# Final North Carolina Greenhouse Gas Inventory and Reference Case Projections 1990-2020

## Center for Climate Strategies
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# Executive Summary

This report presents a summary of North Carolina's anthropogenic greenhouse gas (GHG) emissions and sinks (carbon storage) from 1990 to 2020. The Center for Climate Strategies (CCS) prepared a preliminary draft of North Carolina's GHG emissions and reference case projections under contract to the North Carolina Department of Environment and Natural Resources' (NC DENR) Division of Air Quality (DAQ).[1] The preliminary draft inventory and reference case projections, completed in February 2006, was provided to the North Carolina Climate Action Plan Advisory Group (CAPAG) (and its Technical Work Groups (TWGs)) to assist the CAPAG in understanding past, current, and possible future GHG emissions in North Carolina, and thereby inform the mitigation option development process. The CAPAG and the TWGs provided comments for improving the inventory and reference case projections. Subsequently, the inventory and reference case projection estimates were revised to incorporate revisions approved by the CAPAG. The information presented in this report reflects the revisions to the inventory and reference case projections approved by the CAPAG.

Historical GHG emissions estimates (1990 through 2005)[2] were developed using a set of generally accepted principles and guidelines for State GHG emissions, relying to the extent possible on North Carolina-specific data and inputs. The reference case projections (2006-2020) are based on a compilation of various existing North Carolina 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.

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

Table 1 provides a summary of North Carolina's historical (1990 and 2000) and reference case projection (2010 and 2020) GHG emissions. In 2000, on a gross emissions consumption basis (i.e., excluding carbon sinks), North Carolina accounted for approximately 180 million metric tons (MMt) of $CO_2e$ emissions, an amount equal to 2.5% of total Untied States (US) GHG emissions. On a net emissions basis (i.e., including carbon sinks), North Carolina accounted for approximately 156 $MMtCO_2e$ of emissions in 2000, an amount equal to 2.4% of total US GHG emissions.[3] North Carolina's GHG emissions are rising faster than the nation as a whole. From 1990 to 2000, North Carolina's gross and net GHG emissions were up 33% and 39%, respectively, while national gross and net emissions rose by 17% and 24%, respectively, during

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[1] *Revised Draft North Carolina Greenhouse Gas Inventory and Reference Case Projections, 1990-2020*, prepared by the Center for Climate Strategies for the North Carolina DENR/DAQ, February 2006.
[2] The last year of available historical data varies by sector; ranging from 2000 to 2004.
[3] National emissions from *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2005*, April 2007, USEPA #430-R-07-002, (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

this period.[4] North Carolina forests are a net carbon sink and are estimated to sequester approximately 23.7 $MMtCO_2e$ of carbon annually.

### Table 1.  North Carolina Historical and Reference Case GHG Emissions, by Sector[a]

| $MMtCO_2e$ | 1990 | 2000 | 2005 | 2010 | 2020 | Explanatory Notes for Projections |
|---|---|---|---|---|---|---|
| **Energy Use ($CO_2$, $CH_4$, $N_2O$)** | **121** | **159** | **167** | **187** | **218** | |
| **Electricity Use (Consumption)** | **53.8** | **75.4** | **75.8** | **85.8** | **98.4** | |
| Electricity Production (in-state) | 46.3 | 69.5 | 71.5 | 80.9 | 92.1 | *See electric sector assumptions* |
| *Coal* | *45.9* | *68.3* | *69.6* | *78.6* | *78.8* | *in appendix* |
| *Natural Gas* | *0.15* | *0.70* | *1.30* | *1.55* | *12.5* | |
| *Oil* | *0.16* | *0.49* | *0.56* | *0.64* | *0.80* | |
| *Biomass* | *0.00* | *0.01* | *0.03* | *0.03* | *0.03* | |
| Imported Electricity | 7.52 | 5.89 | 4.26 | 5.05 | 6.28 | |
| **Res/Comm/Ind (RCI)** | **27.3** | **30.9** | **31.8** | **34.5** | **38.5** | |
| Coal | 7.35 | 4.66 | 5.25 | 6.11 | 7.50 | Based on *North Carolina Energy Outlook 2003* |
| Natural Gas[b] | 8.33 [a] | 12.5 | 13.0 | 14.3 | 16.3 | Based on *North Carolina Energy Outlook 2003* |
| Petroleum | 11.4 | 13.5 | 13.4 | 13.9 | 14.4 | Based on *North Carolina Energy Outlook 2003* |
| Wood ($CH_4$ and $N_2O$) | 0.26 | 0.24 | 0.22 | 0.22 | 0.22 | Based on *North Carolina Energy Outlook 2003* |
| **Transportation** | **39.7** | **52.7** | **59.4** | **66.4** | **81.5** | |
| Gasoline | 29.7 | 38.1 | 42.6 | 46.3 | 52.2 | NC DENR VMT, *North Carolina Energy Outlook 2003* |
| Diesel | 6.86 | 11.0 | 12.6 | 15.1 | 22.2 | NC DENR VMT, *North Carolina Energy Outlook 2003* |
| Natural Gas and LPG | 0.92 | 0.76 | 0.75 | 0.74 | 0.75 | NC DENR VMT, *North Carolina Energy Outlook 2003* |
| Jet Fuel and Aviation Gasoline | 2.28 | 2.91 | 3.45 | 4.25 | 6.45 | Based on *North Carolina Energy Outlook 2003* |
| **Industrial Processes** | **1.62** | **3.07** | **5.4** | **7.14** | **15.1** | |
| ODS Substitutes | 0.01 | 2.16 | 4.43 | 6.36 | 14.6 | Based on national projections (US EPA) |
| Semiconductor Manufacturing | 0.01 | 0.03 | 0.04 | 0.03 | 0.02 | Based on national projections (US EPA) |
| Electricity Transmission and Dist. | 1.02 | 0.55 | 0.65 | 0.47 | 0.26 | Based on national projections (US EPA) |
| Aluminum Production | 0.51 | 0.24 | 0.21 | 0.18 | 0.15 | Based on national projections (US EPA) |
| Limestone and Dolomite | NA | 0.01 | 0.01 | 0.01 | 0.01 | Assumed no growth from 2002 |
| Soda Ash | 0.07 | 0.08 | 0.08 | 0.09 | 0.10 | Increases with state population |
| **Agriculture** | **8.33** | **11.0** | **13.3** | **14.1** | **15.5** | Based on historical trends (except swine) |
| **Waste Management** | **4.83** | **6.97** | **6.5** | **6.52** | **6.59** | |
| Solid Waste Management | 4.50 | 6.57 | 6.05 | 6.05 | 6.05 | Assumed no growth from 2005 |
| Wastewater Management | 0.33 | 0.40 | 0.43 | 0.47 | 0.54 | Increases with state population |
| **Gross Emissions (Consumption Basis, Excludes Forest Sink)** | **136** | **180** | **192** | **214** | **256** | |
| *increase relative to 1990* | | *33%* | *42%* | *58%* | *88%* | |
| **Forestry (Sink)** | -23.2 | -23.7 | -23.7 | -23.7 | -23.7 | Assumed no change from 2000 |
| **Net Emissions (Consumption Basis, Includes Forest Sink)** | **112** | **156** | **169** | **191** | **232** | |
| *increase relative to 1990* | | *39%* | *57%* | *70%* | *106%* | |

[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding. NA = not available.
[b] For the Natural Gas Transmission and Distribution sector, emissions for 2000, 2010, and 2020 are included in the totals for the RCI natural gas sector. Data for 1990 were not available to estimate emissions for the Natural Gas Transmission and Distribution sector.

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[4] During the 1990s, population grew by 21% in North Carolina compared with 13% nationally. Furthermore, North Carolina's economy grew faster on a per capita basis (up 60% vs. 52% nationally).

Figure 1 illustrates the State's emissions per capita and per unit of economic output. On a per capita basis, North Carolinians emitted about 22 metric tons (Mt) of gross $CO_2$e emissions in 2000, less than the national average of about 25 $MtCO_2$e. Like the nation as a whole, per capita emissions have remained fairly flat, while economic growth exceeded emissions growth throughout the 1990-2002 period. From 1990 to 2000, emissions per unit of gross product dropped by 32% nationally, and by 17% in North Carolina.[5]

The principal sources of North Carolina's GHG emissions are electricity use (including electricity imports) and transportation, accounting for 42% and 29% of North Carolina's *gross* GHG emissions in 2000, respectively. The next largest contributor to emissions is the remaining direct use of fossil fuels – natural gas, oil products, and coal in the residential, commercial, and industrial (RCI) sectors, constituting another 17% of State emissions in 2000.

As illustrated in Figure 2 and shown numerically in Table 1, under the reference case projections, North Carolina's gross GHG emissions (consumption basis) are projected to climb to 256 $MMtCO_2$e by 2020, 88% above 1990 levels. Net emissions (consumption basis) are projected to be 232 $MMtCO_2$e by 2020, 106% above 1990 levels. As shown in Figure 3, electricity is projected to be the largest contributor to future emission growth by far, followed by HFCs and PFCs used in place of ozone-depleting substances (ODS). Other major sources of emissions growth include gasoline use by vehicles, diesel use for transporting freight, and fuel use in buildings and by industry (RCI sector).

Overall, from 2000 to 2020, the projected average annual rate of emissions growth is 1.8% per year on a gross emissions consumption basis and 2.0% per year on a net emissions consumption basis. The increase in per capita emissions after 2010 are primarily associated with the following four factors: 1) electricity consumption (including imports) growth at a rate faster than population growth; 2) increasing use of vehicles with vehicle-miles traveled (VMT) growing faster than population; 3) freight traffic growing faster than population; and 4) increasing use of HFCs and PFCs as substitutes for ODS in refrigeration, air conditioning, and other applications.

As a result of the CAPAG's and TWG's review of the draft inventory and reference case projections, the CAPAG approved revisions to:

- Eliminate potential double-counting of emissions in RCI subsector associated with independent power producers (IPP) connected to the power grid because these emissions are included in the energy supply sectors.
- Improve the forecast of emissions for 2003 through 2020 associated with both in-state production and electricity imports. The revisions were to the fuel mix assumptions as well as assumptions on electricity transmission and distribution losses.
- Add text to the discussion for the "Industrial Processes Non-Fuel Use" category noting that, following international and national protocols, the GHG emissions associated with the use of ODS are excluded from GHG inventories.

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[5] Based on gross domestic product by state (millions of current dollars), available from the US Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/).

Overall, the revisions approved by the CAPAG lowered 1990 emissions by 2.9 MMtCO$_2$e, 2005 and 2010 emissions by 3.9 MMtCO$_2$e, and 2020 emissions by 11.4 MMtCO$_2$e relative to the emissions presented in the February 2006 draft inventory and reference case projections report.

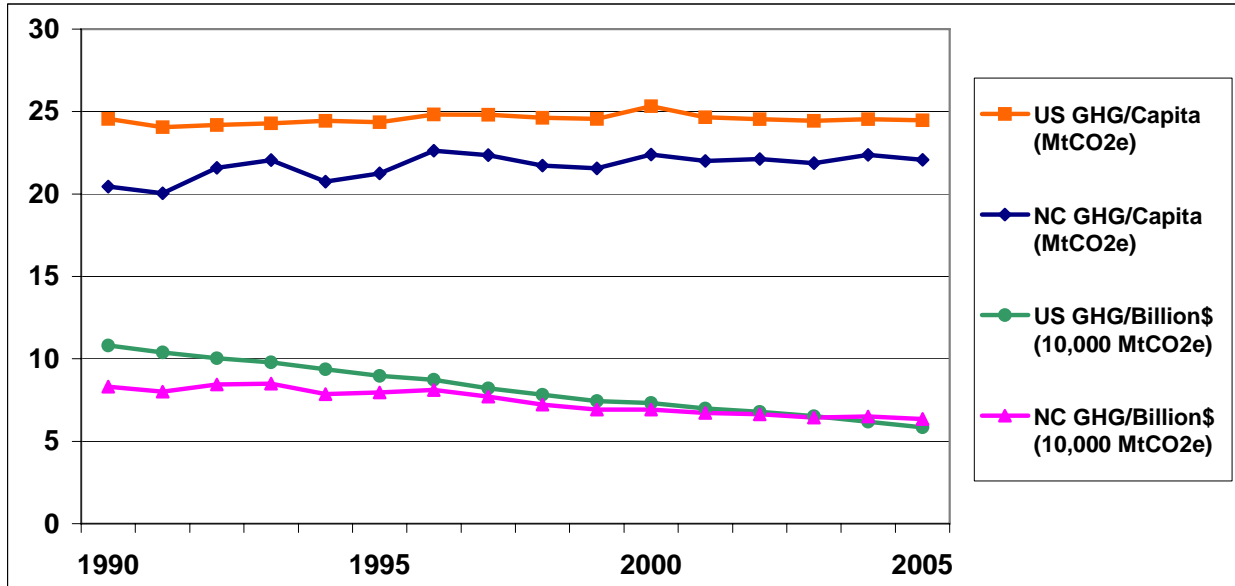**Figure 1.  North Carolina and US Gross GHG Emissions, Per Capita and Per Unit Gross Product**



