South Dakota Greenhouse Gas Inventory and Reference Case Projections 1990-2020

Center for Climate Strategies
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Principal Authors: Randy Strait, Steve Roe, Alison Bailie, Holly Lindquist, Alison Jamison

CENTER FOR CLIMATE STRATEGIES

Disclaimer

The Center for Climate Strategies (CCS) prepared this report for the South Dakota Department of Environment and Natural Resources (SDDENR) through an effort of the Western Regional Air Partnership (WRAP). This report presents a preliminary draft greenhouse gas (GHG) emissions inventory and forecast from 1990 to 2020 for South Dakota. This report provides an initial comprehensive understanding of South Dakota's current and possible future GHG emissions. The information presented provides the State with a starting point for revising the initial estimates as improvements to data sources and assumptions are identified. Please contact Mr. Rick Boddicker of the SDDENR to determine if South Dakota has developed any updates to the information presented in this report.

Executive Summary

The Center for Climate Strategies (CCS) prepared this report for the South Dakota Department of Environment and Natural Resources (SDDENR) through an effort of the Western Regional Air Partnership (WRAP). The report contains an inventory and forecast of the State's greenhouse gas (GHG) emissions from 1990 to 2020 to provide an initial comprehensive understanding of South Dakota's current and possible future GHG emissions. The information presented provides the State with a starting point for revising the initial estimates as improvements to data sources and assumptions are identified.

South Dakota's anthropogenic GHG emissions and anthropogenic 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 South Dakota-specific data and inputs when it was possible to do so. 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.

Activities in South Dakota accounted for approximately 36.5 million metric tons (MMt) of *gross*[1] carbon dioxide equivalent (CO_2e) emissions in 2005, an amount equal to about 0.5% of total US gross GHG emissions (based on 2004 US data). South Dakota's gross GHG emissions are rising faster than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). South Dakota's gross GHG emissions increased about 36% from 1990 to 2005, while national emissions rose by only 16% from 1990 to 2004.

Figure ES-1 illustrates the State's emissions per capita and per unit of economic output. On a per capita basis, South Dakotans emitted about 38 metric tons (Mt) of CO_2e in 1990 and about 44 $MtCO_2e$/yr in 2000 which is higher than the national average of 25 $MtCO_2e$/yr. Per capita emissions increased to about 48 $MtCO_2e$/yr by 2005, while the per capita emissions for the US have remained constant at 25 $MtCO_2e$/yr. The higher per capita emission rates in South Dakota are driven by emissions growth in the agricultural industry (agricultural industry emissions are much higher than the national average), electricity supply, and transportation sectors. As with the nation as a whole, economic growth exceeded emissions growth throughout the 1990-2005 period (leading to declining estimates of GHG emissions per unit of state product). During the 1990s, emissions per unit of gross product dropped by 40% nationally, and by 43% in South Dakota.[2]

The principle source of South Dakota's GHG emissions is agriculture, accounting for 46% of South Dakota's gross GHG emissions in 2005. The next largest contributors are the transportation and electricity supply sectors that together accounted for 38% of gross GHG

[1] Excluding GHG emissions removed due to forestry and other land uses and excluding GHG emissions associated with exported electricity.
[2] Based on gross domestic product by state (millions of current dollars), available from the US Bureau of Economic Analysis, http://www.bea.gov/regional/gsp/. The national emissions used for these comparisons are based on 2004 emissions, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

emissions in 2005. The transportation sector accounted 19% of total gross GHG emissions in 2005. Emissions associated with in-state production and generation of imported electricity to meet South Dakota demand accounted for another 19% of South Dakota's total gross GHG emissions in 2005. A significant change in electricity supply emissions occurred between 2000 and 2005 as a result of changes in the mix of generation sources (see the discussion under the Historical Emissions section of this report and Appendix A for more details on the electricity supply sector). The use of fossil fuels — natural gas, oil products, and coal — in the residential, commercial, and industrial (RCI) sectors contributed another 11% of gross State emissions in 2005. The fossil fuel production, waste, and industrial processes non-energy use categories together accounted for 5% of gross emissions in 2005.

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projections, South Dakota's gross GHG emissions continue to grow, and are projected to climb to 46.6 $MMtCO_2e$ by 2020, reaching 74% above 1990 levels. As shown in Figure ES-3, the agriculture sector is projected to be the largest contributor to future emissions growth, followed by emissions associated with the electricity supply, transportation, and RCI fossil fuel use sectors in South Dakota.

Some data gaps exist in this analysis, particularly for the reference case projections. Key tasks include review and revision of key emissions drivers that will be major determinants of South Dakota's future GHG emissions (such as the growth rate assumptions for agricultural activities, electricity generation and consumption, transportation fuel use, and fossil fuel). Appendices A through H provide the detailed methods, data sources, and assumptions for each GHG sector. Also included are descriptions of significant uncertainties in emission estimates or methods and suggested next steps for refinement of the inventory.

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 South Dakota based on 2002 and 2018 data from the WRAP. The results for current levels of BC emissions were a total of 5.3 $MMtCO_2e$, which is the mid-point of a range of estimated emissions (3.4 – 7.2 $MMtCO_2e$) in 2002. Based on an assessment of the primary contributors, it is estimated that BC emissions will decrease substantially by 2018 after new engine and fuel standards take effect in the onroad and nonroad diesel engine sectors. 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 because a global warming potential for BC has not yet been assigned by the Intergovernmental Panel on Climate Change (IPCC). By including BC emission estimates in the inventory, however, additional opportunities for reducing climate impacts can be identified as the scientific knowledge related to BC emissions improves.

Table ES-1. South Dakota Historical and Reference Case GHG Emissions, by Sector[a]

(Million Metric Tons CO_2e)	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Energy	**13.5**	**14.8**	**18.4**	**19.2**	**21.9**	
Electricity Production	3.1	3.8	3.8	3.9	4.8	
Coal	3.1	3.5	3.7	3.7	4.5	See electric sector assumptions
Natural Gas	0.01	0.2	0.1	0.2	0.2	in Appendix A
Oil	0.01	0.06	0.02	0.02	0.02	
Net Imported/Exported Electricity	0.5	-0.2	3.2	3.1	3.6	Negative values represent exports
Electricity Consumption Based	**3.6**	**3.6**	**7.0**	**7.1**	**8.4**	
Residential/Commercial/Industrial (RCI) Fuel Use	**4.1**	**4.5**	**4.1**	**4.5**	**5.1**	
Coal	0.38	1.19	0.61	0.68	0.77	Based on US DOE regional projections
Natural Gas	1.32	1.48	1.77	2.01	2.31	Based on US DOE regional projections
Oil	2.43	1.78	1.72	1.81	1.98	Based on US DOE regional projections
Wood (CH_4 and N_2O)	0.01	0.01	0.01	0.01	0.01	Based on US DOE regional projections
Transportation	**5.5**	**6.4**	**6.9**	**7.1**	**7.8**	
Motor Gasoline	3.95	4.44	4.27	4.22	4.41	Based on US DOE regional projections
Diesel	1.00	1.46	2.13	2.43	2.93	Based on US DOE regional projections
Natural Gas, LPG, other	0.07	0.07	0.09	0.09	0.10	Based on US DOE regional projections
Jet Fuel and Aviation Gasoline	0.46	0.43	0.41	0.40	0.38	Based on US DOE regional projections
Fossil Fuel Industry	**0.2**	**0.3**	**0.5**	**0.5**	**0.6**	
Natural Gas Industry	0.23	0.34	0.45	0.52	0.60	Based on US DOE regional projections and historic production data
Oil Industry	0.01	0.01	0.01	0.01	0.01	Based on historic production trends
Coal Mining (Methane)	0.00	0.00	0.00	0.00	0.00	There are no coal mines in South Dakota
Industrial Processes	**0.5**	**0.7**	**0.9**	**1.0**	**1.4**	
Cement Manufacture (CO_2)	0.3	0.4	0.4	0.4	0.5	Based on manufacturing employment projections for South Dakota
Lime Manufacture (CO_2)	0.03	0.03	0.04	0.04	0.04	Ditto
Limestone & Dolomite Use (CO_2)	0.02	0.01	0.01	0.01	0.01	Ditto
Soda Ash (CO_2)	0.01	0.01	0.01	0.01	0.01	Based on 2004 and 2009 projections for US production
ODS Substitutes (HFC, PFC, and SF_6)	0.001	0.2	0.3	0.5	0.9	Based on national projections (US State Dept.)
Electric Power T & D (SF_6)	0.07	0.04	0.04	0.03	0.02	Based on national projections (US EPA)
Waste Management	**0.3**	**0.4**	**0.4**	**0.5**	**0.6**	
Solid Waste Management	0.16	0.23	0.27	0.33	0.47	Projections primarily based on population
Wastewater Management	0.13	0.14	0.14	0.14	0.15	Projections based on population
Agriculture (Ag)	**12.5**	**17.1**	**16.7**	**18.3**	**22.6**	
Enteric Fermentation	4.1	4.6	5.0	5.3	6.1	Based on trend in historical emissions from 1990-2002
Manure Management	0.7	0.7	0.7	0.7	0.6	Ditto
Ag. Soils and Residue Burning	7.7	11.8	11.1	12.4	15.9	Ditto
Total Gross Emissions	**26.7**	**33.0**	**36.5**	**39.1**	**46.6**	
increase relative to 1990		*23%*	*36%*	*46%*	*74%*	
Forestry and Land Use	-0.49	-0.49	-0.49	-0.49	-0.49	All years are based on current (2005) estimates from the USFS
Agricultural Soils	-1.04	-1.04	-1.04	-1.04	-1.04	Historical and projected emissions held constant at 1997 levels
Net Emissions (including sinks)	**25.2**	**31.5**	**34.9**	**37.6**	**45.0**	

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

Figure ES-1. Historical South Dakota and US Gross GHG Emissions, Per Capita and Per Unit Gross Product

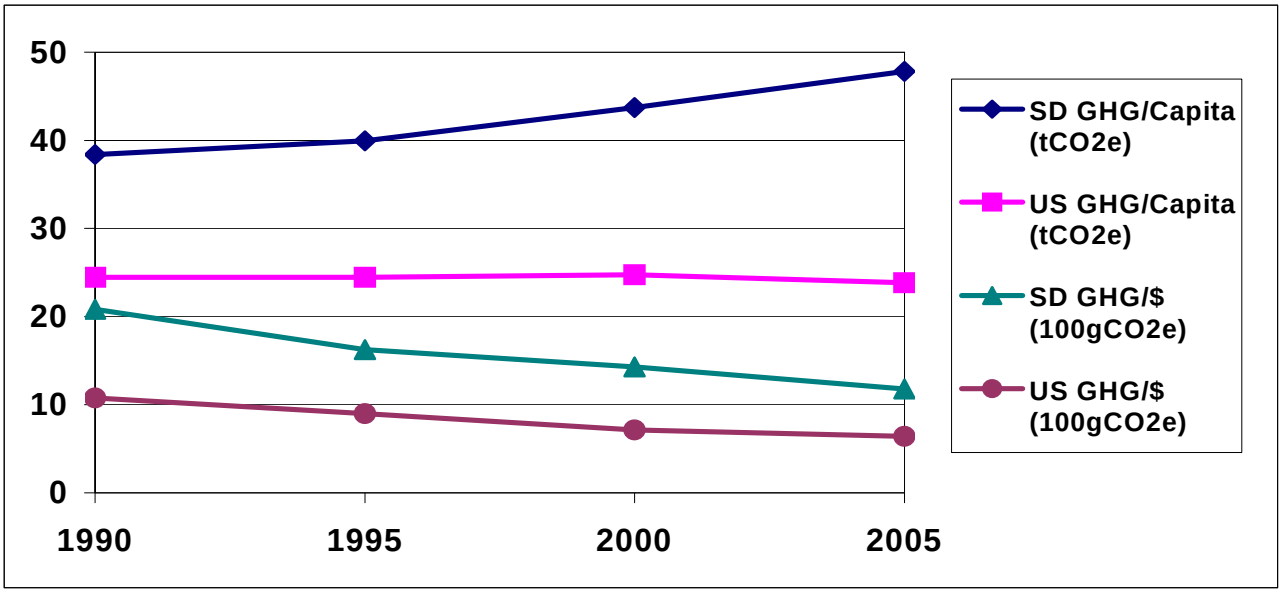
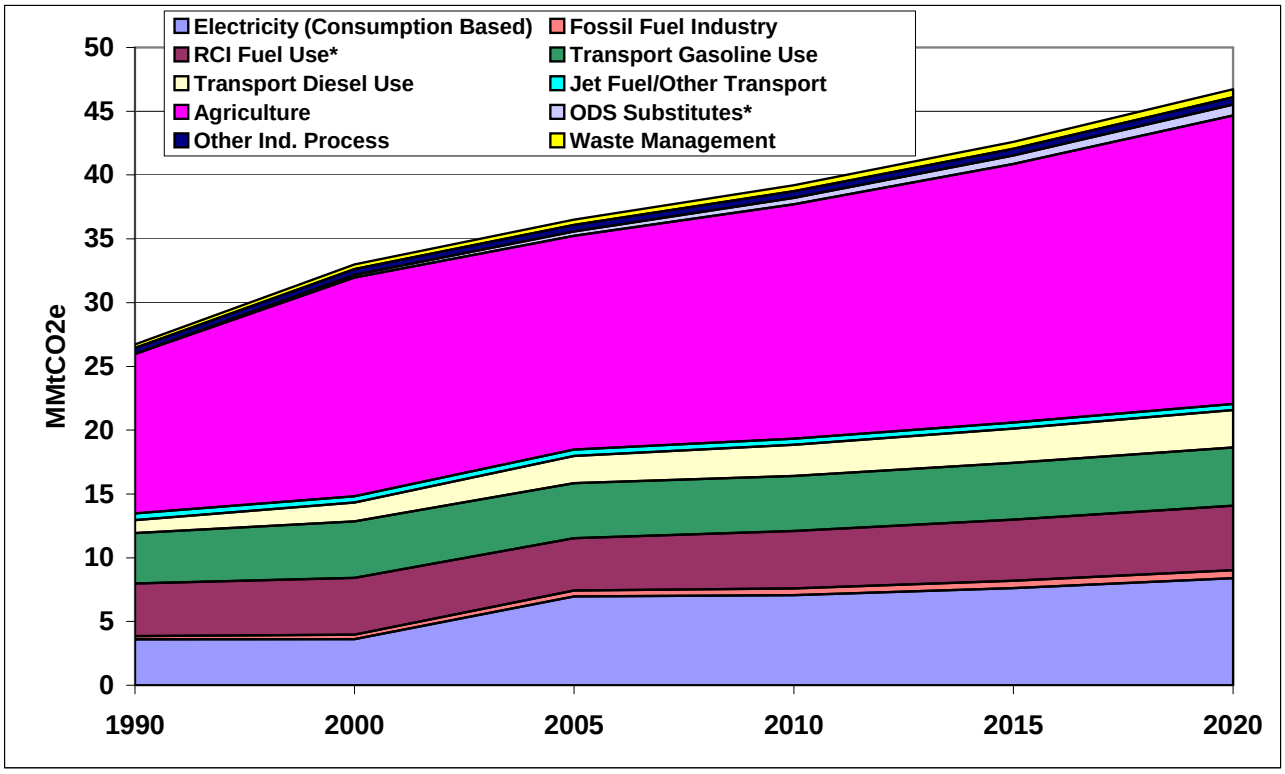
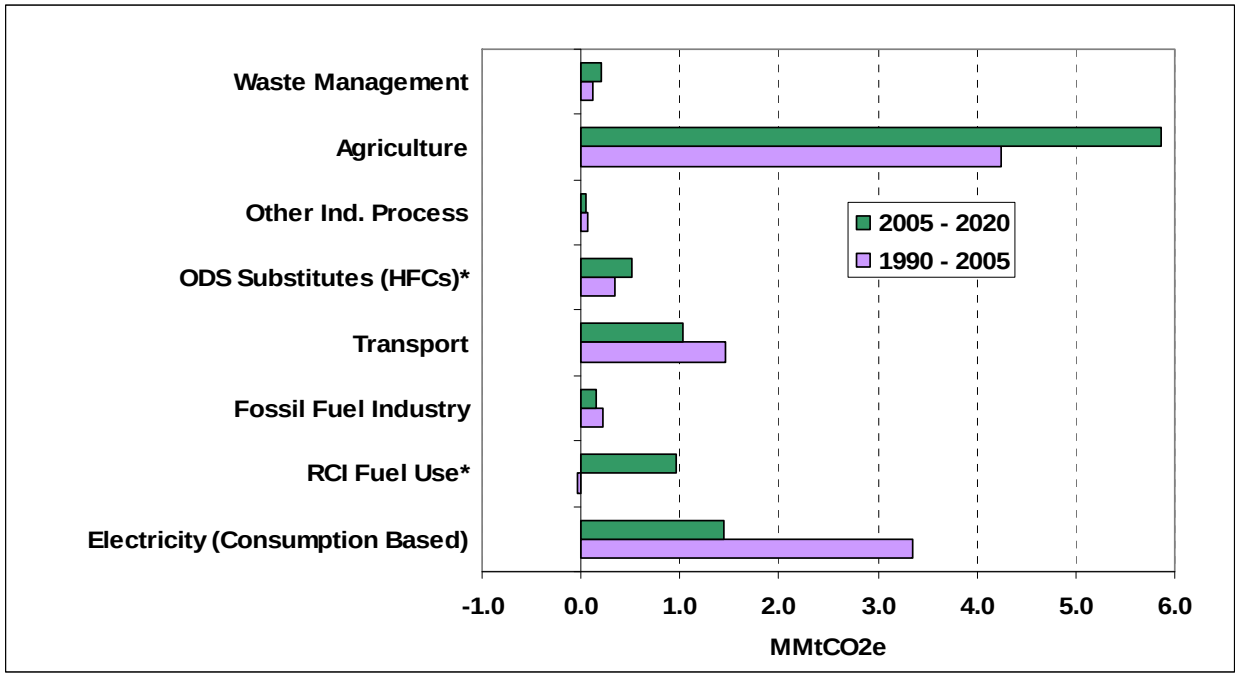


Figure ES-2. South Dakota Gross GHG Emissions by Sector, 1990-2020: Historical and Projected



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

Figure ES-3. Sector Contributions to Gross Emissions Growth in South Dakota, 1990-2020: Reference Case Projections ($MMtCO_2e$ Basis)



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

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Acronyms and Key Terms

AEO – Annual Energy Outlook, EIA

Ag – Agriculture

bbls – Barrels

BC – Black Carbon*

Bcf – Billion cubic feet

BLM – United States Bureau of Land Management

BOD – Biochemical Oxygen Demand

BTU – British thermal unit

C – Carbon*

$CaCO_3$ – Calcium Carbonate

CBM – Coal Bed Methane

CCS – Center for Climate Strategies

CFCs – Chlorofluorocarbons*

CH_4 – Methane*

CO – Carbon Monoxide*

CO_2 – Carbon Dioxide*

CO_2e – Carbon Dioxide equivalent*

CRP – Federal Conservation Reserve Program

EC – Elemental Carbon*

eGRID – US EPA's Emissions & Generation Resource Integrated Database

EGU – Electricity Generating Unit

EIA – US DOE Energy Information Administration

EIIP – Emissions Inventory Improvement Program

Eq. – Equivalent

FAA – Federal Aviation Administration

FIA – Forest Inventory and Analysis

Gg – Gigagram

GHG – Greenhouse Gases*

GWh – Gigawatt-hour

GWP – Global Warming Potential*

HFCs – Hydrofluorocarbons*

IPCC – Intergovernmental Panel on Climate Change*

kWh – Kilowatt-hour

LF – Landfill

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

MSW – Municipal Solid Waste

MW – Megawatt

MWh – Megawatt-hour

N – Nitrogen*

N_2O – Nitrous Oxide*

NO_2 – Nitrogen Dioxide*

NO_x – Nitrogen Oxides*

NAICS – North American Industry Classification System

NASS – National Agricultural Statistics Service

NF – National Forest

NMVOCs – Nonmethane Volatile Organic Compounds*

O_3 – Ozone*

ODS – Ozone-Depleting Substances*

OM – Organic Matter*

PADD – Petroleum Administration for Defense Districts

PFCs – Perfluorocarbons*

PM – Particulate Matter*

ppb – parts per billion

ppm – parts per million

ppt – parts per trillion

PV – Photovoltaic

RCI – Residential, Commercial, and Industrial

RPA – Resources Planning Act Assessment

SAR – Second Assessment Report*

SDDENR – South Dakota Department of Environment and Natural Resources

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.

TAR – Third Assessment Report*

T&D – Transmission and Distribution

Tg – Teragram

TWh – Terawatt-hours

UNFCCC – United Nations Framework Convention on Climate Change

US EPA – United States Environmental Protection Agency

US DOE – United States Department of Energy

USDA – United States Department of Agriculture

USFS – United States Forest Service

USGS – United States Geological Survey

VMT – Vehicle-Miles Traveled

WECC – Western Electricity Coordinating Council

W/m^2 – Watts per Square Meter

WMO – World Meteorological Organization*

WRAP – Western Regional Air Partnership

WW – Wastewater

* – See Appendix J for more information.

Acknowledgements

We appreciate all of the time and assistance provided by numerous contacts throughout South Dakota, as well as in neighboring States, and at federal agencies. Thanks go to in particular the many staff at several South Dakota State Agencies for their inputs, and in particular to Rick Boddicker, Brian Gustafson, and Dale Healey of the South Dakota Department of Environment and Natural Resources (SDDENR) who provided key guidance for this analytical effort.

The authors would also like to express their appreciation to Katie Bickel, Michael Lazarus, Lewison Lem, Katie Pasko, and David Von Hippel of the Center for Climate Strategies (CCS) who provided valuable review comments during development of this report. Thanks also to Michael Gillenwater for directing preparation of Appendix J.

Summary of Preliminary Findings

Introduction

The Center for Climate Strategies (CCS) prepared this report for the South Dakota Department of Environment and Natural Resources (SDDENR) through an effort of the Western Regional Air Partnership (WRAP). This report presents initial estimates of base year and projected anthropogenic greenhouse gas (GHG) emissions and anthropogenic sinks (carbon storage) for the period from 1990 to 2020. These estimates are intended to assist the State with an initial, comprehensive understanding of current and possible future GHG emissions for South Dakota. The information presented provides the State with a starting point for revising the initial estimates as improvements to data sources and assumptions are identified.

Historical GHG emission estimates (1990 through 2005)[3] were developed using a set of generally accepted principles and guidelines for State GHG emissions inventories, as described in the "Approach" section below, relying to the extent possible on South Dakota-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.

This report covers the six gases included in the US 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.[4] The final appendix to this report provides a more complete discussion of GHGs and GWPs. Emissions of black carbon were also estimated. Black carbon (BC) is an aerosol species with a positive climate forcing potential (that is, the potential to warm the atmosphere, as GHGs do); however, black carbon currently does not have a GWP defined by the IPCC due to uncertainties in both the direct and indirect effects of BC on atmospheric processes (see Appendices I and J for more details). Therefore, except for Appendix I, all of the summary tables and graphs in this report cover emissions of just the six GHGs noted above.

It is important to note that the preliminary emissions estimates for the electricity sector reflect the *GHG emissions associated with the electricity sources used to meet South Dakota'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.* This report covers both methods of accounting for emissions, but for consistency, all total results are reported as *consumption-based.*

[3] The last year of available historical data varies by sector; ranging from 2000 to 2005.
[4] These gases and the concepts of radiative forcing and GWP are described in Appendix J.

South Dakota Greenhouse Gas Emissions: Sources and Trends

Table 1 provides a summary of GHG emissions estimated for South Dakota by sector for the years 1990, 2000, 2005, 2010, and 2020. Details on the methods and data sources used to construct these estimates are provided in the appendices to this report**.** 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 for each.

This next section of the report provides a summary of the historical emissions (1990 through 2005) followed by a summary of the reference-case projection-year emissions (2006 through 2020) and key uncertainties. We also provide an overview of the general methodology, principles, 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 and 2018 black carbon (BC) estimates for South Dakota. CCS estimated that BC emissions in 2002 ranged from 3.4 – 7.2 million metric tons (MMt) of carbon dioxide equivalent (CO_2e) with a mid-point of 5.3 $MMtCO_2e$. 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 CO_2e. Emissions in key contributing sectors (onroad and nonroad diesel engines) are expected to decline by about 3.4 $MMtCO_2e$/yr by 2018 as a result of new federal engine and fuel standards. Appendix I contains a detailed breakdown of 2002 emissions contribution by source sector. 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.

Appendix J provides background information on GHGs and climate-forcing aerosols.

