Maryland Climate Action Plan

Appendix C
Inventory & Forecast

FINAL Maryland
Greenhouse Gas Inventory and Reference Case Projections 1990-2020

Center for Climate Strategies
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Executive Summary

The Center for Climate Strategies (CCS) prepared this report for the Maryland Department of the Environment (MDE). The report presents an assessment of the State's greenhouse gas (GHG) emissions from 1990 to 2020. The preliminary inventory and forecast emission estimates served as a starting point to assist the State, as well as the Maryland Greenhouse Gas & Carbon Mitigation Working Group, with an initial comprehensive understanding of Maryland's current and possible future GHG emissions, and thereby informed the identification and analysis of policy options for mitigating GHG emissions.[1] The Mitigation Working Group and Technical Working Groups have reviewed, discussed, and evaluated the draft inventory and methodologies as well as alternative data and approaches for improving the draft GHG inventory and forecast. The inventory and forecast, as well as this report, have been revised to address the comments provided and approved by the Mitigation Working Group.

Maryland's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the period from 1990 to 2020. 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 Maryland-specific data and inputs. The reference case projections (2006-2020) are based on a compilation of various existing Maryland 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 cover 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.[3]

Table ES-1 provides a summary of historical and reference case projection GHG emissions for Maryland for the years 1990, 2000, 2005, 2010, and 2020. Activities in Maryland accounted for approximately 109 million metric tons (MMt) of *gross*[4] CO_2e emissions (consumption basis) in 2005, an amount equal to about 1.5% of total US gross GHG.[5] Maryland's gross GHG emissions

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[1] Draft Maryland Greenhouse Gas Inventory and Reference Case Projections 1990–2020, prepared by the Center for Climate Strategies for the Maryland Department of the Environment, January 2008.

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

[3] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth–atmosphere system (IPCC, 2001). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth). See: Boucher, O., et al. "Radiative Forcing of Climate Change." Chapter 6 in *Climate Change 2001: The Scientific Basis*. Contribution of Working Group 1 of the Intergovernmental Panel on Climate Change Cambridge University Press. Cambridge, United Kingdom. Available at: http://www.grida.no/climate/ipcc_tar/wg1/212.htm.

[4] Excluding GHG emissions removed due to forestry and other land uses.

[5] The national emissions used for these comparisons based on 2005 emissions from *Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2006*, April 15, 2008, US EPA # 430-R-08-005, http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

are rising at a slightly faster rate than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). Maryland's gross GHG emissions increased by about 18% from 1990 to 2005, while national emissions rose by 16% from 1990 to 2005. The growth in Maryland's emissions from 1990 to 2005 is primarily associated with the transportation and electricity consumption sectors.

Estimates of carbon sinks within Maryland's forests, including urban forests and land use changes, have also been included in this report. The current estimates indicate that about 12 $MMtCO_2e$ was stored in Maryland forest biomass and agricultural soils in 2005. This leads to *net* emissions of 98 $MMtCO_2e$ in Maryland in 2005.

Figure ES-1 illustrates the State's emissions per capita and per unit of economic output. On a gross emissions per capita basis, Maryland residents emitted about 19.3 metric tons (t) of gross CO_2e in 1990, lower than the national average of 24.6 tCO_2e in 1990. Per capita emissions in Maryland increased to 19.7 tCO_2e/yr by 2005, while the per capita emissions for the US have decreased slightly to 24.0 tCO_2e/yr by 2005. Like the nation as a whole, Maryland's economic growth exceeded gross emissions growth throughout the 1990-2005 period (leading to declining estimates of GHG emissions per unit of state product). From 1990 to 2005, gross emissions per unit of gross product dropped by 27% nationally, and by 21% in Maryland.[6]

There are three principal sources of GHG emission in Maryland: electricity consumption; transportation; and residential, commercial, and industrial (RCI) fuel use. Electricity consumption accounted for 42% of gross GHG emissions in 2005. Transportation accounted for 30% of Maryland's gross GHG emissions in 2005, while RCI fuel use accounted for 18% of Maryland's 2005 gross GHG emissions.

As illustrated in Figure ES-2 and shown numerically in Table ES-1, under the reference case projections, Maryland's gross GHG emissions continue to grow, and are projected to climb to about 132 $MMtCO_2e$ by 2020, reaching 42% above 1990 levels.[7] As shown in Figure ES-3, the electricity consumption sector is projected to be the largest contributor to future emissions growth in Maryland, followed by the transportation sector and substitutes for ozone-depleting substances (ODS).

Some data gaps exist in this analysis, particularly for the reference case projections. Key refinements include review and revision of key emissions drivers that will be major determinants of Maryland's future GHG emissions (such as the growth rate assumptions for electricity generation and consumption, transportation fuel use, and RCI fuel use). Appendices A through H provide the detailed methods, data sources, and assumptions for each GHG sector. Also included are descriptions of significant uncertainties in emission estimates or methods and suggested next steps for refinement of the inventory. Appendix I provides background information on GHGs and climate-forcing aerosols.

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[6] Based on real gross domestic product (millions of chained 2000 dollars) that excludes the effects of inflation, available from the US Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/). The national emissions used for these comparisons are based on 2005 emissions from the 2008 version of EPA's GHG inventory report (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

[7] Note that electricity sector emission reductions attributable to the Regional Greenhouse Gas Initiative (RGGI) are not included in the reference case emissions inventory. Reductions from RGGI are illustrated in Appendix A.

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

MMtCO$_2$e	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Energy Use (CO$_2$, CH$_4$, N$_2$O)	**84.9**	**93.6**	**99.5**	**102.6**	**117.6**	
Electricity Use (Consumption)[b]	**38.6**	**43.6**	**45.9**	**46.5**	**54.8**	
Electricity Production (in-state)	29.8	35.1	34.0	34.3	39.6	*See electric sector assumptions*
Coal	23.9	30.5	28.8	30.3	35.0	*in appendix A.*
Natural Gas	1.60	1.98	1.52	1.50	1.95	
Oil	4.22	2.42	3.52	2.19	2.35	
Wood	0.003	0.003	0.004	0.009	0.011	
MSW/LFG	0.03	0.21	0.19	0.20	0.22	
Net Imported Electricity	8.83	8.55	11.82	12.27	15.25	
Residential/Commercial/Industrial (RCI) Fuel Use	**21.1**	**19.1**	**20.0**	**20.2**	**20.7**	
Coal	5.54	2.14	3.21	3.23	3.21	Based on US DOE regional projections
Natural Gas	8.25	9.80	9.94	10.4	11.3	Based on US DOE regional projections
Petroleum	7.27	7.04	6.79	6.43	6.16	Based on US DOE regional projections
Wood	0.08	0.10	0.08	0.08	0.07	Based on US DOE regional projections
Transportation	**24.2**	**29.9**	**32.5**	**34.8**	**40.9**	
Onroad Gasoline	17.9	21.6	23.9	25.3	28.8	Based on MDE VMT projections.
Onroad Diesel	2.91	5.09	5.89	6.83	9.18	Based on MDE VMT projections.
Marine Vessels	1.36	1.29	1.18	1.15	1.30	
Rail, Natural Gas, and LPG	0.53	0.22	0.20	0.22	0.25	Based on US DOE regional projections.
Jet Fuel and Aviation Gasoline	1.49	1.68	1.31	1.32	1.42	Based on FAA operations projections.
Fossil Fuel Industry	**0.97**	**0.99**	**1.08**	**1.12**	**1.11**	
Natural Gas Industry	0.76	0.85	0.91	0.91	0.90	Based on historical growth and AEO2006 regional natural gas consumption
Coal Mining	0.21	0.13	0.17	0.21	0.22	Based on AEO2006 coal production growth rates for Northern Appalachia region
Industrial Processes	**2.58**	**3.78**	**4.90**	**6.17**	**8.70**	
Cement Manufacture	0.86	0.86	1.27	1.45	1.82	15-year historical trend in clinker production
Limestone and Dolomite	0.09	0.09	0.11	0.11	0.12	15-year historical trend in consumption
Soda Ash	0.05	0.05	0.05	0.05	0.05	15-year historical trend in consumption
Iron and Steel	0.83	0.75	0.60	0.56	0.50	1997-2005 historical trend in production
ODS Substitutes	0.01	1.53	2.31	3.44	5.63	National emissions projections (US EPA)
Electricity Transmission and Dist.	0.50	0.27	0.25	0.23	0.21	National emissions projections (US EPA)
Semiconductor Manufacturing	0.003	0.009	0.007	0.007	0.005	National emissions projections (US EPA)
Aluminum Production	0.25	0.23	0.30	0.33	0.37	15-year historical trend in production
Agriculture	**2.11**	**2.31**	**1.80**	**1.93**	**1.87**	
Enteric Fermentation	0.47	0.38	0.35	0.33	0.33	Based on projected livestock population
Manure Management	0.34	0.33	0.30	0.32	0.32	Based on projected livestock population
Agricultural Soils	1.29	1.59	1.14	1.28	1.22	Based on 1990-2005 emissions growth
Agricultural Burning	0.01	0.01	0.01	0.01	0.01	Based on 1990-2005 emissions growth
Waste Management	**2.86**	**3.27**	**3.26**	**3.30**	**3.40**	
Waste Combustion	0.00	0.00	0.00	0.00	0.00	Emissions included in the electric sector

	Landfills	2.24	2.57	2.52	2.52	2.52	Based on 1995-2005 emissions growth.
	Wastewater Management	0.58	0.67	0.70	0.75	0.85	Based on 1995-2005 emissions growth.
	Residential Open Burning	0.03	0.03	0.03	0.03	0.03	Based on 2000 data with no growth.
Gross Emissions (Consumption Basis, Excludes Sinks)		**92.4**	**103.0**	**109.4**	**114.0**	**131.5**	
	increase relative to 1990		*11%*	*18%*	*23%*	*42%*	
Emissions Sinks		**-7.9**	**-11.5**	**-11.7**	**-11.9**	**-12.3**	
	Forested Landscape	-2.08	-8.89	-8.89	-8.89	-8.89	Based on estimates from the USFS
	Urban Forestry and Land Use	-5.69	-2.42	-2.62	-2.86	-3.27	
	Agricultural Soils (Cultivation Practices)	-0.15	-0.15	-0.15	-0.15	-0.15	Historical and projected emissions held constant at 1997 levels
Net Emissions (Consumptions Basis) (Including forestry, land use, and ag sinks)		**84.5**	**91.5**	**97.8**	**102.1**	**119.2**	
	increase relative to 1990		*8%*	*16%*	*21%*	*41%*	

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

[b] Note that electricity sector emission reductions attributable to the Regional Greenhouse Gas Initiative (RGGI) are not included in the reference case emissions inventory. Reductions from RGGI are illustrated in Appendix A.

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

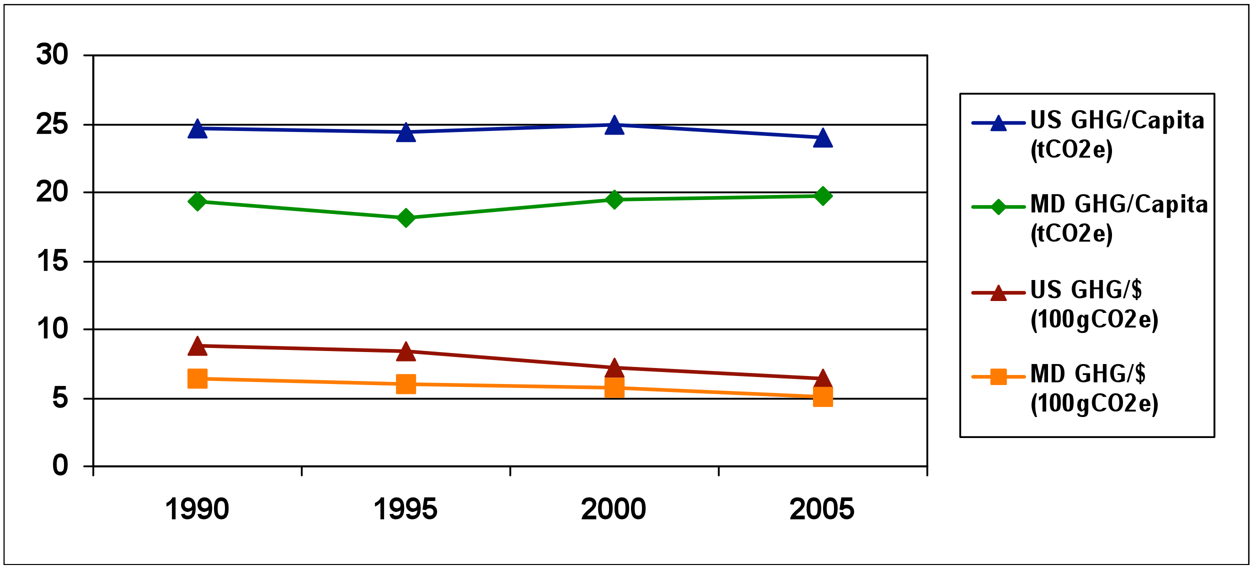
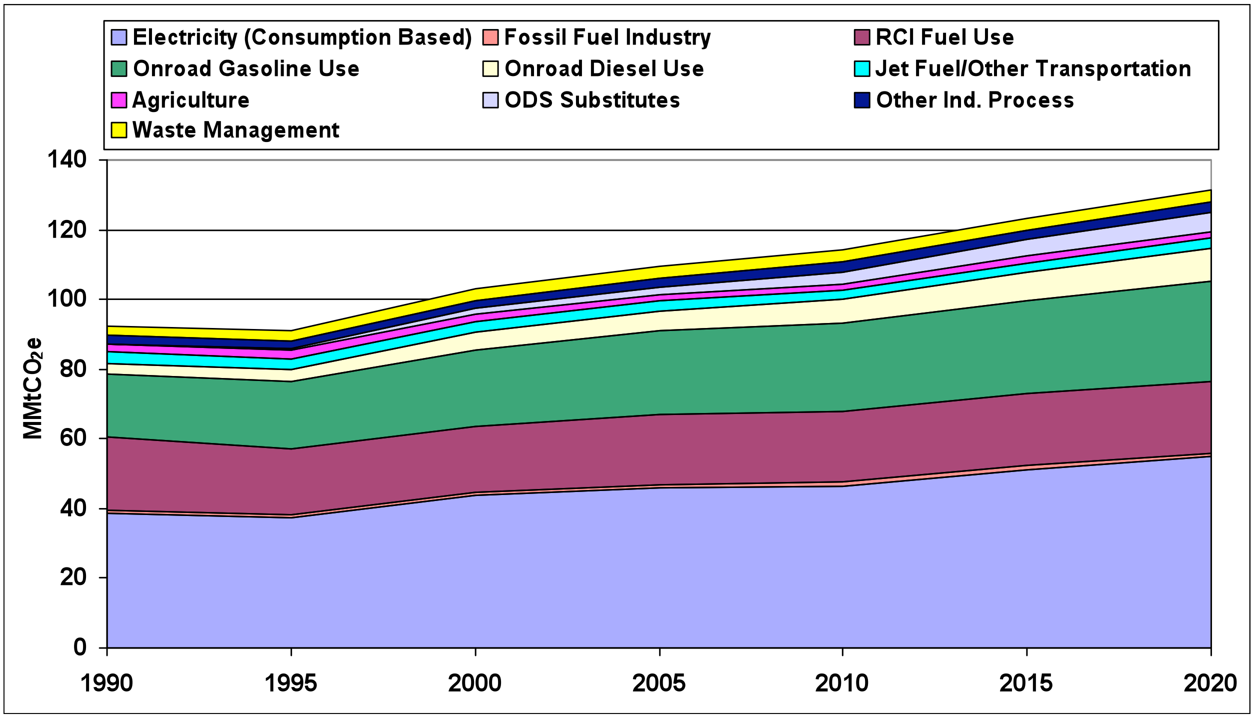
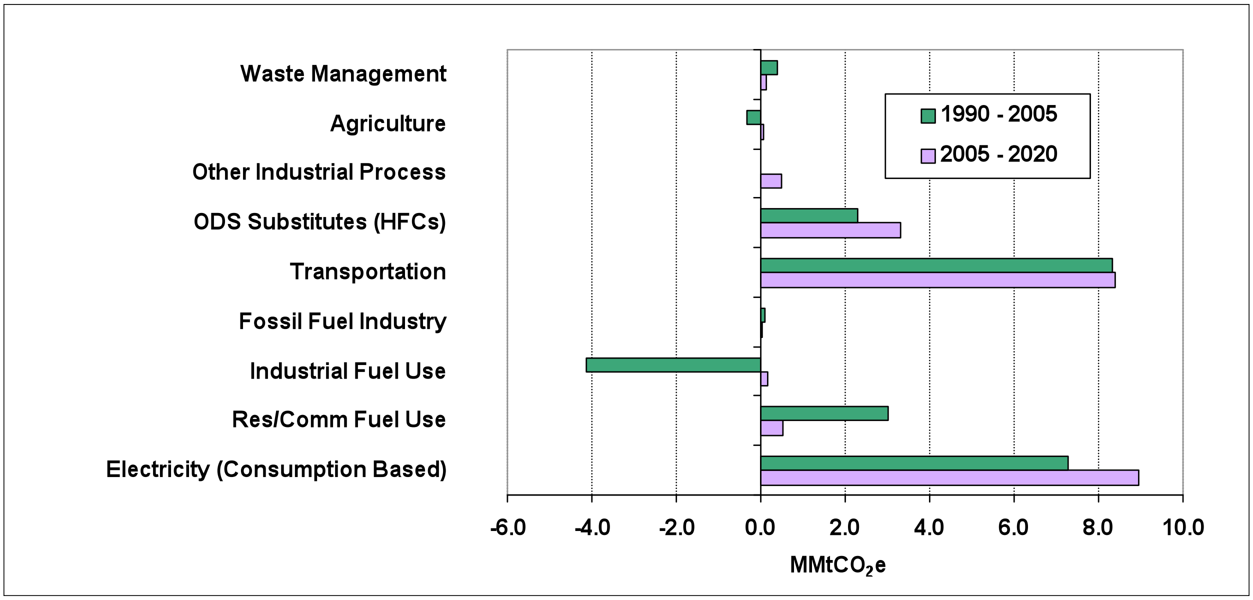


Figure ES-2. Maryland Gross GHG Emissions by Sector, 1990-2020: Historical and Projected



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

Figure ES-3. Sector Contributions to Gross GHG Emissions Growth in Maryland, 1990-2020: Reference Case Projections



Res/Comm – direct fuel use in residential and commercial sectors. ODS – ozone depleting substance. HFCs – hydrofluorocarbons. Emissions associated with other industrial processes include all of the industries identified in Appendix D except emissions associated with ODS substitutes which are shown separately in this graph because of high expected growth in emissions for ODS substitutes.

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Acronyms and Key Terms

AEO2006 – EIA's Annual Energy Outlook 2006

AEO2007 – EIA's Annual Energy Outlook 2007

BOD – Biochemical Oxygen Demand

Btu – British Thermal Unit

C – Carbon*

$CaCO_3$ – Calcium Carbonate

CCS – Center for Climate Strategies

CEC – Commission for Environmental Cooperation in North America

CFCs – Chlorofluorocarbons*

CH_4 – Methane*

CO – Carbon Monoxide*

CO_2 – Carbon Dioxide*

CO_2e – Carbon Dioxide Equivalent*

CRP – Federal Conservation Reserve Program

DOE – Department of Energy

DOT – Department of Transportation

EEZ – Exclusive Economic Zone

EIA – US DOE Energy Information Administration

EIIP – Emission Inventory Improvement Program

FAA – Federal Aviation Administration

FAPRI – Food and Agricultural Policy Research Institute

FERC – Federal Energy Regulatory Commission

FHWA – Federal Highway Administration

FIA – Forest Inventory Analysis

Gg – Gigagrams

GHG – Greenhouse Gas*

GWh – Gigawatt-hour

GWP – Global Warming Potential*

H_2O – Water Vapor*

HBFCs – Hydrobromofluorocarbons*

HC – Hydrocarbon

HCFCs – Hydrochlorofluorocarbons*
HFCs – Hydrofluorocarbons*
HWP – Harvested Wood Products
IPCC – Intergovernmental Panel on Climate Change*
kg – Kilogram
km^2 – Square Kilometers
kWh – Kilowatt-hour
lb – Pound
LF – Landfill
LFG – Landfill Gas
LFGTE – Landfill Gas Collection System and Landfill-Gas-to-Energy
LNG – Liquefied Natural Gas
LPG – Liquefied Petroleum Gas
MAAC – Mid-Atlantic Area Council
MANE-VU – Mid-Atlantic/Northeast Visibility Union
MDDNR – Maryland Department of Natural Resources
MDE – Maryland Department of the Environment
Mg – Megagram
MMBtu – Million British Thermal Units
MMt – Million Metric Tons
MMtC – Million Metric Tons Carbon
$MMtCO_2e$ – Million Metric tons Carbon Dioxide Equivalent
MSW – Municipal Solid Waste
Mt – Metric ton (equivalent to 1.102 short tons)
MWh – Megawatt-hour
N_2O – Nitrous Oxide*
NASS – National Agriculture Statistical Service
NEI – National Emissions Inventory
NEMS – National Energy Modeling System
NF – National Forest
NMVOCs – Nonmethane Volatile Organic Compound*
NO_2 – Nitrogen Dioxide*
NO_x – Nitrogen Oxides*

O_3 – Ozone*

ODS – Ozone-Depleting Substance*

OH – Hydroxyl Radical*

OPS – Office of Pipeline Safety

PFCs – Perfluorocarbons*

ppb – Parts per Billion

ppm – Parts per Million

ppt – Parts per Trillion

ppmv – Parts per Million by Volume

RCI – Residential, Commercial, and Industrial

RGGI – Regional Greenhouse Gas Initiative

RPS – Renewable Portfolio Standard

SAR – Second Assessment Report*

SED – State Energy Data

SF_6 – Sulfur Hexafluoride*

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

SIT – State Greenhouse Gas Inventory Tool

SO_2 – Sulfur Dioxide*

t – Metric Ton

T&D – Transmission and Distribution

TAR – Third Assessment Report*

TOG – Total Organic Gas

TWh – Terawatt-hour

UNFCCC – United Nations Framework Convention on Climate Change

US – United States

US DOE – United States Department of Energy

US EPA – United States Environmental Protection Agency

USDA – United States Department of Agriculture

USFS – United States Forest Service

USGS – United States Geological Survey

VMT – Vehicle Mile Traveled

VOCs – Volatile Organic Compound*

WW – Wastewater
yr – Year

* – See Appendix I for more information.

Acknowledgements

We appreciate all of the time and assistance provided by numerous contacts throughout Maryland, as well as in neighboring States, and at federal agencies. Thanks go to in particular the staff at several Maryland State Agencies for their inputs, and in particular to Tad Aburn, Brian Hug, Roger Thunell, Mohamed Khan, and Walter Simms of the Maryland Department of the Environment who provided key guidance for and review of this analytical effort.

The authors would also like to express their appreciation to Katie Bickel, Steve Roe, Katie Pasko, and Jim Wilson of the Center for Climate Strategies (CCS) who provided valuable review comments during development of this report. Thanks also to Michael Gillenwater for directing preparation of Appendix I.

Summary of Findings

Introduction

The Center for Climate Strategies (CCS) prepared this report for the Maryland Department of the Environment (MDE). The report presents an assessment of the State's greenhouse gas (GHG) emissions from 1990 to 2020. The preliminary inventory and forecast emission estimates served as a starting point to assist the State, as well as the Maryland Greenhouse Gas & Carbon Mitigation Working Group, with an initial comprehensive understanding of Maryland's current and possible future GHG emissions, and thereby informed the identification and analysis of policy options for mitigating GHG emissions.[8] The inventory and forecast, as well as this report, have been revised to address the comments provided and approved by the Mitigation Working Group.

Maryland's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the period from 1990 to 2020. Historical GHG emission estimates (1990 through 2005)[9] were developed using a set of generally accepted principles and guidelines for State GHG emissions inventories, as described in the "Approach" section below, relying to the extent possible on Maryland-specific data and inputs. The reference case projections (2006-2020) are based on a compilation of various existing projections of electricity generation, fuel use, and other GHG-emitting activities, along with a set of simple, transparent assumptions described in the appendices of this report.

This report covers the six gases included in the US Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, CO_2 equivalence (CO_2e), which indicates the relative contribution of each gas to global average radiative forcing on a Global Warming Potential- (GWP) weighted basis.[10]

It is important to note that these emissions estimates reflect the *GHG emissions associated with the electricity sources used to meet Maryland's demands,* corresponding to a consumption-based approach to emissions accounting (see "Approach" section below). Another way to look at electricity emissions is to consider the *GHG emissions produced by electricity generation facilities in the State.* This report covers both methods of accounting for emissions, but for consistency, all total results are reported as *consumption-based.*

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[8] Draft Maryland Greenhouse Gas Inventory and Reference Case Projections 1990–2020, prepared by the Center for Climate Strategies for the Maryland Department of the Environment, January 2008.

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

[10] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth–atmosphere system (IPCC, 2001). Holding everything else constant, increases in GHG concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth). See: Boucher, O., et al. "Radiative Forcing of Climate Change." Chapter 6 in *Climate Change 2001: The Scientific Basis*. Contribution of Working Group 1 of the Intergovernmental Panel on Climate Change Cambridge University Press. Cambridge, United Kingdom. Available at: http://www.grida.no/climate/ipcc_tar/wg1/212.htm.

Maryland Greenhouse Gas Emissions: Sources and Trends

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

This next section of the report provides a summary of the historical emissions (1990 through 2005) followed by a summary of the reference-case projection-year emissions (2006 through 2020) and key uncertainties. We also provide an overview of the general methodology, principles, and guidelines followed for preparing the inventories. Appendices A through H provide the detailed methods, data sources, and assumptions for each GHG sector. Appendix I provides background information on GHGs and climate-forcing aerosols.