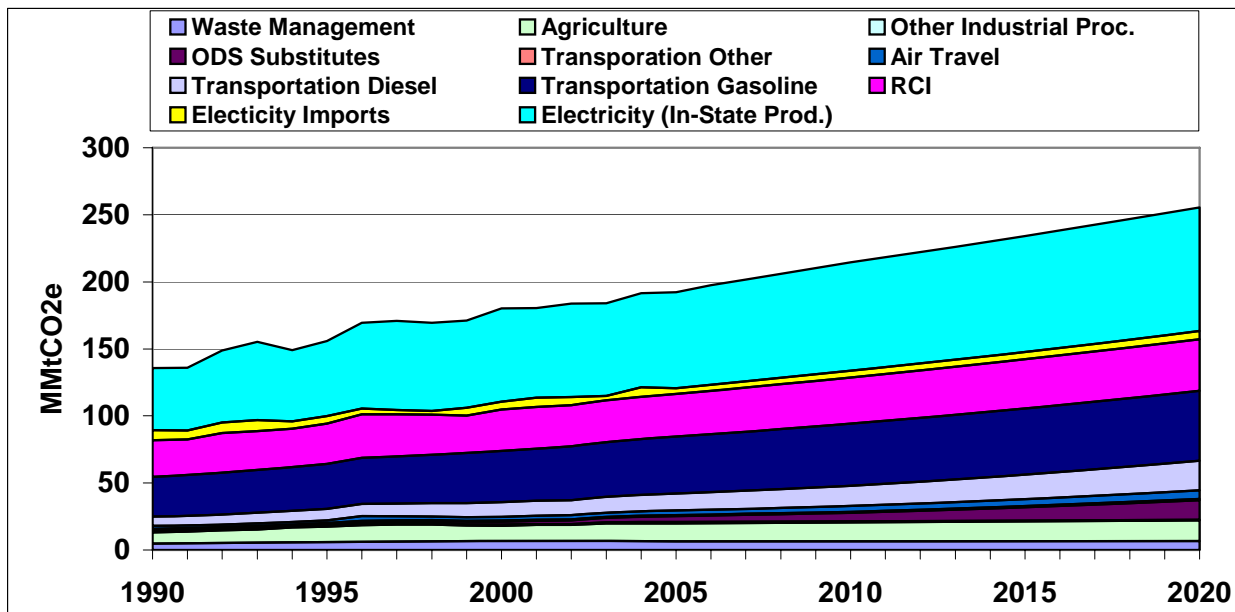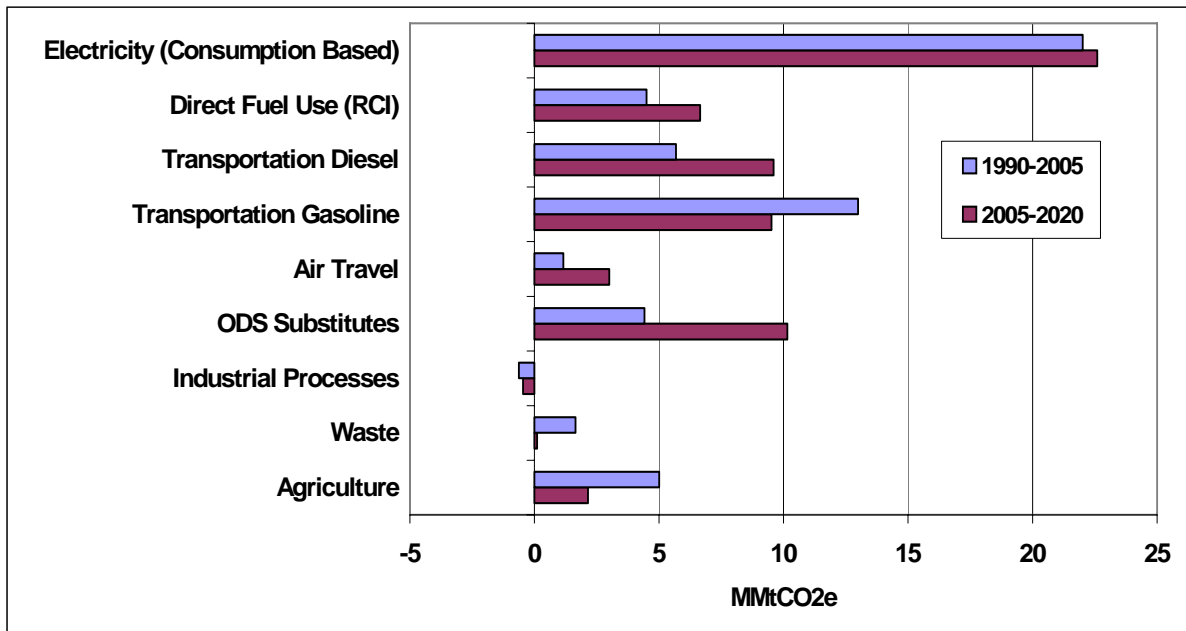**Figure 2.  North Carolina Gross GHG Emissions by Sector, 1990-2020: Historical and Projected**

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**Figure 3. Sector Contributions to Gross GHG Emissions Growth in North Carolina, 1990-2020: Reference Case Projections**



Some data gaps exist in this inventory, including 1990-1999 activity data for natural gas distribution and transmission. Key tasks include developing a better understanding of the electricity generation sources currently used to meet North Carolina loads (in collaboration with North Carolina utilities), and review and revision of key emissions drivers (such as electricity and transportation fuel use growth rates) that will be major determinants of North Carolina's future GHG emissions. Also, emissions of aerosols, particularly black carbon from fossil fuel combustion, could have significant impacts in terms of radiative forcing (i.e., climate) impacts. No estimates have been developed for North Carolina, however, by including black carbon emission estimates in the inventory, additional opportunities for reducing climate impacts may be realized.

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## Acronyms and Key Terms

AEO2005 – United States Department of Energy, Energy Information Administration's Annual Energy Outlook 2005

BOC – Bureau of Census

Btu – British thermal unit

C – Carbon*

CAPAG – Climate Action Plan Advisory Group

CCS – Center for Climate Strategies

CFCs – chlorofluorocarbons

$CH_4$ – Methane*

CO – Carbon monoxide*

$CO_2$ – Carbon Dioxide*

$CO_2e$ – Carbon Dioxide equivalent*

DAQ – Division of Air Quality

EIA – Energy Information Administration

FORCARB – Forest Carbon Model

GHG – Greenhouse Gases*

GWh – gigawatt-hour

GWP – Global Warming Potential*

HCFC – Hydrochlorofluorocarbons

HFCs – Hydrofluorocarbons*

HPMS – Highway Performance Monitoring System

IPCC – Intergovernmental Panel on Climate Change*

IPP – Independent Power Producer

kWh – kilowatt-hour

lb – pound

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

LMOP – Landfill Methane Outreach Program

LNG – liquefied natural gas

LPG – liquefied petroleum gas

MMBtu – Million British thermal units

Mt - Metric ton (equivalent to 1.102 short tons)

MMt – Million Metric tons

MWh – megawatt-hour

$N_2O$ – Nitrous Oxide*

$NO_2$ – Nitrogen Dioxide*

$NO_x$ – Nitrogen Oxides*

NAICS – North American Industry Classification System

NASS – National Agricultural Statistics Service

NC DENR – North Carolina Department of Environment and Natural Resources

NCUC – North Carolina Utilities Commission

NMVOCs – Nonmethane Volatile Organic Compounds*

$NO_x$ – Oxides of Nitrogen*

$O_3$ – Ozone*

ODS – Ozone-Depleting Substances

OPS – United States Office of Pipeline Safety

PFCs – Perfluorocarbons*

ppb – parts per billion

ppm – parts per million

ppt – parts per trillion

RCI – Residential, Commercial, and Industrial

SAR – Second Assessment Report*

SED – State Energy Data

SERC – Southeastern Electric Reliability Council

$SF_6$ – Sulfur Hexafluoride*

SGIT – State Greenhouse Gas Inventory Tool

SIC – Standard Industrial Classification

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

$SO_2$ – Sulfur Dioxide*

TAR – Third Assessment Report*

TWG – Technical Work Group

TWh – terawatt-hours

UNFCCC – United Nations Framework Convention on Climate Change

US – United States

USDA – United States Department of Agriculture

US DOE – United States Department of Energy

US EPA – United States Environmental Protection Agency

USFS – United States Forest Service

VACAR – Virginia-Carolinas Reliability Group

VMT – Vehicle-miles Traveled

VOC – Volatile Organic Compound

* - See Appendix I for more information.

## Summary of Findings

### Introduction

This report presents a summary of North Carolina's anthropogenic greenhouse gas (GHG) emissions and sinks (carbon storage) from 1990 to 2020. The Center for Climate Strategies (CCS) prepared a preliminary draft of North Carolina's GHG emissions and reference case projections under contract to the North Carolina Department of Environment and Natural Resources' (NC DENR) Division of Air Quality (DAQ).[6] The preliminary draft inventory and reference case projections, completed in February 2006, was provided to the North Carolina Climate Action Plan Advisory Group (CAPAG) (and its Technical Work Groups (TWGs)) to assist the CAPAG in understanding past, current, and possible future GHG emissions in North Carolina, and thereby inform the mitigation option development process. The CAPAG and the TWGs provided comments for improving the inventory and reference case projections. Subsequently, the inventory and reference case projection estimates were revised to incorporate revisions approved by the CAPAG. The information presented in this report reflects the revisions to the inventory and reference case projections approved by the CAPAG.

Historical GHG emissions estimates (1990 through 2005)[7] were developed using a set of generally accepted principles and guidelines for State GHG emissions, as described in the "Approach" section of this report, relying to the extent possible on North Carolina-specific data and inputs. The reference case projections (2006-2020) are based on a compilation of various existing North Carolina 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 types of gases included in the US Greenhouse Gas Inventory: carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$). Emissions of these GHGs are presented using a common metric, $CO_2$ equivalence ($CO_2e$), which indicates the relative contribution of each gas to global average radiative forcing on a global warming potential- (GWP-) weighted basis. The final appendix to this report provides a fuller discussion of GHGs and GWPs.

## North Carolina Greenhouse Gas Emissions: Sources and Trends

Table 2 provides a summary of gross and net GHG emissions estimated for North Carolina by sector for the years 1990, 2000, 2005, 2010, and 2020. This section of the report provides a summary of the historical emissions (1990 through 2005) followed by a summary of the forecasted reference case projection year emissions (2006 through 2020), and key uncertainties and next steps. We also provide an overview of the general methodology, principals, and

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[6] *Revised Draft North Carolina Greenhouse Gas Inventory and Reference Case Projections, 1990-2020*, prepared by the Center for Climate Strategies for the North Carolina DENR/DAQ, February 2006.

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guidelines followed for preparing the inventories. Appendices A through H provide the detailed methods, data sources, and assumptions for each GHG sector.

### Table 2.  North Carolina Historical and Reference Case GHG Emissions, by Sector[a]

| MMtCO$_2$e | 1990 | 2000 | 2005 | 2010 | 2020 | Explanatory Notes for Projections |
|---|---|---|---|---|---|---|
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[a] Totals may not equal exact sum of subtotals shown in this table due to independent rounding. NA = not available.
[b] For the Natural Gas Transmission and Distribution sector, emissions for 2000, 2010, and 2020 are included in the totals for the RCI natural gas sector. Data for 1990 was not available to estimate emissions for the Natural Gas Transmission and Distribution sector.

## Historical Emissions

### Overview

In 2000, on a gross emissions consumption basis (i.e., excluding carbon sinks), North Carolina accounted for approximately 180 million metric tons (MMt) of carbon dioxide equivalent ($CO_2e$) emissions, an amount equal to 2.5% of total Untied States (US) gross GHG emissions. On a net emissions basis (i.e., including carbon sinks), North Carolina accounted for approximately 156 $MMtCO_2e$ of emissions in 2000, an amount equal to 2.4% of total US net GHG emissions.[8] North Carolina's GHG emissions are rising faster than the nation as a whole. From 1990 to 2000, North Carolina's gross and net GHG emissions were up 33% and 39%, respectively, while national gross and net emissions rose by 17% and 24%, respectively, during this period.[9] North Carolina forests are a net carbon sink and are estimated to sequester approximately 23.7 $MMtCO_2e$ of carbon annually.

On a per capita basis, North Carolinians emitted about 22 metric tons (Mt) of gross $CO_2e$ in 2000, less than the national average of about 25 $MtCO_2e$. Figure 4 illustrates the State's emissions per capita and per unit of economic output. It also shows that like the nation as a whole, per capita emissions have remained fairly flat, while economic growth exceeded emissions growth throughout the 1990-2002 period. From 1990 to 2000, emissions per unit of gross product dropped by 32% nationally, and by 17% in North Carolina.[10]

**Figure 4.  North Carolina and US Gross GHG Emissions, Per Capita and Per Unit Gross Product**
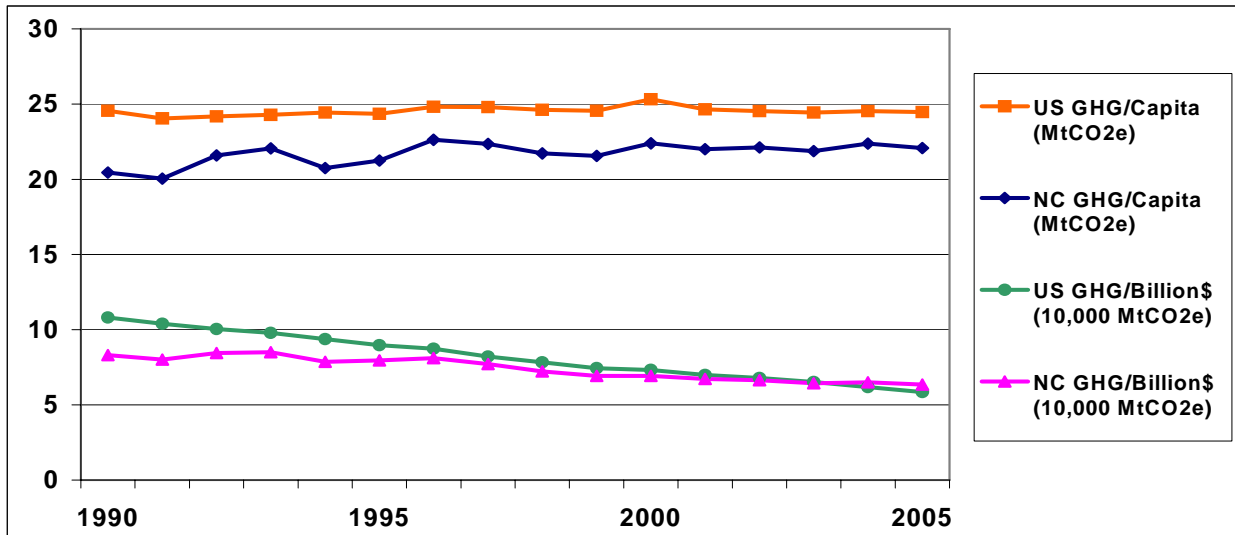


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[8] National emissions from *Inventory of US Greenhouse Gas Emissions and Sinks:  1990-2005*, April 2007, USEPA #430-R-07-002, (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

[9] During the 1990s, population grew by 21% in North Carolina compared with 13% nationally. Furthermore, North Carolina's economy grew faster on a per capita basis (up 60% vs. 52% nationally).

[10] Based on gross domestic product by state (millions of current dollars), available from the US Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/).

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Electricity use and transportation are the State's principal GHG emissions sources. Together, the combustion of fossil fuels in these two sectors accounts for 71% of North Carolina's *gross* GHG emissions, as shown in Figure 5.[11] The remaining use of fossil fuels – natural gas, oil products, and coal -- in the residential, commercial, and industrial (RCI) sectors constitute another 17% of State emissions.