Table 1. South Dakota Historical and Reference Case GHG Emissions, by Sector[a]

(Million Metric Tons CO_2e)	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Energy	**13.5**	**14.8**	**18.4**	**19.2**	**21.9**	
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Natural Gas	0.01	0.2	0.1	0.2	0.2	in Appendix A
Oil	0.01	0.06	0.02	0.02	0.02	
Net Imported/Exported Electricity	0.5	-0.2	3.2	3.1	3.6	Negative values represent exports
Electricity Consumption Based	**3.6**	**3.6**	**7.0**	**7.1**	**8.4**	
Residential/Commercial/Industrial (RCI) Fuel Use	**4.1**	**4.5**	**4.1**	**4.5**	**5.1**	
Coal	0.38	1.19	0.61	0.68	0.77	Based on US DOE regional projections
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Fossil Fuel Industry	**0.2**	**0.3**	**0.5**	**0.5**	**0.6**	
Natural Gas Industry	0.23	0.34	0.45	0.52	0.60	Based on US DOE regional projections and historic production data
Oil Industry	0.01	0.01	0.01	0.01	0.01	Based on historic production trends
Coal Mining (Methane)	0.00	0.00	0.00	0.00	0.00	There are no coal mines in South Dakota
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Cement Manufacture (CO_2)	0.3	0.4	0.4	0.4	0.5	Based on manufacturing employment projections for South Dakota
Lime Manufacture (CO_2)	0.03	0.03	0.04	0.04	0.04	Ditto
Limestone & Dolomite Use (CO_2)	0.02	0.01	0.01	0.01	0.01	Ditto
Soda Ash (CO_2)	0.01	0.01	0.01	0.01	0.01	Based on 2004 and 2009 projections for US production
ODS Substitutes (HFC, PFC, and SF_6)	0.001	0.2	0.3	0.5	0.9	Based on national projections (US State Dept.)
Electric Power T & D (SF_6)	0.07	0.04	0.04	0.03	0.02	Based on national projections (US EPA)
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Manure Management	0.7	0.7	0.7	0.7	0.6	Ditto
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Total Gross Emissions	**26.7**	**33.0**	**36.5**	**39.1**	**46.6**	
increase relative to 1990		*23%*	*36%*	*46%*	*74%*	
Forestry and Land Use	-0.49	-0.49	-0.49	-0.49	-0.49	All years are based on current (2005) estimates from the USFS
Agricultural Soils	-1.04	-1.04	-1.04	-1.04	-1.04	Historical and projected emissions held constant at 1997 levels
Net Emissions (including sinks)	**25.2**	**31.5**	**34.9**	**37.6**	**45.0**	

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

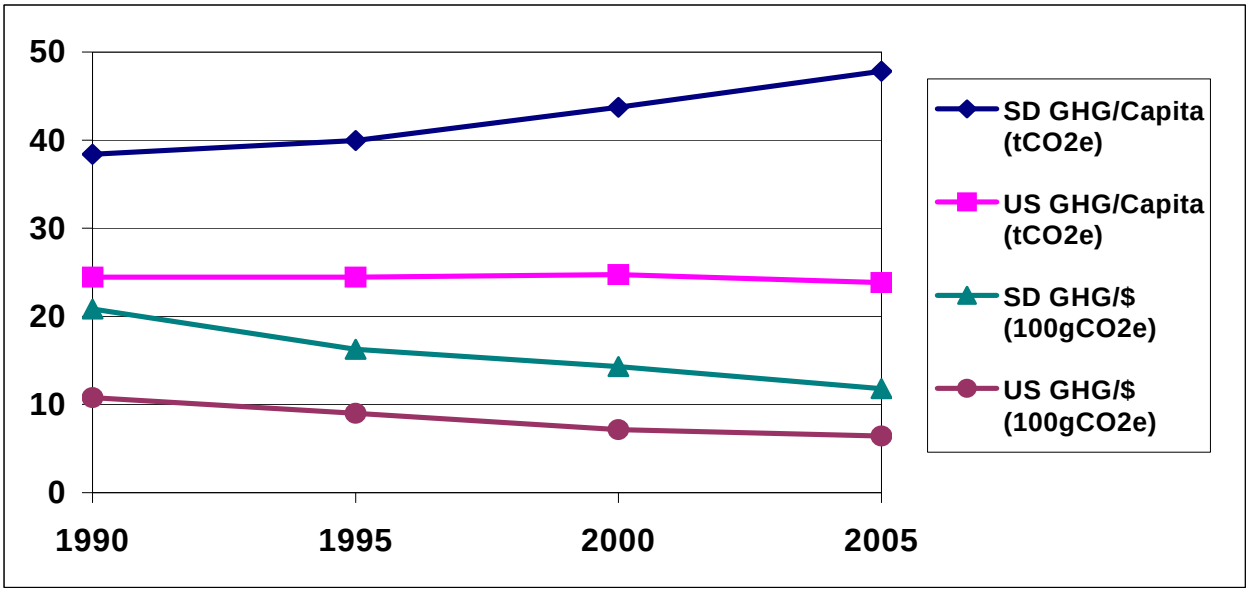
Historical Emissions

Overview

Preliminary analyses suggest that in 2005, activities in South Dakota accounted for approximately 36.5 million metric tons (MMt) of CO_2e emissions, an amount equal to about 0.5% of total US GHG emissions (based on 2004 US emissions[5]). South Dakota's gross GHG emissions are rising faster than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). South Dakota's gross GHG emissions increased 36% from 1990 to 2005, while national emissions rose by only 16% from 1990 to 2004.

Figure 1 illustrates the State's emissions per capita and per unit of economic output. On a per capita basis, South Dakotans emitted about 38 metric tons (Mt) of CO_2e in 1990 and about 44 $MtCO_2e$/yr in 2000 which is higher than the national average of 25 $MtCO_2e$/yr. Per capita emissions increased to about 48 $MtCO_2e$/yr by 2005, while the per capita emissions for the US have remained constant at 25 $MtCO_2e$/yr. The higher per capita emission rates in South Dakota are driven by emissions from the agricultural industry, which are much higher than the national average. As with the nation as a whole, economic growth exceeded emissions growth throughout the 1990-2005 period (leading to declining estimates of GHG emissions per unit of state product). During the 1990s, emissions per unit of gross product dropped by 40% nationally, and by 43% in South Dakota.[6]

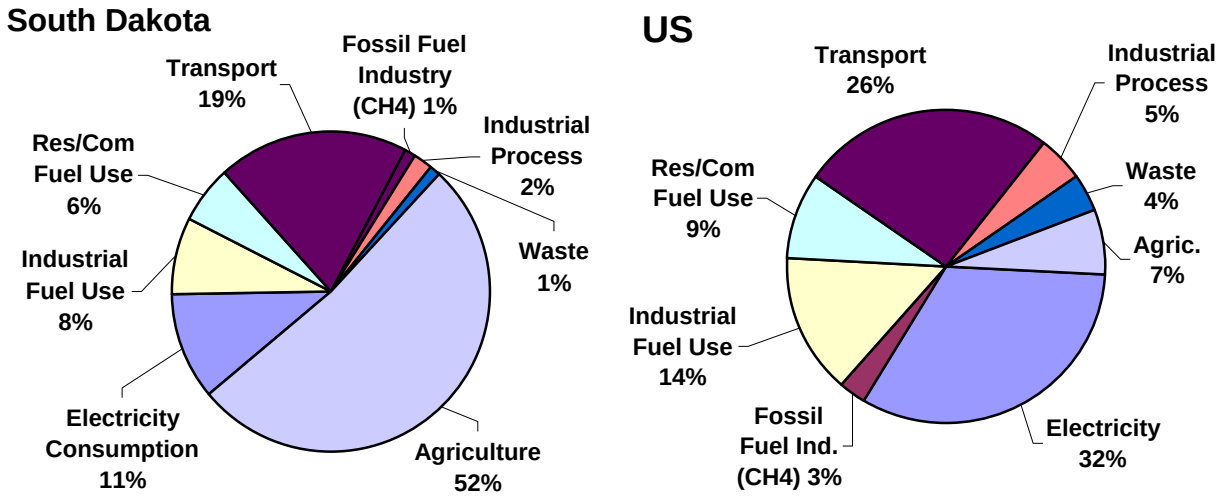
Figure 1. Historical South Dakota and US Gross GHG Emissions, Per Capita and Per Unit Gross Product



[5] United States emissions estimates are drawn from US EPA 2006, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2004*.
[6] Based on gross domestic product by state (millions of current dollars), available from the US Bureau of Economic Analysis, http://www.bea.gov/regional/gsp/. The national emissions used for these comparisons are based on 2004 emissions, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

As shown in Figure 2, the agriculture sector is the principle source of South Dakota's GHG emissions, accounting for 52% of South Dakota's gross GHG emissions in 2000. The next largest contributors are the transportation and electricity supply sectors that together accounted for 30% of gross GHG emissions in 2000. The transportation sector accounted for 19% of total gross GHG emissions. Emissions associated with in-state production and generation of imported electricity to meet South Dakota demand accounted for another about 11% of South Dakota's total gross GHG emissions. A significant change in electricity supply emissions occurred between 2000 and 2005 as a result of changes in the mix of generation sources (see the discussion under the Historical Emissions section of this report and Appendix A for more details on the electricity supply sector). The use of fossil fuels — natural gas, oil products, and coal — in the residential, commercial, and industrial (RCI) sectors constituted another 14% of total State emissions.

Figure 2. Gross GHG Emissions by Sector, 2000, South Dakota and US



Industrial process emissions comprised almost 2% of State GHG emissions in 2000. Although industrial process emissions are rising rapidly due to the increasing use of HFC as substitutes for ozone-depleting chlorofluorocarbons (CFCs), their overall contribution is estimated to be only 3% of South Dakota's gross GHG emissions in 2020 due to significant growth in other sectors.[7] Other industrial process emissions result from CO_2 released during soda ash, limestone, and dolomite use. Landfills and wastewater management facilities, and the fossil fuel industry produced CH_4 and N_2O emissions that together accounted for the remaining 2% of the State's emissions in 2000.

[7] CFCs are also potent GHGs; they are not, however, included in GHG estimates because of concerns related to implementation of the Montreal Protocol (See Appendix I for additional information). HFCs are used as refrigerants in the RCI and transport sectors as well as in the industrial sector; they are included here, however, within the industrial processes emissions.

Forestry activities in South Dakota are estimated to be net sinks for GHG emissions, and forested lands account for a sink of -0.49 $MMtCO_2e$ per year. Agricultural soils account for another GHG sink of -1.0 $MMtCO_2e$ per year.

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

Agricultural Sector

Emissions associated with the agricultural sector include CH_4 and N_2O emissions from enteric fermentation, manure management, and agricultural soils. Methane emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Methane and N_2O emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The agricultural soils category accounts for several sources of N_2O emissions, including decomposition of crop residues, synthetic and organic fertilizer application, manure and sewage sludge application to soils, and nitrogen fixation (see Appendix F for more details).

The management of agricultural soils can result in N_2O emissions and in fluxes of carbon dioxide (CO_2) that make soils net emitters or net sinks of carbon. In general, soil amendments that add nitrogen to soils can also result in N_2O emissions. Nitrogen additions drive underlying soil nitrification and de-nitrification cycles, which produce N_2O as a by-product. The emissions estimation methodologies used in this inventory account for several sources of N_2O emissions from agricultural soils, including decomposition of crop residues, synthetic and organic fertilizer application, manure and sewage sludge application to soils, nitrogen fixation, and cultivation of histosols (high organic soils). Both direct and indirect emissions of N_2O occur from the application of manure, fertilizer, and sewage sludge to agricultural soils. Direct emissions occur at the site of application and indirect emissions occur when nitrogen leaches to groundwater or in surface runoff and is transported off-site before entering the nitrification/denitrification cycle. Methane and N_2O emissions also result when crop residues are burned. Methane emissions occur during rice cultivation; however, rice is not grown in South Dakota.

Emissions associated with the management of agricultural soils are the primary contributor to emissions in the agricultural sector. From 1990 through 2002, emissions associated with the production of crops the use of fertilizers containing nitrogen, and the application of manure to crop lands have increased at an average annual rate of 3.7%, 2.3%, and 0.7%, respectively. Overall, the emissions for the agricultural soils category have increased at an average annual rate of about 2.4% from 1990 through 2002. The growth in the agricultural soils category reflects the high crop production activity in South Dakota over this time period.

Animal husbandry operations are another contributor to emissions in the agricultural sector. From 1990 through 2002, emissions associated with enteric fermentation have increased at an average annual rate of about 1.4%. Emissions associated with manure management, however, have declined by about -0.6% annually from 1990 through 2002. The annual growth rate associated with enteric fermentation is driven by growth in the beef cattle population. Emissions associated with the manure management have declined over the 12-year period because of a decline in the dairy cattle population in South Dakota.

Emissions for the agricultural sector are estimated to grow to about 22.6 $MMtCO_2e$ by 2020 reflecting and average annual growth rate of about 2% from 2005 emission levels. The growth rates applied to forecast emissions are based on the 12-year historical trend in emissions calculated for agricultural soils, enteric fermentation, and manure management. Appendix F provides further details on the methods and data sources used to estimate historical GHG emissions and emissions for the reference case forecast for the agricultural sector.

Transportation Sector

As shown in Figure 2, the transportation sector accounted for about 19% of South Dakota's gross GHG emissions in 2000 (about 6.4 $MMtCO_2e$), which was lower than the national average share of emissions from transportation fuel consumption (26%). The GHG emissions associated with South Dakota's transportation sector increased by 0.9 $MMtCO_2e$ between 1990 and 2000, accounting for about 17% of the State's net growth in gross GHG emissions in this time period.

From 1990 through 2002, GHG emissions from transportation fuel use have risen steadily at an average rate of about 1.7% annually. In 2002, onroad gasoline vehicles accounted for about 64% of transportation GHG emissions. Onroad diesel vehicles accounted for another 28% of emissions, and air travel for roughly 6%. Rail, marine gasoline, and other sources (natural gas- and liquefied petroleum gas- (LPG-) fueled-vehicles used in transport applications) accounted for the remaining 2% of transportation emissions. As a result of South Dakota's population and economic growth and an increase in total vehicle miles traveled (VMT) during the 1990s, onroad gasoline use grew 13% between 1990 and 2002. Meanwhile, onroad diesel use rose 93% during that period, suggesting an even more rapid growth in freight movement within or across the State. Aviation fuel use declined by about 73% from 1990-2002.

Electricity Supply Sector

During recent years, South Dakota's electricity has been characterized primarily by a mix of hydro-electric generation from three dams on the Missouri river, coal-fired generation from the Big Stone power plant, and net imports of electricity from other states. With uncertain levels of future hydro-electric generation plus several proposals for large coal and large wind generating facilities, South Dakota's future generation could change significantly.

As shown in Figure 2, electricity consumption accounted for about 11% of South Dakota's gross GHG emissions in 2000 (about 3.6 $MMtCO_2e$), which was much lower than the national average share of emissions from electricity consumption (32%).[8] The GHG emissions associated with South Dakota's electricity sector increased by 0.01 $MMtCO_2e$ between 1990 and 2000, accounting for only 0.4% of the state's net growth in gross GHG emissions in this time period. However, from 2000 to 2005, GHG emissions increased by 93% to about 7 $MMtCO_2e$. The large increase in emissions between 2000 and 2005 is reflective of a combination of calculation methods for (1) GHG emissions associated with electricity consumption, and (2) increases in electricity consumption by sector. GHG emissions associated with South Dakota's electricity

[8] For the US as a whole, there is relatively little difference between the emissions from electricity use and emissions from electricity production, as the US imports only about 1% of its electricity, and exports far less. South Dakota's situation is different, since it is a net electricity importer.

consumption increased significantly between 2000 (when hydro-electric generation was high) and 2005 (when hydro-electric generation was relatively low).

In 2000, emissions associated with South Dakota's electricity consumption (3.6 $MMtCO_2e$, see Table 1) were slightly lower than those associated with electricity production (3.8 $MMtCO_2e$, see Appendix A). The lower level for consumption-based emissions reflects GHG emissions associated with net exports of electricity to meet the State's electricity demand.[9] However, electricity sales for 2005 through 2020 indicate that South Dakota will be a net importer of electricity. For 2005, emissions associated with electricity consumption (7 $MMtCO_2e$, see Table 1) were higher than those associated with in-state electricity production (3.8 $MMtCO_2e$, see Appendix A). For the period covering 2005 through 2020, the reference case projection assumes that production-based emissions associated with electricity generated in-state will increase by about 1 $MMtCO_2e$, while emissions associated with imported electricity will increase by about 1.5 $MMtCO_2e$.

The consumption-based approach can better reflect the emissions (and emissions reductions) associated with activities occurring in South Dakota, particularly with respect to electricity use (and efficiency improvements), and is particularly useful for policy-making. Under this approach, emissions associated with electricity imported from other states would need to be covered in those states' accounts in order to avoid double-counting or exclusions when reporting regional or national emissions.

Reference Case Projections

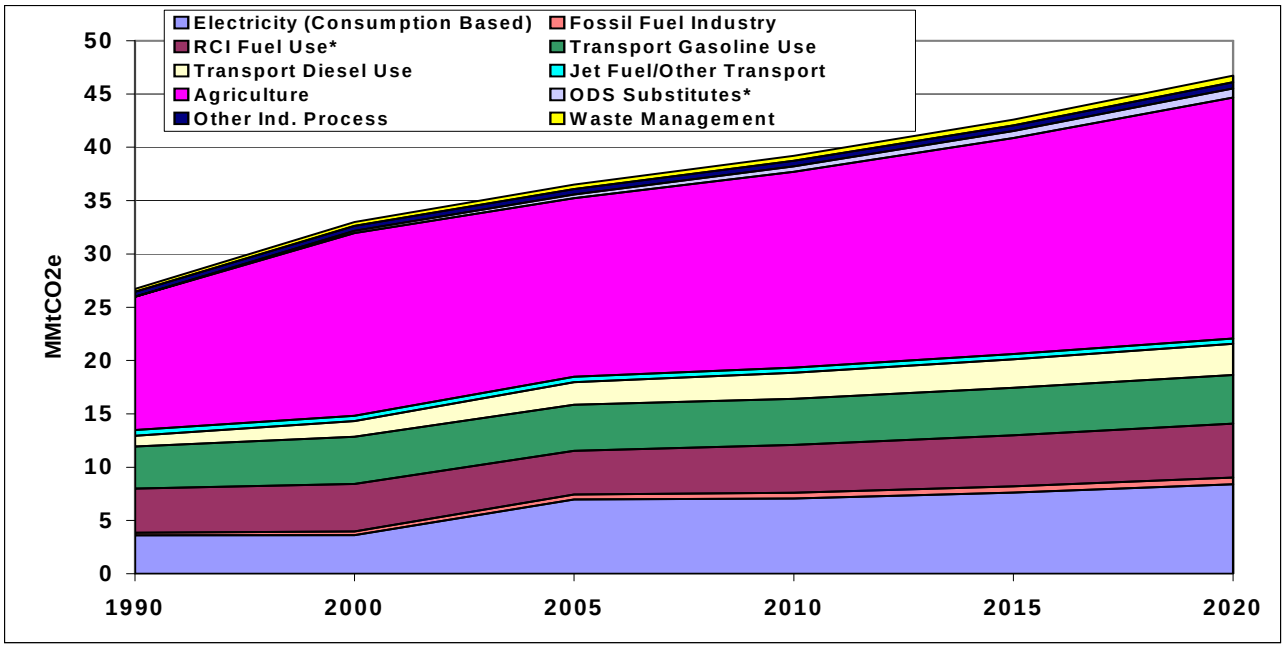
Relying on a variety of sources for projections, as noted below and in the appendices, we developed a simple reference case projection of GHG emissions through 2020. As illustrated in Figure 3 and shown numerically in Table 1, under the reference case projections, South Dakota gross GHG emissions continue to grow steadily, climbing to about 46.7 $MMtCO_2e$ by 2020, 75% above 1990 levels. The agricultural sector is projected to be the largest contributor to future emissions growth, followed by emissions associated with the transportation sector, the consumption of fossil fuels to meet electricity demand, and RCI fossil fuel use, as shown in Figure 4.

Key Uncertainties and Next Steps

Some data gaps exist in this inventory, and particularly in the reference case projections. Key tasks for future refinement of this inventory and forecast include review and revision of key drivers, such as the agriculture, transportation, electricity demand, and RCI fuel use growth rates that will be major determinants of South Dakota's future GHG emissions (See Table 2 and Figure 4). These growth rates are driven by uncertain economic, demographic and land use trends (including growth patterns and transportation system impacts), all of which deserve closer review and discussion.

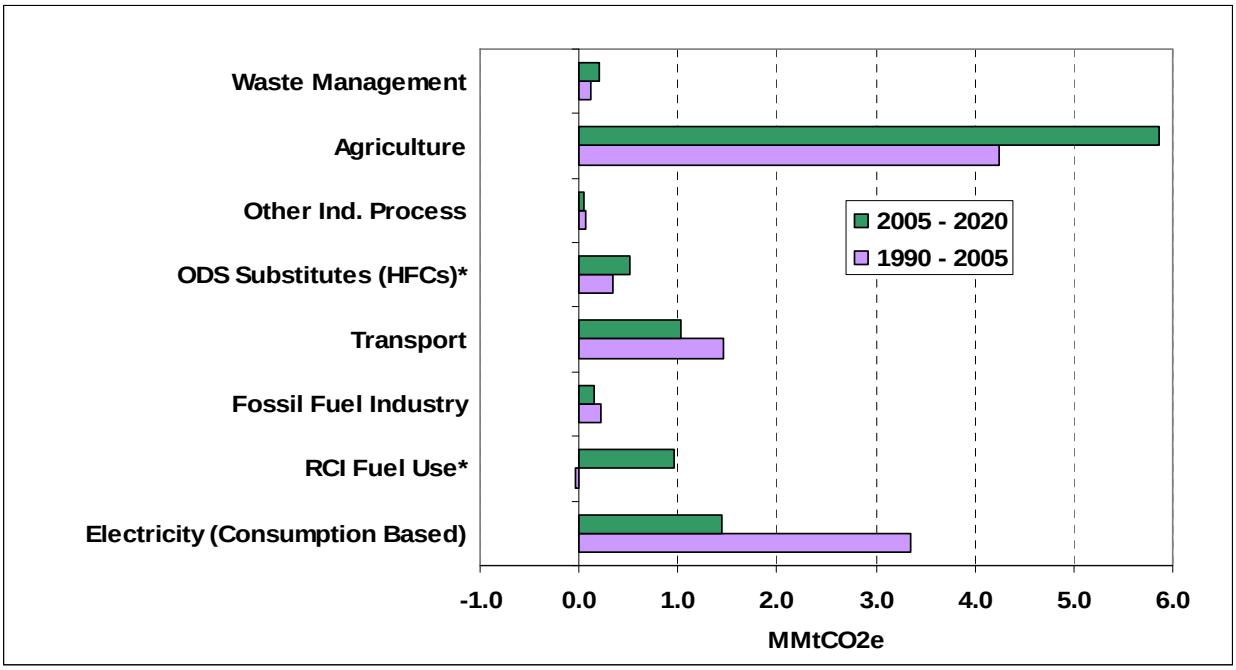
[9] Estimating the emissions associated with electricity use requires an understanding of the electricity sources (both in-state and out-of-state) used by utilities to meet consumer demand. The current estimate reflects some very simple assumptions, as described in Appendix A.

Figure 3. South Dakota Gross GHG Emissions by Sector, 1990-2020: Historical and Projected



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

Figure 4. Sector Contributions to Gross Emissions Growth in South Dakota, 1990-2020: Historic and Reference Case Projections ($MMtCO_2e$ Basis)



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

Table 2. Key Annual Growth Rates for South Dakota, Historical and Projected

	1990-2005	2005-2020	Sources
Population*	0.6%	0.2%	US Bureau of Census
Employment*			
Goods	-0.15%	1.04%	South Dakota Department of Labor, Labor Market Information Center
Services	0.3%	1.47%	
Electricity Sales	2.7%	1.8% - 1.6%	US DOE Energy Information Administration (EIA) data for 1990-2004 (2.7% growth is mix of residential, commercial, and industrial electricity sales). A growth rate of 1.8% was estimated for 2005-2010 and a growth rate of 1.6% was estimated for 2011-2020 based on electricity sales forecasts developed for the energy supply sector (see Appendix A).
Vehicle Miles Traveled	1.6%	1.2%	South Dakota Department of Transportation.