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

MMtCO$_2$e	1990	2000	2005	2010	2020	Explanatory Notes for Projections
Energy Use (CO$_2$, CH$_4$, N$_2$O)	**84.9**	**93.6**	**99.5**	**102.6**	**117.6**	
Electricity Use (Consumption)[b]	**38.6**	**43.6**	**45.9**	**46.5**	**54.8**	
Electricity Production (in-state)	29.8	35.1	34.0	34.3	39.6	*See electric sector assumptions*
Coal	23.9	30.5	28.8	30.3	35.0	*in appendix A.*
Natural Gas	1.60	1.98	1.52	1.50	1.95	
Oil	4.22	2.42	3.52	2.19	2.35	
Wood	0.003	0.003	0.004	0.009	0.011	
MSW/LFG	0.03	0.21	0.19	0.20	0.22	
Net Imported Electricity	8.83	8.55	11.82	12.27	15.25	
Residential/Commercial/Industrial (RCI) Fuel Use	**21.1**	**19.1**	**20.0**	**20.2**	**20.7**	
Coal	5.54	2.14	3.21	3.23	3.21	Based on US DOE regional projections
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Marine Vessels	1.36	1.29	1.18	1.15	1.30	
Rail, Natural Gas, and LPG	0.53	0.22	0.20	0.22	0.25	Based on US DOE regional projections.
Jet Fuel and Aviation Gasoline	1.49	1.68	1.31	1.32	1.42	Based on FAA operations projections.
Fossil Fuel Industry	**0.97**	**0.99**	**1.08**	**1.12**	**1.11**	
Natural Gas Industry	0.76	0.85	0.91	0.91	0.90	Based on historical growth and AEO2006 regional natural gas consumption
Coal Mining	0.21	0.13	0.17	0.21	0.22	Based on AEO2006 coal production growth rates for Northern Appalachia region
Industrial Processes	**2.58**	**3.78**	**4.90**	**6.17**	**8.70**	
Cement Manufacture	0.86	0.86	1.27	1.45	1.82	15-year historical trend in clinker production

Limestone and Dolomite	0.09	0.09	0.11	0.11	0.12	15-year historical trend in consumption
Soda Ash	0.05	0.05	0.05	0.05	0.05	15-year historical trend in consumption
Iron and Steel	0.83	0.75	0.60	0.56	0.50	1997-2005 historical trend in production
ODS Substitutes	0.01	1.53	2.31	3.44	5.63	National emissions projections (US EPA)
Electricity Transmission and Dist.	0.50	0.27	0.25	0.23	0.21	National emissions projections (US EPA)
Semiconductor Manufacturing	0.003	0.009	0.007	0.007	0.005	National emissions projections (US EPA)
Aluminum Production	0.25	0.23	0.30	0.33	0.37	15-year historical trend in production
Agriculture	**2.11**	**2.31**	**1.80**	**1.93**	**1.87**	
Enteric Fermentation	0.47	0.38	0.35	0.33	0.33	Based on projected livestock population
Manure Management	0.34	0.33	0.30	0.32	0.32	Based on projected livestock population
Agricultural Soils	1.29	1.59	1.14	1.28	1.22	Based on 1990-2005 emissions growth
Agricultural Burning	0.01	0.01	0.01	0.01	0.01	Based on 1990-2005 emissions growth
Waste Management	**2.86**	**3.27**	**3.26**	**3.30**	**3.40**	
Waste Combustion	0.00	0.00	0.00	0.00	0.00	Emissions included in the electric sector
Landfills	2.24	2.57	2.52	2.52	2.52	Based on 1995-2005 emissions growth.
Wastewater Management	0.58	0.67	0.70	0.75	0.85	Based on 1995-2005 emissions growth.
Residential Open Burning	0.03	0.03	0.03	0.03	0.03	Based on 2000 data with no growth.
Gross Emissions (Consumption Basis, Excludes Sinks)	**92.4**	**103.0**	**109.4**	**114.0**	**131.5**	
increase relative to 1990		*11%*	*18%*	*23%*	*42%*	
Emissions Sinks	**-7.9**	**-11.5**	**-11.7**	**-11.9**	**-12.3**	
Forested Landscape	-2.08	-8.89	-8.89	-8.89	-8.89	Based on estimates from the USFS
Urban Forestry and Land Use	-5.69	-2.42	-2.62	-2.86	-3.27	
Agricultural Soils (Cultivation Practices)	-0.15	-0.15	-0.15	-0.15	-0.15	Historical and projected emissions held constant at 1997 levels
Net Emissions (Consumptions Basis) (Including forestry, land use, and ag sinks)	**84.5**	**91.5**	**97.8**	**102.1**	**119.2**	
increase relative to 1990		*8%*	*16%*	*21%*	*41%*	

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

[b] Note that electricity sector emission reductions attributable to the Regional Greenhouse Gas Initiative (RGGI) are not included in the reference case emissions inventory. Reductions from RGGI are illustrated in Appendix A.

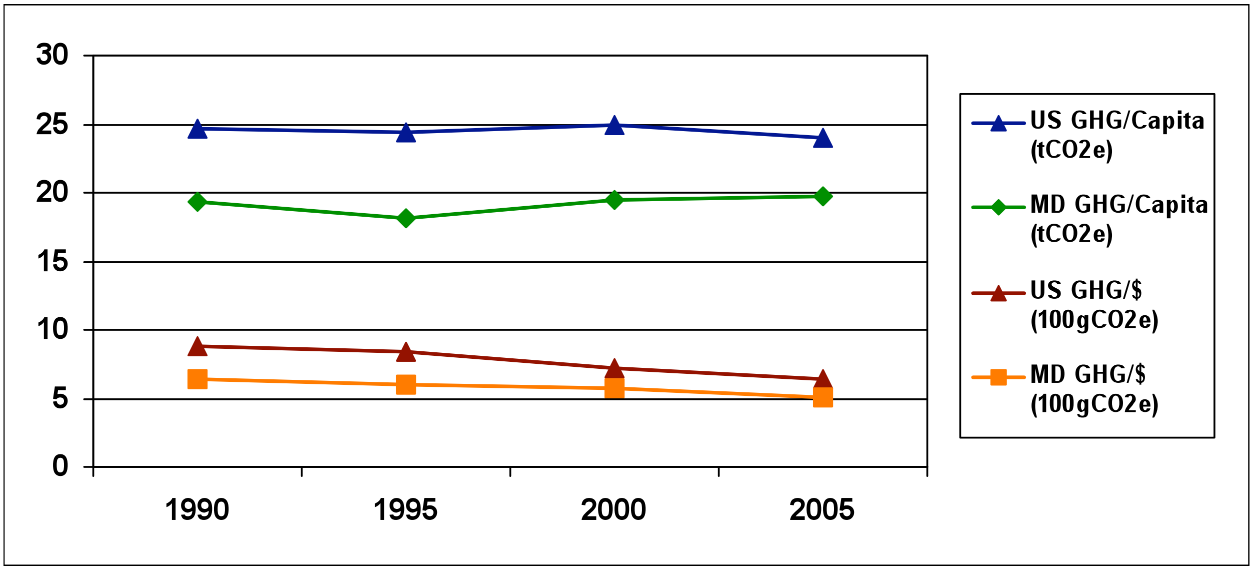
Historical Emissions

Overview

These analyses suggest that in 2005, activities in Maryland accounted for approximately 109 million metric tons (MMt) of gross CO_2e emissions (consumption basis), an amount equal to about 1.5% of total US gross GHG emissions in 2005.[11] Maryland's gross GHG emissions are rising at a slightly faster rate than those of the nation as a whole (gross emissions exclude carbon sinks, such as forests). Maryland's gross GHG emissions increased by about 18% from 1990 to 2005, while national emissions rose by 16% from 1990 to 2005. The growth in Maryland's emissions from 1990 to 2005 is primarily associated with the transportation and electricity consumption sectors.

On a gross emissions per capita basis, Maryland residents emitted about 19.3 metric tons (t) of gross CO_2e in 1990, lower than the national average of 24.6 tCO_2e in 1990. Per capita emissions in Maryland increased to 19.7 tCO_2e/yr by 2005, while the per capita emissions for the US have decreased slightly to 24.0 tCO_2e/yr by 2005. Like the nation as a whole, Maryland's economic growth exceeded gross emissions growth throughout the 1990-2005 period (leading to declining estimates of GHG emissions per unit of state product). From 1990 to 2005, gross emissions per unit of gross product dropped by 27% nationally, and by 21% in Maryland.[12]

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



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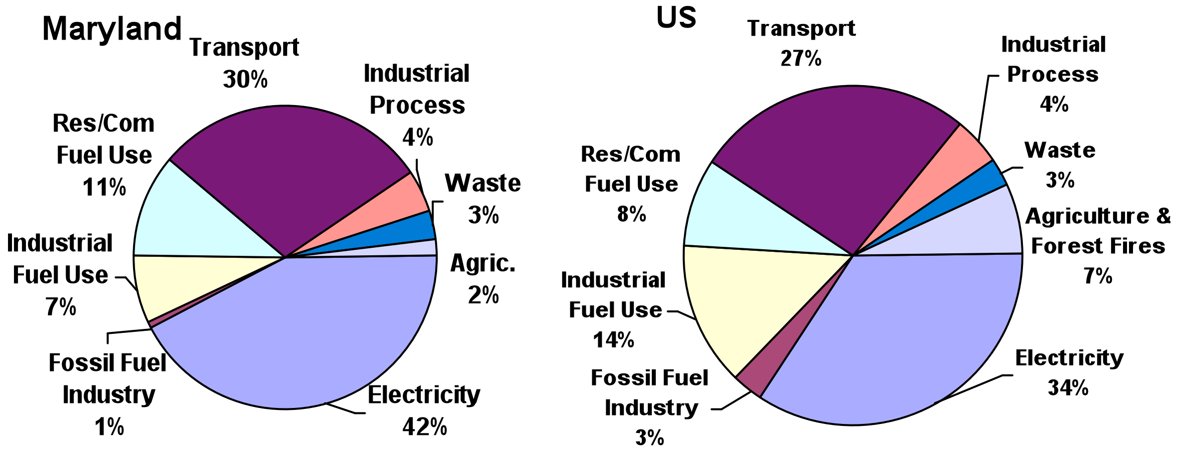
[11] US 2005 emissions estimates are from *Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2006*, April 15, 2008, US EPA # 430-R-08-005, (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

[12] Based on real gross domestic product (millions of chained 2000 dollars) that excludes the effects of inflation, available from the US Bureau of Economic Analysis (http://www.bea.gov/regional/gsp/). The national emissions used for these comparisons are based on 2005 emissions from the 2008 version of EPA's GHG inventory report (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

Figure 2 compares gross GHG emissions estimated for Maryland to emissions for the US for year 2005. Principal sources of Maryland's GHG emissions are the electricity consumption and transportation sectors, accounting for 42% and 30% of Maryland's gross GHG emissions in 2005, respectively. The next largest contributor is residential, commercial, and industrial fuel use (RCI), accounting for 18% of gross GHG emissions in 2005. The waste management and agriculture sectors each contribute 3% and 2% of gross GHG emissions in 2005, respectively.

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



Industrial process emissions comprised 4% of State GHG emissions in 2005. Industrial process emissions are rising rapidly due to the increasing use of HFCs as substitutes for ozone-depleting chlorofluorocarbons (CFCs), and their overall contribution is estimated to grow to be 7% of Maryland's gross GHG emissions in 2020.[13] Other industrial process emissions result from CO_2 released during cement manufacture; soda ash, limestone, and dolomite use; and iron and steel production; releases of SF_6 from transformers used in the transmission and distribution (T&D) of electricity; PFC emissions from aluminum production; and emissions of HFC, PFC, and SF_6 from semiconductor manufacturing.

Methane emissions associated with the extraction and distribution of fossil fuels accounted for 1% of the State's gross GHG emissions in 2005. In Maryland, methane releases to the atmosphere are associated with the operation of natural gas wells, natural gas T&D, and surface and sub-surface coal mining.

The forests and agricultural soils are net sinks of GHG emissions in Maryland, sequestering 12 MMtCO2e in 2005. Overall, activities associated with forestry (including both landscape and urban forests), land use changes, and the cultivation of agricultural soils in Maryland are estimated to be net sinks of GHG emissions throughout the period from 1990 through 2020. Through sequestration, forested lands in Maryland are expected to store about 7.8 $MMtCO_2e$ in

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

1990, increasing to 11.5 MMt CO_2e in 2005, and to 12.2 MMt CO_2e by 2020. The cultivation of agricultural soils is estimated to result in a net sink of about 0.15 MMtCO_2e throughout the 1990 to 2020 period.

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

Electricity Supply Sector

Maryland is a net importer of electricity, meaning that the State consumes more electricity than is produced in the State. For this analysis, it was assumed that all power generated in Maryland was consumed in Maryland, and that remaining electricity demand was met by imported power. Sales associated with imported power accounted for 35% of the electricity consumed in Maryland in 2005.[14] GHG emissions from power produced in-state are dominated by coal use, followed by emissions from oil use and natural gas use. As shown in Figure 2, electricity consumption accounted for about 42% of Maryland's gross GHG emissions in 2005 (about 46 MMtCO_2e), which was higher than the national average share of emissions from electricity consumption (34%).[15] The GHG emissions associated with Maryland's electricity sector increased by about 7 MMtCO_2e between 1990 and 2005, accounting for 43% of the state's net growth in gross GHG emissions in this time period.

In 2005, emissions associated with Maryland's electricity consumption (46 MMtCO_2e) were about 12 MMtCO_2e higher than those associated with electricity production (34.0 MMtCO_2e). The higher level for consumption-based emissions reflects GHG emissions associated with net imports of electricity to meet Maryland's electricity demand.[16] Projections of electricity sales for 2005 through 2020 indicate that Maryland will remain a net importer of electricity. For the period covering 2005 through 2020, the reference case projection assumes that production-based emissions (associated with electricity generated in-state) will increase by about 6 MMtCO_2e, and consumption-based emissions (associated with electricity consumed in-state) will increase by about 9 MMtCO_2e.

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

Transportation Sector

As shown in Figure 2, the transportation sector accounted for about 30% of Maryland's gross GHG emissions in 2005 (about 33 MMtCO_2e), which was higher than the national average share of emissions from transportation fuel consumption (27%). The GHG emissions associated with

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[14] In 2005, total Maryland retail sales were 68,365 GWh, of which 21,870 (i.e., 35%) were estimated to be from imports.

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

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

Maryland's transportation sector increased by 8 $MMtCO_2e$ between 1990 and 2005, accounting for about 49% of the State's net growth in gross GHG emissions in this time period.

From 1990 through 2005, Maryland's GHG emissions from transportation fuel use have risen steadily at an average rate of about 2.0% annually. In 2005, onroad gasoline vehicles accounted for about 74% of transportation GHG emissions. Onroad diesel vehicles accounted for another 18% of emissions, and air travel for roughly 4%. Marine vessels, rail, and other sources (natural gas- and liquefied petroleum gas- (LPG-) fueled-vehicles used in transport applications) accounted for the remaining 4% of transportation emissions. As a result of Maryland's population and economic growth and an increase in total vehicle miles traveled (VMT) during the 1990s, emissions from onroad gasoline use grew about 34% between 1990 and 2005. Meanwhile, emissions from onroad diesel use more than doubled, rising by 103% during that period, suggesting an even more rapid growth in freight movement within or across the State. Emissions from marine fuel use decreased by about 13% from 1990 to 2005, while emissions from rail fuel use decreased about 85% in the same period.

Reference Case Projections (Business as Usual)

Relying on a variety of sources for projections, as noted below and in the appendices, we developed a simple reference case projection of GHG emissions through 2020. As illustrated in Figure 3 and shown numerically in Table 1, under the reference case projections, Maryland's gross GHG emissions continue to grow steadily, climbing to about 132 $MMtCO_2e$ by 2020, 42% above 1990 levels.[17] The electricity consumption sector is projected to be the largest contributor to future emissions growth, followed by emissions associated with transportation and then by ODS substitutes (HFCs), as shown in Figure 4.

Maryland Greenhouse Gas & Carbon Mitigation Working Group Revisions

The following identifies the revisions recommended or approved by the Maryland GHG & Carbon Mitigation Working Group to the inventory and reference case projections, thus explaining the differences between this report and the initial assessment completed during January 2008:

- Energy Supply: Two major changes were made from the first draft of the energy supply inventory and forecast. First, a Maryland-specific electricity sales projection was used instead of the average from the surrounding NERC regions. Second, a Maryland-specific electricity generation projection was used instead of the average from the surrounding NERC regions. These changes resulted in an increase of 2.0 $MMtCO_2e$ emissions from the draft 2020 electricity consumption total of 52.8 $MMtCO_2e$ to the current 2020 estimate of 54.8 $MMtCO_2e$ emissions.

- Fossil Fuel Production and Distribution Industry: Estimates for combustion of natural gas consumed by internal combustion engines to operate pipeline systems in Maryland

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[17] Note that electricity sector emission reductions attributable to the Regional Greenhouse Gas Initiative (RGGI) are not included in the reference case emissions inventory. Reductions from RGGI are illustrated in Appendix A.

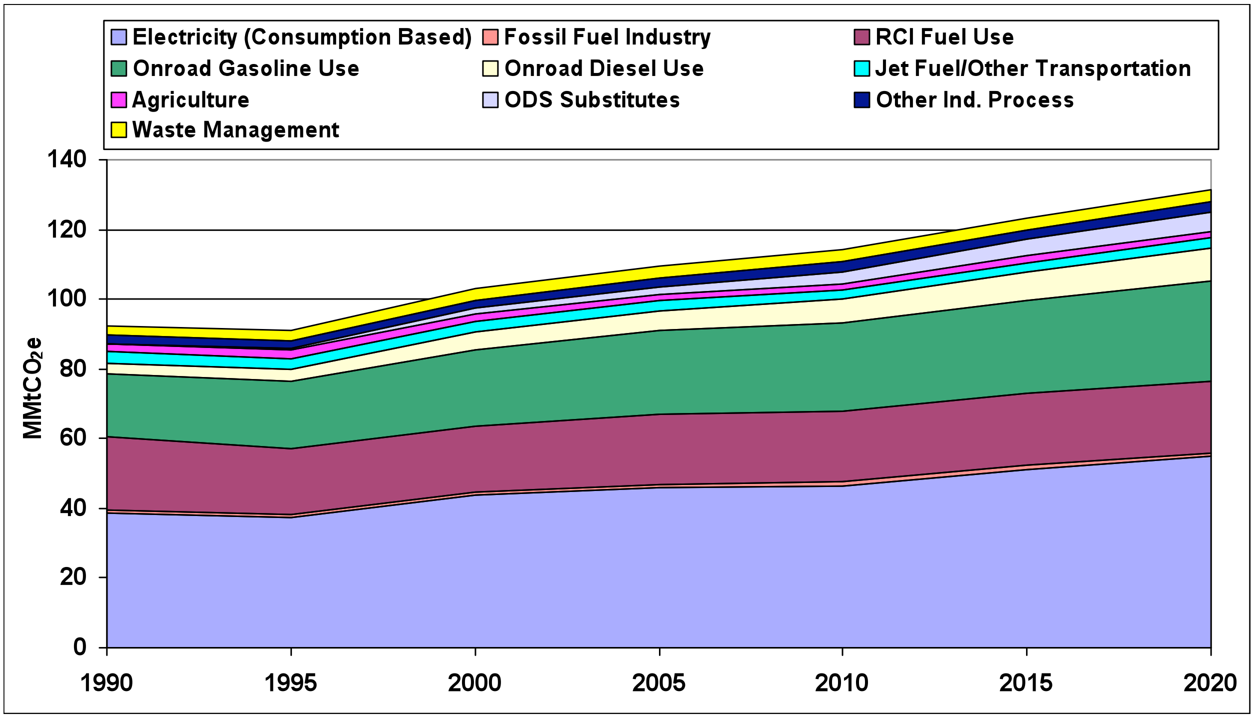
based on SED data were added for 1990 through 2005. In addition, post-2005 emissions were projected using a -0.54%/year rate of decline, representing the state trend in pipeline fuel use over the 1990-2005 period.

- Industrial Processes: As documented in the January draft inventory and forecast report, the growth rate for the iron and steel industry should be -1.4% per year. However, a different growth rate had actually been applied to the iron and steel emissions to estimate the 2006-2020 emissions. The growth rate of -1.4% has been correctly applied to the iron and steel emissions in this final version. This change results in a reduction of the 2020 iron and steel emissions from 0.57 MMtCO$_2$e to 0.50 MMtCO$_2$e.

Key Uncertainties and Next Steps

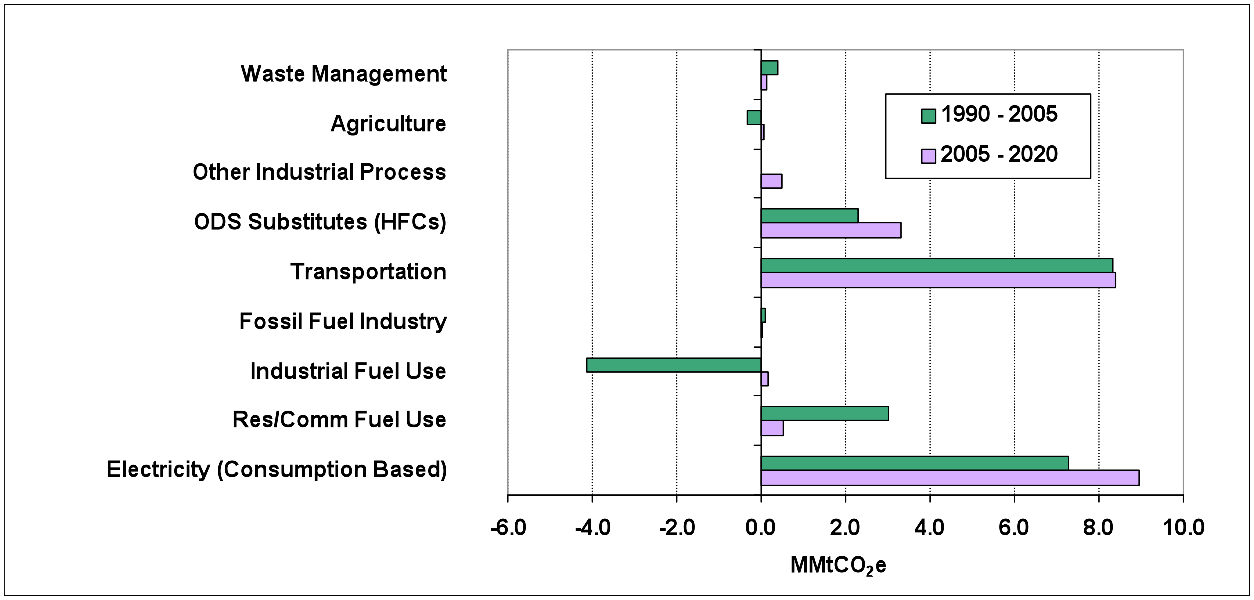
Some data gaps exist in this inventory, and particularly in the reference case projections. Key tasks for future refinement of this inventory and forecast include review and revision of key drivers, such as the transportation, electricity demand, and RCI fuel use growth rates that will be major determinants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

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



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

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



Res/Comm – direct fuel use in residential and commercial sectors. ODS – ozone depleting substance. HFCs – hydrofluorocarbons. Emissions associated with other industrial processes include all of the industries identified in Appendix D except emissions associated with ODS substitutes which are shown separately in this graph because of high expected growth in emissions for ODS substitutes.

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

	1990-2005	2005-2020	Sources
Population[a]	1.01%	0.86%	Maryland Department of Planning, Planning Data Services[18]
Electricity Sales			Inventory period: the total sales growth rate was calculated using historical data for 1990 and 2005 from EIA's State Electricity Profiles; the MD sales growth rate was calculated for 1990 and 2005 using historical data after netting out transmission and distribution losses from net generation statistics; the imported sales growth rate was calculated as the difference between total sales and MD sales for 1990 and 2005. Forecast period: the total, MD and imported sales annual growth rates for 2005-2020 were based on the MD PSC reported entitled, "ELECTRIC SUPPLY ADEQUACY REPORT OF 2007, In compliance with Section 7-505(e) of the Public Utility Companies Article" for the period 2005-2016 (page 9-10).
Total Sales[c]	2.2%	1.5%	
MD Sales[d]	2.9%	1.6%	
Imported Sales[e]	0.9%	1.3%	
Vehicle Miles Traveled	2.3%	1.7%	Maryland Department of the Environment

[a] For the RCI fuel use sectors, growth in annual fuel consumption by sector and type of fuel was calculated from the US DOE EIA's Annual Energy Outlook 2006 (AEO2006) projections of changes in fuel use for the EIA's South Atlantic region. Regional growth rates for the residential sector are adjusted for Maryland's projected population. For instance, growth in Maryland's residential natural gas use is calculated as the Maryland population growth times the change in per capita natural gas use for the South Atlantic region.

[c] Represents annual growth in total sales of electricity met by generators located within and outside Maryland to RCI sectors located within Maryland (consumption basis).

[d] Represents annual growth in total sales of electricity by generators in Maryland to RCI sectors located within Maryland (production basis). Annual growth rate calculated using data for 1990 and 2003.

[e] Represents annual growth rate in sales of electricity imported into Maryland.

Approach

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

General Methodology

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

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[18] Maryland Department of Planning, Planning Data Services. Population data for 1990, 2000, and estimated 2006, 2010, 2020, and 2030 downloaded from http://www.msa.md.gov/msa/mdmanual/01glance/html/pop.html#state.

In most cases, we follow the same approach to emissions accounting for historical inventories used by the US EPA in its national GHG emissions inventory[19] and its guidelines for States.[20] These inventory guidelines were developed based on the guidelines from the Intergovernmental Panel on Climate Change (IPCC), the international organization responsible for developing coordinated methods for national GHG inventories.[21] The inventory methods provide flexibility to account for local conditions. The key sources of activity and projection data used are shown in Table 3. Table 3 also provides the descriptions of the data provided by each source and the uses of each data set in this analysis.

General Principles and Guidelines

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

- **Transparency:** We report data sources, methods, and key assumptions to allow open review and opportunities for additional revisions later based on input from others. In addition, we report key uncertainties where they exist.
- **Consistency:** To the extent possible, the inventory and projections were designed to be externally consistent with current or likely future systems for State and national GHG emission reporting. We have used the EPA tools for State inventories and projections as a starting point. These initial estimates were then augmented and/or revised as needed to conform with State-based inventory and base-case projection needs. For consistency in making reference case projections, we define reference case actions for the purposes of projections as those *currently in place or reasonably expected over the time period of analysis*.
- **Priority of Existing State and Local Data Sources:** In gathering data and in cases where data sources conflicted, we placed highest priority on local and State data and analyses, followed by regional sources, with national data or simplified assumptions such as constant linear extrapolation of trends used as defaults where necessary.
- **Priority of Significant Emissions Sources:** In general, activities with relatively small emissions levels may not be reported with the same level of detail as other activities.

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

Source	Information provided	Use of Information in this Analysis
US EPA State Greenhouse Gas Inventory Tool (SIT)	US EPA SIT is a collection of linked spreadsheets designed to help users develop State GHG inventories for 1990-2005. US EPA SIT contains default data for each State for most of the information required for an inventory. The SIT methods are based on the methods provided in the Volume VIII document series published by the Emissions Inventory Improvement Program (http://www.epa.gov/ttn/chief/eiip/techreport/volum	Where not indicated otherwise, SIT is used to calculate emissions for 1990-2005 from RCI fuel combustion, transportation, industrial processes, agriculture and forestry, and waste. We use SIT emission factors (CO_2, CH_4, and N_2O per British thermal unit (Btu) consumed) to calculate energy use emissions.

