MARYLAND DEPARTMENT OF THE ENVIRONMENT

AIR AND RADIATION MANAGEMENT ADMINISTRATION

Maryland Greenhouse Gas Emissions Inventory Documentation

◆

Base Year

Projection Years

(DRAFT)

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Maryland Department of the Environment
Greenhouse Gas Emissions Inventory Documentation

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A number of agencies participated in preparing various portions of the inventory due to the number of metropolitan planning organization jurisdictions covered by the nonattainment areas.

Source Documentation:

- MDE-Air and Radiation Management Administration
    - MDE – ARMA Compliance Program
    - MDE – ARMA Permits Program
    - MDE – ARMA Air Quality Policy and Planning Program
    - MDE – ARMA Greenhouse Gas Program
    - MDE – ARMA Mobile Source Program
    - MDE – Solid Waste Program
    - MDE – Industrial Wastewater Permits Program
- Maryland Department of Agriculture
- Maryland Department of Transportation
- Maryland Department of Planning
- Center for Climate Strategies

Lead Agency and Quality Assurance: MDE-ARMA Air Quality Policy & Planning Division

The MDE is the agency responsible for preparing and submitting the completed baseline GHG emissions inventory for Maryland. The MDE Air and Radiation Management Administration (ARMA) Air Quality Policy & Planning Division compiled the GHG emissions inventory for the State of Maryland.

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
EPA	United States Environmental Protection Agency
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

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1.0 EXECUTIVE SUMMARY

1.1 OVERVIEW

The Maryland General Assembly passed the Greenhouse Gas Emissions Reduction Act, Senate Bill -SB 278 and House Bill - HB 315 in 2009, which is codified in Maryland Annotated Codes, Title 2, Subtitle 1203[1]. The Bill requires the Department of the Environment to publish and update an inventory of statewide greenhouse gas emissions for calendar year 2006 and requires the State to reduce statewide greenhouse gas emissions by 25% from 2006 levels by 2020. The State is also required to develop and adopt a specified plan, adopt specified regulations, and implement specified programs to reduce greenhouse gas emissions.

The Bill specifically mandates the Department of the Environment to prepare and publish an updated inventory of statewide greenhouse gas emissions for calendar year 2006 and develop a projected "business-as-usual" inventory for calendar year 2020 on or before June 1, 2011.

To comply with this mandate, the Maryland Department of the Environment (MDE) presents this report that estimates the statewide emissions of Greenhouse Gas (GHGs) for calendar year 2006, the baseline year designated by the Legislature, and a "business–as-usual" projected inventory for calendar year 2020. The report and the emissions inventory is divided into seven major sectors that contribute to greenhouse gases emissions in Maryland:

- Electricity use and supply
- Residential, commercial and industrial fossil fuel combustion (RCI)
- Transportation
- Industrial processes
- Fossil fuel industry (fugitive emissions – greenhouse gas released from leakage)
- Waste management
- Agriculture

[1] § 2-1203. Statewide greenhouse gas inventory. http://www.michie.com/maryland/lpExt.dll?f=templates&eMail=Y&fn=main-h.htm&cp=mdcode/dea9.

Maryland's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the base year (2006) using a set of generally accepted principles and guidelines for State GHG emissions, relying to the extent possible on Maryland-specific input data. The projections are based on the application of appropriate growth factors to the base year GHG emission inventory. Growth factors associated with the emissions projections are described in details in the report. The projected inventories were based on a business-as-usual forecast as required in the SB 278/HB 315 Bill, therefore, to the extent possible, no control /reduction program were taken into consideration in the estimation.

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, carbon dioxide 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 (see Section 1.4.1).[2]

Table ES-1 provides a summary of the Base year and projection year GHG emissions for Maryland for the years 2006, 2010, 2015, and 2020. Activities in Maryland accounted for approximately 104.27 million metric tons (MMT) of *gross*[3] CO_2e emissions (consumption basis) in 2006, an amount equal to about 1.5% of total US gross GHG (7,054.2 $MMTCO_2e$).[4]

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 indicated that about 11.8 $MMTCO_2e$ was stored in Maryland forest biomass and agricultural soils in 2006. This leads to *net* emissions of 92.4 $MMTTCO_2e$ in Maryland in 2006.

There are three principal sources of GHG emission in Maryland: electricity consumption; transportation; and residential, commercial, and industrial (RCI) fossil fuel use. Electricity consumption accounted for 41% of gross GHG emissions in 2006. Transportation accounted for 32% of Maryland's gross GHG emissions in 2006, while RCI fuel use accounted for 16% of Maryland's 2006 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

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

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

[4] The national emissions used for these comparisons based on 2006 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.

about 137 MMtCO$_2$e by 2020, reaching 24% above 2006 levels.[5] 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 Residential/Commercial/Industrial fossil fuel use.

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.

1.2 EMISSION SUMMARIES

Table ES-1: Maryland Base Year and Projected GHG Emissions, by Sector[6]

MMtCO$_2$e	2006	2010	2015	2020	Explanatory Notes for Projections
Energy Use (CO_2, CH_4, N_2O)	95.46	108.64	116.90	125.34	
Electricity Use (Consumption)[b]	42.18	51.92	55.28	58.79	Population growth
Electricity Production (in-state)	32.16	41.21	42.46	42.88	Output Optimization.
Coal	28.28	33.79	33.79	33.79	Output Optimization.
Natural Gas	3.65	6.78	8.03	8.45	Output Optimization.
Oil	0.24	0.64	0.64	0.64	Output Optimization.
Wood	0.00	0.00	0.00	0.00	Population growth
MSW/LFG	0.00	0.00	0.00	0.00	Population growth
Net Imported Electricity	10.01	10.72	12.82	15.92	Population growth
Residential/Commercial/Industrial (RCI) Fuel Use	16.87	17.24	18.07	18.84	
Coal	3.00	3.17	3.68	4.20	Household growth
Natural Gas & LPG	9.21	9.42	9.72	10.00	Household growth
Petroleum	4.58	4.57	4.57	4.56	Household growth
Wood	0.09	0.09	0.09	0.09	Household growth
Transportation	35.47	38.66	42.68	46.78	
Onroad Gasoline	23.76	25.75	28.23	30.71	MOVES Modeling
Nonroad Gasoline	1.04	1.05	1.06	1.06	Various
Onroad Diesel	5.91	6.47	7.18	7.88	MOVES Modeling
Nonroad Diesel	1.50	1.60	1.73	1.85	Various
Rail	0.24	0.25	0.27	0.30	EPA RIA
Marine Vessels (Gas & Oil)	1.00	1.21	1.48	1.75	EPA RIA
Lubricants, Natural Gas, and LPG	0.30	0.34	0.40	0.47	Industrial Employment.
Jet Fuel and Aviation Gasoline	1.72	1.98	2.34	2.76	Aircraft Operations
Fossil Fuel Industry	0.94	0.82	0.87	0.92	
Natural Gas Industry	0.81	0.69	0.74	0.79	Industrial Employment.

[5] 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.
[6] Totals may not equal sum of subtotals shown in this table due to independent rounding.

$MMtCO_2e$	2006	2010	2015	2020	Explanatory Notes for Projections
Oil Industry	0.00	0.00	0.00	0.00	Industrial Employment.
Coal Mining	0.13	0.13	0.13	0.13	Production growth
Industrial Processes	7.44	8.21	9.21	10.24	
Cement Manufacture	1.48	1.57	1.83	2.09	Production growth
Limestone and Dolomite	0.11	0.15	0.18	0.21	Production growth
Soda Ash	0.05	0.05	0.05	0.05	Production growth
Iron and Steel	3.60	3.65	3.75	3.85	Production growth
ODS Substitutes	1.97	2.65	3.35	4.04	Population growth
Electricity Transmission and Dist.	0.23	0.14	0.05	0.00	Population growth
Semiconductor Manufacturing	0.00	0.00	0.00	0.00	Industrial Employment.
Ammonia and Urea Production	0.00	0.00	0.00	0.00	Industrial Employment.
Aluminum Production	0.00	0.00	0.00	0.00	Industrial Employment.
Agriculture	1.77	1.85	1.79	1.86	
Enteric Fermentation	0.42	0.44	0.42	0.51	Population growth
Manure Management	0.32	0.32	0.30	0.29	Population growth
Agricultural Soils	1.02	1.08	1.06	1.05	Population growth
Agricultural Burning	0.01	0.01	0.01	0.01	Population growth
Urea Fertilizer Usage	0.01	0.01	0.01	0.01	No Growth
Waste Management	2.26	2.34	2.48	2.60	
Waste Combustion	1.29	1.34	1.42	1.49	Population growth
Landfills	0.39	0.40	0.43	0.45	Population growth
Wastewater Management	0.54	0.56	0.59	0.62	Population growth
Residential Open Burning	0.03	0.03	0.04	0.04	Household growth
Gross Emissions (Consumption Basis, Excludes Sinks)	106.93	121.05	130.38	140.05	
Increase gross emissions relative to 2006					
Emissions Sinks	-11.79	-11.75	-11.75	-11.75	
Forested Landscape	-10.45	-10.45	-10.45	-10.45	
Urban Forestry and Land Use	-1.33	-1.33	-1.33	-1.33	
Agricultural Soils (Cultivation Practices)	-0.05	-0.05	-0.05	-0.05	
Forest Fires	0.04	0.04	0.04	0.04	
Net Emissions (Consumptions Basis) (Including forestry, land use, and agric sinks)	95.14	109.29	118.63	128.30	
Increase net emissions relative to 2006		14.87%	24.68%	34.85%	

FIGURE ES-1: GROSS GHG EMISSIONS BY SECTOR, 2006, MARYLAND

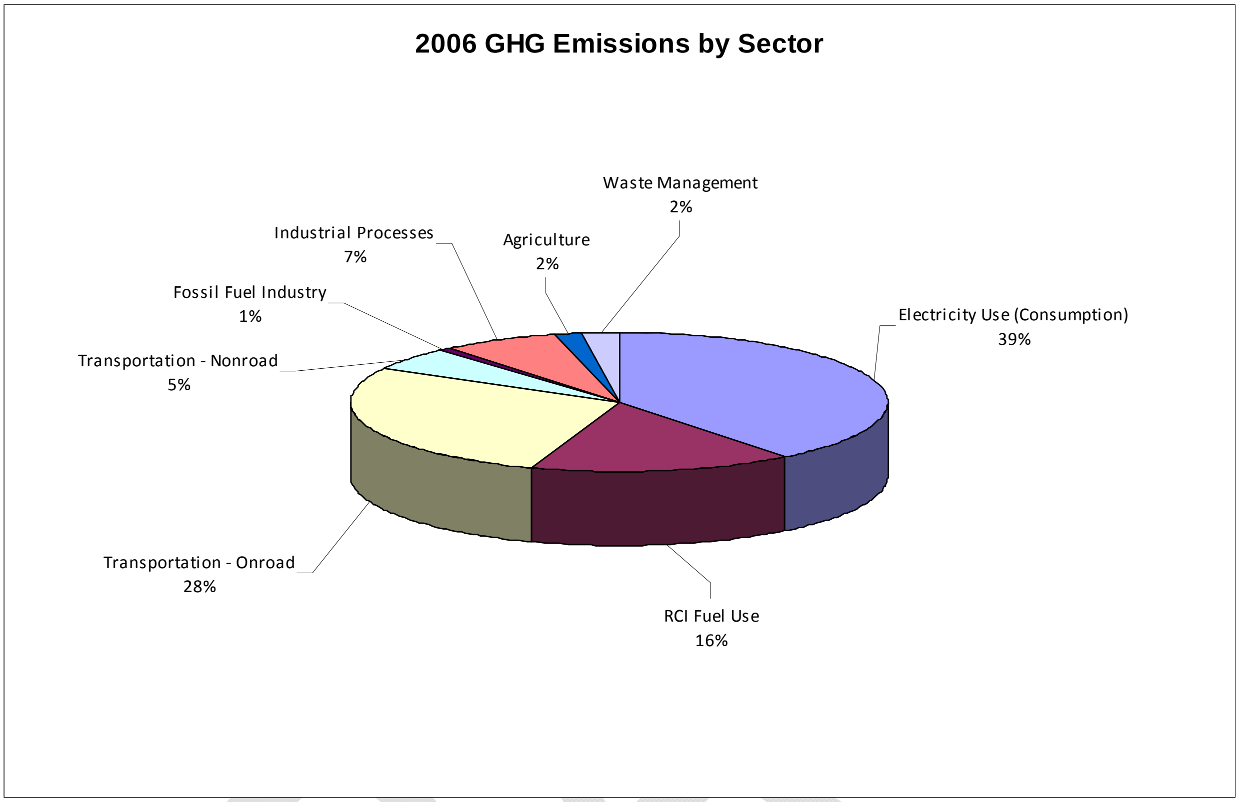


FIGURE ES-2: PROJECTED GROSS GHG EMISSIONS BY SECTOR, 2020, MARYLAND

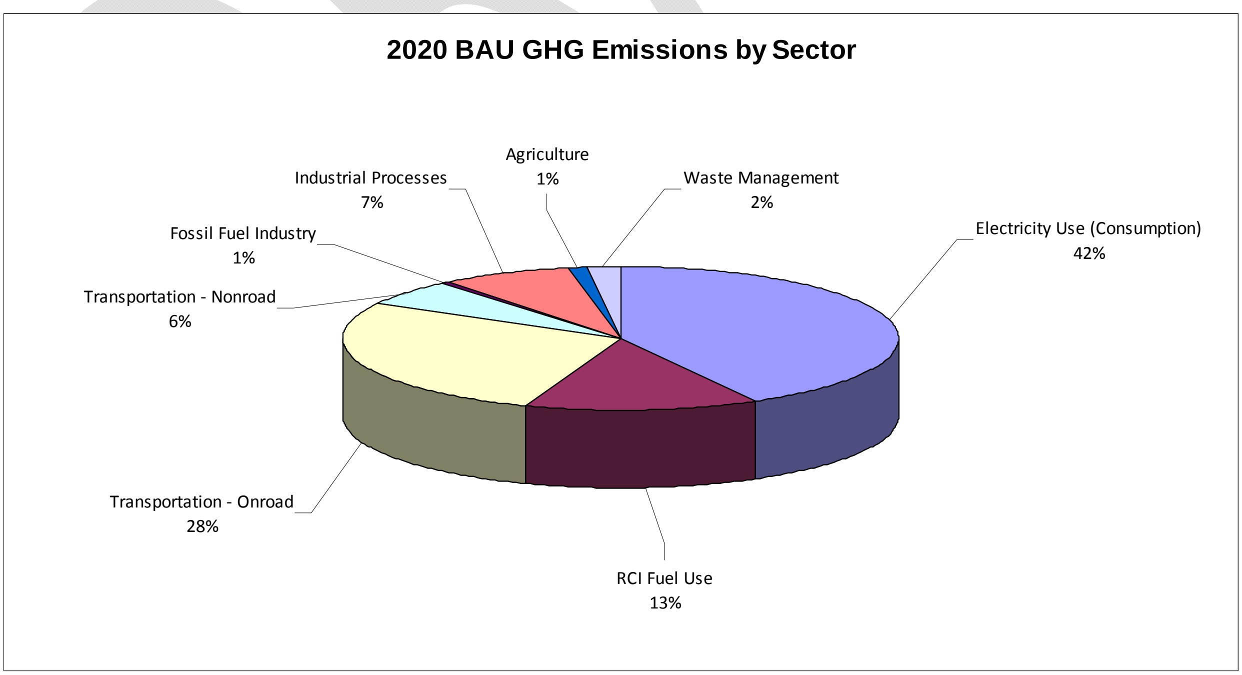


FIGURE ES-3: GROSS GHG EMISSIONS COMPARISONBY SECTOR, 2006 & 2020

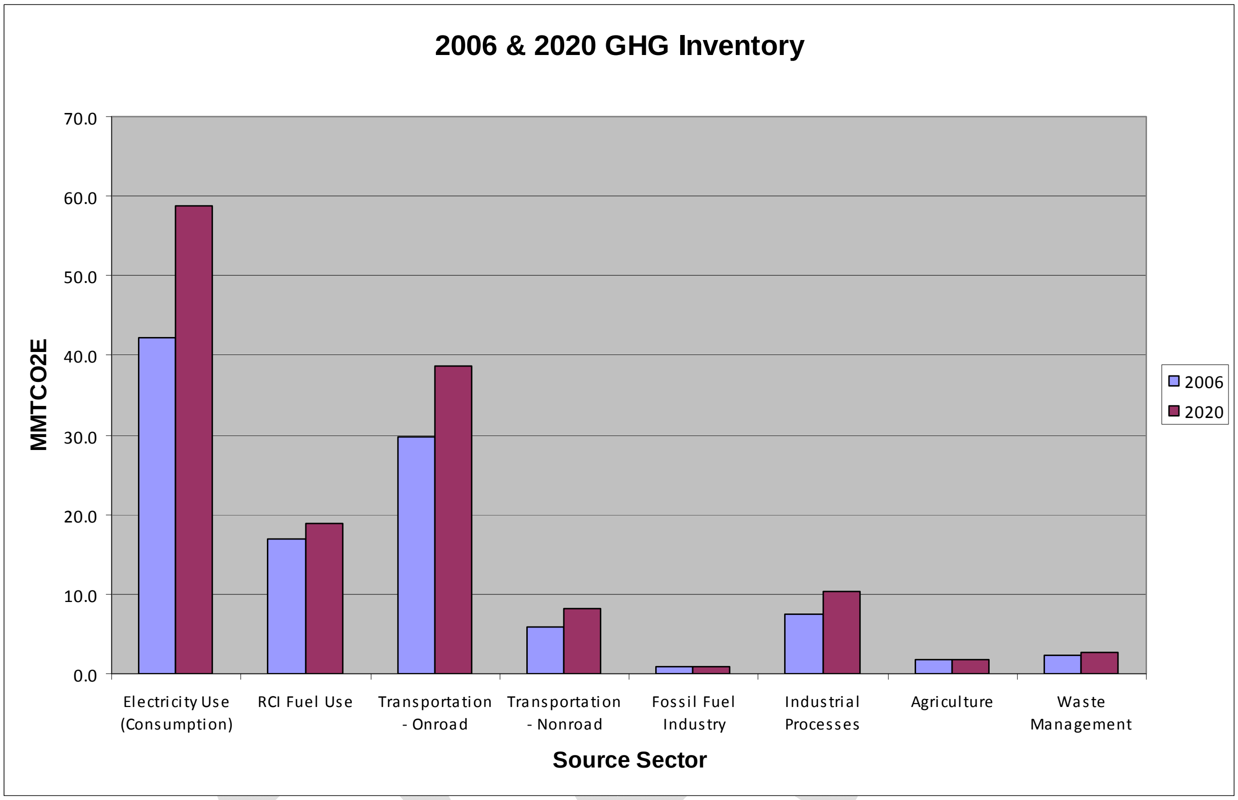
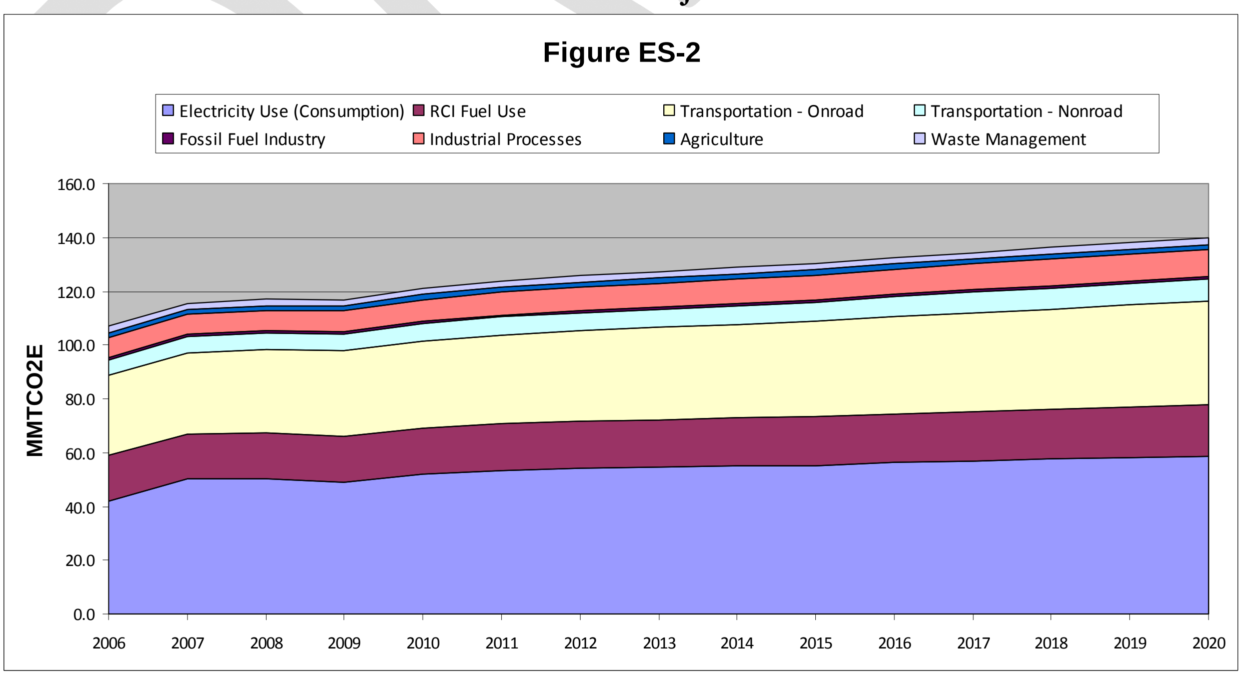


FIGURE ES-4: MARYLAND GROSS GHG EMISSIONS BY SECTOR, 2006-2020: BASE YEAR AND PROJECTED



1.3 SOURCE CATEGORIES

This document describes the inventory procedures the Maryland Department of the Environment (MDE) used to compile the 2006 base year emissions inventory of the greenhouse gas pollutants; carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), Sulfur hexafluoride (SF_6), chlorofluorocarbons (CFC) and hydro chlorofluorocarbons (HCFC). The emission sources are divided into the following eight source categories:

- Electricity Supply
- Residential, Commercial, and Industrial (RCI) Fuel Combustion
- Transportation Energy Use
- Industrial Processes
- Fossil Fuel Production Industry
- Agriculture
- Waste Management
- Forestry and Land Use

The inventory procedures outlined in this document have been calculated on a state-wide basis and have not been spatially allocated to the county level unless otherwise stated.

Descriptions of each emission source category are presented in the following paragraphs:

1.3.1 Electricity Supply

The electricity supply sector account for emissions occurring as a result of the combustion of fossil fuel at electricity generating facilities located both in and outside of the State. Carbon dioxide (CO_2) represented more than 99.5% of total sector emissions, with methane (CH_4) and nitrous oxide (N_2O) CO_2-equivalent emissions comprising the balance.

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 28% of the electricity consumed in Maryland in 2006.[7] 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 41% of Maryland's gross GHG emissions in 2006 (about 42 $MMtCO_2e$), which was higher than the national average share of emissions from electricity consumption (34%).[8]

In 2006, emissions associated with Maryland's electricity consumption (42 $MMtCO_2e$) were about 10 $MMtCO_2e$ higher than those associated with electricity production (32.0 $MMtCO_2e$).

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[7] In 2006, total Maryland retail sales were 63,173 GWh, of which 17,643 (i.e., 28%) were estimated to be from imports.

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

The higher level for consumption-based emissions reflects GHG emissions associated with net imports of electricity to meet Maryland's electricity demand.[9] Projections of electricity sales for 2006 through 2020 indicate that Maryland will remain a net importer of electricity. The 2020 "business as usual" projection inventory assumes that production-based emissions (associated with electricity generated in-state) will increase by about 10 $MMtCO_2e$, and consumption-based emissions (associated with electricity consumed in-state) will increase by about 6 $MMtCO_2e$.

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.

1.3.2 Residential, Commercial, and Industrial (RCI) Fuel Combustion

This section accounts for emissions associated with direct fossil fuel used in the residential, commercial and the industrial sector to provide space and process heating.

1.3.3 Transportation Energy Use

Emissions estimated for this sector are the result of fossil-fuel consumed primarily for transportation purposes, both Onroad mobile sources and Nonroad mobile sources of transportation. Onroad mobile sources include the vehicles traditionally operated on public roadways. These include:

- Cars
- Light-duty trucks
- Vans
- Buses
- Other diesel vehicles

Other modes of transportation, such as airplanes, trains and commercial marine vessels are included under the general category of nonroad mobile sources. Nonroad mobile sources also include motorized vehicles and equipment, which are normally not operated on public roadways. These include:

- Lawn and garden equipments
- Agricultural or farm equipment
- Logging equipment
- Industrial equipment
- Construction equipment
- Airport service equipment
- Recreational land vehicles or equipment
- Recreational marine equipment

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

- Locomotives
- Commercial aviation
- Air taxis
- General aviation
- Military aviation
- Commercial Marine Vessels

As shown in Figure 2, the transportation sector accounted for about 31% of Maryland's gross GHG emissions in 2006 (about 33 $MMtCO_2e$), which was higher than the national average share of emissions from transportation fuel consumption (27%).

2006 onroad gasoline vehicles accounted for about 71% of transportation GHG emissions. Onroad diesel vehicles accounted for another 14% of emissions, and air travel for roughly 5.5%. Marine vessels, rail, and other sources (natural gas- and liquefied petroleum gas- (LPG-) fueled-vehicles used in transport applications) accounted for the remaining 10% of transportation emissions.

1.3.4 Industrial Processes

Emissions estimated in the industrial sector accounts for only process related GHG emission from the four main industrial processes that occurs in the state;

(1) CO_2 emissions from cement production, soda ash, dolomite and lime/ limestone consumption;
(2) CO_2 emissions from iron and steel production;
(3) sulfur hexafluoride (SF6) emissions from electric power transmission and distribution (T&D) system transformers use, and
(4) Hydrofluorocarbons (HFC) and Perfluorocarbons (PFC) emissions resulting from the consumption of substitutes for ozone-depleting substances (ODS) used in cooling and refrigeration equipment.

1.3.5 Fossil Fuel Production Industry

This section reports GHG emissions that are released during the production, processing, transmission, and distribution of fossil fuels, (primarily natural gas and coal) in the state. Methane (CH_4) emissions released via leakage and venting from oil and gas fields, processing facilities, and natural gas pipelines and fugitive CH_4 emission during coal mining are estimated in this section, as well as carbon dioxide (CO_2) emissions associated with the combustion of natural gas in compressor engines (referred to as pipeline fuel).

1.3.6 Agriculture.

The emissions estimated in this section 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 estimated in this section. Energy emissions (combustion of fossil fuels in agricultural equipment) are not included in this section, but are already accounted for under the RCI and Nonroad transportation sub- sector.

1.3.7 Waste Management

GHG emissions from Maryland's waste management practices were estimated in this section, emissions were estimated from the three (3) main classes of waste management in Maryland; (1) solid waste management, mainly in the form of CH_4 emissions from municipal and industrial solid waste landfills (including CH_4 that is flared or captured for energy production); (2) wastewater management, including CH_4 and N_2O from municipal and industrial wastewater (WW) treatment facilities ; and (3) CH_4 and N_2O from municipal solid waste incinerations.

1.3.8 Forestry and Land Use

This section provides an assessment of the net Greenhouse gas flux[10] resulting from land uses, land –use changes, and forests management activities in Maryland. The balance between the emission and uptake of GHGs is known as GHG flux. The GHG emissions estimated in this section includes CO_2 emissions from urea fertilizer use, CH_4 and N_2O emissions from wildfires and prescribed forest burns and N_2O from synthetic fertilizers application to settlement soils. Carbon uptake (sequestration) pathways estimated in this section include; carbon stored in above ground biomass, below ground biomass, dead wood, and litters- (forest carbon flux), carbon stored in the form landfilled yard trimmings and food scraps, carbon stored in harvested wood product/ wood product in landfills as well as carbon stored in urban trees.

1.4 BASIC ASSUMPTIONS

1.4.1 Greenhouse Gas Pollutant Global Warming Potential (GWP)

Carbon dioxide has a Global Warming Potential (GWP) of exactly 1 (since it is the baseline unit to which all other greenhouse gases are compared). Equivalent CO_2 (CO2e) is the concentration of CO2 would cause the same level of radiative forcing as a given type and concentration of greenhouse gas. Maryland used the established Intergovernmental Panel on Climate Change (IPCC) global warming potential's for the greenhouse gas pollutants.

GHG Pollutant	GWP
Carbon Dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310
Sulfur Hexafluoride (SF_6)	23,900
Perfluorocarbons (PFCs)	9,200
Hydro Chlorofluorocarbons (HCFC)	11,700

[10] The term "flux" is used here to encompass both emissions of greenhouse gases to the atmosphere, and removal of C from the atmosphere. Removal of C from the atmosphere is also referred to as "carbon sequestration".

1.4.2 Confidentiality

This document does not contain any confidential information; however, confidential information/data are included in the documentation of emissions calculations for major sources categories.

1.5 DOCUMENT ORGANIZATION

Detailed descriptions of the specific assumptions, source information, and calculations on which the inventory is based are presented in the sections described below.

Section 2.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations for the electricity supply sector.

Section 3.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the residential, commercial, and industrial fuel combustion sector.

Section 4.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the transportation energy use sector.

Section 5.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the industrial processes sector.

Section 6.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the fossil fuel production industry sector.

Section 7.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the agricultural sector.

Section 8.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the waste management sector.

Section 9.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the forestry and land use sector.

2.0 ELECTRICITY SUPPLY

2.1 OVERVIEW

This section describes the data sources, key assumptions, and the methodology used to develop an inventory of greenhouse gas (GHG) emissions over the 1990-2006 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 2007-2020 period associated with meeting electricity demand in the state.

The methodology used to develop the MD inventory of GHG emissions associated with electricity consumption is based on a bottom up approach for in-state electricity generation and also includes emission estimates for imported electricity. There are four fundamental premises of the GHG inventory developed for MD, as briefly described below:

- Developing the consumption estimate involves tallying up the GHG emissions associated with consumption of electricity in MD, regardless of where the electricity is produced. As MD is a net importer of electricity, these estimates will be different.

- The GHG inventory should be estimated based on emissions at the point of electric generation only. That is, GHG emissions associated with upstream fuel cycle process such as primary fuel extraction, transport to refinery/processing stations, refining, beneficiation, and transport to the power station are not included.

- As an approximation, it was assumed that all power generated in MD was consumed in MD. In fact, some of the power generated in MD is exported. However, given the similarity in the average carbon intensity of MD power stations and that of power stations in the surrounding MAPP region, the potential error associated with this simplifying assumption is small, on the order of 2%, plus or minus.

2.2 DATA SOURCES

- Regional Greenhouse Gas Initiative (RGGI): The RGGI program and data sets can be accessed through the following website: http://rggi.org/about.html. States participating in RGGI include Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.

- EPA Clean Air Market Division (CAMD): This is a database file available from the EPA Clean Air Market Division. The information in the database is based on information collected from utilities. Additional data provided includes fuel consumption and net generation in power stations by plant type. This information can be accessed from: http://camddataandmaps.epa.gov/gdm/

- MDE's Annual Emissions Certification Reports

- US EPA State Greenhouse Gas Inventory Tool (SIT): http://www.epa.gov/statelocalclimate/resources/tool.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 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.

- *Ten-Year Plan (2009 - 2018) of Electrical Companies in Maryland, Public Service Commission of Maryland*: Table A-6(b): Maryland Energy Sales Forecast (Net of DSM Programs; GWh): The document can be accessed through the following website: http://webapp.psc.state.md.us/Intranet/Reports/2009-2018%20Ten%20Year%20Plan.pdf

- *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. It can be accessed directly from http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html.

- *Potential Effects of Proposed Climate Change Policies on PJM's Energy Market*, dated January 23, 2009

- *Maryland Comprehensive Energy Outlook*, Maryland Energy Administration, dated July 31, 2009. The document can be accessed directly from the following website: http://www.energy.state.md.us/documents/MDEnergySupplyandDemandOutlookDraft7-31mtg.pdf

- *Electric supply Adequacy Report of 2007*, Public Service Commission of Maryland, dated January 2007. The document can be accessed directly from the following website: http://webapp.psc.state.md.us/Intranet/Reports/2007SupplyAdequacyReport_01172007.pdf

2.3 GREENHOUSE GAS INVENTORY METHODOLOGY

2.3.1 Carbon Dioxide (CO_2) Direct Emissions

Two approaches were used to estimate CO2 emissions from the electric generation sector, one for sources included in the Regional Greenhouse Gas Initiative (RGGI) and the other for sources not included in RGGI.

2.3.1.1 RGGI Sources

The Regional Greenhouse Gas Initiative (RGGI) collects carbon dioxide (CO2) emissions data from fossil fuel fired power plants with a generating capacity of 25 megawatts or greater. Generating facilities supply unit level CO_2 emissions to EPA's Clean Air Markets Division (CAMD) database under the Acid Rain Program. This unit level CO_2 emission data was compiled to the facility level and formed the basis for the estimation of CO_2 emission.

Maryland has a substantial database of both small and large air emission sources compiled over the last eighteen years. Regulated facilities are required to submit annual Emissions Certification Reports to MDE ARMA Compliance Program. The Compliance Program facility inspectors verify the submitted emission estimates for accuracy and completeness.

The RGGI facility emission estimates compiled from the CAMD database were compared to the Annual Emissions Certification reports submitted to MDE as an additional quality control check.

MDE compiled RGGI facility emissions data through the following steps:

1. Identified the RGGI facilities that report CO_2 emissions to EPA through the CAMD database.
2. Compiled a list of RGGI generating unit and facility codes.
3. Cross-referenced the RGGI units with the MD Emission Certification Reports.
4. Downloaded RGGI emissions data from EPA CAMD database from January, 2006 through December 2006 for all facilities and units in Maryland
5. Compiled 2006 CO_2 emissions data for RGGI units.
6. Compiled energy consumption (MMBTU) data from the ARP database for the RGGI units.
7. Compared the RGGI emission estimates to the MD Emission Certification Report emission estimates.
8. Reconciled any discrepancies.

2.3.1.2 Non – RGGI Sources

Non-RGGI electric generating unit CO_2 emissions were estimated utilizing the annual Emissions Certification Report submitted to MDE Air and Radiation Management Administration Compliance Program. The Compliance Program is responsible for collecting annual air emissions that are certified as accurate from large Maryland facilities. Fossil fuel consumption data and facility specific fuel heat content were compiled on a process basis per unit and used to estimate energy consumption in MMBtu. An EPA default emission factor was used to estimate CO_2 emissions.

MDE compiled Non-RGGI facility emissions data through the following steps:

1. Compiled fossil fuel consumption data for all Non-RGGI electric generating units for 2006 from MDE's Emission Certification Reports.
2. Estimate energy consumption (BBTU) from Non-RGGI units using facility specific heat contents from the Emission Certification Reports
3. Enter the energy consumption values as inputs into the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT). [11]
4. Estimate CO_2 Emission using the 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. [12] [13]

2.3.2 Additional Direct Emissions (CH_4 and N_2O)

To calculate CH_4 and N_2O emissions from electricity supply stationary combustion sector, the following data are required:

- Fossil fuel consumption by fuel type;
- Emission factors by fuel type

[11] 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.
[2] CH_4 and N_2O emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 2. "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion", August 2004

[12] 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.
[2] CH_4 and N_2O emissions were calculated using SIT, with reference to Emission Inventory Improvement Program, Volume VIII: Chapter. 2. "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion", August 2004

The general emissions equation is as follows:

$$\text{Emissions (MMTCO2E)} = \text{Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times \text{0.0005 short ton/lbs} \times \text{Combustion Efficiency (\%)} \times \text{0.90718 (Ratio of Short Tons to Metric Tons)} \div 1{,}000{,}000 \times (44/12)$$

Where:

Emissions:	MMTCO2E (Million Metric Tons of CO2 Equivalent)
Consumption:	BBtu (Billion BTUs)
Emission Factor:	(lbs Carbon/BBtu)
0.0005:	Conversion Factor (Short tons to Lbs)
Combustion Eff:	Percentage
0.90718:	Conversion Factor (Short tons to Metric tons)
1,000,000:	Conversion Factor (Metric Tons to Million Metric Tons)
44/12:	Conversion Factor (Carbon to CO_2)

2.3.2.1 RGGI Sources

Fossil fuel energy consumption data was collected from EPA's CAMD database and cross-checked with MDE's annual Emissions Certification Reports submitted to MDE - ARMA's Air Quality Compliance Program. CAMD data is drawn from continuous emissions monitors at each facility and reported in short tons.

Emission factors were utilized from the EPA's State Inventory Tool (SIT).[14] The emission factors are provided within the tool.

2.3.2.2 Non – RGGI Sources

Fossil fuel consumption and facility specific heat content data were collected from MDE's annual Emissions Certification Reports submitted to MDE - ARMA's Air Quality Compliance Program.

Emission factors were utilized from the EPA's SIT. The emission factors are provided within the tool.

2.3.3 Imported Electricity Indirect Emissions (CO_2, CH_4 and N_2O)

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 24.2% of the electricity consumed in Maryland in 2006.[15] GHG emissions from power produced in-state are dominated by coal use, followed by emissions from oil use and natural gas use.

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[14] http://www.epa.gov/statelocalclimate/resources/tool.html

[15] In 2006, total Maryland retail sales were 67,12.464 GWh, of which 16,213.464 (i.e., 24.2%) were estimated to be from imports.

The electricity imported to meet Maryland demand was assume to come from the PJM Interconnection, a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.[16]

The fuel mix within the PJM region required to generate the electricity is presented in Table 2-1.

Table 2-1: PJM Fuel Mix [17]

FUEL TYPE	PJM PERCENTAGE
Coal	57.48
Nuclear	34.98
Natural Gas	5.14
Oil	0.31
Hydroelectric	1.12
Solid Waste	0.57
Wind	0.12
Captured CH4	0.15

The PJM website also provides the data to calculate a CO2 emission rate in metric tons per megawatt-hour for each fuel type. These calculated rates were used as the computed emission factors per fuel type in the analysis. The PJM data is presented in Table 2-2.