**Figure 5. Gross GHG Emissions by Sector, 2000, North Carolina and US**
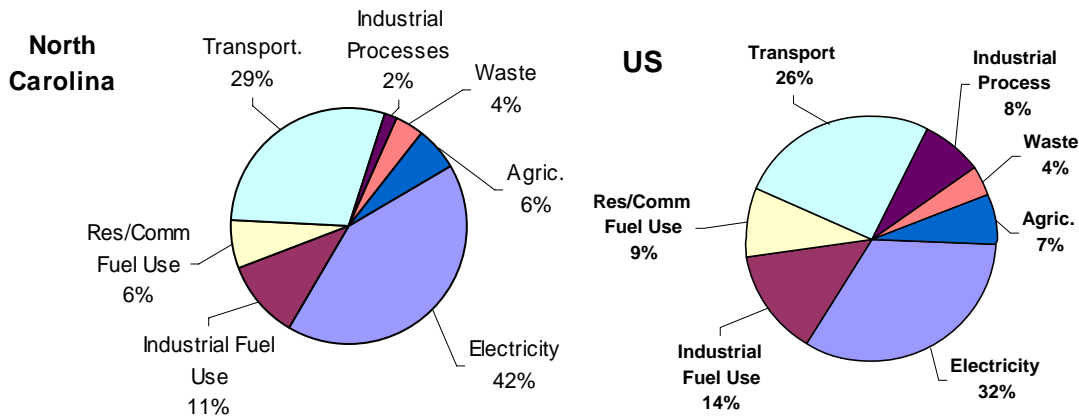


Agricultural activities such as manure management, fertilizer use, and livestock (enteric fermentation) result in $CH_4$ and $N_2O$ emissions that account for another 6% of State GHG emissions. Industrial process emissions comprise about 2% of State GHG emissions in 2000, and these emissions are rising rapidly due to the increasing use of HFCs and PFCs as substitutes for ozone-depleting chlorofluorocarbons.[12] Other industrial processes emissions result from aluminum manufacturing; PFC use in semiconductor manufacture; and $CO_2$ released during soda ash, limestone, and dolomite use. Landfills and wastewater management facilities produce $CH_4$ and $N_2O$ emissions accounting for the remaining 4% of the State's emissions in 2000.

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

As shown in Figure 5, electricity use in 2000 accounts for 42% of North Carolina's gross GHG emissions (about 75 MMtCO$_2$e), which is higher than the national share of emissions from electricity production (32%). On a per capita basis, North Carolina's GHG emissions from electricity consumption are higher than the national average (in 2000, 9.4 MMtCO$_2$e/capita vs. 8.1 MMtCO$_2$e/capita nationally). The average North Carolinian uses more electricity than the average US resident (15,000 kilowatt-hours (kWh) per person per year compared to 12,000 kWh

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[11] *Gross* emissions estimates only include those sources with positive emissions. Carbon sequestration in soils and vegetation is included in *net* emissions estimates.

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

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nationally in 2000). During the 1990s, electricity demand grew at a rate of 2.9% per year, while electricity emissions grew 3.4% annually, reflecting an increase in emissions per kWh.

It is important to note that these electricity emissions estimates reflect the *GHG emissions associated with the electricity sources used to meet North Carolina demands,* corresponding to a consumption-based approach to emissions accounting (See "Approach" section). Another way to look at electricity emissions is to consider the *GHG emissions produced by electricity generation facilities in the State.* For many years, North Carolina power plants have tended to produce less electricity than is consumed in the State – in the year 2000, for example, North Carolina imported 8% of the electricity consumed in the State. As a result, in 2000, emissions associated with electricity consumption (75 MMtCO$_2$e) were higher than those associated with electricity production (70 MMtCO$_2$e).[13]

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

Like electricity emissions, GHG emissions from transportation fuel use have risen steadily from 1990 through 2000 at an average rate of slightly under 3% annually. In 2000, gasoline-powered vehicles account for about 72% of transportation GHG emissions. Diesel vehicles account for another 21%; air travels for roughly 6%, and the remainder of transportation emissions come from and natural gas and liquefied petroleum gas (LPG) vehicles. As the result of North Carolina's rapid expansion and an increase in miles traveled during the 1990s, gasoline use has grown at rate of 2.5% annually. Meanwhile, diesel use has risen 4.8% annually, suggesting an even more rapid growth in freight movement within the State.

**CAPAG Revisions**

As a result of the CAPAG's and TWGs' review of the draft inventory and reference case projections, the CAPAG approved the following revisions to the inventory and reference case projections:

Energy Supply for 2003 through 2020:  The TWG reviewed the inventory and forecast for the electricity supply sector and identified areas for improving the forecast for North Carolina. The CAPAG approved of the revisions recommended by the TWG. The revisions improved the forecast of emissions for 2003 through 2020 associated with both in-state production and

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

electricity imports. The revisions were to the fuel mix assumptions as well as assumptions on transmission and distribution losses.

Industrial Fuel Use for 1990-2020:  When the first draft of the inventory and reference case projections was prepared, the EPA's tool for preparing emissions for 1990 through 2002 included independent power producers connected to the power grid. Emissions associated independent power producers were thus included in the industrial subsector for RCI. This category was also included in the energy supply sector in the first draft, following EIA convention for defining sectors. In order to avoid potential double-counting, the inventory and reference case projections were revised such that emissions associated with independent power producers were reported only with the energy supply sector, not with the industrial subsector for RCI. The EPA subsequently revised their tool for the RCI sectors to remove independent power producers.

Table 3 shows the change in emissions representing the difference between the revised emissions minus the draft emissions. Overall, the revisions approved by the CAPAG lowered 1990 emissions by 2.9 $MMtCO_2e$, 2005 and 2010 emissions by 3.9 $MMtCO_2e$, and 2020 emissions by 11.4 $MMtCO_2e$.

**Table 3.  Revisions to Inventory and Reference Case Projections ($MMtCO_2e$)**

| Sector | 1990 | 2000 | 2005 | 2010 | 2020 |
|---|---|---|---|---|---|
| Electricity Supply - In-State Production | 0.0 | 0.0 | -0.2 | 0.6 | -5.3 |
| Electricity Supply - Imports | 0.0 | 0.0 | 0.3 | 0.3 | -0.1 |
| Industrial Fuel Use | -2.9 | -3.4 | -4.0 | -4.8 | -5.9 |
| Total Change from Draft Inventory and Reference Case Projections | -2.9 | -3.4 | -3.9 | -3.9 | -11.4 |

Industrial Processes Non-Fuel Use:  The CAPAG and RCI TWG added text to the discussion for this category in the final inventory and reference case projections report noting that, following international and national protocols, the GHG emissions associated with the use of ozone-depleting substances (ODS) are excluded from GHG inventories.

**Relationship to Previous Inventories**

Appalachian State University prepared a 1990 inventory for North Carolina, last revised in 1996. However, the underlying data used to prepare the 1990 inventory were archived and not available. Consequently, a comparison of activity data and emission factors could not be made to the Appalachian State University's 1990 inventory. During the development of the inventories presented in this report, DENR chose to focus on preparing the inventories for 2000 forward. Therefore, the pre-2000 inventory data are based on the activity and emission factor data that were readily available.

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# Reference Case Projections

Relying on North Carolina agency projections of electricity and fuel use, and other assumptions noted in the Appendices, we developed a simple reference case projection of GHG emissions through 2020. As illustrated in Figure 6 and shown numerically in Table 2, under the reference case projections, North Carolina gross GHG emissions continue to grow steeply, climbing to 256 MMtCO$_2$e by 2020, 88% above 1990 levels. Electricity is projected to be the largest contributor to future emission growth by far, followed by HFCs and PFCs used in place of ODS, as shown in Figure 7. Other major sources of emissions growth include the transportation sector (diesel and gasoline), and fuel use in buildings and industry (RCI).

**Figure 6.  North Carolina Gross GHG Emissions by Sector, 1990-2020: Historical and Projected**
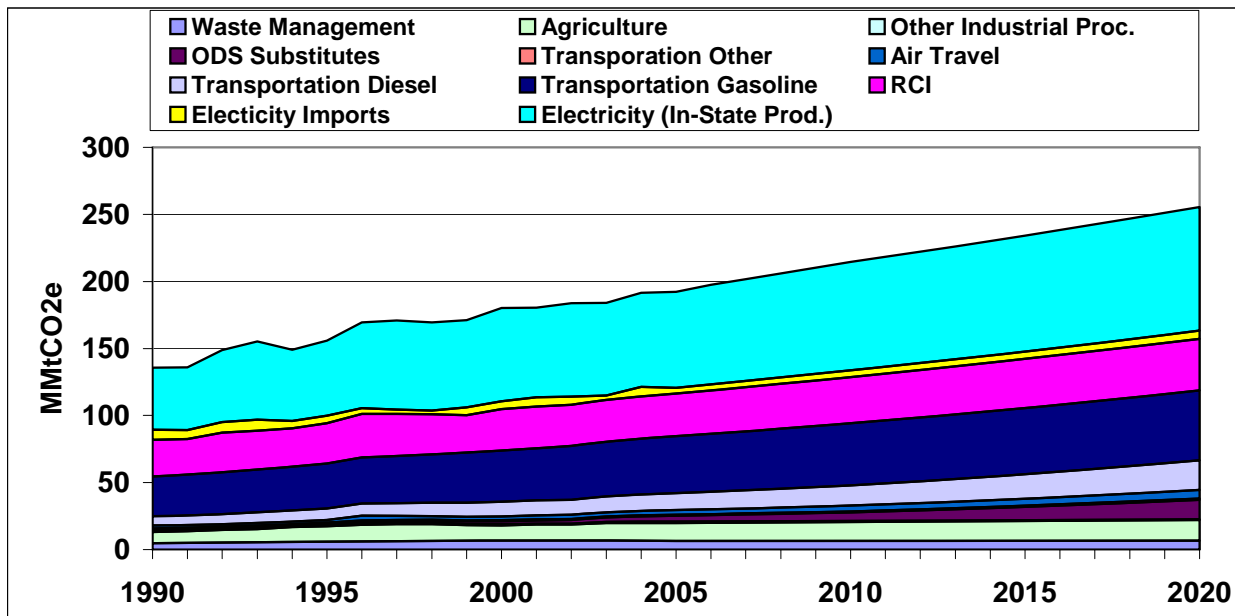


Although North Carolina's demand for electricity is project to continue to increase through 2020, the demand increase is projected to be met through the use of natural gas and imported electricity. As shown in Figure 8, the use of coal and petroleum to meet future electricity demand is not expected to increase after 2010.

Overall, the average annual projected rate of gross GHG emissions growth is 1.8% per year from 2000 to 2020. The increase in emissions after 2010 appears largely as the result of four factors: 1) electricity consumption (including imports) growth at a rate faster than population growth, 2) increasing use of vehicles with vehicle-miles traveled (VMT) growing faster than population, 3) freight traffic growing faster than population, and 4) increasing use of HFCs and PFCs as substitutes for ODS in refrigeration, air conditioning, and other applications. Other sources that are projected to grow faster than population are residential natural gas use, industrial fuel use, gasoline, air travel, and agriculture.

**Figure 7. Sector Contributions to Gross GHG Emissions Growth in North Carolina, 1990-2020: Reference Case Projections**
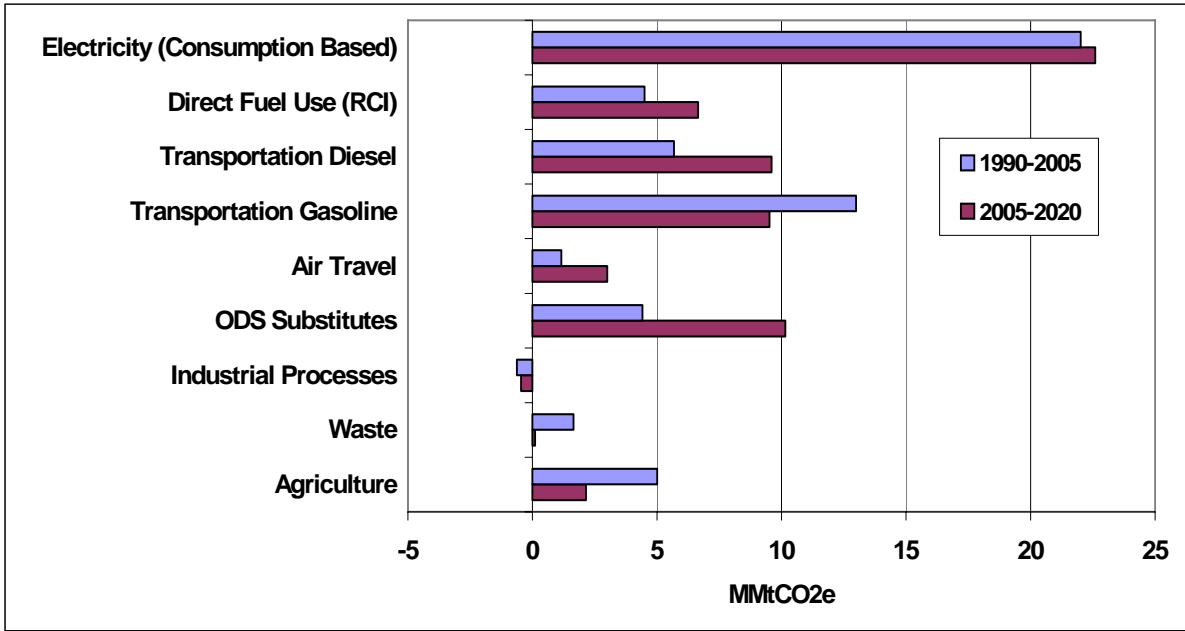