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[19] US EPA 2008, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990 to 2006*; (http://www.epa.gov/climatechange/emissions/usinventoryreport.html).

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

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

Source	Information provided	Use of Information in this Analysis
	e08/index.html).	
US DOE Energy Information Administration (EIA) State Energy Data (SED)	EIA SED provides energy use data in each State, annually to 2005 for all RCI sectors and fuels.	EIA SED is the source for most energy use data. Emission factors from US EPA SIT are used to calculate energy-related emissions.
EIA AEO2006	EIA AEO2006 projects energy supply and demand for the US from 2003 to 2030. Energy consumption is estimated on a regional basis. Maryland is included in the South Atlantic region (SC, DE, MD, DC, WV, VA, NC, GA, FL). Also used to provide projected mix of onroad vehicles and aircraft efficiency gains for transportation sector.	EIA AEO2006 is used to project changes in fuel use for the RCI sectors and the mix of VMT by vehicle type in the projection years. Aircraft efficiency gains are used to adjust the aviation growth factors.
EIA State Electricity Profiles	EIA provides information on the electric power industry generation by primary energy source for 1990 – 2005.	EIA State Electricity Profiles were used to determine the mix of in-state electricity generation by fuel.
US Department of Transportation (DOT), Office of Pipeline Safety (OPS)	Natural gas transmission pipeline mileage, and distribution pipeline mileage and number of services for 1990 – 2005.	OPS historical pipeline mileage and number of services used as input to SIT to calculate historical emissions from natural gas industry.
US EPA GHG Inventory and Sinks Report	CH_4 emissions from coal mining.	Provided historical CH_4 emission estimates from coal mining.
MDE	MDE provided landfill emplacement and control data for Maryland landfills and VMT data	Waste emplacement data used to estimate emissions from solid waste management. VMT used to estimate onroad CH_4 and N_2O emissions and to project all onroad emissions.
Federal Aviation Administration (FAA)	Aircraft operation projections for Maryland.	Aircraft operation data used in calculating aviation growth factors.
US Forest Service	Data on forest carbon stocks and land use cover for multiple years.	Data are used to calculate CO_2 flux over time (terrestrial CO_2 sequestration in forested areas).
USDS National Agricultural Statistics Service (NASS)	USDA NASS provides data on crops and livestock.	Crop production data used in SIT to estimate agricultural residue and agricultural soils emissions; livestock population data used in SIT to estimate manure and enteric fermentation emissions.

- **Comprehensive Coverage of Gases, Sectors, State Activities, and Time Periods:** This analysis aims to comprehensively cover GHG emissions associated with activities in Maryland. It covers all six GHGs covered by US and other national inventories: CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs. The inventory estimates are for the year 1990, with subsequent years included up to most recently available data (typically 2002 to 2005), with projections to 2010 and 2020.
- **Use of Consumption-Based Emissions Estimates:** To the extent possible, we estimated emissions that are caused by activities that occur in Maryland. For example, we reported emissions associated with the electricity consumed in Maryland. The rationale for this method of reporting is that it can more accurately reflect the impact of State-based policy strategies such as energy efficiency on overall GHG emissions, and it resolves double-

counting and exclusion problems with multi-emissions issues. This approach can differ from how inventories are compiled, for example, on an in-state production basis, in particular for electricity.

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

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

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

Appendix I provides additional background information from the US EPA on GHGs and global warming potential values.

Appendix A. Electricity Supply

This appendix describes the data sources, key assumptions, and the methodology used to develop an inventory of greenhouse gas (GHG) emissions over the 1990-2005 period associated with meeting electricity demand in Maryland. It also describes the data sources, key assumptions, and methodology used to develop a forecast of GHG emissions over the 2006-2020 period associated with meeting electricity demand in the state. Specifically, the following topics are covered in this Appendix:

- ☐ *Data sources:* This section provides an overview of the data sources that were used to develop the inventory and forecast, including publicly accessible websites where this information can be obtained and verified.
- ☐ *Greenhouse Gas Inventory methodology:* This section provides an overview of the methodological approach used to develop of the Maryland GHG inventory for the electric supply sector.
- ☐ *Greenhouse Gas Forecast Methodology – Reference Case:* This section provides an overview of methodological approach used to develop the Maryland GHG Reference Case forecast for the electric supply sector. This forecast does not include the impact of RPS (Renewable Portfolio Standard) legislation.
- ☐ *Greenhouse Gas Forecast Methodology – Alternative Reference Case:* This section provides an overview of methodological approach used to develop the Maryland GHG Alternative Reference Case forecast for the electric supply sector. This forecast includes the impact of RPS legislation.
- ☐ *Greenhouse Gas Inventory Results:* This section provides an overview of key results of the Maryland GHG inventory for the electric supply sector.
- ☐ *Greenhouse Gas Forecast Results:* This section provides an overview of key results of the Maryland GHG forecast for the electric supply sector. The results of both Reference Cases are presented.

Data Sources

We considered several sources of information in the development of the inventory and forecast of carbon dioxide equivalent (CO_2e) emissions from Maryland power plants. These are briefly summarized below:

- ☐ *2005 EIA-906/920 Monthly Time Series data.* This is a database file available from the Energy Information Administration (EIA) of the US Department of Energy. The information in the database is based on information collected from utilities in Forms EIA-906/920 and EIA-860 for the forecast Base Year of 2005. Data from these forms provide, among other things, fuel consumption and net generation in power stations by plant type. This information can be accessed from http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html.

North American Electric Reliability Council Region Map—(US)

- *Annual Energy Outlook 2007.* This is an output of an EIA analysis using the National Energy Modeling System (NEMS), a model that forecasts electric expansion/electricity demand in the USA. In particular, regional outputs for Mid-Atlantic Area Council (MAAC) and East Central Area Reliability Coordination region (ECAR) region were used. The MAAC/ECAR regions are the ones in which Maryland is located (see map at right). The results include forecasts of gross generation, net generation, combustion efficiency, total sales, and exports/imports through the year 2025. This information is available in supplemental tables that can be accessed directly from http://www.eia.doe.gov/oiaf/aeo/supplement/index.html. The sources of the above map is http://www.bydesign.com/fossilfuels/crisis/html/NERC_regions_map.html.
- *Monthly Cost and Quality of Fuels for Electric Plants.* This information is available from the Federal Energy Regulatory Commission (FERC). The database relies on information collected from utilities in the FERC-423 form. It was used to determine the share of coal type (i.e., whether bituminous, sub-bituminous, anthracite, or lignite) as well as the coal quantity consumed in Maryland power plants over the period 1990-2005. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/page/ferc423.html.
- *State Electricity Profiles.* This information is available from the EIA. The database compiles capacity, net generation, and total retail electricity sales by state. It was used to determine total sales of electricity across all sectors in the Base Year 2005. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html.
- *Energy conversion factors.* This is based on Table Y-2 of Appendix Y in the USEPA's 2003 GHG Inventory for the USA. The table is entitled "Conversion Factors to Energy Units (Heat Equivalents)". This information can be accessed directly from the following website: http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/LHOD5MJTCL/$File/2003-final-inventory_annex_y.pdf.
- *Fuel combustion oxidation factors:* This is based on Appendix A of the USEPA's 2003 US GHG inventory for the USA. This information can be accessed directly from: http://www.epa.gov/climatechange/emissions/downloads06/06_Annex_Chapter2.pdf.
- *Carbon dioxide, methane, and nitrous oxide emission factors.* For all fuels except MSW, these emission factors are based on Appendix A of the USEPA's 2003 GHG inventory for the USA. This information can be accessed directly from: http://www.epa.gov/climatechange/emissions/downloads06/06_Annex_Chapter2.pdf. For MSW, emission factors are based on the Energy Information Administration, Office of

Integrated Analysis and Forecasting, Voluntary Reporting of Greenhouse Gases Program, Table of Fuel and Energy Source: Codes and Emission Coefficients. This information can be accessed directly from http://www.eia.doe.gov/oiaf/1605/coefficients.html.

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

Greenhouse Gas Inventory Methodology

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

- The GHG inventory should be estimated based on both the production and consumption of electricity. Developing the production estimate involves tallying up the GHG emissions associated with the operation of power plants physically located in Maryland, regardless of ownership. Developing the consumption estimate involves tallying up the GHG emissions associated with consumption of electricity in Maryland, regardless of where the electricity is produced. As Maryland is a net importer of electricity, these estimates will be different.
- The GHG inventory is based on emissions at the point of electric generation only. That is, GHG emissions associated with upstream fuel cycle process such as primary fuel extraction, transport to refinery/processing stations, refining, beneficiation, and transport to the power station are not included as they are addressed in other portions of the Maryland GHG inventory.
- As an approximation, it was assumed that all power generated in Maryland was consumed in Maryland. However, given the similarity in the average carbon intensity of Maryland power stations and that of power stations in the surrounding MAAC/ECAR region, the potential error associated with this simplifying assumption is small, on the order of 2%, plus or minus.
- Several key assumptions were used for making projections of CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions for the electric sector out to 2020. These are summarized in Table A1.

Table A1. Key Assumptions used in the Maryland GHG Forecast

Key Assumptions	2005	2020	Average Annual Growth / Change (%)
MD Electricity Demand (GWh)	68,365	85,216	1.5%
MD Gross generation (GWh)	53,108	66,482	1.5%
MD Gross generation to meet MD demand (GWh)	76,619	94,618	1.4%
Gross generation associated with net imports from MAAC/ECAR regions (GWh)	23,511	28,135	1.2%
Power plant heat rate (BTU/kWh)			
Coal	10,500	9,054	-1.0%
Natural Gas	11,642	11,342	-0.2%
Petroleum	11,750	12,871	0.6%
Nuclear	10,582	10,582	0.0%
Hydroelectric	10,320	10,320	0.0%
Wind	10,320	10,320	0.0%
MSW Landfill gas	10,500	10,500	0.0%
Losses (%)			
From on-site usage	1.1%	0.8%	-2.2%
From T&D and on-site usage	6.1%	5.4%	-0.8%

There were several steps in the methodology for the development of the electric sector GHG inventory for the period 1990-2005. These are briefly outlined below:

- ☐ Determine the coal quality used in Maryland power stations (i.e., share of anthracite, bituminous, lignite, sub-bituminous, and coal wastes used).
- ☐ Determine gross annual primary energy consumption by Maryland power stations by plant and fuel type.
- ☐ Determine gross annual generation associated with net power imports to satisfy Maryland electricity demand.
- ☐ Multiply gross annual primary energy consumption by Maryland power stations by CO_2e emission factors. This provides an estimate of the Maryland GHG inventory on a production basis.
- ☐ Multiply annual gross generation associated with net power imports by the carbon emission intensity (in units of metric tons CO_2-equivalent per megawatt-hour [CO_2e/MWh]) of the MAAC/ECAR region. This provides an estimate of the additional GHG emissions associated with meeting Maryland electricity demand in excess of generation from local power plants.
- ☐ Add the emissions associated with net power imports to the production-based emissions. This provides an estimate of the GHG inventory on a consumption basis.

Greenhouse Gas Forecast Methodology – Reference Case

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

While some of this information was available in Maryland, some key data was not available at the time the forecast was prepared. Therefore, it was necessary to use a top-down approach. A top-down approach uses proxy information regarding future gross in-state generation, supply side efficiency improvements, and changes over time regarding losses. This approach, while less satisfactory for representing state-specific conditions, nonetheless offers an acceptable starting point for exploring projections of GHG emissions from the electric sector in Maryland. The methodological steps used for forecasting CO_2e emissions are described below.

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

- ☐ For the Base Year of 2005, determine the coal quality used in Maryland power stations (i.e., share of anthracite, bituminous, lignite, sub-bituminous, and coal wastes used).
- ☐ For the period 2006 through and including 2020, assume that the coal quality is the same for the Base year.

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

- ☐ For the Base Year of 2005, establish total retail sales in Maryland (i.e. 68,365 gigawatt-hour (GWh)).
- ☐ For the period 2006 through and including 2016, assume the growth rate for in-state electricity sales is consistent with the report entitled "ELECTRIC SUPPLY ADEQUACY REPORT OF 2007". This report was prepared by the Maryland PSC in compliance with Section 7-505(e) of the Public Utility Companies Article (page 9-10). For the period 2017-2020, the average annual growth rate from the 2006-2016 period was used.

Gross Generation for utilities and non-utilities. An overview of the methodology applied to forecast annual gross electricity generation by Maryland electric power stations (utilities and non-utilities only) is briefly summarized below:

- ☐ For the Base Year of 2005, estimate losses associated with on-site usage of electricity by plant type for Maryland power plants. On-site usage losses were assumed to be equal to the MAAC/ECAR regional average of 0.8% of gross generation.
- ☐ For the Base Year of 2005, combine actual net electric generation data (i.e., from the inventory) and assumed average on-site losses (i.e., from the MAAC/ECAR regions) to estimate gross generation by plant type.
- ☐ For the period 2006 through and including 2020, estimate total gross generation of Maryland power stations by multiplying the 2005 value of Maryland total gross generation by plant type by the annual growth rate of gross generation in the MAAC/ECAR regions.
- ☐ For the period 2006 through and including 2020, multiply plant type-specific gross generation by the annual growth rate of total gross generation in the MAAC/ECAR regions.

Then benchmark the plant type-specific totals pro-rata to match the control total of gross generation.

Gross Generation for cogeneration facilities. An overview of the methodology applied to forecast annual gross electricity generation by commercial and industrial cogeneration facilities in Maryland is briefly summarized below:

- For the Base Year of 2005, estimate the shares of electricity that are sold to the grid and consumed onsite for Maryland cogenerators. On-site usage was assumed to be equal to the MAAC/ECAR regional average of 0.8% of gross generation.
- For the period 2006 through and including 2020, estimate total gross generation of Maryland cogenerators by multiplying the 2005 value of Maryland total gross generation by cogenerator plant type by the annual growth rate of gross generation of cogenerators in the MAAC/ECAR region. Identify the shares of generation used to meet retail and non-retail electricity demand.

Combustion efficiency for utilities and non-utilities. An overview of the methodology applied to forecast annual heat rates at Maryland power stations is briefly summarized below:

- For the Base Year of 2005, estimate average gross heat rate of Maryland power stations by dividing the plant type-specific 2005 gross generation estimate by the plant type-specific 2005 gross primary energy consumption estimate.
- For the period 2006 through and including 2020, estimate the annual average gross plant type-specific heat rate for the MAAC/ECAR region.
- For the period 2006 through and including 2020, estimate annual average gross plant type-specific heat rate of Maryland power stations by multiplying the 2005 value of the annual average gross plant type-specific heat rate of Maryland power plants by the annual rate of improvement of gross heat rate in the MAAC/ECAR region.

Combustion efficiency for cogeneration facilities. An overview of the methodology applied to forecast annual heat rates at Maryland commercial and industrial cogeneration facilities is briefly summarized below:

- For the Base Year of 2005, estimate average gross heat rate of Maryland cogenerators by dividing the plant type-specific 2005 gross generation estimate by the plant type-specific 2005 gross primary energy consumption estimate.
- For the period 2006 through and including 2020, assume the annual average gross plant type-specific heat rate is equal to the 2005 value.

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

- For the Base Year of 2005, establish the actual primary energy consumption for Maryland power plants and cogenerators as reported by the databases used to develop the inventory.
- For the period 2006 through and including 2020, multiply annual gross generation by annual heat rate for each plant type in Maryland.

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

- ☐ For the Base Year of 2005, establish actual total sales of electricity in Maryland.
- ☐ For the period 2006 through and including 2020, estimate annual electricity sales in Maryland by multiplying the previous year's sales by the annual growth rate of the MAAC/ECAR region.
- ☐ For the Base Year of 2005 through and including 2020, estimate the sales associated with imports as the difference between total sales in Maryland and the total sales by Maryland power stations.
- ☐ For the Base Year of 2005 through and including 2020, estimate the gross generation associated with imports by dividing sales from imports by one minus the percent losses from on-site usage and transmission and distribution in the MAAC/ECAR region.

Carbon dioxide-equivalent emissions. An overview of the methodology applied to forecast annual CO_2e emissions is briefly summarized below:

- ☐ For the Base Year of 2005 through and including 2020, estimate total CO_2 emissions from Maryland power stations and cogenerators by multiplying total primary energy use by the CO_2 emission factor and the global warming potential.
- ☐ For the Base Year of 2006 through and including 2020, estimate total CH_4 emissions from Maryland power stations and cogenerators by multiplying total primary energy use by the CH_4 emission factor and the global warming potential.
- ☐ For the Base Year of 2005 through and including 2020, estimate total N_2O emissions from Maryland power stations and cogenerators by multiplying total primary energy use by the N_2O emission factor and the global warming potential.
- ☐ For the Base Year of 2005 through and including 2020, estimate total CO_2e emissions from Maryland power stations and cogenerators by adding the CO_2e of CO_2, CH_4, and N_2O.

Carbon dioxide-equivalent emissions from imported electricity. An overview of the methodology applied to forecast annual CO_2e emissions is briefly summarized below:

- ☐ For the Base Year of 2005 through and including 2020, estimate the average annual GHG emission intensity (i.e., metric tons of CO_2, CH_4, and N_2O per MWh of gross generation) for the MAAC/ECAR region from the data sources described earlier.
- ☐ For the Base Year of 2005 through and including 2020, estimate total CO_2 emissions associated with imported electricity by multiplying the gross generation associated with these imports by the CO_2 emission intensity and the global warming potential.
- ☐ For the Base Year of 2005 through and including 2020, estimate total CH_4 emissions associated with imported electricity by multiplying the gross generation associated with these imports by the CH_4 emission intensity and the global warming potential.

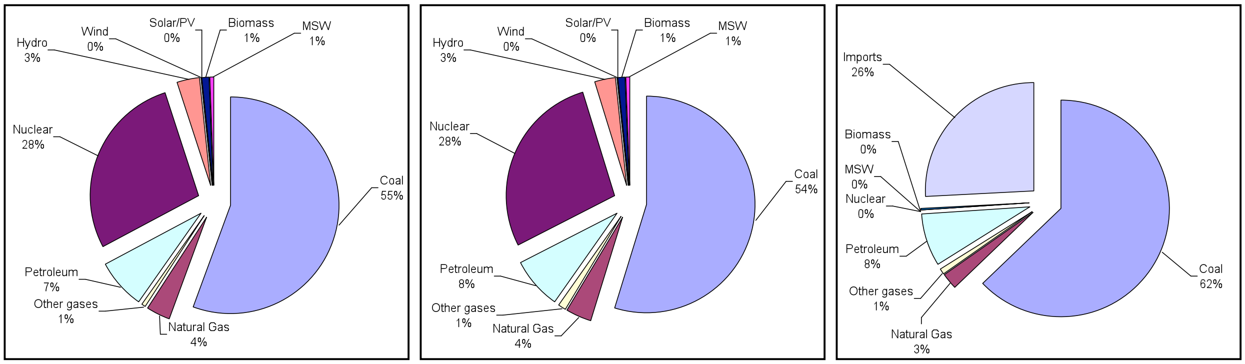
☐ For the Base Year of 2005 through and including 2020, estimate total N_2O emissions associated with imported electricity by multiplying the gross generation associated with these imports by the N_2O emission intensity and the global warming potential.

☐ For the Base Year of 2005 through and including 2020, estimate total CO_2e emissions associated with imported electricity by adding the CO_2e of CO_2, CH_4, and N_2O.

Greenhouse Gas Inventory Results

Figure A1 summarizes gross generation, primary energy use, and CO_2e emissions for Maryland power stations for the year 2005. Table A2 provides a summary of electric generating capacity for power plants located within the borders of Maryland, together with the CO_2 emissions from each unit for the period 2000 through the 2005 Base Year.

Figure A1. Breakdown of Maryland Generation, Capacity and CO_2e Emissions – 2005 Base Year



a. Gross Generation (53.1 TWh)

b. Energy (568 trillion btu)

c. Emissions (34.0 MMtCO_2e)

Table A2. Summary of Maryland Electric Generator and CO_2 Emission Characteristics from 2000 to the 2005 Base Year (source: http://www.rggi.org/docs/co2_2000_2006.xls)

Plant Name	Boiler ID	Generator ID	Nameplate Capacity (MW)	CO_2 Emissions (million short tons)					
				2000	2001	2002	2003	2004	2005
AES WARRIOR RUN COGEN	BLR1	GEN1	229	1.5	1.6	1.6	1.6	1.6	1.8
BRANDON SHORES	1	1	685	5.4	4.0	3.9	3.7	4.0	3.6
BRANDON SHORES	2	2	685	4.2	5.3	3.6	4.5	3.9	4.5
C P CRANE	1	1	190	1.2	1.0	1.4	1.2	1.1	1.1
C P CRANE	2	2	209	1.2	1.5	1.1	1.4	1.1	1.3
Chalk Point	GT3**		103	0.0	0.0	0.1	0.0	0.0	0.1
Chalk Point	GT4**		103	0.0	0.0	0.1	0.0	0.0	0.1
Chalk Point	GT5**		125	0.1	0.0	0.0	0.0	0.0	0.0
Chalk Point	GT6**		125	0.1	0.0	0.1	0.0	0.0	0.1
CHALK POINT	1	ST1	364	1.9	1.6	2.3	1.8	2.3	2.3
CHALK POINT	2	ST2	364	1.7	1.5	2.5	2.0	2.3	2.0
CHALK POINT	3	3	659	0.6	1.0	0.6	1.3	1.0	1.6
CHALK POINT	4	4	659	0.8	1.0	0.8	0.9	1.1	0.9
Chalk Point	GT2		35	0.0	0.0	0.0	0.0	0.0	0.0
Chalk Point	SMECO		90	0.0	0.0	0.0	0.0	0.0	0.0
DICKERSON	1	ST1	196	0.8	1.1	0.9	0.9	1.1	1.0
DICKERSON	2	2	196	1.2	1.1	1.0	0.8	1.1	1.2
DICKERSON	3	3	196	0.9	0.9	1.1	1.0	1.1	1.2
Dickerson	HCT1GT2		163	0.0	0.0	0.1	0.1	0.1	0.1
Dickerson	HCT2GT3		163	0.0	0.0	0.1	0.1	0.1	0.1
GOULD STREET	3	3	104	0.1	0.2	0.2	0.0	0.0	0.0
HERBERT A WAGNER	1	1	133	0.2	0.1	0.1	0.1	0.2	0.2
HERBERT A WAGNER	2	2	136	0.8	0.8	1.0	1.0	1.1	0.9
HERBERT A WAGNER	3	3	359	2.3	1.9	1.6	2.0	1.9	2.3
HERBERT A WAGNER	4	4	415	0.4	0.6	0.6	0.5	0.6	0.5
MORGANTOWN	1	ST1	626	3.8	3.3	4.0	3.8	3.1	2.9
MORGANTOWN	2	ST2	626	3.8	3.8	3.4	3.9	3.2	3.2
Morgantown	GT3		65	0.0	0.0	0.0	0.0	0.0	0.0
Morgantown	GT4		65	0.0	0.0	0.0	0.0	0.0	0.0
Morgantown	GT5		65	0.0	0.0	0.0	0.0	0.0	0.0
Morgantown	GT6		65	0.0	0.0	0.0	0.0	0.0	0.0
Panda Brandywine	1		99	0.2	0.1	0.0	0.0	0.0	0.0
Panda Brandywine	2		99	0.3	0.1	0.1	0.1	0.0	0.0
Panda Brandywine	3		91	0.0	0.0	0.0	0.0	0.0	0.0
Perryman	**51		192	0.1	0.1	0.0	0.0	0.1	0.0
Perryman	CT1		53	0.0	0.0	0.0	0.0	0.0	0.0
Perryman	CT2		53	0.0	0.0	0.0	0.0	0.0	0.0
Perryman	CT3		53	0.0	0.0	0.0	0.0	0.0	0.0
Perryman	CT4		53	0.0	0.0	0.0	0.0	0.0	0.0
R P SMITH	11	4	75	0.6	0.5	0.5	0.4	0.4	0.4
R P SMITH	9	3	35	0.1	0.1	0.1	0.1	0.1	0.1
Riverside	CT6		122	0.0	0.0	0.0	0.0	0.0	0.0

Riverside	4		72	0.0	0.0	0.0	0.0	0.0	0.0
VIENNA	8	8	162	0.3	0.2	0.3	0.1	0.1	0.1
Westport	CT5		122	0.0	0.0	0.0	0.0	0.0	0.0
Rock Springs Generating Facility	366		113	0.0	0.0	0.0	0.1	0.0	0.0
Rock Springs Generating Facility	367		113	0.0	0.0	0.0	0.0	0.0	0.0
Rock Springs Generating Facility	368		227	0.0	0.0	0.0	0.0	0.0	0.1
Rock Springs Generating Facility	369		227	0.0	0.0	0.0	0.0	0.0	0.1
Luke				1.0	1.0	1.1	1.1	1.1	1.1
Mittal				2.6	2.4	2.7	2.1	2.3	2.1
Total			**10,158.5**	**38.4**	**37.0**	**37.1**	**37.1**	**36.3**	**37.3**

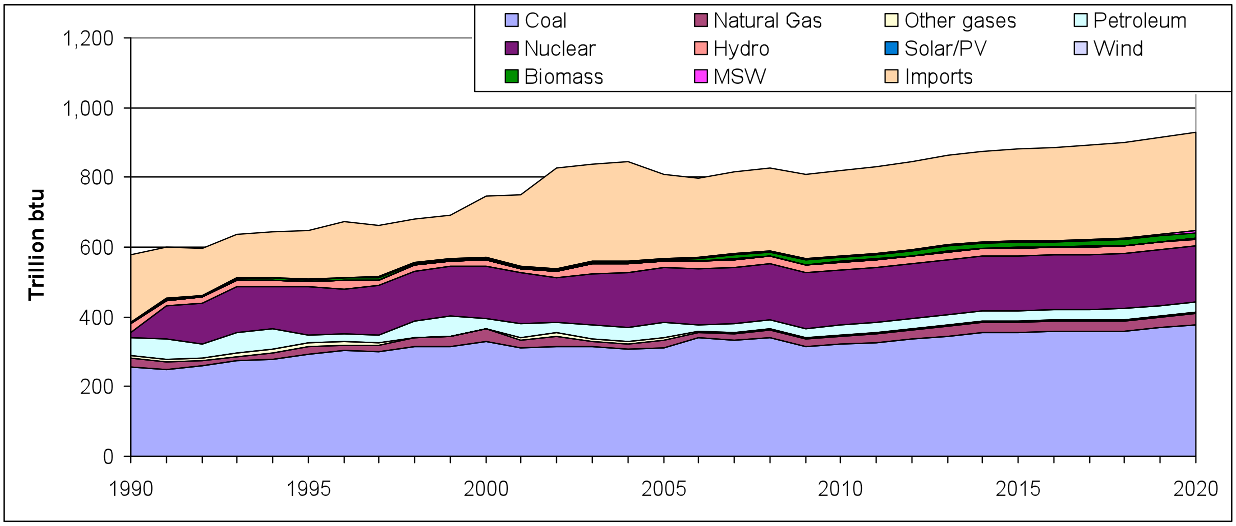
Greenhouse Gas Forecast Results

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

Primary Energy Consumption

Total primary energy consumption associated with electricity generation in Maryland is summarized in Figure A2 for the Reference Case. Primary energy consumption in Maryland is dominated by coal and nuclear resources.

