Final Idaho Greenhouse Gas Inventory and Reference Case Projections 1990-2025

Center for Climate Strategies
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Disclaimer

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

Executive Summary

The Center for Climate Strategies (CCS) prepared this report for the Idaho Department of Environmental Quality (DEQ). The report contains an inventory and forecast of the State's greenhouse gas (GHG) emissions from 1990 to 2025 to provide a comprehensive understanding of Idaho's current and possible future GHG emissions. This report revises and updates the GHG emissions inventory and forecast for Idaho prepared by CCS in 2007 for DEQ through an effort of the Western Regional Air Partnership (WRAP). This report provides a comprehensive understanding of Wyoming's current and possible future GHG emissions. The information presented provides the State with a starting point for further revisions and improvements to data sources and assumptions.

Emissions and Reference Case Projections (Business-as-Usual)

Idaho's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the period from 1990 to 2025. Historical GHG emission estimates (1990 through 2007[1]) 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 Idaho-specific data and inputs when it was possible to do so. The reference case projections (2008-2025) 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 described in the appendices of this report.

The inventory and projections cover the six types of gases included in the U.S. Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates the relative contribution of each gas, per unit mass, to global average radiative forcing on a global warming potential (GWP) weighted basis.[2]

Table ES-1 provides a summary of historical (1990 to 2005) and reference case projection (2010 and 2020) GHG emissions for Idaho. Activities in Idaho accounted for approximately 33 million metric tons (MMt) of *gross*[3] carbon dioxide equivalent (CO_2e) emissions in 2005, an amount equal to about 0.5% of total US gross GHG emissions (based on 2009 US data[4]). These emission

[1] The last year of available historical data varies by sector; ranging from 2004 to 2008.
[2] Changes in the atmospheric concentrations of GHGs 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, 2001). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth), See: Boucher, O., et al. "Radiative Forcing of Climate Change." Chapter 6 in Climate Change 2001: The Scientific Basis. Contribution of Working Group 1 of the Intergovernmental Panel on Climate Change Cambridge University Press. Cambridge, United Kingdom. Available at: http://www.grida.no/climate/ipcc_tar/wg1/212.htm.
[3] Excluding GHG emissions removed due to forestry and other land uses and excluding GHG emissions associated with exported electricity.
[4] The national emissions used for these comparisons are based on 2009 emissions, http://www.epa.gov/climatechange/emissions/downloads09/GHG2007-ES-508.pdf.

estimates focus on activities in Idaho and are *consumption-based;* they include emissions associated with electricity that is imported into the State.[5] Idaho's gross GHG emissions are rising at a faster rate than those of the nation as a whole (gross emissions exclude carbon sinks, such as agricultural soils). Idaho's gross GHG emissions increased 46% from 1990 to 2005, while national emissions rose by only 17% from 1990 to 2005.

Forestland emissions refer to the net CO_2 flux[6] from forested lands in Idaho, which account for about 41% of the state's land area.[7] Idaho's forests are estimated to be carbon sinks in the early 1990s but are net sources of CO_2 emissions by 2005 and later years contributing about 4.7 $MMtCO_2e$ per year to total GHG emissions in Idaho. Agricultural soils, on the other hand, are estimated to be a net GHG emissions sink of 1.2 $MMtCO_2e$ per year.

Figure ES-1 illustrates the State's gross emissions per capita and per unit of economic output. Idaho's per capita emission rate is higher than the national average of 24 metric tCO_2e/yr. Between 1990 and 2005, per capita emissions in Idaho increased slightly from 22.5 tCO_2e in 1990 to 23.4 tCO_2e/yr in 2005. The higher per capita emission rates in Idaho are driven primarily by emissions growth in the agricultural sector (agricultural industry emissions are much higher than the national average). Economic growth exceeded emissions growth both nationally and in Idaho throughout the 1990-2005 period. From 1990 to 2005, emissions per unit of gross product dropped by 28% nationally, and by 45% in Idaho.[8]

In 2005, the principal sources of Idaho's GHG emissions are agriculture and transportation, accounting for about 29% and 26% of Idaho's gross GHG emissions, respectively. The next largest contributor to emissions is the residential, commercial, and industrial (RCI) fuel use sector, accounting for 20% of the total State emissions. Emissions associated with in-state production and generation of imported electricity to meet Idaho demand accounts for about 16% of Idaho's total gross GHG emissions in 2005. Emissions associated with industrial processes, solid and liquid waste management, and fossil fuel production account for about 9% of Idaho's total gross GHG emissions in 2005.

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projections, Idaho's gross GHG emissions continue to grow, and are projected to climb to 42 $MMtCO_2e$ by 2025, reaching 86% above 1990 levels. As shown in Figure ES-3, the transportation sector is projected to be the largest contributor to future emissions growth, followed by emissions associated with electricity consumption and the use of substitutes for ozone depleting substances (ODS) in the State.

[5] See Appendix A for *production-based* GHG emission estimates, which exclude emissions associated with electricity imports.
[6] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.
[7] Total forested acreage is 21.9 million acres. Acreage by forest type available from the USFS at: http://www.fs.fed.us/ne/global/pubs/books/epa/states/ID.htm. The total land area in Idaho is 53.5 million acres http://www.50states.com/idaho.htm
[8] Based on gross domestic product by state (millions of current dollars), available from the US Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/).

Some data gaps exist in this analysis, particularly for the reference case projections. Next steps for further refinement include review and revision of key emissions drivers that will be major determinants of Idaho's future GHG emissions (such as transportation fuel use, agricultural activities, and electricity consumption). Appendices A through H provide the detailed methods, data sources, and assumptions used in estimating GHG emissions for each major sector. Key sources of uncertainty and recommendations for next steps in the refinement of these estimates are also provided.

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 Idaho based on 2002 and 2018 data from the WRAP. The results for current levels of BC emissions were a total of 3.2 $MMtCO_2e$, which is the mid-point of a range of estimated emissions (2.1 – 4.4 $MMtCO_2e$) 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 (decrease of about 2.1 $MMtCO_2e$). 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.

GHG Reductions from Recent Actions

The federal Energy Independence and Security Act (EISA) of 2007 was signed into law in December 2007. This federal law contains several requirements that will reduce GHG emissions as they are implemented over the next few years. During the development of the inventory and forecast, sufficient information was identified (e.g., implementation schedules) to estimate GHG emission reductions associated with implementing the Corporate Average Fuel Economy (CAFE) requirements in Idaho. Further reductions in transportation emissions will be achieved through the Obama plan for adopting the California vehicle CO_2 emission standards nationwide. The GHG emission reductions projected to be achieved by these recent federal actions are summarized in Table ES-2. This table shows a total reduction of about 1.6 $MMtCO_2e$ in 2025 from the business-as-usual reference case emissions, or a 3.8% reduction from the business-as-usual emissions in 2025 for all sectors combined.

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

(Million Metric Tons CO2e)	1990	2000	2005	2010	2020	2025	Explanatory Notes for Projections
Energy Use (CO_2, CH_4, N_2O)	**15.7**	**20.9**	**20.9**	**21.7**	**24.9**	**27.1**	
Electricity Use (Consumption)	**3.93**	**4.90**	**5.34**	**5.81**	**6.30**	**7.23**	
Electricity Production (in state)	0.00	0.10	0.62	0.70	1.23	1.22	*See electric sector assumptions in Appendix A.*
Natural Gas	*0.00*	*0.09*	*0.62*	*0.70*	*1.23*	*1.22*	
Petroleum	*0.001*	*0.002*	*0.000*	*0.000*	*0.000*	*0.000*	
Net Imported Electricity	3.92	4.81	4.72	5.10	5.07	6.01	
Residential/Commercial/Industrial (RCI) Fuel Use	**5.10**	**6.82**	**6.57**	**6.26**	**6.59**	**6.62**	
Coal	0.97	1.30	1.07	0.95	1.07	1.08	Based on USDOE regional projections
Natural Gas	2.18	3.49	3.19	3.45	3.66	3.88	
Oil	1.89	1.97	2.24	1.79	1.79	1.59	
Wood (CH4 and N2O)	0.05	0.06	0.07	0.07	0.07	0.08	
Transportation	**6.31**	**8.74**	**8.54**	**9.21**	**11.44**	**12.63**	
Onroad Gasoline	4.26	5.80	5.28	5.93	6.62	6.93	VMT growth rate based on WRAP projections
Onroad Diesel	1.24	2.24	2.52	2.63	4.14	5.00	
Jet Fuel and Aviation Gasoline	0.46	0.36	0.36	0.36	0.37	0.38	Based on FAA projected operations and AEO2009 efficiency gains
Marine Gasoline	0.06	0.06	0.07	0.06	0.06	0.06	Based on historical growth
Rail, Natural Gas, LPG, other	0.28	0.28	0.32	0.24	0.25	0.25	Based on USDOE regional projections
Fossil Fuel Industry	**0.32**	**0.45**	**0.42**	**0.46**	**0.55**	**0.60**	
Natural Gas Industry	0.32	0.45	0.42	0.46	0.55	0.60	Based on US DOE regional projections for natural gas consumption
Industrial Processes	**0.37**	**0.77**	**1.05**	**1.27**	**1.86**	**2.32**	
Cement Manufacture (CO_2)	0.06	0.06	0.13	0.14	0.16	0.17	Based on ID manuf. employment growth
Lime Manufacture (CO_2)	0.03	0.03	0.06	0.07	0.08	0.08	
Limestone and Dolomite Use (CO_2)	0	0.003	0.01	0.01	0.01	0.01	
Soda Ash (CO_2)	0.01	0.01	0.01	0.01	0.01	0.01	Based on 2004 and 2009 projections for U.S. production
ODS Substitutes (HFC, PFC)	0.001	0.35	0.62	0.89	1.52	1.96	EPA 2004 ODS cost study report
Semiconductor Manufacturing (HFC, PFC, and SF_6)	0.08	0.21	0.13	0.09	0.05	0.05	Based on national projections (USEPA)
Electric Power T & D (SF_6)	0.19	0.11	0.09	0.07	0.04	0.03	
Waste Management	**0.93**	**1.33**	**1.65**	**1.63**	**2.07**	**2.34**	
Solid Waste Management	0.81	1.18	1.50	1.47	1.88	2.14	Based on historical growth
Wastewater Management	0.12	0.14	0.15	0.16	0.19	0.20	Based on population
Agriculture	**5.85**	**7.62**	**9.65**	**9.66**	**10.2**	**10.6**	
Enteric Fermentation	2.60	3.30	3.88	4.08	4.66	4.96	Based on USDA livestock projections
Manure Management	0.68	1.60	2.13	2.36	2.88	3.15	
Agricultural Soils	2.56	2.71	3.64	3.23	2.70	2.47	Based on historical growth

Total Gross Emissions	**22.8**	**30.6**	**33.2**	**34.3**	**39.1**	**42.3**	
increase relative to 1990		*34%*	*46%*	*50%*	*71%*	*86%*	
Emissions Sinks	**-19.58**	**3.50**	**3.56**	**3.56**	**3.56**	**3.56**	
Forested Landscape*	-17.31	5.22	5.22	5.22	5.22	5.22	Based on 2005 USFS estimates
Urban Forestry and Land Use	-1.08	-0.54	-0.47	-0.47	-0.47	-0.47	
Agricultural Soils (cultivation practices)	-1.19	-1.19	-1.19	-1.19	-1.19	-1.19	
Net Emissions (including sinks)	**3.23**	**34.1**	**36.8**	**37.9**	**42.6**	**45.9**	
increase relative to 1990		*957%*	*1039%*	*1073%*	*1220%*	*1321%*	

[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding.
* Forested Landscape Totals are added to Net Emissions and not included in Gross Emissions because for some years emissions are negative.

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

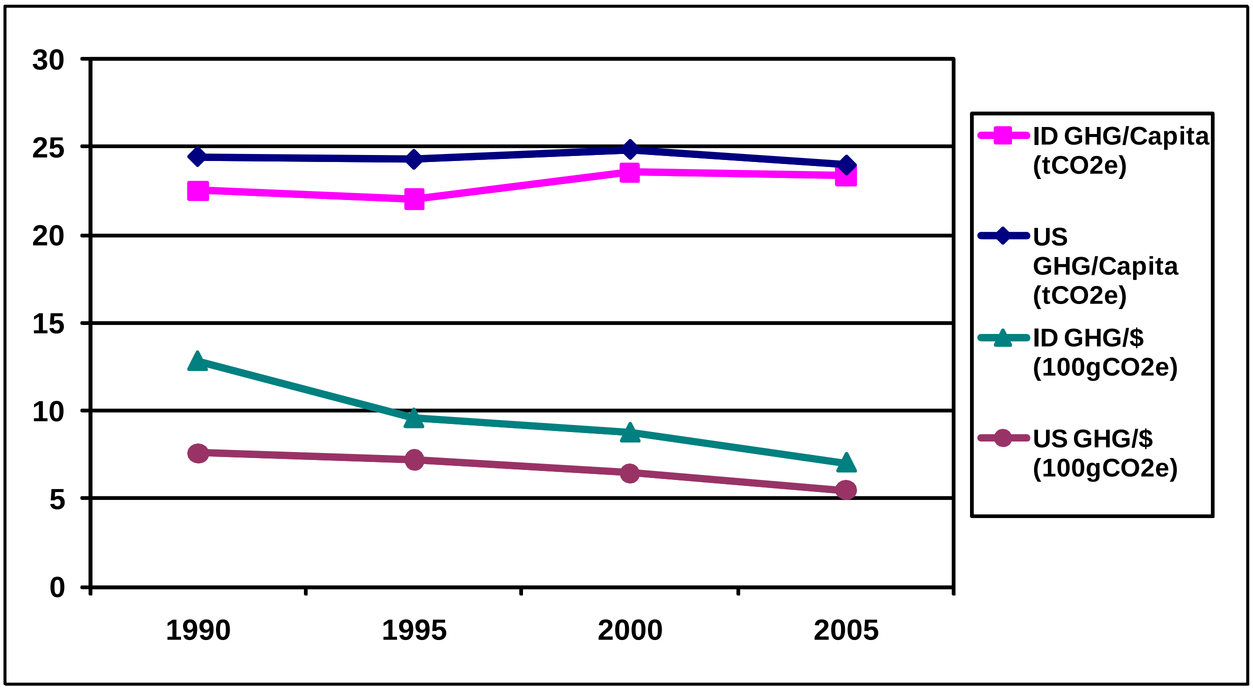
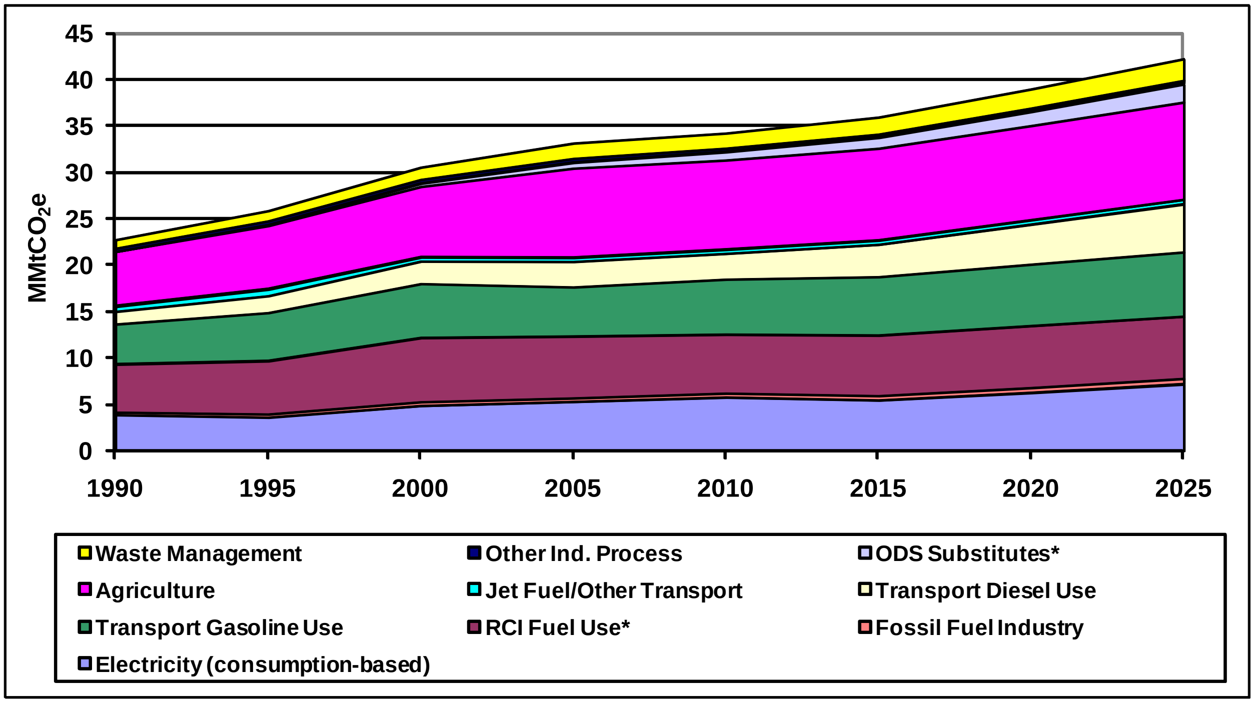
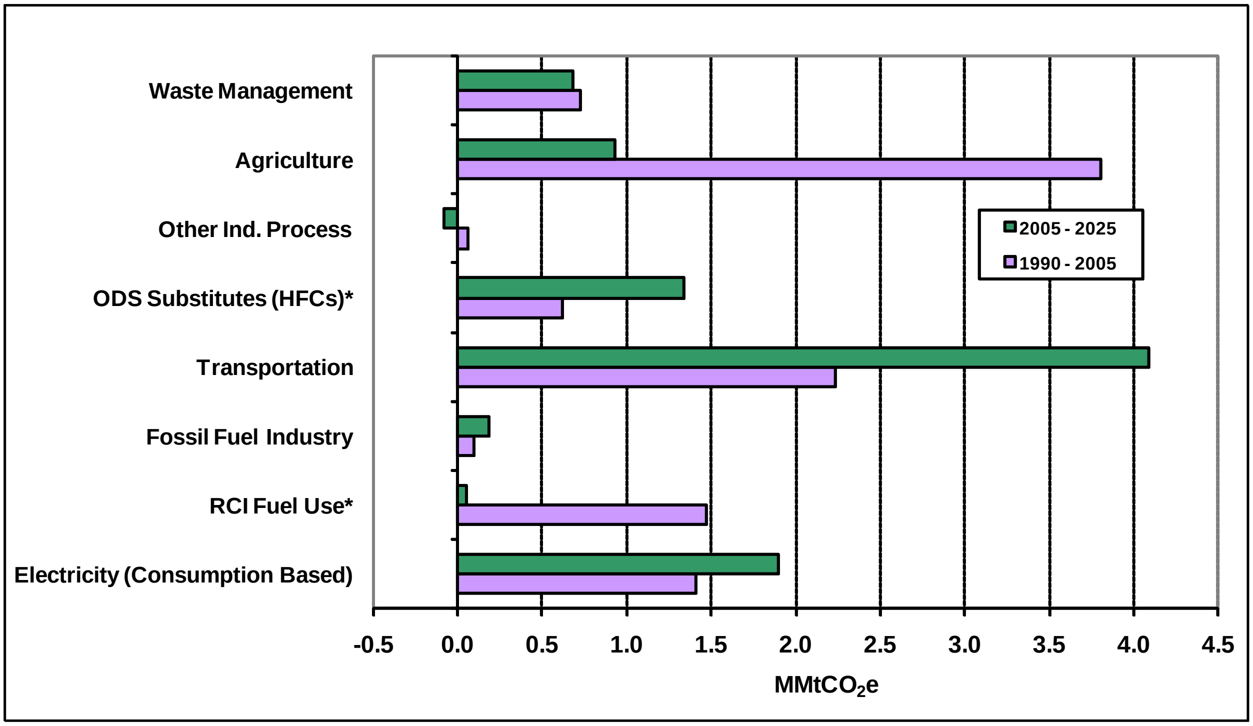


Figure ES-2. Idaho Gross GHG Emissions by Sector, 1990-2025: Historical and Projected



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

Figure ES-3. Sector Contributions to Gross Emissions Growth in Idaho, 1990-2025: Reference Case Projections ($MMtCO_2e$ Basis)



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

Table ES-2. Emission Reduction Estimates Associated with the Effect of Recent Federal Actions in Idaho (Consumption-Basis, Gross Emissions)

Sector / Recent Action	GHG Reductions ($MMtCO_2e$)		GHG Emissions (MMtCO2e)	
			Business as Usual	With Recent Actions
	2020	2025	2025	2025
Transportation and Land Use (TLU)				
Federal Corporate Average Fuel Economy (CAFE) Requirements plus California CO_2 Vehicle Standards	1.22	1.61	12.63	11.02
Total (All Sectors)			**42.33**	**40.72**

Table of Contents

Acronyms and Key Terms

AEO – Annual Energy Outlook, EIA

Ag – Agriculture

bbls – Barrels

BC – Black Carbon*

Bcf – Billion cubic feet

BLM – United States Bureau of Land Management

BOC – Bureau of Census

BOD – Biochemical Oxygen Demand

BTU – British thermal unit

C – Carbon*

$CaCO_3$ – Calcium Carbonate

CBM – Coal Bed Methane

CCS – Center for Climate Strategies

CFCs – Chlorofluorocarbons*

CH_4 – Methane*

CO – Carbon Monoxide*

CO_2 – Carbon Dioxide*

CO_2e – Carbon Dioxide equivalent*

CRP – Federal Conservation Reserve Program

DEQ – Idaho Department of Environmental Quality

EC – Elemental Carbon*

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

EGU – Electricity Generating Unit

EIA – US DOE Energy Information Administration

EIIP – Emissions Inventory Improvement Program

Eq. – Equivalent

FAA – Federal Aviation Administration

FIA – Forest Inventory and Analysis

Gg – Gigagram

GHG – Greenhouse Gases*

GWh – Gigawatt-hour

GWP – Global Warming Potential*

HFCs – Hydrofluorocarbons*

IPCC – Intergovernmental Panel on Climate Change*

kWh – kilowatt-hour

LF – Landfills

LFGTE – Landfill Gas Collection System and Landfill-Gas-to-Energy

LMOP – Landfill Methane Outreach Program

LNG – Liquefied Natural Gas

LPG – Liquefied Petroleum Gas

Mt – Metric ton (equivalent to 1.102 short tons)

MMt – Million Metric tons

MSW – Municipal Solid Waste

MW – Megawatt

MWh – Megawatt-hour

N – Nitrogen*

N_2O – Nitrous Oxide*

NO_2 – Nitrogen Dioxide*

NO_x – Nitrogen Oxides*

NASS – National Agricultural Statistics Service

NF – National Forest

NMVOCs – Non-methane Volatile Organic Compounds*

O_3 – Ozone*

ODS – Ozone-Depleting Substances*

OM – Organic Matter*

PADD – Petroleum Administration for Defense Districts

PFCs – Perfluorocarbons*

PM – Particulate Matter*

ppb – parts per billion

ppm – parts per million

ppt – parts per trillion

PV – Photovoltaic

RCI – Residential, Commercial, and Industrial

RPA – Resources Planning Act Assessment

SAR – Second Assessment Report*

SED – State Energy Data

SF_6 – Sulfur Hexafluoride*

SGIT – State Greenhouse Gas Inventory Tool

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

TAR – Third Assessment Report*

T&D – Transmission and Distribution

Tg – Teragram

TWh – Terawatt-hours

UNFCCC – United Nations Framework Convention on Climate Change

US EPA – United States Environmental Protection Agency

US DOE – United States Department of Energy

USDA – United States Department of Agriculture

USFS – United States Forest Service

USGS – United States Geological Survey

VMT – Vehicle-Miles Traveled

WECC – Western Electricity Coordinating Council

W/m^2 – Watts per Square Meter

WMO – World Meteorological Organization*

WRAP – Western Regional Air Partnership

WW – Wastewater

* – See Appendix J for more information.

Acknowledgements

We appreciate all of the time and assistance provided by numerous contacts throughout Idaho, as well as in neighboring States, and at federal agencies. Thanks go to in particular the many staff at several Idaho State Agencies for their inputs, and in particular to Robert Wilkosz, Martin Bauer, and Christopher Ramsdell of the Idaho Department of Environmental Quality (DEQ) who provided key guidance for this analytical effort.

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

Summary of Findings

Introduction

The Center for Climate Strategies (CCS) prepared this report for the Idaho Department of Environmental Quality (DEQ). The report contains an inventory and forecast of the State's greenhouse gas (GHG) emissions from 1990 to 2025 to provide a comprehensive understanding of Idaho's current and possible future GHG emissions. This report revises and updates the GHG emissions inventory and forecast for Idaho prepared by CCS in 2007 for DEQ through an effort of the Western Regional Air Partnership (WRAP). This report provides a comprehensive understanding of Wyoming's current and possible future GHG emissions. The information presented provides the State with a starting point for further revisions and improvements to data sources and assumptions.

Historical GHG emission estimates (1990 through 2007)[9] 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 Idaho-specific data and inputs. The initial reference case projections (2008-2025) are based on a compilation of various existing projections of electricity generation, fuel use, and other GHG-emitting activities, along with a set of simple, transparent assumptions described in the appendices of this report.

This report covers the six gases included in the US Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates the relative contribution of each gas to global average radiative forcing on a Global Warming Potential- (GWP-) weighted basis.[10] The final appendix to this report provides a more complete discussion of GHGs and GWPs. Emissions of black carbon (BC) were also estimated. Black carbon is an aerosol species with a positive climate forcing potential (that is, the potential to warm the atmosphere, as GHGs do); however, black carbon currently does not have a GWP defined by the IPCC due to uncertainties in both the direct and indirect effects of BC on atmospheric processes (see Appendices I and J for more details). Therefore, except for Appendix I, all of the summary tables and graphs in this report cover emissions of just the six GHGs noted above.

It is important to note that the emissions estimates for the electricity sector reflect the *GHG emissions associated with the electricity sources used to meet Idaho'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.*

[9] The last year of available historical data varies by sector; ranging from 2004 to 2008.
[10] These gases and the concepts of radiative forcing and GWP are described in Appendix J.

Idaho Greenhouse Gas Emissions: Sources and Trends

Table 1 provides a summary of GHG emissions estimated for Idaho by sector for the years 1990, 2000, 2005, 2010, 2020, and 2025. Details on the methods and data sources used to construct these estimates are provided in the appendices to this report**.** In the sections below, we discuss GHG emission sources (positive, or *gross*, emissions) and sinks (negative emissions) separately in order to identify trends, projections, and uncertainties clearly for each.

