FINAL Nevada Greenhouse Gas Inventory and Reference Case Projections, 1990-2020

Center for Climate Strategies
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Executive Summary

The Center for Climate Strategies (CCS) prepared this report for the Nevada Division of Environmental Protection (NDEP) under contract to the Western Regional Air Partnership (WRAP). The report contains an inventory and forecast of the State's greenhouse gas (GHG) emissions from 1990 to 2020.

Nevada's anthropogenic GHG emissions and anthropogenic/natural sinks (carbon storage) were estimated for the period from 1990 to 2020. Historical GHG emission estimates (1990 through 2005) were developed using a set of generally accepted principles and guidelines for state GHG emissions estimates (both historical and forecasted), with adjustments by CCS as needed to provide Nevada-specific data and inputs when it was possible to do so. The initial reference case projections (2006-2020) are based on a compilation of various existing projections of electricity generation, fuel use, and other GHG-emitting activities, along with a set of transparent assumptions.

Table ES-1 provides a summary of annual historical (1990 to 2005) and reference case projection (2010 and 2020) GHG emissions for Nevada. Activities in Nevada accounted for approximately 49.5 million metric tons (MMt) of *gross*[1] carbon dioxide equivalent (CO_2e) emissions in 2005, an amount equal to 0.7% of total U.S. gross GHG emissions. Nevada's gross GHG emissions are rising faster than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). Nevada's gross GHG emissions increased 62% from 1990 to 2004, while national emissions rose by only 16% during this period. As described further below, rapid population growth has been the most important driver in emissions growth in Nevada. Annual population growth from 1990 to 2005 was 4.9%.

Figure ES-1 illustrates the State's emissions per capita and per unit of economic output. On a per-capita basis, Nevadans emit about 22 metric tons (Mt) of CO_2e, which is less than the national average of 25 MtCO_2e. Per capita emissions in Nevada decreased between 1990 and 2004, while national per capita emissions have remained fairly flat. Economic growth in Nevada exceeded emissions growth throughout the 1990-2004 period. From 1990 to 2004, emissions per unit of gross product dropped by 40% nationally, and by 50% in Nevada. Figure ES-2 shows both the historical and projected emissions by sector.

Figure ES-3 shows the contribution of each sector (MMtCO_2e/yr) to emissions growth during both the historic period (1990-2005) and forecast period (2005-2020). The historic bars represent 2005 emissions for the sector minus the 1990 emissions for that sector, while the forecast bars represent 2020 emissions minus 2005 emissions.

The principal sources of Nevada's GHG emissions are electricity use (which exclude electricity exports to other states) and transportation, accounting for 42% and 32% of Nevada's gross GHG emissions, respectively. Nevada's population growth is the underlying driver of the growth in

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

these sectors since 1990. The next largest contributor to emissions is the residential, commercial, and industrial fuel use sector, accounting for 13% of the total State emissions.

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projections, Nevada's gross annual GHG emissions continue to grow, and are projected to climb to 72.3 $MMtCO_2e$ by 2020, or 141% 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 generated to meet Nevada's demands.

Some data gaps exist in this analysis, particularly for the reference case projections. Key tasks include review and revision of key emissions drivers (such as electricity, fossil fuel production, and transportation fuel use growth rates) that will be major determinants of Nevada's future GHG emissions. Details on the methods and data sources used to develop these initial estimates are provided in each of the appendices to this report. 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 Nevada based on 2002 and 2018 data from the WRAP. The results were a total of 2.6 $MMtCO_2e$, which is the mid-point of a range of estimated emissions (1.7 – 3.5 $MMtCO_2e$) in 2002. Based on an assessment of the primary contributors, it is estimated that BC emissions will decrease substantially by 2018 after new engine and fuel standards take effect in the onroad and nonroad diesel engine sectors. Details of this analysis are presented in Appendix I to this report. These estimates are not incorporated into the totals shown in Table ES-1 below because a global warming potential for BC has not yet been assigned by the Intergovernmental Panel on Climate Change (IPCC). By including black carbon emission estimates in the inventory, however, additional opportunities for reducing climate impacts can be identified as the scientific knowledge related to BC emissions improves.

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

(Million Metric Tons CO_2e)	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Electricity Consumption	**13.0**	**19.0**	**20.8**	**20.5**	**27.4**	
Coal	15.1	18.0	17.9	7.8	11.0	See electric sector assumptions in appendix
Natural Gas	1.3	6.6	8.3	10.8	11.3	
Oil	0.3	0.06	0.02	0.03	0.03	
Net Imported Electricity	-3.7	-5.6	-5.3	1.9	5.2	
Res/Comm/Ind (RCI)	**4.4**	**5.9**	**6.4**	**7.8**	**10.7**	
Coal	0.4	0.5	0.5	0.6	0.7	Based on USDOE regional projections
Natural Gas	2.2	3.6	4.1	5.0	6.9	Based on USDOE regional projections
Oil	1.9	1.8	1.8	2.2	3.0	Based on USDOE regional projections
Wood (CH_4 and N_2O)	0.02	0.03	0.02	0.03	0.03	Based on USDOE regional projections
Transportation	**9.6**	**14.7**	**16.1**	**18.4**	**24.7**	
Motor Gasoline	5.7	8.3	9.1	10.1	13.1	VMT projections from MPO's
Diesel	1.4	2.6	3.4	4.3	6.6	VMT projections from MPO's
Natural Gas, LPG, other	0.04	0.06	0.08	0.1	0.2	Based on USDOE regional projections
Jet Fuel and Aviation Gasoline	2.5	3.7	3.5	3.9	4.8	Aircraft operations projections from FAA
Fossil Fuel Industry	**0.4**	**0.5**	**0.7**	**0.7**	**0.9**	
Natural Gas Industry	0.4	0.5	0.6	0.7	0.9	Increase based on current trend to 2009, then USDOE to 2020
Oil Industry	0.03	0.01	0.004	0.003	0.001	Increase based on current trend to 2009, then USDOE to 2020
Industrial Processes	**0.2**	**1.7**	**2.2**	**2.7**	**4.0**	
Cement Manufacture (CO_2)	0.000	0.2	0.2	0.3	0.4	Based on NV Nonmetallic Minerals employment projections (2004-2014)
Lime Manufacture (CO_2)	0.000	0.4	0.4	0.5	0.8	Same as above
Limestone & Dolomite Use (CO_2)	0.000	0.04	0.03	0.04	0.06	Same as above
Soda Ash (CO_2)	0.01	0.02	0.02	0.02	0.02	Based on USGS projections
Nitric Acid Production (N_2O)	0.000	0.3	0.3	0.3	0.3	Based on national projections (US State Dept.)
ODS Substitutes (HFC, PFC, and SF_6)	0.002	0.5	1.0	1.5	2.5	EPA 2004 ODS cost study report
Electric Power T & D (SF_6)	0.2	0.1	0.1	0.09	0.05	Based on national projections (USEPA)
Waste Management	**0.8**	**1.4**	**1.4**	**1.5**	**2.2**	
Solid Waste Management	0.7	1.2	1.1	1.2	1.7	Historical waste emplacement rates
Wastewater Management	0.1	0.2	0.3	0.3	0.4	Projections based on population
Agriculture	**1.6**	**1.8**	**1.6**	**1.7**	**1.8**	
Enteric Fermentation	0.7	0.7	0.7	0.7	0.8	Historical emissions for 1990-2002
Manure Management	0.1	0.1	0.2	0.2	0.2	Historical emissions for 1990-2002
Agricultural Soils	0.8	0.9	0.8	0.8	0.8	Historical emissions for 1990-2002, except growth rate for fertilizers based on NV population growth for 1996-2020
Agricultural Residue Burning	0.0001	0.0001	0.0001	0.0001	0.0001	No growth assumed
Total Gross Emissions	**30.2**	**45.6**	**49.6**	**53.8**	**72.4**	
increase relative to 1990		*51%*	*64%*	*78%*	*140%*	
Forestry	**-4.8**	**-4.8**	**-4.8**	**-4.8**	**-4.8**	Historical and projected emissions held at 2004 level.
Agricultural Soils	**-0.2**	**-0.2**	**-0.2**	**-0.2**	**-0.2**	Historical and projected emissions held at 1997 level.
Net Emissions (incl. sinks*)	**25.1**	**40.5**	**44.5**	**48.7**	**67.4**	

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

Figure ES-1. Historical Nevada and U.S. GHG Emissions, Per Capita and Per Unit Gross Product

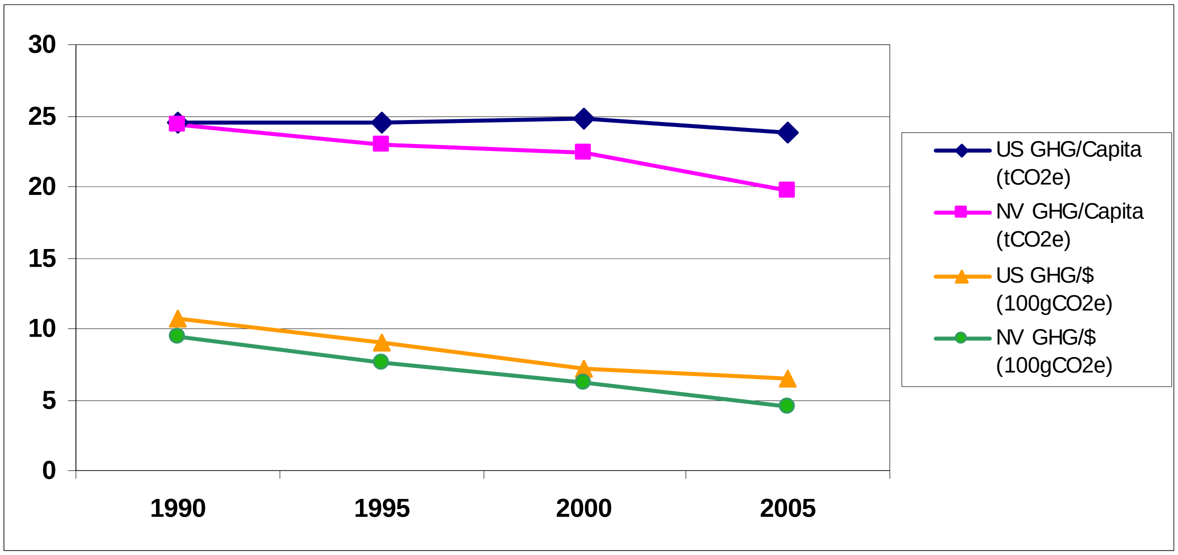
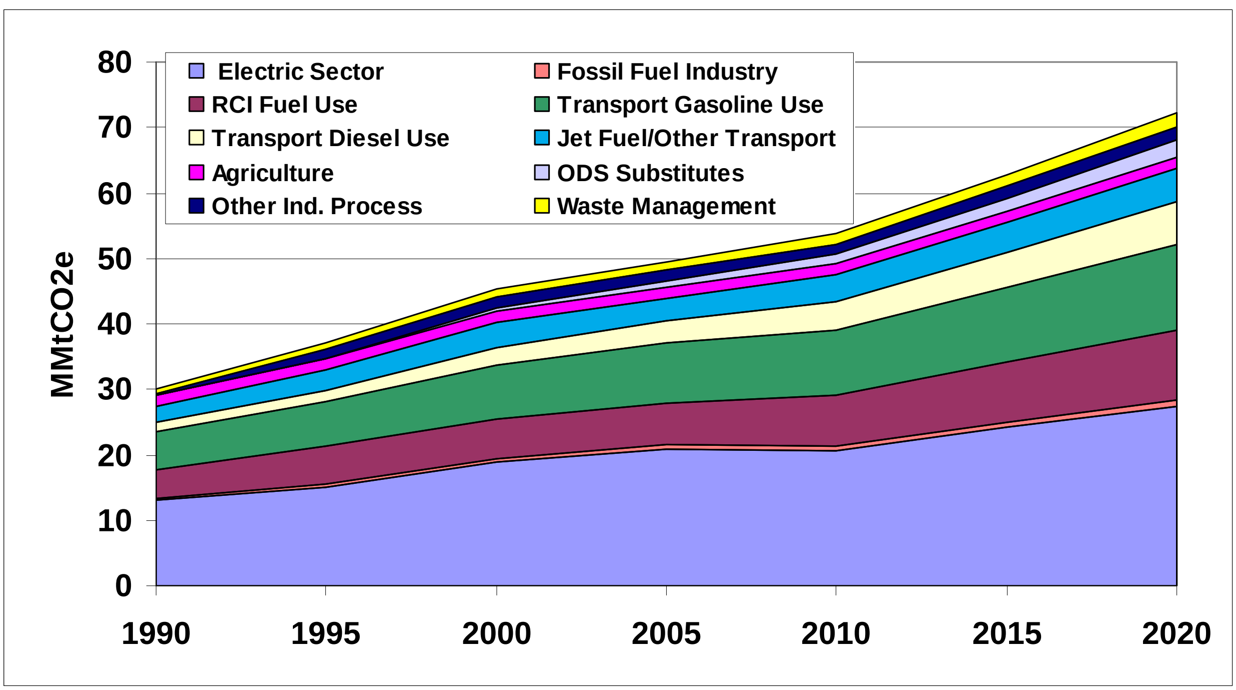
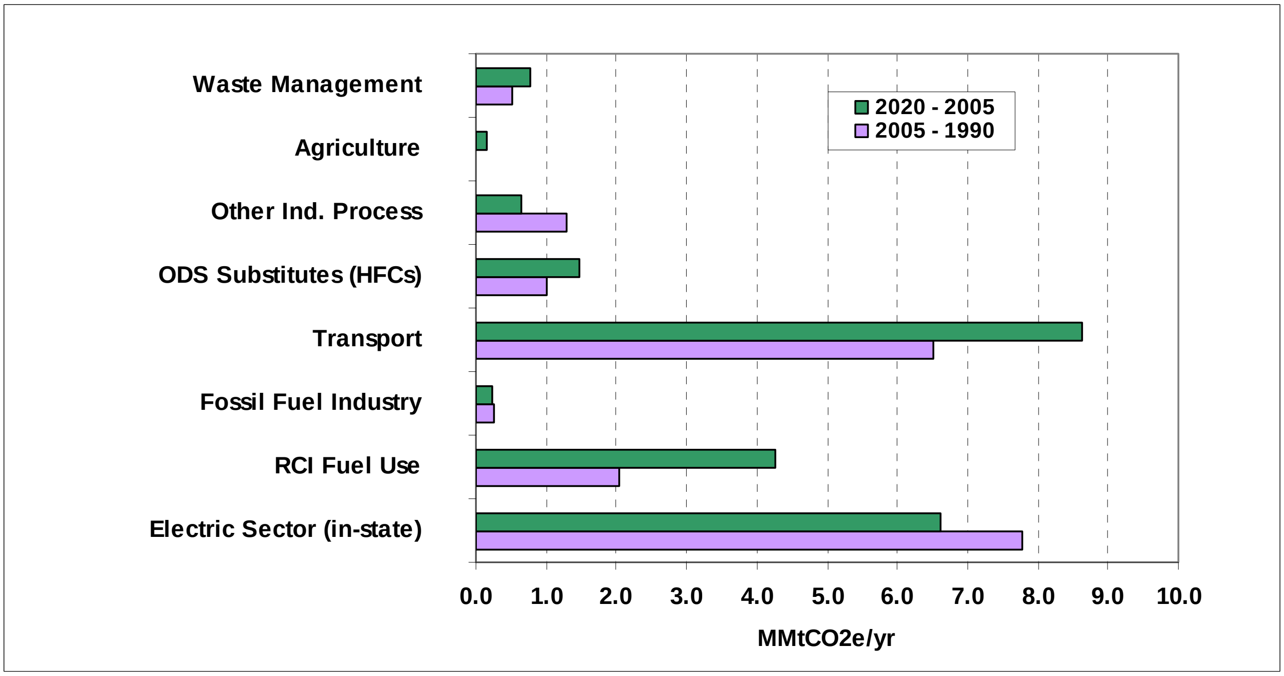


Figure ES-2. Annual Nevada Gross GHG Emissions by Sector, 1990-2020: Historical and Projected



Notes: Fossil Fuel Industry emissions include emissions not associated with fuel combustion (fugitive CH_4). Fossil fuel combustion emissions are included in the RCI Fuel Use sector.
RCI – direct fuel use in residential, commercial and industrial sectors. ODS – ozone depleting substance.

Figure ES-3. Sector Contributions to Emissions Growth in Nevada, 1990-2020: Historical Growth and Reference Case Projections



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

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Acronyms and Key Terms

AEO – *Annual Energy Outlook*

Ag – agriculture

bbls – barrels

BC – black carbon

Bcf – billion cubic feet

BLM – United States Bureau of Land Management

BOC – Bureau of Census

BTU – British thermal unit

C – carbon

$CaCO_3$ – calcium carbonate

CBM – coal bed methane

CCS – Center for Climate Strategies

CFCs - chlorofluorocarbons

NDEP – Nevada Department of Environmental Protection

CFCs – chlorofluorocarbons

CH_4 – methane*

CO_2 – carbon dioxide*

CO_2e – carbon dioxide equivalent*

CRP – Federal Conservation Reserve Program

DAQEM – Department of Air Quality and Environmental Management

EC – elemental carbon

eGRID – U.S. EPA's Emissions & Generation Resource Integrated Database

EIA – U.S. DOE Energy Information Administration

EIIP – Emissions Inventory Improvement Program (US EPA)

FIA – Forest Inventory Analysis (USFS)

GHG – greenhouse gases*

GSP – gross state product

GWh – gigawatt-hour

GWP - global warming potential*

HFCs – hydrofluorocarbons*

HNO_3 – nitric acid

HWP – harvested wood products

IPCC – Intergovernmental Panel on Climate Change*

kWh – kilowatt-hour

LFGTE – landfill-gas-to-energy

LMOP – Landfill Methane Outreach Program

LNG – liquefied natural gas

LPG – liquefied petroleum gas

Mg – mega grams (equivalent to one metric ton)

Mt - metric ton (equivalent to 1.102 short tons)

MMt – million metric tons

MPO – Metropolitan Planning Organization

MSW – municipal solid waste

MW – megawatt

N – nitrogen

N_2O – nitrous oxide*

NO_2 – nitrogen dioxide*

NAICS – North American Industry Classification System

NASS – National Agricultural Statistics Service

NDOT – Nevada Department of Transportation

NO_x – nitrogen oxides

NSCR – non-selective catalytic reduction

NDEP – Nevada Division of Environmental Protection

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

RPS – renewable portfolio standard

RTC – regional transportation commission

SAR – Second Assessment Report (IPCC)

SCR – selective catalytic reduction

SED – State Energy Data (EIA)

SF_6 – sulfur hexafluoride*

SGIT – State Guidance & Inventory Tool (U.S. EPA)

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 (IPCC)

T&D – transmission and distribution

TWh – terawatt-hours

UNFCCC – United Nations Framework Convention on Climate Change

U.S. EPA – United States Environmental Protection Agency

U.S. 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

WAPA – Western Area Power Administration

WECC – Western Electricity Coordinating Council

W/m^2 – watts per square meter

WMO – World Meteorological Organization*

WRAP – Western Regional Air Partnership

* - See Appendix J for more information.

Acknowledgements

We appreciate all of the time and assistance provided by numerous contacts throughout Nevada, as well as in neighboring states, and at federal agencies. Thanks go to in particular the many staff at several Nevada state agencies for their inputs, and in particular to Jennifer Carr, Sigurd Juanarajs, Jean-Paul Huys, Frank Forsgren, Dave Simpson, and the peer review staff of the Nevada Division of Environmental Protection (NDEP) who provided key guidance for this analytical effort.

Summary of Preliminary Findings

Introduction

The Center for Climate Strategies prepared this report for the Nevada Department of Conservation and Natural Resources, Division of Environmental Protection (NDEP) under contract to the Western Regional Air Partnership (WRAP). This report presents initial estimates of base year and projected Nevada anthropogenic greenhouse gas (GHG) emissions and sinks for the period from 1990 to 2020. These estimates are intended to assist the State with an initial, comprehensive understanding of current and possible future GHG emissions for Nevada.

Historical GHG emission estimates (1990 through 2005)[2] were developed using a set of generally accepted principles and guidelines for state GHG emissions inventories, as described in Section 2, relying to the extent possible on Nevada-specific data and inputs. The initial reference case projections (2006-2020) are based on a compilation of various existing projections of electricity generation, fuel use, and other GHG-emitting activities, along with a set of simple, transparent assumptions described in the appendices of this report.

This report covers the six gases included in the U.S. Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates the relative contribution of each gas to global average radiative forcing on a Global Warming Potential- (GWP-) weighted basis. As stated in the Executive Summary, CCS also added emission estimates for black carbon (BC) based on 2002 and 2018 data from the WRAP. Black carbon is an aerosol species with a positive climate forcing potential (i.e., the potential to warm the atmosphere, as GHGs do).

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

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

Nevada Greenhouse Gas Emissions: Sources and Trends

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

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

Appendix I provides information on 2002 and 2018 BC estimates for Nevada. CCS estimated that BC emissions in 2002 ranged from 1.7 – 3.5 $MMtCO_2e$ with a mid-point of 2.6 $MMtCO_2e$. A range is estimated based on the uncertainty in the global modeling analyses that serve as the basis for converting BC mass emissions into their carbon dioxide equivalents (see Appendix I for more details). Since the IPCC has not yet assigned a global warming potential for BC, CCS has excluded these estimates from the GHG summary shown in Table 1 below. Future year estimates (2018) are estimated to drop by about 40% after new Federal emissions standards for new diesel engines and new fuel sulfur content standards are phased in. Appendix I contains a detailed breakdown of emissions contribution by source sector.

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

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

(Million Metric Tons CO_2e)	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Electricity Consumption	**13.0**	**19.0**	**20.8**	**20.5**	**27.4**	
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Res/Comm/Ind (RCI)	**4.4**	**5.9**	**6.4**	**7.8**	**10.7**	
Coal	0.4	0.5	0.5	0.6	0.7	Based on USDOE regional projections
Natural Gas	2.2	3.6	4.1	5.0	6.9	Based on USDOE regional projections
Oil	1.9	1.8	1.8	2.2	3.0	Based on USDOE regional projections
Wood (CH_4 and N_2O)	0.02	0.03	0.02	0.03	0.03	Based on USDOE regional projections
Transportation	**9.6**	**14.7**	**16.1**	**18.4**	**24.7**	
Motor Gasoline	5.7	8.3	9.1	10.1	13.1	VMT projections from MPO's
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Natural Gas, LPG, other	0.04	0.06	0.08	0.1	0.2	Based on USDOE regional projections
Jet Fuel and Aviation Gasoline	2.5	3.7	3.5	3.9	4.8	Aircraft operations projections from FAA
Fossil Fuel Industry	**0.4**	**0.5**	**0.7**	**0.7**	**0.9**	
Natural Gas Industry	0.4	0.5	0.6	0.7	0.9	Increase based on current trend to 2009, then USDOE to 2020
Oil Industry	0.03	0.01	0.004	0.003	0.001	Increase based on current trend to 2009, then USDOE to 2020
Industrial Processes	**0.2**	**1.7**	**2.2**	**2.7**	**4.0**	
Cement Manufacture (CO_2)	0.000	0.2	0.2	0.3	0.4	Based on NV Nonmetallic Minerals employment projections (2004-2014)
Lime Manufacture (CO_2)	0.000	0.4	0.4	0.5	0.8	Same as above
Limestone & Dolomite Use (CO_2)	0.000	0.04	0.03	0.04	0.06	Same as above
Soda Ash (CO_2)	0.01	0.02	0.02	0.02	0.02	Based on USGS projections
Nitric Acid Production (N_2O)	0.000	0.3	0.3	0.3	0.3	Based on national projections (US State Dept.)
ODS Substitutes (HFC, PFC, and SF_6)	0.002	0.5	1.0	1.5	2.5	EPA 2004 ODS cost study report
Electric Power T & D (SF_6)	0.2	0.1	0.1	0.09	0.05	Based on national projections (USEPA)
Waste Management	**0.8**	**1.4**	**1.4**	**1.5**	**2.2**	
Solid Waste Management	0.7	1.2	1.1	1.2	1.7	Historical waste emplacement rates
Wastewater Management	0.1	0.2	0.3	0.3	0.4	Projections based on population
Agriculture	**1.6**	**1.8**	**1.6**	**1.7**	**1.8**	
Enteric Fermentation	0.7	0.7	0.7	0.7	0.8	Historical emissions for 1990-2002
Manure Management	0.1	0.1	0.2	0.2	0.2	Historical emissions for 1990-2002
Agricultural Soils (emissions)	0.8	0.9	0.8	0.8	0.8	Historical emissions for 1990-2002, except growth rate for fertilizers based on NV population growth for 1996-2020
Agricultural Residue Burning	0.0001	0.0001	0.0001	0.0001	0.0001	No growth assumed
Total Gross Emissions	**30.2**	**45.6**	**49.6**	**53.8**	**72.4**	
increase relative to 1990		*51%*	*64%*	*78%*	*140%*	
Forestry	**-4.8**	**-4.8**	**-4.8**	**-4.8**	**-4.8**	Historical and projected emissions held at 2004 level (excludes soil carbon flux).
Agricultural Soils (sinks)	**-0.2**	**-0.2**	**-0.2**	**-0.2**	**-0.2**	Historical and projected emissions held at 1997 level.
Net Emissions (incl. forestry*)	**25.1**	**40.5**	**44.5**	**48.7**	**67.4**	

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

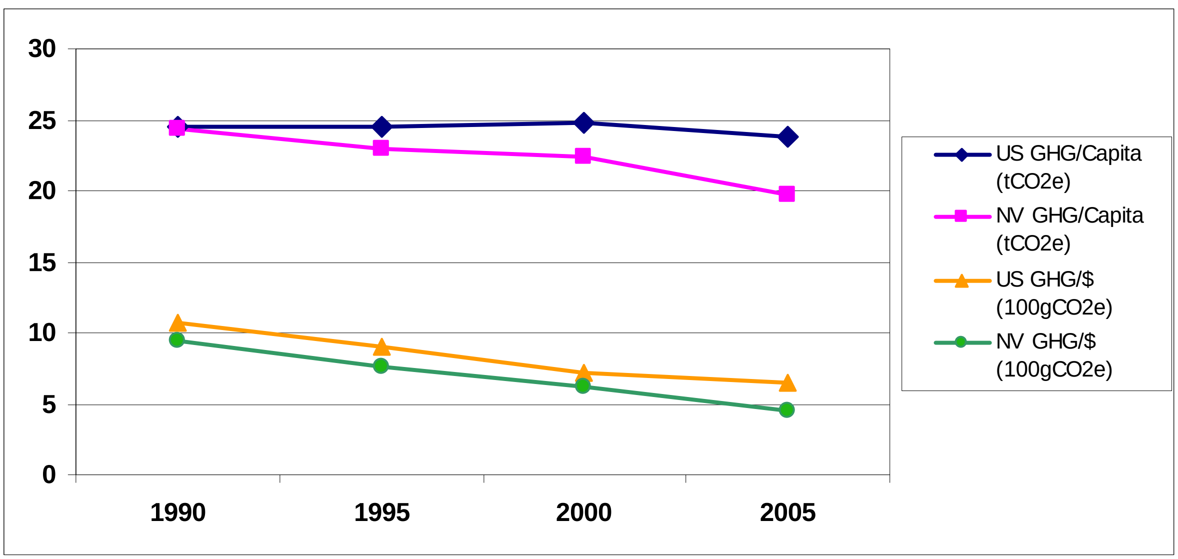
Historical Emissions

Overview

Preliminary analyses suggest that in 2005, activities in Nevada accounted for approximately 49.5 million metric tons (MMt) of CO_2e emissions, an amount equal to 0.7% of total U.S. GHG emissions.[3] Nevada's gross GHG emissions are rising faster than those of the nation as a whole. Nevada's gross GHG emissions were increased by 62% from 1990 to 2004, while national emissions rose only 16% during the same period. As noted further below, these emissions are largely driven by Nevada's rapid population growth during the period of analysis.