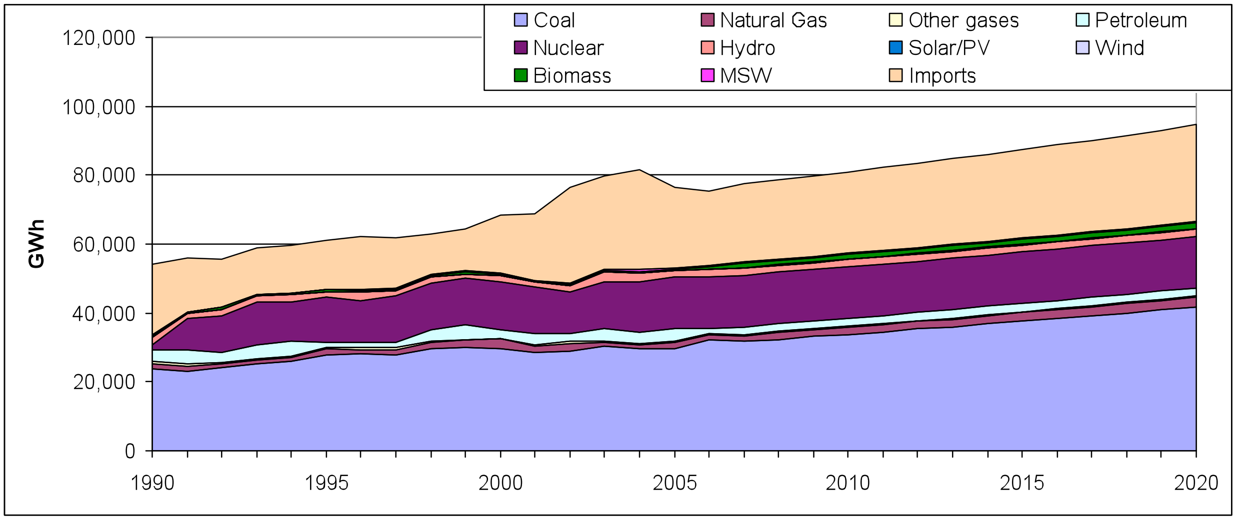
Figure A2. Primary Energy Use at Maryland Power Stations, plus imports



Gross Generation

Total gross generation by Maryland power plants is summarized in Figure A3 for the Reference Case. Gross generation in Maryland is dominated by steam units, which are primarily based on coal and nuclear fuel.

Figure A3. Gross Generation at Maryland Power Stations, plus imports



Total Emissions

Total emissions associated with generation by Maryland power plants as well as emissions from generation by power plants located outside Maryland to meet electricity demand within Maryland are summarized in Figure A4 and in Table A3 for the Reference Case. On a consumption basis, emissions reach 54.8 MMtCO$_2$e in 2020.

Figure A4. Total Emissions Associated with Electric Demand in Maryland (MMtCO$_2$e)

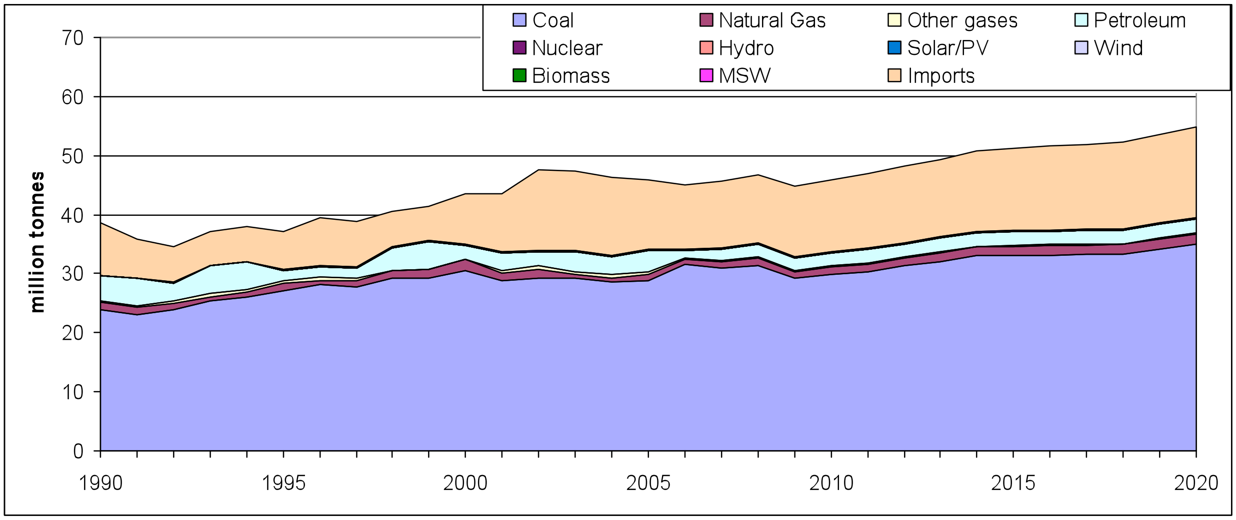
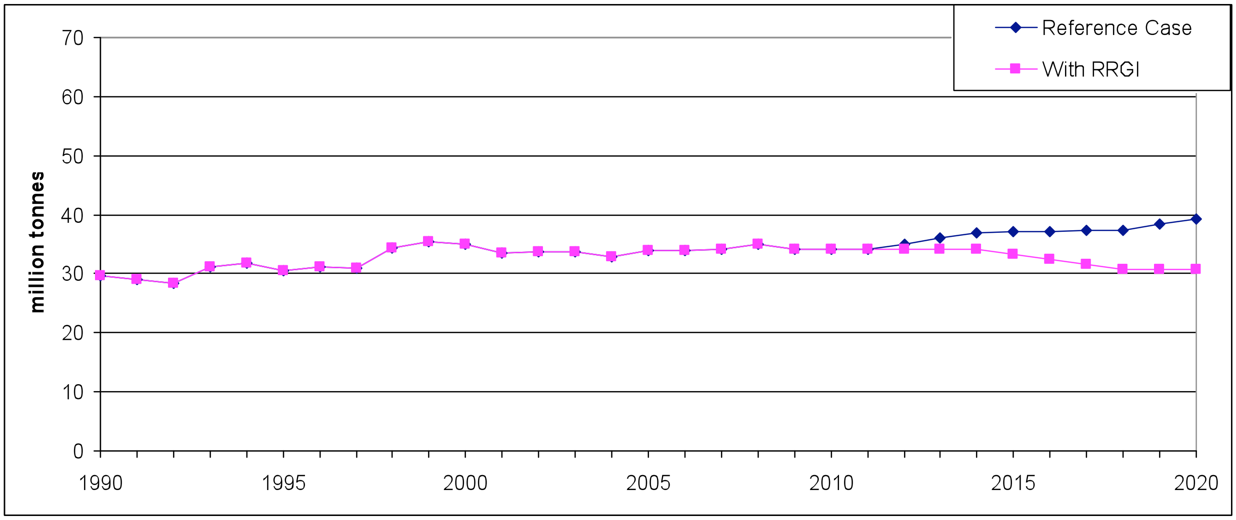


Table A3. Consumption-Based GHG Emissions from Electricity Supply in Maryland ($MMtCO_2e$)

Fuel	1990	1995	2000	2005	2010	2015	2020
Coal	23.89	27.02	30.48	28.80	30.35	33.06	35.04
Natural Gas	1.29	1.27	1.93	1.18	1.31	1.54	1.74
Other Gases	0.31	0.59	0.05	0.35	0.18	0.19	0.20
Petroleum	4.22	1.69	2.42	3.52	2.19	2.28	2.35
Biomass	0.003	0.003	0.003	0.004	0.01	0.01	0.01
MSW	0.03	0.11	0.21	0.19	0.20	0.22	0.22
Imports	8.83	6.51	8.55	11.82	12.27	13.83	15.25
Total (Consumption-based)	**38.58**	**37.19**	**43.64**	**45.86**	**46.52**	**51.13**	**54.82**

Total CO_2 emissions associated with generation by Maryland power plants, with and without the participation of Maryland in the Regional Greenhouse Gas Initiative (RGGI), are summarized in Figure A5. The Maryland CO_2 cap is set at 34.1 $MMtCO_2$ (37.5 million short tons) from 2009 through 2014, declines to 30.6 $MMtCO_2$ (33.8 million short tons) by 2018, and remains at this level through 2020. The CO_2 emission reductions from the RGGI cap are 8.7 $MMtCO_2$ (9.6 million short tons) in 2020. Cumulative CO_2 emission reductions through 2020 from the RGGI CO_2 cap are 44.1 $MMtCO_2$ (48.5 million short tons).

Figure A5. Total Emissions Associated with Electricity Production in Maryland, with and without the RGGI CO_2 cap ($MMtCO_2$)



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

Overview

Activities in the RCI[22] sectors produce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions when fuels are combusted to provide space heating, water heating, process heating, cooking, and other energy end-uses. Carbon dioxide accounts for over 99% of these emissions on a million metric tons (MMt) of CO_2 equivalent (CO_2e) basis in Maryland. In addition, since these sectors consume electricity, one can also attribute emissions associated with electricity generation to these sectors in proportion to their electricity use.[23] Direct use of oil, natural gas, coal, and wood in the RCI sectors accounted for an estimated 20 $MMtCO_2e$ of gross greenhouse gas (GHG) emissions in 2005.[24]

Emissions and Reference Case Projections

Emissions from direct fuel use were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for RCI fossil and wood fuel combustion.[25] The default data used in SIT for Maryland are from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data* (SED). The SIT files were updated to include 2004 and 2005 SED information for Maryland for natural gas, petroleum, coal, and wood for each of the RCI sectors.[26]

Note that the EIIP methods for the industrial sector exclude from CO_2 emission estimates the amount of carbon that is stored in products produced from fossil fuels for non-energy uses. For example, the methods account for carbon stored in petrochemical feedstocks, and in liquefied petroleum gases (LPG) and natural gas used as feedstocks by chemical manufacturing plants

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[22] The industrial sector includes emissions associated with agricultural energy and natural gas consumed as lease and plant fuel. Emissions associated with pipeline fuel use are included in Appendix E.

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

[24] Emissions estimates from wood combustion include only N_2O and CH_4. Carbon dioxide emissions from biomass combustion are assumed to be "net zero", consistent with US EPA and Intergovernmental Panel on Climate Change (IPCC) methodologies, and any net loss of carbon stocks due to biomass fuel use should be accounted for in the land use and forestry analysis.

[25] GHG emissions were calculated using SIT, with reference to *EIIP, Volume VIII*: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004, and Chapter 2 "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion", August 2004.

[26] EIA *State Energy Data through 2005 (*http://www.eia.doe.gov/emeu/states/_seds_updates.html).

(i.e., not used as fuel), as well as carbon stored in asphalt and road oil produced from petroleum. The carbon storage assumptions for these products are explained in detail in the EIIP guidance document.[27] The fossil fuel types for which the EIIP methods are applied in the SIT software to account for carbon storage include the following categories: asphalt and road oil, coking coal, distillate fuel, feedstocks (naphtha with a boiling range of less than 401 degrees Fahrenheit), feedstocks (other oils with boiling ranges greater than 401 degrees Fahrenheit), LPG, lubricants, miscellaneous petroleum products, natural gas, pentanes plus,[28] petroleum coke, residual fuel, still gas, and waxes. Data on annual consumption of the fuels in these categories as chemical industry feedstocks were obtained from the EIA SED.

Table B1 shows historic and projected growth rates for electricity sales by sector. For 2005 to 2020, the annual growth rates are based on AEO2007 regional, sector-level forecasts prepared by the EIA using the National Energy Modeling System (NEMS) for the Mid-Atlantic Area Council (MAAC) region that includes Maryland. These annual growth rates were used to forecast electricity sales from 2005 to 2020 for each sector. The proportion of each RCI sector's sales to total sales was used to allocate emissions associated with the electricity supply sector to each of the RCI sectors. Note that the proportion of commercial electricity sales increased and the proportion of industrial electricity sales decreased by about the same amount from 1995 through 2001, and then in 2002 the proportions changed to those observed from 1990 to 2004. These proportional changes are believed to be associated with how utilities reported customer sales rather than with real changes in electricity demand (sales) for these sectors.

Table B2 shows historic and projected growth rates for energy use by sector and fuel type. Reference case emissions from direct fuel combustion were estimated based on fuel consumption forecasts from EIA's *Annual Energy Outlook 2006* (AEO2006).[29] For the RCI sectors, annual growth rates for natural gas, oil, wood, and coal were calculated from the AEO2006 regional forecast that EIA prepared for the South Atlantic modeling region. For the residential sector, the AEO2006 annual growth rate in fuel consumption from 2005 through 2020 was normalized using the AEO2006 population forecast and then weighted using Maryland's population forecast over this period.[30] Maryland's rate of population growth is expected to average about 0.86% annually between 2005 and 2020.[31] The AEO2006 estimates of growth in regional fuel consumption reflect expected responses of the economy — as simulated by the EIA's National Energy Modeling System — to changing fuel and electricity prices and changing technologies, as well as to structural changes within each sector (such as shifts in subsectoral shares and in energy use patterns).

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

[28] A mixture of hydrocarbons, mostly pentanes and heavier fractions, extracted from natural gas.

[29] EIA AEO2006 with Projections to 2030 (http://www.eia.doe.gov/oiaf/archive.html#aeo).

[30] AEO2006 population and employment projections for EIA's South Atlantic region obtained through special request from EIA (dated September 27, 2006).

[31] Maryland Department of Planning, Planning Data Services. Population data for 1990, 2000, and estimated 2006, 2010, 2020, and 2030 downloaded from http://www.msa.md.gov/msa/mdmanual/01glance/html/pop.html#state.

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

Sector	1990-2005*	2005-2020**
Residential	2.69%	1.34%
Commercial	3.23%	1.81%
Industrial	0.72%	0.23%
Total	**2.12%**	**1.14%**

* 1990-2005 compound annual growth rates calculated from Maryland electricity sales by year from EIA State Electricity Profiles (Table 8) (http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html).

** 2005-2020 compound annual growth rates based on AEO2007 regional, sector-level forecasts prepared by the EIA using the National Energy Modeling System (NEMS) (a model that forecasts electric expansion/electricity demand in the USA) for the Mid-Atlantic Area Council (MAAC) region that includes Maryland.

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

	1990-2005[a]	2005-2010[b]	2010-2015[b]	2015-2020[b]
Residential				
natural gas	1.9%	2.0%	1.3%	1.1%
petroleum	-0.2%	-1.2%	-0.8%	-1.3%
wood	-1.2%	-0.3%	-1.0%	-0.5%
coal	-7.9%	-0.3%	-1.6%	-1.6%
Commercial				
natural gas	7.5%	-0.7%	0.9%	0.02%
petroleum	-2.8%	-2.8%	-0.8%	-1.4%
wood	2.1%	-2.2%	-1.7%	-2.0%
coal	-2.0%	-2.3%	-1.7%	-2.0%
Industrial				
natural gas	-6.1%	1.9%	0.8%	0.3%
petroleum	0.9%	-0.8%	-0.01%	0.3%
wood	0.8%	1.5%	0.9%	0.7%
coal	-3.6%	0.2%	0.04%	-0.1%

[a] Compound annual growth rates calculated from EIA SED historical consumption by sector and fuel type for Maryland. Latest year for which EIA SED information was available for all fuel types was 2005. Petroleum includes distillate fuel, kerosene, and liquefied petroleum gases for all sectors plus residual oil for the commercial and industrial sectors.

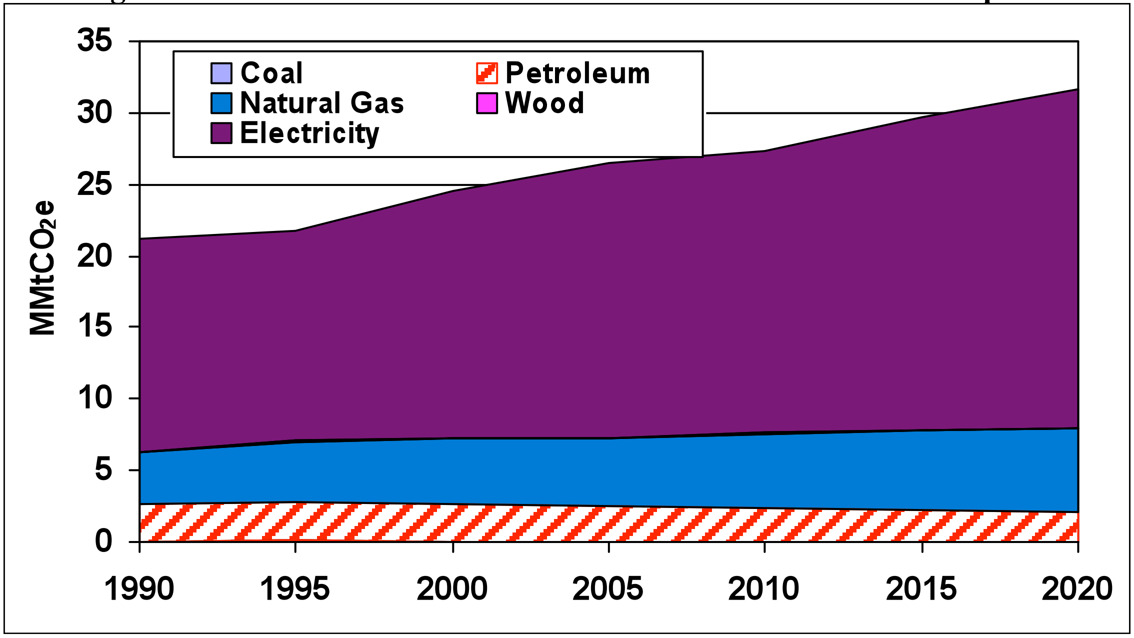
[b] Figures for growth periods starting after 2005 are calculated from AEO2006 projections for EIA's South Atlantic region. Regional growth rates for the residential sector are adjusted for Maryland's projected population.

Results

Figures B1, B2, and B3 show historical and projected emissions for the RCI sectors in Maryland from 1990 through 2020. These figures show the emissions associated with the direct consumption of fossil fuels and, for comparison purposes, show the share of emissions associated with the generation of electricity consumed by each sector. During the period from 1990 through 2020, the residential sector's share of total RCI emissions from direct fuel use and electricity was 35% in 1990, increased to 40% in 2005, and is projected to increase further to 42% in 2020. The commercial sector's share of total RCI emissions from direct fuel use and electricity use was 19% in 1990, increased to 26% in 2005, and is projected to increase slightly to 27% by 2020. The industrial sector's share of total RCI emissions from direct fuel use and electricity use was 45% in 1990, decreased to 34% in 2005, and is projected to decrease further to 31% in 2020. Emissions associated with the generation of electricity to meet RCI demand accounts for about 72% of the emissions for the residential sector, 75% of the emissions for the commercial sector, and 59% of the emissions for the industrial sector, on average, over the 1990 to 2020 time period. From 1990 to 2020, natural gas consumption is the next highest source of emissions for the residential and commercial sectors, accounting, on average, for about 18% and 19% of total emissions, respectively. For the industrial sector, emissions associated with the combustion of coal, natural gas, and petroleum account for about 15%, 10%, and 16% respectively, on average, from 1990 to 2020.

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

Figure B1. Residential Sector GHG Emissions from Fuel Consumption



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

For the residential sector, emissions from electricity and direct fossil fuel use in 1990 were about 21.2 MMtCO$_2$e, and are estimated to increase to about 31.6 MMtCO$_2$e by 2020. Emissions associated with the generation of electricity to meet residential energy consumption demand accounted for about 70% of total residential emissions in 1990, and are estimated to increase to 75% of total residential emissions by 2020. In 1990, natural gas consumption accounted for about 17% of total residential emissions, and is estimated to account for about 19% of total residential emissions by 2020. Residential-sector emissions associated with the use of coal, petroleum, and wood in 1990 were about 2.7 MMtCO$_2$e combined, and accounted for about 13%

of total residential emissions. By 2020, emissions associated with the consumption of these three fuels are estimated to fall to 2.1 $MMtCO_2e$, accounting for about 7% of total residential sector emissions by that year.

For the 15-year period 2005 to 2020, residential-sector GHG emissions associated with the use of electricity and natural gas are both expected to increase at average annual rates of about 1.4%. Emissions associated with the use of petroleum, wood, and coal are expected to decline annually by about -1.1%, -0.6%, and -1.3%, respectively. Total GHG emissions for this sector increase by an average of about 1.2% annually over the 15-year period.

Table B3a. Residential Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	0.02	0.10	0.02	0.01	0.01	0.01	0.01
Petroleum	2.59	2.71	2.60	2.47	2.33	2.23	2.08
Natural Gas	3.63	4.17	4.61	4.78	5.23	5.56	5.84
Wood	0.06	0.08	0.07	0.05	0.05	0.04	0.04
Electricity Consumption	14.88	14.73	17.22	19.21	19.70	21.87	23.66
Total	21.17	21.78	24.53	26.51	27.32	29.72	31.63

Source: CCS calculations based on approach described in text.

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

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	0.1%	0.4%	0.1%	0.03%	0.03%	0.02%	0.02%
Petroleum	12.2%	12.4%	10.6%	9.3%	8.5%	7.5%	6.6%
Natural Gas	17.1%	19.1%	18.8%	18.0%	19.2%	18.7%	18.5%
Wood	0.3%	0.4%	0.3%	0.2%	0.2%	0.1%	0.1%
Electricity Consumption	70.3%	67.6%	70.2%	72.5%	72.1%	73.6%	74.8%

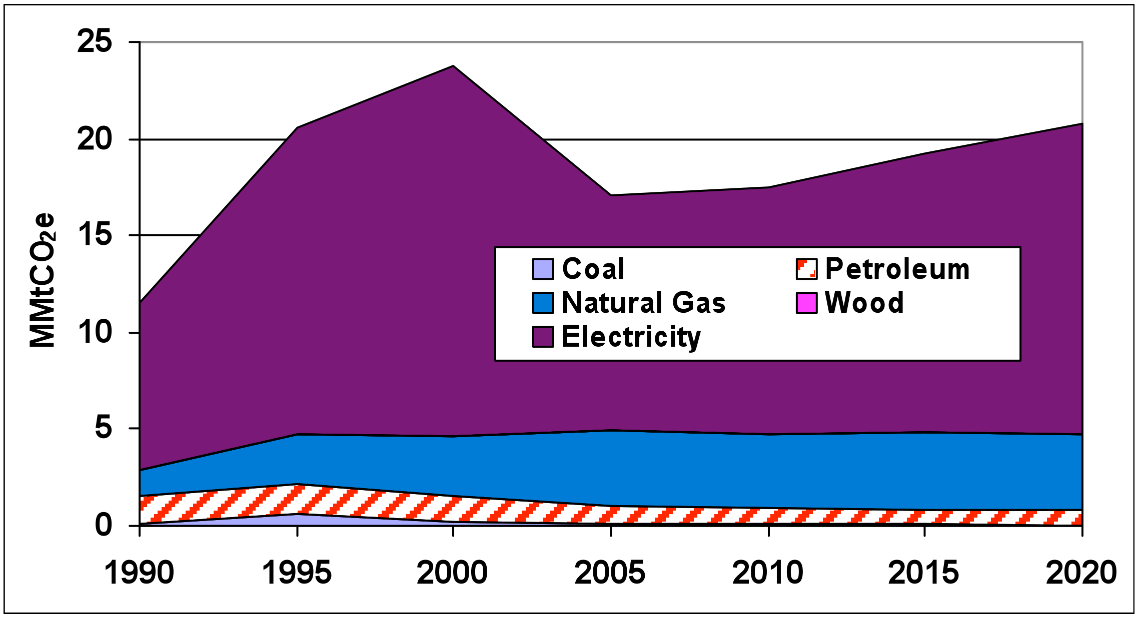
Source: CCS calculations based on approach described in text.
Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B3a.

Commercial Sector

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

For the commercial sector, emissions from electricity and direct fossil fuel use in 1990 were about 11.6 $MMtCO_2e$, and are estimated to increase to about 20.8 $MMtCO_2e$ by 2020. Emissions associated with the generation of electricity to meet commercial energy consumption demand accounted for about 75% of total commercial emissions in 1990, and are estimated to increase to 77% of total commercial emissions by 2020. In 1990, natural gas consumption accounted for about 11% of total commercial emissions and is estimated to account for about 19% of total commercial emissions by 2020. Emissions associated with the consumption of petroleum accounted for about 13% of total commercial emissions in 1990, but are estimated to account for only 4% of total emissions by 2020. Commercial-sector emissions associated with the use of coal and wood in 1990 were about 0.1 $MMtCO_2e$ combined, and accounted for about 1% of total commercial emissions. By 2020, emissions associated with the consumption of these two fuels are estimated to be 0.06 $MMtCO_2e$ and to account for 0.3% of total commercial sector emissions.

Figure B2. Commercial Sector GHG Emissions from Fuel Consumption



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

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

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	0.09	0.61	0.18	0.07	0.06	0.06	0.05
Petroleum	1.49	1.55	1.40	0.96	0.85	0.81	0.76
Natural Gas	1.31	2.55	3.06	3.88	3.81	3.96	3.96
Wood	0.01	0.02	0.01	0.01	0.01	0.01	0.01
Electricity Consumption	8.66	15.81	19.17	12.11	12.71	14.44	15.98
Total	11.57	20.54	23.82	17.03	17.44	19.27	20.76

Source: CCS calculations based on approach described in text.

For the 15-year period from 2005 to 2020, commercial-sector GHG emissions associated with the use of electricity and natural gas are expected to increase at average annual rates of about 1.9% and 0.13%, respectively. Emissions associated with the use of petroleum, wood, and coal are expected to decline annually by about -1.5%, -1.9%, and -2.0%, respectively. Total GHG emissions for this sector increase by an average of about 1.3% annually over the 15-year period.