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

As examples, the assumptions on VMT and electricity sales growth have large impacts on projected GHG emissions growth in the State. Also, uncertainty remains in estimates for future livestock populations in the State. Finally, historic and projected GHG sinks from forestry, which could impact to a small degree the net GHG emissions attributed to South Dakota, should be revised as new estimates are produced by the USFS to support future updates to the national inventory.

Emissions of aerosols, particularly BC from fossil fuel combustion, could have significant impacts in terms of radiative forcing (i.e., climate impacts). Methodologies for conversion of BC mass estimates and projections to global warming potential involve significant uncertainty at present, but CCS has developed and used an approach for estimating BC emissions based on methods used in other States. Current estimates suggest a fairly significant CO_2e contribution from BC emissions, as compared to the CO_2e contributed from the gases (about 16% BC contribution relative to the CO_2e from the gases in 2000). However, emissions in key contributing sectors (onroad and nonroad diesel engines) are expected to decline by 2020 (see Appendix I).

Approach

The principle goal of compiling the inventories and reference case projections presented in this document is to provide the State of South Dakota with a general understanding of South Dakota's historical, current, and projected (expected) GHG emissions. The following explains the general methodology and the general principles and guidelines followed during development of these GHG inventories for South Dakota.

General Methodology

We prepared this analysis in close consultation with South Dakota agencies, in particular, with the SDDENR 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 reliable existing forecasts are lacking, we use straightforward spreadsheet analysis and constant growth-rate 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[10] and its guidelines for States.[11] These inventory guidelines were developed based on the guidelines from the IPCC, the international organization responsible for developing coordinated methods for national GHG inventories.[12] The inventory methods provide flexibility to account for local conditions. The key sources of activity and projection data used are shown in Table 3. Table 3 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:

- **Transparency:** We report data sources, methods, and key assumptions to allow open review and opportunities for additional revisions later based on input from others. In addition, we will report key uncertainties where they exist.

- **Consistency:** To the extent possible, the inventory and projections will be designed to be externally consistent with current or likely future systems for State and national GHG emission reporting. We have used the EPA tools for State inventories and projections as a starting point. These initial estimates were then augmented and/or revised as needed to conform with State-based inventory and base-case projection needs. For consistency in making reference case projections, we define reference case actions for the purposes of projections as those *currently in place or reasonably expected over the time period of analysis.*

- **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 or simplified assumptions such as constant linear extrapolation of trends used as defaults where necessary.

[10] 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.
[11] http://yosemite.epa.gov/oar/globalwarming.nsf/content/EmissionsStateInventoryGuidance.html.
[12] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Table 3. Key Sources for South Dakota 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 VIII 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 RCI fuel combustion, transportation, 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 provides energy use data in each State, annually to 2003 for all fuels and 2004 for oil and natural gas.	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 2003. Emission factors from US EPA SGIT are used to calculate energy-related emissions.
EIA AEO2006	EIA AEO2006 projects energy supply and demand for the US from 2003 to 2030. Energy consumption is estimated on a regional basis. South Dakota is included in the West North Central Census region (IA, KS, MN, MO, ND, NE, and SD).	EIA AEO2006 is used to project changes in per capita (residential), per employee (commercial/industrial).
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.
US Forest Service	Data on forest carbon stocks for multiple years.	Data are used to calculate CO_2 flux over time (terrestrial CO_2 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 agricultural soils emissions; livestock population data used to estimate manure and enteric fermentation emissions.

- **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods.** This analysis aims to comprehensively cover GHG emissions associated with activities in South Dakota. It covers all six GHGs covered by US and other national inventories: CO_2, CH_4, N_2O, SF_6, HFCs, PFCs, and BC. The inventory estimates are for the year 1990, with subsequent years included up to most recently available data (typically 2002 to 2005), with projections to 2010 and 2020.

- **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.

- **Use of Consumption-Based Emissions Estimates:** To the extent possible, we estimated emissions that are caused by activities that occur in South Dakota. For example, we reported emissions associated with the electricity consumed in South Dakota. 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 South Dakota. This entails accounting for the electricity sources used by South Dakota utilities to meet consumer demands. As this analysis is refined in the future, one could also attempt to estimate other sectoral emissions on a consumption basis, such as accounting for emissions from transportation fuel used in South Dakota, 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. 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.

Details on the methods and data sources used to construct the inventories and forecasts for each source sector are provided in the following appendices:

- Appendix A. Electricity Use and Supply;
- Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion;
- Appendix C. Transportation Energy Use;
- Appendix D. Industrial Processes;
- Appendix E. Fossil Fuel Industries;
- Appendix F. Agriculture;
- Appendix G. Waste Management; and
- Appendix H. Forestry.

Appendix I contains a discussion of the inventory and forecast for BC. Appendix J provides additional background information from the US EPA on GHGs and global warming potential values.

Appendix A. Electricity Use and Supply

During recent years, South Dakota's electricity has been characterized primarily by a mix of hydro-electric generation from three dams on the Missouri river, coal-fired generation from the Big Stone power plant, and net imports of electricity from other states. With uncertain levels of future hydro-electric generation plus several proposals for large coal and large wind generating facilities, South Dakota's future generation could change significantly. Simple assumptions were developed for the reference case projections in this analysis, and we welcome comments from reviewers on these.

One of the key questions for the State to consider is how to treat greenhouse gas (GHG) emissions that result from generation of electricity that is produced in South Dakota to meet electricity needs in other 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 assesses South Dakota's electricity sector in terms of net consumption and production emissions, and describes the assumptions used to develop the reference case projections. It then describes inter-state 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.

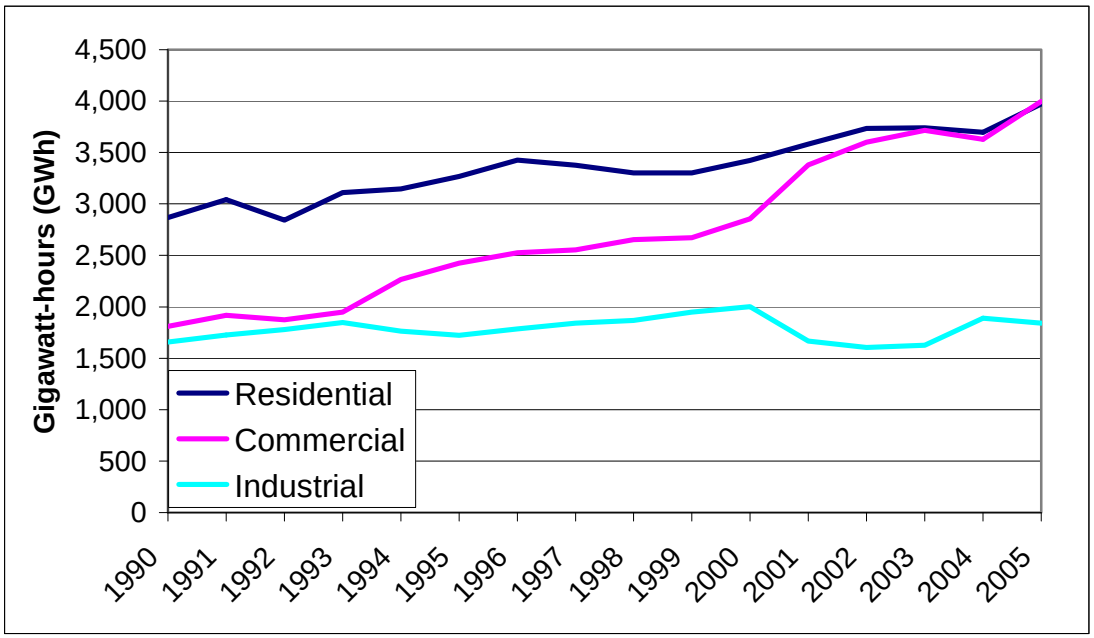
Electricity Consumption

At about 12,200 kilowatt-hours (kWh) per capita (2004 data), South Dakota's electricity consumption per capita is similar to the national average. By way of comparison, the per capita consumption for the US was about 12,000 kWh per year.[13] Many components influence a state's per capita electricity consumption including the impact of weather on demand for cooling, the size and type of industries in the State, and the type and efficiency of equipment in the residential, commercial and industrial sectors.

As shown in Figure A1, both residential sector and commercial sector electricity sales in South Dakota have increased steadily from 1990 through 2005. Industrial sector sales have been relatively constant with decreased sales from 2000 to 2002 being followed by increases through 2005. Overall, total electricity consumption increased at an average annual rate of 2.5% from 1990 to 2005, much higher than the population growth rate of 0.5% per year.[14] During this period, the residential sector grew by an average of 1.7% per year. The commercial sector sales growth average 4.7% per year while the industrial sector had an average growth of 0.9% per year.

[13] Census bureau for US population, Energy Information Administration for electricity sales.
[14] Population from US Census Bureau/ Estimates/Annual Estimates/States, Release Date: December 2005 (http://www.census.gov/popest/states/NST-ann-est.html). Data only provided for 1990 and 2000; population for intermediate years calculated using the compound annual growth rate calculated from the years for which data were published (i.e., 1990 and 2000).

Figure A1. Electricity Consumption by Sector in South Dakota, 1990-2005[15]



Source: EIA State Energy Data (1990-2002) and EIA Electric Power Annual (2003-2005).

Projections for electricity sales from 2006 through 2020 are based on the sales-weighted average of electricity sales projected by the five largest investor-owned utilities in South Dakota, Xcel Energy (previously Northern States Power), Black Hills Corporation, Northwestern Energy, OtterTail Power Company and Montana-Dakota Utilities.[16] These utilities provide 10-year plans, including projected electricity sales to the South Dakota Public Utilities Commission. CCS extrapolated these projections through 2020 based on the growth rates from 2010 to 2015. These four utilities cover approximately 55% of the States electricity sales and the projections from their load forecasts are assumed to be representative of the whole state. Growth rates by sector were estimated based on the relative growth by sector from 1995 to 2005. Table A1 reports historic and projected annual average growth rates.

[15] Note from 1990-2002, the EIA data includes a category referred to as "other," which included lighting for public buildings, streets, and highways, interdepartmental sales, and other sales to public authorities, agricultural and irrigation sales where separately identified, electrified rail and various urban transit systems (such as automated guideway, trolley, and cable). To report total electricity in Figure A1, the sales from the "other" category are included with the commercial sector. The decision to include with commercial rather than the other sectors is based on comparing the trends of electricity sales from 2000-2002 with 2003 sales.

[16] Xcel Energy/Northern States Power. 2006. *Ten Year Plan for Major transmission and generation facilities to the South Dakota Public Utilities Commission.* Black Hills Power. 2006. *2006-2016 Energy Facility Plan, the Subsequent Biennial report of the Ten Year Plan.* Northwestern Energy – South Dakota. 2006. *Ten Year Plan.* Ottertail South Dakota. 2006. *Ten year Biennial Plan.* Projections use the Base Forecast. Montana-Dakota Utilities. 2006. *South Dakota Ten Year Plan.* All reports from the South Dakota Public Utilities website, accessed on December 21, 2006. http://www.state.sd.us/puc/commission/10yearplan/utility10year.htm

Table A1. Electricity Growth Rates, historic and projected

	Historic		Projections	
	1990-2000	2000-2005	2005-2010	2010-2020
Residential	1.8%	3.0%	1.3%	1.2%
Commercial	4.7%	7.0%	2.8%	2.4%
Industrial	1.9%	-1.7%	0.5%	0.5%
Total	**2.7%**	**3.5%**	**1.8%**	**1.6%**

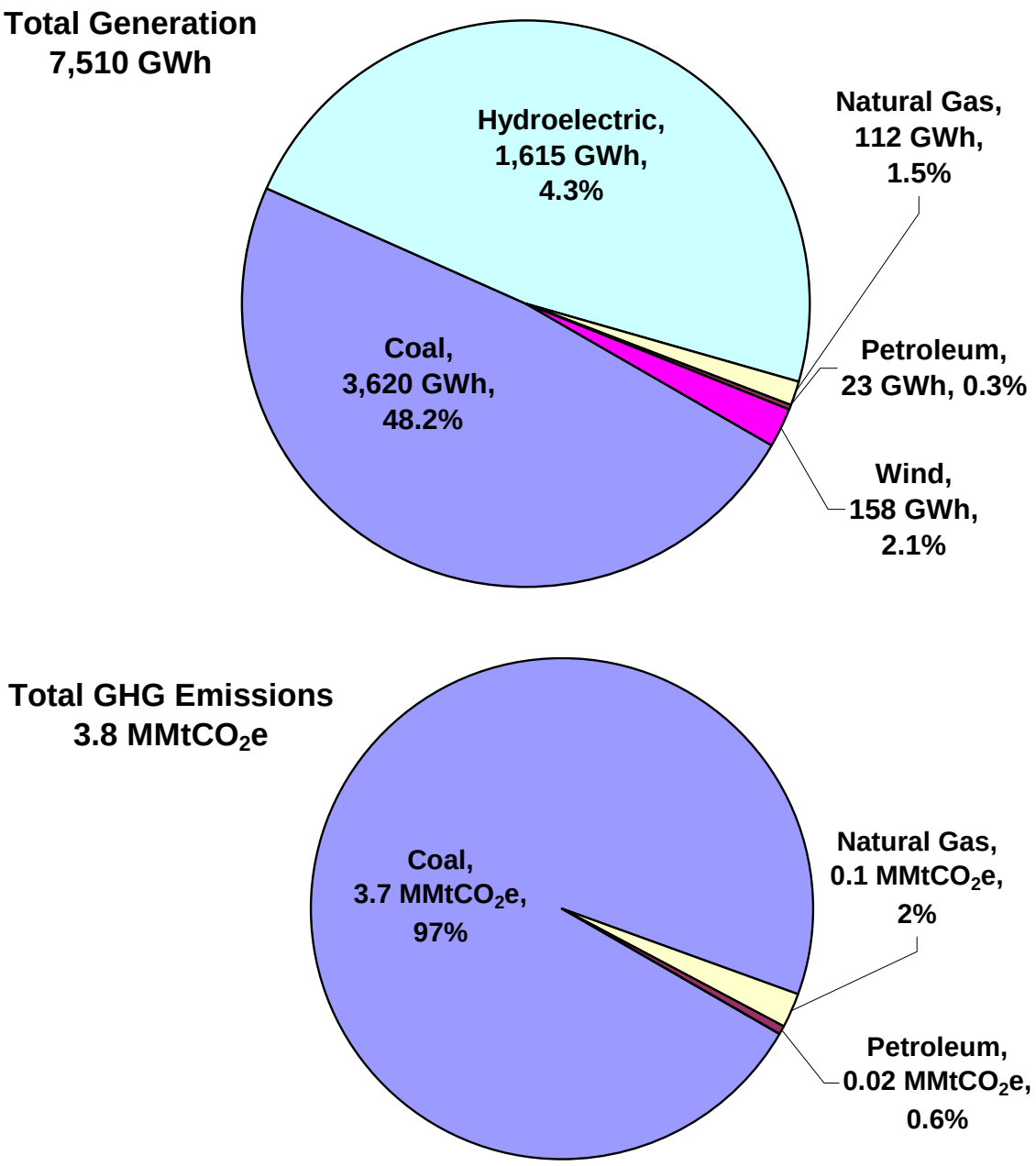
Source: Historic from EIA data, projections are CCS calculations for the sales weighted growth based on Ten Year plans (2006 versions) submitted to South Dakota Public Utilities Commissions by Xcel Energy/Northern States Power, Black Hills Power, Northwestern Energy – South Dakota. ,Ottertail South Dakota (see footnote 16).

Electricity Generation – South Dakota's Power Plants

The following section provides information on GHG emissions and other activity associated with power plants *located in South Dakota*. Note that GHG emissions are reported in this document as metric tons of CO_2 equivalents ($MTCO_2$) or as million metric tons of CO_2 equivalents ($MMTCO_2$). Since most of South Dakota is part of the interconnected Mid-Continent Area Power Pool (with a portion of the state included in the Western Electricity Coordinating Council (WECC) region) – electricity generated in the State can be exported to serve needs in other states and electricity used in South Dakota can be generated in plants outside the state. For this analysis, we estimate emissions on both a *production-basis* (emissions associated with electricity produced in South Dakota, regardless of where it is consumed) and a net *consumption-basis* (emissions associated with electricity consumed in South Dakota). The following section describes production-based emissions while the subsequent section, *Electricity trade and the allocation of GHG emissions*, reports consumption-based emissions.

As displayed in Figure A2, hydro-electricity and coal generation figure prominently in electricity generation in South Dakota. However, since hydro-electricity does not produce GHG emissions, the State's GHG emissions are due almost entirely to the coal generation. Most of South Dakota's GHG emissions related to electricity generation result from the operation of Big Stone, a coal-fired generation plant located along the eastern South Dakota border. This plant has a capacity of 450 megawatts (MW) and is jointly owned by OtterTail Power Company (54%), Northwestern Energy (23%) and Montana-Dakota Utilities (23%). All three utilities provide electricity to customers in South Dakota and in neighboring states.

Figure A2. Electricity Generation and GHG Emissions from South Dakota Power Plants, 2004



Source: Generation data from EIA Electric Power Annual spreadsheets, GHG emissions calculated from EIA data on fuel consumption and SGIT GHG emission factors.

Table A2 shows the growth in generation by fuel type between 1990 and 2004 from power plants in South Dakota. Overall generation grew by 17% over the 15 years, largely from increased coal generation, and some added wind and natural gas. Electricity consumption grew by 45%. Hydro-electric generation shows a decrease between 1990 and 2004, but the table masks the

considerable year-by-year variation from this resource. In the 15-year period, hydro generation ranged between a low of 2,591 Gigawatt-hours (GWh) in 1993 and a high of 9,012 GWh in 1997.

Table A2. Growth in Electricity Generation in South Dakota, 1990-2004

	Generation (GWh)		Growth
	1990	2004	
Coal	2,473	3,620	46%
Hydroelectric	3,934	3,598	-9%
Natural Gas	12	112	805%
Wind	0	158	n/a
Petroleum	8	23	179%
Total	**6,427**	**7,510**	**17%**

Source: EIA data, generation from electric sector, excludes electricity generation from combined heat and power plants in the industrial and commercial sectors

Future Generation and Emissions

Estimating future generation and GHG emissions from South Dakota 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 South Dakota remains uncertain as the trends in type of new builds are influenced by many factors. Since 2003, new power plants in South Dakota have been a mix of natural gas and wind. Proposals for new plants plant in the State are a mix of natural gas, wind and coal. Large projects tend to involve multiple owners and need permits from different States. The proposed Big Stone Unit 2 has 7 co-owners and requires at least 7 permits. Table A3 presents data on new and proposed plants in South Dakota; the list of plants is indicative rather than comprehensive. Also note that proposed plants may not necessarily be built; while others not yet on the drawing boards could well appear prior to 2020.

Individual proposed plants are not modeled in the reference case projections, but the mix of types of proposed plants are considered when developing assumptions.

Table A3. New and Proposed Power Plants in South Dakota

	Plant Name	Fuel	Status	Capacity MW	Expected annual generation GWh	Emissions $MMTCO_2e$	Notes
New plants	Highmore	Wind	On line 2003	40.5	124	0	
	Groton Generation Station	Natural gas - peaking	On line July 2006	95	125	0.0	Uses natural gas produced at the Great Plains Synfuels Plant near Beulah, ND, the only commercial coal-gasification plant in the United States.
	MinnDakota	Wind	Under Construction - scheduled for end of 2007	50	153	0	Xcel Energy project - total farm will be 150MW with 50 MW in South Dakota
Proposed plants	Big Stone Unit 2	coal	in permitting	600	4,625	3.85	Current proposal has plans for plant to be on-line by 2011 or 2012
	Pine Ridge Reservation	wind	Proposed	200-400	1,489	0.00	generation estimate based on 200MW
	Java Wind Farm	wind	Proposed	30	92	0.00	
	Groton Generation Station - additional unit	Natural gas - peaking	Proposed	95	125	0.0	Basin Electric Co-operative
	NextGen	coal	Proposed	400	2,978	2.48	Basin Electric Co-operative plans but undecided on location, could be either North Dakota or South Dakota

Note: This table is not comprehensive, many smaller projects have also been proposed
Sources: American Wind Energy Association website. www.awea.org/projects/SouthDakota.html
Personal Communication. Steve Wegman, South Dakota Public Utilities Commission, January 2007
http://www.bigstoneii.com/PlantProject/PlantProjectTimeline.asp
National Energy Technology Laboratory. *Tracking New Coal Power Plants.* November 2006.
http://www.netl.doe.gov/coal/refshelf/ncp.pdf
Generation estimates based on capacity factors of 0.85 for base load coal, 0.15 for peaking natural gas and 0.35 for wind. Emissions estimates based on heat rates of 9,000 BTU/kWh for coal and 7,000 BTU/kWh for natural gas.

Given the many factors affecting 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 South Dakota's electricity sector is particularly challenging. Therefore, to develop an initial projection, simple assumptions were made, relying to the extent possible on widely-reviewed and accepted modeling assessments.

The reference case projections assume:

- Generation from power plants in South Dakota grows at 1.8% per year from 2007-2010 and at 1.6% per year from 2010 to 2020, following the growth rate in electricity sales. Note that this growth rate is lower than the projected growth rate for the entire MAPP region in EIA's Annual Energy Outlook (AEO2006) – 0.3% from 2010 to 2020, but matches the AEO2006 growth rate for the WECC region.
- Generation from existing non-hydro plants is based on holding generation at 2005 levels. Changes to existing plants due to plant renovations and overhauls that result in higher capacity factors are counted as new generation (thus the mix of new generation discussed below would also apply to plant upgrades).
- Generation from existing hydro-electric plants is assumed to be 4,034 GWh per year in 2013 and subsequent years. Hydro-generation assumptions for years 2006 to 2013 are based on the Army Corps of Engineers 2007-2007 Final Annual Operating Plan (AOP)

for the three dams in South Dakota.[17,18] The generation assumption is significant for the GHG emission projections, since hydro-electricity is a large fraction of South Dakota's electricity generation and the levels have shown large variation.

- New power plants built between 2007 and 2020 will be a mix of 85% coal, 5% natural gas, and 10% wind. This mix is roughly based on the mix of proposed new plants, Table A3.

These assumptions lead to growth of about 230 MW of new power plant capacity by 2020.

Electricity Trade and Allocation of GHG Emissions

The south west area of South Dakota 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 rest of the State is part of the Mid-Atlantic Power Pool - an area covering 2 Canadian provinces, plus at least portions of 7 states (North Dakota, South Dakota Nebraska, Montana, Minnesota, Iowa, and Wisconsin). The inter-connected regions allow 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 South Dakota, 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, South Dakota had 72 entities involved in providing electricity to state customers. The State's six private utilities serve approximately 53% of the customers, and provide the same fraction of the electricity sales. The State's 30 electric cooperatives serve 33% of the customers and 30% of sales. One Federal entity and 35 public utilities account for the remaining 14% of customers and 17% of sales. The top 5 providers of retail electricity in the State are reported in Table A4.

[17] US Army Corps of Engineers, Missouri River Basin Water Management Division. 2006. *Missouri River Mainstem System 2006-2007 Annual Operating Plan*. December 2006. http://www.nwd-mr.usace.army.mil/rcc/reports/pdfs/finalAOP2006-2007.pdf

[18] The AOP provides estimates of electricity generation for the period 2008-2013 under three different assumptions for future run off levels – median, lower quartile and lower decile. Median refers to annual run-off levels that were historically exceeded 50% of the time in the years from 1898 to 1997, lower quartile refers to run-off levels that were exceeded 75% of the time, and 90% refers to run-off levels that were exceeded 90% of the time. The assumed annual generation of 4,034 GWh reflects annual run-off levels from the lower quartile case. The Median run-off case assumes about 5,200 GWh per year in 2013. The Lower Quartile case was used for this analysis, partly reflecting the low generation levels that have been experienced by South Dakota in the last ten years. Note that the generation levels from the Lower Quartile are 30% higher than hydro-generation from the dams in 2005.

Table A4. Retail Electricity Providers in South Dakota (2004)

Entity	Ownership Type	2004 GWh
Xcel Energy (Northern States Power)	Investor-Owned	1,688
Black Hills Corp	Investor-Owned	1,346
Northwestern Energy	Investor-Owned	1,191
Sioux Valley SW Electric Coop	Cooperative	412
Otter Tail Power Company	Investor-Owned	324
Total Sales, Top Five Providers		4,960
Total, All South Dakota		**9,214**

Source: EIA state electricity profiles.