This next section of the report provides a summary of the historical emissions (1990 through 2007) followed by a summary of the reference-case projection-year emissions (2008 through 2025) 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 Idaho. CCS estimated that BC emissions in 2002 ranged from 2.1 – 4.4 million metric tons (MMt) of carbon dioxide equivalent (CO_2e) with a mid-point of 3.2 $MMtCO_2e$. A range is estimated based on the uncertainty in the global modeling analyses that serve as the basis for converting BC mass emissions into their CO_2e. Emissions in key contributing sectors are expected to drop by about 2.1 $MMtCO_2e$/yr by 2018 as a result of new engine and fuel standards affecting onroad and nonroad diesel engines. 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. Idaho Historical and Reference Case GHG Emissions, by Sector[a]

(Million Metric Tons CO2e)	1990	2000	2005	2010	2020	2025	Explanatory Notes for Projections
Energy Use (CO_2, CH_4, N_2O)	**15.7**	**20.9**	**20.9**	**21.7**	**24.9**	**27.1**	
Electricity Use (Consumption)	**3.93**	**4.90**	**5.34**	**5.81**	**6.30**	**7.23**	
Electricity Production (in state)	0.00	0.10	0.62	0.70	1.23	1.22	*See electric sector assumptions in Appendix A.*
Natural Gas	*0.00*	*0.09*	*0.62*	*0.70*	*1.23*	*1.22*	
Petroleum	*0.001*	*0.002*	*0.000*	*0.000*	*0.000*	*0.000*	
Net Imported Electricity	3.92	4.81	4.72	5.10	5.07	6.01	
Residential/Commercial/Industrial (RCI) Fuel Use	**5.10**	**6.82**	**6.57**	**6.26**	**6.59**	**6.62**	
Coal	0.97	1.30	1.07	0.95	1.07	1.08	Based on USDOE regional projections
Natural Gas	2.18	3.49	3.19	3.45	3.66	3.88	
Oil	1.89	1.97	2.24	1.79	1.79	1.59	
Wood (CH4 and N2O)	0.05	0.06	0.07	0.07	0.07	0.08	
Transportation	**6.31**	**8.74**	**8.54**	**9.21**	**11.44**	**12.63**	
Onroad Gasoline	4.26	5.80	5.28	5.93	6.62	6.93	VMT growth rate based on WRAP projections
Onroad Diesel	1.24	2.24	2.52	2.63	4.14	5.00	
Jet Fuel and Aviation Gasoline	0.46	0.36	0.36	0.36	0.37	0.38	Based on FAA projected operations and AEO2009 efficiency gains
Marine Gasoline	0.06	0.06	0.07	0.06	0.06	0.06	Based on historical growth
Rail, Natural Gas, LPG, other	0.28	0.28	0.32	0.24	0.25	0.25	Based on USDOE regional projections
Fossil Fuel Industry	**0.32**	**0.45**	**0.42**	**0.46**	**0.55**	**0.60**	
Natural Gas Industry	0.32	0.45	0.42	0.46	0.55	0.60	Based on US DOE regional projections for natural gas consumption
Industrial Processes	**0.37**	**0.77**	**1.05**	**1.27**	**1.86**	**2.32**	
Cement Manufacture (CO_2)	0.06	0.06	0.13	0.14	0.16	0.17	Based on ID manuf. employment growth
Lime Manufacture (CO_2)	0.03	0.03	0.06	0.07	0.08	0.08	
Limestone and Dolomite Use (CO_2)	0	0.003	0.01	0.01	0.01	0.01	
Soda Ash (CO_2)	0.01	0.01	0.01	0.01	0.01	0.01	Based on 2004 and 2009 projections for U.S. production
ODS Substitutes (HFC, PFC)	0.001	0.35	0.62	0.89	1.52	1.96	EPA 2004 ODS cost study report
Semiconductor Manufacturing (HFC, PFC, and SF_6)	0.08	0.21	0.13	0.09	0.05	0.05	Based on national projections (USEPA)
Electric Power T & D (SF_6)	0.19	0.11	0.09	0.07	0.04	0.03	
Waste Management	**0.93**	**1.33**	**1.65**	**1.63**	**2.07**	**2.34**	
Solid Waste Management	0.81	1.18	1.50	1.47	1.88	2.14	Based on historical growth
Wastewater Management	0.12	0.14	0.15	0.16	0.19	0.20	Based on population
Agriculture	**5.85**	**7.62**	**9.65**	**9.66**	**10.2**	**10.6**	
Enteric Fermentation	2.60	3.30	3.88	4.08	4.66	4.96	Based on USDA livestock projections
Manure Management	0.68	1.60	2.13	2.36	2.88	3.15	
Agricultural Soils	2.56	2.71	3.64	3.23	2.70	2.47	Based on historical growth

Total Gross Emissions	**22.8**	**30.6**	**33.2**	**34.3**	**39.1**	**42.3**	
increase relative to 1990		*34%*	*46%*	*50%*	*71%*	*86%*	
Emissions Sinks	**-19.58**	**3.50**	**3.56**	**3.56**	**3.56**	**3.56**	
Forested Landscape*	-17.31	5.22	5.22	5.22	5.22	5.22	Based on 2005 USFS estimates
Urban Forestry and Land Use	-1.08	-0.54	-0.47	-0.47	-0.47	-0.47	
Agricultural Soils (cultivation practices)	-1.19	-1.19	-1.19	-1.19	-1.19	-1.19	
Net Emissions (including sinks)	**3.23**	**34.1**	**36.8**	**37.9**	**42.6**	**45.9**	
increase relative to 1990		*957%*	*1039%*	*1073%*	*1220%*	*1321%*	

[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding.
* Forested Landscape Totals are added to Net Emissions and not included in Gross Emissions because for some years emissions are negative.

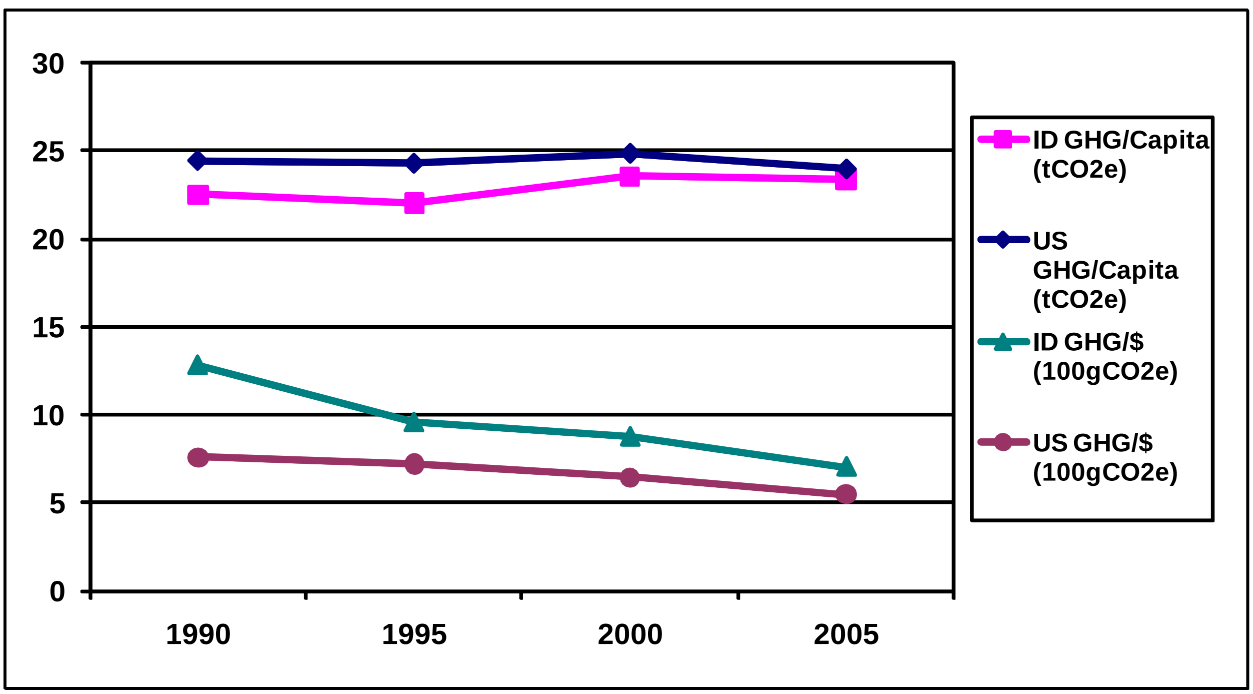
Historical Emissions

Overview

Preliminary analyses suggest that in 2005, activities in Idaho accounted for approximately 33 million metric tons (MMt) of CO_2e emissions, an amount equal to about 0.5% of total US GHG emissions (based on 2009 US emissions estimates).[11] Idaho's gross GHG emissions are rising faster than those of the nation as a whole (gross emissions exclude carbon sinks, such as agricultural soils). Idaho's gross GHG emissions increased 46% from 1990 to 2005, while national emissions rose by only 17% from 1990 to 2005.

Figure 1 illustrates the State's emissions per capita and per unit of economic output. Idaho's per capita emission rate is higher than the national average of 24 metric tCO_2e/yr. Between 1990 and 2005, per capita emissions in Idaho increased slightly from 22.5 metric tCO_2e in 1990 to 23.4 metric tCO_2e/yr in 2005. The higher per capita emission rates in Idaho are driven primarily by emissions growth in the agricultural sector (agricultural industry emissions are much higher than the national average). Economic growth exceeded emissions growth both nationally and in Idaho throughout the 1990-2005 period. From 1990 to 2005, emissions per unit of gross product dropped by 28% nationally, and by 45% in Idaho.[12]

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

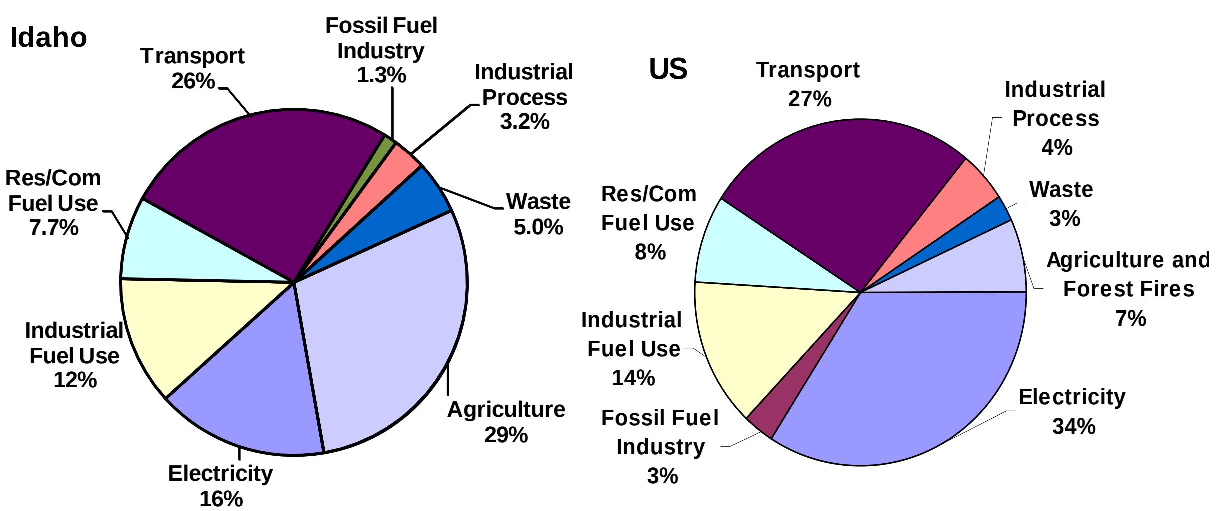


[11] United States emissions estimates are drawn from US EPA 2009, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2009*.

[12] Based on gross domestic product by state (millions of current dollars), available from the US Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/). The national emissions used for these comparisons are based on 2004 emissions, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

Agriculture and transportation are the State's principal GHG emissions sources. Together, these two sectors accounted for 55% of Idaho's *gross* GHG emissions in 2005, as shown in Figure 2. The use of fossil fuels — natural gas, oil products, and coal — in the residential, commercial, and industrial (RCI) sectors constituted another 19% of total State emissions. The combustion of fossil fuels for electricity generation (including emissions associated with the generation of electricity imported from other States) constituted only 13% of total State emissions which is significantly less than the nation as a whole.

Figure 2. Gross GHG Emissions by Sector, 2005, Idaho and US



Notes: Res/Com = residential and commercial fuel use sectors; emissions for the residential, commercial, and industrial fuel use sectors are associated with the direct use of fuels (natural gas, petroleum, coal, and wood) to provide space heating, water heating, process heating, cooking, and other energy end-uses. The commercial sector accounts for emissions associated with the direct use of fuels by, for example, hospitals, schools, government buildings (local, county, and state), and other commercial establishments. The industrial processes sector accounts for emissions associated with manufacturing and excludes emissions included in the industrial fuel use sector. The transportation sector accounts for emissions associated with fuel consumption by all on-road and non-highway vehicles. Non-highway vehicles include jet aircraft, gasoline-fueled piston aircraft, railway locomotives, boats, and ships. Emissions from non-highway agricultural and construction equipment are included in the industrial sector. Electricity = electricity generation sector emissions on a consumption basis (including emissions associated with electricity imported from outside of Idaho and excluding emissions associated with electricity exported from Idaho to other states). At a national level and in some years in Idaho, forests act as a net sink of CO_2; therefore, they do not show up in the above graph of gross U.S. or Idaho emissions sources.

Industrial process emissions comprised 3% of State GHG emissions in 2005. 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 5% of Idaho's gross GHG emissions in 2025 due to growth in other sectors.[13] Other industrial process

[13] 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.

emissions result from CO_2 released during soda ash, limestone, and dolomite use. Landfills and wastewater management facilities, and the fossil fuel industry produced CH_4 and N_2O emissions that together accounted for over 6% of the State's emissions in 2005.

Forestry emissions refer to the net CO_2 flux[14] from forested lands in Idaho, which account for about 41% of the state's land area,[15] and also from urban forestry and land use. The dominant forest types in Idaho are Douglas fir forests which make up about 34% of forested lands and Fir-Spruce forests which make up another 24%. Other important forest types are Ponderosa pine, Lodgepole pine, and Hemlock-Sitka spruce forests. Based on U.S. Forest Service (USFS) data, Idaho's forests are estimated to be a net source of CO_2 emissions in 2005 contributing about 5.2 $MMtCO_2e$ per year to total GHG emissions in Idaho. Note that forestry was estimated to be a net sink in 1990, and therefore, is not included in the gross emission totals for any years. In contrast, urban forestry and land use and also agricultural soil carbon changes due to cultivation practices are estimated to be net sinks in Idaho, sequestering 0.5 $MMtCO_2e$ and 1.2 $MMtCO_2e$ in 2005, respectively.

A Closer Look at the Two Major Sources: Agriculture and Transportation

Agriculture Sector

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

The agricultural sector accounted for about 29% of Idaho's gross GHG emissions in 2005 (about 10 $MMtCO_2e$), which was significantly higher than the national average share of emissions from the agricultural sector (7%). Animal husbandry operations are the primary contributor to emissions in the agricultural sector. From 1990 through 2005, emissions associated with enteric fermentation and manure management have increased at an average annual rate of about 2.7% and 7.8%, respectively. The high growth rates associated with enteric fermentation and manure management are driven by significant growth in primarily the dairy cattle population, and to a lesser extent by the beef cattle and swine populations in Idaho. Emissions associated with the management of agricultural soils contributed an additional 3.6 $MMtCO_2e$ in 2005. Emissions from this category increased at about 2.4% annually from 1990 through 2005.

Transportation Sector

[14] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.
[15] Total forested acreage is 21.9 million acres. Acreage by forest type available from the USFS at: http://www.fs.fed.us/ne/global/pubs/books/epa/states/ID.htm. The total land area in Idaho is 53.5 million acres http://www.50states.com/idaho.htm)

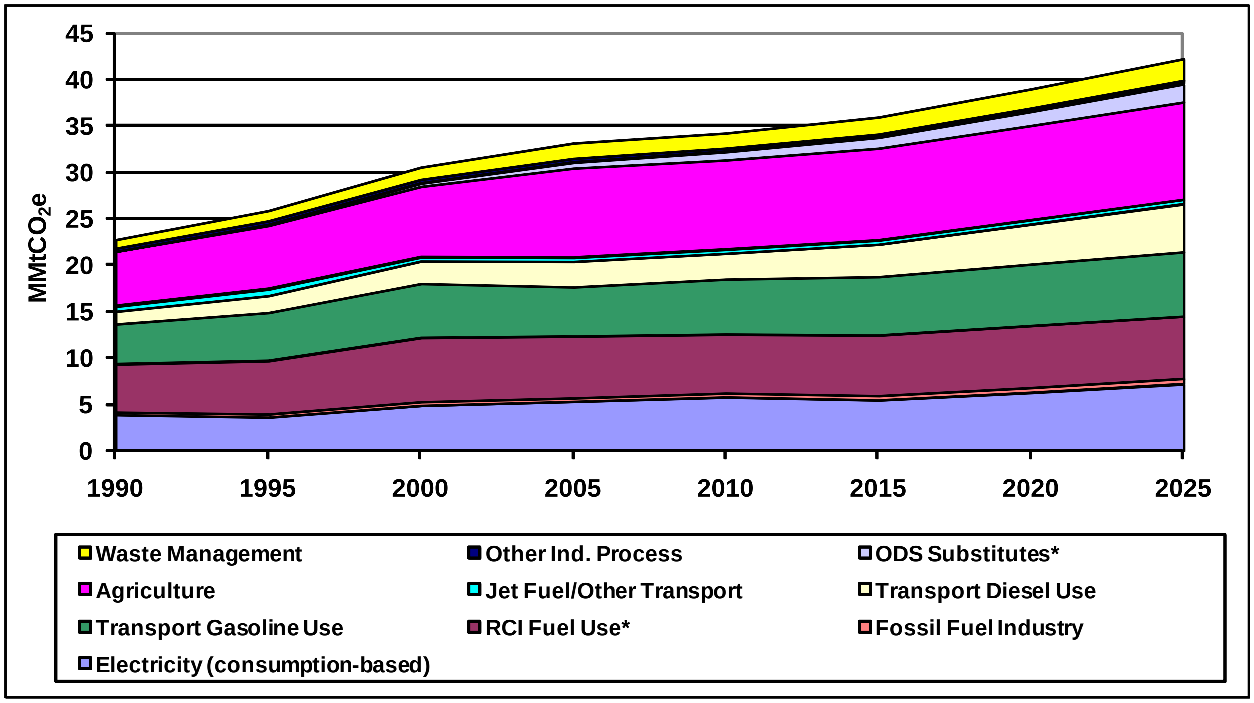
As shown in Figure 2, the transportation sector accounted for about 26% of Idaho's gross GHG emissions in 2005 (about 8.5 $MMtCO_2e$), which was slightly less than the national average share of emissions from transportation fuel consumption (27%). The GHG emissions associated with Idaho's transportation sector increased by 2.2 $MMtCO_2e$ between 1990 and 2005, accounting for about 21% of the State's net growth in gross GHG emissions in this time period.

From 1990 through 2005, GHG emissions from transportation fuel use have risen at an average rate of about 2.0% annually. In 2005, onroad gasoline vehicles accounted for about 62% of transportation GHG emissions. Onroad diesel vehicles accounted for another 30% of emissions, and air travel for roughly 4%. Rail, marine gasoline, and other sources (natural gas- and liquefied petroleum gas- (LPG-) fueled-vehicles used in transport applications) accounted for the remaining 4% of transportation emissions. As a result of Idaho's population and economic growth and an increase in total vehicle miles traveled (VMT) during the 1990s, onroad gasoline emissions grew 24% between 1990 and 2005. Meanwhile, onroad diesel emissions rose 103% during that period. Aviation fuel use declined by about 23% from 1990 to 2005.

Reference Case Projections (Business as Usual)

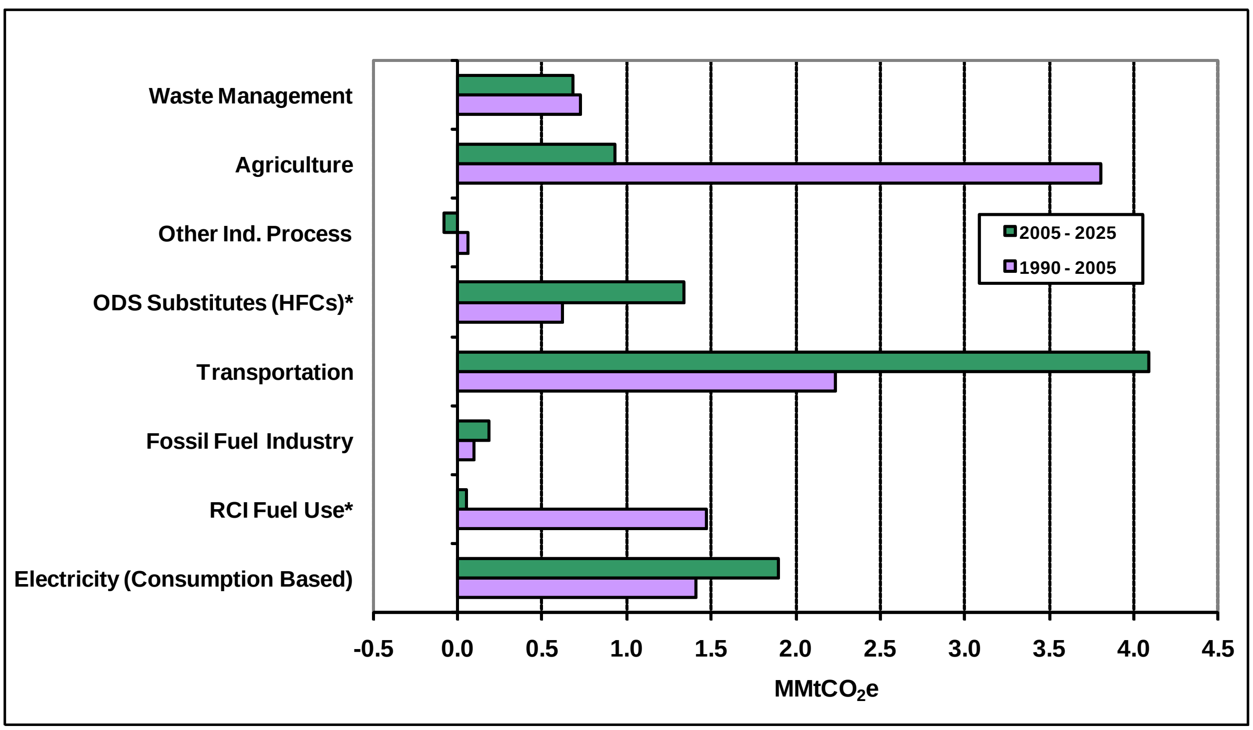
Relying on a variety of sources for projections, as noted below and in the Appendices, we developed a simple reference case projection of GHG emissions through 2025. As illustrated in Figure 3 and shown numerically in Table 1, under the reference case projections, Idaho gross GHG emissions continue to grow steadily, climbing to about 42 $MMtCO_2e$ by 2025, 86% above 1990 levels. The transportation sector is projected to be the largest contributor to future emissions growth, followed by emissions associated with the consumption of fossil fuels to meet electricity demand, with the use of ODS substitutes, with the agriculture sector, and with the waste management sector, as shown in Figure 4.

Figure 3. Idaho 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 Idaho, 1990-2020: Historic and Reference Case Projections ($MMtCO_2e$ Basis)



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

Reference Case Projections with Recent Actions

The federal Energy Independence and Security Act (EISA) of 2007 was signed into law in December 2007. This federal law contains several requirements that will reduce GHG emissions as they are implemented over the next few years. During the development of this inventory and forecast, sufficient information was identified (e.g., implementation schedules) to estimate GHG emission reductions associated with implementing the Corporate Average Fuel Economy (CAFE) requirements in Idaho. Further reductions in transportation emissions will be achieved through the Obama plan for adopting the California vehicle CO_2 emission standards nationwide.

The GHG emission reductions projected to be achieved by this recent federal action are summarized in Table 2. This table shows a total reduction of about 1.61 $MMtCO_2e$ in 2025 from the business-as-usual reference case emissions, or a 3.8% reduction from the business-as-usual emissions in 2025 for all sectors combined.

It is anticipated that the process of developing a climate action plan will result in identifying additional federal and Idaho-specific recent actions that will be quantified in future analyses.

The following provides a brief summary of the component of the EISA that was analyzed as a recent federal action.

Federal Corporate Average Fuel Economy Requirements: Subtitle A of Title I of EISA imposes new CAFE standards beginning with the 2011 model year vehicles. The average combined fuel economy of automobiles will be at least 35 mpg by 2020, with separate standards applying to passenger and non-passenger automobiles. The standard will be phased in, starting with the 2011 model year, so that the CAFE increases each year until the average fuel economy of 35 mpg is reached by 2020.

Table 2. Emission Reduction Estimates Associated with the Effect of Recent Federal Actions in Idaho (Consumption-Basis, Gross Emissions)

	GHG Reductions ($MMtCO_2e$)		GHG Emissions (MMtCO2e)	
			Business as Usual	With Recent Actions
Sector / Recent Action	2020	2025	2025	2025
Transportation and Land Use (TLU)				
Federal Corporate Average Fuel Economy (CAFE) Requirements plus California CO_2 Vehicle Standards	1.22	1.61	12.63	11.02
Total (All Sectors)			**42.33**	**40.72**

Updates from 2007 Inventory and Forecast

The following identifies the revisions that were made in the Idaho GHG I&F by sector, as reported here, compared to the I&F prepared for DEQ and WRAP by CCS in 2007, thus explaining the differences between this report and the initial assessment completed in 2007:

Electricity Supply:

- Updated AEO projections from 2009 and later years to AEO2009 data.
- Added historical electricity sales and generation through 2008.
- Extended the forecast to 2025.

Transportation:

- CH_4 and N_2O emissions were updated based on the latest SIT mobile combustion module. This corrected an error of overestimating CH_4 and N_2O emissions that had existed in previous Idaho I&F.
- Estimates of VMT were updated based on newer SIT mobile combustion module.
- The aviation sector was updated with TAF 2009 data.
- Projected seat-miles/gallon values, which are used in adjusting the jet fuel growth rates, were updated to AEO2009 data.
- Fuel consumption estimates now use updated EIA data through 2007.
- Energy consumption estimates now use AEO 2009 data for the Mountain region for the projections.
- Fuel growth rates now use VMT growth rates in comparison with estimates of future fleet fuel economy, rather than in comparison with new vehicle fuel economy.
- Rail diesel estimate updated through 2007 using EIA Fuel Oil and Kerosene Sales.
- Marine gasoline estimate updated from FHWA "Highway Statistics" through 2007.
- The forecast was extended to 2025.
- An analysis of the reductions from the new CAFE standards was added.

Residential/Commercial/Industrial (RCI):

- Estimates now use the most recent data from SIT modules (Stationary Combustion Module and CO2FFC Module) which includes historical fuel consumption estimates through 2007.
- Energy consumption projections now use AEO2009 data for the Mountain region.
- All RCI estimates were extended to 2025.

Agriculture:

- Estimates use the most recent data from SIT Agriculture Module.
- All agricultural estimates have been extended to 2025.

Forestry:

- The Forest carbon pools were updated with new USFS inventory data that has been published since the last draft (previously the forest carbon pool was based on inventory data that had been personally communicated by USFS staff).
- The harvested wood product carbon pool has been added.

- Total forestry and timberland acreage has been added.
- Urban forestry and land use has been added (includes urban canopy, trimmings and food scraps in landfills, and settlement soils).
- All forestry estimates have been extended to 2025.

Waste:

- EPA's Solid Waste and Wastewater modules were updated with most the most recent version of SIT.
- The LMOP database is now used to determine when CH_4 emissions from controlled at LFGTE facilities began.
- CCS adjusted the oxidation factor that was applied to total potential CH_4 emissions at LFGTE landfills. Now the oxidation factor is only applied to the percentage of emissions that were not collected at the LFGTE landfills. This matches the methodology used by the current SIT Solid Waste module.
- CCS verified that the data and parameters entered into the model were consistent with those originally submitted by IDDEQ.
- All waste estimates have been extended to 2025.

