presented in WMO 1999). The GWPs are drawn from WMO (1999) and the SAR, with updates for those cases where new laboratory or radiative transfer results have been published. Additionally, the atmospheric lifetimes of some gases have been recalculated. Because the revised radiative forcing of CO_2 is about 12 percent lower than that in the SAR, the GWPs of the other gases relative to CO_2 tend to be larger, taking into account revisions in lifetimes. However, there were some instances in which other variables, such as the radiative efficiency or the chemical lifetime, were altered that resulted in further increases or decreases in particular GWP values. In addition, the values for radiative forcing and lifetimes have been calculated for a variety of halocarbons, which were not presented in the SAR. The changes are described in the TAR as follows:

New categories of gases include fluorinated organic molecules, many of which are ethers that are proposed as halocarbon substitutes. Some of the GWPs have larger uncertainties than that of others, particularly for those gases where detailed laboratory data on lifetimes are not yet available. The direct GWPs have been calculated relative to CO_2 using an improved calculation of the CO_2 radiative forcing, the SAR response function for a CO_2 pulse, and new values for the radiative forcing and lifetimes for a number of halocarbons.

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