**Figure 8. Emissions from Electricity Production in North Carolina, by Fuel Source**
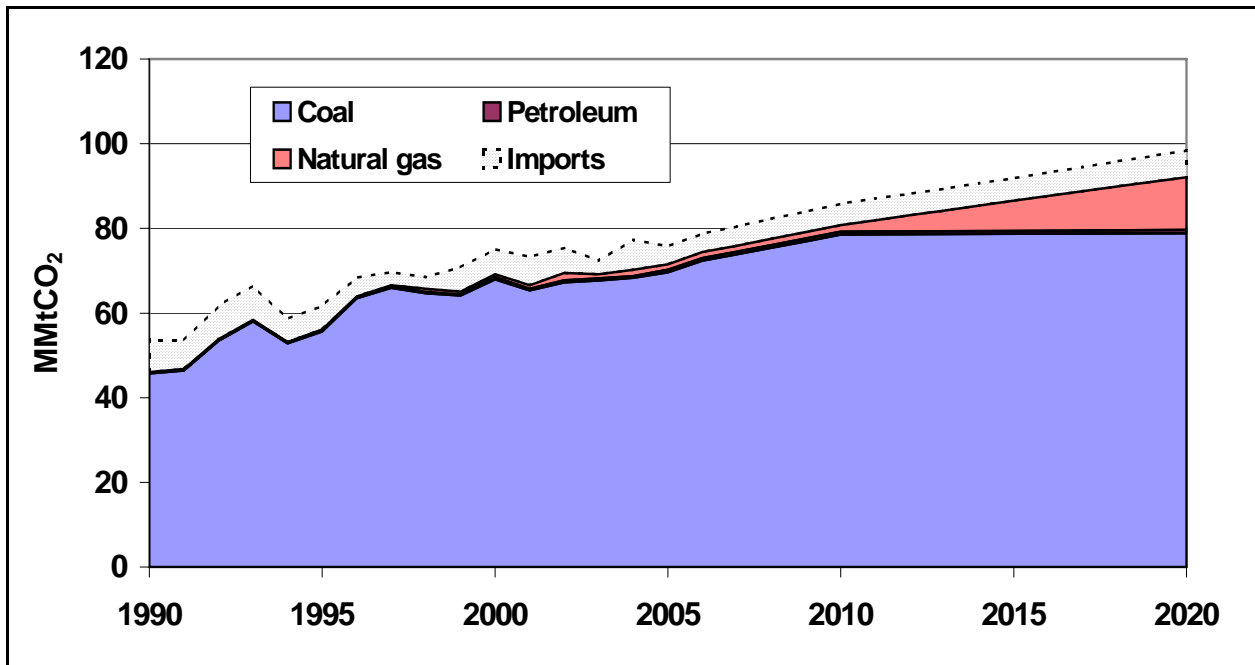
**Figure 9. North Carolina Historical and Projected GHG Emissions, GSP, and Population (Indexed to 1990 Value)**
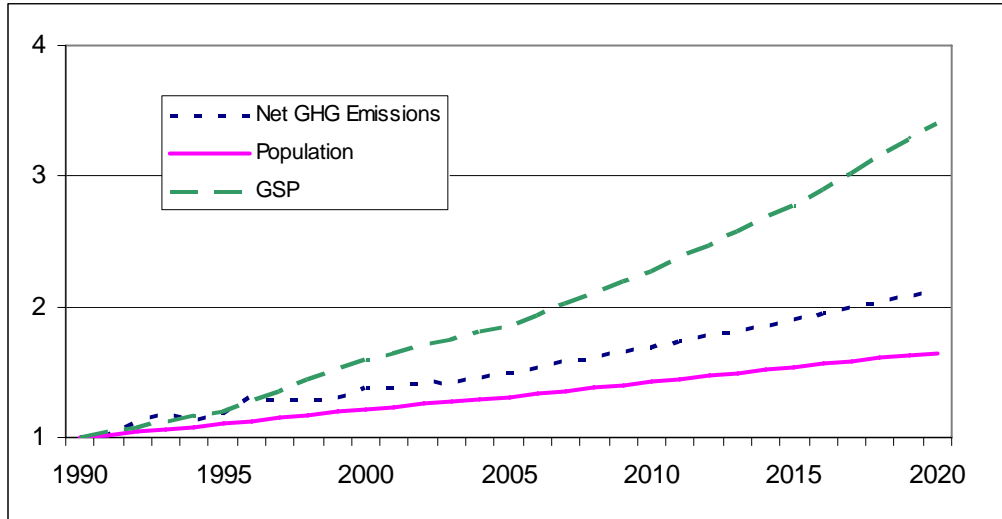


## Key Uncertainties and Next Steps

Some data gaps exist in this inventory, including 1990-1999 activity data for natural gas distribution and transmission. Key tasks, among others, include developing a better understanding of the electricity generation sources currently used to meet North Carolina loads (in collaboration with State utilities), and review and revision of key drivers such as the electricity and transportation fuel use growth rates that will be major determinants of North Carolina's future GHG emissions (See Table 4).

Perhaps the variable with the most important implications for GHG emissions is the type, size, and number of power plants built in North Carolina between now and 2020. There are also significant impacts associated with projecting electricity consumption in the State, as well as in the estimation of consumption-based electricity emissions (i.e., which electricity sources serve North Carolina loads). If a consumption-based emissions approach is adopted by the State, further analysis should be directed towards resources that utilities use to meet North Carolina loads, and methods that can be reliably used to track them.

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. At this time no estimates have been developed for North Carolina. By including black carbon emission estimates in the inventory, additional opportunities for reducing climate impacts are realized.

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**Table 4.  Key Annual Growth Rates for North Carolina, Historical and Projected**

| | 1990-2000 | 2000-2020 | Sources/Uses |
|---|---|---|---|
| **Population** | 2.0% | 1.5% | North Carolina Office of State Budget and Management |
| **GSP** | 4.8% | 3.9% | *North Carolina Energy Outlook 2003* (not used for projections) |
| **Employment** | 2.6% | 1.3% | *North Carolina Energy Outlook 2003* |
| **Electricity Sales** | 2.9% | 1.5% | US DOE Energy Information Administration (EIA) State Energy Data (SED) for historic, Annual Report of the North Carolina Utilities Commission for Projections |
| **Vehicle Miles Traveled** | n/a | 2.4% | Federal Highway's Highway Performance Monitoring System (HPMS) and North Carolina Department of Environment and Natural Resources (NC DENR) |

# Approach

The principal goal of the inventories and reference case projections is to provide the State, CAPAG, and TWGs with a general understanding of North Carolina'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 North Carolina.

**General Methodology**

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

In most cases, we followed the same approach to emissions accounting for historical inventories used by the US EPA in its national GHG emissions inventory[14] and its guidelines for States.[15] These inventory guidelines were developed based on the guidelines from the Intergovernmental

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[14] 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.

[15] http://yosemite.epa.gov/oar/globalwarming.nsf/content/EmissionsStateInventoryGuidance.html.

Panel on Climate Change, the international organization responsible for developing coordinated methods for national GHG inventories.[16] The inventory methods provide flexibility to account for local conditions. The key sources of activity and projection data are shown in Table 5. Table 5 also provides the descriptions of the data provided by each source and the uses of each data set in this analysis.

**Table 5. Key Sources for North Carolina Data, Inventory Methods, and Growth Rates**

| Source | Information provided | Use of Information in this Analysis |
|---|---|---|
| **US EPA State Greenhouse Gas Inventory Tool (SGIT)** | US EPA SGIT is a collection of linked spreadsheets designed to help users develop State GHG inventories. US EPA SGIT contains default data for each State for most of the information required for an inventory. The SGIT methods are based on the methods provided in the Volume 8 document series published by the Emissions Inventory Improvement Program (http://www.epa.gov/ttn/chief/eiip/techreport/volume08/index.html) | Where not indicated otherwise, SGIT is used to calculate emissions from residential/commercial/industrial fuel combustion, industrial processes, agriculture and forestry, and waste. We use SGIT emission factors ($CO_2$, $CH_4$ and $N_2O$ per British thermal unit (Btu) consumed) to calculate energy use emissions. |
| **US DOE Energy Information Administration (EIA) State Energy Data (SED)** | EIA SED source provides energy use data in each State, annually to 2002. | EIA SED is the source for all energy use data except on-road gasoline and diesel consumption. Emission factors from US EPA SGIT are used to calculate energy-related emissions. |
| *North Carolina Energy Outlook 2003* | *North Carolina Energy Outlook 2003* projects fuel consumption to 2020. | *North Carolina Energy Outlook 2003* is used to project res/com/ind fuel use. |
| **US Office of Pipeline Safety (OPS)** | Natural gas transmission and distribution pipeline mileage is available by state from US OPS. | Pipeline mileage from US OPS 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. |
| **USDS National Agricultural Statistics Service (NASS)** | USDA NASS provides data on crops and livestock. | Crop production data used to estimate agricultural residue and agricultural soils emissions; livestock population data used to estimate manure and enteric fermentation emissions |

**General Principles and Guidelines**

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

- **Transparency:** We reported data sources, methods, and key assumptions to provide open review and opportunities for additional revisions by the CAPAG and TWGs.

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[16] http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

- **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 used US EPA tools for State inventories and projections as a starting point. These estimates were then augmented to conform to local data and conditions, as informed by North Carolina-specific sources and experts.

- **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods:** This analysis aims to comprehensively cover GHG emissions associated with activities in North Carolina. It covers all six GHGs covered by US and other national inventories: $CO_2$, $CH_4$, $N_2O$, $SF_6$, HFCs, and PFCs. Presently this report does not cover black carbon emissions.

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

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

- **Use of Consumption-Based Emissions Estimates:** To the extent possible, we estimated emissions that are caused by activities that occur in North Carolina. For example, we reported emissions associated with the electricity consumed in North Carolina. The rationale for this method of reporting is that it can more accurately reflect the impact of State-based mitigation option 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 (i.e., on an in-state production basis) in particular for electricity.

For electricity, we estimated, in addition to the emissions due to fuels combusted at electricity plants in the State, the emissions related to electricity *consumed* in North Carolina. This entails accounting for the electricity sources used by North Carolina utilities to meet consumer demands. In the future, a refinement to the analysis would be to estimate other sectoral emissions on a consumption basis, such as transportation fuel use, which is 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 these activities and their emissions may not occur within the State.)

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# Appendix A.  Electricity Use and Supply

North Carolina has historically consumed more electricity than it produces, importing power from states in the region. In 2000, for instance, North Carolina consumed 8% more electricity than produced, down from nearly 15% imports in 1990.[17] The North Carolina electricity sector is also dominated by coal, which accounts for over 60% of all electricity generated in recent years. Coal-fired power plants produce as much as twice the $CO_2$ emissions per kilowatt-hour of electricity as natural gas-fired power plants. As a result of these factors, North Carolina's power plants are the largest source of GHG emissions in the State.

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

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

We considered two sources of data in developing the inventory of $CO_2$ emissions from North Carolina power plants. We used the EIA's State Energy Data (SED) rather than EPA data because of inconsistencies that we found in the EPA data. Although the two sources agree on total $CO_2$ emissions, the EPA database shows emissions from coal to be 5% greater than SED. We discussed this with EPA and learned that EPA data tend to be conservative (i.e., overestimate emissions) because the data are reported as part of a regulatory program, and this is the likely cause for the 5% difference. We applied SGIT emission factors to EIA's SED to develop the historic inventory in the electricity sector.

## Electricity Consumption

At about 14,300 kWh/capita (2001 data), North Carolina has relatively high electricity consumption per capita. By way of comparison, the per capita consumption for the US is 12,800 kWh per year, with California averaging at 6,800 kWh, South Carolina at 18,400 kWh, and Florida at 12,200 kWh.[18] As shown in Figure 10, the residential sector has the greatest electricity consumption in North Carolina, with strong growth from 1990. The commercial sector has experienced even stronger growth, surpassing the industrial sector and slowly meeting residential

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[17] EGRID2002 software (US EPA, http://www.epa.gov/cleanenergy/egrid/whatis.htm).
[18] California Energy Commission website (http://www.energy.ca.gov/electricity/us_percapita_electricity.html).

sector consumption levels. Industrial sector consumption grew slightly until 1998, when it began to decline and ultimately reached a lower level of consumption in 2003 than in 1990.[19]

**Figure 10.  Electricity Consumption by Sector in North Carolina, 1990-2003**
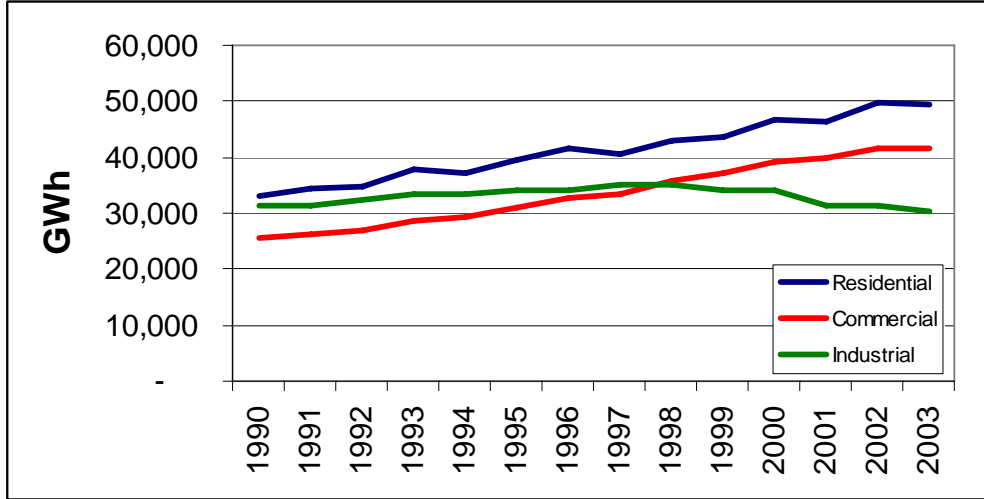


The States' three investor-owned utilities serve approximately 67% of the customers, and generate 75% of the electricity, as illustrated in Table 6. The State's electric cooperatives serve 13.2% of the customers, and municipally owned utilities serve 19.5% of the customers.

**Table 6.  Retail Electricity Generation by North Carolina Utilities (2002)**

|  | 2002 GWh | Percentage |
|---|---|---|
| Investor-Owned Utilities |  |  |
| *Duke Energy* | 53,983,683 | 43% |
| *Carolina Power & Light (Progress Energy)* | 35,327,404 | 28% |
| *Virginia Electric & Power (Dominion)* | 3,860,522 | 3% |
| Total, Investor-Owned Utilities | 93,171,609 | 75% |
|  |  |  |
| Total, All Utilities | 115,597,653 | 93% |
|  |  |  |
| IPP's and Combined Heat & Power | 8,870,377 | 7% |
|  |  |  |
| **Total, North Carolina** | **124,468,030** | **100%** |

Source:  EIA state electricity profiles.

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

Overall, total electricity consumption grew at an average annual rate of 3.9% from 1990 to 2003; about 60% of the rate of gross state product growth (6.5% per year).[20] For the projections, future electricity consumption is projected to grow at a rate of 1.5-1.7% per year[21] through 2020, compared with expected population growth of 1.4% per year[22] and gross state product growth of 4.5% - 5% per year.[23]

## Electricity Generation – North Carolina's Power Plants

As mentioned above and displayed in Figure 11, coal figures prominently in electricity generation and GHG emissions from power plants in North Carolina.

Figure 12 reports the emissions from the five largest plants in 2003. The top three plants, Roxboro, Marshall, and Belews Creek, account for 55% of emissions and the top five plants account for 71%.[24]

*Future Generation and Emissions*

Estimating future generation and GHG emissions from North Carolina 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 North Carolina remains uncertain as the trends in type of new builds are influenced by many factors. The most recent fossil-fuel plants have been natural gas-fired; however, there are concerns that natural gas prices may increase over the next decade, which could cause a trend towards a more coal-dominated mix. Recent announcements by several utilities indicate that coal will dominate new builds, and a number of proposed natural gas plants have been cancelled.

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[20] Gross State Product growth from Bureau of Economic Analysis, http://www.bea.doc.gov/bea/regional/gsp/default.cfm.

[21] Based on recent projections made by Duke, Progress, and Dominion in filings to the North Carolina Utilities Commission.

[22] From Log into North Carolina (LINC), http://data.osbm.state.nc.us/pls/linc/dyn_linc_main.show.

[23] From the *NC Energy Outlook 2003*.

[24] Emissions from the 5 largest power plants were obtained from the EPA Clean Air Markets database, http://cfpub.epa.gov/gdm/index.cfm. Since data from the EPA Clean Air Markets Division excludes plants do not include plants under 25MW, supplemental data were required for complete emissions estimate. Emissions for all remaining power plants were calculated by using the energy consumption for the remaining plants multiplied by EPA emissions factors by fuel, accounting for combustion efficiency and average carbon content of coal.

