

DRAFT South Carolina Greenhouse Gas Inventory and Reference Case Projections 1990-2020

**Center for Climate Strategies
June 2007**

Principal Authors: Randy Strait, Steve Roe, Bill Dougherty, Andy Bollman, Holly Lindquist



[This page intentionally left blank.]

Executive Summary

The Center for Climate Strategies (CCS) prepared this report for the Climate, Energy and Commerce Advisory Committee (CECAC) of the Office of the Governor of South Carolina. The report presents a preliminary assessment of the State's greenhouse gas (GHG) emissions from 1990 to 2020. The inventory and forecast estimates serve as a starting point to assist the CECAC and technical work groups with an initial comprehensive understanding of South Carolina's current and possible future GHG emissions, and thereby inform the upcoming identification and analysis of policy options for mitigating GHG emissions. This preliminary draft report will be provided for review and revised, as needed, to address comments provided by the CECAC.

South Carolina'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 Carolina-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 Carolina accounted for approximately 92 million metric tons (MMt) of *gross*¹ carbon dioxide equivalent (CO₂e) emissions in 2005, an amount equal to about 1.3% of total US gross GHG emissions (based on 2004 US data).² South Carolina's gross GHG emissions are rising faster than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). South Carolina's gross GHG emissions increased by about 38% from 1990 to 2005, while national emissions rose by only 16% from 1990 to 2004. The growth in South Carolina's emissions from 1990 to 2005 is primarily associated with the electricity supply and transportation sectors.

Figure ES-1 illustrates the State's emissions per capita and per unit of economic output. On a per capita basis, South Carolinians emitted about 19 metric tons (Mt) of CO₂e annually from 1990 through 1995, lower than the national average of 25 MtCO₂e/yr. Per capita emissions increased to about 22 MtCO₂e/yr by 2005, while the per capita emissions for the US have remained constant at 25 MtCO₂e/yr. 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 27% nationally, and by 12% in South Carolina.³

¹ Excluding GHG emissions removed due to forestry and other land uses and excluding GHG emissions associated with exported electricity.

² The national emissions used for these comparisons are based on 2004 emissions; (<http://www.epa.gov/climatechange/emissions/usinventoryreport.html>).

³ Based on real gross domestic product (millions of chained 2000 dollars) that excludes the effects of inflation, 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>).

The principle sources of South Carolina's GHG emissions are electricity consumption and transportation, accounting for 36% and 33% of South Carolina's gross GHG emissions in 2005, respectively. The next largest contributor is the residential, commercial, and industrial (RCI) fuel use sector, accounting for about 19% of gross GHG emissions in 2005.

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projections, South Carolina's gross GHG emissions continue to grow, and are projected to climb to about 116 MMtCO_{2e} by 2020, reaching 74% above 1990 levels. As shown in Figure ES-3, the electricity supply sector is projected to be the largest contributor to future emissions growth in South Carolina, followed by transportation.

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 Carolina's future GHG emissions (such as the growth rate assumptions for electricity generation and consumption, transportation fuel use, and RCI fossil fuel use). 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 Carolina based on 2002 and 2018 data from the Visibility Improvement State and Tribal Association of the Southeast (VISTAS) regional planning organization. The results for current levels of BC emissions were a total of 7.0 MMtCO_{2e}, which is the mid-point of a range of estimated emissions (4.5 – 9.6 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 Carolina Historical and Reference Case GHG Emissions, by Sector^a

(Million Metric Tons CO ₂ e)	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Electricity Consumption	18.5	32.0	33.3	31.7	43.4	
Coal	18.1	31.3	32.3	30.5	41.8	See electric sector assumptions in Appendix A
Natural Gas	0.32	0.42	0.87	0.90	1.19	
Oil	0.05	0.29	0.19	0.13	0.16	
Wood (CH ₄ and N ₂ O)	0.02	0.02	0.02	0.14	0.16	
MSW/Landfill Gas	0.00	0.02	0.01	0.01	0.01	
Electricity Production	21.9	36.4	38.0	35.4	49.3	Totals include emissions for electricity consumption plus emissions associated with net exported electricity.
Net Exported Electricity	3.38	4.37	4.64	3.70	5.98	
Residential/Commercial/Industrial (RCI) Fuel Use	17.3	16.9	17.5	18.5	19.5	
Coal	5.40	4.67	4.94	5.48	5.60	Based on US DOE regional projections
Natural Gas	6.45	7.92	6.45	7.02	7.83	Based on US DOE regional projections
Oil	5.33	4.17	5.97	5.80	5.93	Based on US DOE regional projections
Wood (CH ₄ and N ₂ O)	0.16	0.18	0.16	0.16	0.18	Based on US DOE regional projections
Transportation	23.0	28.8	30.8	33.0	39.6	
Onroad Gasoline	16.4	20.2	20.9	21.4	24.5	Based on SCDOT VMT projections
Onroad Diesel	4.10	5.97	7.07	8.37	11.2	Based on SCDOT VMT projections
Marine Vessels	0.86	1.56	1.80	2.14	2.84	Based on historical trends
Rail, Natural Gas, LPG, other	0.43	0.28	0.27	0.28	0.29	Based on US DOE regional projections and historical trends
Jet Fuel and Aviation Gasoline	1.19	0.77	0.73	0.77	0.82	Based on FAA aircraft operations projections
Fossil Fuel Industry	0.67	0.59	0.63	0.68	0.78	
Natural Gas Industry	0.67	0.59	0.63	0.68	0.78	Based on 1997-2005 annual growth rate in State's total natural gas consumption from US DOE
Industrial Processes	2.61	3.28	4.30	5.02	6.62	
Cement Manufacture (CO ₂)	1.10	1.31	1.64	1.65	1.68	Based on State's industrial employment projections (2000-2010)
Limestone & Dolomite Use (CO ₂)	0.01	0.01	0.01	0.01	0.01	Based on State's industrial employment projections (2000-2010)
Soda Ash (CO ₂)	0.04	0.04	0.04	0.04	0.04	Based on 2004 and 2009 projections for US production
ODS Substitutes (HFC, PFC)	0.005	1.07	1.85	2.65	4.30	Based on national projections (US State Dept.)
Electric Power T&D (SF ₆)	0.62	0.36	0.33	0.23	0.14	Based on national projections (US EPA)
Aluminum Manufacturing (PFC)	0.84	0.51	0.43	0.44	0.45	Based on State's industrial employment projections (2000-2010)
Waste Management	1.65	2.77	2.88	3.01	3.38	
Solid Waste Management	1.48	2.57	2.67	2.79	3.14	Based on 2000-2005 growth rates
Wastewater Management	0.17	0.20	0.21	0.22	0.24	Based on population projections
Agriculture	2.93	2.80	2.78	2.77	2.71	
Enteric Fermentation	0.69	0.57	0.54	0.57	0.51	Based on VISTAS inventory methods
Manure Management	0.39	0.47	0.48	0.49	0.57	Based on VISTAS inventory methods
Ag. Soils and Residue Burning	1.85	1.76	1.75	1.71	1.63	Based on 1990-2005 historical trends
Total Gross Emissions (Consumption Basis)	66.7	87.1	92.2	94.6	116.0	
<i>increase relative to 1990</i>		<i>31%</i>	<i>38%</i>	<i>42%</i>	<i>74%</i>	
Forestry and Land Use	-28.8	-28.8	-28.8	-28.8	-28.8	All years are based on current (2005) estimates from the USFS
Agricultural Soils	0.18	0.18	0.18	0.18	0.18	Historical and projected emissions held constant at 1997 levels
Net Emissions (Consumption Basis) (including forestry sinks and agricultural soil emissions)	38.1	58.5	63.6	66.0	87.4	

^aTotals may not equal exact sum of subtotals shown in this table due to independent rounding.

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

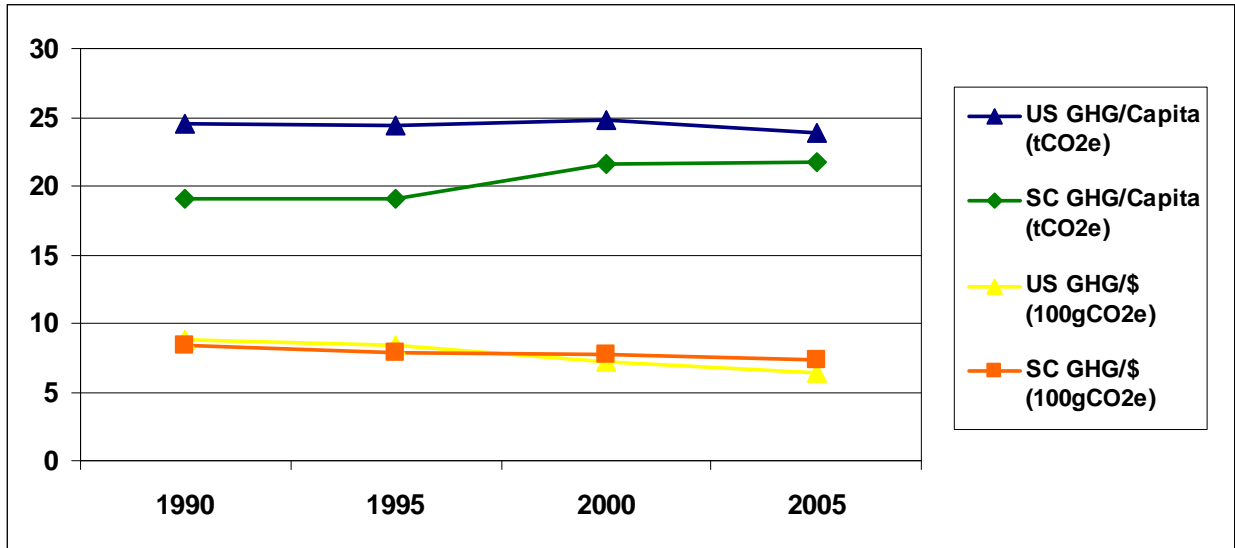
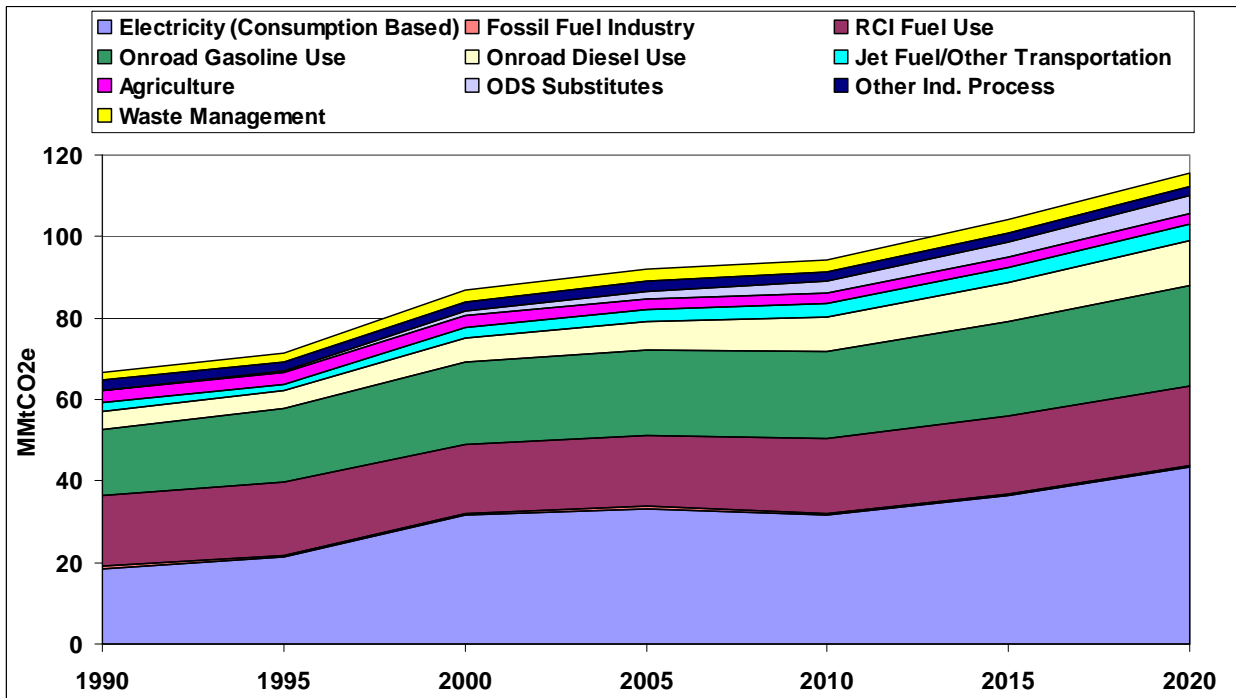
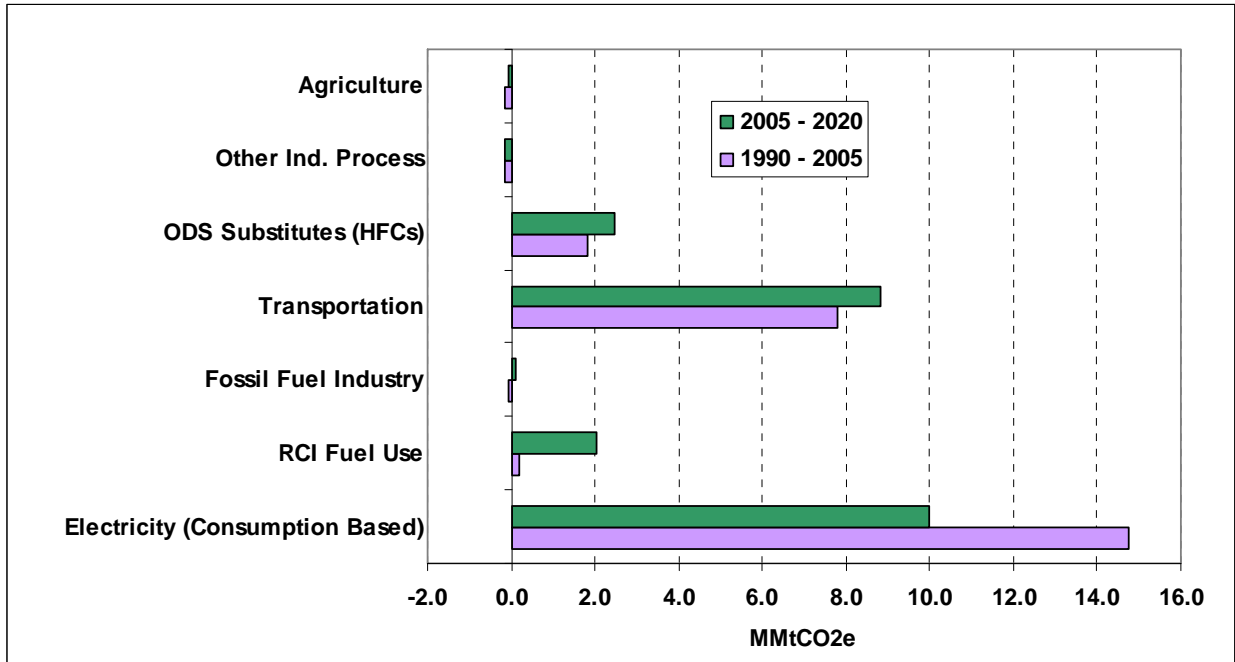


Figure ES-2. South Carolina Gross GHG Emissions by Sector, 1990-2020: Historical and Projected



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

**Figure ES-3. Sector Contributions to Emissions Growth in South Carolina,
1990-2020: Reference Case Projections (MMtCO₂e Basis)**



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

Table of Contents

Executive Summary	iii
Acronyms and Key Terms	vii
Summary of Preliminary Findings.....	1
Introduction.....	1
South Carolina Greenhouse Gas Emissions: Sources and Trends	2
Historical Emissions	4
Overview.....	4
A Closer Look at the Two Major Sources: Transportation and Electricity Supply.....	6
Reference Case Projections.....	7
Key Uncertainties and Next Steps	7
Approach.....	9
General Methodology	10
General Principles and Guidelines.....	10
Appendix A. Electricity Use and Supply	A-1
Appendix B. Residential, Commercial, and Industrial (RCI) Fuel Combustion	B-1
Appendix C. Transportation Energy Use.....	C-1
Appendix D. Industrial Processes	D-1
Appendix E. Fossil Fuel Production Industry.....	E-1
Appendix F. Agriculture	F-1
Appendix G. Waste Management	G-1
Appendix H. Forestry.....	H-1
Appendix I. Inventory and Forecast for Black Carbon.....	I-1
Appendix J. Greenhouse Gases and Global Warming Potential Values: Excerpts from the Inventory of U.S. Greenhouse Emissions and Sinks: 1990-2000.....	J-1

Acronyms and Key Terms

AEO2006 – EIA’s Annual Energy Outlook 2006

Ag – Agriculture

bbls – Barrels

BC – Black Carbon*

Bcf – Billion cubic feet

BLM – United States Bureau of Land Management

BOC – Bureau of Census

BOD – Biochemical Oxygen Demand

BTU – British thermal unit

C – Carbon*

CaCO₃ – Calcium Carbonate

CBM – Coal Bed Methane

CCS – Center for Climate Strategies

CECAC – Climate, Energy and Commerce Advisory Committee

CFCs – Chlorofluorocarbons*

CH₄ – Methane*

CO – Carbon monoxide*

CO₂ – Carbon Dioxide*

CO₂e – Carbon Dioxide equivalent*

CRP – Federal Conservation Reserve Program

EC – Elemental Carbon*

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

EIA – US DOE Energy Information Administration

EIIP – Emissions Inventory Improvement Program

FAA – Federal Highway Administration

FIA – Forest Inventory Analysis

GHG – Greenhouse Gases*

GWh – Gigawatt-hour

GWP – Global Warming Potential*

HFCs – Hydrofluorocarbons*

IPCC – Intergovernmental Panel on Climate Change*

kWh – kilowatt-hour
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*
N₂O – Nitrous Oxide*
NO₂ – Nitrogen Dioxide*
NO_x – Nitrogen Oxides*
NASS – National Agricultural Statistics Service
NEMS – National Energy Modeling System
NMVOCs – Nonmethane Volatile Organic Compounds*
O₃ – 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*
SC DHEC – South Carolina Department of Health and Environmental Control
SCDOT – South Carolina Department of Transportation
SED – State Energy Data

SERC – Southeastern Electric Reliability Council

SF₆ – 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

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

VISTAS – Visibility Improvement State and Tribal Association of the Southeast

VMT – Vehicle-Miles Traveled

W/m² – Watts per Square Meter

WMO – World Meteorological Organization*

WW – Wastewater

* – See Appendix J for more information.

Acknowledgements

We appreciate all of the time and assistance provided by numerous contacts throughout South Carolina, as well as in neighboring States, and at federal agencies. Thanks go to in particular the many staff at several South Carolina State Agencies for their inputs, and in particular to Lynn Barnes and Carla Bedenbaugh of the South Carolina Department of Health and Environmental Control (SC DHEC) who provided key guidance for and review of this analytical effort.

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

Summary of Preliminary Findings

Introduction

The Center for Climate Strategies (CCS) prepared this report for the Climate, Energy and Commerce Advisory Committee (CECAC) of the Office of the Governor of South Carolina. 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. The inventory and forecast estimates serve as a starting point to assist the CECAC and technical work groups with an initial comprehensive understanding of South Carolina's current and possible future GHG emissions, and thereby inform the upcoming identification and analysis of policy options for mitigating GHG emissions. This preliminary draft report will be provided for review and revised, as needed, to address comments provided by the CECAC.

Historical GHG emission estimates (1990 through 2005)⁴ 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 Carolina-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 (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). Emissions of these GHGs are presented using a common metric, CO₂ equivalence (CO₂e), which indicates the relative contribution of each gas to global average radiative forcing on a Global Warming Potential- (GWP-) weighted basis. As stated in the Executive Summary, CCS also added emission estimates for black carbon (BC) based on 2002 and 2018 data from the Visibility Improvement State and Tribal Association of the Southeast (VISTAS) regional planning organization. BC is an aerosol species with a positive climate forcing potential (i.e., the potential to warm the atmosphere, as GHGs do).

It is important to note that the preliminary emissions estimates reflect the *GHG emissions associated with the electricity sources used to meet South Carolina'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*.

⁴ The last year of available historical data varies by sector; ranging from 2000 to 2005.