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 electric sector emissions, when electricity flows across state borders. 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. Under a production-based approach, characteristics of South Dakota electricity consumption would not be fully 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.[19] 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. Since the electricity flowing into or out of South Dakota is a mix of all plants generating on the inter-connected grid, it is impossible to physically track the sources of 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) plus the emissions from the net imports. If the state is a net exporter of electricity, the net-consumption-based emissions are less than the production-based emissions, based on the fraction of exported electricity. If the state is a net importer of electricity, the consumption-based emissions are greater than the production-based emissions, based on the amount and GHG emission-intensity of the imports.

[19] 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.

Emissions for net imports are calculated as net imports multiplied by an emission factor in GHG emissions per electricity generated ($MTCO_2e$/Megawatt-hour, MWh) for the imports. As a proxy for estimating the mix of historic and future GHG emissions for South Dakota's electricity imports, emission factors that reflect the regional fuel mix were used. The region used to reflect electricity imports is the Mid-Atlantic Power Pool from the AEO2006. This regional emission factor was 0.82 $MTCO_2e$/MWh in 2004, decreasing to 0.79 $MTCO_2e$/MWh in 2020, reflecting a small increased regional contribution of renewables and natural gas to the electricity generation mix.

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 simplified method for reflecting the emissions impacts of electricity consumption in the State. The calculation also ignores "gross" imports – since South Dakota plants have contracts to out-of-state entities, some of the in-state electricity generation will be exported and gross imports will be greater than net imports. More sophisticated methods – for example, based on individual utility information on resources used to meet loads – can be considered for further improvements to this approach. One example of the data requirements for this approach can be found in Washington State, which has developed regular fuel disclosure reporting from each of its utilities.[20]

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 A5.

[20] http://www.cted.wa.gov/site/539/default.aspx

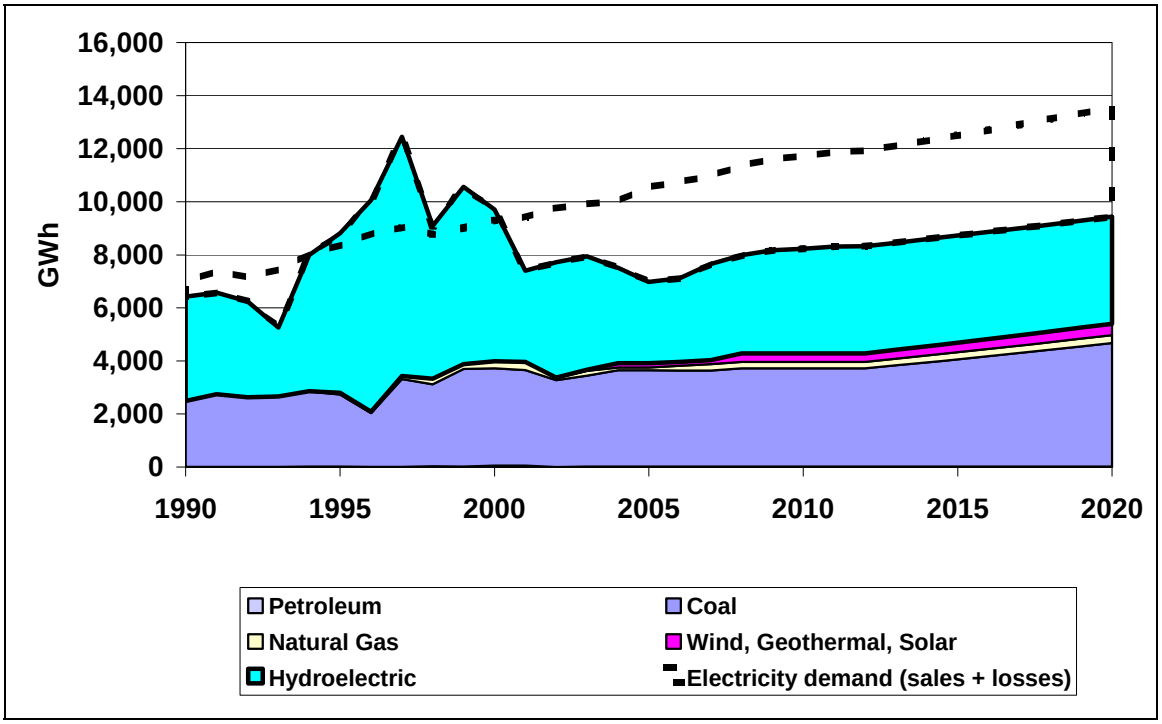
Table A5. Key Assumptions and Methods for Electricity Projections for South Dakota

Electricity sales	Average annual growth of 1.8% from 2006 to 2010 and 1.6% from 2010 to 2020, based on sales-weighted growth rates from the five largest investor-owned utilities in South Dakota (see Table A1).
Electricity generation	Average annual growth in generation is the same as growth in electricity sales.
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[21])
New Generation Sources (2006-2020)	The mix of new generation in this period roughly tracks the mix of proposed new plants in South Dakota (Table A3). 85% coal 5% natural gas, and 10% wind
Heat Rates	The assumed heat rate for new coal and natural gas generation is 9000 Btu/kWh and 7000 Btu/kWh, respectively, based on estimates used in similar analyses.[22]
Operation of Existing Facilities	Existing non-hydro facilities are assumed to continue to operate as they were in 2005. Existing hydro facilities are assumed to generate 4,034 GWh per year from 2013 on, reflecting Lower Quartile run-off assumptions from US Army Corps of Engineers analysis of the Missouri River.[23] Improvements in existing facilities that lead to higher capacity factor and more generation are captured under the new generation sources.

Figure A3 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. Based on the assumptions for new generation, imported electricity continues to play a major role in meeting future electricity demand in South Dakota. Figure A3 shows that South Dakota was a net importer of electricity from 1995 to 2000, when hydro-electric generation levels were high. Future generation from new and existing plants in-state is projected to remain lower than total electricity sales. Generation from existing hydro plus new coal-fired generation show high growth, relative to levels in 2005. Overall in-state electricity generation grows at 2.0% per year from 2005 to 2020 (this rate is slightly higher than the average annual rates in Figure A3 because it includes new plants that have come on line since 2005 or are under construction, Groton Natural Gas Generating Station I and MinnDakota Wind).

[21] http://www.epa.gov/cleanenergy/egrid/index.htm.
[22] See, for instance, the Oregon Governor's Advisory Group On Global Warming http://egov.oregon.gov/ENERGY/GBLWRM/Strategy.shtml.
[23] US Army Corps of Engineers, Missouri River Basin Water Management Division. 2006. *Missouri River Mainstem System 2006-2007 Annual Operating Plan.* December 2006. http://www.nwd-mr.usace.army.mil/rcc/reports/pdfs/finalAOP2006-2007.pdf

Figure A3. Electricity Generated by South Dakota Power Plants 1990-2020



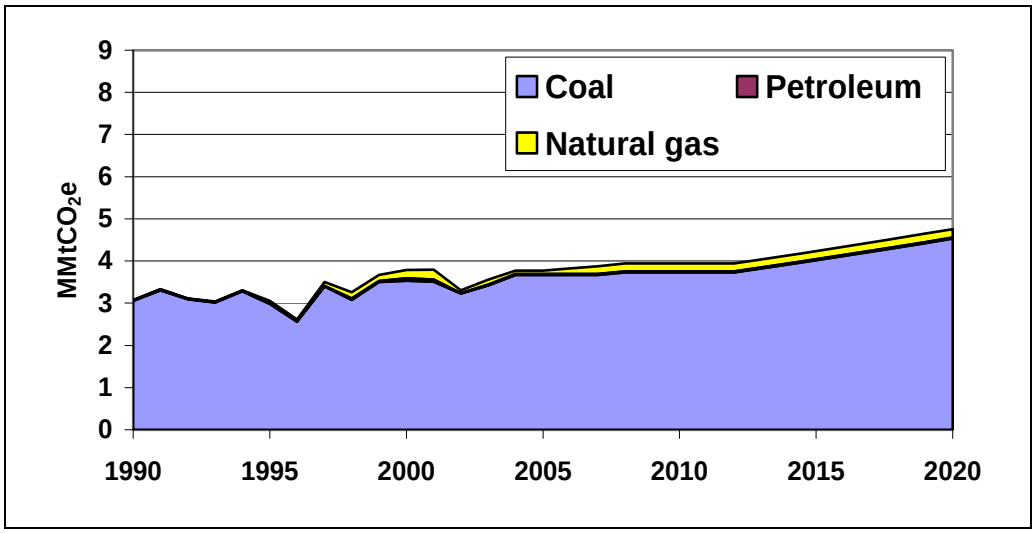
Source: 1990-2005 EIA data, 2006-2020 CCS calculations based on assumptions described above, generation from petroleum and natural gas resources are too small to be visible in the chart

GHG emission estimates were calculated by multiplying the energy consumption by GHG emission factors by fuel. Energy consumption for 2006 to 2020 was calculated based on changes to future generation and heat rate properties described in table A6. The EPA SGIT software provided GHG emission factors by fuel for each state, consistent with factors used for EPA's national GHG inventory report.[24]

Figure A4 illustrates the GHG emissions associated with the mix of electricity generation shown in Figure A3. From 2005 to 2020, the emissions from South Dakota's electricity generation are projected to grow at 1.6% per year, lower than the growth in electricity generation, due to an increased fraction of generation from existing hydro-generation plus new wind. As a result, the emission intensity (GHG emissions per MWh) of South Dakota electricity generation is expected to increase from 0.54 $MTCO_2$/MWh in 2005 to 0.50 $MTCO_2$/MWh in 2020.

[24] SGIT http://www.epa.gov/climatechange/emissions/state_guidance.html, National GHG inventory http://www.epa.gov/climatechange/emissions/usinventoryreport.html

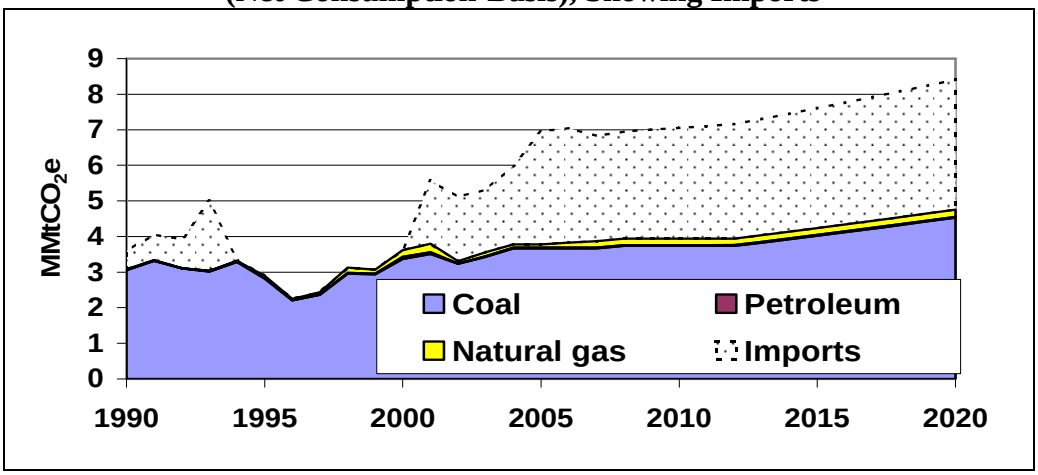
Figure A4. South Dakota GHG Emissions Associated with Electricity Production (Production-Basis)



Source: CCS calculations based on approach described in text.
Note: South Dakota's electric generation GHG emissions from petroleum sources are less than 0.05 million metric tons of CO_2 equivalents ($MMTCO_2$) and too small to be visible in the chart.

Figure A5 shows the "net-consumption-based" emissions from 1990 to 2020. Total emissions are much higher than the production-based emissions due to the GHG emissions associated with net electricity imports. Consumption-based emissions increase by 1.3% per year from 2006 to 2020. The lack of in GHG emissions from imports from 1995 to 2000 reflects years with high hydro-electricity generation, when South Dakota was a net exporter of electricity. In other years previously and under the assumptions for reference case projections, South Dakota is a net importer of electricity, with GHG emissions based on the MAPP GHG emission rate, as described in the *Electricity Trade* section.

Figure A5. South Dakota GHG Emissions Associated with Electricity Use (Net Consumption-Basis), Showing Imports



Source: CCS calculations based on approach described in text.
Note: South Dakota's electric generation GHG emissions from petroleum sources are less than 0.05 $MMTCO_2e$ and too small to be visible in the chart.

Table A6 summarizes the GHG emissions for South Dakota's electric sector from 1990 to 2020. Production-based emissions are assumed to grow by 54% from 1990 to 2020, driven mostly by increased coal-fired generation. Consumption-based emissions grow by 133%, due to both increased electricity sales and increased amount of fossil-based net-imported electricity, relative to 1990.

Table A6. South Dakota GHG Emissions from Electric Sector, Production and Consumption-based estimates, 1990-2020.

(Million Metric Tons CO2e)	1990	2000	2005	2010	2020
Electricity Production	**3.1**	**3.8**	**3.8**	**3.9**	**4.8**
Coal	3.1	3.5	3.7	3.7	4.5
CO_2	3.0	3.5	3.7	3.7	4.5
CH_4 and N_2O	0.0	0.0	0.0	0.0	0.0
Natural Gas	0.0	0.2	0.1	0.2	0.2
CO_2	0.0	0.2	0.1	0.2	0.2
CH_4 and N_2O	0.0	0.0	0.0	0.0	0.0
Petroleum	0.0	0.1	0.0	0.0	0.0
CO_2	*0.0*	*0.1*	*0.0*	*0.0*	*0.0*
CH_4 and N_2O	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Biomass and Waste (CH_4 and N_2O)	0.0	0.0	0.0	0.0	0.0
Net Elecricity Imports (negative for exports)	**0.5**	**-0.2**	**3.2**	**3.1**	**3.6**
Electricity Consumption-based Emissions	**3.6**	**3.6**	**7.0**	**7.1**	**8.4**

Note: Values that are less than 0.05 $MMTCO_2e$ are listed as 0.0 in Table A7.

Key Uncertainties

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

- Amount and mix of new generation. South Dakota's mix of new generation will vary significantly from the reference case projections in this analysis if any of the major plants reported in Table A3 are built in the next 15 years. The GHG emissions associated with these plants is provided in Table A3 and can be used as an indication of the range of potential GHG emissions in South Dakota, on a production-basis. Consumption-based emissions are less independent on the amount of total generation in-state.
- Future generation from existing hydro-electric plants. Generation from hydro plants has varied significantly in the last 15 years and expected levels of future generation could affect plans and operation of new fossil fuel plants.
- Approach for estimating consumption-based GHG emissions. The "net-consumption-based" approach used in this analysis is a rough simplification of electricity trade that does not consider individual utility portfolios. Additional data on the historic and current mix of electricity generation used by South Dakota's utilities to meet their customers' electricity demand could help refine these estimates. Refining the future GHG emission projections would likewise require additional information or assumptions on the utilities' electricity provisions.

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

Overview

Activities in the RCI[25] sectors produce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions when fuels are combusted to provide space heating, process heating, and other applications. CO_2 accounts for over 99% of these emissions on a million metric tons (MMt) of CO_2 equivalent (CO_2e) basis in South Dakota. In addition, since these sectors consume electricity, one can also attribute emissions associated with electricity generation to these sectors in proportion to their electricity use.[26] Direct use of oil, natural gas, coal, and wood in the RCI sectors accounted for an estimated 4.1 $MMtCO_2e$ of gross greenhouse gas (GHG) emissions in 2005.[27]

Emissions and Reference Case Projections

Emissions from direct fuel use were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SGIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for RCI fossil fuel combustion.[28] The default data used in SGIT for South Dakota are from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data* (SED). The SGIT default data for South Dakota were revised using the most recent data available, which includes: (1) 2002 SED information for all fuel types;[29] (2) 2003 SED information for coal, and for wood and wood waste;[30] (3) 2004 SED information for natural gas;[6] (4) 2003 and 2004 SED information for petroleum (distillate oil, kerosene and liquefied petroleum gas) consumption;[6] (5) 2004 electricity consumption data from the EIA's *State*

[25] The industrial sector includes emissions associated with agricultural energy use and fuel used by the fossil fuel production industry.
[26] Emissions associated with the electricity supply sector (presented in Appendix A) have been allocated to each of the RCI sectors for comparison of those emissions to the fuel-consumption-based emissions presented in Appendix B. Note that this comparison is provided for information purposes and that emissions estimated for the electricity supply sector are not double-counted in the total emissions for the state. One could similarly allocate GHG emissions from natural gas transmission and distribution, other fuels production, and transport-related GHG sources to the RCI sectors based on their direct use of gas and other fuels, but we have not done so here due to the difficulty of ascribing these emissions to particular end-users. Estimates of emissions associated with the transportation sector are provided in Appendix C, and estimates of emissions associated with fossil fuel production and distribution are provided in Appendix E.
[27] Emissions estimates from wood combustion include only N_2O and CH_4. Carbon dioxide emissions from biomass combustion are assumed to be "net zero", consistent with US EPA and Intergovernmental Panel on Climate Change (IPCC) methodologies, and any net loss of carbon stocks due to biomass fuel use should be accounted for in the land use and forestry analysis.
[28] GHG emissions were calculated using SGIT, with reference to *EIIP, Volume VIII*: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004, and Chapter 2 "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion", August 2004.
[29] EIA *State Energy Data 2002*, Data through 2002, released June 30, 2006, http://www.eia.doe.gov/emeu/states/state.html?q_state_a=co&q_state=SOUTH_DAKOTA.
[30] EIA *State Energy Data 2003 revisions for all fuels, and first release of 2004 information for natural gas and petroleum*, http://www.eia.doe.gov/emeu/states/_seds_updates.html.

Electricity Profiles;[31] and (6) 2005 natural gas consumption data from the EIA's *Natural Gas Navigator*.[32]

Note that the EIIP methods for the industrial sector exclude from CO_2 emission estimates the amount of carbon that is stored in products produced from fossil fuels for non-energy uses. For example, the methods account for carbon stored in petrochemical feedstocks, and in liquefied petroleum gases (LPG) and natural gas used as feedstocks by chemical manufacturing plants (i.e., not used as fuel), as well as carbon stored in asphalt and road oil produced from petroleum. The carbon storage assumptions for these products are explained in detail in the EIIP guidance document.[33] The fossil fuel categories for which the EIIP methods are applied in the SGIT software to account for carbon storage include the following categories: asphalt and road oil, coking coal, distillate fuel, feedstocks (naphtha with a boiling range of less than 401 degrees Fahrenheit), feedstocks (other oils with boiling ranges greater than 401 degrees Fahrenheit), LPG, lubricants, miscellaneous petroleum products, natural gas, pentanes plus,[34] petroleum coke, residual fuel, still gas, and waxes. Data on annual consumption of the fuels in these categories as chemical industry feedstocks were obtained from the EIA SED.

Reference case emissions from direct fuel combustion were estimated based on fuel consumption forecasts from EIA's *Annual Energy Outlook 2006* (AEO2006),[35] with adjustments for South Dakota's projected population[36] and employment growth. South Dakota employment data for the manufacturing (goods-producing) and non-manufacturing (commercial or services-providing) sectors were obtained from the South Dakota Department of Labor.[37] Regional employment data for the same sectors were obtained from EIA for the EIA's West North Central region.[38]

Table B1 shows historic and projected growth rates for electricity sales by sector. Table B2 shows historic and projected growth rates for energy use by sector and fuel type. For the residential sector, the rate of population growth is expected to be about 0.2% annually between 2004 and 2020; this demographic trend is reflected in the growth rates for residential fuel consumption. Based on the South Dakota Department of Labor's 10-year forecast (2004 to 2014), commercial and industrial employment are projected to increase at compound annual

[31] EIA *Electric Power Annual 2005 - State Data Tables*, http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html.
[32] EIA *Natural Gas Navigator* http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_SSD_a.htm.
[33] EIIP, Volume VIII: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004.
[34] A mixture of hydrocarbons, mostly pentanes and heavier fractions, extracted from natural gas.
[35] EIA AEO2006 with Projections to 2030, http://www.eia.doe.gov/oiaf/aeo/index.html.
[36] Historical population data for 1990 and 2000 for South Dakota from US Census Bureau's *Annual Estimates for States*, Release Date: December 2005 http://www.census.gov/popest/states/NST-ann-est.html. Projections of South Dakota's population to 2030 from US Census Bureau, Population Division, *Interim State Population Projections, 2005*; Internet Release Date: April 21, 2005; "Table 1: Interim Projections: Ranking of Census 2000 and Projected 2030 State Population and Change: 2000 to 2030" http://www.census.gov/population/www/projections/projectionsagesex.html. Population for intermediate years between 1990 and 2000 and 2000 and 2030 calculated using the compound annual growth rate calculated from the years for which data were published.
[37] South Dakota Department of Labor, Labor Market Information Center, http://www.sdjobs.org/lmic/; *Select Projections, By Industry, South Dakota, All industries*.
[38] AEO2006 employment projections for EIA's West North Central region obtained through special request from EIA dated September 27, 2006.

rates of 1.47% and 1.04%, respectively, and these growth rates are reflected in the growth rates in energy use shown in Table B2 for the two sectors. The 2004-to-2014 commercial and industrial employment growth rates were carried forward to 2020 for the purpose of estimating emissions for the reference case projections. These estimates of growth relative to population and employment reflect expected responses of the economy — as simulated by the EIA's National Energy Modeling System — to changing fuel and electricity prices and changing technologies, as well as to structural changes within each sector (such as shifts in subsectoral shares and in energy use patterns).

Table B1. Electricity Sales Annual Growth Rates, Historical and Projected

Sector	1990-2004*	2005-2010**	2010-2020**
Residential	1.8%	1.3%	1.2%
Commercial	6.8%	2.8%	2.4%
Industrial	0.9%	0.5%	0.5%
Total	**2.7%**	**1.8%**	**1.6%**

* 1990-2004 compound annual growth rates calculated from South Dakota electricity sales by year from EIA state electricity profiles (Table 8), http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html.
** 2004-2020 compound annual growth rate for total for all three sectors taken from forecast for the energy supply sector (see Appendix A).

Table B2. Historical and Projected Average Annual Growth in Energy Use in South Dakota, by Sector and Fuel, 1990-2020

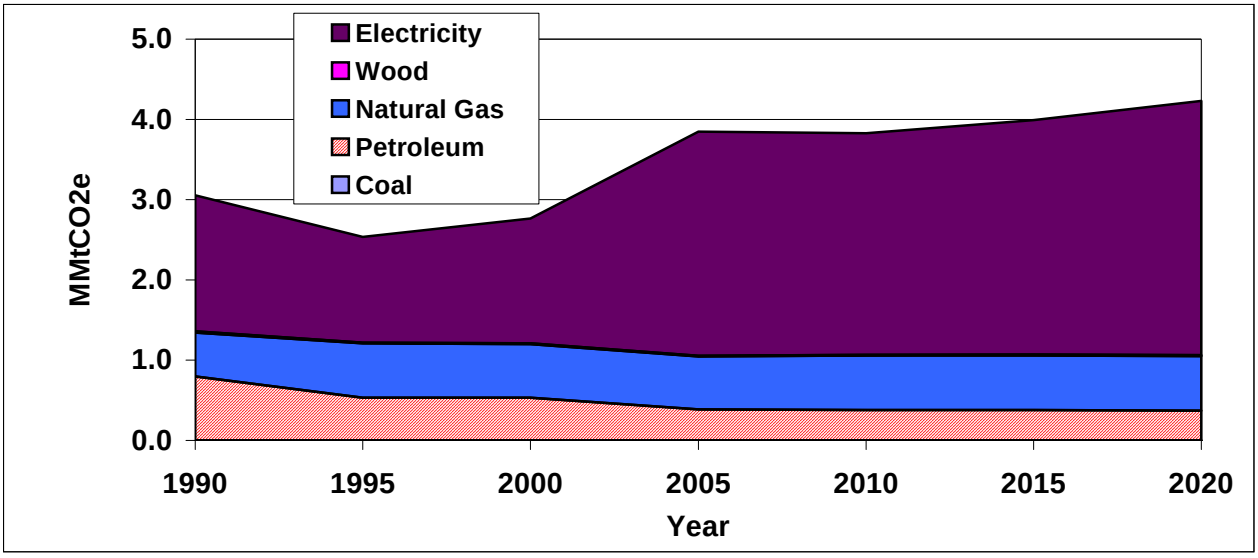
	1990-2004*	2005-2010**	2010-2015**	2015-2020**
Residential				
natural gas	1.3%	0.6%	0.1%	0.0%
petroleum	-4.8%	-0.4%	0.0%	-0.2%
wood	-2.2%	1.0%	-0.4%	0.1%
coal	-11.5%	1.1%	-0.9%	-0.8%
Commercial				
natural gas	1.0%	1.3%	2.5%	1.7%
petroleum	-2.0%	0.0%	1.2%	0.7%
wood	1.4%	0.4%	0.9%	0.5%
coal	-7.9%	0.2%	0.9%	0.5%
Industrial				
natural gas	4.1%	6.2%	3.3%	1.4%
petroleum	-2.4%	1.6%	1.1%	1.2%
wood	-1.9%	2.6%	2.2%	2.0%
coal	3.7%	2.3%	1.2%	1.1%

* Compound annual growth rates calculated from EIA SED historical consumption by sector and fuel type for South Dakota. Latest year for which EIA SED information was available for each fuel type is 2003 for coal and wood/wood waste, 2004 for petroleum, and 2005 for natural gas. Petroleum includes distillate fuel, kerosene, and liquefied petroleum gases for all sectors plus residual oil for the commercial and industrial sectors.
** Figures for growth periods starting after 2004 are calculated from AEO2006 projections for EIA's West North Central region, adjusted for South Dakota's projected population for the residential sector, projections for non-manufacturing employment for the commercial sector, and projections for manufacturing employment for the industrial sector.

