Maryland
Department of
the Environment

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State of Maryland 2017 Greenhouse Gas Emission Inventory Documentation

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Prepared by:
Maryland Department of the Environment

Maryland Department of the Environment
Greenhouse Gas Emissions Inventory Documentation

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Source Documentation:

- MDE-Air and Radiation Administration
    - MDE – ARA Compliance Program
    - MDE – ARA Permits Program
    - MDE – ARA Air Quality Policy and Planning Program
    - MDE – ARA Greenhouse Gas Program
    - MDE – ARA Mobile Source Program
    - MDE – Solid Waste Program
    - MDE - Land and Materials Administration Mining Program

- Maryland Department of Agriculture
- Maryland Department of Transportation
- Maryland Department of Planning

Lead Agency and Quality Assurance:MDE-ARA 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 Administration (ARA) Air Quality Policy & Planning Division compiled the GHG emissions inventory for the State of Maryland.

Acronyms and Key Terms

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; requires the State to reduce statewide greenhouse gas emissions by 25% from 2006 levels by 2020; and requires the State to develop and adopt a specified plan, adopt specified regulations, and implement specified programs to reduce greenhouse gas emissions.

Additionally, the Bill specifically mandates the Department of the Environment to prepare and publish an updated annual inventory of statewide greenhouse gas emissions for calendar year 2017.

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 2017. Statewide activity data from agriculture, fossil fuel combustion, industrial processes, natural gas transmission and distribution, transportation, solid waste, and wastewater treatment were used to develop the periodic 2017 inventory.

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

Maryland's anthropogenic GHG emissions and anthropogenic sinks (carbon storage) were estimated for the periodic year (2017) using a set of generally accepted principles and guidelines for State GHG emissions, relying to the extent possible on Maryland-specific input data.

The inventory covers the six types of gases included in the US Greenhouse Gas Inventory: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Emissions of these GHGs are presented using a common metric, carbon dioxide equivalence (CO_2e), which indicates the relative contribution of each gas,

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[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.

per unit mass, to global average radiative force on a global warming potential- (GWP-) weighted basis (see Section 1.4.1).[1]

Table ES-1 provides a summary of the 2017 GHG emissions for Maryland. Activities in Maryland accounted for approximately 79.12 million metric tons (MMT) of *gross*[2] CO_2e emissions (consumption basis) in 2017, an amount equal to about 26.21 % reduction of the total Maryland gross GHG (107.23 MMTCO2e) emissions in 2006.

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 11.72 $MMTCO_2$e was stored in Maryland forest biomass and agricultural soils in 2017. This leads to *net* emissions of 67.40 $MMTTCO_2$e in Maryland in 2017.

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 31 % of gross GHG emissions in 2017. Transportation accounted for 40 % of Maryland's gross GHG emissions in 2017, while RCI fuel use accounted for 18 % of Maryland's 2017 gross GHG emissions.

A graphical representation of the 2017 GHG emissions by source sector is presented in Figure ES-1.

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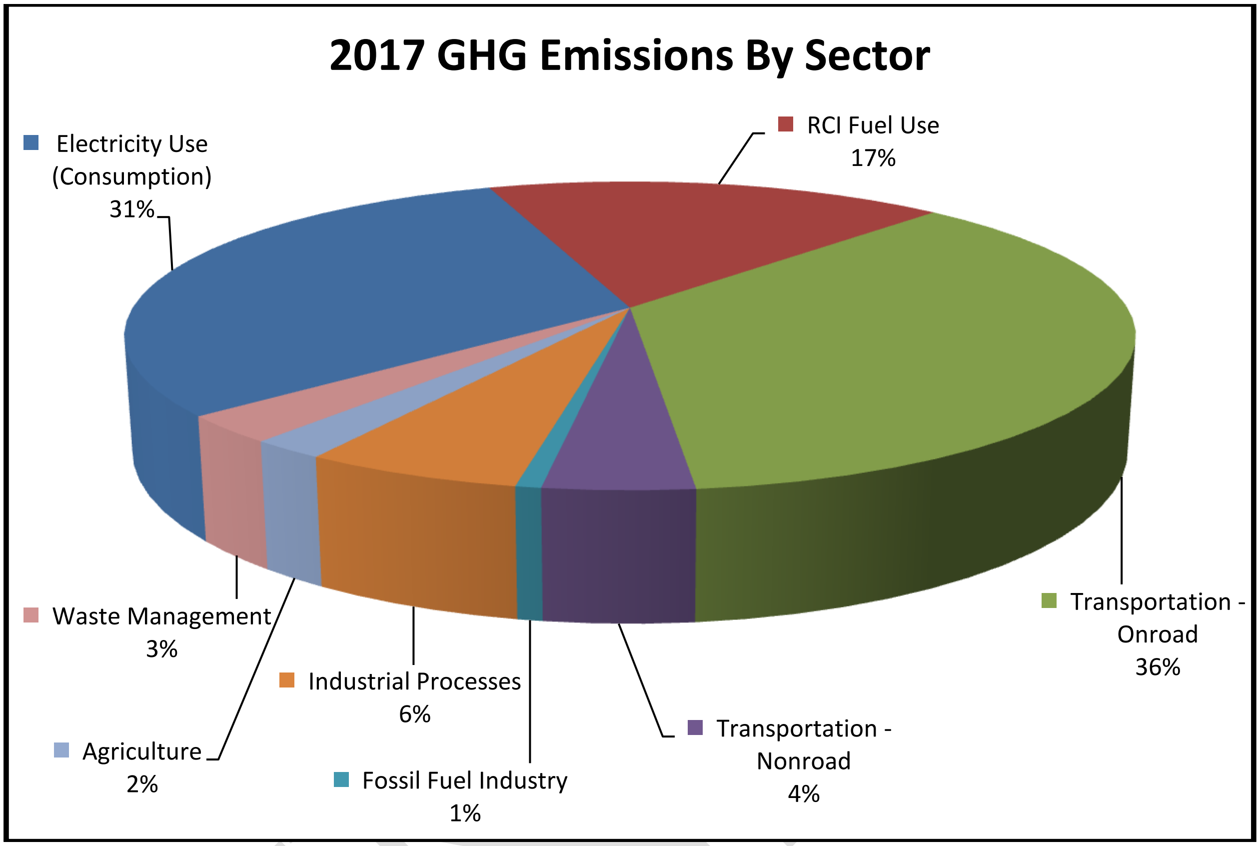
[1] Changes in the atmospheric concentrations of GHGs can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth–atmosphere system (IPCC, 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.

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

FIGURE ES-1: GROSS GHG EMISSIONS BY SECTOR, 2017, MARYLAND



A comparison of the 2006 Base Year, 2017 Periodic and 2020 Business-as-usual inventories, as illustrated in Figure ES-2 and shown numerically in Table ES-1, shows a decline (approximately 26 %) in Maryland's gross GHG emissions in 2017 from the 2006 Base Year.

1.2 EMISSIONS SUMMARY

Table ES-1: Maryland Periodic 2017 GHG Emissions, by Sector

SOURCE CATEGORY		**2006** (**MMtCO$_2$e)**	**2017** (**MMtCO$_2$e)**	**2020** **(MMtCO$_2$e)**
Energy Use (CO_2, CH_4, N_2O)		95.75995003	**70.53129**	125.3426075
Electricity Use (Consumption)[b]		42.47567455	**24.30711**	58.7927804
	Electricity Production (in-state)	32.16484764	**12.27815**	42.87607466
	Coal	28.27769105	9.23663	33.78898734
	CO_2	28.13057387	9.16593	33.61319714
	CH_4	0.006356915	0.02202	0.007595873
	N_2O	0.140760271	0.04869	0.16819432
	Natural Gas	3.649880813	2.89251	8.448329699
	CO_2	3.64841301	2.88733	8.444932197
	CH_4	0.000592766	0.00101	0.001372068
	N_2O	0.000875036	0.00416	0.002025434
	Oil	0.237275776	0.14901	0.638757627
	CO_2	0.236572609	0.14825	0.636878026
	CH_4	0.00017791	0.00038	0.000475562
	N_2O	0.000525257	0.00038	0.00140404
	Wood	0	0.0000	0
	CO_2	0	0.0000	0
	CH_4	0	0.0000	0
	N_2O	0	0.0000	0
	MSW/LFG			
	Net Imported Electricity	10.31082691	**12.02896**	15.91670574
Residential/Commercial/Industrial (RCI) Fuel Use		16.87079695	**13.87073**	18.84224894
	Coal	2.997788692	1.16917	4.197594934
	CO_2	2.976126985	1.16100	4.167405746
	CH_4	0.007134829	0.00254	0.009849136
	N_2O	0.014526878	0.00563	0.020340052
	Natural Gas & LPG	9.21041471	**9.73527**	9.996587616
	CO_2	9.18802397	9.71068	9.971684867
	CH_4	0.016000535	0.01777	0.017922089
	N_2O	0.006390205	0.00683	0.00698066
	Petroleum	4.576524718	**2.91030**	4.556581609
	CO_2	4.557477225	2.89906	4.527502018

SOURCE CATEGORY		2006 ($MMtCO_2e$)	2017 ($MMtCO_2e$)	2020 ($MMtCO_2e$)
	CH_4	0.008508848	0.00558	0.009214914
	N_2O	0.010538645	0.000565	0.019864676
	Wood	0.086068834	**0.05599**	0.091484784
	CO_2	0	0.000000	0
	CH_4	0.061142772	0.04061	0.067513098
	N_2O	0.024926062	0.01538	0.023971687
Transportation		35.47159388	**31.80433**	46.78388945
	Onroad Gasoline	23.7595	22.40003	30.70935375
	CO_2	23.195	22.32288	29.97973274
	CH_4	0.0462	0.00638	0.059713889
	N_2O	0.5183	0.07077	0.669907113
	Nonroad Gasoline	1.044117546	**0.9597071**	1.063830439
	CO_2	1.039550516	0.94240	1.059010076
	CH_4	0.000920455	0.01731	0.000996549
	N_2O	0.003646576	0.0000	0.003823814
	Onroad Diesel	5.9103	**6.17588**	7.8804
	CO_2	5.907	6.15662	7.876
	CH_4	0.0003	0.00009	0.0004
	N_2O	0.003	0.01916	0.004
	Nonroad Diesel	1.503926174	**0.954964**	1.849891371
	CO_2	1.488082933	0.95450	1.830352665
	CH_4	0.004221409	0.00047	0.005243769
	N_2O	0.011621832	0.0000	0.014294937
	Rail	0.238839589	**0.16704**	0.297300341
	CO_2	0.236600579	0.16547	0.294513289
	CH_4	0.000391175	0.00027	0.000486923
	N_2O	0.001847835	0.00129	0.00230013
	Marine Vessels (Gas & Oil)	0.997636149	**0.11507**	1.745970666
	CO_2	0.988598138	0.11444	1.730153174
	CH_4	0.00147329	0.00013	0.002578417
	N_2O	0.00756472	0.00050	0.013239075
	Lubricants, Natural Gas, and LPG	0.295955146	**0.33332**	0.474922542
	CO_2	0.295955146	0.33028	0.474922542
	CH_4	0	0.00304	0
	N_2O	0	0.0000	0
	Jet Fuel and Aviation Gasoline	1.721319275	**0.69832**	2.762220349

SOURCE CATEGORY		2006 (MMtCO$_2$e)	2017 (MMtCO$_2$e)	2020 (MMtCO$_2$e)
	CO$_2$	1.703343607	0.69118	2.733374593
	CH$_4$	0.001626024	0.00062	0.0026093
	N$_2$O	0.016349643	0.00652	0.026236456
Fossil Fuel Industry		0.941884638	**0.549117**	0.923688683
	Natural Gas Industry	0.811536367	0.458283	0.793340412
	CO$_2$	0.000128636	0.000442	0.000125751
	CH$_4$	0.811336294	0.457596	0.793144825
	N$_2$O	7.14367E-05	0.000246	6.9835E-05
	Oil Industry	0	0.0000	0
	CO$_2$	0	0.0000	0
	CH$_4$	0	0.0000	0
	N$_2$O	0	0.0000	0
	Coal Mining	0.130348272	0.090834	0.130348272
	CO$_2$	0	0.0000	0
	CH$_4$	0.130348272	0.090834	0.130348272
	N$_2$O	0	0.000000	0
Industrial Processes		7.441042334	**4.69577**	10.24474052
	Cement Manufacture	1.483241728	1.51184	2.092130448
	CO$_2$	1.483241728	1.51184	2.092130448
	CH$_4$	0	0.0000	0
	N$_2$O	0	0.0000	0
	Limestone and Dolomite	0.113941192	0.14589	0.212053625
	CO$_2$	0.113941192	0.14589	0.212053625
	CH$_4$	0	0.0000	0
	N$_2$O	0	0.0000	0
	Soda Ash	0.04761102	0.03957	0.047600367
	CO$_2$	0.04761102	0.03957	0.047600367
	CH$_4$	0	0.0000	0
	N$_2$O	0	0.0000	0
	Iron and Steel	3.597116387	0.0000	3.851428544
	CO$_2$	3.597116387	0.0000	3.851428544
	CH$_4$	0	0.0000	0
	N$_2$O	0	0.0000	0
	ODS Substitutes	1.971282442	2.95664	4.041527541
	CO$_2$	0	0.0000	0
	CH$_4$	0	0.0000	0

SOURCE CATEGORY		**2006 (MMtCO$_2$e)**	**2017 (MMtCO$_2$e)**	**2020 (MMtCO$_2$e)**
	HFC, PFC, SF$_6$	1.971282442	2.95664	4.041527541
	Electricity Transmission and Dist.	0.227222585	0.04037	0
	CO$_2$	0	0.0000	0
	CH$_4$	0	0.0000	0
	HFC, PFC, SF$_6$	0.227222585	0.04037	0
	Semiconductor Manufacturing	0	0.0000	0
	CO$_2$	0	0.0000	0
	CH$_4$	0	0.0000	0
	HFC, PFC, SF$_6$	0	0.0000	0
	Ammonia and Urea Production (Nonfertilizer Usage)	0.000626981	0.00147	0.001553245
	CO$_2$	0.000626981	0.00147	0.001553245
	CH$_4$	0	0.0000	0
	HFC, PFC, SF$_6$	0	0.0000	0
	Aluminum Production	0	0.0000	0
	CO$_2$	0	0.0000	0
	CH$_4$	0	0.0000	0
	HFC, PFC, SF$_6$	0	0.0000	0
Agriculture		1.771426158	**1.61428**	1.8593378
	Enteric Fermentation	0.41906793	0.38195	0.513375915
	CO$_2$	0	0.0000	0
	CH$_4$	0.41906793	0.38195	0.513375915
	N$_2$O	0	0.0000	0
	Manure Management	0.32126318	0.30721	0.288792819
	CO$_2$	0	0.0000	0
	CH$_4$	0.091393836	0.09387	0.056315177
	N$_2$O	0.229869344	0.21334	0.232477642
	Agricultural Soils	1.019673739	0.908171	1.046309668
	CO$_2$	0	0.0000	0
	CH$_4$	0	0.0000	0
	N$_2$O	1.019673739	0.90817	1.046309668
	Agricultural Burning	0.006273052	0.00628	0.00571114
	CO$_2$	0	0.0000	0
	CH$_4$	0.003893109	0.00378	0.003563812
	N$_2$O	0.002379944	0.00250	0.002147328
	Urea Fertilizer Usage	0.005148257	0.01067	0.005148257
	CO$_2$	0.005148257	0.01067	0.005148257

SOURCE CATEGORY		2006 (MMtCO$_2$e)	2017 (MMtCO$_2$e)	2020 (MMtCO$_2$e)
	CH$_4$	0	0.0000	0
	N$_2$O	0	0.0000	0
Waste Management		2.257117951	**2.27859**	2.602876711
	Waste Combustion	1.292301717	**1.18778**	1.492576145
	CO$_2$	1.272171161	1.18749	1.469325857
	CH$_4$	0	0.00025	0
	N$_2$O	0.020130556	3.28E-05	0.023250289
	Landfills	0.388955279	**0.45721**	0.449233614
	CO$_2$	0.151585044	0.12296	0.175076933
	CH$_4$	0.237370235	0.33426	0.274156681
	N$_2$O	0	0.0000	0
	Wastewater Management	0.542860955	**0.60060**	0.622952777
	CO$_2$	0	0.0000	0
	CH$_4$	0.377311419	0.40799	0.431747205
	N$_2$O	0.165549536	0.19261	0.191205572
	Residential Open Burning	0.033	**0.0330**	0.038114174
	CO$_2$	0.033	0.0330	0.038114174
	CH$_4$	0	0.0000	0
	N$_2$O	0	0.0000	0
Gross Emissions (Consumption Basis, Excludes Sinks)		107.2295365	**79.11993**	140.0495625
	decrease relative to 2006		26.21 %	
Emissions Sinks		-11.79034917	-11.72206	-11.75139092
	Forested Landscape	-10.44657783	-10.4466	-10.44657783
	Urban Forestry and Land Use	-1.331309142	-1.24056	-1.331309142
	Agricultural Soils (Cultivation Practices)	-0.051420445	-0.05142	-0.051420445
	Forest Fires	0.038958248	0.016502	0.038958248
	CH$_4$	0.032452487	0.013746	0.032452487
	N$_2$O	0.00650576	0.002756	0.00650576
Net Emissions (Consumptions Basis) (Including forestry, land use, and ag sinks)		95.4391873	**67.39788**	128.2981716
	decrease relative to 2006		29.38 %	