South Carolina Greenhouse Gas Emissions: Sources and Trends

Table 1 provides a summary of GHG emissions estimated for South Carolina by sector for the years 1990, 2000, 2005, 2010, and 2020. Details on the methods and data sources used to construct these draft 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 Carolina. CCS estimated that BC emissions in 2002 ranged from 4.5 – 9.6 million metric tons (MMt) of carbon dioxide equivalent (CO₂e) with a mid-point of 7.0 MMtCO₂e. 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 CO₂e. Emissions in key contributing sectors (onroad and nonroad diesel engines) are expected to decline by about 3.4 MMtCO₂e/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 Carolina Historical and Reference Case GHG Emissions, by Sector^a

(Million Metric Tons CO ₂ e)	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Electricity Consumption	18.5	32.0	33.3	31.7	43.4	
Coal	18.1	31.3	32.3	30.5	41.8	See electric sector assumptions in Appendix A
Natural Gas	0.32	0.42	0.87	0.90	1.19	
Oil	0.05	0.29	0.19	0.13	0.16	
Wood (CH ₄ and N ₂ O)	0.02	0.02	0.02	0.14	0.16	
MSW/Landfill Gas	0.00	0.02	0.01	0.01	0.01	
Electricity Production	21.9	36.4	38.0	35.4	49.3	Totals include emissions for electricity consumption plus emissions associated with net exported electricity.
Net Exported Electricity	3.38	4.37	4.64	3.70	5.98	
Residential/Commercial/Industrial (RCI) Fuel Use	17.3	16.9	17.5	18.5	19.5	
Coal	5.40	4.67	4.94	5.48	5.60	Based on US DOE regional projections
Natural Gas	6.45	7.92	6.45	7.02	7.83	Based on US DOE regional projections
Oil	5.33	4.17	5.97	5.80	5.93	Based on US DOE regional projections
Wood (CH ₄ and N ₂ O)	0.16	0.18	0.16	0.16	0.18	Based on US DOE regional projections
Transportation	23.0	28.8	30.8	33.0	39.6	
Onroad Gasoline	16.4	20.2	20.9	21.4	24.5	Based on SCDOT VMT projections
Onroad Diesel	4.10	5.97	7.07	8.37	11.2	Based on SCDOT VMT projections
Marine Vessels	0.86	1.56	1.80	2.14	2.84	Based on historical trends
Rail, Natural Gas, LPG, other	0.43	0.28	0.27	0.28	0.29	Based on US DOE regional projections and historical trends
Jet Fuel and Aviation Gasoline	1.19	0.77	0.73	0.77	0.82	Based on FAA aircraft operations projections
Fossil Fuel Industry	0.67	0.59	0.63	0.68	0.78	
Natural Gas Industry	0.67	0.59	0.63	0.68	0.78	Based on 1997-2005 annual growth rate in State's total natural gas consumption from US DOE
Industrial Processes	2.61	3.28	4.30	5.02	6.62	
Cement Manufacture (CO ₂)	1.10	1.31	1.64	1.65	1.68	Based on State's industrial employment projections (2000-2010)
Limestone & Dolomite Use (CO ₂)	0.01	0.01	0.01	0.01	0.01	Based on State's industrial employment projections (2000-2010)
Soda Ash (CO ₂)	0.04	0.04	0.04	0.04	0.04	Based on 2004 and 2009 projections for US production
ODS Substitutes (HFC, PFC)	0.005	1.07	1.85	2.65	4.30	Based on national projections (US State Dept.)
Electric Power T&D (SF ₆)	0.62	0.36	0.33	0.23	0.14	Based on national projections (US EPA)
Aluminum Manufacturing (PFC)	0.84	0.51	0.43	0.44	0.45	Based on State's industrial employment projections (2000-2010)
Waste Management	1.65	2.77	2.88	3.01	3.38	
Solid Waste Management	1.48	2.57	2.67	2.79	3.14	Based on 2000-2005 growth rates
Wastewater Management	0.17	0.20	0.21	0.22	0.24	Based on population projections
Agriculture	2.93	2.80	2.78	2.77	2.71	
Enteric Fermentation	0.69	0.57	0.54	0.57	0.51	Based on VISTAS inventory methods
Manure Management	0.39	0.47	0.48	0.49	0.57	Based on VISTAS inventory methods
Ag. Soils and Residue Burning	1.85	1.76	1.75	1.71	1.63	Based on 1990-2005 historical trends
Total Gross Emissions (Consumption Basis)	66.7	87.1	92.2	94.6	116.0	
<i>increase relative to 1990</i>		<i>31%</i>	<i>38%</i>	<i>42%</i>	<i>74%</i>	
Forestry and Land Use	-28.8	-28.8	-28.8	-28.8	-28.8	All years are based on current (2005) estimates from the USFS
Agricultural Soils	0.18	0.18	0.18	0.18	0.18	Historical and projected emissions held constant at 1997 levels
Net Emissions (Consumption Basis) (including forestry sinks and agricultural soil emissions)	38.1	58.5	63.6	66.0	87.4	

^aTotals may not equal exact sum of subtotals shown in this table due to independent rounding.

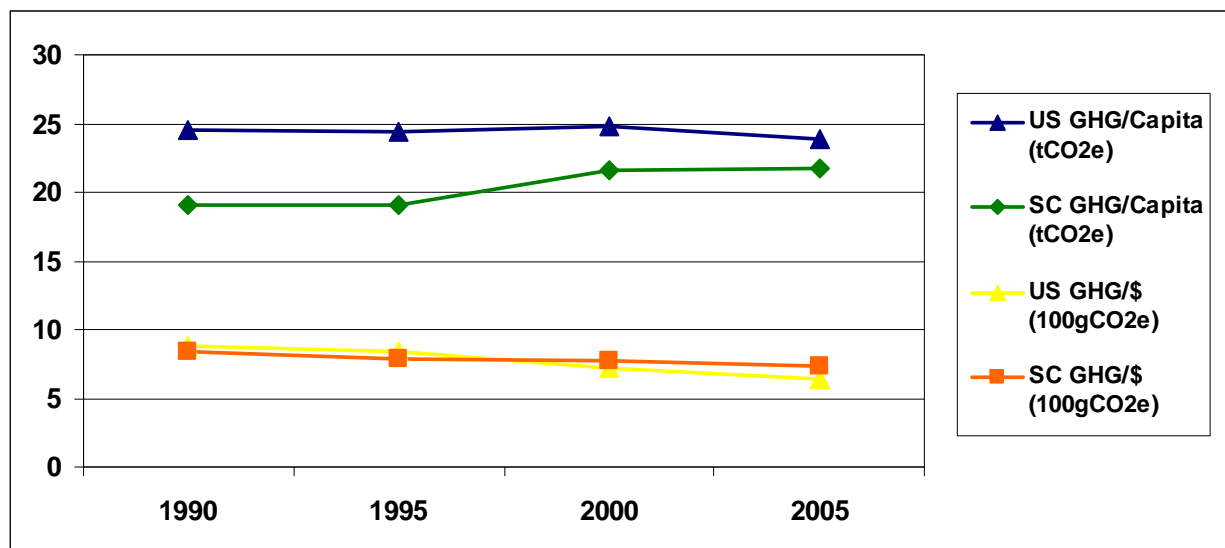
Historical Emissions

Overview

Preliminary analyses suggest that in 2005, activities in South Carolina accounted for approximately 92 million metric tons (MMt) of CO₂e emissions, an amount equal to about 1.3% of total US GHG emissions (based on 2004 US emissions⁵). South Carolina's gross GHG emissions are rising faster than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). South Carolina's gross GHG emissions increased 38% 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 Carolinians emitted about 19 metric tons (Mt) of CO₂e annually from 1990 through 1995, lower than the national average of 25 MtCO₂e/yr. Per capita emissions increased to about 22 MtCO₂e/yr by 2005, while the per capita emissions for the US have remained constant at 25 MtCO₂e/yr. 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 27% nationally, and by 12% in South Carolina.⁶

Figure 1. Historical South Carolina 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*.

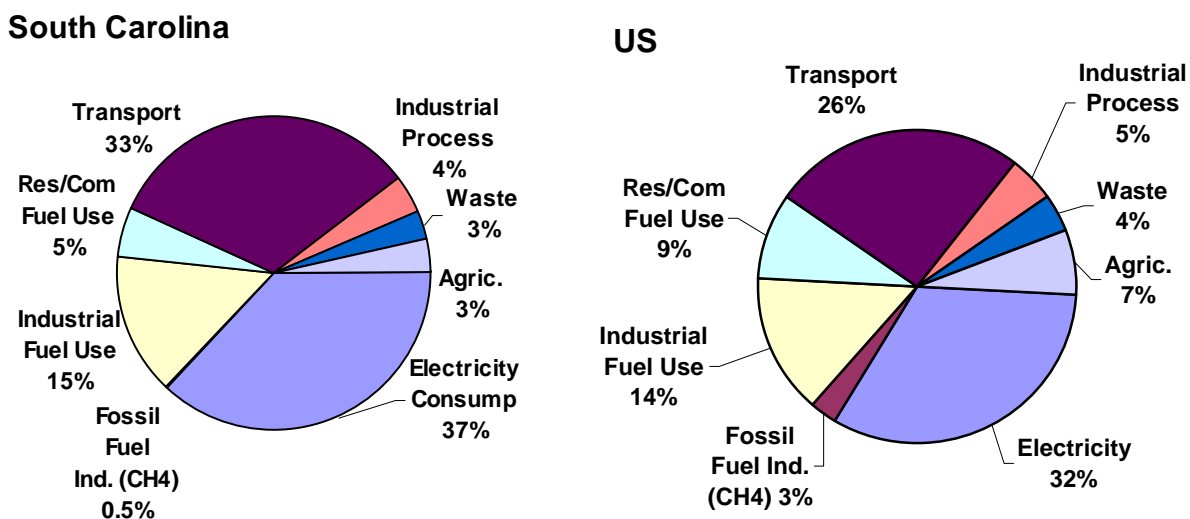
⁶ Based on real gross domestic product (millions of chained 2000 dollars) that excludes the effects of inflation, available from the US Bureau of Economic Analysis (<http://www.bea.gov/regional/gsp/>). The national emissions used for these comparisons are based on 2004 emissions.

(<http://www.epa.gov/climatechange/emissions/usinventoryreport.html>).

Figure 2 compares gross GHG emissions estimated for South Carolina to emissions for the US for year 2000. Principle sources of South Carolina’s GHG emissions are electricity consumption and transportation, accounting for 37% and 33% of South Carolina’s gross GHG emissions in 2000, respectively. The next largest contributor is the residential, commercial, and industrial (RCI) fuel use sector, accounting for 20% of gross GHG emissions in 2000. The waste management and agriculture sectors each contribute 3% of gross GHG emissions in 2000.

Industrial process emissions comprised 4% 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 4% of South Carolina’s gross GHG emissions in 2020 due to significant growth in other sectors.⁷ Other industrial process emissions result from CO₂ released during soda ash, limestone, and dolomite use. Methane emissions associated with natural gas transmission and distribution (T&D) (included under the fossil fuel industry category) accounted for less than 1% of the State’s gross GHG emissions in 2000.

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



Forestry activities in South Carolina are estimated to be net sinks for GHG emissions, and forested lands account for a sink of 28.8 MMtCO₂e per year. Agricultural soils account for net emissions of 0.18 MMtCO₂e per year.

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.

A Closer Look at the Two Major Sources: Transportation and Electricity Supply

Transportation Sector

As shown in Figure 2, the transportation sector accounted for about 33% of South Carolina's gross GHG emissions in 2000 (about 29 MMtCO₂e), which was higher than the national average share of emissions from transportation fuel consumption (26%). The GHG emissions associated with South Carolina's transportation sector increased by 7.8 MMtCO₂e between 1990 and 2005, accounting for about 31% of the State's net growth in gross GHG emissions in this time period.

From 1990 through 2002, South Carolina's GHG emissions from transportation fuel use have risen steadily at an average rate of about 2.1% annually. In 2002, onroad gasoline vehicles accounted for about 70% of transportation GHG emissions. Onroad diesel vehicles accounted for another 21% of emissions, and marine vessels for roughly 6%. Air travel, rail, and other sources (natural gas- and liquefied petroleum gas- (LPG-) fueled-vehicles used in transport applications) accounted for the remaining 3% of transportation emissions. As a result of South Carolina's population and economic growth and an increase in total vehicle miles traveled (VMT) during the 1990s, onroad gasoline use grew 25% between 1990 and 2002. Meanwhile, onroad diesel use rose 52% during that period, suggesting an even more rapid growth in freight movement within or across the State. Marine fuel use increased by about 101% from 1990-2002.

Electricity Supply Sector

Electricity generation in South Carolina is dominated by steam units, which are primarily based on coal and nuclear fuel. Part of total gross generation by South Carolina power plants helps to meet annual demand for electricity outside of the state. As shown in Figure 2, electricity consumption accounted for about 37% of South Carolina's gross GHG emissions in 2000 (about 32 MMtCO₂e), which was higher than the national average share of emissions from electricity consumption (32%).⁸ The GHG emissions associated with South Carolina's electricity sector increased by 15 MMtCO₂e between 1990 and 2005, accounting for 58% of the state's growth in gross GHG emissions in this time period.

In 2000, emissions associated with South Carolina's electricity consumption (32 MMtCO₂e, see Table 1) were about 4 MMtCO₂e lower than those associated with electricity production (36 MMtCO₂e, see Appendix A). The lower level for consumption-based emissions reflects GHG emissions associated with net exports of electricity to meet the other states' electricity demand.⁹ Projections of electricity sales for 2005 through 2020 indicate that South Carolina will remain a net exporter of electricity. 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 11 MMtCO₂e, and consumption-based emissions (associated with electricity consumed in-state) will increase by about 10 MMtCO₂e.

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 Carolina's situation is different, since it is a net electricity exporter.

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.

The consumption-based approach can better reflect the emissions (and emissions reductions) associated with activities occurring in South Carolina, particularly with respect to electricity use (and efficiency improvements), and is particularly useful for policy-making.

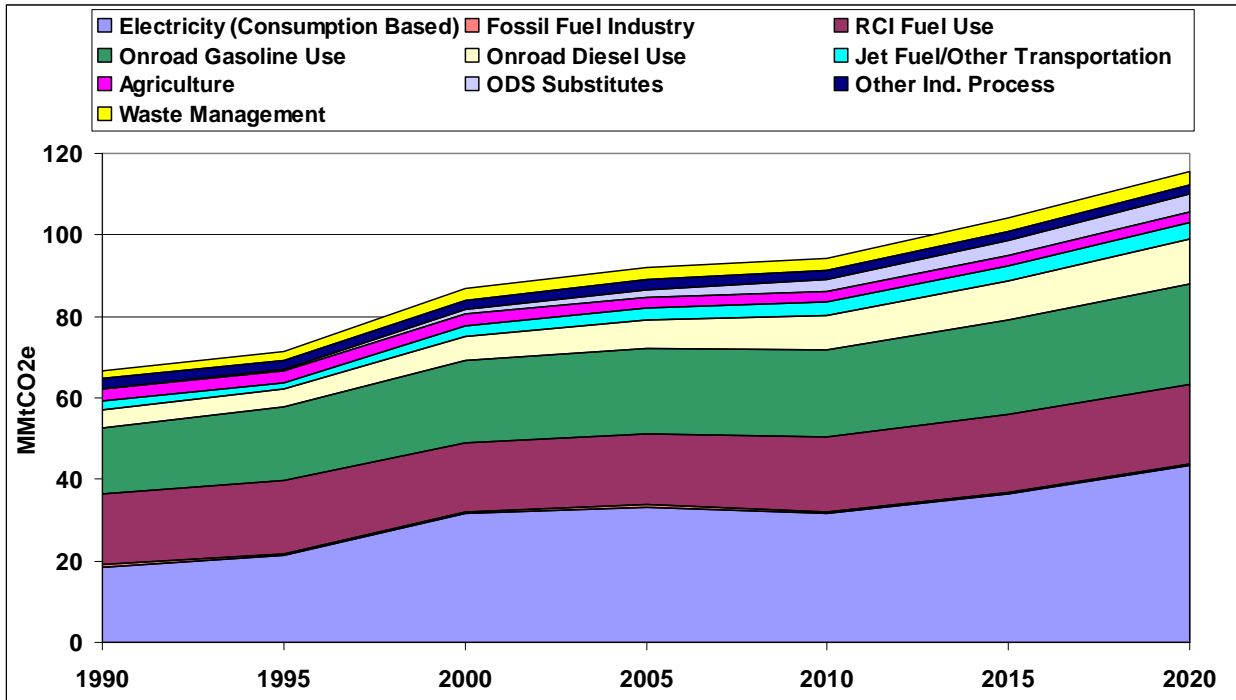
Reference Case Projections

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 Carolina gross GHG emissions continue to grow steadily, climbing to about 116 MMtCO_{2e} by 2020, 74% above 1990 levels. The electricity supply sector is projected to be the largest contributor to future emissions growth, followed by emissions associated with the transportation sector, as shown in Figure 4.

Key Uncertainties and Next Steps

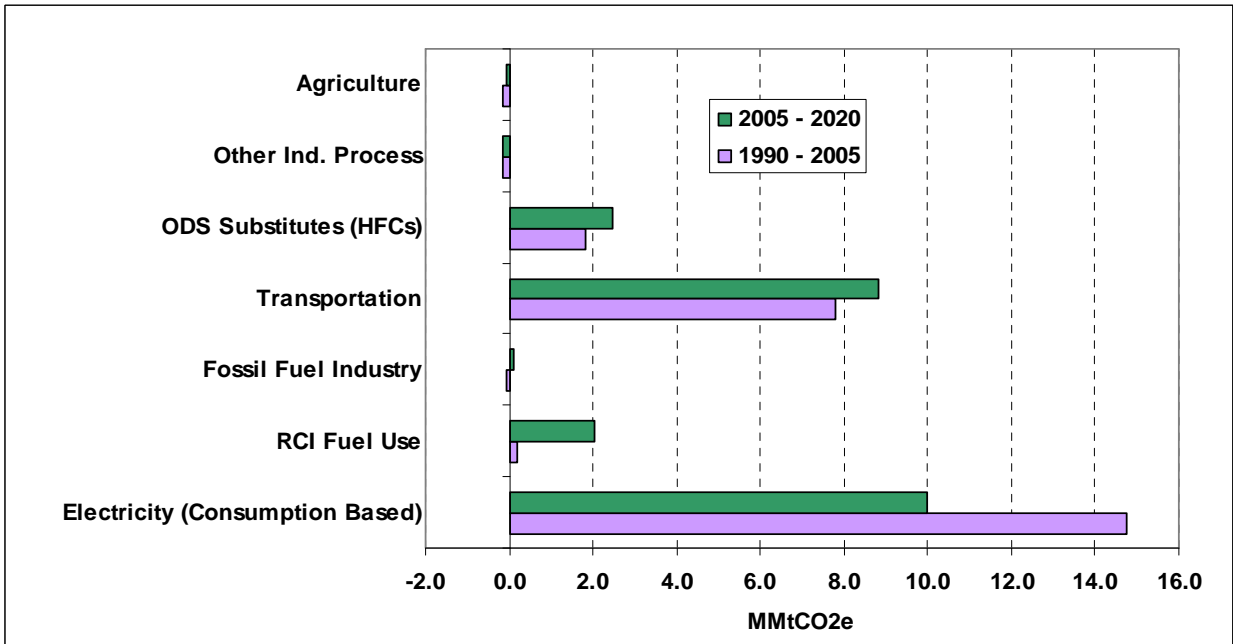
Some data gaps exist in this inventory, and particularly in the reference case projections. Key tasks for future refinement of this inventory and forecast include review and revision of key drivers, such as the transportation, electricity demand, and RCI fuel use growth rates that will be major determinants of South Carolina'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.

**Figure 3. South Carolina 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 Carolina, 1990-2020:
 Historic and Reference Case Projections (MMtCO₂e 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 Carolina, Historical and Projected

	1990-2005	2005-2020	Sources
Population^a	1.3%	1.0%	South Carolina Budget and Control Board, Office of Research and Statistics
Employment^a Goods Services	NA ^b NA	0.2% 1.7%	Growth rates based on employment data for 2000-2010 available from the South Carolina Employment Security Commission, Labor Market Information Online, Economic Data, South Carolina Data, Current Employment Statistics, Projections, Industry Projections (http://www.sces.org/lmi/data/project/projections.asp).
Electricity Sales Total Sales^c SC Sales^d	% %	1.68% 1.42%	US DOE Energy Information Administration (EIA) data for 1990-2003. Reference case sales based on data from South Carolina Energy Office for 2003-2020 (see Appendix A).
Vehicle Miles Traveled	2.6%	2.0%	South Carolina Department of Transportation.

^a For the RCI fuel consumption sectors, population and employment projections for South Carolina were used together with US DOE EIA's Annual Energy Outlook 2006 (AEO2006) projections of changes in fuel use for the EIA's South Atlantic 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 Carolina's residential natural gas use is calculated as the South Carolina population growth times the change in per capita natural gas use for the South Atlantic region.

^b NA – Not available; historical employment data for South Carolina for the goods producing and services providing sectors could not be identified during development of this report.

^c Represents annual growth in total sales of electricity by generators in South Carolina to RCI sectors located within and outside of South Carolina.

^d Represents annual growth in total sales of electricity by generators in South Carolina to RCI sectors located within South Carolina.

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 CO₂e contribution from BC emissions, as compared to the CO₂e contributed from the gases (about 16% BC contribution relative to the CO₂e 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 Carolina with a general understanding of South Carolina's historical, current, and projected (expected) GHG emissions. The following sections explain the general methodology and the general principles and guidelines followed during development of these GHG inventories for South Carolina.

General Methodology

We prepared this analysis in close consultation with South Carolina agencies, in particular, with the South Carolina Department of Health and Environmental Control (SC DHEC) 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 inventory¹⁰ 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 Carolina 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 for 1990-2003. 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 for 1990-2003 from RCI fuel combustion, transportation, industrial processes, agriculture and forestry, and waste. We use SGIT emission factors (CO ₂ , CH ₄ , and N ₂ O 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, 2004 for oil and natural gas, and 2005 for 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 Carolina is included in the South Atlantic region (SC, DE, MD, DC, WV, VA, NC, GA, and FL).	EIA AEO2006 is used to project changes in per capita (residential), per employee (commercial/industrial).
US Department of Transportation (DOT), Office of Pipeline Safety (OPS)	Natural gas transmission pipeline mileage, and distribution pipeline mileage and number of services for 1990 – 2005.	Emissions projected to increase at an average annual rate of 1.4%; growth rate based on historical annual rate of increase in total natural gas consumption for South Carolina from 1997 through 2005.
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.

- **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.

- **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods.** This analysis aims to comprehensively cover GHG emissions associated with activities in South Carolina. It covers all six GHGs covered by US and other national inventories: CO₂, CH₄, N₂O, SF₆, 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.
- **Use of Consumption-Based Emissions Estimates:** To the extent possible, we estimated emissions that are caused by activities that occur in South Carolina. For example, we reported emissions associated with the electricity consumed in South Carolina. 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 Carolina. This entails accounting for the electricity sources used by South Carolina 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 Carolina, 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 Production Industry;
- 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

Overview

This appendix describes the data sources, key assumptions, and the methodology used to develop an inventory of greenhouse gas (GHG) emissions over the 1990-2003 period associated with meeting electricity demand in South Carolina. It also describes the data sources, key assumptions, and methodology used to develop a forecast of GHG emissions over the 2004-2020 period associated with meeting electricity demand in the state. Specifically, the following topics are covered in this appendix:

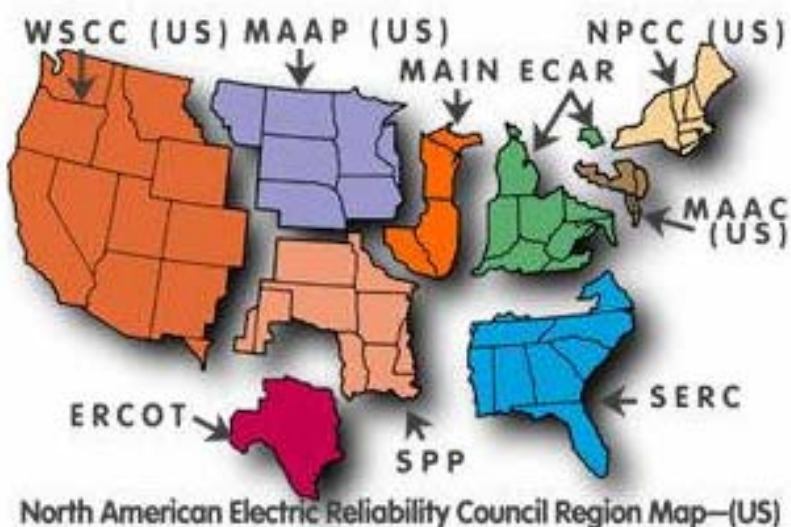
- ❑ *Data sources:* This section provides an overview of the data sources that were used to develop the inventory and forecast, including publicly accessible websites where this information can be obtained and verified.
- ❑ *GHG Inventory methodology:* This section provides an overview of the methodological approach used to develop of the South Carolina GHG inventory for the electric supply sector.
- ❑ *GHG Forecast Methodology - Reference Case:* This section provides an overview of methodological approach used to develop the South Carolina GHG Reference Case forecast for the electric supply sector.
- ❑ *GHG Inventory Results:* This section provides an overview of key results of the South Carolina GHG inventory for the electric supply sector.
- ❑ *GHG Forecast Results:* This section provides an overview of key results of the South Carolina GHG forecast for the electric supply sector.