[16] http://www.epjm.net/about-pjm/who-we-are.aspx
[17] https://gats.pjm-eis.com/myModule/rpt/myrpt.asp?r=227&TabName=System%20Mix%20By%20Fuel

Table 2-2: PJM System Mix – Year 2006

PJM System Mix - Year: 2006 - System Mix By Fuel
(Contribution to 1 MWh of System Mix emissions from each Fuel in lbs/MWh)

Year	Fuel	# of Certificates (MWh)	Percentage by Fuel	Carbon Dioxide	Total CO_2 (lbs)	CO_2 Emission Rate (lbs/MWh)	CO_2 Emission Rate (metric tons/MWh)
2006	Captured Methane - Coal Mine Gas	79,684	0.01111	0.13256	95,065,107.9		
2006	Captured Methane - Landfill Gas	1,010,731	0.14093	0.30227	216,776,363.5		
		1,090,415	**0.15204**		**311,841,471.4**	**285.984**	**0.12970**
2006	Coal - Bituminous and Anthracite	361,266,339	50.37384	1013.15364	726,603,907,170.3		
2006	Coal - Coal-based Synfuel	2,116,069	0.29506	7.72974	5,543,544,668.0		
2006	Coal - Sub-Bituminous	36,990,788	5.15788	117.48579	84,257,344,328.0		
2006	Coal - Waste/Other	11,849,015	1.65219	36.70249	26,321,946,083.4		
		412,222,211	**57.47897**		**842,726,742,249.8**	**2044.351**	**0.92714**
2006	Gas - Natural Gas	36,855,939	5.13908	64.39395	46,181,444,026.6		
2006	Gas – Other	18,135	0.00253	0.07668	54,989,226.7		
		36,874,074	**5.14160**		**46,236,433,253.2**	**1253.901**	**0.56866**
2006	Hydro – Conventional	8,035,173	**1.12040**	0.00000	0.0		
2006	Nuclear	250,833,758	**34.97547**	0.00000	0.0		
2006	Oil - Distillate Fuel Oil	484,531	0.06756	1.44590	1,036,955,968.3		
2006	Oil - Jet Fuel	743	0.00010	0.00241	1,730,412.3		
2006	Oil - Kerosene	29,245	0.00408	0.07590	54,431,497.2		
2006	Oil - Residual Fuel Oil	1,683,377	0.23472	4.45536	3,195,255,518.1		
2006	Oil - Waste/Other Oil	14,915	0.00208	0.04827	34,617,715.0		
		2,212,811	**0.30855**		**4,322,991,110.9**	**1953.620**	**0.88600**
2006	Solid Waste - Municipal Solid Waste	4,084,202	**0.56949**	5.62694	**4,035,472,669.5**	**988.069**	**0.44810**
2006	Wind	831,140	**0.11589**	0.00000	0.0		
2006	Wood - Black Liquor	268,568	0.03745	0.10503	75,324,462.5		
2006	Wood - Wood/Wood Waste Solids	718,152	0.10014	0.01494	10,713,285.0		
		986,720	**0.13759**		**86,037,747.5**	**87.196**	**0.03954**
	Total	**717,170,504**	**100.00000**		**897,719,518,502.4**	**1251.752**	**0.56769**

MDE compiled CO_2 emission estimates from imported electricity by;

- Obtain the total electricity consumption for the State of Maryland from EIA State Energy Data System (SEDS)[18]
- Obtain the total electricity generated in the State of Maryland from EIA[19] .
- Estimate the amount of imported electricity (MWh) in 2006 by subtracting the total generated from the total consumed.
- Download PJM electricity generation fuel mix.[20]
- Apportion the amount of imported electricity by fuel type using the PJM fuel mix
- Compute the CO_2 emission factors per fuel type (tons/MWh) from the PJM data.[21]
- Estimate CO_2 emissions.

Table 2-3: Electricity Imported to Maryland (mWh)

		2006	Source of Data	Data Source Web Address
A	**Total Electric Consumption (Mwh) - Retail Sales**	63,173,143	EIA SEDS	http://www.eia.gov/cneaf/electricity/epa/sales_state.xls
B	MD In-State Net - Electricity Generated (MWh)	48,956,880	EIA SEDS	http://www.eia.gov/cneaf/electricity/epa/generation_state.xls
C	**MD -Electricity Losses (MWh) (Transmission and Distribution) Assume 7.0 %**	3,426,982	PJM Document	http://www.energy.state.md.us/documents/MDEnergySupplyandDemandOutlookDraft7-31mtg.pdf Section 2.3
D	**Net In -State Generated Electricity**	45,529,898	B – C	
E	**Imported Electricity to Meet MD Demand (MWh)**	**17,643,245**	A – D	

Table 2-4: Electricity Imported to Maryland by Fuel Type, (MWH)

	Coal	Nuclear	Natural Gas	Oil	Hydro-electric	Solid Waste	Wind	Captured CH_4	Total
PJM Electricity Generation Fuel Mix 2006 (%)	57.479	34.975	5.142	0.309	1.120	0.569	0.116	0.152	100
Maryland 2006 Import Share by Fuel Type (MWh)	10,141,155	6,170,808	907,146	54,438	197,675	100,476	20,447	26,826	17,618,970
Imported Electric CO_2 Emissions Factors (tons/MWh)	0.93		0.57	0.89		0.45		0.13	
Imported Electric CO_2 Emissions (metric tons)	9,402,303		515,860	48,232		45,024		3,479	10,014,897
Imported Electric CO_2 Emissions ($MMTCO_2$)	9.402		0.516	0.048		0.045		0.003	10.0149

[18] http://www.eia.gov/cneaf/electricity/epa/sales_state.xls
[19] http://www.eia.gov/cneaf/electricity/epa/generation_state.xls
[20] https://gats.pjm-eis.com/myModule/rpt/myrpt.asp?r=227&TabName=System%20Mix%20By%20Fuel
[21] https://gats.pjm-eis.com/myModule/rpt/myrpt.asp?r=227&TabName=System%20Mix%20By%20Fuel

2.4 GREENHOUSE GAS INVENTORY RESULTS

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

The result of the RGGI / MD Emission Certification Reports compilation is shown in Table 2-5 and the Non-RGGI EGU units data is shown in Table 2-6.

Table 2-5: RGGI CO_2 Emissions by Fuel Type

Electric Power Sector CO_2 Emissions – RGGI Units – 2006					
Fuel Type	MMBTU	CO_2 Emission (short tons)	CO_2 Emission (metric tons)	CO_2 Emission ($MMTCO_2$)	CO_2 Emission (MMTC)
Coal	302,014,703	31,008,128	28,130,574	28.13	7.67
Petroleum	2,537,117	212,276	192,577	0.19	0.05
Natural Gas	29,554,406	4,011,554	3,639,282	3.64	0.99
Total		**35,231,958**	**31,962,432**	**31.96**	**8.72**

Table 2-6: Non-RGGI CO_2 Emissions by Fuel Type

Electric Power Sector CO_2 Emissions - Non RGGI Units – 2006						
Fuel Type	Consumption (Billion Btu)	Emission Factor (lbs C/Million Btu)	Combustion Efficiency (%)	Emissions (short tons carbon)	Emissions (short tons CO_2)	Emissions (metric tons CO_2)
Coal	-	55.80	100.0%	-	-	0.0000
Distillate Fuel	557	43.94	100.0%	12,229	44,841	0.0407
Residual Fuel	42	47.33	100.0%	997	3,655	0.0033
Natural Gas	172	31.87	100.0%	2,745	10,066	0.0091
Total					**58,562**	**0.0531**

Figures 2-1 and 2-2 summarize gross generation and CO_2e emissions for Maryland power stations for the year 2006. Table 2-9 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 2006 Base Year.

CH_4 and N_2O Emissions from Electric Generating Units

Since, US EPA does not collect data on methane (CH_4) or nitrous oxide (N_2O) emissions) from power plants, Maryland CH_4 and N_2O emission was estimated by multiplying energy consumption data from ARP (for RGGI Units) and estimated energy consumption data from Emissions Certification Report (for Non RGGI) by the EPA's SIT[22] emission factors provided with the tool.

Table 2-7: Electric Power - RGGI GHG Emissions by Pollutant – 2006 Base Year

Fuel Type	Consumption (Billion Btu)	Emissions CO_2 ($MMTCO_2E$)	Emissions N_2O ($MMTCO_2E$)	Emissions CH_4 ($MMTCO_2E$)	Emissions Total ($MMTCO_2E$)
Coal	302,015	28.131	0.1408	0.0064	28.2777
Distillate Fuel	813	0.067	0.0002	0.0001	0.0676
Residual Fuel	1,406	0.109	0.0003	0.0001	0.1097
Natural Gas	29,554	3.639	0.0009	0.0006	3.6407
		31.9465	0.1420	0.0071	32.0957

Table 2-8: Electric Power – Non RGGI GHG Emissions by Pollutant – 2006 Base Year

Fuel Type	Consumption (Billion Btu)	Emissions CO_2 ($MMTCO_2E$)	Emissions N_2O ($MMTCO_2E$)	Emissions CH_4 ($MMTCO_2E$)	Emissions Total ($MMTCO_2E$)
Coal	-	0.000	0.0000	0.0000	-
Distillate Fuel	557	0.041	0.0001	0.0000	0.0408
Residual Fuel	42	0.003	0.0000	0.0000	0.0033
Natural Gas	172	0.009	0.0000	0.0000	0.0091
		0.053	0.0001	0.0000	0.0533

[22] http://www.epa.gov/statelocalclimate/resources/tool.html

FIGURE 2-1: GROSS ENERGY GENERATION BY ENERGY SOURCE (MWH)

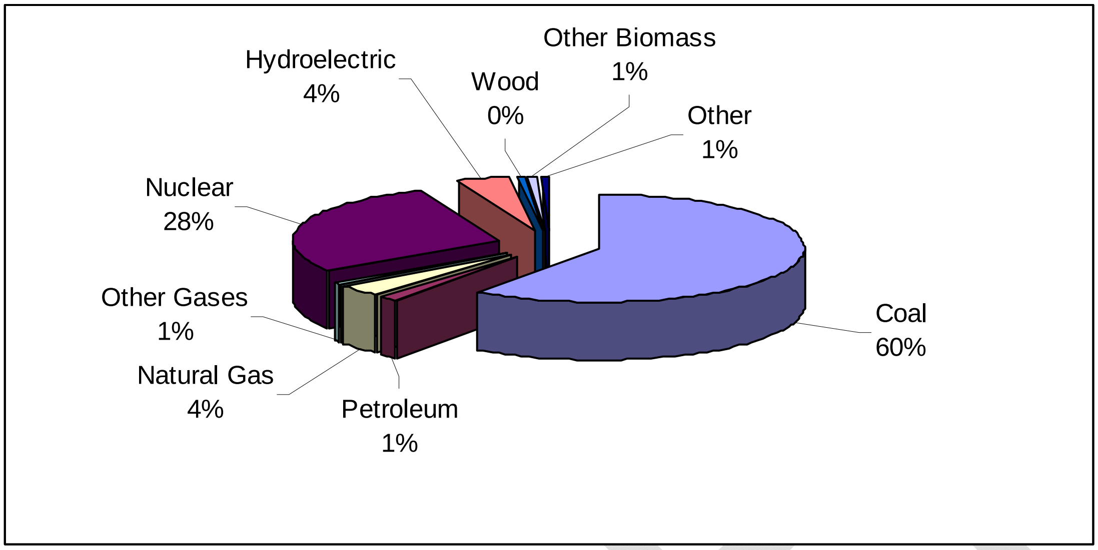


FIGURE 2-2: EMISSIONS BY ELECTRIC GENERATING SOURCE SECTORS (MMTCO2E)

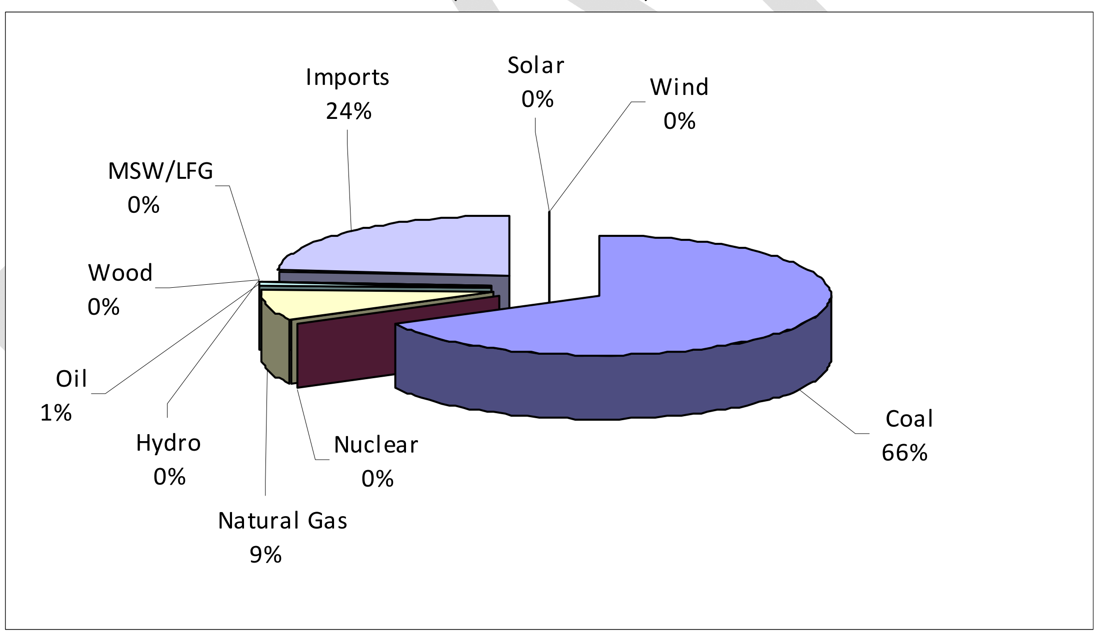


Table 2-9: Summary of Maryland Electric Generator and CO_2 Emission Characteristics for 2006[1]

Plant Name	Unit ID	Generator ID	Nameplate Capacity (MW)	CO2 Emissions (MMTCO2E)						
				2000	2001	2002	2003	2004	2005	2006
Brandon Shores	1	1	685	5,418,567	3,980,548	3,925,409	3,677,040	3,995,923	3,639,544	4,090,213
Brandon Shores	2	2	685	4,224,994	5,280,442	3,648,528	4,471,846	3,879,083	4,495,395	4,004,229
C P Crane	1	1	190	1,221,875	1,025,216	1,356,979	1,240,241	1,119,804	1,123,190	1,110,644
C P Crane	2	2	209	1,225,664	1,502,482	1,089,277	1,361,150	1,077,159	1,262,477	976,659
GOULD STREET	3	3	104	109,334	204,519	209,193	34,929	0	0	0
Herbert A Wagner	1	1	133	166,480	109,584	65,239	90,529	187,414	199,208	38,237
Herbert A Wagner	2	2	136	846,837	769,749	1,004,538	998,481	1,075,476	918,202	898,338
Herbert A Wagner	3	3	359	2,276,517	1,861,547	1,558,624	2,010,422	1,899,259	2,283,444	1,850,845
Herbert A Wagner	4	4	415	363,909	593,526	592,117	513,085	558,639	452,667	100,937
Perryman	**51		192	51,936	147,785	34,757	33,014	96,421	37,002	38,852
Perryman	CT1		53	2,696	14,602	20,605	20,483	11,276	20,545	8,241
Perryman	CT2		53	8,022	18,075	20,772	23,945	11,746	23,288	8,488
Perryman	CT3		53	5,026	17,343	20,672	25,332	6,661	22,682	9,497
Perryman	CT4		53	7,368	20,783	17,731	17,165	12,204	5,277	0
Riverside	4		72	8,161	35,258	32,412	8,305	2,873	13,167	10,540
Riverside	CT6		122	12,357	16,517	13,046	2,795	2,920	21,772	17,510
Westport	CT5		122	11,642	7,283	2,855	378	694	2,989	5,665
Vienna	8	8	162	304,411	193,554	287,152	103,158	52,551	139,698	13,643
R. Paul Smith Power Station	9	3	35	67,181	68,439	116,065	122,129	50,341	114,757	129,294
R. Paul Smith Power Station	11	4	75	557,226	539,882	502,390	422,584	359,805	374,021	485,957
Mirant Chalk Point	1	ST1	364	1,898,856	1,631,061	2,289,199	1,817,373	2,266,557	2,267,840	2,031,754
Mirant Chalk Point	2	ST2	364	1,688,238	1,469,887	2,450,467	2,037,947	2,293,952	2,025,578	2,170,183
Mirant Chalk Point	3	3	659	598,057	998,727	609,063	1,305,301	992,185	1,574,307	272,718
Mirant Chalk Point	4	4	659	821,609	978,570	814,219	924,123	1,120,050	863,725	279,485
Mirant Chalk Point	**GT3		103	43,165	30,726	56,365	42,693	27,820	56,180	13,612
Mirant Chalk Point	**GT4		103	41,927	32,805	60,280	46,142	29,327	61,961	14,539
Mirant Chalk Point	**GT5		125	97,473	37,472	36,988	32,459	45,823	49,771	17,585
Mirant Chalk Point	**GT6		125	80,736	17,268	71,051	43,629	38,448	52,893	19,063
Mirant Chalk Point	GT2		35	1,736	5,568	2,446	561	2,703	2,703	1,029
Mirant Chalk Point	SMECO		90	37,521	25,726	32,505	41,382	22,537	47,246	14,593
Mirant Dickerson	1	ST1	196	827,113	1,057,730	913,454	858,309	1,104,090	1,030,495	1,057,336
Mirant Dickerson	2	2	196	1,158,203	1,074,656	990,037	785,513	1,133,934	1,198,510	918,164
Mirant Dickerson	3	3	196	917,641	937,688	1,131,013	953,865	1,107,446	1,182,222	1,225,103
Mirant Dickerson	GT2		163	15,728	41,102	70,406	83,615	63,146	65,905	24,853
Mirant Dickerson	GT3		163	43,415	33,795	77,281	80,506	64,308	50,816	24,246
Mirant Morgantown	1	ST1	626	3,766,077	3,250,128	3,995,554	3,840,867	3,122,572	2,937,699	3,625,816
Mirant Morgantown	2	ST2	626	3,788,324	3,792,761	3,440,191	3,918,755	3,196,179	3,219,080	3,600,877
Mirant Morgantown	GT3		65	5,135	13,663	8,562	8,472	7,839	40,614	13,156
Mirant Morgantown	GT4		65	11,805	12,409	8,112	7,572	7,804	40,140	0
Mirant Morgantown	GT5		65	8,154	12,338	9,217	7,097	8,814	41,167	16,356
Mirant Morgantown	GT6		65	12,962	8,666	8,055	4,362	8,224	40,275	14,621
Rock Springs Generating Facility	1		113	0	0	0	52,893	37,175	41,105	19,679

[1] Source: http://www.rggi.org/docs/co2_2000_2006.xls

Plant Name	Unit ID	Generator ID	Nameplate Capacity (MW)	CO2 Emissions (MMTCO2E)						
				2000	2001	2002	2003	2004	2005	2006
Rock Springs Generating Facility	2		113	0	0	0	46,137	38,089	36,766	19,595
Rock Springs Generating Facility	3		227	0	0	0	36,124	22,393	64,987	17,004
Rock Springs Generating Facility	4		227	0	0	0	30,554	31,779	75,409	25,880
Sparrows Point (Severstal)				2,632,646	2,431,214	2,740,381	2,074,514	2,310,381	2,076,293	2,994,206
AES Warrior Run	1	GEN1	229	1,536,726	1,599,235	1,570,012	1,606,756	1,580,557	1,751,923	1,546,789
Luke Mill				1,037,679	977,750	1,071,727	1,093,709	1,132,738	1,142,763	1,297,583
Panda Brandywine	1		99	221,656	51,207	47,003	49,458	35,702	37,569	90,209
Panda Brandywine	2		99	264,071	51,269	62,595	57,039	28,645	38,419	69,247
Panda Brandywine	3		91	---	---	---	---	---	---	0
Total (million short tons)				**38.45**	**36.98**	**37.08**	**37.06**	**36.28**	**37.26**	**35.23**

2.5 GREENHOUSE GAS FORECAST METHODOLOGY

There are four fundamental premises of the GHG inventory developed for MD, as briefly described below:

- Developing the consumption estimate involves tallying up the GHG emissions associated with consumption of electricity in MD, regardless of where the electricity is produced. As MD is a net importer of electricity, these estimates will be different.

- The GHG inventory should be estimated based on emissions at the point of electric generation only. That is, GHG emissions associated with upstream fuel cycle process such as primary fuel extraction, transport to refinery/processing stations, refining, beneficiation, and transport to the power station are not included.

- As an approximation, it was assumed that all power generated in MD was consumed in MD. In fact, some of the power generated in MD is exported. However, given the similarity in the average carbon intensity of MD power stations and that of power stations in the surrounding MAPP region, the potential error associated with this simplifying assumption is small, on the order of 2%, plus or minus.

- The projection methodology does not consider any future CO_{2E} reduction programs and is as close to an uncontrolled future year inventory as possible.

2.5.1 Projected Emissions from Existing Electric Generating Units

Future year projections from the existing electric power generating units were done on a fuel type basis.

2.5.1.1 Projection of Coal-Fired Base Load Units

The projection of the emissions from the coal-fired base load electric generating units utilized a two step process:

1. Calculating the additional capacity due to optimization of the existing units
2. Adding in any planned new generating capacity

The electrical generating units surveyed for the 2006 base year inventory did not operate optimally when compared to previous years of service. MDE compiled data from the EPA CAMD Program on each electric generating unit from the base year inventory between 1995 and 2009. The data was sorted by unit and fuel type. For the coal-fired base units, maximum operating hours and corresponding emissions were compiled over the fifteen years of data. The maximum heat input was then compared to the base year heat input. Dividing the 15-year maximum heat input by the base year heat input represents the optimization of the units and provides a basis for the growth in GHG emissions due to the optimization of the existing units themselves. An example for the coal fired CAMD units is presented in Table 2-10 below:

Table 2-10: Coal-Fired EGU Optimization

FAC_UNIT	PRIMARY FUEL INFO	Max Operating Time Data: YEAR	MAX OP TIME	HEAT INPUT	Base Year Data: Base Year	OPERATING TIME	HEAT INPUT
AES Warrior Run_1	COAL	2005	8686.78	16,186,820	2006	7702.4	14,291,498
Brandon Shores_1	COAL	1998	8495.25	52,450,450	2006	8363.75	39,865,596
Brandon Shores_2	COAL	2003	8560.25	43,585,260	2006	7486.5	39,027,527
C P Crane_1	COAL	2002	8105	13,098,633	2006	6955	10,825,025
C P Crane_2	COAL	2001	8406.75	14,644,149	2006	6588.5	9,519,110
Herbert A Wagner_2	COAL	2004	8254.75	10,482,192	2006	7667.5	8,755,729
Herbert A Wagner_3	COAL	2005	8163	22,255,775	2006	6938	18,039,441
Luke Paper Company_PR003	COAL	2001	8757.3		2006	8527.35	
Luke Paper Company_PR004	COAL	2001	8757.3		2006	8504.84	
Mirant Chalk Point_1	COAL	2004	8223.15	22,104,682	2006	7126.1	19,830,382
Mirant Chalk Point_2	COAL	2002	8457.41	23,910,157	2006	7530.46	21,186,709
Mirant Dickerson_1	COAL	1998	8140.25	13,285,718	2006	7680.27	10,305,447
Mirant Dickerson_2	COAL	2005	8481.42	11,681,408	2006	6672.49	8,948,983
Mirant Dickerson_3	COAL	1998	8642.5	13,908,143	2006	8489.12	11,940,584
Mirant Morgantown_1	COAL	1996	8533.5	37,010,519	2006	7638.59	35,354,741
Mirant Morgantown_2	COAL	1998	8492	43,364,798	2006	7726.83	35,112,681
R. Paul Smith Power Station_9	COAL	2007	6588.15	1,783,642	2006	4583.46	1,260,200
R. Paul Smith Power Station_11	COAL	2007	7958.11	5,573,595	2006	7278.89	4,736,436
Grand Total	COAL		8757.3	345,325,942			289,000,087
				COAL GF			1.195

No new coal-fired electric generating units are planned for the future.

2.5.1.2 Projection of Natural Gas-Fired Peaking/Load Following Units

The projection of the emissions from the natural gas-fired electric generating units utilized a two step process:

1. Calculating the additional capacity due to optimization of the existing units
2. Adding in any planned new generating capacity

The electrical generating units surveyed for the 2006 base year inventory did not operate optimally when compared to previous years of service. MDE compiled data from the EPA CAMD Program on each electric generating unit from the base year inventory between 1995 and 2009. The data was sorted by unit and fuel type. For the natural gas-fired peaking and load following units, average operating hours and corresponding were calculated per fuel type over the fifteen years of data. The average heat input was then compared to the base year heat input. Dividing the 15-year average heat input by the base year heat input represents the optimization of the units and provides a basis for the growth in GHG emissions due to the optimization of the existing units themselves.

Table 2-11: Natural Gas-Fired EGU Optimization

FAC_UNIT	PRIMARY FUEL INFO	YEARS	SUM OP TIME	HEAT INPUT	Base Year	OPERATING TIME	HEAT INPUT
		Average Operating Time Data			Base Year Data		
Gould Street_3	Natural Gas	1995 - 2009	212.01	96,089	2006		
Luke Paper Company_PR005	Natural Gas	1995 - 2009	2710.734545		2006	574.07	
Mirant Chalk Point_**GT3	Natural Gas	1995 - 2009	545.4253846	477,746	2006	263.43	223,457
Mirant Chalk Point_**GT4	Natural Gas	1995 - 2009	554.0707692	502,840	2006	267.08	237,292
Mirant Chalk Point_**GT5	Natural Gas	1995 - 2009	549.6153846	682,497	2006	231	290,042
Mirant Chalk Point_**GT6	Natural Gas	1995 - 2009	526.4915385	642,130	2006	255.83	311,222
Mirant Dickerson_GT2	Natural Gas	1995 - 2009	603.3692308	661,611	2006	410	413,560
Mirant Dickerson_GT3	Natural Gas	1995 - 2009	794.0815385	767,291	2006	372.88	403,584
Panda Brandywine_1	Natural Gas	1995 - 2009	2765.736154	2,318,085	2006	3041.59	2,477,714
Panda Brandywine_2	Natural Gas	1995 - 2009	2921.778462	2,327,802	2006	1915.07	1,538,356
Perryman_**51	Natural Gas	1995 - 2009	647.6245455	723,992	2006	391.5	620,987
Riverside_4	Natural Gas	1995 - 2009	430.5636364	265,064	2006	310.75	177,348
Riverside_CT6	Natural Gas	1995 - 2009	16	17,118	2006		
Rock Springs Generating Fac_1	Natural Gas	1995 - 2009	237.3366667	385,748	2006	199.74	331,146
Rock Springs Generating Fac_2	Natural Gas	1995 - 2009	247.8266667	402,246	2006	198.82	329,722
Rock Springs Generating Fac_3	Natural Gas	1995 - 2009	330.7728571	537,244	2006	176.87	286,121
Rock Springs Generating Fac_4	Natural Gas	1995 - 2009	372.27	609,104	2006	266.95	435,478
Westport_CT5	Natural Gas	1995 - 2009	11	26,812	2006		
			14237.69738	11,303,401		8875.58	8,076,028
				NAT GAS GF			1.400

Several new natural gas-fired electric generating units are being planned within the State of Maryland.

Table 2-12: Planned New In-State EGUs

Resource Developer Location	Capacity MW	Fuel	Full Year On-Line	Approximate Heat Input	Capacity GWh
Criterion Power Partners, LLC., Garrett Co.	70	Wind	2011		183.96
Gould Street, Constellation Energy, Baltimore City (reactivation)	101	Gas	2016	923,759	884.76
UniStar (Constellation Energy), Calvert Co.	1710	Nuclear	2016		14979.6
Competitive Power Ventures, Charles Co.	645	Gas	2011	2,771,277	5650.2
Riverside, Constellation Energy, Baltimore Co. (reactivation)	85	Gas	2010	923,759	744.6
Perryman, Constellation Energy, Harford Co. Allegheny County	600	Gas/Oil	2010	2,771,277	5256
Synergics Wind Energy, Roth Rock Windpower Project, Garrett Co.	50	Wind	2011		131.4
Energy Answers International, Inc. Baltimore City	120	Municipal Solid Waste	2011		1051.2

To compute the overall projected growth factor for a particular year, the following steps were followed:

1. Multiply the 2006 base year overall natural gas heat input by the optimization growth factor (1.40)
2. Add the heat inputs from any new natural gas-fired that will be on-line that year to Step 1
3. Divide the sum of Steps 1 and 2 by the base year natural gas heat input.

2.5.1.3 Projection of Oil-Fired Peaking/Load Following Units

The projection of the emissions from the oil-fired electric generating units utilized a two step process:

1. Calculating the additional capacity due to optimization of the existing units
2. Adding in any planned new generating capacity

The electrical generating units surveyed for the 2006 base year inventory did not operate optimally when compared to previous years of service. MDE compiled data from the EPA CAMD Program on each electric generating unit from the base year inventory between 1995 and 2009. The data was sorted by unit and fuel type. For the oil-fired peaking and load following units, average operating hours and corresponding were calculated per fuel type over the fifteen years of data. The average heat input was then compared to the base year heat input. Dividing the 15-year average heat input by the base year heat input represents the optimization of the units and provides a basis for the growth in GHG emissions due to the optimization of the existing units themselves.

No new oil-fired electric generating units are being planned within the State of Maryland.

Table 2-13: Oil-Fired EGU Optimization

		Average Operating Time Data			Base Year Data		
FAC_UNIT	PRIMARY FUEL INFO	YEARS	SUM OP TIME	HEAT INPUT	Base Year	OPERATING TIME	HEAT INPUT
Herbert A Wagner_1	Diesel Oil	1995 - 2009	2,723	1127228.176	2006	953.25	565015.1
Herbert A Wagner_4	Diesel Oil	1995 - 2009	2,018	3954929.493	2006	536.5	1168170.875
Grand Max	Diesel Oil			5,082,158			1,733,186
				Oil GF			2.932

2.5.2 Projected Emissions from Imported Electricity

2.5.2.1 Projected Electricity Consumption

The methodology used to develop the MD inventory of GHG emissions associated with electricity consumption is based on methods developed by the PJM in the document entitled, "*Ten-Year Plan (2009 - 2018) of Electrical Companies in Maryland, Public Service Commission of Maryland*". Table A-6(b) of the plan was used to forecast energy sales in MD. The table is reproduced below with actual data for years 2006, 2007, 2008, and 2009 added into the table for completeness.

Table A-6(b): Maryland Energy Sales Forecast (Net of DSM Programs; GWh)

Year	Berlin	BGE	Choptank	DPL	Easton	Hagerstown	PE/AP	Pepco	SMECO	Thurmont	Williamsport	Total
2006												63,173
2007												65,390
2008												63,325
2009												62,403
2010	39	32,115	964	4,333	295	330	7,321	15,178	3,569	83	19	64,246
2011	40	32,552	983	4,416	300	299	7,379	15,090	3,646	84	19	64,808
2012	40	33,059	1,011	4,533	306	300	7,505	15,189	3,713	84	19	65,760
2013	41	33,443	1,035	4,598	312	302	7,575	15,225	3,773	84	19	66,406
2014	41	33,810	1,058	4,651	318	303	7,650	15,219	3,826	84	19	66,981
2015	42	34,130	1,084	4,681	324	305	7,725	15,188	3,874	85	19	67,457
2016	43	34,579	1,108	4,765	329	308	7,863	15,333	3,921	85	19	68,352
2017	43	34,996	1,133	4,855	335	311	8,024	15,506	3,966	85	19	69,272
2018	44	35,438	1,159	4,939	341	314	8,173	15,679	4,010	86	19	70,203
2019	45	35,901	1,185	5,042	347	317	8,315	15,870	4,047	86	19	71,174
2020	45	36,410	1,209	5,137	353	320	8,447	16,063	4,088	86	19	72,178
2021	46	36,903	1,234	5,236	358	323	8,591	16,230	4,131	86	19	73,157
2022	47	37,431	1,258	5,327	364	326	8,757	16,397	4,175	87	19	74,187
2023	47	37,952	1,281	5,426	370	330	8,927	16,566	4,209	87	19	
Change (2009-2023)	8	6,351	334	1,121	81	-10	1,696	1,243	753	4	0	11,580
Percent Change	21.4%	20.1%	35.3%	26.0%	28.1%	-3.1%	23.4%	8.1%	21.8%	4.3%	0.0%	
Annual Growth Rate	1.4%	1.3%	2.2%	1.7%	1.8%	-0.2%	1.5%	0.6%	1.4%	0.3%	0.0%	

The total sales forecast was multiplied by a factor of 1.0625 to account for transmission and distribution losses. The result is the amount of electricity that needs to be generated to satisfy Maryland's consumption appetite.

2.5.3 Projected In-State Generation of Electricity

The basis for the projected in-state generation of electricity was taken from a Maryland Public Service Commission report, titled "Electricity Adequacy Report of 2007", date January 2007. Table II.C.2: Maryland Electricity Consumption Forecast (GWh) of the report was used and is presented below.

Table 2-14: Maryland's Net Generation of Electricity

Year	Estimated Total Sales[24]	Sales + Loss Factor[25]	Net Generation[26]	Net Imports[27]	Import Percentage[28]
2006	67,429	71,644	50,908	20,736	28.9%
2007	69,152	73,474	50,908	22,566	30.7%
2008	70,213	74,601	50,908	23,693	31.8%
2009	71,410	75,873	50,908	24,965	32.9%
2010	72,525	77,058	50,908	26,150	33.9%
2011	73,657	78,261	50,908	27,353	35.0%
2012	74,854	79,532	50,908	28,624	36.0%
2013	76,022	80,773	50,908	29,865	37.0%
2014	77,244	82,071	50,908	31,163	38.0%
2015	78,487	83,393	50,908	32,485	39.0%
2016	79,789	84,776	50,908	33,868	40.0%

Maryland only utilized the net generation data from this report when calculating net imports. Maryland added the generating capacity of the planned new units in their estimated first full year on-line to the net generation data presented in Table 2-14. These units are shown in Table 2-11.

2.5.4 Projected Net Imports of Electricity

The projected net import of electricity is simply the estimated net generation capacity subtracted from the estimated consumption/sales.

To illustrate, Maryland combined the following data into the one table, Table 2-15:

- Projected energy consumption from Table A-6(b)
- Net generation from Table 2-14 + the additional generating capacity of the planned new units in their estimated first full year on-line
- Subtracting the "Net Generation" from the "Estimated Total Sales" yields the "Net Imports"
- Dividing a future year net imports" by the 2006 net import yields a growth factor for future year imports.

[24] "Estimated Total Sales" is the total that the Commission estimated based upon sales forecast data received from Maryland energy suppliers. Delmarva Power and Light, Potomac Edison, and Somerset did not submit a Maryland specific forecast. Therefore tha Commission had to estimate those companies' forecasted demand.
[25] "Sales + Loss Factor" is the estimated total including the 6.25% loss factor.
[26] "Net Generation" is the average of Maryland's net generation for the years 2000-2005.
[27] "Net Imports" is (Sales + Loss Factor) – Net Generation.
[28] "Import Percentage" is Net Imports as a percent of "Sales + Loss Factor".

Table 2-15: Net Imports Growth Factor Analysis

YEAR	Estimated Total Sales[22] (GWh)	Sales + Loss Factor[23] (GWh)	Net Generation[24] (GWh)	Net Imports[25]	GF IMPORTS[29]	BASIS / SOURCE
2006	63,173,143	67,121,464	50,908,000	16,213,464		Actual Data
2007	65,390,660	69,477,576	50,908,000	18,569,576	1.1453182	Actual Data
2008	63,325,777	67,283,638	50,908,000	16,375,638	1.0100024	Actual Data
2009	62,403,106	66,303,300	50,908,000	15,395,300	0.949538	Actual Data
2010	64,246,000	68,261,375	50,914,001	17,347,374	1.0699363	
2011	64,808,000	68,858,500	50,921,017	17,937,483	1.1063325	
2012	65,760,000	69,870,000	50,921,017	18,948,983	1.1687189	
2013	66,406,000	70,556,375	50,921,017	19,635,358	1.2110526	
2014	66,981,000	71,167,313	50,921,017	20,246,295	1.2487334	Table A-6(b): Maryland Energy Sales Forecast (Net of DSM Programs; GWh): TEN-YEAR PLAN (2009 - 2018) OF ELECTRICAL COMPANIES IN MARYLAND, PSC
2015	67,457,000	71,673,063	50,921,017	20,752,045	1.2799266	
2016	68,352,000	72,624,000	50,921,017	21,702,983	1.3385777	
2017	69,272,000	73,601,500	50,921,017	22,680,483	1.3988671	
2018	70,203,000	74,590,688	50,921,017	23,669,670	1.4598774	
2019	71,174,000	75,622,375	50,921,017	24,701,358	1.5235089	
2020	72,178,000	76,689,125	50,921,017	25,768,108	1.589303	

2.6 GREENHOUSE GAS FORECAST RESULTS

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

Primary Energy Consumption

Total primary energy consumption associated with electricity generation in Maryland is summarized in Figure 2-3 for years 2000 through 2007. The primary energy consumption in Maryland is dominated by coal and nuclear resources.

Gross Generation

Total gross generation by MD power plants is summarized in Figure 2-4 for years 1991 through 2007.

[29] "GF IMPORTS" is the ratio of a future year Net Imports divided by the Net Imports from 2006.