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, agriculture, electricity demand, and RCI fuel use growth rates that will be major determinants of Idaho's future GHG emissions (See Table 3 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.

Table 3. Key Annual Growth Rates for Idaho, Historical and Projected

	1990-2008	2008-2025	Sources
Population*	2.2%	1.9%	Idaho Power *2006 Integrated Resource Plan - Appendix C - Economic Forecast*
Electricity Sales	1.6%	1.8%	US DOE Energy Information Administration (EIA) data for 1990-2008
Vehicle Miles Traveled	2.8%	1.6%	VMT growth rate from WRAP mobile source inventory

* For the RCI fuel consumption sectors, population and employment projections for Idaho were used together with US DOE EIA's Annual Energy Outlook 2009 (AEO2009) projections of changes in fuel use for the EIA's Mountain 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 Idaho's residential natural gas use is calculated as the Idaho population growth times the change in per capita natural gas use for the Mountain region.

As examples, the assumptions on VMT and air travel growth have large impacts on projected GHG emissions growth in the State. Also, uncertainty remains on estimates for future livestock populations in the State. Finally, historic and projected GHG sinks or emissions from forestry, which can greatly affect the net GHG emissions attributed to Idaho, should be revised as new estimates are produced by the USFS to support the national inventory.

Emissions of aerosols, particularly BC from fossil fuel combustion, could have significant impacts in terms of radiative forcing (i.e., climate impacts). Methodologies for conversion of BC mass estimates and projections to global warming potential involve significant uncertainty at present, but CCS has developed and used an approach for estimating BC emissions based on methods used in other States. Current estimates suggest a fairly significant CO_2e contribution from BC emissions, as compared to the CO_2e contributed from the gases (about 10% BC contribution relative to the CO_2e from the gases in 2000). However, emissions in key contributing sectors (onroad and nonroad diesel engines) are expected to decline in the 2018 forecast; see Appendix I).

Approach

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

General Methodology

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

In most cases, we follow the same approach to emissions accounting for historical inventories used by the US EPA in its national GHG emissions inventory[16] and its guidelines for States.[17] These inventory guidelines were developed based on the guidelines from the IPCC, the international organization responsible for developing coordinated methods for national GHG inventories.[18] The inventory methods provide flexibility to account for local conditions. The key sources of activity and projection data used are shown in Table 4. Table 4 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:

[16] 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.
[17] http://yosemite.epa.gov/oar/globalwarming.nsf/content/EmissionsStateInventoryGuidance.html.
[18] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm

- **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*.

- **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods.** This analysis aims to comprehensively cover GHG emissions associated with activities in Idaho. It covers all six GHGs covered by US and other national inventories: CO_2, CH_4, N_2O, SF_6, HFCs, PFCs, and BC. The inventory estimates are for the year 1990, with subsequent years included up to most recently available data (typically 2004 to 2008), with projections to 2010, 2020, and 2025.

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

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

- **Use of Consumption-Based Emissions Estimates:** To the extent possible, we estimated emissions that are caused by activities that occur in Idaho. For example, we reported emissions associated with the electricity consumed in Idaho. 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.

Table 4. Key Sources for Idaho Data, Inventory Methods, and Growth Rates

Source	Information provided	Use of Information in this Analysis
US EPA State Greenhouse Gas Inventory Tool (SIT)	US EPA SIT is a collection of linked spreadsheets designed to help users develop State GHG inventories. US EPA SIT	Where not indicated otherwise, SIT is used to calculate emissions from RCI fuel combustion, transportation,

	contains default data for each State for most of the information required for an inventory. The SIT 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).	industrial processes, agriculture and forestry, and waste. We use SGIT emission factors (CO_2, CH_4, and N_2O per BTU consumed) to calculate energy use emissions.
US DOE Energy Information Administration (EIA) State Energy Data (SED)	EIA SED provides energy use data in each State, annually to 2007 for all fuels	EIA SED is the source for most energy use data.. Emission factors from US EPA SIT are used to calculate energy-related emissions.
EIA AEO2009	EIA AEO2009 projects energy supply and demand for the US from 2006 to 2030. Energy consumption is estimated on a regional basis. Idaho is included in the Mountain Census region (AZ, CO, ID, MT, NM, NV, UT, and WY).	EIA AEO2009 is used to project changes in per capita (residential), per employee (commercial/industrial).
American Gas Association - Gas Facts	Natural gas transmission and distribution pipeline mileage.	Pipeline mileage from Gas Facts used with SGIT to estimate natural gas transmission and distribution emissions.
US EPA Landfill Methane Outreach Program (LMOP)	LMOP provides landfill waste-in-place data.	Waste-in-place data used to estimate annual disposal rate, which was used with SGIT to estimate emissions from solid waste.
US Forest Service	Data on forest carbon stocks for multiple years.	Data are used to calculate CO_2 flux over time (terrestrial CO_2 sequestration in forested areas).
USDS National Agricultural Statistics Service (NASS)	USDA NASS provides data on crops and livestock.	Crop production data used to estimate agricultural residue and agricultural soils emissions; livestock population data used to estimate manure and enteric fermentation emissions.

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 Idaho. This entails accounting for the electricity sources used by Idaho utilities to meet consumer demands. As we refine this analysis, we may also attempt to estimate other sectoral emissions on a consumption basis, such as accounting for emissions from transportation fuel used in Idaho, but purchased out-of-state. In some cases this can require venturing into the relatively complex terrain of life-cycle analysis. In general, we recommend considering a consumption-based approach where it will significantly improve the estimation of the emissions impact of potential mitigation strategies. For example re-use, recycling, and source reduction can lead to emission reductions resulting from lower energy requirements for material production (such as paper, cardboard, and aluminum), even though production of those materials, and emissions associated with materials production, may not occur within the State.

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

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

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

Appendix A. Electricity Use and Supply

Historically, much of Idaho's electricity has been imported into the State from power plants in neighboring states. The relatively low amount of in-state generation is dominated by hydro-electric plants and a few natural gas plants. This situation – high levels of imports combined with a mix of renewable and natural gas generation in-state – is projected to continue throughout the projection period of this analysis. This section examines electricity-related emissions from both a production and consumption basis, but the emission totals in the main section of the report are on a consumption basis.

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

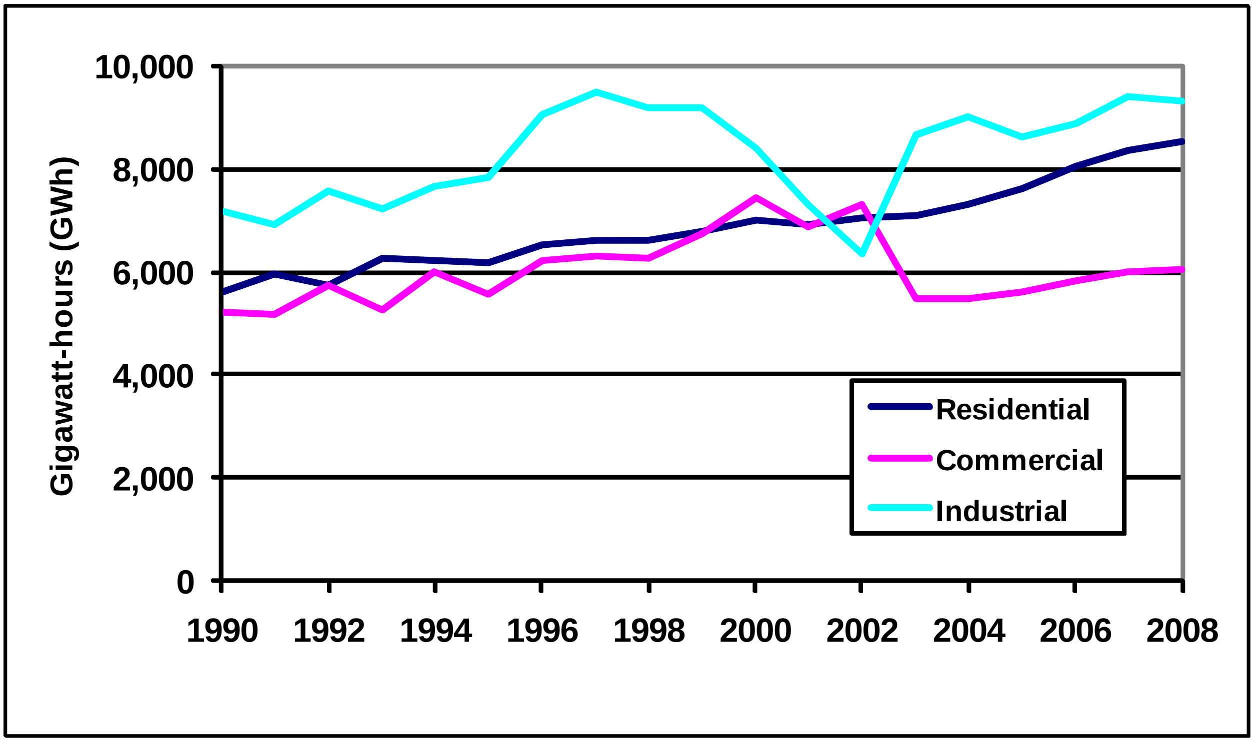
Electricity Consumption

At about 15,900 kWh/capita (2008 data), Idaho has relatively high electricity consumption per capita. By way of comparison, the per capita consumption for the U.S. was about 12,200 kWh per year.[19] Many components influence a state's per capita electricity consumption including the impact of weather on demand for heating and cooling, the price of electricity, the size and type of industries in the State, the prevalence of electric heating, and the type and efficiency of equipment in the residential, commercial and industrial sectors.

As shown in Figure A1, electricity sales in Idaho have generally shown increases from 1990 through 2008. Overall, total electricity consumption increased at an average annual rate of 1.6% from 1990 to 2008, lower than the population growth rate of 2.2% per year.[20] During this period, electricity sales in the residential sector grew by an average of 2.3% per year. Both the commercial sector and the industrial sector showed significant increases and decreases since 2000.[21] The average annual growth in electricity sales between 1990 and 2008 was 0.8% for the commercial sector and 1.5% for the industrial sector.

[19] Census bureau for U.S. population, Energy Information Administration for electricity sales.
[20] Population from Idaho Power, 2006 Integrated Resource Plan, Appendix C – Economic Forecast, "Forecast of Population, Households, and Persons per Household", Compiled and prepared by John Church, Idaho Economics, P.O. Box 45694, Boise, ID 83711-5694, (208) 323-0732, e-mail: ideconomics@earthlink.net.
[21] CCS has attempted to determine if the changes in electricity sales by sector are related to data reporting by sector, rather than actual changes in sales. The data source for this information is the Energy Information Administration (EIA) - State Energy Data and Electric Power Annual. EIA staff responded that the data are provided by utilities based on filling out consistent data forms. However EIA were unable to verify the data beyond what utilities provided.

Figure A1. Electricity Consumption by Sector in Idaho, 1990-2008[22]



Source: EIA State Energy Data.

Projections for electricity sales from 2009 through 2025 are based on a sales weighted average of electricity sales projected by the three largest utilities in Idaho, Idaho Power, Pacificorp and Avista.[23] Since these three utilities account for over 87% of Idaho's retail electricity sales, the projections from their load forecasts are assumed to be representative of the whole state and have been applied to total electricity sales. Table A1 reports historic and projected annual average growth rates.

[22] Note from 1990-2002, the EIA data includes a category referred to as "other," which included lighting for public buildings, streets, and highways, interdepartmental sales, and other sales to public authorities, agricultural and irrigation sales where separately identified, electrified rail and various urban transit systems (such as automated guideway, trolley, and cable). To report total electricity in Figure A2, the sales from the "other" category are included with the commercial sector. The decision to include with commercial rather than the other sectors is based on comparing the trends of electricity sales from 2000-2002 with 2003 sales.

[23] Idaho Power. *2006 Integrated Resource Plan.* Pacificorp's projections for Idaho were found in a powerpoint presentation from one of Pacificorp's Public Input Meeting for the 2006 Integrated Resource Plan (April 20, 2006). http://www.utah-power.com/File/File64180.pdf. Accessed on November 14, 2006. Avista. *2005 Integrated Resource Plan.*

Table A1. Electricity Growth Rates, Historical and Projected

Sector	Historical		Projections		
	1990-2000	2000-2008	2008-2010	2010-2020	2020-2025
Residential	2.2%	2.5%	2.0%	1.7%	1.8%
Commercial	3.6%	-2.5%	2.7%	2.2%	2.4%
Industrial	1.6%	1.3%	1.8%	1.5%	1.6%
Total	**2.4%**	**0.6%**	**2.1%**	**1.8%**	**1.9%**

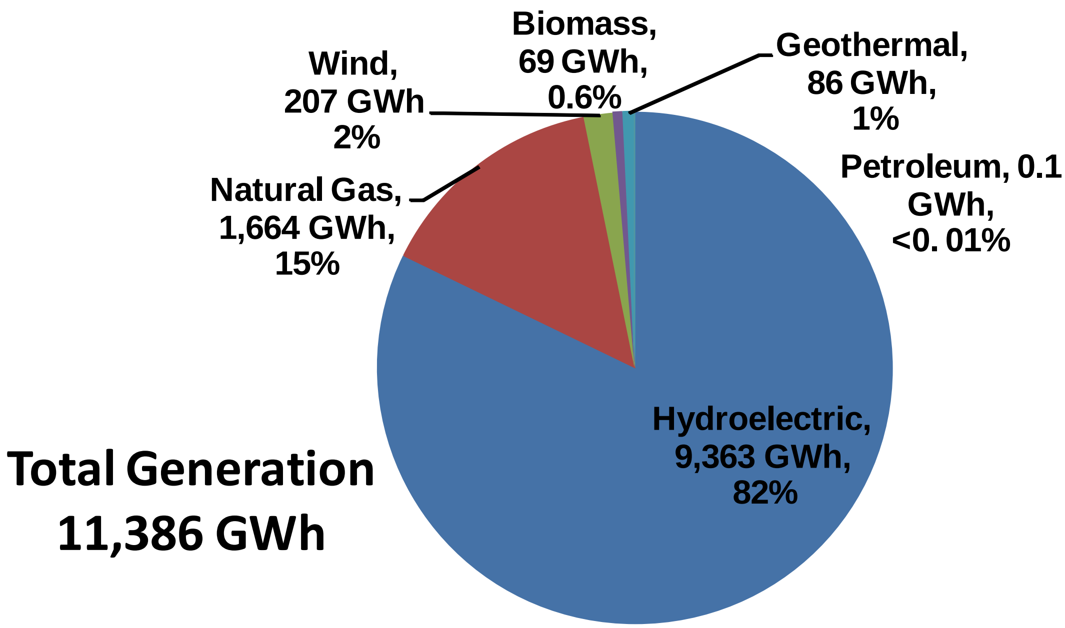
Source: Historic from EIA data, projections are CCS calculations for the sales weighted growth based on Idaho Power 2006 Integrated Resource Plan; PacifiCorp 2006 Load Forecast; and Avista 2005 Integrated Resource Plan.

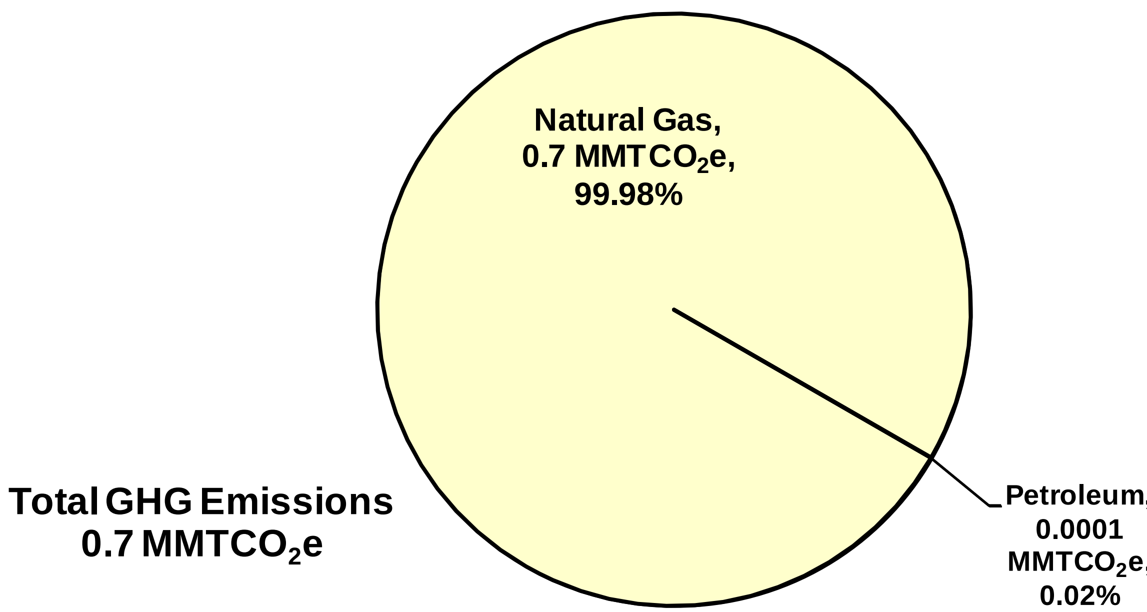
Electricity Generation – Idaho's Power Plants

The following section provides information on GHG emissions and other activity associated with power plants *located in Idaho*. Since Idaho is part of the interconnected Western Electricity Coordinating Council (WECC) region, electricity generated in Idaho can be exported to serve needs in other states and electricity used in Idaho can be generated in plants outside the state. For this analysis, we estimate emissions on both a *production-basis* (emissions associated with electricity produced in Idaho, regardless of where it is consumed) and a net *consumption-basis* (emissions associated with electricity consumed in Idaho). The following section describes production-based emissions while the subsequent section, *Electricity trade and the allocation of GHG emissions*, reports consumption-based emissions.

As displayed in Figure A2, hydroelectric generation figures prominently in electricity generation in Idaho. However, since hydro-electricity does not produce GHG emissions, the State's GHG emissions from electricity production are due almost entirely to the natural gas generation. At 0.7 $MMtCO_2e$ of emissions in 2008, Idaho has the second lowest level for GHG emissions from electricity generation of any US state. Idaho's GHG emissions result mostly from the Rathdrum Power Plant (a 270 MW combined cycle plant) and the Rathdrum Combustion Turbine plants operated by Avista.

Figure A2. Electricity Generation and GHG Emissions from Idaho Power Plants, 2008





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

Table A2 shows the growth in generation by fuel type between 1990 and 2008 from power plants in Idaho. Overall generation grew by 24% during this period. Natural gas generation has had particularly strong growth, from no generation in 1990 to 15% of the State's generation in 2008. Hydro-electric generation shows a growth between 1990 and 2008, but the table masks the considerable year-by-year variation from this resource. In the 18-year period, hydro generation ranged between a low of 6,654 GWh in 1992 and a high of 14,676 GWh in 1997.

Table A2. Growth in Electricity Generation in Idaho, 1990-2008

	Generation (GWh)		
	1990	2008	Growth
Hydroelectric	9,115	9,363	3%
Natural Gas	0	1,664	n/a
Wind	0	207	n/a
Biomass	81	69	-14%
Geothermal	0	86	n/a
Petroleum	1	0	-80%
Total	9,197	11,389	24%

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

Future Generation and Emissions

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

The future mix of plants in Idaho remains uncertain as the trends in type of new builds are influenced by many factors. Since 2004, new plants in Idaho have been a mix of natural gas, wind, and geothermal. The Raft River plant is Idaho's first geothermal plant. Most new plant proposals rely on these natural gas and wind resources but new coal and geothermal plants have also been proposed. The proposed coal plants either use advanced combustion technology (such as the proposed CCG (clean coal gasification) 500 plant in South Eastern Idaho) or may be located outside of the State (such as Idaho Power's proposed coal plant). Table A3 presents data on new and proposed plants in Idaho. Note that it seems unlikely that all of the proposed plants will be built prior to 2025.

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

Table A3. New and Proposed Power Plants in Idaho

	Plant Name	Fuel	Status	Capacity MW	Illustrative Annual generation GWh	Illustrative Annual Emissions $MMtCO_2e$	Notes
New plants	Bennett Mountain	Natural gas	On line 2005	162	213	0.08	
	Fossil Gulch	Wind	On line 2005	10.5	32	0.00	
	Wolverine Creek	Wind	On line 2005	64.5	198	0.00	
	Raft River Phase I	Geothermal	Construction	13.0	97	0.0	expected on line date is September 2007
Proposed plants	Burley Butte	Wind	Planned	10.5	32	0.00	planned 2006
	Danskin GT 2	Natural gas	Planned	170.0	223	0.19	planned for 2008
	Golden Valley	Wind	Planned	10.5	32	0.00	planned for 2006
	Lava Beds	Wind	Planned	18.0	55	0.00	planned for 2007
	Milner Dam Wind Park	Wind	Planned	18.0	55	0.00	planned for 2007
	Notch Butte Wind Park	Wind	Planned	18.0	55	0.00	planned for 2007
	Oregon Trail	Wind	Planned	10.5	32	0.00	planned for 2007
	Pilgrim Stage Station	Wind	Planned	10.5	32	0.00	planned for 2007
	Salmon Falls	Wind	Planned	21.0	n/a	0.00	planned for 2007
	Schwendiman	Wind	Planned	17.5	54	0.00	planned for 2007
	Thousand Springs	Wind	Planned	10.5	32	0.00	planned for 2007
	Tuana Gulch	Wind	Planned	10.5	32	0.00	planned for 2007
	CCG 500	Coal Gasification	Proposed	520.0	3,872	3.2	GHG emissions estimated with no CO_2 sequestration. Sequestration technologies have been estimated to reduce emissions by 85% to 90%.
	Cotterel	Wind	Proposed	200.0	613	0.00	
	Raft River Phase II and III	Geothermal	Proposed	26.0	194	negligible	Air-cooled binary technology.
	Renewable Energy	Biomass	Proposed	17.5	54	negligible	Site of Boise plant idled Jul 2001.
	Shoshone Falls 4	Hydro	Proposed	50.0	350	0.00	(1) 50 MW unit. Units 1 and 2 to be retired.
	Willow Creek	Geothermal	Proposed	100.0	745	negligible	Capacity is estimated total for full development.
	Idaho Power Wind	Wind	proposed in 2006 IRP	150	460	0.0	Integrated Resource Plan, 2006, projects that this will be on-line in 2012
	Idaho Power Coal, plant in Wyoming	Coal	proposed in 2006 IRP	250	1,862	1.5	Integrated Resource Plan, 2006, projects that this will be on-line in 2013 but the plant will likely be located in Wyoming.

Sources: Northwest Power and Conservation Council. Power Plant Development in the Pacific Northwest. From www.nwcouncil.org, accessed on November 17, 2006. Idaho Power, 2006 Integrated Resource Plan. Generation estimates based on capacity factors of 0.85 for base load coal and 0.35 for wind. Emissions estimates based on heat rates of 9,000 BTU/kWh of coal.

Given the many factors affecting electricity-related emissions and a diversity of assumptions by stakeholders within the electricity sector, developing a "reference case" projection for the most likely development of Idaho's electricity sector is particularly challenging. Therefore, to develop an initial projection, simple assumptions were made, relying to the extent possible on widely-reviewed and accepted modeling assessments.

The reference case projections assume:

- Generation from power plants in Idaho grows at 1.6% per year from 2008-2010, following growth rate in electricity sales
- Generation from power plants in Idaho grows at 3.6% per year from 2010 to 2015, 0.8% from 2015 to 2020, and decreases by 0.1% per year from 2020 to 2025. This reflects the generation growth rate for the Northwest Power Pool region in Annual Energy Outlook 2009 (AEO2009).

- Generation from existing non-hydro plants is based on holding generation at 2008 levels. Generation from existing hydro-electric plants is assumed to be 9,544 GWh per year, the average generation from the last ten years. New plants and changes to existing plants due to plant renovations and overhauls that result in higher capacity factors are counted as new generation (thus the mix of new generation discussed below would also apply to plant upgrades).
- New power plants built between 2009 and 2025 will be a mix of 50% natural gas, 40% wind and 10% geothermal or biomass. This mix is roughly based on the mix of proposed new plants, Table A3.

Electricity Trade and Allocation of GHG Emissions

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

In 2008, Idaho had 32 entities involved in providing electricity to state customers. The State's three private utilities serve approximately 84% of the customers, and provide 87% of the electricity sales. The State's 16 electric cooperatives serve 10% of the customers and 8% of sales. Eleven public utilities account for the remaining 6% of customers and 5% of sales. The top 5 providers of retail electricity in the State are reported in Table A4.

Table A4. Retail Electricity Providers in Idaho (2008)

Entity	Ownership Type	2008 GWh
1. Idaho Power Co	Investor-Owned	13,874
2. Avista Corp	Investor-Owned	3,503
3. PacifiCorp	Investor-Owned	3,391
4. Idaho Falls City of	Public	667
5. Kootenai Electric Coop Inc	Cooperative	406
Total Sales, Top Five Providers		21,840
Total, All Idaho		**23,901**

Source: EIA state electricity profiles

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

In many ways the simplest approach is *production-based* – emissions from power plants within the state are included in the state's inventory. The data for this estimate are publicly available and unambiguous. However, this approach is problematic for states that import or export significant amounts of electricity. Under a production-based approach, characteristics of Idaho electricity consumption would not be fully captured since only emissions from in-state generation would be considered.

An alternative is to estimate *consumption-based* or *load-based* GHG emissions, corresponding to the emissions associated with electricity consumed in the state. The load-based approach is currently being considered by states that import significant amounts of electricity, such as California, Oregon, and Washington.[24] By accounting for emissions from imported electricity, states can account for increases or decreases in fossil fuel consumed in power plants outside of the State, due to demand growth, efficiency programs, and other actions in the state. The difficulty with this approach is properly accounting for the emissions from imports and exports. Since the electricity flowing into or out of Idaho is a mix of all plants generating on the inter-connected grid, it is impossible to physically track the sources of the electrons.

The approach taken in this inventory is a simplification of the consumption-based approach. This approach, which one could term "*Net-Consumption-based,*" estimates consumption-based emissions as in-state (production-based) emissions times the ratio of total in-state electricity consumption to in-state generation (net of losses) plus the emissions from the net imports. If the state is a net exporter of electricity, the net-consumption-based emissions are less than the production-based emissions, based on the fraction of exported electricity. If the state is a net importer of electricity, the consumption-based emissions are greater than the production-based emissions, based on the amount and GHG emission-intensity of the imports.

Emissions for net imports are calculated as net imports multiplied by an emission factor in GHG emissions per electricity generated ($MtCO_2e$/Megawatt-hour, MWh) for the imports. As a proxy for estimating the mix of historic and future GHG emissions for Idaho's electricity imports, emission factors that reflect the regional fuel mix were used. The region used to reflect electricity imports is the Northwest Power Pool[25] portion of the WECC (excluding Idaho's emissions) from the AEO2009. This regional emission factor was 0.39 $MtCO_2e$/MWh in 2008, decreasing to 0.32 $MtCO_2e$/MWh by 2025, reflecting an increased regional contribution of renewables and natural gas to the electricity generation mix.