Data Sources

We considered several sources of information in the development of the inventory and forecast of GHG emissions, on a million metric tons (MMt) of carbon dioxide (CO₂) equivalent (CO₂e) basis, from South Carolina power plants. These are briefly summarized below:

- ❑ *2003 EIA-906/920 Monthly Time Series data.* This is a database file available from the Energy Information Administration (EIA) of the United States (US) Department of Energy (DOE). The information in the database is based on information collected from utilities in Forms EIA-906/920 and EIA-860 for the forecast Base Year of 2003. Data was extracted for South Carolina as well as neighboring states NC, GA, AL, parts of MS, TN, parts of KY, and parts of VA. Data from these forms provide, among other things, fuel consumption and net generation in power stations located in these states for 2003 by plant type. This information can be accessed from http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html.
- ❑ *South Carolina Energy Office statistical modeling results.* These are the results of model runs conducted by Dr. Yvonne Michel who works as a contractor to the South Carolina Energy Office. These modeling results were used to establish a forecast of total sales in South Carolina over the period 2004-2020.

- ❑ *Annual Energy Outlook 2007*. This is an output of an EIA analysis using the National Energy Modeling System (NEMS), a model that forecasts electric expansion/electricity demand in the US. In particular, regional outputs for the Southeastern Electric Reliability Council (SERC) region was used. The SERC region is the one in which South Carolina is located (see map at right). The SERC results include forecasts of gross generation, net generation, combustion efficiency, total sales, and exports/imports through the year 2025. This information is available in supplemental tables that can be accessed directly from <http://www.eia.doe.gov/oiaf/aeo/supplement/index.html>. The sources of the above map is



- http://www.bydesign.com/fossilfuels/crisis/html/NERC_regions_map.html.
- ❑ *Monthly Cost and Quality of Fuels for Electric Plants*. This information is available from the Federal Energy Regulatory Commission (FERC). The database relies on information collected from utilities in the FERC-423 form. It was used to determine the share of coal type (i.e., whether bituminous, sub-bituminous, anthracite, or lignite) as well as the coal quantity consumed in South Carolina power plants over the period 1990-2003. It can be accessed directly from <http://www.eia.doe.gov/cneaf/electricity/page/ferc423.html>.
- ❑ *State Electricity Profiles*. This information is available from the EIA. The database compiles capacity, net generation, and total retail electricity sales by state. It was used to determine total sales of electricity across all sectors in the Base Year 2003. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html.
- ❑ *Energy conversion factors*. This is based on Table Y-2 of Appendix Y in the US Environmental Protection Agency's (EPA) 2003 GHG Inventory for the US. The table is entitled "Conversion Factors to Energy Units (Heat Equivalents)". This information can be accessed directly from the following website: [http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/LHOD5MJTCL/\\$File/2003-final-inventory_annex_y.pdf](http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/LHOD5MJTCL/$File/2003-final-inventory_annex_y.pdf)
- ❑ *Fuel combustion oxidation factors*: This is based on Appendix A of the US EPA's 2003 US GHG inventory for the US. This information can be accessed directly from: http://www.epa.gov/climatechange/emissions/downloads06/06_Annex_Chapter2.pdf
- ❑ *Carbon dioxide, methane (CH₄), and nitrous oxide (N₂O) emission factors*. For all fuels except municipal solid waste (MSW), these emission factors are based on Appendix A of the US EPA's 2003 GHG inventory for the US. This information can be accessed directly from: http://www.epa.gov/climatechange/emissions/downloads06/06_Annex_Chapter2.pdf. For

MSW, emission factors are based on the EIA, Office of Integrated Analysis and Forecasting, Voluntary Reporting of Greenhouse Gases Program, Table of Fuel and Energy Source: Codes and Emission Coefficients. This information can be accessed directly from <http://www.eia.doe.gov/oiaf/1605/coefficients.html>.

- ❑ *Global warming potentials:* These are based on values proposed by the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report. This information can be accessed directly from <http://www.ipcc.ch/pub/reports.htm>

GHG Inventory Methodology

The methodology used to develop the South Carolina inventory of GHG emissions associated with electricity production and consumption is based on methods developed by the IPCC and used by the US EPA in the development of the US GHG inventory. There are four fundamental premises of the GHG inventory developed for South Carolina, as briefly described below:

- ❑ The GHG inventory should be estimated based on both the production and consumption of electricity. Developing the production estimate involves tallying up the GHG emissions associated with the operation of power plants physically located in South Carolina, regardless of ownership. Developing the consumption estimate involves tallying up the GHG emissions associated with consumption of electricity in South Carolina, regardless of where the electricity is produced. As South Carolina is a net exporter of electricity, these estimates will be different.
- ❑ The GHG inventory should be estimated based on emissions at the point of electric generation only. That is, GHG emissions associated with upstream fuel cycle process such as primary fuel extraction, transport to refinery/processing stations, refining, beneficiation, and transport to the power station are not included.
- ❑ As an approximation, it was assumed that all power generated in South Carolina was consumed in South Carolina.
- ❑ Several key assumptions were used for making projections of CO₂, CH₄, and N₂O emissions for the electric sector out to 2020. These are summarized in Table A1.

There were several steps in the methodology for the development of the electric sector GHG inventory for the period 1990-2003. These are briefly outlined below:

- ❑ Determine the coal quality used in South Carolina power stations (i.e., share of anthracite, bituminous, lignite, sub-bituminous, and coal wastes used);
- ❑ Determine gross annual primary energy consumption by South Carolina power stations by plant and fuel type;
- ❑ Determine gross annual generation associated with net power imports to satisfy South Carolina electricity demand.
- ❑ Multiply gross annual primary energy consumption by South Carolina power stations by CO₂e factors. This provides an estimate of the South Carolina GHG inventory on a production basis.
- ❑ Multiply annual gross generation associated with net power imports by the carbon emission intensity (in units of metric tons of CO₂e per mega-watt hour (MWh)) of the SERC region. This provides an estimate of the additional GHG emissions associated with meeting South Carolina electricity demand in excess of generation from local power plants.

- ❑ Add the emissions associated with net power imports to the production-based emissions. This provides an estimate of the GHG inventory on a consumption basis.

Table A1. Key Assumptions Used in the South Carolina GHG Forecast

Key Assumptions	2003	2020	Average Annual Growth / Change (%)
SC electricity demand (GWh)	77,054	107,253	1.96%
SC Gross generation (GWh)	94,125	122,843	1.58%
Gross generation exports to SERC (GWh)	9,198	14,882	2.87%
Power plant heat rate (BTU/kWh)			
Coal	9,789	9,650	-0.08%
Petroleum	7,223	7,242	0.01%
Natural Gas	8,304	7,384	-0.69%
Other Gases	0	0	0.00%
Nuclear	10,384	10,384	0.00%
Hydroelectric Conventional	10,320	10,320	0.00%
Other Renewables (biomass)	10,500	10,500	0.00%
Other (MSW/LFG)	10,500	10,500	0.00%
Pumped Storage	10,320	10,320	0.00%
Losses (%)			
From on-site usage	0.35%	0.79%	5.48%
From T&D and on-site usage	9.27%	5.34%	-3.62%

Notes: GWh = giga-watt hours, BTU = British thermal units, kWh = kilowatt hours, MSW = municipal solid waste, LFG = landfill gas, T&D = transmission and distribution.

GHG Forecast Methodology – Reference Case

We consider that the most useful methodology for constructing a GHG forecast is one that attempts to build information from the bottom-up. That is, the GHG forecast is developed using detailed State-specific data regarding projected sales, gross in-state generation, supply side efficiency improvements, planned capacity additions and retirements by plant type/vintage, and changes over time regarding losses associated with on-site use and transmission and distribution.

While some of this information was available in South Carolina, some key data was not available at the time the forecast was prepared. Therefore, it was necessary to use a top-down approach. A top-down approach uses proxy information regarding future gross in-state generation, supply side efficiency improvements, and changes over time regarding losses. This approach, while less satisfactory for representing state-specific conditions, nonetheless offers an acceptable starting point for exploring projections of GHG emissions from the electric sector in South Carolina. The methodological steps used for forecasting CO₂e emissions are described below.

Coal quality. An overview of the methodology applied to forecast annual gross electricity generation by South Carolina power stations is briefly summarized below:

- ❑ For the Base Year of 2003, determine the coal quality used in South Carolina power stations (i.e., share of anthracite, bituminous, lignite, sub-bituminous, and coal wastes used);
- ❑ For the period 2004 through and including 2020, assume that the coal quality is the same for the Base year.

Total Sales. An overview of the methodology applied to forecast annual sales of electricity to South Carolina consumers is briefly summarized below:

- ❑ For the Base Year of 2003, establish total retail sales in South Carolina (i.e., 77,054 giga-watt hour (GWh));
- ❑ For the period 2004 through and including 2020, obtain in-state electricity sale projections from South Carolina-based utilities (note: this was obtained from Dr. Yvonne Michel)
- ❑ For the period 2004 through and including 2020, compute the annual growth rate associated with electricity sales by South Carolina-based utilities to South Carolina consumers and apply this growth rate to the 2003 retail sale level to forecast annual sales.

Gross Generation. An overview of the methodology applied to forecast annual gross electricity generation by South Carolina power stations is briefly summarized below:

- ❑ For the Base Year of 2003, estimate losses associated with on-site usage of electricity by plant type for South Carolina power plants. On-site usage losses were assumed to be equal to the SERC regional average of 0.4% of gross generation;
- ❑ For the Base Year of 2003, combine actual net electric generation data (i.e., from the inventory) and assumed average on-site losses (i.e., from the SERC region) to estimate gross generation by plant type;
- ❑ For the period 2004 through and including 2020, estimate total gross generation of South Carolina power stations by multiplying the 2003 value of South Carolina total gross generation by plant type by the annual growth rate of gross generation in the SERC region;
- ❑ For the period 2004 through and including 2020, multiply plant type-specific gross generation by the annual growth rate of total gross generation in the SERC region. Then benchmark the plant type-specific totals pro-rata to match the control total of gross generation;

Combustion efficiency. An overview of the methodology applied to forecast annual heat rates at South Carolina power stations is briefly summarized below:

- ❑ For the Base Year of 2003, estimate gross heat rate of South Carolina power stations by dividing the plant type-specific 2003 gross generation estimate by the plant type-specific 2003 gross primary energy consumption estimate.
- ❑ For the period 2004 through and including 2020, estimate the annual average gross plant type-specific heat rate for the SERC region.
- ❑ For the period 2004 through and including 2020, estimate annual average gross plant type-specific heat rate of South Carolina power stations by multiplying the 2003 value of the annual average gross plant type-specific heat rate of South Carolina power plants by the annual rate of improvement of gross heat rate in the SERC region;

Energy use. An overview of the methodology applied to forecast annual primary energy use at South Carolina power stations is briefly summarized below:

- ❑ For the Base Year of 2003, establish the actual primary energy consumption for South Carolina power plants as reported by the databases used to develop the inventory.
- ❑ For the period 2004 through and including 2020, multiply annual gross generation by annual heat rate for each plant type in South Carolina.

Electricity imports. An overview of the methodology applied to forecast annual net electricity imports to meet South Carolina demand is briefly summarized below:

- ❑ For the Base Year of 2003, establish actual total sales of electricity in South Carolina
- ❑ For the period 2004 through and including 2020, estimate annual electricity sales in South Carolina by multiplying the previous year's sales by the annual growth rate of the SERC region.
- ❑ For the Base Year of 2003 through and including 2020, estimate the sales associated with imports as the difference between total sales in South Carolina and the total sales by South Carolina power stations;
- ❑ For the Base Year of 2003 through and including 2020, estimate the gross generation associated with imports by dividing sales from imports by one minus the percent losses from on-site usage and transmission and distribution in the SERC region.

Carbon dioxide-equivalent emissions from South Carolina power stations. An overview of the methodology applied to forecast annual CO₂e emissions is briefly summarized below:

- ❑ For the Base Year of 2003 through and including 2020, estimate total CO₂ emissions from South Carolina power stations by multiplying total primary energy use by the CO₂ emission factor and the global warming potential
- ❑ For the Base Year of 2003 through and including 2020, estimate total CH₄ emissions from South Carolina power stations by multiplying total primary energy use by the CH₄ emission factor and the global warming potential
- ❑ For the Base Year of 2003 through and including 2020, estimate total N₂O emissions from South Carolina power stations by multiplying total primary energy use by the N₂O emission factor and the global warming potential
- ❑ For the Base Year of 2003 through and including 2020, estimate total CO₂e emissions from South Carolina power stations by adding emissions for CO₂, CH₄, and N₂O.

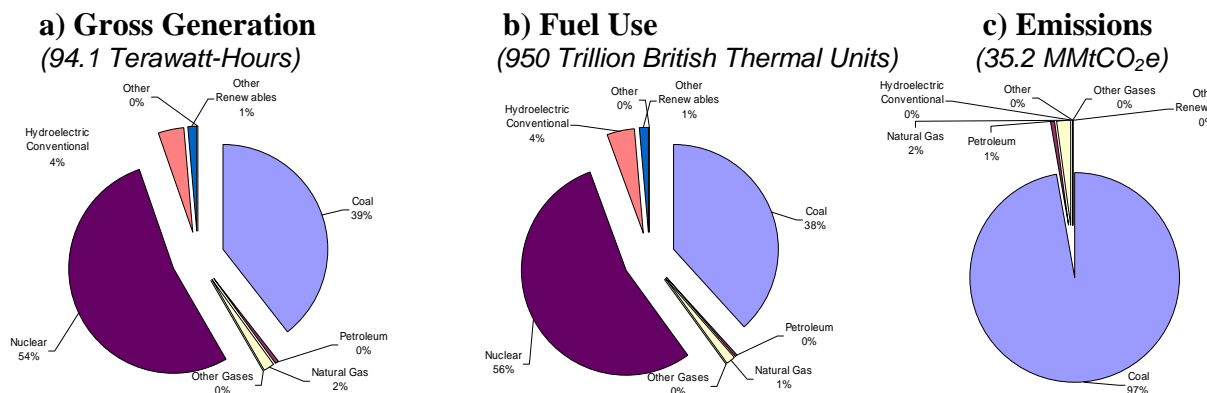
Carbon dioxide-equivalent emissions associated with exported electricity. An overview of the methodology applied to forecast annual CO₂e emissions is briefly summarized below:

- ❑ For the Base Year of 2003 through and including 2020, estimate the total CO₂e emissions associated with electricity production in South Carolina;
- ❑ For the Base Year of 2003 through and including 2020, estimate the total CO₂e emissions associated with electricity demand in South Carolina;
- ❑ For the Base Year of 2003 through and including 2020, the CO₂e emissions associated with exports is the difference of the total CO₂e emissions associated with electricity production in South Carolina from and the total CO₂e emissions associated with electricity demand in South Carolina.

GHG Inventory Results

Figure A1 and Table A2 summarize the characteristics of the electric generation system in South Carolina, together with a breakdown in generation and carbon-equivalent emissions for South Carolina power stations in the Base year of 2003.

**Figure A1. Breakdown of South Carolina Generation, Capacity, and Emissions
2003 Base Year**



**Table A2. Summary of South Carolina Electric Generator Characteristics
2003 Base Year**

Resource	Gross Generation (GWh)	Fuel Use (Million BTU)	Heat rate (BTU/kWh)	Million tonnes CO ₂ e
Coal	37,565	367,719	9,789	34.20
Petroleum	458	3,312	7,223	0.24
Natural Gas	1,669	13,856	8,304	0.74
Other Gases	0	0	0	0.00
Nuclear	50,596	525,403	10,384	0.00
Hydroelectric Conventional	3,678	37,961	10,320	0.00
Other Renewables	1,349	14,169	10,500	0.02
Other	15	161	10,500	0.01
Pumped Storage	-1,207	-12,454	10,320	0.00
Total	94,125	950,126		35.21

GHG Forecast Results

The following subsections provide an overview of the results obtained after applying the methodological approach described above.

Primary Energy Consumption

Total primary energy consumption associated with electricity generation in South Carolina is summarized in Figure A2. Primary energy consumption in South Carolina is dominated by coal and nuclear resources.

Gross Generation

Total gross generation by South Carolina power plants is summarized in Figure A3. Gross generation in South Carolina is dominated by steam units, which are primarily based on coal and nuclear fuel. Part of the total gross generation by South Carolina power plants helps to meet annual demand for electricity outside South Carolina. As indicated earlier, it was assumed that this power is exported to the SERC region. The portion of gross generation that is exported beyond South Carolina borders is shown as the top layer in Figure A3.

Carbon Dioxide-equivalent Emissions

Total CO₂e emissions associated with generation by South Carolina power plants is summarized in Figure A4. Emissions reach 49.3 MMtCO₂e in 2020. Part of the CO₂e emissions by South Carolina power plants is associated with meeting annual demand for electricity outside South Carolina. As indicated earlier, it was assumed that this power is exported to the SERC region. The top layer in Figure A4 shows the portion of CO₂e emissions that are exported beyond South Carolina's border.