FIGURE 2-3: PRIMARY ENERGY USE AT MARYLAND POWER STATIONS, PLUS IMPORTS

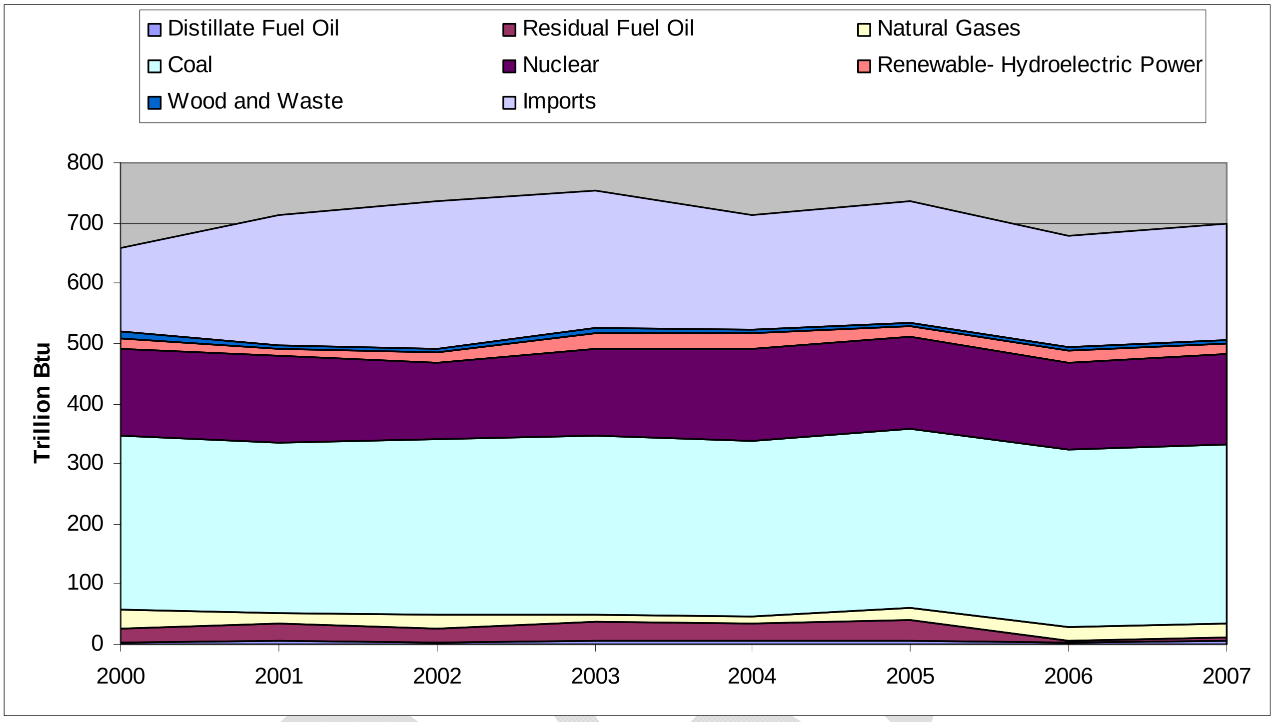
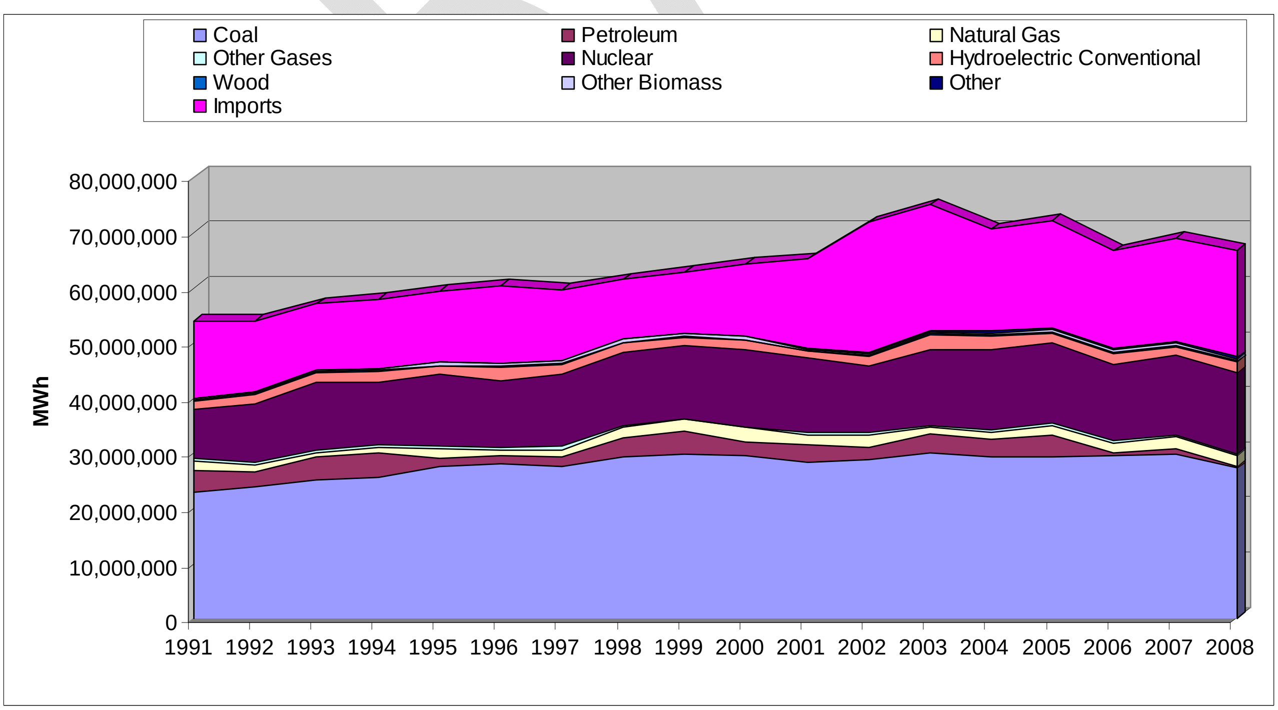


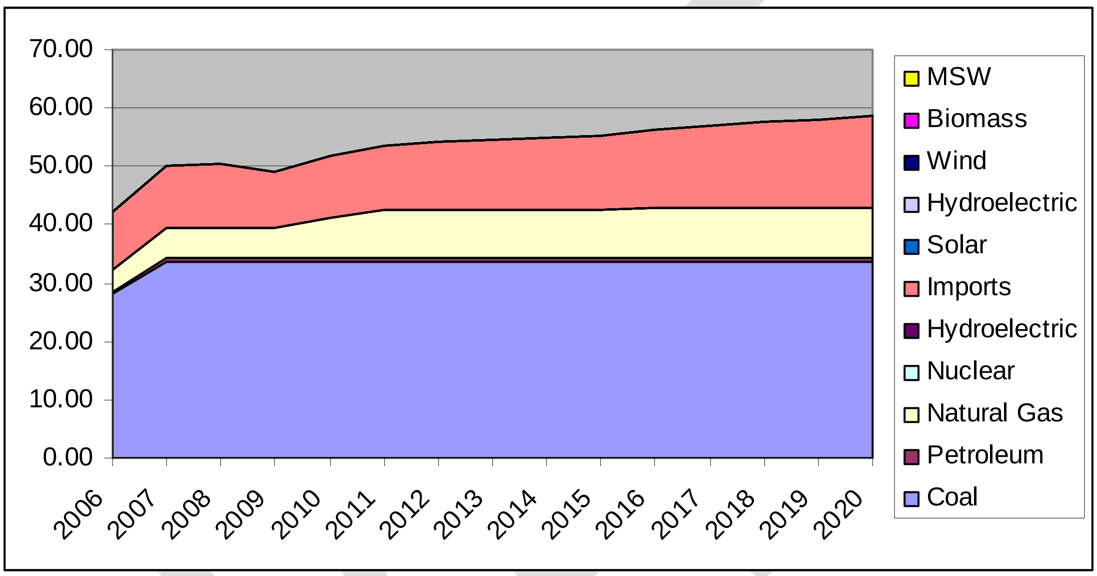
FIGURE 2-4: GROSS GENERATION AT MARYLAND POWER STATIONS, PLUS IMPORTS



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 2-5.

FIGURE 2-5: TOTAL EMISSIONS ASSOCIATED WITH ELECTRIC DEMAND IN MARYLAND ($MMtCO_2e$)



Imported Electricity

To meet annual demand for electricity in Maryland, total gross generation by Maryland power plants needs to be augmented by electricity imports. As indicated earlier, it was assumed that this power is imported from the PJM region. Table 2-16 summarizes the gross generation within and beyond Maryland border needed to satisfy electricity demand in Maryland.

Table 2-16: Consumption-Based GHG Emissions from Electricity Supply in Maryland ($MMtCO_2e$)

Fuel	2006	2010	2015	2020
Coal	28.28	33.79	33.79	33.79
Natural Gas	3.65	6.78	8.03	8.45
Petroleum	0.24	0.64	0.64	0.64
Imports	10.01	10.72	12.82	15.92
Total (Consumption-based)	**42.18**	**51.92**	**55.28**	**58.79**

3.0 Residential, Commercial, and Industrial (RCI) Fuel Combustion

3.1 OVERVIEW

This section describes the data sources, key assumptions, and the methodology used to develop an inventory of greenhouse gas (GHG) emissions for the base year 2006 associated with residential, commercial and industrial (RCI) sector fuel combustion in Maryland. Maryland GHG emissions were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[30] [31] The 2006 GHG inventory for the RCI sector was prepared using the SIT software with the state-specific defaults provided with the tool.

This section addresses only RCI sector emissions associated with the direct use of energy sources such as; natural gas, petroleum, coal and wood, to provide space heating, water heating, process heating, cooking and other energy end-uses. Emissions associated with RCI sector electricity consumption are accounted for under the electric generation section. Activities in the RCI sectors produce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions.

Results are presented in units of carbon dioxide equivalents (CO_2E), often in million metric tons ($MMTCO_2E$), for each gas for comparative purposes following the guidance of the Intergovernmental Panel on Climate Change[32], a widely accepted procedure for greenhouse gas analysis. Selected results for emissions in Maryland and a detailed description of the 2006 inventory are presented here.

This section also describes the data sources, key assumptions, and methodology used to develop a forecast of GHG emissions over the 2007-2020 period associated with meeting RCI fuel combustion demand in the state

3.2 DATA SOURCES

- Default state-level data derived from EIA's State Energy Consumption, Price, and Expenditure Estimates (SEDS) 2007: Consumption Estimates (EIA 2009) http://www.eia.doe.gov/emeu/states/_seds.html

[30] CO_2 emissions wer 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.
[31] CH_4 and N_20 emissions wer 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.
[32] Intergovernmental Panel on Climate Change

- Default state synthetic natural gas data obtained from Table 12 of EIA's Historical Natural Gas Annual (EIA 2009), and Table 8 for Natural Gas Annual publications from 2001-2007 http://www.eia.doe.gov/oil_gas/natural_gas/data_publications/natural_gas_annual/nga.html

- In-state agencies, such as state energy commissions or public utility commissions

- US EPA State Greenhouse Gas Inventory Tool (SIT) http://www.epa.gov/statelocalclimate/resources/tool.html

3.3 GREENHOUSE GAS INVENTORY METHODOLOGY

Maryland historic and base year (2006) GHG emissions from the RCI sector was estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[33]

Several key variables are necessary for estimating CO_2 emissions for fossil fuel combustion from the State Greenhouse Gas Inventory Tool (SIT). These variables include combustion efficiencies, carbon contents, and non-energy use storage factors. Default data is provided within the SIT program and Maryland selected the default data for the emission estimates. Information for combustion efficiencies, carbon contents, and non-energy use storage factors are discussed individually below.

Combustion Efficiencies

Combustion efficiency is defined as the percent carbon oxidized by the fuel type. This percent is applied if the carbon is not completely oxidized during the combustion of fossil fuels. The fraction oxidized was assumed to be 100 percent for petroleum, coal, and natural gas based on guidance from IPCC (2006).

Carbon Contents

Another data type required is the carbon content data. The carbon content coefficients used in the SIT module are from the EIA's *Electric Power Annual* EIA (2009a). Carbon content represents the maximum amount of carbon emitted per unit of energy released, assuming 100 percent combustion efficiency. Coal has the highest carbon content of the major fuel types, petroleum has roughly 75 percent of carbon per energy as compared to coal, and natural gas has about 55 percent. However, carbon contents also vary within the major fuel types, as noted below:

- Carbon emissions per ton of coal vary considerably depending on the coal's composition of carbon, hydrogen, sulfur, ash, oxygen, and nitrogen. While variability of carbon emissions on a mass basis can be considerable, carbon emissions per unit of energy (e.g., per Btu) vary less.

[33] Emission Inventory Improvement Program, Volume VIII: Chapter. 1. "Methods for Estimating Carbon Dioxide Emissions from Combustion of Fossil Fuels", August 2004. (ii) Emission Inventory Improvement Program, Volume VIII: Chapter. 2. "Methods for Estimating Methane and Nitrous Oxide Emissions from Stationary Combustion", August 2004.

- The carbon/energy ratio of different petroleum fractions generally correlates with API (American Petroleum Institute) gravity (Marland and Rotty 1984).[34] Lighter fractions (e.g., gasoline) usually have less carbon per unit energy than heavier fractions (e.g., residual fuel oil).
- Natural gas is a mixture of several gases, and the carbon content depends on the relative proportions of methane, ethane, propane, other hydrocarbons, CO_2, and other gases, which vary from one gas production site to another.

The carbon contents of fuels used in the 2006 base year are listed in Table 3-1 below.

Table 3-1: Carbon Content of Fuels

Fuel	2006 Carbon Content (lb C/MBTU)
Asphalt and Road Oil	45.4
Aviation Gasoline	41.6
Distillate Fuel	43.9
Jet Fuel, Kerosene	42.63
Jet Fuel, Naphtha	43.5
Kerosene	43.4
LPG (industrial)	37.45
LPG (energy only)	37.91
Lubricants	44.6
Motor Gasoline	45.62
Residual Fuel	47.3
Misc. Petro Products	44.82
Feedstocks, Naphtha	40.0
Feedstocks, Other Oils	43.9
Pentanes Plus	40.2
Petroleum Coke	61.3
Still Gas	38.6
Special Naphthas	43.7
Unfinished Oils	44.82

[34] Variations in petroleum are most often expressed in terms of specific gravity at 15 degrees Celsius. The API gravity, where API gravity = 141.5/specific gravity – 131.5, is an indication of the molecular size, carbon/hydrogen ratio, and hence carbon content of a crude oil.

Fuel	2006 Carbon Content (lb C/MBTU)
Waxes	43.6
Residential Coal	56.79
Commercial Coal	56.79
Industrial Coking Coal	56.20
Industrial Other Coal	56.85
Electric Power Coal	55.8
Natural Gas	31.9
Aviation Gasoline Blending Components	41.6
Motor Gasoline Blending Components	42.62
Crude Oil	20.33

Non-Energy Use Storage Factors

The final type of data needed in the worksheet is the percent of carbon in each fuel that is stored from non-energy uses. Many fossil fuels have potential non-energy uses. For example, LPG is used for production of solvents and synthetic rubber; oil is used to produce asphalt, naphthas, and lubricants; and coal is used to produce coke, yielding crude light oil and crude tar as by-products that are used in the chemical industry.

However, not all non-energy uses of fossil fuels result in carbon storage. For example, the carbon from natural gas used in ammonia production is oxidized quickly; many products from the chemical and refining industries are burned or decompose within a few years; and the carbon in coke is oxidized when the coke is used. The SIT module provides national default values for storage factors. The national defaults were used as Maryland state-level fractions and are presented below:

Table 3-2: Non-Energy Use Storage Factors

Fuel	2006 Storage Factor Used
Asphalt and Road Oil	100%
Distillate Fuel	50%
LPG	70%
Lubricants	9%
Residual Fuel	50%
Feedstocks, Naphtha	98%
Feedstocks, Other Oils	72%

Fuel	2006 Storage Factor Used
Misc. Petro Products	0%
Pentanes Plus	75%
Petroleum Coke	50%
Still Gas	80%
Special Naphthas	0%
Waxes	58%
Industrial Coking Coal	10%
Natural Gas	5%

3.3.1 Carbon Dioxide (CO2) Direct Emissions

CO_2 emissions for fossil fuel combustion in the residential and commercial sectors were calculated by multiplying energy consumption in these sectors by carbon content coefficients for each fuel. These quantities are then multiplied by fuel-specific percentages of carbon oxidized during combustion (a measure of combustion efficiency). The resulting fuel emission values, in pounds of carbon, are then converted to $MMTCO_2e$.

Industrial sector CO_2 emissions are calculated in the same way, except emissions from fossil fuels not used for energy production are factored separately. In accordance with the EIIP guidelines, non-energy sector consumption of fossil fuel is first subtracted from total fuels, and then multiplied by carbon storage factors for each fuel type. This is necessary because a portion of the fossil fuel is used for non-energy uses and can be sequestered (stored) for a significant period of time (e.g., more than 20 years). For example, LPG is used for the production of solvents and synthetic rubber, and oil is used to produce asphalt, napthas, and lubricants. The carbon that is stored is assumed to remain unoxidized for long periods of time, meaning that the carbon is not converted to CO_2. After the portion of stored carbon is subtracted, the resulting (net) combustible consumption for each fuel is then used to calculate industrial sector emissions.

3.3.1.1 Residential Fossil Fuel Combustion

Emissions associated with the residential fossil fuel combustion sector was estimated using default data used in SIT from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data (SED)*[35]; containing annual amount of coal, oil, natural gas and other fuel types in Billion Btu consumed by each sector.

[35] Energy Information Administration (EIA), State Energy Data, http://www.eia.doe.gov/emeu/states/state.html?q_state_a=MD&q_state=MARYLAND

The general equation used for converting residential energy consumption to $MMTCO_2e$ is as follows:

$$\text{Emissions (MMTCO2E)} = \frac{\text{Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times \text{Combustion Efficiency (\%)} \times 0.90718 \times (44/12)}{1{,}000{,}000}$$

Where:

Consumption (BBtu)	=	total heat content of the applicable fuel consumed
Emission Factor	=	established factor per fuel type that converts total heat content of the fuel consumed to pounds of carbon
Combustion Efficiency (%)	=	percentage completeness of the combustion of the fuel.
0.90718	=	constant used to convert from short tons to metric tons.
0.0005	=	constant used to convert from pounds to short tons.
1,000,000	=	conversion factor converts metric tons to Million metric tons
44/12	=	conversion factor converts from carbon to carbon dioxide

3.3.1.2 Commercial Fossil Fuel Combustion

Emissions associated with the commercial fossil fuel combustion sector was estimated using default data used in SIT from the United States Department of Energy (US DOE) Energy Information Administration's (EIA) *State Energy Data (SED)*[36]; containing annual amount of coal, oil, natural gas and other fuel types in Billion Btu consumed by each sector.

The general equation used for converting commercial energy consumption to $MMTCO_2e$ is as follows:

$$\text{Emissions (MMTCO2E)} = \frac{\text{Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times \text{Combustion Efficiency (\%)} \times 0.90718 \times (44/12)}{1{,}000{,}000}$$

Where:

Consumption (BBtu)	=	total heat content of the applicable fuel consumed
Emission Factor	=	established factor per fuel type that converts total heat content of the fuel consumed to pounds of carbon
Combustion Efficiency (%)	=	percentage completeness of the combustion of the fuel.
0.90718	=	constant used to convert from short tons to metric tons.
0.0005	=	constant used to convert from pounds to short tons.
1,000,000	=	conversion factor converts metric tons to Million metric tons
44/12	=	conversion factor converts from carbon to carbon dioxide

3.3.1.3 Industrial Fossil Fuel Combustion

Emissions associated with the industrial fossil fuel combustion sector was estimated using default data used in SIT from the United States Department of Energy (US DOE) Energy Information

[36] Energy Information Administration (EIA), State Energy Data, http://www.eia.doe.gov/emeu/states/state.html?q_state_a=MD&q_state=MARYLAND

Administration's (EIA) *State Energy Data (SED)*[37]; containing annual amount of coal, oil, natural gas and other fuel types in Billion Btu consumed by each sector.

The general equations used for converting industrial energy consumption to $MMTCO_2e$ are as follows:

$$\text{Net Consumption (BBtu)} = [\text{Total Consumption (BBtu)} - \text{Non-Energy Consumption (BBtu)}] \times \text{Storage Factor (\%)}$$

$$\text{Emissions (MMTCO2E)} = \frac{\text{Net Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times \text{Combustion Efficiency (\%)} \times 0.90718 \times (44/12)}{1{,}000{,}000}$$

Where:

Total Consumption (BBtu)	=	total heat content of the applicable fuel consumed
Non-Energy Consumption (BBtu)	=	Non-energy use of the fuel type
Storage Factor (%)	=	Non-energy use storage factor
Net Consumption (BBtu)	=	total heat content of the applicable fuel consumed
Emission Factor	=	established factor per fuel type that converts total heat content of the fuel consumed to pounds of carbon
Combustion Efficiency (%)	=	percentage completeness of the combustion of the fuel.
0.90718	=	constant used to convert from short tons to metric tons.
0.0005	=	constant used to convert from pounds to short tons.
1,000,000	=	conversion factor converts metric tons to Million metric tons
44/12	=	conversion factor converts from carbon to carbon dioxide

Emission estimates from wood combustion include only N_2O and CH_4. Carbon dioxide emissions from biomass combustion are assumed to be "net zero", consistent with U.S. EPA and 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.

3.3.2 Additional Direct Emissions (CH_4 and N_2O)

CH_4 and N_2O Emissions from RCI

Similar to CO_2 emission estimation, CH_4 and N_2O emission from the RCI sector were calculated by multiplying the State's energy consumption (in BBtu) by the default EPA –SIT emissions factors and the resulting emission in metric tons was then multiply by the global warming potential (GWP) of the respective pollutants. (CH_4 =21, N_2O =310).

Table 3-3: General CH_4/N_2O Emissions Equation.

Fuel Type	Consumption (Billion Btu)	X	Emission Factor (metric tons CH_4 /BBtu)	=	CH_4 /N_2O Emissions (metric tons)	x	GWP	=	Emissions ($MMTCO_2E$)

[37] Energy Information Administration (EIA), State Energy Data, http://www.eia.doe.gov/emeu/states/state.html?q_state_a=MD&q_state=MARYLAND

3.4 GREENHOUSE GAS INVENTORY RESULTS

3.4.1 Residential Fossil Fuel Combustion Results

Table 3-4: 2006 Residential Sector CO_2 Emissions by Fuel Type

Fuel Type	Consumption (Billion Btu)	Emission Factor (lbs C/Million Btu)	Combustion Efficiency (%)	Emissions (short tons carbon)	Emissions ($MMTCO_2E$)
Coal	94	56.79	100.0%	2,671.70	0.0089
Distillate Fuel	19,719	43.94	100.0%	433,253.20	1.4412
Kerosene	2,477	43.44	100.0%	53,804.95	0.1790
LPG	6,645	37.91	100.0%	125,950.01	0.4190
Natural Gas	73,811	31.87	100.0%	1,176,266.15	3.9127
				Total	**5.9607**

Table 3-5: 2006 Residential Sector CH_4 Emissions by Fuel Type

Fuel Type	Consumption (Billion Btu)	Emission Factor (metric tons CH_4 /BBtu)	Emissions (metric tons CH_4)	GWP	Emissions ($MMTCO_2E$)
Coal	94	0.30069	28.291	21	0.0006
Distillate Fuel	19,719	0.01002	197.644	21	0.0042
Kerosene	2,477	0.01002	24.831	21	0.0005
LPG	6,645	0.01002	66.607	21	0.0014
Natural Gas	73,811	0.00475	350.438	21	0.0074
Wood	6,903	0.28487	1,966.454	21	0.0413
				Total	**0.0553**

Table 3-6: 2006 Residential Sector N_2O Emissions by Fuel Type

Fuel Type	Consumption (Billion Btu)	Emission Factor (metric tons N_2O/BBtu)	Emissions (metric tons N_2O)	GWP	Emissions $MMTCO_2E$)
Coal	94	0.00150	0.1415	310	0.0000
Distillate Fuel	19,719	0.00060	11.8586	310	0.0037
Kerosene	2,477	0.00060	1.4899	310	0.0005
LPG	6,645	0.00060	3.9964	310	0.0012
Natural Gas	73,811	0.00009	7.0088	310	0.0022
Wood	6,903	0.00380	26.2194	310	0.0081
				Total	**0.0157**

3.4.2 Commercial Fossil Fuel Combustion Results

Table 3-7: 2006 Commercial Sector CO_2 Emissions by Fuel Type

Fuel Type	Consumption (Billion Btu)	Emission Factor (lbs C/Million Btu)	Combustion Efficiency (%)	Emissions (short tons carbon)	Emissions ($MMTCO_2E$)
Coal	951	56.79	100.0%	27,013.87	0.0899
Distillate Fuel	10,494	43.94	100.0%	230,565.76	0.7670
Kerosene	353	43.44	100.0%	7,676.42	0.0255
LPG	1,173	37.91	100.0%	22,226.47	0.0739
Motor Gasoline	171	42.62	100.0%	3,642.41	0.0121
Residual Fuel	302	47.33	100.0%	7,136.37	0.0237
Natural Gas	65,041	31.87	100.0%	1,036,500.61	3.4478
				Total	**4.4400**

Table 3-8: 2006 Commercial Sector CH_4 Emissions by Fuel Type

Fuel Type	Consumption (Billion Btu)	Emission Factor (metric tons CH_4 /BBtu)	Emissions (metric tons CH_4)	GWP	Emissions ($MMTCO_2E$)
Coal	951	0.01002	9.54	21	0.00020024
Distillate Fuel	10,494	0.01002	105.18	21	0.0022088
Kerosene	353	0.01002	3.54	21	7.4397E-05
LPG	1,173	0.01002	11.75	21	0.00024684
Motor Gasoline	178	0.01002	1.79	21	3.7507E-05
Residual Fuel	302	0.01002	3.02	21	6.3467E-05
Natural Gas	65,041	0.00475	308.80	21	0.00648476
Wood	2,101	0.28487	598.56	21	0.01256972
				Total	**0.0218**

Table 3-9: 2006 Commercial Sector N_2O Emissions by Fuel Type

Fuel Type	Consumption (Billion Btu)	Emission Factor (metric tons N_2O/BBtu)	Emissions (metric tons N_2O)	GWP	Emissions ($MMTCO_2E$)
Coal	951	0.00150	1.430	310	0.0004
Distillate Fuel	10,494	0.00060	6.311	310	0.0020
Kerosene	353	0.00060	0.213	310	0.0001
LPG	1,173	0.00060	0.705	310	0.0002
Motor Gasoline	178	0.00060	0.107	310	0.0000
Residual Fuel	302	0.00060	0.181	310	0.0001
Natural Gas	65,041	0.00009	6.176	310	0.0019
Wood	2,101	0.00380	7.981	310	0.0025
				Total	**0.0072**

3.4.3 Industrial Fossil Fuel Combustion Results

Table 3-10: 2006 Industrial Sector CO_2 Emissions by Fuel Type

Fuel Type	Total Consumption (Billion Btu)	Non-Energy Consumption (Billion Btu)	Storage Factor (%)	Net combustible Consumption (Billion Btu)	Emission Factor (lbs C/Million Btu)	Combustion Efficiency (%)	Emissions (short tons carbon)	Emissions ($MMTCO_2E$)
Coking Coal	-	-	10%	-	56.20	100.0%	-	-
Other Coal	30,431	307	0%	30,431	56.85	100.0%	865,033.23	2.8774
Asphalt and Road Oil	19,576	19,576	100%	-	45.42	100.0%	-	-
Aviation Gasoline Blending Components	-	-	0%	-	41.56	100.0%	-	-
Crude Oil	-	-	0%	-	44.82	100.0%	-	-
Distillate Fuel	12,446	119	50%	12,387	43.94	100.0%	272,151.82	0.9053
Feedstocks, Naphtha less than 401 F	726	715	62%	283	39.96	100.0%	5,659.86	0.0188
Feedstocks, Other Oils greater than 401 F	913	661	62%	503	43.94	100.0%	11,059.28	0.0368
Kerosene	172	-	0%	172	43.44	100.0%	3,740.84	0.0124
LPG	3,241	2,264	62%	1,839	37.45	100.0%	34,445.56	0.1146
Lubricants	2,154	2,154	9%	1,955	44.58	100.0%	43,581.08	0.1450
Motor Gasoline	5,174	-	0%	5,174	42.62	100.0%	110,269.38	0.3668
Motor Gasoline Blending Components	-	-	0%	-	42.62	100.0%	-	-
Misc. Petro Products	157	157	0%	157	44.82	100.0%	3,520.25	0.0117
Petroleum Coke	-	-	50%	-	61.34	100.0%	-	-
Pentanes Plus	162	122	62%	86	40.18	100.0%	1,731.75	0.0058
Residual Fuel	4,767	-	50%	4,767	47.33	100.0%	112,820.31	0.3753
Still Gas	-	-	80%	-	38.57	100.0%	-	-
Special Naphtha	3,077	3,034	0%	3,077	43.74	100.0%	67,299.59	0.2239
Unfinished Oils	-	-	0%	-	44.82	100.0%	-	-
Waxes	241	241	58%	101	43.63	100.0%	2,209.92	0.0074
Natural Gas	23,811	1,280	62%	23,018	31.87	100.0%	366,824.56	1.2202
						Total	1,900,347.42	**6.3213**

Table 3-11: 2006 Industrial Sector CH_4 Emissions by Fuel Type

Fuel Type	Total Consumption (Billion Btu)	Non-Energy Consumption (Billion Btu)	Emission Factor (metric tons CH_4 /BBtu)	Emissions (metric tons CH_4)	GWP	Emissions ($MMTCO_2E$)
Coking Coal	-	-	0.01002	-	21	-
Other Coal	30,431	307	0.01002	301.9279	21	0.0063
Asphalt and Road Oil	19,576	19,576	0.00301	-	21	-
Aviation Gasoline Blending Components	-	-	0.00301	-	21	-
Crude Oil	-	-	0.00301	-	21	-
Distillate Fuel	12,446	119	0.00301	37.0669	21	0.0008
Feedstocks, Naphtha less than 401 F	726	715	0.00301	0.0330	21	0.0000
Feedstocks, Other Oils greater than 401 F	913	661	0.00301	0.7561	21	0.0000
Kerosene	172	-	0.00301	0.5179	21	0.0000
LPG	3,241	2,264	0.00301	2.9387	21	0.0001
Lubricants	2,154	2,154	0.00301	-	21	-
Motor Gasoline	5,395	-	0.00301	16.2213	21	0.0003
Motor Gasoline Blending Components	-	-	0.00301	-	21	-
Misc. Petro Products	157	157	0.00301	-	21	-
Petroleum Coke	-	-	0.00301	-	21	-
Pentanes Plus	162	122	0.00301	0.1195	21	0.0000
Residual Fuel	4,767	-	0.00301	14.3337	21	0.0003
Still Gas	-	-	0.00301	-	21	-
Special Naphthas	3,077	3,034	0.00301	0.1276	21	0.0000
Unfinished Oils	-	-	0.00301	-	21	-
Waxes	241	241	0.00301	-	21	-
Natural Gas	23,811	1,280	0.00095	21.3944	21	0.0004
Wood	12,165	NA	0.02849	346.5487	21	0.0073
					Total	**0.0156**

Table 3-12: 2006 Industrial Sector N_2O Emissions by Fuel Type

Fuel Type	Total Consumption (Billion Btu)	Non-Energy Consumption (Billion Btu)	Emission Factor (metric tons N_2O/BBtu)	Emisssions (metric tons N_2O)	GWP	Emissions ($MMTCO_2E$)
Coking Coal	-	-	0.00150	-	310	-
Other Coal	30,431	307	0.00150	45.289	310	0.0140
Asphalt and Road Oil	19,576	19,576	0.00060	-	310	-
Aviation Gasoline Blending Components	-	-	0.00060	-	310	-
Crude Oil	-	-	0.00060	-	310	-
Distillate Fuel	12,446	119	0.00060	7.413	310	0.0023
Feedstocks, Naphtha less than 401 F	726	715	0.00060	0.007	310	0.0000
Feedstocks, Other Oils greater than 401 F	913	661	0.00060	0.151	310	0.0000
Kerosene	172	-	0.00060	0.104	310	0.0000
LPG	3,241	2,264	0.00060	0.588	310	0.0002
Lubricants	2,154	2,154	0.00060	-	310	-
Motor Gasoline	5,395	-	0.00060	3.244	310	0.0010
Motor Gasoline Blending Components	-	-	0.00060	-	310	-
Misc. Petro Products	157	157	0.00060	-	310	-
Petroleum Coke	-	-	0.00060	-	310	-
Pentanes Plus	162	122	0.00060	0.024	310	0.0000
Residual Fuel	4,767	-	0.00060	2.867	310	0.0009
Still Gas	-	-	0.00060	-	310	-
Special Naphthas	3,077	3,034	0.00060	0.026	310	0.0000
Unfinished Oils	-	-	0.00060	-	310	-
Waxes	241	241	0.00060	-	310	-
Natural Gas	23,811	1,280	0.00009	2.139	310	0.0007
Wood	12,165	NA	0.00380	46.206	310	0.0143
					Total	0.0335

3.5 GREENHOUSE GAS FORECAST METHODOLOGY

The projected inventories are derived by applying the appropriate growth factors to the 2006 Base-Year Greenhouse Gas Emissions Inventory. The projected inventories were required to be a business-as-usual forecast and thus were not to take into account any control/reduction programs. EPA guidance describes four typical indicators of growth. In order of priority, these are product output, value added, earnings, and employment. Surrogate indicators of activity, for example population growth, are also acceptable methods.

Surrogate growth factors for future years were applied to the 2006 base year inventory. These surrogates were calculated using population, household, and employment data. Dividing the state population, household, and employment forecasts for the analysis year by the 2006 value produced the growth factors for the projection years. The growth factors were applied to emissions categories.

MDE applied Maryland-specific annual growth rates developed from forecasted future growth to the base year emission .The projection of emissions from direct fuel combustion in the RCI sector were based on surrogates designed to forecast business-as-usual fuel consumption and were developed by MDE based on a two step process:

- Developing the appropriate state specific growth factors to be applied to the base year inventory.
- Applying the growth factors to develop emissions forecasts.

Each source category was matched to an appropriate growth surrogate based on an activity that reflected the base-year emission estimates. Surrogates were chosen as follows:

3.5.1 Residential Fuel Combustion

Household data was chosen as the growth surrogate for all fuels in the residential fuel combustion sector. Projected county level housing data was collected from the Baltimore Metropolitan Council Cooperative Forecast (Round 7-B), Metropolitan Council of Governments Forecast (Round 7.2A), and Maryland Department of Planning, Planning Data Services (February, 2009). The data was compiled to provide an overall State of Maryland housing forecast.

3.5.2 Commercial Fuel Combustion

Employment data was chosen as the growth surrogate (NAICS 237: reflecting the heavy construction sector) for the commercial fuel combustion sector. Actual (2006) and projected state-level employment data was collected from the Maryland Department of Labor and were based on the North American Industry Classification System (NAICS).

3.5.3 Industrial Fuel Combustion

Production of cement was chosen as the growth surrogate in the industrial coal fuel combustion sector. Cement production was chosen because most of the industrial coal combusted in Maryland occurs in the cement industry. Actual cement production data was collected from the Maryland

State Archives[38]. Cement projection forecasts were calculated using the FORECAST methodology in Microsoft Excel. The FORECAST methodology uses the sum of least squares to project data.

Employment data was chosen as the growth surrogate (NAICS 237: reflecting the heavy construction sector) for the commercial fuel combustion sector. Actual (2006) and projected state-level employment data was collected from the Maryland Department of Labor and were based on the North American Industry Classification System (NAICS).

Table 3-13: Growth Factors for the R/C/I Fossil Fuel Combustion Source Sector

Year	Surrogate	Growth Factor from 2006	Surrogate	Growth Factor from 2006	Surrogate	Growth Factor from 2006	Surrogate	Growth Factor from 2006
2007	Cement	0.953819	Housing	1.009925	Employment - Manufacturing	0.987765	Employment - Heavy Construction	1.006916
2008	Cement	0.988949	Housing	1.01985	Employment - Manufacturing	0.97553	Employment - Heavy Construction	1.013833
2009	Cement	1.024079	Housing	1.029775	Employment - Manufacturing	0.963295	Employment - Heavy Construction	1.020749
2010	Cement	1.059209	Housing	1.0397	Employment - Manufacturing	0.95106	Employment - Heavy Construction	1.027666
2011	Cement	1.09434	Housing	1.052053	Employment - Manufacturing	0.938825	Employment - Heavy Construction	1.034582
2012	Cement	1.12947	Housing	1.064406	Employment - Manufacturing	0.92659	Employment - Heavy Construction	1.041499
2013	Cement	1.1646	Housing	1.076759	Employment - Manufacturing	0.914355	Employment - Heavy Construction	1.048415
2014	Cement	1.19973	Housing	1.089111	Employment - Manufacturing	0.902119	Employment - Heavy Construction	1.055331
2015	Cement	1.234861	Housing	1.101464	Employment - Manufacturing	0.889884	Employment - Heavy Construction	1.062248
2016	Cement	1.269991	Housing	1.112166	Employment - Manufacturing	0.877649	Employment - Heavy Construction	1.069164
2017	Cement	1.305121	Housing	1.122869	Employment - Manufacturing	0.865414	Employment - Heavy Construction	1.076081
2018	Cement	1.340252	Housing	1.133571	Employment - Manufacturing	0.853179	Employment - Heavy Construction	1.082997

[38] http://www.msa.md.gov/msa/mdmanual/01glance/html/mineral.html

2019	Cement	1.375382	Housing	1.144273	Employment - Manufacturing	0.840944	Employment - Heavy Construction	1.089914
2020	Cement	1.410512	Housing	1.154975	Employment - Manufacturing	0.828709	Employment - Heavy Construction	1.09683

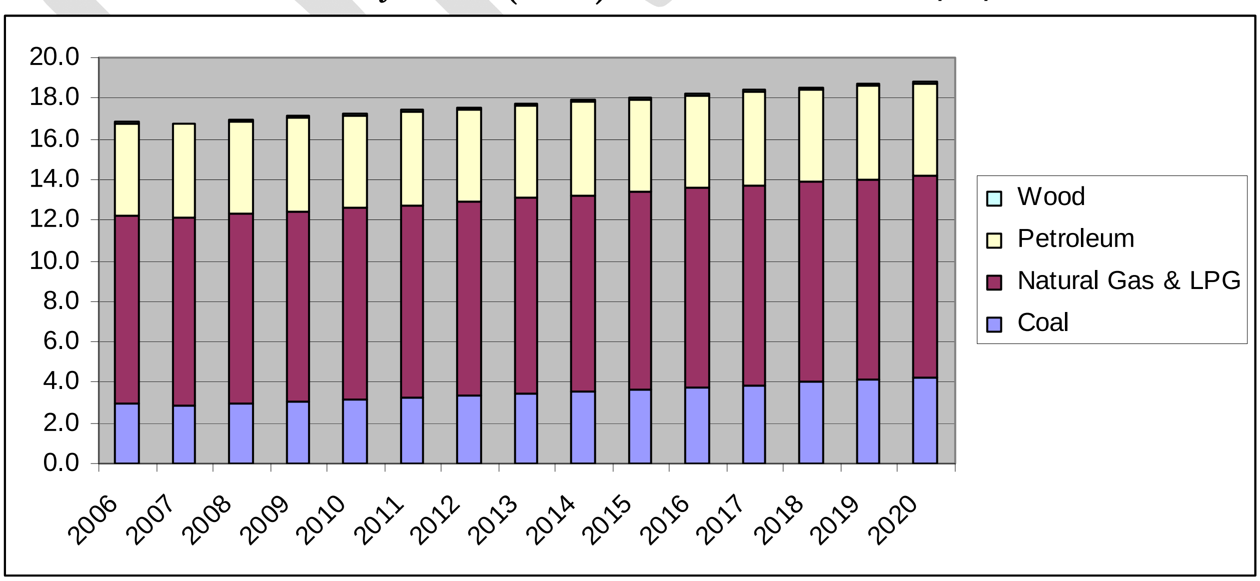
3.6 GREENHOUSE GAS FORECAST RESULTS

The following section provides an overview of the results obtained after applying the projection methodological approach described above. The projected inventories were required to be a business-as-usual forecast and thus were not to take into account any control/reduction programs.