This method does not account for differences in the type of electricity that is imported or exported from the State, and as such, it provides a simplified method for reflecting the emissions

[24] See for example, the reports of the Puget Sound Climate Protection Advisory Committee http://www.pscleanair.org/specprog/globclim, the Oregon Governor's Advisory Group On Global Warming http://egov.oregon.gov/ENERGY/GBLWRM/Strategy.shtml, and the California Climate Change Advisory Committee, Policy Options for Reducing Greenhouse Gas Emissions From Power Imports - Draft Consultant Report http://www.energy.ca.gov/2005publications/CEC-600-2005-010/CEC-600-2005-010-D.PDF.
[25] The Northwest Power Pool region in AEO2009 includes Washington, Oregon, Idaho, Colorado, Utah and portions on Nevada, Montana and South Dakota. http://www.eia.doe.gov/oiaf/aeo/supplement/supmap.pdf

impacts of electricity consumption in the State. The calculation also ignores "gross" imports – since Idaho plants have contracts to out-of-state entities, some of the in-state electricity generation will be exported and gross imports will be greater than net imports. More sophisticated methods – for example, based on individual utility information on resources used to meet loads – can be considered for further improvements to this approach. One example of the data requirements for this approach can be found in neighboring Washington State, which has developed regular fuel disclosure reporting from each of its utilities.[26]

Summary of Assumptions and Reference Case Projections

As noted, projecting generation sources, sales, and emissions for the electric sector out to 2025 requires a number of key assumptions, including economic and demographic activity, changes in electricity-using technologies, regional markets for electricity (and competitiveness of various technologies and locations), access to transmission and distribution, the retirement of existing generation plants, the response to changing fuel prices, and the fuel/technology mix of new generation plants. The key assumptions described above are summarized in Table A5.

Table A5. Key Assumptions and Methods for Electricity Projections for Idaho

Electricity sales	Average annual growth of 1.8% from 2008 to 2025, based on growth rates from the three largest utilities in Idaho (see Table A1).
Electricity generation	1.6% per year from 2008-2010, based on consumption growth and proposed plants and 1.5% per year from 2010 to 2025, based on regional growth rates in AEO2009.
Transmission and Distribution losses	5% losses are assumed, based on average statewide losses, 1994-2000, (data from the US EPA Emission & Generation Resource Integrated Database[27])
New Generation Sources (2009-2025)	The mix of new generation in this period roughly tracks the mix of proposed new plants in Idaho (Table A3). 50% natural gas 40% wind, and 10% biomass or geothermal
Heat Rates	The assumed heat rate for new natural gas generation is 7,000 Btu/kWh, based on estimates used in similar analyses.[28]
Operation of Existing Facilities	Existing non-hydro facilities are assumed to continue to operate as they were in 2008. Existing hydro facilities are assumed to generate 9,544 GWh per year the average generation over the period 1999-2008. Improvements in existing facilities that lead to higher capacity factor and more generation are captured under the new generation sources.

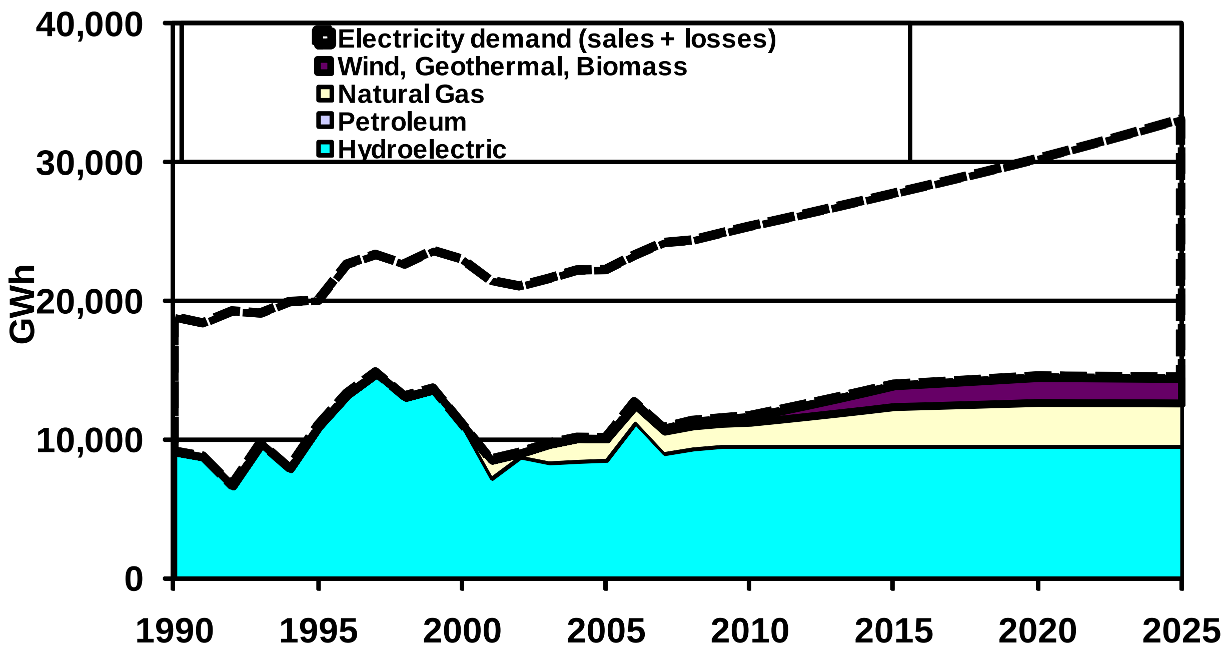
Figure A3 shows historical sources of electricity generation in the state by fuel source, along with projections to the year 2025 based on the assumptions described above. Based on the assumptions for new generation, imported electricity continues to dominate new generation throughout the forecast period (2009-2025). Generation from existing hydro plus new wind and

[26] http://www.cted.wa.gov/site/539/default.aspx
[27] http://www.epa.gov/cleanenergy/egrid/index.htm.
[28] See, for instance, the Oregon Governor's Advisory Group On Global Warming http://egov.oregon.gov/ENERGY/GBLWRM/Strategy.shtml.

natural gas generation show high growth, relative to levels in 2008. Overall in-state electricity generation grows at 1.5% per year from 2008 to 2025.

GHG emission estimates were calculated by multiplying the energy consumption by GHG emission factors by fuel. Energy consumption for 2009 to 2025 was calculated based on changes to future generation and heat rate properties described in table A6. The EPA SIT software provided GHG emission factors by fuel for each state, consistent with factors used for EPA's national GHG inventory report.[29]

Figure A3. Electricity Generated by Idaho Power Plants 1990-2025

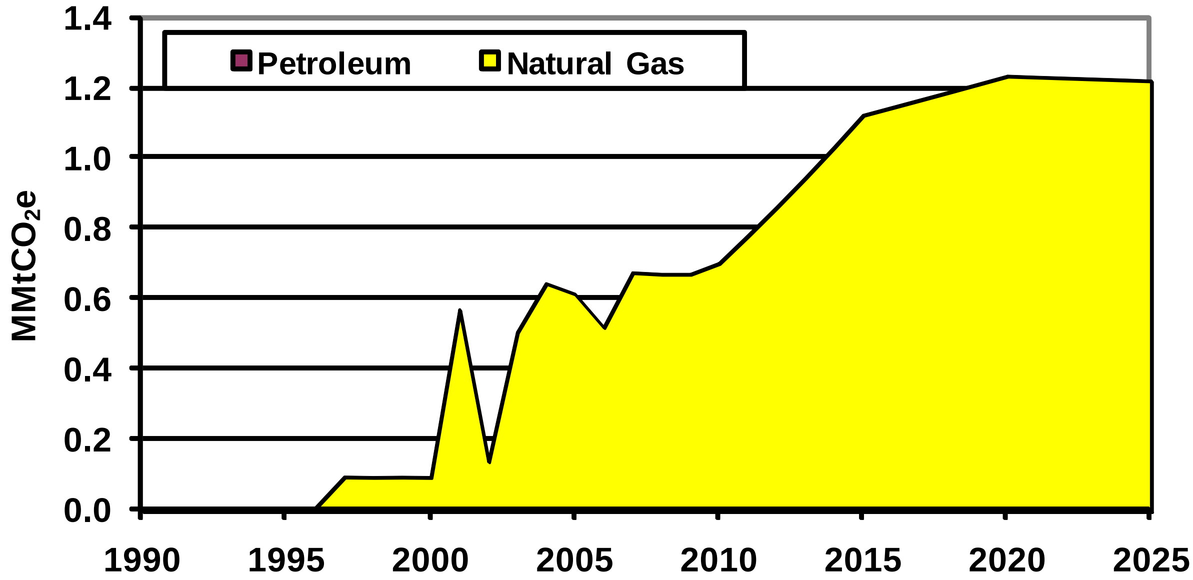


Source: 1990-2005 EIA data, 2006-2020 CCS calculations based on assumptions described above, generation from petroleum and natural gas resources are too small to be visible in the chart.

Figure A4 illustrates the GHG emissions associated with the mix of electricity generation shown in Figure A3. From 2008 to 2025, the emissions from Idaho electricity generation are projected to grow at 3.6% per year, higher than the growth in electricity generation, due to an increased fraction of generation from natural gas. As a result, the emission intensity (GHG emissions per MWh) of Idaho electricity is expected to increase from 0.059 $MtCO_2$/MWh in 2008 to 0.084 $MtCO_2$/MWh in 2025. Due to the large fraction of renewable generation (especially existing hydro-electric plants), Idaho has one of the lowest GHG emission intensities in the country for electricity generation. The large spike in GHG emissions in 2001 reflects a period of low water availability and subsequent low hydro-electric generation. Natural gas generation was relied on to provide more electricity generation. This situation lessened in 2002 but natural gas generation increased through 2005 and is assumed to increase through 2025.

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

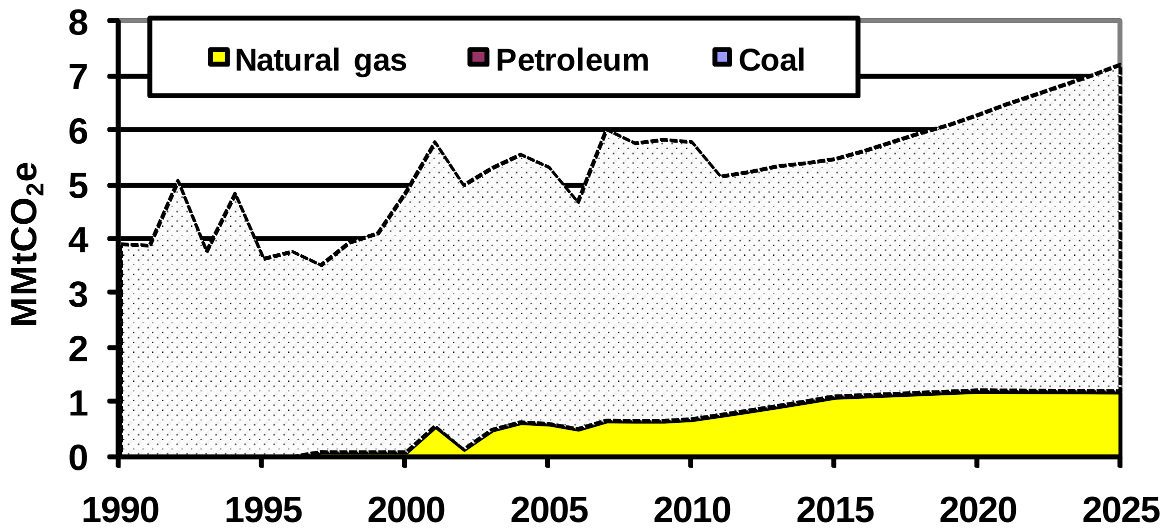
Figure A4. Idaho GHG Emissions Associated with Electricity Production (Production-Basis)



Source: CCS calculations based on approach described in text.
Note: Idaho's electric generation GHG emissions from petroleum sources are less than 0.05 $MMtCO_2e$ and too small to be visible in the chart.

Figure A5 shows the "net-consumption-based" emissions from 1990 to 2025. Total emissions are much higher than the production-based emissions due to the GHG emissions associated with net electricity imports. Note that the vertical scale (y-axis) for Figure A5 is about seven times greater than that for Figure A4. Consumption-based emissions increase by 1.3% per year from 2008 to 2025. The "spikes" in GHG emissions in 1992, 1994 and 2001 reflect years with low hydro-electricity generation (low water years). GHG emissions are estimated to increase due to additional net imports in 1992 and 1994, and due to both increased natural gas generation and electricity imports.

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



Source: CCS calculations based on approach described in text.
Note: Idaho's electric generation GHG emissions from petroleum sources are less than 0.05 $MMtCO_2e$ and too small to be visible in the chart.

Table A6 summarizes the GHG emissions for Idaho's electric sector from 1990 to 2025. As described above, GHG emissions from net imported electricity are the main source of GHG emissions for this sector.

Table A6. Idaho GHG Emissions from Electric Sector, Production and Consumption-based Estimates, 1990-2025.

(Million Metric Tons CO2e)	1990	2000	2005	2010	2020	2025
Electricity Production	**0.00**	**0.10**	**0.62**	**0.70**	**1.23**	**1.22**
Coal	0.00	0.00	0.00	0.00	0.00	0.00
Natural Gas	0.00	0.09	0.62	0.70	1.23	1.22
Petroleum	0.00	0.00	0.00	0.00	0.00	0.00
Wood (CH4 and N2O)	0.00	0.00	0.00	0.00	0.00	0.00
Net Elecricity Imports (negative for exports)	**3.92**	**4.81**	**4.72**	**5.10**	**5.07**	**6.01**
Electricity Consumption-based Emissions	**3.93**	**4.90**	**5.34**	**5.81**	**6.30**	**7.23**

Note: Values that are less than 0.005 $MMTCO_2e$ are listed as 0.00 in Table A7.

Key Uncertainties

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

- Amount and mix of new generation. Idaho's mix of new generation will depend, in part, on policies in Idaho and in states that export electricity to Idaho.
- Future generation from existing hydro-electric plants. Generation from hydro plants has varied significantly in the last 15 years and expected levels of future generation could affect plans and operation of new fossil fuel plants.
- Approach for estimating consumption-based GHG emissions. The "net-consumption-based" approach used in this analysis is a rough simplification of electricity trade that does not consider individual utility portfolios. Additional data on the historic and current mix of electricity generation used by Idaho's utilities to meet their customers' electricity demand could help refine these estimates. Refining the future GHG emission projections would likewise require additional information or assumptions on the utilities' electricity provisions.

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

Overview

Activities in the RCI[30] sectors produce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions when fuels are combusted to provide space heating, process heating, and other energy applications. Carbon dioxide accounts for over 99% of these emissions on a million metric tons (MMt) of CO_2 equivalent (CO_2e) basis in Idaho. 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.[31] If emissions from the generation of the electricity they consume are not included, the RCI sectors are between them the third-largest source of gross greenhouse gas (GHG) emissions in Idaho. Direct use of oil, natural gas, coal, and wood in the RCI sectors accounted for an estimated 6.57MMtCO_2e of gross GHG emissions in 2005.[32]

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 (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for RCI fossil fuel combustion.[33] The default data used in SIT for Idaho are from United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data* (SED). The SIT default data for Idaho were revised using the most recent data available, which includes 2007 SED information for all fuel types.[34]

[30] The industrial sector includes emissions associated with agricultural energy use and fuel used by the fossil fuel production industry.
[31] Emissions associated with the electricity supply sector (presented in Appendix A) have been allocated to each of the RCI sectors for comparison of those emissions to the fuel-consumption-based emissions presented in Appendix B. Note that this comparison is provided for information purposes and that emissions estimated for the electricity supply sector are not double-counted in the total emissions for the state. One could similarly allocate GHG emissions from natural gas transmission and distribution, other fuels production, and transport-related GHG sources to the RCI sectors based on their direct use of gas and other fuels, but we have not done so here due to the difficulty of ascribing these emissions to particular end-users. Estimates of missions associated with the transportation sector are provided in Appendix C, and estimates of emissions associated with fossil fuel production and distribution are provided in Appendix E.
[32] Emissions estimates from wood combustion include only N_2O and CH_4. Carbon dioxide emissions from biomass combustion are assumed to be "net zero", consistent with US EPA and Intergovernmental Panel on Climate Change (IPCC) methodologies, and any net loss of carbon stocks due to biomass fuel use should be accounted for in the land use and forestry analysis.
[33] GHG emissions were calculated using SIT, 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.
[34]EIA *State Energy Data 2007*, Data through 2007, released February 2010 (http://www.eia.doe.gov/emeu/states/_seds.html).

Note that the EIIP methods for the industrial sector exclude from CO_2 emission estimates the amount of carbon that is stored in products produced from fossil fuels for non-energy uses. For example, the methods account for carbon stored in petrochemical feedstocks, and in liquefied petroleum gases (LPG) and natural gas used as feedstocks by chemical manufacturing plants (i.e., not used as fuel), as well as carbon stored in asphalt and road oil produced from petroleum. The carbon storage assumptions for these products are explained in detail in the EIIP guidance document.[35] The fossil fuel categories for which the EIIP methods are applied in the SIT 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,[36] 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 2009* (AEO2009),[37] with adjustments for Idaho's projected population and employment growth. Idaho employment data for the manufacturing (goods-producing) and non-manufacturing (commercial or services-providing) sectors were obtained from Idaho Power's *2006 Integrated Resource Plan*, which provides population and employment forecasts to 2030.[38] Regional employment data for the same sectors and forecast period were obtained from EIA for the EIA's Mountain region.[39]

Table B1 shows historic and projected growth rates for electricity sales by sector. Table B2 shows historic and projected growth rates for energy use by sector and fuel type. For the residential sector, the rate of population growth is expected to be about 1.7% annually between 2005 and 2025; this demographic trend is reflected in the growth rates for residential fuel consumption. Based on data provided in Idaho Power's *2006 Integrated Resource Plan*, over the period 2005 through 2025, commercial and industrial employment are projected to increase at compound annual rates of 2.3% and 1.3%, respectively, and these growth rates are reflected in the growth rates in energy use shown in Table B2 for the two sectors. These estimates of growth relative to population and employment reflect expected responses of the economy — as simulated by the EIA's National Energy Modeling System — to changing fuel and electricity prices and changing technologies, as well as to structural changes within each sector (such as shifts in subsectoral shares and in energy use patterns).

[35] EIIP, Volume VIII: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004.
[36] A mixture of hydrocarbons, mostly pentanes and heavier fractions, extracted from natural gas.
[37] EIA AEO2009 with Projections to 2030, (http://www.eia.doe.gov/oiaf/archive/aeo09/index.html).
[38] Idaho Power, *2006 Integrated Resource Plan,* Appendix C – "Economic Forecast" and "Forecast of Population, Households, and Persons per Household," Compiled and prepared by Idaho Economics, Boise, ID (http://www.idahopower.com/2006irp/2006irpfinal.htm).
[39] AEO2006 employment projections for EIA's Mountain region obtained through special request from EIA (dated September 27, 2006).

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

Sector	1990-2008*	2008-2010**	2010-2020**	2020-2025**
Residential	2.3%	2.0%	1.7%	1.8%
Commercial	0.8%	2.7%	2.2%	2.4%
Industrial	1.5%	1.8%	1.5%	1.6%
Total	**1.6%**	**2.1%**	**1.8%**	**1.9%**

* 1990-2008 compound annual growth rates calculated from Idaho electricity sales by year from EIA state electricity profiles (Table 8), (http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html).
** Compound annual growth rates for total electricity sales and for each of the three sectors individually are taken from the forecast for the energy supply sector (see Appendix A).

Table B2. Historical and Projected Average Annual Growth in Energy Use in Idaho, by Sector and Fuel, 1990-2025

	1990-2005*	2005-2010**	2010-2015**	2015-2020**	2020-2025**
Residential					
Natural Gas	6.3%	1.0%	-0.1%	0.6%	0.6%
Petroleum	2.9%	-3.2%	-2.4%	-1.0%	-0.3%
Wood	-2.6%	15.2%	-0.2%	0.6%	-0.3%
Coal	-14.0%	-6.7%	-2.4%	-1.2%	-1.3%
Commercial					
Natural Gas	2.9%	3.7%	1.6%	1.3%	2.2%
Petroleum	2.0%	-2.8%	0.5%	0.7%	1.1%
Wood	1.0%	1.5%	1.1%	0.7%	0.8%
Coal	-10.6%	-11.3%	1.1%	0.7%	0.8%
Industrial					
Natural Gas	-0.2%	1.2%	0.2%	0.1%	1.5%
Petroleum	-0.8%	0.4%	-0.1%	1.4%	-4.3%
Wood	-0.2%	-3.2%	1.2%	1.2%	1.2%
Coal	1.0%	-1.1%	2.8%	0.3%	0.3%

* Compound annual growth rates calculated from EIA SED historical consumption by sector and fuel type for Idaho. Latest year for which EIA SED information was available for each fuel type is 2007. Petroleum includes distillate fuel, kerosene, and liquefied petroleum gases for all sectors plus residual oil for the commercial and industrial sectors.
** Figures for growth periods starting after 2007 are calculated from AEO2009 projections for EIA's Mountain region, adjusted for Idaho'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.

Population and economic forecast data are also available from the State of Idaho's Division of Financial Management that covered the period from 1992 through 2009. The forecast data available from Idaho Power was used for the reference case projections, however, because it covered the full period covered by the inventory and forecast timeframe (i.e., 1990 through 2025). For the period during which the two forecasts overlapped (i.e., 1992 through 2009), the annual growth rates for population and employment are generally similar, as illustrated in Table B3. Note that Idaho Power supplies about two-thirds of the electricity used in Idaho and the forecast information provided in Idaho Power's *2006 Integrated Resource Plan* were also used to support the forecast assumptions for the electric supply sector provided in Appendix A.

Table B3. Comparison of Compound Annual Growth Rates from Idaho Power and Idaho Division of Financial Management Population and Economic Forecasts

Idaho Power Forecast[1]

	1990 – 1995	1995 - 2000	2000 - 2005	2005 - 2010	2010 - 2015	2015 - 2020	2020-2025
Population	3.1%	2.0%	1.8%	1.8%	1.7%	1.7%	1.7%
Goods-Producing Employment	3.9%	2.3%	-0.2%	1.7%	0.9%	1.4%	1.5%
Services-Providing Employment	4.6%	3.3%	1.9%	2.4%	2.3%	2.2%	2.2%

Idaho Division of Financial Management Forecast[2]

	1992 - 1995	1995 - 2000	2000 - 2005	2005 - 2009
Population	3.2%	2.0%	1.9%	2.3%
Goods-Producing Employment	5.0%	2.6%	0.1%	1.5%
Services-Providing Employment	4.9%	3.4%	2.3%	3.3%

[1] Idaho Power, *2006 Integrated Resource Plan* - Appendix C - Economic Forecast" (http://www.idahopower.com/2006irp/2006irpfinal.htm).
[2] State of Idaho, Division of Financial Management, *October 2006 Idaho Economic Forecast* - Annual Tables (http://dfm.idaho.gov/Publications/EAB/Forecast/2006/October/iefoctober2006.html). Data are only available for 1992 through 2009.

Results

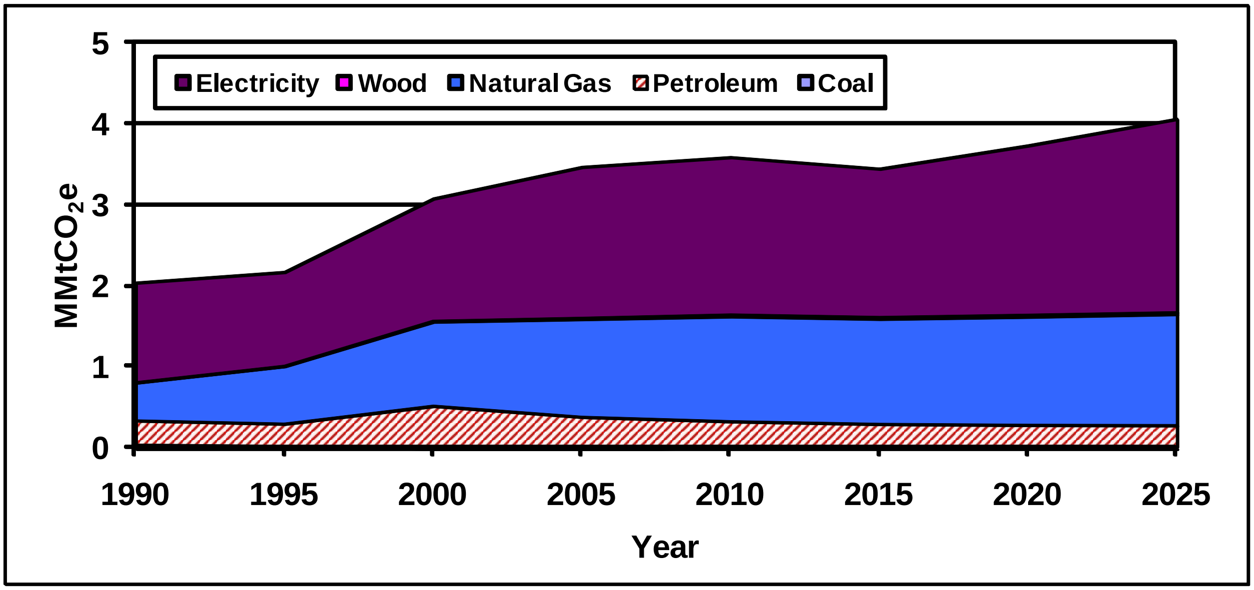
Figures B1, B2, and B3 show historic and projected emissions for the RCI sectors in Idaho from 1990 through 2025. These figures show the emissions associated with the direct consumption of fossil fuels and, for comparison purposes, show the share of emissions associated with the generation of electricity consumed by each sector. These emissions are also listed in Tables B4a, B4b, B5a, B5b, B6a, and B6b.

The residential sector's share of total RCI emissions from direct fuel use and electricity use was 23% in 1990, then increased to 29% in 2005, and is projected to remain at 29% by 2025. The commercial sector's share of total RCI emissions from direct fuel use and electricity use was 21% in 1990, fell to 20% in 2005, and is projected to increase to 24% by 2025. The industrial sector's share of total RCI emissions from direct fuel use and electricity use was 56% in 1990, declined to 51% in 2005, and is projected to decline further to 46% by 2025. Emissions associated with the generation of electricity to meet RCI demand from 1990 through 2025 accounts for about, on average, 55% of the emissions for the residential sector, 58% of the emissions for the commercial sector, and 36% of the emissions for the industrial sector. Natural gas consumption is the next-highest source of emissions for all three sectors, accounting for about 34% of total emissions in the residential sector, 31% for the commercial sector, and 24% for the industrial sector when averaged over the 1990 to 2025 period.

Residential Sector

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

Figure B1. Residential Sector GHG Emissions from Fuel Consumption



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

Table B4a. Residential Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	0.03	0.01	0.00	0.00	0.01	0.01	0.01	0.01
Petroleum	0.30	0.28	0.51	0.37	0.31	0.28	0.27	0.27
Natural Gas	0.47	0.71	1.04	1.21	1.30	1.30	1.34	1.38
Wood	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03
Electricity	1.23	1.15	1.50	1.86	1.94	1.82	2.08	2.38
Total	2.04	2.17	3.08	3.46	3.59	3.44	3.73	4.06

Source: CCS calculations based on approach described in text.

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

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	1.3%	0.5%	0.2%	0.1%	0.2%	0.2%	0.2%	0.2%
Petroleum	14.9%	12.9%	16.5%	10.8%	8.7%	8.2%	7.2%	6.6%
Natural Gas	22.9%	32.8%	33.9%	34.9%	36.2%	37.8%	35.9%	33.9%
Wood	0.7%	0.7%	0.6%	0.6%	0.8%	0.8%	0.8%	0.7%
Electricity	60.1%	53.1%	48.9%	53.6%	54.0%	53.0%	55.9%	58.7%

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.