On a per capita basis, Nevadans emit about 22 metric tons (Mt) of CO_2e annually, which is similar to the national average of 25 MtCO_2e/yr. Figure 1 illustrates the State's emissions per capita and per unit of economic output. Per capita emissions in Nevada decreased between 1990 and 2004, while national per capita emissions have remained fairly flat. Economic growth exceeded emissions growth in Nevada throughout the 1990-2004 period. From 1990 to 2004, emissions per unit of gross product dropped by 40% nationally, and by 50% in Nevada.

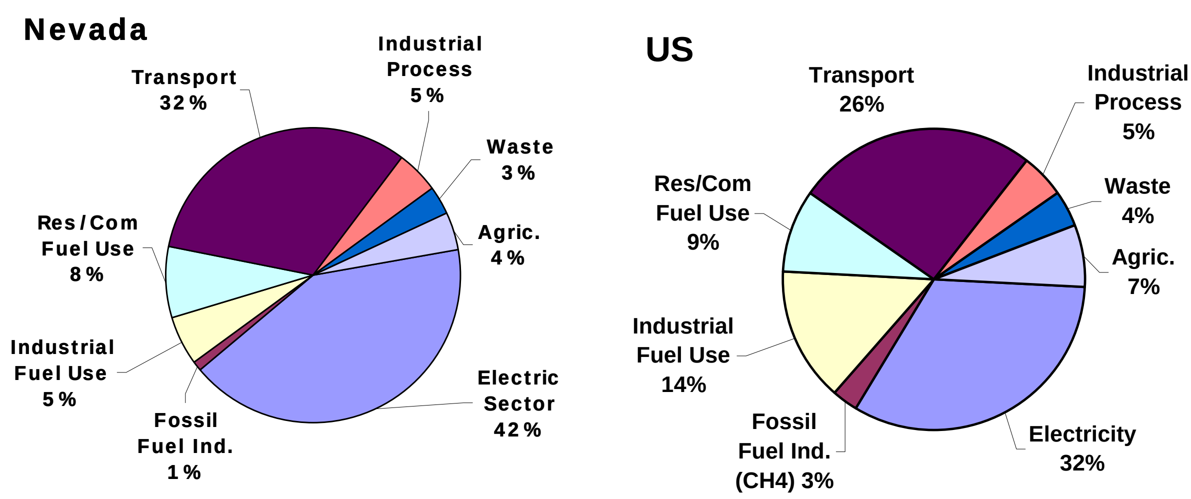
Figure 1. Nevada and US Gross GHG Emissions, Per Capita and Per Unit Gross Product



Electricity use and transportation are the State's principal GHG emissions sources. Together, the combustion of fossil fuels for electricity generation and in the transportation sector accounted for 74% of Nevada's *gross* GHG emissions in 2000, as shown in Figure 2. The remaining use of fossil fuels — natural gas, oil products, and coal — in the residential, commercial, and industrial (RCI) sectors, plus the emissions from fossil fuel production, constituted another 13% of total State emissions.

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

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



Industrial process emissions comprised almost 5% of State GHG emissions in 2000, but these emissions are rising rapidly due to the increasing use of HFC as substitutes for ozone-depleting chlorofluorocarbons (note that HFC use extends throughout the RCI sector and into the transportation sector, as well).[4] Other industrial process emissions result from carbon dioxide (CO_2) released during soda ash, limestone, and dolomite use. Agriculture (methane and N_2O emissions from manure management, fertilizer use, and livestock), landfills and wastewater management facilities, and the fossil fuel industry produced CH_4 and N_2O emissions together accounted for the remaining 8% of the State's emissions in 2000.

Figure 3 shows annual historic and projected GHG emissions by source sector. These emissions include all six GHGs in carbon dioxide equivalents. Figure 4 shows the contribution of each sector ($MMtCO_2e$/yr) to emissions growth during both the historic period (1990-2005) and forecast period (2005-2020). The historic bars represent 2005 emissions for the sector minus the 1990 emissions for that sector, while the forecast bars represent 2020 emissions minus 2005 emissions.

Forestry activities in Nevada are estimated to be net sinks for GHG emissions and forested lands account for a sink of 4.8 $MMtCO_2e$. Agricultural soils account for another GHG sink of 0.18 $MMtCO_2e$.

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

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

As shown in Figure 2, electricity consumption accounted for about 42% of Nevada's gross GHG emissions in 2000 (about 19 $MMtCO_2e$), which was higher than the national share of emissions from electricity consumption (32%).[5] In total (across the residential, commercial and industrial sectors) Nevada's electricity use per person is typical for the US (13,400 kWh per person per year compared to 12,000 kWh/person-yr nationally).

It is important to note that these electricity emission estimates reflect the *GHG emissions associated with the electricity sources used to meet Nevada demands,* corresponding to a consumption-based approach to emissions accounting (see Section 2). Another way to look at electricity emissions is to consider the *GHG emissions produced by electricity generation facilities in the State.* In 2000, Nevada exported about 23% of the electricity produced in the State. As a result, in 2000, emissions associated with electricity consumption (19.0 $MMtCO_2e$) were lower than those associated with electricity production (24.5 $MMtCO_2e$).[6]

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

Like electricity emissions, GHG emissions from transportation fuel use have risen steadily since 1990 at an average rate of slightly over 4% annually. In 2002, onroad gasoline vehicles accounted for about 58% of transportation GHG emissions. Onroad diesel vehicles accounted for another 19% of emissions, and air travel for roughly 22%. Rail, marine gasoline, and other sources (natural gas and liquefied petroleum gas (LPG) vehicles and lubricants) accounted for the remaining 1% of transportation emissions. As the result of Nevada's population and economic growth and an increase in total vehicle miles traveled during the 1990s, onroad gasoline use grew 52% between 1990 and 2002. Meanwhile, onroad diesel use rose 111% during that period, suggesting an even more rapid growth in freight movement within or across the State. Aviation fuel use grew by 34% from 1990-2002.

For both of these sectors, rapid population growth is the key underlying driver in both historic and future emissions growth. From 1990-2000, Nevada's population grew by 66%, while the population is projected to grow 47% from 2005 to 2020.

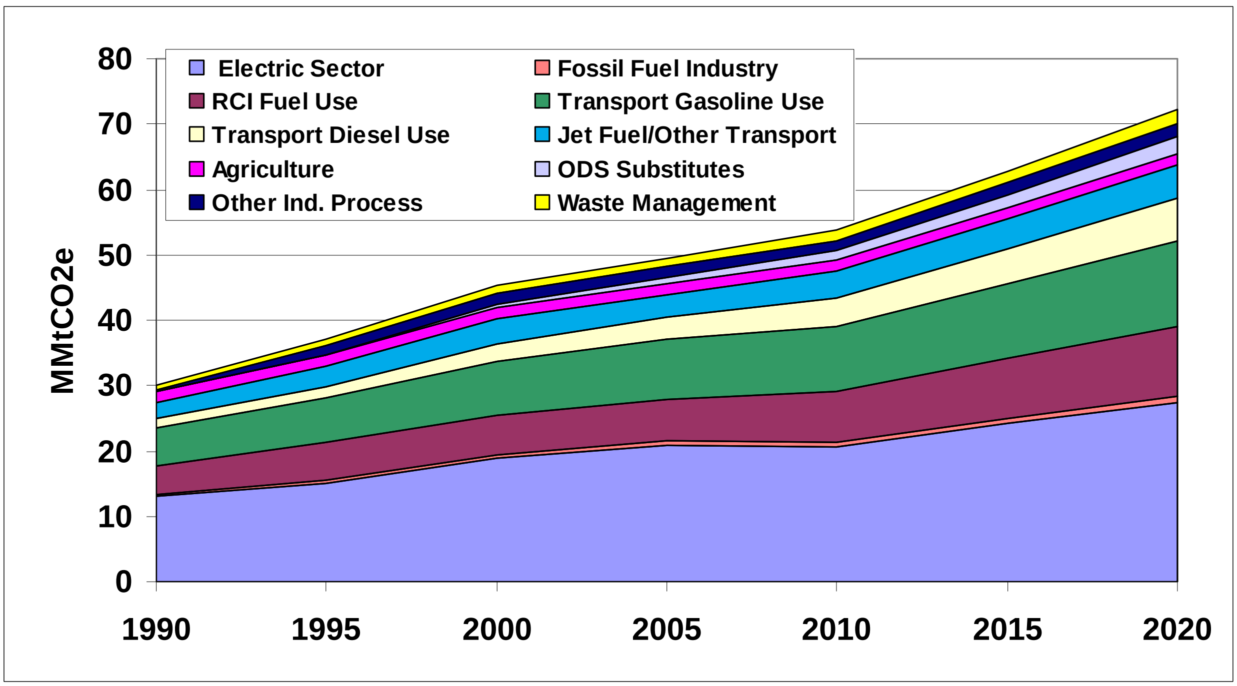
[5] Unlike for Nevada, for the US as a whole, there is relatively little difference between the emissions from electricity use and emissions from electricity production, as the US imports only about 1% of its electricity, and exports far less.

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

Reference Case Projections

Relying on a variety of sources for projections of electricity and fuel use, as noted below and in the Appendices, we developed a simple reference case projection of GHG emissions through 2020. As illustrated in Figure 3 and shown numerically in Table 1, under the reference case projections, Nevada gross GHG emissions continue to grow steadily, climbing to 72 MMtCO_2e by 2020, 141% above 1990 levels. The transportation sector is projected to be the largest contributor to future emission growth, followed by the electric sector, as shown in Figure 4. Other major sources of emissions growth include fuel use in buildings and industrial energy use other than in the fossil fuel industry (RCI).

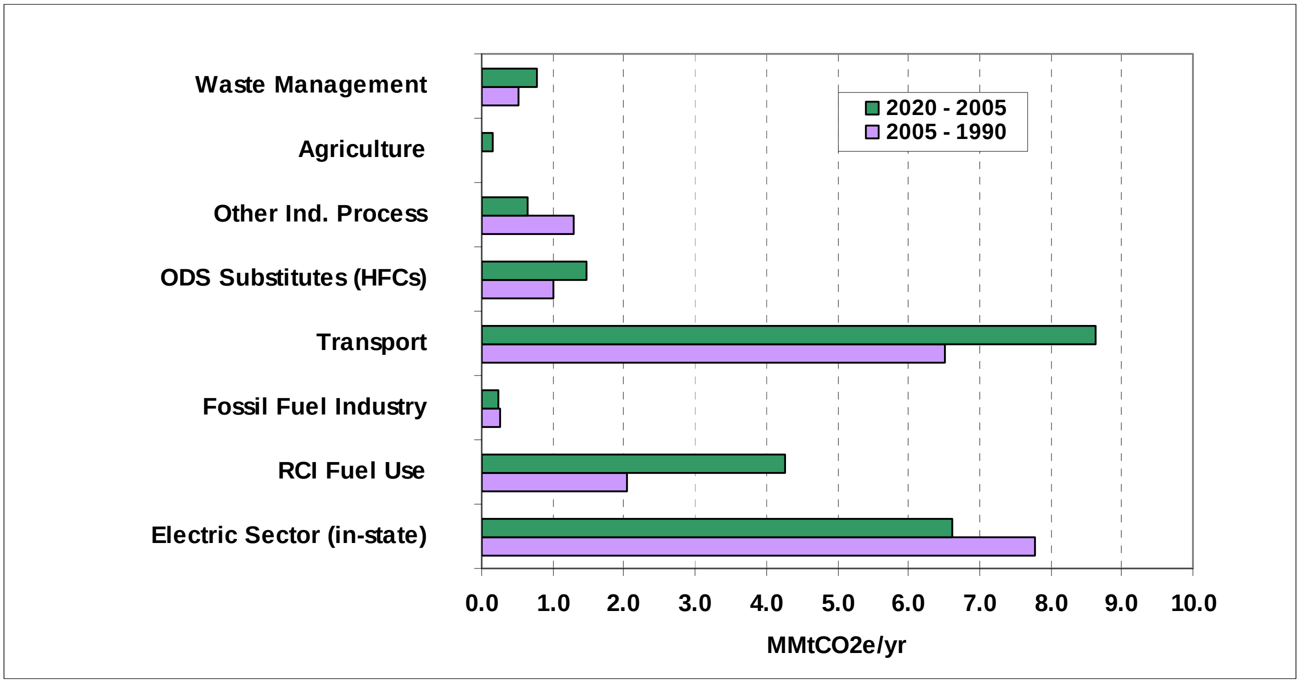
Figure 3. Annual Nevada Gross GHG Emissions by Sector, 1990-2020: Historical and Projected



Notes: Fossil Fuel Industry emissions include emissions not associated with fuel combustion (fugitive CH_4). Fossil fuel combustion emissions are included in the RCI Fuel Use sector.
RCI – direct fuel use in residential, commercial and industrial sectors. ODS – ozone depleting substance.

The lower level of emissions growth in the 2005-2010 period compared to the 2010-2020 period are a result of the assumptions used to forecast growth in the electric sector. Most notably, the emissions are influenced by the temporary shutdown of the Mohave Generating Station. The effects of Nevada's renewable portfolio standard are also included (see Appendix A for more details on the forecast assumptions).

Figure 4. Sector Contributions to Emissions Growth in Nevada, 1990-2020: Historical Growth and Reference Case Projections



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

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 electricity and transportation fuel use growth rates that will be major determinants of Nevada's future GHG emissions (See Table 2). 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.

One of the variables with important implications for GHG emissions is the type and number of power plants built in Nevada between now and 2020. The assumptions on vehicle miles traveled (VMT) and air travel growth also have large impacts on the GHG emission growth in the State. Finally, uncertainty remains on estimates for historic and projected GHG sinks from forestry, which can greatly affect the net GHG emissions attributed to Nevada.

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

	1990-2005	2005-2020	Sources
Population[a]	4.9%	3.1%	Nevada State Demography Office. Cumulative growth from 2005-2020 is estimated to be 47%.[7]
Employment[a]			Nevada Department of Employment website, 2004-2014 trend assumed to continue to 2020
Goods	5.4%	3.7%	
Services	4.5%	3.2%	
Electricity Sales	4.7%	3.1%	EIA data for 1990-2005. Growth rate for 2005-2020 provided by Nevada PUC.
Vehicle Miles Traveled	5.0%	3.3%	Nevada Department of Transportation, Regional Transportation Commissions of Washoe and Southern Nevada, WRAP projections

[a] For the RCI fuel consumption sectors, population and employment projections for Nevada were used together with US DOE EIA's Annual Energy Outlook 2006 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 Nevada's residential natural gas use is calculated as the Nevada population growth times the change in per capita natural gas use for the Mountain region.

Emissions of aerosols, particularly black carbon from fossil fuel combustion, could have significant impacts in terms of radiative forcing (i.e., climate impacts). Methodologies for conversion of black carbon mass estimates and projections to global warming potential involve significant uncertainty at present, but CCS has developed and used a recommended approach for estimating black carbon emissions based on methods used in other States. Current estimates suggest a relatively small CO_2e contribution overall from BC emissions, as compared to the CO_2e contributed from the gases.

[7] Additional information on population growth can be found at the following links: http://quickfacts.census.gov/qfd/rankings/PL0120000r.html and page 13 of the report at http://www.nsbdc.org/what/data_statistics/demographer/pubs/docs/NV_2006_Projections.pdf.

Approach

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

General Methodology

We prepared this analysis in close consultation with Nevada agencies, in particular, the NDEP staff. The overall goal of this effort is to provide simple and straightforward estimates, with an emphasis on robustness, consistency and transparency. As a result, we rely on reference forecasts from best available state and regional sources where possible. Where this is lacking, we use straightforward spreadsheet analysis and linear 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[8] and its guidelines for States.[9] These inventory guidelines were developed based on the guidelines from the Intergovernmental Panel on Climate Change, the international organization responsible for developing coordinated methods for national GHG inventories.[10] The inventory methods provide flexibility to account for local conditions. The key sources of activity and projection data are shown in Table 3. Table 3 also provides the descriptions of the data provided by each source and the uses of each data set in this analysis.

[8] 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.
[9] http://yosemite.epa.gov/oar/globalwarming.nsf/content/EmissionsStateInventoryGuidance.html.
[10] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Table 3. Key Sources for Nevada Data, Inventory Methods, and Growth Rates

Source	Information provided	Use of Information in this Analysis
US EPA State Greenhouse Gas Inventory Tool (SGIT)	US EPA SGIT is a collection of linked spreadsheets designed to help users develop State GHG inventories. US EPA SGIT contains default data for each State for most of the information required for an inventory. The SGIT methods are based on the methods provided in the Volume 8 document series published by the Emissions Inventory Improvement Program (http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html)	Where not indicated otherwise, SGIT is used to calculate emissions from residential/commercial/industrial fuel combustion, transportation, industrial processes, agriculture and forestry, and waste. We use SGIT emission factors (CO_2, CH_4 and N_2O per BTU consumed) to calculate energy use emissions.
US DOE Energy Information Administration (EIA) State Energy Data (SED)	EIA SED provides energy use data in each State, annually to 2002.	EIA SED is the source for most energy use data. We also use the more recent data for electricity and natural gas consumption (including natural gas for vehicle fuel) from EIA website for years after 2002. Emission factors from US EPA SGIT are used to calculate energy-related emissions.
US DOE Energy Information Administration Annual Energy Outlook 2006 (AEO2006)	EIA AEO2006 projects energy supply and demand for the US from 2005 to 2030. Energy consumption is estimated on a regional basis. Nevada is included in the Mountain Census region (AZ, CO, ID, MT, NM, NV, UT, and WY)	EIA AEO2006 is used to project changes in per capita (residential), per employee (commercial/industrial) energy consumption.
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 carbon dioxide flux over time (terrestrial CO_2 sequestration in forested areas)
USDA 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

General Principles and Guidelines

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

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

- **Consistency:** To the extent possible, the inventory and projections were 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[11], 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 Nevada. It covers all six GHGs covered by U.S. and other national inventories: CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs and black carbon. The inventory estimates are for the year 1990, with subsequent years included up to most recently available data (typically 2002 to 2005), with projections to 2010 and 2020.

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

- **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 Nevada. For example, we reported emissions associated with the electricity consumed in Nevada. 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.

[11] "Reference case" is similar to the term "base year" used in criteria pollutant inventories. However, it also generally contains both a most current year estimate (e.g., 2002 or 2005), as well as estimates for historical years (e.g., 1990, 2000). Projections from this reference case are made to future years based on business-as-usual assumptions of future year source activity.

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 Nevada. This entails accounting for the electricity sources used by Nevada utilities to meet consumer demands. As we refine this analysis, we may also attempt to estimate other sectoral emissions on a consumption basis, such as accounting for transportation fuel used in Nevada, 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

Nevada's electricity demand has experienced strong growth in the last 15 years, driven by the State's rapid population and economic growth, growth that appears likely to continue for some time. Historically, Nevada's electricity generation has been dominated by coal, leading to high levels of GHG emissions per unit of electricity generated. However, the largest coal-fired power plant in the State, Mohave, went into temporary shutdown on December 31, 2005 and the State has implemented a strong renewable portfolio standard that is expected to encourage growth in renewable generation. As a result, in the future, the GHG emissions associated with electricity production and consumption in Nevada could be significantly lower than in recent history.

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

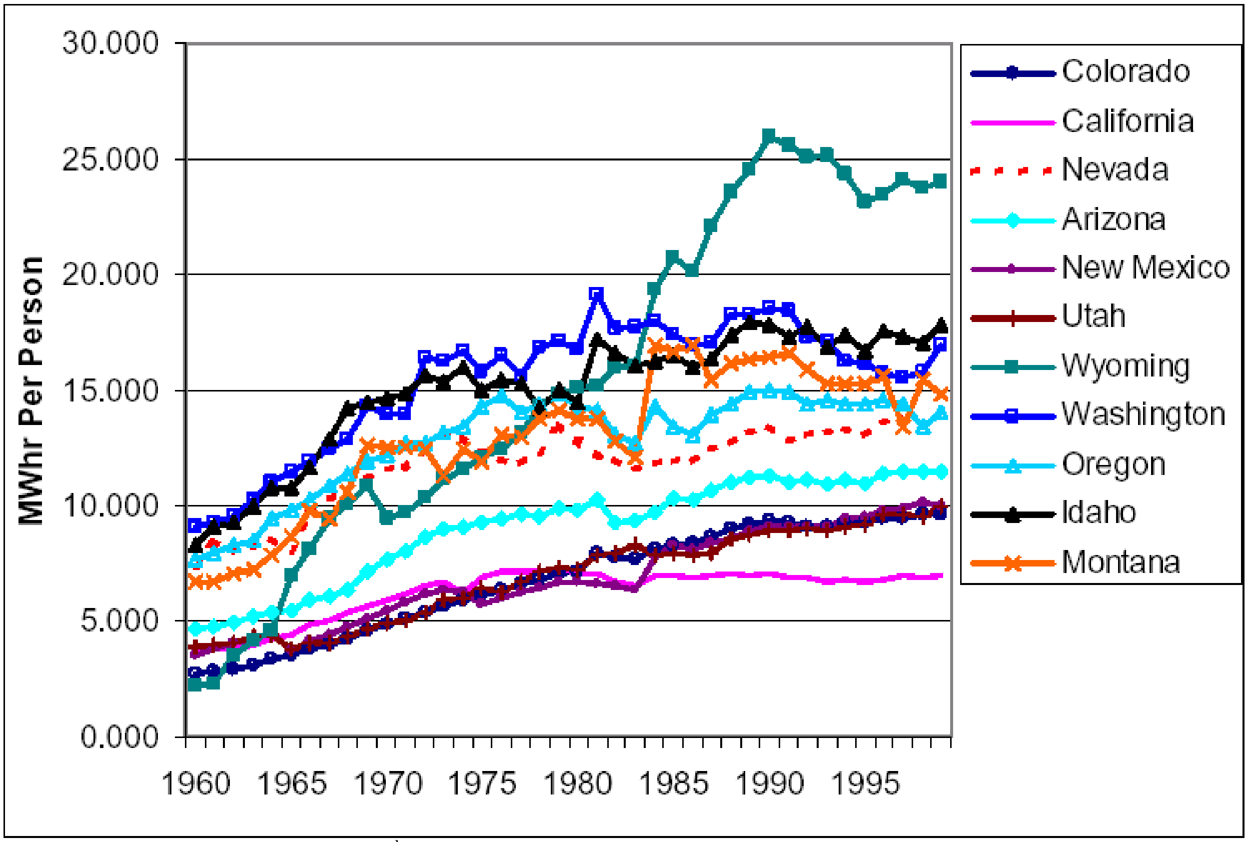
This appendix describes Nevada's electricity sector in terms of net consumption and production, including the assumptions used to develop the reference case projections. It then describes Nevada's electricity trade and potential approaches for allocating GHG emissions for the purpose of determining the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

Electricity Consumption

At about 13,400 kWh/capita/year (2004 data), Nevada's electricity use per person is typical for the U.S. By way of comparison, the per capita consumption for the U.S. was about 12,000 kWh per year.[12] Figure A1 shows Nevada's rank compared to other western states from 1960-1999; Nevada's per capita consumption has been in the mid-range for states in this region. Many components influence a state's per capita electricity consumption including the impact of weather on demand for cooling and heating, the size and type of industries in the State, and the type and efficiency of equipment in the residential, commercial and industrial sectors.