Table 3-14: Projected (BAU) Emissions in the R/C/I Sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Residential/ Commercial/ Industrial (RCI) Fuel Use	16.87	16.79	16.94	17.09	17.24	17.41	17.57	17.74	17.90	18.07	18.22	18.38	18.53	18.69	18.84
Coal	2.998	2.865	2.967	3.070	3.172	3.275	3.377	3.480	3.582	3.685	3.787	3.890	3.993	4.095	4.198
Natural Gas & LPG	9.210	9.262	9.313	9.364	9.415	9.477	9.539	9.600	9.662	9.724	9.778	9.833	9.887	9.942	9.997
Petroleum	4.577	4.581	4.577	4.573	4.569	4.569	4.570	4.570	4.570	4.570	4.567	4.564	4.562	4.559	4.557
Wood	0.086	0.086	0.087	0.087	0.087	0.088	0.088	0.089	0.089	0.090	0.090	0.090	0.091	0.091	0.091

FIGURE 3.1: PROJECTED (BAU) EMISSIONS IN THE R/C/I SECTOR



4.0 Transportation On-Road Mobile Energy Use

4.1 OVERVIEW

This technical analysis report documents the methodology and assumptions used to produce the greenhouse gas (GHG) inventory for Maryland's on-road portion of the transportation sector. Statewide emissions have been estimated for a 2006 baseline and a 2020 forecast business-as-usual (BAU) scenario. The inventory was calculated by estimating emissions for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Those emissions were then converted to carbon dioxide equivalents that are measured in the units of million metric tons (mmt CO_2e). Carbon dioxide represents about 97 percent of the transportation sector's GHG emissions.

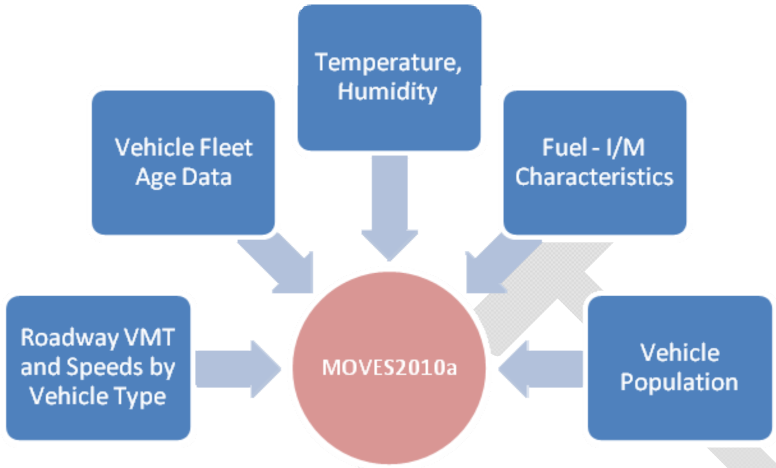
The on-road portion of the inventory was developed using EPA's new emissions model MOVES (Motor Vehicle Emissions Simulator). The inventory results represent an update of previous analyses conducted by the Center for Climate Strategies (CCS) for the Climate Action Plan (CAP) in 2008 and MDOT's November 2009 Draft Implementation Plan. Those inventory efforts were performed with EPA's MOBILE6.2 emission factor model. The MOVES model provides a more robust estimate of greenhouse gas emissions as compared to the simplified approaches used in MOBILE6.2. In MOVES, greenhouse gases are calculated from vehicle energy consumption rates and vary by vehicle operating characteristics including speed. In addition, the MOVES model includes the affects of current legislation on future vehicle fuel economy standards.

4.2 GREENHOUSE GAS INVENTORY METHODOLOGY

The data, tools and methodologies employed to conduct the on-road vehicle GHG emissions inventory were developed in close consultation with MDE and are consistent with the *Technical Guidance on the Use of MOVES2010 for Emission Inventory Preparation in State Implementation Plans and Transportation Conformity, EPA-420-B-10-023, April 2010*. EPA's MOVES model was officially released on March 2, 2010 and was followed with a revised version (MOVES2010a) in August 2010. The MOVES2010a version incorporates new car and light truck greenhouse gas emissions standards for model years 2012-2016 and updates effects of corporate average fuel economy standards for model years 2008-2011. The MOVES2010a model estimates the reductions in greenhouse gases associated with those standards in future calendar years.

As illustrated in Figure A.1, the MOVES2010a model has been integrated with local traffic, vehicle fleet, environmental, fuel, and control strategy data to estimate statewide emissions.

Figure 4.1 Emission Calculation Data Process



The modeling assumptions and data sources were developed in coordination with MDE and are consistent with other SIP-related inventory efforts. The process represents a "bottom-up" approach to estimating statewide GHG emissions based on available roadway and traffic data. A "bottom-up" approach provides several advantages over simplified "top-down" calculations using statewide fuel consumption. These include:

- Addresses potential issues related to the location of purchased fuel. Vehicle trips with trip ends outside of the state (e.g. including "thru" traffic) create complications in estimating GHG emissions. For example, commuters living in Maryland may purchase fuel there but may spend much of their traveling in Washington D.C. The opposite case may include commuters from Pennsylvania working in Maryland. With a "bottom-up" approach emissions are calculated for all vehicles using the transportation system.
- Allows for a more robust forecasting process based on historic trends of VMT or regional population and employment forecasts and their relationship to future travel. For example, traffic data can be forecasted using growth assumptions determined by the MPO through their analytic (travel model) and interagency consultation processes.

GHG emission values are reported as annual numbers for the 2006 baseline and 2020 BAU scenarios. The annual values were calculated based on 12 monthly MOVES runs as summarized in Figure A.2. Each monthly run used traffic volumes, speeds, temperatures and fuel values specific to an average day in each month.

Figure 4.2 Calculation of Annual Emissions

For the 2006 and 2020 BAU emissions inventory, the traffic data was based on roadway segment data obtained from the Maryland State Highway Administration (SHA). This data does not contain information on congested speeds and the hourly detail needed by MOVES. As a result, post processing software (PPSUITE) was used to calculate hourly congested speeds for each roadway link, apply vehicle type fractions, aggregate VMT and VHT, and prepare MOVES traffic-related input files. The PPSUITE software and process methodologies are consistent with that used for regional inventories and transportation conformity analyses throughout Maryland.

Other key inputs including vehicle population, temperatures, fuel characteristics and vehicle age were obtained from and/or prepared in close coordination with MDE staff. The following sections summarize the key input data assumptions used for the inventory runs.

4.3 DATA SOURCES

A summary of key input data sources and assumptions are provided in Table 4.1. Many of these data inputs are consistent to those used SIP inventories and conformity analyses. There are several data items that require additional notes.

Traffic volumes and VMT are forecasted for the 2020 BAU analysis. A discussion of forecasted traffic volumes and vehicle miles of travel (VMT) is discussed in more detail in the following section.

Vehicle population is a key input that has an important impact on start and evaporative emissions. At the time of this study, final decisions (per MDE consultation) had not been made on the use of Maryland registration data as a surrogate for vehicle population. In urban areas, registration data can over-estimate the actual number of daily vehicle trips due to high transit usage. As a result, for this study, vehicle population was calculated from VMT using MOVES default estimates for the typical miles per vehicle by source type (e.g. vehicle type). The PPSUITE post processor automatically prepares the vehicle population file under this method. This alternative was determined to be acceptable for this inventory, especially considering that start and evaporative emissions are much lower for CO_2 as compared to other pollutants.

The vehicle mixes is another important file that is used to disaggregate total vehicle volumes and VMT to the 13 MOVES source types. MDE is still reviewing options to prepare these data input assumptions. For this inventory, the vehicle mix was calculated based on 2008 SHA vehicle type pattern percentages by functional class, which disaggregates volumes to four vehicle types: light-duty vehicles, heavy-duty vehicles, buses, and motorcycles. As illustrated in Figure A.3, the four vehicle groups were related to EPA's MOBILE6.2 weight-based vehicle categories. EPA's MOVES Technical Guidance was then used to convert the MOBILE6.2 categories to the MOVES source types.

FIGURE 4.3 DEFINING VEHICLE TYPES

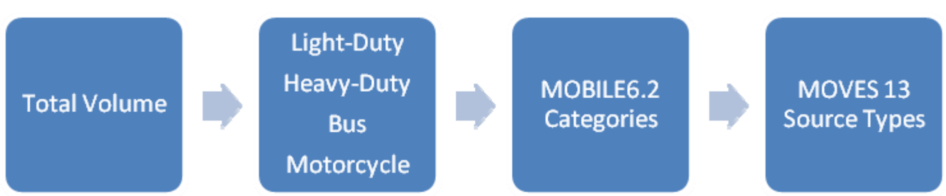


Table 4.1 Summary of Key Data Sources

Data Item	Source	Description	Difference between 2006 and 2020BAU
Roadway Characteristics	2008 Maryland State Highway Administration (SHA) Universal Database	Includes lanes, segment distance, facility type, speed limit	*Same Data Source*
Traffic Volumes	2008 Maryland State Highway Administration (SHA) Universal Database	Average Annual Daily Traffic Volumes (AADT)	Volumes forecasted for 2020 BAU
Seasonal Adjustments	SHA 2008 *ATR Station Reports in the Traffic Trends System Report Module* from the SHA website	Adjust AADT to average day in each month	*Same Data Source*
VMT	Highway Performance Monitoring System 2006	Used to adjust VMT to the reported 2006 HPMS totals by county and functional Class	VMT forecasted for 2020 BAU
Hourly Patterns	SHA 2008 *Traffic Trends System Report Module* from the SHA website	Used to disaggregated volumes and VMT to each hour of the day	*Same Data Source*
Vehicle Type Mix	2008 SHA vehicle pattern data; MOVES Technical Guidance	Used to split traffic volumes to the 13 MOVES vehicle source types	*Same Data Source*
Ramp Fractions	MOVES Defaults	MOVES Defaults	*Same Data Source*
Vehicle Ages	2008 Maryland Registration data	Provides the percentage of vehicles my each model year age	*Same Data Source*
Hourly Speeds	Calculated by PPSUITE Post Processor	Hourly speed distribution file used by MOVES to estimate emission factors	Higher volumes produce lower speeds in 2020 BAU
I/M Data	Provided by MDE	Based on 2006 and current I/M program	Different I/M Program Characteristics
Fuel Characteristics	Provided by MDE	Fuel characteristics vary from 2006-2012 then constant to 2020	Different Fuel Characteristics
Temperatures	Provided by MDE	Average Monthly Temperature sets	*Same Data Source*
Vehicle Population	Calculated by PPSUITE Post Processor; MOVES Default Miles/Vehicle Data	Vehicle population calculated by PPSUITE from VMT using MOVES Default miles/vehicle estimates	2020 BAU based on VMT growth

4.3.1 Traffic Volume and VMT Forecasts

The traffic volumes and VMT within the SHA traffic database were forecast to estimate future year emissions. Several alternatives are available to determine forecast growth rates, ranging from historical VMT trends to the use of MPO-based travel models that include forecast demographics for distinct areas in each county.

For the 2020 BAU scenario, the forecasts were determined using assumptions from the original Maryland CAP, which was based on historic trends of 1990-2006 HPMS VMT growth. Table 4.2 summarizes the growth rates by county. The average statewide annualized growth rate was assumed to be 1.8%. Table 4.3 summarizes total 2006 baseline and 2020 forecast VMT by vehicle type.

Table 4.2 VMT Annual Growth Rates (Per Maryland CAP) for 2020 BAU

County	Annualized 2006-2020 Growth
Allegany	1.3%
Anne Arundel	2.0%
Baltimore	1.3%
Calvert	2.5%
Caroline	1.3%
Carroll	1.9%
Cecil	2.4%
Charles	2.2%
Dorchester	0.9%
Frederick	2.5%
Garrett	1.4%
Harford	1.8%
Howard	3.2%
Kent	0.5%
Montgomery	1.5%
Prince George's	1.7%
Queen Anne's	2.2%
Saint Mary's	2.0%
Somerset	0.9%
Talbot	1.8%
Washington	2.1%
Wicomico	1.5%
Worcester	1.3%
Baltimore City	0.8%
Statewide	***1.8%***

Table 4.3 2006 Baseline and 2020 BAU VMT by Vehicle Type

Annual VMT	2006 Baseline (Millions)	2020 BAU (Millions)
Light Duty	51,212	63,878
Medium/Heavy Duty Truck & Bus	5,406	6,775
Total VMT	***56,618***	***70,653***

The analysis process (e.g. using PPSUITE post processor) re-calculates roadway speeds based on the forecast volumes. As a result, future year emissions are sensitive to the impact of increasing traffic growth on regional congestion.

4.3.2 Vehicle Technology Adjustments

The MOVES2010a emission model includes the effects of the following post-2006 vehicle programs on future vehicle emission factors:

- *CAFÉ Standards (Model Years 2008-2011)* – Vehicle model years through 2011 are covered under existing CAFE standards that will remain intact under the Obama Administration's national program.
- *National Program (Model Years 2012-2016)* – The light-duty vehicle fuel economy for model years between 2012 and 2016 are based on the May 7, 2010 Rule "*Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule*" *(EPA-HQ-OAR-2009-0472-11424:http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2009-0472-11424)*. Fuel economy improvements begin in 2012 until an average 250 gram/mile CO_2 standard is met in year 2016. This equates to an average fuel economy near 35 mpg.

The above technology programs were not included in the 2020 BAU, as they are included as credits applied to BAU emissions. To remove the potential emission credits of both of these programs, the MOVES2010a default database was revised. Fuel economy assumptions within MOVES2010a are provided as vehicle energy consumption rates within the "EmissionRates" table as illustrated in Figure A.4.

FIGURE 4.4 MOVES DEFAULT "EMISSIONRATE" TABLE

sourceBinID	polProcessID	opModeID	meanBaseRate	meanBaseRate...	meanBaseRateIM	meanBaseRate...	dataSourceId
1010146900000000000	601	300	0.814636	NULL	0.814636	NULL	406
1010147900000000000	601	300	0.814636	NULL	0.814636	NULL	406
1010146900000000000	602	100	0.294065	NULL	0.294065	NULL	406
1010147900000000000	602	100	0.294065	NULL	0.294065	NULL	406
1010146940000000000	601	300	0.814636	NULL	0.814636	NULL	406
1010147940000000000	601	300	0.814636	NULL	0.814636	NULL	406
1010146940000000000	602	100	0.294065	NULL	0.294065	NULL	406
1010147940000000000	602	100	0.294065	NULL	0.294065	NULL	406
1010146850000000000	601	300	0.517222	NULL	0.517222	NULL	406
1010146850000000000	602	100	0.186705	NULL	0.186705	NULL	406
1010146950000000000	601	300	0.814636	NULL	0.814636	NULL	406
1010147950000000000	601	300	0.814636	NULL	0.814636	NULL	406
1010146950000000000	602	100	0.294065	NULL	0.294065	NULL	406
1010147950000000000	602	100	0.294065	NULL	0.294065	NULL	406
1010146960000000000	601	300	1.55422	NULL	1.55422	NULL	406
1010147960000000000	601	300	1.55422	NULL	1.55422	NULL	406
1010146960000000000	602	100	0.56104	NULL	0.56104	NULL	406
1010147960000000000	602	100	0.56104	NULL	0.56104	NULL	406
1010146970000000000	601	300	1.66641	NULL	1.66641	NULL	406
1010147970000000000	601	300	1.66641	NULL	1.66641	NULL	406
1010146970000000000	602	100	0.601537	NULL	0.601537	NULL	406
1010147970000000000	602	100	0.601537	NULL	0.601537	NULL	406
1010146980000000000	601	300	1.69944	NULL	1.69944	NULL	406

To remove the benefits of the 2008-2011 CAFÉ standards and the 2012-2016 National Program, the database was revised so that all energy rates beyond 2007 were the same for each vehicle type, model year and fuel type. The table was updated per the following steps:

1. Open the "EmissionRate" table in the latest MOVES2010a default database (named: movesdb20100830). The fields to be modified include: *meanBaseRate* & *meanBaseRateIM* (values in both fields are the same)
2. Select records in the table that are related to energy consumption. This includes records with the polProcessID = 9101, 9102 and 9190.
3. Use the sourceBinID field to determine how each record correlates to vehicle type, model year and fuel type.
4. Modify meanBaseRate & meanBaseRateIM fields to be same for all model years beyond 2007 for each vehicle type, model year and fuel type.

4.4 GREENHOUSE GAS INVENTORY RESULTS

The 2006 emission results for the Maryland statewide GHG inventory are provided in Table 4.4. Within the table, emissions are also provided by fuel type and vehicle type.

4.4.1 Emission Estimates

Table 4.4 2006 Annual On-Road GHG Emissions (MMtCO2e)

	VMT (Millions)	CO2	CH4	N2O	CO2e
TOTAL	**56,618**	**29.101**	**0.047**	**0.521**	**29.67**
By Fuel Type					
Gasoline	52,720	23.195	0.0462	0.5183	23.76
Diesel	3,898	5.907	0.0003	0.0030	5.91
By MOVES Vehicle Type					
Motorcycle	319	0.120	0.0005	0.0004	0.12
Passenger Car	29,337	10.959	0.0178	0.1722	11.15
Passenger Truck	18,070	9.460	0.0202	0.2571	9.74
Light Commercial Truck	5,833	3.117	0.0067	0.0833	3.21
Intercity Bus	15	0.027	0.0000	0.0000	0.03
Transit Bus	40	0.052	0.0000	0.0000	0.05
School Bus	129	0.124	0.0002	0.0008	0.13
Refuse Truck	33	0.056	0.0000	0.0000	0.06
Single Unit Short-haul Truck	655	0.656	0.0008	0.0054	0.66
Single Unit Long-haul Truck	49	0.047	0.0000	0.0003	0.05
Motor Home	20	0.021	0.0000	0.0002	0.02
Combination Short-haul Truck	1,163	2.339	0.0001	0.0008	2.34
Combination Long-haul Truck	953	2.123	0.0001	0.0006	2.12

4.4.2 Fuel Consumption Estimates

The MOVES output energy rates can be converted to fuel consumption values using standard conversion rates for gasoline and diesel fuel. Table 4.5 provides the estimated 2006 and 2020BAU fuel consumption values. The 2006 values were compared to available information from FHWA and the Energy Information Administration (EIA). Differences result from the application of a "bottom-up" analysis approach and the issues discussed in section 4.2 of this report.

Table 4.5 2006 and 2020 BAU Fuel Consumption

Scenario	Fuel Type	MOVES2010a Output		Actual Statewide Fuel Sales[2] *(Thousand gallons)*
		Energy Consumption *(Trillion BTU)*	Estimated Fuel Consumption[1] *(Thousand Gallons)*	
2006	Gasoline	305.9	2,462,240	2,642,371
	Diesel	76.3	550,454	558,703
2020 BAU	Gasoline	402.3	3,237,943	-----
	Diesel	101.6	732,275	-----

[1] Assumes following conversion rates:

- 1BTU = 124,238 gallons of gasoline fuel
- 1BTU = 138,690 gallons of diesel fuel

[2] On-highway Gasoline Fuel Consumption:

- FHWA - Highway Statistics 2007: Highway use of motor fuel - 2006, Table MF-27
- http://www.fhwa.dot.gov/policy/ohim/hs06/motor_fuel.htm

On-highway Diesel Fuel Consumption:

- EIA - Sales of Distillate Fuel Oil by End Use - Maryland
- http://tonto.eia.doe.gov/dnav/pet/pet_cons_821dst_dcu_SMD_a.htm

4.5 GREENHOUSE GAS FORECAST METHODOLOGY

As stated in Section 4.3.1, the 2020 BAU forecast scenario was determined using assumptions from the original Maryland CAP, which was based on historic trends of 1990-2006 HPMS VMT growth. Table 4.2 summarizes the growth rates by county. The average statewide annualized growth rate was assumed to be 1.8%. Table 4.3 summarizes total 2006 baseline and 2020 forecast VMT by vehicle type.

For inventory years between 2006 and 2020, MDE linearly interpolated the CO2e emissions per fuel type. These interpolated emissions were used to develop growth factors per year.

4.6 GREENHOUSE GAS FORECAST RESULTS

The 2020 BAU emission results for the Maryland statewide GHG inventory are provided in Table 4.6. Within the table, emissions are provided by fuel type and vehicle type.

Table 4.6 2020 BAU Annual On-Road GHG Emissions (MMtCO2e)

	VMT (Millions)	CO2	CH4	N2O	CO2e
TOTAL	**70,653**	**38.360**	**0.048**	**0.186**	**38.59**
By Fuel Type					
Gasoline	65,686	30.502	0.0277	0.1815	30.71
Diesel	4,967	7.858	0.0201	0.0041	7.88
By MOVES Vehicle Type					
Motorcycle	402	0.155	0.0005	0.0006	0.16
Passenger Car	36537	14.247	0.0102	0.0744	14.33
Passenger Truck	22587	12.693	0.0137	0.0786	12.79
Light Commercial Truck	7295	4.177	0.0056	0.0268	4.21
Intercity Bus	18	0.033	0.0000	0.0000	0.03
Transit Bus	48	0.064	0.0001	0.0000	0.06
School Bus	155	0.155	0.0004	0.0004	0.16
Refuse Truck	45	0.077	0.0001	0.0000	0.08
Single Unit Short-haul Truck	805	0.852	0.0012	0.0024	0.86
Single Unit Long-haul Truck	75	0.075	0.0001	0.0002	0.08
Motor Home	27	0.029	0.0000	0.0001	0.03
Combination Short-haul Truck	1349	2.791	0.0016	0.0010	2.79
Combination Long-haul Truck	1309	3.013	0.0144	0.0010	3.03

5.0 Transportation Non-Road Mobile Energy Use

5.1 OVERVIEW

This section describes the data sources, key assumptions, and the methodology used to develop an inventory of greenhouse gas (GHG) emissions for the base year 2006 associated with Maryland's off-road transportation sector. It also describes the data sources, key assumptions, and methodology used to develop a forecast of GHG emissions over the 2007-2020 period, associated with Maryland transportation sector fossil fuel consumption. The primary GHGs produced by the transportation sector are carbon dioxide, methane and nitrous oxide.

Transportation GHGs are emitted largely as a result of energy combustion, with different levels of emissions associated with different fuels. Energy consumption, in turn, is a function of vehicle travel activity and vehicle fuel economy, which is determined based on vehicle stock (including vehicle type, size, and fuel type), speeds and other operating characteristics of vehicles (including idling), and levels of vehicle maintenance and care.

Sources of GHG emission in the non-road mobile transportation sector include modes of transportation, such as airplanes, trains and commercial marine vessels. Nonroad mobile sources also include motorized vehicles and equipment, which are normally not operated on public roadways. These include:

- Lawn and garden equipment.
- Agricultural or farm equipment
- Logging equipment
- Industrial equipment
- Construction equipment
- Airport service equipment
- Recreational land vehicles or equipment
- Recreational marine equipment
- Locomotives
- Commercial aviation
- Air taxis
- General aviation
- Military aviation
- Commercial Marine Vessels.

5.2 DATA SOURCES

- EIA's State Energy Data.
  http://www.eia.doe.gov/emeu/states/state.html?q_state_a=md&q_state=MARYLAND.

- US EPA State Greenhouse Gas Inventory Tool (SIT)
  http://www.epa.gov/statelocalclimate/resources/tool.html

- FHWA Highway Statistics
  http://www.fhwa.dot.gov/policy/ohim/hs06/index.htm.

- EIA, Fuel Oil and Kerosene Sales.
  http://tonto.eia.doe.gov/dnav/pet/pet_cons_top.asp.
  (Choose adjusted sales).

5.3 GREENHOUSE GAS INVENTORY METHODOLOGY

5.3.1 Carbon Dioxide (CO2) Direct Emissions

Carbon dioxide emissions generally are a direct product of fossil fuel combustion. The amount of CO_2 produced is a product of the amount of fuel combusted, the carbon content of the fuel, and the fraction of carbon that is oxidized when the fuel is combusted. Maryland transportation sector CO_2 emissions were estimated using methods developed by the EPA (and consistent with international guidelines on GHG emissions developed by the Intergovernmental Panel on Climate Change).

For fuel used for non-energy purposes (e.g. lubricants), the fuel quantity was multiplied by a storage factor and then subtracted from the carbon emissions, to avoid double-counting.

Maryland base year (2006) non-road mobile transportation sector CO_2 emissions were estimated based on data provided by EIA (State Energy Data) for; aviation gasoline, distillate fuel, jet fuel kerosene, jet fuel naphtha, LPG, motor gasoline, residual fuel, natural gas, and lubricants. The EIA State Energy Data for gasoline consumption was compared to the Maryland Comptroller data on gasoline sales. The gasoline consumption was essentially equal once ethanol was removed from the MD Comptroller data. The 2006 fossil fuel consumption data for locomotive was obtained from MDE compliance survey. Fuel consumption data is presented in Table 5.1.

Table 5.1: Default Energy Consumption in Maryland, Billion Btu

Fuel Type	Consumption (gallon)	Consumption (Billion Btu)	Source of Data
Aviation Gasoline	4,526,231	544	EIA State Energy Data
Distillate Fuel - Farm	16,854,000	2,337	EIA Adjusted Sales Data
Distillate Fuel - Construction	118,516,224	16,437	FHWA Data MF-24
Distillate Fuel - Ind HD Diesel	11,441,263	1,587	EIA State Energy Data
Distillate Fuel - Locomotive	23,342,572	3,237	MDE Survey
Distillate Fuel - Marine	16,137,077	2,238	EIA State Energy Data
Jet Fuel, Kerosene	4,144	23,497	EIA State Energy Data

Jet Fuel, Naphtha	-	-	EIA State Energy Data
LPG	1,832,182	157	EIA State Energy Data
Motor Gasoline - Farm	11,991,000	9,632	FHWA Data MF-24
Motor Gasoline - Construction	10,970,000	1,363	FHWA Data MF-24
Motor Gasoline - Ind HD Utility	19,725,000	2,451	FHWA Data MF-24
Motor Gasoline - Ind Small Utility	9,811,178	1,219	FHWA Data MF-24
Motor Gasoline - Marine	25,033,000	3,110	FHWA Data MF-24
Residual Fuel	51,301,975	7,679	EIA State Energy Data
Natural Gas	3,236	3,348	EIA State Energy Data
Transportation Lubricants		1,613	

The transportation fossil fuel combustion data are converted to energy consumption by multiplying the fossil fuel data (in m^3, tons, ft^3) by the carbon content coefficients for each fuel. These quantities are then multiplied by a combustion efficiency factor (a fuel-specific percentage of carbon oxidized during combustion). The resulting emissions, in pounds of carbon, are then converted to million metric tons of carbon dioxide equivalent ($MMTCO_2e$). The general equation for calculating CO_2 emissions from transportation energy consumption is as follows:

$$\text{Emissions } (MMTCO_2E) = \frac{\text{Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times \text{Combustion Efficiency (\%)} \times 0.90718 \times (44/12)}{1{,}000{,}000}$$

Where:

Consumption (BBtu)	=	total heat content of the applicable fuel consumed
Emission Factor	=	established factor per fuel type that converts total heat content of the fuel consumed to pounds of carbon
Combustion Efficiency (%)	=	Combustion efficiency refers to the percentage of the fuel that is actually consumed when the fuel is combusted; many fuels often do not combust entirely, and the leftover fuel is emitted as soot or particulate matter. For the fuels analyzed in this report, the combustion efficiencies ranged from 99.0 to 99.5 percent.
0.90718	=	constant used to convert from short tons to metric tons.
0.0005	=	constant used to convert from pounds to short tons.
1,000,000	=	conversion factor converts metric tons to Million metric tons
44/12	=	conversion factor converts from carbon to carbon dioxide

5.3.2 Additional Direct Emissions (CH_4 and N_2O)

To calculate CH_4 and N_2O emissions from non-road transportation sector, the following data are required:

- Fossil fuel consumption by fuel type;
- Emission factors by fuel type

The general emissions equation is as follows:

$$\text{Emissions (MMTCO2E)} = \frac{\text{Consumption (Btu or Gallon)} \times \text{Density (kg/gal) OR Energy Content (kg/MBtu)} \times \text{Emission Factor (g/kg fuel)} \times \text{Combustion Efficiency (\%)} \times \text{GWP}}{1{,}000{,}000}$$

Where:

Emissions:	MMTCO2E (Million Metric Tons of CO2 Equivalent)
Consumption:	MBtu (Million BTUs or Gallons)
Density:	Kg/gal
Energy Content:	kg/MBtu
Emission Factor:	(grams per kilograms fuel)
Combustion Eff:	Percentage (100%)
GWP:	Global Warming Potential (N_20 = 310, CH_4 = 21)
1,000,000:	Conversion Factor (Metric Tons to Million Metric Tons)

5.4 GREENHOUSE GAS INVENTORY RESULTS

Table 4-1: 2006 Transportation Sector CO_2 Emissions from Fossil fuel Consumption.

Fuel Type	Consumption (gallon)	Consumption (Billion Btu)	Emission Factor (lbs C/Million Btu)	Combustion Efficiency (%)	Emissions (tons carbon)	Emissions ($MMTCO_2E$)
Aviation Gasoline	4,526,231	544	41.56	100.0%	11,306	0.038
Distillate Fuel - Farm	16,854,000	2,337	43.94	100.0%	51,358	0.171
Distillate Fuel - Construction	118,516,224	16,437	43.94	100.0%	361,144	1.201
Distillate Fuel - Ind HD Diesel	11,441,263	1,587	43.94	100.0%	34,864	0.116
Distillate Fuel - Locomotive	23,342,572	3,237	43.94	100.0%	71,130	0.237
Distillate Fuel - Marine	16,137,077	2,238	43.94	100.0%	49,173	0.164
Jet Fuel, Kerosene	4,144	23,497	42.63	100.0%	500,774	1.666
Jet Fuel, Naphtha	-	-	43.50	100.0%	-	0.000
LPG	1,832,182	157	37.91	100.0%	2,981	0.010
Motor Gasoline - Farm	11,991,000	9,632	42.62	100.0%	205,275	0.683
Motor Gasoline - Construction	10,970,000	1,363	42.62	100.0%	29,045	0.097
Motor Gasoline - Ind HD Utility	19,725,000	2,451	42.62	100.0%	52,225	0.174
Motor Gasoline - Ind Small Utility	9,811,178	1,219	42.62	100.0%	25,977	0.086
Motor Gasoline - Marine	25,033,000	3,110	42.62	100.0%	66,279	0.220
Residual Fuel	51,301,975	7,679	47.33	100.0%	181,752	0.605
Natural Gas	3,236	3,348	31.87	100.0%	53,354	0.177
Other					-	0.000

Table 4-2: 2006 Transportation Sector CO_2 Emissions from Lubricant Consumption.

Consumption (Billion Btu)	Non-Energy Consumption (Billion Btu)	Storage Factor (%)	Net combustible Consumption (Billion Btu)	Emission Factor (lbs C/Million Btu)	Combustion Efficiency (%)	Emissions (short tons carbon)	Emissions ($MMTCO_2E$)
1,613	1,613	9%	1,464.22	44.58	100.0%	32,638.64	0.1085691

Table 4-3: 2006 Non-road Transportation Sector CH_4 and N_2O Emissions

Fuel Type	Consumption (gallon)	Consumption (Billion Btu)	N2O EF g/kg fuel	CH4 EF g/kg fuel	Emissions N2O ($MTCO_2E$)	Emissions CH4 ($MTCO_2E$)
Aviation Gasoline	4,526,231	544	0.04	2.64	150.146	671.299258
Distillate Fuel - Farm	16,854,000	2,337	0.08	0.45	1334.190	508.390798
Distillate Fuel - Construction	118,516,224	16,437	0.08	0.45	9381.934	3,574.970792
Distillate Fuel - Ind HD Diesel	11,441,263	1,587	0.08	0.18	905.709	138.047536
Distillate Fuel - Locomotive	23,342,572	3,237	0.08	0.25	1847.835	391.174821
Distillate Fuel - Marine	16,137,077	2,238	0.08	0.23	1277.437	248.791119
Jet Fuel, Kerosene	4,144	23,497	0.10	0.09	16199.497	954.725191
Jet Fuel, Naphtha	-	-	0.10	0.09		
Motor Gasoline - Farm	11,991,000	9,632	0.08	0.45	832.923	317.383843
Motor Gasoline - Construction	10,970,000	1,363	0.08	0.45	762.002	290.359500
Motor Gasoline - Ind HD Utility	19,725,000	2,451	0.08	0.18	1370.144	208.836504
Motor Gasoline - Ind Small Utility	9,811,178	1,219	0.08	0.18	681.507	103.874891
Motor Gasoline - Marine	25,033,000	3,110	0.08	0.23	1738.850	338.655110
Residual Fuel	51,301,975	7,679	0.08	0.23	4548.433	885.844024

5.5 GREENHOUSE GAS FORECAST METHODOLOGY

The projected inventories are derived by applying the appropriate growth factors to the 2006 Base-Year Greenhouse Gas Emissions Inventory. The projected inventories were required to be a business-as-usual forecast and thus were not to take into account any control/reduction programs. EPA guidance describes four typical indicators of growth. In order of priority, these are product output, value added, earnings, and employment. Surrogate indicators of activity (e.g., population growth) are also acceptable methods.

Surrogate growth factors for future years were applied to the 2006 base year inventory. These surrogates were calculated using population, household, and employment data. Dividing the state population, household, and employment forecasts for the analysis year by the 2006 value produced the growth factors for the projection years. The growth factors were applied to emissions categories.

MDE applied Maryland specific annual growth rates developed from forecasted future growth to the base year emission .The projection of emissions from fuel combustion in the non-road transportation sector were based on surrogates designed to forecast business-as-usual fuel consumption and were developed by MDE based on a two step process:

- Developing the appropriate state specific growth factors to be applied to the base year inventory.
- Applying the growth factors to develop emissions forecasts.

Each source category was matched to an appropriate growth surrogate based on an activity that reflected the base-year emission estimates. Surrogates were chosen as follows:

5.5.1 Aviation Gasoline

Total enplanements based on the FAA's Terminal Area Forecast (TAF was chosen as the growth surrogate for all aviation fuels in the non-road transportation aviation sector. Projected enplanement data was collected for the Baltimore-Washington International Airport and applied to the source category.

5.5.2 Farm Equipment

Agricultural land in farms data was chosen as the growth surrogate for the non-road transportation farm equipment sector. Data was collected from the U.S. Department of Agriculture, Agricultural Census reports.

5.5.3 Construction Equipment

Employment data was chosen as the growth surrogate (NAICS 15: reflecting the construction sector) for the non-road transportation construction equipment sector. Actual (2006) and projected state-level employment data was collected from the Maryland Department of Labor and were based on the NAICS.

5.5.4 Industrial Heavy Duty Utility Equipment

Employment data was chosen as the growth surrogate (NAICS 31-33: reflecting the manufacturing sector) for the non-road transportation industrial heavy duty utility equipment sector. Actual (2006) and projected state-level employment data was collected from the Maryland Department of Labor and were based on the NAICS.

5.5.5 Industrial Small Utility Equipment

Employment data was chosen as the growth surrogate (NAICS 31-33: reflecting the manufacturing sector) for the non-road transportation industrial heavy duty utility equipment sector. Actual (2006) and projected state-level employment data was collected from the Maryland Department of Labor and were based on the NAICS.

5.5.6 Marine Equipment

Growth factors were selected from EPA's Regulatory Impact Analysis (RIA) for marine vessels for the non-road transportation marine equipment sector. Projected marine carbon monoxide emissions were translated into growth factors for the sector using 2006 as the base year.

5.5.7 Railway Locomotive Equipment

Growth factors were selected from EPA's Regulatory Impact Analysis (RIA) for marine vessels for the non-road transportation marine equipment sector. Projected marine carbon monoxide emissions were translated into growth factors for the sector using 2006 as the base year.