Figure ES-2: Gross GHG Emissions Comparison by Sector, 2006, 2011, 2014, 2017 & 2020

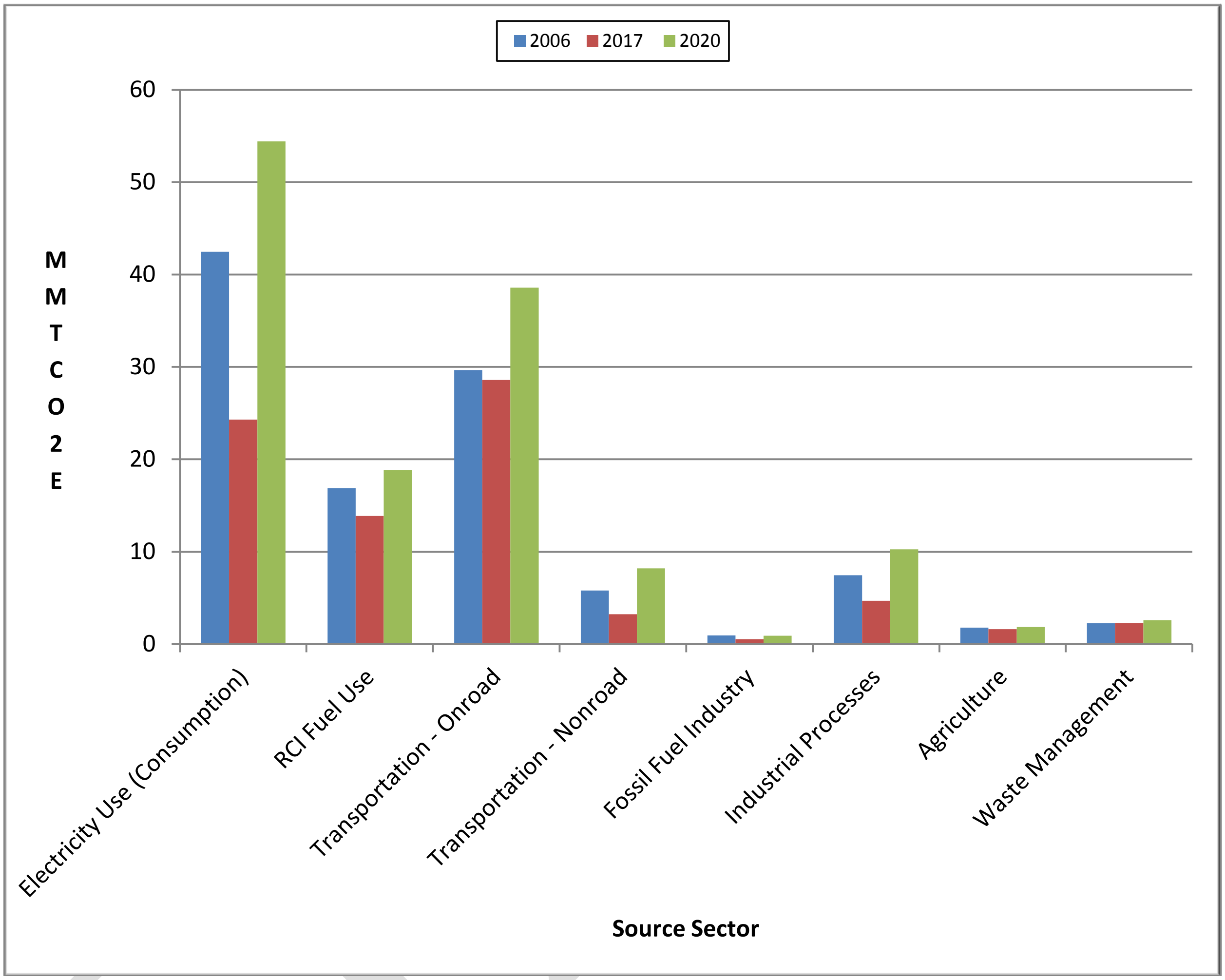
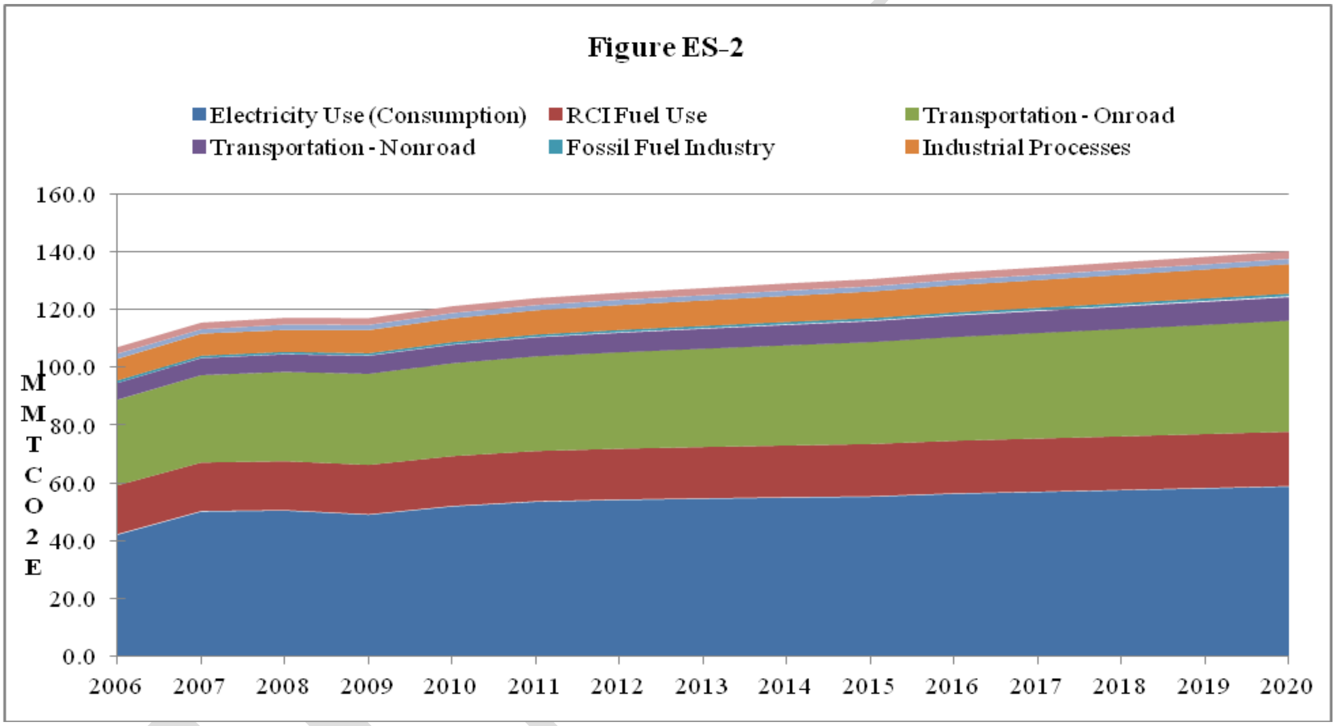


FIGURE ES-3: MARYLAND GROSS GHG EMISSIONS BY SECTOR, 2006-2020: BASE YEAR AND PROJECTED



1.3 SOURCE CATEGORIES

This document describes the inventory procedures the Maryland Department of the Environment (MDE) used to compile the 2017 periodic 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 99.38 % 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 49.49 % of the electricity consumed in Maryland in 2017.[1] 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 ES-1, electricity consumption accounted for about 31 % of Maryland's gross GHG emissions in 2017 (about 24 $MMtCO_2e$).

In 2017, emissions associated with Maryland's electricity consumption (24.31 $MMtCO_2e$) were about 12.03 $MMtCO_2e$ higher than those associated with electricity production (12.28 $MMtCO_2e$). The higher level for consumption-based emissions reflects GHG emissions associated with net imports of electricity to meet Maryland's electricity demand.[2] 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

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[1] In 2017, Total Maryland Retail Sales of Electricity (gross) were 62,873,438 MWh, of which 28,769,198 MWh (i.e., 46 %) were estimated to be from imports.

[2] 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.

- 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 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

As shown in Figure ES-1, the transportation sector accounted for about 40 % of Maryland's gross GHG emissions in 2017 (about 32 MMtCO$_2$e). Maryland's 2017 Onroad gasoline vehicles accounted for about 70 % of transportation GHG emissions. Onroad diesel vehicles accounted for another 19 % of emissions, and air travel for roughly 2 %. Marine vessels, rail, and other sources (natural gas- and liquefied petroleum gas- (LPG-) fueled-vehicles used in transport applications) accounted for the remaining 9 % of transportation emissions.

1.3.4 Industrial Processes

Emissions estimated in the industrial sector account 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 (SF_6) 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 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[1] 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 (CO_2e) is the concentration of CO_2 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.

Table ES-2: IPCC Global Warming Potential for GHG

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

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.

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[1] 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".

1.5 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 on-road mobile transportation energy use sector.

Section 5.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the non-road mobile transportation energy use sector.

Section 6.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the industrial processes sector.

Section 7.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the fossil fuel production industry sector.

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

Section 9.0 contains more detailed analysis and a general description of methodologies used in the emissions calculations of the waste management sector.

Section 10.0 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 the periodic 2017 inventory of greenhouse gas (GHG) emissions associated with meeting electricity demand in Maryland. It also describes the data sources and key assumptions used in developing the periodic 2017 GHG emissions 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, a consumption-based emission estimate will be different than a production-based estimate.

- The GHG inventory is 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

- MDE's Annual Emissions Certification Reports (MD ECR): The annual emission certification reports from electric generating facilities are the primary source of information for the emission estimates for the 2017 GHG periodic inventory. The certification reports were validated by the electric power facilities and submitted to the Air and Radiation Administration (ARA) Compliance Program. Engineers with the compliance program reviewed the emission certification reports for accuracy.

- Regional Greenhouse Gas Initiative (RGGI): The RGGI program (Summary Level Emission Report) report and data sets can be accessed through the following website: https://rggi-coats.org/eats/rggi/index.cfm?fuseaction=search.rggi_summary_report_input&clearfuseattribs=true.). This report was used to QA/QC emission data reported in MD ECR.

- EPA Clean Air Market Division (CAMD): This is a database file available from the EPA Clean Air Market Division under the Emissions Collection and Monitoring Plan System (ECMPS). 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. The ECMPS report and data was used to QA/QC heat input data reported in MD Emission Certification Reports. This information can be accessed from: http://ampd.epa.gov/ampd/QueryToolie.html.

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

- US Energy Information Administration: Electricity Data Browser-Retail Sales of Electricity. This database was used to determine total sales of electricity across all sectors. The document can be accessed through the following website:

  http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_use_es.html&sid=MD

  https://www.eia.gov/electricity/data/browser/

2.3 GREENHOUSE GAS INVENTORY METHODOLOGY

2.3.1 Carbon Dioxide (CO_2) Direct Emissions

Maryland 2017 electric generating unit CO_2 emissions were compiled from the annual Emissions Certification Reports submitted to MDE Air and Radiation Administration Compliance Program. The Compliance Program is responsible for collecting annual air emissions that are certified as accurate from large Maryland facilities. The MDE Annual Emissions Certification Report formed the basis for the estimation of CO_2 emission from electric power plants.

The 2017 annual emission certification reports data, submitted by power plant operators in Maryland, were cross-checked against both the EPA's Clean Air Markets Division (CAMD) emissions reporting and tracking database and the EPA's Mandatory Green House Gases Reporting Program (GHGRP) – GHG data. The CAMD data reports CO_2 emissions from fossil fuel fired plants with a generating capacity of 25 megawatts or greater; through EPA's Emissions Collection and Monitoring Plan System (ECMPS), where reported data are; hourly value for measured parameters, calculated hourly emission value, instrument calibration data and aggregated summary data. While the GHGRP database - (GHG data) provides the same information as well as CH_4, and N_2O emissions; this database covers additional units (electricity generators) not reported under the acid rain program. These databases provide a readily accessible, annually updated source of GHG emissions from the electric power plant and were accessed by MDE during verification of emissions reported in MDE Annual Emission Certification Report.

2.3.1.1 Clean Air Markets Division (CAMD) Sources.

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 ARA Compliance Program. The Compliance Program facility inspectors verify the submitted emission estimates for accuracy and completeness. This unit level CO_2 emission data was compiled to the facility level and formed the basis for the estimation of CO_2 emission for the state.

MDE verified CAMD facility emissions data with MDE Certification Report emission data through the following steps:

1. Identified the CAMD facilities that report CO_2 emissions to EPA through the CAMD database.
2. Compiled a list of CAMD generating unit and facility codes.
3. Cross-referenced the CAMD units with the MD Emission Certification Reports.
4. Downloaded CAMD emissions data from EPA CAMD database from January 2014 through December 2017 for all facilities and units in Maryland
5. Compiled 2017 CO_2 emissions data for RGGI units.
6. Compiled energy consumption (MMBTU) data from the ARP database for the CAMD units.
7. Compared the CAMD emission estimates to the MD Emission Certification Report emission estimates.
8. Reconciled any discrepancies.

2.3.1.2 Greenhouse Gas Reporting Program (GHGRP) Sources

The entire fossil fuel electric generation units' annual GHG emissions data submitted under the U.S. Environmental Protection Agency's (EPA) Mandatory GHG Reporting program were reviewed, the verification focused primarily on direct emissions from fossil fuel usage for electric power generation, a review of the procedures used to compile the emission estimates, a review of estimated emissions for completeness and accuracy in calculations. Data in supporting spreadsheets were also examined, including reviews of combined emissions from unit's combusting a mixture of fuels.

For electric power plant units without Continuous Emissions Monitors (CEM), the fuel-use methodology was used to review the emission estimates. Fossil fuel consumption data and facility specific fuel heat content were compiled on a unit basis and used to estimate energy consumption in MMBtu. EPA Mandatory Greenhouse Reporting Program, 40 CFR parts 98, Subpart C default Emission factors was used to estimate CO_2 emissions.

MDE verified the reported emissions from the GHGRP sources through the following steps:

1. Compiled fossil fuel consumption data for all electric power generating units from the MDE Emission Certification Reports.
2. Estimated energy consumption (BBTU) from all generating units using facility specific heat contents from the MDE Emission Certification Reports.
3. Applied EPA 40 CFR part 98, Subpart C default Emission factors to estimate emissions.

4. Compared the emissions estimates to the emissions reported through the EPA GHGRP.
5. Reconciled any discrepancies.

2.3.2 Additional Direct Emissions (CH_4 and N_2O)

2017 annual direct emissions of CH_4 and N_2O from Maryland electric generating units were compiled from the annual Emissions Certification Report submitted to MDE Air and Radiation Administration Compliance Program.

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 46 % of the electricity consumed in Maryland in 2017.[1] GHG emissions from power produced in-state are dominated by coal use, followed by emissions from oil use and natural gas use.

The electricity imported to meet the Maryland's demand was assume to have 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.[2]

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

Table 2-1: PJM 2017 Fuel Mix [3]

FUEL TYPE	PJM PERCENTAGE
Coal	32.20
Nuclear	35.90
Natural Gas	26.7
Oil	0.20
Hydroelectric	1.10
Solid Waste	0.50
Wind	2.60
Captured CH_4	0.30

The PJM website also provides the data to calculate a CO_2 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.

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[1] In 2017, Total Maryland Retail Sales(gross) were 62,873,438 MWh, of which 28,769,198 (i.e., 46 %) were estimated to be from imports.

[2] http://www.pjm.com/about-pjm/who-we-are.aspx.

[3] https://gats.pjm-eis.com/myModule/rpt/myrpt.asp?r=243.