[12] Census bureau for U.S. population, Energy Information Administration for electricity sales.

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

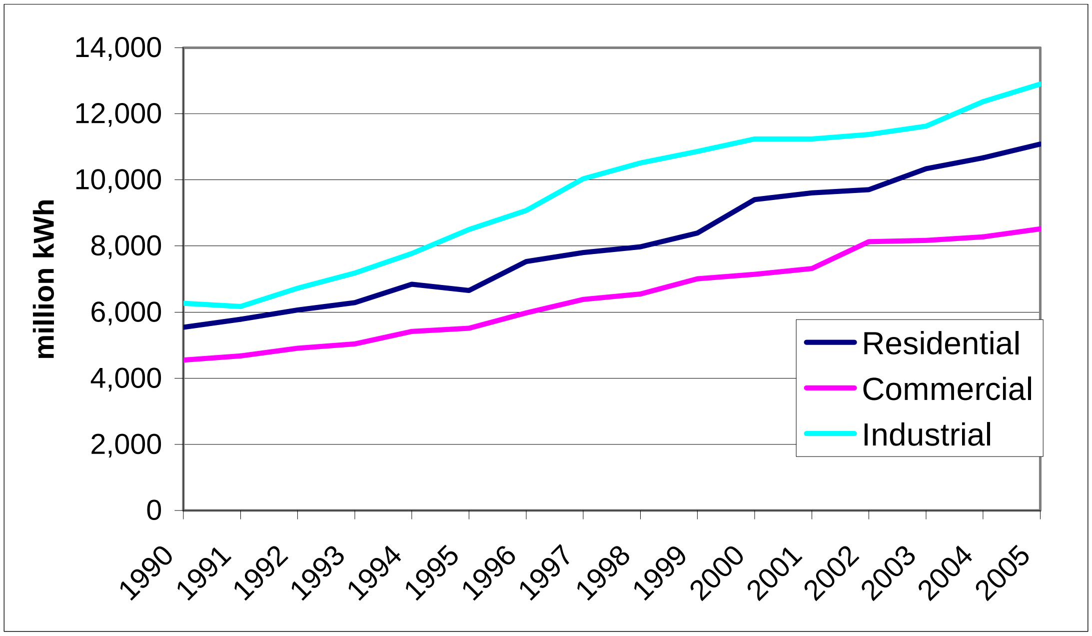


Source: Northwest Power Council, 5th Power Plan, Appendix A

As shown in Figure A2, electricity sales in the Nevada have generally increased steadily from 1990 through 2005. Overall, total electricity consumption increased at an average annual rate of 4.4 percent from 1990 to 2005, comparable to the population growth rate of 4.9 percent per year and gross state product increase of over 8 percent.[13] During this period, the residential sector grew by an average of 4.5 percent per year, the commercial sector by 4.1 percent per year, and the industrial sector by 4.6 percent per year.

[13] Population from The Nevada State Demographer's Office, Nevada County Population Estimates July 1, 1990 to July 1, 2005, Includes Cities and Towns, (Certified Estimates for 2001 to 2005 and estimates prior to 2001 reflect information from the 1990 and 2000 Censuses). Gross State Production from Bureau of Economic analysis. http://bea.gov/bea/newsrelarchive/2006/gsp1006.xls

Figure A2. Electricity Consumption by Sector in Nevada, 1990-2005



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

Projections for electricity sales from 2006 through 2020 were provided by the Public Utilities Commission of Nevada, from their Internal 2006 Energy and Peak Demand Policy Forecasts. Table A1 reports historic and projected annual average growth rates.

Table A1. Annual Electricity Growth Rates, historic and projected

	Historic		Projections	
	1990-2000	2000-2005	2005-2010	2010-2020
Residential	5.4%	3.3%	3.4%	3.4%
Commercial	4.6%	3.6%	3.4%	3.4%
Industrial	6.0%	2.8%	2.5%	2.5%
Total	**5.4%**	**3.2%**	**3.0%**	**3.1%**

Source: Historic from EIA data, projections from Public Utilities Commission of Nevada, *Internal 2006 Energy and Peak Demand Policy Forecasts.*

Electricity Generation – Nevada's Power Plants

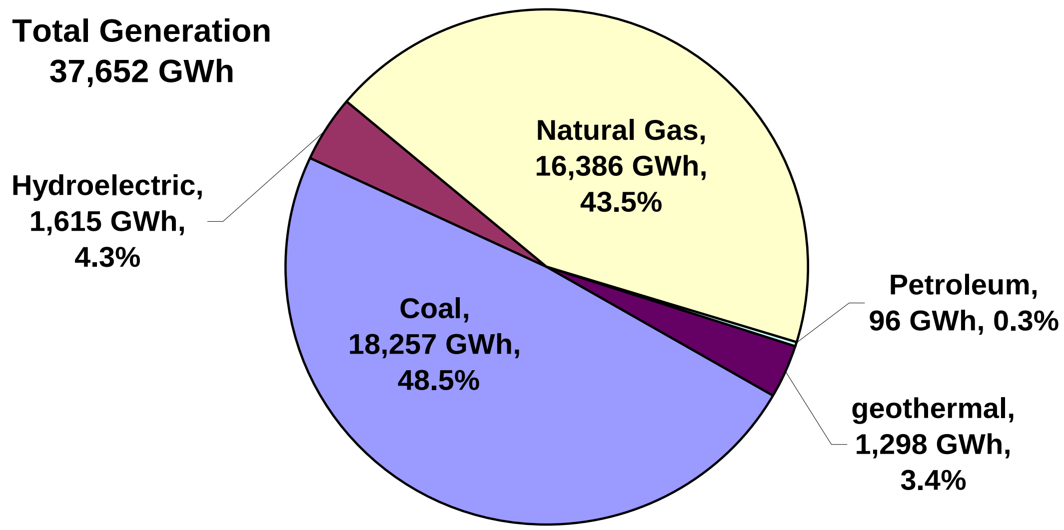
The following section provides information on GHG emissions and other activity associated with power plants *located in Nevada*. Since Nevada is part of the interconnected Western Electricity Coordinating Council (WECC) region – electricity generated in Nevada can be exported to serve needs in other states and electricity used in Nevada 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 Nevada, regardless of where it is consumed) and a *net consumption-basis* (emissions associated with electricity consumed in Nevada). 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 A3, coal and natural gas were used to generate the vast majority (over 90%) of Nevada's electricity in 2004. Since coal generation yields higher GHG emissions per MWh generated than natural gas, coal accounts for 70 percent of the GHG emissions from power plants in Nevada. Table A2 reports the emissions from the five plants in Nevada with the highest emissions from 2000 to 2005. The plant with the highest GHG emissions, Mohave, accounted for about 40 percent of Nevada's GHG emissions. Mohave went into temporary shut down at the end of 2005, leading to a large decrease in GHG emissions in 2006, as will be discussed in the results section. The Nevada Power Company owned 14% of the Mohave generating station with Southern California Edison, City of Los Angeles and the Salt River Project of Arizona owning the remainder.[14] Electricity trade and GHG allocation are discussed in section below.

We considered two sources of data in developing the historic inventory of GHG emissions from Nevada power plants – EIA State Energy Data (SED), which need to be multiplied by GHG emission factors for each type of fuel consumed, and EPA data on CO_2 emissions by power plant. For total electric sector GHG emissions, we used the EIA's SED rather than EPA data because of the comprehensiveness of the EIA-based data. The EPA data are limited to plants over 25 MW and include only CO_2 emissions (EPA does not collect data on CH_4 or N_2O emissions). Through discussions with EPA we also learned that EPA data tend to be conservative (i.e., overestimate emissions) because the data are reported as part of a regulatory program, and that during early years of the data collection program, missing data points were sometimes assigned a large value as a placeholder. However, EPA provides easily accessible data for each power plant (over 25 MW), which would be much more difficult to extract from EIA data, and the CO_2 emissions from the two sources differ by less than 2 percent in most years. Based on this information, we chose to report both data sources but rely on the EIA data for the inventory values. For total GHG emissions from electricity production in Nevada, we applied SGIT emission factors to EIA's SED. For CO_2 emissions from individual plants, we used the EPA database.

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

Figure A3. Electricity Generation and CO_2 Emissions from Nevada Power Plants, 2004



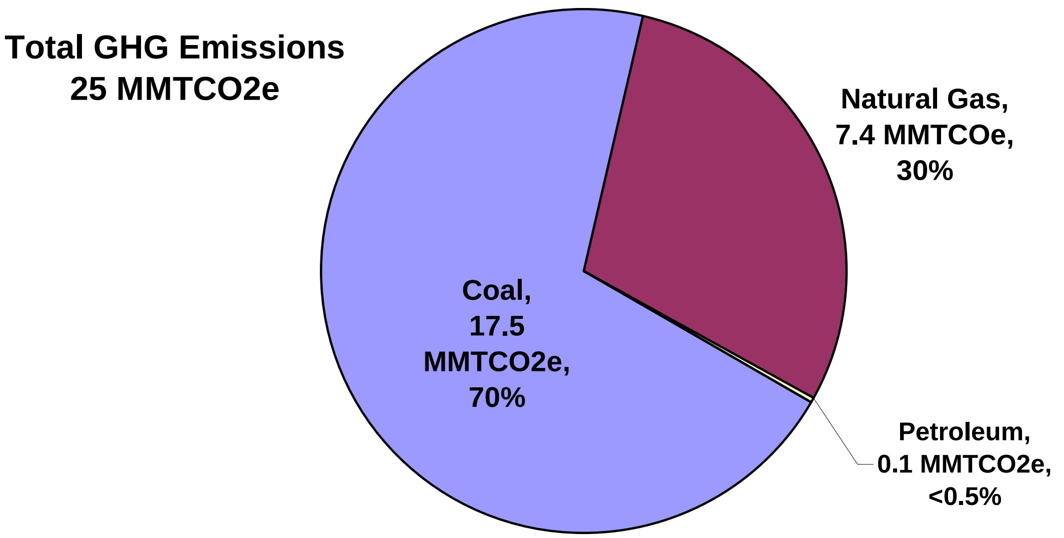


Table A2. CO_2 Emissions from Individual Nevada Power Plants, 2000-2005

(Million metric tons CO2)	2000	2001	2002	2003	2004	2005
El Dorado Energy	*0.8*	*0.9*	*1.3*	*1.3*	*1.2*	*1.3*
Mohave	*9.8*	*9.4*	*9.2*	*8.7*	*9.7*	*9.8*
North Valmy	*3.6*	*3.4*	*4.1*	*3.3*	*4.0*	*4.0*
Reid Gardner	*4.8*	*4.4*	*4.9*	*5.0*	*4.8*	*4.8*
Tracy	*1.5*	*1.7*	*0.8*	*0.8*	*0.9*	*0.8*
Other Plants	*3.8*	*4.1*	*0.5*	*3.4*	*4.6*	*5.4*
Total CO2 emissions	**24.5**	**23.8**	**20.7**	**22.6**	**25.2**	**26.0**

Source: U.S. EPA Clean Air Markets database for named plants (http://cfpub.epa.gov/index.cfm). Total emissions calculated from fuel use data provided by SED (US DOE Energy Information Administration).

Table A3 shows the growth in generation by fuel type between 1990 and 2004. Overall generation grew by 4.7 percent over the 15 years, while electricity consumption grew by 4.6 percent. In Nevada, natural gas generation has had particularly strong growth, increasing by more than seven times from 1990 to 2004. Coal generation grew more slowly but remains the dominant source of electricity in the State. Hydro generation shows a decrease between 1990 and 2004, but the table masks the considerable year-by-year variation from this resource. In the 15-year period, hydro generation ranged from a low of 1,615 GWh in 2004 to a high of 3,166 GWh in 1998.

Table A3. Growth in Electricity Generation in Nevada 1990-2004.

	Generation (GWh)		Growth
	1990	2004	
Coal	15,053	18,257	21%
Hydroelectric	1,735	1,615	-7%
Natural Gas	2,217	16,386	639%
geothermal, solar, wind	761	1,298	70%
Petroleum	284	96	-66%
Total	20,051	37,652	88%

Source: EIA Electric Power Annual Data

Future Generation and Emissions

Estimating future generation and GHG emissions from Nevada 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 Nevada remains uncertain as the trends in type of new builds are influenced by many factors. Since 2000, new fossil-fuel plants in Nevada have been natural gas-fired; however, coal dominates the new plants that have been proposed recently in the State. Sierra Pacific Power and Nevada Power Company are also showing interest in new wind and geothermal plants, in part to meet new renewable generation requirements. Table A4 presents data on new and proposed plants in Nevada. 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 A4. New and Proposed Power Plants in Nevada

	Plant Name	Fuel	Status	Capacity MW	Expected Annual generation GWh	Expected Annual Emissions MMTCO2e	Notes
Retired Plant	Mohave	Coal	retired 2005	1580	-10,705	-9	generation and emission estimates are average levels 2000-2005, EPA Clean Air Markets Data
New plants	Richard Burdett Power Plant	Geothermal	On line 2005	20	149	negligible	generation and emission estimates are average levels 2000-2005, EPA Clean Air Markets Data
	Chuck Lenzie	Natural gas, combustion turbine	On line 2006	1160	1,524	0.6	completed ahead of schedule
	Western 102	Natural gas, baseload	On line 2005	116	864	0.3	Decentralized generation for Barrick Goldstrike Mines
	Harry Allen	Natural gas, peaking	On line 2006	80	105	0.0	
	Desert Peak 2	Geothermal	On line 2006	15	112	negligible	
	Ormat	Geothermal	On line 2006	13	97	negligible	
	Boulder City Solar Project 2	solar	under construction	50	105	0.0	planned for 2007
	Tracy Combined Cycle GT	Natural gas, combined cycle	under construction	514	3,827	1.4	Planned for 2008 Sierra Pacific Power Company
Proposed plants	Ely Wind Generation Facility 3	wind	Permits under review	50	153	0.00	planned for 2007, construction has not started
	Ely Energy Project	coal	under construction	200	1,489	1.23	Newmont mining corp. planned for 2008
	Granite Fox Power Project	coal (pulverized)	permits delayed	1450	10,797	9.17	Sempra Generations has announced plans to sell its development rights for Granite Fox Power.
	Blue Mountain Geothermal	geothermal	Permits under review	35	261	0.22	planned for 2007
	Salt Wells Geothermal Project	geothermal	Permits under review	10	74	negligible	planned for 2007
	TS Power Plant	geothermal	proposed	30	223	negligible	Phase I planned for 2008
	White Pine Project	coal (pulverized)	Permits under review	1600	11,914	0.00	planned for 2010
	Ely Energy Project	coal	Permits under review	1500	11,169	6.33	750 MW planned for 2011, 750 MW for 2014
	Ely Energy Project	coal gasification	proposed	1000	n/a	n/a	
	Toquop Energy Project	coal	Permits under review	750	5,585	3.54	planned for 2010
	No. Nevada Corrections Center	biomass	under construction	1	7	negligible	planned for early 2007

Sources: Public Utilities Commission of Nevada, *Proposed Generation Plants in Nevada* (http://puc.state.nv.us/ELECTRIC/propgen.pdf), Western Resource Advocates website: (http://www.westernresourceadvocates.org/energy/coal/nevada.php). Generation and emission estimates based on 0.15 capacity factor for peaking plants, 0.85 for baseload, 0.35 for wind and 0.239 for solar. NDEP indicates that the first listing of Ely Energy Project on line 2 of the Proposed Plants section will actually be the TS Power facility operated by Newmont Nevada Energy Investments. Also, the Granite Fox Power Project does not have an application in to NDEP and it is not expected to submit an application in light of new regulations in California requiring the use of clean power. NDEP is also unaware of a geothermal plant designated TS Power Plant, it may have a different name.

Nevada has also implemented a renewable portfolio standard (RPS), requiring the State’s two investor-owned utilities, Sierra Pacific Power and Nevada Power Company, to generate (or purchase) a minimum amount of electricity from renewable sources or through energy efficiency. Nevada’s RPS requires minimum annual contributions of electricity from qualifying resources of 6 percent in 2005 and 2006, increasing to 9 percent in 2007 and 2008, 12 percent in 2009 and 2010, 15 percent in 2011 and 2012, 18 percent in 2013 and 2014, and 20 percent in 2015 and 2016. Qualifying resources include energy efficiency and a wide mix of renewables and cleaner energy (wind, solar, geothermal, waste tires (using microwave reduction), biodiesel and others).[15] Of the electricity generated each year from qualifying sources, at least 5 percent must come from solar electric technologies and no more that 25 percent can come from energy efficiency (50 percent of the energy efficiency portion must come from measures installed at locations of residential customers).[16]

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 Nevada'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:

- Total generation from plants in Nevada decreases by 24 percent from 2005 to 2006, due to the temporary shut down of the Mohave power plant at the end of 2005.
- Generation from plants in Nevada grows at 6.6 percent per year from 2007-2010, based on generation estimates from plants that are currently under construction (see table A3).
- Generation from plants in Nevada grows at 2.5 percent per year from 2010 to 2015 and 2.0 percent from 2015 to 2020. This reflects the generation growth rate for the Rocky Mountain region in Annual Energy Outlook 2006 (AEO2006). These assumptions lead to capacity growth of about 2800 MW of new power plant capacity by 2020.
- Generation from existing non-hydro plants is based on holding generation at 2004 levels. Generation from existing hydro-electric plants is assumed to be 2,302 MWh 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.
- The Renewable Portfolio Standard requirements are assumed to be met by Sierra Pacific Power and Nevada Power Companies, which together account for about 88% of electricity sales in the State. The resources used to meet the RPS will be 5% solar, and 18%-20% energy efficiency[17], with the remainder split between wind and geothermal.
- New non-renewable power plants built between 2010 and 2020 will be a mix of 75 percent coal and 25 percent natural gas. This mix of proposed plants is based on regional projections from the EIA AEO2006.

[15] Database of State Incentives for Renewables and Efficiency. Accessed December 10, 2006. http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=NV01R&state=NV&CurrentPageID=1&RE=1&EE=1
[16] Nevada Power Company and Sierra Pacific Power Company. *Revised Portfolio Standard Compliance Plan*. PUCN Docket No. 05-4003. December 15, 2005.
[17] Energy efficiency portion is based on results in the Nevada Power Company and Sierra Pacific Power Company. *Revised Portfolio Standard Compliance Plan*. PUCN Docket No. 05-4003. December 15, 2005

Electricity Trade and Allocation of GHG Emissions

Nevada 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 Nevada, and secondly in estimating these emissions both historically and into the future. Some utilities track and report electricity sales to meet consumer demand by fuel source and plant type; however, tracing sales to individual power plants may not be possible.

In 2004, Nevada had 20 entities involved in providing electricity to state customers. The State's two investor-owned utilities serve approximately 95 percent of the customers, and sell 88 percent of the electricity used. The State's eight electric cooperatives serve 3 percent of the customers and account for 4.6 percent of sales. One federal and 8 public utilities account for the remaining 2.4 percent of customers and 7 percent of sales. The top 5 providers of retail electricity in the State are reported in Table A5.

Table A5. Retail Electricity Providers in Nevada (2004)

Entity	Ownership Type	2004 GWh
1. Nevada Power Co	Investor-Owned	19,014
2. Sierra Pacific Power Co	Investor-Owned	8,627
3. Colorado River Comm of Nevada	Public	1,564
4. Wells Rural Electric Co	Cooperative	655
5. Valley Electric Assn, Inc	Cooperative	391
Total Sales, Top Five Providers		30,251
Total, All Nevada		**31,312**

Source: EIA state electricity profiles

In 2004, electricity demand (sales + losses[18]) in Nevada was about 34,894 GWh, while electricity generation in the State was 37,652 GWh. Net exported electricity to other states accounts for the additional 2,758 GWh, but net exports generally encompass a mix of both imports and exports from the State. As mentioned above, 86 percent of the capacity at the Mohave power plant was under contract with out-of-state utilities. Other power plants have contracts with out-of-state utilities and Nevada utilities may own or have contracts with power plants outside of the State. Thus, electricity trade counts for a significant portion of the electric power associated with Nevada.

[18] Nevada's electricity losses are assumed to be 10 percent based on information from EPA's Emission & Generation Resource Integrated database (EGRID), http://www.epa.gov/cleanenergy/egrid/index.htm. 10 percent is the average rate of losses, according to this dataset, over the period 1994-2000.

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 Nevada electricity consumption would not be fully captured since only emissions from in-state generation would be considered.

An alternative is to estimate *consumption-based* or *load-based* GHG emissions, corresponding to the emissions associated with electricity consumed in the state. The load-based approach is currently being considered by states that import significant amounts of electricity, such as California, Oregon, and Washington.[19] By accounting for emissions from imported electricity, states can account for increases or decreases in fossil fuel consumed in power plants outside of the State, due to demand growth, efficiency programs, and other actions in the state. The difficulty with this approach is properly accounting for the emissions from imports and exports. Since the electricity flowing into or out of Nevada is a mix of all plants generating on the inter-connected grid, it is impossible to physically track the sources of the electrons.

The approach taken in this initial inventory is a simplification of the consumption-based approach. This approach, which one could term "*Net-Consumption-based*," estimates consumption-based emissions as in-state (production-based) emissions times the ratio of total in-state electricity consumption to in-state generation (net of losses) plus the emissions from the net imports. These figures were then adjusted to exclude contracted exports from the Mohave plant, which accounts for 40 percent of production-based emissions but provides only 14% of its power to in-state electricity consumers.[20]

Emissions for net imports are calculated as net imports in GWh multiplied by an emission factor in GHG emissions per electricity generated ($MTCO_2e$/GWh) for the imports. Estimating the mix of electricity generation for the imports/export of a state is possible and several states are developing data collection approaches to do this. Washington State has developed regular fuel disclosure reporting.[21] As a proxy for estimating the mix of historic and future GHG for Nevada's electricity imports, emission factors that reflect the regional fuel mix were used. The region used for future emission factors is the Rocky Mountain portion of the WECC (excluding Nevada's emissions) from the AEO2006. These regional emission factors were 0.66

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[19] See for example, the reports of the Puget Sound Climate Protection Advisory Committee (http://www.pscleanair.org/specprog/globclim/), the Oregon Governor's Advisory Group On Global Warming (http://egov.oregon.gov/ENERGY/GBLWRM/Strategy.shtml), and the California Climate Change Advisory Committee, Policy Options for Reducing Greenhouse Gas Emissions From Power Imports - Draft Consultant Report (http://www.energy.ca.gov/2005publications/CEC-600-2005-010/CEC-600-2005-010-D.PDF).
[20] Ideally, similar adjustments would be made for all power plants in state, as well as accounting for specific sources of contracted resources from out of state. However, such complete information is currently lacking. See text below.
[21] http://www.cted.wa.gov/site/539/default.aspx

$MtCO_2e$/MWh in 2004, increasing to 0.71 $MtCO_2e$/MWh in 2020, reflecting an increasing domination of coal generation.

This method does not account for differences in the type of electricity that is imported or exported from the State, and as such, it provides a simple method for reflecting the emissions impacts of electricity consumption in the State. The calculation also ignores "gross" imports – since Nevada 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, expanding the adjustments that were made for Mohave exports to other plants based on individual utility information on resources used to meet loads – can be considered for further improvements to this approach. Estimating the mix of electricity generation for the imports/export of a state is possible and several states are developing data collection approaches to do this. Washington State has developed regular fuel disclosure reporting.[22]

Summary of Assumptions and Reference Case Projections

As noted, projecting generation sources, sales, and emissions for the electric sector out to 2020 requires a number of key assumptions, including economic and demographic activity, changes in electricity-using technologies, regional markets for electricity (and competitiveness of various technologies and locations), access to transmission and distribution, the retirement of existing generation plants, the response to changing fuel prices, and the fuel/technology mix of new generation plants. The key assumptions described above are summarized in Table A6.