Results

Figures B1, B2, and B3 show historical and projected emissions for the RCI sectors in South Dakota from 1990 through 2020. These figures show the emissions associated with the direct consumption of fossil fuels and, for comparison purposes, show the share of emissions associated with the generation of electricity consumed by each sector. During the period from 1990 through 2020, the residential sector's share of total RCI emissions from direct fuel use and electricity was 40% in 1990, decreased to 35% in 2005, and is projected to decline further to 31% in 2020. The commercial sector's share of total RCI emissions from direct fuel use and electricity use was 20% in 1990, increased to 31% in 2005, and is projected to increase to 35% by 2020. The industrial sector's share of total RCI emissions from direct fuel use and electricity use was 40% in 1990 and ranges from 34% to 35% percent over the 2005-through-2020 time period. Emissions associated with the generation of electricity to meet RCI demand accounts for about 65% of the emissions for the residential sector, 70% of the emissions for the commercial sector, and 31% of the emissions for the industrial sector, on average, over the 1990 to 2020 time period. From 1990 to 2020, natural gas consumption is the next highest source of emissions for all three sectors accounting, on average, for about 20% of total emissions in the residential sector, 22% for the commercial sector, and 15% for the industrial sector.

Figure B1. Residential Sector GHG Emissions from Fuel Consumption

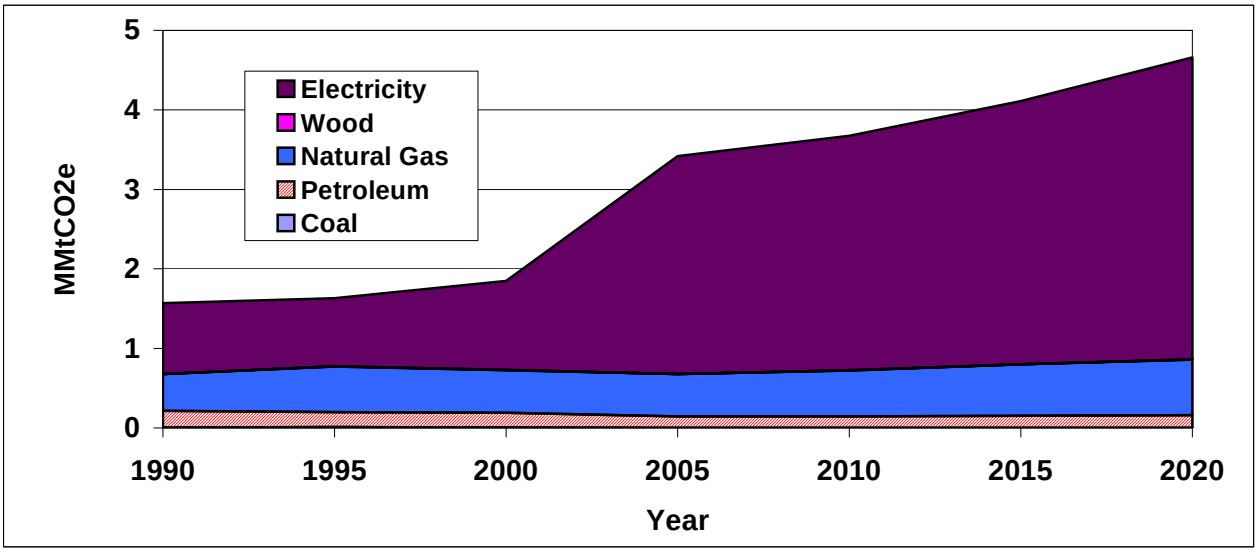


Source: CCS calculations based on approach described in text.
Note: Emissions associated with wood and coal combustion are too small to be seen on this graph.

For the residential sector, emissions from electricity and direct fossil fuel use in 1990 were about 3.1 $MMtCO_2e$, and are estimated to increase to about 4.2 $MMtCO_2e$ by 2020. Emissions associated with the generation of electricity to meet residential energy consumption demand accounted for about 56% of total residential emissions in 1990, and are estimated to increase to 75% of total residential emissions by 2020. In 1990, natural gas consumption accounted for about 18% of total residential emissions, and is estimated to account for about 16% of total residential emissions by 2020. Residential-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 0.81 $MMtCO_2e$ combined, and accounted for about

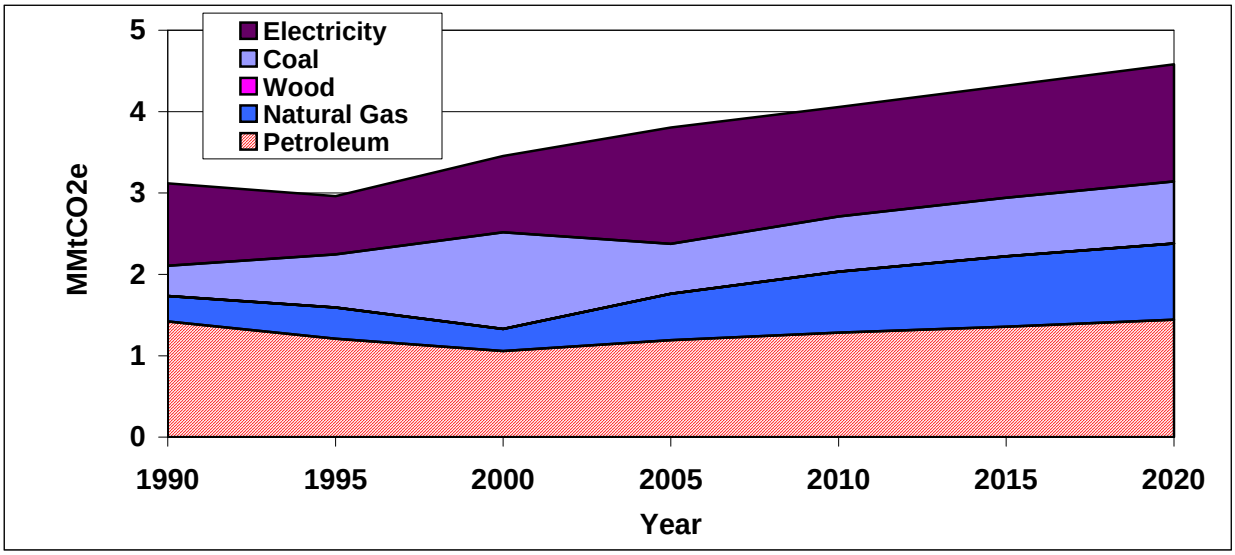
26% of total residential emissions. By 2020, emissions associated with the consumption of these three fuels are estimated to fall to 0.38 $MMtCO_2e$, accounting for 9% of total residential sector emissions by that year.

Figure B2. Commercial Sector GHG Emissions from Fuel Consumption



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

Figure B3. Industrial Sector GHG Emissions from Fuel Consumption



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

For the 15-year period 2005 to 2020, residential-sector GHG emissions associated with the use of electricity, natural gas, and wood are expected to increase at average annual rates of about 0.9%, 0.2%, and 0.2% respectively. Emissions associated with the use of coal and petroleum are

expected to decline annually by about -0.4% and -0.2%, respectively. Total GHG emissions for this sector increase by an average of about 0.6% annually over the 15-year period.

For the commercial sector, emissions from electricity and direct fossil fuel use in 1990 were about 1.6 $MMtCO_2e$, and are estimated to increase to about 4.7 $MMtCO_2e$ by 2020. Emissions associated with the generation of electricity to meet commercial energy consumption demand accounted for about 57% of total commercial emissions in 1990 and are estimated to increase to 82% of total commercial emissions by 2020. In 1990, natural gas consumption accounted for about 29% of total commercial emissions and is estimated to account for about 15% of total commercial emissions by 2020. Commercial-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 0.22 $MMtCO_2e$ combined, and accounted for about 14% of total commercial emissions. By 2020, emissions associated with the consumption of these three fuels are estimated to be 0.16 $MMtCO_2e$ and to account for 3% of total commercial sector emissions.

For the 15-year period 2005 to 2020, commercial-sector GHG emissions associated with the use of electricity, natural gas, and petroleum are expected to increase at average annual rates of about 2.2%, 1.8%, and 0.7% respectively. Emissions associated with the use of wood and coal are expected to increase annually by about 0.6% each for both of these fuels. Total GHG emissions for this sector increase by an average of about 2.1% annually over the 15-year period.

For the industrial sector, emissions from electricity and direct fuel use in 1990 were about 3.1 $MMtCO_2e$ and are estimated to increase to about 4.6 $MMtCO_2e$ by 2020. Emissions associated with the generation of electricity to meet industrial energy consumption demand accounted for about 32% of total industrial emissions in 1990, and are estimated decline slightly to about 31% of total industrial emissions by 2020. In 1990, natural gas consumption accounted for about 10% of total industrial emissions, and is estimated to account for about 21% of total industrial emissions by 2020. Industrial-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 1.8 $MMtCO_2e$ combined, and accounted for about 58% of total industrial emissions. For 2020, emissions associated with the consumption of these three fuels are estimated to be 2.2 $MMtCO_2e$, and to account for 48% of total industrial sector emissions.

For the 15-year period 2005 to 2020, industrial-sector GHG emissions associated with the use of electricity, natural gas, and petroleum are expected to increase at average annual rates of about 0.1%, 3.3%, and 1.3% respectively. Emissions associated with the use of wood and coal are expected to increase annually by about 2.2% and 1.5%, respectively. Total GHG emissions for the industrial sector increase by an average of about 1.2% annually over the 15-year period.

Note that the EIA's historical electricity sales data were used to allocate emissions associated with the electricity supply sector to each of the RCI sectors. As shown in Figures B1 through B3, this allocation shows a significant growth in electricity supply emissions from 2000 to 2005 for the residential, commercial, and industrial sectors, respectively. In particular, the large increases in emissions for the commercial sector between 2000 and 2005 are reflective of a combination of calculation methods for (1) GHG emissions associated with electricity consumption and (2) increases in electricity consumption by sector. GHG emissions associated with South Dakota's electricity consumption increase significantly between 2000 (when hydro-electric generation was

high) and 2005 (when hydro-electric generation was relatively low). Appendix A describes the calculation method for this sector, the large annual variation for South Dakota, and the uncertainties produced in calculations based on these electricity generation data. Data on electricity consumption by sector are taken from EIA compendia. A change in EIA accounting procedures in 2003 for reporting sales by sector also contributes to the increase in estimated commercial sector emissions between 2000 and 2005 that is shown in Figure B2.

Key Uncertainties

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

- Population and economic growth are the principal drivers for electricity and fuel use. The reference case projections are based on regional fuel consumption projections for EIA's West North Central modeling region scaled for South Dakota population and employment growth projections. Consequently, there are significant uncertainties associated with the projections. Future work should attempt to base projections of GHG emissions on fuel consumption estimates specific to South Dakota to the extent that such data become available.
- The AEO2006 projections assume no large long-term changes in relative fuel and electricity prices, relative to current price levels and to US DOE projections for fuel prices. Price changes would influence consumption levels and, to the extent that price trends for competing fuels differ, may encourage switching among fuels, and thereby affect emissions estimates.
- The exception to the AEO2006 assumption of no large changes in prices or fuels consumption is the AEO2006 reference case projections for industrial coal consumption. The AEO2006 model's forecast for the EIA's West North Central region assumes that new coal-to-liquids plants would be constructed near active coal mines when low-sulfur distillate prices reach high enough levels to make coal-to-liquids processing economic. Plants are assumed to be co-production plants with generation capacity of 758 MW and the capability of producing 33,200 barrels of liquid fuel per day. The technology assumed is similar to an integrated gasification combined cycle plant, first converting the coal feedstock to gas, and then subsequently converting the synthetic gas to liquid hydrocarbons using the Fisher-Tropsch process. As a result, AEO2006 projections assume a rather significant increase in coal consumption by the coal-to-liquids industrial sector starting in 2011. For the EIA's West North Central region, this sector accounts for 7.4% of total coal consumption in 2011 and 40% of total coal consumption in 2020, with an annual growth rate of 21% from 2011 to 2020.[39] This increase in coal consumption, associated with the installation of coal-to-liquids plants starting in 2011, was excluded from the industrial coal consumption forecasts for South Dakota because it is considered to represent technology that is beyond the "business-as-usual" assumptions associated with the reference case projections for the industrial coal consumption sector. In addition, there are no producing coal mines in South Dakota, as reported by the EIA.

[39] Coal Market Module of the National Energy Modeling System 2006, as described in *Assumptions to the Annual Energy Outlook 2006, Coal Market Module*, Report #: DOE/EIA-0554(2006), March 2006 http://www.eia.doe.gov/oiaf/aeo/assumption/index.html.

Appendix C. Transportation Energy Use

Overview

The transportation sector is one of the largest sources of greenhouse gas (GHG) emissions in South Dakota. Carbon dioxide (CO_2) accounts for about 87% of transportation GHG emissions from fuel use. Most of the remaining GHG emissions from the transportation sector are due to nitrous oxide (N_2O) emissions from gasoline engines.

Emissions and Reference Case Projections

Greenhouse gas emissions for 1990 through 2002 were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SGIT) and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[40,41] For onroad vehicles, the CO_2 emission factors are in units of pounds per million British Thermal Units (lb/MMBTU) and the methane (CH_4) and N_2O emission factors are both in units of grams per vehicle miles traveled (g/VMT). Key assumptions in this analysis are listed in Table C1. The default data within SGIT were used to estimate emissions, with the most recently available fuel consumption data (2002) from the United States Department of Energy (US DOE) Energy Information Administration (EIA) *State Energy Data* (SED) added.[42] The default VMT data in SGIT were replaced with state-level annual VMT from the South Dakota Department of Transportation (SDDOT).[43] State-level VMT was allocated to vehicle types using the default vehicle mix data in SGIT.

Onroad vehicle gasoline and diesel emissions were projected based on the 2020 VMT projection provided by SDDOT[4] and growth rates developed from national vehicle type VMT forecasts reported in EIA's *Annual Energy Outlook* 2006 (AEO2006). The AEO2006 data were incorporated because they indicate significantly different VMT growth rates for certain vehicle types (e.g., 34% growth between 2002 and 2020 in heavy-duty gasoline vehicle VMT versus 284% growth in light-duty diesel truck VMT over this period). The procedure first applied the AEO2006 vehicle type-based national growth rates to 2002 estimates of South Dakota VMT by vehicle type. These data were then used to calculate the estimated proportion of total VMT by vehicle type in each year. Next, these proportions were applied to the SDDOT estimates for total VMT in the State for each year to yield the vehicle type VMT estimates and compound annual average growth rates are displayed in Tables C2 and C3, respectively.

[40] CO_2 emissions were calculated using SGIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 1. "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004.
[41] CH_4 and N_2O emissions were calculated using SGIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 3. "Methods for Estimating Methane and Nitrous Oxide Emissions from Mobile Combustion", August 2004.
[42] Energy Information Administration, State Energy Consumption, Price, and Expenditure Estimates (SED), http://www.eia.doe.gov/emeu/states/_seds.html
[43] Kevin Tveidt, South Dakota Department of Transportation.

Table C1. Key Assumptions and Methods for the Transportation Inventory and Projections

Vehicle Type and Pollutants	Methods
Onroad gasoline, diesel, natural gas, and LPG vehicles – CO_2	**Inventory (1990 – 2002)** EPA SGIT and fuel consumption from EIA SED **Reference Case Projections (2003 – 2020)** Gasoline and diesel fuel projected using VMT projections from SDDOT, adjusted by fuel efficiency improvement projections from AEO2006. Other onroad fuels projected using West North Central Region fuel consumption projections from EIA AEO2006 adjusted using state-to-regional ratio of population growth.
Onroad gasoline and diesel vehicles – CH_4 and N_2O	**Inventory (1990 – 2002)** EPA SGIT, onroad vehicle CH_4 and N_2O emission factors by vehicle type and technology type within SGIT were updated to the latest factors used in the US EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003.* State total VMT replaced with VMT provided by SDDOT, VMT allocated to vehicle types using default data in SGIT. **Reference Case Projections (2003 – 2020)** VMT projection from SDDOT.
Non-highway fuel consumption (jet aircraft, gasoline-fueled piston aircraft, boats, locomotives) – CO_2, CH_4 and N_2O	**Inventory (1990 – 2002)** EPA SGIT and fuel consumption from EIA SED. **Reference Case Projections (2003 – 2020)** Aircraft projected using prime supplier sales volumes from EIA, aircraft operations projections from Federal Aviation Administration (FAA), and jet fuel efficiency improvement projections from AEO2006. Rail and marine gasoline projected based on historical data.

Table C2. South Dakota Vehicle Miles Traveled
Compound Annual Growth Rates

Vehicle Type	2002-2005	2005-2010	2010-2015	2015-2020
Heavy Duty Diesel Vehicle	3.64%	2.42%	2.06%	1.96%
Heavy Duty Gasoline Vehicle	2.35%	0.91%	1.52%	1.53%
Light Duty Diesel Truck	5.12%	5.94%	5.88%	6.03%
Light Duty Diesel Vehicle	5.12%	5.94%	5.88%	6.03%
Light Duty Gasoline Truck	0.94%	0.99%	0.92%	0.81%
Light Duty Gasoline Vehicle	0.94%	0.99%	0.92%	0.81%
Motorcycle	0.94%	0.99%	0.92%	0.81%

Onroad gasoline and diesel fuel consumption was forecasted by developing a set of growth factors that adjusted the VMT projections to account for improvements in fuel efficiency. Fuel efficiency projections were taken from EIA's *Annual Energy Outlook* (AEO). These projections suggest onroad fuel consumption growth rates of 0.1% per year for gasoline and 2.4% per year for diesel between 2002 and 2020.

Gasoline consumption estimates for 1990-2002 were adjusted by subtracting ethanol consumption. SDDOT provided an estimate of 2006 ethanol consumption, which was subtracted from 2006 projected gasoline consumption. Projections for ethanol consumption were not available[44], so post-2006 ethanol consumption was to remain at the 2006 level (7% of total gasoline) in the reference case projections. Gasoline consumption projections adjusted to account for increased ethanol consumption result in compound annual growth rates of 0.07% for 2002-2020. Biodiesel and other biofuel consumption were not considered in this inventory because historical and projection data were not available.

For the aircraft sector, emission estimates for 1990 to 2002 are based on SGIT methods and fuel consumption from EIA. Emissions were projected from 2002-2005 using historical prime supplier volumes of jet fuel and aviation gasoline in South Dakota from EIA.[45] Emissions were projected from 2005 to 2020 using general aviation and commercial aircraft operations for 2005 to 2020 from the Federal Aviation Administration's (FAA) Terminal Area Forecast System[46] and national aircraft fuel efficiency forecasts. To estimate changes in jet fuel consumption, itinerant aircraft operations from air carrier, air taxi/commuter, and military aircraft were first summed for each year of interest. The jet fuel projections were adjusted to reflect the projected increase in national aircraft fuel efficiency (indicated by increased number of seat miles per gallon), as reported in AEO2006. Because AEO2006 does not estimate fuel efficiency changes for general aviation aircraft, forecast changes in aviation gasoline consumption were based solely on the projected number of itinerant general aviation aircraft operations in South Dakota, which was obtained from the FAA source noted above. These projections resulted in the compound annual growth rates shown in Table C3.

[44] Kevin Tveidt, SDDOT, provided projections for SD ethanol production (800 million gallons in 2007 and 1 billion gallons in 2008).
[45] Prime Supplier Volumes, Petroleum Navigator, Energy Information Administration, http://tonto.eia.doe.gov/dnav/pet/pet_cons_prim_dcu_SSD_a.htm.
[46] Terminal Area Forecast, Federal Aviation Administration, http://www.apo.data.faa.gov/main/taf.asp.

Table C3. South Dakota Aviation Fuel Compound Annual Growth Rates

Fuel	2002-2005	2005-2010	2010-2015	2015-2020
Aviation Gasoline	-14.64%	0.16%	0.50%	0.37%
Jet Fuel	2.60%	-0.47%	-0.51%	-0.62%

For the rail and marine sectors, 1990 – 2004 estimates are based on SGIT methods and fuel consumption from EIA. Emissions from marine gasoline was projected based on the historical 1990-2004 data, which results in compound annual growth rates of 0.06% for 2005-2020. Historical consumption of diesel fuel for locomotives does not show a significant positive or negative trend, so no growth was assumed for this sector.

Fuel consumption data from EIA includes nonroad gasoline and diesel fuel consumption in the commercial and industrial sectors. Therefore, nonroad emissions are included in the RCI emissions in this inventory (see Appendix B). Table C4 shows how EIA divides gasoline and diesel fuel consumption between the transportation, commercial, and industrial sectors.

Table C4. EIA Classification of Gasoline and Diesel Consumption

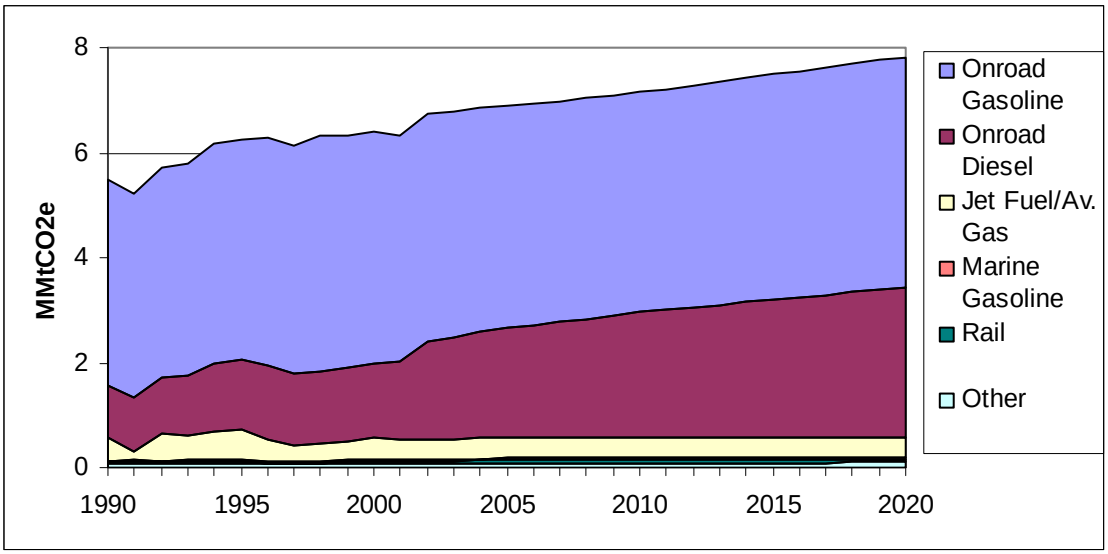
Sector	Gasoline Consumption	Diesel Consumption
Transportation	Highway vehicles, marine	Vessel bunkering, military use, railroad, highway vehicles
Commercial	Public non-highway, miscellaneous use	Commercial use for space heating, water heating, and cooking
Industrial	Agricultural use, construction, industrial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

Results

As shown in Figure C1, onroad gasoline and diesel consumption accounts for the largest share of transportation GHG emissions. Emissions from onroad gasoline vehicles increased by about 10% from 1990-2002 to cover 64% of total transportation emissions in 2002. GHG emissions from onroad diesel fuel consumption increased by 94% from 1990 to 2002, and by 2002 accounted for 28% of GHG emissions from the transportation sector. Emissions from aviation fuels decreased by 18% from 1990-2002 to cover less than 6% of total transportation emissions in 2002. Emissions from all other categories combined (marine gasoline, locomotives, natural gas and LPG, and oxidation of lubricants) contributed only 2% of total transportation emissions in 2002.