Table 2-2: PJM System Mix – Year 2017

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)
2017	Biomass – Other Biomass Liquids						
	Biomass – Other Biomass Gases	**6,944**	**0.0009**	**0.0005**	**385,777.78**	**55.5556**	**0.0252**
2017	Captured Methane - Coal Mine Gas	174,422	0.0218	0.2534	202,745,572.48		
2017	Captured Methane - Landfill Gas	2,434,489	0.3043	0.3383	270,649,894.41		
		2,608,911	**0.3261**		**473,395,466.89**	**181.4533**	**0.0823**
2017	Coal - Bituminous and Anthracite	218,197,895	27.2697	573.2461	458,681,585,558.18		
2017	Coal - Sub-Bituminous	28,312,580	3.5384	80.4875	64,402,237,812.29		
2017	Coal - Waste/Other	11,298,702	1.4121	37.8107	30,253,652,837.01		
		257,809,177	**32.2202**		**553,337,476,207.48**	**2,146.3064**	**0.9734**
2017	Gas - Natural Gas	213,401,721	26.6702	239.4274	191,577,937,977.80		
2017	Gas – Other	314,490	0.0393	0.6546	523,829,908.40		
2017	Gas – Propane	260	0.0000	0.00009	0.000		
		213,716,471	**26.7095**		**192,101,767,886.20**	**898.8627**	**0.4076**
2017	Hydro – Conventional	**9,018,092**	**1.1271**	0.00000	0.0		
2017	Nuclear	**287,461,082**	**35.926**	0.00000	0.0		
2017	Oil - Distillate Fuel Oil	152,409	0.019	0.3665	293,988,939.47		
2017	Oil - Jet Fuel	2719	0.0000	0.0007	0.0		
2017	Oil - Residual Fuel Oil	101142	0.0126	0.3179	255,182,871.43		
2017	Oil – Petroleum Coke	1,042145	0.1302	3.6492	2,920,887,506.91		
2017	Oil - Waste/Other Oil	13,666	0.0017	0.0026	2,090,094.12		
		1,309,633	**0.1635**		**3,472,149,411.93**	**2,651.2385**	**1.2024**
2017	Solar- Photovoltaic	**1,467,762**	**0.1834**	**0.0000**	**0.0**		
2017	Solid Waste - Municipal Solid Waste	3,734,939	0.4668	11.0547	8,845,036,453.15		
2017	Solid Waste – Tire Derived Fuel	1,239	0.0002	0.0043	2,663,850.00		
		3,736,178	**0.467**		**8,847,700,303.15**	**2,368.1153**	**1.0740**
2017	Wind	**21,025,373**	**2.6277**	**0.00000**	**0.0**		
2017	Wood - Black Liquor	308,906	0.0386	0.1956	156,533,713.99		
2017	Wood - Wood/Wood Waste Solids	1,453,764	0.1817	0.6161	492,935,608.37		
		1,762,670	**0.2203**		**649,469,322.36**	**368.4577**	**0.1671**
	Total	**800,148,957**	**100.00**		**758,882,344.78**	**948.43**	**0.4301**

MDE compiled CO_2 emission estimates from imported electricity by utilizing the following methods and sources of information:

- Obtain the total electricity consumption for the State of Maryland from EIA Electricity Data Browser database (SEDS)[1];
- Adjust the Total Retail Sales (Consumption) data to account for electricity transmission and distribution loss (6.25%) to estimate the Gross State Electricity Consumption data;
- Obtain the total gross electricity generated in the State of Maryland from EIA[2];
- Estimate the amount of imported electricity (MWh) in 2017 by subtracting the Gross State Electricity generated from the Gross State Electricity Consumption;
- Download PJM electricity generation fuel mix.[3]
- 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.[4];
- Estimate CO_2 emissions.

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

		2017	Source of Data	Data Source Web Address
A	**Total Electric Consumption (MWh) - Retail Sales**	59,175,000	EIA Electricity Data	http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_use_es.html&sid=MD
B	**MD -Electricity Losses (MWh) (Transmission and Distribution)**	6.25%	MEA	
C	**Total Electricity Consumption (MWh) –** Gross Consumption	62,873,438	A*(1+B)	
D	MD In-State Gross - Electricity Generated (MWh)	34,104,240	EIA SEDS	http://www.eia.gov/electricity/data/state/
E	**Imported Electricity to Meet MD Demand (MWh)**	**28,769,198**	C – D	

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[1] http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_use_es.html&sid=MD.

[2] http://www.eia.gov/electricity/data/state/

[3] https://gats.pjm-eis.com/myModule/rpt/myrpt.asp?r=243.

[4] https://gats.pjm-eis.com/myModule/rpt/myrpt.asp?r=227&TabName=System%20Mix%20By%20Fuel

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 2017 (%)	32.2	35.9	26.7	0.2	1.1	0.5	2.6	0.3	100
Maryland 2017 Import Share by Fuel Type (MWh)	9,028,638	10,068,249	7,484,635	45,956	315,806	130,862	736,975	91,351	28,015,764
Imported Electric CO_2 Emissions Factors (tons/MWh)	0.97		0.41	1.20		1.07		0.08	
Imported Electric CO_2 Emissions (metric tons)	8,757,779		3,068,700	55,147		140,022		7,308	12,028,957
Imported Electric CO_2 Emissions ($MMTCO_2$)	11.45		3.07	0.06		0.14		0.01	12.028957

2.4 GREENHOUSE GAS INVENTORY RESULTS

The result of Maryland 2017 GHG emissions from the electricity generating units is shown in Table 2-5 and 2-6. The annual GHG emission from units sharing a common stack, or units with multiple fossil fuel combustion were disaggregated by apportioning the emissions to the respective fuel type by the following equation:

$$(\text{CO}_2\ \text{Emission})_A = \frac{(\text{Heat Input})_A}{(\text{Heat Input})_A + (\text{Heat Input})_B} \times (\text{ECMPS CO}_2\ \text{Emission})_{\text{Unit}}$$

Where $(\text{CO}_2\ \text{Emission})_A$: Cumulative CO_2 Emission (e.g. units with both coal and oil combustion)

$(\text{Heat Input})_A$: Heat Input of Fossil Fuel A (e.g. Coal)
$(\text{Heat Input})_B$: Heat Input of Fossil Fuel B (e.g. Natural Gas)
$(\text{ECMPS CO}_2\ \text{Emissions})_{\text{Unit}}$: Direct Unit’s CO_2 measurement either CEM or Calculated.

Heat input is calculated according to appendix D of 40 CFR part 75 or 40 CFR 75.19. The high heat values used in the GHG emissions disaggregation calculations for each fuel in MMBtu were from the facility’s specific heating values reported in the emission certification reports.

Table 2-5: CO$_2$ Emissions from Electric Generating Units by Fuel Type.

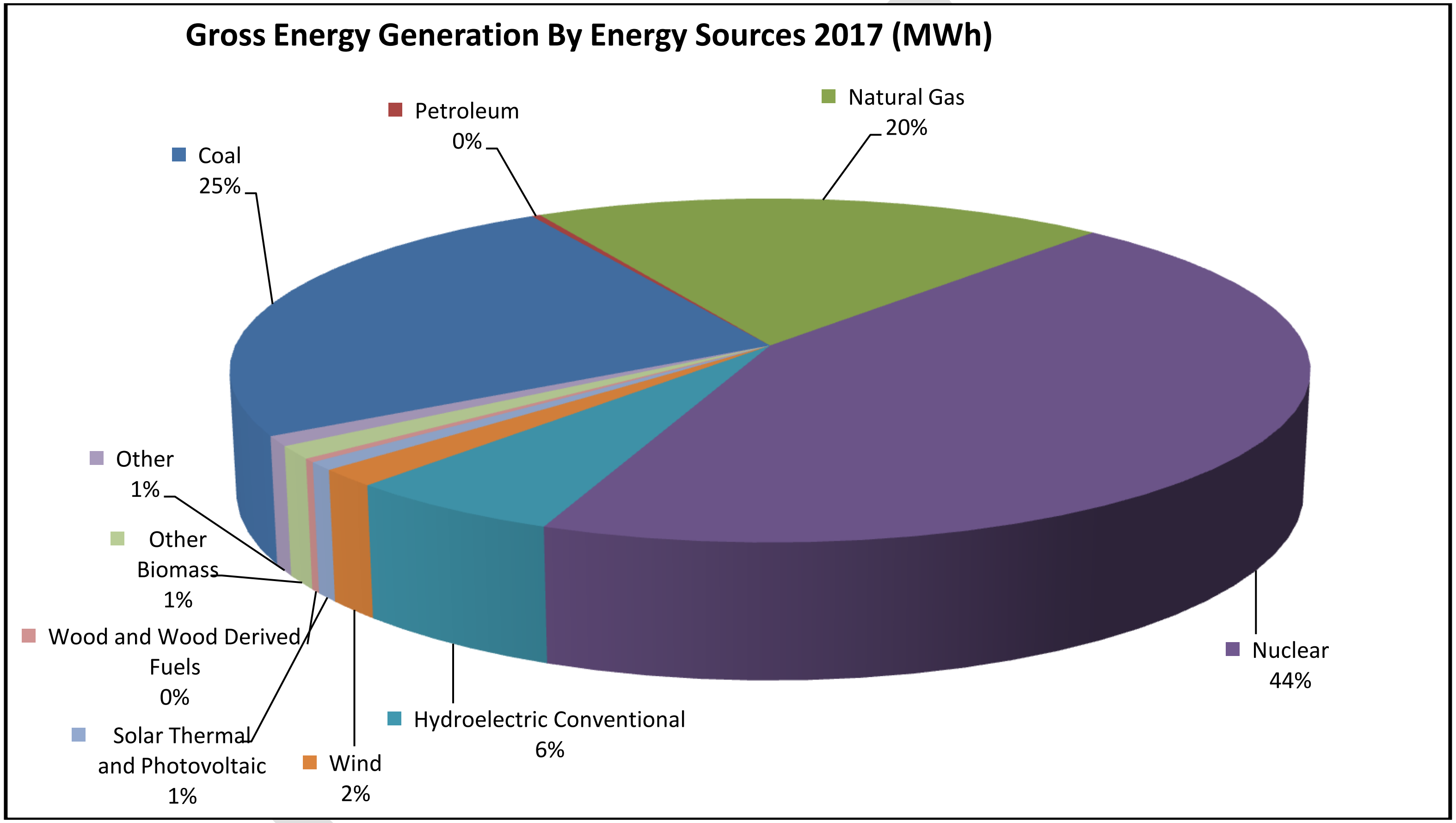
Electric Power Sector CO$_2$ Emissions – ALL Units – 2017					
Fuel Type	**MMBTU**	**CO$_2$ Emission (short tons)**	**CO$_2$ Emission (metric tons)**	**CO$_2$ Emission (MMTCO$_2$)**	**CO$_2$ Emission (MMTC)**
Coal	115,817,330	10,103,714	9,165,927	9.17	2.500
Distillate Fuel	1,836,609	159,907	145,065	0.15	0.040
Residual Fuel	220,827	3,515	3,189	0.00	0.001
Natural Gas	445,980,278	3,182,741	2,887,332	2.89	0.787
Total		**13,449,877**	**12,201,513**	**12.20**	**3.328**

Table 2-6: Electric Power - GHG Emissions by Pollutant – 2017 Year

Fuel Type	**Consumption (Billion Btu)**	**Emissions CO$_2$ (MMTCO$_2$E)**	**Emissions N$_2$O (MMTCO$_2$E)**	**Emissions CH$_4$ (MMTCO$_2$E)**	**Emissions Total (MMTCO$_2$E)**
Coal	115,817.33	9.17	0.048685075	0.022021825	9.236634319
Distillate Fuel	1,836.61	0.15	0.000344233	0.000366191	0.145775529
Residual Fuel	220.83	0.000	3.3886E-05	1.3782E-05	0.003236637
Natural Gas	445,980.28	2.89	0.004160328	0.001013507	2.892505349
		12.2015	**0.0532**	**0.0234**	**12.27815**

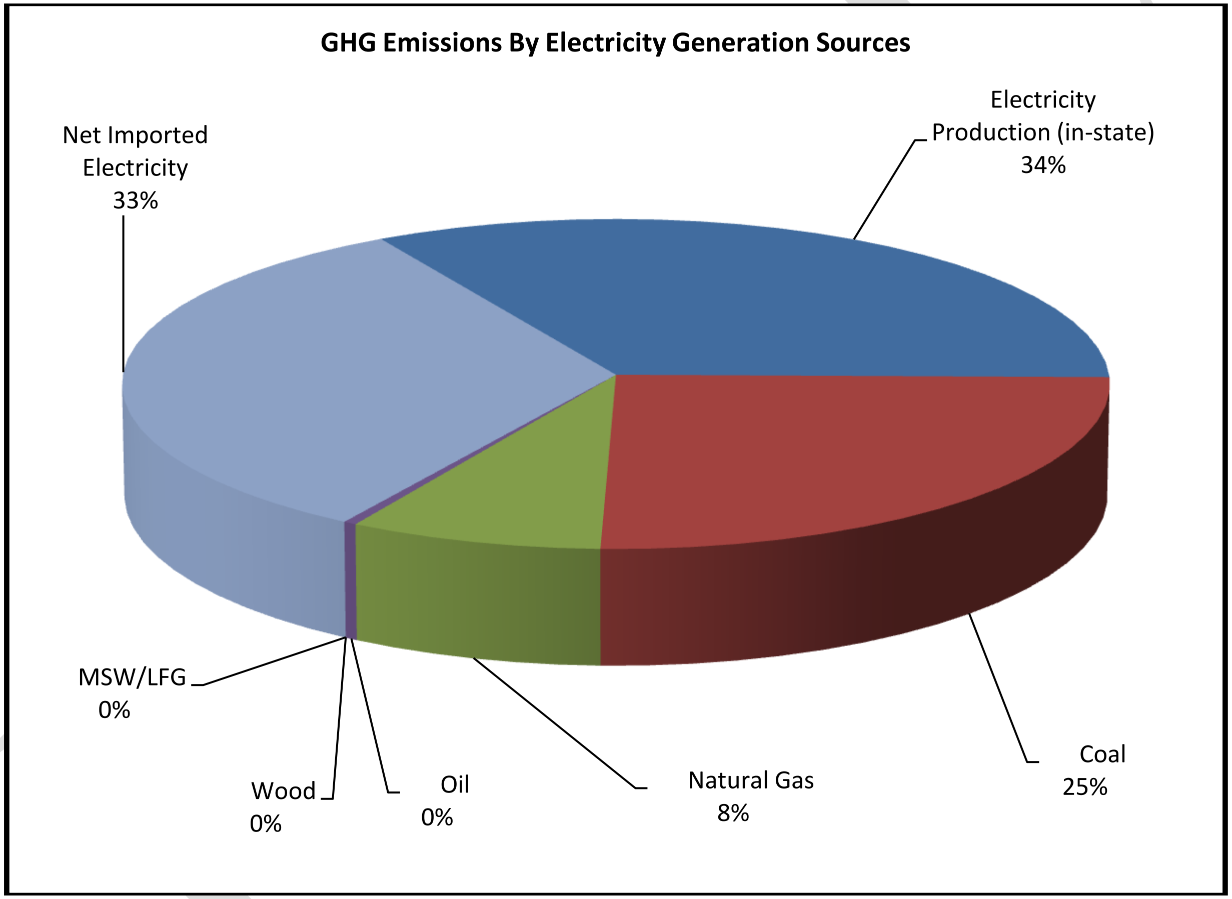
The gross energy generated by source type is shown in Figure 2-1.

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



The greenhouse gas emission generated by source type is shown in Figure 2-2.

Figure 2-2: Emissions by Electric Generating Source Sectors (MMTCO$_2$E)



The primary energy used to produce electricity consumed in Maryland is shown in Figure 2-3.