Figure A2. Primary Energy Use at South Carolina Power Stations

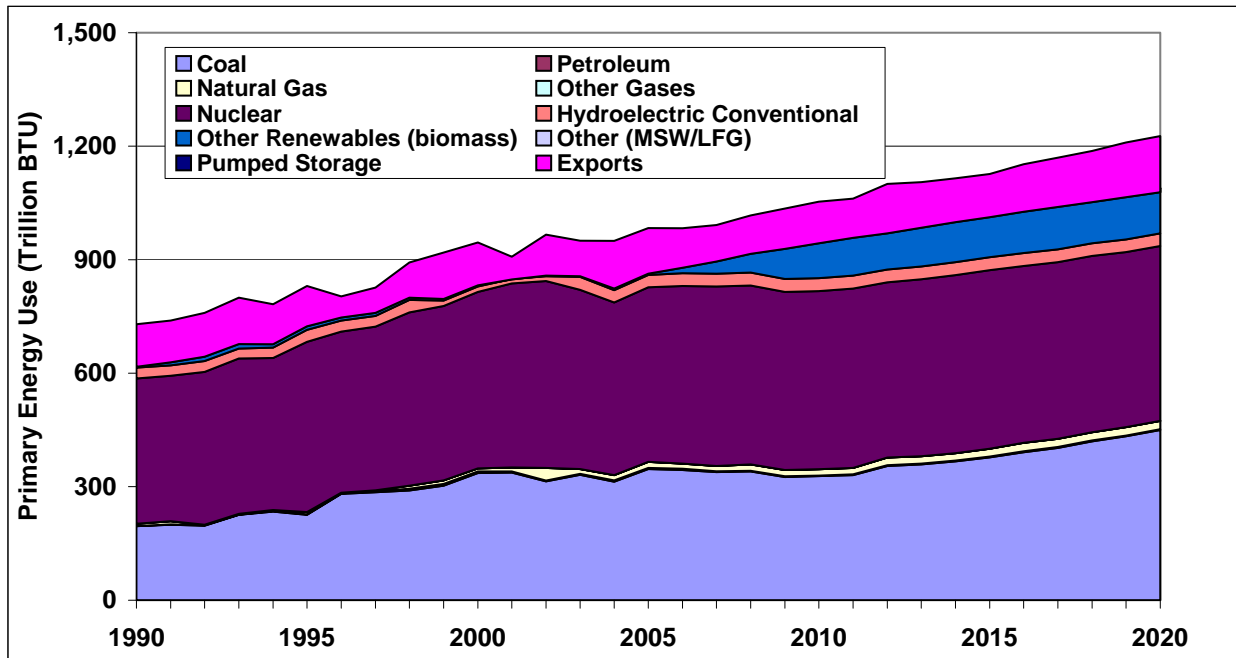


Figure A3. Gross Generation at South Carolina Power Stations

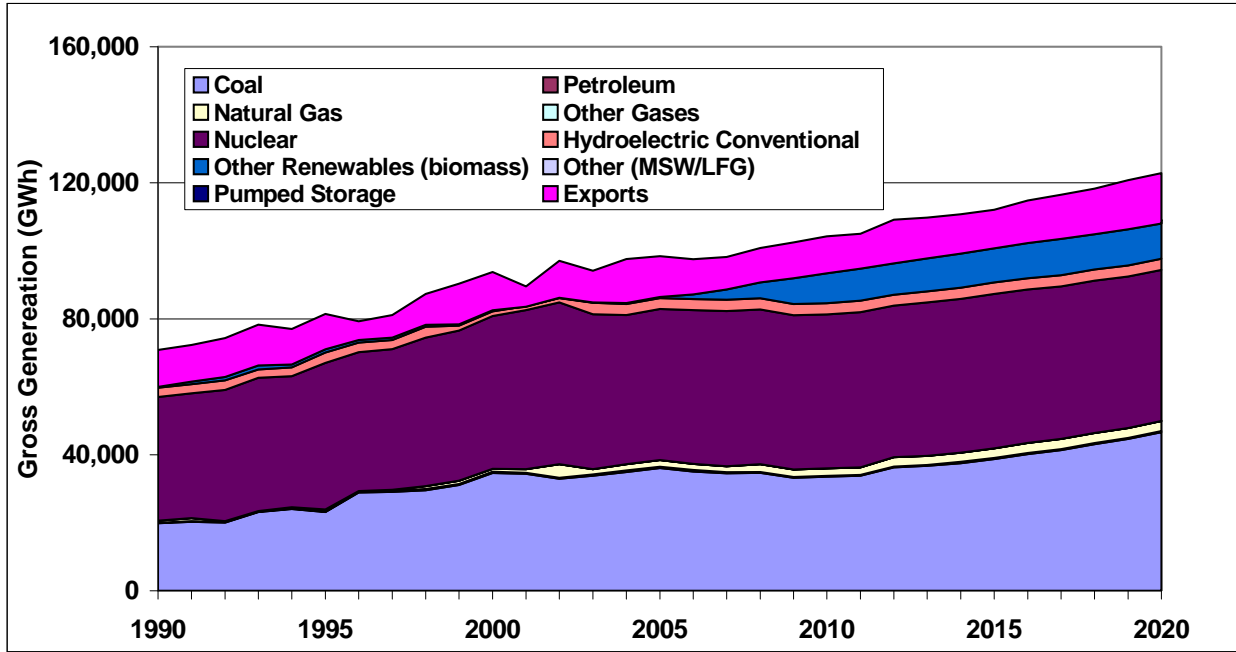
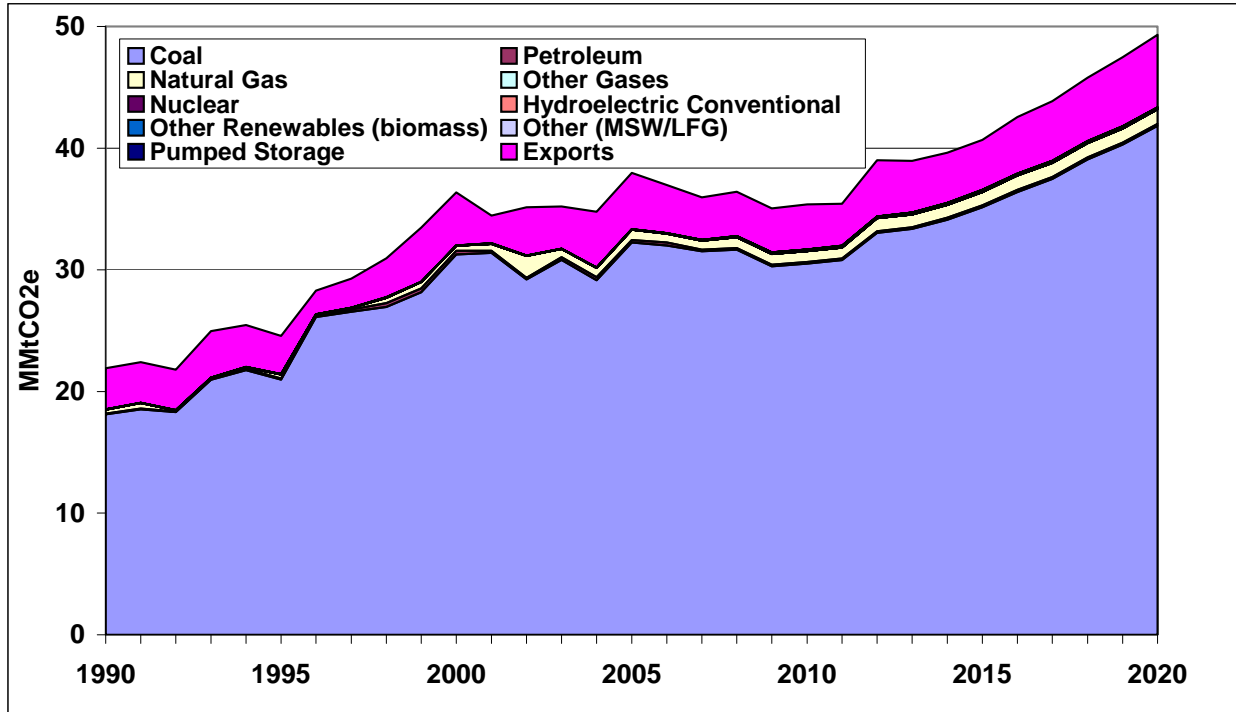


Figure A4. Total Carbon Dioxide-Equivalent Emissions in South Carolina



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

Overview

Activities in the RCI¹³ sectors produce carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) emissions when fuels are combusted to provide space heating, water heating, process heating, cooking, and other energy end-uses. Carbon dioxide accounts for over 99% of these emissions on a million metric tons (MMt) of CO₂ equivalent (CO₂e) basis in South Carolina. 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.¹⁴ Direct use of oil, natural gas, coal, and wood in the RCI sectors accounted for an estimated 17.5 MMtCO₂e of gross greenhouse gas (GHG) emissions in 2005.¹⁵

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.¹⁶ The default data used in SGIT for South Carolina 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 Carolina were revised using: (1) 2002 SED information for all fuel types;¹⁷ (2) 2003 SED information for coal, and for wood and wood waste;¹⁸ (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 Electricity Profiles*;¹⁹ and (6) 2005 natural gas consumption data from the EIA's *Natural Gas Navigator*.²⁰

¹³ The industrial sector includes emissions associated with agricultural energy use and fuel used by natural gas transmission and distribution (T&D) industry.

¹⁴ Emissions associated with the electricity supply sector (presented in Appendix A) have been allocated to each of the RCI sectors for comparison of those emissions to the fuel-consumption-based emissions presented in Appendix B. Note that this comparison is provided for information purposes and that emissions estimated for the electricity supply sector are not double-counted in the total emissions for the state. One could similarly allocate GHG emissions from natural gas T&D, other fuels production, and transport-related GHG sources to the RCI sectors based on their direct use of gas and other fuels, but we have not done so here due to the difficulty of ascribing these emissions to particular end-users. Estimates of emissions associated with the transportation sector are provided in Appendix C, and estimates of emissions associated with natural gas T&D are provided in Appendix E.

¹⁵ Emissions estimates from wood combustion include only N₂O and CH₄. Carbon dioxide emissions from biomass combustion are assumed to be "net zero", consistent with US EPA and Intergovernmental Panel on Climate Change (IPCC) methodologies, and any net loss of carbon stocks due to biomass fuel use should be accounted for in the land use and forestry analysis.

¹⁶ 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.

¹⁷ 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_CAROLINA).

¹⁸ 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).

¹⁹ EIA *Electric Power Annual 2005 - State Data Tables*, (http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html).

²⁰ EIA *Natural Gas Navigator* (http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_SSC_a.htm).

Note that the EIIP methods for the industrial sector exclude from CO₂ emission estimates the amount of carbon that is stored in products produced from fossil fuels for non-energy uses. For example, the methods account for carbon stored in petrochemical feedstocks, and in liquefied petroleum gases (LPG) and natural gas used as feedstocks by chemical manufacturing plants (i.e., not used as fuel), as well as carbon stored in asphalt and road oil produced from petroleum. The carbon storage assumptions for these products are explained in detail in the EIIP guidance document.²¹ The fossil fuel types 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,²² 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),²³ with adjustments for South Carolina's projected population²⁴ and employment growth. South Carolina employment data for the manufacturing (goods-producing) and non-manufacturing (commercial or services-providing) sectors were obtained from the South Carolina Employment Security Commission.²⁵ Regional employment data for the same sectors were obtained from EIA for the EIA's South Atlantic region.²⁶

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 average about 1% annually between 2004 and 2020; this demographic trend is reflected in the growth rates for residential fuel consumption. Based on the South Carolina Employment Security Commission (2000 to 2010), commercial and industrial employment are projected to increase at compound annual rates averaging about 1.7% and 0.2%, respectively, and these growth rates are reflected in the growth rates in energy use shown in Table B2 for the two sectors. The 2000-to-2010 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

²¹ EIIP, Volume VIII: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004.

²² A mixture of hydrocarbons, mostly pentanes and heavier fractions, extracted from natural gas.

²³ EIA AEO2006 with Projections to 2030, (<http://www.eia.doe.gov/oiaf/aeo/index.html>).

²⁴ South Carolina Budget and Control Board, Office of Research and Statistics, South Carolina Population Reports, *South Carolina State and County Population 1900-2000* (<http://www.ors2.state.sc.us/population/pop1900.asp>) and *South Carolina Population Projections 2005-2030* (<http://www.ors2.state.sc.us/population/proj2030.asp>).

²⁵ South Carolina Employment Security Commission, Labor Market Information Online, Economic Data, South Carolina Data, Current Employment Statistics, Projections, Industry Projections (<http://www.sces.org/lmi/data/project/projections.asp>).

²⁶ AEO2006 employment projections for EIA's South Atlantic region obtained through special request from EIA (dated September 27, 2006).

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	1990-2005*	2005-2010**	2010-2020**
Residential	3.1%	2.7%	2.3%
Commercial	3.2%	2.9%	1.7%
Industrial	1.8%	1.1%	1.2%
Total	2.6%	2.1%	1.7%

* 1990-2005 compound annual growth rates calculated from South Carolina electricity sales by year from EIA state electricity profiles (Table 8), http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html.

** 2005-2020 compound annual growth rates based on sector-level forecast prepared by the South Carolina Energy Office.

Results

Figures B1, B2, and B3 show historical and projected emissions for the RCI sectors in South Carolina 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 23% in 1990, increased to 28% in 2005, and is projected to increase further to 31% in 2020. The commercial sector's share of total RCI emissions from direct fuel use and electricity use was 16% in 1990, increased to 19% in 2005, and is projected to increase to 21% by 2020. The industrial sector's share of total RCI emissions from direct fuel use and electricity use was 62% in 1990, decreased to 53% in 2005, and is projected to decrease further to 49% in 2020. Emissions associated with the generation of electricity to meet RCI demand accounts for about 80% of the emissions for the residential sector, 80% of the emissions for the commercial sector, and 46% of the emissions for the industrial sector, on average, over the 1990 to 2020 time period. From 1990 to 2020, natural gas consumption is the next highest source of emissions for the residential and commercial sectors, accounting, on average, for about 12% and 13% of total emissions, respectively. For the industrial sector, emissions associated with the combustion of coal, natural gas, and petroleum account for about 20%, 17%, and 16% respectively, on average, from 1990 to 2020.

Residential Sector

Figure B1 presents the emission inventory and reference case projections for the residential sector. Figure B1 was developed from the emissions data in Table B3a. Table B3b shows the relative contributions of emissions associated with each fuel type to total residential sector emissions.

For the residential sector, emissions from electricity and direct fossil fuel use in 1990 were about 8.24 MMtCO₂e, and are estimated to increase to about 19.2 MMtCO₂e by 2020. Emissions associated with the generation of electricity to meet residential energy consumption demand accounted for about 74% of total residential emissions in 1990, and are estimated to increase to 86% of total residential emissions by 2020. In 1990, natural gas consumption accounted for about 12% of total residential emissions, and is estimated to account for about 10% of total residential emissions by 2020. Residential-sector emissions associated with the use of coal,

petroleum, and wood in 1990 were about 1.2 MMtCO₂e combined, and accounted for about 14% of total residential emissions. By 2020, emissions associated with the consumption of these three fuels are estimated to fall to 0.74 MMtCO₂e, accounting for 3.8% of total residential sector emissions by that year.

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

	1990-2004 ^a	2005-2010 ^b	2010-2015 ^b	2015-2020 ^b
Residential				
natural gas	2.8%	1.8%	1.6%	1.3%
petroleum	-1.9%	-1.4%	-0.5%	-1.0%
wood	-1.1%	-0.4%	-0.7%	-0.2%
coal ^c	9.4%	-0.4%	-1.3%	-1.3%
Commercial				
natural gas	2.2%	1.0%	2.7%	1.7%
petroleum	-0.6%	-1.2%	0.9%	0.3%
wood	1.0%	-0.6%	0.0%	-0.4%
coal ^d	19.5%	-0.7%	0.0%	-0.4%
Industrial				
natural gas ^e	-1.3%	2.1%	0.9%	0.5%
petroleum	2.2%	-0.6%	0.2%	0.5%
wood	-0.4%	1.7%	1.1%	0.9%
coal ^f	-0.8%	2.6%	0.3%	0.1%

^a Compound annual growth rates calculated from EIA SED historical consumption by sector and fuel type for South Carolina. 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.

^b Figures for growth periods starting after 2004 are calculated from AEO2006 projections for EIA's South Atlantic region, adjusted for South Carolina's projected population for the residential sector, projections for non-manufacturing employment for the commercial sector, and projections for manufacturing employment for the industrial sector.

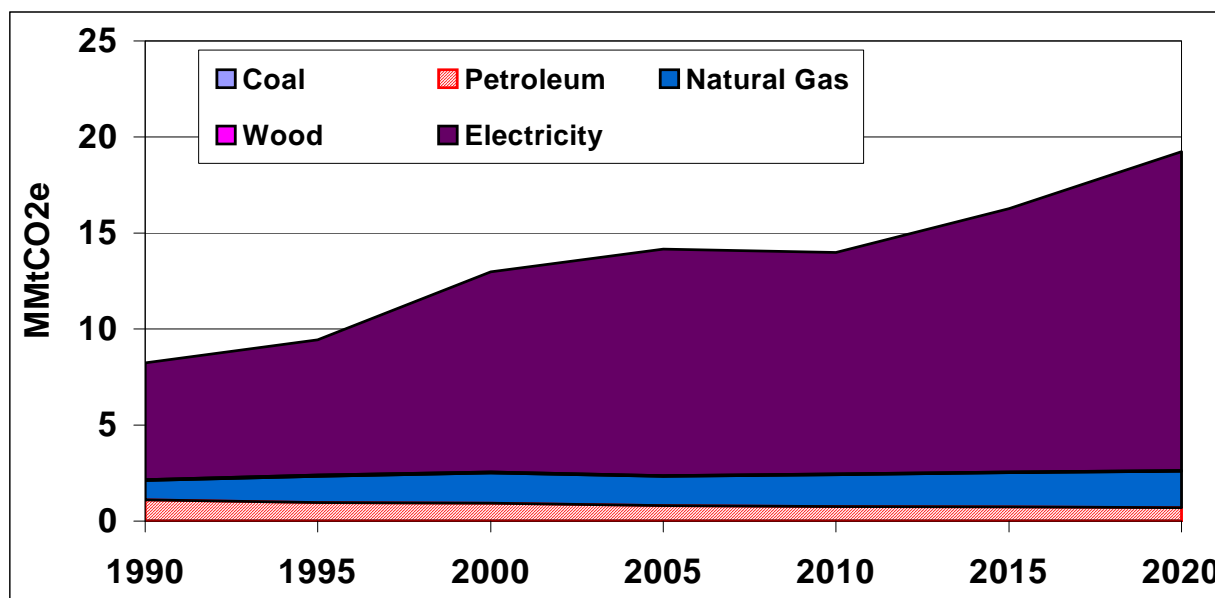
^c Residential coal consumption varied significantly from 1990 through 2003. The average annual growth rate for residential coal consumption is based on EIA SED for 1990 through 1998. Coal consumption was reported as 749 billion BTUs in 1999; zero for 2000, 2001, and 2003; and 0.07 billion BTUs in 2002. Data for 1999 through 2003 were not included in the calculation of the growth rate because of the large differences in 1999 consumption relative to years before and after 1999, and because coal consumption was zero for three of the four years following 1999. From 1990 through 1998, coal consumption ranged from a low of 2.4 billion BTUs in 1997 to a high of 488 billion BTUs in 1993.

^d Commercial coal consumption varied significantly from 1990 through 2003. The average annual growth rate for commercial coal consumption is based on EIA SED for 1990 through 1998. Coal consumption was reported as 5,495 billion BTUs in 1999; zero for 2000, 2001, and 2003; and 0.51 billion BTUs in 2002. Data for 1999 through 2003 were not included in the calculation of the growth rate because of the large differences in 1999 consumption relative to years before and after 1999, and because coal consumption was zero for three of the four years following 1999. From 1990 through 1998, coal consumption ranged from a low of 19.6 billion BTUs in 1997 to a high of 2,224 billion BTUs in 1993.

^e The declining average annual growth rate reflects the historical trend in industrial natural gas consumption from 1990 through 2005. Natural gas consumption increased from 89,283 billion BTUs in 1990 to a high of 106,140 billion BTUs in 1997, and then declined to 73,486 billion BTUs in 2005.

^f Industrial coal consumption varied from 1990 through 2003 but not as significantly as for the residential and commercial sectors. The average annual growth rate for industrial coal consumption is based on EIA SED from 1990 through 2003. Industrial coal consumption ranged from a low of 46,580 billion BTUs in 1999 to a high of 60,292 billion BTUs in 1993.

Figure B1. Residential Sector GHG Emissions from Fuel Consumption



Source: CCS calculations based on approach described in text.

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

For the residential sector, emissions from electricity and direct fossil fuel use in 1990 were about 8.24 MMtCO₂e, and are estimated to increase to about 19.2 MMtCO₂e by 2020. Emissions associated with the generation of electricity to meet residential energy consumption demand accounted for about 74% of total residential emissions in 1990, and are estimated to increase to 86% of total residential emissions by 2020. In 1990, natural gas consumption accounted for about 12% of total residential emissions, and is estimated to account for about 10% of total residential emissions by 2020. Residential-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 1.2 MMtCO₂e combined, and accounted for about 14% of total residential emissions. By 2020, emissions associated with the consumption of these three fuels are estimated to fall to 0.74 MMtCO₂e, accounting for 3.8% of total residential sector emissions by that year.

For the 15-year period 2005 to 2020, residential-sector GHG emissions associated with the use of electricity and natural gas are expected to increase at average annual rates of about 2.3%, 1.5%, and 0.2% respectively. Emissions associated with the use of wood and petroleum are expected to decline annually by about -1% and -0.5%, respectively. Total GHG emissions for this sector increase by an average of about 2.1% annually over the 15-year period.

Table B3a. Residential Sector Emissions Inventory and Reference Case Projections (MMtCO₂e)

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	0.00	0.01	0.00	0.000	0.00	0.00	0.00
Petroleum	1.12	0.97	0.93	0.82	0.77	0.75	0.70
Natural Gas	1.00	1.37	1.58	1.51	1.65	1.79	1.90
Wood	0.04	0.06	0.05	0.04	0.04	0.04	0.04
Electricity Consumption	6.08	7.04	10.41	11.80	11.53	13.70	16.59
Total	8.24	9.44	12.98	14.17	13.99	16.27	19.24

Source: CCS calculations based on approach described in text.

Table B3b. Residential Sector Proportions of Total Emissions by Fuel Type (%)

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Petroleum	13.6	10.2	7.2	5.8	5.5	4.6	3.7
Natural Gas	12.1	14.5	12.2	10.7	11.8	11.0	9.9
Wood	0.5	0.7	0.4	0.3	0.3	0.2	0.2
Electricity Consumption	73.7	74.5	80.2	83.3	82.4	84.2	86.3

Source: CCS calculations based on approach described in text.

Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B3a.

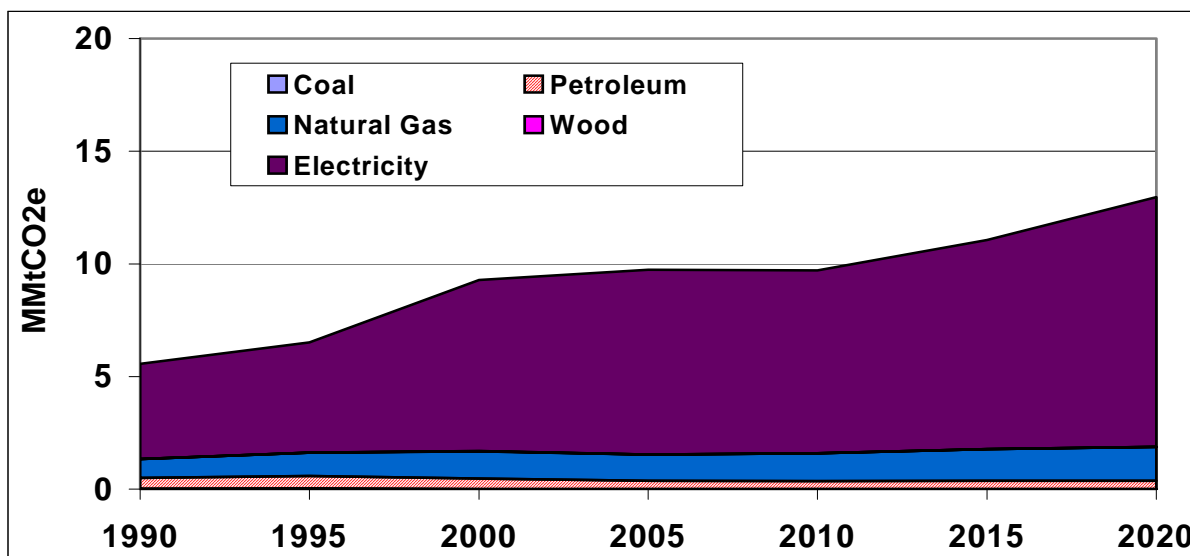
Commercial Sector

Figure B2 presents the emission inventory and reference case projections for the commercial sector. Figure B2 was developed from the emissions data in Table B4a. Table B4b shows the relative contributions of emissions associated with each fuel type to total commercial sector emissions.

For the commercial sector, emissions from electricity and direct fossil fuel use in 1990 were about 5.6 MMtCO₂e, and are estimated to increase to about 13 MMtCO₂e by 2020. Emissions associated with the generation of electricity to meet commercial energy consumption demand accounted for about 76% of total commercial emissions in 1990, and are estimated to increase to 86% of total commercial emissions by 2020. In 1990, natural gas consumption accounted for about 15% of total commercial emissions and is estimated to account for about 12% of total commercial emissions by 2020. Commercial-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 0.5 MMtCO₂e combined, and accounted for about 9% of total commercial emissions. By 2020, emissions associated with the consumption of these three fuels are estimated to be 0.4 MMtCO₂e and to account for 2.8% 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%, 1.7%, and 0.01% respectively. Emissions associated with the use of wood expected to decline by about -0.4%, and coal use is expected to be negligible. Total GHG emissions for this sector increase by an average of about 1.9% annually over the 15-year period.

Figure B2. Commercial Sector GHG Emissions from Fuel Consumption



Source: CCS calculations based on approach described in text.