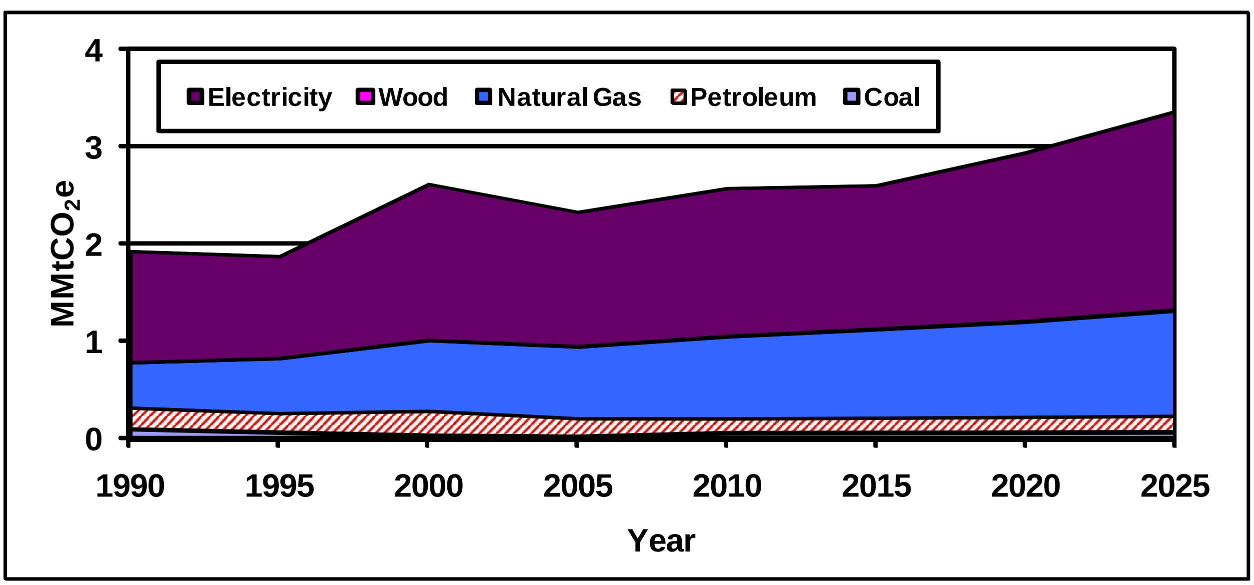
For the residential sector, emissions from electricity and direct fossil fuel use in 1990 were about 2.0 $MMtCO_2e$, and are estimated to increase to about 4.1 $MMtCO_2e$ by 2025. Emissions associated with the generation of electricity to meet residential demand accounted for about 60% of total residential emissions in 1990, and are estimated to decline to about 59% of total residential emissions by 2025. In 1990, natural gas consumption accounted for about 23% of total residential emissions, and gas use is estimated to account for about 34% of total residential emissions by 2025. Residential sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 0.35 $MMtCO_2e$ combined, and accounted for about 17% of total residential GHG emissions. By 2025, emissions associated with the consumption of these three fuels are estimated to be 0.30 MMtCO2e and to account for 7% of total residential sector emissions.

For the 20-year period from 2005 to 2025, residential-sector GHG emissions associated with the use of electricity and natural gas are expected to increase at average annual rates of about 1.2% and 0.6%, respectively. Emissions associated with the use coal and wood are expected to increase annually by 5.6% and 1.5%, respectively. Finally, emissions associated with the use of petroleum are expected to decline at an average annual rates of about -1.7%. Total GHG emissions for this sector increase by an average of about 0.8% annually over the 20-year period.

Commercial Sector

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

Figure B2. Commercial 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. Commercial Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	0.10	0.07	0.04	0.02	0.06	0.07	0.07	0.07
Petroleum	0.23	0.20	0.26	0.19	0.15	0.16	0.16	0.17
Natural Gas	0.47	0.57	0.73	0.74	0.85	0.92	0.99	1.09
Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electricity	1.14	1.04	1.59	1.37	1.51	1.46	1.72	2.03
Total	1.93	1.88	2.62	2.33	2.58	2.60	2.94	3.36

Source: CCS calculations based on approach described in text.

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

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	5.3%	3.7%	1.4%	1.0%	2.4%	2.5%	2.3%	2.1%
Petroleum	11.7%	10.7%	9.8%	8.3%	5.9%	6.0%	5.5%	5.1%
Natural Gas	24.1%	30.2%	27.9%	31.8%	32.9%	35.1%	33.5%	32.4%
Wood	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%
Electricity	58.8%	55.4%	60.8%	58.8%	58.6%	56.2%	58.5%	60.3%

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 B5a.

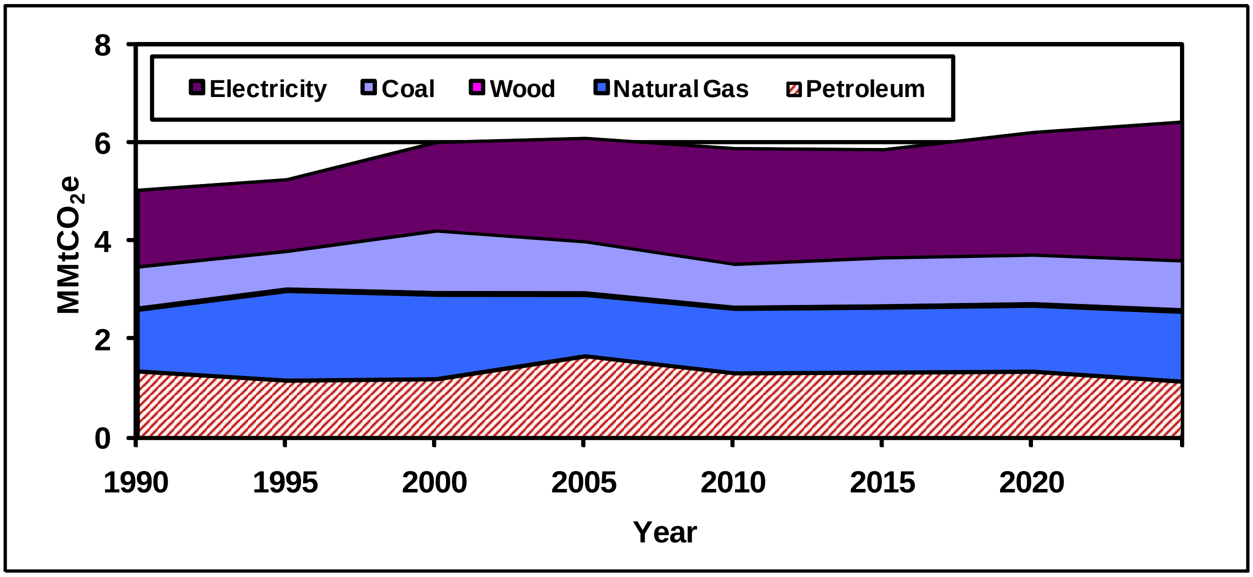
For the commercial sector, emissions from electricity and direct fuel use in 1990 were about 1.9 $MMtCO_2e$, and are estimated to increase to about 3.4 MMtCO2e by 2025. Emissions associated with the generation of electricity to meet commercial sector demand accounted for about 59% of total commercial emissions in 1990, and are estimated to increase slightly, to about 60% of total commercial emissions, by 2025. In 1990, natural gas consumption accounted for about 24% of total commercial emissions, and is estimated to account for about 33% of total commercial emissions by 2025. Commercial-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 0.33 $MMtCO_2e$ combined, and accounted for about 17% of total commercial emissions. For 2025, emissions associated with the consumption of these three fuels are estimated to be 0.23 MMtCO2e, and to account for 7% of total commercial sector emissions.

For the 20-year period 2005 to 2025, commercial-sector GHG emissions associated with the use of electricity, natural gas, and coal are expected to increase at average annual rates of about 2.0%, 1.9%, and 5.8%, respectively. Emissions associated with the use of wood are expected to increase at an annual rate of about 0.8%. Finally, emissions associated with the use of petroleum are expected to decline by about -0.6% annually. Total GHG emissions for this sector increase by an average of about 1.8% annually over the 20-year period.

Industrial Sector

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

Figure B3. Industrial Sector GHG Emissions from Fuel Consumption



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

Table B6a. Industrial Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	0.85	0.78	1.26	1.05	0.88	0.98	1.00	1.00
Petroleum	1.36	1.17	1.20	1.67	1.32	1.34	1.36	1.15
Natural Gas	1.25	1.82	1.71	1.24	1.30	1.31	1.34	1.41
Wood	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Electricity	1.56	1.46	1.81	2.11	2.36	2.21	2.50	2.83
Total	5.05	5.27	6.03	6.11	5.90	5.88	6.23	6.44

Source: CCS calculations based on approach described in text.

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

Fuel Type	1990	1995	2000	2005	2010	2015	2020	2025
Coal	16.7%	14.7%	21.0%	17.1%	14.9%	16.7%	16.0%	15.6%
Petroleum	27.0%	22.3%	20.0%	27.4%	22.5%	22.8%	21.8%	17.9%
Natural Gas	24.7%	34.6%	28.4%	20.3%	22.1%	22.3%	21.4%	21.9%
Wood	0.7%	0.7%	0.7%	0.7%	0.6%	0.6%	0.6%	0.7%
Electricity	30.9%	27.7%	30.0%	34.5%	40.0%	37.5%	40.1%	43.9%

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 B6a.

For the industrial sector, emissions in 1990 were about 5.1 $MMtCO_2e$, and are estimated to increase to about 6.4 MMtCO2e by 2025. Emissions associated with the generation of electricity to meet industrial demand accounted for about 31% of total industrial emissions in 1990 and are estimated to increase to about 44% of total industrial emissions by 2025. In 1990, natural gas consumption accounted for about 25% of total industrial emissions and is estimated to account for about 22% of total industrial emissions by 2025. Industrial sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 2.2 $MMtCO_2e$ combined, and accounted for about 44% of total industrial emissions. For 2025, emissions associated with the consumption of these three fuels are estimated to be 2.2MMtCO2e and to account for 34% of total industrial sector emissions.

For the 20-year period 2005 to 2025, industrial sector GHG emissions associated with the use of electricity and natural gas are expected to increase at average annual rates of about 1.5% and 0.7%, respectively. Emissions associated with the use of wood are expected to increase annually by about 0.3%. Emissions associated with the use of petroleum and coal are expected to decrease annually by about -1.9% and -0.2%, respectively. Total GHG emissions for this sector increase at an average rate of about 0.3% annually over the 20-year period.

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 Mountain modeling region scaled for Idaho 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 Idaho to the extent that such data become available.
- The AEO2009 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

The transportation sector is one of the largest sources of greenhouse gas (GHG) emissions in Idaho. In 2005, carbon dioxide (CO_2) accounted for about 97% of transportation GHG emissions from fuel use. Most of the remaining GHG emissions from the transportation sector are due to nitrous oxide (N_2O) emissions from gasoline engines.

Emissions and Reference Case Projections

Historical GHG emissions were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[40,41] For onroad vehicles, the CO_2 emission factors are in units pounds (lb) per million British thermal unit (MMBtu) and the methane (CH_4) and N_2O 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 data within SIT were used to estimate emissions, with the most recently available fuel consumption data (2007) from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data* (SED) included in the SIT.[42] State-level VMT was allocated to vehicle types using the default vehicle mix data in SIT from the Federal Highway Administration (FHWA)[43].

Onroad Vehicles

Onroad vehicle gasoline and diesel emissions were projected based on total VMT growth rates for Idaho from the WRAP mobile source emission inventory[44] and growth rates by vehicle type developed from national vehicle type VMT forecasts reported in EIA's *Annual Energy Outlook* 2009 (AEO2009). The AEO2009 data were incorporated because they indicate significantly different VMT growth rates for certain vehicle types (e.g., much higher growth rates for heavy-duty diesel VMT compared to light-duty gasoline vehicle VMT over this period). The AEO2009 vehicle type-based national growth rates were first applied to 2007 estimates of Idaho 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 projected estimates of total VMT in the State for each year to yield the vehicle type VMT estimates and compound annual average growth rates. The resulting VMT growth rates by vehicle type are displayed in Table C2. These growth rates were used to project CH_4 and N_2O emissions from onroad vehicles.

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[40] CO_2 emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 1. "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004.

[41] CH_4 and N_2O emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 3. "Methods for Estimating Methane and Nitrous Oxide Emissions from Mobile Combustion", August 2004.

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

[43] Highway Statistics, Federal Highway Administration, http://www.fhwa.dot.gov/policy/ohpi/hss/index.htm.

[44] "WRAP Mobile Source Emission Inventories Update, Final Report," prepared for Western Governors' Association, prepared by ENVIRON Internation Corporation, May 2006, http://www.swapca.org/gorgedata/WRAP_MobileSourceEI.pdf.

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

Vehicle Type and Pollutants	Methods
Onroad gasoline, diesel, natural gas, and LPG vehicles – CO_2	**Inventory (1990 – 2007)** EPA SIT and fuel consumption from EIA SED **Reference Case Projections (2008 – 2025)** Gasoline and diesel fuel projected using VMT projections from AEO2009, adjusted by fuel efficiency improvement projections from AEO2009. Other onroad fuels projected using Mountain Region fuel consumption projections from EIA AEO2009 adjusted using state-to-regional ratio of population growth.
Onroad gasoline and diesel vehicles – CH_4 and N_2O	**Inventory (1990 – 2007)** EPA SIT, onroad vehicle CH_4 and N_2O emission factors by vehicle type and technology type within SIT were updated to the latest factors used in the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009.* VMT allocated to vehicle types using default data in SIT. **Reference Case Projections (2008 – 2025)** VMT projections from WRAP; allocation to vehicle from AEO2009 data.
Non-highway fuel consumption (jet aircraft, gasoline-fueled piston aircraft, boats, locomotives) – CO_2, CH_4 and N_2O	**Inventory (1990 – 2007)** EPA SIT and fuel consumption from EIA SED. **Reference Case Projections (2008 – 2025)** Aircraft growth rates are based on estimates of operations data for Idaho in the FAA's Terminal Area Forecast for 2008-2025 data. Rail and marine gasoline projected based on historical data.

Table C2. Idaho Vehicle Miles Traveled Compound Annual Growth Rates

Vehicle Type	2007-2010	2010-2015	2015-2020	2020-2025
Heavy Duty Diesel Vehicle	-1.17%	4.71%	3.75%	2.46%
Heavy Duty Gasoline Vehicle	-4.70%	2.20%	1.81%	1.52%
Light Duty Diesel Truck	2.84%	6.26%	10.72%	12.20%
Light Duty Diesel Vehicle	2.84%	6.26%	10.72%	12.20%
Light Duty Gasoline Truck	2.02%	1.33%	1.11%	0.97%
Light Duty Gasoline Vehicle	2.02%	1.33%	1.11%	0.97%
Motorcycle	2.02%	1.33%	1.11%	0.97%

CO_2 emissions from onroad vehicles were projected using projected fuel consumption growth rates. Onroad gasoline and diesel fuel consumption was forecasted by developing a set of growth factors that adjusted the VMT projections to account for improvements in fuel efficiency. Fuel efficiency projections were taken from EPA's MOBILE6.2 model to represent projected fleetwide in-use fuel consumption, prior to the implementation of the new fuel efficiency standards resulting from the 2007 Energy Independence and Security Act. The resulting onroad fuel consumption growth rates are shown in Table C3. Growth rates for projecting CO_2 emissions from natural gas and LPG vehicles were calculated by allocating the AEO2009 consumption of these fuels in the Mountain region and allocating this to Idaho based on the ratio of the State's projected population to the region's projected population. Similarly, growth rates for projecting CO_2 emissions from lubricants consumption were calculated based on the AEO2009 Mountain "other petroleum" category growth, also normalized using state to regional population projections.

Gasoline consumption estimates for 1990-2007 were adjusted by subtracting ethanol consumption. Ethanol, biodiesel and other biofuel consumption were not considered in the forecast period because projection data were not available.

Table C3. Idaho Onroad Fuel Consumption Compound Annual Growth Rates

Fuel Growth Factors	2007-2010	2010-2015	2015-2020	2020-2025
Onroad gasoline	1.64%	1.18%	1.03%	0.93%
Onroad diesel	-0.88%	4.84%	4.45%	3.85%
Natural Gas	3.12%	-0.99%	-1.13%	-0.45%
LPG	0.77%	-0.73%	0.23%	0.04%
Lubricants	0.12%	0.04%	-0.03%	0.05%

Aviation

For the aircraft sector, emission estimates for 1990 to 2007 are based on SIT methods and fuel consumption from EIA. Emissions were projected from 2008 to 2025 using general aviation and commercial aircraft operations for 2008 to 2025 from the Federal Aviation Administration's (FAA) Terminal Area Forecast System[45] and national aircraft fuel efficiency forecasts. To estimate changes in jet fuel consumption, itinerant aircraft operations from air carrier, air

[45] Terminal Area Forecast, Federal Aviation Administration, http://www.apo.data.faa.gov/main/taf.asp.

taxi/commuter, and military aircraft were first summed for each year of interest. The jet fuel projections were adjusted to reflect the projected increase in national aircraft fuel efficiency (indicated by increased number of seat miles per gallon), as reported in AEO2009. Because AEO 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 Idaho, which was obtained from the FAA source noted above. These projections resulted in the compound annual growth rates shown in Table C4.

Table C4. Idaho Aviation Fuels Compound Annual Growth Rates

Fuel	2007-2010	2010-2015	2015-2020	2020-2025
Aviation Gasoline	0.99%	2.02%	2.03%	2.06%
Jet Fuel	-3.14%	0.36%	0.23%	0.16%

Rail and Marine Vehicles

For the rail and marine sectors, 1990 through 2007 emission estimates are based on SIT methods and fuel consumption from EIA. Marine gasoline consumption and rail diesel consumption were both projected to 2025 based on linear regressions of the 1990 through 2007 historical data. Table C5 shows the resulting annual growth rates for fuel consumption from these sectors.

Table C5. Idaho Rail and Marine Fuels Compound Annual Growth Rates

Fuel	2007-2010	2010-2015	2015-2020	2020-2025
Marine Gasoline	-2.64%	0.02%	0.02%	0.02%
Rail	-3.18%	0.15%	0.15%	0.15%

Nonroad Engines

Fuel consumption data from EIA includes nonroad gasoline and diesel fuel consumption in the commercial and industrial sectors. Therefore, nonroad emissions are included in the RCI emissions in this inventory (see Appendix B). Table C6 shows how EIA divides gasoline and diesel fuel consumption between the transportation, commercial, and industrial sectors.

Table C6. 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

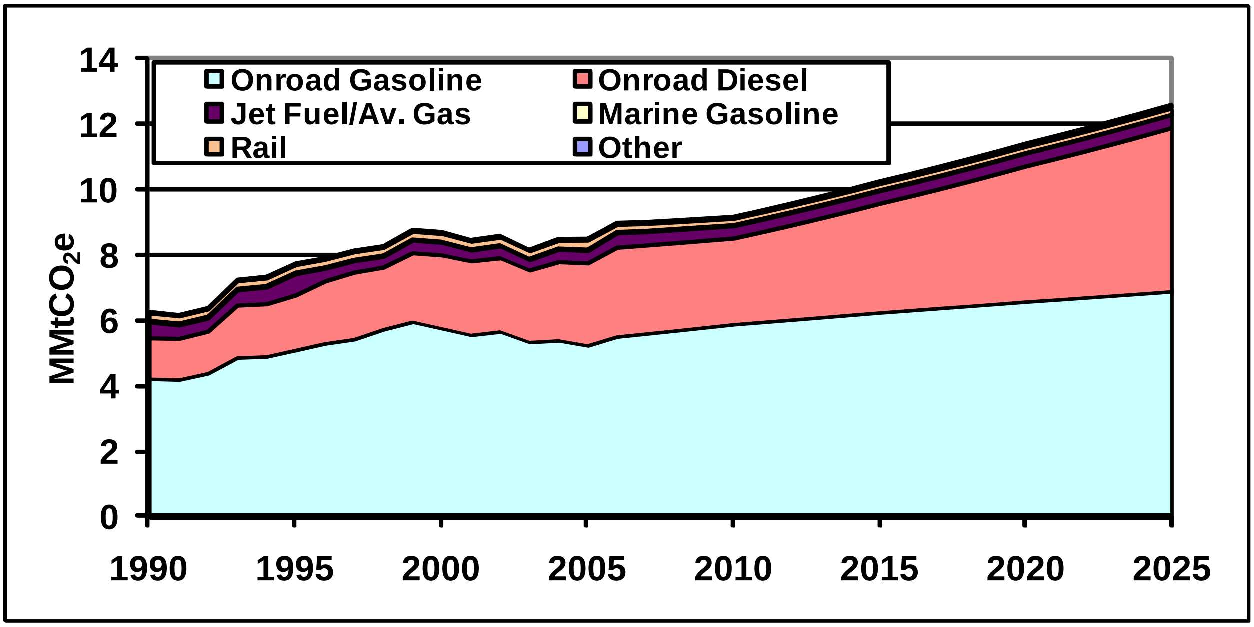
As shown in Figure C1 and Table C7, GHG emissions from the transportation sector in Idaho were about 6.3 MMtCO_2e in 1990, increasing to 8.5 MMtCO_2e in 2005. Onroad gasoline and diesel consumption account for the largest share of transportation GHG emissions. Emissions from onroad gasoline vehicles increased by about 24% from 1990 to 2005, accounting for 62% of total transportation emissions in 2005. GHG emissions from onroad diesel fuel consumption increased by 103% from 1990 to 2005, and by 2005 accounted for 30% of GHG emissions from the transportation sector. Emissions from aviation fuels decreased by 24% from 1990 to 2005 and accounted for 4% of total transportation emissions in 2005. Emissions from all other categories combined (marine gasoline, locomotives, natural gas and LPG, and oxidation of lubricants) contributed less than 4% of total transportation emissions in 2005.

GHG emissions from the transportation sector are expected to increase by 48% from 2005 to 2025 to 12.6 MMtCO_2e in 2025. Emissions from onroad diesel vehicles are projected to increase by 99% between 2005 and 2025 to 5.0 MMtCO_2e. Emissions from onroad gasoline vehicles are expected to grow at a slower pace, with an increase of 31% from 2005 to 2025, reaching 6.9 MMtCO_2e by 2025. Emissions from aviation and natural gas, LPG, and lubricants are also expected to grow, by 6.9% and 16.7%, respectively, from 2005 to 2025. In contrast, emission from the rail and marine gasoline sectors are both expected to decline, by 31% and 9.6%, respectively, from 2005 to 2025.

Table C7. Transportation GHG Emissions by Source Fuel, MMtCO_2e

	1990	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**
Onroad Gasoline	4.26	5.14	5.80	5.28	5.93	6.29	6.62	6.93
Onroad Diesel	1.24	1.68	2.24	2.52	2.63	3.33	4.14	5.00
Jet Fuel/Av. Gas	0.46	0.63	0.36	0.36	0.36	0.37	0.37	0.38
Marine Gasoline	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06
Rail	0.21	0.22	0.22	0.26	0.17	0.17	0.18	0.18
Other	0.07	0.06	0.07	0.06	0.06	0.07	0.07	0.07
Total	**6.31**	**7.79**	**8.74**	**8.54**	**9.21**	**10.29**	**11.44**	**12.63**

Figure C1. Transportation GHG Emissions by Source and Fuel, 1990-2025



Source: CCS calculations based on approach described in text.

Key Uncertainties

Uncertainties in Onroad Fuel Consumption

A major uncertainty in this analysis is the conversion of the projected VMT to fuel consumption. These are based on first allocating Idaho's total VMT projections by vehicle type using national vehicle type growth projections from AEO2009 modeling, which may not reflect Idaho conditions. The conversion of the VMT data to fuel consumption also includes national assumptions regarding fuel economy by vehicle type.

Energy Independence and Security Act of 2007

The reference case projections documented here do not include the corporate average fuel economy (CAFE) or biofuels provisions (or any other provisions) of the Energy Independence and Security Act of 2007. Increases in vehicle fuel economy resulting from this act would lead to reduced CO_2 emissions from onroad vehicles. Reductions attributable to the CAFE provisions of this Act are quantified as a recent action.

Uncertainties in Aviation Fuel Consumption

The jet fuel and aviation gasoline fuel consumption from EIA is actually fuel *purchased* in the state, and therefore includes fuel consumed during state-to-state flights and international flights. The fuel consumption associated with international air flights should not be included in the state inventory; however, data were not available to subtract this consumption from total jet fuel estimates. Another uncertainty associated with aviation emissions is the use of general aviation forecasts to project aviation gasoline consumption. General aviation aircraft consume both jet fuel and aviation gasoline, but fuel specific data were not available.

Appendix D. Industrial Processes

Overview

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

- Carbon Dioxide (CO_2) from:
  - Production of cement and lime;
  - Consumption of limestone, dolomite, and soda ash;
- Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) from semiconductor manufacture;
- SF_6 from transformers used in electric power transmission and distribution (T&D) systems; and
- 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 Idaho include the following:

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

Emissions and Reference Case Projections

GHG emissions for 1990 through 2005 were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for this sector.[46] Table D1 identifies for each emissions source category the information needed for input into SIT 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 Idaho Department of Environmental Quality (DEQ) provided data for annual clinker production and annual lime production for 1999, 2002, and 2005. Table D1 provides additional details on how the data provided were used to calculate historical emissions for these two categories.

[46] GHG emissions were calculated using SIT, 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 SIT	Data Source
Cement Manufacturing - Clinker Production	1990 - 2005	Metric tons (Mt) of clinker produced each year.	Idaho Department of Environmental Quality (DEQ) provided annual clinker production data for one plant (Ash Grove Cement) for 1999, 2002, and 2005. Data for 1999 were used as a surrogate for data for 1990, 1995, and 2000.
Lime Manufacture	1990 - 2005	Mt of high-calcium lime and dolomitic produced each year.	DEQ provided total lime production for two plants owned by TASCO for 1999, 2002, and 2005. Data for 1999 were used as surrogate for data for 1990, 1995, and 2000. Information on the type of lime manufactured was not available; assumed production was for high-calcium lime.
Limestone and Dolomite Consumption	1990 - 2002	Mt of limestone and dolomite consumed.	Used default consumption data available in SIT for 1994 through 2002. Default data for 1990 through 1993 were not available in SIT. For default data, the state's total limestone consumption (as reported by USGS) is multiplied by the ratio of national limestone consumption for industrial uses to total national limestone consumption. Additional information on these calculations, including a definition of industrial uses, is available in Chapter 6 of the EIIP guidance document.
Soda Ash Consumption	1990 - 2002	Mt of soda ash consumed.	*USGS Minerals Yearbook, 2004: Volume I, Metals and Minerals*, (http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/). For population data, see references for ODS substitutes.
ODS Substitutes	1990 - 2002	Based on state's population and estimates of emissions per capita from the US EPA national GHG inventory.	-- Population data for 1990 through 2002 from Idaho Power, *2006 Integrated Resource Plan*, Appendix C – "Forecast of Population, Households, and Persons per Household," Compiled and prepared by Idaho Economics, Boise, Idaho (http://www.idahopower.com/2006irp/2006irpfinal.htm). -- 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).
Semiconductor Manufacturing	1990 - 2002	State and national value of semiconductor shipments for NAICS code 334413 (Semiconductor and Related Device Manufacturing). Method uses ratio of state-to-national value of semiconductor shipments to estimate state's proportion of national emissions for 1990 -	National emissions from US EPA 2005 "Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2003" (http://www.epa.gov/climatechange/emissions/usgginv_archive.html). Value of shipments from U.S Census Bureau's "1997 Economic Census" (http://www.census.gov/econ/census02/). Note: Idaho data for NAICS code 334413 withheld in 2002 Economic Census.
Electric Power T&D Systems	1990 - 2002	Emissions from 1990 to 2003 based on the national emissions per kWh and state's electricity use provided in SIT.	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.