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

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	0.8%	3.0%	0.7%	0.4%	0.3%	0.3%	0.2%
Petroleum	12.9%	7.5%	5.9%	5.6%	4.9%	4.2%	3.7%
Natural Gas	11.4%	12.4%	12.8%	22.8%	21.8%	20.5%	19.1%
Wood	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.05%
Electricity Consumption	74.9%	77.0%	80.5%	71.1%	72.9%	74.9%	77%

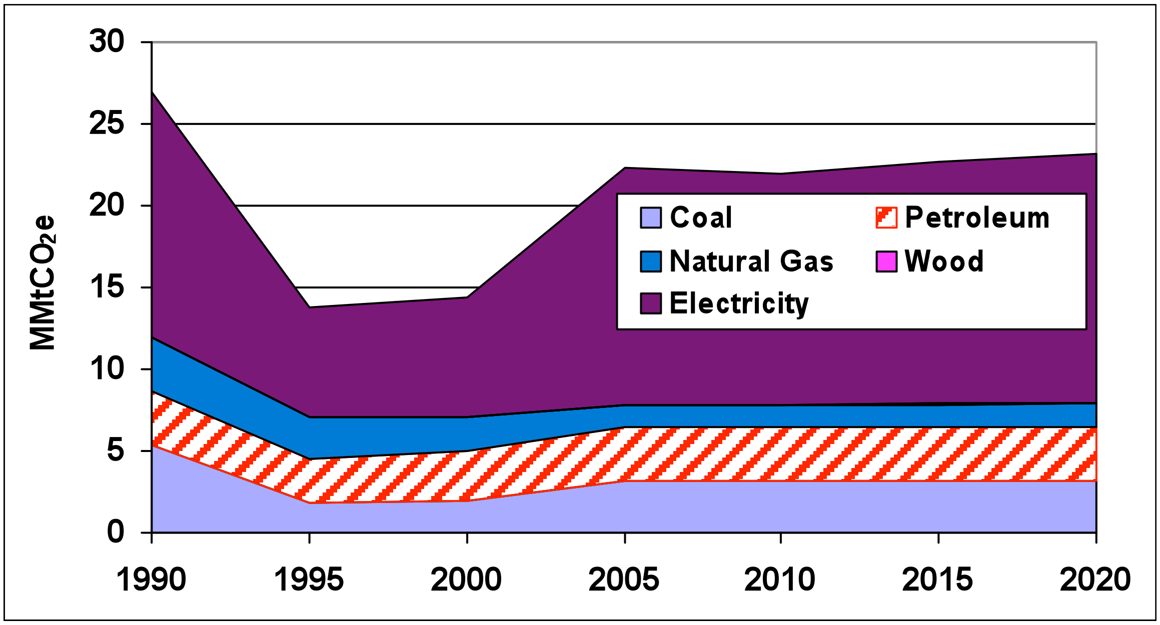
Source: CCS calculations based on approach described in text.
Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B4a.

Industrial Sector
Figure B3 presents the emission inventory and reference case projections for the industrial sector. Figure B3 was developed from the emissions data in Table B5a. Table B5b show the relative contributions of emissions associated with each fuel type to total industrial sector emissions.

For the industrial sector, emissions from electricity and direct fuel use in 1990 were about 27.0 MMtCO$_2$e and are estimated to decline to about 23.1 MMtCO$_2$e by 2020. Emissions associated with the generation of electricity to meet industrial energy consumption demand accounted for about 56% of total industrial emissions in 1990, and are estimated increase to about 66% of total industrial emissions by 2020. In 1990, natural gas consumption accounted for about 12% of total industrial emissions, and is estimated to account for about 6% of total industrial emissions by 2020. Emissions associated with the consumption of petroleum accounted for about 12% of total industrial emissions in 1990, but are estimated to increase slightly to account for about 14% of total emissions by 2020. Industrial-sector emissions associated with the use of coal and wood in 1990 were about 5.4 MMtCO$_2$e combined, and accounted for about 20% of total industrial emissions. For 2020, emissions associated with the consumption of coal and wood are estimated to decrease to 3.2 MMtCO$_2$e, and to account for 14% of total industrial sector emissions. Note that industrial-sector emissions associated with the use of wood from 1990 to 2020 are negligible.

For the 15-year period 2005 to 2020, industrial-sector GHG emissions associated with the use of electricity, natural gas, coal, and wood are expected to increase at average annual rates of about 0.29%, 0.90%, 0.04%, and 1.0%, respectively. Emissions associated with the use of petroleum are expected to decrease annually by about -0.08%. Total GHG emissions for the industrial sector increase by an average of about 0.24% annually over the 15-year period.

Figure B3. Industrial Sector GHG Emissions from Fuel Consumption



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

Table B5a. Industrial Sector Emissions Inventory and Reference Case Projections ($MMtCO_2e$)

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	5.42	1.83	1.93	3.14	3.16	3.16	3.16
Petroleum	3.19	2.63	3.04	3.36	3.25	3.26	3.32
Natural Gas	3.31	2.61	2.13	1.28	1.39	1.44	1.47
Wood	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Electricity Consumption	15.04	6.66	7.24	14.53	14.11	14.82	15.17
Total	26.97	13.75	14.37	22.34	21.94	22.71	23.14

Source: CCS calculations based on approach described in text.

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

Fuel Type	1990	1995	2000	2005	2010	2015	2020
Coal	20.1%	13.3%	13.5%	14.1%	14.4%	13.9%	13.6%
Petroleum	11.8%	19.1%	21.2%	15.1%	14.8%	14.4%	14.4%
Natural Gas	12.3%	19.0%	14.9%	5.7%	6.3%	6.3%	6.3%
Wood	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Electricity Consumption	56%	48.4%	50.4%	65.1%	64.3%	65.3%	65.6%

Source: CCS calculations based on approach described in text.
Note: The percentages shown in this table reflect the emissions for each fuel type as a percentage of total emissions shown in Table B5a.

Key Uncertainties

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

- Population and economic growth are the principal drivers for electricity and fuel use. The reference case projections are based on regional fuel consumption projections for EIA's South Atlantic modeling region. Consequently, there are significant uncertainties associated with the projections. Future work should attempt to base projections of GHG emissions on fuel consumption estimates specific to Maryland to the extent that such data become available.
- The AEO2006 projections assume no large long-term changes in relative fuel and electricity prices, relative to current price levels and to US DOE projections for fuel prices. Price changes would influence consumption levels and, to the extent that price trends for competing fuels differ, may encourage switching among fuels, and thereby affect emissions estimates.

Appendix C. Transportation Energy Use

Overview

Transportation is one the largest greenhouse gas (GHG) source sectors in Maryland. The transportation sector includes light- and heavy-duty onroad vehicles, aircraft, rail engines, and marine engines. Carbon dioxide (CO_2) accounted for about 97% of the transportation sector's GHG emissions in 1990 and is projected to increase to about 98% of transportation GHG emissions by 2020. Most of the remaining GHG emissions from the transportation sector are due to nitrous oxide (N_2O) emissions from gasoline engines.

Historical Emissions and Reference Case Projections

Historical greenhouse gas emissions were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[32,33] For on-road vehicles, the CO_2 emission factors are in units of pounds (lb) per million British thermal unit (MMBtu) and the methane (CH_4) and N_2O emission factors are both in units of grams per vehicle mile traveled (VMT). Key assumptions in this analysis are listed in Table C1. The default fuel consumption data within SIT were used to estimate emissions, with the most recently fuel consumption data (2004), available at the time of the calculations, from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data* (SED) added.[34] The default VMT data in SIT were replaced with annual VMT from the Maryland Department of the Environment (MDE).[35] Default data from the Federal Highway Administration (FHWA)[36] were used to allocate the VMT by vehicle type in the state.

Onroad Vehicles

Onroad vehicle gasoline and diesel CH_4 and N_2O emissions were projected based on VMT forecasts from MDE and growth rates developed from national vehicle type VMT forecasts reported in EIA's *Annual Energy Outlook* 2006 (AEO2006). The AEO2006 data were incorporated because they indicate significantly different VMT growth rates for certain vehicle types (e.g., 20% growth between 2005 and 2020 in light-duty gasoline vehicle VMT versus 44% growth in heavy-duty diesel truck VMT over this period). The procedure first applied the AEO2006 vehicle type-based national growth rates to 2005 estimates of VMT by vehicle type in Maryland. These data were then used to calculate the estimated proportion of total VMT by vehicle type in each year. Next, these proportions were applied to the MDE estimates for total VMT in the state for each year to yield the vehicle type VMT estimates and compound annual

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

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

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

[35] Maryland VMT forecast data provided by Mohamed Khan, Maryland Department of the Environment

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

average growth rates which are displayed in Tables C2 and C3, respectively. The VMT growth rates from gasoline vehicles were also applied to natural gas vehicles.

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

Vehicle Type and Pollutants	Methods
Onroad gasoline, diesel, natural gas, and liquefied petroleum gas (LPG) vehicles – CO_2	**Inventory (1990 – 2004)** US EPA SIT and fuel consumption from EIA State Energy Data (SED) **Reference Case Projections (2005 – 2020)** Gasoline and diesel fuel projected using VMT projections provided by MDE adjusted by fuel efficiency improvement projections from AEO2006. Other onroad fuels projected using South Atlantic Region fuel consumption projections from EIA AEO2006 adjusted using state-to-regional ratio of population growth.
Onroad gasoline and diesel vehicles – CH_4 and N_2O	**Inventory (1990 – 2005)** US EPA SIT, onroad vehicle CH_4 and N_2O emission factors by vehicle type and technology type within SIT were updated to the latest factors used in the US EPA's *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2005.* State total VMT replaced with VMT provided by MDE, VMT allocated to vehicle types using default data in SIT. **Reference Case Projections (2006 – 2020)** VMT projections from MDE allocated to vehicle types using vehicle specific growth rates from AEO2006.
Non-highway fuel consumption (jet aircraft, gasoline-fueled piston aircraft, boats, locomotives) – CO_2, CH_4 and N_2O	**Inventory (1990 – 2004)** US EPA SIT and fuel consumption from EIA SED. Commercial marine based on allocation of national fuel consumption, offshore emissions pulled from Commission for Environmental Cooperation in North America (CEC) inventory. **Reference Case Projections (2005 – 2020)** Aircraft projected using aircraft operations projections from Federal Aviation Administration (FAA). No growth assumed for rail diesel. Marine fuels projected based on linear regression of historical data.

Table C2. Maryland Vehicle Miles Traveled Estimates (millions)

Vehicle Type	2002	2005	2010	2015	2020
Heavy-Duty Diesel Vehicle	3,634	3,795	4,402	5,027	5,694
Heavy-Duty Gasoline Vehicle	533	560	603	671	744
Light-Duty Diesel Truck	531	574	788	1,081	1,489
Light Duty-Diesel Vehicle	165	172	237	325	447
Light-Duty Gasoline Truck	17,657	19,079	20,629	22,269	23,836
Light-Duty Gasoline Vehicle	31,058	32,351	34,981	37,760	40,418
Motorcycle	180	194	209	226	242
Total	53,759	56,725	61,849	67,359	72,870

Table C3. Maryland Vehicle Miles Traveled Compound Annual Growth Rates

Vehicle Type	2002-2005	2005-2010	2010-2015	2015-2020
Heavy-Duty Diesel Vehicle	1.45%	3.01%	2.69%	2.52%
Heavy-Duty Gasoline Vehicle	1.64%	1.49%	2.15%	2.09%
Light-Duty Diesel Truck	2.61%	6.55%	6.53%	6.61%
Light-Duty Diesel Vehicle	1.37%	6.55%	6.53%	6.61%
Light-Duty Gasoline Truck	2.61%	1.58%	1.54%	1.37%
Light-Duty Gasoline Vehicle	1.37%	1.58%	1.54%	1.37%
Motorcycle	2.50%	1.58%	1.54%	1.37%

For forecasting CO_2 emissions, growth in fuel consumption is also needed along with VMT. Onroad gasoline and diesel fuel consumption were forecasted by developing a set of growth factors that adjusted the VMT projections to account for expected improvements in fuel efficiency. Fuel efficiency projections were taken from EPA. The resulting onroad fuel consumption growth rates are shown in Table C4. Growth rates for projecting CO_2 emissions from natural gas vehicles, lubricants, and other fuel consumption were calculated by allocating the AEO2006 consumption of these fuels in the South Atlantic region to Maryland based on the ratio of the state's projected population to the region's projected population.

Table C4. Maryland Onroad Fuel Consumption Compound Annual Growth Rates

Fuel Growth Factors	2002-2005	2005-2010	2010-2015	2015-2020
Onroad diesel	1.32%	2.98%	3.02%	2.87%
Onroad gasoline	1.83%	1.10%	1.28%	1.31%

Gasoline consumption estimates for 1990-2004 were adjusted by subtracting ethanol consumption, per the methodology used in SIT. The historical EIA ethanol consumption data show that use of ethanol in Maryland began in 1995, peaked in 2002, and dropped off considerably in 2003 and 2004, with ethanol consumption ranging from less than 0.01% to

0.77% of the gasoline consumption on a Btu basis. For the reference case projections, ethanol consumption was assumed to remain at the 2004 level.

Aviation

For the aircraft sector, emission estimates for 1990 to 2004 are based on SIT methods and fuel consumption from EIA. Emissions were projected from 2005 to 2020 using general aviation and commercial aircraft operations for Maryland from 2005 through 2020 from the Federal Aviation Administration's (FAA) Terminal Area Forecast System[37] and national aircraft fuel efficiency forecasts. To estimate changes in jet fuel consumption, itinerant aircraft operations from air carrier, air taxi/commuter, and military aircraft were first summed for each year of interest. The post-2004 estimates were adjusted to reflect the projected increase in national aircraft fuel efficiency (indicated by increased number of seat miles per gallon), as reported in AEO2006. Because AEO2006 does not estimate fuel efficiency changes for general aviation aircraft, forecast changes in aviation gasoline consumption were based solely on the projected number of itinerant general aviation aircraft operations in Maryland, which was obtained from the FAA. The resulting compound annual average growth rates are displayed in Table C5.

Table C5. Maryland Aviation Fuels Compound Annual Growth Rates

Fuel	2002-2005	2005-2010	2010-2015	2015-2020
Aviation Gasoline	3.64%	0.08%	0.50%	0.41%
Jet Fuel	1.02%	0.15%	0.75%	0.70%

Rail and Marine Vehicles

For the rail and recreational marine (gasoline fuel) sectors, 1990 to 2004 estimates are based on SIT methods and fuel consumption from EIA. Marine gasoline consumption was projected to 2020 based on a linear regression of the 1990 through 2004 historical Maryland fuel consumption data. The historic data for rail shows no significant positive or negative trend; therefore, no growth was assumed for this sector.

For the commercial marine sector (marine diesel and residual fuel), 1990-2004 emission estimates are based on SIT emission rates applied to estimates of Maryland marine vessel diesel and residual fuel consumption. Because the SIT default relies on marine vessel fuel consumption estimates that represent the state in which fuel is sold rather than consumed, an alternative method was used to estimate Maryland marine vessel fuel consumption. Maryland fuel consumption estimates were developed by allocating 1990-2004 national diesel and residual oil vessel bunkering fuel consumption estimates obtained from EIA[38] after subtracting out the portion of national marine fuel consumed during international transport.[39] Marine vessel fuel consumption was allocated to Maryland using the marine vessel activity allocation methods/data

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

[38] US Department of Energy, Energy Information Administration, "Petroleum Navigator" (diesel data obtained from http://tonto.eia.doe.gov/dnav/pet/hist/kd0vabnus1a.htm; residual data obtained from http://tonto.eia.doe.gov/dnav/pet/hist/kprvatnus1a.htm).

[39] International marine fuel consumption obtained from EPA's *2007 Inventory of Greenhouse Gas Emissions and Sinks*, http://www.epa.gov/climatechange/emissions/downloads06/07Energy.pdf, table 3-51

compiled to support the development of EPA's National Emissions Inventory (NEI).[40] In keeping with the NEI, 75% of each year's distillate fuel and 25% of each year's residual fuel were assumed to be consumed within the port area (remaining consumption was assumed to occur while ships are underway). National port area fuel consumption was allocated to Maryland based on year-specific freight tonnage data for the top 150 ports in the nation as reported in "Waterborne Commerce of the United States, Part 5 – Waterways and Harbors National Summaries."[41] Offshore CO_2 and hydrocarbon (HC) emissions for Maryland's exclusive economic zone (EEZ) was taken from a study by Corbett for the Commission for Environmental Cooperation in North America (CEC).[42] Offshore CH_4 emissions were estimated by speciating the HC emissions using the California Air Resources Board's total organic gas (TOG) profile (#818).[43] Offshore N_2O emissions were estimated by applying the ratio of N_2O to CH_4 emission factors to the CH_4 emission estimate. The 2002 offshore emissions from the CEC inventory were scaled to other historic years based on the estimated port fuel consumption. Port and offshore commercial marine emissions were projected based on the 1990-2004 growth rates.

Nonroad Engines

It should be noted that fuel consumption data from EIA includes nonroad gasoline and diesel fuel consumption in the commercial and industrial sectors. Emissions from these nonroad engines are included in the inventory and forecast for the residential, commercial, and industrial (RCI) sectors. Table C6 shows how EIA divides gasoline and diesel fuel consumption between the transportation, commercial, and industrial sectors.

Table C6. EIA Classification of Gasoline and Diesel Consumption

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

Results

As shown in Figure C1 and Table C7, onroad gasoline consumption accounts for the largest share of transportation GHG emissions. Emissions from onroad gasoline vehicles increased by about 34% from 1990-2005, accounting for 74% of total transportation emissions in 2005. GHG emissions from onroad diesel fuel consumption increased by 103% from 1990 to 2005, and by 2005 accounted for 18% of GHG emissions from the transportation sector. Emissions from boats and ships decreased by 13% from 1990 to 2005, accounting for 4% of transportation emissions in

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

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

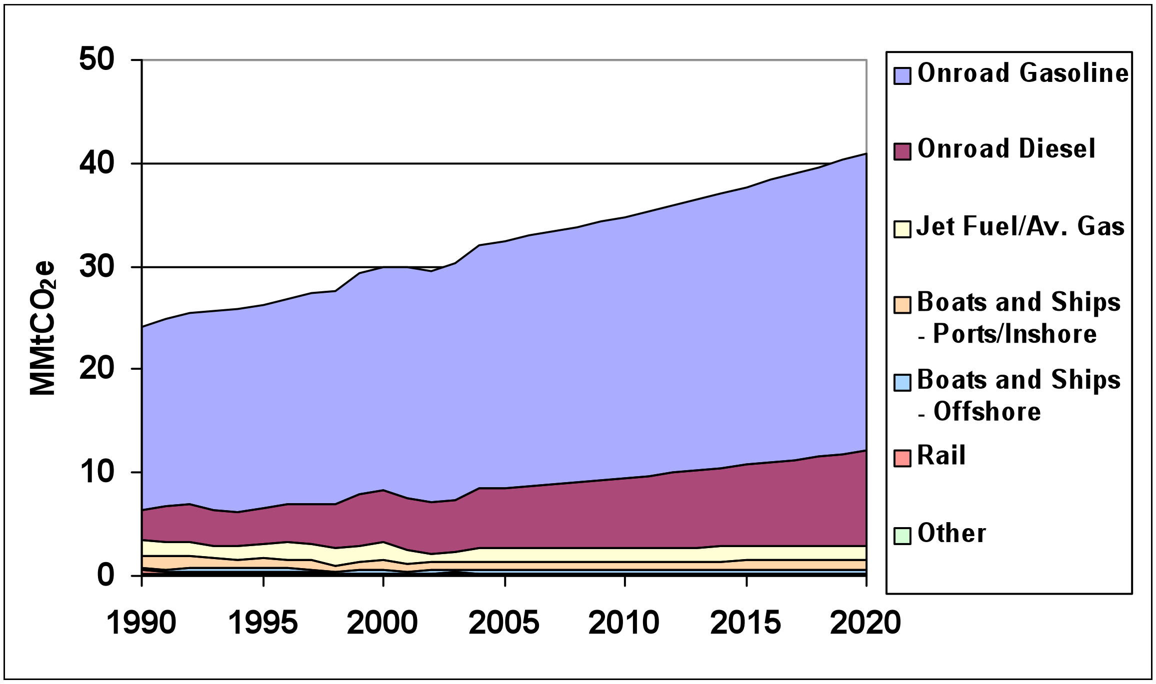
[42] Estimate, Validation, and Forecasts of Regional Commercial Marine Vessel Inventories, submitted by J. Corbett, prepared for the California Air Resources Board, California Environmental Protection Agency, and Commission for Environmental Cooperation in North America, http://coast.cms.udel.edu/NorthAmericanSTEEM/.

[43] California Air Resources Board, Speciation Profiles, http://www.arb.ca.gov/ei/speciate/speciate.htm.

2005. Emissions from all other categories combined (aviation, locomotives, natural gas and liquefied petroleum gas (LPG), and oxidation of lubricants) contributed to about 5% of total transportation emissions in 2005.

GHG emissions from onroad gasoline consumption are projected to increase by about 20%, and emissions from onroad diesel consumption are expected to increase by 56% between 2005 and 2020. GHG emissions from the aviation and marine sectors are projected to increase by 8% and 10%, respectively, from 2005 to 2020, while emissions from rail are expected to remain constant during this same period.

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



SSource: CCS calculations based on approach described in text.

Table C7. Gross GHG Emissions from Transportation (MMtCO$_2$e)

Source	1990	1995	2000	2005	2010	2015	2020
Onroad Gasoline	17.91	19.67	21.61	23.94	25.29	26.97	28.78
Onroad Diesel	2.91	3.42	5.09	5.89	6.83	7.91	9.18
Jet Fuel/Av. Gas	1.49	1.41	1.68	1.31	1.32	1.37	1.42
Boats and Ships - Ports/Inshore	1.16	0.90	0.90	0.87	0.81	0.87	0.93
Boats and Ships - Offshore	0.21	0.35	0.39	0.31	0.33	0.35	0.37
Rail	0.39	0.27	0.05	0.06	0.06	0.06	0.06
Other	0.14	0.14	0.16	0.14	0.16	0.18	0.19
Total	**24.20**	**26.16**	**29.90**	**32.52**	**34.81**	**37.71**	**40.93**

Key Uncertainties

Projections of VMT

A major uncertainty in this analysis is the projected increase in on-road VMT and gasoline consumption from 2005 to 2020. The VMT projections are based on developing growth rates from 1990 to 2005 historical MDE VMT data, and projected MDE VMT from 2008, 2010, and 2020, as well as national projections of the VMT mix from EIA AEO2006 data. The future year vehicle mix, which was calculated based on national growth rates for specific vehicle types, adds uncertainty because this mix may not appropriately reflect vehicle-specific growth in Maryland.

Uncertainties in Aviation Fuel Consumption

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

Uncertainties in Marine Fuel Consumption

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

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

Appendix D. Industrial Processes

Overview

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

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

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

- Nitrous oxide (N_2O) from nitric and adipic acid production;
- SF_6 from magnesium processing;
- CO_2 from ammonia manufacture; and
- HFCs from HCFC-22 production.

The following discusses the data sources, methods, assumptions, and results used to construct the inventory and reference case projections for this sector. The reference case projections assume business-as-usual practices.

Emissions and Reference Case Projections

Greenhouse gas emissions for 1990 through 2005 were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software, and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for this sector.[44] Table D1 identifies for each emissions source category the information needed for input into SIT to calculate emissions, the data sources used for the analysis described here, and the historical years for which emissions were calculated based on the availability of data.

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

Table D1. Approach to Estimating Historical Emissions

Source Category	Time Period	Required Data for SIT	Data Source
Cement Manufacturing - Clinker Production and Masonry Cement Production	Clinker: 1990 – 2005 Masonry: 1993 - 2001	Metric tons (Mt) of clinker produced and masonry cement produced each year.	Historical production for Maryland from US Geological Survey (USGS) Minerals Yearbook, Cement Statistics and Information. Data for masonry cement not available prior to 1993 and after 2001. (http://minerals.usgs.gov/minerals/pubs/commodity/cement/index.html#myb).
Limestone and Dolomite Consumption	1994 - 2005	Mt of limestone and dolomite consumed.	Historical consumption (sales) for Maryland from USGS Minerals Yearbook, Crushed Stone Statistics and Information, (http://minerals.usgs.gov/minerals/pubs/commodity/stone_crushed/). The USGS data includes limestone and dolomite reported together with no distinction between the two kinds of stone. In SIT, the state's total limestone consumption (as reported by USGS) is multiplied by the ratio of national limestone consumption for industrial uses to total national limestone consumption. Additional information on these calculations, including a definition of industrial uses, is available in Chapter 6 of the EIIP guidance document. Default limestone production data are not available in SIT for 1990 – 1993; data for 1994 were used for 1990 – 1993 as a surrogate to fill in production data missing for these years.
Soda Ash Consumption	1990 - 2005	Mt of soda ash consumed for use in consumer products such as glass, soap and detergents, paper, textiles, and food.	Historical emissions are calculated in SIT based on the state's population and national per capita soda ash consumption from the US EPA national GHG inventory. -- National historical consumption (sales) for US from USGS Minerals Yearbook, Soda Ash Statistics and Information (http://minerals.usgs.gov/minerals/pubs/commodity/soda_ash/). -- National emissions from *US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005*, US EPA, Report #430-R-07-002, April 2007 (http://epa.gov/climatechange/emissions/usinventoryreport.html). -- US (1990-2000 and 2000-2005) and state (2000-2005) population from US Census Bureau (http://www.census.gov/popest/states/NST-ann-est.html). -- State (1990-2000) population from US Census Bureau (http://www.census.gov/popest/archives/2000s/vintage_2001/CO-EST2001-12/CO-EST2001-12-24.html).
Iron and Steel Production	1997-2005	Mt of crude steel produced by production method.	The basic activity data needed are the quantities of crude steel produced (defined as first cast product suitable for sale or further processing) by production method. Default SIT values are based on the state-level production data assigned to production method based on the national distribution of production by method. National production data are from the Annual Statistics Report published by the American Iron and Steel Institute, Washington, DC (http://www.steel.org/AM/Template.cfm?Section=Bookstore&CONTENTID=12259&TEMPLATE=/CM/HTMLDisplay.cfm). Default production data are not available in SIT for 1990-1996; data for these years are based on 1997 production.
Aluminum Production	1990 - 2005	Mt of aluminum produced each year.	Historical production for Maryland from USGS Minerals Yearbook, Aluminum Statistics and Information (http://minerals.usgs.gov/minerals/pubs/commodity/aluminum/).
ODS Substitutes	1990 - 2005	Based on state's population and estimates of emissions per capita from the US EPA national GHG inventory.	References for US EPA national emissions and US Census Bureau national and state population figures are cited under the data sources for soda ash above.

Source Category	Time Period	Required Data for SIT	Data Source
Electric Power T&D Systems	1990 - 2005	Emissions from 1990 to 2005 based on the national emissions per kilowatt-hour (kWh) and state's electricity use provided in SIT.	National emissions are apportioned to the state based on the ratio of state-to-national electricity sales data provided in the Energy Information Administration's (EIA) Electric Power Annual (http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html). Reference for US EPA national emissions is cited under the data sources for soda ash above.
Semiconductor Manufacture	1990 - 2005	State and national value of semiconductor shipments for NAICS code 334413 (Semiconductor and Related Device Manufacturing).	Method uses ratio of state-to-national value of semiconductor shipments to estimate state's proportion of national emissions for 1990–2005. Value of shipments from U.S Census Bureau's 1997 and 2002 Economic Census (http://www.census.gov/econ/ census02/). Reference for US EPA national emissions is cited under the data sources for soda ash above.