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

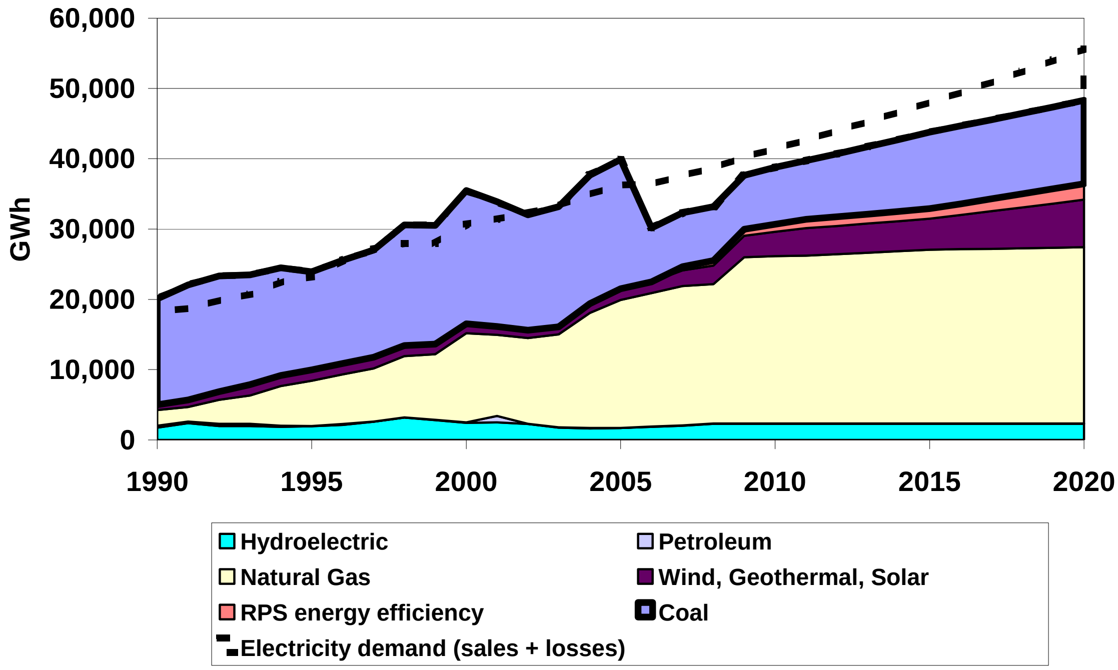
Table A6. Key Assumptions and Methods for Electricity Projections for Nevada

Electricity sales	Average annual growth of 3.1 percent from 2006 to 2020, based on growth rates provided by the Public Utilities Commission of Nevada.
Electricity generation	Average annual growth of 6.6 percent from 2007 to 2010, based on plants under construction and 2.2 percent per year from 2010 to 2020, based on regional growth rates in AEO2006.
Transmission and Distribution losses	10 percent losses are assumed, based on average statewide losses, 1994-2000, (data from the US EPA Emission & Generation Resource Integrated Database[23])
New Renewable Generation Sources	Nevada's Renewable Portfolio Standard will be met by 2 investor-owned utilities (88% of electricity sales), 9% of the utilities' sales met by renewable generation by 2007, increasing to 20% by 2015 and in subsequent years. Resources to meet the RPS are assumed to be 5% solar 18%-20% energy efficiency (based on Utilities' Compliance Plan) remainder of new resource requirement are met by a split between geothermal and wind
New Non-Renewable Generation Sources (2006-2010)	The mix of new non-renewable generation is based on plants under construction for this period (table A4).
New Non-Renewable Generation Sources (2010-2020)	The mix of new generation in this period is based on regional projections from the AEO2006. 75% coal 25% natural gas
Heat Rates	The assumed heat rates for new gas and coal generation are 7000 Btu/kWh and 9000 Btu/kWh, respectively, based on estimates used in similar analyses.[24]
Operation of Existing Facilities	Existing non-hydro facilities are assumed to continue to operate as they were in 2005. Existing hydro facilities are assumed to generate 2,302 GWh per year, the average generation over the period 1996-2005. Improvements in existing facilities that lead to higher capacity factor and more generation are captured under the new generation sources.

Figure A4 shows historical sources of electricity generation in the state by fuel source, along with projections to the year 2020 based on the assumptions described above. With these assumptions and the temporary shut down of the Mohave plant, natural gas is projected to take over from coal as the dominant source of electricity by 2020. Renewable generation also shows high growth, relative to levels in 2005 due to the State RPS. Overall electricity generation grows at 3.4 percent per year from 2006 to 2020.

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

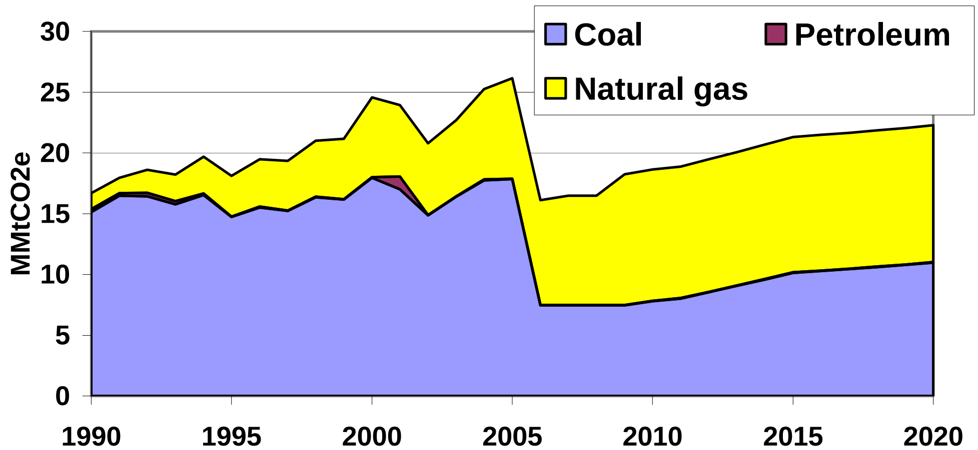
Figure A4. Electricity Generated by Nevada Power Plants 1990-2020



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

Figure A5 illustrates the GHG emissions associated with the mix of electricity generation shown in Figure A4. The temporary shutdown of Mohave results in a 38% decrease in emissions from 2005 to 2006. From 2006 to 2020, the emissions from Nevada electricity generation are projected to grow at 2.3 percent per year, lower than the growth in electricity generation, due to an increased fraction of generation from renewables and natural gas. The GHG emission intensity (emissions per MWh) of Nevada electricity is expected to decrease from 0.66 $MtCO_2/MWh$ in 2005 to 0.53 $MtCO_2/MWh$ in 2006. The intensity then continues to decrease, at a slower rate, to 0.46 $MtCO_2/MWh$ in 2020.

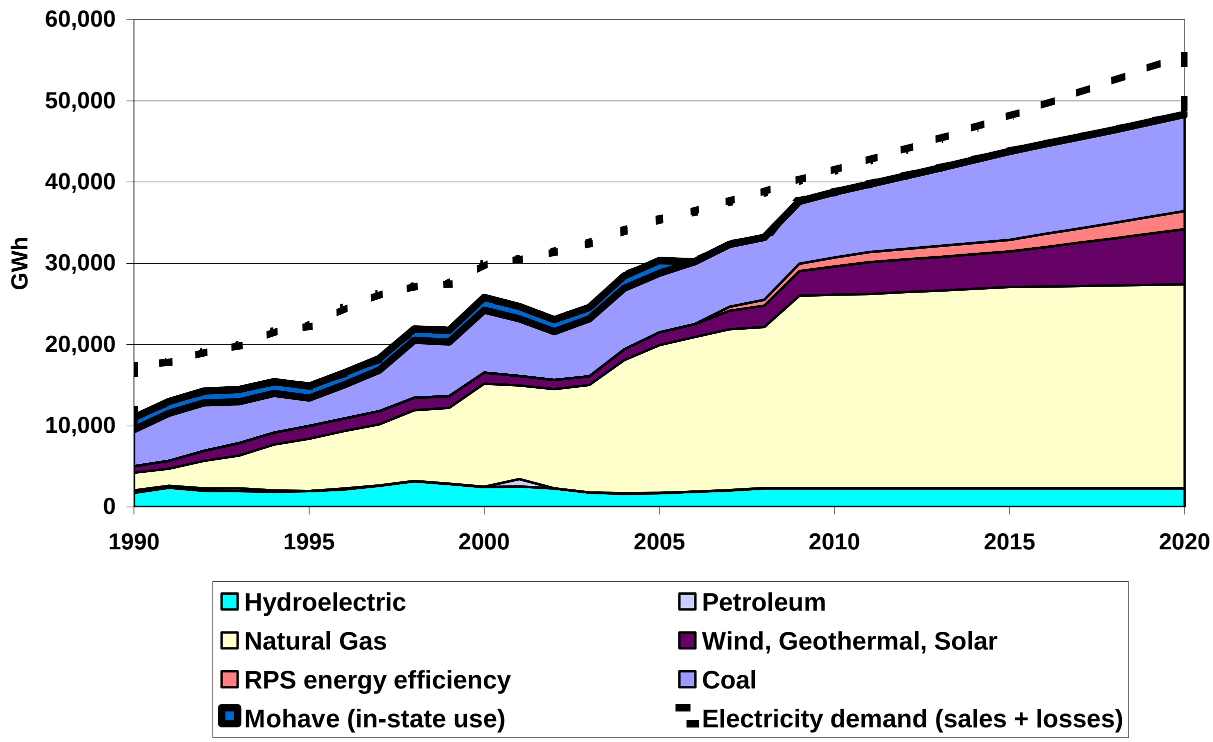
Figure A5. Nevada GHG Emissions Associated with Electricity Production (Production-Basis)



Source: CCS calculations based on approach described in text.

As described above, the net-consumption based emissions for Nevada were estimated by first accounting for the emissions associated with exports from the Mohave power plant. Figure A6 shows Nevada electricity demand and the generation from Nevada power plants, excluding Mohave exports. Note that the State's electricity demand exceeds the generation from in-state resources in each year. Compared with Figure A4, the decreased generation resulting from the temporary shut down of the Mohave at the end of 2005 is hardly noticeable as projected increases in generation from new natural gas plants compensates for the lost in-state electricity from Mohave.

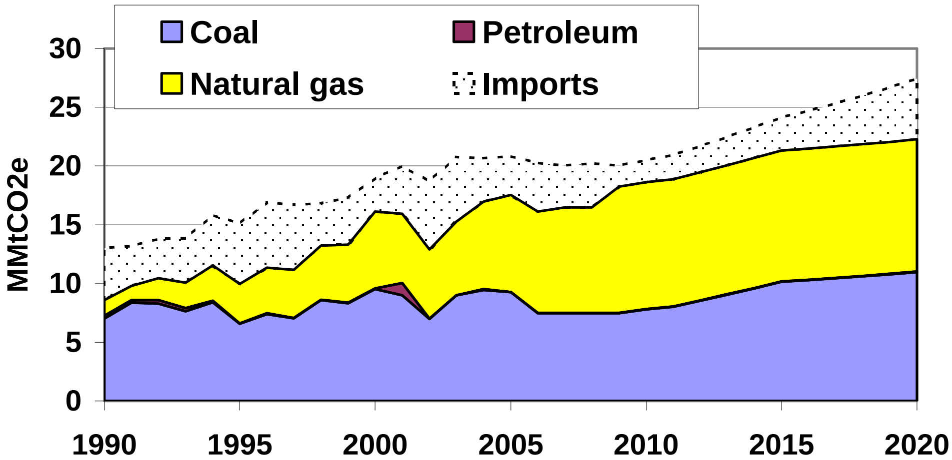
Figure A6. Electricity Generated by Nevada Power Plants 1990-2020, excluding exports from Mohave Power Plant



Note: "Mohave" refers to estimated generation by the Mohave generating plant for in-state electricity sales, "Coal" refers to estimated generation from all other coal plants located in Nevada

Figure A7 shows the "net-consumption-based" emissions from 1990 to 2020, based on the generation mix in Figure A7 and the emissions from imports that are based on the projected average generation mix from the Rocky Mountain region of the WECC, based on results of the AEO2006. The estimated regional emission factor is about 0.66 $MtCO_2e/MWh$ in 2004, increasing to 0.71 $MtCO_2e/MWh$ in 2020, higher than Nevada's GHG emission rate (see *Electricity Trade* section above for further information on this factor). Consumption-based emissions increase by 1.7 percent per year from 2005 to 2020.

Figure A7. Nevada GHG Emissions Associated with Electricity Use (Consumption-Basis), showing Exports



Source: CCS calculations based on approach described in text.

Table A7 summarizes the GHG emissions for Nevada's electric sector from 1990 to 2020. During this time period, emissions are projected to increase by 33 percent on a production-basis and 111 percent on a consumption-basis.

Table A7. Nevada GHG Emissions from Electric Sector, Production and Consumption-based estimates, 1990-2020.

(Million Metric Tons CO2e)	1990	2000	2005	2010	2020
Electricity Production	**16.7**	**24.6**	**26.1**	**18.6**	**22.3**
Coal	15.1	18.0	17.9	7.8	11.0
CO2	15.0	17.9	17.8	7.8	10.9
CH4 and N2O	0.1	0.1	0.1	0.0	0.1
Natural Gas	1.3	6.5	8.3	10.8	11.3
CO2	1.3	6.5	8.3	10.8	11.3
CH4 and N2O	0.0	0.0	0.0	0.0	0.0
Petroleum	0.3	0.1	0.0	0.0	0.0
CO2	*0.3*	*0.1*	*0.0*	*0.0*	*0.0*
CH4 and N2O	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Elecricity Imports (negative for exports)	**-3.7**	**-5.6**	**-5.3**	**1.9**	**5.2**
Electricity Consumption-based Emissions	**13.0**	**19.0**	**20.8**	**20.5**	**27.4**

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

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

Overview

Activities in the RCI[25] sectors produce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions when fuels are combusted to provide space heating, process heating, and other applications. Carbon dioxide accounts for over 99% of these emissions on a million metric tons of CO_2 equivalent ($MMtCO_2e$) basis in Nevada. In addition, since these sectors consume electricity, one can also attribute emissions associated with electricity generation to these sectors in proportion to their electricity use.[26] 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 GHG emissions in Nevada. Direct use of oil, natural gas, coal, and wood in the RCI sectors accounted for an estimated 6.4 $MMtCO_2e$ (13%) of gross GHG emissions in 2005.[27]

Emissions and Reference Case Projections

Emissions from direct fuel use were estimated using the U.S. EPA's SGIT software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for RCI fossil fuel combustion.[28] The default data used in SGIT for Nevada are from EIA's *State Energy Data (SED)*. The SGIT default data for Nevada were revised using the most recent data available, which includes: (1) 2002 SED information for all fuel types;[29] (2) 2003 SED information for coal, and wood and wood waste;[30] (3) 2003 and 2004 SED information for natural gas and petroleum (distillate oil, kerosene and liquefied petroleum gas) consumption (same citation as previous data source); (4) 2004 electricity consumption data from the EIA's *State Electricity Profiles*;[31] and (5) 2005 natural gas consumption data from the EIA's *Natural Gas Navigator*.[32]

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[25] The industrial sector includes emissions associated with agricultural energy use and fuel used by the fossil fuel production industry.
[26] Emissions associated with the electricity supply sector (presented in Appendix A) have been allocated to each of the RCI sectors for comparison of those emissions to the fuel-consumption-based emissions presented in Appendix B. Note that this comparison is provided for information purposes and that emissions estimated for the electricity supply sector are not double-counted in the total emissions for the state. One could similarly allocate GHG emissions from natural gas transmission and distribution, other fuels production, and transport-related GHG sources to the RCI sectors based on their direct use of gas and other fuels, but we have not done so here due to the difficulty of ascribing these emissions to particular end-users. Estimates of emissions associated with the transportation sector are provided in Appendix C, and estimates of emissions associated with fossil fuel production and distribution are provided in Appendix E.
[27] Emissions estimates from wood combustion include only N_2O and CH_4. Carbon dioxide emissions from biomass combustion are assumed to be "net zero", consistent with U.S. EPA and IPCC methodologies, and any net loss of carbon stocks due to biomass fuel use should be accounted for in the land use and forestry analysis.
[28] GHG emissions were calculated using SGIT, with reference to *EIIP, Volume VIII*: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004; and Chapter 2 "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion", August 2004.
[29] EIA *State Energy Data 2002*, Data through 2002, released June 30, 2006, (http://www.eia.doe.gov/emeu/states/state.html?q_state_a=co&q_state=NEVADA).
[30] EIA *State Energy Data 2003 revisions for all fuels, and first release of 2004 information for natural gas and petroleum*, (http://www.eia.doe.gov/emeu/states/_seds_updates.html).
[31] EIA *Electric Power Annual 2005 - State Data Tables*, (http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html).
[32] EIA *Natural Gas Navigator* (http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_SNV_a.htm).

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

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

Table B1 shows historic and projected growth rates for electricity sales by sector. Table B2 shows historic and projected growth rates for energy use by sector and fuel type. For the residential sector, the rate of population growth is expected to increase at about 3.2% annually between 2004 and 2020; this demographic trend is reflected in the growth rates for residential fuel consumption. Based on the Nevada Department of Employment's 10-year forecast (2004 to 2014), commercial and industrial employment are projected to increase at compound annual

[33] EIIP, Volume VIII: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004.
[34] A mixture of hydrocarbons, mostly pentanes and heavier fractions, extracted from natural gas.
[35] EIA AEO2006 with Projections to 2030, (http://www.eia.doe.gov/oiaf/aeo/index.html).
[36] Population data for 1990 through 2005 from the Nevada State Demographer's Office, University of Nevada, Reno, Nevada, "Nevada County Population Estimates July 1, 1990 to July 1, 2005
Includes Cities and Towns" (http://www.nsbdc.org/what/data_statistics/demographer/pubs/pdfs/NVpopul05.pdf). Population forecasts for 2006 to 2020 also from the Nevada State Demographer's Office, University of Nevada, Reno, Nevada, "Nevada County Population Projections 2006 to 2026" (http://www.nsbdc.org/what/data_statistics/demographer/pubs/docs/NV_2006_Projections.pdf).
[37] Employment data for 2000 through 2005 from Nevada Department of Employment, Training & Rehabilitation; Nevada Workforce Informer; Current Employment Statistics (http://www.nevadaworkforce.com/cgi/dataanalysis/): Select Data Analysis, Current Employment Statistics, Select Years = 2000 – 2005, Select Time Periods = Annual, Select Industries = Goods Producing, Services Providing, Select Seasonally Adjusted = Not, Select Data Series = No. of Employed, Select View Data, Select Download = Text. Employment Data for 2004 and 2014, Nevada Department of Employment, Training & Rehabilitation; Nevada Workforce Informer; Current Employment Statistics (http://www.nevadaworkforce.com/cgi/dataanalysis/): Select 10 Year Industry Employment Projections, Select Area Types = Nevada, Select Areas = Nevada, Select Time Periods = 2004-2014, Select Industry Code Type = NAICS, Select One or More Industries = Goods-Producing, Services-Providing, Select Data Series = Estimated Employment and Projected Employment, Select View Data, Select Download = Text.
[38] AEO2006 employment projections for EIA's Mountain region obtained through special request from EIA (dated September 27, 2006).

rates of 3.7% and 3.2%, respectively, and these growth rates are reflected in the growth rates in energy use shown in Table B2 for the two sectors. The 2004 to 2014 commercial and industrial employment growth rates were carried forward to 2020 for the purpose of estimating emissions for the reference case projections. These estimates of growth relative to population and employment reflect expected responses of the economy — as simulated by the EIA's National Energy Modeling System — to changing fuel and electricity prices and changing technologies, as well as to structural changes within each sector (such as shifts in subsectoral shares and in energy use patterns).

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

Sector	1990-2004[a]	2005-2010[b]	20010-2020[b]
Residential	4.8%	3.4%	3.4%
Commercial	5.6%	3.4%	3.4%
Industrial	5.0%	2.5%	2.5%
Total	**4.7%**	**3.0%**	**3.1%**

[a] 1990-2004 compound annual growth rates calculated from Nevada electricity sales by year from EIA state electricity profiles (Table 8), (http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html).
[b] 2005-2020 compound annual growth rate for total for all three sectors taken from forecast for the energy supply sector (see Appendix A).

Results

Figures B1, B2, and B3 show historic and projected emissions for the RCI sectors in Nevada from 1990 through 2020. These figures show the emissions associated with the direct consumption of fossil fuels and, for comparison purposes, show the share of emissions associated with the generation of electricity consumed by each sector. During the period from 1990 through 2020, the residential sector's share of total RCI emissions from direct fuel use and electricity use ranges from 30% to 35%, the commercial sector's share of total emissions ranges from 26% to 28%, and the industrial sector's share of total emissions ranges from 37% to 44%.

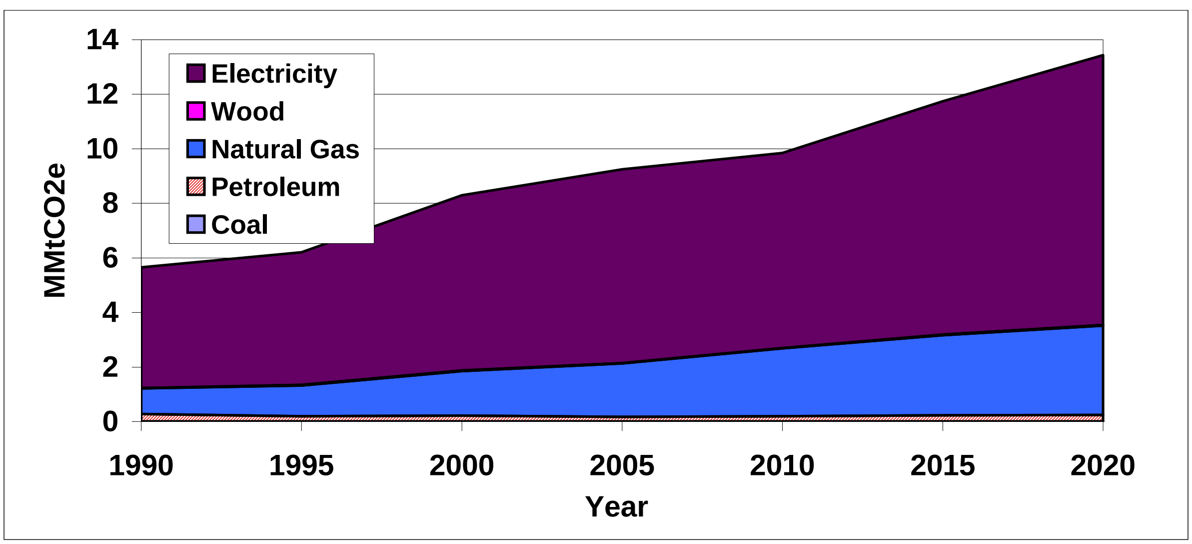
For the residential sector, emissions from electricity and direct fossil fuel use in 1990 were about 5.7 $MMtCO_2e$, and are estimated to increase to about 13.4 $MMtCO_2e$ by 2020. Emissions associated with the generation of electricity to meet residential energy consumption demand accounted for about 78% of total residential emissions in 1990 and are estimated to decrease to 74% of total residential emissions by 2020. In 1990, natural gas consumption accounted for about 17% of total residential emissions, and gas use is estimated to account for about 24% of total residential emissions by 2020. Residential sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 0.3 $MMtCO_2e$ combined, and accounted for about 5% of total residential emissions. By 2020, emissions associated with the consumption of these three fuels are estimated to drop to 0.27 $MMtCO_2e$, and to account for 2% of total residential sector emissions in that year.