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

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

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	0.01	0.04	0.00	0.00	0.00	0.00	0.00
Petroleum	0.48	0.55	0.47	0.36	0.35	0.36	0.36
Natural Gas	0.84	1.03	1.20	1.17	1.25	1.41	1.51
Wood	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Electricity Consumption	4.23	4.89	7.59	8.21	8.12	9.29	11.09
Total	5.56	6.51	9.28	9.74	9.71	11.06	12.96

Source: CCS calculations based on approach described in text.

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

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	0.2	0.5	0.0	0.0	0.0	0.0	0.0
Petroleum	8.7	8.5	5.1	3.7	3.6	3.3	2.8
Natural Gas	15.1	15.7	13.0	12.0	12.8	12.7	11.6
Wood	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Electricity Consumption	76.0	75.1	81.8	84.2	83.5	84.0	85.5

Source: CCS calculations based on approach described in text.

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

Industrial Sector

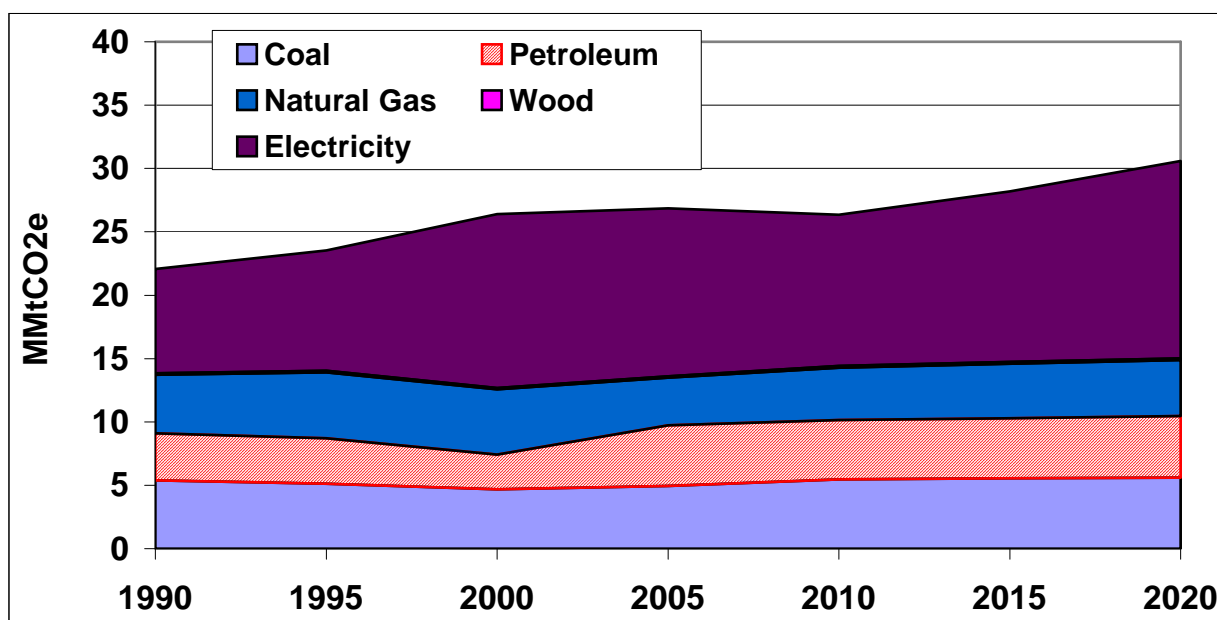
Figure B3 presents the emission inventory and reference case projections for the industrial sector. Figure B3 was developed from the emissions data in Table B5a. Table B5b shows the

relative contributions of emissions associated with each fuel type to total industrial sector emissions.

For the industrial sector, emissions from electricity and direct fuel use in 1990 were about 22 MMtCO₂e and are estimated to increase to about 30.6 MMtCO₂e by 2020. Emissions associated with the generation of electricity to meet industrial energy consumption demand accounted for about 37% of total industrial emissions in 1990, and are estimated decline slightly to about 51% of total industrial emissions by 2020. In 1990, natural gas consumption accounted for about 21% of total industrial emissions, and is estimated to account for about 15% of total industrial emissions by 2020. Industrial-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 9.2 MMtCO₂e combined, and accounted for about 42% of total industrial emissions. For 2020, emissions associated with the consumption of these three fuels are estimated to be 10.6 MMtCO₂e, and to account for 35% 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 1.1%, 1.1%, and 0.1% respectively. Emissions associated with the use of wood and coal are expected to increase annually by about 1.2% and 0.8%, respectively. Total GHG emissions for the industrial sector increase by an average of about 0.9% annually over the 15-year period.

Figure B3. Industrial Sector GHG Emissions from Fuel Consumption



Source: CCS calculations based on approach described in text.

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

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

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	5.39	5.12	4.67	4.94	5.48	5.55	5.60
Petroleum	3.72	3.58	2.76	4.79	4.68	4.74	4.87
Natural Gas	4.61	5.21	5.13	3.77	4.13	4.31	4.42
Wood	0.11	0.14	0.12	0.11	0.12	0.13	0.13
Electricity Consumption	8.22	9.48	13.72	13.25	11.95	13.47	15.57
Total	22.06	23.53	26.40	26.86	26.36	28.19	30.59

Source: CCS calculations based on approach described in text.

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

/Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	24.4	21.8	17.7	18.4	20.8	19.7	18.3
Petroleum	16.9	15.2	10.5	17.9	17.8	16.8	15.9
Natural Gas	20.9	22.1	19.4	14.0	15.7	15.3	14.5
Wood	0.5	0.6	0.4	0.4	0.5	0.4	0.4
Electricity Consumption	37.3	40.3	52.0	49.3	45.3	47.8	50.9

Source: CCS calculations based on approach described in text.

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

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 South Atlantic modeling region scaled for South Carolina 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 Carolina 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.

Appendix C. Transportation Energy Use

Overview

Transportation is one of the largest greenhouse gas (GHG) source sectors in South Carolina. The transportation sector includes light- and heavy-duty (onroad) vehicles, aircraft, rail engines, and marine engines. Carbon dioxide (CO₂) accounts for about 96 percent of transportation GHG emissions from fuel use. Most of the remaining GHG emissions from the transportation sector are due to nitrous oxide (N₂O) 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) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.^{27,28} For on-road vehicles, the CO₂ emission factors are in units of pounds (lb) per million British thermal unit (MMBtu) and the methane (CH₄) and N₂O emission factors are both in units of grams per vehicle mile traveled (VMT). Key assumptions in this analysis are listed in Table C1. The default fuel consumption 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's (EIA) *State Energy Data* (SED) added.²⁹ The default VMT data for 1993, 1994, and 1997-2002 in SGIT were replaced with annual VMT from the South Carolina Department of Transportation (SCDOT).³⁰ Default data from the Federal Highway Administration (FHWA) were used for the remaining years. The SCDOT VMT was broken-down by road types. This data was then allocated to vehicle types using vehicle mix by road type from the FHWA.³¹

Onroad Vehicles

Onroad vehicle gasoline and diesel emissions were projected based on VMT forecasts from SCDOT⁴ and growth rates developed from national vehicle type VMT forecasts reported in EIA's *Annual Energy Outlook 2006* (AEO2006). The AEO2006 data were incorporated because they indicate significantly different VMT growth rates for certain vehicle types (e.g., 34 percent growth between 2002 and 2020 in heavy-duty gasoline vehicle VMT versus 284 percent growth in light-duty diesel truck VMT over this period). The procedure first applied the AEO2006 vehicle type-based national growth rates to 2002 South Carolina estimates of 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 SCDOT estimates for total VMT in

²⁷ CO₂ 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.

²⁸ CH₄ and N₂O 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.

²⁹ Energy Information Administration, State Energy Consumption, Price, and Expenditure Estimates (SED), http://www.eia.doe.gov/emeu/states/_seds.html

³⁰ SCDOT VMT forecast data provided by Carla Bedenbaugh, South Carolina Department of Health and Environmental Control.

³¹ Highway Statistics, Federal Highway Administration, <http://www.fhwa.dot.gov/policy/ohpi/hss/index.htm>.

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.

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

Vehicle Type and Pollutants	Methods
<p>Onroad gasoline, diesel, natural gas, and liquefied petroleum gas (LPG) vehicles – CO₂</p>	<p>Inventory (1990 – 2002) US EPA SGIT and fuel consumption from EIA SED</p> <p>Reference Case Projections (2003 – 2020) Gasoline and diesel fuel projected using VMT projections provided by SCDOT adjusted by fuel efficiency improvement projections from AEO2006. Other onroad fuels projected using South Atlantic Region fuel consumption projections from EIA AEO2006 adjusted using state-to-regional ratio of population growth.</p>
<p>Onroad gasoline and diesel vehicles – CH₄ and N₂O</p>	<p>Inventory (1990 – 2002) US EPA SGIT, onroad vehicle CH₄ and N₂O emission factors by vehicle type and technology type within SGIT were updated to the latest factors used in the US EPA’s <i>Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2003</i>.</p> <p>State total VMT replaced with VMT provided by SCDOT, VMT allocated to vehicle types using default data in SGIT.</p> <p>Reference Case Projections (2003 – 2020) VMT projections from SCDOT allocated to vehicle types using vehicle specific growth rates from AEO2006.</p>
<p>Non-highway fuel consumption (jet aircraft, gasoline-fueled piston aircraft, boats, locomotives) – CO₂, CH₄ and N₂O</p>	<p>Inventory (1990 – 2002) US EPA SGIT and fuel consumption from EIA SED. Commercial marine based on allocation of national fuel consumption, offshore emissions pulled from Commission for Environmental Cooperation in North America (CEC) inventory.</p> <p>Reference Case Projections (2003 – 2020) Aircraft projected using aircraft operations projections from Federal Aviation Administration (FAA). No growth assumed for rail diesel. Marine gasoline projected based on historical data.</p>

Table C2. South Carolina Vehicle Miles Traveled Estimates (millions)

Vehicle Type	2002	2005	2010	2015	2020
Heavy Duty Diesel Vehicle	3,978	4,566	5,306	6,181	7,087
Heavy Duty Gasoline Vehicle	517	571	616	699	784
Light Duty Diesel Truck	465	557	766	1,072	1,494
Light Duty Diesel Vehicle	140	168	231	324	452
Light Duty Gasoline Truck	15,446	16,382	17,747	19,539	21,174
Light Duty Gasoline Vehicle	26,360	27,959	30,287	33,346	36,136
Motorcycle	169	179	194	213	231
Total	47,074	50,381	55,147	61,373	67,359

Table C3. South Carolina Vehicle Miles Traveled Compound Annual Growth Rates

Vehicle Type	2002-2005	2005-2010	2010-2015	2015-2020
Heavy Duty Diesel Vehicle	4.70%	3.05%	3.10%	2.77%
Heavy Duty Gasoline Vehicle	3.40%	1.53%	2.55%	2.34%
Light Duty Diesel Truck	6.20%	6.59%	6.96%	6.87%
Light Duty Diesel Vehicle	6.20%	6.59%	6.96%	6.87%
Light Duty Gasoline Truck	1.98%	1.61%	1.94%	1.62%
Light Duty Gasoline Vehicle	1.98%	1.61%	1.94%	1.62%
Motorcycle	1.98%	1.61%	1.94%	1.62%

For forecasting GHG emissions, growth in fuel consumption is also needed along with VMT. Onroad gasoline and diesel fuel consumption were forecasted by developing a set of growth factors that adjusted the VMT projections to account for improvements in fuel efficiency. Fuel efficiency projections were taken from AEO2006. These projections suggest average onroad fuel consumption growth rates of 1% per year for gasoline and 3.3% per year for diesel between 2002 and 2020.

Gasoline consumption estimates for 1990-2002 were adjusted by subtracting ethanol consumption. While the historical ethanol consumption suggests continued growth, projections for ethanol consumption in South Carolina were not available. Therefore, ethanol consumption was assumed to remain at the 2002 level in the reference case projections. Current biodiesel consumption is less than 1% of total diesel consumption in the State and estimates of future consumption of biodiesel were not available. Therefore, biodiesel consumption was not considered in this inventory.

Aviation

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 to 2020 using general aviation and commercial aircraft operations for 2002 and 2020 from the Federal Aviation Administration's Terminal Area Forecast System³² and national aircraft fuel efficiency forecasts. To estimate changes in jet fuel consumption, itinerant aircraft operations from air carrier, air taxi/commuter, and military aircraft were first summed for each year of interest. The post-2002 estimates were

³² Terminal Area Forecast, Federal Aviation Administration, <http://www.apo.data.faa.gov/main/taf.asp>.

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 Carolina, which was obtained from the Federal Aviation Administration (FAA) source noted above. The resulting compound annual average growth rates are displayed in Table C4. The negative growth for aviation gasoline for the 2002-2005 period is supported by prime supplier sales volumes from EIA, which shows sales of 6.1 thousand gallons per day in 2002 and 3 thousand gallons per day in 2005.³³

Table C4. South Carolina Aviation Fuels Compound Annual Growth Rates

Fuel	2002-2005	2005-2010	2010-2015	2015-2020
Aviation Gasoline	-2.80%	0.78%	0.75%	0.52%
Jet Fuel	4.12%	0.97%	0.67%	0.61%

Rail and Marine Vehicles

For the rail and recreational marine sectors, 1990 – 2004 estimates are based on SGIT methods and fuel consumption from EIA. The default annual consumption data for marine gasoline was much higher for 1990-1992 than for the years 1993-2004. Since the consumption data for these two time periods are not comparable, possibly due to a difference in estimation methods, marine gasoline consumption for 1990-1992 was estimated by projecting the 1993-2004 data back to 1990. Marine gasoline consumption was projected to 2020 using historical data, which shows an average annual growth rate of 3.2%. The historic data for rail shows no significant positive or negative trend; therefore, no growth was assumed for this sector.

For the commercial marine sector (marine diesel and residual fuel), 1990-2004 emission estimates are based on SGIT emission rates applied to estimates of South Carolina marine vessel diesel and residual fuel consumption. Because the SGIT default relies on marine vessel fuel consumption estimates that represent the State in which fuel is sold rather than consumed, an alternative method was used to estimate South Carolina marine vessel fuel consumption. South Carolina fuel consumption estimates were developed by allocating 1990-2004 national diesel and residual oil vessel bunkering fuel consumption estimates obtained from EIA.³⁴ Marine vessel fuel consumption was allocated to South Carolina using the marine vessel activity allocation methods/data compiled to support the development of EPA’s National Emissions Inventory (NEI).³⁵ In keeping with the NEI, 75 percent of each year’s distillate fuel and 25 percent of each year’s residual fuel were assumed to be consumed within the port area (remaining consumption was assumed to occur while ships are underway). National port area fuel consumption was allocated to South Carolina based on year-specific freight tonnage data for the top 150 ports in

³³ US Department of Energy, Energy Information Administration, “Petroleum Navigator”, <http://tonto.eia.doe.gov/dnav/pet/hist/c400013451a.htm>.

³⁴ US Department of Energy, Energy Information Administration, “Petroleum Navigator” (diesel data obtained from <http://tonto.eia.doe.gov/dnav/pet/hist/kd0vabnus1a.htm>; residual data obtained from <http://tonto.eia.doe.gov/dnav/pet/hist/kprvatnus1a.htm>).

³⁵ See methods described in ftp://ftp.epa.gov/EmisInventory/2002finalnei/documentation/mobile/2002nei_mobile_nonroad_methods.pdf

the nation as reported in “Waterborne Commerce of the United States, Part 5 – Waterways and Harbors National Summaries.”³⁶ Offshore CO₂ and hydrocarbon (HC) emissions for South Carolina’s exclusive economic zone (EEZ) was taken from a study by Corbett for the Commission for Environmental Cooperation in North America (CEC).³⁷ Offshore CH₄ emissions were estimated by speciating the HC emissions using the California Air Resources Board’s total organic gas (TOG) profile (#818).³⁸ Offshore N₂O emissions were estimated by applying the ratio of N₂O to CH₄ emission factors to the CH₄ emission estimate. The 2002 offshore emissions from the CEC inventory were scaled to other historic years based on the estimated port fuel consumption. Port and offshore commercial marine emissions were projected based on the 1990-2004 growth rates.

Nonroad Engines

It should be noted that fuel consumption data from EIA includes nonroad gasoline and diesel fuel consumption in the commercial and industrial sectors. Emissions from these nonroad engines are included in the inventory and forecast for the residential, commercial, and industrial (RCI) sectors. Table C5 shows how EIA divides gasoline and diesel fuel consumption between the transportation, commercial, and industrial sectors.

Table C5. EIA Classification of Gasoline and Diesel Consumption

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

Results

As shown in Figure C1, onroad gasoline consumption accounts for the largest share of transportation GHG emissions. Emissions from onroad gasoline vehicles increased by about 25% from 1990-2002 to cover 70% of total transportation emissions in 2002. GHG emissions from onroad diesel fuel consumption increased by 52% from 1990 to 2002, and by 2002 accounted for 21% of GHG emissions from the transportation sector. Emissions from boats and ships grew by 104% from 1990-2002 to cover 6% of transportation emissions in 2002. Emissions from all other categories combined (aviation, locomotives, natural gas and liquefied petroleum gas (LPG), and oxidation of lubricants) contributed less than 4% of total transportation emissions in 2002.

GHG emissions from onroad gasoline consumption are projected to increase by about 19%, and emissions from onroad diesel consumption are expected to increase by 79% between 2002 and

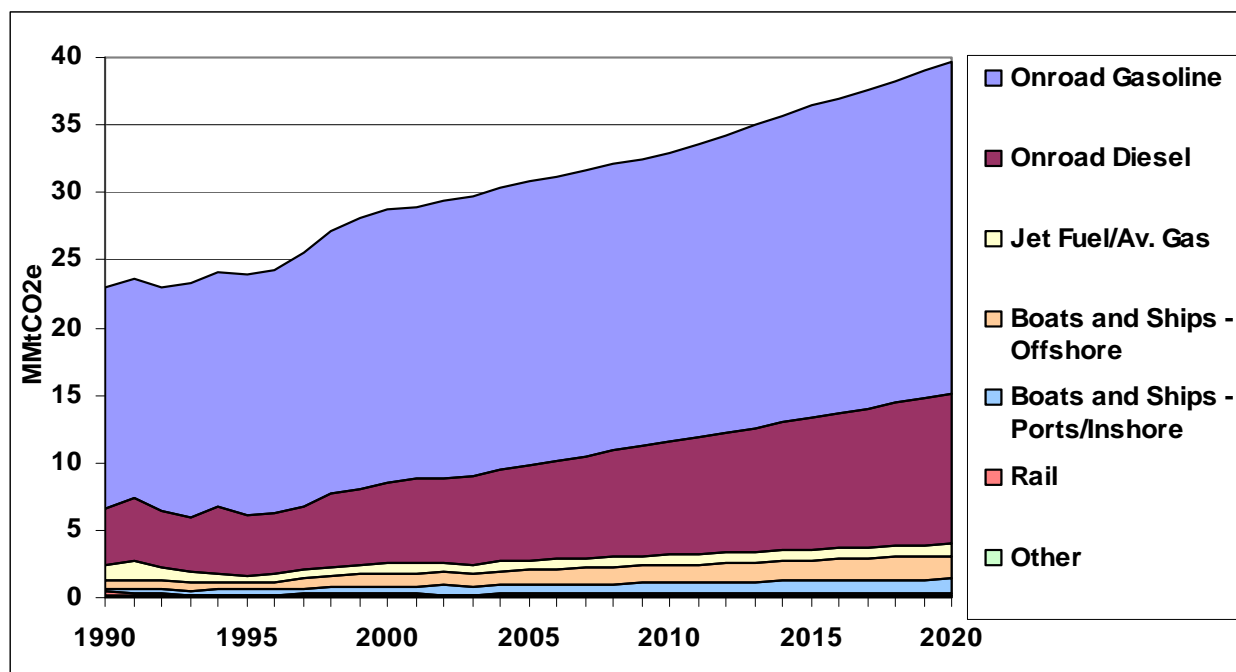
³⁶ Note that it was necessary to estimate 1991-1995 values by interpolating between the available 1990 and 1996 estimates.

³⁷ Estimate, Validation, and Forecasts of Regional Commercial Marine Vessel Inventories, submitted by J. Corbett, prepared for the California Air Resources Board, California Environmental Protection Agency, and Commission for Environmental Cooperation in North America, <http://coast.cms.udel.edu/NorthAmericanSTEEM/>.

³⁸ California Air Resources Board, Speciation Profiles, <http://www.arb.ca.gov/ei/speciate/speciate.htm>.

2020. Marine fuel (gasoline, diesel, and residual) consumption is projected to increase by 65% 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 2005 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.

Uncertainties in Marine Fuel Consumption

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

- 75% of marine diesel and 25% of residual fuel is consumed in port; and
- The proportion of freight tonnage at the Ports of Charleston and Georgetown to the total freight tonnage for the top 150 US ports reflects the proportion of national marine fuel that is consumed in South Carolina.

Appendix D. Industrial Processes

Overview

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

- Carbon Dioxide (CO₂) from:
 - Production of cement;
 - Consumption of limestone, dolomite, and soda ash;
- Perfluorocarbons (PFCs) (i.e., tetrafluoromethane (CF₄), and hexafluoroethane (C₂F₆)) from aluminum production;
- Sulfur hexafluoride (SF₆) from transformers used in electric power transmission and distribution (T&D) systems; and
- Hydrofluorocarbons (HFCs) and 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 Carolina include the following:

- Nitrous oxide (N₂O) from nitric and adipic acid production;
- HFCs, PFCs, and SF₆ from semiconductor manufacture;
- SF₆ from magnesium production and processing;
- CO₂ from lime and soda ash production; and
- HFCs from HCFC-22 production.

Emissions and Reference Case Projections

Greenhouse gas 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.³⁹ 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 Carolina Department of Health and Environmental Control (SCDHEC) provided data for annual clinker production, masonry cement production, and aluminum production for 1990 through 2005. Table D1 provides additional details on how the data provided were used to calculate historical emissions for these three categories.