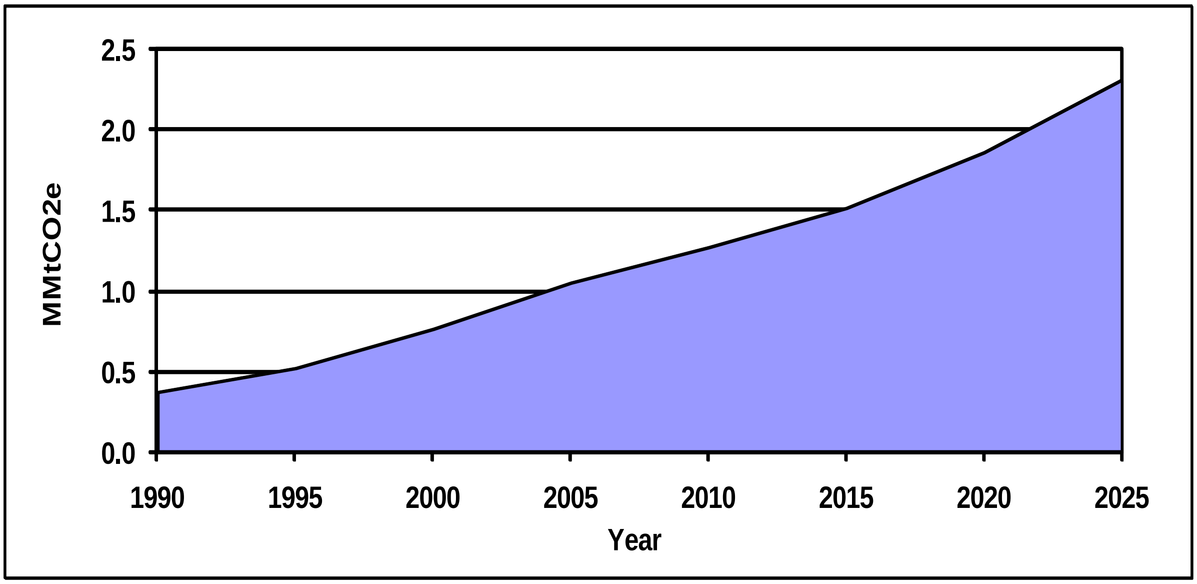
Table D2. Approach to Estimating Projections

Source Category	Time Period	Projection Assumptions	Data Source	Annual Growth Rates (%)				
				2000 to 2005	2005 to 2010	2010 to 2015	2015 to 2020	2020 to 2025
Cement Manufacturing - Clinker Production	2006 - 2025	Compound annual growth rate for Idaho's goods-producing sector. The goods-producing sector includes employment in the natural resources and mining, construction, and manufacturing sectors.	Idaho Power, *2006 Integrated Resource Plan*, Appendix C – "Economic Forecast," Compiled and prepared by Idaho Economics, Boise, Idaho (http://www.idahopower.com/2006irp/2006irpfinal.htm).	None, actual data used for 2000 and 2005	1.7	0.9	1.4	1.5%
Lime Manufacture	2006 - 2025	Ditto	Ditto	Ditto	1.7	0.9	1.4	1.5%
Limestone and Dolomite Consumption	2003 - 2025	Ditto	Ditto	-0.2	1.7	0.9	1.4	1.5%
Soda Ash Consumption	2003 - 2025	Growth between 2004 and 2009 is projected to be about 0.5% per year for US production. Assumed growth is same for 2010 – 2025.	*Minerals Yearbook, 2005: Volume I, Soda Ash*, (http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/soda_myb05.pdf).	0.5	0.5	0.5	0.5	0.5%
ODS Substitutes	2003 - 2025	Based on national growth rate for use of ODS substitutes.	EPA, 2004 ODS substitutes cost study report (http://www.epa.gov/ozone/snap/emissions/TMP6si9htnvca.htm).	15.8	7.9	5.8	5.3	5.3%
Semiconductor Manufacturing	2003 - 2025	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	-2.8%
Electric Power T&D Systems	2003 - 2025	Ditto	Ditto	3.3	-6.2	-9.0	-2.8	-2.8%

Results

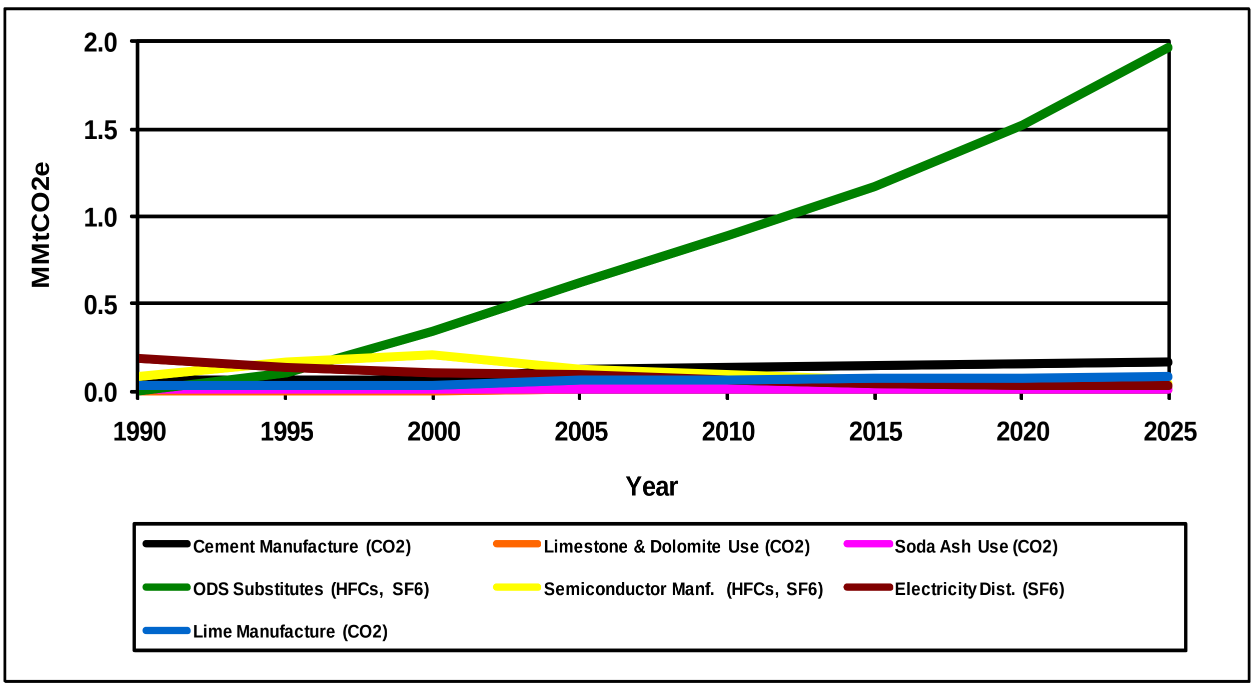
Figures D1 and D2 show historic and projected emissions for the industrial processes sector from 1990 to 2025. Total gross GHG emissions from industrial processes were about 1.1 MMTCO_2e in 2005 (3% of total gross Idaho GHG emissions), rising to about 2.3 MMTCO_2e in 2025 (5% of total gross GHG emissions). Emissions from the overall industrial processes category are expected to grow rapidly, as shown in Figures D1 and D2 and in Table D3, 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, 1990-2025



Source: CCS calculations based on approach described in text.

Figure D2. GHG Emissions from Industrial Processes, 1990-2025, by Source



Source: CCS calculations based on approach described in text.

Table D3. Historical and Projected Emissions for the Industrial Processes Sector ($MMtCO_2e$)

Industry / Pollutant	1990	1995	2000	2005	2010	2015	2020	2025
Cement Manufacture (CO2)	0.060	0.060	0.060	0.131	0.141	0.148	0.158	0.170
Lime Manufacture (CO2)	0.028	0.028	0.028	0.063	0.068	0.071	0.076	0.082
Limestone & Dolomite Use (CO2)	-	0.007	0.003	0.008	0.008	0.009	0.009	0.010
Soda Ash Use (CO2)	0.011	0.012	0.012	0.013	0.013	0.013	0.014	0.014
ODS Substitutes (HFCs, SF6)	0.001	0.107	0.346	0.619	0.888	1.173	1.517	1.962
Semiconductor Manuf. (HFCs, SF6)	0.082	0.169	0.211	0.129	0.091	0.061	0.053	0.046
Electricity Dist. (SF_6)	0.192	0.140	0.106	0.093	0.065	0.044	0.038	0.033
Total	**0.374**	**0.523**	**0.766**	**1.054**	**1.274**	**1.518**	**1.864**	**2.316**

Substitutes for Ozone-Depleting Substances (ODS)

HFCs and PFCs are used as substitutes for ODS, most notably CFCs (CFCs are also potent warming gases, with global warming potentials on the order of thousands of times that of CO_2 per unit of emissions) in compliance with the *Montreal Protocol* and the *Clean Air Act Amendments of 1990*.[47] Even low amounts of HFC and PFC emissions, for example, from leaks and other releases associated with normal use of the products, can lead to high GHG emissions on a carbon-equivalent basis. GHG-equivalent emissions from the use of ODS substitutes in Idaho were calculated using the default methods in SIT (see Table D3 and dark green line in Figure D2). Emissions have increased from 0.0014 $MMtCO_2e$ in 1990 to about 0.62 $MMtCO_2e$ in 2005, and are expected to increase at an average rate of 5.9% per year from 2005 to 2025 due to increased substitutions of these gases for ODS. The projected rate of increase for these emissions is based on projections for national emissions from the US EPA report referenced in Table D2.

Electricity Distribution

Emissions of SF_6 from electrical equipment have experienced declines since the early nineties (see brown line in Figure D2), mostly due to voluntary action by industry. SF_6 is used as an electrical insulator and interrupter in electricity T&D systems. Emissions for Idaho from 1990 to 2002 were estimated based on the estimates of emissions per kWh from the US EPA GHG inventory and Idaho's electricity consumption estimates provided in SIT. The *US Climate Action Report* shows expected decreases in these emissions at the national level, and the same rate of

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

decline is assumed for emissions in Idaho. The decline in SF_6 emissions in the future reflects expectations of future actions by the electric industry to reduce these emissions. Relative to total industrial non-combustion process emissions, SF_6 emissions from electrical equipment are low (about 0.19 $MMtCO_2e$ in 1990 and 0.03 $MMtCO_2e$ in 2025), and therefore, appear at the bottom of the graph because of scaling effects in Figure D2.

Semiconductor Manufacture
Emissions of SF_6 and HFCs from the manufacture of semiconductors have experienced declines since 2000 (see Table D3 and yellow line in Figure D2). Emissions for Idaho from 1990 to 2002 were estimated based on the default estimates provided in SIT, which uses the ratio of the state-to-national value of semiconductor shipments to estimate the state's proportion of national emissions from the US EPA GHG inventory (US EPA 2005 *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2003*). 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 Idaho. The decline in emissions in the future reflects expectations of future actions by the semiconductor industry to reduce these emissions. Relative to total industrial non-combustion process emissions, emissions associated with semiconductor manufacturing are low (about 0.08 $MMtCO_2e$ in 1990 and 0.05 $MMtCO_2e$ in 2025), and therefore, appear at the bottom of the graph because of scaling effects in Figure D2.

Clinker Production for Cement Manufacture
Idaho has one cement plant (Ash Grove Cement Company) that produces clinker (an intermediate product from which finished Portland and masonry cement are made). Clinker production releases CO_2 when calcium carbonate ($CaCO_3$) is heated in a cement kiln to form lime (calcium oxide) and CO_2 (see Chapter 6 of the EIIP guidance document). Emissions are calculated by multiplying annual clinker production and annual production of masonry cement by emission factors for these processes. The clinker production data for the plant was summed and entered into the SIT to calculate GHG emissions (see Table D3 and black line in Figure D2). Information on masonry cement production for the plant was not available. The employment growth rate for Idaho's goods-producing sector was used to project emissions to 2025. As shown in Figure D2, emissions increase slightly from 0.13 $MMtCO_2e$ in 2005 to 0.17 $MMtCO_2e$ in 2025, reflecting an overall average annual increase of about 1.3% over that time period.

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

Emissions are estimated by multiplying the amount of high-calcium and dolomitic lime produced by CO_2 emission factors for high-calcium and dolomitic lime. Information on the type of lime produced by the two plants in Idaho was not available. For this initial analysis, it was assumed that both plants produce high-calcium lime for the purpose of calculating emissions. The high-calcium lime production data for both plants were summed and entered into the SIT to calculate statewide GHG emissions from this source (see Table D3 and dark blue line in Figure D2). The employment growth rate for Idaho's goods-producing sector was used to project emissions to 2025. As shown in Figure D2, emissions increase slightly from 0.06 $MMtCO_2e$ in 2005 to 0.08 $MMtCO_2e$ in 2025, reflecting an overall average annual increase of about 1.3% over that time period.

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.[48] Recent historical data for Idaho were not available from the USGS; consequently, the default data provided in SIT were used to calculate emissions for Idaho from the use of these materials (see Table D3 and orange line in Figure D2). The employment growth rate for Idaho's goods-producing sector was used to project emissions from 2003 through 2025. Relative to total industrial non-combustion process emissions, emissions associated with limestone and dolomite consumption are low (about 0.008 $MMtCO_2e$ in 2005 and 0.01 $MMtCO_2e$ in 2025), and therefore, appear at the bottom of the graph in Figure D2 due to scaling effects. Note that for this sector, SIT did not contain default consumption data for Idaho for 1990 through 1993, and therefore emissions were not estimated for these years.

Soda Ash Consumption
Commercial soda ash (sodium carbonate) is used in the manufacture of many consumer products such as glass, soap and detergents, paper, textiles, and food. CO_2 is also released when soda ash is consumed (see Chapter 6 of the EIIP guidance document). SIT estimates historical emissions (see Table D3 and 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 2025. Relative to total industrial non-combustion process emissions, emissions associated with soda ash consumption are low (about 0.01 $MMtCO_2e$ in 1990 and 0.014 $MMtCO_2e$ in 2025), and therefore cannot be seen in the graph due to scaling effects in Figure D2.

Key Uncertainties

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

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

- Data for all of the historical years could not be obtained because of time and resource constraints. The inventory can be improved upon in the future by obtaining actual production and consumption data for all of the historical years.
- DEQ noted that there is one plant (J.R. Simplot - Don Siding in Pocatello, Idaho) that may manufacture nitric acid. DEQ did not have information to verify if this plant has either manufactured in the past or currently manufactures nitric acid. Future work should include an assessment to verify if this plant has manufactured nitric acid. If this plant has manufactured nitric acid, the production and control data for the plant should be obtained to calculate emissions associated with this sector. Note that the 100-year global warming potential for N_2O emissions, which are associated with the manufacture of nitric acid, is 310 times more potent than that of CO_2; consequently, emissions for the industrial processes category could be significantly underestimated (on a $MMtCO_2e$ basis) if nitric acid manufacture in Idaho (if it takes place) is not included in the inventory and forecast.
- 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 Idaho manufacturers in these industries, and on the specific nature of the production processes used in Idaho.
- 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; Idaho-specific estimates are currently unavailable. In addition, emissions through 2025 and beyond will be driven by future choices regarding mobile and stationary air conditioning technologies and the use of refrigerants in commercial applications, for which several options currently exist.
- Greenhouse gases are emitted from several additional industrial processes that are not covered in the EIIP guidance documents, due in part to a lack of sufficient state data on non-energy uses of fossil fuels for these industrial processes. These sources include:
    - Iron and Steel Production (CO_2 and CH_4);
    - Ammonia Manufacture and Urea Application (CO_2, CH_4, N_2O);
    - Aluminum Production (CO_2);
    - Titanium Dioxide Production (CO_2);
    - Phosphoric Acid Production (CO_2);
    - CO_2 Consumption (CO_2);
    - Ferroalloy Production (CO_2);
    - Petrochemical Production (CH_4); and
    - Silicon Carbide Production (CH_4).

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

Appendix E. Fossil Fuel Industries

Overview

This appendix reports the greenhouse gas (GHG) emissions that are released during the production, processing, transmission, and distribution of fossil fuels. Known as fugitive emissions, these are methane (CH_4) and carbon dioxide (CO_2) emissions released via leakage and venting from oil and gas fields, processing facilities, and pipelines. Nationally, fugitive emissions from natural gas systems, petroleum systems, and coal mines accounted for 2.7% of total US GHG emissions in 2005.[49] Emissions associated with energy consumed by these processes are included in Appendix B, Residential, Commercial, and Industrial Sectors.

Oil, Gas and Coal Production

Idaho's oil and gas industry is limited to two product pipelines that traverse the state from refineries in Montana and Utah[50], as well as one LNG storage compressor station.[51] There are no active wells, refineries or processing plants. Idaho has no producing coal mines, nor coal bed CH_4 production or proved reserves, as reported by the EIA.[52]

Natural Gas Industry Emissions

Emissions of CH_4 can occur at many stages of production, processing, transmission, and distribution of oil and gas. Since there is no oil or gas production in Idaho, fugitive emissions from this sector are released primarily from over 8,000 miles of natural gas transmission and distribution pipelines in the state.[53] As there are no regulatory requirements to track CH_4 emissions from oil and gas systems, estimates based on emissions measurements in Idaho are not possible at this time.

The State Greenhouse Gas Inventory Tool (SIT), developed by the US EPA, facilitates estimation of state-level GHG emissions.[54] Methane emission estimates are calculated by multiplying emissions-related activity levels (e.g. miles of pipeline, number of compressor stations) by aggregate industry-average emission factors. Key information sources for the activity data are the US DOE EIA[55] and American Gas Association's annual publication *Gas*

[49] "The *U.S. Inventory of Greenhouse Gas Emissions and Sinks*", US EPA, 2005.
[50] "Petroleum Profile: Idaho" US DOE Energy Information Administration website, October 2006, Accessed at <http://tonto.eia.doe.gov/oog/info/state/id.html> &
[51] "US LNG Markets and Uses" EIA Office of Oil and Gas 2003,
http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2003/lng/lng2003.pdf
Map on pg 2 shows 1 LNG Storage facility in ID
Per Bruce Wilding (Program and Technical Manager, Idaho National Laboratory) This singular LNG plant came into operation in 1996. <http://www.inl.gov/lng/projects/nozzles.shtml>
[52] US DOE Energy Information Administration website, December 2006.
[53] Data from Gas Facts.
[54] Methane emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems", March 2005.
[55] "Petroleum Navigator" and "Natural Gas Navigator", US DOE Energy Information Administration website, November 2006, http://www.eia.doe.gov

Facts.[56] Methane emissions were estimated using SIT, with reference to the EIIP guidance document.

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

- Consumption – See Appendix A, Electricity, and Appendix B, Residential, Commercial and Industrial Sector for assumptions used in projecting natural gas consumption in Idaho. Based on those assumptions, Idaho's natural gas consumption is projected to grow at an annual average rate of 1.9% between 2006 and 2025.[57]
- Production –Simple assumptions were made for natural gas transmission and transport.

Table E1 provides an overview of data sources and approach used to project future emissions.

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

	Approach to Estimating Historical Emissions		**Approach to Estimating Projections**
Activity	***Required Data for SIT***	***Data Source***	***Projection Assumptions***
Natural Gas Drilling and Field Production	Number wells	EIA	There is no natural gas production in Idaho, as reported by the EIA.
	Miles of gathering pipeline	Gas Facts[53]	
Natural Gas Processing	Number gas processing plants	EIA[58]	Idaho does not have any operating gas processing plants.
Natural Gas Transmission	Miles of transmission pipeline	Gas Facts[53]	Emissions assumed to follow State gas consumption trend - annual average growth rate of 1.9% between 2006 and 2025.[59]
	Number of gas transmission compressor stations	EIIP[60]	
	Number of gas storage compressor stations	EIIP[61]	
	Number of LNG storage compressor stations	Idaho National Laboratory[62]	

[56] American Gas Association "Gas Facts, A Statistical Record of the Gas Industry" Referenced annual publications from 1992 to 2004.
[57] Based on US DOE regional projections and electric sector growth assumptions (see Appendix A and B).
[58] EIA reports no gas processing facilities in Idaho.
[59] Based on US DOE regional projections and electric sector growth assumptions (see Appendix A and B).
[60] Number of gas transmission compressor stations = miles of transmission pipeline x 0.006 EIIP. Volume VIII: Chapter 5. March 2005.
[61] Number of gas storage compressor stations = miles of transmission pipeline x 0.0015 EIIP. Volume VIII: Chapter 5. March 2005.
[62] "US LNG Markets and Uses" EIA Office of Oil and Gas 2003, http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2003/lng/lng2003.pdf
Map on pg 2 shows 1 LNG Storage facility in ID
Per Bruce Wilding (Program and Technical Manager, Idaho National Laboratory) Idaho's only LNG plant started operating in 1996. http://www.inl.gov/lng/projects/nozzles.shtml

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

Natural Gas Distribution	Miles of distribution pipeline	Gas Facts[10]	Distribution emissions follow State gas consumption trend - annual average growth rate of 1.9% between 2006 and 2025.[63]
	Total number of services	Gas Facts	
	Number of unprotected steel services	Ratio estimated from 2002 data[64]	
	Number of protected steel services	Ratio estimated from 2002 data[16]	
Oil Production	Annual production	EIA[65]	There is no oil production in Idaho, as reported by EIA.
Oil Refining	Annual amount refined	EIA[66]	There are no oil refineries in Idaho, as reported by EIA.
Oil Transport	Annual oil transported	Unavailable, assumed oil refined = oil transported	Emissions from transport of oil in Idaho are assumed to be negligible.

Note that potential improvements to production, processing, and pipeline technologies resulting in GHG emissions reductions have not been accounted for in this analysis.

Results

Table E2 displays the estimated CH_4 emissions from the fossil fuel industry in Idaho from 1990 to 2005, with projections to 2025. Emissions from this sector grew by 30% from 1990 to 2005 and are projected to increase by a further 44% between 2005 and 2025. Emissions are based solely on natural gas transmission and distribution systems.

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

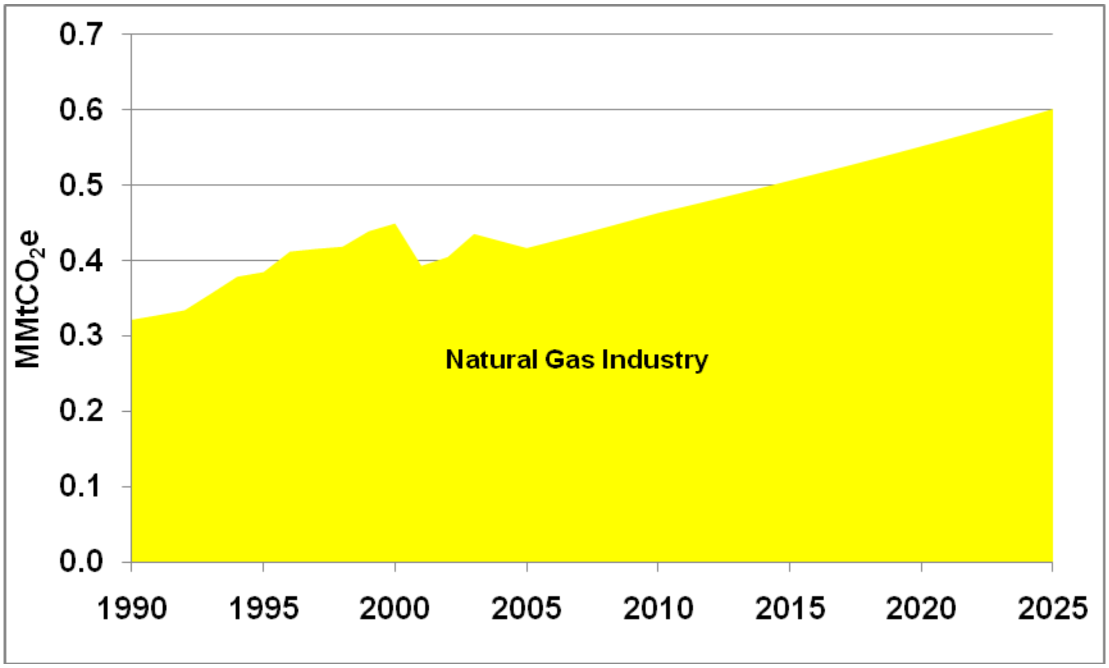
	1990	1995	2000	2005	2010	2015	2020	2025
Fossil Fuel Industry	**0.32**	**0.39**	**0.45**	**0.42**	**0.46**	**0.51**	**0.55**	**0.60**
Natural Gas Industry	0.32	0.39	0.45	0.42	0.46	0.51	0.55	0.60
Transmission (CH4)	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
Distribution (CH4)	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Oil Industry (CH4)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coal Mining (CH4)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note that 0.0 in the above table indicates no activity in this sector.

Figure E1 displays the CH_4 emissions from natural gas systems in Idaho, on a $MMtCO_2e$ basis.

[63] Based on US DOE regional projections and electric sector growth assumptions (see Appendix A and B).
[64] Gas Facts reported unprotected and protected steel services for 2002-3, but only total services for other years. Therefore the ratio of unprotected and protected steel services in 2003 was assumed to be the ratio for all other years (0.325 for protected services and 0 for unprotected services). This yields more congruent results than the EIIP guidance of using multipliers of 0.2841 for protected steel services, and 0.0879 for unprotected steel services.
[65] EIA and Petroleum Supply Annual report no crude oil production in Idaho.
[66] There is no refining data for the state of Idaho.

Figure E1. Fossil Fuel Industry Emission Trends (MMtCO$_2$e)



Source: CCS calculations based on approach described in text.

Key Uncertainties

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

- Current levels of fugitive emissions. These are based on industry-wide averages, and until estimates are available for pipelines or local facilities, uncertainties remain.
- Any future transmission lines through Idaho would impact fugitive emission projections.
- Any future production of coal, oil or natural gas in Idaho would increase fugitive emission levels.
- Other uncertainties include potential emission reduction improvements to pipeline technologies.

Appendix F. Agriculture

Overview

The emissions discussed in this appendix refer to non-energy methane (CH_4) and nitrous oxide (N_2O) emissions from enteric fermentation, manure management, and agricultural soils. Emissions and sinks of carbon dioxide (CO_2) in agricultural soils are also covered. Energy emissions related to agricultural practices (combustion of fossil fuels to power agricultural equipment) are included in the residential, commercial, and industrial (RCI) fuel consumption sector estimates.

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

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

The net flux of CO_2 in or out of agricultural soils depends on the balance of carbon losses from management practices and gains from organic matter inputs to the soil. Carbon dioxide is absorbed by plants through photosynthesis and ultimately becomes the carbon source for organic matter inputs to agricultural soils. When inputs are greater than losses, the soil accumulates carbon and there is a net sink of CO_2 into agricultural soils. Conversely, soil disturbance from the cultivation of high organic carbon soils (such as histosols) releases large stores of carbon from the soil to the atmosphere. Finally, the practice of adding limestone and dolomite to agricultural soils results in CO_2 emissions as these compounds are broken down in soil reactions.