Table B2. Historic and Projected Average Annual Growth in Energy Use in Nevada, by Sector and Fuel, 1990-2020

	1990-2004[a]	2005-2010[b]	2010-2015[b]	2015-2020[b]
Residential				
natural gas	5.1%	5.0%	3.7%	2.4%
petroleum	-3.9%	3.6%	3.0%	1.6%
wood	-0.8%	3.5%	1.0%	0.5%
coal	-13.0%	3.4%	0.5%	-0.5%
Commercial				
natural gas	3.7%	3.2%	5.0%	4.3%
petroleum	0.1%	0.4%	3.2%	2.8%
wood	2.9%	1.9%	2.4%	2.1%
coal	-9.5%	1.8%	2.4%	2.1%
Industrial				
natural gas	3.5%	3.3%	2.3%	2.3%
petroleum	-0.8%	4.3%	3.7%	3.1%
wood[c]	13.6%	4.9%	4.1%	4.0%
coal	2.2%	2.9%	2.0%	1.8%

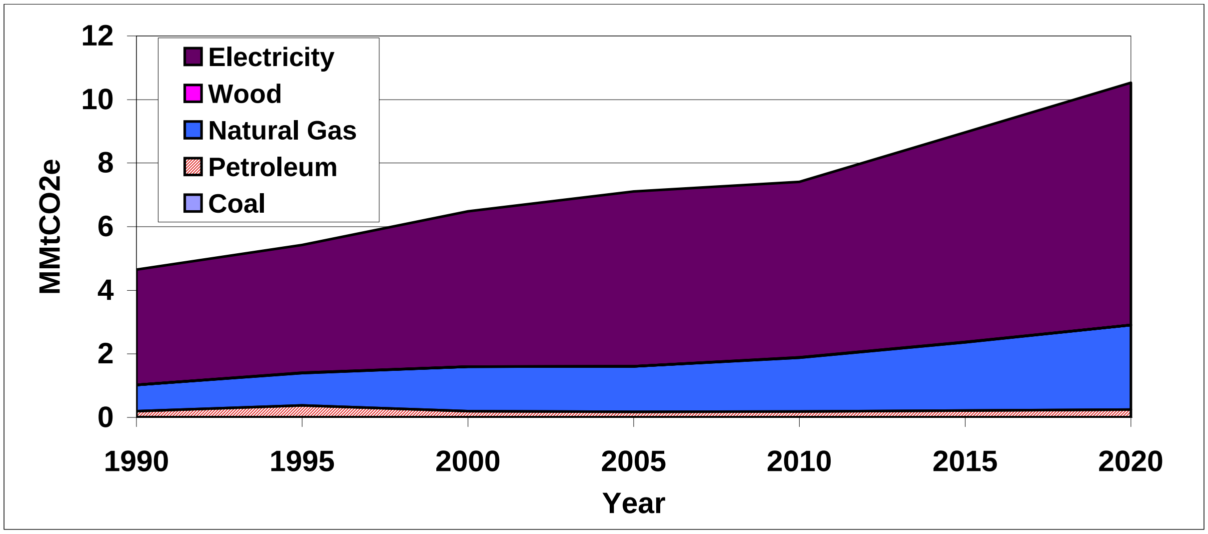
[a] Compound annual growth rates calculated from EIA SED historical consumption by sector and fuel type for Nevada. Latest year for which EIA SED information was available for each fuel type is 2003 for coal and wood/wood waste, 2004 for petroleum, and 2005 for natural gas. Petroleum includes distillate fuel, kerosene, and liquefied petroleum gases for all sectors plus residual oil for the commercial and industrial sectors.
[b] Figures for growth periods starting after 2004 are calculated from AEO2006 projections for EIA's Mountain region, adjusted for Nevada's projected population for the residential sector, projections for non-manufacturing employment for the commercial sector, and projections for manufacturing employment for the industrial sector.
[c] Industrial wood consumption is zero for 1990 through 1995; industrial wood consumption growth rate is based on SED information reported for 1996 through 2003.

Figure B1. Residential Sector GHG Emissions from Fuel Consumption



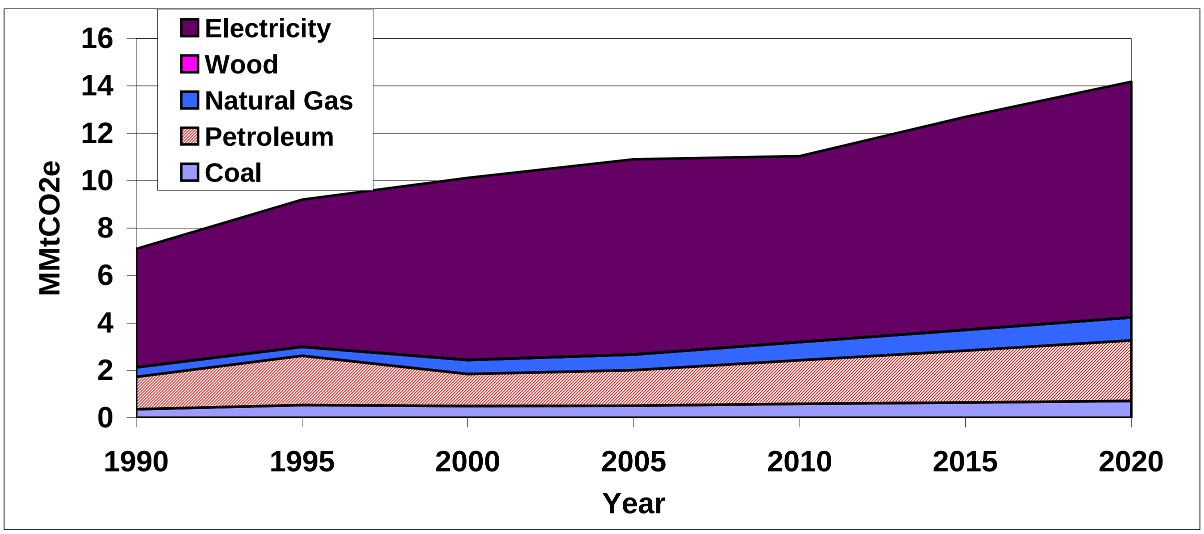
Source: CCS calculations based on approach described in text.
Note: Emissions associated with coal and wood combustion are too small to be seen on this graph.

Figure B2. Commercial Sector GHG Emissions from Fuel Consumption



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

Figure B3. Industrial Sector GHG Emissions from Fuel Consumption



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

For the 15-year period 2005 through 2020, residential-sector GHG emissions associated with the use of electricity and natural gas are expected to increase at average annual rates of about 2.2% and 3.5%, respectively. Emissions associated with the use of coal, petroleum, and wood fuels are expected to increase annually by about 0.8%, 2.5%, and 1.4% on average, respectively, from

2005 through 2020. Total GHG emissions for this sector increase by an average of about 2.5% annually over the 15-year period.

For the commercial sector, emissions from electricity and direct fuel use in 1990 were about 4.7 $MMtCO_2e$ and are estimated to increase to about 10.5 $MMtCO_2e$ by 2020. Emissions associated with the generation of electricity to meet commercial energy consumption demand accounted for about 78% of total commercial-sector emissions in 1990, and are estimated to decrease to about 72% of total commercial emissions by 2020. In 1990, natural gas consumption accounted for about 18% of total commercial emissions, and is estimated to account for about 25% of total emissions from the commercial sector by 2020. Commercial-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 0.21 $MMtCO_2e$ combined, and accounted for about 4% of total commercial emissions. For 2020, emissions associated with the consumption of these three fuels are estimated to be 0.26 $MMtCO_2e$, and to account for 3% of total commercial sector emissions.

For the 15-year period 2005 through 2020, commercial-sector GHG emissions associated with the use of electricity and natural gas are expected to increase at average annual rates of about 2.2% and 4.2%, respectively. Emissions associated with the use of coal, petroleum, and wood are expected to increase annually by about 2.1%, 2.3%, and 2.2% on average, respectively, from 2005 through 2020. Total GHG emissions for this sector increase by an average of about 2.6% annually over the 15-year period.

For the industrial sector, emissions in 1990 were about 7.1 $MMtCO_2e$; industrial emissions are estimated to increase to about 14.2 $MMtCO_2e$ by 2020. Emissions associated with the generation of electricity to meet industrial energy consumption demand accounted for about 70% of total industrial emissions in 1990, and are estimated to remain at about 70% of total industrial emissions through 2020. In 1990, natural gas consumption accounted for about 6% of total industrial emissions, and gas use is estimated to account for about 7% of total industrial emissions by 2020. The consumption of petroleum accounted for about 19% of total industrial emissions in 1990, and is estimated to decline slightly to about 18% of total industrial emissions by 2020. Industrial sector emissions associated with the use of coal and wood in 1990 were about 0.4 $MMtCO_2e$ combined and accounted for about 5% of total industrial emissions. For 2020, emissions associated with the consumption of these two fuels are estimated to be 0.7 $MMtCO_2e$, and to account for 5% of total industrial sector emissions combined.

For the 15-year period 2005 to 2020, industrial sector GHG emissions associated with the use of electricity and natural gas are expected to increase at average annual rates of about 1.3% and 2.6%, respectively. Emissions associated with the use of coal, petroleum, and wood are expected to increase annually by about 2.2%, 3.6%, and 4.3% on average, respectively, from 2005 through 2020. Total GHG emissions for this sector increase by an average of about 1.8% annually over the 15-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 Nevada 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 Nevada to the extent that such data become available.
- The AEO2006 projections assume no large long-term changes in relative fuel and electricity prices, relative to current price levels and to U.S. DOE projections for fuel prices. Price changes would influence consumption levels and, to the extent that price trends for competing fuels differ, may encourage switching among fuels, and thereby affect emissions estimates.
- The exception to the AES2006 assumption of no large changes in prices or fuels consumption is the AEO2006 reference case projections for industrial coal consumption. The AEO2006 model's forecast for the EIA's Mountain region assumes that new coal-to-liquids plants would be constructed near active coal mines when low-sulfur distillate prices reach high enough levels to make coal-to-liquids processing economic. Plants are assumed to be co-production plants with generation capacity of 758 MW and the capability of producing 33,200 barrels of liquid fuel per day. The technology assumed is similar to an integrated gasification combined cycle plant, first converting the coal feedstock to gas, and then subsequently converting the synthetic gas to liquid hydrocarbons using the Fisher-Tropsch process. As a result, AEO2006 projections assume a rather significant increase in coal consumption by the coal-to-liquids industrial sector starting in 2011. For the EIA's Mountain region, this sector accounts for 17.5% of total coal consumption in 2011 and 63% of total coal consumption in 2020, with an annual growth rate of 26% from 2011 to 2020.[39] This increase in coal consumption, associated with the installation of coal-to-liquids plants starting in 2011, was excluded from the industrial coal consumption forecasts for Nevada because it is considered to represent technology that is beyond the "business-as-usual" assumptions associated with the reference case projections for the industrial coal consumption sector. In addition, Nevada does not have any active coal mines.

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

Appendix C. Transportation Energy Use

Overview

The transportation sector is the largest source of GHG emissions in Nevada – accounting for 32% of Nevada's gross GHG emissions in 2000. Carbon dioxide accounts for about 97 percent of transportation GHG emissions from fuel use. Most of the remaining GHG emissions from the transportation sector are due to N_2O emissions from gasoline engines.

Emissions and Reference Case Projections

GHG emissions for 1990 through 2002 were estimated using SGIT and the methods provided in the EIIP guidance document for the sector.[40,41] For onroad vehicles, the CO_2 emission factors are in units of lb/MMBtu and the CH_4 and N_2O emission factors are both in units of grams/VMT. Key assumptions in this analysis are listed in Table C2. The default data within SGIT were used to estimate emissions, with the most recently available fuel consumption data (2002) from EIA SED added.[42] The default VMT data in SGIT were replaced with state-level annual VMT from Nevada Department of Transportation (NDOT).[43] State-level VMT was allocated to vehicle types using the default vehicle mix data in SGIT.

Onroad gasoline and diesel emissions were projected based on VMT projections provided by the Regional Transportation Commissions (RTC) of Southern Nevada and Washoe County[44,45] and projected VMT from the WRAP mobile source inventory.[46] VMT projections from RTC of Southern Nevada and RTC of Washoe County were applied to the urban VMT for Clark and Washoe counties, respectively. All other VMT was projected based on the future VMT estimates from the WRAP inventory. The resulting VMT projections suggest that the overall state VMT will grow at an average rate of 3.3 percent per year between 2002 and 2020. These projected VMT were applied to vehicle mix fractions calculated from EIA's *Annual Energy Outlook* 2006 (AEO2006). The AEO2006 data were incorporated because they indicate significantly different VMT growth rates for certain vehicle types (e.g., 34 percent growth between 2002 and 2020 in heavy-duty gasoline vehicle VMT versus 284 percent growth in light-duty diesel truck VMT over this period). The procedure first applied the AEO2006 vehicle type-based national growth rates to 2002 Nevada estimates of VMT by vehicle type. These data were then used to calculate the estimated proportion of total VMT by vehicle type in each year. Next, these proportions were applied to the projected state-total VMT year to yield the vehicle-type compound annual average growth rates are displayed in Tables C1.

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

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

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

[43] Gaelen Lamb, Transportation Planner/Analyst, Nevada Department of Transportation

[44] Stan Anderson, Senior Planner, Regional Transportation Commission of Southern Nevada.

[45] Judy Althoff, Planner, Regional Transportation Commission of Washoe County.

[46] WRAP Mobile Source Emission Inventories Update, Western Regional Air Partnership, http://www.wrapair.org/forums/ef/UMSI/index.html

Table C1. Nevada Vehicle Miles Traveled Compound Annual Growth Rates

Vehicle Type	2002-2005	2005-2010	2010-2015	2015-2020
Heavy Duty Diesel Vehicle	5.77%	4.55%	4.25%	4.21%
Heavy Duty Gasoline Vehicle	4.45%	3.01%	3.70%	3.77%
Light Duty Diesel Truck	7.29%	8.14%	8.15%	8.37%
Light Duty Diesel Vehicle	7.29%	8.14%	8.15%	8.37%
Light Duty Gasoline Truck	3.02%	3.09%	3.08%	3.04%
Light Duty Gasoline Vehicle	3.02%	3.09%	3.08%	3.04%
Motorcycle	3.02%	3.09%	3.08%	3.04%

Onroad gasoline and diesel fuel consumption was forecasted by developing a set of growth factors that adjusted the VMT projections to account for improvements in fuel efficiency. Fuel efficiency projections were taken from EIA's *Annual Energy Outlook* (AEO). These projections suggest onroad fuel consumption growth rates of 2.3% per year for gasoline and 4.7% per year for diesel between 2002 and 2020.

Gasoline consumption estimates for 1990-2002 were adjusted by subtracting ethanol consumption. While the historical ethanol consumption suggests continued growth, projections for ethanol consumption in Nevada were not available. Therefore, ethanol consumption was assumed to remain at the 2002 level (3.8% of total gasoline) in the reference case projections. Biodiesel and other biofuel consumption were not considered in this inventory because historical and projection data were not available.

For the aircraft sector, emission estimates for 1990 to 2002 are based on SGIT methods and fuel consumption from EIA. Emissions were projected from 2002 to 2020 using general aviation and commercial aircraft operations for 2002 to 2020 from the Federal Aviation Administration's Terminal Area Forecast System[47] and national aircraft fuel efficiency forecasts. To estimate changes in jet fuel consumption, itinerant aircraft operations from air carrier, air taxi/commuter, and military aircraft were first summed for each year of interest. The post-2002 estimates were adjusted to reflect the projected increase in national aircraft fuel efficiency (indicated by increased number of seat miles per gallon), as reported in AEO2006. Because AEO2006 does not estimate fuel efficiency changes for general aviation aircraft, forecast changes in aviation gasoline consumption were based solely on the projected number of itinerant general aviation aircraft operations in Nevada, which was obtained from the FAA source noted above. These projections resulted in compound annual growth rates of 2.3% for aviation gasoline and 2.1% for jet fuel.

Nevada DOT provided aircraft operations projections[48]; however, these data were not broken down by commercial and general aviation. Also, military operations were not available. Commercial aircraft operations were estimated by summing the total operations for the four

[47] Terminal Area Forecast, Federal Aviation Administration, http://www.apo.data.faa.gov/main/taf.asp.
[48] Matthew Furedy, Nevada Department of Transportation, Aviation Planning.

largest airports (Reno-Tahoe, McCarran, North Las Vegas, and Elko). The aircraft operations for the remaining airports were assumed to be general aircraft operations. These projections resulted in growth rates of 2.8% for general gasoline and 0.6% for jet fuel (-0.6% when the fuel efficiency adjustment was applied). Since this approximation does not produce realistic growth rates for jet fuel consumption, FAA data (described above) were used to project aviation emissions instead of the available state data.

For the rail and marine sectors, 1990 – 2004 estimates are based on SGIT methods and fuel consumption from EIA. For rail, the historic data show no significant positive or negative trend. The historic marine sector gasoline consumption data show growth from 1990 to 2000; however, there was no growth between 2000 and 2004. Therefore, no growth was assumed for these two sectors.

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 C3 shows how EIA divides gasoline and diesel fuel consumption between the transportation, commercial, and industrial sectors.

Table C2. Key Assumptions and Methods for the Transportation Inventory and Projections

Vehicle Type and Pollutants	Methods
Onroad gasoline, diesel, natural gas, and LPG vehicles – CO_2	**Inventory (1990 – 2002)** EPA SGIT and fuel consumption from EIA SED **Reference Case Projections (2003 – 2020)** Gasoline and diesel fuel projected using VMT projections from Metropolitan Planning Organizations (MPOs) and WRAP, adjusted by fuel efficiency improvement projections from AEO2006. Other onroad fuels projected using Mountain Region fuel consumption projections from EIA AEO2006 adjusted using state-to-regional ratio of population growth.
Onroad gasoline and diesel vehicles – CH_4 and N_2O	**Inventory (1990 – 2002)** EPA SGIT, onroad vehicle CH_4 and N_2O emission factors by vehicle type and technology type within SGIT were updated to the latest factors used in the U.S. EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003.* State total VMT replaced with VMT provided by NDOT, VMT allocated to vehicle types using default data in SGIT. **Reference Case Projections (2003 – 2020)** VMT projections from MPOs and WRAP.
Non-highway fuel consumption (jet aircraft, gasoline-fueled piston aircraft, boats, locomotives) – CO_2, CH_4 and N_2O	**Inventory (1990 – 2002)** EPA SGIT and fuel consumption from EIA SED. **Reference Case Projections (2003 – 2020)** Aircraft projected using aircraft operations projections from FAA and jet fuel efficiency improvement projections from AEO2006.

Table C3. EIA Classification of Gasoline and Diesel Consumption

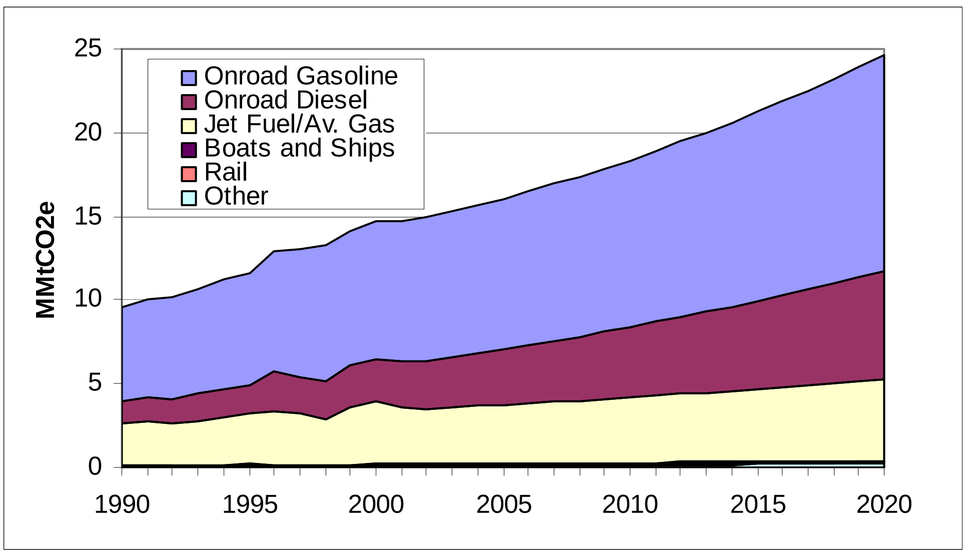
Sector	Gasoline Consumption	Diesel Consumption
Transportation	Highway vehicles, marine	Vessel bunkering, military use, railroad, highway vehicles
Commercial	Public non-highway, miscellaneous use	Commercial use for space heating, water heating, and cooking
Industrial	Agricultural use, construction, industrial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

Results

As shown in Figure C1, onroad gasoline consumption accounts for the largest share of transportation GHG emissions. Emissions from onroad gasoline vehicles increased by about 52% from 1990-2002 to cover almost 58% of total transportation emissions in 2002. GHG emissions from onroad diesel fuel consumption increased by 111% from 1990 to 2002, and by 2002 accounted for 19% of GHG emissions from the transportation sector. Emissions from aviation grew by 34% from 1990-2002 to cover 22% of transportation emissions in 2002. Emissions from all other categories combined (boats and ships, locomotives, natural gas and LPG, and oxidation of lubricants) contributed only 1% of total transportation emissions in 2002.

GHG emissions from onroad gasoline consumption are projected to increase by about 43%, and emissions from onroad diesel consumption are expected to increase by 97% between 2002 and 2020. Aviation fuel consumption is projected to increase by 37% between 2002 and 2020.

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



Key Uncertainties

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

One source of uncertainty is the future year vehicle mix, which was calculated based on national growth rates for specific vehicle types. These growth rates may not reflect vehicle-specific VMT growth rates for the state. Also, onroad gasoline and diesel growth rates may be slightly overestimated because increased consumption of biofuels between 2005 and 2020 was not taken into account (due to a lack of data).

Uncertainties in Aviation Fuel Consumption

The consumption of international bunker fuels included in jet fuel consumption from EIA is another uncertainty. This fuel consumption associated with international air flights should not be included in the state inventory (as much of it is actually consumed out of state); 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.

Since military jet fuel use could be an important component of the aviation fuel use emissions in Nevada, future work to improve upon these initial emission estimates should focus on military fuel consumption. CCS suggests that contacts with the environmental staff at military air stations in the state could provide information on fuel consumption or landings and take-offs that could be used to estimate GHG emissions for the military sector.

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 Nevada, and for which emissions are estimated in this inventory, include the following:

- CO_2 from:
  - Production of cement and lime;
  - Consumption of limestone, dolomite, and soda ash;
- N_2O from nitric acid production;
- 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 GHGs emissions but are not found in Nevada include the following:

- N_2O from adipic acid production;
- PFCs from aluminum production;
- HFCs, PFCs, and SF_6 from semiconductor manufacture;
- HFCs from HCFC-22 production; and
- SF_6 from magnesium production and processing.

Emissions and Reference Case Projections

GHG emissions for 1990 through 2005 were estimated using SGIT and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for this sector.[49] Table D1 identifies for each emissions source category the information needed for input into SGIT to calculate emissions, the data sources used, and the historical years for which emissions were calculated based on the availability of data. 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.

The NDEP provided annual production data for 1994 – 2005 for one cement plant, one lime plant, and one nitric acid plant. The NDEP did not have production data for these plants prior to 1994; therefore, emissions for 1990 through 1993 were not estimated for these three industries.

[49] GHG emissions were calculated using SGIT, with reference to the Emission Inventory Improvement Program, Volume VIII: Chapter. 6. "Methods for Estimating Non-Energy Greenhouse Gas Emissions from Industrial Processes", August 2004. This document is referred to as "EIIP" below.

Table D1. Approach to Estimating Historical Emissions

Source Category	Time Period	Required Data for SGIT	Data Source
Cement Manufacturing - Clinker Production	1994 - 2002	Metric tons of clinker produced each year.	-- The NDEP provided annual clinker production data for 1994 – 2005 for Nevada Cement (production data were not available for years prior to 1994). -- Clark County had one plant (Royal Cement) that closed in 2004, but the County does not have any clinker production data for the plant. Therefore, emissions were not estimated for this plant. -- Washoe County does not have any cement plants.
Cement Manufacturing - Masonry Cement Production	Not applica ble	Metric tons of masonry cement produced each year.	-- The NDEP confirmed that masonry cement is not manufactured by Nevada Cement. -- Clark County thought that the Royal Cement plant, which closed in 2004, probably did not produce masonry cement. -- Washoe County does not have any cement plants.
Lime Manufacture	1994 - 2005	Metric tons of high-calcium and dolomitic lime produced each year.	-- The NDEP provided annual high-calcium lime production data for 1994 – 2005 for Graymont Western (production data were not available prior to 1994). -- Clark County provided annual high-calcium and dolomitic lime production data for Chemical Lime Company for 1999, 2000, 2001, and 2003. -- Washoe County does not have any lime plants.
Limestone and Dolomite Consumption	1994 - 2002	Consumption of limestone and dolomite by industrial sectors.	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 (see footnote 1 for reference to EIIP guidance document).
Soda Ash	1990 - 2005	Consumption of soda ash used in consumer products such as glass, soap and detergents, paper, textiles, and food. Emissions based on state's population and estimates of emissions per capita from the US EPA national GHG inventory.	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 2005 from the Nevada State Demographer's Office, University of Nevada, Reno, Nevada, "Nevada County Population Estimates July 1, 1990 to July 1, 2005, Includes Cities and Towns" (http://www.nsbdc.org/what/data_statistics/demographer/pubs/pdfs/NVpopul05.pdf). -- Population forecasts for 2006 to 2020 also from the Nevada State Demographer's Office, "Nevada County Population Projections 2006 to 2026" (http://www.nsbdc.org/what/data_statistics/demographer/pubs/docs/NV_2006_Projections.pdf). -- U.S. 2000-2005 population from U.S. Census Bureau (http://www.census.gov/population/projections/SummaryTabA1.xls).
Electric Power T&D Systems	1990 - 2002	Emissions from 1990 to 2003 based on the national emissions per kWh and state's electricity use.	National emissions per kWh from US EPA 2005 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003 (http://www.epa.gov/climatechange/emissions/usgginv_archive.html).