³⁹ 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 and Masonry Cement Production	1990 - 2005	Metric tons (Mt) of clinker produced and masonry cement produced each year.	South Carolina Department of Health and Environmental Control (SCDHEC).
Aluminum Production	1990 - 2005	Mt of aluminum produced each year.	SCDHEC
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 EIIIP guidance (see footnote 1 for reference to EIIIP 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 Carolina.
Soda Ash Consumption	1990 - 2002	Mt of soda ash consumed for use in consumer products such as glass, soap and detergents, paper, textiles, and food. Emissions based on state's population and estimates of emissions per capita from the US EPA national GHG inventory.	<i>USGS Minerals Yearbook, 2004: Volume I, Metals and Minerals</i> , (http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/).
ODS Substitutes	1990 - 2002	Based on state's population and estimates of emissions per capita from the US EPA national GHG inventory.	-- South Carolina Budget and Control Board, Office of Research and Statistics, South Carolina Population Reports, "South Carolina State and County Population 1900-2000" (http://www.ors2.state.sc.us/population/pop1900.asp) and "South Carolina Population Projections 2005-2030" (http://www.ors2.state.sc.us/population/proj2030.asp). -- 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 and Masonry Cement Production	2006 - 2020	Compound annual employment growth rate for South Carolina's goods-producing sector for 2000-2010. The goods-producing sector includes employment in the natural resources and mining, construction, and manufacturing sectors. Assumed growth is same for 2010 – 2020.	South Carolina Employment Security Commission, "Industry Employment In South Carolina 2000 – 2010" (http://www.sces.org/1mi/data/project/projind.htm)	Actual data used for 2000 and 2005	0.2	0.2	0.2
Aluminum Production	2006 - 2020	Ditto	Ditto	Ditto	0.2	0.2	0.2
Limestone and Dolomite Consumption	2003 - 2020	Ditto	Ditto	0.2	0.2	0.2	0.2
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.	<i>Minerals Yearbook, 2005: Volume I, Soda Ash</i> , (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/zone/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. Table D3 shows the historic and projected emission values upon which Figures D1 and D2 are based. Total gross South Carolina GHG emissions were about 2.6 MMTCO₂e in 1990, 4.3 MMTCO₂e in 2005, and are projected to increase to about 6.6 MMTCO₂e in 2020. Emissions from the overall industrial processes category are expected to grow by about 2.9%

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.

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

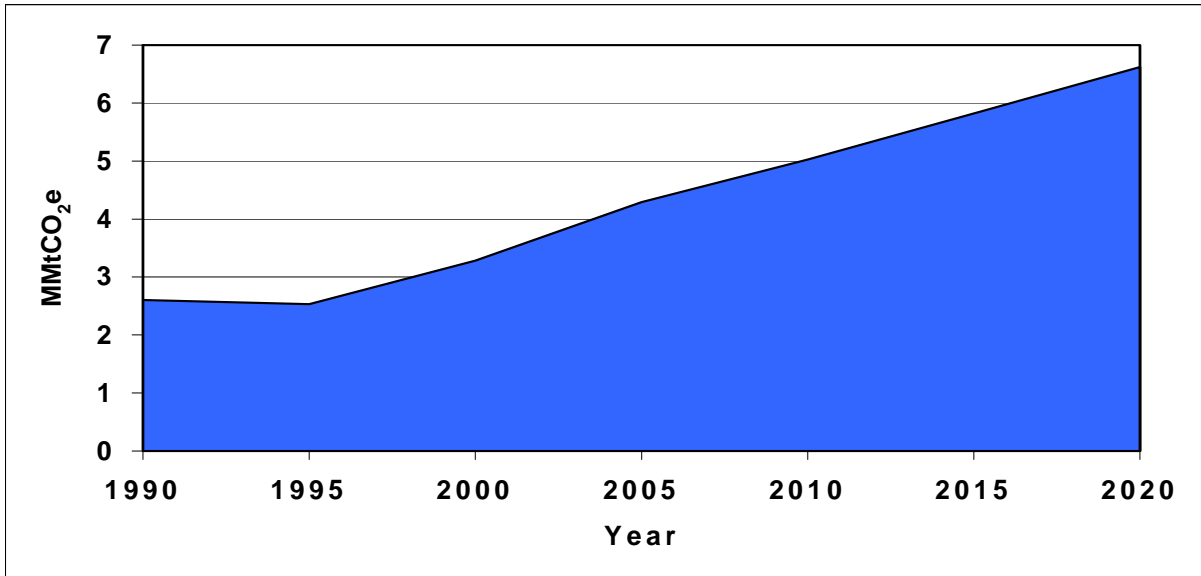
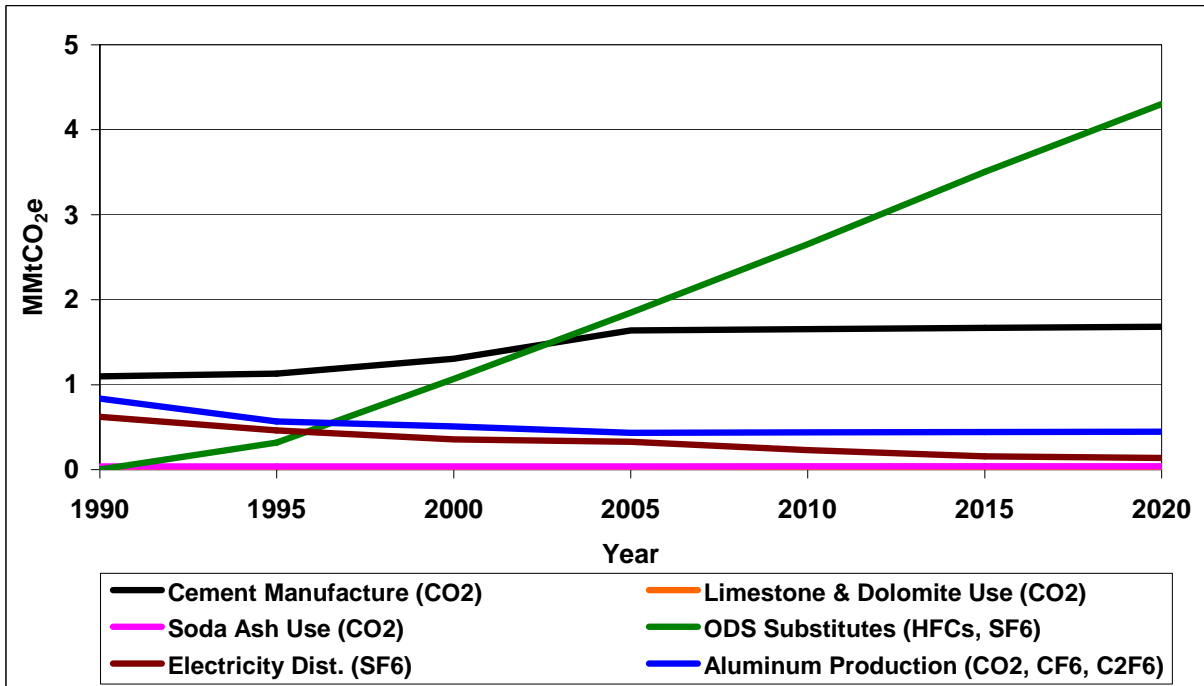


Figure D2. GHG Emissions from Industrial Processes, 1990-2020, by Source



**Table D3. Historic and Projected Emissions for the Industrial Processes Sector
 (MMtCO₂e)**

Industry	1990	1995	2000	2005	2010	2015	2020
Cement Manufacture (CO ₂)	1.099	1.128	1.306	1.638	1.654	1.669	1.682
Limestone & Dolomite Use (CO ₂)	0.007	0.013	0.009	0.007	0.008	0.008	0.008
Soda Ash Use (CO ₂)	0.038	0.038	0.038	0.039	0.040	0.041	0.041
ODS Substitutes (HFCs, SF ₆)	0.005	0.318	1.067	1.848	2.653	3.505	4.305
Electricity Dist. (SF ₆)	0.622	0.463	0.355	0.329	0.232	0.155	0.138
Aluminum Production (CO ₂ , CF ₄ , C ₂ F ₆)	0.836	0.570	0.510	0.435	0.439	0.443	0.447
Total	2.607	2.529	3.285	4.295	5.024	5.820	6.620

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 CO₂ per unit of emissions) in compliance with the *Montreal Protocol* and the *Clean Air Act Amendments of 1990*.⁴⁰ 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 CO₂e basis. Emissions from the use of ODS substitutes in South Carolina were calculated using the default methods in SGIT (see dark green line in Figure D2). Emissions have increased from 0.005 MMtCO₂e in 1990 to about 1.07 MMtCO₂e in 2000, and are expected to increase at an average rate of 7.2% 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 SF₆ from electrical equipment have experienced declines since the early nineties (see brown line in Figure D2), mostly due to voluntary action by industry. SF₆ is used as an electrical insulator and interrupter in the electricity T&D system. Emissions for South Carolina from 1990 to 2002 were estimated based on the estimates of emissions per kWh of electricity consumed from the US EPA GHG inventory, and South Carolina'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 Carolina. The decline in SF₆ 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, SF₆ emissions from electrical equipment are about 0.62 MMtCO₂e in 1990 and 0.14 MMtCO₂e in 2020.

⁴⁰ As noted in EIIIP 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.

Cement Manufacture

South Carolina has three cement plants (Giant Cement Company, LaFarge Building Materials, and Holcim) that produce clinker and masonry cement. The SCDHEC provided clinker and masonry cement production data for 1990 through 2005 for all three plants. Clinker is an intermediate product from which finished Portland and masonry cement are made. Clinker production releases CO₂ when calcium carbonate (CaCO₃) is heated in a cement kiln to form lime (calcium oxide) and CO₂ (see footnote 1 for reference to EIIP guidance document). Emissions are calculated by multiplying annual clinker production by emission factors for this process.

Masonry cement requires additional lime, over and above the lime used in the clinker. During the production of masonry cement, non-plasticizer additives such as lime, slag, and shale are added to the cement, increasing its weight by 5%. Lime accounts for approximately 60% of the added substances. About 0.0224 metric tons of additional CO₂ is emitted for every metric ton of masonry cement produced, relative to the CO₂ emitted during the production of a metric ton of clinker (see footnote 1 for reference to EIIP guidance document). Emissions are calculated by multiplying annual masonry cement production by emission factors for this process.

The clinker and masonry cement production data were entered into the SGIT to calculate GHG emissions (see black line in Figure D2). The annual employment growth rate (0.2% annual) for South Carolina's goods-producing sector for 2000 through 2010 was used to project emissions from 2006 to 2020. As shown in Figure D2, emissions from this source increase from 1.1 MMtCO₂e in 1990 to about 1.6 MMtCO₂e 2005, and to about 1.7 MMtCO₂e 2020.

Aluminum Production

South Carolina has one primary aluminum production plant (ALUMAX). The SCDHEC provided annual aluminum production data for 1990 through 2005 for the plant. The aluminum production industry is thought to be the largest source of emissions of CF₄ and C₂F₆. Emissions of these two potent GHGs occur during the reduction of alumina in the primary smelting process (see footnote 1 for reference to EIIP guidance document). As with emissions from cement production, the annual employment growth rate (0.2% annual) for South Carolina's goods-producing sector for 2000 through 2010 was used to project emissions from 2006 to 2020. As shown in Figure D2 (see dark blue line), emissions in 1990 were 0.84 MMtCO₂e, and are estimated to have declined by 58%, to 0.435 MMtCO₂e, by 2005. After 2005, emissions from this source are projected to increase slowly to 0.45 MMtCO₂e in 2020, for an overall 1990 to 2020 decline of about 54%.

Production for this one aluminum plant in South Carolina increased by an average annual rate of about 1.3% from 1990 through 2005, and by 1.4% over the last five years of this period (i.e., 2000 through 2005). Emissions, however, declined due to a decline in the value of the emission factors presented in the EIIP guidance document for 1990 through 2002.⁴¹ According to the EIIP guidance, the emission factors are based on data provided by the aluminum smelters participating in the US EPA Climate Protection Partnerships Division's Voluntary Aluminum Industrial Partnership. Voluntary Aluminum Industrial Partnership partners provide data on their emission

⁴¹ The SGIT file used to calculate emissions associated with aluminum production uses the EIIP emission factors for 1990 through 2002, and uses the emission factor for 2002 to estimate emissions for 2003 through 2005.

reduction progress to the US EPA on an annual basis. Using these data, which generally consists of either frequency or duration of anode effects, along with aluminum production estimates, the US EPA has developed estimates of national PFC emissions from aluminum smelting. The method is based on facility-specific estimates for Voluntary Aluminum Industrial Partnership partners and estimates of emissions—based on an average emission factor, in terms of emissions per metric ton of production—for other facilities.

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.⁴² Historical data for South Carolina were not available from the USGS; consequently, the default data provided in SGIT were used to calculate emissions for South Carolina (see orange line in Figure D2). The annual employment growth rate (0.2% annual) for South Carolina's goods-producing sector for 2000 through 2010 was used to project emissions from 2003 through 2020. Relative to total industrial non-combustion process emissions, estimated emissions associated with limestone and dolomite consumption are low (about 0.007 MMtCO₂e in 1990 and 0.008 MMtCO₂e in 2020), and therefore, cannot be seen in Figure D2 due to scaling effects. Note that SGIT did not provide any dolomite consumption data for any historical year for South Carolina.

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 footnote 1 for reference to 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 0.038 MMtCO₂e in 1990 and 0.041 MMtCO₂e in 2020), and therefore appear at the bottom of Figure D2 due to scaling effects.

Key Uncertainties

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

- 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

⁴² 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 CO₂ 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).

Carolina manufacturers in these industries, and the specific nature of the production processes used in South Carolina.

- 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 Carolina-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.
- The annual employment growth rate (0.2% annual) for South Carolina's goods-producing sector for 2000 through 2010 was used to project emissions from 2006 to 2020 for the cement and aluminum production industries as well as for limestone consumption. There is significant uncertainty associated with the use of this annual growth rate for the following reasons:
 - The growth rate is based on forecasts prepared for 2000 through 2010; consequently, the growth rate was used to forecast emissions to 2020 due to a lack of forecast data for the 2011 through 2020 period.
 - For the aluminum industry in South Carolina, the average annual growth rate was 1.3% from 1990 through 2005, and 1.4% from 2000 through 2005. However, the 10-year employment forecast for 2000 to 2010 for the "Primary Smelting & Refining of Nonferrous Metals" sector is -0.42%.
 - For clinker production in South Carolina, the average annual growth rate was 2.7% from 1990 through 2005, and 4.6% from 2000 through 2005. However, the 10-year employment forecast for 2000 to 2010 for the "Cement" sector is -1.0%.

Given that it is difficult to predict if these industries will continue to grow through 2020 at a rate similar to their historical growth rates, and the uncertainty with using an annual growth rate based on the 10-year employment forecasts for these industries, the annual growth rate for the goods producing sector was used until a better growth rate can be developed for these industries in South Carolina. Note that if these industries have implemented significant production improvements to increase the efficiency for producing their goods, it is possible that these industries would show a decline in employment.

- Given that South Carolina has only one aluminum plant, and the degree to which that plant has adopted or will adopt measures to reduce PFC emissions is not specifically known, there is substantial uncertainty in the estimation of both historical and future emissions from aluminum production.
- 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 (CO₂ and CH₄);
 - Ammonia Manufacture and Urea Application (CO₂, CH₄, N₂O);

- Aluminum Production (CO₂);
- Titanium Dioxide Production (CO₂);
- Phosphoric Acid Production (CO₂);
- CO₂ Consumption (CO₂);
- Ferroalloy Production (CO₂);
- Petrochemical Production (CH₄); and
- Silicon Carbide Production (CH₄).

The CO₂ emissions from the above CO₂ sources (other than CO₂ 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, the 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 Production Industry

Overview

The inventory for this subsector of the Energy Supply sector includes only methane (CH₄) emissions associated with the transmission and distribution (T&D) of natural gas in South Carolina. There is no oil or natural gas production or processing or coal mining in South Carolina. In 2005, emissions from natural gas T&D account for an estimated 0.63 million metric tons (MMt) of CO₂ equivalent (CO₂e) of total gross greenhouse gas (GHG) emissions in South Carolina, and are estimated to increase to about 0.78 MMtCO₂e by 2020.

Natural Gas T&D Emissions and Reference Case Projections

Methane 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 natural gas T&D.⁴³ Table E1 provides an overview of the required data, data sources, and the approach to projecting future emissions. The activity data were entered into the SGIT to calculate emissions for 1990 through 2005. Methane emissions were calculated by multiplying emissions-related activity levels (e.g., miles of pipeline) by aggregate emission factors.

The annual activity data for miles of T&D pipeline and number of service connections to distribution pipeline were obtained from databases provided by the Office of Pipeline Safety (OPS).⁴⁴ For the distribution system, annual CH₄ emissions were estimated using OPS' pipeline mileage and the SGIT emission factors for (1) distribution pipeline constructed of cast iron, unprotected steel, protected steel, and plastic, and (2) the number of protected and unprotected service connections. For the transmission system, the SGIT methods use total miles of pipeline as the basis for calculating CH₄ emissions; separate emission factors are not provided for pipeline constructed of different materials.

The SGIT methods also include emission factors for estimating CH₄ emissions associated with leaks from gas transmission compressor stations, gas storage compressor stations, and liquefied natural gas (LNG) storage compressor stations. Information on the type and number of compressor stations was not readily available for South Carolina. Therefore, the default factors in SGIT for estimating the number of gas transmission compressor stations and gas storage compressor stations from the miles of transmission pipeline for each year were used. The SGIT assumes 0.006 gas transmission compressor station per mile of transmission pipeline and 0.0015 gas storage compressor station per mile of transmission pipeline. For gas transmission compressor stations, the default SGIT methods estimated a total of 11 stations for 1990 and 1991, 12 stations for each year from 1992 through 1995, and 13 stations for each year from 1996 through 2005. For gas storage compressor stations, the SGIT methods estimated a total of three stations for each year from 1990 through 2005. Note that the SGIT does not provide default

⁴³ 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.

⁴⁴ US Office of Pipeline Safety, Distribution and Transmission Annuals Data for 1990-2005, <http://ops.dot.gov/stats/DT98.htm>.

methods for estimating the number of LNG storage compressor stations in a state; therefore, emissions were not estimated for LNG storage compressor stations.

A compound annual average growth rate of 1.4% was applied to forecast emissions associated with natural gas T&D from 2006 through 2020. This annual growth assumption is based on the historical annual average growth rate for total natural gas consumption for South Carolina from 1997 through 2005, based on consumption data available from the US Department of Energy (DOE), Energy Information Administration (EIA).⁴⁵ Note that South Carolina’s annual average growth rate in total natural gas consumption for the more recent period of 2000 through 2005 was also 1.4%.

Table E1. Approach to Estimating Historical and Future Methane Emissions from Natural Gas Transmission and Distribution

<i>Activity</i>	Approach to Estimating Historical Emissions		Approach to Estimating Projections
	<i>Required Data for SGIT</i>	<i>Data Source</i>	<i>Projection Assumptions</i>
Natural Gas Transmission	Miles of transmission pipeline	OPS	Based on 1.4% average annual growth in natural gas consumption in South Carolina from 1997 through 2005.
	Number of gas transmission compressor stations	US EPA EIIP default assumptions	
	Number of gas storage compressor stations	US EPA EIIP default assumptions	
	Number of LNG storage compressor stations	No data available	
Natural Gas Distribution	Miles of distribution pipeline	OPS	Based on 1.4% average annual growth in natural gas consumption in South Carolina from 1997 through 2005.
	Total number of services	OPS	
	Number of unprotected steel services	OPS	
	Number of protected steel services	OPS	

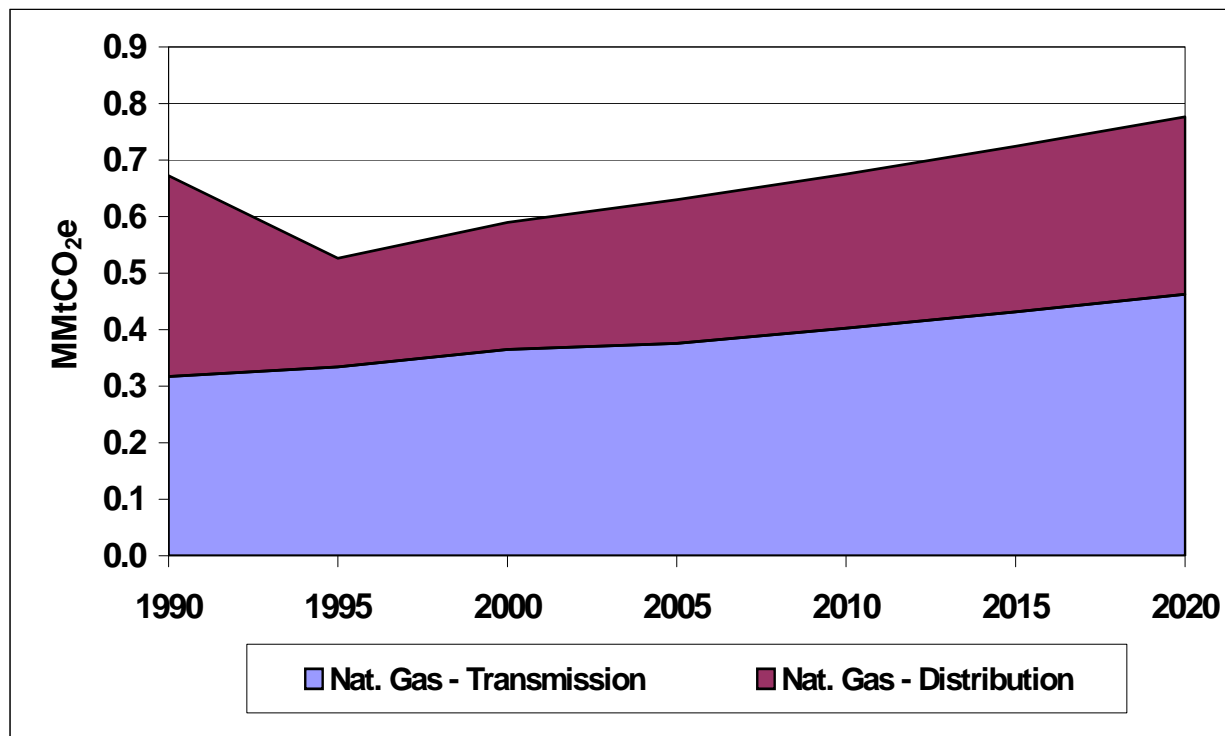
Results

Figure E1 displays the estimated GHG emissions associated with natural gas T&D system in South Carolina from 1990 to 2005, with projections to 2020. Emissions associated with this sector are estimated to be about 0.67 MMtCO₂e in 1990, 0.63 MMtCO₂e in 2005, and 0.78 MMtCO₂e in 2020. As shown in Figure E1, CH₄ emissions associated with South Carolina’s distribution system declined slightly from 1990 through 1995. This decline in emissions is associated with natural gas companies in South Carolina replacing cast iron and unprotected steel distribution pipe with protected steel and plastic pipe. Gas companies also replaced unprotected steel service connections with protected steel and plastic service connections that helped reduce emissions during this five-year period. Based on the data obtained from OPS, upgrades of the distribution system to replace highly corrosive pipeline was nearly completed by 1995. The

⁴⁵ US DOE, EIA Natural Gas Navigator, South Carolina Natural Gas Total Consumption [million cubic feet (MMcf)] from 1997 through 2005, http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_SSC_a.htm.

increase in distribution emissions after 1995 is associated with the expansion of the distribution pipeline system to accommodate growth using cathodically protected and coated or plastic pipeline and service connections.