**Figure 11.  Electricity Generation and CO$_2$ Emissions from North Carolina Power Plants, 2003**

Hydroelectric
7,201 GWh
6%

Natural Gas
1,580 GWh
1%

Nuclear
40,907 GWh
32%

biomass, waste,
other
renewables
2,031 GWh
2%

Coal
74,776 GWh
58%

Petroleum
784 GWh
1%

Petroleum
0.5 MMTCO2
1%

Coal
67.1 MMTCO2
98%

Natural Gas
0.8 MMTCO2
1%

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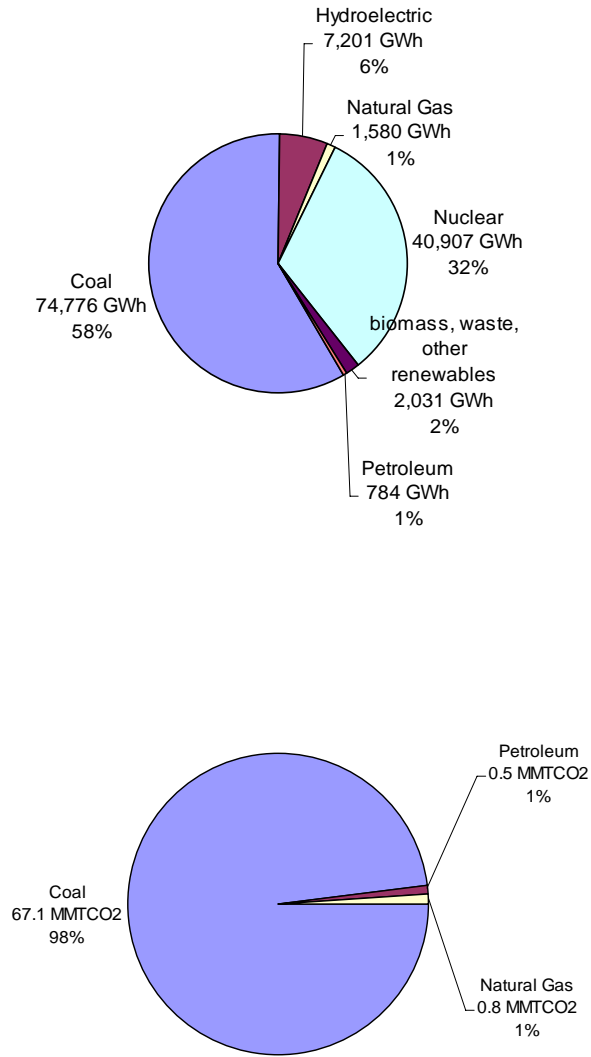
**Figure 12. CO₂ Emissions from Individual North Carolina Power Plants, 2003**

**CO2 Emissions (MMtCO2)**
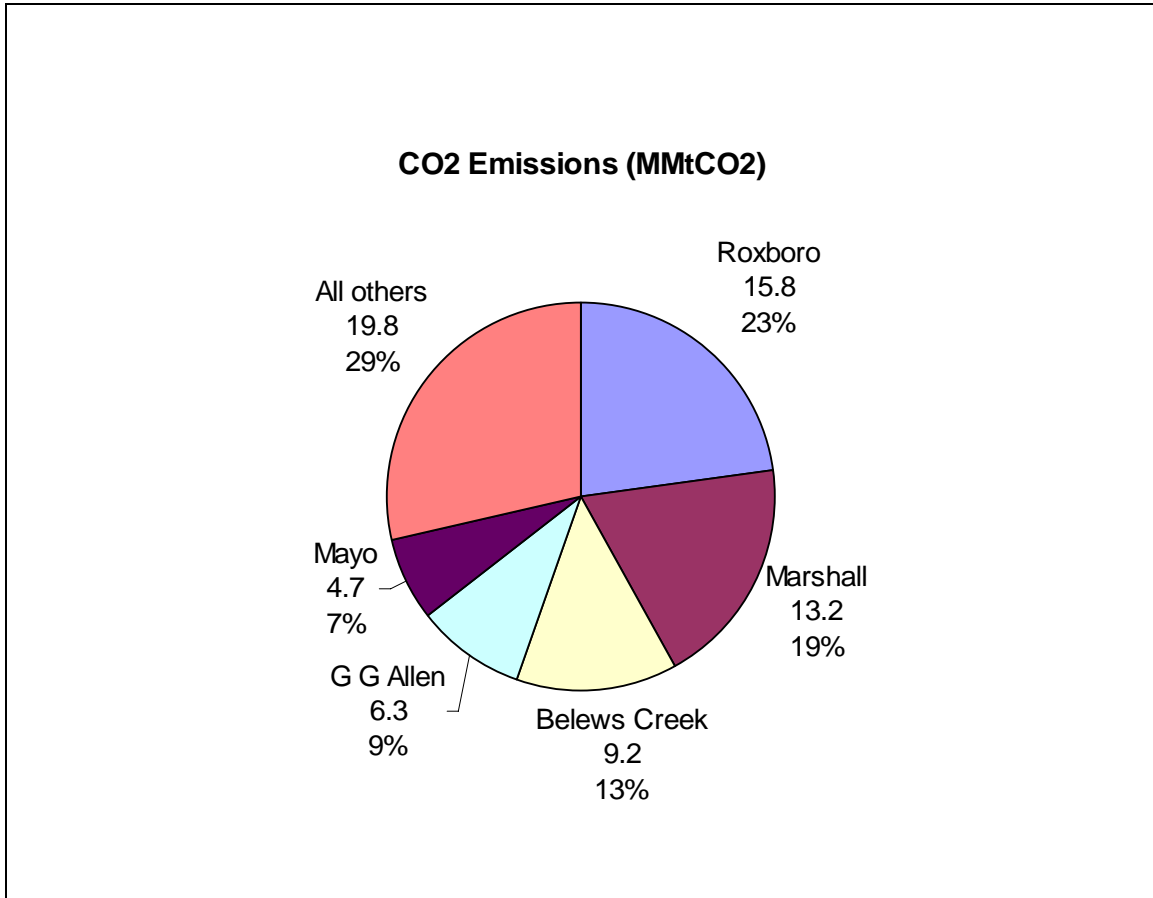


Source: US EPA Clean Air Markets database for named plants (http://cfpub.epa.gov/index.cfm). Other units calculated from fuel use data provided by US DOE EIA.

Given the many factors impacting electricity related emissions, and a diversity of assumptions by stakeholders within the electricity sector, developing a "reference case" projection for the most likely development of North Carolina's electricity sector is particularly challenging. Therefore, simplifying assumptions were made, relying to the extent possible on widely reviewed and accepted modeling assessments. The reference case projections assume:

- Generation grows at a rate equal to the growth in new capacity as projected by North Carolina utilities. Growth in total electricity demand in North Carolina equals growth in electricity sales, also projected by North Carolina utilities.[25]

- Generation from existing plants is based on projecting 2003 data from the SED forward. New plants and changes to existing plants due to plant renovations and overhauls that

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[25] Annual Report of the North Carolina Utilities Commission Regarding Long Range Needs for Expansion of Electric Generation Facilities for Service in North Carolina, July 2005

result in higher capacity factors are counted as new generation and are derived from the fuel mix forecast for new generation in the *North Carolina Energy Outlook 2003*.[26]

## Electricity Trade and Allocation of GHG Emissions

North Carolina is part of the interconnected Southeastern Electric Reliability Council (SERC) region – a large area covering North Carolina and all or parts of Virginia, South Carolina, Tennessee, Georgia, Alabama, Mississippi, Louisiana, Arkansas, Missouri, and Florida. SERC is divided into four sub regions, and North Carolina belongs to the Virginia-Carolinas Reliability Group (VACAR) within SERC. 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 defining which emissions should be allocated to North Carolina is challenging, as is 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 2003, electricity consumption in North Carolina was 121.3 terawatt-hours (TWh) while delivered electricity from in-state generation after accounting for on-site use and transmission and distribution losses was 115.7 TWh. Thus a small portion of the electricity consumed in North Carolina came from sources outside the state. The SERC region had a higher average $CO_2$ emissions rate per gigawatt-hours (GWh) of generation (578 MMt$CO_2$ per GWh) than North Carolina (537 MMt$CO_2$ per GWh) in 2003. Although imports were small (i.e., less than 5%), they resulted in proportionally higher $CO_2$.

Since almost all states are part of regional trading grids, many states that have developed GHG inventories have grappled with this problem, and several approaches have been developed to allocate GHG emissions from the electric sector to individual states for inventories.

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

An alternative is to estimate *consumption-based* or *load-based* GHG emissions, corresponding to the emissions associated with electricity consumed in the State. The load-based approach is currently being considered by states that import significant amounts of electricity, such as

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[26] http://www.energync.net/docs/energyoutlook.pdf.

California, Oregon, and Washington.[27] 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 in or out of North Carolina is a mix of all plants generating on the inter-connected grid, it is impossible to physically track the electrons.

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

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

## Summary of Assumptions and Reference Case Projections

As noted, projecting generation sources, sales, and emissions for the electric sector out to 2020 requires a number of key assumptions, including economic and demographic activity, changes in electricity-using technologies, regional markets for electricity (and competitiveness of various technologies and locations), access to transmission and distribution, the retirement of existing generation plants, the response to changing fuel prices, and the fuel/technology mix of new generation plants. The key assumptions described above are summarized in Table 7.

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[27] 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).

**Table 7. Key Assumptions and Methods for Electricity Projections for North Carolina**

| | |
|---|---|
| **Electricity sales** | 1.6% based on reported growth in electricity sales by North Carolina utilities[28] |
| **Electricity generation** | 1.5% based on reported growth in new capacity (as a proxy for growth in generation) reported by North Carolina utilities.[29] |
| **Transmission and Distribution losses** | 10% losses are assumed, based on average statewide losses in 2003, (data from the US EPA Emission & Generation Resource Integrated Database[30]). For the period 2004-2020, the SERC average was used (6.0% by 2020) |
| **Renewable Generation Sources** | Renewable energy accounts for 7.5% of total generation in 2003. New renewables are assumed to be biomass and wind, together accounting for 1.3% of total generation in 2020. |
| **New Non-Renewable Generation Sources (2004-2010)** | In 2003, non-fossil generation in 2003 is coal (60%), natural gas (1%), nuclear (32%), and oil (2%). By 2003, non-fossil generation is coal (54%), natural gas (16%), nuclear (25%), and oil (1%). |
| **Heat Rates** | The assumed heat rates for new natural gas combined cycle units is 7,000 British thermal unit per kilowatt hour (Btu/kWh), for natural gas combustion turbines, 10,450 Btu/kWh, and for pulverized coal units 8,500 Btu/kWh. based on estimates used in similar analyses.[31] |
| **Operation of Existing Facilities** | Capacity factors for existing facilities are assumed to decrease as new, more efficient units come on line. |

Figure 13 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. Table 8 shows generation by fuel type between 1990 and 2003 growing significantly across all fuel types in North Carolina except for hydropower. Coal and nuclear generation are the largest and have grown the most in absolute terms over the 13-year period. Natural gas grew by the greatest percentage, but started at an extremely low level. Natural gas represents 65% of new generation over the 2003-2020 period, followed by coal at 33%.

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[28] Annual Report of the North Carolina Utilities Commission Regarding Long Range Needs for Expansion of Electric Generation Facilities for Service in North Carolina, July 2005
[29] Ibid.
[30] http://www.epa.gov/cleanenergy/egrid/index.htm.
[31] See, for instance, the Oregon Governor's Advisory Group On Global Warming http://egov.oregon.gov/ENERGY/GBLWRM/Strategy.shtml.

**Figure 13. Electricity Generated by North Carolina Power Plants, 1990-2020**
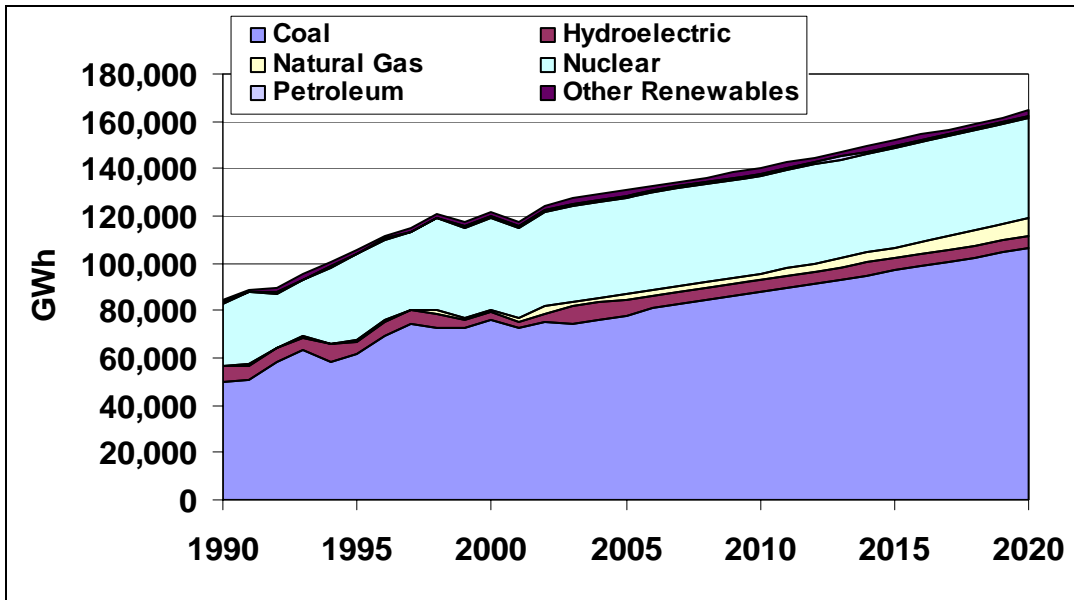


**Table 8. Growth in Generation by Fuel Type in North Carolina, 1990-2003**

| Growth in Generation in North Carolina 1990 -2003 | |
|---|---|
| Coal | 50% |
| Hydroelectric | 3% |
| Natural Gas | 677% |
| Nuclear | 58% |
| biomass and waste | 39% |
| Petroleum | 139% |
| Total | 50% |

Figure 14 illustrates the GHG emissions associated with the mix of electricity generation shown in Table 8. From 2003 to 2020, emissions from North Carolina electricity generation are projected to grow at 1.7% per year, faster than the 1.5% growth in electricity generation, due to continued dominant role of coal generation with only small increases in renewable generation. As a result, the emission intensity (emissions per MWh) of North Carolina electricity is expected to increase by about 6% (from 0.54 $MtCO_2$/MWh in 2003 to 0.57 $MtCO_2$/MWh in 2020).