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

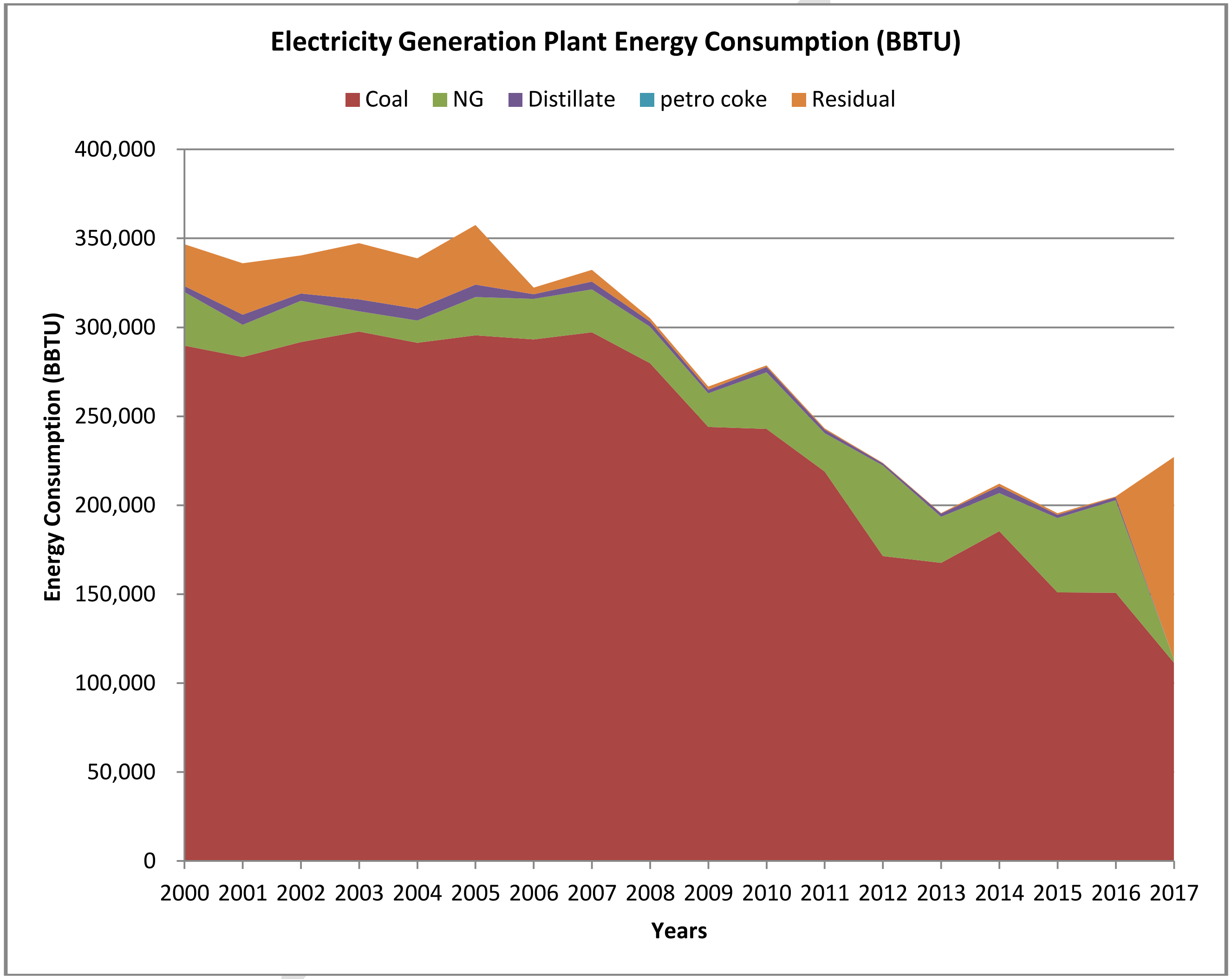
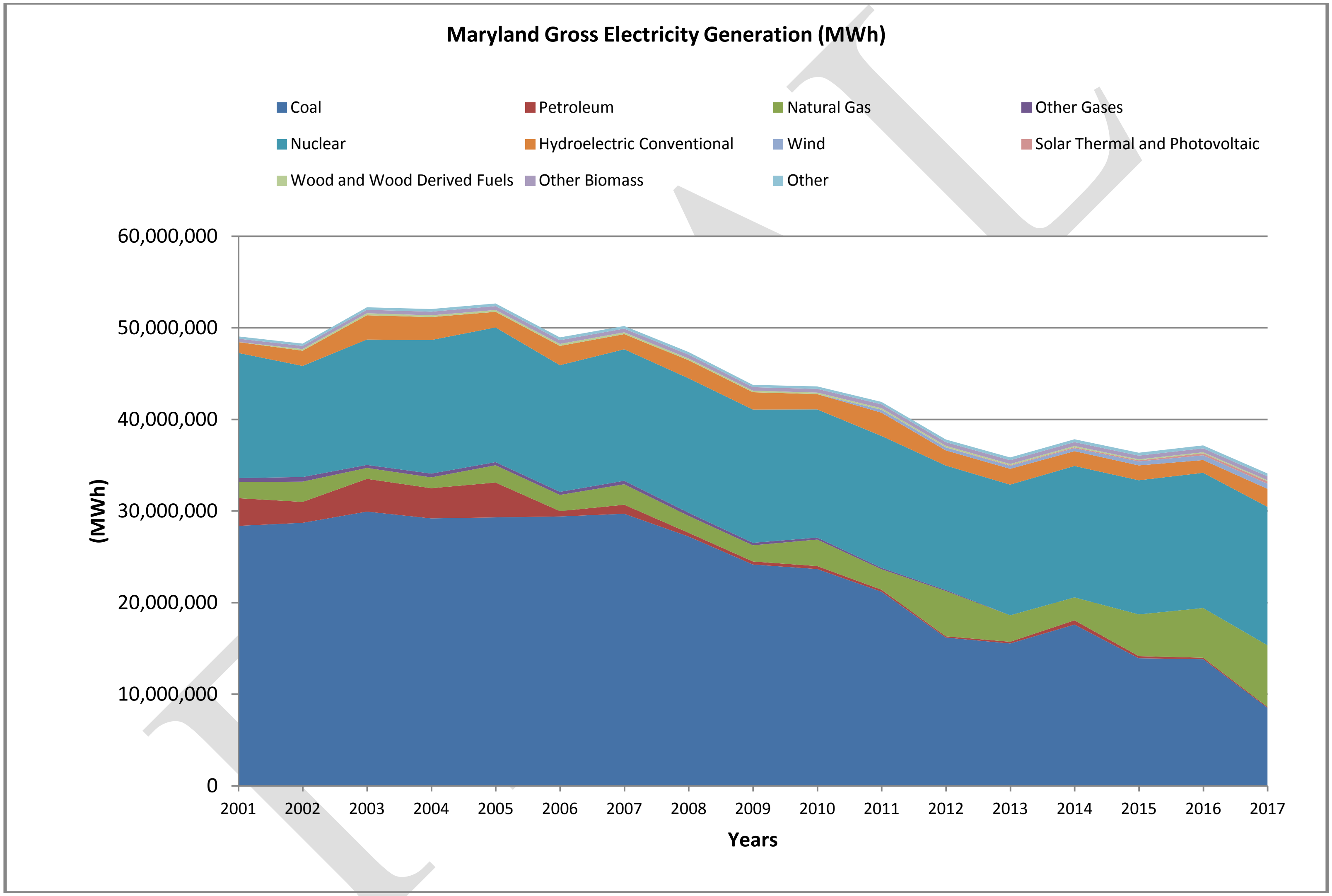


FIGURE 2-4: GROSS GENERATION AT MARYLAND POWER STATIONS, PLUS IMPORTS



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 year 2017 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.[1], [2] The 2017 GHG inventory for the RCI sector was prepared using the SIT software with the state-specific updated input data imported to 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[3], a widely accepted procedure for greenhouse gas analysis. Selected results for emissions in Maryland and a detailed description of the 2017 inventory are presented here.

3.2 DATA SOURCES

- State-consumption data derived from EIA's State Energy Consumption, Price, and Expenditure Estimates (SEDS) 2017: State Energy Data System (SEDS): 2017 (updates by energy source). Consumption Estimates (EIA 2017). https://www.eia.gov/state/seds/seds-data-complete.php?sid=US
- Default state synthetic natural gas data obtained from Table 2 of EIA's Historical Natural Gas Annual (EIA 2017), and Table 2 for Natural Gas Annual publications from 2010-2017 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

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[1] 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_20 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.
[3] Intergovernmental Panel on Climate Change

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

3.3 GREENHOUSE GAS INVENTORY METHODOLOGY

Maryland base year (2006) and periodic year (2017) GHG emissions from the RCI sector were 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.[1]

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 consumption by fuel type and sector, 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.

Energy Consumption by Fuel Type and Sector
Energy consumption data for Maryland was collected from the EIA's State Energy Consumption, Price, and Expenditure Estimates (SEDS) EIA (June 28, 2019 Release). [2]

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.

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[1] 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.

[2] EIA SEDS data are available at https://www.eia.gov/state/seds/seds-data-complete.php?sid=MD

- The carbon/energy ratio of different petroleum fractions generally correlates with API (American Petroleum Institute) gravity (Marland and Rotty 1984).[1] 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 2017 periodic GHG emissions inventory are listed in Table 3-1 below.

Table 3-1: Carbon Content of Fuels

Fuel	2017 Carbon Content (lb C/MBTU)
Asphalt and Road Oil	45.27
Aviation Gasoline	41.57
Distillate Fuel	44.47
Jet Fuel, Kerosene	43.43
Jet Fuel, Naphtha	43.51
Kerosene	43.97
LPG (industrial)	37.28
LPG (energy only)	37.11
Lubricants	44.53
Motor Gasoline	42.90
Residual Fuel	45.15
Misc. Petro Products	44.42
Feedstocks, Naphtha	40.86
Feedstocks, Other Oils	43.43
Pentanes Plus	40.06
Petroleum Coke	61.34
Still Gas	40.08
Special Naphthas	43.47
Unfinished Oils	44.77
Waxes	43.60

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[1] 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	2017 Carbon Content (lb C/MBTU)
Residential Coal	56.79
Commercial Coal	56.79
Industrial Coking Coal	56.20
Industrial Other Coal	56.85
Electric Power Coal	55.80
Natural Gas	31.90
Aviation Gasoline Blending Components	41.56
Motor Gasoline Blending Components	42.90
Crude Oil	44.77

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, naphtha, 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	2017 Storage Factor Used
Asphalt and Road Oil	100%
Distillate Fuel	50%
LPG	62%
Lubricants	9%
Residual Fuel	50%
Feedstocks, Naphtha	62%
Feedstocks, Other Oils	62%
Misc. Petro Products	0%
Pentanes Plus	62%
Petroleum Coke	30%
Still Gas	80%
Special Naphthas	0%
Waxes	58%
Industrial Coking Coal	10%
Natural Gas	62%

3.3.1 Carbon Dioxide (CO_2) 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)*[1]; 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 residential energy consumption to $MMTCO_2e$ is as follows:

$$\text{Emissions }(\text{MMTCO}_2\text{E}) = \frac{\text{Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times \text{Combustion Efficiency (\%)} \times 0.90718474 \times (44/12)}{1{,}000{,}000}$$

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.
0.90718474 = 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)*[2]; 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:

$$\text{Emissions }(\text{MMTCO}_2\text{E}) = \frac{\text{Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times \text{Combustion Efficiency (\%)} \times 0.90718474 \times (44/12)}{1{,}000{,}000}$$

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.
0.90718474 = constant used to convert from short tons to metric tons.
0.0005 = constant used to convert from pounds to short tons.

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[1] Energy Information Administration (EIA), State Energy Data, https://www.eia.gov/state/seds/seds-data-complete.php?sid=US

[2] Energy Information Administration (EIA), State Energy Data, https://www.eia.gov/state/seds/seds-data-complete.php?sid=US

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 Administration's (EIA) *State Energy Data (SED)*[1]; 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:

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

$$\text{Emissions } (\text{MMTCO}_2\text{E}) = \frac{\text{Net Consumption (BBtu)} \times \text{Emission Factor (lbs C/BBtu)} \times 0.0005 \times \text{Combustion Efficiency (\%)} \times 0.90718474 \times (44/12)}{1{,}000{,}000}$$

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.
0.90718474 = 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.

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[1] Energy Information Administration (EIA), State Energy Data, https://www.eia.gov/state/seds/seds-data-complete.php?sid=US

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 emissions 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 ($MMTCO_2E$)

3.4 GREENHOUSE GAS INVENTORY RESULTS

3.4.1 Residential Fossil Fuel Combustion Results

Table 3-4: 2017 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	0	56.79	100.0%	0.0	0.0000
Distillate Fuel	10,426	44.47	100.0%	231,822.11	0.771337920
Kerosene	149	44.01	100.0%	3,278.75	0.010909315
LPG	6,277	37.11	100.0%	116,470.62	0.387530808
Natural Gas	79,376	31.90	100.0%	1,266,047.20	4.212498170
				Total	**5.382276213**

Table 3-5: 2017 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	0	0.30069	0.000	21	0.0000
Distillate Fuel	10,426	0.01002	104.50	21	0.0022
Kerosene	149	0.01002	1.49	21	0.0000
LPG	6,277	0.01002	62.92	21	0.0013
Natural Gas	79,376	0.00475	376.86	21	0.0079
Wood	4,790	0.28487	1,364.50	21	0.0287
				Total	**0.0401**

Table 3-6: 2017 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	0	0.00150	0.0000	310	0.0000
Distillate Fuel	10,426	0.00060	6.27	310	0.0019
Kerosene	149	0.00060	0.0896	310	0.0000
LPG	6,277	0.00060	3.7749	310	0.0012
Natural Gas	79,376	0.00009	7.5372	310	0.0023
Wood	4,790	0.00380	18.1934	310	0.0056
				Total	**0.0111**

3.4.2 Commercial Fossil Fuel Combustion Results

Table 3-7: 2017 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	0	56.79	100.0%	0.00	0.0000
Distillate Fuel	5,563	44.47	100.0%	123,693.31	0.4116
Kerosene	47	44.01	100.0%	1,034.24	0.0034
LPG	3,078	37.11	100.0%	57,112.73	0.1900
Motor Gasoline	8,686	42.90	100.0%	186,317.92	0.6199
Residual Fuel	33	45.11	100.0%	744.32	0.0025
Natural Gas	75,700	31.90	100.0%	1,207,415.00	4.0174
				Total	**5.2449**

Table 3-8: 2017 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	0	0.01002	0.00	21	0.00000
Distillate Fuel	5,563	0.01002	55.76	21	0.0011709
Kerosene	47	0.01002	0.47	21	9.892E-06
LPG	3,078	0.01002	30.85	21	0.00647869
Motor Gasoline	8,686	0.01002	87.06	21	0.001828269
Residual Fuel	33	0.01002	0.33	21	6.9459E-06
Natural Gas	75,700	0.00475	359.40	21	0.0075475
Wood	1,301	0.28487	370.61	21	0.0077877
				Total	**0.01899**

Table 3-9: 2017 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	0	0.00150	0.00	310	0.0000
Distillate Fuel	5,563	0.00060	3.345	310	0.0010
Kerosene	47	0.00060	0.028	310	0.0000
LPG	3,078	0.00060	1.851	310	0.0006
Motor Gasoline	8,686	0.00060	5.224	310	0.0016
Residual Fuel	33	0.00060	0.020	310	0.0000
Natural Gas	75,700	0.00009	7.188	310	0.0022
Wood	1,301	0.00380	4.941	310	0.0015
				Total	**0.0070**

3.4.3 Industrial Fossil Fuel Combustion Results

Table 3-10: 2017 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	0.0	0	10%	0	56.20	100.0%	0.00	0.00
Other Coal	12,275	201	0%	12,275	56.85	100.0%	348,933.61	1.1610
Asphalt and Road Oil	16,869	16,869	100%	0	45.31	100.0%	0.00	0.00
Aviation Gasoline Blending Components	0	0	0%	0	41.57	100.0%	0.00	0.00
Crude Oil	0	0	0%	0	44.77	100.0%	0.00	0.00
Distillate Fuel	5,309	32	50%	5,293	44.47	100.0%	117,691.51	0.3916
Feedstocks, Naphtha less than 401 F	0.0	0	62%	0	40.86	100.0%	0.00	0.00
Feedstocks, Other Oils greater than 401 F	0.0	0	62%	0	44.43	100.0%	0.00	0.00
Kerosene	7	7	0%	7	43.97	100.0%	153.90	0.0005
LPG	1,486	1,224	62%	728	37.11	100.0%	13,508.67	0.0449
Lubricants	946	946	9%	859	44.53	100.0%	18,687.33	0.0622
Motor Gasoline	2,865	2,865	0%	2,865	42.90	100.0%	61,455.31	0.2045
Motor Gasoline Blending Components	0	0	0%	0	42.90	100.0%	0.00	0.00
Misc. Petro Products	293	293	0%	293	44.77	100.0%	6,559.34	0.0218
Petroleum Coke	0	0	30%	0	61.34	100.0%	0.00	0.00
Pentanes Plus	0.0	0	62%	0	42.06	100.0%	0.00	0.00
Residual Fuel	91	91	50%	46	45.15	100.0%	1,027.16	0.0034
Still Gas	0	0	80%	0	40.11	100.0%	0.00	0.00
Special Naphtha	2,795	2,649	0%	2,795	43.51	100.0%	60,805.23	0.2023
Unfinished Oils	0	0	0%	0	44.77	100.0%	0.00	0.00
Waxes	100	100	58%	42	43.64	100.0%	916.44	0.0030
Natural Gas	16,489	512	62%	16,172	31.90	100.0%	257,945.39	0.8583
						Total	887,683.90	**2.9536**