5.6 GREENHOUSE GAS FORECAST RESULTS

Table 6-9: Projected (BAU) Emissions in the Non-road Transportation Sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Nonroad Gasoline	1.04	1.01	1.05	1.05	1.05	1.05	1.05	1.05	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Nonroad Diesel	1.50	1.52	1.55	1.58	1.60	1.63	1.65	1.68	1.70	1.73	1.75	1.78	1.80	1.83	1.85
Rail	0.24	0.24	0.25	0.25	0.25	0.26	0.26	0.27	0.27	0.27	0.28	0.28	0.29	0.29	0.30
Marine Vessels (Gas & Oil)	1.00	1.05	1.10	1.16	1.21	1.26	1.32	1.37	1.43	1.48	1.53	1.59	1.64	1.69	1.75
Lubricants, Natural Gas, and LPG	0.30	0.31	0.32	0.33	0.34	0.35	0.36	0.38	0.39	0.40	0.42	0.43	0.44	0.46	0.47
Jet Fuel and Aviation Gasoline	1.72	1.79	1.85	1.92	1.98	2.05	2.12	2.19	2.26	2.34	2.42	2.50	2.58	2.67	2.76

6.0 Industrial Processes

6.1 OVERVIEW

Industry emits greenhouse gases in two basic ways: through the combustion of fossil fuels for energy production and through a variety of raw material transformation and production processes. The emissions associated with fossil fuel combustion have already been accounted for under the energy use section – Industrial (RCI), "Carbon Dioxide Emissions from Fossil Fuel Combustion" and the indirect CO_2 emissions from consumption of electricity have also been accounted for under the Energy Use section - Electric Generation. This section of the report will focus on additional industrial processes related to greenhouse gas emissions. Industrial process GHG emissions occur in the following industrial source sectors:

- Iron and Steel Production
- Cement Manufacture
- Lime Manufacture
- Limestone and Dolomite Use
- Nitric Acid Production
- Adipic Acid Production
- Ozone Depleting Substances Substitution
- Semiconductor Manufacture
- Magnesium Production
- Electric Power Transmission and Distribution Systems
- HCFC-22 Production
- Aluminum Production

Many of these industrial processes did not have production facilities in Maryland in 2006. Calculating emissions from these source categories was not necessary. These industries are:

- Nitric acid production
- Adipic acid production
- HCFC-22 production
- Aluminum production

The following sections discuss the data sources, methods, assumptions, and results used to construct the base year inventory and future year projections for this sector. The future year projections assume business-as-usual practices.

6.2 DATA SOURCES

- MDE's Annual Emissions Certification Reports.

- World Business Council for Sustainable Development Protocol. http://www.wbcsdcement.org/index.php?option=com_content&task=view&id=53&Itemid=114.

- US EPA State Greenhouse Gas Inventory Tool (SIT) http://www.epa.gov/statelocalclimate/resources/tool.html

6.3 GREENHOUSE GAS INVENTORY METHODOLOGY

This section provides the methodologies used to estimate CO_2, N_2O, and HFC, PFC, and SF_6 emissions from Industrial Processes. The sectors included in Industrial Processes are cement production, lime manufacture, limestone and dolomite use, soda ash manufacture and consumption, iron and steel production, ammonia manufacture, consumption of substitutes for ozone depleting substances, semiconductor manufacture, electric power transmission and distribution, and magnesium production and processing. Since the methodology varies by sector, they are discussed separately below.

Three primary methods were used in the calculation of greenhouse gas emissions inventory for the industrial sector.

- The Maryland 2006 industrial process CO_2 emission inventory methodology for **Cement Industries** follows the World Business Council for Sustainable Development Protocol (Cement Sustainability Initiative), "CO_2 Emissions Inventory Protocol, Version 2.0". This widely used international accounting tool for GHG estimation in the Cement Industry was used by cement industries operating in Maryland to report their annual emissions to MD Compliance Program.

- Iron and Steel production process CO_2 emissions estimation was extrapolated from the physical energy intensity (defined as primary energy use for SIC 331 and 332 per metric ton of steel produced [1]) of steel produced in Maryland in 2008 using 2006 iron and steel production data because direct 2006 emissions data was not available.

- Maryland 2006 GHG emissions from limestone and dolomite use, soda ash consumption, ammonia and non- agriculture urea consumption, ozone depleting substances substitute, and electric power transmission and distribution system (SF6, HFCs and PFCs) use , was estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software, with default state consumption data and emission factors, in accordance with the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector. SIT input data for Maryland is based on the state's population and the national per capital consumption data from the US EPA national GHG inventory 2006

[1] Documentation for Emissions of Greenhouse Gases in the United States 2006 (October 2008) –DOE/EIA 0636 (2006)

6.3.1 Carbon Dioxide (CO2) Industrial Process Emissions

6.3.1.1 Cement Manufacture

Cement production creates CO_2 emissions from process and energy sources. Direct energy related emissions from the combustion of fossil fuels in the rotary kiln including coal, petroleum coke, carbon, fuel oil and natural gas have been addressed in the R/C/I fossil fuel combustion section. An indirect and significantly smaller amount of CO_2 emissions from the consumption of electricity have also been accounted for under the energy use section - electric generation.

This section of the report focuses on the cement manufacturing processes that produce greenhouse gas emissions. Predominant sources of *process-related* CO_2 emissions arise from calcination of carbonates that form clinker and from calcination of carbonates that formed clinker kiln dust (CKD). Additional process-related CO_2 emissions arise from the non-carbonate, total organic carbon contained in the raw materials consumed for clinker production. Another very significant source of process CO_2 emissions is from the calcination of limestone (carbonates) that forms clinker and from calcination of carbonates that forms clinker kiln dust (CKD).

Cement manufacturing *process-related* CO_2 emissions estimated in this section includes:

Carbon Dioxide (CO_2) from:

- Raw materials converted to Clinker;
- Calcinations of Clinker Kiln Dust (CKD) leaving the Kiln system;
- Organic carbon content of Raw Meal.

Emissions from cement production consist of emissions produced during the cement clinker process. (Emissions from masonry cement are accounted for in the Lime Production estimates). Cement clinker emissions are calculated by multiplying the clinker production quantity by an emission factor and adding the product to the emissions from cement kiln dust (a by-product of cement clinker production). The emissions are then converted into metric tons of carbon equivalents (MTCE) and metric tons of carbon dioxide equivalents (MTCO2E).

The general equation used to estimate greenhouse gas emissions from the cement industry is as follows:

$$\text{Emissions}_{TOTAL}\ (\text{MMTCO2E}) = \text{Emissions}_{RM\text{-}C} + \text{Emissions}_{CKD} + \text{Emissions}_{OCC\text{-}RM}$$

Where:

Emissions $_{TOTAL}$	=	Total emissions from the Cement Manufacture industry
Emissions $_{RM\text{-}C}$	=	Emissions from the conversion of Raw Meal to Clinker
Emissions $_{CKD}$	=	Emissions from the calcination of the Clinker Kiln Dust leaving the kiln system
Emissions $_{OCC\text{-}RM}$	=	Emissions from the Original Carbon Content of Raw Meal

The equation used to estimate emissions when converting raw meal into clinker is as follows:

$$\text{Emissions}_{RMC}\ (\text{MTCO2E}) = \text{Clinker Produced (metric tones)} \times \text{Emission Factor (kg CO2/tones Clinker)}$$

1,000

Where:

Emissions $_{RMC}$	=	Emissions from the conversion of Raw Meal to Clinker
Clinker Produced	=	Amount of Clinker Produced by the Maryland cement industry (from MD Emission Certification Reports)
Emission Factor	=	Emission factor from WBCSD[1]
1,000	=	conversion factor converts kilograms to metric tons

The equation used to estimate emissions for the calcination of the clinker leaving the kiln system is as follows:

$$\text{Emissions}_{CalcCLK}\ (\text{MTCO2E}) = \text{Clinker Produced (metric tonnes)} \times \text{Emission Factor (metric tonnes CO2/tones Clinker)} \times \text{Calcination Rate}$$

Where:

Emissions $_{CalcCLK}$	=	Emissions from the calcination of the Clinker leaving the kiln system
Clinker Produced	=	Amount of Clinker Produced by the Maryland cement industry (from MD Emission Certification Reports)
Emission Factor	=	Emission factor from WBCSD[2]
Calcination Rate	=	Calcination rate of Clinker (100%)

The equation used to estimate emissions from the Organic Carbon Content of the Raw Meal is as follows:

$$\text{Emissions}_{OCC\text{-}RM}\ (\text{MTCO2E}) = \text{Clinker Produced (metric tonnes)} \times \text{Raw Meal to Clinker Ratio (default)} \times \text{Raw Meal Consumption (metric tones)} \times \text{Organic Carbon Content of Raw Meal (Average)}$$

Where:

Emissions $_{CalcCLK}$	=	Emissions from the calcination of the Clinker leaving the kiln system
Clinker Produced	=	Amount of Clinker Produced by the Maryland cement industry (from MD Emission Certification Reports)
Raw Meal to Clinker	=	Default Ratio (1.55) [Essroc reported 1.78]
Raw Meal Consumption	=	Metric tonnes
Organic C Content or Raw Meal	=	Average Carbon Content (0.20%)

6.3.1.2 Iron and Steel Industry – Not finished

Steel production creates CO_2 emissions from process and energy sources. Direct energy related emissions from the combustion of fossil fuels including coal, petroleum coke, carbon, fuel oil and natural gas have been addressed in the R/C/I fossil fuel combustion section. An indirect and significantly smaller amount of CO_2 emissions from the consumption of electricity have also been accounted for under the energy use section - electric generation.

Steel is an alloy of iron usually containing less than one percent carbon[3]. The process of steel production occurs in several sequential steps. The two types of steelmaking technology in use today

[1] World Business Council for Sustainable Development Protocol (Cement Sustainability Initiative); "CO_2 Emissions Inventory Protocol, Version 2.0

[2] World Business Council for Sustainable Development Protocol (Cement Sustainability Initiative); "CO_2 Emissions Inventory Protocol, Version 2.0

[3] EPA Office of Compliance Notebook Project. Profile of the Iron and Steel Industry, Sept 1995.

are the basic oxygen furnace (BOF) and the electric arc furnace (EAF). Although these two technologies use different input materials, the output for both furnace types is molten steel which is subsequently formed into steel mill products. The BOF input materials are molten iron, scrap, and oxygen. In the EAF, electricity and scrap are the input materials used. For a full description of the Iron and Steel manufacturing process, refer to the U.S. EPA office of Compliance Notebook Project report - Profile of the Iron and Steel Industry which is available at this website: http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/iron.html

This section of the report focuses on the iron manufacturing processes that produce greenhouse gas emissions. Predominant sources of *process-related* CO_2 emissions arise from calcination of carbonates that form clinker and from calcination of carbonates that formed clinker kiln dust (CKD). Additional process-related CO_2 emissions arise from the non-carbonate, total organic carbon contained in the raw materials consumed for clinker production. Another very significant source of process CO_2 emissions is from the calcination of limestone (carbonates) that forms clinker and from calcination of carbonates that forms clinker kiln dust (CKD).

This section of the report focuses on the iron and steel manufacturing processes that produce greenhouse gas emissions. Predominant sources of *process-related* CO_2 emissions in the iron and steel manufacturing estimated in this section include:

Carbon Dioxide (CO_2) from:

- Sinter Strand;
- L-Blast Furnace (Iron production);
- Basic Oxygen Furnace –Steel Production (BOF).

Sintering is one of the first processes involved in primary iron and steel making; sinter strand is where the raw material mix (including iron ore fines, pollution control dusts, coke breeze, water treatment plant sludge, and flux) are agglomerated into a porous mass for charging to the blast furnace[1]. In the sinter production process, direct CO_2 emissions occur due to fuel used in the sintering process, from the recycling of residue materials and in form of process emissions from limestone calcination.

Blast Furnace, crude iron is produced by the reduction of iron oxide ores in the blast furnace. The combustion of coke, petroleum coke, or coal provides the carbon monoxide (CO) to reduce the iron oxides to iron and provides additional heat to melt the iron and impurities[2]. Carbon dioxide (CO_2) emissions are produced as the coal/coke is oxidized. Furthermore, during iron production, CO_2 emissions occur through the calcination of carbonate fluxes. Calcination occurs when the heat of the blast furnace causes fluxes containing limestone ($CaCO_3$) and magnesium carbonate ($MgCO_3$) to form lime (CaO), magnesium oxide (MgO), and CO_2. The CaO and MgO are needed to balance acid constituents from the coke and iron ore. Although some carbon is retained in the iron (typically 4 percent carbon by weight), most of the carbon is emitted as CO_2.

[1] http://ec.europa.eu/clima/policies/ets/docs/BM%20study%20-Iron%20and%20steel.pdf .
[2] Climate Leaders Greenhouse Gas Inventory Protocol Core Module Guidance. http://www.epa.gov/climateleaders/documents/resources/ironsteel.pdf.

Steelmaking Using the Basic Oxygen Furnace (BOF); Low carbon steel is produced in the BOF, where a mixture of crude iron and scrap steel (typically 30% scrap and 70% molten iron) is converted in the presence of pure oxygen to molten steel[2]. CO_2 emissions also occur, although to a much lesser extent, during the production of steel. CO_2 emissions occur as carbon present in the iron is oxidized to CO_2 or CO. The produced crude steel has a 0.5 to 2 percent carbon content by weight.

2006 CO_2 Emissions Estimation

The general equation used to estimate greenhouse gas process emissions from the iron and steel industry is as follows:

$$\text{Emissions}_{TOTAL}\ (\text{MMTCO2E}) = \text{Emissions}_{SS} + \text{Emissions}_{BF} + \text{Emissions}_{BOF}$$

Where:

Emissions_{TOTAL}	=	Total emissions from the Iron and Steel industry
Emissions_{SS}	=	Emissions from Sinter Strand
Emissions_{BF}	=	Emissions from the Blast Furnace
Emissions_{BOF}	=	Emissions from the Basic Oxygen Furnace

Ideally the emissions would be directly computed from input data for a particular year. However, due to insufficient detail in the plant level input data (metric tons of coke breeze, dolomite and natural gas) for 2006; Maryland used an industry-provided metric to apportion 2006 emissions from 2008 input data. Maryland 2006 direct CO_2 process emissions from the Iron and Steel industry was estimated by applying the available 2008 Iron and Steel facility, Carbon Intensity metric (tons CO_2/ tons of production). The carbon intensity metric of the steel plant was estimated by dividing the 2008 CO_2 emissions ($MMTCO_2$) reported under MDE Title V Compliance program, by the 2008 production output from the steel plant. The 2008 Carbon intensity (metric tons CO_2 / metric tons sinter produced) was then multiplied by 2006 production data (metric tons) to estimate 2006 CO_2 emissions.

$$\text{Emissions}_{SS\text{-}2006}\ (\text{MTCO2E}) = \frac{\text{Emission}_{SS\text{-}2008}\ (\text{metric tons})}{\text{Production}_{SS\text{-}2008}\ (\text{metric tons})} \times \text{Production}_{SS\text{-}2006}\ (\text{metric tons})$$

Where:

$$\frac{\text{Emission}_{SS\text{-}2008}}{\text{Production}_{SS\text{-}2008}} = \text{2008 Carbon Intensity for Sinter Strand}$$

$$\text{Emissions}_{BF\text{-}2006}\ (\text{MTCO2E}) = \frac{\text{Emission}_{BF\text{-}2008}\ (\text{metric tons})}{\text{Production}_{BF\text{-}2008}\ (\text{metric tons})} \times \text{Production}_{BF\text{-}2006}\ (\text{metric tons})$$

Where:

$$\frac{\text{Emission}_{BF\text{-}2008}}{\text{Production}_{BF\text{-}2008}} = \text{2008 Carbon Intensity for Blast Furnace}$$

$$\text{Emissions}_{BOF\text{-}2006}\ (\text{MTCO2E}) = \frac{\text{Emission}_{BOF\text{-}2008}\ (\text{metric tons})}{\text{Production}_{BOF\text{-}2008}\ (\text{metric tons})} \times \text{Production}_{BOF\text{-}2006}\ (\text{metric tons})$$

Where:

$$\frac{\text{Emission}_{BOF\text{-}2008}}{\text{Production}_{BOF\text{-}2008}} = \text{2008 Carbon Intensity for Basic Oxygen Furnace}$$

$$\text{Emissions}_{TOTAL\text{-}2006}\ (\text{MMTCO2E}) = \text{Emissions}_{SS\text{-}2006} + \text{Emissions}_{BF\text{-}2006} + \text{Emissions}_{BOF\text{-}2006}$$

Where:

$\text{Emissions}_{TOTAL\ 2006}$ = 2006 Total emissions from the Iron and Steel industry

$\text{Emissions}_{SS\text{-}2006}$ = 2006 Emissions from Sinter Strand

$\text{Emissions}_{BF\text{-}2006}$ = 2006 Emissions from the Blast Furnace

$\text{Emissions}_{BOF\text{-}2006}$ = 2006 Emissions from the Basic Oxygen Furnace

Available 2008 CO_2 emissions were estimated using the World Business Council for Sustainable Development (WBCSD), Greenhouse Gas (GHG) Protocol Initiative tool (Irons and Steel Sector), a widely used international accounting tool to quantify and manage greenhouse gas emissions. The GHG Protocol methodology basically works by estimating a simplified carbon balance around the iron and steel production processes, all carbon input (from raw materials) and outputs (from all carbon bearing products/by-products) are estimated. The CO_2 emissions from the process are estimated by assuming that the net carbon is converted to CO_2. Table 6.1 shows the CO_2 emissions sources in the Iron and Steel manufacturing processes.

Table 6-1: Iron and Steel Manufacturing Process CO_2 emissions Sources.

Process	Carbon Input Sources (raw materials)	Carbon Output Sources (products and by-products)	Net Carbon
Sinter Strand	Coke Breeze	Molten Iron	**(CO_2 Emissions)**
	Dolomite		
	Natural Gas		
L Blast Furnace	Coke	Iron (Pigged + Beached)	**(CO_2 Emissions)**
	Coal		
	Limestone		
	Dolomite	Blast Furnace Gas	
	Natural Gas		
	Blast Furnace Gas		
Basic Oxygen Furnace	Scrap	Steel	**(CO_2 Emissions)**
	Coal		
	Limestone		
	Dolomite		
	Molten Iron		

The general equation used to estimate CO_2 emissions from the Iron and Steel manufacturing processes is as follows:

$$Emissions = AMT_{RW} \times CC_{RW} - AMT_{PROD} \times CC_{PROD} - AMT_{BY\text{-}PROD} \times CC_{BY\text{-}PROD} \times 44/12$$

Where:

Emissions	=	Total emissions from the Iron and Steel Manufacturing
AMT_{RW}	=	Amount of Raw Materials (tons)
CC_{RW}	=	Carbon Content of raw materials (tons C/ton raw material)
AMT_{PROD}	=	Amount of Product (tons)
CC_{PROD}	=	Carbon Content of Product (tons C/ton product)
$AMT_{BY\text{-}PROD}$	=	Amount of By-Product (tons)
$CC_{BY\text{-}PROD}$	=	Carbon Content of By-Product (tons C/ton by-product)
44/12	=	Conversion Factor Carbon to CO2 (molecular wt CO2 over molecular wt C)

6.3.1.3 Limestone and Dolomite Use.

The primary source of CO_2 emissions from limestone consumption is the calcination of limestone ($CaCO_3$) and dolomite ($CaCO_3MgCO_3$) to create lime (CaO). These compounds are basic raw materials used by a wide variety of industries, including construction, agriculture, chemicals, metallurgy, glass manufacture, and environmental pollution control. Limestone and dolomite are collectively referred to as limestone by the industry. Limestone (including dolomite) can be used as a flux or purifier in metallurgical furnaces, as a sorbent in flue gas desulfurization systems in utility and industrial plants, as a raw material in glass manufacturing, or as an input for the production of dead-burned dolomite. Limestone is heated during these processes, generating carbon dioxide as a byproduct.[1]

Emissions from limestone and dolomite use result from industrial consumption. The quantities of limestone consumed for industrial purposes, dolomite consumed for industrial purposes, and magnesium produced from dolomite are multiplied by their respective emission factors. Industrial uses include the consumption of limestone and dolomite for flux stone production, glass manufacturing, flue gas desulfurization (FGD), Mg production through the thermic reduction of dolomite, chemical stone manufacturing, mine dusting or acid water treatment, acid neutralization, and sugar refining. The emissions are then converted from metric tons of carbon equivalents (MTCE) to metric tons of carbon dioxide equivalents (MTCO2E). For default data, each 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.

Equation 5.1: Emission Equation for Limestone and Dolomite Use

$$\text{Emissions } (MTCO_2E) = \text{Consumption (metric tons)} \times \text{Emission Factor } (MT\ CO_2/MT \text{ Production})$$

Where:

Emissions	=	Total emissions from the Limestone and Dolomite Use
Consumption	=	Quantity of limestone/dolomite consumed
Emission Factor	=	Emission Factor (0.44)

[1] Documentation for Emissions of Greenhouse Gases in the United States 2006 (October 2008) –DOE/EIA 0636 (2006)

6.3.1.4 Soda Ash Manufacture and Consumption

Commercial soda ash (sodium carbonate) is used in many familiar consumer products, such as glass, soap and detergents, paper, textiles, and food. Most soda ash is consumed in glass and chemical production. Other uses include water treatment, flue gas desulfurization, soap and detergent production, and pulp and paper production. Carbon dioxide is also released when soda ash is consumed (See Chapter 6 of EIIP guidance documents).

Emissions from soda ash manufacture and consumption are calculated by multiplying the quantity of soda ash manufactured (Wyoming only) and the quantity of soda ash consumed by their respective emission factors. The emissions are then converted from metric tons of carbon equivalents (MTCE) to metric tons of carbon dioxide equivalents (MTCO2E).

Equation 5.2: Emission Equation for Soda Ash Manufacture and Consumption

$$\text{Emissions } (MTCO_2E) = \text{Manufacture/Consumption (metric tons)} \times \text{Emission Factor } (MT\ CO_2/MT\ Production$$

Where:

Emissions	=	Total emissions from the Soda Ash Manufacture and Consumption
Consumption	=	Quantity of soda ash manufactured/consumed
Emission Factor	=	Emission Factor (0.4150)

6.3.1.5 Non-Fertilizer Urea Use CO_2 Emissions

Urea is consumed in a variety of uses, including as a nitrogenous fertilizer, in urea-formaldehyde resins, and as a deicing agent. The Carbon (C) in the consumed urea is assumed to be released into the environment as CO_2 during use. The majority of CO_2 emissions associated with urea consumption are those that results from its use as a fertilizer.[1] These emissions are accounted for in Land Use. CO_2 emissions associated with other uses of Urea are accounted for in this section.

Emissions from urea application are calculated by multiplying the quantity of urea applied by their respective emission factors. Emissions from urea application are subtracted from emissions due to ammonia production. The emissions are then converted from metric tons of carbon equivalents (MTCE) to metric tons of carbon dioxide equivalents (MTCO2E).

Equation 5.3: Emission Equation for Urea Consumption

$$\text{Emissions } (MTCO_2E) = \text{Urea Consumption (metric tons)} \times \text{Emission Factor } (MT\ CO_2/MT\ Activity$$

Where:

Emissions	=	Total emissions from the Urea Consumption
Urea Consumption	=	Quantity of urea consumed
Emission Factor	=	Emission Factor (0.73)

[1] Inventory of U.S.Greenhouse Gas Emissions and Sinks: 1990- 2006

6.3.2 Additional Direct Emissions (SF6, HFC, PFC)

6.3.2.1 SF6 from Electrical Transmission and Distribution Equipment.

Sulfur hexafluoride (SF_6) is used for electrical insulation, arc quenching, and current interruption in electrical transmission and distribution equipment. SF_6 emissions from electrical transmission and distribution systems are the largest global source category for SF_6.[1] Emissions of SF_6 stem from a number of sources including, switch gear through seals (especially from older equipment), equipment
installation, servicing and disposal.

Emissions from electric power transmission and distribution are calculated by multiplying the quantity of SF6 consumed by an emission factor. The resulting emissions are then converted from metric tons of SF6 to metric tons of carbon equivalents (MTCE) and metric tons of carbon dioxide equivalents (MTCO2E). The default assumption is that the emission factor is 1, i.e. all SF6 consumed is used to replace SF6 that was emitted. Default activity data for this sector equals national SF6 emissions apportioned by state electricity sales divided by national electricity sales.

The general equation used to estimate greenhouse gas emissions from transmission and distribution equipment is as follows:

Equation 5.4: Emission Equation for Electric Power Transmission and Distribution

$$\text{Emissions } (MTCO_2E) = SF_6 \text{ Consumption (metric tons } SF_6) \times \text{Emission Factor } (MT\ SF_6/MT \text{ Consumption}) \times GWP_{SF6}$$

Where:

Emissions	=	Total emissions from the Transmission and Distribution Equipment
SF_6 Consumption	=	Quantity of SF_6 consumed
Emission Factor	=	Emission Factor (1)
GWP_{SF6}	=	Global Warming Potential

6.3.2.2 HFCs and PFCs from Ozone-Depleting Substance (ODS) Substitutes.

Hydrofluorocarbons (HFCs) and **Perfluorocarbons** (PFCs) are used as substitutes for ozone-depleting substances (ODS), used in cooling and refrigeration equipment. Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) have hundreds of uses, but the bulk of emissions come from a few broad categories of use such : (a) as refrigerants or working fluids in air conditioning and refrigeration equipment, (b)as solvents in various industrial processes, and (c) as blowing agents for making insulating foams.[2]

Emissions of HFCs, PFCs, and SF6 from ODS substitute production are estimated by apportioning national emissions to each state based on population. State population data was provided by the U.S. Census Bureau (http://www.census.gov). The resulting state emissions are then converted from metric tons of CO2 equivalents to metric tons of carbon equivalents (MTCE) and metric tons of carbon dioxide equivalents (MTCO2E).

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[1] Documentation for *Emissions of Greenhouse Gases in the United States 2006* ***October 2008***
[2] Documentation for *Emissions of Greenhouse Gases in the United States 2006 October 2008*

Equation 5.5: Emission Equation for Apportioning Emissions from the Consumption of Substitutes for ODS

$$\text{Emissions } (MTCO_2E) = \text{National ODS Substitute Emissions } (MTCO_2E) \times \frac{\text{State Population}}{\text{National Population}}$$

Where:

Emissions	=	Total emissions from the Consumption of Substitutes for ODS
National ODS	=	National ODS Substitute Emissions
State Population	=	Maryland State Population
National Population	=	United States Population

6.4 GREENHOUSE GAS INVENTORY RESULTS.

Table 6-2: Cement Industry Process CO_2 Emissions

CO_2 from Raw Meal Converted to Clinker	
	MD Total
Year	**2006**
Clinker Produced (metric tons)	**2,693,252**
Calcination Emission Factor (kg CO_2/ tons Clinker)	530
Clinker CO_2 Emission (tons CO_2/yr)	1,442,719
CO_2 from Calcination of CKD leaving the Kiln system	
CKD Produced (metric tons)	18,173
CKD Emission Factor (t CO_2/ tons CKD)	0.525
Calcination rate of CKD [%]-Default	100%
CKD CO_2 Emission (tons CO_2/yr)	9,541
CO_2 from Organic Carbon Content of Raw Meal	
Clinker Produced (metric tons)	2,693,252
Raw Meal to Clinker Ratio (Default)	1.63
Raw Meal Consumption (metric tons)	4,381,023
Organic Carbon Content of Raw Meal (Average)	0.20%
CO_2 Emission (metric tons CO_2/yr)	30,982
MD Total Cement Process CO_2 (metric tons)	**1,483,242**
MD Total Cement Process CO_2 ($MMTCO_2E$)	**1.4832**

Table 6-3: Iron and Steel Industry Process CO_2 Emissions.

Processes	Product	CO_2 Emission (short tons)	CO_2 Emission (metric tons)	CO_2 Emission ($MMTCO_2E$)
Sinter Strand	Sinter	625,019	567,017	0.5670
L Blast Furnace	Iron	3,082,535	2,796,476	2.7965
BOF	Steel	257,521	233,623	0.2336
			3,597,116	**3.5971**

Table 6-4: Soda Ash Consumption CO_2 Emissions.

	Consumption (Metric Tons)	Emission Factor (t CO_2/t production)	Emissions ($MTCO_2E$)	Emissions ($MMTCO_2E$)
Soda Ash	114,725	0.4150	47,611	**0.05**

Table 6-5: Limestone and Dolomite Use CO_2 Emissions.

	Consumption (Metric Tons)	Emission Factor (t CO_2/t production)	Emissions ($MTCO_2E$)	Emissions ($MMTCO_2E$)
Limestone	258,957	0.44	113,941	**0.114**

Table 6-6: 2006 Non-Fertilizer Urea Use CO_2 Emissions.

	Non-Fertilizer Consumption (Metric Tons)	Emission Factor (mt CO_2/mt activity)	Emissions ($MTCO_2E$)	Emissions ($MMTCO_2E$)
Urea	859	0.73	627	0.0006

Table 6-7: SF_6 Emissions from Electrical T &D System.

Total US SF_6 Emissions from Electric Power T & D ($MTCO_2E$)	13,200,047	A
SF_6 GWP	23,900	B
US Total SF_6 Consumed (metric tons)	552.30	= A/B
Total US Electric Sales (million kWh)	3,669,919	D
MD Total Electric Sales (million kWh)	63,173	E
MD Apportioned SF6 Consumption (metric tons)	9.51	= C x D/E
Emission Factor	1.0	
SF6 Emissions (metric tons)	9.51	
SF6 Emissions ($MTCO_2E$)	227,223	
SF6 Emissions ($MMTCO_2E$)	0.23	

Table 6-8: HFC & PFCs Emissions from ODS Substitutes

Total US GHG 2006 Emissions from ODS substitute (Metric tons CO_2 Eq.)	104,985,827
MD 2006 Population	5,602,258
US 2006 Population	298,362,973
Apportioned State Emissions ($MMTCO_2E$)	1,971,282.44

6.5 GREENHOUSE GAS FORECAST METHODOLOGY

The projected inventories are derived by applying the appropriate growth factors to the 2006 Base-Year Greenhouse Gas Emissions Inventory. The projected inventories were required to be a business-as-usual forecast and thus were not to take into account any control/reduction programs. EPA guidance describes four typical indicators of growth. In order of priority, these are product output, value added, earnings, and employment. Surrogate indicators of activity, for example population growth, are also acceptable methods.

Surrogate growth factors for future years were applied to the 2006 base year inventory. These surrogates were calculated using population, household, and employment data. Dividing the state population, household, and employment forecasts for the analysis year by the 2006 value produced the growth factors for the projection years. The growth factors were applied to emissions categories.

MDE applied Maryland specific annual growth rates developed from forecasted future growth to the base year emission .The projection of emissions from direct fuel combustion in the RCI sector were based on surrogates designed to forecast business-as-usual fuel consumption and were developed by MDE based on a two step process:

- Developing the appropriate state specific growth factors to be applied to the base year inventory.
- Applying the growth factors to develop emissions forecasts.

Each source category was matched to an appropriate growth surrogate based on an activity that reflected the base-year emission estimates. Surrogates were chosen as follows:

6.5.1 Cement Industry

Historical cement production data was chosen as the growth surrogate for the cement industry process emissions sector. State-wide production of cement was collected from the U.S. Geological Survey (USGS) [1] for years 1990 through 2006. Cement projection growth factors were calculated using the FORECAST methodology in Microsoft Excel. The FORECAST MS Excel function returns the predicted value of the dependent variable (production) for a specific year (independent variable) by using the best fit (sum of least squares) linear regression to predict future year production values from known production per year values.

6.5.2 Iron and Steel Industry

Historical steel production was chosen as the growth surrogate for the iron and steel process emissions sector. Raw steel production data was collected from the U.S. Geological Survey (USGS) for year 1990 through 2008. Raw steel production was estimated for years 2009 thorugh 2020 using the FORECAST methodology in Microsoft Excel. The FORECAST MS Excel function returns the predicted value of the dependent variable (production) for a specific year (independent variable) by using the best fit (sum of least squares) linear regression to predict future year production values from known production per year values.

[1] U.S. Geological Survey, Cement: Annual Report

6.5.3 Limestone and Dolomite Industry

Historical limestone and dolomite production data was chosen as the growth surrogate for the cement industry process emissions sector. State-wide production of cement was collected from the U.S. Geological Survey (USGS)[1] for years 1990 through 2006. Projection growth factors were calculated using the FORECAST methodology in Microsoft Excel. The FORECAST MS Excel function returns the predicted value of the dependent variable (production) for a specific year (independent variable) by using the best fit (sum of least squares) linear regression to predict future year production values from known production per year values.

6.5.4 Soda Ash Industry

Historical soda ash consumption data was chosen as the growth surrogate for the soda ash industry process emissions sector. State-wide consumption of soda ash was collected from the U.S. Geological Survey (USGS) [2] for years 1990 through 2006. Soda ash projection growth factors were calculated using the FORECAST methodology in Microsoft Excel. The FORECAST MS Excel function returns the predicted value of the dependent variable (consumption) for a specific year (independent variable) by using the best fit (sum of least squares) linear regression to predict future year consumption values from known production per year values.

6.5.5 Ozone Depleting Substances (ODS)

Historical ODS consumption data was chosen as the growth surrogate for this category. National consumption of ODS allocated to the states by population was collected for years 1990 through 2006. ODS consumption growth factors were calculated using the FORECAST methodology in Microsoft Excel. The FORECAST MS Excel function returns the predicted value of the dependent variable (consumption) for a specific year (independent variable) by using the best fit (sum of least squares) linear regression to predict future year production values from known production per year values.

6.5.5.1 Non-Fertilizer Urea Consumption

Historical urea consumption data was chosen as the growth surrogate for this category. State-wide consumption of urea was collected from the AAPFCO [3] for years 1995 through 2006 and the TVA [4] for years 1991 through 1994. Urea consumption growth factors were calculated using the FORECAST methodology in Microsoft Excel. The FORECAST MS Excel function returns the predicted value of the dependent variable (consumption) for a specific year (independent variable) by using the best fit (sum of least squares) linear regression to predict future year production values from known production per year values.

6.5.6 Semi-conductor Industry

Historical semi-conductor production data was chosen as the growth surrogate for the semi-conductor industry process emissions sector. National emissions of fluorinated gases used in the semi-conductor industry allocated to the states by the value of semi-conductor shipments was collected for years 1990 through 2006. Semi-conductor industry growth factors were calculated

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[1] U.S. Geological Survey, Maryland State Minerals Information, http://minerals.usgs.gov/minerals/pubs/state/md.html
[2] U.S. Geological Survey2009c. Soda Ash: Minerals Yearbook 200; http://minerals.er.usgs.gov/minerals/pubs/commodity/soda_ash/index.html
[3] Association of American Plant Food Control Officials (AAPFCO); http://minerals.er.usgs.gov/minerals/pubs/commodity/soda_ash/index.html
[4] Tennessee Valley Authority, Muscle Shoals, AL; Commercial Fertilizers

using the FORECAST methodology in Microsoft Excel. The FORECAST MS Excel function returns the predicted value of the dependent variable (production) for a specific year (independent variable) by using the best fit (sum of least squares) linear regression to predict future year production values from known production per year values.

6.5.7 Electrical Power Transmissions and Distribution System

Historical SF_6 consumption data was chosen as the growth surrogate for the electrical power transmissions and distribution industry process emissions sector. State-wide consumption of SF_6 was collected from the U.S. Department of Energy, Energy Information Administration for years 1990 through 2006. SF_6 consumption projection growth factors were calculated using the FORECAST methodology in Microsoft Excel. The FORECAST MS Excel function returns the predicted value of the dependent variable (production) for a specific year (independent variable) by using the best fit (sum of least squares) linear regression to predict future year production values from known production per year values.

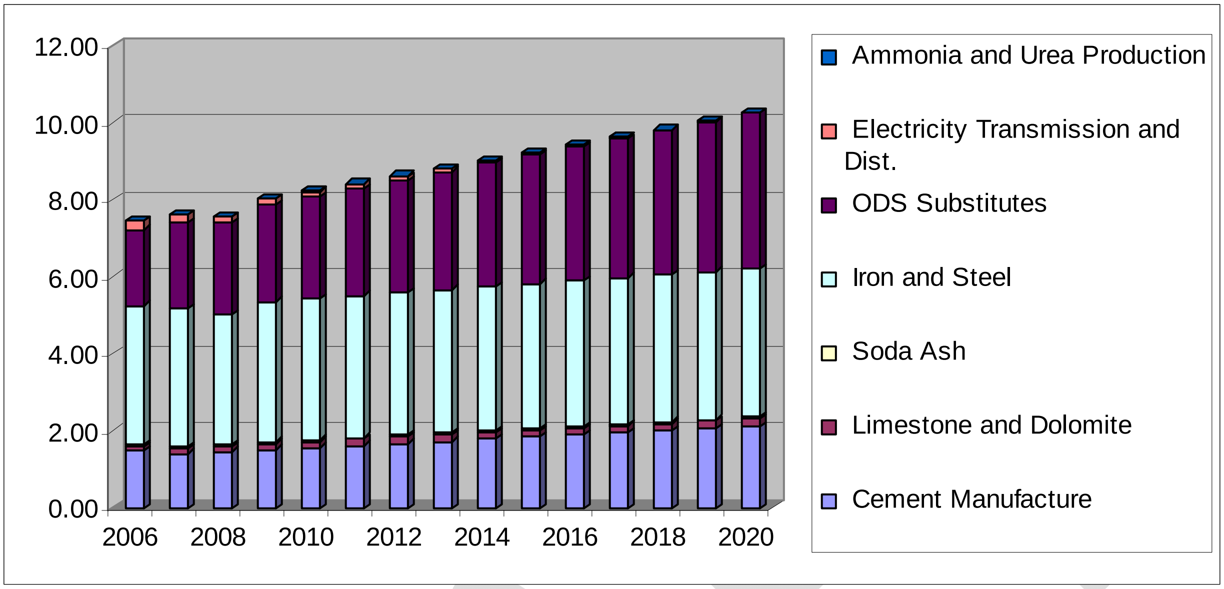
6.6 GREENHOUSE GAS FORECAST RESULTS

The following section provides an overview of the results obtained after applying the projection methodological approach described above. The projected inventories were required to be a business-as-usual forecast and thus were not to take into account any control/reduction programs.

Table 6-9: Projected (BAU) Emissions in the Industrial Process Sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Industrial Processes	**7.44**	**7.61**	**7.56**	**8.01**	**8.21**	**8.41**	**8.61**	**8.81**	**9.01**	**9.21**	**9.41**	**9.61**	**9.81**	**10.03**	**10.24**
Cement Mfg	1.48	1.41	1.47	1.52	1.57	1.62	1.68	1.73	1.78	1.83	1.88	1.94	1.99	2.04	2.09
Limestone and Dolomite	0.11	0.13	0.14	0.15	0.15	0.16	0.16	0.17	0.18	0.18	0.19	0.19	0.20	0.21	0.21
Soda Ash	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Iron and Steel	3.60	3.59	3.37	3.63	3.65	3.67	3.69	3.71	3.73	3.75	3.77	3.79	3.81	3.83	3.85
ODS Substitutes	1.97	2.23	2.37	2.51	2.65	2.79	2.93	3.07	3.21	3.35	3.48	3.62	3.76	3.90	4.04
Electricity Transmission and Distribution	0.23	0.19	0.17	0.16	0.14	0.12	0.11	0.09	0.07	0.05	0.04	0.02	0.00	0.00	0.00
Semi-Conductor Mfg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ammonia and Urea Production	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aluminum Production	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

FIGURE 5.1: PROJECTED (BAU) EMISSIONS IN THE INDUSTRIAL PROCESS SECTOR



7.0 Fossil Fuel Production Industry

7.1 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. The emissions from the Fossil Fuel Production Industry in Maryland include emissions from natural gas systems (including production, transmission, venting and flaring, and distribution) and coal production. There is no oil production or oil or natural gas processing in Maryland.