**Figure 14.  North Carolina CO$_2$ Emissions Associated with Electricity Production (Production-Basis), excludes Net Imports**



Figure 15 shows the "net-consumption-basis" emissions from 1990 to 2020. Total emissions match those shown in the previous "production-basis" chart; here, however, a small addition attributed to net electricity imports is shown in the top area.
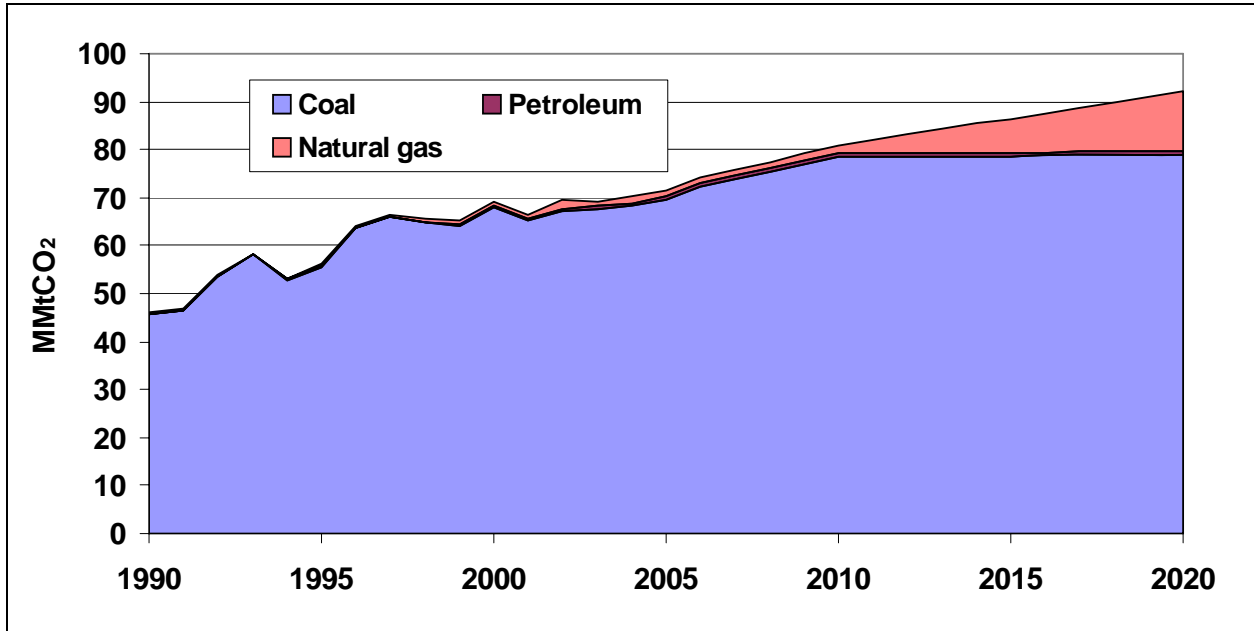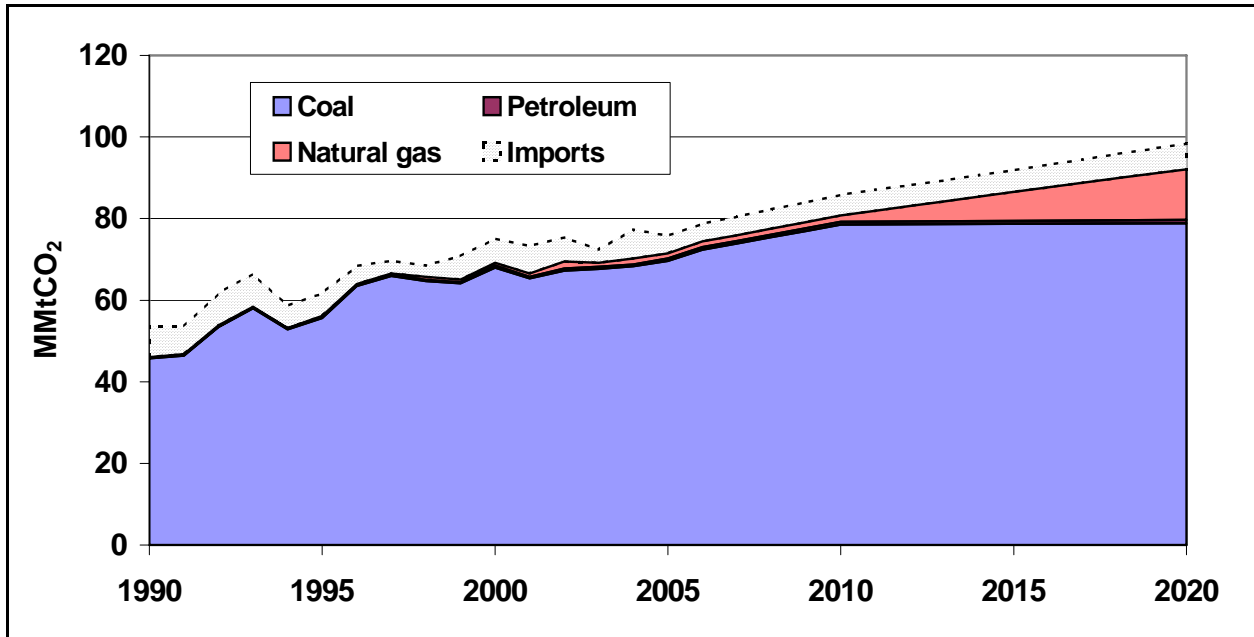
**Figure 15.  North Carolina CO$_2$ Emissions Associated with Electricity Use (Consumption-Basis) and Imports**

# Appendix B. Residential, Commercial, and Industrial Fuel Combustion

The RCI[32] sectors produce $CO_2$, $CH_4$, and $N_2O$ emissions when fuels are combusted for space heating, process heating, and other applications. Carbon dioxide accounts for over 99% of these emissions on an MMtCO2e basis. In addition, since these sectors consume electricity, one can also attribute electricity use emissions to these sectors.[33] This is particularly important to consider as the CAPAG begins to explore options to improve energy efficiency (see Figures 16-18) because the emissions associated with electricity use exceed those from direct fuel use in each sector, especially in residential and commercial buildings.

Direct use of coal, oil, natural gas, and wood[34] in the RCI sectors accounted for about 19% of gross GHG emissions in 2000. However, if emissions associated with RCI electricity use are included, RCI energy use then accounts for 62% of gross GHG emissions.

Emissions for direct fuel use were estimated using the US EPA's SGIT. Two changes were made to the default data provided in SGIT. First, the 2000 consumption estimates were updated using data from EIA's *State Energy Data 2001.*[35] The default data in the SGIT workbook are from EIA's *State Energy Data 2000*; however, the 2000 consumption estimates were revised in the 2001 edition of State Energy Data.

The second change made to the default data in SGIT was to the non-fuel consumption estimates. For industrial stationary sources, the non-fuel usage for each fuel type must be subtracted from the total consumption to give the amount of fuel combusted. The SGIT calculates this non-fuel usage using the national percentage of fuel used for non-energy purposes. According to Mr. Perry Lindstrom at EIA, using national percentages will over-estimate non-fuel usage for states that do not have a large petrochemical industry.[36] Based on communication with Mr. Lindstrom, revised non-fuel consumption was estimated for distillate fuel, petroleum coke, residual fuel, and natural gas. For these fuels the amount of non-fuel use was estimated by multiplying the total national non-fuel consumption by the ratio of the state-to-national value of shipments for North American Industry Classification System (NAICS) 3251 (Basic chemical manufacturing) for 1997-2001 and Standard Industrial Classification (SIC) 281 (Industrial Inorganic Chemicals) and 286 (Industrial Organic Chemicals) for 1992-1996. The value of shipments was not available for 1990 and 1991, so the 1992 ratio was used for these years. The value of shipments was obtained from the Bureau of Census' (BOC's) Annual Survey of

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[32] The industrial sector includes agricultural energy use as well.

[33] One could similarly allocate GHG emissions due to natural gas transmission and distribution and other sources, but we have not done so here due to the relatively small level of emissions.

[34] Emissions from wood combustion include only $N_2O$ and $CH_4$. Carbon dioxide emissions from biomass are assumed to be "net zero" consistent with USEPA and IPCC methodologies, and any net loss of carbon stocks due to biomass fuel use should be picked up in the land use and forestry analysis.

[35] *State Energy Data 2001,* Energy Information Administration, Department of Energy

[36] Mr. Perry Lindstrom, Energy Information Administration, Department of Energy. Personal communication with H. Lindquist, E.H. Pechan & Associates, email titled "RE: Data Request", June 9, 2005.

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Manufacturers. Mr. Lindstrom indicated that for LPG, the non-fuel percentage for North Carolina is zero.

Reference case emissions for direct fuel combustion were estimated using fuel consumption forecasts from *North Carolina Energy Outlook 2003*.[37] Figures 16, 17, and 18 illustrate base year and projected emissions for the RCI sectors from 1990 to 2020. Electricity consumption accounts for the largest component of each sector's emissions. The commercial sector shows the highest emissions growth, due to assumed strong growth in both electricity and natural gas consumption. Commercial electricity use grows faster than employment, while per-employee direct fuel use decreases. Residential sector emissions show strong growth with electricity and natural gas use growing faster than population. The assumed growth rate for industrial sector fuel and electricity consumption is also higher than the growth in employment. For both the commercial and industrial sectors, energy consumption and resulting GHG emissions grow at a slower pace than GSP indicating an overall decrease in GHG intensity.[38]

**Figure 16.  Residential Sector GHG Emissions from Fuel Combustion**



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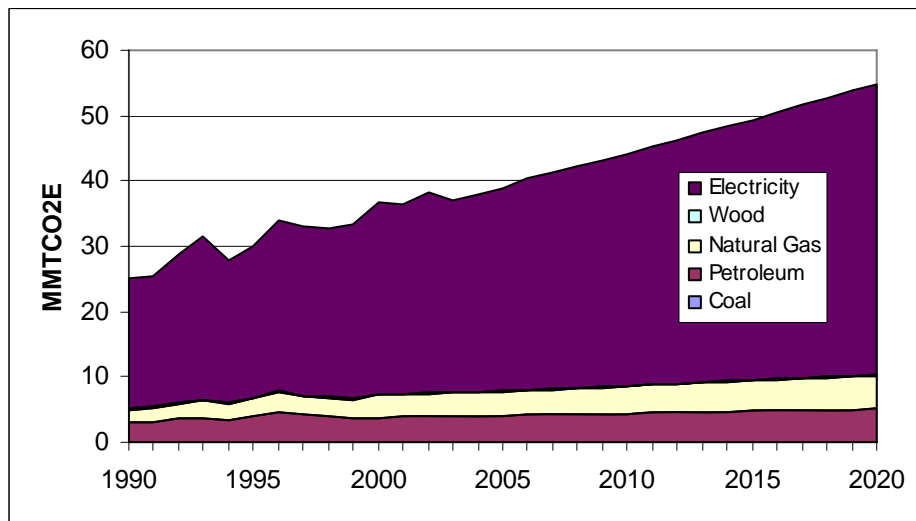
[37] *NC Energy Outlook 2003*. Prepared by Global Insight for State Energy Office, North Carolina Department of Administration, May 2003.

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

**Figure 17.  Commercial Sector GHG Emissions from Fuel Combustion**
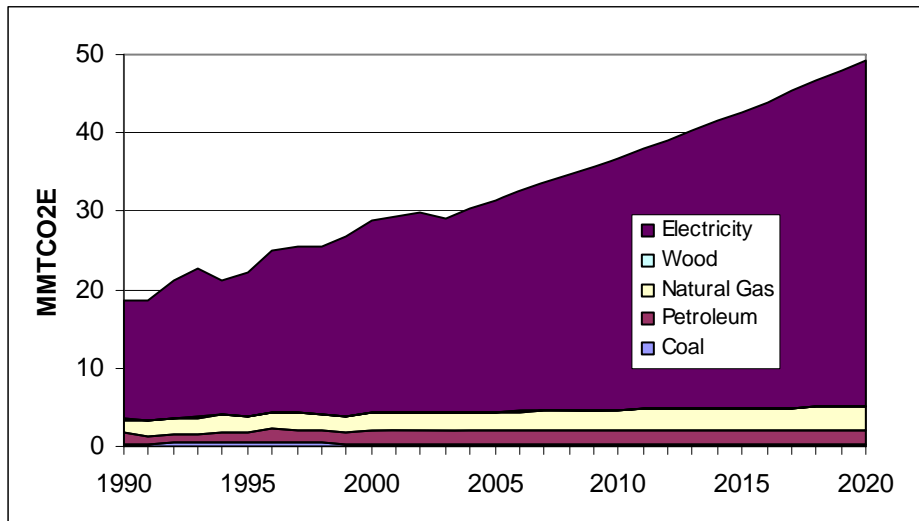


**Figure 18.  Industrial Sector GHG Emissions from Fuel Combustion**
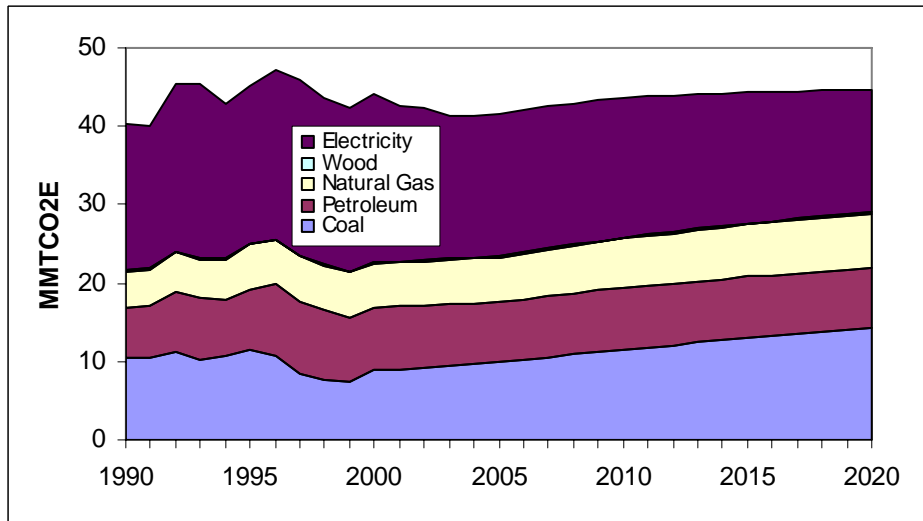


Key sources of uncertainty underlying the estimates are as follows:

- The average emission factors in the SGIT do not capture differences in emissions from different combustion technologies;
- There are uncertainties associated with the activity data from EIA. For example, in the EIA data sets, wood used in fireplaces, wood stoves, and campfires is not fully captured. Uncertainties are also associated with the allocation of fuel consumption data to individual end-use sectors; and
- Non-energy fuel consumption was estimated based on national consumption estimates.