GHG emissions from all onroad vehicles combined are projected to increase by only 17% between 2002 and 2020, due to a 23% increase in VMT during this period, projected fuel efficiency improvements, and increased ethanol consumption. Most of this growth is predicted to occur in the diesel sector, with onroad gasoline consumption projected to increase by only 1%, and emissions from onroad diesel consumption projected to increase by 52% between 2002 and 2020. Emissions from aviation fuels are projected to remain flat, decreasing by 0.3% between 2002 and 2020.

Figure C1. Transportation GHG Emissions by Fuel, 1990-2020



Source: CCS calculations based on approach described in text.

Key Uncertainties

Projections of Vehicle Miles of Travel (VMT) and Biofuels Consumption

One source of uncertainty is the future year vehicle mix, which was calculated based on national growth rates for specific vehicle types. These growth rates may not reflect vehicle-specific VMT growth rates for the state. Also, onroad gasoline and diesel growth rates may be slightly overestimated because increased consumption of biofuels between 2006 and 2020 was not taken into account (due to a lack of data).

Uncertainties in Aviation Fuel Consumption

The jet fuel and aviation gasoline fuel consumption from EIA is actually fuel *purchased* in the state, and therefore includes fuel consumed during state-to-state flights and international flights. The 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 uncertainty associated with aviation emissions is the use of general aviation forecasts to project aviation gasoline consumption. General aviation aircraft consume both jet fuel and aviation gasoline, but fuel specific data were not available.

Appendix D. Industrial Processes

Overview

Emissions in the industrial processes category span a wide range of activities, and reflect non-combustion sources of GHG emissions from several industrial processes. The industrial processes that exist in South Dakota, and for which emissions are estimated in this inventory, include the following:

- Carbon Dioxide (CO_2) from:
  - Production of cement and lime;
  - Consumption of limestone, dolomite, and soda ash;
- Sulfur hexafluoride (SF_6) from transformers used in electric power transmission and distribution (T&D) systems; and
- Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) from consumption of substitutes for ozone-depleting substances (ODS) used in cooling and refrigeration equipment.

Other industrial processes that are sources of GHG emissions but are not found in South Dakota include the following:

- Nitrous oxide (N_2O) from nitric and adipic acid production;
- HFCs, PFCs, and SF_6 from semiconductor manufacture;
- SF_6 from magnesium production and processing;
- CO_2 from soda ash production;
- PFCs from aluminum production; and
- HFCs from HCFC-22 production.

Emissions and Reference Case Projections

GHG emissions for 1990 through 2005 were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SGIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for this sector.[47] Table D1 identifies for each emissions source category the information needed for input into SGIT to calculate emissions, the data sources used for the analysis described here, and the historical years for which emissions were calculated based on the availability of data. The South Dakota Department of Environment and Natural Resources (SDDENR) provided data for annual clinker production and annual lime production for 1990, 1995, 2000, and 2005. Table D1 provides additional details on how the data provided were used to calculate historical emissions for these two categories.

[47] GHG emissions were calculated using SGIT, with reference to EIIP, Volume VIII: Chapter. 6. "Methods for Estimating Non-Energy Greenhouse Gas Emissions from Industrial Processes", August 2004. Referred to as "EIIP" below.

Table D1. Approach to Estimating Historical Emissions

Source Category	Time Period	Required Data for SGIT	Data Source
Cement Manufacturing - Clinker Production	1990, 1995, 2000, 2005	Metric tons (Mt) of clinker produced each year.	South Dakota Department of Environment and Natural Resources (SDDENR) provided annual clinker production data for 1990, 1995, 2000, and 2005.
Lime Manufacture	1990, 1995, 2000, 2005	Mt of high-calcium lime and dolomite produced each year.	SDDENR provided total lime manufacture production for 1990, 1995, 2000, and 2005. Information on the type of lime manufactured was not available; assumed production was for high-calcium lime.
Limestone and Dolomite Consumption	1994 - 2002	Mt of limestone and dolomite consumed.	For default limestone data, the state's total limestone consumption (as reported by USGS) is multiplied by the ratio of national limestone consumption for industrial uses to total national limestone consumption. Additional information on these calculations, including a definition of industrial uses, is available in Chapter 6 of the EIIP guidance document. Default limestone production data are not available in SGIT for 1990 - 1993; data for 1994 were used for 1990 – 1993 as a surrogate to fill in production data missing for these years. SGIT does not contain default consumption data for dolomite for any year for South Dakota.
Soda Ash Consumption	1990 - 2002	Mt of soda ash consumed.	*USGS Minerals Yearbook, 2004: Volume I, Metals and Minerals*, (http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/). For population data, see references for ODS substitutes.
ODS Substitutes	1990 - 2002	Based on state's population and estimates of emissions per capita from the US EPA national GHG inventory.	-- Historical population data for 1990 and 2000 for South Dakota from US Census Bureau's Annual Estimates for States, Release Date: December 2005 (http://www.census.gov/ popest/states/NST-ann-est.html). Data only provided for 1990 and 2000; population for intermediate years calculated using the compound annual growth rate calculated from the years for which data were published (i.e., 1990 and 2000). -- Projections of South Dakota's population to 2030 from US Census Bureau, Population Division, Interim State Population Projections, 2005; Internet Release Date: April 21, 2005; "Table 1: Interim Projections: Ranking of Census 2000 and Projected 2030 State Population and Change: 2000 to 2030" (http://www.census.gov/population/www/projections/projectionsagesex.html). -- US 1990-2000 population from US Census Bureau (http://www.census.gov/popest/archives/EST90INTERCENSAL/US-EST90INT-01.html). -- US 2000-2005 population from US Census Bureau (http://www.census.gov/population/projections/SummaryTabA1.xls).
Electric Power T&D Systems	1990 - 2002	Emissions from 1990 to 2002 based on the national emissions per kWh and state's electricity use provided in SGIT.	National emissions per kWh from US EPA 2005 "Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2003" (http://www.epa.gov/climatechange/emissions/usgginv_archive.html).

Table D2 lists the data sources used to quantify activities related to industrial process emissions, the annual compound growth rates implied by estimates of future activity used, and the years for which the reference case projections were calculated.

Table D2. Approach to Estimating Projections

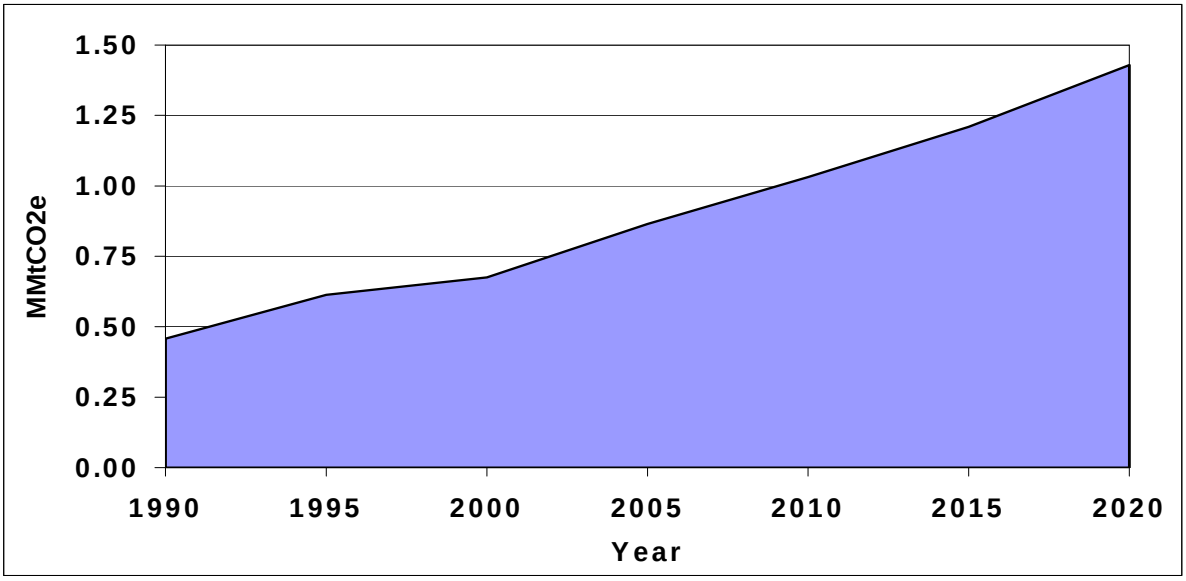
Source Category	Time Period	Projection Assumptions	Data Source	Annual Growth Rates (%)			
				2000 to 2005	2005 to 2010	2010 to 2015	2015 to 2020
Cement Manufacturing - Clinker Production	2006 – 2020	Compound annual growth rate for South Dakota's goods-producing sector. The goods-producing sector includes employment in the natural resources and mining, construction, and manufacturing sectors.	South Dakota Department of Labor, Labor Market Information Center, (http://www.sdjobs.org/lmic/); Select Projections, By Industry, South Dakota, All industries.	None, actual data used for 2000 and 2005	1.04	1.04	1.04
Lime Manufacture	2006 – 2020	Ditto	Ditto	Ditto	1.04	1.04	1.04
Limestone and Dolomite Consumption	2003 – 2020	Ditto	Ditto	-0.15	1.04	1.04	1.04
Soda Ash Consumption	2003 – 2020	Growth between 2004 and 2009 is projected to be about 0.5% per year for US production. Assumed growth is same for 2010 – 2020.	*Minerals Yearbook, 2005: Volume I, Soda Ash*, (http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/soda_myb05.pdf).	0.5	0.5	0.5	0.5
ODS Substitutes	2003 – 2020	Based on national growth rate for use of ODS substitutes.	EPA, 2004 ODS substitutes cost study report (http://www.epa.gov/ozone/snap/emissions/TMP6si9htnvca.htm).	15.8	7.9	5.8	5.3
Electric Power T&D Systems	2003 – 2020	National growth rate (based on aggregate for all stewardship program categories provided in referenced data source).	US Department of State, US Climate Action Report, May 2002, Washington, D.C., May 2002 (Table 5-7). (http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/SHSU5BNQ76/$File/ch5.pdf).	3.3	-6.2	-9.0	-2.8

Results

Figures D1 and D2 show historic and projected emissions for the industrial processes sector from 1990 to 2020. Total gross South Dakota GHG emissions were about 0.46 $MMTCO_2e$ in 2000, rising to about 1.4 $MMTCO_2e$ in 2020. Emissions from the overall industrial processes category are expected to grow by about 3.4% annually from 2005 through 2020, as shown in Figures D1

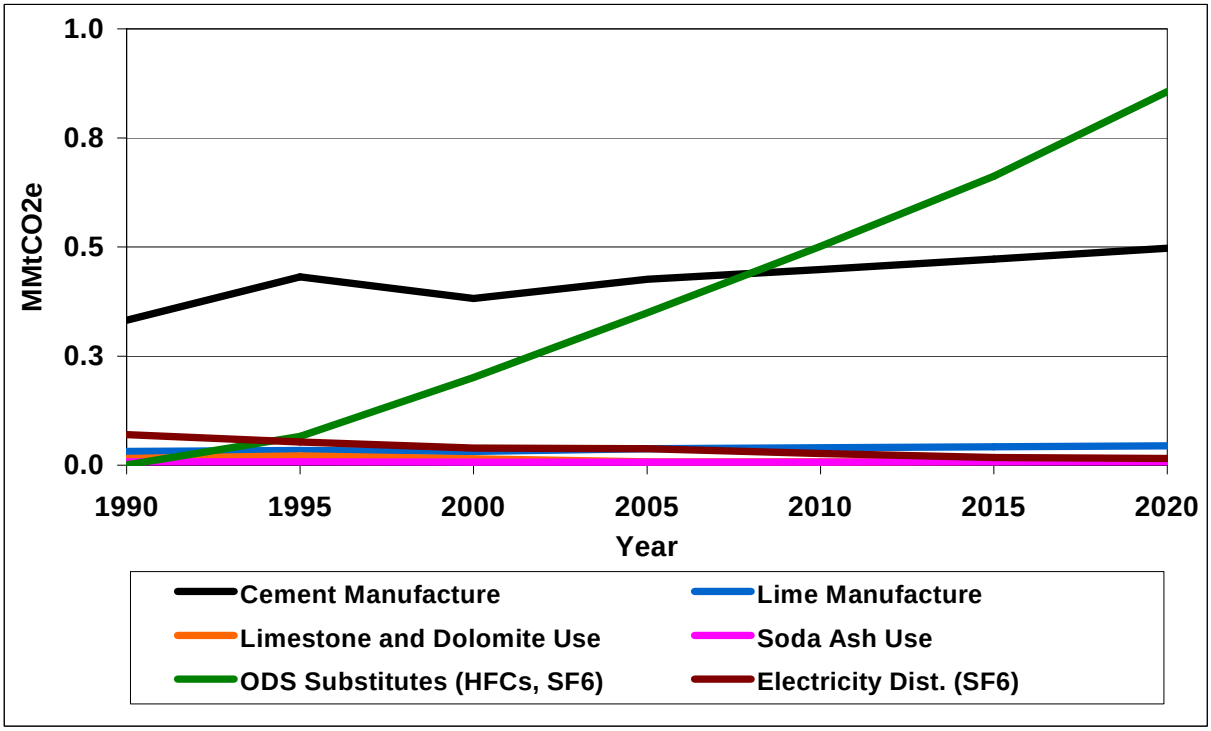
and D2, with emissions growth primarily associated with increasing use of HFCs and PFCs in refrigeration and air conditioning equipment, and to a lesser extent in the cement manufacturing industry.

Figure D1. GHG Emissions from Industrial Processes, 1990-2020



Source: CCS calculations based on approach described in text.

Figure D2. GHG Emissions from Industrial Processes, 1990-2020, by Source



Source: CCS calculations based on approach described in text.

Substitutes for Ozone-Depleting Substances (ODS)
HFCs and PFCs are used as substitutes for ODS, most notably CFCs (CFCs are also potent warming gases, with global warming potentials on the order of thousands of times that of CO_2 per unit of emissions) in compliance with the *Montreal Protocol* and the *Clean Air Act Amendments of 1990*.[48] Even low amounts of HFC and PFC emissions, for example, from leaks and other releases associated with normal use of the products, can lead to high GHG emissions on a carbon-equivalent basis. Emissions from the use of ODS substitutes in South Dakota were calculated using the default methods in SGIT (see dark green line in Figure D2). Emissions have increased from 0.001 $MMtCO_2e$ in 1990 to about 0.20 $MMtCO_2e$ in 2000, and are expected to increase at an average rate of 7.5% per year from 2000 to 2020 due to increased substitutions of these gases for ODS. The projected rate of increase for these emissions is based on projections for national emissions from the US EPA report referenced in Table D2.

Electricity Distribution
Emissions of SF_6 from electrical equipment have experienced declines since the early nineties (see brown line in Figure D2), mostly due to voluntary action by industry. SF_6 is used as an electrical insulator and interrupter in the electricity T&D system. Emissions for South Dakota from 1990 to 2002 were estimated based on the estimates of emissions per kWh from the US EPA GHG inventory and South Dakota's electricity consumption estimates provided in SGIT. The *US Climate Action Report* shows expected decreases in these emissions at the national level, and the same rate of decline is assumed for emissions in South Dakota. The decline in SF_6 emissions in the future reflects expectations of future actions by the electric industry to reduce these emissions. Relative to total industrial non-combustion process emissions, SF_6 emissions from electrical equipment are low (about 0.07 $MMtCO_2e$ in 1990 and 0.02 $MMtCO_2e$ in 2020), and therefore, appear at the bottom of the graph because of scaling effects in Figure D2.

Clinker Production for Cement Manufacture
South Dakota provided clinker production data for 1990, 1995, 2000, and 2005. Clinker is an intermediate product from which finished Portland and masonry cement are made. Clinker production releases CO_2 when calcium carbonate ($CaCO_3$) is heated in a cement kiln to form lime (calcium oxide) and CO_2 (see Chapter 6 of the EIIP guidance document). Emissions are calculated by multiplying annual clinker production by emission factors for this process. The clinker production data were entered into the SGIT to calculate GHG emissions (see black line in Figure D2). Information on masonry cement production was not available. The growth rate (1.04% annual) for South Dakota's goods-producing sector was used to project emissions to from 2006 to 2020. As shown in Figure D2, emissions increase slightly from 0.43 $MMtCO_2e$ in 2005 to 0.50 $MMtCO_2e$ 2020, reflecting an overall average annual increase of about 1.0% over that time period.

[48] As noted in EIIP Chapter 6, ODS substitutes are primarily associated with refrigeration and air conditioning, but also many other uses including as fire control agents, cleaning solvents, aerosols, foam blowing agents, and in sterilization applications. The applications, stocks, and emissions of ODS substitutes depend on technology characteristics in a range of equipment types. For the US national inventory, a detailed stock vintaging model was used to track ODS substitutes uses and emissions, but this modeling approach has not been completed at the state level.

Lime Manufacture

South Dakota provided lime production data for 1990, 1995, 2000, and 2005. Lime is a manufactured product that is used in many chemical, industrial, and environmental applications including steel making, construction, pulp and paper manufacturing, and water and sewage treatment. Lime is manufactured by heating limestone (mostly $CaCO_3$) in a kiln, creating calcium oxide and CO_2. The CO_2 is driven off as a gas and is normally emitted to the atmosphere, leaving behind a product known as quicklime. Some of this quicklime undergoes slaking (combining with water), which produces hydrated lime. The consumption of lime for certain uses, specifically the production of precipitated $CaCO_3$ and refined sugar, results in the reabsorption of some airborne CO_2 (see Chapter 6 of the EIIP guidance document).

Emissions are estimated by multiplying the amount of high-calcium and dolomitic lime produced by an emission factor for high-calcium and dolomitic lime. Information on the type of lime produced in South Dakota was not available. For this initial analysis, it was assumed that the lime is high-calcium lime for the purpose of calculating emissions. The high-calcium lime production data were entered into the SGIT to calculate GHG emissions (see dark blue line in Figure D2). The growth rate (1.04% annual) for South Dakota's goods-producing sector was used to project emissions from 2006 to 2020. Relative to total industrial non-combustion process emissions, emissions associated with lime manufacturing are low (about 0.031 $MMtCO_2e$ in 1990 and 0.044 $MMtCO_2e$ in 2020), and therefore, appear at the bottom of the graph because of scaling effects in Figure D2.

Limestone and Dolomite Consumption

Limestone and dolomite are basic raw materials used by a wide variety of industries, including the construction, agriculture, chemical, glass manufacturing and environmental pollution control industries, as well as in metallurgical industries such as magnesium production.[49] Historical data for South Dakota were not available from the USGS; consequently, the default data provided in SGIT were used to calculate emissions for South Dakota (see orange line in Figure D2). The employment growth rate for South Dakota's goods-producing sector was used to project emissions from 2003 through 2020. Relative to total industrial non-combustion process emissions, emissions associated with limestone and dolomite consumption are low (about 0.016 $MMtCO_2e$ in 1990 and 0.009 $MMtCO_2e$ in 2020), and therefore, appear at the bottom of the graph in Figure D2 due to scaling effects. The slight decline in emissions is associated with the trend in the SGIT activity data from 1995 and 2002 and the declining growth rate applied to estimate emissions for 2003 through 2005. From 2005 through 2020, emissions for this category are estimated to increase by about 1.04% annually. Note that SGIT did not provide any dolomite consumption data for any historical year for South Dakota.

[49] In accordance with EIIP Chapter 6 methods, emissions associated with the following uses of limestone and dolomite are not included in this category: (1) crushed limestone consumed for road construction or similar uses (because these uses do not result in CO_2 emissions), (2) limestone used for agricultural purposes (which is counted under the methods for the agricultural sector), and (3) limestone used in cement production (which is counted in the methods for cement production).

Soda Ash Consumption
Commercial soda ash (sodium carbonate) is used in many consumer products such as glass, soap and detergents, paper, textiles, and food. Carbon dioxide is also released when soda ash is consumed (see Chapter 6 of the EIIP guidance document). SGIT estimates historical emissions (see dark pink line in Figure D2) based on the state's population and national per capita emissions from the US EPA national GHG inventory. According to the USGS, this industry is expected to grow at an annual rate of 0.5% from 2004 through 2009 for the US as a whole. Information on growth trends for years later than 2009 was not available; therefore, the same 0.5% annual growth rate was applied for estimating emissions to 2020. Relative to total industrial non-combustion process emissions, emissions associated with soda ash consumption are low (about 0.0076 $MMtCO_2e$ in 1990 and 0.0077 $MMtCO_2e$ in 2020), and therefore, cannot be seen in the graph due to scaling effects in Figure D2.

Key Uncertainties

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

- Data for all of the historical years for key industrial process sources of GHGs could not be obtained because of time and resource constraints. The inventory can be improved upon in the future by obtaining actual production and consumption data for all of the historical years.
- Since emissions from industrial processes are determined by the level of production and the production processes of a few key industries—and in some cases, a few key plants—there is relatively high uncertainty regarding future emissions from the industrial processes category as a whole. Future emissions depend on the competitiveness of South Dakota manufacturers in these industries, and the specific nature of the production processes used in South Dakota.
- The projected largest source of future industrial emissions, HFCs and PFCs used in cooling applications, is subject to several uncertainties as well. First, historical emissions are based on national estimates; South Dakota-specific estimates are currently unavailable. In addition, emissions through 2020 and beyond will be driven by future choices regarding mobile and stationary air conditioning technologies and the use of refrigerants in commercial applications, for which several options currently exist.
- Greenhouse gases are emitted from several additional industrial processes that are not covered in the EIIP guidance documents, due in part to a lack of sufficient state data on non-energy uses of fossil fuels for these industrial processes. These sources include:
    - Iron and Steel Production (CO_2 and CH_4);
    - Ammonia Manufacture and Urea Application (CO_2, CH_4, N_2O);
    - Aluminum Production (CO_2);
    - Titanium Dioxide Production (CO_2);
    - Phosphoric Acid Production (CO_2);
    - CO_2 Consumption (CO_2);

- Ferroalloy Production (CO_2);
- Petrochemical Production (CH_4); and
- Silicon Carbide Production (CH_4).

The CO_2 emissions from the above CO_2 sources (other than CO_2 consumption and phosphoric acid production) result from the non-energy use of fossil fuels. Although the US EPA estimates emissions for these industries on a national basis, US EPA has not developed methods for estimating the emissions at the state level due to data limitations. If state-level data on non-energy uses of fuels become available, future work should include an assessment of emissions for these other categories.

Appendix E. Fossil Fuel Industries

Overview

This appendix reports the GHG emissions that are released during the production, processing, transmission, and distribution of fossil fuels. Known as fugitive emissions, these are methane (CH_4) and carbon dioxide (CO_2) emissions released via leakage and venting from 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 greenhouse gas emissions in 2004.[50] Emissions associated with energy consumed by these processes are included in Appendix B, Residential, Commercial and Industrial Sectors.

Oil and Gas Production

South Dakota's oil and gas industry is small and has declined to very low levels in recent years. Current crude oil production across the entire State is only about 4,000 barrels (bbls) per day.[51] South Dakota's proved crude oil reserves account for less than 1% of the US total. There are no operational oil refineries in South Dakota.[52]

South Dakota's annual marketed natural gas production peaked in 1989 at 4,369 million cubic feet (MMcf) and had decreased to about 992 MMcf in 2005.[53] In comparison, South Dakota consumed 42,575 MMcf of natural gas in 2005, of which 98% was imported.[54] Since South Dakota has minimal natural gas reserves, the State will likely continue to rely almost entirely on imports of natural gas. There is no coal bed CH_4 production or proved reserves in South Dakota.[55]

Coal Production

There are no producing coal mines in South Dakota, as reported by the EIA.

Oil and Gas Industry Emissions

Emissions of CH_4 can occur at many stages of production, processing, transmission, and distribution of oil and gas. South Dakota has just over 200 active gas and oil wells, and over 6,200 miles of gas pipelines.[56] Uncertainties associated with estimates of South Dakota's GHG emissions from this sector are compounded by the fact that there are no regulatory requirements

[50] "The *U.S. Inventory of Greenhouse Gas Emissions and Sinks*", US EPA, 2005. Greenhouse gas emissions calculated on a CO_2 equivalent basis.
[51] "Petroleum Profile: South Dakota", US DOE Energy Information Administration website, October 2006, http://tonto.eia.doe.gov/oog/info/state/sd.html
[52] "Petroleum Navigator", US DOE Energy Information Administration website, October 2006, http://tonto.eia.doe.gov/dnav/pet/hist/mcrfpsd2a.htm
[53] "Natural Gas Navigator", US DOE Energy Information Administration website, December 2006, http://tonto.eia.doe.gov/dnav/ng/hist/na1140_ssd_2a.htm
[54] "Natural Gas Navigator", US DOE Energy Information Administration website, November, 2006, http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_SSD_a.htm
[55] "Natural Gas Navigator", US DOE Energy Information Administration website, December 2006, http://tonto.eia.doe.gov/dnav/ng/ng_enr_cbm_a_EPG0_r51_Bcf_a.htm
[56] Data from EIA and Gas Facts.

to track CH_4 emissions. Therefore, estimates based on emissions measurements in South Dakota are not possible at this time.