Table D2. Approach to Estimating Projections

Source Category	Time Period	Projection Assumptions	Data Source	Annual Growth Rates (%) 2000 to 2005	2005 to 2010	2010 to 2015	2015 to 2020
Cement Manufacturing - Clinker Production	2006-2020	Compound annual growth rate from Nevada's Nonmetallic Minerals sector employment projections (2004-2014). Assumed growth is same for 2015 – 2020 as in previous periods.	Nevada Department of Employment; (http://www.nevadaworkforce.com/cgi/dataanalysis/).	3.7	3.7	3.7	3.7
Lime Manufacture	2006-2020	Ditto	ditto	3.7	3.7	3.7	3.7
Limestone and Dolomite Consumption	2003 - 2020	Ditto	ditto	3.7	3.7	3.7	3.7
Soda Ash Consumption	2003 - 2020	Growth between 2004 and 2009 is projected to be about 0.5% per year for U.S. production. Assumed growth is same for 2010 – 2020.	Minerals Yearbook, 2005: Volume I, Soda Ash, (http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/soda_myb05.pdf).	0.5	0.5	0.5	0.5
Nitric Acid Production	2006-2020	Compound annual growth rate from Nevada's Other Chemical Product and Preparation Manufacturing sector employment projections (2004-2014). Assumed growth is same for 2015 – 2020 as in previous periods.	Nevada Department of Employment; (http://www.nevadaworkforce.com/cgi/dataanalysis/).	-1.1	-1.1	-1.1	-1.1
ODS Substitutes	2003 - 2020	Based on national growth rate for use of ODS substitutes.	US EPA, 2004 ODS substitutes cost study report (http://www.epa.gov/ozone/snap/emissions/TMP6si9htnvca.htm).	15.8	7.9	5.8	5.3
Electric Power T&D Systems	2003 - 2020	Ditto	ditto	3.3	-6.2	-9.0	-2.8

Semiconductor manufacturing is classified under NAICS code 334413. The *1997 Economic Census* (http://www.census.gov/econ/ census02/) did not report any data for NAICS code 334413 for Nevada. The *2002 Economic Census* reported four establishments each with from 100 to 240 paid employees. Value of shipments information, which is needed to estimate emissions for Nevada in the SGIT, was, however, withheld for confidentiality reasons in the *2002 Economic Census* for these four establishments. Therefore, emissions were not estimated for this industrial sector.

The Clark County Department of Air Quality and Environmental Management (DAQEM) and Washoe County District Health Department have permitting authority over air pollution sources in their respective counties. Washoe County confirmed that they do not have any industrial processes covered by the EIIP guidance.

The Clark County DAQEM provided production data for one lime manufacturing plant for 1999, 2000, 2001, and 2003. The Clark County DAQEM indicated that it had one cement plant, which closed in 2004 and which produced clinker, but was unable to identify any production data for the plant. The Clark County DAQEM noted that it has one titanium metals plant that uses magnesium in a reduction furnace for purifying titanium, but it was not clear if this process is a source of SF_6 emissions. Otherwise, Clark County does not have any other industrial processes covered by the EIIP guidance.

Results

Figures D1 and D2 show historic and projected emissions for the Nevada industrial processes sector from 1990 to 2020. Total gross GHG emissions were about 2.1 $MMTCO_2e$ in 2000 (4.6% of total emissions), rising to about 4.6 $MMTCO_2e$ in 2020 (6.4% of total emissions). Emissions from the overall industrial processes category are expected to grow rapidly, as shown in Figures D1 and D2, with emissions growth almost entirely due to the increasing use of HFCs and PFCs in refrigeration and air conditioning equipment, and, to a lesser extent, as a result of emissions of CO_2 associated with the production of lime and cement.

Substitutes for Ozone-Depleting Substances (ODS)

HFCs and PFCs are used as substitutes for ODS, most notably chlorofluorocarbons (CFCs [CFCs are also potent warming gases]) in compliance with the *Montreal Protocol* and the *Clean Air Act Amendments of 1990*.[50] Even low amounts of HFC and PFC emissions, for example, from leaks and other releases associated with normal use of the products, can lead to high GHG emissions on a carbon-equivalent basis. Emissions from the use of ODS substitutes in Nevada were calculated using the default methods in SGIT (see dark green line in Figure D2). Emissions have increased from 0.0017 $MMtCO_2e$ in 1990 to about 0.54 $MMtCO_2e$ in 2000, and are expected to increase at an average rate of 8.0% per year from 2000 to 2020 due to increased substitutions of these gases for ODS. The projected rate of increase for these emissions is based on projections for national emissions from the US EPA report referenced in Table D2.

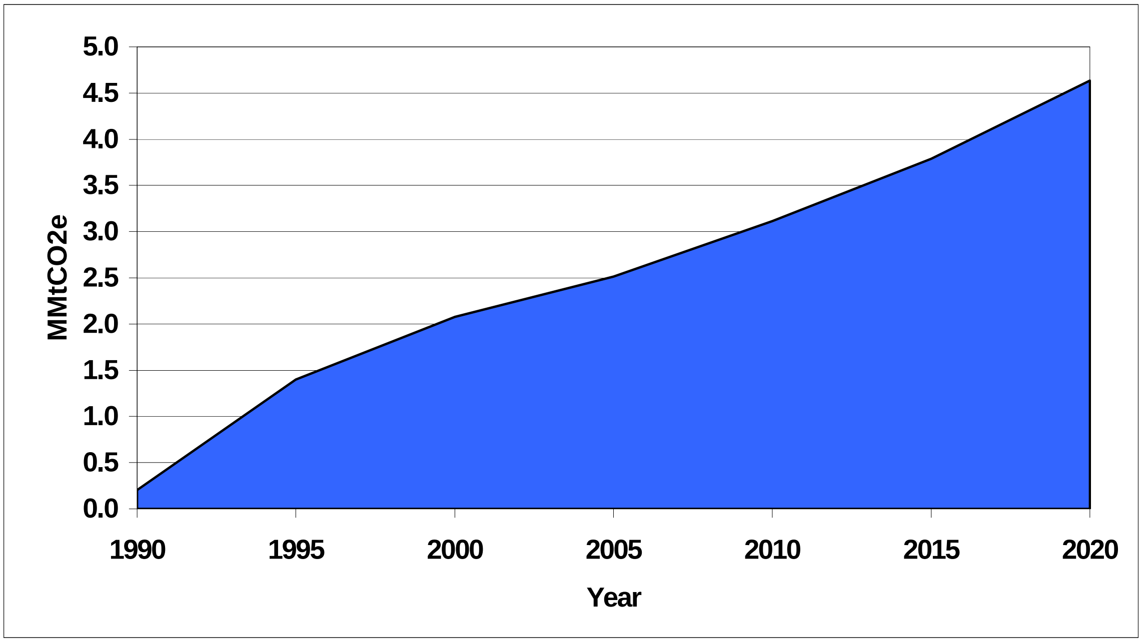
Electricity Distribution

Emissions of SF_6 from electrical equipment have experienced declines since the early-nineties (see brown line in Figure D2), mostly due to voluntary action by industry. SF_6 is used as an electrical insulator and interrupter in electricity T&D systems. Emissions for Nevada from 1990 to 2002 were estimated based on the estimates of emissions per kWh from the U.S. EPA GHG inventory and on Nevada's electricity consumption estimates provided in SGIT. The U.S.

[50] As noted in EIIP Chapter 6, ODS substitutes are primarily associated with refrigeration and air conditioning, but also have 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. For the US national inventory, a detailed stock vintaging model was used, but this modeling approach has not been completed at the state level.

Climate Action Report shows expected decreases in these emissions at the national level, and the same rate of decline is assumed for emissions in Nevada. The decline in SF_6 emissions in the future reflects expectations of future actions by the electric industry to reduce these emissions.

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



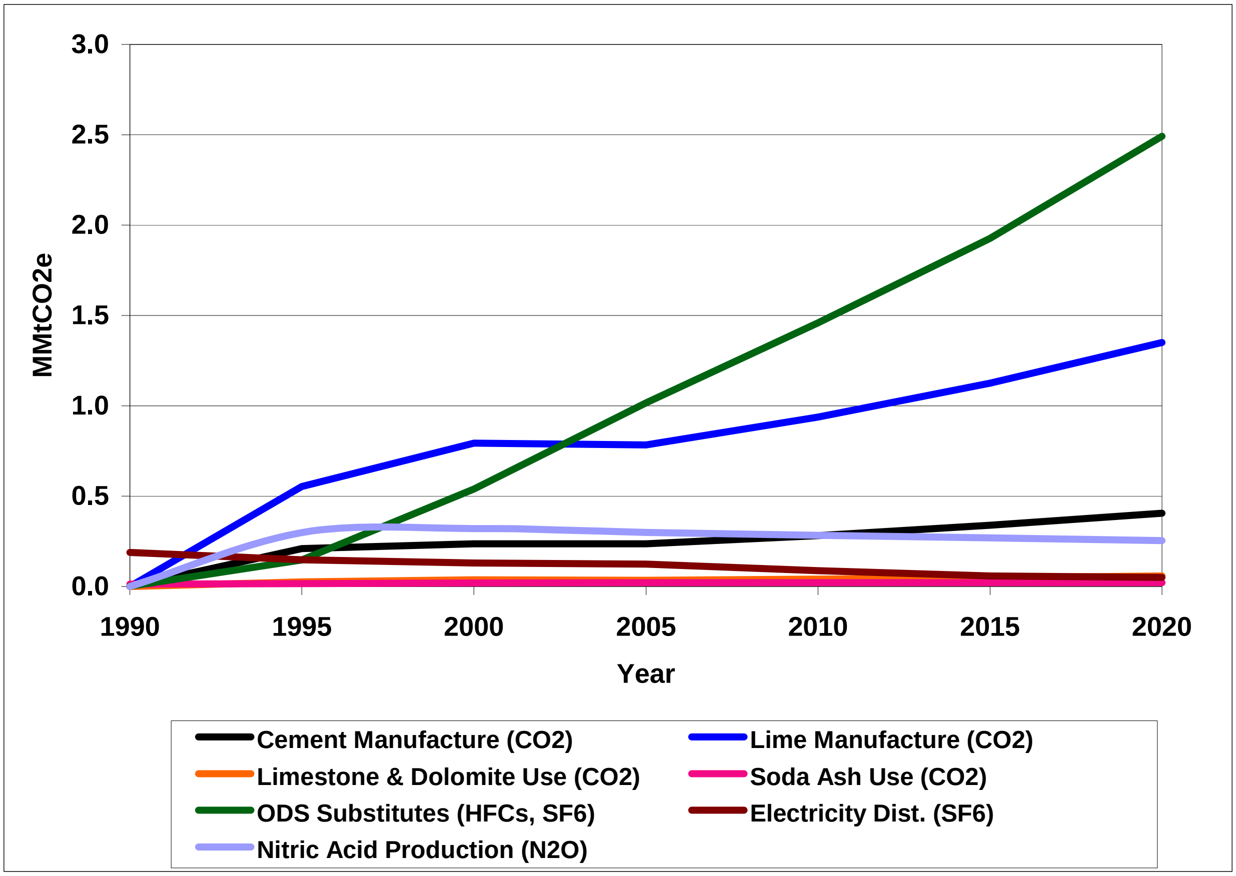
Cement Manufacture

Nevada has two cement plants (Nevada Cement and Royal Cement) that produce clinker (an intermediate product from which finished Portland and masonry cement are made) but do not produce masonry cement. 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 footnote 1 for reference to EIIP guidance document). Emissions are calculated by multiplying annual clinker production by an emission factor for the process. The NDEP provided clinker production for Nevada Cement for 1994 through 2005; information was not available for 1990 through 1993. The production data were entered into the SGIT to calculate GHG emissions for this plant (see black line in Figure D2). The growth rate for Nevada's nonmetallic minerals sector (an annual average of 3.7%) was used to project emissions to 2020. According to the Clark County DAQEM, Royal Cement closed its plant in 2004. The Clark County DAQEM does not have any clinker production data for this plant; consequently, historical emissions were not estimated for the plant.

Lime Manufacture

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 footnote 1 for reference to EIIP guidance document). Emissions are estimated by multiplying the amount of high-calcium and dolomitic lime produced by emission factors for each product.

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



The NDEP provided high-calcium lime production data for Graymont Western for 1994 through 2005; information was not available for 1990 through 2003. Clark County DAQEM provided annual high-calcium and dolomitic lime production data for Chemical Lime Company for 1999, 2000, 2001, and 2003. The Clark County DAQEM noted that the historical production capacity for this plant has not changed significantly. Based on this information, the average annual production rate (based on the four years of production data provided by the Clark County DAQEM) was used as a surrogate to estimate production for 1994 through 1998 and for 2002, 2004, and 2005.[51]

[51] Given the uncertainty associated with using an average annual production rate as a surrogate for production for years for which data were not available, and that production data for 1990 through 2003 were not available for Graymont Western, the average production rates for Chemical Lime Company were not used as a surrogate to estimate production for 1990 through 2003.

The high-calcium lime production for both plants was summed and entered into the SGIT, as well as the dolomitic lime production data for the one plant, to calculate GHG emissions associated with lime production (see dark blue line in Figure D2). The growth rate for Nevada's nonmetallic minerals sector (an annual average of 3.7%) was used to project emissions to 2020. The NDEP and Clark County DAQEM confirmed that the lime produced by the two plants in Nevada do not use processes (e.g., sugar refining) that reabsorb CO_2 during the manufacturing process.

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.[52] Recent historical data for Nevada were not available from the USGS or NDEP; consequently, the default data provided in SGIT were used to calculate emissions for Nevada (see orange line in Figure D2). The growth rate for Nevada's nonmetallic minerals sector (i.e., 3.7% annual) was used to project emissions to 2020. Relative to total industrial non-combustion process emissions, emissions associated with limestone and dolomite consumption are low (about 0.037 $MMtCO_2e$ in 1995 and 0.059 $MMtCO_2e$ in 2020), and therefore, appear at the bottom of the graph in Figure D2 due to scaling effects.

Soda Ash Consumption
Commercial soda ash (sodium carbonate) is used in many consumer products such as glass, soap and detergents, paper, textiles, and food. CO_2 is also released when soda ash is consumed (see footnote 1 for reference to EIIP guidance document). Recent historical data for Nevada were not available from the USGS or NDEP; consequently, the default data provided in SGIT were used to calculate emissions for Nevada (see dark pink line in Figure D2). SGIT estimates historical emissions 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 U.S as a whole. Information on growth trends for the soda ash industry for years later than 2009 was not available; therefore, the same 0.5% annual growth rate was applied for estimating emissions to 2020. Relative to total industrial non-combustion process emissions, emissions associated with soda ash consumption are low (about 0.013 $MMtCO_2e$ in 1990 and 0.022 $MMtCO_2e$ in 2020), and therefore, cannot be seen in the graph due to scaling effects in Figure D2.

Nitric Acid Production
The manufacture of nitric acid (HNO_3) produces nitrous oxide (N_2O) as a by-product, via the oxidation of ammonia. Nitric acid is a raw material used primarily to make synthetic commercial fertilizer. It is also a major component in the production of adipic acid (a feedstock for nylon) and explosives. Relatively small quantities of nitric acid are also employed for stainless steel

[52] 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).

pickling, metal etching, rocket propellants, and nuclear fuel processing.[53] The NDEP provided nitric acid production data for Dyno Nobel, Inc. (owned by Coastal Chemical prior to 2001) for 1994 through 2005; information was not available for 1990 through 1993. The production data were entered into the SGIT to calculate GHG emissions for this plant (see purple line in Figure D2).

The SGIT uses a default emission factor of 0.008 metric tons of N_2O emissions per metric ton of nitric acid produced based on a weighted-average calculated over the different types of emissions control technologies typically employed by nitric acid plants nationwide.[54] The NDEP verified that the nitric acid plant has used and continues to use selective catalytic reduction (SCR) control technology. Therefore, the emission factor in SGIT was changed to 0.0095 metric tons of N_2O emissions per metric ton of nitric acid produced for application in the Nevada case. The growth rate for Nevada's other chemical product and preparation manufacturing sector (an annual average of -1.1%) was used to project emissions to 2020.

Key Uncertainties

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

- Since emissions from industrial processes are determined by the level of production in and the production processes of a few key industries, and, in some cases, of 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 Nevada manufacturers in these industries, and the specific nature of the production processes used in plants in Nevada.
- 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; Nevada-specific estimates are currently unavailable. In addition, emissions through 2020 and beyond will be driven by future choices regarding mobile and stationary air conditioning technologies and the use of refrigerants in commercial applications, for which several options currently exist.
- Historical clinker production data for Royal Cement in Clark County were not available. Consequently, historical emissions associated with cement production in Nevada are underestimated for 1990 through 2003. Future work on this sector should attempt to obtain the clinker production data for this plant in order to complete the historical inventory for cement production.

[53] See footnote 1 for reference to EIIP guidance document.

[54] According to Chapter 6 of the EIIP (see footnote 1 for reference to EIIP guidance document), the nitric industry controls for oxides of nitrogen through two technologies: non-selective catalytic reduction (NSCR) and SCR. Only one of these technologies, NSCR, is effective at destroying N_2O emissions in the process of destroying oxides of nitrogen emissions. NSCR technology was widely installed in nitric acid plants built between 1971 and 1977. Due to high-energy costs and associated high gas temperatures, this technology has not been popular with modern plants. Only about 20% of the current plants have NSCR technology installed. All other plants have installed SCR technology. Since 80% of the current plants have SCR technology installed and 20% have NSCR technology, the weighted-average emission factor used in the SGIT is equal to (0.0095 x 0.80) x (0.002 x 0.20) = 0.008 metric tons N_2O per metric ton of nitric acid produced.

- Production data for cement, lime, and nitric acid production and limestone and dolomite use were not available for 1990 through 1993. Consequently, total emissions for the industrial non-energy process sector are underestimated for these three years. If the production (or consumption) levels for these industries in 1990 were similar to 1994 production (or consumption) levels, the 1990 emissions would be approximately 0.7 $MMtCO_2e$. Additional limestone/dolomite and soda ash production numbers may be available from the Nevada Bureau of Mines and Geology. These data should be investigated during future efforts to revise this inventory.
- 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. Note that NDEP verified that these industries do not exist in the counties in Nevada for which it administers air pollution permitting. Washoe County confirmed that it does have one small titanium dioxide manufacturing plant, but does not have plants in any of the other industries. The Clark County DAQEM did not provide any information indicating if any of these industries existed in Clark County.

Appendix E. Fossil Fuel Industries

This appendix reports the GHG emissions that are released during the production, processing, transmission, and distribution of fossil fuels. Known as fugitive emissions, these are methane and carbon dioxide emissions released via leakage and venting from oil and gas fields, processing facilities, and pipelines. In 2004, fugitive emissions from natural gas systems, petroleum systems, and coal mines accounted for 2.8% of total US greenhouse gas emissions.[55] Emissions associated with energy consumed by these processes are included in Appendix B, Residential, Commercial and Industrial Sector.

Oil and Gas Production

Nevada's oil and gas industry is small and has declined to very low levels in recent years. Current crude oil production across the entire State is only about 1,000 barrels per day (bbls), which ranks Nevada 27th out of 31 producing States.[56] Nevada's proved crude oil reserves account for less than 1% of the US total. Oil production in Nevada peaked in 1990 at 11,000 bbls per day, and has been declining steadily ever since.[57] Nevada has one petroleum refinery with a crude oil distillation capacity of 2,000 barrels per day.[58]

Nevada's marketed natural gas production peaked in 1991 at 53 MMcf and has steadily decreased since that time, to about 5 MMcf in 2004.[59] In comparison, Nevada consumed over 200,000 MMcf of natural gas in 2004, and consumption has grown an average of 7% since the year 2000.[60] Since Nevada has no additional known reserves of natural gas (conventional or coalbed methane), Nevada will likely continue to rely almost entirely on imports of natural gas.[61] There is no coalbed methane production or proved reserves in Nevada.[62]

Coal Production

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

Oil and Gas Industry Emissions

Emissions of methane (CH_4) can occur at many stages of production, processing, transmission, and distribution of oil and gas. Nevada has 74 active gas and oil wells, one oil refinery, and over 9,000 miles of gas pipelines.[63] Uncertainties associated with estimates of Nevada's GHG emissions from this sector are compounded by the fact that there are no regulatory requirements

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[55] "The US Inventory of Greenhouse Gas Emissions and Sinks", US EPA, 2005.
[56] "Petroleum Profile: Nevada", US DOE Energy Information Administration website, October 2006, Accessed at http://tonto.eia.doe.gov/oog/info/state/nv.html.
[57] "Petroleum Navigator", US DOE Energy Information Administration website, October 2006, Accessed at http://tonto.eia.doe.gov/dnav/pet/hist/mcrfpnv2a.htm.
[58] "Petroleum Profile: Nevada", US DOE Energy Information Administration website, October 2006, Accessed at http://tonto.eia.doe.gov/oog/info/state/nv.html.
[59] "Natural Gas Navigator", US DOE Energy Information Administration website, December 2006, Accessed at http://tonto.eia.doe.gov/dnav/ng/hist/na1140_snv_2a.htm.
[60] "Natural Gas Navigator", US DOE Energy Information Administration website, November, 2006, Accessed at http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_SNV_a.htm.
[61] "Nevada Energy Status Report 2005" Nevada State Office of Energy, Accessed at http://energy.state.nv.us/2005%20Report/Final%20CD/Chapter%203%20-%20Final.doc.
[62] "Natural Gas Navigator", US DOE Energy Information Administration website, December 2006.
[63] Data from EIA and Gas Facts.

to track methane emissions. Therefore, estimates based on emissions measurements in Nevada are not possible at this time.

The SGIT, developed by the US EPA, facilitates estimation of state-level greenhouse gas emissions.[64] 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[65] and American Gas Association's annual publication *Gas Facts*.[66] Methane emissions were estimated using SGIT, with reference to the EIIP guidance document.

Future projections of methane 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 Nevada. Based on those assumptions, Nevada's natural gas consumption is projected to grow at an annual average rate at 3.5% between 2006 and 2020.[67]
- Production –As a simple estimate for projections, oil and natural gas production are forecast to continue to decline at rates seen in the past 5 years in the State. Oil and gas production has been declining steadily for more than a decade in Nevada, and production of both appears to be nearing the end of the decline curve, with only small amounts of production now occurring. Simple assumptions were made for natural gas transmission, oil refining and transport.

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

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[64] Methane emissions were calculated using SGIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems", March 2005.
[65] "Petroleum Navigator" and "Natural Gas Navigator", US DOE Energy Information Administration website, November 2006, Accessed at http://www.eia.doe.gov.
[66] American Gas Association "Gas Facts, A Statistical Record of the Gas Industry" Referenced annual publications from 1992 to 2004.
[67] Based on US DOE regional projections and electric sector growth assumptions (see Appendix A and B).

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

	Approach to Estimating Historical Emissions		Approach to Estimating Projections
Activity	***Required Data for SGIT***	***Data Source***	***Projection Assumptions***
Natural Gas Drilling and Field Production	Number wells	EIA	Emission projections assume that natural gas production will continue to decline at 8.4% annually until 2020.[68]
	Miles of gathering pipeline	Gas Facts[69]	
Natural Gas Processing	Number gas processing plants	EIA[70]	There is no natural gas processing in the state of Nevada.
Natural Gas Transmission	Miles of transmission pipeline	Gas Facts[18]	Emissions are held flat at 2004 levels. Note this reflects a situation where no new gas transmission lines are built in Nevada; such activity could significantly increase projected emission levels.
	Number of gas transmission compressor stations	EIIP[71]	
	Number of gas storage compressor stations	EIIP[72]	
	Number of LNG storage compressor stations	Paiute Pipeline Company[73]	
Natural Gas Distribution	Miles of distribution pipeline	Gas Facts[18]	Distribution emissions follow State gas consumption trend - annual average growth rate of 3.5% between 2006 and 2020.[74]
	Total number of services	Gas Facts	
	Number of unprotected steel services	Ratio estimated from 2002 data[75]	
	Number of protected steel services	Ratio estimated from 2002 data[24]	
Oil Production	Annual production	EIA[76]	Emissions follow State oil production trends, which continues to decline at 6.3% annually.[77]
Oil Refining	Annual amount refined	EIA[78]	Emissions projected to hold flat at 2004 levels.[79]
Oil Transport	Annual oil transported	Unavailable, assumed oil refined = oil transported	Emissions follow trend of state oil refining, as above.