Table D2 lists the data and methods that were used to estimate future activity levels related to industrial process emissions and the annual compound growth rates computed from the data/methods for the reference case projections. Because available forecast information is generally for economic sectors that are too broad to reflect trends in the specific emissions producing processes, the majority of projections are based on historical activity trends. In particular, state historical trends were analyzed for three periods: 1990-2005, 1995-2005, and 2000-2005 (or the closest available approximation of these periods).

Results

Figures D1 and D2 show historic and projected emissions for the industrial processes sector from 1990 to 2020. Table D3 shows the historic and projected emission values upon which Figures D1 and D2 are based. Total gross GHG emissions were about 2.6 MMtCO$_2$e in 1990, 4.9 MMtCO$_2$e in 2005, and are projected to increase to about 8.8 MMtCO$_2$e in 2020. Emissions from the overall industrial processes category are expected to grow by about 4.0% annually from 2005 through 2020, as shown in Figures D1 and D2, with emissions growth primarily associated with increasing use of HFCs and PFCs in refrigeration and air conditioning equipment.

Table D2. Approach to Estimating Projections for 2005 through 2020

			Annual Growth Rates (%)		
Source Category	Projection Assumptions	Data Source	2005 to 2010	2010 to 2015	2015 to 2020
Cement Production	Based on 15-year historical annual increase in state production from each of three periods analyzed.	Annual change in Maryland clinker production: 1990-2005 = 2.6%; 1995-2005 = 9.1%; and 2000-2005 = 8.3%	2.6	2.6	2.6
Limestone and Dolomite Consumption	Based on 15-year historical annual increase in state production from each of three periods analyzed.	Annual change in Maryland limestone and dolomite consumption: 1990-2005 = 1.0%; 1995-2005 = -1.0% 2000-2005 = 3.8%	1.0	1.0	1.0
Soda Ash Consumption	Based on 15-year historical annual change in state production from each of three periods analyzed.	Annual change in Maryland soda ash consumption: 1990-2005 = -0.5% 1995-2005 = -0.6% 2000-2005 = -0.6%	-0.5	-0.5	-0.5

Iron and Steel Production	Based on historical annual change in state production from each of two periods analyzed.	Annual change in Maryland iron and steel production: 1997-2005 = -1.4% 2000-2005 = -1.4%	-1.4	-1.4	-1.4
Aluminum Production	Based on 15-year historical annual increase in state production from each of three periods analyzed.	Annual change in Maryland aluminum production: 1990-2005 = 1.4% 1995-2005 = 3.3% 2000-2005 = 5.5%	1.4	1.4	1.4
ODS Substitutes	National growth in emissions associated with the use of ODS substitutes.	Annual growth rates calculated based on sum of US national emissions projections from 2005 through 2020 for six categories of ODS substitutes presented in Appendix D, Tables D-1 through D-6 in the US EPA report, *Global Anthropogenic Emissions of Non-*CO_2 *Greenhouse Gases 1990-2020*, EPA Report #430-R-06-003 (http://www.epa.gov/nonco2/econ-inv/international.html).	8.7	6.4	5.0
Electric Power T&D Systems	National growth rate (based on technology adoption forecast scenario reflecting industry participation in EPA voluntary stewardship program to control emissions).	Annual growth rates calculated based on US national emissions projections from 2005 through 2020 presented in Appendix D, Table D-10 in the US EPA report, *Global Anthropogenic Emissions of Non-*CO_2 *Greenhouse Gases 1990-2020* , EPA Report 430-R-06-003 (http://www.epa.gov/nonco2/econ-inv/international.html).	-1.6	-0.8	-0.7
Semiconductor Manufacturing	Ditto	Ditto	0.7	-4.2	-1.4

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

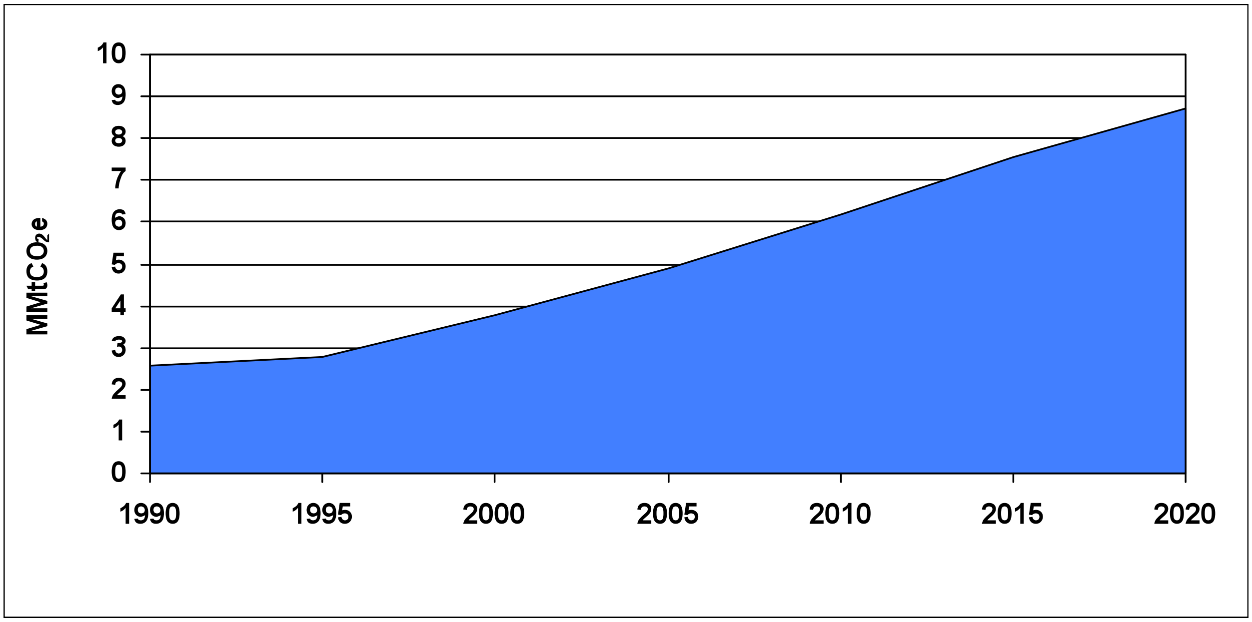

Figure D2. GHG Emissions from Industrial Processes, 1990-2020, by Source

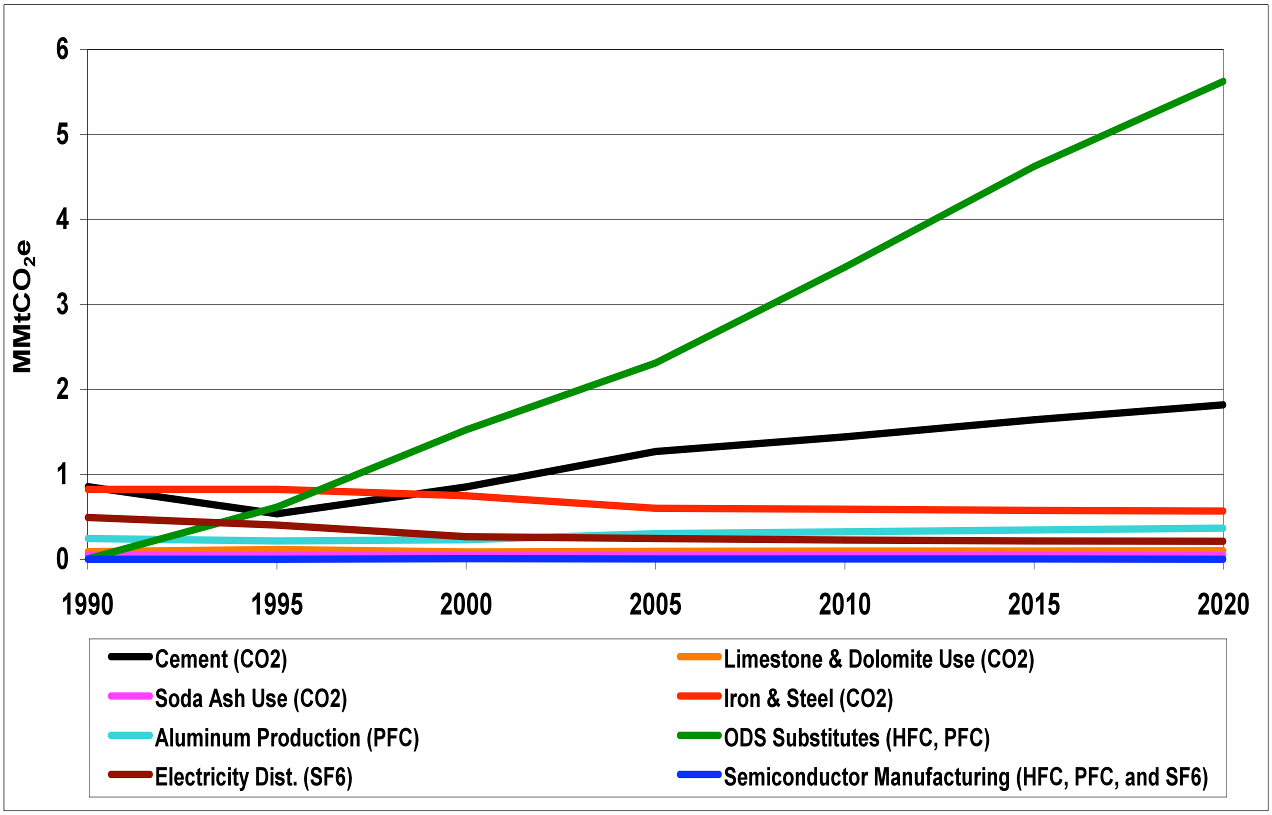

Table D3. Historic and Projected Emissions for the Industrial Processes Sector ($MMtCO_2e$)

Industry / Pollutant	1990	1995	2000	2005	2010	2015	2020
Cement (CO_2)	0.86	0.54	0.86	1.27	1.45	1.64	1.82
Limestone & Dolomite Use (CO_2)	0.09	0.12	0.09	0.11	0.11	0.12	0.12
Soda Ash Use (CO_2)	0.052	0.052	0.050	0.049	0.047	0.046	0.045
Iron & Steel (CO_2)	0.83	0.83	0.75	0.60	0.56	0.53	0.50
Aluminum Production (PFCs)	0.25	0.22	0.23	0.30	0.33	0.35	0.37
ODS Substitutes (HFC, PFC)	0.01	0.62	1.53	2.31	3.44	4.62	5.63
Electricity Dist. (SF_6)	0.50	0.41	0.27	0.25	0.23	0.22	0.21
Semiconductor Manufacturing (HFC, PFC, and SF_6)	0.003	0.004	0.009	0.007	0.007	0.005	0.005
Total	**2.58**	**2.78**	**3.78**	**4.90**	**6.17**	**7.53**	**8.70**

Cement Manufacture

Clinker is an intermediate product from which finished Portland and masonry cement are made. Clinker production releases CO_2 when calcium carbonate ($CaCO_3$) is heated in a cement kiln to form lime (calcium oxide) and CO_2 (see Chapter 6 of EIIP guidance document). Emissions are calculated by multiplying annual clinker production by emission factors to estimate emissions associated with the clinker production process (0.507 metric ton (Mt) of CO_2 emitted per Mt of clinker produced) and cement kiln dust (0.020 $MtCO_2$ emitted per Mt of clinker CO_2 emitted).

Masonry cement requires additional lime, over and above the lime used in the clinker. During the production of masonry cement, non-plasticizer additives such as lime, slag, and shale are added to the cement, increasing its weight by 5%. Lime accounts for approximately 60% of the added substances. About 0.0224 $MtCO_2$ is emitted for every Mt of masonry cement produced, relative to the CO_2 emitted during the production of a Mt of clinker (see Chapter 6 of EIIP guidance document).

As shown in Figure D2 (see black line) and Table D3, emissions from this source are estimated to be about 0.86 $MMtCO_2e$ in 1990 and are projected to increase to about 1.82 $MMtCO_2e$ by 2020. Historical clinker production data obtained from the US Geological Survey (USGS) (see Table D1) and the default emission factors in SIT were used to calculate CO_2 emissions for 1990-2005. The annual average rate of increase in Maryland clinker/masonry cement production over the 1990-2005 period (2.6% per year) was used to project emissions from 2006 to 2020. Masonry cement production was not included in the growth rate analysis because of a lack of data prior to 1993 and after 2001 and because masonry cement production was highly variable over this time period. Masonry cement production ranged from a low of less than 1% to a high of 7% of clinker production in 1991 and 1996 through 2001, but was as high as 17% and 18% of total clinker production in 1995 and 1994, respectively.

Limestone and Dolomite Consumption

Limestone and dolomite are basic raw materials used by a wide variety of industries, including the construction, agriculture, chemical, glass manufacturing, and environmental pollution control industries, as well as in metallurgical industries such as magnesium production. Emissions associated with the use of limestone and dolomite to manufacture steel and glass and for use in flue-gas desulfurization scrubbers to control sulfur dioxide emissions from the combustion of coal in boilers are included in the industrial processes sector.[45]

As shown in Figure D2 and Table D3, emissions from this source are estimated to be about 0.09 $MMtCO_2e$ in 1990 and are projected to increase to about 0.12 $MMtCO_2e$ by 2020 (see orange line at the bottom of Figure D2). Historical limestone and dolomite consumption (sales) data for Maryland obtained from the USGS (see Table D1) and the default emission factors in SIT were used to calculate CO_2 emissions for 1990-2005. Note that the USGS limestone and dolomite consumption are combined. For this analysis, it was assumed that the majority of the consumption was limestone rather than dolomite; therefore, the SIT emission factor for limestone (0.044 $MtCO_2$ per Mt of limestone) was used to calculate emissions rather than the emission factor for dolomite (0.0484 Mt CO_2 per Mt of dolomite). The annual average rate of increase in Maryland limestone and dolomite consumption over the 1990-2005 period (1.0% per year) was used to project emissions from 2006 to 2020.

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

Soda Ash Use

Commercial soda ash (sodium carbonate) is used in many consumer products such as glass, soap and detergents, paper, textiles, and food. Carbon dioxide is also released when soda ash is consumed (see Chapter 6 of EIIP guidance document). As shown in Table D3, emissions from this source are estimated to be about 0.052 MMtCO_2e in 1990 and are projected to decline to about 0.045 MMtCO_2e in 2020 (due to scale effects the emissions cannot be seen Figure D2). Historical emissions are calculated in SIT based on the state's population and national per capita soda ash consumption from the US EPA national GHG inventory. The annual average rate of change in Maryland soda ash use over the 1990-2005 15-year period (-0.5% per year) was used to project emissions from 2006 to 2020.

Iron and Steel Production

The production of iron and steel generate process-related CO_2 emissions. Iron is produced by reducing iron ore with metallurgical coke in a blast furnace to produce pig iron; this process emits CO_2 emissions. Pig iron is used as a raw material in the production of steel. The production of metallurgical coke from coking coal produces CO_2 emissions as well.

Historical CO_2 emissions were estimated using the SIT default activity data (see Table D1) for 1997-2005 and emission factors for the following production methods: basic oxygen furnace at integrated mill with coke ovens, basic oxygen furnace at integrated mill without coke ovens, electric arc furnace, and open hearth furnace. The basic activity data needed are the quantities of crude steel produced (defined as first cast product suitable for sale or further processing) by production method. Default values are based on the state-level production data assigned to each production method based on the national distribution of production by method. The national production data were obtained from the Annual Statistics Report published by the American Iron and Steel Institute, Washington, DC (see Table D1). Production data are not available in SIT for 1990-1996; data for these years are based on 1997 production. As shown in Figure D2 (see red line) and Table D3, emissions in 1990 were 0.83 MMtCO_2e and are projected to decline to about 0.50 MMtCO_2e in 2020. The annual average rate of change in Maryland's iron and steel production over the 1997-2005 period (-1.4% per year) was used to project emissions from 2006 to 2020.

Aluminum Production

The aluminum production industry is thought to be the largest source of two perfluorocarbons (PFCs) – tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6). Emissions of these two potent GHGs occur during the reduction of alumina in the primary smelting process (see Chapter 6 of the EIIP guidance document). As shown in Figure D2 (see turquoise line) and Table D3, emissions in 1990 were 0.25 MMtCO_2e and are projected to increase to about 0.37 MMtCO_2e in 2020. Historical aluminum production data obtained from the USGS (see Table D1) and the default emission factors in SIT were used to calculate CO_2 emissions for 1990-2005. The annual average rate of increase in Maryland aluminum production over the 1990-2005 period (1.4% per year) was used to project emissions from 2006 to 2020.

Substitutes for Ozone-Depleting Substances (ODS)

HFCs and PFCs are used as substitutes for ODS, most notably CFCs (CFCs are also potent warming gases, with global warming potentials on the order of thousands of times that of CO_2 per unit of emissions) in compliance with the *Montreal Protocol* and the *Clean Air Act Amendments of 1990*.[46] Even low amounts of HFC and PFC emissions, for example, from leaks and other releases associated with normal use of the products, can lead to high GHG emissions on a CO_2e basis. Emissions have increased from 0.01 MMtCO_2e in 1990 to about 1.53 MMtCO_2e in 2000, and are expected to increase at an average rate of 6.7% per year from 2000 to 2020 due to increased substitutions of these gases for ODS (see dark green line in Figure D2). The projected rate of increase for these emissions is based on projections for national emissions from the US EPA report referenced in Table D2.

Electric Power Transmission and Distribution

Emissions of SF_6 from electrical equipment have experienced declines since the mid nineties (see brown line in Figure D2), mostly due to voluntary action by industry. Sulfur hexafluoride is used as an electrical insulator and interrupter in the electric power T&D system. The largest use for SF_6 is as an electrical insulator in electricity T&D equipment, such as gas-insulated high-voltage circuit breakers, substations, transformers, and transmission lines, because of its high dielectric strength and arc-quenching abilities. Not all of the electric utilities in the US use SF_6; use of the gas is more common in urban areas where the space occupied by electric power T&D facilities is more valuable.[47]

As shown in Figure D2 and Table D3, SF_6 emissions from electric power T&D are about 0.50 MMtCO_2e in 1990 and 0.21 MMtCO_2e in 2020. Emissions in Maryland from 1990 to 2005 were estimated based on the estimates of emissions per kilowatt-hour (kWh) of electricity consumed from the US EPA GHG inventory, and the ratio of Maryland’s to the US electricity consumption (sales) estimates available from the Energy Information Administration’s (EIA) Electric Power Annual and provided in SIT (see Table D1). The national trend in US emissions estimated for 2005-2020 for the technology-adoption scenario shows expected decreases in these emissions at the national level (see Table D2), and the same rate of decline is assumed for emissions in Maryland. The decline in SF_6 emissions in the future reflects expectations of future actions by the electric power industry to reduce these emissions.

Semiconductor Manufacture

The semiconductor industry uses fluorinated gases (PFCs [CF_4, C_2F_6, and C_3F_8]; HFC-23; and SF_6) in plasma etching and chemical vapor deposition processes. Emissions of SF_6 and HFCs from the manufacture of semiconductors have experienced declines since 2000. Emissions for Maryland from 1990 to 2005 were estimated based on the default estimates provided in SIT, which uses the ratio of the state-to-national value of semiconductor shipments to estimate the

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

[47] US EPA, Draft User’s Guide for Estimating Carbon Dioxide, Nitrous Oxide, HFC, PFC, and SF_6 Emissions from Industrial Processes Using the State Inventory Tool, prepared by ICF International, March 2007.

state's proportion of national emissions from the US EPA GHG inventory (see Table D1). The national trend in US emissions estimated for 2005-2020 for the technology-adoption scenario shows expected decreases in these emissions at the national level (see Table D2), and the same rate of decline is assumed for emissions in Maryland. The decline in emissions in the future reflects expectations of future actions by the semiconductor industry to reduce these emissions. Relative to total industrial non-combustion process emissions, estimated emissions associated with semiconductor manufacturing are low (about 0.003 MMtCO$_2$e in 1990, 0.007 MMtCO$_2$e in 2005, and 0.005 MMtCO$_2$e in 2020), and therefore, cannot be seen in Figure D2 due to scaling effects.

Key Uncertainties

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

- Since emissions from industrial processes are determined by the level of production and the production processes of a few key industries—and in some cases, a few key plants—there is relatively high uncertainty regarding future emissions from the industrial processes category as a whole. Future emissions depend on the competitiveness of Maryland manufacturers in these industries, and the specific nature of the production processes used in Maryland.
- The projected largest source of future industrial emissions, HFCs and PFCs used in cooling applications, is subject to several uncertainties as well. Emissions through 2020 and beyond will be driven by future choices regarding mobile and stationary air conditioning technologies and the use of refrigerants in commercial applications, for which several options currently exist.
- Due to the lack of reasonably specific projection surrogates, historical trend data were used to project emission activity level changes for multiple industrial processes. There is significant uncertainty associated with any projection, including a projection that assumes that past historical trends will continue in future periods.
- For the industries for which EPA default activity data and methods were used to estimate historical emissions, future work should include efforts to obtain state-specific data to replace the default assumptions. In particular, for the iron and steel, aluminum, electric power T&D, and semiconductor industries, future efforts should include a survey of companies within these industries to determine the extent to which they are implementing techniques to minimize emissions to improve the emission projections for these industries.
- Because of a lack of activity data for the early 1990's, iron and steel production for 1997 activity data were used as a surrogate to estimate emissions for 1990 through 1996. For limestone and dolomite consumption, 1994 activity data were used as a surrogate to estimate emissions for 1990 through 1993. Future work should include efforts to obtain actual activity data for the years for which the data were not available for this analysis to minimize uncertainties associated with the use of the surrogate data.

Appendix E. Fossil Fuel Production Industry

Overview

The inventory for this subsector of the Energy Supply sector includes methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) emissions associated with the production, processing, transmission, and distribution of fossil fuels in Maryland.[48] There is no oil production or oil or natural gas processing in Maryland. In 2005, the fossil fuel production industry accounted for an estimated 1.08 million metric tons (MMt) of CO_2 equivalent (CO_2e) of total gross greenhouse gas (GHG) emissions in Maryland, and is estimated to increase to about 1.11 $MMtCO_2e$ by 2020.

Emissions and Reference Case Projections

Emissions for 1990 through 2005 were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for natural gas and oil systems.[49] Table E1 provides an overview of the required data, data sources, and the approach to projecting future emissions. The activity data were entered into the SIT to calculate emissions for 1990 through 2005. Emissions were calculated by multiplying emissions-related activity levels (e.g., miles of pipeline) by aggregate emission factors.

Oil and Gas Production

Natural gas production emissions are estimated for the number of operating natural gas producing wells in the state (no oil production emissions are estimated for Maryland because the state does not produce crude oil or have any petroleum refineries).[50] Natural gas production emissions were held constant in forecast years because the number of operating natural gas producing wells was fairly constant throughout the historical period.

Based on the information provided in the Emission Inventory Improvement Program (EIIP) guidance[51] for estimating emissions for this sector, transmission pipelines are large diameter, high-pressure lines that transport gas from production fields, processing plants, storage facilities, and other sources of supply over long distances to local distribution companies or to large volume customers. Sources of CH_4 emissions from transmission pipelines include leaks, compressor fugitives, vents, and pneumatic devices. Distribution pipelines are extensive networks of generally small diameter, low-pressure pipelines that distribute gas within cities or towns. Sources of CH_4 emissions from distribution pipelines are leaks, meters, regulators, and mishaps. Carbon dioxide, CH_4, and N_2O emissions occur as the result of the combustion of natural gas by internal combustion engines used to operate compressor stations.

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[48] Note that emissions from natural gas consumed as lease fuel (used in well, field, and lease operations) and plant fuel (used in natural gas processing plants) are included in Appendix B in the industrial fuel combustion category.

[49] Methane emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems," March 2005.

[50] US Department of Energy, Energy Information Administration, "State Energy Profile – Maryland," accessed from http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=MD, December 2007.

[51] Emission Inventory Improvement Program, Volume VIII: Chapter 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems," August 2004.

Table E1. Approach to Estimating Historical and Future GHG Emissions from the Fossil Fuel Production Industry

	Approach to Estimating Historical Emissions		Approach to Estimating Projections
Activity	*Required Data for SIT*	*Data Source*	*Projection Assumptions*
Natural Gas Drilling and Field Production	Number of wells	EIA[52]	No change because no change in activity over 3 periods analyzed (1990-2005; 1995-2005; and 2000-2005)
	Miles of gathering pipeline	Office of Pipeline Safety (OPS)[53]	
Natural Gas Transmission	Miles of transmission pipeline	OPS[49]	Based on AEO2006[54] projected average annual growth in natural gas consumption in the South Atlantic Region over three periods: 1.96 % from 2005 to 2010, 1.75% from 2010 to 2015, and 1.46% from 2015 to 2020.
	Number of gas transmission compressor stations	EIIP[55]	
	Number of gas storage compressor stations	EIIP[56]	
	Number of LNG storage compressor stations	Not estimated because data unavailable	
Natural Gas Distribution	Miles of distribution pipeline	OPS[49]	Same as Natural Gas Transmission above.
	Total number of services		
	Number of unprotected steel services		
	Number of protected steel services		
Natural Gas Pipeline Fuel Use (CO_2, CH_4, N_2O)	Volume of natural gas consumed by pipelines	EIA[57]	Application of smallest annualized decline in pipeline fuel consumption (-0.54%) from each of 3 periods analyzed (1990-2005).
Coal Mining	Methane emissions in million cubic feet	US. Environmental Protection Agency (EPA)[58]	Based on AEO2006[50] projected average annual growth/decrease in coal production in the North Appalachian region over three periods: 4.63 % from 2005 to 2010, 0.52% from 2010 to 2015, and –0.22% from 2015 to 2020.

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[52] US Department of Energy, Energy Information Administration, "Natural Gas Navigator - Maryland Natural Gas Number of Gas and Gas Condensate Wells," accessed from http://tonto.eia.doe.gov/dnav/ng/hist/na1170_smd_8a.htm, December 2007.

[53] US Department of Transportation, Office of Pipeline Safety, "Distribution and Transmission Annuals Data: 1990 to 2005," accessed from http://ops.dot.gov/stats/DT98.htm, December 2007.

[54] US Department of Energy, Energy Information Administration, "Annual Energy Outlook 2006 with Projections to 2030," accessed from, December 2007.