Emissions and Reference Case Projections

Methane and Nitrous Oxide

GHG emissions for 1990 through 2005 were estimated using SIT and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[67] In general, the SIT methodology applies emission factors developed for the US to activity data for the agriculture sector. Activity data include livestock population statistics, amounts of fertilizer applied to crops, and trends in manure management practices. This methodology is based on international guidelines developed by sector experts for preparing GHG emissions inventories.[68]

Data on crop production in Idaho from 1990 to 2005 and on the number of animals in the state from 1990 to 2006 were obtained from the United States Department of Agriculture (USDA), National Agriculture Statistical Service (NASS) and incorporated as defaults in SIT.[69] Future reference case emissions from enteric fermentation and manure management were estimated based on the annual growth rate in emissions (million metric tons [MMt] carbon dioxide equivalent [CO_2e] basis) associated with historical livestock populations in Idaho for 1990 to 2006. The default data in SIT accounting for the percentage of each livestock category using each type of manure management system was used for this inventory. Default SIT assumptions were available for 1990 through 2005.

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

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

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

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

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

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

Table F1 shows the annual growth rates applied to estimate the reference case projections by agricultural sector. These annual growth rates were applied to the most recent year for which historical emissions were estimated (2005). The annual growth factors for fertilizers, agricultural crop residues, and nitrogen-fixing crops were developed based on the annual growth rate in historical emissions ($MMtCO_2e$ basis) for these categories in Idaho.

Table F1. Annual Growth Rates Applied for the Agricultural Sector

	Annual Growth Rates				
Agricultural Category	**2005-2010**	**2010-2015**	**2015-2020**	**2020-2025**	**Basis for Annual Growth Rate[a]**
Enteric Fermentation	0.9%	1.4%	1.3%	1.3%	Historical emissions for 1990-2005.
Manure Management	2.0%	2.3%	1.9%	1.9%	Historical emissions for 1990-2005.
Agricultural Burning	-1.0%	-0.4%	-0.4%	-0.4%	Historical emissions for 1990-2005.
Agricultural Soils – Direct Emissions					
Fertilizers	1.5%	-2.7%	-3.1%	-3.1%	Historical emissions for 1990-2005.
Crop Residues	-1.4%	0.7%	0.7%	0.7%	Historical emissions for 1990-2005.
Nitrogen-Fixing Crops	-2.8%	-0.8%	-0.9%	-0.9%	Historical emissions for 1990-2005.
Histosols	0.0%	0.0%	0.0%	0.0%	No historical data available.
Livestock	-5.6%	-1.9%	-2.1%	-2.1%	Historical emissions for 1990-2005.
Agricultural Soils – Indirect Emissions					
Fertilizers	-3.4%	-0.7%	-0.7%	-0.7%	Historical emissions for 1990-2005.
Livestock	-3.9%	-3.6%	-4.4%	-4.4%	Historical emissions for 1990-2005.
Leaching/Runoff	-3.5%	-1.4%	-1.5%	-1.5%	Historical emissions for 1990-2005.

[a] The compound annual growth rates were calculated using the growth rate in historical emissions from 1990 through 2005 ($MMtCO_2e$ basis) or historical animal population growth from 1990 through 2006, and applied to forecast emissions through 2025.

For enteric fermentation and manure management, historical emissions were driven primarily by the relatively high growth (about 7.2% annually) in the dairy cattle population from 1990 through 2006. The beef cattle population remained relatively constant with an annual growth rate of 0.5% from 1990 through 2006. Swine populations declined by about 5.6% annually during the 1990 through 2006 period.

Emissions for each of the enteric fermentation and manure management categories for 2005 through 2025 were estimated based on the historical growth seen in the various animal populations. Dairy and beef cattle were estimated to increase at 2.0% and 0.5%, respectively. Swine and chicken populations are estimated to decline at 8.6% and 1.7%, respectively.

Growth factors shown in Table F1 were calculated from the total emissions calculated for the enteric fermentation and manure management categories and then applied to total emissions in 2005 for each of these categories to forecast emissions through 2025. For the agricultural soils – livestock category, annual growth factors were calculated based on the historical 15-year trend in emissions for 1990 through 2005 to estimate emissions for 2006 through 2025.

Soil Carbon

Net carbon fluxes from agricultural soils have been estimated by researchers at the Natural Resources Ecology Laboratory at Colorado State University, and are reported in the *U.S. Inventory of Greenhouse Gas Emissions and Sinks*[70] and the *U.S. Agriculture and Forestry Greenhouse Gas Inventory*. The estimates are based on the IPCC methodology for soil carbon adapted to conditions in the US preliminary state-level estimates of CO_2 fluxes from mineral soils and emissions from the cultivation of organic soils were reported in the *U.S. Agriculture and Forestry Greenhouse Gas Inventory*.[71] Currently, these are the best available data at the state-level for this category. The inventory did not report state-level estimates of CO_2 emissions from limestone and dolomite applications; hence, this source is not included in this inventory at present.

Carbon dioxide fluxes resulting from specific management practices were reported. These practices include: conversions of cropland resulting in either higher or lower soil carbon levels; additions of manure; participation in the Federal Conservation Reserve Program (CRP); and cultivation of organic soils (with high organic carbon levels). For Idaho, Table F2 shows a summary of the latest estimates available from the USDA, which are for 1997. These data show that changes in agricultural practices are estimated to result in a net sink of 1.19 $MMtCO_2e$/yr in Idaho. Since data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing, the net sink of 1.19 $MMtCO_2e$/yr is assumed to remain constant.

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

Changes in cropland			Changes in Hayland				Other			Total[4]
Plowout of grassland to annual cropland[1]	Cropland manage-ment	Other cropland[2]	Cropland converted to hayland[3]	Hayland manage-ment	Cropland converted to grazing land[3]	Grazing land manage-ment	CRP	Manure application	Cultivation of organic soils	Net soil carbon emissions
1.10	(0.07)	0.00	(1.03)	(0.04)	(0.26)	(0.04)	(0.59)	(0.34)	0.07	(1.19)

[70] *U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2004* (and earlier editions), US Environmental Protection Agency, Report # 430-R-06-002, April 2006. Available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

[71] *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001*. Global Change Program Office, Office of the Chief Economist, US Department of Agriculture. Technical Bulletin No. 1907, 164 pp. March 2004. http://www.usda.gov/oce/global_change/gg_inventory.htm; the data are in appendix B table B-11. The table contains two separate IPCC categories: "carbon stock fluxes in mineral soils" and "cultivation of organic soils." The latter is shown in the second to last column of Table F2. The sum of the first nine columns is equivalent to the mineral soils category.

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.

Update: A more recent estimate of soil carbon change by state has been released, but this occurred too late to be included in the overall Idaho GHG estimate. The revised figure is from the 2010 *U.S. Greenhouse Gas Inventory Report.*[72] This new estimate is similar to the estimate made in 1997, but indicates that soil carbon now sequesters 1.42 $MMtCO_2e$ annually as of 2008, up from 1.19 $MMtCO_2e$ in 1997.

Results

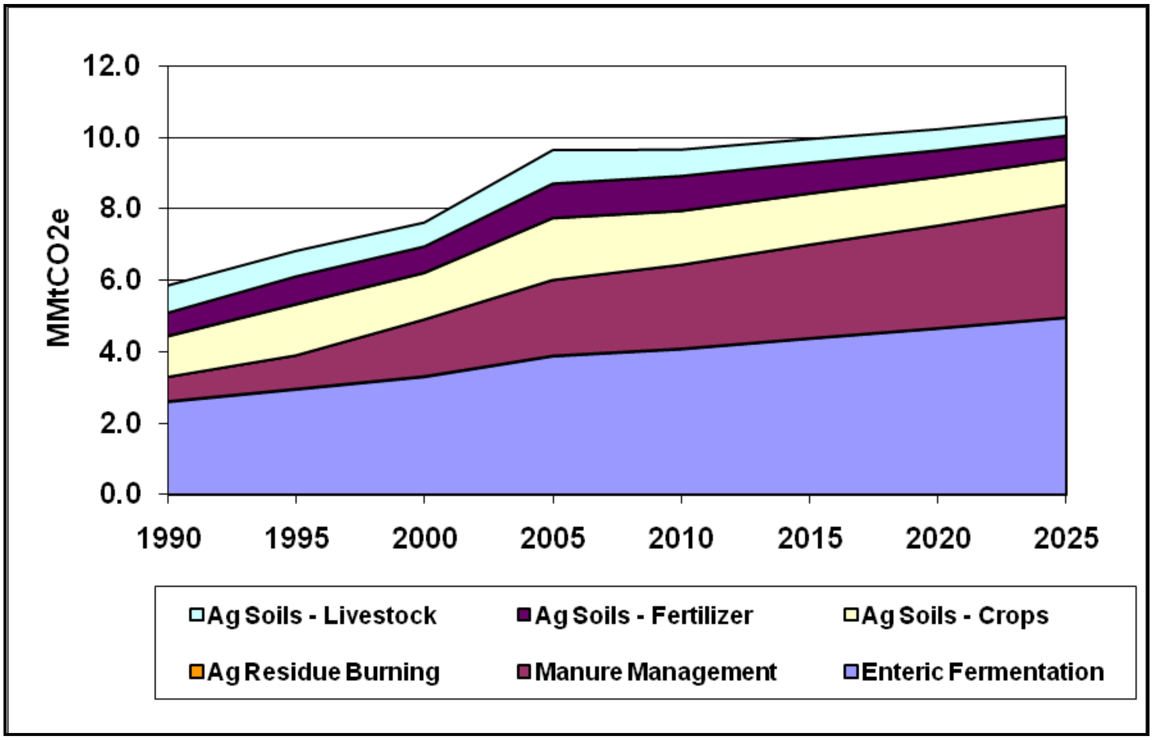
As shown in Figure F1, gross GHG emissions from agricultural sources are projected to grow from about 5.8 $MMtCO_2e$ in 1990 to 10.6 $MMtCO_2e$ in 2025. In 1990, enteric fermentation accounted for about 44% (2.6 $MMtCO_2e$) of total agricultural emissions and is estimated to account for about 47% (5.0 $MMtCO_2e$) of total agricultural emissions in 2025. The manure management category accounted for 12% (0.7 $MMtCO_2e$) of total agricultural emissions in 1990 and is estimated to account for about 30% (2.3 $MMtCO_2e$) of total agricultural emissions in 2025. The agricultural soils sector shows 1990 emissions accounting for 44% (2.6 $MMtCO_2e$) of total agricultural emissions and 2025 emissions estimated to be about 23% (2.5 $MMtCO_2e$) of total agricultural emissions. Including the estimates of annual CO_2 sequestration from soil carbon changes (-1.2 $MMtCO_2e$), the historic and projected emissions for the agriculture sector on a net basis would range between about 4.7 and 9.0 $MMtCO_2e$/yr from 1990 through 2025, respectively.

Table F3. Gross GHG Emissions from Agriculture ($MMtCO_2e$)

Sector	1990	1995	2000	2005	2010	2015	2020	2025
Enteric Fermentation	2.60	2.95	3.30	3.88	4.08	4.38	4.66	4.96
Manure Management	0.68	0.94	1.60	2.13	2.36	2.62	2.88	3.15
Ag Residue Burning	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ag Soils - Crops	1.14	1.43	1.30	1.73	1.51	1.43	1.36	1.29
Ag Soils - Fertilizer	0.65	0.78	0.73	0.96	0.97	0.86	0.74	0.64
Ag Soils - Livestock	0.77	0.71	0.67	0.94	0.74	0.66	0.59	0.53
Total Emissions	**5.85**	**6.82**	**7.62**	**9.65**	**9.66**	**9.95**	**10.2**	**10.6**

[72] *U.S. Inventory of Greenhouse Gas Emissions and Sinks: 1990-2008* (and earlier editions), US Environmental Protection Agency, Report # 430-R-10-002, April 2010. Available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

Figure F1. Gross GHG Emissions from Agriculture



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

For the entire inventory and forecast period, agricultural burning emissions account for less than 1% of Idaho's total gross GHG emissions associated with the agricultural sector. 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 $MMtCO_2e$). Thus, even though these initial emission estimates using the SIT are low relative to emissions associated with the other agricultural categories in Idaho, the emission estimates for agricultural burning in Idaho using the SIT methodology are inconsistent with other data and should be refined using actual activity data for Idaho, if available.

The only standard IPCC source categories missing from this report are N_2O emissions from the cultivation of histosol soils and CO_2 emissions from limestone and dolomite application. Estimates for Idaho were not available; however, the USDA's national estimate for soil liming is about 9 $MMtCO_2e$/yr.[73]

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

Key Uncertainties

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

As mentioned above, for emissions associated with changes in agricultural soil carbon levels, the data used in this analysis is from 1997. Newer data, which could not be incorporated into the overall Idaho estimate, were recently released by the USDA. These indicate that the soil carbon estimate from 1997 is relatively accurate, as the estimate for 2008 was very similar (-1.19 and -1.42 respectively). As mentioned above, emission estimates for soil liming have not been developed for Idaho.

Another contributor to uncertainty in the emission estimates is the projection assumptions. For the fertilizers, agricultural crop residues, and nitrogen-fixing crops 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. For example, the historical data show an increase in fertilizer use between 1990-2005. However, that increase occurred entirely by the year 2000, and fertilizer use between 2000-2005 actually declined. Given these conflicting trends, it is difficult to use historical data to forecast fertilizer use in Idaho. Future work should focus on improving on the growth rate assumptions for fertilizer use, crop production and animal populations in Idaho.

Although the agricultural burning emissions estimated using the SIT method are low relative to emissions associated with the other agricultural categories covered by this sector, the emissions account for about one-half of the US total estimated for this category. Future work on the agricultural sector should include efforts to improve the estimates for agricultural burning.

Appendix G. Waste Management

Overview

GHG emissions from waste management include:

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

Inventory and Reference Case Projections

Solid Waste Management

For solid waste management, we used the US EPA SIT software and the US EPA Landfill Methane Outreach Program (LMOP) landfills database[74] as starting points to estimate emissions. The LMOP data serve as input data to estimate annual waste emplacement for each landfill modeled by SIT. SIT then estimates CH_4 generation for each landfill site. Additional post-processing outside of SIT to account for controls is then performed to estimate final CH_4 emissions.

DEQ provided a list of landfills in the state with annual waste emplacement data that was used to supplement the LMOP database. These additional data included information on many sites that were not present in the LMOP database, as well as updated information on sites that were present in the database (e.g. waste emplacement data, information on controls). In the combined LMOP and DEQ dataset for Idaho, there are over 100 sites represented (both open and closed landfills). Two of these sites collect landfill gas (LFG) for use in a LFG to energy (LFGTE) plant (Fighting Creek Farm and Hidden Hollow). The rest of the sites were assumed to be uncontrolled. Information regarding landfills utilizing passive or active flares to combust captured was not available.

Annual waste emplacement was only available for one year, so this rate was assumed for all years that the landfill was operating. For sites where the years of operation were not available, CCS assumed that the landfill opened prior to 1961. Waste emplacement data were not available for 12 landfills. For landfills with waste emplacement values of 0.00 tons per day in the DEQ list, the waste emplacement was assumed to be 0.001 tons per day.

CCS performed two different runs of SIT to estimate emissions from municipal solid waste (MSW) landfills: (1) uncontrolled landfills, and (2) landfills with a LFG collection system and

[74] LMOP database is available at: http://www.epa.gov/lmop/proj/index.htm. Retrieved on December 12, 2009.

LFGTE plant. SIT produced annual estimates through 2006 for each of these landfill categories. CCS then performed some post-processing of the landfill emissions to account for landfill gas controls (at LFGTE sites) and to project the emissions through 2025. For the controlled landfills, CCS assumed that the overall methane collection and control efficiency is 75%.[75] Of the methane not captured by a landfill gas collection system, it is further assumed that 10% is oxidized before being emitted to the atmosphere (consistent with the SIT default). Recent literature corroborates the use of an oxidation rate, supporting a default oxidation rate of 10%.[76]

According to the LMOP database, LFGTE operations at Fighting Creek Farm Landfill began February 26, 1999 and the Hidden Hollow Landfill began July 31, 2006. Thus, the amount of CH_4 captured in the first year of LFGTE operations at each landfill is calculated by multiplying potential CH_4 emissions by the control efficiency by the proportion of the year the LFGTE operations were in place.

Growth rates were estimated by using the historic (1995-2006) growth rates of emissions in both the controlled and uncontrolled landfill categories. The period from 1995 to 2006 was used since there were a large number of landfill closures during the period in 1994 (which could have affected overall waste management practices in ID). Hence, the post-1995 period is thought to be most representative of waste emplacement rates in the future which affects the subsequent emissions. The annual growth rate applied to all landfills is 3.6%.

CCS used the SIT default for industrial solid waste landfills. This default is based on national data indicating that industrial landfilled waste is emplaced at approximately 7 percent of the rate of MSW emplacement. We assumed that this additional industrial waste emplacement occurs beyond that already addressed in the emplacement rates for MSW sites described above. Due to a lack of data, no controls were assumed for industrial waste landfilling. For industrial landfills, the overall growth rate in MSW emissions from 1995 to 2006 (3.6 %/yr) was used to project emissions to 2025 (based on the assumption that industrial waste landfilling will continue to grow at the same rate as MSW landfilling overall).

Solid Waste Combustion

There are no solid waste incinerators operating in Idaho; however, DEQ has estimated a significant level of residential waste open burning (e.g. backyard burn barrels). DEQ provided estimates of MSW open burning from their 2005 area source criteria pollutant inventory. The DEQ estimates were based on the EPA's burnable waste factor (8.56 lbs/household), which is based on national data. The estimated tons of waste burned for 2005 were scaled to other years based on rural population data. Emissions were projected to 2020 based on 2005-2020 population projections.[77]

[75] As per EPA's AP-42 Section on Municipal Solid Waste Landfills: http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf.
[76] Jeffrey P. Chanton, David K. Powelson, and Roger B. Green , "Methane Oxidation in Landfill Cover Soils, is a 10% Default Value Reasonable?" J Environ Qual 2009 38: 654-663. Review available at: http://www.terradaily.com/reports/Landfill_Cover_Soil_Methane_Oxidation_Underestimated_999.html
[77] 2006 Integrated Resource Plan, Idaho Power, http://www.idahopower.com/2006irp/2006irpfinal.htm.

Wastewater Management

GHG emissions from municipal WW treatment were also estimated. For municipal WW treatment, emissions are calculated in EPA's SIT based on state population, assumed biochemical oxygen demand (BOD) and protein consumption per capita, and emission factors for N_2O and CH_4. The key SIT default values are shown in Table G1 below. A revised value for the percentage of state residents on septic (60%) was provided by DEQ. Municipal wastewater emissions were based on population projections for 2006-2025 for a growth rate of 1.7% per year.

Table G1. SIT Key Default Values for Municipal Wastewater Treatment

Variable	Default Value
BOD	0.09 kg /day-person
Amount of BOD anaerobically treated	16.25%
CH_4 emission factor	0.6 kg/kg BOD
Idaho residents not on septic	60%
Water treatment N_2O emission factor	4.0 g N_2O/person-yr
Biosolids emission factor	0.005 kg N_2O-N/kg sewage-N

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

For industrial WW treatment emissions, SIT provides default assumptions and emission factors for three industrial sectors: Fruits & Vegetables, Red Meat & Poultry, and Pulp & Paper. DEQ provided 2005 data on WW flow and chemical oxygen demand (COD) for 20 industrial treatment plants in the fruit and vegetable sector and 2 plants in the meat and poultry sector. Emissions for 2005 were scaled to other years based on County Business Patterns employment data.[78] Employment data for SIC 2030 and NAICS 3114 were used for the fruit and vegetable sector; employment data for SIC 2010 or NAICS 3115 were used for the meat and poultry sector. Employment data were only available for 1993-2004, so employment estimates were forecasted for 2005 and back-casted for 1990-1992 based on the 1993-2004 data. Emissions were projected to 2025 based on the 1990-2005 annual growth rate (-2.6%).

Results

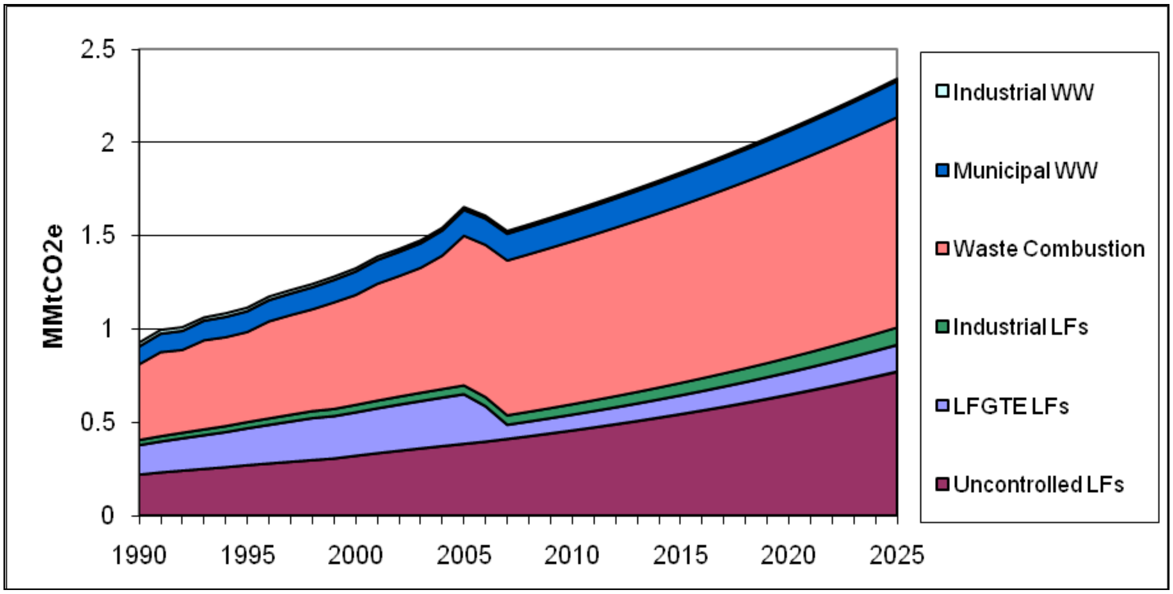
Figure G1 and Table G2 show the emission estimates for the waste management sector. Overall, the sector accounts for 1.7 $MMtCO_2e$ in 2005. By 2025, emissions are expected to grow to 2.3 $MMtCO_2e$/yr. The largest contributor to waste management emissions is the solid waste sector, in particular, waste combustion. In 2005, uncontrolled and LFGTE municipal landfills accounted for 23% and 16% of total waste management emissions, respectively. By 2025, the contribution from these sites is expected to be about 33% and 6%. Waste combustion accounted for about 49% of the waste sector emissions in 2005 and 48% in 2025.

In 2005, about 8% of the waste management sector emissions were contributed by municipal WW treatment systems and 1% of emissions were contributed by industrial WW treatment. Note

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

that these estimates for municipal WW treatment are based on the default parameters listed in Table G1 above, and might not adequately account for existing controls or management practices (e.g. anaerobic digesters served by a flare or other combustion device). By 2025, the contribution to the total waste sector emissions from the municipal and industrial WW treatment sectors are expected to remain roughly constant from 2005.

Figure G1. Idaho GHG Emissions from Waste Management



Notes: LF – landfill; WW – wastewater; LFGTE – landfill gas to energy; there are no flared landfills in Idaho.

Table G2. Idaho GHG Emissions from Waste Management ($MMtCO_2e$)

Sector	1990	1995	2000	2005	2010	2015	2020	2025
Uncontrolled LFs	0.22	0.27	0.32	0.39	0.46	0.55	0.65	0.77
LFGTE LFs	0.16	0.20	0.23	0.26	0.08	0.10	0.12	0.14
Industrial LFs	0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.09
Waste Combustion	0.41	0.48	0.59	0.80	0.88	0.95	1.04	1.13
Municipal WW	0.10	0.11	0.12	0.14	0.15	0.16	0.18	0.19
Industrial WW	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
Total	**0.93**	**1.11**	**1.33**	**1.65**	**1.63**	**1.84**	**2.07**	**2.34**

Key Uncertainties

The modeling of municipal landfill emissions does not account for uncontrolled sites that will need to apply controls during the period of analysis due to triggering the requirements of the federal New Source Performance Standards/Emission Guidelines. As noted above, the available data do not cover all of the open and closed landfills in Idaho. For this reason, emissions could be slightly underestimated for landfills. Also, as described under Solid Waste Management above, several assumptions on waste emplacement had to be made in order to develop the necessary inputs for LFG modeling.

For industrial landfills, emissions were estimated using national defaults (with industrial landfill wastes buried at 7% of the rate of MSW emplacement). It could be that the available MSW emplacement data within the combined LMOP/DEQ data used to model the MSW emissions already captures industrial LF emplacement (to the extent that industrial waste is emplaced in municipal landfills). As with overall MSW landfill emissions, industrial landfill emissions are projected to increase between 2005 and 2025. Hence, the industrial landfill inventory and forecast has a significant level of uncertainty and should be investigated further. For example, the existence of active industrial landfills that are not already represented in the LMOP database should be determined. If these sites do not exist and the existing municipal waste emplacement data are thought to include industrial wastes, then the separate estimate for industrial landfill emissions can be excluded from the inventory.

According to DEQ, about 75% of wastewater biosolids are applied to soils. In this inventory, N_2O emissions associated with these biosolids are included in the wastewater sector. Since most of the emissions probably occur after land application, these emissions could be included in the agricultural soils sector instead. These emissions are estimated to equal 0.03 $MMtCO_2e$ in 2005. Other key uncertainties with the wastewater sector are associated with the application of SIT default values for the parameters listed in Table G1 above (e.g. the fraction of BOD that is anaerobically decomposed). The SIT defaults for emission factors used to estimate WW treatment emissions were derived from national data. Waste combustion emissions were also based on a factor derived from national data.

Appendix H. Forestry

Overview

Forestland emissions refer to the net carbon dioxide (CO_2) flux[79] from forested lands in Idaho, which account for about 41% of the state's land area.[80] The dominant forest types in Idaho are Douglas fir forests which make up about 34% of forested lands and Fir-Spruce forests which make up another 24%. Other important forest types are Ponderosa pine, Lodgepole pine, and Hemlock-Sitka spruce forests.

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

The forestry sector CO_2 flux is categorized into two primary subsectors:

- *Forested Landscape:* this consists of carbon flux occurring on lands that are not part of the urban landscape. Fluxes covered include net carbon sequestration, carbon stored in harvested wood products (HWP) or landfills, and emissions from forest fires.
- *Urban Forestry and Land Use:* this covers carbon sequestration in urban trees, flux associated with carbon storage from landscape waste and food scraps in landfills, and nitrous oxide (N_2O) emissions from settlement soils (those occurring as a result of application of synthetic fertilizers).