Table 3-11: 2017 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	0.0	0.0	0.01002	0.0	21	0.0
Other Coal	12,275	201	0.01002	121.017	21	0.0025
Asphalt and Road Oil	16,869	16,869	0.00301	0.0	21	0.00
Aviation Gasoline Blending Components	0.0	0.0	0.00301	0.0	21	0.00
Crude Oil	0.0	0.0	0.00301	0.0	21	0.00
Distillate Fuel	5,309	32	0.00301	15.87	21	0.0003
Feedstocks, Naphtha less than 401 F	0.0	0.0	0.00301	0.00	21	0.00
Feedstocks, Other Oils greater than 401 F	0.0	0.0	0.00301	0.00	21	0.00
Kerosene	7	7	0.00301	0.00	21	0.00
LPG	1,486	1,224	0.00301	0.7874	21	0.0000
Lubricants	946	946	0.00301	0.0	21	0.00
Motor Gasoline	2,865	2,865	0.00301	0.0	21	0.0000
Motor Gasoline Blending Components	0.0	0	0.00301	0.0	21	0.00
Misc. Petro Products	293	293	0.00301	0.0	21	0.0000
Petroleum Coke	0.0	0	0.00301	0.0	21	0.00
Pentanes Plus	0.0	0	0.00301	0.0	21	0.00
Residual Fuel	91	91	0.00301	0.0	21	0.0000
Still Gas	0	0	0.00301	0.0	21	0.00
Special Naphthas	2,795	2,649	0.00301	0.4397	21	0.000
Unfinished Oils	0.0	0	0.00301	0.0	21	0.00
Waxes	100	100	0.00301	0.00	21	0.0000
Natural Gas	16,489	512	0.00095	15.17	21	0.0003
Wood	6,971	NA	0.02849	198.58	21	0.0042
					Total	**0.0074**

Table 3-12: 2017 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)	Emissions (metric tons N_2O)	GWP	Emissions ($MMTCO_2E$)
Coking Coal	0.0	0.0	0.00150	0.00	310	0.00
Other Coal	12,275	201	0.00150	18.15	310	0.0056
Asphalt and Road Oil	16,869	16,869	0.00060	0.00	310	0.00
Aviation Gasoline Blending Components	0.0	0	0.00060	0.00	310	0.00
Crude Oil	0.0	0	0.00060	0.00	310	0.00
Distillate Fuel	5,309	32	0.00060	3.17	310	0.0010
Feedstocks, Naphtha less than 401 F	0	0	0.00060	0.00	310	0.00
Feedstocks, Other Oils greater than 401 F	0	0	0.00060	0.00	310	0.00
Kerosene	7	7	0.00060	0.00	310	0.000
LPG	1,486	1,224	0.00060	0.16	310	0.000
Lubricants	946	946	0.00060	0.00	310	0.00
Motor Gasoline	2,865	2,865	0.00060	0.00	310	0.000
Motor Gasoline Blending Components	0	0	0.00060	0.00	310	0.00
Misc. Petro Products	293	293	0.00060	0.00	310	0.0000
Petroleum Coke	0	0	0.00060	0.00	310	0.00
Pentanes Plus	0	0	0.00060	0.00	310	0.00
Residual Fuel	91	91	0.00060	0.00	310	0.00
Still Gas	0	0	0.00060	0.00	310	0.00
Special Naphthas	2,795	2,649	0.00060	0.09	310	0.000
Unfinished Oils	0	0	0.00060	0.00	310	0.00-
Waxes	100	100	0.00060	0.00	310	0.000
Natural Gas	16,489	512	0.00009	1.52	310	0.0005
Wood	6,971	NA	0.00380	26.48	310	0.0082
					Total	**0.0154**

4.0 Transportation On-Road Mobile Energy Use

4.1 OVERVIEW

The purpose of this section is to explain how Maryland estimates emissions from highway vehicles for inclusion in its emission inventories and State Implementation Plans (SIP).

In accordance with the standard methodology for the development of highway vehicle emissions inventories, all of the emissions estimates documented herein are based on emission factors developed using the United States Environmental Protection Agency's (U.S. EPA's) latest version of the MOVES emissions factor model and appropriate activity levels i.e., vehicle miles traveled (VMT) estimates developed from the vehicle count data maintained by the State Highway Administration (SHA) of the Maryland Department of Transportation (MDOT).

The official highway vehicle inventory for the Maryland portion of the Washington, D.C. Ozone Non-attainment Area (comprising the counties of Calvert, Charles, Frederick, Montgomery, and Prince George's) has been developed by the Metropolitan Washington Council of Governments (MWCOG) and has been documented by that Organization under separate cover.

4.1.1 Highway Vehicle Emissions Inventory

The operation of highway vehicles has proven to be a significant contributor to air pollution, particularly to ground-level ozone, as they emit both Volatile Organic Compounds (VOCs), and Oxides of Nitrogen (NOx) during operation. Ground-level ozone is not created directly rather, it is formed through a chemical reaction between VOCs and NOx in the presence of sunlight. Highway vehicles also emit other pollutants such as Carbon Monoxide (CO), Particulate Matter smaller than 2.5 microns (PM2.5), Particulate Matter smaller than 10 microns (PM10), Sulfur Dioxide (SO_2), and Ammonia (NH_3) in addition to the greenhouse gases such as Carbon Dioxide, Methane, and Nitrous Oxide.

This inventory includes all the pollutants mentioned above, in summer daily and yearly time periods, appropriately.

Estimating the emission rate and activity levels of all vehicles on the road during a typical day is a complicated endeavor. If every vehicle emitted the same amount of pollution all the time, one could simply multiply those emission standards (emission rate in grams of pollution per mile) times the number of miles driven (activity level) to estimate total emissions. The fact is that emission rates from all vehicles vary over the entire range of conditions under which they operate. These variables include ambient air temperature, speed, traffic conditions, road types, road topography, operating mode (whether started cold or started hot, whether accelerating or decelerating) and fuel. The inventory must also account for non-exhaust or evaporative emissions. In addition, the fleet is composed of several generations, types of vehicles and their emission control technologies, each of which performs differently. This requires that the composition of the fleet (vehicle ages and types) must also be included in the estimation algorithm.

In order to estimate both the rate at which emissions are being generated and to calculate vehicle miles traveled (VMT), Maryland examines its road network and fleet to estimate vehicle activity. For ozone-related inventories, this is done for a typical summer weekday in 2017. For the annual inventories, this is done for each of the twelve months in 2017 and aggregated for the entire year. The entire process is extremely complex and involves large amounts of various data sets.

Computer models have been developed to perform these calculations by simulating the travel of vehicles on the State's roadway system. These models then generate emission rates (or emission factors) for different vehicle types for area-specific conditions and then combine them in summary form. The "area-specific conditions" include fleet characteristics such as vehicle population and vehicle age distribution, roadway and travel characteristics, meteorology, control programs in place, mandated fuel requirements, etc.

4.1.2 Periodic Inventory Methodology:

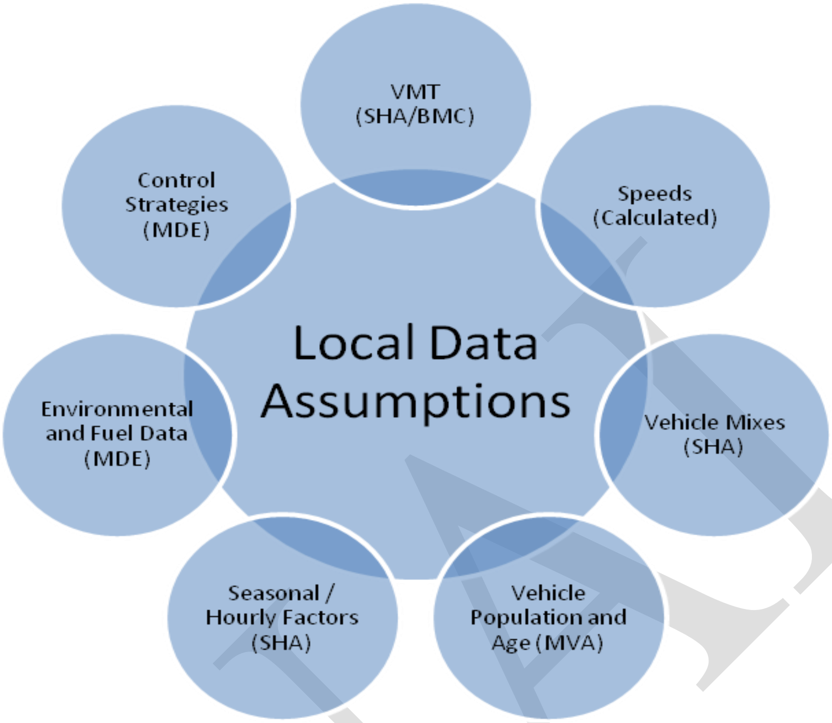
Guidance documents from EPA were used to develop the highway emissions inventory. They include:

Policy Guidance on the Use of MOVES2014 and Subsequent Minor Revisions for SIP Development, Transportation Conformity, and Other Purposes, US EPA Office of Air and Radiation, EPA-420-B-12-010, April 2012.

Using MOVES to prepare Emission Inventories in State Implementation Plans and Transportation Conformity: Technical Guidance for MOVES2014b and MOVES2014b. US EPA Office of Air and Radiation, and Office of Transportation and Air Quality, EPA-420-B-12-028, April 2012.
Motor Vehicle Emission Simulator, User Guide for MOVES2014a, EPA-420-B-10-036, August 2014 and *User Guide for MOVES2014b*, EPA-420-B-12-001b June 2012

The methodologies used to produce the emission data conform to the recommendations provided in EPA's technical guidance. A mix of local data and national default (internal to MOVES2014a) data has been used for this submission. As illustrated in Figure 4.1, local data has been used for the primary data items that have a significant impact on emissions. Local data inputs to the analysis process reflect the latest available planning assumptions using data obtained from the Maryland Department of Environment (MDE), Motor Vehicle Administration (MVA), Maryland State Highway Administration (SHA), Baltimore Metropolitan Council (BMC), Metropolitan Washington Council of Governments (MWCOG) and other local/national sources.

FIGURE 4-1: LOCAL DATA INPUTS USED FOR EMISSIONS INVENTORY



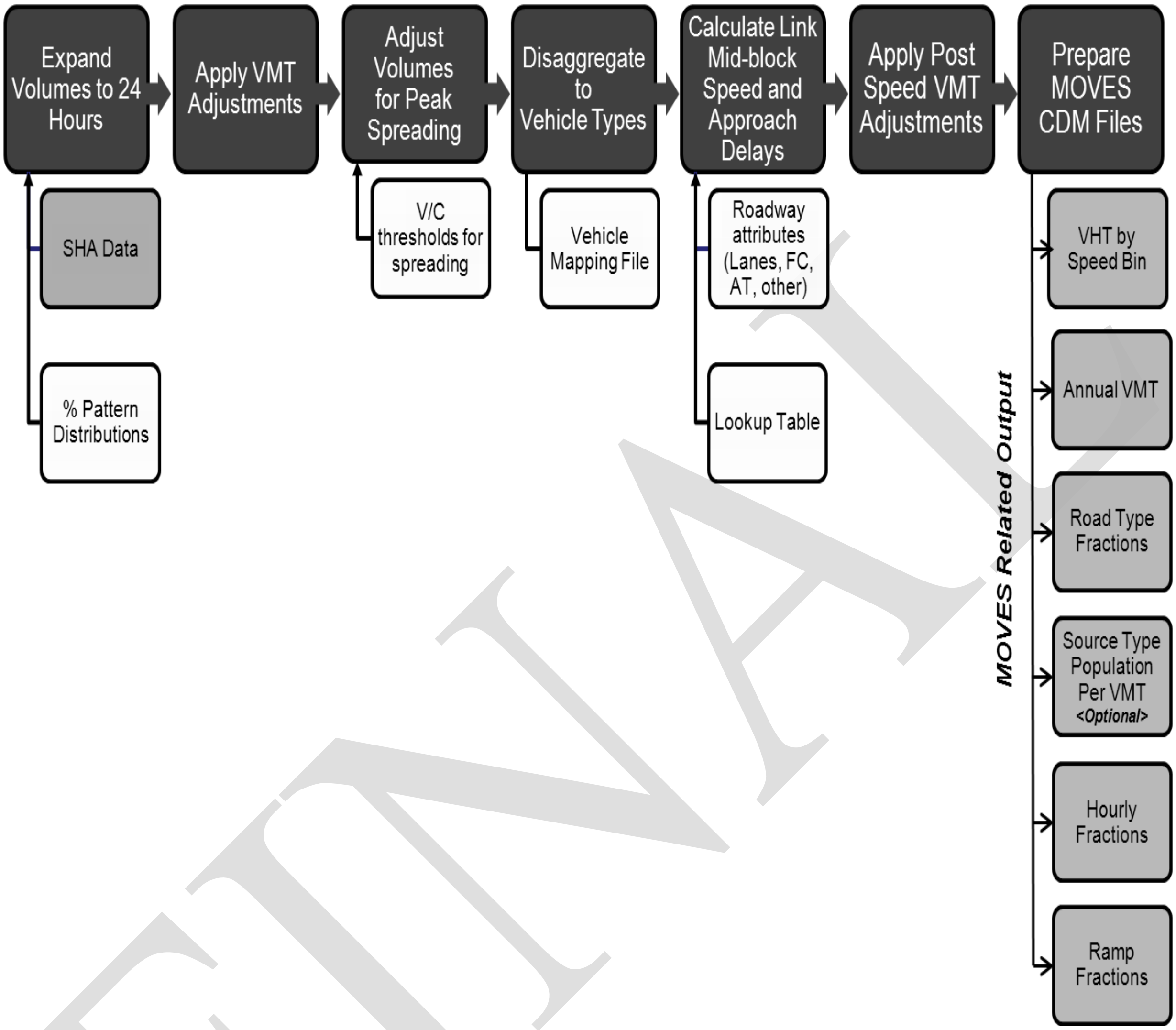
The analysis methodology is consistent with past statewide inventory efforts including the 2017 National Emissions Inventory (NEI) submission. This includes the use of statewide traffic roadway data and custom post-processing software (PPSUITE) to calculate hourly speeds and prepare key traffic input files to the MOVES2014a emission model. PPSUITE consists of a set of programs that perform the following functions:

- Analyzes highway operating conditions.
- Calculates highway speeds.
- Compiles vehicle miles of travel (VMT) and vehicle type mix data.
- Prepares MOVES runs and processes MOVES outputs.

PPSUITE is a widely used and accepted tool for estimating speeds and processing emissions rates. It is has been used for past SIP highway inventories in Maryland, Pennsylvania, and New Jersey. The software is based upon accepted transportation engineering methodologies. For example, PPSUITE utilizes speed and delay estimation procedures based on planning methods provided in the Highway Capacity Manual, a report prepared by the Transportation Research Board (TRB) summarizing current knowledge and analysis techniques for capacity and level-of-service analyses of the transportation system.

The PPSUITE process is integral to producing key input files to the MOVES emission model. Figure4.2 summarizes the key functions of PPSUITE and the traffic-related input files prepared for MOVES.