Natural Gas Production; In natural gas production, wells are used to withdraw raw gas from underground formations. Wells must be drilled to access the underground formations, and often require natural gas well completion procedures or other practices that vent gas from the well depending on the underground formation. The produced raw gas commonly requires treatment in the form of separation of gas/liquids, heating, chemical injection, and dehydration before being compressed and injected into gathering lines. Combustion emissions, equipment leaks, and vented emissions arise from the wells themselves, gathering pipelines, and all well-site natural gas treatment processes and related equipment and control devices.[1] Methane emissions estimation from the natural gas production depends on the number of producing wellheads and the amount of produced natural gas.

Natural Gas Venting and Flaring; The final step after a well is drilled is to clean the well bore and reservoir near the well. This is accomplished by producing the well to pits or tanks where sand, cuttings, and other reservoir fluids are collected for disposal. This step is also useful to evaluate the well production rate to properly size the production equipment.[2] The natural gas produced from this completion process are either vented to atmosphere or flared. During normal operation of the natural gas production, natural gas liquids and various other constituents from the raw gas are separated, resulting in "pipeline quality" gas that is compressed and injected into the transmission pipelines. These separation processes include acid gas removal, dehydration, and fractionation, methane emissions produced from this separation process are either vented to atmosphere or flared. Methane emissions estimation depends on the number and size of gas processing facilities.

[1] EPA GREENHOUSE GAS EMISSIONS REPORTING FROM THE PETROLEUM AND NATURAL GAS INDUSTRY- (BACKGROUND TECHNICAL SUPPORT DOCUMENT) http://www.epa.gov/climatechange/emissions/downloads10/Subpart-W_TSD.pdf.

[2] Methane Emission Factor Development Project for Select Sources in the Natural Gas Industry http://www.utexas.edu/research/ceer/GHG/files/Task-1-Update-Draft.pdf.

Natural Gas Transmission; Natural gas transmission involves high pressure, large diameter pipelines that transport natural 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. A variety of facilities support the overall system, including metering stations, maintenance facilities, and compressor stations located along pipeline routes. Compressor station facilities containing large reciprocating and / or centrifugal compressors, move the gas throughout the transmission pipeline system. Methane emissions estimation from the natural gas transmission depends on the number and size of compressor stations and the length of transmission pipelines.[1]

Natural gas is also injected and stored in underground formations, or stored as LNG in above ground storage tanks during periods of low demand (e.g., spring or fall), and then withdrawn, processed, and distributed during periods of high demand (e.g., winter and summer). Compressors, pumps, and dehydrators are the primary contributors to methane emissions from these underground and LNG storage facilities. Emission estimation from such facilities will depend on the number of storage stations. Imported and exported LNG also requires transportation and storage. These processes are similar to LNG storage and require compression and cooling processes. GHG emissions in this segment are related to the number of LNG import and export terminals and LNG storage facilities.

Natural Gas Distribution; Natural gas distribution pipelines take high-pressure gas from the transmission pipelines at “city gate” stations, reduce and regulate the pressure, and distribute the gas through primarily underground mains and service lines to individual end users. There are also underground regulating vaults between distribution mains and service lines. GHG emissions from distribution systems are related to the pipelines, regulating stations and vaults, and customer/residential meters. Equipment counts and GHG emitting practices can be related to the number of regulating stations and the length of pipelines.

Coal Mining; Methane (CH_4) is produced during the process of coal formation.[1] Only a fraction of this produced methane remains trapped under pressure in the coal seam and surrounding rock strata. This trapped methane is released during the mining process when the coal seam is fractured. Methane released in this fashion will escape into the mine works, and will eventually escape into the atmosphere. The amount of methane (CH_4) released during coal mining depends on a number of factors, the most important of which are coal rank, coal seam depth, and method of mining. Underground coal mining releases more methane than surface or open-pit mining because of the higher gas content of deeper seams.

CH_4 is a serious safety threat in underground coal mines because it is highly explosive in atmospheric concentrations of 5 to 15 percent. There are two methods for controlling CH_4 in underground mines: use of ventilation systems and use of degasification systems. Ventilation systems are employed at most underground mines, but in especially gassy mines, the use of a ventilation system alone may be inadequate to degasify a mine so that it meets federal regulations with regard to maximum CH_4 concentrations. In such cases, a degasification system may be installed to help degasify the mine prior to, during, or after mining. The CH_4 recovered from these systems is usually of sufficient quality that the CH_4 can be sold to a pipeline or used for any number

[1] CH4 EMISSIONS: COAL MINING AND HANDLING (IPCC -*Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories)*
http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_7_Coal_Mining_Handling.pdf.

of applications, including electricity generation. Methane emissions from coal mining are estimated from the sum of emissions from underground mining, surface mining, post-mining activities, and emissions avoided due to recovery.

7.2 DATA SOURCES

- U.S Department of Transport, Office of Pipeline Safety (OPS). http://phmsa.dot.gov/pipeline/library/data-stats
- EIA's State Energy Data. http://www.eia.doe.gov/emeu/states/state.html?q_state_a=md&q_state=MARYLAND.
- U.S. Department of Energy, Energy Information Administration. http://tonto.eia.doe.gov/dnav/ng/ng_prod_wells_s1_a.htm.
- Emission Inventory Improvement Program (EIIP), *Volume VIII: Chapter 5.*[57]
- Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter 1.[58]

7.3 GREENHOUSE GAS INVENTORY METHODOLOGY

2006 emissions from natural gas production, transmission and distribution are estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SIT) software default emission factors and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the natural gas and oil system. Pipeline natural gas combustion GHG emission was estimated with the SIT fossil fuel combustion method and emission factors. Emissions were estimated by multiplying the SIT default emissions factor by the activities data for each section.

7.3.1 Carbon Dioxide (CO_2) Direct Emissions

Table 7-1: Natural Gas Compressor Combustion Activity Data.

	Activity Data and Emission factors Required	Activity Data Sources
Natural Gas – Combustion as Pipeline fuel	Billion Btu of natural gas consumed as pipeline fuel.	EIA[59]

[57] Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter. 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems", March 2005

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

[59] Energy Information Administration (EIA). State Energy Data. http://www.eia.doe.gov/emeu/states/state.html?q_state_a=md&q_state=MARYLAND

7.3.1.1 Natural Gas – Compressor Engines.

Compressor stations, which maintain the pressure in the natural gas transmission and distribution pipeline, generally include upstream scrubbers, where the incoming gas is cleaned of particles and liquids before entering the compressors. Reciprocating engines and turbines are used to drive the compressors. Compressor stations normally use pipeline gas to fuel the compressor. They also use the gas to fuel electric power generators to meet the compressor stations' electricity requirements.

Maryland 2006 GHG emissions from pipeline natural gas consumption for compressor station were estimated using Equation 6.0. EIA State's natural gas consumption data (as pipeline natural gas) data provided in British thermal units (Btu) was multiply by emissions factors supplied by EPA in SIT to estimate emissions from pipeline natural combustion in 2006.

Equation 6.0: Emission Equation for Natural Gas Production, Transmission and Distribution

$$\text{Emissions }(\text{MTCO}_2\text{E}) = \frac{\text{Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times 0.90718 \times 44/12}{1{,}000{,}000}$$

Where:

Emissions	=	Total emissions from the Production, Transmission and Distribution of Natural Gas
Consumption	=	Quantity of Natural Gas (BBtu)
Emission Factor	=	Emission Factor
0.0005	=	Conversion Factor (Lbs to Tons)
0.90718	=	Conversion Factor (Tons to Metric Tons)
44/12	=	Conversion Factor (Carbon to CO_2)
1,000,000	=	Conversion Factor (Metric Tons to Million Metric Tons)

7.3.1.2 Natural Gas Combustion –Vented and Flared

Since no new natural gas production well was developed in Maryland in 2006, no emission was estimated for this sub section of the inventory. The U.S. Energy Information Administration (EIA)[60] does not report any natural gas venting and flaring in Maryland.

7.3.2 Additional Direct Emissions (CH_4, N_2O).

To estimate methane (CH_4) and nitrous oxide (N_2O) emissions from natural gas systems, MDE followed the general methodology outlined in the EIIP guidance.[61] Maryland specific activities data in 2006 (see table 7.2) were multiply by the respective EPA SIT default emissions factors to estimate emission from natural gas system. Similarly, CH_4 and N_2O emissions from coal mining operations were estimated using the EPA SIT and the EIIP guidance[62]. The Default SIT coal production data was used to estimate emission from coal mining.

[60] EIA's Natural Gas Navigator. http://tonto.eia.doe.gov/dnav/ng/ng_prod_sum_dcu_NUS_m.htm
[61] Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter. 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems", March 2005
[62] Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter. 4. "Methods for Estimating Methane Emissions from Coal Mining", March 2005.

Table 7-2: Natural Gas Activity Data.

	Activity Data and Emission factors Required	Activity Data Sources
Natural Gas – Production.	Number of Wells	EIA[63]
Natural Gas - Transmissions	Miles of transmission pipelines	OPS[64]
	Number of gas processing plants	
	Number of gas transmission compressor stations	
	Number of gas storage compressor station.	
Natural Gas - Distribution	Miles of cast iron distribution pipeline	OPS
	Miles of unprotected steel distribution pipelines	
	Miles of protected steel distribution pipeline	
	Miles of plastic distribution pipelines	
	Number of services	
	Number of unprotected steel services	
Natural Gas – Combustion as Pipeline fuel	Billion Btu of natural gas consumed as pipeline fuel.	EIA[65]
Coal Mining	Metric tons of coal produced	SIT[66]

7.3.2.1 Natural Gas Production

Emissions from Natural Gas Production are calculated as the sum of methane emissions from the three categories of production sites: onshore wells, offshore shallow water platforms, and offshore deepwater platforms. Emissions from the natural gas production are estimated using Equation 6.2 by multiplying the number of gas production sites (wells or platforms) by a site-specific emission factor. The resulting methane emissions are then converted to metric tons of CO_2 equivalent and metric tons of carbon equivalent, and summed across the three types of production sites. The State of Maryland does not have any offshore water platforms; therefore, all emissions estimated are from Maryland onshore natural gas production.

[63] US Department of Energy, Energy Information Administration, "Natural Gas Navigation- Maryland Natural Gas Number of Gas and Gas Condensate Wells," accessed from: http://tonto.eia.doe.gov/dnav/ng/ng_prod_wells_s1_a.htm, January 3, 2011

[64] U.S Department of Transport, Office of Pipeline Safety, "2006 Distribution and Transmission Annuals Data" accessed from: http://phmsa.dot.gov/pipeline/library/data-stats.

[65] Energy Information Administration (EIA). State Energy Data. http://www.eia.doe.gov/emeu/states/state.html?q_state_a=md&q_state=MARYLAND

[66] Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter. 5. "Methods for Estimating Methane Emissions from Natural Gas and Oil Systems", March 2005

Equation 6.2: Emission Equation for Natural Gas Production

Emissions ($MTCO_2E$)	=	Activity Data (No. of Wells)	x	Emission Factor (metric tons CH_4/Year/Activity Unit)	x	GWP

Where:

Emissions	=	Total emissions from Natural Gas Combustion
Activity Data	=	Number of Natural Gas Wellheads in Maryland
Emission Factor	=	Emission Factor
GWP	=	Global Warming Potential of CH_4

7.3.2.2 Natural Gas Transmission.

Emissions from Natural Gas Transmission are calculated as the sum of methane emissions from the pipelines that transport the natural gas, the natural gas processing stations, the natural gas transmission compressor stations, and gas storage compressor facilities. Emissions from the natural gas transmission are estimated using Equation 6.3, by multiplying the activity factor (e.g., miles of pipeline or number of stations) for each sources and the source-specific emission factor. Methane emissions are then converted to metric tons of CO_2 equivalent and metric tons of carbon equivalent, and then summed across all sources.

Equation 6.3: Emission Equation for Natural Gas Systems

Emissions ($MTCO_2E$)	=	Activity Data (BBtu)	x	Emission Factor (metric tons CH_4/ Activity data units)	x	GWP

Where:

Emissions	=	Total emissions from Natural Gas Transmission
Activity Data	=	Varies but includes: Miles of transmission pipeline, Number of gas processing plants, Number of gas storage compressor stations, Number of gas transmission compressor stations
Emission Factor	=	Emission Factor
GWP	=	Global Warming Potential of CH_4

7.3.2.3 Natural Gas Distribution

Emissions from Natural Gas Distribution are calculated as the sum of methane emissions from the natural gas distribution pipelines and end services. Methane emissions from the distribution pipelines were estimated by multiplying the activity factor for each type of pipeline (e.g., miles of plastic distribution pipeline) by the corresponding emission factor. Methane emissions from the end services were estimated using Equation 6.4 by multiplying the number of services by a general emission factor and type-specific emission factors. The combined methane emissions from the pipeline and services are then converted to metric tons of CO_2 equivalent and metric tons of carbon equivalent, and summed.

Equation 6.4: Emission Equation for Natural Gas Distributions

$$\text{Emissions }(MTCO_2E) = \text{Activity Data (BBtu)} \times \text{Emission Factor (metric tons } CH_4\text{/ Activity data units)} \times \text{GWP}$$

Where:

Emissions	=	Total emissions from Natural Gas Distribution
Activity Data	=	Varies but includes: Total number of services, Number of unprotected steel services, Number of protected steel services, Miles of cast iron pipeline, Miles of protected steel pipe, Miles of unprotected steel pipe, Miles of plastic pipe
Emission Factor	=	Emission Factor
GWP	=	Global Warming Potential of CH_4

7.3.2.4 Natural Gas Venting and Flaring.

Emissions from Natural Gas Venting and Flaring are calculated as the sum of the percent of methane emissions flared (20%) and the percent of the methane emissions vented (80%) into the atmosphere during the natural gas production well development process. Since no new well was developed in 2006, no emissions were estimated for this section in 2006.

7.3.2.5 Coal Mining.

There are three sources of methane (CH_4) emissions from coal mining: underground mining, surface mining, and post-mining activities. Emissions from post-mining activities may be further subdivided into emissions from underground-mined coal and emissions from surface mined coal. Net methane emissions from coal mining are estimated as the sum of methane emissions from underground mining, surface mining, and post-mining activities.

$$\text{Total Emissions} = \textbf{Emissions from Underground Mines} + \textbf{Emissions from Surface Mines} + \textbf{Emissions From Post-Mining Emissions}$$

Emissions from the surface coal mining operation are estimated by multiplying the amount of coal produced (tons) by a basin-specific emission factor.

$$\text{Surface Mining } CH_4 \text{ Emissions } (ft^3) = \text{Coal Production (short tons)} \times \text{Basin-Specific Emissions Factor } (ft^3\text{/ short tons})$$

Methane emissions from Underground mines, accounted for CH_4 recovered by the two controlling measures deployed in underground mining operations: methane emitted from ventilation systems and methane emitted from degasification systems. The net emissions from the degasification systems and the methane recovered from degasification system (and used for energy purpose) are added to the measured ventilation emissions to estimated methane emissions from the Underground mines.

$$\text{Underground Mining } CH_4 \text{ Emissions (Mcf)} = \text{Measured Ventilation Emissions (Mcf)} + \text{Degasification System Emissions (Mcf)} - \text{Methane Recovered from Degasification System and used for Energy (Mcf)}$$

Emissions from the post mining operations such as transportation and coal handling are estimated by summing the post-mining emissions from underground and surface mines; the emissions are each calculated as the product of coal production times an emission factor specific to the basin and mine-type. The resulting methane emissions are then converted to metric tons of CO_2 equivalent and metric tons of carbon equivalent. No emissions were estimated for underground coal mining operation in Maryland.

$$\text{Post-Mining Activities } CH_4 \text{ Emissions } (ft^3) = \text{Coal Production (short tons)} \times \text{Basin/Mine-Specific Emissions Factor } (ft^3/\text{ short tons})$$

Emissions from Abandoned Coal Mines are calculated by summing the emissions from mines that are vented, sealed, or flooded.

7.4 GREENHOUSE GAS INVENTORY RESULTS

Table 7.3: 2006 GHG Emissions from Pipeline Natural Gas Combustion

	CO_2 (lbs/MMBtu)	N_2O (Mt/BBtu)	CH_4 (Mt/BBtu)	Total Emissions
Emission Factors	31.87	9.496E-05	0.00094955	
Total Natural Gas Consumption (Billion Btus)	2,426.8	2,426.8	2,426.8	
Combustion Efficiency (%)	100%	100%	100%	
Emissions ($MMTCO_2E$)	0.000128636	7.144E-05	4.8393E-05	**0.0002**

Table 7.4: 2006 GHG Emissions from Natural Gas Production

Production Sector	Activity Data	Emission Factor (metric tons CH_4 per year per activity unit)	CH_4 Emissions (metric tons)	CH_4 Emissions ($MMTCO_2E$)
Total number of wells	7	4.10	28.72	0.00060
Total			**28.72**	**0.00060**

Table 7.5: 2006 GHG Emissions from Natural Gas Transmission

Transmission Sector	Activity Data	Emission Factor (metric tons CH_4 per year per activity unit)	CH_4 Emissions (metric tons)	CH_4 Emissions ($MMTCO_2E$)
Miles of transmission pipeline	899	0.6185	556	0.01168
Number of gas transmission compressor stations	5	983.7	5,306	0.11142
Number of gas storage compressor stations	1	964.1	1,300	0.02730
Total			**7,162**	**0.15040**

Table 7.6: 2006 GHG Emissions from Natural Gas Distribution

Distribution Sector	Activity Data	Emission Factor (metric tons CH_4 per year per activity unit)	CH_4 Emissions (metric tons)	CH_4 Emissions ($MMTCO_2E$)
Distribution pipeline				
Miles of cast iron distribution pipeline	1,467	5.80	8,514.06	0.179
Miles of unprotected steel distribution pipeline	602	2.12	1,278	0.027
Miles of protected steel distribution pipeline	5,402	0.06	324	0.007
Miles of plastic distribution pipeline	6,309	0.37	2,345	0.049
Services				
Total number of services	964,468	0.02	14,725	0.309
Number of unprotected steel services	111,375	0.03	3,648	0.077
Number of protected steel services	179,097	0.00	609	0.013
Total			**31,442**	**0.660**

Table 7.7: 2006 CH4 Emissions from Coal Mining.

Underground Mines					
Measured Ventilation Emissions (mcf)	**Degasification System Emissions (mcf)**	**Methane Recovered from Degasification Systems and Used for Energy (mcf)**	**Emissions (mcf CH_4)**	**Emissions ($MTCH_4$)**	**Emissions ($MTCO_2E$)**
0	0	0	0.00	-	-
Surface Mines					
Surface Coal Production ('000 short tons)		Basin-specific EF (ft^3/short ton)	Emissions ('000 ft^3 CH_4)	Emissions ($MTCH_4$)	Emissions ($MTCO_2E$)
2,228		119.0	265,132	5,091	106,901

Post Mining Activity – Underground Mines				
Coal Production ('000 short tons)	Basin & Mine-specific EF (ft^3/short ton)	Emissions ('000 ft^3 CH_4)	Emissions ($MTCH_4$)	Emissions ($MTCO_2E$)
2,826	45.0	127,113	2,441	51,252
Post Mining Activity – Surface Mines				
Coal Production ('000 short tons)	Basin- & Mine-specific EF (ft^3/short ton)	Emissions ('000 ft^3 CH_4)	Emissions ($MTCH_4$)	Emissions ($MTCO_2E$)
2,228	19.3	43,084	827	17,371
Post Mining Activity – SubTotal		Emissions ('000 ft^3 CH_4)	Emissions ($MTCH_4$)	Emissions ($MTCO_2E$)
		170,197	3,268	68,624

Total Coal Mining Emissions ($MTCO_2e$)	**175,525**
Total Coal Mining Emissions ($MMTCO_2e$)	**0.1755**

7.5 GREENHOUSE GAS FORECAST METHODOLOGY

The projected inventories are derived by applying the appropriate growth factors to the 2006 Base-Year Greenhouse Gas Emissions Inventory. The projected inventories were required to be a business-as-usual forecast and thus were not to take into account any control/reduction programs. EPA guidance describes four typical indicators of growth. In order of priority, these are product output, value added, earnings, and employment. Surrogate indicators of activity, for example population growth, are also acceptable methods.

MDE applied Maryland specific annual growth rates developed from forecasted future growth to the base year emission .The projection of emissions from the fossil fuel industry were based on surrogates designed to forecast business-as-usual industry production and were developed by MDE based on a two step process:

- Developing the appropriate state specific growth factors to be applied to the base year inventory.
- Applying the growth factors to develop emissions forecasts.

Actual emissions from fossil fuel production were forecasted to the projection years using surrogates specific to the source category. For fossil fuel production, MDE used the EPA SIT program to estimate emissions from 1990 through 2006. MDE then used the MS Excel "Forecast" function. The Forecast function calculates, or predicts, a future value by using existing values. The predicted value is a y-value (emissions) for a given x-value (year). The known values are existing x-values and y-values, and the new value is predicted by using the sum of least squares linear regression.

The historical data on Natural Gas Production, Transmission, and Distribution were used to develop the projection year growth factors. The emissions from coal mines were not used as number of active and closed coal mines has remained constant in Maryland over the time in question.

Table 7.8: Growth Factors for the Fossil Fuel Production Industry

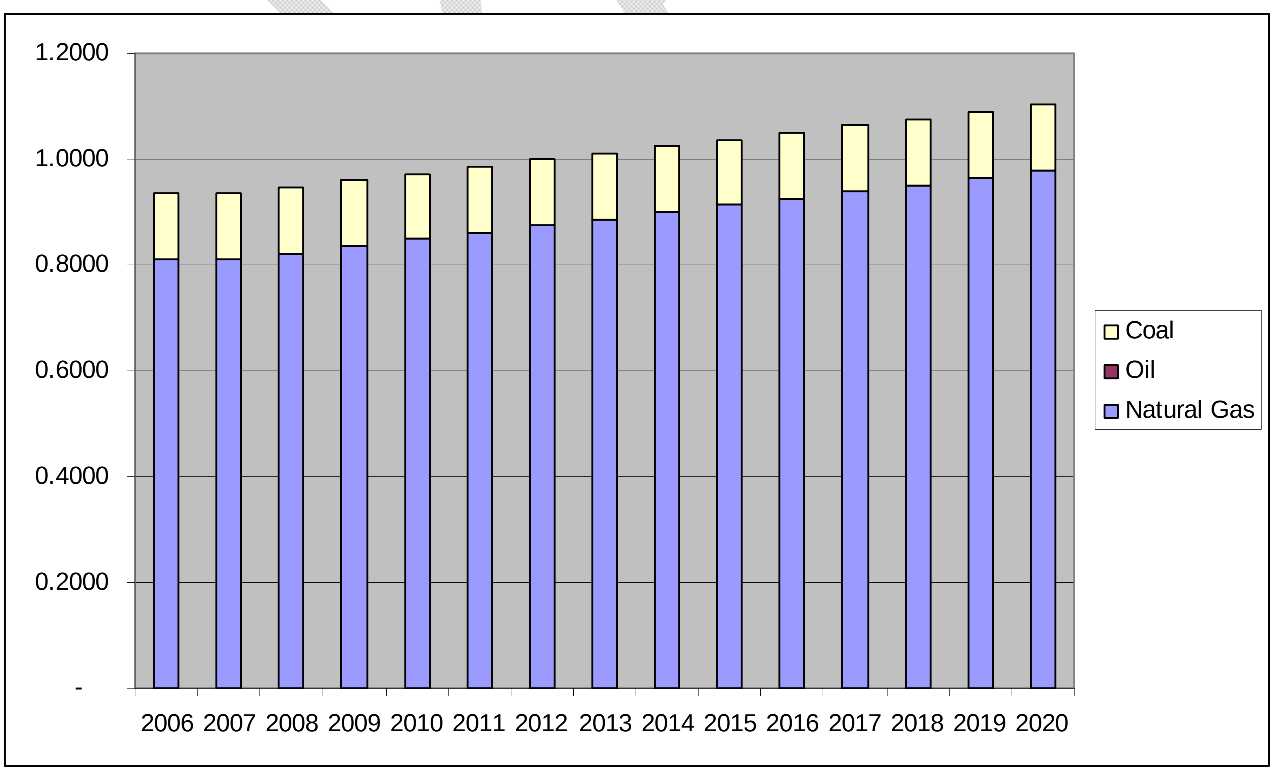
YEAR	SIT Emission Estimate for the Natural Gas Industry	Growth Factor from 2006 Base	Source of DATA
2007	0.81	0.998	Regression Analysis
2008	0.82263	1.014	Regression Analysis
2009	0.83554	1.03	Regression Analysis
2010	0.84845	1.045	Regression Analysis
2011	0.86137	1.061	Regression Analysis
2012	0.87428	1.077	Regression Analysis
2013	0.88719	1.093	Regression Analysis
2014	0.9001	1.109	Regression Analysis
2015	0.91302	1.125	Regression Analysis
2016	0.92593	1.141	Regression Analysis
2017	0.93884	1.157	Regression Analysis
2018	0.95175	1.173	Regression Analysis
2019	0.96467	1.189	Regression Analysis
2020	0.97758	1.205	Regression Analysis

7.6 GREENHOUSE GAS FORECAST RESULTS

Table 7-9: Projected (BAU) Emissions in the Fossil Fuel Industry Sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Fossil Fuel Industry Total	**0.94**	**0.76**	**0.77**	**0.79**	**0.80**	**0.81**	**0.82**	**0.84**	**0.85**	**0.86**	**0.87**	**0.88**	**0.90**	**0.91**	**0.92**
Natural Gas Industry	0.81	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.79
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CH_4	0.81	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.73	0.74	0.75	0.76	0.77	0.78	0.79
N_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal Mining Industry	0.13	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13
CO2	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CH4	0.13	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13
N2O	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0

FIGURE 7.1: PROJECTED (BAU) EMISSIONS IN THE FOSSIL FUEL INDUSTRY SECTOR



8.0 Agriculture

8.1 OVERVIEW

The emissions discussed in this section 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.

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 break down food and emit CH_4 as a by-product. More CH_4 is produced in ruminant livestock because of digestive activity in the large fore-stomach. Methane and N_2O emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The environmental conditions of decomposition drive the relative magnitude of emissions. In general, the more anaerobic the conditions are, the more CH_4 is produced because decomposition is aided by CH_4-producing bacteria that thrive in oxygen-limited aerobic conditions. Under aerobic conditions, N_2O emissions are dominant.

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 denitrification 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. Indirect emissions occur when nitrogen leaches to groundwater/surface runoff or volatilizes and is transported off-site before entering the nitrification/denitrification cycle.

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. Other agricultural soils emissions include CH_4 and N_2O from crop residue burning. Also, CH_4 emissions occur during rice cultivation. Finally, the practice of adding limestone and dolomite to agricultural soils results in CO_2 emissions.

8.2 DATA SOURCES

- United States Department of Agriculture (USDA) http://www.nass.usda.gov/Statistics_by_State/Maryland/index.asp.
- Fertilizers Institute; http://www.tfi.org/mediacenter/stats.cfm.
- Food and Agricultural Policy Research Institute (FAPRI) http://www.fapri.iastate.edu/outlook/2007/
- US EPA State Greenhouse Gas Inventory Tool (SIT).
- EIIP, *Volume VIII*: Chapter 8.[67]
- EIIP, *Volume VIII*: Chapter 10.[68]
- EIIP, *Volume VIII*: Chapter 11.[69]

8.3 GREENHOUSE GAS INVENTORY METHODOLOGY

Maryland Agricultural GHG emission was estimated using the (US EPA) State Greenhouse Gas Inventory Tool (SIT) software with reference to the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector [5, 6, 7] and the national GHG inventory.[70] The input data that are needed to estimate these emissions are the populations of domestic animals, metric tonnes of nitrogen fertilizer consumed, metric tonnes of crop produced and the agriculture-waste management system adopted. The input data are multiplied by the default SIT emission factor developed for the US for each type of animal. The input data used for these calculations are shown in Table 8.1.

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[67] EIIP, Volume VIII: Chapter 8." Methods for Estimating Greenhouse Gas Emissions from Livestock Manure Management", August 2004

[68] EIIP, Volume VIII: Chapter 10." Methods for Estimating Greenhouse Gas Emissions from Agricultural Soil Management", August 2004.

[69] EIIP, Volume VIII: Chapter 11." Methods for Estimating Greenhouse Gas Emissions from Field Burning of Agricultural Residues", August 2004

[70] US Inventory of greenhouse Gas Emissions and Sinks: 1990 -2006, US Environmental Protection Agency, (April 2008). (http://epa.gov/climatechange/emissions/index.html)

8.3.1 Carbon Dioxide (CO2) Direct Emissions

Estimation of carbon dioxide (CO_2) emission from urea fertilizer, limestone and dolomite application (liming) to agriculture soils in Maryland was accounted for under the Land Use, Land use change and Forestry section of the inventory.

8.3.2 Additional Direct Emissions (CH_4, N_2O)

8.3.2.1 Methane Emissions from Domestic Animals –Enteric Fermentation.

Methane produced during digestion is a significant part of the global methane budget. As food is digested, microbes break down the organic matter creating methane by enteric fermentation. Ruminant animals, such as cows, emit an especially large amount of methane through their digestive process. In Maryland, the most significant methane from animal sources originates from livestock on farms.

8.3.2.2 Methane and N_2O from Manure management

Methane is produced by the anaerobic decomposition of the organic matter in manure. The amount of methane produced by manure varies depending on the storage system used to manage it. Emissions estimates from manure management are based on manure that is stored and treated at livestock operations. The emissions are estimated as a function of the domestic animal population, and the types of waste management systems used.

8.3.2.3 Methane and N_2O Emissions from Agricultural soils.

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 this section; in addition, emissions from fertilizer application to agricultural soil are also estimated under this subsection. Synthetic fertilizers emission was estimated by multiplying the total amount of fertilizer nitrogen consumed in Maryland by the SIT default emissions factor. This emissions factor is the amount of N_2O, in kilograms, emitted in each year, per kilogram of nitrogen applied to the soil in that year. The N_2O emissions from manure application to agriculture were estimated as a function of domestic animal population in the state in the inventory years.

Emissions from agriculture residue burnings was estimated 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, the resultant dry matter, the carbon/nitrogen content of the dry matter, and the fraction of residue burned.

Details of the input data used for the estimations are described in the input data tables;

Table 8.0: 2006 MD Input Data - Animal Populations

	Number of Animals ('000 head)
Dairy Cattle	
Dairy Cows	70
Dairy Replacement Heifers	30
Beef Cattle	
Feedlot Heifers	4
Feedlot Steer	7
Bulls	3
Calves	37
Beef Cows	49
Beef Replacement Heifers	13
Steer Stockers	18
Heifer Stockers	10
Swine	
Breeding Swine	6
Market Under 60 lbs	10
Market 60-119 lbs	6
Market 120-179 lbs	7
Market over 180 lbs	4
Poultry	
Layers	
Hens > 1 yr	2,560
Pullets	938
Chickens	16
Broilers	54,091
Turkeys	243
Other	
Sheep on Feed	0
Sheep Not on Feed	22
Goats	10
Horses	66

Table 8.1: 2006 MD Input Data - Fertilizer Consumption.

	Total Fertilizer Use (kg N)	Total N (kg) in Fertilizers (Calendar Year)
Synthetic	49,456,900	51,202,458
Organic	572,100	592,292
Dried Blood	-	-
Compost	-	-
Dried Manure	2,900	3,002
Activated Sewage Sludge	494,982	512,453
Other	74,218	76,838
Dried Manure(%)	1%	1%
Non-Manure Organics	569,200	589,290
Manure Organics	2,900	39,420,248
Non-Manure Organics	2,900	369,980

Table 8.2: 2006 MD Input Data - Crop Productions.

Crop Type	Units	Crop Production	Crop Production (metric tons)
Alfalfa	'000 tons	156	141,523
Corn for Grain	'000 bushels	60,350	1,532,959
All Wheat	'000 bushels	8,500	231,331
Barley	'000 bushels	2,784	60,613
Soybeans	'000 bushels	15,810	430,280
TOTAL			**2,396,707**

Table 8.3: 2006 MD Crop Residues Dry Matter Burned.

Crop	Crop Production (metric tons)	Residue/Crop Ratio	Fraction Residue Burned	Dry Matter Fraction	Burning Efficiency	Combustion Efficiency	Amt of Dry Matter Burned (metric tons)
Barley	60,613	1.2	0.03	0.93	0.930	0.880	1,660.7981
Corn	1,532,959	1.0	0.03	0.91	0.930	0.880	34,249.8601
Peanuts	-	1.0	0.03	0.86	0.930	0.880	-
Rice	-	1.4		0.91	0.930	0.880	-
Soybeans	430,280	2.1	0.03	0.87	0.930	0.880	19,300.8563
Sugarcane	-	0.8	0.03	0	0.930	0.880	-
Wheat	231,331	1.3	0.03	0.93	0.930	0.880	6,866.6830

Table 8.4: 2006 CH_4 Generation from Manure Management.

	Number of Animals ('000 head)	Typical Animal Mass (TAM) (kg)	Volatile Solids (VS) [kg VS/1000 kg animal mass/day]	Total VS (kg/yr)	Max Pot. Emissions (m^3 CH_4/ kg VS)	Weighted MCF	CH_4 Emissions (m^3)
Dairy Cattle							
Dairy Cows	70	604	7.8	119,744,062	0.24	0.117	3,352,621
Dairy Replacement Heifers	30	476	6.7	34,896,873	0.17	0.012	73,652
Beef Cattle							
Feedlot Heifers	4	420	3.5	2,098,088	0.33	0.013	9,041
Feedlot Steer	7	420	3.2	3,599,128	0.33	0.013	15,394
Bulls	3	750	6.0	4,960,350	0.17	0.011	9,276
Calves	37	118	6.4	10,214,912	0.17	0.011	19,102
Beef Cows	49	533	6.9	65,938,592	0.17	0.011	123,305
Beef Replacement Heifers	13	420	7.5	14,922,891	0.17	0.011	27,906
Steer Stockers	18	318	7.9	16,586,863	0.17	0.011	31,017
Heifer Stockers	10	420	8.3	12,777,341	0.17	0.011	23,894
Swine							
Breeding Swine	6	198	2.6	1,127,412	0.48	0.296	160,265
Market Under 60 lbs	10	16	8.8	510,066	0.48	0.297	72,627
Market 60-119 lbs	6	41	5.4	480,136	0.48	0.297	68,366
Market 120-179 lbs	7	68	5.4	935,713	0.48	0.297	133,234
Market over 180 lbs	4	91	5.4	715,473	0.48	0.297	101,875
Poultry							
Layers							
Hens > 1 yr	2,560	2	10.8	18,164,736	0.39	0.051	361,127
Pullets	938	2	9.7	5,977,780	0.39	0.051	118,842
Chickens	16	2	10.8	113,530	0.39	0.051	2,257
Broilers	54,091	1	15	266,532,954	0.36	0.015	1,439,278
Turkeys	243	7	9.7	5,858,339	0.36	0.015	31,635
Other							
Sheep on Feed	0	27	9.2	-	0.36	0.012	-
Sheep Not on Feed	22	27	9.2	1,995,840	0.19	0.011	4,171
Goats	10	64	9.5	2,138,335	0.17	0.011	3,998
Horses	66	450	10	107,601,818	0.33	0.011	391,268
TOTAL							**6,574,150**

Table 8.5: 2006 N_2O Generation from Manure Management.