Inventory and Reference Case Projections

Forested Landscape

For over a decade, the United State Forest Service (USFS) has been developing and refining a forest carbon modeling system for the purposes of estimating forest carbon inventories. The methodology is used to develop national forest CO_2 fluxes for the official US Inventory of Greenhouse Gas Emissions and Sinks.[81] The national estimates are compiled from state-level data. The Idaho forest CO_2 flux data in this report come from the national analysis and are provided by the USFS. See the footnotes below for the most current documentation for the forest

[79] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.
[80] Total forested acreage is 21.9 million acres. Acreage by forest type available from the USFS at: http://www.fs.fed.us/ne/global/pubs/books/epa/states/ID.htm. The total land area in Idaho is 53.5 million acres http://www.50states.com/idaho.htm
[81] US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2004 (and earlier editions), US Environmental Protection Agency, Report # 430-R-06-002, April 2006. http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

carbon modeling.[82] Additional forest carbon information is in the form of specific carbon conversion factors.[83]

The forest CO_2 flux methodology relies on input data in the form of plot level forest biomass volume statistics from the Forest Inventory Analysis (FIA). FIA data on forest biomass volumes are converted to values for ecosystem carbon stocks (i.e., the amount of carbon stored in various forest carbon pools) using the FORCARB2 modeling system. Coefficients from FORCARB2 are applied to the plot level survey data to give estimates of C density (Mg per hectare) for a number of separate C pools. Additional background on the FORCARB system is provided in a number of publications.[84]

Carbon dioxide flux is estimated as the change in carbon mass for each carbon pool over a specified time frame. Forest volume data from at least two points in time are required. The change in carbon stocks between time intervals is estimated at the plot level for specific carbon pools (Live Tree, Standing Dead Wood, Under-story, Down & Dead Wood, Forest Floor, and Soil Organic Carbon) and divided by the number of years between inventory samples. Annual increases in carbon density reflect carbon sequestration in a specific pool; decreases in carbon density reveal CO_2 emissions or carbon transfers out of that pool (e.g., death of a standing tree transfers carbon from the live tree to standing dead wood pool). Since the plot level data are used to estimate total state level carbon pools, the amount of carbon in each pool at the state-level is also influenced by changes in overall forest area (e.g. an increase in area could lead to an increase in the associated forest carbon pools and the estimated flux). The sum of carbon stock changes for all forest carbon pools yields a total net CO_2 flux for forest ecosystems.

In preparing these estimates, USFS estimates the amount of forest carbon in different forest types as well as different carbon pools. The different forests include those in the national forest (NF) system and those that are not federally-owned (private and other public forests). USFS also provides information on forests categorized as being either woodlands (forests with low productivity) and non-woodlands (e.g. timberlands or productive forest systems). In Idaho, there is very little of the woodlands forest type (e.g. pinyon-juniper forests). Additional details on the forest carbon inventory methods can be found in Annex 3 to the US EPA's 2007 GHG inventory

[82] The most current citation for an overview of how the USFS calculates the inventory based forest carbon estimates as well as carbon in harvested wood products is from the US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005 (and earlier editions), US Environmental Protection Agency, Report # USEPA #430-R-07-002, April 2007, available at: http://epa.gov/climatechange/emissions/usinventoryreport.html. Both Annex 3.12 and Chapter 7 LULUCF are useful sources of reference. See also Smith, J.E., L.S. Heath, and M.C. Nichols (in press), *US Forest Carbon Calculation Tool User's Guide: Forestland Carbon Stocks and Net Annual Stock Change*, Gen Tech Report, Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station.
[83] Smith, J.E., and L.S. Heath (2002). "A model of forest floor carbon mass for United States forest types," Res. Pap. NE-722. Newtown Square, PA: US Department of Agriculture, Forest Service, Northeastern Research Station. 37 p., or Jenkins, J.C., D.C. Chojnacky, L.S. Heath, R.A. Birdsey (2003), "National-scale biomass estimators for United States tree species", *Forest Science*, 49:12-35.
[84] Smith, J.E., L.S. Heath, and P.B. Woodbury (2004). "How to estimate forest carbon for large areas from inventory data", *Journal of Forestry*, 102: 25-31; Heath, L.S., J.E. Smith, and R.A. Birdsey (2003), "Carbon trends in US forest lands: A context for the role of soils in forest carbon sequestration", In J. M. Kimble, L. S. Heath, R. A. Birdsey, and R. Lal, editors. *The Potential of US Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect.* CRC Press, New York; and Woodbury, Peter B.; Smith, James E.; Heath, Linda S. 2007, "Carbon sequestration in the US forest sector from 1990 to 2010", *Forest Ecology and Management*, 241:14-27.

for the US.[85]

Carbon pool data for three FIA cycles to estimate flux for two different periods were available for Idaho. The carbon pool data for 1987, 1991, and 2005 were run through the US Forest Service Carbon Calculation Tool to estimate annual CO_2 flux for each pool

Carbon pool data for two periods are used to estimate CO_2 flux for each pool. The data shown in Table H1a below are based on the most recent estimates from the USFS and are included in the 2005 estimates in EPA's national GHG inventory.

Carbon pool data for four FIA cycles to estimate flux for three different periods were available for Idaho. The carbon pool data for three years are shown in Table H1a below. Note that prior to 1993, FIA had a variable schedule for taking Idaho forest inventory samples. Beginning in 2000, Idaho transitioned from periodic to annual inventories as modifications to the FIA program were applied.

The underlying FIA data, as shown in Table H1b, display a net increase in forested area of 12,921 thousand acres between 1987 and 1991. A net decrease of 3,551 was recorded from 1991 to 2005. Most of the forested lands in Idaho are considered timberland, meaning they are unreserved productive forest land producing, or capable of producing, crops of industrial wood. The timberland area is shown to have increased by 13.3 million acres between 1987 and 1991 and decrease by 5.6 million acres between 1991 and 2005.

The decrease in carbon stocks between 1990 and 2000 appears to be nearly fully explained by the loss of forest land. Based on results from the Carbon Calculation Tool, rough approximations of forest carbon density between 1990 and 2005 show a slight decrease from about 0.121 MMtC/kHa in 1990 to around 0.119 MMtC/kHa in 2000. It is important to note that there were changes in inventory sampling methods between 1987 and 1991 and 2005 FIA reporting years, which could lead to bias or error in the estimates (including a more comprehensive coverage of forest types in surveys conducted after 2000). It is not clear how much of the disappearance of forestland, in particular timberland, is the result of forest conversion versus loss from wildfire.

[85] Annex 3 to EPA's 2007 report, which contains estimates for calendar year 2005, can be downloaded at: http://www.epa.gov/climatechange/emissions/downloads06/07Annex3.pdf.

Table H1a. Forest Carbon Flux Estimates for Idaho

Forest Pool	1990 (MMtC/yr)	2000 (MMtC/yr)	2005 (MMtC/yr)
Live Tree	-1.18	1.77	1.77
Understory	-0.11	-0.13	-0.13
Standing Dead	-0.70	0.02	0.02
Down Dead	-0.47	0.05	0.05
Forest Floor	-1.76	0.22	0.22
Soil Carbon	-1.68	-0.24	-0.24
Harvested Wood Products	-0.50	-0.50	-0.50
Totals	**-6.40**	**1.18**	**1.18**
Totals (without soil carbon)	**-4.72**	**1.42**	**1.42**

MMtC = million metric tons of carbon. Positive numbers indicate net emission. Multiply MMtC by 3.67 (44/12) to convert to $MMtCO_2$.

Totals may not sum exactly due to independent rounding.

Data source: Smith, James, et al. *US Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change* (http://www.nrs.fs.fed.us/pubs/2394), July 2009.

Table H1b. Forest Area Estimates for Idaho

Forest Area	1987 (10^3 acres)	1991 (10^3 acres)	2005 (10^3 acres)
All Forests	12,060	24,981	21,430
Timberland	8,405	21,762	16,203

In addition to the forest carbon pools, additional carbon stored as biomass is removed from the forest for the production of durable wood products. Carbon remains stored in the products pool or is transferred to landfills where much of the carbon remains stored over a long period of time. The USFS uses a model referred to as WOODCARB2 for the purposes of modeling national HWP carbon storage.[86] State-level information for Idaho was provided to CCS by USFS.[87]

As shown in Table H2, 1.85 $MMtCO_2$/yr are estimated by the USFS to be sequestered annually (1980-2005) in wood products. Also, as shown in this table, the total average annual flux estimate including all forest pools is -12.5 $MMtCO_2$ between 1990 and 2008 based on forest pool estimates from the Carbon Calculation Tool.[88] Additional details on the forest carbon inventory

[86] Skog, K.E., and G.A. Nicholson (1998), "Carbon cycling through wood products: the role of wood and paper products in carbon sequestration", *Forest Products Journal*, 48(7/8):75-83; or Skog, K.E., K. Pingoud, and J.E. Smith (2004), "A method countries can use to estimate changes in carbon stored in harvested wood products and the uncertainty of such estimates", *Environmental Management*, 33(Suppl. 1): S65-S73.
[87] Obtained from the Harvested Wood Product model developed by Ken Skog, USFS.
[88] Jim Smith, USFS, *US. Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change* (http://www.nrs.fs.fed.us/pubs/2394), July, 2009.

methods can be found in Annex 3 to the US EPA's 2006 GHG inventory for the US.[89]

Based on discussions with the USFS, CCS recommends excluding the soil carbon pool from the overall forest flux estimates due to a high level of uncertainty associated with these estimates. The forest carbon flux estimates provided in the summary tables at the front of this report are those without the soil carbon pool. The resulting estimates provided at the bottom of Table H2 are in line with the observed changes in forest area during this time period.

Table H2. USFS Average Annual Forest CO_2 Flux for Idaho

Forest Pool	1990-2008 Average Flux ($MMtCO_2$/yr)
Forest Carbon Pools (non-soil)	-6.27
Soil Organic Carbon	-4.37
Harvested Wood Products	-1.85
Total	**-12.5**
Total (excluding soil carbon)	**-10.6**

Totals may not sum exactly due to independent rounding.
Data source: Smith, James, et al. US Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change (http://www.nrs.fs.fed.us/pubs/2394), USFS, July 2009.

For historic emission estimates, CCS used the average flux calculated using the Carbon Calculation Tool as shown in Table H1a. For the reference case projections (2005-2025), the forest area and carbon densities of forestlands were assumed to remain at the same levels as in 2005 (i.e. a net source of CO_2 to the atmosphere). Information is not available on the near term effects of climate change and their impacts on forest productivity and carbon flux. Nor were data readily-available on projected losses in forested area.

Forest Fires and Prescribed Burning

In order to provide a more comprehensive understanding of GHG sources/sinks from the forestry sector, CCS also developed some rough estimates of state-wide emissions for methane (CH_4) and nitrous oxide (N_2O) from wildfires and prescribed burns. A 2006 study published in *Science* indicated an increasing frequency of wildfire activity in the western US driven by a longer fire season and higher temperatures.[90]

CCS used 2002 emissions data developed by the Western Regional Air Partnership (WRAP) to

[89] Annex 3 to EPA's 2006 report, which contains estimates for calendar year 2004, http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/RAMR6MBLNQ/$File/06_annex_Chapter3.pdf.
[90] Westerling, A.L. et al, "Warming and Earlier Spring Increases Western US Forest Wildfire Activity", *Sciencexpress*, July 6, 2006.

estimate CO_2e emissions for wildfires and prescribed burns.[91] The CO_2e from CH_4 emissions from this study were added to an estimate of CO_2e for N_2O to estimate a total CO_2e estimate for fires (the carbon dioxide emissions from fires are captured within the carbon pool accounting methods described above). The N_2O estimate was made assuming that N_2O was 1% of the emissions of nitrogen oxides (NO_x) from the WRAP study. The 1% estimate is a common rule of thumb for the N_2O content of NO_x from combustion sources.

The results for 2002 are that wildfires and prescribed burns contributed about 0.24 $MMtCO_2$e of CH_4 and N_2O. About 90% of the CO_2e was contributed by CH_4. In 2002, there were about 172,000 acres burned by wildfires and prescribed burns in Idaho. Note that this 2002 level of wildfire activity compares to over 900,000 acres burned in Idaho in 1996.[92]

A comparison estimate was made using emission factors from a 2001 global biomass burning study[93] and the total tons of biomass burned from the 2002 WRAP fires emissions inventory. This estimate is 0.29 $MMtCO_2$e with about equal contributions from CH_4 and N_2O on a CO_2e basis. Given the large swings in fire activity from year to year and the current lack of data for multiple years, CCS did not include these estimates in with the annual forestry flux estimates presented in the emissions summaries of this report. However, on the basis of total acres burned in 1996 and 2002, it appears that forest fires contribute on the order of 0.3 – 1.3 $MMtCO_2$e annually in Idaho from CH_4 and N_2O emissions.

Urban Forestry & Land Use

GHG emissions for 1990 through 2005 were estimated using the EPA State Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[94] In general, the SIT methodology applies emission factors developed for the US to activity data for the urban forestry sector. Activity data include urban area, urban area with tree cover, amount of landfilled yard trimmings and food scraps, and the total amount of synthetic fertilizer applied to settlement soils (e.g., parks, yards, etc.). This methodology is based on international guidelines developed by sector experts for preparing GHG emissions inventories.[95] Table H3 displays the emissions and reference case projections for Idaho.

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[91] *2002 Fire Emission Inventory for the WRAP Region Phase II*, prepared by Air Sciences, Inc. for the Western Regional Air Partnership, July 22, 2005.

[92] *1996 Fire Emission Inventory*, Draft Final Report, prepared by Air Sciences, Inc. for the Western Regional Air Partnership, December 2002.

[93] M. O. Andreae and P. Merlet, "Emission of trace gases and aerosols from biomass burning", *Global Biogeochemical Cycles*, Vol. 15, No. 4, pp. 955-966, December 2001.

[94] GHG emissions were calculated using SIT, with reference to EIIP, Volume VIII: Chapter 8.

[95] Revised 1996 1ntergovermental 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/).

Table H3. Urban Forestry & Land Use Emissions and Reference Case Projections ($MMtCO_2e$)

Source Sector	1990	2000	2005	2010	2020	2025
Urban Trees	(0.17)	(0.22)	(0.25)	(0.25)	(0.25)	(0.25)
Landfilled Yard Trimmings and Food Scraps	(0.97)	(0.40)	(0.33)	(0.33)	(0.33)	(0.33)
N_2O from Settlement Soils[a]	0.06	0.08	0.10	0.10	0.10	0.10
Total	**(1.08)**	**(0.54)**	**(0.47)**	**(0.47)**	**(0.47)**	**(0.47)**

[a] Data for settlement soils was obtained from AAPFCO (2006) Commercial Fertilizers 2005. Association of American Plant Food Control Officials and The Fertilizer Institute, University of Kentucky, Lexington, KY.

Changes in carbon stocks in urban trees are equivalent to tree growth minus biomass losses resulting from pruning and mortality. Net carbon sequestration was calculated using data on crown cover area. The default urban area data in SIT (which varied from 817 square kilometers [km^2] to 1,174 km^2 between 1990 and 2005) was multiplied by the state estimate of the percent of urban area with tree cover (26% for Idaho) to estimate the total area of urban tree cover. These default SIT urban area tree cover data represent area estimates taken from the US Census and coverage for years 1990 and 2000.[96] Estimates of urban area in the intervening years (1990-1999) and subsequent years (2001-2005) are interpolated and extrapolated, respectively.

Estimates of net carbon storage of landfilled yard trimmings and food scraps were calculated by estimating the change in landfill carbon stocks between inventory years. The SIT estimates for the amount of landfilled yard trimmings decreased significantly during the 1990's. CCS believes that this is consistent with changes in the waste management industry nationally during this period.

Settlement soils include all developed land, transportation infrastructure and human settlements of any size. Projections for urban trees, landfilled yard trimmings and food scraps, and settlement soils were kept constant at 2005 levels.

Table H4 provides a summary of the estimated flux for the entire forestry and land use sector.

Table H4. Forestry and Land Use Flux and Reference Case Projections ($MMtCO_2e$)

Subsector	1990	2000	2005	2010	2020	2025
Forested Landscape (excluding soil carbon)	-17.3	5.22	5.22	5.22	5.22	5.22
Urban Forestry and Land Use	-1.08	-0.54	-0.47	-0.47	-0.47	-0.47
Forest Wildfires (N_2O & CH_4)	N/A	N/A	N/A	N/A	N/A	N/A
Sector Total	**-18.4**	**4.69**	**4.75**	**4.75**	**4.75**	**4.75**

N/A – not available.

[96] Dwyer, John F.; Nowak, David J.; Noble, Mary Heather; Sisinni, Susan M. 2000. *Connecting people with ecosystems in the 21st century: an assessment of our nation's urban forests.* Gen. Tech. Rep. PNW-GTR-490.

Key Uncertainties

It is important to note that there were methodological differences in the FIA surveys (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 (low productivity forests such as pinyon-juniper), 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). Given that woodlands do not make up much of Idaho's forests, these methodological differences are not thought to have a substantial effect on the flux estimates.

Also, FIA surveys since 1999 include all dead trees on the plots, but data prior to that are variable in terms of these data. The modifications to FIA surveys are a result of an expanded focus in the FIA program, which historically was only concerned with timber resources, while more recent surveys have aimed at a more comprehensive gathering of forest biomass data. The effect of these changes in survey methods has not been estimated by the USFS. Western National Forests show a relatively large rate of carbon sequestration concurrent with an increase in forest area. It is possible that changes in FIA sampling resulted in more forest area coming into the inventory sample in the second time period.

Regarding the forecast for the forested landscape, potentially the largest source of uncertainty relates to the influence that future changes in climate will have on Idaho's forests to sequester carbon (e.g. longer warmer summers, changing levels of precipitation). Additionally, conversion of forested area to other land use could further impact forest carbon sequestration potential.

Finally, much of the urban forestry & land use emission estimates rely on national default data and could be improved with state-specific data.

Appendix I. Inventory and Forecast for Black Carbon

This appendix summarizes the methods, data sources, and results of the development of an inventory and forecast for black carbon (BC) emissions in Idaho. Black carbon is an aerosol (particulate matter or PM) species with positive climate forcing potential but currently without a global warming potential defined by the Intergovernmental Panel on Climate Change (IPCC; see Appendix J for more information on BC and other aerosol species). Black carbon is synonymous with elemental carbon (EC), which is a term common to regional haze analysis. An inventory for 2002 was developed based on inventory data from the Western Regional Air Partnership (WRAP) regional planning organization and other sources.[97] This appendix describes these data and methods for estimating mass emissions of BC and then transforming the mass emission estimates into carbon dioxide (CO_2) equivalents (CO_2e) in order to present the emissions within a greenhouse gas (GHG) context.

In addition to the PM inventory data from WRAP, PM speciation data from the United States Environmental Protection Agency's (US EPA) SPECIATE database were also used: these data include PM fractions of EC (also known as BC) and primary organic aerosols (also known as organic material or OM). These data come from ongoing work being conducted by E.H. Pechan & Associates, Inc. (Pechan) for the US EPA on updating the SPECIATE database.[98] These new profiles have just recently been released by EPA. As will be further described below, both BC and OM emission estimates are needed to assess the CO_2e of BC emissions. While BC and OM emissions data are available from the WRAP regional haze inventories, the Center for Climate Strategies (CCS) favored the newer speciation data available from the US EPA for the purposes of estimating BC and OM for most source sectors (BC and OM data from the WRAP were used only for the nonroad engines sector). In particular, better speciation data are now available from the US EPA for important BC emissions sources (e.g., most fossil fuel combustion sources).

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

Development of BC and OM Mass Emission Estimates

The BC and OM mass emission estimates were derived by multiplying the emissions estimates for PM with an aerodynamic diameter of less than 2.5 micrometers ($PM_{2.5}$) by the appropriate aerosol fraction for BC and OM. The aerosol fractions were taken from Pechan's ongoing work to update US EPA's SPECIATE database as approved by US EPA's SPECIATE Workgroup members.

After estimating both BC and OM emissions for each source category, we used the BC estimate as described below to estimate the CO_2e emissions. Also, as described further below, the OM emission estimate was used to determine whether the source was likely to have positive climate forcing potential. The mass emission results for 2002 are shown in Table I1.

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

Development of CO_2e for BC+OM Emissions

We used similar methods to those applied previously in Maine and Connecticut for converting BC mass emissions to CO_2e.[99] These methods are based on the modeling of Jacobson (2002)[100] and his updates to this work (Jacobson, 2005a).[101] Jacobson (2005a) estimated a range of 90:1 to 190:1 for the climate response effects of BC+OM emissions as compared to the amount of carbon in CO_2 emissions (depending on either a 30-year or 95-year atmospheric lifetime for CO_2). It is important to note that the BC+OM emissions used by Jacobson were based on a 2:1 ratio of OM:BC (his work in these papers focused on fossil fuel BC+OM; primarily diesel combustion, which has an OM:BC ratio of 2:1 or less).

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

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

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

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

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

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

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

[99] 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.

[100] 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.

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

effect or a net cooling effect). Therefore, for source categories where the PM is dominated by OM (e.g., biomass burning), the net climate response associated with these emissions is highly uncertain and could potentially produce a net negative climate forcing potential. Further, OM:BC ratios of 4 or more are well beyond the 2:1 ratio used by Jacobson in his work.

Results and Discussion

We estimate that BC mass emissions in Idaho total about 3.2 $MMtCO_2e$ in 2002. This is the mid-point of the estimated range of emissions. The estimated range is 2.1 – 4.4 $MMtCO_2e$ (see Table I1). The primary contributing sectors in 2002 were nonroad diesel (73%), onroad diesel (14%), nonroad gasoline (6%), and rail (4%).

The nonroad diesel sector includes engine exhaust emissions used for construction/mining, commercial, industrial and agricultural purposes, and recreational vehicles. Agricultural engines contributed about 78% of the nonroad diesel total, while construction and mining engines contributed another 13%. For nonroad gasoline engines, primary contributors included recreational equipment (41%) and pleasure craft (35%).

Wildfires and miscellaneous sources such as fugitive dust from paved and unpaved roads contributed a significant amount of PM and subsequent BC and OM mass emissions (see Table I1); however the OM:BC ratio is >4 for these sources, so the BC emissions were not converted to CO_2e.

Based on 2018 projected emission estimates from the WRAP[102], there will be a drop in the future BC emissions for the onroad and nonoad diesel sectors due to new Federal engine and fuels standards that are currently being phased in to reduce PM emissions. For the nonroad diesel sector the estimated 2.4 $MMtCO_2e$ in 2002 drops to 0.7 $MMtCO_2e$ in 2018. For the onroad diesel sector, 0.5 $MMtCO_2e$ was estimated for 2002 dropping to 0.07 $MMtCO_2e$ in 2018. Emissions from the rail and nonroad gasoline sectors rose slightly in 2018 compared to 2002. 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).[103] There are also a number of other indirect radiative effects that have been modeled (see, for example, Jacobson, 2002, as noted in the footnotes on the previous pages).

The quantification of aerosol radiative forcing is more complex than the quantification of radiative forcing by GHGs because of the direct and indirect radiative forcing effects, and the fact that aerosol mass and particle number concentrations are highly variable in space and time.

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

This variability is largely due to the much shorter atmospheric lifetime of aerosols compared with the important GHGs (i.e. CO_2). Spatially and temporally resolved information on the atmospheric concentration and radiative properties of aerosols is needed to estimate radiative forcing.

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

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

Table I1. 2002 BC Emission Estimates

Sector	Subsector	Mass Emissions BC	OM	BC + OM	CO_2 Equivalents Low	High	Contribution to CO_2e
		Metric Tons			Metric Tons		%
Electricity Generating Units (EGUs)	Coal	0	0	0	0	0	0.0%
	Oil	0	0	0	0	0	0.0%
	Gas	0	1	1	0	0	0.0%
	Other	0	0	0	0	0	0.0%
Non-EGU Fuel Combustion (Residential, Commercial, Industrial)							
	Coal	9	14	23	9,383	19,817	0.5%
	Oil	0	0	0	225	476	0.0%
	Gas	0	22	22	0	0	0.0%
	Other[a]	322	1,559	1,881	13,497	28,508	0.7%
Onroad Gasoline (Exhaust, Brake Wear, & Tire Wear)		54	214	269	20,780	43,891	1.0%
Onroad Diesel (Exhaust, Brake Wear, & Tire Wear)		326	138	464	290,659	613,906	14.0%
Aircraft		17	33	50	16,626	35,117	0.8%
Railroad[b]		83	27	110	81,784	172,737	3.9%
Other Energy Use	Nonroad Gas	134	378	512	132,786	280,460	6.4%
	Nonroad Diesel	1,521	499	2,020	1,505,809	3,180,451	72.7%
	Other Combustion[c]	0	0	0			0.0%
Industrial Processes		1	32	33	31	65	0.0%
Agriculture[d]		56	1,401	1,457	0	0	0.0%
Waste Management	Landfills	0	0	0	0	0	0.0%
	Incineration	0	0	0	0	0	0.0%
	Open Burning	295	3,791	4,086	0	0	0.0%
	Other	0	0	0	0	0	0.0%
Wildfires/Prescribed Burns		1,216	11,990	13,206	0	0	0.0%
Miscellaneous[e]		301	4,922	5,223	0	0	0.0%
Total		**4,336**	**25,021**	**29,356**	**2,071,580**	**4,375,428**	**100%**

[a] Industrial wood combustion and large bore diesel internal combustion engines.
[b] Railroad includes Locomotives and Railroad Equipment Emissions.
[c] Other Combustion includes Motor Vehicle Fire, Structure Fire, and Aircraft/Rocket Engine Fire & Testing Emissions.
[d] Agriculture includes Agricultural Burning, Agriculture/Forestry and Agriculture, Food, & Kindred Spirits Emissions.
[e] Miscellaneous includes Paved/Unpaved Roads and Catastrophic/Accidental Release Emissions.

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

Original Reference: Material for this Appendix is taken from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2000*, U.S. Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-02-003, April 2002 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 inventories[104] were developed prior to the publication of the TAR. Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. This excerpt of the U.S. *Inventory* addresses in detail the differences between emission estimates using these two sets of GWPs. Overall, these revisions to GWP values do not have a significant effect on U.S. emission trends.

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

What is Climate Change?

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

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

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

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

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

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

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

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

Greenhouse Gases

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

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

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

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

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

Table 10. Global Atmospheric Concentration (ppm Unless Otherwise Specified), Rate of Concentration Change (ppb/year) and Atmospheric Lifetime (Years) of Selected Greenhouse Gases

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

Source: IPCC (2001)
[a] Concentrations in parts per trillion (ppt) and rate of concentration change in ppt/year.
[b] Rate is calculated over the period 1990 to 1999.
[c] Rate has fluctuated between 0.9 and 2.8 ppm per year for CO_2 and between 0 and 0.013 ppm per year for CH4 over the period 1990 to 1999.
[d] No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.
[e] This lifetime has been defined as an "adjustment time" that takes into account the indirect effect of the gas on its own residence time.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Global Warming Potentials

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

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

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

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

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

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

Table 11. Global Warming Potentials (GWP) and Atmospheric Lifetimes (Years) Used in the Inventory

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

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

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

Table 12. Net 100-year Global Warming Potentials for Select Ozone Depleting Substances*

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

Source: IPCC (2001)
* Because these compounds have been shown to deplete stratospheric ozone, they are typically referred to as ozone depleting substances (ODSs). However, they are also potent greenhouse gases. Recognizing the harmful effects of these compounds on the ozone layer, in 1987 many governments signed the *Montreal Protocol on Substances that Deplete the Ozone Layer* to limit the production and importation of a number of CFCs and other halogenated compounds. The United States furthered its commitment to phase-out ODSs by signing and ratifying the Copenhagen Amendments to the *Montreal Protocol* in 1992. Under these amendments, the United States committed to ending the production and importation of halons by 1994, and CFCs by 1996. The IPCC Guidelines and the UNFCCC do not include reporting instructions for estimating emissions of ODSs because their use is being phased-out under the *Montreal Protocol*. The effects of these compounds on radiative forcing are not addressed here.

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

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

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