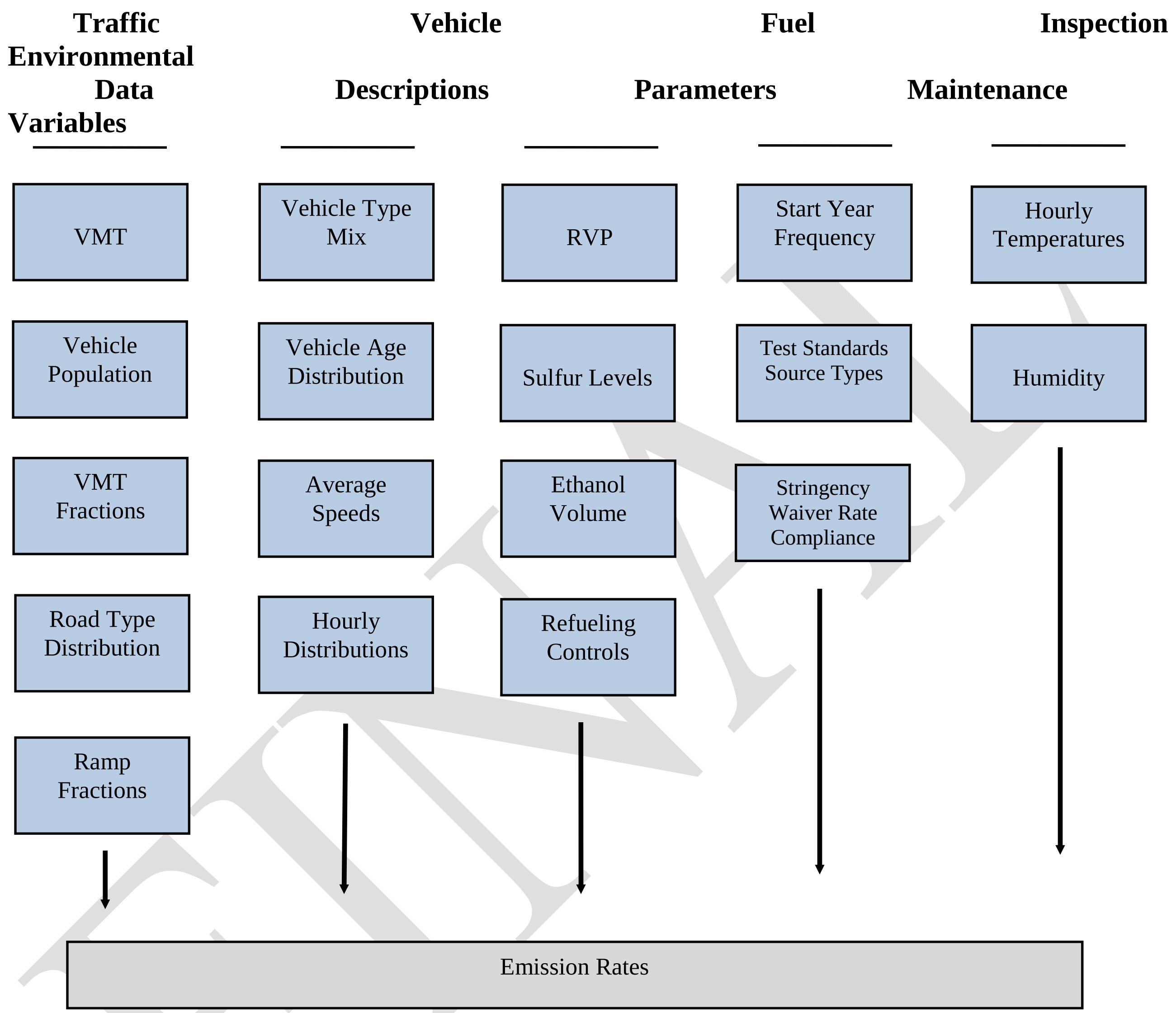
FIGURE 4-2: EMISSION CALCULATION PROCESS



4.2 DATA SOURCES

A large number of inputs to MOVES are needed to fully account for the numerous vehicle and environmental parameters that affect emissions levels. These include traffic flow characteristics, vehicle descriptions, fuel parameters, inspection/maintenance program parameters, and environmental variables as shown in Figure 4.3.

FIGURE 4-3: EXAMPLES OF KEY MOVES INPUT DATA



MOVES includes a default national database of meteorology, vehicle fleet, vehicle activity, fuel, and emission control program data for every county; but EPA cannot certify that the default data is the most current or best available information for any specific area. As a result, local data is recommended for use for analyses SIPs.

A mix of local and default data is used for this inventory. Local data sources are used for all inputs that have a significant impact on calculated emission rates. These data items are discussed in the following sections.

Roadway Data:
The roadway data input to emissions calculations for this inventory is based on information from the "universal" highway database maintained by the Maryland SHA. SHA obtains this information from periodic visual and electronic traffic counts. The SHA data is dynamic, since it is continually reviewed and updated from new traffic counts. Information on roadways included in the National Highway System is reviewed at least annually, while information on other roadways is reviewed at least biennially.

On a triennial basis, a current "snapshot" of the SHA database is taken and downloaded to provide an up-to-date record of the state's highway system for estimating emissions. This emissions inventory is based on 2017 data which is the most current "snapshot" of the SHA data. The following information is extracted from the database for emission calculations:

- Lanes and distances
- volumes representing Average Annual Daily Traffic (AADT)
- truck percentages and urban/rural classifications
- functional class codes

The volumes and distances are used in calculating highway VMT totals for each county. As discussed in the next section, adjustments are needed to convert the volumes to an average summer weekday . The lane values, area type, and functional class are important inputs for determining the congestion and speeds for individual highway segments. Truck percentages are used in the speed determination process and are used to split volumes to individual vehicle types used by the MOVES software.

Maryland classifies its road segments by function, as well as whether it is located in an urban or rural area, as indicated below in Figure 4.4. The urban/rural (UR) and functional classes (FC) are important indicators of the type and function of each roadway segment. These values are also used to determine the MOVES Road Type classification that has an important impact on the emission factors for each roadway segment. Equivalencies between the SHA and MOVES indices are discussed in later sections.

FIGURE 4-4: MDOT URBAN/RURAL AND FUNCTIONAL CLASS CODES

Urban/Rural Code	1=Rural	
	2=Small Urban	
	3=Urban	
Functional Class	Rural Functional Classes Used For Rural Areas	Urban Functional Classes Used For Urban Areas
	1=Rural Freeway	11=Urban Freeway
	2=Rural Other Principal Arterial	12=Urban Expressway
	6=Rural Minor Arterial	14=Urban Principal Arterial
	7=Rural Major Collector	16=Urban Minor Arterial
	8=Rural Minor Collector	17=Urban Collector
	9=Rural Local	19=Urban Local

The PPSUITE processing software allows for many additional variables other than those available in the SHA database. Using these variables improves the calculation of congested speeds. Such variables include information regarding free-flow speeds and capacities and other physical roadway features (e.g. traffic signals) that can affect a roadway's calculated congested speed. This data can be determined from lookup tables based on a roadway segment's urban/rural code and functional class. Much of the lookup table data was developed from information contained in the Highway Capacity Manual.

4.2.1 Other Supporting Traffic Data:

Other traffic data is used to adjust and disaggregate traffic volumes. Key sources used in these processes include the following:

HPMS VMT: According to EPA guidance, baseline inventory VMT computed from the SHA highway segment volumes must be adjusted to be consistent with HPMS VMT totals. Although it has some limitations, the HPMS system is currently in use in all 50 states and is being improved under FHWA direction. Adjustment factors are calculated which adjust the base year 2017 SHA download VMT to be consistent with the reported 2017 HPMS totals for that year. These factors are applied to all county, urban/rural code, and facility group combinations within the region. These adjustments are important for accounting for missing local roadway VMT that is not contained within or represented by the state-owned roadway system.

Seasonal Factors: The SHA contains AADT volumes that are an average of all days in the year, including weekends and holidays. An ozone emission analysis, however, is based on a typical July or summer weekday. Therefore, the SHA volumes must be seasonally adjusted. The seasonal factors were developed based on the 2017 report *ATR Station Reports in the Traffic Trends System Report Module* from the SHA website. These factors are applied to the existing SHA AADT to produce July weekday volumes. The same factors are also used to develop the MOVES daily and monthly VMT fraction files.

Hourly Patterns: Speeds and emissions vary considerably depending on the time of day. Therefore, it is important to estimate the pattern by which roadway volume varies by hour of the day. Pattern data is in the form of a percentage of the daily volumes for each hour. Distributions are provided for all the counties within the region and by each facility type grouping. This data was developed from 2017 24-hour count data obtained from the SHA website. The same factors are also used to develop the MOVES hourly fraction file.

4.2.2 Vehicle Class Data:

Emission rates within MOVES vary significantly by the type of vehicle. The MOVES model produces emissions and rates by thirteen MOVES vehicle source types. However, VMT is input to MOVES by six HPMS vehicle groups. Figure 4.5 summarizes the distinction between each classification scheme.

Figure 4-5: MOVES Source Types and HPMS Vehicle Groups

SOURCE TYPES		HPMS Class Groups	
11	Motorcycle	10	Motorcycle
21	Passenger Car	20	Passenger Car
31	Passenger Truck	30	Passenger/Light Truck
32	Light Commercial Truck	40	Buses
41	Intercity Bus	50	Single Unit Trucks
42	Transit Bus	60	Combination Trucks
43	School bus		
51	Refuse Truck		
52	Single Unit Short-haul Truck		
53	Single Unit Long-haul Truck		
54	Motor Home		
61	Combination Short-haul Truck		
62	Combination Long-haul Truck		

For this regional inventory, vehicle type pattern data was developed for each county and functional class combination based on SHA classification counts and internal MOBILE6.2 and MOVES defaults. As the first step, SHA count data was used to develop percentage splits to the following four vehicle groups:

- Autos
- Heavy trucks
- Motorcycles
- Buses

Following procedures used for previous SIP efforts, the vehicle groups were expanded to the 28 MOBILE6.2 weight-based vehicle types. Using procedures provided in EPA technical guidance, the MOBILE6.2 vehicle classes were mapped to the MOVES source type and HPMS class groups.

The vehicle type percentages are also provided to the capacity analysis section of PPSUITE to adjust the speeds in response to trucks. That is, a given number of larger trucks take up more roadway space than a given number of cars, and this is accounted for in the speed estimation process by adjusting capacity using information from the Highway Capacity Manual.

4.2.3 Vehicle Ages:

Vehicle age distributions are input to MOVES for each county by the thirteen source types. The distributions reflect the percentage of vehicles in the fleet up to 31 years old. The vehicle age distributions were prepared by MDE based on information obtained from MVA registration data.

The vehicle age distributions are based on 2017 MVA registration data that included cleaning of duplicate, expired, and non-eligible vehicles such as trailers and the farm tractors accounted for in the Area Source category of emissions. The data was transformed into two sets of MOBILE6 vehicle types; one conforming to MOBILE6-28 vehicle type and the other to MOBILE6-16 composite vehicle type system using a SAS-based computer program.

The MOVES model input age distributions were produced utilizing the available EPA MS-Excel-based vehicle registration converter tool. This tool assisted in converting the MOBILE6.2-based data into the MOVES source type categories.

4.2.4 Vehicle Population Data:

The information on the vehicle fleet including the number and age of vehicles impacts forecasted start and evaporative emissions within MOVES. MOVES model requires the population of vehicles by the thirteen source type categories. This data was prepared in-house by MDE for the analysis year 2017 utilizing another SAS-based computer program similar to the one discussed in the previous vehicle age section. Maryland county vehicle registration data was used to estimate vehicle population for light-duty and medium duty vehicles for all counties in the region. MOVES default values were adopted for the heavy duty MOVES vehicle types 52, 53, 61 and 62.

4.2.5 Environmental and Fuel Data:

Information on environmental, fuel, vehicle technology and other control strategy assumptions were determined based on a review of MOVES2014a default information by MDE.

Evaporative emissions are influenced significantly by the temperatures of the surrounding air. Ozone analysis temperature and humidity values were determined by MDE as follows using the procedures documented in EPA’s technical guidance.

Meteorological Data*:* Along the lines of MD fuel data, 2017 meteorological data for hourly average MOVES inputs of temperature and relative humidity was also compiled on a triennial basis for every county in MD. The month by month raw hourly-data sets came from the National Climate Data Center of NOAA based on weather data collected at the airport situated closest to the county modeled. Hourly average temperature and humidity computations were developed from the 24 hourly values for every hour in a given month. For the Baltimore Area, since the data source is one for the entire area (BWI Airport situated in Anne Arundel County of MD), the same set of data was used for all the constituent city/counties of the Baltimore Area.

Fuel Data: MDE obtains monthly fuel data reports regularly from the MD Fuel Laboratory which is under the jurisdiction of MD Fuel Tax Division of the Office of the Comptroller of MD. These fuel reports are generated by testing samples collected in the field (gas stations) for the purpose of fuel regulation enforcement. It covers all counties in MD. Since the data entry of these samples is a huge task, compilation of fuel data to yield input parameters for MOBILE or MOVES modeling is confined only to the years for which emission inventories are due for submission to EPA on a triennial basis beginning with the baseline year of 1990. 2017 happens to be a year of such periodic emission inventories. As such 2017 fuel data was compiled and fuel data parameters were developed separately for the 14 MD counties with EPA mandates to dispense only reformulated gasoline requirements and the 10 remaining counties dispensing conventional gasoline.

Two sets of fuel data inputs (Fuel Formulation and Fuel Supply tables) required by MOVES model were developed in-house for every county in MD. The fuel parameters changed from the MOVES defaults are as follows:

fuelFormulationID	Unique ID used for easy recognition
fuelSubtypeID	Selected per guidance based on ethanol content of gasoline
sulfurLevel	Computed from the local fuel data
ETOHVolume	Computed from the local fuel data
aromaticContent	Computed from the local fuel data
olefinContent	Computed from the local fuel data
benzineContent	Computed from the local fuel data
E200	Computed from the local fuel data
E300	Computed from the local fuel data

4.2.6 Other Vehicle Technology and Control Strategy Data:

The MOVES2014a default I/M data was reviewed and updated by MDE for all the counties in the region. The current I/M program known as Vehicle Emission Inspection Program (VEIP) assumed for the analysis year 2017 is described below.

MD Vehicle Emission Inspection Program: This program tests model year 1977 and newer gasoline powered vehicles weighing up to 26,000 lb. The test is done biennially, and on change of ownership. There is a two year grace period for new vehicles. Light duty vehicles model year 1996 and newer, and model year 2014 and newer vehicles weighing up to 14,000 lb get the OBD test. All other vehicles get an idle test with a gas cap pressure test and a visual check for the presence of a catalytic converter. The compliance factors reflect the observed fail and waiver rates observed in the program, combined with an assumed 96% compliance rate for vehicles showing up for testing. Heavy duty vehicles have an additional factor, reflecting the fraction of vehicles in the weight range covered by the program. This was derived from documentation comparing the MOVES and MOBILE vehicle classes. The significantly higher compliance rate for the gas cap check reflects the much higher retest pass rate for this check.

Federal Programs: Current federal vehicle emissions control and fuel programs are incorporated into the MOVES2014a software. These include the National Program standards covering model year vehicles through 2016. Modifications of default emission rates are required to reflect the early implementation of the National Low Emission Vehicle Program (NLEV) program in Maryland. To reflect these impacts, EPA has released instructions and input files that can be used to model these impacts. This inventory utilized the August 2014 version of the files (http://www.epa.gov/oms/models/moves/tools.htm).

4.2.7 State Vehicle Technology Programs:

MD Clean Car Program: Under the Maryland Clean Cars Act of 2007 Maryland adopted the California Low Emission Vehicle (LEV II) program. This program began implementation in 2014. This program requires all 2014 model year and newer vehicles (GVWR up to 14,000 lbs.) registered in Maryland to meet California emission standards for both criteria and greenhouse gas pollutants. This program also contains a zero emission vehicles component that requires the manufactures to produce a certain percentage of zero emission vehicles (electric, fuel cell, etc.) for purchase in the state. California has just adopted new amendments to the Low-Emission Vehicle regulation entitled LEV III (third generation low emission vehicle standards). These amendments create more stringent emission standards for new motor vehicles. These new standards will be phased-in over the 2015-2025 model years.

The impacts of this program were modeled for all analysis years using EPA's guidance document, *Instructions for Using LEV and NLEV Inputs for MOVES, EPA-420-B-10-003, January 2010*. EPA provided input files to reflect the CAL LEVII program with the standard phase-in schedules for new emission standards. Modifications to those schedules were done as per EPA's instructions, to reflect a later start for the State of Maryland beginning with vehicle model year 2014.

4.3 ANALYSIS METHODOLOGY

The previous sections have summarized the input data used for computing speeds and emission rates for this highway emissions inventory. This section explains how PPSUITE and MOVES uses that input data to produce emission estimates. Figure 4.6 provides a more detailed overview of the PPSUITE analysis procedure using the available traffic data information described in the previous section.

4.3.1 VMT Preparation

Producing an emissions inventory with PPSUITE requires a complex process of disaggregation and aggregation of vehicle activities. Data is available and used on a very small scale -- individual ½ mile roadway segments for each of the 24 hours of the day. This data needs to be processed individually to determine the distribution of vehicle hours of travel (VHT) by speed and then aggregated by vehicle class to determine the input VMT to the MOVES emission model. As an example key steps in the preparation of VMT for a summer daily run include:

- *Apply Seasonal Adjustments* - PPSUITE takes the input daily volumes from SHA (which represents AADT traffic) and seasonally adjusts the volumes to an average weekday in July. This adjustment utilizes factors developed for each functional class and urban/rural code. VMT can then be calculated for each link using the adjusted weekday volumes.

- *Disaggregate to Hours* - After seasonally adjusting the link volume, the volume is split to each hour of the day. This allows for more accurate speed calculations (effects of congested hours) and allows PPSUITE to prepare the hourly VMT and speeds for input to the MOVES model.