	Number of Animals ('000 head)	Typical Animal Mass (TAM) (kg)	Nitrogen Produced (kg/1000 kg Animal mass/day)	Total K-Nitrogen Excreted (kg)
Dairy				
Dairy Cows	70	604	0.440	6,790,168
Dairy Replacement Heifers	30	476	0.310	1,615,782
Beef Cattle				
Feedlot Heifers	4	420	0.300	179,913
Feedlot Steer	7	420	0.300	340,096
Swine				
Breeding Swine	6	198	0.235	101,901
Market Under 60 lbs	10	16	0.600	34,777
Market 60-119 lbs	6	41	0.420	37,344
Market 120-179 lbs	7	68	0.420	72,778
Market over 180 lbs	4	91	0.420	55,648
Poultry				
Layers				
Hens > 1 yr	2,560	2	0.830	1,395,994
Pullets	938	2	0.620	382,085
Chickens	16	2	0.830	8,725
Broilers	54,091	1	1.100	19,545,750
Turkeys	243	7	0.740	446,925
Other				
Sheep on Feed	0	27	0.420	-
Sheep Not on Feed	22	27	0.420	91,060
TOTAL				**31,098,945**

Table 8.6: 2006 Agriculture Crop Residue Nitrogen Generated (kg)

Crop Type	Crop Production (metric tons)	Residue ; Crop Mass Ratio	Fraction Residue Applied	Residue Dry Matter Fraction	N Content of Residue	N Returned to Soils (kg)	N- content of aboveground Biomass for N-fixing Crop	N-Fixed by Crops (kg)
Alfalfa	141,523	0	0	0.85	NA	NA	0.03	3,608,842
Corn for Grain	1,532,959	1	0.9	0.91	0.0058	7,281,863		NA
All Wheat	231,331	1.3	0.9	0.93	0.0062	1,560,612		NA
Barley	60,613	1.2	0.9	0.93	0.0077	468,776		NA
Sorghum for Grain		1.4	0.9	0.91	0.0108			NA
Oats		1.3	0.9	0.92	0.0070			NA
Rye		1.6	0.9	0.90	0.0048			NA
Millet		1.4	0.9	0.89	0.0070			NA
Rice		1.4		0.91	0.0072			NA
Soybeans	430,280	2.1	0.9	0.87	0.0230	16,272,720	0.03	34,813,962
Peanuts		1	0.9	0.86	0.0106			-
Dry Edible Beans		2.1	1.6	0.87	0.0168			-
Dry Edible Peas		1.5	0.9	0.87	0.0168			-
Austrian Winter Peas		1.5	0.9	0.87	0.0168			-
Lentils		2.1	1.6	0.87	0.0168			-
Wrinkled Seed Peas		1.5	0.9	0.87	0.0168			-
Red Clover						NA		-
White Clover						NA		-
Birdsfoot Trefoil						NA		-
Arrowleaf Clover						NA		-
Crimson Clover						NA		-
TOTAL	**2,396,707**					**25,583,970**		**38,422,804**

8.4 GREENHOUSE GAS INVENTORY RESULTS

Table 8.7: 2006 CH_4 Emissions from Enteric fermentation

Animal	Number of Animals ('000 head)	Emission Factor (kg CH_4/head)	Emissions (kg CH_4/year)	Emissions (MMT-CH_4/Year)	Emissions ($MMTCO_2E$)
Dairy Cattle					
Dairy Cows	70	129.1	129.1	9,040,054	0.190
Dairy Replacement Heifers	30	62.6	62.6	1,877,403	0.039
Beef Cattle					
Beef Cows	49	93.5	93.5	4,580,184	0.096
Beef Replacement Heifers	13	65.8	65.8	855,763	0.018
Heifer Stockers	10	59.1	59.1	591,105	0.012
Steer Stockers	18	57.3	57.3	1,031,677	0.022
Feedlot Heifers	4	33.2	33.2	129,873	0.003
Feedlot Steer	7	32.2	32.2	237,853	0.005
Bulls	3	53.0	53.0	159,000	0.003
Other					
Sheep	22	8.0	8.0	176,000	0.004
Goats	10	5.0	5.0	48,005	0.001
Swine	33	1.5	1.5	49,500	0.001
Horses	66	18.0	18.0	1,179,198	0.025
TOTAL				**19,955,616**	**0.419**

Table 8.8: 2006 CH_4 Emissions from Manure Management

	Emissions (m^3 CH_4)	Emissions (Metric Tons CH_4)	Emissions ($MMTCH_4$)	Emissions ($MMTCO_2E$)
Dairy Cattle				
Dairy Cows	3,352,621	2,273	0.002	0.048
Dairy Replacement Heifers	73,652	50	0.000	0.001
Beef Cattle				
Feedlot Heifers	9,041	6	0.000	0.000
Feedlot Steer	15,394	10	0.000	0.000
Bulls	9,276	6	0.000	0.000
Calves	19,102	13	0.000	0.000
Beef Cows	123,305	84	0.000	0.002
Beef Replacement Heifers	27,906	19	0.000	0.000
Steer Stockers	31,017	21	0.000	0.000
Heifer Stockers	23,894	16	0.000	0.000
Swine				
Breeding Swine	160,265	109	0.000	0.002
Market Under 60 lbs	72,627	49	0.000	0.001
Market 60-119 lbs	68,366	46	0.000	0.001
Market 120-179 lbs	133,234	90	0.000	0.002
Market over 180 lbs	101,875	69	0.000	0.001
Poultry				
Layers				
Hens > 1 yr	361,127	245	0.000	0.005
Pullets	118,842	81	0.000	0.002
Chickens	2,257	2	0.000	0.000
Broilers	1,439,278	976	0.001	0.020
Turkeys	31,635	21	0.000	0.000
Other				
Sheep on Feed	-	-	0.000	0.000
Sheep Not on Feed	4,171	3	0.000	0.000
Goats	3,998	3	0.000	0.000
Horses	391,268	265	0.000	0.006
TOTAL	**6,574,150**	**4,457**	**0.004**	**0.094**

Table 8.9: 2006 CH_4 from Agricultural Residue Burning

Crop	Crop Production (metric tons)	Amt of Dry Matter Burned (metric tons)	Carbon Content (tons C/ tons dm)	Total C Released (metric tons C)	CH_4-C Emission ratio	CH_4 Emission (metric tons CH_4)	CH_4 GWP	CH_4 Emissions ($MMTCO_2E$)
Barley	60,613	1,660.7981	0.4485	745	0.007	4.97	21	0.0001
Corn	1,532,959	34,249.8601	0.4478	15,337	0.007	102.25	21	0.0021
Peanuts	-	-	0.4500	-	0.007	-	21	-
Rice	-	-	0.3806	-	0.007	-	21	-
Soybeans	430,280	19,300.8563	0.4500	8,685	0.007	57.90	21	0.0012
Sugarcane	-	-	0.4235	-	0.007	-	21	-
Wheat	231,331	6,866.6830	0.4428	3,041	0.007	20.27	21	0.0004
Total CH_4 from Agriculture Residue Burning ($MMTCO_2E$)								**0.0039**

Table 8.10: 2006 N_2O from Agricultural Residue Burning

Crop	Crop Production (metric tons)	Amt of Dry Matter Burned (metric tons)	N Content (metric tons N/ metric tons dm)	Total N Released (metric tons N)	N_2O -N Emission Ratio	(N_2O - N) Emissions (metric tons N_2O)	N_2O Emissions (metric tons N_2O)	N_2O GWP	N_2O Emissions ($MMTCO_2E$)
Barley	60,613	1,660.7981	0.0077	12.79	0.007	0.09	0.1407	310	0.00004
Corn	1,532,959	34,249.8601	0.0058	198.65	0.007	1.39	2.1851	310	0.00068
Peanuts	-	-	0.0106	-	0.007	-	0.0000	310	-
Rice	-	-	0.0072	-	0.007	-	0.0000	310	-
Soybeans	430,280	19,300.8563	0.023	443.92	0.007	3.11	4.8831	310	0.00151
Sugarcane	-	-	0.004	-	0.007	-	0.0000	310	-
Wheat	231,331	6,866.6830	0.0062	42.57	0.007	0.30	0.4683	310	0.00015
Total N_2O from Agriculture Residue Burning ($MMTCO_2E$)									**0.00238**

Table 8.11: 2006 N_2O Emissions from Manure Management

	Total N Emission from Manure Management (kg N_2O-N)	Total N Emission from Manure Management (kg N_2O)	Total N_2O Emission (MMT)	Total N_2O Emission from Manure Management ($MMTCO_2E$)
Dairy				
Dairy Cows	36,870.6	57,940	0.00006	0.0180
Dairy Replacement Heifers	16,206.3	25,467	0.00003	0.0079
Beef Cattle				
Feedlot Heifers	3,598.3	5,654	0.00001	0.0018
Feedlot Steer	6,801.9	10,689	0.00001	0.0033
Swine				
Breeding Swine	157.9	248	0.00000	0.0001
Market Under 60 lbs	53.9	85	0.00000	0.0000
Market 60-119 lbs	57.9	91	0.00000	0.0000
Market 120-179 lbs	112.8	177	0.00000	0.0001
Market over 180 lbs	86.3	136	0.00000	0.0000
Poultry				
Layers				
Hens > 1 yr	6,700.8	10,530	0.00001	0.0033
Pullets	1,834.0	2,882	0.00000	0.0009
Chickens	41.9	66	0.00000	0.0000
Broilers	390,915.0	614,295	0.00061	0.1904
Turkeys	8,938.5	14,046	0.00001	0.0044
Other	0.0	0		
Sheep on Feed	0.0	0	0.00000	0.0000
Sheep Not on Feed	0.0	0	0.00000	0.0000
TOTAL		**742,305**	**0.000742**	**0.2301**

Table 8.12: 2006 Direct N_2O Emissions from Fertilizer Application (Agriculture Soils).

	Synthetic Fertilizer	Organic Fertilizer
Total Fertilizer Use (kg N)	49,456,900	572,100
Total N in Fertilizers (Calendar Year)	51,202,458	592,292
Volatilization Rate	10%	20%
Nitrogen Content of Fertilizer	0	4.1%
Unvolatized N (kg)	46,082,212	19,427
Direct Emission factor (N_20 -N)	0.0100	0.0125
Direct Emission (kg N_20 -N)	460,822	243
Direct Emission (kg N_20)	724,149	382
Direct Emission (metric tons N_20)	724	0.3816
Direct Emission (MMT N_20)	0.0007	0.000000
Direct Emission ($MMTCO_2E$)	0.2245	0.0001
Total Direct Emission ($MMTCO_2E$)	**0.2246**	

Table 8.13: 2006 Indirect N_2O Emissions from Fertilizer Application (Released to Atmosphere)

	Synthetic Fertilizer	Organic Fertilizer
Total Fertilizer Use (kg N)	49,456,900	572,100
Total N in Fertilizers (Calendar Year)	51,202,458	592,292
Volatilization Rate	10%	20%
Nitrogen Content of Fertilizer	0	4.1%
Volatized N (kg)	5,120,246	4,857
N_2O from Volatilization Emission Factor (N_20 -N)	0.01	0.01
Indirect Emission (kg N_20 -N)	51,202	49
Indirect Emission (kg N_20)	80,461	76
Indirect Emission (metric tons N_20)	80	0.0763
Indirect Emission (MMT N_20)	0.00008	0.00000008
Indirect Emission ($MMTCO_2E$)	0.0249	0.0000
Total Indirect Emission ($MMTCO_2E$)	**0.0250**	

Table 8.14: 2006 Indirect N_2O Emissions from Fertilizer Application (Runoff /Leaching).

	Synthetic Fertilizer	Organics Fertilizer	Manure Excreted
Total Fertilizer Use (kg N)	49,456,900	572,100	
Total N in Fertilizers-kg (Calendar Year)	51,202,458	592,292	39,420,248
Volatilization Rate	10%	20%	0%
Nitrogen Content of Fertilizer	100%	4.1%	100%
Unvolatized N (kg)	46,082,212	19,427	39,420,248
Leached / Runoff Rate	30%	30%	30%
Leached / Runoff N (kg)	13,824,664	142,150	11,826,075
Indirect Emission factor (N_20 -N)	0.0075	0.0075	0.0075
Indirect Emission (kg N_20 -N)	103,685	1,066	88,696
Indirect Emission (kg N_20)	162,934	1,675	139,379
Leached /Runoff Emission (metric tons N_20)	163	1.6753	139
Indirect Emission (MMT N_20)	0.000163	0.000002	0.000139
Leached /Runoff Emission ($MMTCO_2E$)	0.0505094	0.0005194	0.0432074
Total Leached /Runoff Emission ($MMTCO_2E$)		**0.0942**	

Table 8.15: 2006 Direct N_2O Emissions from Agriculture Crop Residue

	Crop Residues	**Legumes**
	N Returned to Soils (kg)	**N-Fixed by Crops (kg)**
	25,583,970	38,422,804
Direct N_2O Emissions Factor	0.0100	0.0100
Direct N_2O Emission kg (N_2O -N)/ Yr	255,839.7	384,228.0
Direct N_2O Emission (kg N_2O)	402,034	603,787
Direct N_2O Emission (metric tons)	402	604
Direct N_2O Emission (MMT)	0.0004	0.0006
Direct Emissions ($MMTCO_2E$)	0.1246	0.1872
Total N_2O Emission from Residue ($MMTCO_2E$)	**0.3118**	

Table 8.16: 2006 N_2O Emissions from Manure Application

	Livestock Emissions (metric tons N_2O)	**N_2O GWP**	**Livestock Emissions** (MMT CO_2E)
Indirect N_2O Emissions	123.89	310	0.0384
Direct N_2O Emissions -Manure Applied to Soil	754.32	310	0.2338
Direct N_2O Emissions -Pasture, Range and Paddock	297.87	310	0.0923
Sum Direct N_2O Emissions	**1,052.19**		**0.3262**
Total Animal N_2O Emissions ($MMTCO_2E$)	**0.3646**		

Table 8.17: 2006 Indirect N_2O Emissions from Animal Waste Runoff (Released to the Atmosphere).

	Number of Animals ('000 head)	**Total K-Nitrogen Excreted** (kg)	**Volatilization Rate**	**NH_3-NOx Emission Factor**	**Indirect Animal N_2O Emissions** (metric tons N)	**Indirect Animal N_2O Emissions** (metric tons N_2O)	**N_2O GWP**	**Indirect Animal N_2O Emissions** ($MMTCO_2E$)
Dairy Cattle								
Dairy Cows	70.0	6,790,168	20%	1%	14	21.34	310	0.0066
Dairy Replacement Heifers	30.0	1,615,782	20%	1%	3	5.08	310	0.0016
Beef Cattle								
Feedlot Heifers	3.9	179,913	20%	1%	0.36	0.57	310	0.0002
Feedlot Steer	7.4	340,096	20%	1%	0.68	1.07	310	0.0003
Bulls	3.0	254,588	20%	1%	1	0.80	310	0.0002
Calves	37.0	478,077	20%	1%	1	1.50	310	0.0005
Beef Cows	49.0	3,145,793	20%	1%	6.29	9.89	310	0.0031
Steer Stockers	13.0	467,762	20%	1%	0.94	1.47	310	0.0005
Total Beef Heifers	23.0	1,093,029	20%	1%	2	3.44	310	0.0011
Swine								
Breeding Swine	6.0	101,901	20%	1%	0	0.32	310	0.0001
Market Under 60 lbs	10.0	34,777	20%	1%	0	0.11	310	0.0000
Market 60-119 lbs	6.0	37,344	20%	1%	0	0.12	310	0.0000
Market 120-179 lbs	7.0	72,778	20%	1%	0	0.23	310	0.0001
Market over 180 lbs	4.0	55,648	20%	1%	0	0.17	310	0.0001
Poultry								
Layers								
Hens > 1 yr	2,560.0	1,395,994	20%	1%	3	4.39	310	0.0014
Pullets	938.0	382,085	20%	1%	1	1.20	310	0.0004
Chickens	16.0	8,725	20%	1%	0	0.03	310	0.0000
Broilers	54,090.9	19,545,750	20%	1%	39	61.43	310	0.0190
Turkeys	-	-						
Other								
Sheep on Feed	-	-						
Sheep Not on Feed	22.0	91,060	20%	1%	0	0.29	310	0.0001
Goats	9.6	100,926	20%	1%	0	0.32	310	0.0001
Horses	65.5	**3,228,055**	20%	1%	6	10.15	310	0.0031
TOTAL		39,420,248			79	123.89		**0.0384**

Table 8.18: 2006 Direct N_2O Emissions from Manure Applied to Soil

	Number of Animals ('000 head)	**K-N Excreted by System (kg)** Managed Systems	**Volatili-zation Rate**	**Ground Nitrogen Emission Factor**	**Poultry Manure Not Mnage**	**Direct Animal N_2O Emissions** (metric tons N) Manure Applied to Soils	**Direct Animal N_2O Emissions** (metric tons N_2O)	**N_2O GWP**	**Direct Animal N_2O Emissions** ($MMTCO_2E$)
Dairy Cattle									
Dairy Cows	70	3,328,753	20%	0.0125		63.42	99.66	310	0.0309
Dairy Replacement Heifers	30	792,107	20%	0.0125		15.09	23.72	310	0.0074
Beef Cattle									
Feedlot Heifers	4	179,913	20%	0.0125		1.80	2.83	310	0.0009
Feedlot Steer	7	340,096	20%	0.0125		3.40	5.34	310	0.0017
Bulls	3	NA	20%						-
Calves	37	NA	20%						-
Beef Cows	49	NA	20%						-
Steer Stockers	13	NA	20%						-
Total Beef Heifers	23	NA	20%						-
Swine									
Breeding Swine	6	80,358	20%	0.0125		0.80	1.26	310	0.0004
Market Under 60 lbs	10	27,425	20%	0.0125		0.27	0.43	310	0.0001
Market 60-119 lbs	6	29,449	20%	0.0125		0.29	0.46	310	0.0001
Market 120-179 lbs	7	57,392	20%	0.0125		0.57	0.90	310	0.0003
Market over 180 lbs	4	43,884	20%	0.0125		0.44	0.69	310	0.0002
Poultry									
Layers									
Hens > 1 yr	2,560	1,395,994	20%	0.0125	4.20%	13.37	21.02	310	0.0065
Pullets	938	382,085	20%	0.0125	4.20%	3.66	5.75	310	0.0018
Chickens	16	8,725	20%	0.0125	4.20%	0.08	0.13	310	0.0000
Broilers	54,091	19,545,750	20%	0.0125	4.20%	187.25	294.25	310	0.0912
Turkeys	-	-							
Other									
Sheep on Feed	-	-							
Sheep Not on Feed	22	-	20%					310	-
Goats	10	NA	20%					310	-
Horses	66	NA	20%					310	-
TOTAL						**290.47**	**456.45**		**0.1415**

Table 8.19: 2006 Direct N_2O Emissions from Pasture, Range and Paddock.

	Number of Animals ('000 head)	K-N Excreted by System (kg):	Direct Animal N_2O Emissions (metric tons N)	Direct Animal N_2O Emissions (metric tons N_2O)	N_2O GWP	Direct Animal N_2O Emissions ($MMTCO_2E$)
		Unmanaged Systems - Pasture, Range, and Paddock		Pasture, Range, and Paddock		
Dairy Cattle						
Dairy Cows	70.0	447,882	8.96	14.08	310	0.0044
Dairy Replacement Heifers	30.0	106,578	2.13	3.35	310	0.0010
Beef Cattle						
Feedlot Heifers	3.9	NA				
Feedlot Steer	7.4	NA				
Bulls	3.0	254,588	5.09	8.00	310	0.0025
Calves	37.0	478,077	9.56	15.03	310	0.0047
Beef Cows	49.0	3,145,793	62.92	98.87	310	0.0306
Steer Stockers	13.0	467,762	9.36	14.70	310	0.0046
Total Beef Heifers	23.0	1,093,029	21.86	34.35	310	0.0106
Swine						
Breeding Swine	6.0	21,543	0.43	0.68	310	0.0002
Market Under 60 lbs	10.0	7,352	0.15	0.23	310	0.0001
Market 60-119 lbs	6.0	7,895	0.16	0.25	310	0.0001
Market 120-179 lbs	7.0	15,386	0.31	0.48	310	0.0001
Market over 180 lbs	4.0	11,764	0.24	0.37	310	0.0001
Poultry						
Layers						
Hens > 1 yr	2,560.0	NA				
Pullets	938.0	NA				
Chickens	16.0	NA				
Broilers	54,090.9	NA				
Turkeys	-	-				
Other						
Sheep on Feed	-	-				
Sheep Not on Feed	22.0	91,060	1.82	2.86	310	0.0009
Goats	9.6	100,926	2.02	3.17	310	0.0010
Horses	65.5	3,228,055	64.56	101.45	310	0.0315
TOTAL			**189.55**	297.87		**0.0923**

8.5 GREENHOUSE GAS FORECAST METHODOLOGY

8.5.1 Enteric Fermentation

Emissions from enteric fermentation were projected based on an analysis of historical animal populations, projected animal populations and resulting enteric emissions. The trend in animal population has been downward since 1990; however since 2001 animal populations have been relatively stable. Projections for all livestock categories, except sheep, were estimated based on linear forecasts of the historical 2001- 2006 populations. The sheep population fluctuated greatly during the 1990-2006 period and linear projection resulted in a negative sheep population. As a result, no growth is projected for the sheep population after 2006. Projected enteric fermentation emissions were calculated using the projected livestock population. The total enteric emissions per year were divided by the 2006 base year emissions to arrive at a growth factor for the enteric fermentation source category. Enteric fermentation growth rates are shown in Table 8-20.

8.5.2 Manure Management

Emissions from manure management were projected based on an analysis of historical animal populations, projected animal populations and resulting enteric emissions. The trend in animal population has been downward since 1990; however since 2001 animal populations have been relatively stable. Projections for all livestock categories, except sheep, were estimated based on linear forecasts of the historical 2001- 2006 populations. The sheep population fluctuated greatly during the 1990-2006 period and linear projection resulted in a negative sheep population. As a result, no growth is projected for the sheep population after 2006. Projected manure management emissions were calculated using the projected livestock population. The total manure management emissions per year per pollutant were divided by the 2006 base year emissions to arrive at a growth factor for the manure management source category. Manure management growth rates are shown in Table 8-20.

8.5.3 Agricultural Soils

Projections for agricultural soils were based on linear extrapolation of the 1990-2005 historical data. Table 8-20 shows the 2006-2020 annual growth rates estimated for each category.

8.5.4 Agricultural Burning

Projections for agricultural burning were based on linear extrapolation of the 1990-2005 historical data. Table 8-20 shows the 2006-2020 annual growth rates estimated for each category.

Table 8.20: Growth Factors for the Agriculture Source Sectors

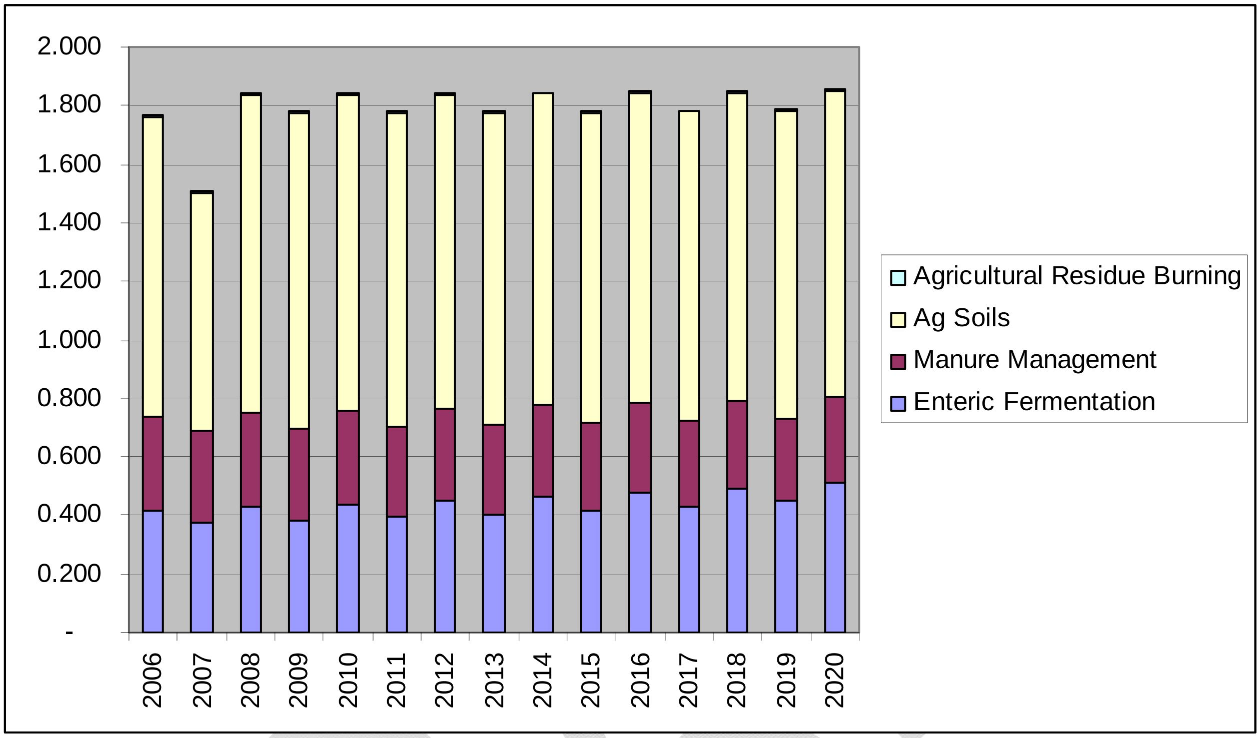
YEAR	Growth Factor from 2006 Base				
	Enteric Fermentation	CH_4 Manure Management	N_2O Manure Management	Agricultural Soils	Agricultural Burning
2007	0.89875	0.927354	0.978587	0.801753	0.74495
2008	1.021242	1.009238	1.000519	1.063456	0.951735
2009	1.022824	0.996781	1.000701	1.060344	0.947612
2010	1.024405	0.984324	1.000884	1.057233	0.943489
2011	1.023918	0.971867	1.001066	1.054122	0.939366
2012	1.025551	0.95941	1.001249	1.051011	0.935243
2013	1.027184	0.946953	1.001431	1.0479	0.93112
2014	1.028817	0.934496	1.001613	1.044789	0.926997
2015	1.03045	0.922039	1.001796	1.041678	0.922875
2016	1.032083	0.909582	1.001978	1.038567	0.918752
2017	1.033716	0.897125	1.002161	1.035455	0.914629
2018	1.035349	0.884668	1.002343	1.032344	0.910506
2019	1.036982	0.872211	1.002525	1.029233	0.906383
2020	1.038615	0.859754	1.002708	1.026122	0.90226

8.6 GREENHOUSE GAS FORECAST RESULTS

Table 8-21: Projected (BAU) Emissions in the Agricultural Sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Enteric Fermentation	0.419	0.377	0.428	0.385	0.438	0.394	0.450	0.405	0.463	0.418	0.477	0.432	0.494	0.448	0.513
Manure Management	0.321	0.310	0.322	0.310	0.321	0.307	0.318	0.303	0.312	0.298	0.305	0.291	0.297	0.283	0.289
Ag Soils	1.020	0.818	1.084	1.081	1.078	1.075	1.072	1.069	1.065	1.062	1.059	1.056	1.053	1.049	1.046
Ag Residue Burning	0.006	0.005	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Total	**1.766**	**1.509**	**1.840**	**1.782**	**1.843**	**1.783**	**1.845**	**1.783**	**1.846**	**1.783**	**1.848**	**1.784**	**1.850**	**1.786**	**1.854**

FIGURE 8.1: PROJECTED (BAU) EMISSIONS IN THE AGRICULTURAL SECTOR



9.0 Waste Management

9.1 OVERVIEW

Greenhouse gas (GHG) emissions from waste management include:

- Solid waste management
  - methane (CH_4) emissions from waste decomposition at municipal and industrial solid waste landfills, 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 controlled combustion of solid waste in incinerators or waste to energy plants or open burning of waste (e.g. at city dumps or in residential burn barrels); and
- Wastewater (WW) management
  - CH_4 and N_2O from municipal wastewater
  - CH_4 from industrial WW treatment facilities.

9.2 DATA SOURCES

- EPA Landfill Gas Emissions Models Version 3.02. http://www.epa.gov/ttn/catc/products.html#software. http://www.epa.gov/ttn/catc/dir1/landgem-v302-guide.pdf.

- MDE's Annual Emissions Certification Reports

- MDE's Annual Solid Waste Reports

- US EPA State Greenhouse Gas Inventory Tool (SIT) http://www.epa.gov/statelocalclimate/resources/tool.html

- EPA Mandatory Greenhouse Gas Reporting Rule (40 CFR Part 98) http://www.epa.gov/climatechange/emissions/ghgrulemaking.html

9.3 GREENHOUSE GAS INVENTORY METHODOLOGY

Historic GHG emissions (1990 – 2005) from municipal solid waste (MSW) landfills in Maryland was estimated by MDE using the default input data (tonnes of waste –in-place) of 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.[1] The key factor in the estimation of Landfill emissions is the rate of CH_4 generation within the waste mass. Although other factors, such as the rate of oxidation as CH_4 passes through overlying soil, and the presence and efficiency of landfill gas collection systems are also important.

For the base year (2006) , MDE estimated the MSW landfills GHG emissions inventory from the available MSW Landfills data, with landfills specific input data (year opened, year closed, waste acceptance rate) and control device information (LFG collection efficiency and flares efficiency), from the State's Title V permit (Annual Compliance Certification Report). MDE solid waste Department provided addition list of landfills in the state with annual waste emplacement data that were used to supplement the Title V permit landfills. These additional data included information on many sites that do not submit annual compliance certification report, as well as updated information on sites that do submit. (E.g. waste emplacement data, information on control devices).

Maryland's MSW Landfills were classified into two main groups; Controlled and Uncontrolled Landfills. Controlled Landfill sites have devices installed on them to collect the Landfill gases (LFG) which are either flared or combusted to generate energy or electricity (LFGTGE) while uncontrolled landfill sites does not have any LFG collection devices.

In 2006, there were 39 active sites in Maryland. Nine of these sites are controlled by flares, two are landfill- gas- to- energy (LFGTE) plants, the rest (28) of the sites were assumed to be uncontrolled. The list of landfills did not include the approximately 300 small town landfills that have closed since 1960.

9.3.1 Carbon Dioxide (CO_2) Direct Emissions

9.3.1.1 Municipal Solid Waste Landfills

Estimation of carbon dioxide (CO_2) emission from Landfill gas flaring / conversion to energy generation was based on the amount of CH_4 collected by the collection system from the total amount of CH_4 generated from the Landfill and the control devices efficiency. CO_2 emission estimate was based on the stoichiometric combustion reaction; equation (1) below.

$$CH_4 + 2O_2 \Rightarrow CO_2 + 2H_2O$$ …………….. (Equation 1)

1 Kmol CH_4 => 1 Kmol CO_2
16 g CH_4 => 44 g CO_2
1 g CH_4 => 2.75 g CO_2

9.3.1.2 Municipal Solid Waste Combustion

Carbon dioxide (CO_2) emission from Municipal Solid Waste (MSW) combustion in incinerators was estimated by multiplying the tonnages of MSW combusted in Maryland in 2006 by the default EPA Municipal Solid Waste heat value and CO_2 emission factor[1].

[1] Emission Inventory Improvement Program, Volume VIII: Chapter. 13. "Methods for Estimating Greenhouse Gas Emissions from Municipal Solid Waste", August 2004.

9.3.1.3 Open Burning Combustion

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.[2] 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.

9.3.2 Additional Direct Emissions (CH_4 and N_2O)

9.3.2.1 Methane Gas Emissions from Landfill Gas

MDE calculated the 2006 methane (CH_4) emissions from the Municipal Solid Waste (MSW) landfills operating in Maryland through the following steps:

1. Identified all the MSW Landfills sites that report annual emissions to the MDE Title V Compliance Program.

2. Compiled detailed information about the listed Landfill facilities, including reported amount of waste in place, LFG collection efficiency, flare control efficiency and Landfills CH_4 generation rate (LandGEM output).

3. Identified the Landfill facilities that do not report annual emissions to MDE Title V Compliance Program.

4. Compiled detailed information of Landfill facility that do not submit annual emission certificate report from the MDE Solid Waste Annual Report, including landfills ; year of opening, closure year, waste design capacity, annual waste acceptance rate from open year to current year or closure year and the collection/ control efficiencies.

5. Grouped the Landfills into broad two categories; Landfills with control device- Controlled Landfills and those without control device-Uncontrolled landfills.

6. Controlled Landfills are further sub divided into Flared Landfills and Landfill –Gas-To-Energy (LFGTE) landfills.

7. Back calculate **2006 CH_4 generation rate** from available data. (No CH_4 generation rate data was available for 2006, but waste-in-place data was available).

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[1] Table C -1 To Subpart C of Part 98- Default CO2 Emission factors and High Heat Values for Various Type of Fuel. Federal Register, Vol.74, No.209.

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

8. Applied CH_4 GWP to CH_4 generated (metric tons) to estimate **MSW CH_4 generation** ($MTCO_2E$).

9. Assumed Industrial Solid Waste Landfill CH_4 generation = 7% of MSW CH_4 Generation.

10. Estimated **Industrial Solid Waste Landfills**, CH_4 generation ($MTCO_2E$).

11. Summed both MSW and Industrial Solid Waste CH_4 generation to obtain **Potential CH_4** ($MTCO_2E$)

12. Applied Landfills specific LFG collection efficient to CH_4 generated to estimate amount of **CH_4 collected.**
13. Applied Landfills specific flare control efficiency to the amount of CH_4 collected to estimate amount of **CH_4 flared and Landfill –Gas-To- Energy (LFGTE)** CH_4 usage.

14. Summed both Flared CH_4 and LFGTE CH_4 to obtain **CH_4 Avoided.**

15. Subtract amount of **CH_4 collected** by the collection devices from the total amount of **CH_4 generated** (LandGEM Output) by the Municipal Solid Waste Landfills to estimate the amount of **Uncollected CH_4**.
16. Apply EPA default surface oxidation factor (10%) to **Uncollected CH_4** to estimate Municipal Landfills **fugitive CH_4 emission.**

17. Assumed Industrial Solid Waste Landfill CH_4 Uncollected = 7% of MSW CH4 Uncollected.

18. Estimated **Industrial Solid Waste Landfills**, Uncollected CH_4 ($MTCO_2E$).

19. Summed both Municipal and Industrial Uncollected CH4 to obtain **Oxidized CH_4**.

20. Calculated Net CH_4 Emissions from Landfills by Equation (2).

Net CH_4 Emissions	=	Municipal Landfill CH_4 Generation	-	Municipal Landfill CH_4 Flaring or Recovery	-	CH_4 Oxidation by Soil at MSW Landfills	+	Industrial Landfill CH_4 Generation	-	CH_4 Oxidation by Soil at Industrial Landfills

9.3.2.2 Methane Gas Emissions from Wastewater

The estimation of GHG emissions from municipal wastewater treatment were calculated using SIT based on state population, assumed biochemical oxygen demand (BOD), and emission factors for N_2O and CH_4. The key SIT default values are shown in Table 9.1.

Table 8.1: SIT Key Default Values for Municipal Wastewater Treatment.

Default Values for Municipal Wastewater Treatment Variables [74]	Value
BOD	0.09 kg /day-person
Amount of BOD anaerobically treated	16.25%
CH_4 emission factor	0.6 kg/kg BOD
Maryland residents not on septic	75%
Water treatment N_2O emission factor	4.0 g N_2O/person-yr
Biosolids emission factor	0.01 kg N_2O-N/kg sewage-N

9.4 GREENHOUSE GAS INVENTORY RESULTS

Table 9.2: 2006 CO_2 and N_2OEmissions from MSW Combustion

MSW Processed (tons)	**1,410,068.19**
CO2 Emissions	
Default high Heat Value (MMBtu/S tons)	9.95
Default CO_2 Emission factor (kg /MMBtu)	90.7
CO_2 Emissions (tons/yr)	1,402,336
CO_2 Emissions (metric tons/yr)	**1,272,199**
CO_2 Emissions (million metric tons/yr)	1.2722
N2O Emissions	
Default N_2O Emission factor (kg /MMBtu)	4.20E-03
N_2O Emissions (metric tons/yr)	64.94
N_2O GWP	310
N_2O Emissions ($MMTCO_2E$)	**0.0201**

[74] Emission Inventory Improvement Program, Volume 8, Chapter 12.

Table 9.3: 2006 GHG Emissions from Landfills

MSW CH_4 Generation (short ton CH_4)	(A)	147,220.97
CH_4 GWP	(B)	21
MSW Generation ($MTCO_2E$)	(C) = (A) x (B) x0.9072	2,804,736
Industrial Generation ($MTCO_2E$)	(D) = (C) *7%	196,332
Potential CH_4 ($MTCO_2E$)	(E) = (C) +(D)	3,001,068
Flared CH_4 (tons)	(F)	49,962
Flared CH_4 ($MTCO_2E$)	(G) = (F) *(B)	951,838
Landfill Gas-to-Energy (tons)	(H)	10,798.31
Landfill Gas-to-Energy ($MTCO_2E$)	(I) = (H)*(B)	205,721
CH_4 Avoided ($MTCO_2E$)	(J) =(I) +(G)	**1,157,559**
Oxidation at MSW Landfills (tons)	(K)	78,791.07
Oxidation at MSW Landfills ($MTCO_2E$)	(L) =(K) *(B)	1,501,064
Oxidation at Industrial Landfills ($MTCO_2E$)	(M) =(L) *7%	**105,075**
Total CH_4 Emissions ($MTCO_2E$)	(N) =(E) -(J)-(M)-(M)	**237,370**
CO_2 Emission from (Flaring + LFGTE) ($MMTCO_2E$)	(O)	**0.1516**

Table 9.4: 2006 CH_4 Emissions Calculation for Municipal Wastewater Treatment.

	Formula	Result
Population (person – 2006)	A	5,602,258
Wastewater BOD_5 Generation Rate (kg BOD_5/capital/day)	B	0.0900
Number of Days	C = 365	
BOD_5 Generated (kg BOD_5/day)	D = A * B	
Fraction of BOD_5 Removed as Sludge	E = 0.0	
Fraction of wastewater Treated Anaerobically	F =16.25%	
Quantity of BOD_5 Treated Anaerobically (kg BOD_5/yr)	G = D * (1– E) *F* C	29,905,553.49
Quantity of BOD_5 Treated Anaerobically (metric tons BOD_5/yr)	H = G/1,000	29,905.55
CH_4 Emissions Factor (G_g CH_4/ G_g BOD)	I = 0.60	
CH_4 Emissions (metric tons CH_4)	J = I* H	17,943.33
CH_4 Recovered (metric tons CH_4)	K = 0.0	
Net CH_4 Emissions (metric tons CH_4)	L = (J – K)	17,943.33
CH_4 GWP	M = 21	
Net CH_4 Emissions ($MMTCO_2E$)	**N = (L*M) /10^6**	**0.3768**

Table 9.6: 2006 N_2O Emissions from Municipal Wastewater Treatment.

	Formula	Result
Population (person – 2006)	A	5,602,258
Fraction of Population not on septic	B = 79%	79%
Direct N_2O Emission Factor from Wastewater Treatment (g N_2O/person/yr)	C = 4.0	4.0
Direct N_2O Emission from Wastewater Treatment (g N_2O)	D = (A *B*C)	17,703,135
Direct N_2O Emission from Wastewater Treatment (metric tons N_2O)	E = (D/10^6)	17.70
N_2O GWP	F = 310	310
Direct N_2O Emission from Wastewater Treatment ($MMTCO_2E$)	**G =(F * E)/10^6**	**0.005**

Table 9.7: 2006 N_2O Emissions from Biosolids Fertilizers.