# Appendix C.  Transportation Energy Use

The transportation sector is a major source of GHG emissions in North Carolina – currently accounting for about 30% of North Carolina's gross GHG emissions from 1990-2020. Carbon dioxide accounts for about 96% of transportation GHG emissions from fuel use in 1990 and increases to about 99 % of transportation GHG emissions from fuel use by 2020. Most of the remaining GHG emissions from the transportation sector are due to $N_2O$ emissions from gasoline engines.

As shown in Figure 19, on-road gasoline consumption accounts for the majority of transportation GHG emissions in 1990 and in 2000 – increasing by about 28% during this period. GHG emissions from on-road diesel fuel consumption increased by 60% from 1990 to 2000, and by 2000 accounted for nearly 21% of GHG emissions from the transportation sector. Air travel energy consumption had a rate of growth similar to on-road gasoline consumption, yet the share of emissions from air travel decreased slightly from 1990 to 2000. Consumption of natural gas and propane plus emissions from petroleum lubricants accounted for only about 2% of transportation emissions in 1990 and the total emissions from these sources declined by nearly 20% from 1990 to 2000.

**Figure 19.  Transportation GHG Emissions for North Carolina, 1990-2020**
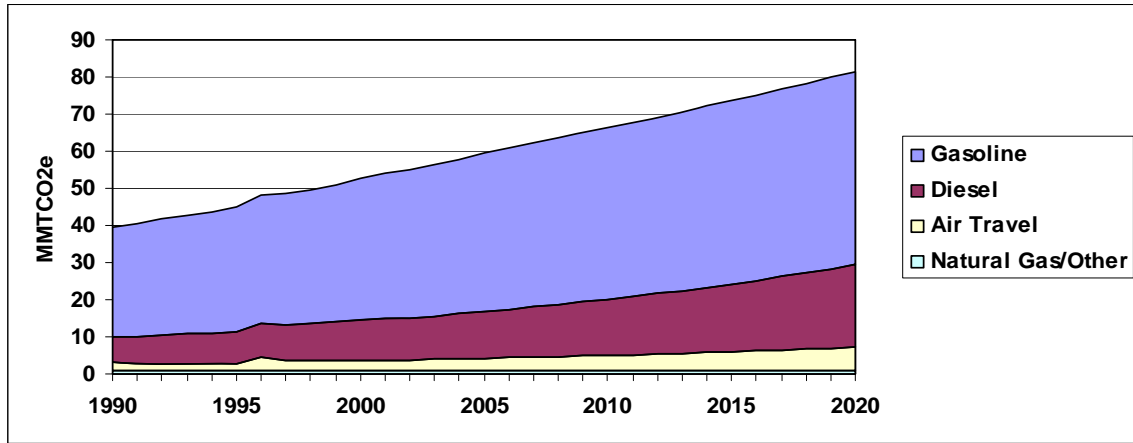


GHG emissions from transportation are expected to grow considerably over the next 15 years due to increased demand for current modes of transportation. North Carolina studies suggest on-road vehicle miles traveled (VMT) will continue to grow faster than population. VMT projections supplied by NC DENR suggest that VMT will grow at a rate of about 2.4 % per year between 2002 and 2009. We assumed that this annual VMT growth rate would continue through 2020. The *North Carolina Energy Outlook 2003* showed similar rates of growth in onroad fuel consumption between 2002 and 2020.

These assumptions combine to produce more than a doubling of GHG emissions from the transportation sector from 1990 to 2020. GHG emissions from on-road diesel consumption are

expected to more than triple during this time period, while GHG emissions associated with air travel in 2020 are slightly less than triple their 1990 emissions. While onroad gasoline emissions still account for the greatest share of the transportation emissions in 2020, the share of these emissions shrinks from 75% in 1990 to 64% in 2020, with the increased rate of diesel emissions accounting for the decreased share of onroad gasoline emissions. The high overall growth in transportation sector emissions suggests many opportunities and challenges for reducing North Carolina's GHG emissions.

The EPA SGIT was used to prepare the inventory and reference case projections. For onroad vehicles, the $CO_2$ emission factor is in units of pound per million Btu (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 9. NC DENR has developed detailed VMT data for selected years and, as shown in Table 9, this VMT data was used to adjust default VMT data in the SGIT to improve the accuracy of the emission estimates for North Carolina. However, resource constraints precluded the direct conversion of the North Carolina VMT data to fuel consumption. Thus, for the $CO_2$ emission calculations, fuel consumption data for North Carolina was obtained from the *North Carolina Energy Outlook 2003*.

*Key uncertainties*

One uncertainty in this analysis is the projected increase in on-road VMT and gasoline consumption from 2002 to 2020. The VMT projections are based on developing growth rates for this entire period based on the modeled growth from 2002 to 2009. Whether this growth rate will actually continue through 2020 is uncertain. However, the growth rate in VMT corresponds reasonably well with the expected growth rate in on-road gasoline fuel consumption, found in the *North Carolina Energy Outlook 2003*. Another concern is that the 2002 North Carolina VMT is considerably greater than the Federal Highway's Highway Performance Monitoring System (HPMS) VMT for 2002 (about 15 % greater). Since it was our understanding that the NC DENR had spent considerable resources to improve on the HPMS data, we are assuming that the North Carolina 2002 VMT data are an improvement over the HPMS data. The FHWA HPMS VMT data from 1990 through 2001 were adjusted to be better aligned with the VMT data developed by NC DENR by applying the ratio of the North Carolina 2002 VMT to the HPMS 2002 VMT data for North Carolina and then multiplying by the HMPS VMT data for each of the base years (1990 through 2001). This adjustment was applied at the vehicle class level of detail.

**Table 9.  Key Assumptions and Methods for Transportation Projections for North Carolina**

| Vehicle Type and Pollutants | Methods |
|---|---|
| **On-road gasoline and diesel vehicles – $CO_2$** | **Inventory (1990 – 2002)** <br><br> EPA SGIT and fuel consumption from *North Carolina Energy Outlook 2003*. <br><br> **Reference Case Projections (2003 – 2020)** <br><br> On-road gasoline and diesel fuel consumption projections from *North Carolina Energy Outlook 2003*. |
| **On-road gasoline and diesel vehicles – $CH_4$ and $N_2O$** | **Inventory (1990 – 2002)** <br><br> The onroad vehicle $CH_4$ and $N_2O$ emission factors by vehicle type and technology type were updated to the latest factors used in the US EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks:  1990-2003*. <br><br> VMT from 1990 through 2001 was calculated by adjusting the FHWA HPMS VMT data according to the ratio of NC DENR's 2002 VMT data to the 2002 HPMS VMT data. <br><br> Composition of on-road fleet by vehicle type and age - NC DENR provided VMT mix by vehicle type information for 2002 and 2009 by geographic area. The VMT mix data were weighted by VMT in each geographic area to obtain a statewide VMT mix. Similarly, NC DENR provided 2002 age distributions by these same geographic areas. Again the data were weighted according to VMT to obtain a statewide age distribution. <br><br> **Reference Case Projections (2003 – 2020)** <br><br> The average annual growth rate for VMT is assumed to be 2.4% per year from 2002 to 2020, based on detailed 2002 and 2009 VMT data files provided by NC DENR. |
| **Non-highway fuel consumption (jet aircraft, gasoline-fueled piston aircraft, agricultural and construction equipment, railway locomotives, boats, and ships) – $CH_4$  and $N_2O$** | **Inventory (1990 – 2002)** <br><br> EPA SGIT and Non-highway fuel consumption from the *North Carolina Energy Outlook 2003*. <br><br> **Reference Case Projections (2003 – 2020)** <br><br> Non-highway fuel consumption projections (including aviation fuel consumption) are based on data from the *North Carolina Energy Outlook 2003*. |

# Appendix D.  Industrial Processes

Emissions in this category span a wide range of activities, and reflect GHG emissions from $CO_2$ produced through soda ash, limestone, and dolomite use to the release of high GWP gases from semiconductor manufacture (PFCs, HFCs, and $SF_6$), electricity transformers ($SF_6$), and ozone-depleting substances (ODS) substitutes (HFCs and PFCs).

Emissions from this category are expected to continue to grow rapidly, as shown in Figure 20, almost entirely due to the increasing use of HFCs in refrigeration and air conditioning equipment. HFCs are being used as substitutes for ODS, most notably CFCs (chlorofluorocarbons) in compliance with the *Montreal Protocol*.[39] Following guidelines developed by the IPCC and followed by the US EPA and others, ODS are excluded from these estimates of GHG emissions because the production of these compounds is now controlled by the *Montreal Protocol* (see Appendix I for more information).[40] Even low amounts of HFC emissions, from leaks and other releases under normal use of the products, can lead to high GHG emissions in $CO_2$ equivalent terms, due to the high global warming potential of these substances. Emissions from the ODS substitutes in North Carolina have increased from 0.008 MMtCO2e in 1990 to 2.2 MMtCO2e in 2000, and are expected to increase an average of 10% per year from 2000 to 2020.[41]

Emissions of $SF_6$ from electrical equipment have experienced declines since the mid-nineties and emissions of PFCs in the semiconductor industry began to decline in the late nineties, mostly due to voluntary action by industry. Future emissions could increase due to expected increases in semiconductor manufacturing and electricity supply, or decrease due to process changes and continued industry efforts. Projections from the U.S. Climate Action Report[42] show expected

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[39] ODS substitutes are primarily associated with refrigeration and air conditioning, but also many other uses such as fire extinguishers, solvent cleaning, aerosol sprays, foam production and sterilization.

[40] Note that the US EPA provides estimates of national GHG emissions from ODS and a range of GWP factors to convert emissions to $CO_2$e. There is much uncertainty about the appropriate GWP factors to use:  ODS 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. Using the range of GWP factors and allocating the national emissions to North Carolina based on the State's population, we calculated rough ranges of estimates of the GHG emissions from ODS as follows

        GHG Emissions from ODS in North Carolina
        1990          0.06-87.07 MMtCO$_2$e
        2002          0.02-21.33 MMtCO$_2$e

These values are excluded from the emissions reported in this report but are provided here as additional information. The net climate impact of the expanding use of HFCs used as ODS substitutes, considering also the emissions that would have accrued from use of the ODS that the HFCs replace, is thus unclear.

[41] Growth rates are based on growth in projected national emissions from U.S. Department of State, *U.S. Climate Action Report 2002*, Washington, D.C., May 2002.
http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/SHSU5BNQ76/$File/ch5.pdf.

[42] U.S. Department of State, *U.S. Climate Action Report 2002*, Washington, D.C., May 2002.
http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/SHSU5BNQ76/$File/ch5.pdf.

decreases in these emissions at the national level due to a variety of industry actions to reduce emissions, and we have assumed the same rate of decline for emissions in North Carolina.

**Figure 20.  GHG Emissions from Industrial Processes for North Carolina**
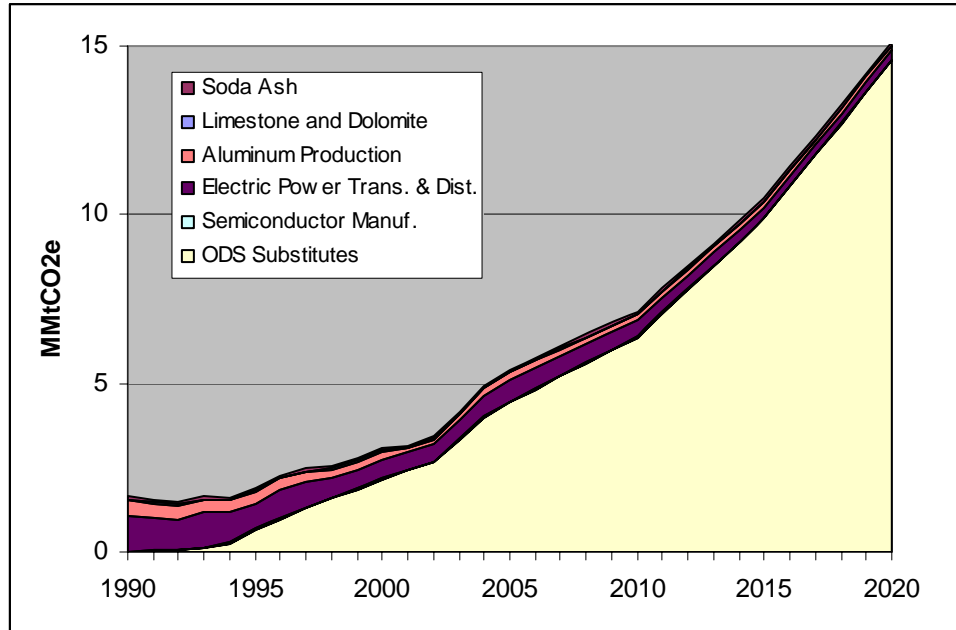


Emissions from aluminum production have decreased since 1990 and are expected to remain below 1990 levels out to 2020. We have assumed the same rate of decline as used for national emissions in the U.S. Climate Action Report.

Limestone and dolomite consumption data were not available for the years 1990 to 1993. There is no clear trend in limestone and dolomite use from 1994 to 2002, because the consumption in 1996 and 1999 is much higher (3-4 times) than the other years. Emissions from soda ash consumption declined in the early nineties but steadily increased between 1994 and 2003. For 2003 to 2020, we applied the following assumptions for projected changes:

- Emissions from soda ash consumption increase at the same rate as population growth (1.8% per year); and
- Emissions from limestone and dolomite show no change from 2002 levels.

# Appendix E.  Natural Gas Transmission and Distribution

Methane emissions from natural gas distribution and transmission were estimated using the US EPA's SGIT. For natural gas distribution pipelines, the length and type of pipeline in North Carolina and the number of services (i.e., local connections in North Carolina) were obtained from the US Office of Pipeline Safety (OPS).[43] For natural gas transmission pipelines (including interstate lines), the OPS data do not provide pipeline mileage for each state; therefore, the mileage in North Carolina for interstate lines was obtained from the North Carolina Utilities Commission (NCUC).[44] The number of liquefied natural gas (LNG) storage, gas storage, and gas transmission compressor stations was also provided by NCUC. Because of limited time to collect data, estimates were only made for 2000 and the projection years. Key sources of uncertainty underlying the estimates are as follows:

- The pipeline system in North Carolina is relatively new compared to that of other states; therefore, the use of US EPA's average emission factors may overestimate emissions in North Carolina; and
- Most of the compressor stations in North Carolina are much smaller than the compressor stations found on large interstate lines. A single average emission factor does not accurately represent both types of compressor stations.

Reference case estimates were calculated using projected natural gas consumption from *North Carolina Energy Outlook 2003*. Figure 21 illustrates base year and projected emissions for Natural Gas Transmission and Distribution.