- *Peak Spreading* - After dividing the daily volumes to each hour of the day, PPSUITE identifies hours that are unreasonably congested. For those hours, PPSUITE then spreads a portion of the volume to other hours within the same peak period, thereby approximating the "peak spreading" that normally occurs in such over-capacity conditions.

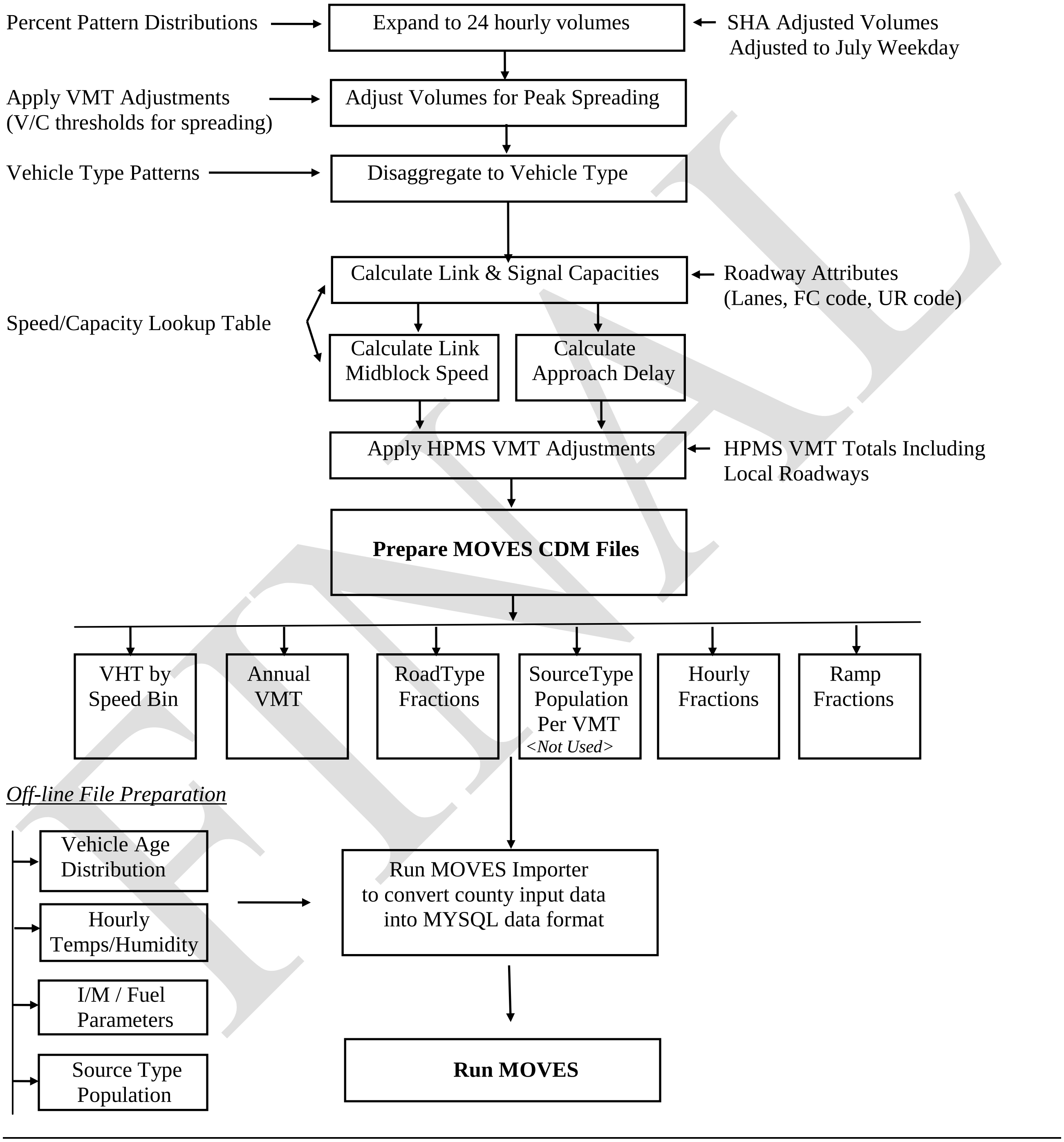
- *Disaggregation to Vehicle Types* - EPA requires VMT estimates to be prepared by source type, reflecting specific local characteristics. As a result, for Maryland's emission inventory runs, the hourly volumes are disaggregated to the six HPMS MOVES vehicle grouping based on count data assembled by SHA in combination with MOVES defaults as described in the previous section.

- *Apply HPMS VMT Adjustments* - Volumes must also be adjusted to account for differences with the HPMS VMT totals, as described previously. VMT adjustment factors are provided as input to PPSUITE, and are applied to each of the roadway segment volumes. These factors were developed from the latest HPMS download (conducted triennially); however, they are also applied to any future year runs. The VMT added or subtracted to the SHA database assumes the speeds calculated using the original volumes for each roadway segment for each hour of the day.

FIGURE 4-6: PPSUITE SPEED/EMISSION ESTIMATION PROCEDURE

PPSUITE Analysis Process

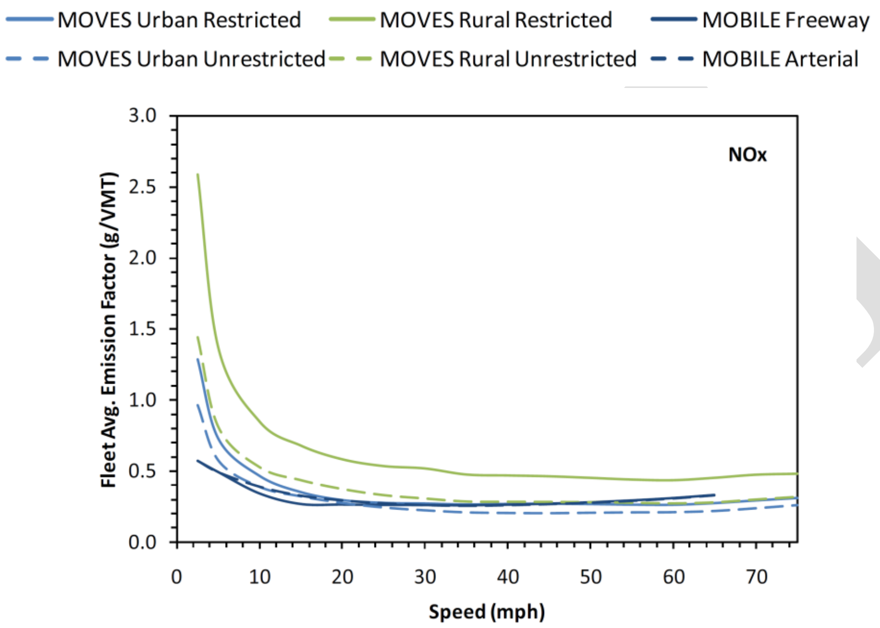
(The Following steps are Performed For Each SHA Roadway Segment)



Speed Estimation:

Emissions for many pollutants (including both VOC and NOx) vary significantly with travel speed. While VOCs generally decrease as speed increases, NOx decreases at the low speed range and increases at higher speeds, as illustrated in Figure 4.7.

FIGURE 4-7: EMISSION FACTOR VS. SPEED VARIANCES (NOX)



Source: Figure 3 from Implications of the MOVES2010 Model on Mobile Source Emission Estimates, Air & Waste Management Association, July 2010.

EPA recognizes that the estimation of vehicle speeds is a difficult and complex process. Because emissions are so sensitive to speeds, it recommends special attention be given to developing reasonable and consistent speed estimates; it also recommends that VMT be disaggregated into subsets that have roughly equal speed, with separate emission factors for each subset. At a minimum, speeds should be estimated separately by road type.

The computational framework used for this analysis meets and exceeds that recommendation. Speeds are individually calculated for each roadway segment and hour and include the estimated delays encountered at signals. Rather than accumulating the roadway segments into a particular road type and calculating an average speed, each individual link hourly speed is represented in the MOVES vehicle hours of travel (VHT) by speed bin file. This MOVES input file allows the specification of a distribution of hourly speeds. For example, if 5% of a county's arterial VHT operates at 5 mph during the AM peak hour and the remaining 95% operates at 65 mph, this can be represented in the MOVES speed input file. For the highway emissions inventory, distributions of speeds are input to MOVES by road type and source type by each hour of the day.

To calculate speeds, PPSUITE first obtains initial capacities (how much volume the roadway can serve before heavy congestion) and free-flow speeds (speeds assuming no congestion) from the speed/capacity lookup data. As described in previous sections, this data contains default roadway information indexed by the urban/rural code and functional class. For areas with known characteristics, values can be directly coded to the SHA database and the speed/capacity data can be overridden. However, for most areas where known information is not available, the speed/capacity lookups provide valuable default information regarding speeds, capacities, signal characteristics, and other capacity adjustment information used for calculating congested delays and speeds. The result of this process is an estimated average travel time for each hour of the day for each highway segment. The average time multiplied by the volume produces vehicle hours of travel (VHT).

4.3.2 Developing the MOVES Traffic Input Files:

The PPSUITE software is responsible for producing the following MOVES input files during any analysis run:

- VMT by HPMS vehicle class
- VHT by speed bin
- Road type distributions
- Ramp fractions

These files are text formatted files with a *.csv extension. The files are provided as inputs within the MOVES county data importer.

VMT Input File: VMT is the primary traffic input that affects emission results. The roadway segment distances and traffic volumes are used to prepare estimates of VMT. PPSUITE performs these calculations and outputs the MOVES annual VMT input file to the County Data Manager (CDM).

VHT by Speed Bin File: As described in the previous section, the PPSUITE software prepares the MOVES VHT by speed bin file which summarizes the distribution of speeds across all links into each of 16 MOVES speed bins for each hour of the day by road type. This robust process ensures that MOVES emission rates are used to the fullest extent and is consistent with the methods and recommendations provided in EPA's technical guidance.

Road Type Distributions: In MOVES, typical drive cycles and associated operating conditions vary by the type of roadway. MOVES define five different road types as follows:

1	Off-Network
2	Rural Restricted Access
3	Rural Unrestricted Access
4	Urban Restricted Access
5	Urban Unrestricted Access

For this inventory, the MOVES road type distribution file is automatically generated by PPSUITE using defined equivalencies. The off-network road type includes emissions from vehicle starts, extended idle activity, and evaporative emissions. Off-network activity in MOVES is primarily determined by the Source Type Population input. The remaining distribution among road types is determined by equating the functional class with each MOVES road type as follows:

- MOVES Road Type (2) = SHA Functional Class (1)
- MOVES Road Type (3) = SHA Functional Class (2,6,7,8,9)
- MOVES Road Type (4) = SHA Functional Class (11,12)
- MOVES Road Type (5) = SHA Functional Class (14,16,17,19)

Ramp Fractions: Since ramps are not directly represented within the SHA database information, it is assumed that 8% of the Freeway VHT is ramp VHT. This is consistent with national default values within MOVES and recommendations provided in EPA's technical guidance.

4.3.3 MOVES Runs:

After computing speeds and aggregating VMT and VHT, PPSUITE prepares traffic-related inputs needed to run EPA's MOVES2014a software. Additional required MOVES inputs are prepared external to the processing software and include temperatures, I/M program parameters, fuel characteristics, vehicle fleet age distributions and source type population.

The MOVES county importer is run in batch mode. This program converts all data files into the MYSQL formats used by the MOVES model. At that point a MOVES run specification file (*.mrs) is created which specifies options and key data locations for the run. MOVES is then executed in batch mode.

MOVES can be executed using either the *inventory* or *rate-based* approaches. For this highway emissions inventory, MOVES is applied using the *inventory-based* approach. Under this method, actual VMT and population are provided as inputs to the model; MOVES is responsible for producing the total emissions for the region. Under the rate-based approach, MOVES would produce emission factors, after which PPSUITE would apply the emission factors to the link data and calculate total regional emissions.

4.4 GREENHOUSE GAS INVENTORY RESULTS

The 2017 emission results for the Maryland statewide GHG inventory are provided in Table 4.1.

4.4.1 Emission Estimates

Table 4-1: 2017 Annual Highway Vehicle Emissions Inventories for Greenhouse Gases (Metric tons per year)

2017 PEI GHG Annual Estimates for MD using MOVES2014a Model						
	CO_2 E in grams per year					CO_2 E in MMTons
County	Gasoline	Diesel	CNG	Ethanol (E85)	All Fuels	2017 PEI
Allegany	3.08001E+11	1.22747E+11	2.61387E+08	1.69249E+09	4.32702E+11	0.43
Anne Arundel	2.31063E+12	5.87374E+11	1.02115E+09	1.34278E+10	2.91246E+12	2.91
Baltimore	3.18991E+12	9.01693E+11	9.31873E+08	1.80212E+10	4.11056E+12	4.11
Calvert	2.81481E+11	5.21102E+10	1.25760E+08	1.60742E+09	3.35324E+11	0.34
Caroline	1.45260E+11	4.74093E+10	2.22157E+07	7.53482E+08	1.93445E+11	0.19
Carroll	5.20561E+11	1.13378E+11	1.67540E+08	3.00682E+09	6.37113E+11	0.64
Cecil	4.55752E+11	2.35577E+11	4.37007E+08	2.53163E+09	6.94298E+11	0.69
Charles	4.87875E+11	1.03256E+11	1.23812E+08	2.60843E+09	5.93863E+11	0.59
Dorchester	1.35056E+11	3.83858E+10	2.09591E+08	6.76566E+08	1.74328E+11	0.17
Frederick	1.20906E+12	3.24125E+11	5.06871E+08	6.88356E+09	1.54058E+12	1.54
Garrett	1.79262E+11	9.10803E+10	1.63034E+08	1.16410E+09	2.71669E+11	0.27
Harford	9.50935E+11	2.46234E+11	6.01613E+08	5.55978E+09	1.20333E+12	1.20
Howard	1.56975E+12	4.45846E+11	9.70677E+08	9.24606E+09	2.02582E+12	2.03
Kent	7.50820E+10	2.64686E+10	7.40913E+07	3.94144E+08	1.02019E+11	0.10
Montgomery	2.97240E+12	7.08430E+11	3.29952E+09	1.66322E+10	3.70076E+12	3.70
Prince George's	3.56562E+12	8.51768E+11	2.09049E+09	1.76185E+10	4.43710E+12	4.44
Queen Anne's	3.21539E+11	1.31287E+11	1.67345E+08	1.83868E+09	4.54833E+11	0.45
Saint Mary's	3.50739E+11	9.51675E+10	1.42719E+08	1.90235E+09	4.47951E+11	0.45
Somerset	9.80952E+10	2.78526E+10	1.93020E+07	4.93160E+08	1.26460E+11	0.13
Talbot	2.27129E+11	6.69189E+10	5.21762E+07	1.27472E+09	2.95375E+11	0.30
Washington	7.55019E+11	3.90304E+11	3.80486E+08	3.85812E+09	1.14956E+12	1.15
Wicomico	3.79141E+11	9.95495E+10	4.12890E+08	1.98666E+09	4.81090E+11	0.48
Worcester	3.04289E+11	8.80718E+10	5.76077E+08	1.70333E+09	3.94640E+11	0.39
Baltimore City	1.40851E+12	3.61590E+11	3.39877E+09	6.89540E+09	1.78039E+12	1.78
State of MD	2.22011E+13	6.15662E+12	1.61564E+10	1.21777E+11	2.84957E+13	**28.50**
CO_2 Emissions ($MMTCO_2E$)	**2.22E+01**	**6.16E+00**	**1.62E-02**	**1.22E-01**	**2.85E+01**	

Notes: Column totals may not add due to rounding.

Table 4-2: 2017 Annual State Summary On-Road GHG Emissions (MMtCO$_2$e)

	VMT (Millions)	CO$_2$	CH$_4$	N$_2$O	CO$_2$e
TOTAL	**59,892**	**28.50**	**0.006467**	**0.08993**	**28.5964**

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 4.3 below provides the estimated 2017 fuel consumption values. The 2017 values were compared to available information from FHWA and the Energy Information Administration (EIA).