	Formula	Result
Population (person – 2006)	A	5,602,258
Per Capital Protein Consumption (kg / capital/day)	B = 41.90	41.9
Protein Consumed (kg)	C = A * B	234,734,610
Fraction of Nitrogen in Protein ($FRAC_{NPR}$)	D = 16%	16%
Nitrogen Consumed (kg)	E = C *D	37,557,537.63
Fraction of Non Consumption Nitrogen	F = 1.75	1.75
Total Nitrogen in Domestic Wastewater (kg)	G = E * F	65,725,690.86
Total Nitrogen in Domestic Wastewater (metric tons)	**H = G / 1,000**	**65,725.69**
Direct N_2O Emission from Wastewater Treatment (metric tons N_2O)	I	**17.70**
Biosolids Available N (metric tons)	**J = (H – I)**	**65,707.99**
Percentage Biosolids used as Fertilizer	K= 50%	50%
Biosolids Fertilizer (metric ton N)	L = (J*K)	32,853.99
Indirect Emission factor for Biosolids fertilizer (kg N_2O-N/kg Sewage Nitrogen Produced)	M	0.01
Conversion from N to N_2O - Ratio of (N_2O-N)	N = (44/28)	1.5714
N_2O Emissions from Biosolids Fertilizer (metric tons N_2O)	O = J* (1 -K)*M*N	516.28
N_2O GWP	P	310
N_2O Emissions from Biosolids Fertilizer (MMTCO2E)	**Q =(O*P)/10^6**	**0.1600**

9.5 GREENHOUSE GAS FORECAST METHODOLOGY – Need to Finish

The projected inventories are derived by applying appropriate growth factors to the 2006 Base-Year Greenhouse Gas Emissions Inventory. The projected inventories were required to be a business-as-usual forecast and thus were not to take into account any control/reduction programs. EPA guidance describes four typical indicators of growth. In order of priority, these are product output, value added, earnings, and employment. Surrogate indicators of activity, for example population growth, are also acceptable methods.

Surrogate growth factors for future years were applied to the 2006 base year inventory. These surrogates were calculated using population and household data. Dividing the state population, and household forecasts for the analysis year by the 2006 value produced the growth factors for the projection years. The growth factors were applied to emissions categories based on a two-step process:

- Developing the appropriate state specific growth factors to be applied to the base year inventory.
- Applying the growth factors to develop emissions forecasts.

Each source category was matched to an appropriate growth surrogate based on an activity that reflected the base-year emission estimates. Surrogates were chosen as follows:

9.5.1 Solid Waste Management – Landfills

Population data was chosen as the growth surrogate for emissions from the solid waste landfill sector. Projected county level population data was collected from the Baltimore Metropolitan Council Cooperative Forecast (Round 7-B), Metropolitan Council of Governments Forecast (Round 7.2A), and Maryland Department of Planning, Planning Data Services (February, 2009). The data was compiled to provide an overall State of Maryland population forecast. Projection year population data was divided by the 2006 base year population to arrive at a growth factor for the solid waste management landfill source category. Solid waste management/landfill growth rates are shown in Table 9-8.

9.5.2 Solid Waste Combustion – Incinerators

Household data was chosen as the growth surrogate for emissions from the solid waste combustion sector. Projected county level housing data was collected from the Baltimore Metropolitan Council Cooperative Forecast (Round 7-B), Metropolitan Council of Governments Forecast (Round 7.2A), and Maryland Department of Planning, Planning Data Services (February, 2009). The data was compiled to provide an overall State of Maryland housing forecast. Projection year housing estimates were divided by the 2006 base year housing data to arrive at a growth factor for the solid waste management landfill source category. Solid waste combustion/incinerator growth rates are shown in Table 9-8.

9.5.3 Wastewater Management

Household data was chosen as the growth surrogate for emissions from the wastewater management sector. Projected county level housing data was collected from the Baltimore Metropolitan Council Cooperative Forecast (Round 7-B), Metropolitan Council of Governments Forecast (Round 7.2A), and Maryland Department of Planning, Planning Data Services (February, 2009). The data was compiled to provide an overall State of Maryland housing forecast. Projection year housing estimates were divided by the 2006 base year housing data to arrive at a growth factor for the solid waste management landfill source category. Solid waste combustion/incinerator growth rates are shown in Table 9-8.

9.5.4 Open Burning

Household data was chosen as the growth surrogate for emissions from the open burning sector. Projected county level housing data was collected from the Baltimore Metropolitan Council Cooperative Forecast (Round 7-B), Metropolitan Council of Governments Forecast (Round 7.2A), and Maryland Department of Planning, Planning Data Services (February, 2009). The data was compiled to provide an overall State of Maryland housing forecast. Projection year housing estimates were divided by the 2006 base year housing data to arrive at a growth factor for the open burning source category. Open burning growth rates are shown in Table 9-8.

Table 9-8: Growth Factors for the Waste Management Source Sector

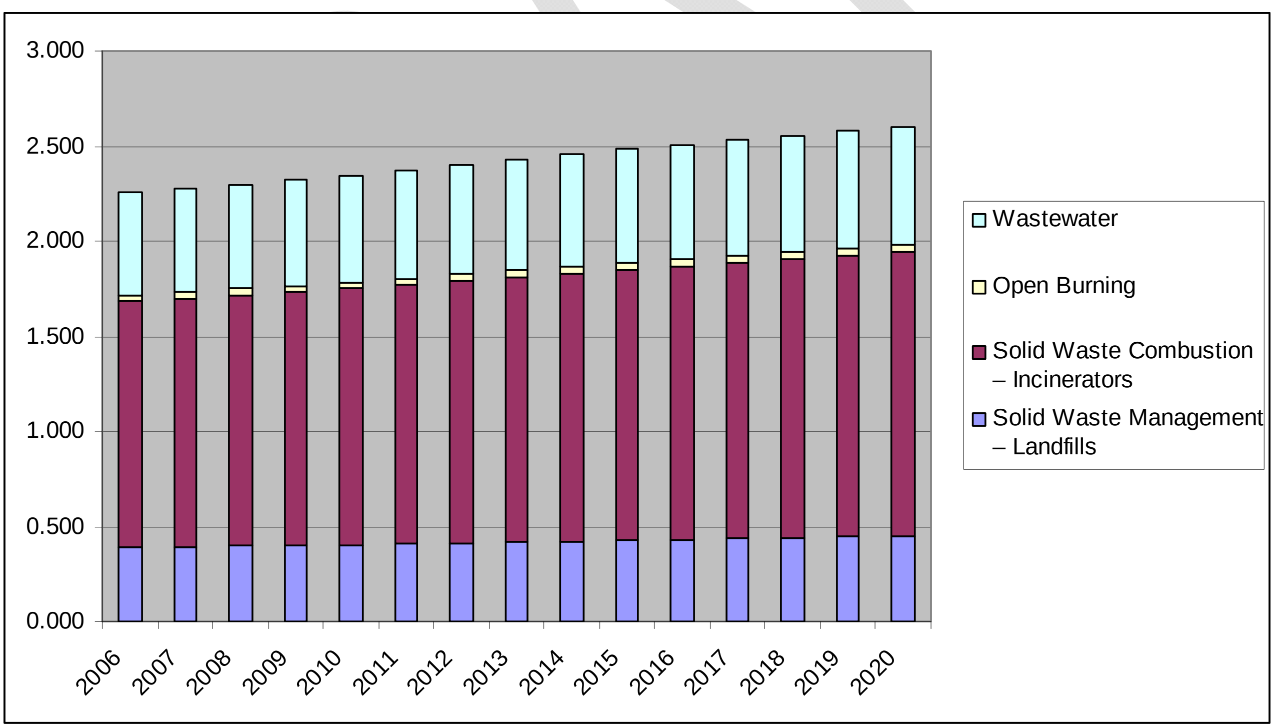
YEAR	Growth Factor from 2006 Base			
	Solid Waste Management – Landfills	Solid Waste Combustion – Incinerators	Open Burning	Wastewater
2007	1.009314	1.009925	1.009925	1.009925
2008	1.018628	1.01985	1.01985	1.01985
2009	1.027942	1.029775	1.029775	1.029775
2010	1.037256	1.0397	1.0397	1.0397
2011	1.046963	1.052053	1.052053	1.052053
2012	1.05667	1.064406	1.064406	1.064406
2013	1.066376	1.076759	1.076759	1.076759
2014	1.076083	1.089111	1.089111	1.089111
2015	1.08579	1.101464	1.101464	1.101464
2016	1.093181	1.112166	1.112166	1.112166
2017	1.100572	1.122869	1.122869	1.122869
2018	1.107963	1.133571	1.133571	1.133571
2019	1.115354	1.144273	1.144273	1.144273
2020	1.122746	1.154975	1.154975	1.154975

9.6 GREENHOUSE GAS FORECAST RESULTS

Table 9-9: Projected (BAU) Emissions in the Waste Management Sector

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Solid Waste Management – Landfills	0.389	0.393	0.397	0.401	0.404	0.409	0.414	0.419	0.424	0.428	0.433	0.437	0.441	0.445	0.449
Solid Waste Combustion – Incinerators	1.292	1.305	1.318	1.331	1.344	1.360	1.376	1.391	1.407	1.423	1.437	1.451	1.465	1.479	1.493
Open Burning	**0.033**	**0.033**	**0.034**	**0.034**	**0.034**	**0.035**	**0.035**	**0.036**	**0.036**	**0.036**	**0.037**	**0.037**	**0.037**	**0.038**	**0.038**
Wastewater	**0.543**	**0.545**	**0.550**	**0.555**	**0.561**	**0.566**	**0.573**	**0.580**	**0.587**	**0.593**	**0.600**	**0.606**	**0.611**	**0.617**	**0.623**
Total	**2.257**	**2.276**	**2.298**	**2.321**	**2.343**	**2.370**	**2.398**	**2.426**	**2.454**	**2.481**	**2.506**	**2.530**	**2.555**	**2.579**	**2.603**

FIGURE 9.1: PROJECTED (BAU) EMISSIONS IN THE AGRICULTURAL SECTOR



10.0 Forestry and Land Use

10.1 OVERVIEW

This section provides an assessment of the "net carbon dioxide flux" resulting from land uses, land–use changes, and forests (LULUCF) management activities in Maryland. The term "net carbon dioxide flux" is used here to encompass both emissions of greenhouse gases to the atmosphere, and removal (sinks) of carbon dioxide from the atmosphere. The balance between the emission and uptake is known as flux.

As a result of biological processes (e.g., growth and mortality) and anthropogenic activities (e.g., harvesting, thinning, and other removals), carbon is continuously cycled through ecosystem components, as well as between the forest ecosystem and the atmosphere. For example, the growth of trees results in the uptake of carbon from the atmosphere and storage in living trees. Through photosynthesis, CO_2 is taken up by trees and plants and converted to carbon in biomass within the forests. As these trees age, they continue to accumulate carbon until they reach maturity, at which point their carbon storage remains relatively constant. As trees die or drop branches and leaves on the forest floor, decay processes will release carbon to the atmosphere and also increase soil carbon. Some carbon from forests is also stored in wood products, such as lumber, furniture and other durable wood products; and also in landfills, because when wood products are disposed of, they do not decay completely, and a portion of the carbon gets stored indefinitely, as with landfilled yard trimmings and food scraps. The net change in forest carbon is the change in the amount of carbon stored in each of these pools (i.e., in each ecosystem component) over time.

Activities in Maryland that can contribute to the GHG flux includes; clearing an area of forest to create cropland, restocking a logged forest, draining a wetland, or allowing a pasture to revert to grassland. In the United States, forest management is believed to be the primary activity responsible for net sources of carbon dioxide to the atmosphere. Carbon in the form of yard trimmings and food scraps can also be sequestered in landfills, as well as in trees in urban areas.

In addition to carbon flux from forest management, urban trees, and landfills, other sources of GHGs under the category of land-use change and forestry are CO_2 emissions from liming of agricultural soils, emissions of methane (CH_4), and nitrous oxide (N_2O) from forest fires, and N_2O emissions from fertilization of settlement and forest soils.

GHG emission estimates for 2006 were calculated using the EPA SIT software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[75] In general, the SIT methodology applies emission factors developed for the US to activity data for the land use and forestry sectors.

Within the EPA SIT software LULUCF module, there are six sections:

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

- forest carbon flux;
- liming of agricultural soils;
- urban trees;
- N_20 from settlement soils;
- non-CO_2 emissions from forest fires; and
- carbon storage in landfilled yard trimmings and food scraps

Since the methodology varies considerably among these sources/sinks, the details of each will be discussed in its respective step, following this general methodology discussion.

10.2 DATA SOURCES

- USDA Urban Forest Data.
  http://nrs.fs.fed.us/pubs/gtr/nrs_gtr50/MD_TABS.xls.

- US EPA State Greenhouse Gas Inventory Tool (SIT).
  http://www.epa.gov/statelocalclimate/resources/tool.html

- Municipal Solid Waste in the United States; 2006 Facts and Figures (EPA 2007)
  http://www.epa.gov/osw/nonhaz/municipal/pubs/msw06.pdf.

- AAPFCO (2007) Commercial Fertilizers 2007.
  Association of American Plant Food Control Officials. University of Kentucky, Lexington, KY.

10.3 GREENHOUSE GAS INVENTORY METHODOLOGY

10.3.1 Forest Carbon Flux

The method used for calculating forest carbon flux is shown in Equation 1.3.1. The calculation is a sum of the fluxes for above- and belowground biomass, dead wood, litter, soil organic carbon, and wood products in use and in landfills.

Two methodologies are used to calculate carbon emissions/storage (flux) from forest carbon using USDA Forest Service estimates of each state's forest carbon stocks.

(1) The first methodology applies to aboveground biomass, belowground biomass, dead wood, and forest floor litter and soil organic carbon. USDA Forest Service estimates for each state's forest carbon stocks are provided for 1990-2007. These estimates are outputs of the Carbon Calculation Tool (CCT) which produces state-level annualized estimates of carbon stock and flux. The Carbon Calculation Tool is a computer application that reads publicly available forest inventory data collected by the U.S. Forest Service's Forest Inventory and Analysis Program (FIA) and generates state-level annualized estimates of carbon stocks on forest land based.

(2) The second methodology used applies to wood products and landfills (i.e. harvested wood products). Since the CCT does not produce estimates for the entire time series, default carbon emissions/storage from forest carbon flux are calculated by using USDA Forest Service estimates of each state's harvested wood stocks in 1987, 1992, and 1997. Changes from 1987-1992 and from 1992-1997 are each divided by 5 (the number of intervening years) to determine the average annual change. This average annual change is then applied for each year, giving total annual change. For the years 1998-2007, the average annual change for 1992-1997 is used as proxy data.

For more information, please consult the Land Use, Land-Use Change, and Forestry chapter of the EPA SIT Program User's Guide.

Equation 1.3.1: Forest Carbon Flux Equation

$$\text{Emissions or Sequestration (MMTCO2E)} = \text{Aboveground Biomass Carbon Flux} + \text{Belowground Biomass Carbon Flux} + \text{Dead Wood Carbon Flux} + \text{Litter Carbon Flux} + \text{Soil Organic Carbon Flux} + \text{Wood Products Carbon Flux} + \text{Landfills Carbon Flux}$$

10.3.2 Liming of Agricultural Soils

Limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are added to soils by land managers to remedy acidification. When these compounds come in contact with acidic soils, they degrade, thereby generating CO_2. This section presents the methodology MDE used to estimate the CO_2 emissions from the application of limestone and dolomite to agricultural soils.

The emissions are calculated by summing carbon emissions from the application of both limestone and dolomite to soil. The quantity of limestone and dolomite applied to agricultural soil in Maryland (metric tons) are multiplied by their default carbon emission factors, the resulting Carbon emissions are then converted to million metric tons of carbon dioxide equivalent, and then summed.

The default emission factors are based on West & McBride (2005).

For more information please consult the Land Use, Land-Use Change, and Forestry chapter of the User's Guide.

Equation 1.3.2: Liming Emissions Equation

$$\textbf{Emissions (MMTCO2E)} = \frac{\textbf{Total Limestone or Dolomite Applied to Soil (1000 metric tons)} \times \textbf{Emission Factor (tons C/ ton limestone or dolomite)} \times \textbf{44/12 (ratio of CO2 to C)}}{\textbf{1,000,000 (MT/MMTCO}_2\textbf{E)}}$$

No data on the application of limestone and dolomite could be found for the State of Maryland. Therefore emissions from this source sector are set to zero.

10.3.3 Urea Fertilization

The use of urea as a fertilizer results in CO2 emissions that were previously fixed during the industrial production process. According to U.S. EPA (2009), urea in the presence of water and urease enzymes is converted into ammonium (NH_4^-), hydroxyl ion (OH^-) and bicarbonate (HCO_3^-). The bicarbonate then evolves into CO_2 and water. This section presents the methodology for calculating the CO_2 emissions from the application of urea to agricultural soils.

The amount of urea applied to soil is multiplied by the carbon emission factor, and then converted to million metric tons carbon dioxide equivalent. The amount of urea applied to soils was obtained from two sources within the EPA SIT Program:

1. APFCO (2008) Commercial Fertilizers 2007. Association of American Plant Food Control Officials and The Fertilizer Institute. University of Kentucky, Lexington, KY.

2. TVA (1992b) Fertilizer Summary Data 1992. Tennessee Valley Authority, Muscle Shoals, AL.

The emission factor for urea application as a fertilizer to soils is recorded in metric tons of carbon per metric ton of urea. The default emission factor is based on IPCC (2006).

The SIT modules estimated CO_2 emissions due to the application of urea fertilizer using Equation 1.3.3.

Equation 1.3.3: Urea Emissions Equation

$$\text{Emissions (MMTCO2E)} = \frac{\text{Total Urea Applied to Soil (metric tons)} \times \text{Emission Factor (tons C/ton urea)} \times \text{44/12 (ratio of } CO_2 \text{ to C)}}{\text{1,000,000 (MT/MMTCO}_2\text{E)}}$$

Where:

Emissions	=	Amount of carbon dioxide emitted from urea fertilization (MMTCO2E)
Total Urea Applied	=	Amount of urea applied for the year in which carbon stocks are being estimated (metric tons)
Emission Factor	=	Emission factor for direct emissions of CO_2 (0.2 tons C / ton Urea)
0.01	=	Conversion Factor – converts metric tons N2O-N to metric tons N (0.01)
44/28	=	Conversion Factor – converts C to CO_2 (44/12)
1,000,000	=	Conversion Factor – converts Metric Tons to Million Metric Tons

10.3.4 Urban Trees

Carbon can be sequestered in trees in urban areas. Changes in carbon stocks in urban trees are equivalent to tree growth minus biomass losses resulting from pruning and mortality. Net carbon sequestration can be calculated using data on crown cover area or number of trees.

To estimate CO_2 sequestration by urban trees, the following steps were followed:
1. Obtain data on the area of urban tree cover;
2. Calculate CO_2 flux; and
3. Convert units to metric tons of carbon dioxide equivalent (MT CO_2E).

Maryland historic net carbon flux from urban tree was adopted from the EPA SIT software; this tool uses default urban area data multiplied by a state estimate of the percent of urban area with tree cover to estimate the total area of urban tree cover. The 2006 base year estimate was calculated using Equation 1.3.4 below, with updated input data; total urban area (km^2) and percent of urban area with tree cover.

MDE estimated the year 2006 Total Urban Area (km^2) data through the following steps:

1. Downloaded the latest Urban Forest Data from USDA. http://nrs.fs.fed.us/pubs/gtr/nrs_gtr50/MD_TABS.xls.
2. Determined the annual growth rate between the available 1990 and 2000 data.
3. Applied the (1990- 2000) growth rate to extrapolate year 2006 total urban area.
4. Applied the (1900 -2000) percentage of urban area tree coverage.
5. Estimated the Sequestration from Urban Tree with the equation below, using SIT default C sequestration factor.

Equation 1.3.4: Urban Trees Equation

$$\text{Sequestration (MMTCO2E)} = \frac{\text{Total Urban Area } (km_2) \times \text{Urban Area with Tree Cover } (\%) \times 100\ (ha/km_2) \times \text{Carbon Sequestration Factor (metric tons C/ha/yr)} \times 44/12 \text{ (ratio of } CO_2 \text{ to C)}}{1{,}000{,}000\ (MT/MMTCO_2E)}$$

10.3.5 Settlement Soils

Settlement soils include all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories.

MDE utilized the EPA SIT software for the estimation of nitrous oxide (N_2O) emissions from synthetic fertilizer application to soil in settled area such as lawns, golf courses, and other landscaping occurring within settled areas. The SIT modules estimated N_2O emissions due to the application of synthetic fertilizer to settlement soils using Equation 1.3.5.

Equation 1.3.5: Emission Equation for Direct N_2O Emissions from Settlement Soils

$$\text{Sequestration (MMTCO2E)} = \frac{\text{Total Synthetic Fertilizer (metric ton N)} \times \text{Emission Factor (percent)} \times 0.01 \text{ (metric tons N20-N/ metric ton N)} \times \text{GWP (310)} \times 44/28 \text{ (ratio of } N_2O \text{ to } N_2O\text{ -N)}}{1{,}000{,}000\ (MT/MMTCO_2E)}$$

Where:

Sequestration	=	Amount of carbon removed (MMTCO2E)
Total Synthetic Fertilizer	=	Amount of synthetic fertilizer applied for the year in which carbon stocks are being estimated (metric tons of nitrogen)
Emission Factor	=	Emission factor for direct emissions on N_2O (1.0 percent default value)
0.01	=	Conversion Factor - converts metric tons N2O-N to metric tons N (0.01)

GWP	=	Global Warming Potential, N_20 to CO_2 (310)
44/28	=	Conversion Factor - converts N2O-N to N20 (44/28)
1,000,000	=	Conversion Factor – converts Metric Tons to Million Metric Tons

10.3.6 Forest Fires

Biomass burned in forest fires emits CO_2, CH_4 and N_2O, in addition to many other gases and pollutants. CO_2 emissions from forest fires are inherently captured under total forest carbon flux calculations, but CH_4 and N_2O must be estimated separately. All fires—wildfires and prescribed burns—emit these greenhouse gases.

Calculating the emissions of N_2O and CH_4 from burned forests requires determining the amount of carbon released by the fire (by multiplying the area burned, the fuel load, and the combustion efficiency) and then factoring in the emission ratio for each gas.

Data on the area burned (hectares) per forest type was collected from the Maryland DNR, Forest Services Department for the base year. MDE applied the 2006 DNR wildfires and prescribed burns data to the EPA SIT default emission factors (grams of gas/kilogram of dry matter combusted), fuel load (kilograms dry matter per hectare) and combustion efficiency (percent) to estimate the base year non-CO_2 GHG emissions. Fuel load default biomass densities were adapted from Smith et al. (2001) and U.S. EPA 92009).

For more information, please consult the Land Use, Land-Use Change, and Forestry chapter of the EPA SIT Program User's Guide.

The equation below shows the method used to calculate N_2O and CH_4 emissions from forest fires.

Equation 1.3.6: Forest Fires Emissions Equation

Emissions (MMTCO2E)	=	**Area Burned (ha)**	X	**Average Biomass Density (kg dry matter/ha)**	x	**Combustion Efficiency (%)**	x	**Emission Factor (g gas/kg dry matter burned)**	x	**GWP**

Table 10.1: Forest Fire Data Inputs

Forest Type	Area Burned (ha)	Average Biomass Density (kg d.m. / ha)	Combustion Efficiency	CH_4 Emission Factor (g/kg dry matter burned)	N_2O Emission Factor (g/kg dry matter burned)	CH_4 GWP	N_2O GWP
Primary tropical forests	0	152,440	36%	8.1	0.11	21	310
Secondary tropical forests	0	152,440	55%	8.1	0.11	21	310
Tertiary tropical forests	0	152,440	59%	8.1	0.11	21	310
Boreal forest	0	152,440	34%	8.1	0.11	21	310
Eucalypt forests	0	152,440	63%	8.1	0.11	21	310

Forest Type	Area Burned (ha)	Average Biomass Density (kg d.m. / ha)	Combustion Efficiency	CH_4 Emission Factor (g/kg dry matter burned)	N_2O Emission Factor (g/kg dry matter burned)	CH_4 GWP	N_2O GWP
Other temperate forests	2,458	152,440	45%	8.1	0.11	21	310
Shrublands	202	152,440	72%	8.1	0.11	21	310
Savanna woodlands (early/dry season burns)		152,440	40%	4.6	0.12	21	310
Savanna woodlands (mid/late season burns)		152,440	74%	4.6	0.12	21	310

10.3.7 Landfilled Yard Trimmings and Food Scraps

When wastes of biogenic origin (such as yard trimming and food scraps) are landfilled and do not completely decompose, the carbon that remains is effectively removed from the global carbon cycle. This section of the inventory account for such carbon, it estimates the carbon stored in landfills by yard trimmings and food scraps.

Estimates of net carbon flux of landfilled yard trimmings and food scraps can be calculated by estimating the change in landfill carbon stocks between inventory years based on methodologies presented in IPCC (2003) and IPCC (2006). Carbon stock estimates were calculated by:

Step 1. determining the mass of landfilled carbon resulting from yard trimmings or food scraps discarded in a given year;
Step 2. adding the accumulated landfilled carbon from previous years; and
Step 3. Subtracting the portion of carbon landfilled in previous years that have decomposed.

The EPA SIT software module uses equation 1.3.7 below to calculate carbon sequestration associated with landfilled yard trimmings and food scraps.

Equation 1.3.7: Emission Equation for Landfilled Yard Trimmings and Food Scraps

$$LFC_{i,t} = \sum W_{i,n} \times (1 - MC_i) \times ICC_i \times \{[CS_i \times ICC_i] + [(1 - (CS_i \times ICC_i)) \times e - kx(t-n)]\}$$

Where:

$LFC_{i,t}$	=	the stock of carbon in landfills in year t, for waste i (grass, leaves, branches, food scraps)
t	=	the year for which carbon stocks are being estimated
$W_{i,n}$	=	the mass of waste I disposed in landfills in year n, in units of wet weight
n	=	the year in which the waste was disposed, where 1960 < n < t
MC_i	=	moisture content of waste i
CSi	=	the proportion of initial carbon that is stored for waste i
ICC_i	=	the initial carbon content of waste i
e	=	the natural logarithm
k	=	the first order rate constant for waste i, and is equal to 0.693 divided by the half-life for decomposition

Due to the complexity of these calculations, more detail about the methodology is provided below. For more information, please consult the Land Use, Land-Use Change, and Forestry Chapter of the User's Guide to the EPA SIT program.

The required basic data inputs include:

- Grass, leaves, and branches constituting yard trimmings (percent)
- Yard trimmings and foods scraps landfilled, 1960-present (tons)
- Initial carbon content of yard trimmings and food scraps (percent)
- Dry weight/wet weight ratio of yard trimmings and foods scraps (percent)
- Proportion of carbon stored permanently for yard trimmings and foods scraps (percent)
- Half-life of degradable carbon for yard trimmings and foods scraps (years)

Step 1: Mass of Landfilled Carbon

To determine the total landfilled carbon stocks for a given year, the following factors are estimated:

1. the composition of the yard trimmings,
2. the mass of yard trimmings and food scraps discarded in the state's landfills,
3. the carbon storage factor of the landfilled yard trimmings and food scraps, and
4. the rate of decomposition of the degradable carbon (based on a model of carbon fate).

Due to the number of factors involved, the Landfilled Yard Trimmings and Food Scraps sector worksheet is arranged by a series of steps, presented below:

1. The amount of landfilled yard trimmings and food scraps is calculated from default data provided within the tool.

a. Apportion the total landfilled yard trimmings to individual components, as a percent of grass, leaves, and branches. Default percentages are available within the module, and are provided by Oshins and Block (2000) and are presented in the table below.

Table 10.2 - Default Composition of Yard Trimmings

Content of yard trimmings	Default
% Grass	30%
% Leaves	40%
% Branches	30%

b. Default data for the total annual landfilled yard trimmings and food scraps from 1960 to the present in short tons of wet weight is provided within the module and was used by MDE. The default data from Franklin Associates (2008) is a national total for yard trimmings and food scraps, and is distributed to each state based on state population. The tool uses the percentage entered for yard trimmings in the previous step to allocate the amount of yard trimmings distributed among grass, leaves, and branches.

State Total Landfilled Trimmings (grass/leaves/branches)	=	State Population	x	National per Capita landfilled Total yard trimmings factor	x	Content of Yard Trimmings (%)

Where:

State Total Landfilled Trimmings (grass/leaves/branches)	=	Total Amount of Grass, Leaves and Branches landfilled in Maryland in a given year
State Population	=	Population of Maryland in a given year 2006 = 5,602,258
National per Capita landfilled total Yard Trimmings Factor	=	National per capita factor for Landfilled Yard Trimmings 2006 = 0.0335680699
Content of Yard Trimmings (%)	=	Default composition of Yard Trimmings from Table *.*

State Total Landfilled Food Scraps	=	**State Population**	**x**	**National per Capita landfilled Food Scraps Factor**

Where:

State Total Landfilled Food Scraps	=	Total Amount of Food Scraps landfilled in Maryland in a given year
State Population	=	Population of Maryland in a given year 2006 = 5,602,258
National per Capita landfilled total Yard Trimmings Factor	=	National per capita factor for Landfilled Yard Trimmings 2006 =

Step 2: Amount of Carbon Added Annually

To calculate the amount of carbon added to landfills annually, the following steps were taken:

a. Default data for the initial carbon content percent for grass, leaves, branches, and food scraps is provided in the module and are taken from Barlaz (1998).

Table 10.3: Initial Carbon Content

Key Assumptions

Initial Carbon Content	Default
Grass	45%
Leaves	46%
Branches	49%
Food Scraps	51%

b. Default data on the dry weight to wet weight ratio for grass, leaves, branches, and food scraps, is drawn from Tchobanoglous, et al. (1993).

Table 10.4: Dry Weight/Wet Weight Ratio

Dry Weight/Wet Weight ratio	Default
Grass	30%
Leaves	70%
Branches	90%
Food Scraps	30%

Step 3: Total Annual Stock of Landfilled Carbon

The amount of carbon added annually to landfills is then calculated from the above data using the equation below:

$$\text{Mass additions of carbon} = \frac{\text{landfilled materials, wet weight} \times \text{initial carbon content} \times \text{dry weight} \times \text{Metric tons to short ton}}{\text{wet weight ratio}}$$

The total annual stocks of landfilled carbon is calculated by the following steps:

a. Use the default proportions, based on Barlaz (1998, 2005, and 2008).

Table 10.5: Proportion of Carbon Stored Permanently

Proportion of Carbon Stored Permanently	Default
Grass	53%
Leaves	85%
Branches	77%
Food Scraps	16%

b. Use the default data from IPCC (2006) for the half-life of the degradable carbon in each of the materials in years..

Table 10.6: Half-life of Degradable Carbon

Half-life of degradable carbon (years)	Default
Grass	5
Leaves	20
Branches	23.1
Food Scraps	3.7

Step 4: Annual Flux of Carbon Stored

Annual carbon stocks are calculated by summing the carbon remaining from all previous years' deposits of waste. The stock of carbon remaining in landfills from any given year is calculated as follows:

$$\text{Remaining Carbon Stock} = \text{Initial C Addition} \times \left[\text{Proportion of C Stored Permanently} + \text{(1- Proportion of C Stored Permanently)} \times e^{\frac{\text{(ln(0.5)}}{\text{Half-life of degradable C}}} \right]$$

To calculate stocks for any given year, the remaining stocks for all previous years are summed.

10.4 GREENHOUSE GAS INVENTORY RESULTS

Table 10.7: 2006 Summary of Land Use, Land –Use Change, and Forestry Emissions and Sequestration in Maryland. ($MMTCO_2E$)

	2006
Forest Carbon Flux	(10.4980)
Aboveground Biomass	(7.4829)
Belowground Biomass	(1.4221)
Dead Wood	(0.5848)
Litter	(0.2320)
Soil Organic Carbon	(0.0514)
Total wood products and landfills	(0.7248)
Liming of Agricultural Soils	-
Limestone	-
Dolomite	-
Urea Fertilization	0.0051
Urban Trees	(1.1695)
Landfilled Yard Trimmings and Food Scraps	(0.1677)
Grass	(0.0085)
Leaves	(0.0619)
Branches	(0.0560)
Landfilled Food Scraps	(0.0582)
Forest Fires	0.0390
CH_4	0.0325
N_2O	0.0065
N_2O from Settlement Soils	0.0228
Total	(11.7682)

Table10.8: 2006 CO_2 Emissions from Urea Fertilizer Use

Year	Total Urea Applied to Soil (Metric Tons)		Emission Factor (Ton C/Ton urea)		Carbon Emissions (MT)		Carbon Dioxide-to - Carbon Ratio (44/12)		Carbon Dioxide Emissions ($MTCO_2E$)	Carbon Dioxide Emissions ($MMTCO_2E$)
2006	7,020	x	0.20	=	1,404	x	3.66667	=	5,148.26	0.0051

Table 10.9: 2006 CO_2 Emissions from Liming of Soil

Year		Total Applied to Soil ('000 Metric Tons)		Emission Factor (Ton C/Ton limestone)		Carbon Dioxide Emissions ($MTCO_2E$)		Total Carbon Dioxide Emissions ($MMTCO_2E$)
2006	Limestone	-	x	0.059	=	-	=	-
2006	Dolomite	-	x	0.064	=	-	=	-

Table 10.10: 2006 CH_4 Emissions from Forest Fire.

Forest Type	Area Burned (ha)	Average Biomass Density (kg d.m. / ha)	Combustion efficiency	Emission Factor (g/kg dry matter burned)	CH_4 Emitted (metric tons)	CH_4 GWP	Emissions $MMTCO_2E$
Primary tropical forests		152,440	36%	8.1	-	21	-
Secondary tropical forests		152,440	55%	8.1	-	21	-
Tertiary tropical forests		152,440	59%	8.1	-	21	-
Boreal forest		152,440	34%	8.1	-	21	-
Eucalypt forests		152,440	63%	8.1	-	21	-
Other temperate forests	2,458	152,440	45%	8.1	1,366	21	0.029
Shrublands	202	152,440	72%	8.1	180	21	0.004
Savanna woodlands (early dry season burns)		152,440	40%	4.6	-	21	-
Savanna woodlands (mid/late season burns)		152,440	74%	4.6	-	21	-
Total							0.0325

Table 10.11: 2006 N_2O Emissions from Synthetic Fertilizer Application to Settlement Soils.

Year	Total Synthetic Fertilizer Applied to Settlements (Metric Tons N)	Emission Factor (percent)	N_2O-N	Direct N_2O Emissions (Metric Tons N_2O Emitted)	N_2O GWP	Carbon Dioxide Emissions ($MTCO_2E$)	Total Carbon Dioxide Emissions ($MMTCO_2E$)
2006	4,686	1%	1.57	73.6	310	22,827	0.0228

Table 10.12: 2006 N_2O Emissions from Forest Fire.

Forest Type	Area Burned (ha)	Average Biomass Density (kg d.m. / ha)	Combustion efficiency	Emission Factor (g/kg dry matter burned)	N_2O Emitted (metric tons)	N_2O GWP	Emissions $MMTCO_2E$
Primary tropical forests	0	152,440	36%	0.11	-	310	-
Secondary tropical forests	0	152,440	55%	0.11	-	310	-
Tertiary tropical forests	0	152,440	59%	0.11	-	310	-
Boreal forest	0	152,440	34%	0.11	-	310	-
Eucalypt forests	0	152,440	63%	0.11	-	310	-
Other temperate forests	2,458	152,440	45%	0.11	19	310	0.006
Shrublands	202	152,440	72%	0.11	2	310	0.001
Savanna woodlands (early dry season burns)	0	152,440	40%	0.12	-	310	-
Savanna woodlands (mid/late season burns)	0	152,440	74%	0.12	-	310	-
Total							0.0065

Table 10.13: 2006 C- Storage in Urban Trees.

Year	**2006**
Total Urban Area (km^2)	5,108
Urban Area with Tree Cover (Percent)	28%
Total Area of Urban Tree Cover (km^2)	1,430.24
hectare/ km^2	100
Total Area of Urban Tree Cover (ha)	143,024.00
Carbon Sequestration Factor (metric tons C /hectare/year)	2.23
Carbon Sequested (metric tons)	318,943.52
Carbon dioxide-to-Carbon Ratio (44/12)	3.67
Carbon Dioxide Removed (metric tons)	1,169,459.57
Carbon Sequested ($MMTCO_2E$)	(1.1695)

Table 10.14: Net Sequestrations/ Emissions ($MMTCO_2E$)- Landfilled Yard Trimmings and Food Scraps (2000 -2006).

	2000	2001	2002	2003	2004	2005	2006
Grass	(0.008)	(0.010)	(0.011)	(0.008)	(0.007)	(0.008)	(0.008)
Leaves	(0.076)	(0.078)	(0.079)	(0.067)	(0.060)	(0.062)	(0.062)
Branches	(0.071)	(0.073)	(0.074)	(0.061)	(0.054)	(0.056)	(0.056)
Food Scraps	(0.058)	(0.058)	(0.058)	(0.057)	(0.066)	(0.062)	(0.058)
Total	(212.317)	(0.218)	(0.223)	(0.192)	(0.187)	(0.187)	(0.185)

Table 10.15: -Net Séquestration/ Emissions ($MMTCO_2E$)- Forest Carbon Flux (2000 -2006).

	2000	2001	2002	2003	2004	2005	2006
Aboveground Biomass	(1.42)	(1.42)	(1.42)	(1.42)	(1.42)	(1.42)	(1.42)
Belowground Biomass	(0.58)	(0.58)	(0.58)	(0.58)	(0.58)	(0.58)	(0.58)
Dead Wood	(0.23)	(0.23)	(0.23)	(0.23)	(0.23)	(0.23)	(0.23)
Litter	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Soil Organic Carbon	(22.09)	(22.09)	(22.09)	(22.09)	(22.09)	(22.09)	(22.09)
Total	(24.38)	(24.38)	(24.38)	(24.38)	(24.38)	(24.38)	(24.38)

Table 10.16: Net Sequestrations/ Emissions ($MMTCO_2E$)- Wood Products and Landfills (2000 -2006).

	2000	2001	2002	2003	2004	2005	2006
Total wood products and landfills	(0.72)	(0.72)	(0.72)	(0.72)	(0.72)	(0.72)	(0.72)

10.5 GREENHOUSE GAS FORECAST METHODOLOGY

Forestland emissions refer to the net carbon dioxide (CO_2) flux[1] from forested lands in Maryland. 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).

The projected inventories were required to be a business-as-usual forecast and thus were not to take into account any control/reduction programs. For this reason, it did not seem appropriate to apply growth in the acres of forest land or acres of urban forest. In addition, Maryland completed a trend analysis of projected emissions from this sector based on linear extrapolation of the 2000-2006 historical data. Estimated projected emissions were within 0.4% of the base-year 2006 emissions. As a result, no growth is projected for the land use emissions/sinks after 2006.

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