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[43] U.S. Office of Pipeline Safety, http://ops.dot.gov/stats/DT98.htm
[44] Bill Gilmore, North Carolina Utilities Commission. Personal communication with H. Lindquist, E.H. Pechan & Associates, email titled "RE: Greenhouse Gas Inventory", July 12, 2005.

**Figure 21.  GHG Emissions from Natural Gas Transmission and Distribution for North Carolina**
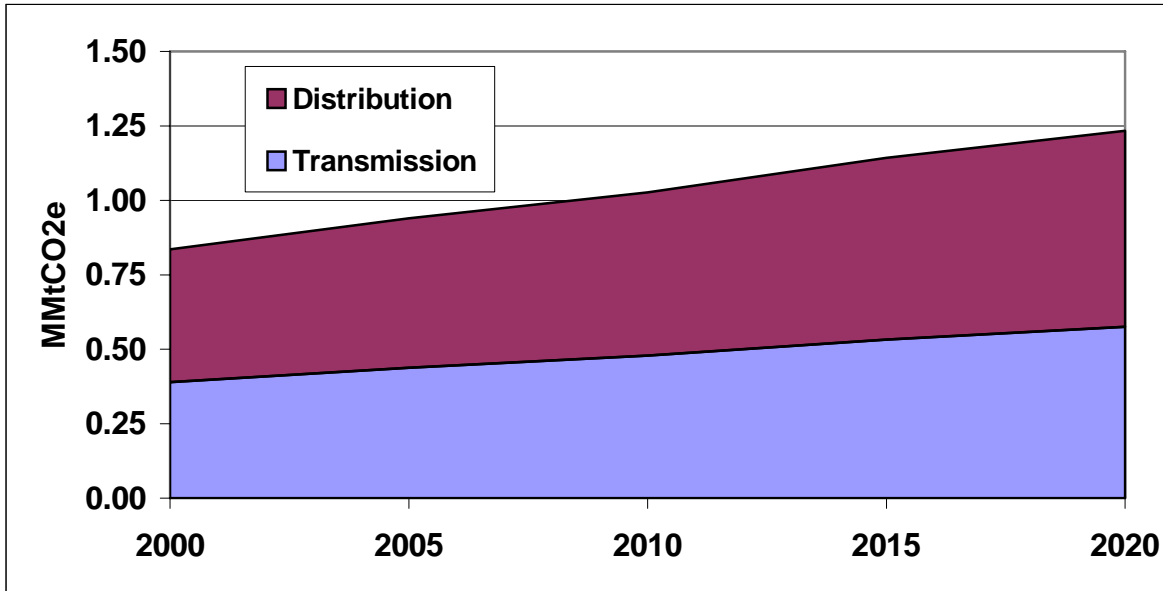
# Appendix F.  Agriculture

The emissions discussed in this appendix refer to non-energy emissions from agricultural production. These include emissions from livestock, agricultural soil management, and field burning.

Agriculture emissions include $CH_4$ and $N_2O$ emissions from enteric fermentation, manure management, agriculture soils, and agriculture residue burning. Data on crops and animals in the state from 1990 to 2000 are available from the USDA National Agriculture Statistical Service.[45] As shown in Figure 22, emissions from these sources remained stable from 1990 to 2000 for all but one source sector. Manure management GHG emissions have increased steadily in North Carolina since 1990. GHG emissions in 2000 are about 37% above 1990 levels. Emissions from agricultur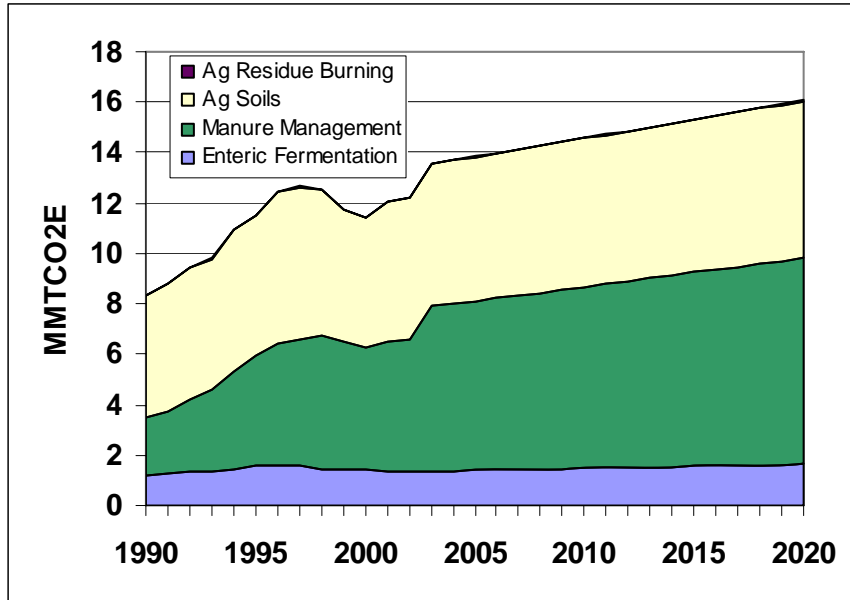al soils account for the largest portion (about 50%) of agricultural emissions from 1990 to 2000. Enteric fermentation and manure management accounted for about 13% and 36% of agricultural emissions, respectively. Enteric fermentation emissions remained relatively constant to 2000, but manure management emissions rose by 8% per year (presumably due to the growth in swine production). Emissions from agricultural residue burning are very small and also remained relatively constant from 1990 to 2000. There was no rice cultivation in North Carolina, and therefore, no emissions from this sector.

Other than the swine population, which is assumed to remain at the 2000 level, livestock populations for 2001 to 2020 are based on the growth factors calculated from 1990 to 2000 population data from the USDA. Post 2000 population estimates were made by extrapolating historical population estimates. Due to the August 1997 moratorium on new and expanded swine farms, swine populations were kept static in the post-2000 period (the moratorium applies to operations with 250 or more hogs; however most of the growth in swine production has been in large production facilities). Once the future population estimates were made, emissions were calculated accordingly using the SGIT. Future year total GHG emissions increase slightly, mainly due to emissions from the manure management sector. After 2003, manure management emissions became the largest contributor to agricultural emissions (~50%).

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[45] USDA (2001), *Published Estimates Database.* U.S. Department of Agriculture, National Agriculture Statistics Service, Washington, DC, http://www.nass.usda.gov:81/ipedb/.

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**Figure 22. North Carolina GHG Emissions from Agriculture**



Note: From 2000 forward, swine populations are held constant to account for the
August 1997 moratorium on new and expanded swine farms with 250 or more head.

# Appendix G.  Waste Management

GHG emissions from waste management include:

- Solid waste management – $CH_4$ emissions from landfills and waste combustion, accounting for identified $CH_4$ that is flared or captured for energy production; and
- Wastewater management – $CH_4$ and $N_2O$ from municipal wastewater treatment facilities.

We used the US EPA SGIT and the US EPA LMOP landfills database to estimate emissions. However, our contact, Ed Mussler, from the Division of Waste Management, NC DENR, indicated that these data were collected in the early 1990s and may not be up-to-date. Some newer data on waste-in-place in hard copy report format were obtained for 41 large landfills in North Carolina. Unfortunately, the effort required to incorporate these data into the LMOP database are beyond the resources currently available. The most important data need for this analysis was information on which sites employed landfill gas collection and control systems. These data could also be obtained in hard copy format through the office of waste management; however, the significant effort required is beyond the resources available in this project.

LMOP provides waste-in-place data for North Carolina landfills. To obtain the annual disposal 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.

Of particular concern are emissions from landfills where the SGIT estimates emissions based on $CH_4$ recovery methods– this tool uses different methods to estimate emissions from: (1) uncontrolled landfills;[46] (2) landfills with a landfill gas collection system and flare;[47] and (3) landfills with a landfill gas collection system and landfill-gas-to-energy (LFGTE) plant.[48] The information on whether or not a particular landfill has collection and flaring or LFGTE controls is not available for all of the landfills that are in the LMOP database. Of the 129 landfills in the LMOP database, only 22 were shown to have any type of collection and control. We expect that many more landfills have some type of collection and control in place. For the landfills that we identified as having either collection and flaring or LFGTE, we assumed that the overall collection and control efficiency is 75%.[49]

Figure 23 shows emissions for the waste management sector. For the reference case projections for landfills, no growth from the 2005 level was assumed, because the emissions for the past two decades did not follow the population. On a per capita basis, $CH_4$ emissions from landfills are expected to continue to decline due to Federal requirements (New Source Performance Standards and Emission Guidelines), which require landfills to collect and control landfill gas emissions. Emissions from wastewater were also estimated using the SGIT. These emissions increased by

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[46] Estimates are based on EPA LMOP data on municipal solid waste generation from landfills.
[47] Based on information supplied by Vincent Throop, NC State Energy Office.
[48] Based on information supplied by Vincent Throop, NC State Energy Office.
[49] As per EPA's AP-42 Section on Municipal Solid Waste Landfills.

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0.7% per year from 1990 to 2000.[50] Projected emissions are assumed to increase with population growth, 2.1% per year from 2003 to 2020.

We also made an effort to obtain data to estimate industrial wastewater emissions. The SGIT provides default assumptions and emission factors for three industrial sectors: Fruits & Vegetables, Red Meat & Poultry, and Pulp & Paper. Production rates for each of these three sectors are needed to estimate $CH_4$ emissions. Some information is available through the North Carolina Department of Agriculture.[51] However, the available data are incomplete; therefore, emissions from industrial wastewater were not estimated for this inventory. For example, SGIT requires information on the amount of meat or fruits/vegetables processed. State-level production estimates are available (e.g., for cattle, certain produce items), however the amount of these products that is processed in state was not identified. Further effort could be made to see if the North Carolina Department of Agriculture or other source has the more detailed production data needed for each of these industrial sectors.

Wastewater permit data including both municipal and industrial categories have also been obtained through the North Carolina Division of Water Quality.[52] These data include permitted wastewater flow (gallons per day) for each facility. These data could be utilized to perform quality control of emission estimates in the future; however, we cannot use them to produce emission estimates now, because emission factors have not been identified to pair with the wastewater flow data (SGIT uses industrial production to estimate GHG emissions).

**Figure 23.  North Carolina GHG Emissions from Waste Management**



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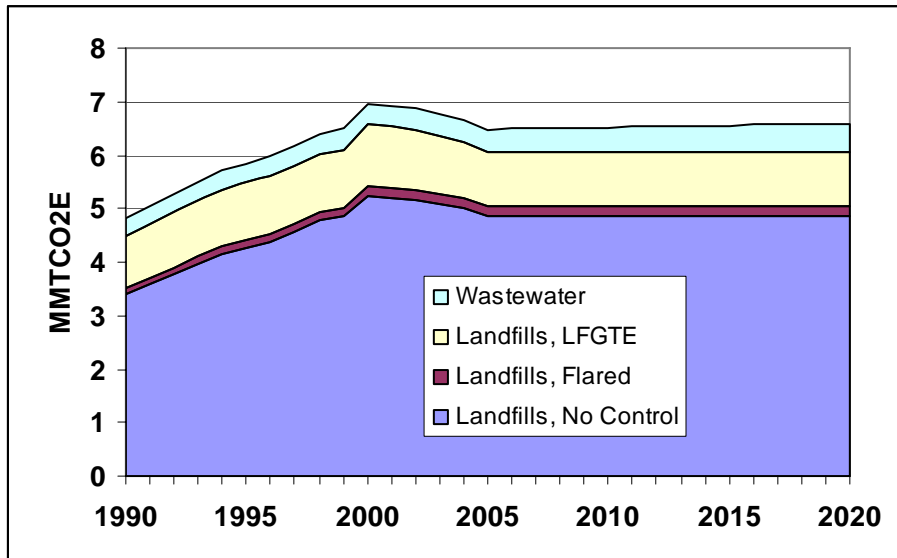
[50] Emissions are calculated in EPA SGIT based on state population, assumed biochemical oxygen demand and protein consumption per capita, and emission factors for $N_2O$ and $CH_4$.
[51] Information from www.ncagr.com/stats/index.htm. Phone: (919) 856-4394
[52] Supervisor: David Goodrich at 919-733-5083 ext 517 provided the data.

# Appendix H.  Forestry

Forestland emissions refer to the net $CO_2$ flux[53] from forested lands in North Carolina, which account for about 56% of the state's land area. Forestlands are net sinks for North Carolina, with carbon sinks from forest soils accounting for the largest removal fraction (see Table 10). Because of an increase harvested wood products and landfill carbon storage from 1987 to 1997, as well as biomass growth on private nonindustrial lands, the size of the total emissions being removed increased between 1990 and 2000 even though significant carbon storage was lost due to land use change.

The default activity data in SGIT were used to estimate forestland $CO_2$ flux. These data come from the United States Forest Service (USFS) data referred to as the Forest Carbon Model (FORCARB). Updated FORCARB data was not available for the inventory. For the reference case projections, the area of forestlands was assumed to remain constant at 1987-1997 levels.

**Table 10.  North Carolina GHG Emissions and Sinks from Forestry and Other Activities**

| Estimated Annual MMtCO$_2$e Flux | 1990-2000 |
|---|---|
| Biomass | -6.9 |
| Forest floor and coarse woody debris | -0.8 |
| Soils | -3.1 |
| Wood products and landfills | -13.0 |
| **Total** | **-23.7** |

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

# Appendix I. 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[54] 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 $33^{\circ}$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

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[54] 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 $0.6 \pm 0.2°C$ 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

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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 11.

**Table 11.  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 $CH_4$ 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:

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

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

GWP values allow policy makers to compare the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of roughly ±35 percent, though some GWPs have larger uncertainty than others, especially those in which lifetimes have not yet been ascertained. In the following decision, the parties to the UNFCCC have agreed to use consistent GWPs from the IPCC Second Assessment Report (SAR), based upon a 100 year time horizon, although other time horizon values are available (see Table 12).

> *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 12.  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 13 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 13. Net 100-year Global Warming Potentials for Select Ozone-Depleting Substances***

| Gas | Direct | Net$_{min}$ | Net$_{max}$ |
|---|---|---|---|
| CFC-11 | 4,600 | (600) | 3,600 |
| CFC-12 | 10,600 | 7,300 | 9,900 |
| CFC-113 | 6,000 | 2,200 | 5,200 |
| HCFC-22 | 1,700 | 1,400 | 1,700 |
| HCFC-123 | 120 | 20 | 100 |
| HCFC-124 | 620 | 480 | 590 |
| HCFC-141b | 700 | (5) | 570 |
| HCFC-142b | 2,400 | 1,900 | 2,300 |
| CHCl$_3$ | 140 | (560) | 0 |
| CCl$_4$ | 1,800 | (3,900) | 660 |
| CH$_3$Br | 5 | (2,600) | (500) |
| Halon-1211 | 1,300 | (24,000) | (3,600) |
| Halon-1301 | 6,900 | (76,000) | (9,300) |

Source: IPCC (2001)

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

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

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

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