[68] Nevada natural gas production declined at an average annual rate of 8.4% between 2000 and 2004, as reported by the EIA. Production has been declining since first reported by the EIA in 1991.
[69] No Gas Facts available for 1991 and 1993, so a linear relationship was assumed to extrapolate from the previous and subsequent year.
[70] EIA reports no gas processing facilities in Nevada.
[71] Number of gas transmission compressor stations = miles of transmission pipeline x 0.006 EIIP. Volume VIII: Chapter 5. March 2005.
[72] Number of gas storage compressor stations = miles of transmission pipeline x 0.0015 EIIP. Volume VIII: Chapter 5. March 2005.
[73] Paiute Pipeline Co. owns the only LNG storage facility in NV, which began in 1982. Per phone conversation with Jeff Maples, Director gas operations. Reference http://www.paiutepipeline.com/ and http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2003/lng/lng2003.pdf.
[74] Based on US DOE regional projections and electric sector growth assumptions (see Appendix A and B).
[75] Gas Facts reported unprotected and protected steel services for 2002, but only total services for other years. Therefore the ratio of unprotected and protected steel services in 2002 was assumed to be the ratio for all other years (0.4891 for protected services and 0.0045 for unprotected services). This yields more congruent results than the EIIP guidance of using multipliers of 0.2841 for protected steel services, and 0.0879 for unprotected steel services.
[76] Data extracted from the Petroleum Supply Annual for each year.
[77] Oil production has been declining since the early 1990's. Average annual decline rate between 2001 and 2005 was 6.3%.
[78] Refining assumed to be equal to the total input of crude oil into PADD V times the ratio of Nevada's refining capacity to PADD V's total refining capacity. No data for 1995 and 1997, so linear relationship assumed from previous and subsequent years.
[79] There is currently only one operating refinery in Nevada. More accurate projections may be obtained through contact with the refinery regarding future capacity projections.

Note that potential emission reduction improvements to production and pipeline technologies have not been accounted for in this analysis.

Results

Table E2 displays the estimated methane emissions from the fossil fuel industry in Nevada from 1990 to 2005, with projections to 2020. Emissions from this sector grew by 72% from 1990 to 2005 and are projected to increase by a further 37% from 2005 to 2020. Natural gas transmission and distribution systems are the major contributors to historic fugitive GHG emissions, with natural gas distribution driving future emissions growth for this sector.

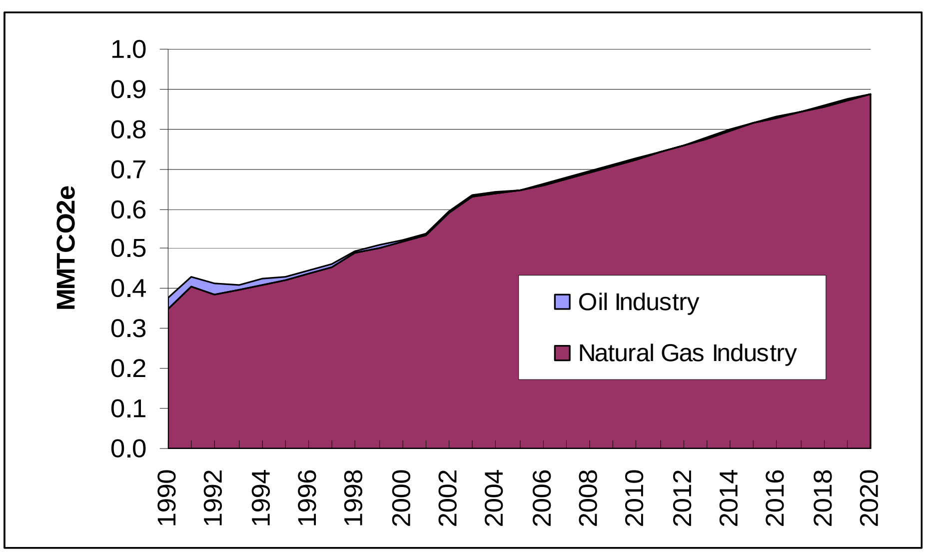
Table E2. Methane Emissions and Projections from the Fossil Fuel Industry

(Million Metric Tons CO2e)	1990	1995	2000	2005	2010	2015	2020
Fossil Fuel Industry	**0.38**	**0.43**	**0.52**	**0.65**	**0.73**	**0.82**	**0.89**
Natural Gas Industry	0.35	0.42	0.52	0.64	0.72	0.81	0.89
Production (CH4)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Processing (CH4 & CO2)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Transmission (CH4)	0.22	0.24	0.26	0.31	0.31	0.31	0.31
Distribution (CH4)	0.13	0.18	0.25	0.33	0.41	0.50	0.57
Oil Industry	0.03	0.01	0.01	0.00	0.00	0.00	0.00
Production (CH4)	0.03	0.01	0.00	0.00	0.00	0.00	0.00
Refineries (CH4)	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: Emissions less than 0.005 $MMtCO_2e$ are shown as 0.00 in the above table.

Figure E1 displays the methane emissions from natural gas and oil systems, on a million metric tons CO_2 equivalency basis.

Figure E1. Annual Fossil Fuel Industry Emission Trends



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 local facilities significant uncertainties remain.
- Projections of future production of fossil fuels. These industries are difficult to forecast with the mix of drivers: economics, resource supply, demand, and regulatory procedures. The assumptions used for the projections, extending historical decline or growth trends out to 2020, do not include any significant changes in energy prices, relative to today's prices. Large price swings, resource limitations, or changes in regulations could significantly change future production and the associated GHG emissions.
- Any future transmission lines through Nevada would impact fugitive emission projections. Input from reviewers is welcomed.
- Other uncertainties include the extent of renewed interest in Nevada oil exploration, and potential emission reduction improvements to production, processing, and pipeline technologies.

Appendix F. Agriculture

Overview

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

There are two livestock sources of 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 because of digestive activity in the large fore-stomach. 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 aerobic conditions. Under aerobic conditions, N_2O emissions are dominant. Emissions estimates from manure management are based on manure that is stored and treated on livestock operations. Emissions from manure that is applied to agricultural soils as an amendment or deposited directly to pasture and grazing land by grazing animals are accounted for in the agricultural soils emissions.

The management of agricultural soils can result in N_2O emissions and net fluxes of CO_2 causing emissions or sinks. 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 application, sewage sludge, nitrogen fixation, and histosols (high organic soils, such as wetlands or peatlands) cultivation. 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 Nevada.

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

Emissions and Reference Case Projections

Methane and Nitrous Oxide

GHG emissions for 1990 through 2005 were estimated using SGIT and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[80] In general, the SGIT methodology applies emission factors developed for the U.S. 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.[81]

Data on crop production in Nevada from 1990 to 2005 and the number of animals in the state from 1990 to 2002 were obtained from the USDA National Agriculture Statistical Service (NASS) and incorporated as defaults in SGIT.[82] The default SGIT manure management system assumptions for each livestock category were used for this inventory. Data on fertilizer usage for 1990 through 1999 is based on the data provided for Nevada in the SGIT.[83] The Nevada Department of Agriculture provided data for fertilizers containing nitrogen for 2003 through 2005, confirmed the accuracy of the historical SGIT data for 1990 through 1999, and provided slight revisions to the SGIT data for 2000 through 2002.[84] Activity data for fertilizer includes all potential uses in addition to agriculture, such as residential and commercial (for example, golf courses). The estimates are reported in the Agriculture sector but they represent emissions occurring on other land uses.

Crop production data from USDA NASS were available through 2005; therefore, N_2O emissions from crop residues and crops that use nitrogen (i.e., nitrogen fixation) and CH_4 emissions from agricultural residue burning were calculated through 2005. Emissions for the other agricultural crop production categories (i.e., synthetic and organic fertilizers) were calculated through 2002.

Data were not available to estimate nitrogen released by the cultivation of histosols (including data such as the number of acres of high organic content soils). However, as discussed in the following section for soil carbon, the Natural Resources Ecology Laboratory at Colorado State University estimated zero CO_2 emissions for organic soils in Nevada for 1997, suggesting that

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

[81] 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/).

[82] USDA, NASS (http://www.nass.usda.gov/Statistics_by_State/Nevada/index.asp).

[83] The Association of American Plant Food Control Officials and The Fertilizer Institute. 2002. Commercial Fertilizers. "Table 9 - Consumption of Primary Plant Nutrients. Total Nutrients-All Fertilizers (N)." Data based on "growing year" (i.e., data are reported for the last six months of one year starting July 1, and the first six months of the following year ending June 30).

[84] Data provided by Dr. Chris Mason, Nevada Department of Agriculture, Plant Industry Division on December 15, 2006.

the area of cultivated high organic content soils was either very small or zero in Nevada. Therefore, N_2O emissions from cultivated histosol soils were also assumed to be zero.

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

Emissions from enteric fermentation, manure management, and agricultural soils (except fertilizers) were projected based on the annual growth rate in historical emissions ($MMtCO_2e$ basis) for these categories in Nevada for 1990 to 2002 (1990 to 2005 for crop residues and nitrogen fixing crops). Table F1 shows the annual growth rates applied to estimate the reference case projections by agricultural sector. The compound annual growth rate for fertilizer (containing nitrogen) usage in Nevada was about 6.6% from 1990 to 2005, and the annual growth rate was about -3.7% from 2000 through 2005.

Table F1. Growth Rates Applied for the Agricultural Sector

Agricultural Category	Growth Rate	Basis for Annual Growth Rate[a]
Enteric Fermentation	0.3%	Historical emissions for 1990-2002.[a]
Manure Management	2.3%	Historical emissions for 1990-2002.[a]
Agricultural Burning	0.0%	Assumed no growth.
Agricultural Soils – Direct Emissions		
Fertilizers	2.1% - 4.3%	Based on Nevada's population growth.[b]
Crop Residues	-3.3%	Historical emissions for 1990-2005.[a]
Nitrogen-Fixing Crops	1.6%	Historical emissions for 1990-2005.[a]
Histosols	0.0%	No historical data available.
Livestock	-0.17%	Historical emissions for 1990-2002.[a]
Agricultural Soils – Indirect Emissions		
Fertilizers	2.1% - 4.3%	Based on Nevada's population growth.[b]
Livestock	-0.1%	Historical emissions for 1990-2002.[a]
Leaching/Runoff	2.1% - 4.3%	Based on Nevada's population growth.[b]

[a] Compound annual growth rate was calculated using the growth rate in historical emissions ($MMtCO_2e$ basis) from 1990 through the most recent year of data. These growth rates were applied to forecast emissions from the latest year of data to 2020.
[b] The human population annual growth rates applied are as follows: 4.2% for 2005 to 2010, 3.2% for 2010 to 2015, and 2.1% for 2015 to 2020.

According to the Nevada Department of Agriculture, fertilizer usage increased significantly from 1990 to 2000 due to the growth in the residential and commercial sectors over this time period in Nevada's urban areas. For example, many golf courses were built thus increasing the demand for fertilizer. Over the past five years, fertilizer usage has declined due to the slowing in economic growth from 2000 to 2005 and because of higher energy prices for producing fertilizer which resulted in increased fertilizer prices. Future fertilizer use in Nevada is most likely to follow human population growth associated with the use of fertilizer by the residential and commercial sectors. Therefore, the growth rate for fertilizers is based on Nevada's population growth rate.[85, 86]

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[87] and the U.S. Agriculture and Forestry Greenhouse Gas Inventory. The estimates are based on the IPCC methodology for soil carbon adapted to conditions in the U.S. Preliminary state-level estimates of CO_2 fluxes from mineral soils and emissions from the cultivation of organic soils were reported in the U.S. Agriculture and Forestry Greenhouse Gas Inventory.[7] Currently, these are the best available data at the state-level for this category. The inventory did not report state-level estimates of CO_2 emissions from limestone and dolomite applications; hence, this source is not included in this inventory at present.

Carbon dioxide fluxes resulting from specific management practices were reported. These practices include: conversions of cropland resulting in either higher or lower soil carbon levels; additions of manure; participation in the Federal Conservation Reserve Program (CRP); and cultivation of organic soils (with high organic carbon levels). For Nevada, Table F2 shows a summary of the latest estimates available from the USDA, which are for 1997.[88] These data show that changes in agricultural practices are estimated to result in a net sink of 0.18 $MMtCO_2e$/yr in Nevada. Since data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing, the net sink of 0.18 $MMtCO_2e$/yr is assumed to remain constant.

Results

As shown in Figure F1, gross emissions from agricultural sources range between about 1.6 and 1.8 $MMtCO_2e$ from 1990 through 2020, respectively. In 1990, enteric fermentation accounted for about 43% (0.70 $MMtCO_2e$) of total agricultural emissions and is estimated to account for the same proportion 43% (0.77 $MMtCO_2e$) of total agricultural emissions in 2020. The manure management category, which shows the highest rate of growth relative to the other categories, accounted for 6.5% (0.11 $MMtCO_2e$) of total agricultural emissions and is estimated to account for about 11.5% (0.21 $MMtCO_2e$) of total agricultural emissions in 2020. The agricultural soils category shows emissions to remain constant from 1990 to 2020, with 1990 emissions

[85] Personal communication between R. Strait, The Center for Climate Strategies, and Dr. Chris Mason, Nevada Department of Agriculture, Plant Industry Division on December 15, 2006.

[86] Population forecasts for 2006 to 2020 from the Nevada State Demographer's Office, University of Nevada, Reno, Nevada, "Nevada County Population Projections 2006 to 2026" (http://www.nsbdc.org/what/data_statistics/demographer/pubs/docs/NV_2006_Projections.pdf).

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

[88] U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001. Global Change Program Office, Office of the Chief Economist, U.S. Department of Agriculture. Technical Bulletin No. 1907, 164 pp. March 2004. http://www.usda.gov/oce/global_change/gg_inventory.htm; the data are in appendix B table B-11. The table contains two separate IPCC categories: "carbon stock fluxes in mineral soils" and "cultivation of organic soils." The latter is shown in the second to last column of Table F1. The sum of the first nine columns is equivalent to the mineral soils category.

accounting for 50% (0.82 $MMtCO_2e$) of total agricultural emissions and 2020 emissions estimated to be about 46% (0.82 $MMtCO_2e$) of total agricultural emissions. Including the CO_2 sequestration from soil carbon changes, the historic and projected emissions for the agriculture sector would range between about 1.4 and 1.6 $MMtCO_2e$/yr.

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

Changes in cropland			Changes in Hayland				Other			Total[d]
Plowout of grassland to annual cropland[a]	Cropland manage-ment	Other cropland[b]	Cropland converted to hayland[c]	Hayland manage-ment	Cropland converted to grazing land[c]	Grazing land manage-ment	CRP	Manure application	Cultivation of organic soils	Net soil carbon emissions
0.11	0.00	0.00	(0.18)	(0.04)	(0.07)	0.04	0.00	(0.04)	0.00	(0.18)

Based on USDA 1997 estimates. Parentheses indicate net sequestration.
[a] 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).
[b] Perennial/horticultural cropland and rice cultivation.
[c] Gains in soil carbon sequestration due to land conversions from annual cropland into hay or grazing land.
[d] 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.

Agricultural burning emissions were estimated to be very small based on the SGIT activity data (<0.0001 $MMtCO_2e$/yr from 1990 to 2002). This agrees with the USDA Inventory which also reports a low level of residue burning emissions (0.02 $MMtCO_2e$).

The only standard IPCC source category missing from this report is CO_2 emissions from limestone and dolomite application. Estimates for Nevada were not available; however, the USDA's national estimate for soil liming is about 9 $MMtCO_2e$/yr (see reference in footnote 9).

Key Uncertainties

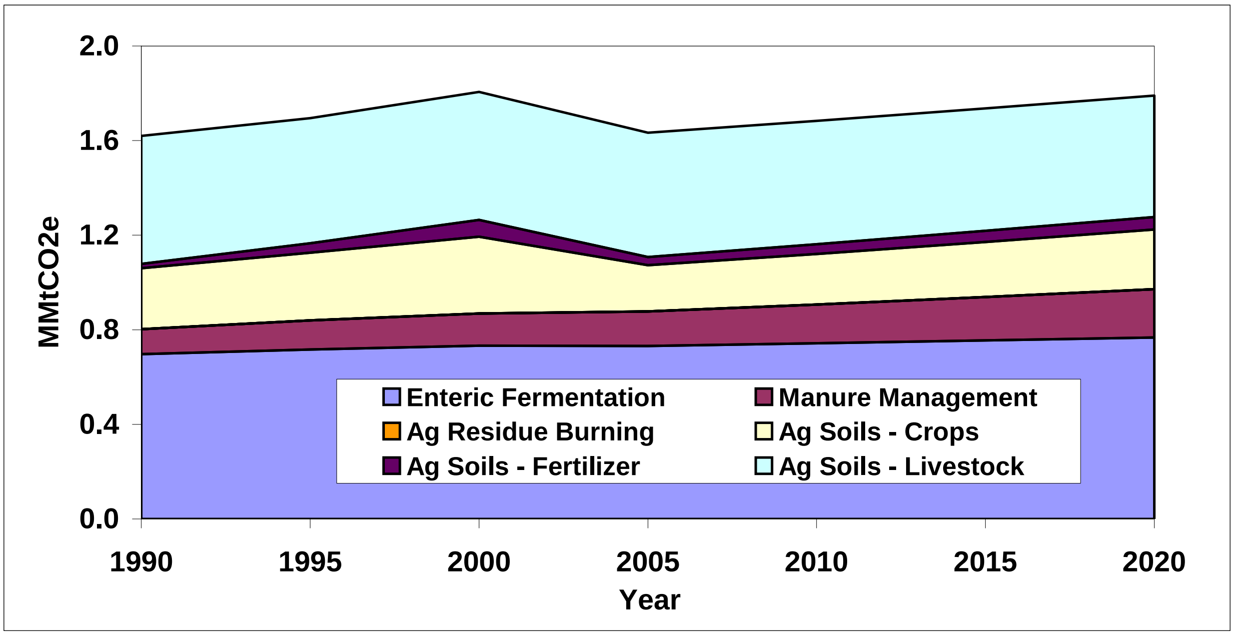
Emissions from enteric fermentation and manure management are dependent on the estimates of animal populations and the various factors used to estimate emissions for each animal type and manure management system (i.e., emission factors which are derived from several variables including manure production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

As mentioned above, for emissions associated with changes in agricultural soil carbon levels, the only data currently available are for 1997. When newer data are released by the USDA, these should be reviewed to represent current conditions as well as to assess trends. In particular, given the potential for some CRP acreage to retire and possibly return to active cultivation prior to

2020, the current size of the CO_2 sink could be appreciably affected. As mentioned above, emission estimates for soil liming have not been developed for Nevada.

Another contributor to the uncertainty in the emission estimates is the projection assumptions. This inventory assumes that the average annual rate of change in future year emissions will follow the historical average annual rate of change from 1990 through the most recent year of data.

Figure F1. Gross GHG Emissions from Agriculture



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

Appendix G. Waste Management

Overview

GHG emissions from waste management include:

- Solid waste management – CH_4 emissions from municipal and industrial solid waste landfills, accounting for CH_4 that is flared or captured for energy production;
- Solid waste combustion – CH_4, CO_2, and N_2O emissions from the combustion of solid waste in incinerators or waste to energy plants; and
- Wastewater management – CH_4 and N_2O from municipal and industrial wastewater (WW) treatment facilities.

Inventory and Reference Case Projections

Solid Waste Management

For solid waste management, we used the U.S. EPA SGIT and the U.S. EPA Landfill Methane Outreach Program (LMOP) landfills database[89] as starting points to estimate emissions. The LMOP data serve as input data to estimate annual waste emplacement for each landfill needed by SGIT. SGIT then estimates CH_4 generation for each landfill site. Additional post-processing outside of SGIT to account for controls is then needed to estimate CH_4 emissions. Additional information from NDEP solid waste staff were also used to fill data gaps in the LMOP data.[90] In addition, contacts at the health departments in Washoe and Clark County provided additional information on the application of controls at the State's three largest landfills (Lockwood, Sunrise and Apex).[91]

The data from NDEP included 2005 emplacement rates for both municipal solid waste (MSW) and industrial waste. The available data indicate that only one of the State's 25 landfills is currently controlled (Apex was flared and was to have a landfill gas to energy (LFGTE) plant installed by December 2006). Sunrise landfill is to have an LFG collection system and flare operational by early 2007 (for this site, waste emplacement rates were estimated based on available LMOP data to be an average of 1,000,000 tons/year from 1960-1993; this is also the annual mass of waste that the Apex LF began accepting when it opened to replace the Sunrise site). For Lockwood, the Washoe County contact indicated that a flare would probably be installed within the next three years. Unfortunately, data for a total of only 10 landfills (including the largest thee mentioned above) were available in the LMOP database, and historical emplacement data were not available through NDEP. The remaining seven landfills are uncontrolled as are the 15 or so other small landfills for which no data are available.[92]

[89] LMOP database is available at: http://www.epa.gov/lmop/proj/index.htm. Updated version of the database provided by Rachel Goldstein, Program Manager, EPA Landfill Methane Outreach Program, October 2006.
[90] Dave Simpson, NDEP, personal communication with S. Roe, CCS, November 2006.
[91] Jeannie Rucker, Washoe County Department of Health and Dennis Campbell, Clark County Department of Health, personal communications with S. Roe, CCS, December 2006. In Washoe County, the Lockwood LF will likely need to install controls by 2010. These controls have not been included in the emissions forecast.
[92] The remaining sites for which no data were available are: Carson City Sanitary LFl, Russell Pass LF, Wells Cargo Industrial LF, West Wendover LF, City of Goldfield Sanitary LF, Eureka Sanitary LF, Humboldt County Regional

To obtain the annual disposal needed by SGIT for each landfill, the waste-in-place was divided by the number of years of operation. This average annual disposal rate for each landfill was assumed for all years that the landfill was operating. In cases where the estimated annual disposal rate was much lower than the 2005 disposal rate provided by NDEP, the estimated disposal rates in recent years were adjusted to reflect the higher emplacement rates.

CCS performed three different runs of SGIT to estimate emissions from MSW landfills: (1) uncontrolled landfills; (2) landfills with a landfill gas collection system and LFGTE plant (Apex); and (3) landfills with a landfill gas collection system and flare (Sunrise). Lockwood was modeled with the other uncontrolled sites (future year emissions were adjusted by assuming a flare is installed in 2010). SGIT produced annual estimates through 2005 for each of these landfill categories. CCS then performed some post-processing of the landfill emissions to account for landfill gas controls (at LFGTE and flared sites) and to project the emissions through 2020. For the controlled landfills, CCS assumed that the overall methane collection and control efficiency is 75%.[93] Of the methane not captured by a landfill gas collection system, it is further assumed that 10% is oxidized before being emitted to the atmosphere (consistent with the SGIT default).

For the uncontrolled LFs and LFGTE LFs, growth rates were estimated by using the waste emplacement rates (1990-2005) in each category. For uncontrolled LFs, the annual growth rate is 2.9% and for LFGTE LFs it is 5.6%.[94] These growth rates are consistent with the State's rapid population growth from 1990-2005 (4.9%/yr), although waste imports also add to the growth in waste emplacement. The only flared LF is the closed Sunrise LF. The growth rate (-3.4%/yr) of emissions from this landfill was calculated based on the SGIT-estimated landfill gas generation rate from 1993-2005 (flaring is assumed to occur beginning in 2007).

CCS adjusted the SGIT default for industrial landfills. The SGIT default is based on national data indicating that industrial landfills generate methane at approximately 7% of the rate of MSW landfills. In NV, there is a significant amount of industrial and special wastes emplaced in the State's landfills. Based on summary data from NDEP, the amount of industrial waste in 2005 was nearly the same as MSW. Given that a large fraction of industrial/special wastes is likely to be non-degradable, CCS assumed that landfill gas generation from industrial waste landfilling was 50% of the rate of MSW generation. A large fraction of this waste is emplaced at Apex and Lockwood; however, it is not clear whether this waste would be controlled along with the MSW at Apex (and at Lockwood in the future). Therefore, no controls were assumed for industrial waste landfilling. For industrial landfills, the overall growth rate in MSW emissions from 1990 to 2005 (4.5%/yr) was used to project emissions to 2010 and 2020.

LF, Battle Mountain LF, Crestline Class II LF, Mesquite Municipal Waste LF, Western Elite LF, Hawthorne LF, NTS - Area 23 LF, Tonopah LF, Pershing County LF.

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

[94] The only LFGTE site is Apex, and the growth rate reflects a doubling of the emplacement rate between 1993 and 2005.

Solid Waste Combustion
NDEP indicates that there has been no solid waste combustion activity in the State from 1990 to present.[95]

Wastewater Management
GHG emissions from municipal wastewater treatment were also estimated. Emissions are calculated in EPA's SGIT based on state population, assumed biochemical oxygen demand (BOD) and protein consumption per capita, and emission factors for N_2O and CH_4. The key SGIT default values are shown in Table G1 below.