Figure E1. Methane Emissions and Projections from the Fossil Fuel Industry



Key Uncertainties

The main uncertainties are associated with the reference case projection assumptions. For this preliminary forecast, it was assumed that emissions would increase at the historical rate of total natural gas consumption in South Carolina. Market factors (e.g., price of natural gas relative to other available energy sources) could have a significant impact on the growth for this sector. In addition, neither potential future application of improvements to pipeline technologies that can yield emission reductions nor the potential effect of demand-side management programs in reducing gas consumption have not been accounted for in the emissions projections shown here.

Future improvements to the estimates for the inventory should include the collection of activity data from gas companies to (1) verify the OPS data used for the miles of T&D pipeline and distribution service connections, (2) replace the SGIT defaults for estimating the number of gas transmission compressor stations and gas storage compressor stations, and (3) estimate emissions associated with LNG storage compressor stations if it is determined that these stations exist in South Carolina.

Appendix F. Agriculture

Overview

The emissions discussed in this appendix refer to non-energy methane (CH₄) and nitrous oxide (N₂O) emissions from enteric fermentation, manure management, and agricultural soils. Emissions and sinks of carbon in agricultural soils are also covered. Energy emissions (combustion of fossil fuels in agricultural equipment) are included in the residential, commercial, and industrial (RCI) sector estimates (see Appendix B).

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 CH₄ as a by-product. More CH₄ is produced in ruminant livestock because of digestive activity in the large fore-stomach. Methane and N₂O 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 CH₄ is produced because decomposition is aided by CH₄ producing bacteria that thrive in oxygen-limited aerobic conditions. Under aerobic conditions, N₂O emissions are dominant. Emissions estimates from manure management are based on manure that is stored and treated on 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 the agricultural soils emissions.

The management of agricultural soils can result in N₂O emissions and net fluxes of carbon dioxide (CO₂) causing emissions or sinks. In general, soil amendments that add nitrogen to soils can also result in N₂O emissions. Nitrogen additions drive underlying soil nitrification and denitrification cycles, which produce N₂O as a by-product. The emissions estimation methodologies used in this inventory account for several sources of N₂O emissions from agricultural soils, including decomposition of crop residues, synthetic and organic fertilizer application, manure application, sewage sludge, nitrogen fixation, and histosols (high organic soils, such as wetlands or peatlands) cultivation. Both direct and indirect emissions of N₂O 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 N₂O emissions also result when crop residues are burned. Methane emissions occur during rice cultivation; however, rice is not grown in South Carolina.

The net flux of CO₂ in 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 CO₂ into agricultural soils. In addition, 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 CO₂ emissions.

Emissions and Reference Case Projections

Methane and Nitrous Oxide

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 the sector.⁴⁶ 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, crop production 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.⁴⁷

Data on crop production in South Carolina from 1990 to 2005 and 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.⁴⁸ The default SGIT manure management system assumptions for each livestock category were used for this inventory. SGIT data on fertilizer usage came from *Commercial Fertilizers*, a report from the Fertilizer Institute. Activity data for fertilizer includes all potential uses in addition to agriculture, such as residential and commercial (e.g., golf courses). The estimates are reported in the agriculture sector but they represent emissions occurring on other land uses.

Crop production data from USDA NASS were available through 2005; therefore, N₂O emissions from crop residues and crops that use nitrogen (i.e., nitrogen fixation) and N₂O and CH₄ emissions from agricultural residue burning were calculated through 2005. Emissions for the other agricultural crop production 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). Given that cultivation of organic soils is a source of CO₂ emissions in South Carolina (see below), N₂O emissions are also probably occurring.

There is some agricultural residue burning conducted in South Carolina; however, emissions are estimated to be relatively small (<0.01 MMTCO₂e). The default SGIT method was used to calculate emissions. 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.

⁴⁶ GHG emissions were calculated using SGIT, with reference to EIIP, 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.

⁴⁷ Revised 1996 Intergovernmental Panel on Climate Change (IPCC) 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, available at: (<http://www.ipcc-nggip.iges.or.jp/public/gp/english/>).

⁴⁸ USDA, NASS (http://www.nass.usda.gov/Statistics_by_State/South_Carolina/index.asp).

Emissions from enteric fermentation and manure management were projected based on the methods used in the emission inventory prepared by the Visibility Improvement State and Tribal Association of the Southeast (VISTAS) regional planning organization.⁴⁹ The VISTAS inventory projected livestock populations for all animal types, except sheep, goats, and horses, based on growth factors from the US EPA’s National Emissions Inventory (NEI) for ammonia (NH₃).⁵⁰ Sheep and goat populations were projected based on the growth factors that the US EPA used in its future-year emissions inventory to support air quality modeling studies for the federal Interstate Air Quality Rule (IAQR).⁵¹ No growth was assumed for horses. Livestock population growth rates are shown in Table F1.

Table F1. Growth Rates Applied for the Enteric Fermentation and Manure Management Categories

Livestock Category	2002-2010	2010-2015	2015-2020	Source
Beef	1.3%	-1.0%	-0.3%	US EPA NEI for NH ₃
Dairy	-0.7%	-10.5%	-5.9%	US EPA NEI for NH ₃
Layers	-2.4%	3.1%	3.9%	US EPA NEI for NH ₃
Broilers	1.4%	2.8%	1.7%	US EPA NEI for NH ₃
Turkeys	-0.1%	0.2%	-0.1%	US EPA NEI for NH ₃
Swine	1.7%	1.2%	0.8%	US EPA NEI for NH ₃
Sheep	3.1%	2.0%	1.7%	Interstate Air Quality Rule (IAQR)
Goats	3.1%	2.0%	1.7%	IAQR
Horses	0.0%	0.0%	0.0%	US EPA NEI for NH ₃

Growth rates for agricultural burning, agricultural soils – livestock, and fertilizers were based on the historical trends for 1990-2002. Growth rates for agricultural crops were based on the historical trend for 1990-2005. The growth rates for these categories are shown in Table F2.

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 US Inventory of Greenhouse Gas Emissions and Sinks⁵² and the US Agriculture and Forestry Greenhouse Gas Inventory. The estimates are based on the Intergovernmental Panel on Climate Change (IPCC) methodology for soil carbon adapted to conditions in the US. Preliminary state-level estimates of

⁴⁹ Documentation of the Base G 2002 Base Year, 2009 and 2018, Emission Inventories for VISTAS, prepared for Visibility Improvement State and Tribal Association of the Southeast, prepared by MACTEC, Inc.

⁵⁰ National Emission Inventory – Ammonia Emissions from Animal Agricultural Operations, Environmental Protection Agency, April, 2005, http://ftp.epa.gov/EmisInventory/2002finalnei/documentation/nonpoint/nh3inventory_draft_042205.pdf.

⁵¹ Development of Growth Factors for Future Year Modeling Inventories; prepared for the Emission Factor and Inventory Group, Environmental Protection Agency; prepared by E.H. Pechan & Associates, http://www.epa.gov/cair/pdfs/Non-EGU_nonpoint_Growth_Development.pdf.

⁵² US 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>.

CO₂ fluxes from mineral soils and emissions from the cultivation of organic soils were reported in the US Agriculture and Forestry Greenhouse Gas Inventory.⁷ Currently, these are the best available data at the state-level for this category. The inventory did not report state-level estimates of CO₂ emissions from limestone and dolomite applications; hence, this source is not included in this inventory at present.

Table F2. Growth Rates Applied for the Agricultural Soils and Burning

Agricultural Category	Growth Rate	Basis for Annual Growth Rate*
Agricultural Burning	0.7%	Historical emissions for 1990-2002.
Agricultural Soils – Direct Emissions		
Fertilizers	0.1%	Historical emissions for 1990-2002.
Crop Residues	-2.9%	Historical emissions for 1990-2005.
Nitrogen-Fixing Crops	-2.5%	Historical emissions for 1990-2005.
Histosols	0.0%	No historical data available.
Livestock	-0.2%	Historical emissions for 1990-2002.
Agricultural Soils – Indirect Emissions		
Fertilizers	0.1%	Historical emissions for 1990-2002.
Livestock	1.0%	Historical emissions for 1990-2002.
Leaching/Runoff	0.5%	Historical emissions for 1990-2002.

* Compound annual growth rates shown in this table were calculated by linearly extrapolating historical emissions (MMtCO₂e basis) from 1990 through the most recent year of data to 2020.

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 Carolina, Table F3 shows a summary of the latest estimates available from the USDA, which are for 1997.⁵³ These data show that changes in agricultural practices are estimated to result in emissions of 0.18 million metric tons (MMt) of CO₂ equivalent (CO₂e) per year (yr) in South Carolina, this is driven largely by the amount of organic (i.e., histosol) soils that are cultivated in South Carolina. Since data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing, emissions of 0.18 MMtCO₂e/yr are assumed to remain constant.

⁵³ US 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 F3. The sum of the first nine columns is equivalent to the mineral soils category.

Table F3. GHG Emissions from Soil Carbon Changes Due to Cultivation Practices (MMtCO₂e)

Changes in cropland			Changes in Hayland				Other			Total ⁴
Plowout of grassland to annual cropland ¹	Cropland management	Other cropland ²	Cropland converted to hayland ³	Hayland management	Cropland converted to grazing land ³	Grazing land management	CRP	Manure application	Cultivation of organic soils	Net soil carbon emissions
0.15	(0.04)	0.00	(0.15)	0.04	(0.18)	0.00	(0.07)	(0.19)	0.62	0.18

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.

Results

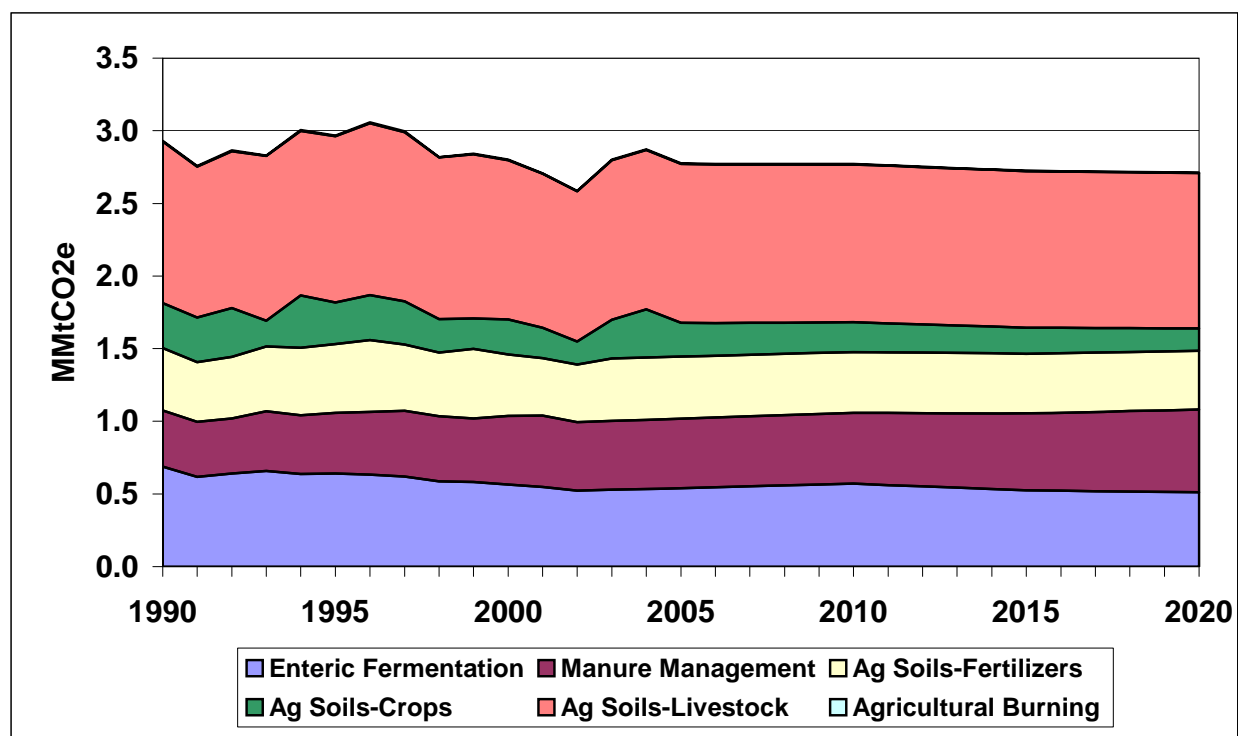
Figure F1 shows gross GHG emissions associated with the agricultural sector from 1990 through 2020. In 1990, enteric fermentation accounted for about 23% (0.69 MMtCO₂e) of total agricultural emissions. Enteric fermentation emissions decreased to 0.52 MMtCO₂e (20% of total agricultural emissions) due to the decline in beef and dairy cattle populations between 1990 and 2002. While the beef cattle population is projected to increase slightly, this increase does not offset the large decrease projected for the dairy cattle population, and enteric fermentation emissions are estimated to be 0.51 MMtCO₂e in 2020.

The manure management category accounted for 13% (0.39 MMtCO₂e) of total agricultural emissions in 1990 and increased to 18% (0.47 MMtCO₂e) in 2002. Manure management, which shows the highest rate of growth relative to the other categories, is estimated to account for about 21% (0.57 MMtCO₂e) of total agricultural emissions in 2020. This emissions growth is mainly due to historical and projected increases in the poultry population and a projected increase in the swine population.

The agricultural soils category decreases from 1990 to 2020, with 1990 emissions accounting for 69% (2.0 MMtCO₂e) of total agricultural emissions and 2020 emissions estimated to be about 65% (1.8 MMtCO₂e) of total agricultural emissions. This decrease is due to the historical decline in emissions from crops (i.e., agricultural residues and legumes).

Agricultural burning emissions were estimated to be very small based on the SGIT activity data (<0.01 MMtCO₂e/yr from 1990 to 2002). Emissions for this category account for about one-half of the national emissions included in the USDA Inventory which, relative to other agricultural categories, reports a low level of residue burning emissions (0.02 MMtCO₂e). Even though these initial emission estimates using the SGIT are low relative to emissions associated with the other agricultural categories in South Carolina, the emission estimates for agricultural burning in South Carolina using the SGIT methodology are inconsistent with other data and should be refined using actual activity data for South Carolina, if available.

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); emissions for agricultural residue burning are too small to be seen in this chart.

The only standard IPCC source categories missing from this report are CO₂ emissions from limestone and dolomite application and N₂O emissions from the cultivation of histosols. Estimates for limestone and dolomite application in South Carolina were not available; however, the USDA’s national estimate for soil liming is about 9 MMtCO₂e/yr.⁵⁴

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 which are derived from several variables including manure production levels, volatile solids content, and CH₄ 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.

⁵⁴ US 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.

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 emissions could be appreciably affected. As mentioned above, emission estimates for soil liming have not been developed for South Carolina.

Another contributor to the uncertainty in the emission estimates is the projection assumptions. The growth rates for most livestock categories are based on the national projection data from USDA that was used in the VISTAS inventory. For other emission categories, 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.

Appendix G. Waste Management

Overview

Greenhouse gas (GHG) emissions from waste management include:

- Solid waste management – methane (CH₄) emissions from municipal and industrial solid waste landfills (LFs), accounting for CH₄ that is flared or captured for energy production (this includes both open and closed landfills);
- Solid waste combustion – CH₄, carbon dioxide (CO₂), and nitrous oxide (N₂O) emissions from the combustion of solid waste in incinerators or waste to energy plants; and
- Wastewater management – CH₄ and N₂O from municipal wastewater and CH₄ from industrial wastewater (WW) treatment facilities.

Inventory and Reference Case Projections

Solid Waste Management

For solid waste management, we used the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SGIT) and the US EPA Landfill Methane Outreach Program (LMOP) landfills database⁵⁵ as starting points to estimate emissions. The LMOP data serve as input data to estimate annual waste emplacement for each landfill needed by SGIT. SGIT then estimates CH₄ generation for each landfill site. Additional post-processing outside of SGIT to account for controls is then performed to estimate CH₄ emissions.

The LMOP database was shared with South Carolina Department of Health and Environmental Control's (SCDHEC) solid waste staff, and the Center for Climate Strategies (CCS) was supplied with additional data on South Carolina landfills. These additional data included information on 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).⁵⁶ In the combined LMOP and SCDHEC dataset for South Carolina, there are over 50 sites represented (both open and closed landfills).

To obtain the annual waste emplacement rate needed by SGIT for each landfill, the waste-in-place estimate 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. Data were available to calculate the average emplacement rate for each of the 13 controlled sites and 38 of the uncontrolled sites.

CCS performed three different runs of SGIT to estimate emissions from municipal solid waste (MSW) landfills: (1) uncontrolled landfills; (2) landfills with a landfill gas collection system and landfill gas to energy (LFGTE) plant; and (3) landfills with landfill gas collection and a flare. SGIT produced annual estimates of CH₄ emissions through 2005 for each of these landfill

⁵⁵ 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.

⁵⁶ John McCain, Solid Waste Permitting Section, Bureau of Land and Waste Management, South Carolina Department of Health and Environmental Control, personal communication with H. Lindquist, CCS, February 2007.

categories. CCS then performed post-processing of the landfill emissions to account for landfill gas controls (at LFGTE and flared sites) and to project the emissions through 2020. CCS assumed that 10% of CH₄ emissions are oxidized before being emitted to the atmosphere (consistent with the SGIT default). For the controlled landfills, CCS assumed that the overall CH₄ collection and control efficiency is 75%.⁵⁷

Growth rates were estimated by using the historic (2000-2005) growth rates of emissions in both the controlled and uncontrolled landfill categories. The period from 2000 to 2005 was used since there were a large number of landfill closures during the period from 1990 to 2000 (which could have affected waste management practices). Hence, the post-2000 period is thought to be most representative of waste emplacement rates and subsequent emissions. The annual growth rates are: 0.2% for uncontrolled sites and 4.5% for controlled landfills. The small growth for the uncontrolled category is due to smaller rates of waste emplacement at these sites in the post-2000 period.

CCS used the SGIT default for industrial landfills. This default is based on national data indicating that industrial landfilled waste is emplaced at approximately 7% of the rate of MSW emplacement. We assumed that this additional industrial waste emplacement occurs beyond that already addressed in the emplacement rates for MSW sites. Due to a lack of data, no controls were assumed for industrial waste landfilling. For industrial landfills, the growth rate in emissions from 2000 to 2005 (2.3%/yr) was used to project emissions to 2010 and 2020 (equal to the overall growth in MSW landfill emissions).

Solid Waste Combustion

SCDHEC provided throughput data for the only municipal waste combustion facility currently operating in South Carolina.⁵⁸ SGIT defaults (emission factors, waste characteristics) were used to estimate emissions using these data. No information was identified on plans for additional plants in the future or expanded capacity at the existing plant, so emissions were held constant in the forecast years.

Open burning of MSW at residential or municipal sites can also contribute GHG emissions. If data are available, future inventory work should attempt to capture this source of emissions.

Wastewater Management

GHG emissions from municipal and industrial wastewater treatment were also estimated. For municipal wastewater treatment, emissions were calculated in SGIT based on State population, assumed biochemical oxygen demand (BOD) and protein consumption per capita, and emission factors for N₂O and CH₄. The key SGIT default values are shown in Table G1.

For industrial wastewater emissions, SGIT provides default assumptions and emission factors for three industrial sectors: Fruits & Vegetables, Red Meat & Poultry, and Pulp & Paper. There is only one facility of significant size operating in South Carolina in any of these industries.

⁵⁷ As per EPA's AP-42 Section on Municipal Solid Waste Landfills:
<http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf>.

⁵⁸ John McCain, Solid Waste Permitting Section, Bureau of Land and Waste Management, South Carolina Department of Health and Environmental Control, personal communication with H. Lindquist, CCS, February 2007.

SCDHEC was able to provide information on flows for this fruit and vegetable processing facility.⁵⁹ The data on annual wastewater flows from SCDHEC were used to back-calculate an annual production value using SGIT data (3.8 cubic meters of wastewater for every ton processed; SGIT requires annual production data). The resulting emission estimates for this facility are very small [less than 0.0002 million metric tons (MMt) of CO₂ equivalent (CO₂e) per year] and are not significant compared to the total waste sector emissions.

Table G1. SGIT Key Default Values for Municipal Wastewater Treatment

Variable	Value
BOD	0.065 kg /day-person
Amount of BOD anaerobically treated	16.25%
CH ₄ emission factor	0.6 kg/kg BOD
SC residents not on septic	75%
Water treatment N ₂ O emission factor	4.0 g N ₂ O/person-yr
Biosolids emission Factor	0.01 kg N ₂ O-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/.