The State Greenhouse Gas Inventory Tool (SGIT), developed by the US EPA, facilitates estimation of state-level greenhouse gas emissions.[57] Methane emission estimates are calculated by multiplying emissions-related activity levels (e.g. miles of pipeline, number of compressor stations) by aggregate industry-average emission factors. Key information sources for the activity data are the US DOE EIA[58] and American Gas Association's annual publication *Gas Facts*.[59] Methane emissions were estimated using SGIT, with reference to the EIIP guidance document.

Future projections of CH_4 emissions from oil and gas systems are calculated based on the following key drivers:

- Consumption – See Appendix B, Residential, Commercial and Industrial Sector for assumptions used in projecting natural gas consumption in South Dakota. Based on those assumptions, South Dakota's natural gas consumption is projected to grow at an average annual rate of 1.9% between 2006 and 2020.[60]

- Production –As a simple estimate for projections, natural gas and crude oil production are forecast to follow current decline trends in the State, based on EIA reported production since 1990.

Table E1 provides an overview of data sources and approach used to project future emissions. Note that potential emission reduction improvements to production and pipeline technologies have not been accounted for in this analysis.

Results

Table E2 displays the estimated CH_4 emissions from the fossil fuel industry in South Dakota from 1990 to 2005, with projections to 2020. Emissions from this sector grew by 91% from 1990 to 2005 and are projected to increase by a further 31% between 2005 and 2020. Natural gas transmission and distribution systems are the major contributors of both historic and projected CH_4 emissions from the fossil fuel sector. Figure E1Figure E1 displays the CH_4 emissions from natural gas and oil systems, on an $MMtCO_2e$ basis.

[57] 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.
[58] "Petroleum Navigator" and "Natural Gas Navigator", US DOE Energy Information Administration website, November 2006, Accessed at <http://www.eia.doe.gov>
[59] American Gas Association "Gas Facts, A Statistical Record of the Gas Industry" Referenced annual publications from 1992 to 2004.
[60] Based on US DOE regional projections (see Appendix B).

Table E1. Approach to Estimating Historical and Projected Methane Emissions from Natural Gas and Oil Systems

	Approach to Estimating Historical Emissions		Approach to Estimating Projections
Activity	***Required Data for SGIT***	***Data Source***	***Projection Assumptions***
Natural Gas Drilling and Field Production	Number wells	EIA	Emission projections assume that natural gas production will continue to decline at 2.0% annually until 2020.[61]
	Miles of gathering pipeline	Gas Facts[62]	
Natural Gas Processing	Number gas processing plants	EIA[63]	There is no natural gas processing in the state of South Dakota.
Natural Gas Transmission	Miles of transmission pipeline	Gas Facts[13]	Emissions assumed to follow State gas consumption trend - annual average growth rate of 1.9% between 2006 and 2020.[64]
	Number of gas transmission compressor stations	EIIP[65]	
	Number of gas storage compressor stations	EIIP[66]	
	Number of LNG storage compressor stations	Unavailable, assumed negligible.	
Natural Gas Distribution	Miles of distribution pipeline	Gas Facts[13]	Distribution emissions follow State gas consumption trend - annual average growth rate of 1.9% between 2006 and 2020.[67]
	Total number of services	Gas Facts	
	Number of unprotected steel services	Ratio estimated from 2002 data[68]	
	Number of protected steel services	Ratio estimated from 2002 data[18]	
Oil Production	Annual production	EIA[69]	Emissions follow State oil production trends, which continue to decline at 0.4% annually.[70]
Oil Refining	Annual amount refined	EIA[71]	There is not oil refining in South Dakota.
Oil Transport	Annual oil transported	Unavailable, assumed oil refined = oil transported	Emissions from transport of oil in South Dakota are assumed to be negligible.[72]

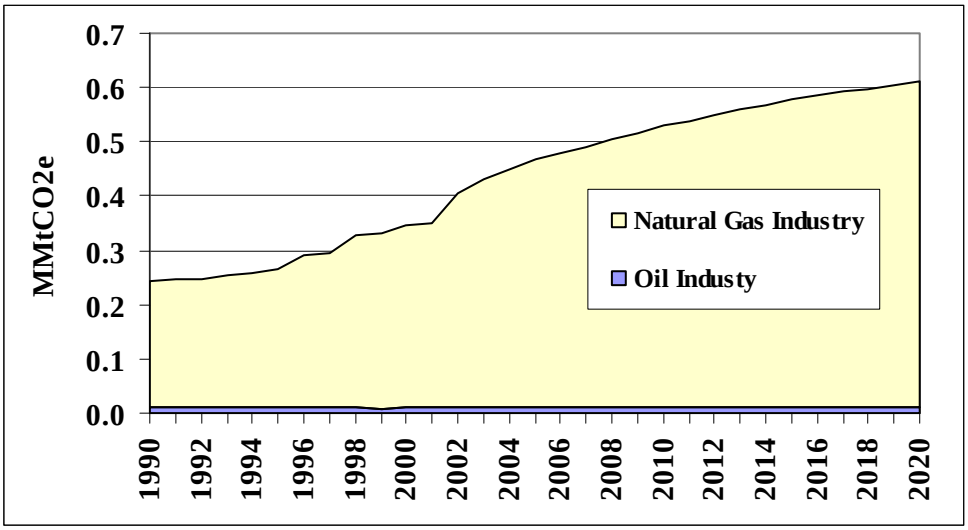
[61] South Dakota natural gas production declined at an average annual rate of 2.0% between 1992 and 2005, as reported by the EIA. Growth data from 1990 and 1991 excluded, given erratic production in early 1990's.
[62] No Gas Facts available for 1991 and 1993, so a linear relationship was assumed to extrapolate from the previous and subsequent year.
[63] EIA reports no gas processing facilities in South Dakota.
[64] Based on US DOE regional projections (see Appendix B).
[65] Number of gas transmission compressor stations = miles of transmission pipeline x 0.006 EIIP. Volume VIII: Chapter 5. March 2005.
[66] Number of gas storage compressor stations = miles of transmission pipeline x 0.0015 EIIP. Volume VIII: Chapter 5. March 2005.
[67] Based on US DOE regional projections (see Appendix B).
[68] Gas Facts reported unprotected and protected steel services for 2002-3, but only total services for other years. Therefore the ratio of unprotected and protected steel services in 2003 was assumed to be the ratio for all other years (0.4275 for protected services and 0.0083 for unprotected services). This yields more congruent results than the EIIP guidance of using multipliers of 0.2841 for protected steel services, and 0.0879 for unprotected steel services.
[69] Data extracted from the Petroleum Supply Annual for each year.
[70] Average annual decline in crude oil production reported by the EIA is between 1990 and 2005 was 0.4%.
[71] There is no refining data for the state of South Dakota.
[72] Likely a reasonable assumption as the Emission Inventory Improvement Program's "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems", states that at a national level, crude oil production field operations account for 97 percent of total oil industry fugitive emissions, while crude transportation account for only 1% of the total.

Table E2. Methane Emissions and Projections from the Fossil Fuel Industry

(Million Metric Tons CO2e)	1990	1995	2000	2005	2010	2015	2020
Fossil Fuel Industry	**0.24**	**0.27**	**0.34**	**0.47**	**0.53**	**0.58**	**0.61**
Natural Gas Industry	0.23	0.26	0.34	0.45	0.52	0.57	0.60
Production (CH_4)	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Processing (CH_4)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Transmission (CH_4)	0.16	0.17	0.22	0.29	0.33	0.36	0.38
Distribution (CH_4)	0.07	0.08	0.11	0.16	0.19	0.21	0.22
Oil Industry	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Production (CH_4)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Refineries (CH_4)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal Mining (CH_4)	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: The value 0.00 in the above table indicates no activity in the sector, except for natural gas production, where 0.00 indicates emissions less than 0.005 MMTCO2e.

Figure E1. Fossil Fuel Industry Emission Trends (Million metric tons CO_2e)



Source: CCS calculations based on approach described in text.

Key Uncertainties

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

- Current levels of fugitive emissions are based on industry-wide averages, and until estimates are available for pipelines or local facilities, uncertainties remain.

- While South Dakota has very limited crude oil and natural gas reserves, the assumptions used for the projections, extending historical decline trends out to 2020, do not include any significant changes in energy prices, relative to today's prices. Large price swings, resource limitations, or changes in regulations could significantly change future production and the associated GHG emissions.

- Any future transmission lines through South Dakota would impact fugitive emission projections.

- Other uncertainties include the extent of renewed interest in South Dakota oil exploration, and potential emission reduction improvements to production and pipeline technologies.

Appendix F. Agriculture

Overview

The emissions discussed in this appendix refer to non-energy methane (CH_4) and nitrous oxide (N_2O) emissions from enteric fermentation, manure management, and agricultural soils. Emissions and sinks of carbon in agricultural soils are also covered. Energy emissions related to agricultural practices (combustion of fossil fuels to power agricultural equipment) are included in the residential, commercial, and industrial (RCI) fuel consumption sector estimates.

There are two livestock sources of greenhouse gas (GHG) emissions: enteric fermentation and manure management. Methane emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Microbes in the animal digestive system breakdown food and emit CH_4 as a by-product. More CH_4 is produced in ruminant livestock than in other animals because of digestive activity in the large fore-stomach to break down grasses and other high-fiber feeds. Methane and N_2O emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The environmental conditions of decomposition drive the relative magnitude of emissions. In general, the more anaerobic the conditions are, the more CH_4 is produced because decomposition is aided by CH_4 producing bacteria that thrive in oxygen-limited (or oxygen-free) anaerobic conditions. Under aerobic conditions, N_2O emissions are the dominant GHG emissions of concern. Emissions estimates from manure management are based on estimates of the volumes of manure that are stored and treated in livestock operations. Emissions from manure that is applied to agricultural soils as an amendment or deposited directly to pasture and grazing land by grazing animals are accounted for in inventories of emissions from agricultural soils.

The management of agricultural soils can result in N_2O emissions and in fluxes of carbon dioxide (CO_2) that make soils net emitters or net sinks of carbon. In general, soil amendments that add nitrogen to soils can also result in N_2O emissions. Nitrogen additions drive underlying soil nitrification and de-nitrification cycles, which produce N_2O as a by-product. The emissions estimation methodologies used in this inventory account for several sources of N_2O emissions from agricultural soils, including decomposition of crop residues, synthetic and organic fertilizer application, manure and sewage sludge application to soils, nitrogen fixation, and cultivation of histosols (high organic soils, such as wetlands or peatlands). Both direct and indirect emissions of N_2O occur from the application of manure, fertilizer, and sewage sludge to agricultural soils. Direct emissions occur at the site of application and indirect emissions occur when nitrogen leaches to groundwater or in surface runoff and is transported off-site before entering the nitrification/denitrification cycle. Methane and N_2O emissions also result when crop residues are burned. Methane emissions occur during rice cultivation; however, rice is not grown in South Dakota.

The net flux of CO_2 in or out of agricultural soils depends on the balance of carbon losses from management practices and gains from organic matter inputs to the soil. Carbon dioxide is absorbed by plants through photosynthesis and ultimately becomes the carbon source for organic matter inputs to agricultural soils. When inputs are greater than losses, the soil accumulates carbon and there is a net sink of CO_2 into agricultural soils. Conversely, soil disturbance from the

cultivation of histosols releases large stores of carbon from the soil to the atmosphere. Finally, the practice of adding limestone and dolomite to agricultural soils results in CO_2 emissions.

Emissions and Reference Case Projections

Methane and Nitrous Oxide

GHG emissions for 1990 through 2005 were estimated using SGIT and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[73] In general, the SGIT methodology applies emission factors developed for the US to activity data for the agriculture sector. Activity data include livestock population statistics, amounts of fertilizer applied to crops, and trends in manure management practices. This methodology is based on international guidelines developed by sector experts for preparing GHG emissions inventories.[74]

Data on crop production in South Dakota from 1990 to 2005 and on the number of animals in the state from 1990 to 2002 were obtained from the United States Department of Agriculture (USDA), National Agriculture Statistical Service (NASS) and incorporated as defaults in SGIT.[75] Future reference case emissions from enteric fermentation and manure management were estimated based on the annual growth rate in emissions (million metric ton [MMt] carbon dioxide equivalent [CO_2e] basis) associated with historical livestock populations in South Dakota for 1990 to 2002. The default data in SGIT accounting for the percentage of each livestock category using each type of manure management system was used for this inventory. Default SGIT assumptions were available for 1990 through 2002.

Data on fertilizer usage came from *Commercial Fertilizers*, a report from the Fertilizer Institute. Data on crop production in South Dakota from 1990 to 2005 from the USDA NASS were used to calculate N_2O emissions from crop residues and crops that use nitrogen (i.e., nitrogen fixation) and CH_4 emissions from agricultural residue burning through 2005. Emissions for the other agricultural crop production practices categories (i.e., synthetic and organic fertilizers) were calculated through 2002.

Data were not available to estimate nitrogen released by the cultivation of histosols (i.e., the number of acres of high organic content soils). As discussed in the following section for soil carbon, the Natural Resources Ecology Laboratory at Colorado State University estimated 0.07 $MMtCO_2$ of emissions from cultivated high organic content soils in South Dakota for 1997. Therefore, future work should attempt to obtain data to estimate N_2O emissions from cultivated histosol soils in South Dakota to improve the emission estimates for this category.

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[73] GHG emissions were calculated using SGIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter 8. "Methods for Estimating Greenhouse Gas Emissions from Livestock Manure Management", August 2004; Chapter 10. "Methods for Estimating Greenhouse Gas Emissions from Agricultural Soil Management", August 2004; and Chapter 11. "Methods for Estimating Greenhouse Gas Emissions from Field Burning of Agricultural Residues", August 2004.

[74] Revised 1996 1ntergovermental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories, published by the National Greenhouse Gas Inventory Program of the IPCC, available at http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm; and Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, published in 2000 by the National Greenhouse Gas Inventory Program of the IPCC, http://www.ipcc-nggip.iges.or.jp/public/gp/english/

[75] USDA, NASS http://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.asp.

Agricultural residue burning is conducted in South Dakota. The SGIT methodology calculates emissions by multiplying the amount (e.g., bushels or tons) of each crop produced by a series of factors to calculate the amount of crop residue produced and burned, the resultant dry matter, and the carbon/nitrogen content of the dry matter. For South Dakota, the default SGIT method was used to calculate emissions because activity data in the form used in the SGIT were not readily available. Future work on this category should include an assessment to refine the SGIT default assumptions.

Table F1 shows the annual growth rates applied to estimate the reference case projections by agricultural sector. Emissions from enteric fermentation and agricultural soils were projected based on the annual growth rate in historical emissions ($MMtCO_2e$ basis) for these categories in South Dakota for 1990 to 2002 (1990 to 2005 for crop residues and nitrogen fixing crops).

Table F1. Growth Rates Applied for the Agricultural Sector

Agricultural Category	Growth Rate	Basis for Annual Growth Rate*
Enteric Fermentation	1.4%	Historical emissions for 1990-2002.
Manure Management	-0.6%	Historical emissions for 1990-2002.
Agricultural Burning	0.0%	Assumed no growth.
Agricultural Soils – Direct Emissions		
Fertilizers	2.3%	Historical emissions for 1990-2002.
Crop Residues	4.1%	Historical emissions for 1990-2005.
Nitrogen-Fixing Crops	4.8%	Historical emissions for 1990-2005.
Histosols	0.0%	No historical data available.
Livestock	1.3%	Historical emissions for 1990-2002.
Agricultural Soils – Indirect Emissions		
Fertilizers	2.3%	Historical emissions for 1990-2002.
Livestock	1.1%	Historical emissions for 1990-2002.
Leaching/Runoff	1.6%	Historical emissions for 1990-2002.

* Compound annual growth rates shown in this table were calculated using the growth rate in historical emissions ($MMtCO_2e$ basis) from 1990 through the most recent year of data. These growth rates were applied to forecast emissions from the latest year of data to 2020.

The growth rates for crop residues, nitrogen fixing crops, and fertilizer reflect the significant amount of crop production in South Dakota. For the period 1997 through 2002, beef cattle populations have increased slightly by about 0.5% annually, swine populations have increased by about 1% annually, and dairy cattle populations have declined by about -2.35% annually. The annual growth rates (calculated from the trend in emissions) shown in Table F1 for enteric fermentation and manure management reflect the trends in the livestock industry and the SGIT assumptions on enteric fermentation emission factors for dairy and beef cattle. In SGIT, the enteric fermentation emission factor is about 30% higher for dairy cattle than for beef cattle. In addition, the SGIT assumes that manure from dairy operations will be managed in high methane-producing systems (e.g., anaerobic lagoon, liquid/ slurry, and deep pit) while manure from beef cattle will be managed in low methane-producing systems (e.g., dry lot). Note that the SGIT assumes that the majority of manure from swine operations will also be managed in high methane-producing systems (e.g., anaerobic lagoon, liquid/ slurry, and deep pit), and the growth in the swine population offsets somewhat the effect of the decline in the dairy population on emissions associated with manure management.

Soil Carbon

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*[76] 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 US 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*.[77] 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.

Table F2. GHG Emissions from Soil Carbon Changes Due to Cultivation Practices ($MMtCO_2e$)

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
4.07	(0.18)	0.00	(2.09)	(0.04)	(0.44)	0.07	(1.39)	(0.31)	0.07	(1.04)

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.

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 South Dakota, Table F2 shows a summary of the latest estimates available from the USDA, which are for 1997.[78] These data show that changes in agricultural practices are estimated to result in a net sink of 1.04 $MMtCO_2e$/yr in South Dakota. Since data are not yet available from USDA to make a

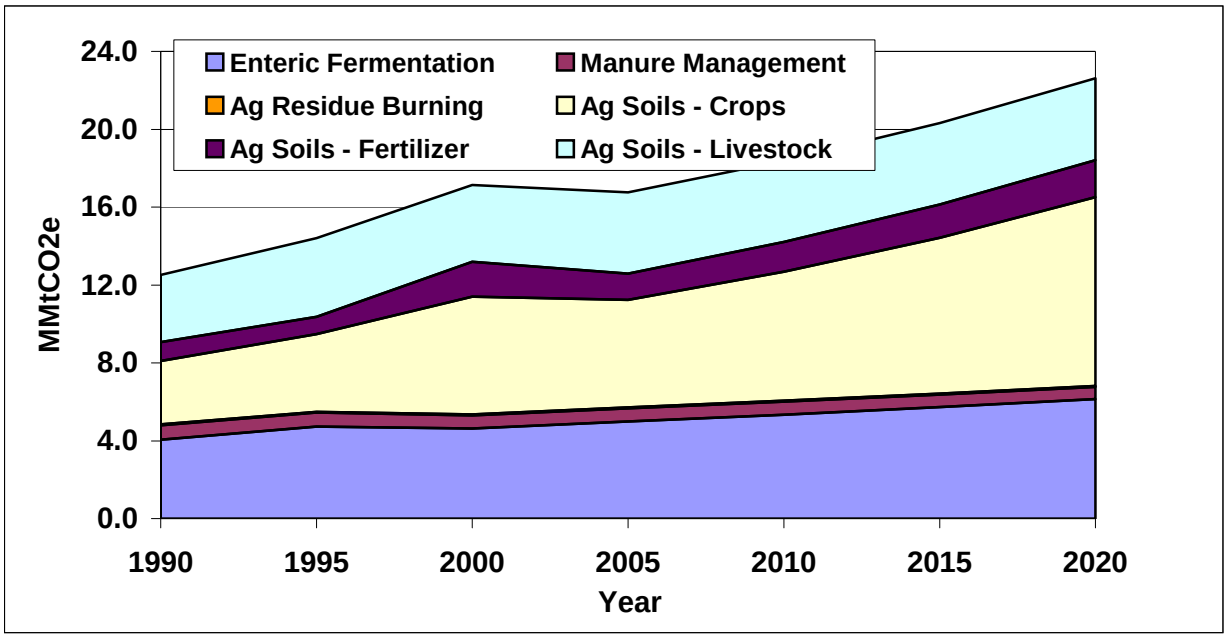
[76] *U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2004* (and earlier editions), US Environmental Protection Agency, Report # 430-R-06-002, April 2006. Available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.
[77] *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001*. Global Change Program Office, Office of the Chief Economist, US 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 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 F2. The sum of the first nine columns is equivalent to the mineral soils category.
[78] *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001*. Global Change Program Office, Office of the Chief Economist, US 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 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 F2. The sum of the first nine columns is equivalent to the mineral soils category.

determination of whether the emissions are increasing or decreasing, the net sink of 1.04 $MMtCO_2e$/yr is assumed to remain constant.

Results

As shown in Figure F1, gross GHG emissions from agricultural sources range between about 12.5 and 22.6 $MMtCO_2e$ from 1990 through 2020, respectively. In 1990, enteric fermentation accounted for about 32% (4.05 $MMtCO_2e$) of total agricultural emissions and is estimated to account for about 27% (6.14 $MMtCO_2e$) of total agricultural emissions in 2020. The manure management category, which is the only source projected to decline, accounted for 6% (0.75 $MMtCO_2e$) of total agricultural emissions in 1990 and is estimated to account for about 2.8% (0.62 $MMtCO_2e$) of total agricultural emissions in 2020. The agricultural soils category shows 1990 emissions accounting for 61% (7.68 $MMtCO_2e$) of total agricultural emissions and 2020 emissions estimated to be about 70% (15.8 $MMtCO_2e$) of total agricultural emissions. Including the CO_2 sequestration from soil carbon changes, the historic and projected emissions for the agriculture sector on a net basis would range between about 11.5 and 21.6 $MMtCO_2e$/yr from 1990 through 2020, respectively.

Figure F1. Gross GHG Emissions from Agriculture



Source: CCS calculations based on approach described in text.
Notes: Ag Soils – Crops category includes: incorporation of crop residues and nitrogen fixing crops (no cultivation of histosols estimated in South Dakota); emissions for agricultural residue burning are too small to be seen in this chart. Soil carbon sequestration is not shown (see Table F2).

Agricultural burning emissions were estimated to be relatively large for South Dakota (compared to the US total) based on the SGIT activity data (about 0.03 $MMtCO_2e$/yr in 1990 and 0.05 MMtCO2e in 2020). For South Dakota, this category accounts for about 0.24% of total gross GHG emissions associated with the agricultural sector from 1990 through 2020, respectively. Emissions for this category are higher than the national emissions included in the USDA

Inventory which, relative to other agricultural categories, reports a low level of residue burning emissions (0.02 $MMtCO_2e$). Thus, even though these initial emission estimates using the SGIT are low relative to emissions associated with the other agricultural categories in South Dakota, the emission estimates for agricultural burning in South Dakota using the SGIT methodology are inconsistent with other data sources and should be refined using actual activity data for South Dakota, if available.

The only standard IPCC source categories missing from this report are N_2O emissions from cultivation of histosols and CO_2 emissions from limestone and dolomite application. Estimates for South Dakota were not available; however, the USDA's national estimate for soil liming is about 9 $MMtCO_2e/yr$.[79]

Key Uncertainties

Emissions from enteric fermentation and manure management are dependent on the estimates of animal populations and the various factors used to estimate emissions for each animal type and manure management system (i.e., emission factors that are dependent on several variables, including manure production levels, volatile solids contents of manures, and CH_4 formation potential). Each of these factors has some level of uncertainty. Also, animal populations fluctuate throughout the year, and thus using point estimates introduces uncertainty into the average annual estimates of these populations. In addition, there is uncertainty associated with the original population survey methods employed by USDA. The largest contributors to uncertainty in emissions from manure management are the emission factors, which are derived from limited data sets.

As mentioned above, for emissions associated with changes in agricultural soil carbon levels, the only data currently available are for 1997. When newer data are released by the USDA, these should be reviewed to represent current conditions as well as to assess trends. In particular, given the potential for some CRP acreage to retire and possibly return to active cultivation prior to 2020, the current size of the CO_2 sink could be appreciably affected. As mentioned above, emission estimates for soil liming have not been developed for South Dakota.

Another contributor to uncertainty in the emission estimates is the projection assumptions. This inventory assumes that the average annual rate of change in future year emissions will follow the historical average annual rate of change from 1990 through the most recent year of data. For example, the historical data show an increase in the use of fertilizers; however, there may be a leveling-off in fertilizer use trends due to recent efficiency gains that may be close to reaching their full technical potential.