[55] Number of gas transmission compressor stations = miles of transmission pipeline x 0.006 – EIIP, Volume VIII: Chapter 5, March 2005.

[56] Number of gas storage compressor stations = miles of transmission pipeline x 0.0015 EIIP. Volume VIII: Chapter 5, March 2005.

[57] US DOE, Energy Information Administration, *State Energy Consumption, Price, and Expenditure Estimates (SEDS)*, (http://www.eia.doe.gov/emeu/states/_seds.html).

[58] US Environmental Protection Agency, "Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2005, USEPA #430-R-07-002, http://www.epa.gov/climatechange/emissions/usinventoryreport.html, April 2007.

The annual activity data for miles of T&D pipeline and number of service connections to distribution pipelines were obtained from databases provided by the Office of Pipeline Safety (OPS).[49] For the distribution system, annual CH_4 emissions were estimated using OPS' pipeline mileage and the SIT emission factors for (1) distribution pipeline constructed of cast iron, unprotected steel, protected steel, and plastic, and (2) the number of protected and unprotected service connections. For the transmission system, the SIT methods use total miles of pipeline as the basis for calculating CH_4 emissions; separate emission factors are not provided for pipeline constructed of different materials.

Three revisions to the OPS' data were implemented for Maryland. Year 1991, 1992, and 2002 distribution pipeline mileage and service count values were interpolated from the OPS' values for the surrounding years (i.e., values for 1990 and 1993 were used to interpolate values for 1991) because Washington Gas Light Company (Washington), which accounts for a significant portion of total distribution mileage/service counts, was missing from the data set in 1991, 1992, and 2002. Similarly, transmission pipeline mileage was interpolated for 1991, 1992 and 1993 based on the available OPS' 1990 and 1994 values because Washington was also missing from the OPS' transmission data set in these years.[59]

The SIT methods also include emission factors for estimating CH_4 emissions associated with leaks from gas transmission compressor stations, gas storage compressor stations, and liquefied natural gas (LNG) storage compressor stations. Information on the type and number of compressor stations was not readily available for Maryland. Therefore, the per mile of transmission pipeline-based SIT default factors were used to estimate the number of gas transmission compressor stations and gas storage compressor stations.[51,52] For gas transmission compressor stations, the default SIT methods estimates only one station for each year from 1990 through 2000, three stations for 2001, and five stations for each year from 2002 through 2005. For gas storage compressor stations, the SIT methods estimated no stations for 1990 through 2000 and only one station for each year afterwards. Note that the SIT does not provide default data or methods for estimating the number of LNG storage compressor stations in a state; therefore, emissions were not estimated for LNG storage compressor stations. Emissions of CO_2, CH_4, and N_2O associated with pipeline natural gas combustion are estimated using SIT emission factors[60] and Maryland 1990-2005 natural gas data from EIA for the "consumed as pipeline fuel" category.[53]

The following compound annual average growth rates were applied to forecast emissions associated with natural gas T&D: 2005-2010 = 1.96%; 2011-2015 = 1.75%; and 2016-2020 = 1.46%. These growth rate assumptions are based on US Department of Energy (DOE), Energy Information Administration (EIA)'s South Atlantic region natural gas consumption forecasts.[50] A -0.54% compound annual average growth rates was applied to forecast post-2005 emissions associated with natural gas pipeline fuel use.

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[59] An additional anomaly that was identified in the OPS data was that the Baltimore Gas & Electric Company record for 1991 appears to miscategorize more than 100,000 service connections as protected steel instead of plastic. This concern is addressed via the interpolation of the 1991 service connection values noted earlier.

[60] GHG emissions were calculated using SIT, with reference to *EIIP, Volume VIII*: Chapter 1 "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels," August 2004, and Chapter 2 "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion," August 2004.

Coal Production Emissions

Methane occurs naturally in coal seams, and is typically vented during mining operations for safety reasons. Coal mine CH_4 emissions are usually considerably higher, per unit of coal produced, from underground mining than from surface mining.

Maryland's 16 operational coal mines, only three of which are underground, produced 5.2 million short tons of coal in 2005.[61] As reported in this inventory, CH_4 emissions from coal mines are as reported by the EPA, and include emissions from surface and underground coal mines, as well as post-mining activities.[54]

With increasing coal production in the state, coal mine CH_4 emissions grew at an average annual rate of 4.93% between 2000 and 2005. Projections of future coal mine CH_4 emissions are based on EIA's forecast of coal production in the North Appalachian region: +4.63 % from 2005 to 2010, +0.52% from 2010 to 2015, and –0.22% from 2015 to 2020.[50]

Results

Table E2 displays the estimated emissions from the fossil fuel production industry in Maryland for select years over the period 1990 to 2020. Emissions from this sector grew by 12% from 1990 to 2005 and are projected to increase by a further 3% between 2005 and 2020. The natural gas industry is the major contributor to emissions throughout the analysis period.

Table E2. Historical and Projected Emissions for the Fossil Fuel Production Industry

(Million Metric Tons CO_2e)	1990	1995	2000	2005	2010	2015	2020
Fossil Fuel Production Industry	0.97	0.90	0.99	1.08	1.12	1.12	1.11
Natural Gas Industry	0.76	0.80	0.85	0.91	0.91	0.90	0.90
Production	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Transmission	0.04	0.03	0.04	0.14	0.16	0.17	0.19
Distribution	0.59	0.62	0.63	0.65	0.71	0.78	0.84
Pipeline Fuel	0.13	0.15	0.18	0.12	0.12	0.11	0.11
Coal Mining	0.21	0.10	0.13	0.17	0.21	0.22	0.22

Source: Calculations based on approach described in text.

Figure E1 displays the estimated GHG emissions associated with Maryland's fossil fuel production industry from 1990 to 2005, with projections to 2020. Emissions associated with this sector are estimated to be about 0.97 $MMtCO_2e$ in 1990, 1.08 $MMtCO_2e$ in 2005, and 1.11 $MMtCO_2e$ in 2020.

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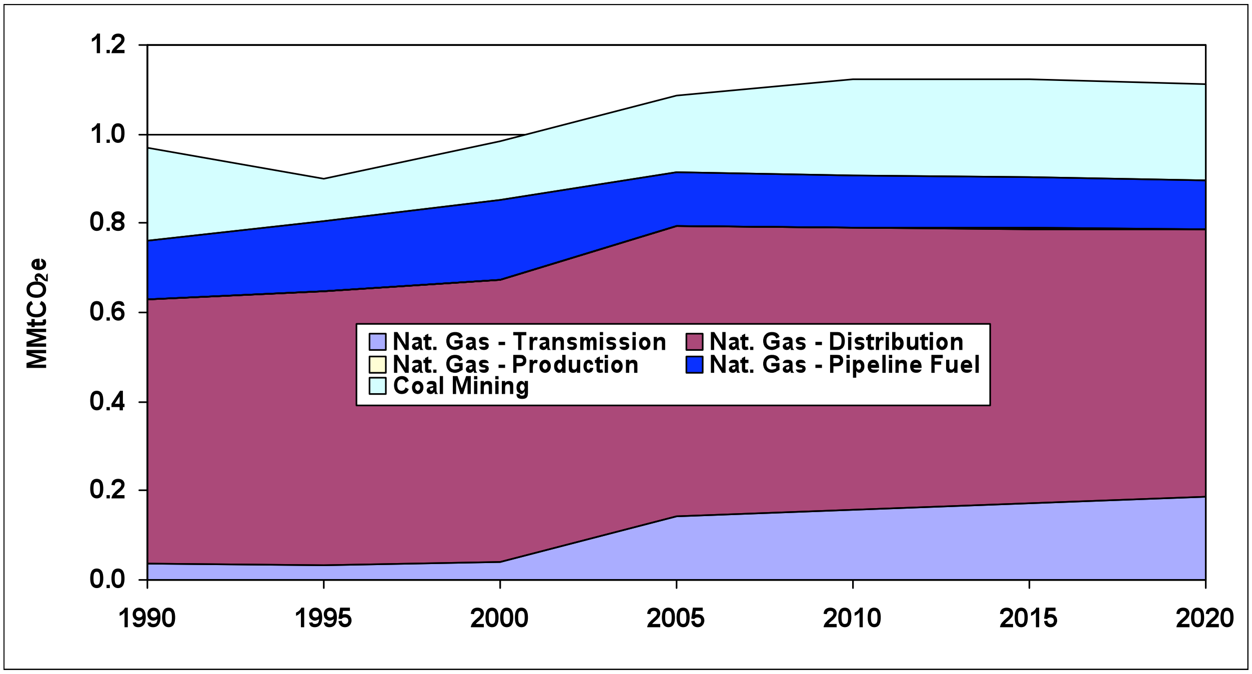
[61] EIA coal data accessed at http://www.eia.doe.gov/cneaf/coal/page/acr/table1.html, December 2007.

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



Source: Calculations based on approach described in text.

Key Uncertainties

The main uncertainties are associated with the reference case projection assumptions. For most source categories, the forecasts assumed that emissions would increase at the projected rate of total natural gas consumption for the AEO2006 South Atlantic modeling region, which consists of eight other states. Market factors (e.g., price of natural gas relative to other available energy sources) could have a significant impact on the growth for this sector. In addition, neither potential future application of improvements to pipeline technologies that can yield emission reductions nor the potential effect of demand-side management programs in reducing gas consumption have been accounted for in the emissions projections shown here.

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

For the natural gas T&D sector, there are limitations to the OPS data and emissions for Maryland. The OPS has revised its forms such that operators must now report their activity data by state starting in 2001 for transmission pipelines and 2004 for distribution pipelines and service connections. Prior to 2001 for transmission pipelines and 2004 for distribution pipelines and service connections, operators in Maryland have been allowed to report on the OPS form their pipeline system information as a total across multiple states. Thus, for these years the activity data for operators that included multi-state data in their reporting forms cannot be disaggregated to the state level without the assistance of the operators. Because of this constraint, pipeline activity data were included only when Maryland was reported as the only state of record. To the extent that operators of Maryland pipelines reported their mileage/service connections from 1990 to 2000 for transmission pipelines and 1990 to 2003 for distribution pipelines as multi-state totals, this inventory is under-reporting activity/emissions in these years. In addition, the OPS has noted that the reporting of activity data by individual operators may not be consistent between years over which an ownership transfer occurs, thus causing one operator's mileage to decrease while another operator's mileage increases. This issue can be associated with transfers in ownership, which may cause one operator's mileage to decrease while another operator's mileage increases. Future work should ask that operators in Maryland review and correct the historical data to ensure that T&D pipeline mileage and service connections exclude data for other states.

Appendix F. Agriculture

Overview

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

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

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

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

Emissions and Reference Case Projections

Methane and Nitrous Oxide

GHG emissions for 1990 through 2005 were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[62] In general, the SIT methodology applies emission factors developed for the US to activity data for the agriculture sector. Activity data include livestock population statistics, crop production statistics, amounts of fertilizer applied to crops, and trends in manure management practices. This methodology is based on international guidelines developed by sector experts for preparing GHG emissions inventories.[63]

Data on crop production in Maryland from 1990 to 2005 and the number of animals in the state from 1990 to 2005 were obtained from the United States Department of Agriculture (USDA) National Agriculture Statistical Service (NASS) and incorporated as defaults in SIT.[64] The default SIT manure management system assumptions for each livestock category were used for this inventory. SIT data on fertilizer usage came from *Commercial Fertilizers*, a report from the Fertilizer Institute. Activity data for fertilizer includes all potential uses in addition to agriculture, such as residential and commercial (e.g., golf courses). The estimates are reported in the agriculture sector but they represent emissions occurring on other land uses.

Crop production data from USDA NASS were available through 2005; therefore, N_2O emissions from crop residues and crops that use nitrogen (i.e., nitrogen fixation) and N_2O and CH_4 emissions from agricultural residue burning were calculated through 2005. Emissions for the other agricultural crop production categories (i.e., synthetic and organic fertilizers) were also calculated through 2005. Data were not available to estimate nitrogen released by the cultivation of histosols (i.e., the number of acres of high organic content soils). Given that cultivation of organic soils is a source of CO_2 emissions in Maryland (see below), N_2O emissions are also probably occurring.

There is some agricultural residue burning conducted in Maryland; however, emissions are estimated to be relatively small (<0.01 million metric tons (MMt) of CO_2 equivalent (CO_2e)). The default SIT method was used to calculate emissions. The SIT methodology calculates emissions by multiplying the amount (e.g., bushels or tons) of each crop produced by a series of factors to calculate the amount of crop residue produced and burned, the resultant dry matter, and the carbon/nitrogen content of the dry matter.

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

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

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

Emissions from enteric fermentation and manure management were projected based on forecasted animal populations. Dairy cattle forecasts were based on state-level projections of dairy cows from the Food and Agricultural Policy Research Institute (FAPRI).[65] Projections for all other livestock categories, except swine and sheep, were estimated based on linear forecasts of the historical 1990-2005 populations. The sheep population fluctuated greatly during the 1990-2005 period and linear projection results in a negative population at year 2020. Therefore, sheep population was projected based on the 1995-2005 historical data. The swine population showed a sharp decline in the late 1990s and early 2000s, and linear projection of the 1990-2005 populations result in negative populations before 2020. As a result, no growth is projected for the swine population after 2005. Livestock population growth rates are shown in Table F1.

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

Livestock Category	2005-2020 Annual Growth
Dairy Cattle	-0.7%
Beef Cattle	0.3%
Swine	0%
Sheep	-9.2%
Goats	0.3%
Horses	-4.2%
Turkeys	2.9%
Layers	0.03%

Projections for agricultural burning and agricultural soils were based on linear extrapolation of the 1990-2005 historical data. Table F2 shows the 2005-2020 annual growth rates estimated for each category.

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

Agricultural Category	2005-2020 Growth Rate
Agricultural Burning	0.1%
Agricultural Soils – Direct Emissions	
Fertilizers	2.9%
Crop Residues	0.3%
Nitrogen-Fixing Crops	0%
Histosols	0%
Livestock	-3.3%
Agricultural Soils – Indirect Emissions	
Fertilizers	2.9%
Livestock	-1.3%
Leaching/Runoff	1.3%

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[65] FAPRI Agricultural Outlook 2006, Food and Agricultural Policy Research Institute, http://www.fapri.iastate.edu/outlook2006.

Soil Carbon

Net carbon fluxes from agricultural soils have been estimated by researchers at the Natural Resources Ecology Laboratory at Colorado State University and are reported in the US Inventory of Greenhouse Gas Emissions and Sinks[66] and the US Agriculture and Forestry Greenhouse Gas Inventory. The estimates are based on the Intergovernmental Panel on Climate Change (IPCC) methodology for soil carbon adapted to conditions in the US. Preliminary state-level estimates of CO_2 fluxes from mineral soils and emissions from the cultivation of organic soils were reported in the US Agriculture and Forestry Greenhouse Gas Inventory. Currently, these are the best available data at the state-level for this category. The inventory did not report state-level estimates of CO_2 emissions from limestone and dolomite applications; hence, this source is not included in this inventory at present.

Carbon dioxide fluxes resulting from specific management practices were reported. These practices include: conversions of cropland resulting in either higher or lower soil carbon levels; additions of manure; participation in the Federal Conservation Reserve Program (CRP); and cultivation of organic soils (with high organic carbon levels). For Maryland, Table F3 shows a summary of the latest estimates available from the USDA, which are for 1997.[67] These data show that changes in agricultural practices are estimated to result in net sequestration of 0.15 $MMtCO_2e$ per year (yr) in Maryland; this is driven largely by the amount of land conversions from cropland to hay or grazing land in Maryland. Since data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing, emissions of -0.15 $MMtCO_2e$/yr are assumed to remain constant.

Table F3. GHG Emissions from Soil Carbon Changes Due to Cultivation Practices ($MMtCO_2e$)

Changes in cropland			**Changes in Hayland**				**Other**			**Total[4]**
Plowout of grassland to annual cropland[1]	Cropland manage-ment	Other cropland[2]	Cropland converted to hayland[3]	Hayland manage-ment	Cropland converted to grazing land[3]	Grazing land manage-ment	CRP	Manure application	Cultivation of organic soils	Net soil carbon emissions
0.18	(0.04)	0.00	(0.15)	0.00	(0.07)	0.00	0.00	(0.08)	0.00	(0.15)

Based on USDA 1997 estimates. Parentheses indicate net sequestration.
[1] Losses from annual cropping systems due to plow-out of pastures, rangeland, hayland, set-aside lands, and perennial/horticultural cropland (annual cropping systems on mineral soils, e.g., corn, soybean, cotton, and wheat).
[2] Perennial/horticultural cropland and rice cultivation.
[3] Gains in soil carbon sequestration due to land conversions from annual cropland into hay or grazing land.
[4] Total does not include change in soil organic carbon storage on federal lands, including those that were previously under private ownership, and does not include carbon storage due to sewage sludge applications.

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[66] US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005 (and earlier editions), US Environmental Protection Agency, Report # 430-R-07-002, April 2007. Available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

[67] US Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001. Global Change Program Office, Office of the Chief Economist, US Department of Agriculture. Technical Bulletin No. 1907, 164 pp. March 2004. http://www.usda.gov/oce/global_change/gg_inventory.htm; the data are in appendix B table B-11. The table contains two separate IPCC categories: "carbon stock fluxes in mineral soils" and "cultivation of organic soils." The latter is shown in the second to last column of Table F3. The sum of the first nine columns is equivalent to the mineral soils category.

Results

Figure F1 and Table F4 show gross GHG emissions associated with the agricultural sector from 1990 through 2020. In 1990, enteric fermentation accounted for about 22% (0.47 MMtCO_2e) of total agricultural emissions. Enteric fermentation emissions decreased to 0.35 MMtCO_2e by 2005 (19% of total agricultural emissions) due to the decline in beef and dairy cattle populations between 1990 and 2005. While the beef cattle population is projected to increase slightly, this increase does not offset the decrease projected for the dairy cattle population, and enteric fermentation emissions are estimated to be 0.33 MMtCO_2e in 2020.

The manure management category accounted for 16% (0.34 MMtCO_2e) of total agricultural emissions in 1990 and remained relatively unchanged at 17% (0.30 MMtCO_2e) in 2005. Manure management is projected to increase slightly to 0.32 MMtCO_2e by 2020. This category stays relatively constant primarily due to the assumption of no growth in the swine population between 2005 and 2020.

The largest source of emissions in the agricultural sector is the agricultural soils category, which includes crops (legumes and crop residues), cultivated histosols, fertilizer, manure application, and indirect sources (leaching, runoff, and atmospheric deposition). Agricultural soils stay relatively constant from 1990 to 2020, with 1990 emissions accounting for 61% (1.3 MMtCO_2e) of total agricultural emissions and 2020 emissions estimated to be about 65% (1.2 MMtCO_2e) of total agricultural emissions.

Agricultural burning emissions were estimated to be very small based on the SIT activity data (<0.01 MMtCO_2e/yr from 1990 to 2005). Emissions for this category account for about one-half of the national emissions included in the USDA Inventory which, relative to other agricultural categories, reports a low level of residue burning emissions (0.02 MMtCO_2e). Even though these emission estimates using the SIT are low relative to emissions associated with the other agricultural categories in Maryland, the emission estimates for agricultural burning in Maryland using the SIT methodology are inconsistent with other data and should be refined using actual activity data for Maryland, if available.

The only standard IPCC source categories missing from this report are CO_2 emissions from limestone and dolomite application and N_2O emissions from the cultivation of histosols. Estimates for limestone and dolomite application in Maryland were not available; however, the USDA's national estimate for soil liming is about 9 MMtCO_2e/yr.[68]

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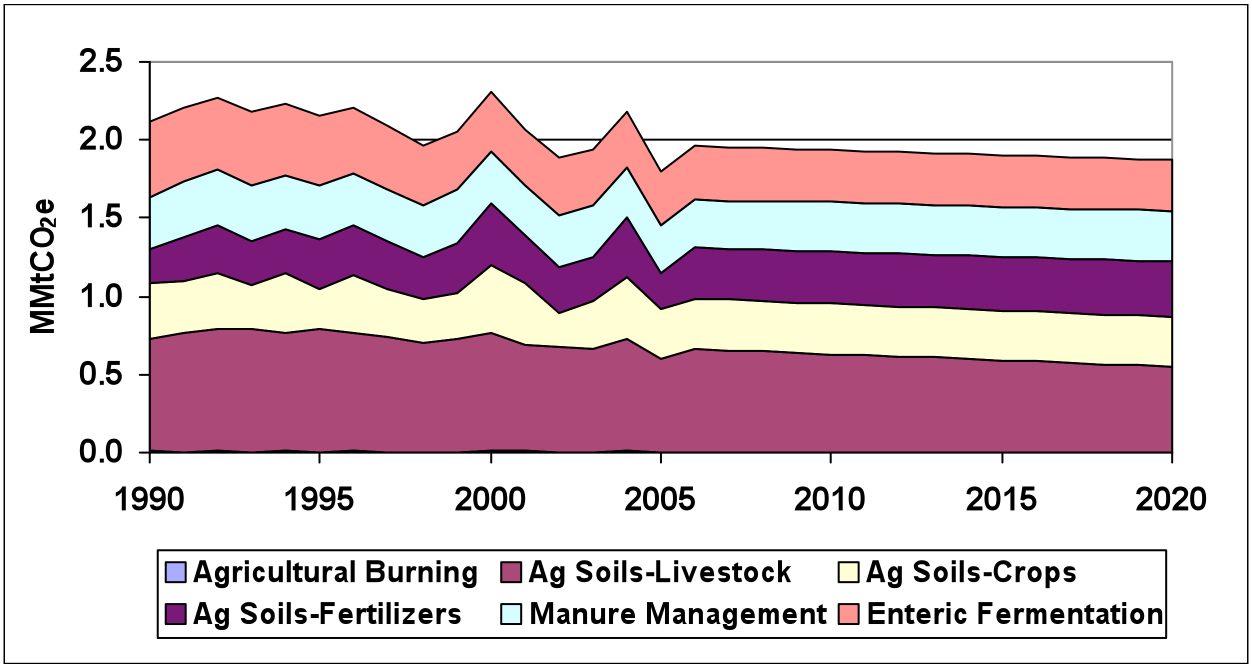
[68] US Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001. Global Change Program Office, Office of the Chief Economist, US Department of Agriculture. Technical Bulletin No. 1907. 164 pp. March 2004.

Figure F1. Gross GHG Emissions from Agriculture



Source: CCS calculations based on approach described in text.
Notes: Agricultural soils – crops category includes: incorporation of crop residues and nitrogen fixing crops (no cultivation of histosols estimated); emissions for agricultural residue burning are too small to be seen in this chart.

Table F4. Gross GHG Emissions from Agriculture ($MMtCO_2e$)

Source	1990	1995	2000	2005	2010	2015	2020
Enteric Fermentation	0.475	0.452	0.375	0.349	0.331	0.329	0.327
Manure Management	0.340	0.343	0.332	0.303	0.320	0.320	0.320
Ag Soils-Fertilizers	0.217	0.317	0.399	0.232	0.331	0.344	0.357
Ag Soils-Crops	0.359	0.253	0.433	0.312	0.323	0.320	0.317
Ag Soils-Livestock	0.715	0.786	0.759	0.597	0.624	0.584	0.544
Agricultural Burning	0.006	0.005	0.008	0.006	0.006	0.006	0.006
TOTAL	**2.112**	**2.158**	**2.306**	**1.800**	**1.935**	**1.903**	**1.871**

Key Uncertainties

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

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

Another contributor to the uncertainty in the emission estimates is the forecast assumptions. The growth rates for most categories are assumed to continue growing at historical 1990-2005 growth rates.

Appendix G. Waste Management

Overview

Greenhouse gas (GHG) emissions from waste management include:

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

Inventory and Reference Case Projections

Solid Waste Management

For solid waste management, Center for Climate Strategies (CCS) used the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) with landfill data provided by the Maryland Department of the Environment (MDE) to estimate emissions.[69] The landfill data provided by MDE included individual landfill information on landfill location (county), capacity, annual and average waste acceptance rates from 1990 through 2005, the year the landfill opened and the year the landfill closed or is expected to close, as well as control information. The MDE data indicate that 11 of the State's landfills are controlled--two with landfill gas to energy (LFGTE) plants, and nine with flares. The remaining 48 landfills throughout the state are uncontrolled. The total annual waste emplaced was summed separately for uncontrolled landfills, flared landfills, and LFGTE facilities for each year from 1990 through 2005.

CCS performed three different runs in SIT to estimate emissions from municipal solid waste (MSW) landfills: (1) uncontrolled landfills; (2) landfills with an LFGTE plant; and (3) landfills with a flare. For each of these three runs, the total annual waste emplaced at landfills in the specified control category for each year from 1990 through 2005 was entered as input to SIT. The SIT default waste emplacement rates were used for years from 1960 through 1989. SIT produced annual estimates of CH_4 emissions through 2005 for each of these landfill categories. CCS then performed post-processing of the landfill emissions to account for landfill gas controls (at LFGTE and flared sites) and to project the emissions through 2020.For the controlled landfills, CCS assumed that the overall CH_4 collection and control efficiency is 75%.[70]

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[69] Walter A. Simms, Public Health Engineer, Air Quality Planning Division, Air and Radiation Management Administration, MDE, personal communication with M. Mullen, CCS, July, 2007.

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

Growth rates were estimated by using the historic (1995-2005) growth rates of emissions in both the controlled and uncontrolled landfill categories. The period from 1995 to 2005 was used due to a large number of landfill closures in the US between 1985 and 1995 (which could have affected waste management practices). Hence, the post-1995 period is thought to be the most representative of the growth in waste emplacement rates and subsequent emissions. The annual growth rates are: -0.14% for uncontrolled sites, 0.28% for landfills with flares, and 1.7% for LFTGE facilities. The decrease in the uncontrolled category is due to smaller rates of waste emplacement at these sites in the post-1995 period.

CCS used the SIT default for industrial landfills. This default is based on national data indicating that industrial landfilled waste is emplaced at approximately 7% of the rate of MSW emplacement. Hence, the assumption is that this additional industrial waste emplacement occurs in addition to that already addressed in the emplacement rates for MSW sites. Due to a lack of data, no controls were assumed for industrial waste landfilling. For industrial landfills, the growth rate in emissions from 1995 to 2005 (0.15%/yr) was used to project emissions from 2006 to 2020.

Maryland is a net exporter of waste. While a small amount of waste is generally imported annually from Pennsylvania and West Virginia, a much larger amount of waste generated in Maryland is exported out of the state, on the order of 25%. CCS prepared an estimate of the emissions from the exported waste, based on MDE reports of the mass of MSW exported out of the state from 1999 through 2005. The amount of MSW exported in 1999 was assumed for all years prior to 1999. These waste emplacement values were entered in a separate SIT run, assuming all this waste was uncontrolled. The resulting uncontrolled emissions were then distributed in the same proportion as the results of the uncontrolled Maryland SIT runs, for uncontrolled landfills, flared sites, and LFTGE sites. For the controlled landfills, CCS assumed that the overall CH_4 collection and control efficiency is 75%, the same as for the in-state landfills, along with the assumption that 10% of CH_4 emissions are oxidized before being emitted to the atmosphere. Growth rates for these out-of-state emissions, by landfill type, were calculated based on the historic growth rate at these landfills from 1995 to 2005.