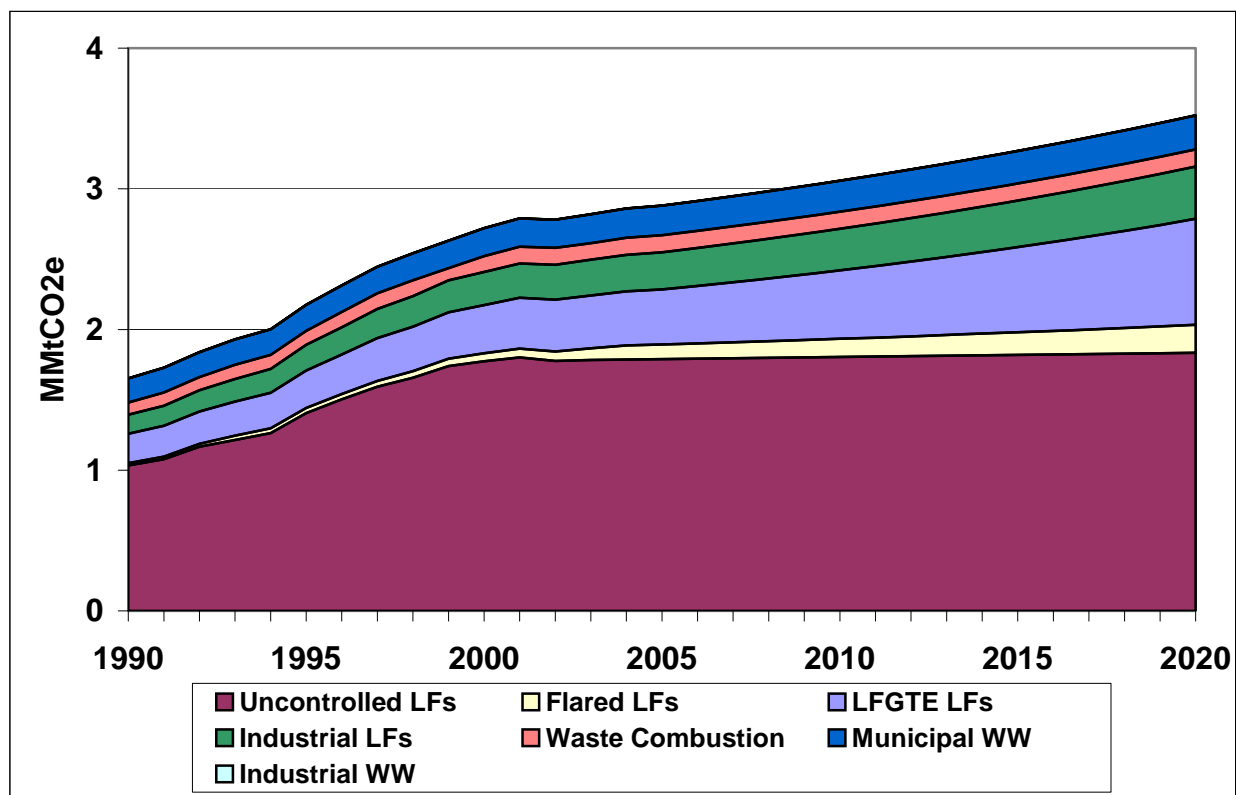
Results

Figure G1 shows the emission estimates for the waste management sector. Overall, the sector accounts for 2.9 MMtCO₂e in 2005. By 2020, emissions are expected to grow to 3.5 MMtCO₂e/yr. In 2005, 62% of the emissions were contributed by the uncontrolled landfills sector; however, by 2020 the contribution from these sites is expected to decline to about 52%. Controlled landfills (flared and LFGTE sites) contributed 17% of total waste emissions in 2005 and are expected to grow to 27% in 2020.

As mentioned above, CCS modeled only emissions from fruit and vegetable processors in the industrial wastewater treatment sector. Less than 0.01% of the emissions were contributed by the industrial wastewater treatment sector. In 2005, 7% of the waste management sector emissions were contributed from municipal wastewater treatment systems. The contribution is expected to remain the same through 2020. Note that these estimates are based on the default parameters listed in Table G1 and might not adequately account for existing controls (e.g., anaerobic digesters served by a flare or other combustion device) or specific wastewater treatment methods in SC (e.g., anaerobic digestion versus aerobic digestion).

⁵⁹ Melinda Vickers, Wastewater Section, Bureau of Land and Waste Management, South Carolina Department of Health and Environmental Control, personal communication with S. Roe, CCS, December 2006.

Figure G1. South Carolina GHG Emissions from Waste Management



Source: CCS calculations based on approach described in text.
 Notes: LF – landfill; WW – wastewater; LFGTE – landfill gas to energy.

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. Hence, for landfills, the historical emissions are less certain than current emissions and future emissions for this reason (since each site that is currently controlled was modeled as always being controlled, the historic emissions are low 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 requirements of the federal New Source Performance Standards/Emission Guidelines.

For industrial landfills, these were estimated using national defaults (7% of the rate of MSW emplacement). It could be that the available MSW emplacement data within the combined LMOP/SCDHEC data used to model the MSW emissions already captures industrial LF waste 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.

For the wastewater sector, the key uncertainties are associated with the application of SGIT default values for the parameters listed in Table G1 (e.g., fraction of the SC population on septic; fraction of BOD which is anaerobically decomposed). The SGIT defaults were derived from

national data. Hence, they may not adequately characterize the wastewater treatment processes currently employed or to be employed in the future.

Appendix H. Forestry

Overview

Forestland emissions refer to the net carbon dioxide (CO₂) flux⁶⁰ from forested lands in South Carolina, which account for about 62% of the state's land area.⁶¹ The dominant forest type in South Carolina is Loblolly-short leaf pine which makes up about 39% of forested lands. Other common forest types are Oak-Hickory (20%), Oak-Gum-Cypress (19%), and Oak-Pine (15%).

Forestlands are net sinks of CO₂ in South Carolina. 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 CO₂ fluxes for the official *US Inventory of Greenhouse Gas Emissions and Sinks*.⁶² The national estimates are compiled from state-level data. The South Carolina forest CO₂ flux data in this report come from the national analysis and are provided by the USFS.

The forest CO₂ flux methodology relies on input data in the form of plot level forest volume statistics from the Forest Inventory Analysis (FIA). FIA data on forest volumes are converted to values for ecosystem carbon stocks (i.e., the amount of carbon stored in forest carbon pools) using the FORCARB2 modeling system. Coefficients from FORCARB2 are applied to the plot level survey data to give estimates of C density [megagrams (Mg) 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 CO₂ emissions or carbon transfers out of that pool (e.g., death of a standing tree transfers carbon from the live tree to standing dead wood pool). The amount of carbon in each

⁶⁰ "Flux" refers to both emissions of CO₂ to the atmosphere and removal (sinks) of CO₂ from the atmosphere.

⁶¹ Total forested acreage is 12.7 million acres. Acreage by forest type available from the USFS at: <http://www.fs.fed.us/ne/global/pubs/books/epa/states/SC.htm>. The total land area in South Carolina is 20.5 million acres (<http://www.50states.com/scarolin.htm>).

⁶² US 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>.

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 CO₂ 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). 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.⁶³

Carbon pool data for two periods are used to estimate CO₂ flux for each pool (approximately 2001-2005, with an average interval of 4 years). The data shown in Table H1 are based on the most recent estimates from the USFS and will be included in the upcoming 2005 estimates in EPA's national greenhouse gas (GHG) inventory. The underlying FIA data show a net increase in forest area of about 331,000 acres from 2001-2005, with the forest area starting at about 12,414,000 acres and increasing to 12,745,000 acres.

Table H1. Forest Carbon Flux Estimates for South Carolina

Forest Pool	Carbon Flux (MMtC)	Carbon Flux (MMtCO₂)
Live Tree	-4.7	-17
Understory	-0.2	-0.8
Standing Dead & Down Dead	-0.4	-1.5
Forest Floor	-0.04	-0.15
Soil Carbon	7.6	28
Harvested Wood Products	-2.5	-9.0
Totals	-0.3	-1.0
Totals (excluding soil carbon)	-7.8	-28.5

Totals may not sum exactly due to independent rounding.

Data source: Jim Smith, USFS, personal communications with S. Roe, CCS, November 2006 and February 2007.

In addition to the forest carbon pools, additional carbon is stored in biomass 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 H1, 9.0 million metric tons (MMt) of CO₂ (CO₂) per year (yr) is estimated to be sequestered annually in wood products.⁶⁴

The total flux estimate including all forest pools is -1.0 MMtCO₂e/yr. This total includes a very large net source estimate for soil carbon (28 MMtCO₂e/yr). USFS acknowledges that the soil carbon pool estimates have a large degree of uncertainty. This level of flux would indicate a large transition of forested area from one forest type to another with the second forest type

⁶³ 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](http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/RAMR6MBLNQ/$File/06_annex_Chapter3.pdf).

⁶⁴ Jim Smith, USFS, personal communication with S. Roe, CCS, October 2006.

having lower soil carbon levels. Given that the survey interval is less than 4 years, a large transition in forest type does not seem likely. In consultation with USFS, CCS excluded the soil carbon pool from the total net flux estimate used in the summary tables to this report.⁶⁵

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. 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.

Key Uncertainties

It should be noted that methane (CH₄) and nitrous oxide (N₂O) emissions from wildfires and prescribed burns have not been included in the estimates presented in Table H1. In work that the Center for Climate Strategies (CCS) has completed for a number of western states, where wildfire activity is significant, emission estimates have tended to range from <1 to 3 MMtCO₂e/yr. We expect that the emissions from wildfires in South Carolina would be much lower than these levels.

Emissions of CH₄ from anaerobic forest soils (e.g., swamps, wetlands) have not been captured in this assessment. This is an area that should be investigated in the future, pending availability of data, to provide a more comprehensive picture of GHG emissions from forests.

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 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 in South Carolina; however CCS' understanding is that these issues have tended to be most important in some western states with significant woodland forested area.

Also, FIA surveys since 1999 include all dead trees on the plots, but data prior to that are variable in terms of these data. 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. In addition, the FIA program has moved from periodic to annual inventory methods. The effect of these changes in survey methods has not been estimated by the USFS.

⁶⁵ Jim Smith, USFS, personal communication with S. Roe, CCS, February 2007.

Appendix I. Inventory and Forecast for Black Carbon

Overview

This appendix summarizes the methods, data sources, and results of the development of an inventory and forecast for black carbon (BC) emissions in South Carolina. Black carbon is an aerosol (particulate matter (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 Visibility Improvement State and Tribal Association of the Southeast (VISTAS).⁶⁶ An assessment of 2018 BC contributions from important source sectors was also performed based on forecast data from VISTAS. This appendix describes these data and methods for estimating mass emissions of BC and then transforming the mass emission estimates into CO₂e equivalents (CO₂e) in order to present the emissions within a greenhouse gas (GHG) context.

In addition to the PM inventory data from VISTAS, 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 ongoing work being conducted by E.H. Pechan & Associates, Inc. for the US EPA on updating the Version 4 of the SPECIATE database that the US EPA released to the public during January 2007.⁶⁷ As will be further described below, both BC and OM emission estimates are needed to assess the CO₂e of BC emissions. Importantly for this effort, better speciation data are now available in Version 4 of the SPECIATE database 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 CO₂e estimates using information from recent global climate modeling. This transformation is described in later sections below.

Emissions and Reference Case Projections

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 10 micrometers (PM₁₀) by the appropriate aerosol fraction for BC and OM. The aerosol fractions were taken from Version 4 of the SPECIATE database.

After estimating both BC and OM emissions for each source category, we used the BC estimate as described below to estimate the CO₂e emissions. Also, as described further below, the OM

⁶⁶ SCDHEC obtained the data for the Center for Climate Strategies (CCS) from VISTAS: Carla Bedenbaugh personal communications with S. Roe, January and February 2007.

⁶⁷ Version 4.0 of the SPECIATE database and report:
<http://www.epa.gov/ttn/chief/software/speciate/index.html#related>.

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 II.

Development of CO₂e for BC+OM Emissions

We used similar methods to those applied previously in Maine and Connecticut for converting BC mass emissions to CO₂e.⁶⁸ These methods are based on the modeling of Jacobson (2002)⁶⁹ and his updates to this work (Jacobson, 2005a).⁷⁰ Jacobson (2005a) estimated a range of 90:1 to 190:1 for the climate response effects of BC+OM emissions as compared to CO₂ carbon emissions (depending on either a 30-year or 95-year atmospheric lifetime for CO₂). 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 CO₂e 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 CO₂ carbon (not CO₂). Therefore, in order to express the BC emissions as CO₂e, the climate response factors should have been adjusted upward by a factor of 3.67 to account for the molecular weight of CO₂ to carbon (44/12).

For this inventory, we started with the 90 and 190 climate response factors adjusted to CO₂e factors of 330 and 697 to obtain a low and high estimate of CO₂e for each sector. An example calculation of the CO₂e emissions for 10 tons of PM₁₀) from onroad diesel exhaust follows:

BC mass = (10 short tons PM₁₀) x (0.613 ton EC/ton PM₁₀) = 6.13 short tons BC

Low estimate CO₂e = (6.13 tons BC) (330 tons CO₂e/ton BC+OM) (3 tons BC+OM/ton BC) (0.907 metric ton/ton) = 5,504 metric tons CO₂e

High estimate CO₂e = (6.13 tons BC) (697 tons CO₂e/ton BC+OM) (3 tons BC+OM/ton BC) (0.907 metric ton/ton) = 11,626 metric tons CO₂e

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 CO₂e estimates. The reason for this is that the net heating effects of

⁶⁸ 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.

⁶⁹ 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.

⁷⁰ Jacobson, 2005a. Jacobson, M.Z., "Updates to 'Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming'", *Journal of Geophysical Research Atmospheres*, February 15, 2005.

OM are not currently well understood (overall OM is thought to have a negative climate forcing effect or a net cooling effect). Therefore, for source categories where the PM is dominated by 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

We estimate that BC mass emissions in South Carolina total about 7.0 million metric tons (MMt) of CO₂ equivalent (CO₂e) in 2002. This is the mid-point of the estimated range of emissions. The estimated range is 4.5 – 9.6 MMtCO₂e (see Table I1). The primary contributing sectors in 2002 were nonroad diesel (35%), onroad diesel (28%), electricity generating unit coal combustion (17%), aircraft (5%), and rail (4%).

The nonroad diesel sector includes engine exhaust emissions used for construction/mining, commercial, industrial and agricultural purposes, and recreational vehicles. Construction and mining engines contributed 56% of the total nonroad diesel emissions, while agricultural engines contributed 12%, commercial marine vessels 11%, and industrial equipment 9%.

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 CO₂e.

The Center for Climate Strategies (CCS) also performed an assessment of the primary BC contributing sectors from the 2018 VISTAS forecast. A drop in the future BC emissions for the onroad and nonroad diesel sectors is expected due to new engine and fuels standards that will reduce PM emissions. For the nonroad diesel sector, the estimated 2.5 MMtCO₂e in 2002 drops to 0.8 MMtCO₂e in 2018. For the onroad diesel sector, 2.0 MMtCO₂e was estimated for 2002 dropping to 0.3 MMtCO₂e in 2018. No significant reductions are expected in the other emission sectors. The development of emission estimates for each of the smaller source sectors was beyond the scope of this analysis.

While the state of science in aerosol climate forcing is still developing, there is a good body of evidence supporting the net warming impacts of 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).⁷¹ There are also a number of other indirect radiative effects that have been modeled (e.g., Jacobson, 2002).

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 with the important GHGs (i.e., CO₂). Spatially and temporally resolved information on the

⁷¹ IPCC, 2001. Climate Change 2001: The Scientific Basis, Intergovernmental Panel on Climate Change, 2001.

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 CO₂, the IPCC estimated the radiative forcing for a doubling of the earth's CO₂ concentration to be 3.7 watts per square meter (W/m²). For BC, various estimates of current radiative forcing have ranged from 0.16 to 0.42 W/m² (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 CO₂ and other GHGs. There are even higher uncertainties associated with the assessment of the indirect radiative forcing of aerosols.

Table II. 2002 BC Emission Estimates

Sector	Subsector	Mass Emissions			CO ₂ Equivalents		% Contribution
		BC	OM	BC + OM	Low	High	
		Metric Tons			Metric Tons		
Electric Generating Units (EGUs)	Coal	774	1,106	1,880	766,179	1,618,264	17%
	Oil	2	3	5	2,025	4,277	0%
	Gas	0	20	20	0	0	0%
	Other	2	3	5	1,744	3,684	0%
Non-EGU Fuel Combustion (Residential, Commercial, Industrial)							
	Coal	71	102	173	70,605	149,127	2%
	Oil	146	137	283	144,807	305,850	3%
	Gas	0	798	798	0	0	0%
	Other ^a	857	3,948	4,804	137,733	290,909	3%
Onroad Gasoline (Exhaust, Brake Wear, & Tire Wear)		181	591	772	75,075	158,567	2%
Onroad Diesel (Exhaust, Brake Wear, & Tire Wear)		1,281	453	1,734	1,267,209	2,676,499	28%
Aircraft		239	132	371	236,438	499,386	5%
Railroad ^b		198	66	265	196,453	414,933	4%
Other Energy Use	Nonroad Gas	72	773	844	0	0	0%
	Nonroad Diesel	1,589	529	2,119	1,573,313	3,323,028	35%
	Other Combustion ^c	54	67	120	50,000	105,606	1%
Industrial Processes		35	548	583	0	0	0%
Agriculture ^d		95	1,543	1,638	0	0	0%
Waste Management	Landfills	0	0	0	0	0	0%
	Incineration	0	0	0	0	0	0%
	Open Burning	292	3,754	4,047	0	0	0%
	Other	0	0	0	0	0	0%
Wildfires/Prescribed Burns		1,917	16,684	18,601	0	0	0%
Miscellaneous ^e		947	15,808	16,755	0	0	0%
Total		8,752	47,066	55,818	4,521,582	9,550,129	100%

^a Primarily 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 (agricultural engines are included in the "Other Energy Use" sector).

^e Miscellaneous includes Paved/Unpaved Roads and Catastrophic/Accidental Release Emissions.

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

Original Reference: Material for this Appendix is taken from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2000*, U.S. Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-02-003, April 2002 (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 U.S. anthropogenic greenhouse gas emissions and removals for the years 1990 through 2000. The estimates are presented on both a full molecular mass basis and on a Global Warming Potential (GWP) weighted basis in order to show the relative contribution of each gas to global average radiative forcing.

The Intergovernmental Panel on Climate Change (IPCC) has recently updated the specific global warming potentials for most greenhouse gases in their Third Assessment Report (TAR, IPCC 2001). Although the GWPs have been updated, estimates of emissions presented in the U.S. *Inventory* continue to use the GWPs from the Second Assessment Report (SAR). The guidelines under which the *Inventory* is developed, the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines for national inventories⁷² were developed prior to the publication of the TAR. Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. This excerpt of the U.S. *Inventory* addresses in detail the differences between emission estimates using these two sets of GWPs. Overall, these revisions to GWP values do not have a significant effect on U.S. emission trends.

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

What is Climate Change?

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

The Earth naturally absorbs and reflects incoming solar radiation and emits longer wavelength terrestrial (thermal) radiation back into space. On average, the absorbed solar radiation is balanced by the outgoing terrestrial radiation emitted to space. A portion of this terrestrial radiation, though, is itself absorbed by gases in the atmosphere. The energy from this absorbed terrestrial radiation warms the Earth's surface and atmosphere, creating what is known as the

⁷² See FCCC/CP/1999/7 at <www.unfccc.de>.

“natural greenhouse effect.” Without the natural heat-trapping properties of these atmospheric gases, the average surface temperature of the Earth would be about 33°C lower (IPCC 2001).

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 $0.6 \pm 0.2^{\circ}\text{C}$ 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 (CO₂), methane (CH₄), nitrous oxide (N₂O), and ozone (O₃). 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 (SF₆)—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 (NO₂), sulfur dioxide (SO₂), and tropospheric (ground level) ozone (O₃). 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 ₂ O	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 CO₂ 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 CO₂ 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 (H₂O). 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 (CO₂). 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 CO₂. 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 CO₂ increase is caused by anthropogenic emissions of CO₂” (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 (CH₄). 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 CH₄, 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 CH₄ 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 CO₂. 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 (N₂O). Anthropogenic sources of N₂O 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 (N₂O) 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 (O₃). 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 CO₂ and CH₄. 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 (SO₂), nitrogen dioxide (NO₂) 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 (SF₆). 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 (SF₆) 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 SF₆ 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 SF₆ 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 CH₄ and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radical, OH) that would otherwise assist in destroying CH₄ 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 CO₂. 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 NO₂) 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 (N₂O). 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 (CO₂) 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 CO₂ Eq. can be expressed as follows:

$$\text{Tg CO}_2 \text{ Eq} = (\text{Gg of gas}) \times (\text{GWP}) \times \left(\frac{\text{Tg}}{1,000 \text{ Gg}} \right) \quad \text{where,}$$

Tg CO₂ Eq. = Teragrams of Carbon Dioxide Equivalents
GWP = Global Warming Potential

Gg = Gigagrams (equivalent to a thousand metric tons)
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., CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆) 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., SO₂ 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 ₂ O)	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 ₂ F ₆	10,000	9,200	6,200	14,000
C ₄ F ₁₀	2,600	7,000	4,800	10,100
C ₆ F 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 CO₂ 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 ₃ Br	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 CO₂ radiative forcing and an improved CO₂ 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 CO₂ is about 12 percent lower than that in the SAR, the GWPs of the other gases relative to CO₂ 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 CO₂ using an improved calculation of the CO₂ radiative forcing, the SAR response function for a CO₂ pulse, and new values for the radiative forcing and lifetimes for a number of halocarbons.

References

- FCCC (1996) Framework Convention on Climate Change; FCCC/CP/1996/15/Add.1; 29 October 1996; Report of the Conference of the Parties at its second session. Revised Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention, p18. Geneva 1996.
- IPCC (2001) *Climate Change 2001: A Scientific Basis*, Intergovernmental Panel on Climate Change; J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, C.A. Johnson, and K. Maskell, eds.; Cambridge University Press. Cambridge, U.K.
- IPCC (2000) *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC National Greenhouse Gas Inventories Programme Technical Support Unit, Kanagawa, Japan. Available online at <<http://www.ipcc-nggip.iges.or.jp/gp/report.htm>>.
- IPCC (1999) *Aviation and the Global Atmosphere*. Intergovernmental Panel on Climate Change; Penner, J.E., et al., eds.; Cambridge University Press. Cambridge, U.K.
- IPCC (1996) *Climate Change 1995: The Science of Climate Change*. Intergovernmental Panel on Climate Change; J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell, eds.; Cambridge University Press. Cambridge, U.K.
- IPCC/UNEP/OECD/IEA (1997) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*. Paris: Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency.
- Jacobson, M.Z. (2001) Strong Radiative Heating Due to the Mixing State of Black Carbon in Atmospheric Aerosols. *Nature*. In press.
- UNEP/WMO (2000) *Information Unit on Climate Change*. Framework Convention on Climate Change (Available on the internet at <<http://www.unfccc.de>>.)
- WMO (1999) *Scientific Assessment of Ozone Depletion, Global Ozone Research and Monitoring Project-Report No. 44*, World Meteorological Organization, Geneva, Switzerland.