Although the agricultural burning emissions estimated using the SGIT method are low relative to emissions associated with the other agricultural categories covered by this sector, South Dakota's emissions estimated using SGIT are higher than the US total estimated for this category. Future work on the agricultural sector should include efforts to improve the estimates for agricultural burning.

[79] *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001*. Global Change Program Office, Office of the Chief Economist, US Department of Agriculture.

Appendix G. Waste Management

Overview

GHG emissions from waste management include:

- Solid waste management – methane (CH_4) emissions from municipal and industrial solid waste landfills (LFs), accounting for CH_4 that is flared or captured for energy production (this includes both open and closed landfills);
- Solid waste combustion – CH_4, carbon dioxide (CO_2), and nitrous oxide (N_2O) emissions from the combustion of solid waste in incinerators or waste to energy plants; and
- Wastewater management – CH_4 and N_2O from municipal wastewater and CH_4 from industrial wastewater (WW) treatment facilities.

Inventory and Reference Case Projections

Solid Waste Management
For solid waste management, we used the US EPA SGIT software and the US EPA Landfill Methane Outreach Program (LMOP) landfills database[80] as starting points to estimate emissions. The LMOP data serve as input data to estimate annual waste emplacement for each landfill modeled by SGIT. SGIT then estimates CH_4 generation for each landfill site. Additional post-processing outside of SGIT to account for controls is then performed to estimate final CH_4 emissions.

SDDENR provided a list of landfills in the state with annual waste emplacement data that were used to supplement the LMOP database.[81] These additional data included information on many sites that were not present in the LMOP database, as well as updated information on sites that were present in the database (e.g. waste emplacement data, information on controls). In the combined LMOP and SDDENR dataset for South Dakota, there were 14 active sites and 1 closed site represented. One of these sites is controlled by flares and is in the first of three phases to install a landfill gas to energy (LFGTE) plant (City of Sioux Falls). This landfill is listed under flared landfills in this inventory. The rest of the sites were assumed to be uncontrolled.

The combined LMOP and SDDENR list of landfills did not include the approximately 300 small town landfills that have closed since 1960. By 1990, these small sites had closed. Although waste emplacement data are not available for these sites, most of the waste had been open burned, so little waste is left.[2] For the remaining waste, CCS assumes that, due to its age, very little methane is still being emitted (most methane is emitted from landfilled waste within the first 15-30 years of emplacement).

To obtain the annual disposal needed by SGIT for each landfill, 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.

[80] LMOP database is available at: http://www.epa.gov/lmop/proj/index.htm. Updated version of the database provided by Rachel Goldstein, Program Manager, EPA Landfill Methane Outreach Program, October 2006.
[81] Steven Kropp, Solid Waste Program, South Dakota Department of Environment and Natural Resources.

CCS performed two different runs of SGIT to estimate emissions from municipal solid waste (MSW) landfills: (1) uncontrolled landfills, and (2) flared landfills. SGIT produced annual estimates through 2005 for each of these landfill categories. CCS then performed some post-processing of the landfill emissions to account for landfill gas controls (at LFGTE sites) and to project the emissions through 2020. For the controlled landfills, CCS assumed that the overall methane collection and control efficiency is 75%.[82] Of the methane not captured by a landfill gas collection system, it is further assumed that 10% is oxidized before being emitted to the atmosphere (consistent with the SGIT default).

Growth rates were estimated by using the historic (1990-2005) growth rates of emissions in both the controlled and uncontrolled landfill categories. The annual growth rates are: 3.8% for uncontrolled sites and 2.6% for controlled (flared) landfills.

CCS used the SGIT default for industrial solid waste landfills. This default is based on national data indicating that industrial landfilled waste is emplaced at approximately 7 percent of the rate of MSW emplacement. We assumed that this additional industrial waste emplacement occurs beyond that already addressed in the emplacement rates for MSW sites described above. Due to a lack of data, no controls were assumed for industrial waste landfilling. For industrial landfills, the overall growth rate in MSW emissions from 1990 to 2005 (3.6 %/yr) was used to project emissions to 2020 (based on the assumption that industrial waste landfilling will continue to grow at the same rate as MSW landfilling overall).

Solid Waste Combustion

There are no solid waste incinerators operating in South Dakota. There may be a significant level of residential waste open burning (e.g., backyard burn barrels); however, estimates of the amount of waste burned were not available. Also, at many small landfills, waste was open burned after these sites were closed, but estimates of the amount of waste burned were not available.

Wastewater Management

GHG emissions from municipal wastewater treatment were also estimated. For municipal wastewater treatment, 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. Municipal wastewater emissions were based on population projections for 2005-2020 for a growth rate of 0.61% per year.

[82] As per EPA's AP-42 Section on Municipal Solid Waste Landfills: http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf.

Table G1. SGIT Key Default Values for Municipal Wastewater Treatment

Variable	Default Value
BOD	0.065 kg /day-person
Amount of BOD anaerobically treated	16.25%
CH_4 emission factor	0.6 kg/kg BOD
South Dakota residents not on septic	75%
Water treatment N_2O emission factor	4.0 g N_2O/person-yr
Biosolids emission factor	0.01 kg N_2O-N/kg sewage-N

Source: US EPA State Inventory Tool – Wastewater Module; methodology and factors taken from US EPA, Emission Inventory Improvement Program, Volume 8, Chapter 12, October 1999: www.epa.gov/ttn/chief/eiip/techreport/volume08/.

For industrial wastewater emissions, SGIT provides default assumptions and emission factors for three industrial sectors: Fruits & Vegetables, Red Meat & Poultry, and Pulp & Paper. SDDENR provided average wastewater flow data for 4 plants in the meat and poultry sector. These flow values were used for all years from 1990 to 2005. Emissions were projected based on County Business Patterns employment data (SIC 2010 or NAICS 3115) for 1993-2004, resulting in an annual growth rate of 0.3%.[83] Data were not available to estimate emissions from any other industrial wastewater sector.

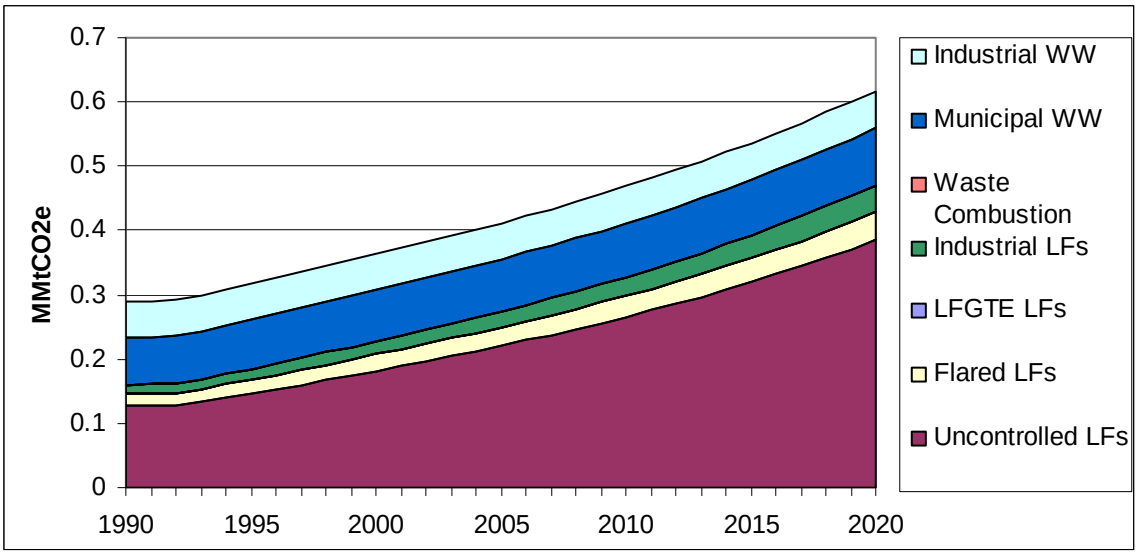
Results

Figure G1 shows the emission estimates for the waste management sector. Overall, the sector accounts for 0.4 $MMtCO_2e$ in 2005. By 2020, emissions are expected to grow to 0.6 $MMtCO_2e$/yr. The largest contributor to waste management emissions is the solid waste sector, in particular, uncontrolled municipal solid waste landfills. In 2005, uncontrolled municipal solid waste landfills accounted for 54% of total waste management emissions. These sites are also expected to be the largest contributor to emissions growth. By 2020, the contribution from these sites is expected to be about 62%.

In 2005, about 20% of the waste management sector emissions were contributed by municipal wastewater treatment systems and 14% of emissions were contributed by industrial wastewater. Note that these estimates are based on the default parameters listed in Table G1, and might not adequately account for existing controls or management practices (e.g. anaerobic digesters served by a flare or other combustion device). By 2020, municipal and industrial wastewater treatment sectors are expected to contribute about 14% and 9% of the waste management sector emissions.

[83] County Business Patterns, US Census Bureau, http://www.census.gov/epcd/cbp/view/cbpview.html.

Figure G1. South Dakota GHG Emissions from Waste Management



Source: CCS calculations based on approach described in text.
Notes: LF – landfill; WW – wastewater; LFGTE – landfill gas to energy; there are none of these sites currently operating in South Dakota.

Key Uncertainties

The methods used to model landfill gas emissions do not adequately account for the points in time when controls were applied at individual sites. Also, many small closed landfills were not included in the estimates. While most of these sites burned their waste, some waste may have been in place after 1990 and therefore contributed to the overall state waste-in-place. Hence, for landfills, the historical emissions are less certain than current emissions and future emissions (since each site that is currently controlled was modeled as always being controlled, the historic emissions estimates are lower than they should be as a result).

The modeling also does not account for uncontrolled sites that will need to apply controls during the period of analysis due to triggering the requirements of the federal New Source Performance Standards/Emission Guidelines. Finally, CCS assumed that the contributions from 300 or so small closed municipal sites are negligible since a large amount of this waste was open burned and the remaining waste is too old to have a significant methane generation potential (methane generation potential of landfilled waste typically drops dramatically after about 15 years).

For industrial landfills, emissions were estimated using national defaults (with industrial landfill wastes buried at 7% of the rate of MSW emplacement). It could be that the available MSW emplacement data within the combined LMOP data used to model the MSW emissions already captures industrial LF emplacement. As with overall MSW landfill emissions, industrial landfill emissions are projected to increase between 2005 and 2020. Hence, the industrial landfill inventory and forecast has a significant level of uncertainty and should be investigated further. For example, the existence of active industrial landfills that are not already represented in the LMOP database should be determined. If these sites do not exist and the existing municipal

waste emplacement data are thought to include industrial wastes, then the separate estimate for industrial landfill emissions can be excluded from the inventory.

Key uncertainties with the wastewater sector are associated with the application of SGIT default values for the parameters listed in Table G1 (e.g. the fraction of BOD that is anaerobically decomposed). The SGIT defaults for emission factors used to estimate wastewater emissions were derived from national data. For industrial wastewater treatment, data on wastewater flows were only available from the meat & poultry sector. Additional investigation should focus on whether other sectors employ wastewater treatment and contribute GHG emissions (e.g. pulp & paper, fruit & vegetable processors).

Appendix H. Forestry

Overview

Forestland emissions refer to the net carbon dioxide (CO_2) flux[84] from forested lands in South Dakota, which account for about 3% of the state's land area.[85] The dominant forest types in South Dakota are White-Red-Jack pine forests which make up about 75% of forested lands with the remaining forests primarily being a variety of hardwood forest types.

Forestlands are net sinks of CO_2 in South Dakota. 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, decay of dead biomass, and fires. In addition, carbon is stored for long time periods when forest biomass is harvested for use in durable wood products. Carbon dioxide 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 *U.S. Inventory of Greenhouse Gas Emissions and Sinks*.[86] The national estimates are compiled from state-level data. The South Dakota 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 and 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 (megagrams of C per hectare) for a number of separate C pools.

Carbon dioxide 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 CO_2 emissions or carbon transfers out of that pool (e.g., death of a standing tree

[84] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.
[85] Total forested acreage is 1.6 million acres. Acreage by forest type available from the USFS at: http://www.fs.fed.us/ne/global/pubs/books/epa/states/SD.htm. The total land area in South Dakota is 49.4 million acres http://www.50states.com/sdakota.htm.
[86] *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.
http://www.epa.gov/climatechange/emissions/usinventoryreport.html

transfers carbon from the live tree to standing dead wood 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 (NF) system and those that are not federally-owned (private and other public forests).

Carbon pool data for two periods are used to estimate CO_2 flux for each pool. The data shown in Table H1 are based on the most recent estimates from the USFS and are included in the upcoming 2005 estimates in EPA's national GHG inventory. CCS provided totals with and without the soil carbon pool. 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.[87]

Table H1. Forest Carbon Flux Estimates for South Dakota

Forest Pool	Carbon Flux (MMtC)	Carbon Flux ($MMtCO_2$)
Live Tree (above ground)	-0.03	-0.11
Live Tree (below ground)	-0.008	-0.03
Standing Dead & Down Dead	0.002	0.007
Forest Floor	-0.03	-0.11
Soil Carbon	0.02	0.07
Harvested Wood Products	-0.07	-0.25
Totals	**-0.12**	**-0.42**
Totals (excluding soil carbon)	**-0.14**	**-0.49**

Totals may not sum exactly due to independent rounding.
Data source: Jim Smith, USFS, personal communications with S. Roe, CCS, October 2006 and February 2007.

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. As shown in the table above, 0.25 $MMtCO_2$/yr is estimated to be sequestered annually in wood products.[88] Additional details on the forest carbon inventory methods can be found in Annex 3 to the US EPA's 2006 GHG inventory for the US.[89]

For the 1990 and 2000 historic emission estimates as well as the reference case projections, the forest area and carbon densities of forestlands were assumed to be at the same levels as those shown in the Table H1 above. Information is not currently available on the near term effects of climate change and their impacts on forest productivity. Hence, there is no change in the estimated future sinks for 2010 and 2020.

[87] Rich Birdsey, USFS, personal communication with CCS, May 2007.
[88] Jim Smith, USFS, personal communication with S. Roe, CCS, October 2006.
[89] Annex 3 to EPA's 2006 report, which contains estimates for calendar year 2004, can be downloaded at: http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/RAMR6MBLNQ/$File/06_annex_Chapter3.pdf.

In order to provide a more comprehensive understanding of GHG sources/sinks from the forestry sector, the Center for Climate Strategies (CCS) also developed some rough estimates of state-wide emissions for methane (CH_4) and nitrous oxide (N_2O) from wildfires and prescribed burns. A study published earlier this year in *Science* indicated an increasing frequency of wildfire activity in the western US driven by a longer fire season and higher temperatures.[90]

CCS used 2002 emissions data developed by the Western Regional Air Partnership (WRAP) to estimate CO_2e emissions for wildfires and prescribed burns.[91] The CO_2e from CH_4 emissions from this study were added to an estimate of CO_2e for N_2O 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 N_2O 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 wildfires and prescribed burns on forested lands contributed about 0.03 $MMtCO_2e$ of CH_4 and N_2O. Over 90% of the CO_2e was contributed by CH_4 emissions. In 2002, there were about 87,000 acres burned by wildfires and prescribed burns in South Dakota. Note that this 2002 level of wildfire activity compares to about 13,000 acres burned in South Dakota in 1996.[92]

A comparison estimate was made using emission factors from a 2001 global biomass burning study[93] and the total tons of biomass burned from the 2002 WRAP fires emissions inventory. This estimate is 0.04 $MMtCO_2e$ with about equal contributions from CH_4 and N_2O on a CO_2e basis. Given the large swings in fire activity from year to year 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, on the basis of total acres burned in 1996 and 2002, it appears that forest fires contribute on the order of 0.005 – 0.05 $MMtCO_2e$ annually in SD from CH_4 and N_2O emissions.

Key Uncertainties

It is important to note that there were methodological differences in the two FIA cycles (used to calculate carbon pools and flux) that can produce different estimates of forested area and carbon density. For example, the FIA program modified the definition of forest cover for the woodlands class of forestland (considered to be non-productive forests). Earlier FIA cycles defined woodlands as having a tree cover of at least 10%, while the newer sampling methods used a woodlands definition of tree cover of at least 5% (leading to more area being defined as woodland). In woodland areas, the earlier FIA surveys might not have inventoried trees of

[90] Westerling, A.L. et al, "Warming and Earlier Spring Increases Western US Forest Wildfire Activity", *Sciencexpress*, July 6, 2006.
[91] *2002 Fire Emission Inventory for the WRAP Region Phase II*, prepared by Air Sciences, Inc. for the Western Regional Air Partnership, July 22, 2005.
[92] *1996 Fire Emission Inventory*, Draft Final Report, prepared by Air Sciences, Inc. for the Western Regional Air Partnership, December 2002.
[93] 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.

certain species or with certain tree form characteristics (leading to differences in both carbon density and forested acreage). It is not clear whether these definitional issues have had a substantial effect on the flux estimates.

Also, FIA surveys since 1999 include all dead trees on the plots, but data prior to that are variable in terms of these data. As shown in Table H1, the standing dead and down/dead pools contribute only about 0.007 $MMtCO_2e$ of the net estimated forest flux. The modifications to FIA surveys are a result of an expanded focus in the FIA program, which historically was only concerned with timber resources, while more recent surveys have aimed at a more comprehensive gathering of forest biomass data. The effect of these changes in survey methods has not been estimated by the USFS. It is possible that changes in FIA sampling resulted in more forest area coming into the inventory sample in the second time period.

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. In South Dakota, the soil carbon pool was estimated by USFS to lose a small amount of carbon annually, and hence its removal does not have a large effect on the overall forest flux estimates.

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 South Dakota. Black carbon is an aerosol (particulate matter or PM) species with positive climate forcing potential but currently without a global warming potential defined by the Intergovernmental Panel on Climate Change (IPCC; see Appendix J for more information on BC and other aerosol species). Black carbon 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 and other sources.[94] This appendix describes these data and methods for estimating mass emissions of BC and then transforming the mass emission estimates into carbon dioxide (CO_2) equivalents (CO_2e) in order to present the emissions within a greenhouse gas (GHG) context.

In addition to the PM inventory data from WRAP, PM speciation data from the United States Environmental Protection Agency's (US EPA) SPECIATE database were also used: these data include PM fractions of EC (also known as BC) and primary organic aerosols (also known as organic material or OM). These data come from work recently completed on updating the US EPA's SPECIATE database.[95] These new profiles have just recently been released by the US EPA. As will be further described below, both BC and OM emission estimates are needed to assess the CO_2e of BC emissions. While BC and OM emissions data are available from the WRAP regional haze inventories, the Center for Climate Strategies (CCS) favored the newer speciation data available from the US EPA for the purposes of estimating BC and OM for most source sectors (BC and OM data from the WRAP were used only for the nonroad engines sector). In particular, better speciation data are now available from the US EPA for important BC emissions sources (e.g., most 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 emissions estimates for PM with an aerodynamic diameter of less than 2.5 micrometers ($PM_{2.5}$) by the appropriate aerosol fraction for BC and OM. The aerosol fractions were taken from Pechan's ongoing work to update the US EPA's SPECIATE database as approved by the US EPA's SPECIATE Workgroup members.

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 I1.

[94] Tom Moore, Western Regional Air Partnership, data files provided to Steve Roe, CCS, December 2006.
[95] Version 4.0 of the SPCIATE database and report is expected to be finalized during the Fall of 2006 and will be provided via EPA's web site (http://www.epa.gov/ttn/chief/emch/speciation/index.html).

Development of CO_2e for BC+OM Emissions

We used similar methods to those applied previously in Maine and Connecticut for converting BC mass emissions to CO_2e.[96] These methods are based on the modeling of Jacobson (2002)[97] and his updates to this work (Jacobson, 2005a).[98] Jacobson (2005a) estimated a range of 90:1 to 190:1 for the climate response effects of BC+OM emissions as compared to the amount of carbon in CO_2 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 less than 2.5 microns ($PM_{2.5}$) from onroad diesel exhaust follows:

BC mass = (10 short 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 emissions 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

[96] 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.
[97] 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.
[98] 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.

effect or a net cooling effect). Therefore, for source categories where the PM is dominated by OM (e.g., biomass burning), the net climate response associated with these emissions is highly uncertain and could potentially produce a net 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 South Dakota total about 5.3 $MMtCO_2e$ in 2002. This is the mid-point of the estimated range of emissions. The estimated range is 3.4 – 7.2 $MMtCO_2e$ (see Table I1). The primary contributing sectors in 2002 were nonroad diesel (84%) and onroad diesel (7.9%).

The nonroad diesel sector includes engine exhaust emissions used for construction/mining, commercial, industrial and agricultural purposes, and recreational vehicles. Agricultural engines contributed about 93% of the nonroad diesel total, while construction and mining engines contributed about another 5%.

Wildfires and miscellaneous sources such as fugitive dust from paved and unpaved roads contributed a significant amount of PM and subsequent BC and OM mass emissions (see Table I1); however the OM:BC ratio is >4 for these sources, so the BC emissions were not converted to CO_2e. Note that for South Dakota, the ratio is much lower than that seen in other states (the reason for this in the WRAP's emissions inventory is not known).

Based on 2018 projected emission estimates from the WRAP[99], there will be a drop in the future BC emissions for the onroad and nonoad diesel sectors due to new Federal engine and fuels standards that are currently being phased in to reduce PM emissions. For the nonroad diesel sector the estimated 4.5 $MMtCO_2e$ in 2002 drops to 1.4 $MMtCO_2e$ in 2018. For the onroad diesel sector, 0.4 $MMtCO_2e$ was estimated for 2002 dropping to 0.08 $MMtCO_2e$ in 2018. 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 BC. 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).[100] There are also a number of other indirect radiative effects that have been modeled (see, for example, Jacobson, 2002, as noted in footnotes on the previous pages).

The quantification of aerosol radiative forcing is more complex than the quantification of radiative forcing by GHGs because of the direct and indirect radiative forcing effects, 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

[99] Tom Moore, Western Regional Air Partnership, personal communication and data files provided to S. Roe, CCS, January 2007.
[100] IPCC, 2001. Climate Change 2001: The Scientific Basis, Intergovernmental Panel on Climate Change, 2001.

with the important GHGs (i.e., CO_2). Spatially and temporally resolved information on the atmospheric concentration 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 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. 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 IPCC 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 I1. 2002 BC Emission Estimates

Sector	Subsector	Mass Emissions			CO_2 Equivalents		Contribution to CO_2e
		BC	OM	BC + OM	Low	High	
		Metric Tons			Metric Tons		%
Electricity Generating Units (EGUs)	Coal	9	12	21	8,592	18,147	0.3%
	Oil	0	0	0	0	0	0.0%
	Gas	0	4	4	0	0	0.0%
	Other	0	0	0	0	0	0.0%
Non-EGU Fuel Combustion (Residential, Commercial, Industrial)							
	Coal	89	128	217	88,362	186,632	2.6%
	Oil	11	9	20	10,919	23,062	0.3%
	Gas	0	86	86	0	0	0.0%
	Other[a]	326	1,673	1,999	9,185	19,400	0.3%
Onroad Gasoline (Exhaust, Brake Wear, & Tire Wear)		30	117	148	12,007	25,359	0.4%
Onroad Diesel (Exhaust, Brake Wear, & Tire Wear)		303	128	430	269,506	569,229	7.9%
Aircraft		13	39	52	13,031	27,524	0.4%
Railroad[b]		66	22	88	65,831	139,044	1.9%
Other Energy Use	Nonroad Gas	54	152	206	53,474	112,943	1.6%
	Nonroad Diesel	2,911	955	3,866	2,881,977	6,087,084	84%
	Other Combustion[c]	0	2	2	0	0	0.0%
Industrial Processes		11	57	68	8,138	17,189	0.2%
Agriculture[d]		529	8,773	9,302	0	0	0.0%
Waste Management	Landfills	0	0	0	0	0	0.0%
	Incineration	4	7	11	3,615	7,635	0.1%
	Open Burning	67	862	930	0	0	0.0%
	Other	0	0	0	0	0	0.0%
Wildfires/Prescribed Burns		677	2,685	3,362	0	0	0.0%
Miscellaneous[e]		255	4,165	4,420	0	0	0.0%
Total		**5,357**	**19,876**	**25,233**	**3,424,637**	**7,233,248**	**100%**

[a] Industrial wood combustion.
[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*, US Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-02-003, April 2002 www.epa.gov/globalwarming/publications/emissions. 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 US 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 US *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[101] 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 US *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 US 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^{o}C lower (IPCC 2001).

[101] 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. Currently, 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. In 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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