Solid Waste Combustion

Sources of solid waste combustion in Maryland include solid waste burning in municipal and medical waste incinerators and hazardous waste incineration. The SIT defaults were used to specify the amount of solid waste combusted from 1990-1998. For the years from 1999 to 2005, the amounts of waste combusted were obtained from MDE[71] and used as an input to SIT. The SIT default emission factors and waste characteristics were also used to estimate emissions from solid waste combustion. No information was identified on plans for additional plants in the future or expanded capacity at the existing plants, so emissions were held constant in the forecast years. As mentioned in the results section below, the emissions estimated for municipal waste combustors are captured in the energy supply sector; therefore, they have been left out of the emissions summaries for the waste management sector to avoid double-counting. The mass of wasted disposed of by incineration in Maryland may include a small amount of medical and

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[71] Annual Report Solid Waste Management in Maryland 1999-2005, MDE: http://www.mde.state.md.us/ResearchCenter/Publications/Land/index.asp#solidwaste.

hazardous waste that would not have been captured in the energy supply sector. However, the amount of these wastes could not be separately quantified at this time.

Open burning of MSW at residential sites (e.g. backyard burn barrels) also contributes to GHG emissions. According to a Mid-Atlantic/Northeast Visibility Union (MANE-VU) report on open burning in residential areas, 62,404 tons of MSW was burned in Maryland in 2000.[72] This contributes to only 0.03 $MMtCO_2e$ in GHG emissions in 2000 based on SIT default waste characteristics and emission factors. Due to a lack of historical data from other years, it is assumed that open burning of MSW stays constant from 1990-2005. Emissions are held constant after 2005 due to uncertainty in the future levels of open burning activity.

Wastewater Management

GHG emissions from municipal and industrial wastewater treatment were also estimated. For municipal wastewater treatment, emissions were calculated in SIT based on state population, assumed biochemical oxygen demand (BOD) and protein consumption per capita, and emission factors for N_2O and CH_4. The key SIT default values are shown in Table G1. Municipal wastewater treatment emissions were projected based on the historical growth rate in these emissions in Maryland over the 1990-2005 time period. This leads to an annual growth rate of 1.25%.

Table G1. SIT Key Default Values for Municipal Wastewater Treatment

Variable	Value
BOD	0.09 kg /day-person
Amount of BOD anaerobically treated	16.25%
CH_4 emission factor	0.6 kg/kg BOD
MD residents not on septic	75%
Water treatment N_2O emission factor	4.0 g N_20/person-yr
Biosolids emission Factor	0.01 kg N_2O-N/kg sewage-N

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

For industrial wastewater emissions, SIT provides default assumptions and emission factors for three industrial sectors: Fruits & Vegetables, Red Meat & Poultry, and Pulp & Paper. Default data for Red Meat & Poultry were used for Maryland, but the emissions are very small (about 0.001 $MMtCO_2e$ per year) and are not significant compared to the total waste sector emissions. No industrial wastewater treatment data were identified for the other two industrial sectors. Industrial wastewater emissions in the projection years were held constant at 2005 emission levels.

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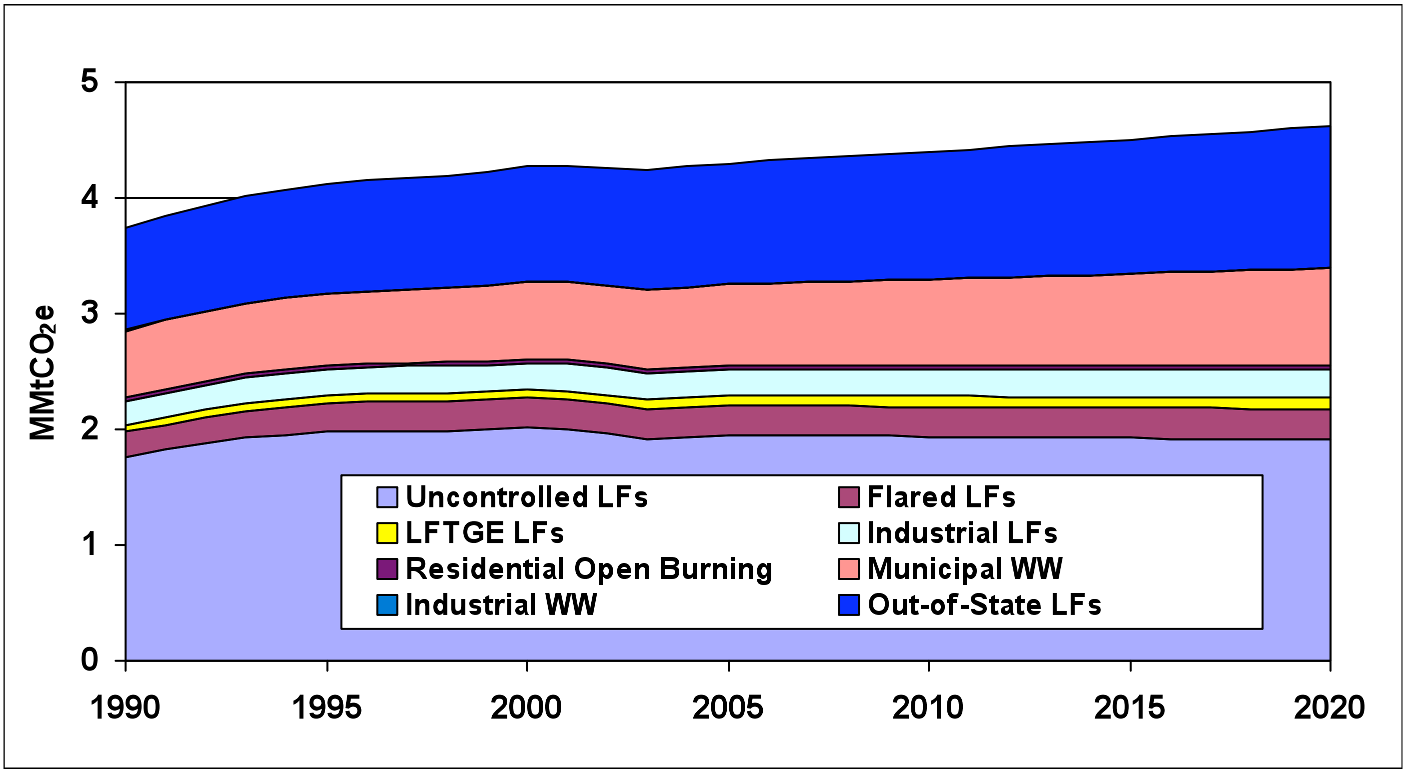
[72] Open Burning in Residential Areas, Emissions Inventory Development Report, MANE-VU, prepared by E. H. Pechan & Associates, Inc, January, 2004.

Results

Figure G1 and Table G2 show the resulting emission estimates for the waste management sector. Combustion emissions from solid waste combustion are captured in the energy supply sector. Therefore, these emissions are not included in the summaries here. Because the emissions resulting from MSW exported to landfills outside of Maryland should be captured in the emission inventories of the receiving states, these emissions are shown separately, outside the total of the in-state waste management emissions, in Table G2. Overall, the waste management sector accounts for 4.3 MMtCO$_2$e in 2005. By 2020, emissions are expected to increase slightly to 4.6 MMtCO$_2$e. In 2005, 45% of the emissions were contributed by the uncontrolled landfills sector, with another 24% contributed by out-of-state landfills. By 2020, the contribution from the uncontrolled in-state landfills is expected to decrease slightly to about 41%, while the out-of-state landfill emission contribution increases to 26%. Controlled landfills (flared sites) contributed 6% of total waste emissions in both 2005 and in 2020, while emissions at LFGTE landfill sites contributed about 2% of the waste management emissions in both 2005 and 2020. Industrial landfills contributed just over 5% of the waste management emissions in both 2005 and 2020.

Figure G1. Maryland GHG Emissions from Waste Management



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

Emissions from municipal wastewater are the third largest contributor to the waste management sector in Maryland. Municipal wastewater accounts for 16% of the waste management emissions in 2005, growing to 18% by 2020. Note that these estimates are based on the default parameters listed in Table G1 and might not adequately account for existing controls (e.g., anaerobic digesters served by a flare or other combustion device) or specific wastewater treatment methods in Maryland (e.g., anaerobic digestion versus aerobic digestion). As mentioned above, CCS modeled only emissions from Red Meat & Poultry processors in the industrial wastewater treatment sector. Approximately 0.03% of the emissions were contributed by the industrial wastewater treatment sector in both 2005 and 2020. Residential open burning accounts for the remaining 1% of emissions in 2005 and 2020.

Table G2. Maryland GHG Emissions from Waste Management (MMtCO$_2$e)

Source	1990	1995	2000	2005	2010	2015	2020
Uncontrolled LFs	1.77	1.98	2.01	1.95	1.94	1.92	1.91
Flared LFs	0.21	0.25	0.26	0.26	0.26	0.26	0.27
LFTGE LFs	0.06	0.07	0.07	0.08	0.09	0.10	0.11
Industrial LFs	0.20	0.23	0.23	0.23	0.23	0.23	0.24
Residential Open Burning	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Municipal WW	0.58	0.62	0.67	0.70	0.75	0.79	0.84
Industrial WW	0.002	0.001	0.001	0.001	0.001	0.001	0.001
Total	**2.86**	**3.18**	**3.27**	**3.26**	**3.30**	**3.35**	**3.40**
Out-of-State LFs	0.89	0.94	1.00	1.05	1.10	1.16	1.22
Total with Out-of-State LFs	**3.74**	**4.12**	**4.27**	**4.30**	**4.40**	**4.51**	**4.62**

Key Uncertainties

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

In addition to the inherent uncertainties in modeling CH$_4$ emissions from landfills, there are two important variables in adjusting these emissions to account for the amount emitted to the atmosphere. The first is the EPA assumption that 10% of the methane generated is oxidized in the surface layers of the landfill. There is little empirical evidence to assess the validity of this assumption, so it was not applied for this assessment. More importantly, for controlled sites, the EPA default assumption is that 75% of the methane is collected by the LFG collection system. Currently, this assumption is fairly contentious with estimates from differing entities ranging from 20% to 99%. EPA is currently planning studies using remote sensing techniques in an attempt to better address this issue. Several different factors affect the amount of LFG collected: landfill design, including whether the site is fully lined and capped, as well as the surrounding soil type; quality of the LFG collection system (e.g. proper siting of wells); and proper operation of the collection system (landfills are dynamic systems, so the LFG collection system must be continually monitored and adjusted to assure optimum collection efficiency; also, LFGTE site operators will try to optimize collection for gas quality (methane content) and have to balance quality versus overall collection efficiency.

In estimating emissions from the MSW exported out of Maryland, the assumption that the waste was emplaced in controlled versus uncontrolled landfills using the same mix as the Maryland waste contributes to uncertainty in this sector.

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

For solid waste combustion, emissions from residential open burning are based only on data for the year 2000. Hence, historical and projected emissions from residential open burning contain a high level of uncertainty, however this subsector contributes relatively little to the GHG total.

For the wastewater sector, the key uncertainties are associated with the application of SIT default values for the parameters listed in Table G1 (e.g., fraction of the MD population on septic; fraction of BOD which is anaerobically decomposed). The SIT defaults were derived from national data. Hence, they may not adequately characterize the wastewater treatment processes currently employed or to be employed in the future.

Appendix H. Forestry & Land Use

Overview

Forestland emissions refer to the net carbon dioxide (CO_2) flux[73] from forested lands in Maryland, which account for about 43% of the state's land area.[74] The dominant forest type in Maryland is Oak-Hickory which makes up about 63% of forested lands. Other common forest types are Loblolly-shortleaf pine at 11% of forested land, and Oak-Pine at 10% of forested land. All other forest types make up less than 6% each of the state's forests.

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

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

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

Inventory and Reference Case Projections

Forested Landscape

For over a decade, the United States Forest Service (USFS) has been developing and refining a forest carbon modeling system for the purposes of estimating forest carbon inventories. The methodology is used to develop national forest CO_2 fluxes for the official *US Inventory of Greenhouse Gas Emissions and Sinks*. The national estimates are compiled from state-level data. The Maryland forest CO_2 flux data in this report come from the national analysis and are provided by the USFS. See the footnotes below for the most current documentation for the forest carbon modeling.[75] Additional forest carbon information is in the form of specific carbon conversion factors.[76]

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[73] "Flux" refers to both emissions of CO_2 to the atmosphere and removal (sinks) of CO_2 from the atmosphere.

[74] Total forested acreage is 2.7 million acres in 1997. Acreage by forest type available from the USFS at: http://www.fs.fed.us/ne/global/pubs/books/epa/states/MD.htm. The total land area in Maryland is 6.3 million acres (http://www.50states.com/maryland.htm).

[75] The most current citation for an overview of how the USFS calculates the inventory based forest carbon estimates as well as carbon in harvested wood products is from the *US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2006* (and earlier editions), US Environmental Protection Agency, Report # USEPA #430-R-08-005, April 2008, available at: http://epa.gov/climatechange/emissions/usinventoryreport.html. Both Annex 3.12 and Chapter 7 are useful sources of reference. See also Smith, J.E., L.S. Heath, and M.C. Nichols (in press), *US Forest Carbon*

The forest CO_2 flux methodology relies on input data in the form of plot-level forest volume statistics from the Forest Inventory Analysis (FIA). FIA data on forest volumes are converted to values for ecosystem carbon stocks (i.e., the amount of carbon stored in forest carbon pools) using the FORCARB2 modeling system. Coefficients from FORCARB2 are applied to the plot level survey data to give estimates of C density [megagrams (Mg) per hectare] for a number of separate C pools. Additional background on the FORCARB system is provided in a number of publications.[77]

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

In preparing these estimates, the USFS estimates the amount of forest carbon in different forest types as well as different carbon pools. The different forests also include differences in ownership class: those in the national forest (NF) system and those that are not federally-owned (private and other public forests). Additional details on the forest carbon inventory methods can be found in Annex 3 to the US EPA's GHG inventory for the US.[78]

Carbon pool data for three FIA cycles to estimate flux for two different periods were available for Maryland. The carbon pool data are shown in Table H1. These are the most recent USFS estimates available and will be included in EPA's latest national greenhouse gas (GHG) inventory. The underlying FIA data show a net decrease in forested area of 87,000 acres between 1990 and 1999 and a net increase in forested area of 74,000 acres in the 1990-2005 period. Most of the forested lands in Maryland are considered timberland, meaning that these are productive

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Calculation Tool User's Guide: Forestland Carbon Stocks and Net Annual Stock Change, Gen Tech Report, Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station.

[76] Smith, J.E., and L.S. Heath (2002). "A model of forest floor carbon mass for United States forest types," Res. Pap. NE-722. Newtown Square, PA: US Department of Agriculture, Forest Service, Northeastern Research Station. 37 p., or Jenkins, J.C., D.C. Chojnacky, L.S. Heath, R.A. Birdsey (2003), "National-scale biomass estimators for United States tree species", *Forest Science*, 49:12-35.

[77] Smith, J.E., L.S. Heath, and P.B. Woodbury (2004). "How to estimate forest carbon for large areas from inventory data", *Journal of Forestry*, 102: 25-31; Heath, L.S., J.E. Smith, and R.A. Birdsey (2003), "Carbon trends in US forest lands: A context for the role of soils in forest carbon sequestration", In J. M. Kimble, L. S. Heath, R. A. Birdsey, and R. Lal, editors. *The Potential of US Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect.* CRC Press, New York; and Woodbury, Peter B.; Smith, James E.; Heath, Linda S. 2007, "Carbon sequestration in the US forest sector from 1990 to 2010", *Forest Ecology and Management*, 241:14-27.

[78] Annex 3 to EPA's 2008 report, which contains estimates for calendar year 2005, can be downloaded at: http://epa.gov/climatechange/emissions/downloads/08_Annex_3.pdf.

forests. The timberland area is shown to increase by 112,000 acres between 1990 and 2005, which appears to be driving the total gain of 16 million metric tons (MMt) of carbon from forested areas during that period.

Table H1. USFS Forest Carbon Pool Data for Maryland

Forest Pool	1990 (MMtC)	1999 (MMtC)	2005 (MMtC)
Live Tree – Above Ground	77.8	80.9	91.9
Live Tree – Below Ground	15.0	15.6	17.7
Understory	2.2	2.1	2.2
Standing Dead	4.3	4.2	4.3
Down Dead	6.3	6.5	7.4
Forest Floor	14.4	15.0	13.8
Soil Carbon	68.6	67.1	67.1
Totals	**189**	**191**	**204**
Forest Area	**1990 (10^3 acres)**	**1999 (10^3 acres)**	**2005 (10^3 acres)**
All Forests	2,659	2,572	2,646
Timberland	2,407	2,374	2,519

Totals may not sum exactly due to independent rounding.

Data source: Smith, James, et al. *US Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change* (http://www.nrs.fs.fed.us/pubs/2394), USFS, August 2007.

In addition to the forest carbon pools, additional carbon is stored in biomass removed from the forest for the production of HWP. Carbon remains stored in the durable wood products pool or is transferred to landfills where much of the carbon remains stored over a long period of time. The USFS uses a model referred to as WOODCARB2 for the purposes of modeling national HWP carbon storage.[79] State-level information for Maryland was provided to CCS by the USFS.[80]

As shown in Table H2, about 0.3 $MMtCO_2$ per year (yr) is estimated by the USFS to be sequestered annually (1999-2005) in wood products. Also, as shown in this table, the total flux estimate including all forest pools is -8.94 $MMtCO_2e$/yr.[81] This total includes a small net sink estimate for soil carbon (-0.05 $MMtCO_2$/yr). Note that from 1986 to 1999, soil carbon was considered a net source. Given the changes noted above in timberland, it appears that much of the negative carbon flux (sequestration) is from the increase in timberland between 1999 and 2005.

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[79] Skog, K.E., and G.A. Nicholson (1998), "Carbon cycling through wood products: the role of wood and paper products in carbon sequestration", *Forest Products Journal*, 48(7/8):75-83; or Skog, K.E., K. Pingoud, and J.E. Smith (2004), "A method countries can use to estimate changes in carbon stored in harvested wood products and the uncertainty of such estimates", *Environmental Management*, 33(Suppl. 1): S65-S73.

[80] Obtained from the Harvested Wood Product model developed by Ken Skog, USFS

[81] Jim Smith, USFS, *US Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change* (http://www.nrs.fs.fed.us/pubs/2394), August 2007.

Table H2. USFS Annual Forest Carbon Fluxes for Maryland

Forest Pool	1986-1999 Flux (MMtC)	1999-2005 Flux (MMtC)	1986-1999 Flux ($MMtCO_2$)	1999-2005 Flux ($MMtCO_2$)
Forest Carbon Pools (non-soil)	-0.49	-2.34	-1.78	-8.60
Soil Organic Carbon	0.16	-0.01	0.60	-0.05
Harvested Wood Products	-0.08	-0.08	-0.30	-0.30
Forest Wildfires	0.00	0.00	0.01	0.01
Totals	**-0.40**	**-2.44**	**-1.48**	**-8.94**
Totals (excluding soil carbon)	**-0.57**	**-2.42**	**-2.08**	**-8.89**

Totals may not sum exactly due to independent rounding.

Data source: Smith, James, et al. US Forest Carbon Calculation Tool: Forest-Land Carbon Stocks and Net Annual Stock Change (http://www.nrs.fs.fed.us/pubs/2394), USFS, August 2007.

Data source for forest wildfires from the Maryland Department of Natural Resources (MDDNR) Forest Service under Wild Fire Acres Burned 2000-2006: http://www.dnr.state.md.us/forests/fire/index.asp.

Based on discussions with the USFS, CCS recommends excluding the soil carbon pool from the overall forest flux estimates due to high level of uncertainty associated with these estimates. The forest carbon flux estimates provided in the summary tables at the front of this report are those without the soil carbon pool.

For historic emission estimates, CCS used the 1986-1999 carbon flux to represent forest carbon flux prior to 1999. Current flux estimates (1999 to 2005) are those based on the USFS average for those years. For the reference case projections (2005-2020), the forest area and carbon densities of forestlands were assumed to remain at the same levels as in 2005. Information is not available on the near term effects of climate change and their impacts on forest productivity. Nor were data readily-available on projected losses in forested area.

Biomass burned in forest fires emits CO_2, methane (CH_4), and N_2O, in addition to many other gases and pollutants. Since CO_2 emissions are captured under total carbon flux calculations, CCS used the SIT to estimate CH_4 and N_2O emissions. CCS used state data (2000-2005) available from the Maryland Department of Natural Resources (MDDNR) Forest Service on the number of acres burned by forest type. An average of the 2000-2006 activity data was used for the years 1990-2005 and the forest type of "other temperate forests" was assumed in the SIT to calculate historical emissions. Projected emissions for 2005-2020 were assumed to be held constant at 2005 emissions.

Urban Forestry & Land Use

GHG emissions for 1990 through 2005 were estimated using the EPA SIT software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[82] In general, the SIT methodology applies emission factors developed for the US to activity data for the urban forestry sector. Activity data include urban area, urban area with

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

tree cover, amount of landfilled yard trimmings and food scraps, and the total amount of synthetic fertilizer applied to settlement soils (e.g. parks, yards, etc.). This methodology is based on international guidelines developed by sector experts for preparing GHG emissions inventories.[83] Table H3 displays the emissions and reference case projections for Maryland.

Table H3. Urban Forestry Emissions and Reference Case Projections (MMtCO$_2$e)

Subsector	1990	2000	2005	2010	2020
Urban Trees	-1.20	-1.45	-1.58	-1.70	-1.95
Landfilled Yard Trimmings and Food Scraps	-4.51	-1.01	-1.08	-1.20	-1.34
N_2O from Settlement Soils	0.02	0.04	0.03	0.03	0.03
Total	**-5.69**	**-2.42**	**-2.62**	**-2.86**	**-3.27**

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

Changes in carbon stocks in urban trees are equivalent to tree growth minus biomass losses resulting from pruning and mortality. Net carbon sequestration was calculated using data on crown cover area. The default urban area data in SIT (which varied from 3,873 km^2 to 5,083 km^2 between 1990 and 2005) was multiplied by the state estimate of the percent of urban area with tree cover (40% for Maryland) to estimate the total area of urban tree cover. These default SIT urban area tree cover data represent area estimates taken from the US Census and coverage for years 1990 and 2000.[84] Estimates of urban area in the intervening years (1990-1999) and subsequent years (2001-2005) are interpolated and extrapolated, respectively.

Estimates of net carbon flux of landfilled yard trimmings and food scraps were calculated by estimating the change in landfill carbon stocks between inventory years. The SIT estimates for the amount of landfilled yard trimmings decreased significantly during the 1990's. CCS believes that this is consistent with changes in the waste management industry during this period. Therefore, the forecast was based on an extrapolation of the flux from 2000-2005, which show relatively constant rates of landfilling these materials.

Settlement soils include all developed land, transportation infrastructure and human settlements of any size. Projections for urban trees and settlement soils were based on linear extrapolation of the 1990-2005 historical data.

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

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

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

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

	1990	**2000**	**2005**	**2010**	**2020**
Forested Landscape (excluding soil carbon)	-2.08	-8.89	-8.89	-8.89	-8.89
Urban Forestry and Land Use	-5.69	-2.42	-2.62	-2.86	-3.27
Sector Total	**-7.77**	**-11.31**	**-11.51**	**-11.75**	**-12.16**

Key Uncertainties

Emissions from wildfires in Maryland were estimated based on an average of acres burned from 2000-2006. 1990-1999 historic emissions were not available to give a better estimate. Future forecasts are hard to estimate given the large swings in fire activity from year to year. Emissions from wildfires in Maryland are very small, so they do not impact the estimated flux significantly.

It is important to note that there were methodological differences in the three FIA cycles (used to calculate carbon pools and flux) that can produce different estimates of forested area and carbon density. For example, the FIA program modified the definition of forest cover for the woodlands class of forestland (considered to be non-productive forests). Earlier FIA cycles defined woodlands as having a tree cover of at least 10%, while the newer sampling methods used a woodlands definition of tree cover of at least 5% (leading to more area being defined as woodland). In woodland areas, the earlier FIA surveys might not have inventoried trees of certain species or with certain tree form characteristics (leading to differences in both carbon density and forested acreage). Given that the forested land in Maryland is dominated by timberlands (productive forests), CCS does not believe that the definitional differences noted above have had a significant impact on the forest flux estimates provided in this report.

Also, FIA surveys since 1999 include all dead trees on the plots, but data prior to that are variable in terms of these data. The modifications to FIA surveys are a result of an expanded focus in the FIA program, which historically was only concerned with timber resources, while more recent surveys have aimed at a more comprehensive gathering of forest biomass data. In addition, the FIA program has moved from periodic to annual inventory methods. The effect of these changes in survey methods has not been estimated by the USFS.

Much of the urban forestry and land use emission estimates rely on national default data and could be improved with state-specific information.

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*, US Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-02-003, April 2002 www.epa.gov/globalwarming/publications/emissions. Michael Gillenwater directed the preparation of this appendix.

Introduction

The *Inventory of U.S. Greenhouse Gas Emissions and Sinks* presents estimates by the United States government of US anthropogenic greenhouse gas emissions and removals for the years 1990 through 2000. The estimates are presented on both a full molecular mass basis and on a Global Warming Potential (GWP) weighted basis in order to show the relative contribution of each gas to global average radiative forcing.

The Intergovernmental Panel on Climate Change (IPCC) has recently updated the specific global warming potentials for most greenhouse gases in their Third Assessment Report (TAR, IPCC 2001). Although the GWPs have been updated, estimates of emissions presented in the US *Inventory* continue to use the GWPs from the Second Assessment Report (SAR). The guidelines under which the *Inventory* is developed, the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines for national inventories[85] were developed prior to the publication of the TAR. Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. This excerpt of the US *Inventory* addresses in detail the differences between emission estimates using these two sets of GWPs. Overall, these revisions to GWP values do not have a significant effect on US emission trends.

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

What is Climate Change?

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

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

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

"natural greenhouse effect." Without the natural heat-trapping properties of these atmospheric gases, the average surface temperature of the Earth would be about 33^{o}C lower (IPCC 2001).

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

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

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

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

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

Greenhouse Gases

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Global Warming Potentials

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

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

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

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

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

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

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

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

Source: IPCC (1996)

[a] GWPs used here are calculated over 100 year time horizon

[b] The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

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

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

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

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

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

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

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