For industrial wastewater emissions, SGIT provides default assumptions and emission factors for three industrial sectors: Fruits & Vegetables, Red Meat & Poultry, and Pulp & Paper. Based on discussions with NDEP, there are no pulp and paper operations in the State. No data were identified on the operation of fruit & vegetable or meat & poultry plants were identified. According the Dunn & Bradstreet, there were no significant operations in any of the above industrial categories in 2002.[96] Therefore, emissions from the industrial wastewater treatment sector are considered to be negligible.

Table G1. SGIT Key Default Values for Municipal Wastewater Treatment

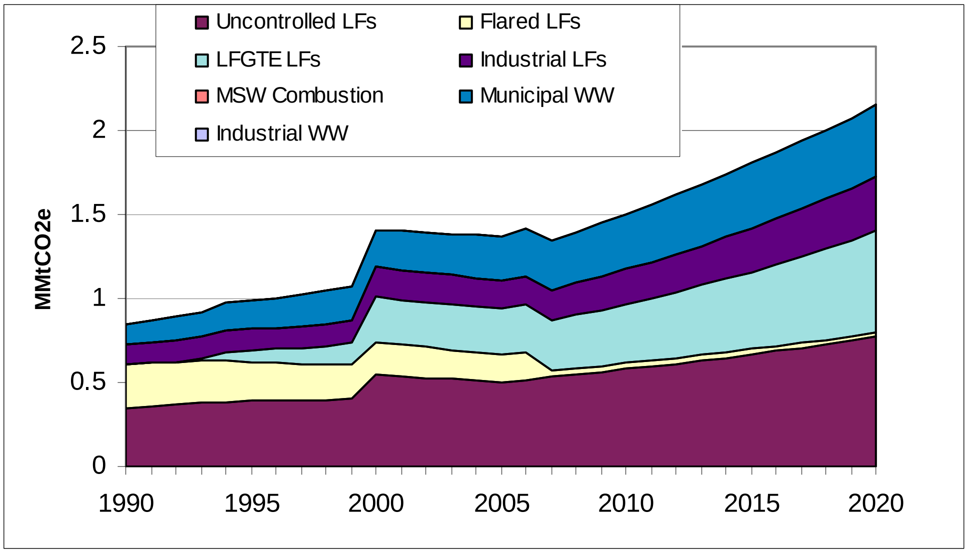
Variable	Value
BOD	0.065 kg /day-person
Amount of BOD anaerobically treated	16.25%
CH_4 emission factor	0.6 kg/kg BOD
Nevada residents not on septic	75%
Water treatment N_2O emission factor	4.0 g N_2O/person-yr
Biosolids emission Factor	0.01 kg N_2O-N/kg sewage-N

Figure G1 shows the emission estimates for the waste management sector. Overall, the sector accounts for 1.5 $MMtCO_2e$ in 2005. By 2020, emissions are expected to grow to 2.2 $MMtCO_2e$/yr. In 2005, about 36% of the emissions were contributed by the uncontrolled landfills sector with this contribution maintained through 2020. For the LFGTE sector, the emissions contribution is 19% in 2005 growing to 27% in 2020 (the only LFGTE site is assumed to be Apex). There is only one site in Nevada assumed for the flared LF sector (Sunrise). The contributions from this site decrease from 0.2 $MMtCO_2e$ in 2005 (pre-control) to 0.02 in 2020.

Emissions from municipal wastewater treatment were estimated to be 0.28 $MMtCO_2e$ in 2005 or about 15% of the waste management sector total. Industrial wastewater treatment was estimated to contribute less than 0.1 $MMtCO_2e$/yr which is less than 4% of the sector total.

[95] Jennifer Carr and Jean-Paul Huys, NDEP, personal communication with S. Roe, CCS, August 2006.
[96] Dun & Bradstreet, *MarketPlace CD*, Jan-Mar 2002. The data include some business operations in the Standard Industrial Classification codes for the industries of interest; however the number of employees is too small to indicate significant industrial operations.

Figure G1. Nevada GHG Emissions from Waste Management



Notes: LF – landfill; WW – wastewater; LFGTE – landfill gas to energy; there were no emissions estimated for the Industrial WW sector.

Key Uncertainties

The methods used to model landfill gas emissions do not adequately account for the points in time when controls were applied at individual sites. Hence, for LFGTE landfills (Apex), the historical emissions are less certain than current emissions and future emissions for this reason (the site was modeled as always being controlled, so the historic emissions are low as a result). The modeling also does not account for uncontrolled sites that will need to apply controls during the period of analysis due to triggering requirements of the federal New Source Performance Standards/Emission Guidelines (e.g. Lockwood).

Although the very large sites were captured in this analysis, data were not available for all of the landfills in NV. Therefore, the emissions estimated for uncontrolled sites are probably under-estimated. Also, according to NDEP two new landfills (one permitted but not constructed and the other in permitting) are proposed for operation in western Nevada. These facilities will be dedicated to waste imported from California. The proposed emplacement rates are between 5,000 and 10,000 tons per day. Future updates to this inventory should incorporate the effects of these sites beginning in the year in which they are expected to begin operation.

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

Appendix H. Forestry

Overview

Forestland emissions refer to the net CO_2 flux[97] from forested lands in Nevada, which account for about 14% of the state's land area.[98] The dominant forest type in NV is pinyon-juniper forests which make up about 90% of forested lands. Forestlands are net sinks of CO_2 in Nevada. Through photosynthesis, carbon dioxide is taken up by trees and plants and converted to carbon in biomass within the forests. Carbon dioxide emissions occur from respiration in live trees, decay of dead biomass, and fires. In addition, carbon is stored for long time periods when forest biomass is harvested for use in durable wood products. CO_2 flux is the net balance of carbon dioxide removals from and emissions to the atmosphere from the processes described above.

Inventory and Reference Case Projections

Forest Carbon

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.[99] The national estimates are compiled from state-level data. The Nevada forest CO_2 flux data in this report come from the national analysis and are provided by the USFS.

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

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

[97] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.
[98] Total forested acreage is 9.9 million acres. Acreage by forest type available from the USFS at: http://www.fs.fed.us/ne/global/pubs/books/epa/states/NV.htm. The total land area in NV is 70.3 million acres (http://www.50states.com/Nevada.htm).
[99] 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.

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 data, USFS estimates the amount of forest carbon in different forest types as well as different carbon pools. The different forests include those in the national forest system and those that are not federally-owned (private and other public forests). USFS also provides information on forests categorized as being either woodlands (forests not used for timber harvesting) and non-woodlands (such as timberlands).

The data shown in Table H1 are a summary of the FIA data used to derive the carbon pool and flux estimates that are shown in Table H2. The previous inventory data came from either a previous FIA cycle or data from the Resources Planning Act Assessment (RPA). The Resources Planning Act requires the USFS to report on the state of US forest resources on a regular basis; the USFS publishes the RPA assessment every five years. FIA is a key contributor to RPA. RPA data, which are generally lower in resolution, are sometimes used in place of FIA cycles. The FIA has transitioned from a periodic to annual sampling design, which has created some data sets that are not comparable over time, in which case the RPA data are better suited for estimating carbon densities.[100] As shown in Table H1, the current forest carbon pool estimates are derived from 2005 FIA data. The previous inventory data came from a previous FIA cycle or RPA data.

Table H1. Forest Inventory Data Used to Estimate Forest CO_2 Flux

Forest	Current Inventory Data Source	Past Inventory Data Source	Avg. Year[a]	Interval[b] (yr)	Current Forest Area (10^3 hectares)	Previous Forest Area (10^3 hectares)
National Forest - Timberland/Reserved/Low Productivity	FISDB21_NV_02_2005	FISDB21_NV_01_1989	2005.1	8.5	290	251
National Forest -Woodlands	FISDB21_NV_02_2005	FISDB21_NV_01_1989	2005.1	8.5	1,126	1,041
Other Public/Private Forest – Timberland/ Reserved/Low Productivity	FISDB21_NV_02_2005	RPAdata_NV____1997	2005.2	19.8	480	212
Other Public/Private Forest - Woodlands	FISDB21_NV_02_2005	FISDB21_NV_01_1989	2005.2	24.7	2,912	2,637
				Totals	**4,807**	**4,140**

[a] Average year for the measurements that make up the current FIA inventory data (early 2005 for all forest types).
[b] The number of years between the current inventory source and the past inventory source.

The data in Table H1 show an increase of 667 kilo-hectares (1.6 million acres) in forested area during the period of analysis (1993-2003). Over 40% of this increase occurred in woodland forests (as mentioned under key uncertainties below, some of this difference is likely driven by methodological differences in survey methods between the two FIA cycles).

[100] Jim Smith, USFS, personal communication with K. Bickel, CCS, November 7, 2006.

Table H2. Forestry CO_2 Flux Estimates for Nevada

Forest	Current Carbon Stocks by Pool (MMt Carbon)					
	Live Tree	Standing Dead	Under-story	Down & Dead	Forest Floor	Soil Organic Carbon
National Forest - Timberland/Reserved/Low Productivity	9.4	1.4	1.0	0.6	7.6	9.6
National Forest -Woodlands	36.8	0.2	3.3	1.2	24.9	22.8
Other Public/Private Forest – Timberland/ Reserved/Low Productivity	9.9	2.6	1.8	0.7	10.6	12.8
Other Public/Private Forest - Woodlands	67.5	0.1	8.3	2.1	62.9	58.6
Totals	**124**	**4.2**	**14.4**	**4.6**	**106**	**104**

Forest	Average Carbon Flux by Pool (MMt C/yr)					
	Live Tree	Standing Dead	Under-story	Down & Dead	Forest Floor	Soil Organic Carbon
National Forest - Timberland/Reserved/Low Productivity	0.34	0.02	-0.03	0.03	-0.04	-0.05
National Forest -Woodlands	-0.80	-0.02	-0.02	-0.02	-0.18	-0.18
Other Public/Private Forest – Timberland/ Reserved/Low Productivity	-0.02	-0.10	-0.06	-0.01	-0.26	-0.31
Other Public/Private Forest - Woodlands	0.17	0.00	-0.04	0.00	-0.27	-0.26
Totals	**-0.31**	**-0.10**	**-0.15**	**0.00**	**-0.75**	**-0.79**

Forest	Average Carbon Pool Flux (MMt CO_2/yr)					
	Live Tree	Standing Dead	Under-story	Down & Dead	Forest Floor	Soil Organic Carbon
National Forest - Timberland/Reserved/Low Productivity	1.24	0.07	-0.11	0.10	-0.14	-0.17
National Forest -Woodlands	-2.94	-0.07	-0.08	-0.07	-0.66	-0.65
Other Public/Private Forest – Timberland/ Reserved/Low Productivity	-0.08	-0.38	-0.21	-0.04	-0.96	-1.13
Other Public/Private Forest - Woodlands	0.64	-0.01	-0.14	0.01	-1.01	-0.95
Totals	**-1.14**	**-0.38**	**-0.55**	**0.00**	**-2.76**	**-2.91**

Total Forest Flux ($MMtCO_2e$) =	**-7.7**
Harvested Wood Products[a] =	**0.0**
Total Statewide Flux =	**-7.7**
Total Excluding Soil Organic Carbon	**-4.8**

[a] Source: http://www.fs.fed.us/ne/global/pubs/books/epa/states; For Nevada, HWP are estimated to sequester 0.0 MMtC during the period 1987-1997).

Table H2 provides a summary of the size of the forest carbon pools for the final survey period and the carbon flux estimates (in units of C and CO_2) developed by the USFS.[101] By convention, negative flux values indicate carbon sequestration. A total of 7.7 $MMtCO_2$ is estimated to be sequestered in Nevada forests each year with most of this accumulating in the forest floor and soil organic carbon pools. The live tree carbon pool sequesters about 1.4 $MMtCO_2$/yr. No net flux was estimated in the down & dead carbon pool. Note that this analysis averages out annual fluctuations in carbon sequestration rates over an approximate 8-24 year time interval depending on forest type (see Table H1).

Recent discussions with the USFS have indicated a large level of uncertainty associated with the soil organic carbon flux estimates. Due to this uncertainty, USFS has recommended leaving the flux associated with this pool out of the statewide totals. In Table H2, a final flux estimate of -4.8 $MMtCO_2$ is provided, which excludes the soil organic carbon flux. CCS used this value to report the totals in the summary tables at the front of this report.

In addition to the forest carbon pools, additional carbon stored as biomass can be 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. In Nevada, zero net carbon is estimated to be sequestered annually in wood products; these data are based on a USFS study from 1987 to 1997.[102] Presumably this is due to very little timber harvesting in NV. Additional details on all of the forest carbon inventory methods can be found in Annex 3 to EPA's 2006 GHG inventory for the U.S.[103]

For the 1990 and 2000 historic emission estimates as well as the reference case projections, the forest area and carbon densities of forestlands were assumed to be at the same levels as those shown in Table H2. Hence, there is no change in the estimated future sinks for 2010 and 2020.

Non-CO_2 Emissions from Forest Fires

In order to provide a more comprehensive understanding of GHG sources/sinks from the forestry sector, CCS also developed rough estimates of state-wide emissions for methane and nitrous oxide from wildfires and prescribed burns. A study published earlier this year in *Science* indicated an increasing frequency of wildfire activity in the western U.S. driven by a longer fire season and higher temperatures.[104] CO_2 emission from burning are addressed within the methodology described above for carbon stock changes (biomass lost during burning is registered as decreases in the relevant carbon pools).

CCS used 2002 emissions data developed by the WRAP to estimate methane and nitrous oxide emissions for wildfires and prescribed burns.[105] Methane emissions from this study were added to an estimate of nitrous oxide emissions based on nitrogen oxides (NO_x). Emissions of both

[101] Jim Smith, USFS, personal communication with S. Roe, CCS, October 2006.
[102] http://www.fs.fed.us/ne/global/pubs/books/epa/states. See data for Nevada
[103] Annex 3 to EPA's 2006 report can be downloaded at:
http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/RAMR6MBLNQ/$File/06_annex_Chapter3.pdf.
[104] Westerling, A.L. et al, "Warming and Earlier Spring Increases Western U.S. Forest Wildfire Activity", *Sciencexpress*, July 6, 2006.
[105] *2002 Fire Emission Inventory for the WRAP Region Phase II*, prepared by Air Sciences, Inc. for the Western Regional Air Partnership, July 22, 2005.

gases were converted to their CO_2 equivalents and summed to estimate total emissions from fires. The nitrous oxide estimate was made assuming that N_2O was 1% of the emissions of NO_x from the WRAP study. The 1% estimate is a common rule of thumb for the N_2O content of NO_x from combustion sources.

The results for 2002 are that fires contributed about 0.23 $MMtCO_2e$ of methane and nitrous oxide from about 88,958 acres burned (82,163 acres by wildfires). About 94% of the CO_2e was contributed by CH_4. For the purposes of comparison, another 2002 estimate was made using emission factors from a 2001 global biomass burning study[106] and the total tons of biomass burned from the 2002 WRAP fires emissions inventory. This estimate is nearly 0.27 $MMtCO_2e$ showing good agreement with the estimate above; however, there were about equal contributions from methane and nitrous oxide on a CO_2e basis.

Note that the 2002 level of activity compares to almost 950,000 acres burned in Nevada in 1996.[107] 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 fires contribute on the order of 0.2 – 2.0 $MMtCO_2e$ annually in NV from methane and nitrous oxide emissions.

Key Uncertainties

It is important to note that there were methodological differences in the two FIA cycles that can produce different estimates of forested area and carbon density. For example, in the Rocky Mountain Region of the US, the FIA program modified the definition of forest cover for the woodlands class of forestland. Earlier FIA cycles defined woodlands as having a tree cover of at least 10%, while the newer sampling methods used a woodlands definition of tree cover of at least 5% (leading to more area being defined as woodland). In woodland areas, the earlier FIA surveys might not have inventoried trees of certain species or with certain tree form characteristics (leading to differences in both carbon density and forested acreage). Also, 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 comprehensively estimated by the USFS. In states like Nevada that are in the Rocky Mountain Region and have substantial areas of woodlands, the change in definition could contribute significantly to the increases seen in forested area, which would translate into increases in CO_2 pools and large net negative CO_2 fluxes. For these reasons, the USFS provided flux estimates separately for woodlands, so that the relative influence of the woodlands class on total net CO_2 fluxes in NV could be discerned. As shown in Table H2, the contribution from the woodland areas drives a significant fraction of the flux estimate statewide (over 75%). Given the modifications to the FIA survey methods, the forest flux estimates for Nevada (-7.7 $MMtCO_2$) may be viewed as high.

[106] 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.
[107] *1996 Fire Emission Inventory*, Draft Final Report, prepared by Air Sciences, Inc. for the Western Regional Air Partnership, December 2002.

One approach to adjusting the USFS estimates to account for the possible overestimate of carbon fluxes on woodlands in Nevada is to assume that there was no net increase in forest area or forest growth in the woodlands category. In this case, the carbon stocks would remain constant over time and the carbon flux can be assumed to be zero. This approach gives a total forest CO2 flux for Nevada of about -1.8 $MMtCO_2$ (77% lower rate of sequestration). This may overcompensate for the USFS definition change in the woodlands class. State-level data on the woodlands land area could also be used to refine the USFS estimate.

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 Nevada. 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 IPCC (see Appendix J for more information on black carbon and other aerosol species). BC is synonymous with elemental carbon (EC), which is a term common to regional haze analysis. An inventory for 2002 was developed based on inventory data from the Western Regional Air Partnership (WRAP) regional planning organization and other sources. This appendix describes these data and methods for estimating mass emissions of BC and then transforming the mass emission estimates into CO_2 equivalents (CO_2e) in order to present the emissions within a GHG context. Data from the WRAP for their 2018 forecast inventory were also analyzed to assess the changes in future year BC emissions.

In addition to the PM inventory data from WRAP, PM speciation data from EPA's SPECIATE database were also used: these data include PM fractions of elemental carbon (also known as black carbon) 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 EPA on updating the SPECIATE database.[108] These new profiles have just recently been released by EPA. As will be further described below, both BC and OM emission estimates are needed to assess the CO_2e of black carbon emissions. While BC and OM emissions data are available from the WRAP regional haze inventories, CCS favored the newer speciation data available from EPA for the purposes of estimating BC and OM 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 EPA for important BC emissions sources (including 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 particulate matter 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 EPA's SPECIATE database as approved by 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.

[108] 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.[109] These methods are based on the modeling of Jacobson (2002)[110] and his updates to this work (Jacobson, 2005a).[111] Jacobson (2005a) estimated a range of 90:1 to 190:1 for the climate response effects of BC+OM emissions as compared to CO_2 carbon emissions (depending on either a 30-year or 95-year atmospheric lifetime for CO_2). It is important to note that the BC+OM emissions used by Jacobson were based on a 2:1 ratio of OM:BC (his work in these papers focused on fossil fuel BC+OM; primarily diesel combustion, which has an OM:BC ratio of 2:1 or less).

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

For this inventory, we started with the 90 and 190 climate response factors adjusted to CO_2e factors of 330 and 697 to obtain a low and high estimate of CO_2e for each sector. An example calculation of the CO_2e emissions for 10 tons of PM 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

[109] 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.

[110] 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.

[111] 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 Nevada total about 2.6 MMtCO_2e in 2002. This is the mid-point of the estimated range of emissions. The estimated range is 1.7 – 3.5 MMtCO_2e (see Table I1). The primary contributing sectors in 2002 were nonroad diesel (53%), rail (14%), and onroad diesel (9%). The nonroad diesel sector includes exhaust emissions from construction/mining, industrial and agricultural engines. Construction and mining engines contributed about 75% of the diesel nonroad engine total while agricultural engines contributed about 15%.

Other significant contributing sectors to BC emissions in NV are coal-fired electricity generating units (EGUs) and nonroad gasoline engines at around 5% each of the total CO_2e. The coal-fired EGU contribution should drop in the future due to the temporary shut down of the Mohave Generating Station. Pleasure craft and lawn and garden equipment engines contributed about one-third each to the nonroad gasoline total.

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.

The WRAP's 2018 forecast inventory was used to assess the changes in future year emissions for the most significant contributors to the BC inventory. Generally, these are diesel engines in both the onroad (e.g. heavy-duty vehicles) and nonroad categories. In 2002, the high estimate for the onroad diesel sector was 0.32 MMtCO_2e, while in 2018, the estimated emissions drop to 0.07 MMtCO_2e. For nonroad engines, the high estimate for emissions drops from 1.9 MMtCO_2e in 2002 to 0.49 MMtCO_2e in 2018. These reductions in BC are the result of new engine and lower sulfur diesel standards being phased in prior to 2018. Overall, BC emissions are estimated to drop by about 40% by 2018.

While the state of science in aerosol climate forcing is still developing, there is a good body of evidence supporting the net warming impacts of black carbon. Aerosols have a *direct* radiative forcing because they scatter and absorb solar and infrared radiation in the atmosphere. Aerosols also alter the formation and precipitation efficiency of liquid water, ice and mixed-phase clouds, thereby causing an *indirect* radiative forcing associated with these changes in cloud properties (IPCC, 2001).[112] There are also a number of other indirect radiative effects that have been modeled (see, for example, Jacobson, 2002, as noted in footnote on the previous page).

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

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

fact that aerosol mass and particle number concentrations are highly variable in space and time. This variability is largely due to the much shorter atmospheric lifetime of aerosols compared with the important GHGs (i.e. 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	Mass Emissions OM	Mass Emissions BC+OM	CO_2 Equivalents Low	CO_2 Equivalents High	Contribution to CO_2e
		Metric Tons			Metric Tons		
Electric Generating Units (EGUs)							
	Coal	105	150	256	104,216	220,116	6.2%
	Oil	3	4	7	2,968	6,268	0.2%
	Gas	0	120	120	0	0	0.0%
	Other	0	1	1	156	330	0.0%
Non-EGU Fuel Combustion (Residential, Commercial, and Industrial)							
	Coal	28	40	67	27,429	57,933	1.6%
	Oil	8	6	14	7,750	16,368	0.5%
	Gas	0	167	167	0	0	0.0%
	Other[a]	168	455	623	80,591	170,218	4.8%
Onroad Gasoline (Exhaust, Brake Wear, & Tire Wear)		62	230	292	29,643	62,609	1.8%
Onroad Diesel (Exhaust, Brake Wear, & Tire Wear)		171	75	246	152,017	321,078	9.1%
Aircraft		49	44	93	48,082	101,554	2.9%
Railroad[b]		231	76	307	228,500	482,620	13.7%
Other Energy Use							
	Nonroad Gas	110	310	419	108,745	229,683	6.5%
	Nonroad Diesel	891	292	1,183	881,871	1,862,618	52.7%
	Other Combustion[c]	1	11	13	0	0	0.0%
Industrial Processes		17	102	118	1,645	3,474	0.1%
Agriculture[d]		3	130	133	0	0	0.0%
Waste Management							0.0%
	Landfills	0	0	0	0	0	0.0%
	Incineration	0	0	1	190	402	0.0%
	Open Burning	30	381	411	0	0	0.0%
	Other	0	0	0	0	0	0.0%
Wildfires/Prescribed Burns		1,132	11,352	12,484	0	0	0.0%
Miscellaneous[e]		247	4,024	4,271	0	0	0.0%
Totals		**3,253**	**17,972**	**21,225**	**1,673,802**	**3,535,273**	**100%**

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

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

Original Reference: Material for this Appendix is taken from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2000*, U.S. Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-02-003, April 2002 (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[113] 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).

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

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

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 J1.

Table J1. 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 J2).

> *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 J2. 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 J3 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 J3. Net 100-year Global Warming Potentials for Select Ozone Depleting Substances[a]

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)

[a] 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.

References

FCCC (1996) Framework Convention on Climate Change; FCCC/CP/1996/15/Add.1; 29 October 1996; Report of the Conference of the Parties at its second session. Revised Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention, p18. Geneva 1996.

IPCC (2001) *Climate Change 2001: A Scientific Basis,* Intergovernmental Panel on Climate Change; J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, C.A. Johnson, and K. Maskell, eds.; Cambridge University Press. Cambridge, U.K.

IPCC (2000) *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.* IPCC National Greenhouse Gas Inventories Programme Technical Support Unit, Kanagawa, Japan. Available online at http://www.ipcc-nggip.iges.or.jp/gp/report.htm.

IPCC (1999) *Aviation and the Global Atmosphere*. Intergovernmental Panel on Climate Change; Penner, J.E., et al., eds.; Cambridge University Press. Cambridge, U.K.

IPCC (1996) *Climate Change 1995: The Science of Climate Change*. Intergovernmental Panel on Climate Change; J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell, eds.; Cambridge University Press. Cambridge, U.K.

IPCC/UNEP/OECD/IEA (1997) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.* Paris: Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency.

Jacobson, M.Z. (2001) Strong Radiative Heating Due to the Mixing State ofBlack Carbon in Atmospheric Aerosols. Nature. In press.

UNEP/WMO (2000) *Information Unit on Climate Change*. Framework Convention on Climate Change (Available on the internet at http://www.unfccc.de).

WMO (1999) *Scientific Assessment of Ozone Depletion*, *Global Ozone Research and Monitoring Project-Report No. 44*, World Meteorological Organization, Geneva, Switzerland.