Table 4-3: 2017 Fuel Consumption Estimates

Scenario	Fuel Type	MOVES2014a Output		Actual Statewide Fuel Sales[2] *(Thousand gallons)*
		Energy Consumption *(Trillion BTU)*	Estimated Fuel Consumption[1] *(Thousand Gallons)*	
2017	Gasoline	290.3	2,410,004	2,786,302
	Diesel	78.7	572,693	521,857

[1] Assumes following conversion rates:

- 1 gallon of gasoline fuel = 120,452 BTU
- 1 gallon of diesel fuel = 137,381 BTU

[2] On-highway Gasoline Fuel Consumption:

- Statement of Gasoline Consumption Report from the following web page of the Comptroller of MD https://finances.marylandtaxes.gov/static_files/revenue/motorfuel/annualreport/FuelAnnualReportFY2017.pdf

On-highway Diesel Fuel Consumption:

- 2017 Sale of Distillate Fuel Oil by End Use, Maryland – On Highway Report from U.S Energy Information Administration http://www.eia.gov/dnav/pet/PET_CONS_821USEA_A_EPD2D_VAH_MGAL_A.htm

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 a periodic 2017 inventory of greenhouse gas (GHG) emissions associated with Maryland's non-road transportation sector. 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. Nonroad mobile sources are broken up into NONROAD Model source categories and Off-model source categories. The two types of nonroad source categories are listed below:

NONROAD Model Source Categories	**Off-Model Source Categories**
• Lawn and Garden Equipment	• Railroads
• Airport Service Equipment	• Aviation
• Recreational Land Vehicles or Equipment	• Commercial Marine Vessels
• Recreational Marine Equipment	
• Light Commercial Equipment	
• Industrial Equipment	
• Construction Equipment	
• Agricultural or Farm Equipment	
• Logging Equipment	

In order to enhance the accuracy of the 2017 GHG emissions in the transportation sector, the Department used two methodologies approved by the EPA for developing the 2017 emissions inventory for nonroad categories. The NONROAD Model source categories listed above were estimated using the NONROAD Model that EPA recently incorporated into the MOVES Model. The other source categories were estimate using traditional EPA emission factors.

5.2 NONROAD MODEL SOURCE CATEGORIES

The Motor Vehicle Emissions Simulator (MOVES) incorporates the current version of the NONROAD model to calculate emissions. EPA integrated the NONROAD model into the MOVES model to produce county-level mobile source emission inventories from a national county database that can be easily updated which includes onroad and Nonroad data for each state.

Both MOVES-NONROAD and previous versions of the NONROAD Model use the same formulas and methods to calculate emissions. However, MOVES-NONROAD and MOVES-ONROAD now share the same input files for meteorology and fuel parameters, to estimate emissions.

5.2.1 Emission Calculation Methodology

The MOVES-NONROAD Model calculates past, present, and future emission inventories (i.e., tons of pollutant) for all Nonroad equipment categories except commercial marine, locomotives, and aircraft. Fuel types included in the model are: gasoline, diesel, compressed natural gas, and liquefied petroleum gas. The model estimates exhaust and evaporative hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM), sulfur dioxide (SO_2), methane (CH_4) and carbon dioxide (CO_2). The user may select a specific geographic area (i.e., national, state, or county) and time period (i.e., annual, monthly, seasonal, or daily) for analysis.

The NONROAD model estimates emissions for each specific type of Nonroad equipment by multiplying the following input data estimates:

- Equipment population for base year (or base year population grown to a future year), distributed by age, power, fuel type, and application;
- Average load factor expressed as average fraction of available power;
- Available power in horsepower;
- Activity in hours of use per year; and
- Emission factor with deterioration and/or new standards.

The emissions are then temporally and geographically allocated using appropriate allocation factors. There are several input files that provide necessary information to calculate and allocate emissions estimates. These input files correspond to the basic data needed to provide the calculations: emission factors, base year equipment population, activity, load factor, average lifetime, scrap page function, growth estimates, and geographic and temporal allocation. Maryland specific input files were utilized to synchronize the MOVES-NONROAD Model emissions with the MOVES-ONROAD Model emissions.

The MOVES-NONROAD Model output files produced monthly daily emission estimates. Annual NONROAD Model emission estimates were calculated from these daily model output files.

5.3 OFF MODEL SOURCE CATEGORIES

5.3.1 Emission Calculation Methodology

Off-Model nonroad source category emissions are calculated by collecting fossil fuel consumption fuel estimates.

5.3.1.1 Carbon Dioxide (CO_2) 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 2017 periodic non-road mobile transportation sector CO_2 emissions were estimated based on data provided by EIA (State Energy Data) for the following fuels: 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 2017 fossil fuel consumption data for locomotives was obtained from MDE compliance survey. Fuel consumption data is presented in Table 5.1.

Table 5-1: Default Energy Consumption in Maryland

Fuel Type	Consumption (gallon)	Consumption (Billion Btu)	Source of Data
Aviation Gasoline	1,638,000	196	EIA State Energy Data – Maryland Consumption
Jet Fuel, Kerosene	69,510,000	9,381	EIA State Energy Data – Maryland Consumption
Distillate Fuel - Locomotive	16,285,444	2,237	MDE Survey
Distillate Fuel – Vessel Bunkering	3,584,000	424	EIA State Energy Data/EIA Sales Data – Maryland Consumption
Residual Fuel –Vessel Bunkering	2,436,000	170	EIA State Energy Data – Maryland Consumption
Transportation Lubricants	14,784,000	2,135	EIA State Energy Data – Maryland Consumption

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:

$$\text{Emissions (MMTCO}_2\text{E)} = \frac{\text{Consumption (BBtu)} \ X \ \text{Emission Factor (lbs C/ BBtu)} \ X \ 0.0005 \ X \ \text{Combustion Efficiency (\%)} \ X \ 0.90718474 \ X \ (44/12)}{1{,}000{,}000}$$

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.

0.9071847 = 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

5.3.1.2 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 and;
- Emission factors by fuel type

The general emissions equation is as follows:

$$\text{Emissions (MMTCO}_2\text{E)} = \frac{\text{Consumption (Btu or Gallon)} \ x \ \text{Density (kg/gal) OR Energy Content (kg/MBtu)} \ x \ \text{Emission Factor (g/kg fuel)} \ x \ \text{Combustion Efficiency (\%)} \ x \ \text{GWP}}{1{,}000{,}000}$$

Where:

Emissions: $MMTCO_2E$ (Million Metric Tons of CO_2 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 DATA SOURCES

- EIA's State Energy Data.
- http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=US

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

- EIA, Distillate Fuel Oil and Kerosene Sales By End-Use.
  http://www.eia.gov/dnav/pet/pet_cons_821usea_dcu_SMD_a.htm.

- EPA Non-Road Model.
  http://www.epa.gov/otaq/nonrdmdl.htm.

- Controller of Maryland - Statement of Gasoline Consumption.
  https://finances.marylandtaxes.gov/static_files/revenue/motorfuel/annualreport/FuelAnnualReportFY2017.pdf

5.5 GREENHOUSE GAS INVENTORY RESULTS

Table 5-2: 2017 MOVES-NONROAD Model Transportation Sector GHG Emissions

MOVES-NONROAD Model Source Category	CH_4 (short tons)	CO_2 (short tons)	CH_4 ($MMTCO_2E$)	CO_2 ($MMTCO_2E$)	Total Emissions ($MMTCO_2E$)
Compressed Natural Gas	144.77	15,882.55	0.0028	0.0144	0.172
Non-Road Gasoline	908.43	1,038,820.12	0.0173	0.9424	0.9597
Liquefied Petroleum Gas (LPG)	14.77	166,851.41	0.0003	0.1514	0.1516
Marine Diesel Fuel	1.56	55,961.49	0.0000	0.0508	0.0508
Non-Road Diesel Fuel	24.46	1,052,155.32	0.0005	0.9545	0.9550
TOTAL	**1,093.99**	**2,329,670.88**	**0.0208**	**2.1134**	**2.1343**

Table 5-3: 2017 Off-Model Nonroad Transportation Sector CO_2 Emissions

Fuel Type	Consumption (gallon)	Consumption (Billion Btu)	Emission Factor (lbs C/Million Btu)	Combustion Efficiency (%)	Emissions (tons carbon)	Emissions ($MMTCO_2E$)
Aviation Gasoline	1,638,000	196	41.57	100.0%	4,074	0.014
Jet Fuel, Kerosene	69,510,000	9,381	43.43	100.0%	203,717	0.678
Distillate Fuel - Locomotive	16,285,444	2,237	44.47	100.0%	49,747	0.165
Distillate Fuel – Vessel Bunkering	3,584,000	492	44.47	100.0%	10,948	0.036
Residual Fuel – Vessel Bunkering	2,436,000	363	45.15	100.0%	8,195	0.027
TOTAL						**0.920**

Table 5-4: 2017 Off-Model Nonroad Transportation Sector 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 ($MMTCO_2E$)
2,135	1,427	9%	2,003	44.53	100.0%	44,600	0.148

Table 5-5: 2017 Off-Model Nonroad Transportation Sector CH_4 and N_2O Emissions

Fuel Type	Consumption (gallon)	Consumption (Billion Btu)	N_2O EF g/kg fuel	CH_4 EF g/kg fuel	Emissions N_2O ($MTCO_2E$)	Emissions CH_4 ($MTCO_2E$)
Aviation Gasoline	1,638,000	196	0.04	2.64	0.1745	11.51718
Jet Fuel, Kerosene	69,510,000	9,381	0.08	0.45	20.8633	18.15111
Distillate Fuel - Locomotive	16,285,444	2,237	0.08	0.45	4.1587	12.99578
Distillate Fuel – Vessel Bunkering	3,584,000	492	0.08	0.18	0.9152	2.86003
Residual Fuel – Vessel Bunkering	2,436,000	363	0.08	0.25	0.6967	2.00300

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 are accounted for in the energy use section – Industrial (RCI), 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 2017. Calculating emissions from these source categories was not necessary. These industries are:

- Nitric acid production
- Adipic acid production
- HCFC-22 production
- Aluminum production
- Iron and Steel Production

The following sections discuss the data sources, methods, assumptions, and results used to construct the 2017 periodic emissions inventory.

6.2 DATA SOURCES

- MDE's Annual Emissions Certification Reports 2017.
- EPA ghgdata: Greenhouse Gas Emissions from Large Facilities. http://ghgdata.epa.gov/ghgp.
- 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. The two primary methods used in the calculation of greenhouse gas emissions inventory for the industrial process sector were the MD annual emission certification report and the EPA SIT. Since the methodology varies by sector, they are discussed separately below.

6.3.1 Carbon Dioxide (CO_2) Industrial Process Emissions

6.3.1.1 Cement Manufacture

The cement production process comprises the following two steps: (1) clinker production and (2) finish grinding. Essentially, all GHG emissions from cement manufacturing are CO_2 emissions from clinker production. There are no CO_2 emissions from the finish grinding process, during which clinker is ground finely with gypsum and other materials to produce cement[1]. However, CO_2 emissions are associated with the electric power consumed by plant equipment such as the grinders; which have been accounted for under the energy use section – electric generation.

Cement is produced from raw materials such as limestone, chalk, shale, clay, and sand. These raw materials are quarried, crushed, finely ground, and blended to the correct chemical composition. Small quantities of iron ore, alumina, and other minerals may be added to adjust the raw material composition. The fine raw material is fed into a large rotary kiln (cylindrical furnace) that rotates while the contents are heated to extremely high temperatures. The high temperature causes the raw material to react and form a hard nodular material called "clinker". Clinker is cooled and ground with approximately 5 percent gypsum and other minor additives to produce Portland cement. The heart of clinker production is the rotary kiln where the pyroprocessing stage occurs.

Three important processes occur with the raw material mixture during pyroprocessing. First, all moisture is driven from the materials. Second, the calcium carbonate in limestone dissociates into CO_2 and calcium oxide (free lime); this process is called calcination. Third, the lime

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[1] EPA Office of Air and Radiation: Available And Emerging Technology for Reducing Greenhouse Gas Emission from the Portland Cement Industry. http://www.epa.gov/nsr/ghgdocs/cement.pdf

and other minerals in the raw materials react to form calcium silicates and calcium aluminates, which are the main components of clinker. This third step is known as clinkering or sintering. The formation of clinker concludes the pyroprocessing stage.[1]

Clinker production GHG emissions are from the combustion of carbon-based fuels such as coal, petroleum coke, fuel oil and natural gas in the cement kiln. Another 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 and;
- 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).

2017 CO_2 Industrial Process Emissions Estimation

The industrial process 2017 GHG emission inventory for the cement industry in Maryland was compiled from the annual emission certification reports from cement industries operating in Maryland. The certification reports were validated by the cement facilities and submitted to the Air and Radiation Administration (ARA) Compliance Program. Engineers with the compliance program reviewed the emission certification reports for accuracy. The emission certification reports were then cross-checked with a report the facility submitted to the EPA GHG Reporting Program (GHGRP) under 40 CFR 98 by an engineer with the ARA Planning Program.

6.3.1.2 Iron and Steel Industry

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[1]. The process of steel production occurs in several sequential steps. The two types of steelmaking technology in use today 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. A more detailed description of the Iron and Steel manufacturing process is available in 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

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

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:

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

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-related 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) required 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.

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 0.5 to 2 percent carbon content by weight.

Bleeders; The vast majority of GHGs (CO_2) emission in iron and steel production are emitted from the blast furnaces stove stacks during the fusion of raw material mix (iron ore fines, coke breeze) and limestone to form high quality sinter for use as feed to the L-Blast Furnace. A significant amount of emissions also result from the combustion of the excess blast furnace gases produced during the chemical reaction process of the L-Blast Furnace. The blast furnace gas is mostly nitrogen, carbon monoxide, and particulate matter.

Bleeder valves are located on top of the blast furnace to act as safety valves to prevent over-pressurization of the furnace structure that could result in an explosion. Combustion of the excess blast furnace gas (that were not needed for power) generates GHG emissions that are released to the atmosphere through the stove stacks.

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[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.

2017 CO_2 Industrial Process Emissions Estimation

No GHG emissions was estimated for the Iron and Steel industry in Maryland for the periodic year 2017 GHG emissions, due to the closure of Maryland only Iron and Steel plant.

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.

There are a variety of emissive and non-emissive uses of Limestone. Emissive application of Limestone (including dolomite) includes; limestone's used as a flux or purifier in metallurgical furnaces, as a sorbent in flue gas desulfurization systems in utility and industrial plants, and as a raw material in glass manufacturing, or as an input for the production of dead-burned dolomite, mine dusting or acid water treatment, acid neutralization, and sugar refining. Limestone is heated during these processes, generating carbon dioxide as a byproduct.[1]

$$CaCO_3 + \text{Heat} \rightarrow CaO + CO_2$$

Non-emissive application of Limestone includes; limestone used in poultry grit, as asphalt fillers and in the manufacture of papers.[2] Greenhouse gas emissions from limestone and dolomite use for industrial purposes were estimated by multiplying the quantity of limestone and dolomite consumed and an emission factor.

Emissions from limestone and dolomite- 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 report [3] 1990-2016.

The emissions are then converted from metric tons of carbon equivalents (MTCE) to metric tons of carbon dioxide equivalents ($MTCO_2e$). 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 6.1: Emission Equation for Limestone and Dolomite Use

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

[2] Technical Support Document: Limestone and Dolomite Use, Office of Air and Radiation, U.S. EPA, January 22, 2009.

[3] U.S. Greenhouse Gas Inventory Report 1990 -2016.
https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html

Emissions ($MTCO_2E$) = Consumption (metric tons) x Emission Factor (MT CO_2/MT Production

Where:

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

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 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[1].

Equation 5.2: Emission Equation for Soda Ash Manufacture and Consumption

Emissions ($MTCO_2E$) = MD per capital Consumption (metric tons) x Emission Factor (MT CO_2/MT Production)

Where:

Emissions = Total emissions from the Soda Ash Manufacture and Consumption

MD per capital Consumption = (MD Pop/USA Pop) * (US Total Soda Ash Consumption)

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.[2] These emissions are accounted for in

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[1] U.S. Greenhouse Gas Inventory Report 1990 -2016 https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

[2] Inventory of U.S.Greenhouse Gas Emissions and Sinks: 1990- 2016

Land Use section of this document, Section 10. CO_2 emissions associated with other uses of Urea are accounted for in this section.

Emissions from non-fertilizer urea 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 [1].

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 ($MTCO_2e$).

Equation 5.3: Emission Equation for Urea Consumption

$$\begin{array}{c} \text{Emissions} \\ (\text{MTCO}_2\text{E}) \end{array} = \begin{array}{c} \text{Urea} \\ \text{Consumption} \\ \text{(metric tons)} \end{array} \text{ x } \begin{array}{c} \text{Emission Factor} \\ (\text{MT CO}_2\text{/MT} \\ \text{Activity} \end{array}$$

Where:

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

6.3.2 Additional Direct Emissions (SF_6, HFC, PFC)

6.3.2.1 SF_6 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 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[2].

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

[2] U.S. Greenhouse Gas Inventory Report 1990 -2016 https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

Emissions from electric power transmission and distribution are calculated by multiplying the quantity of SF_6 consumed by an emission factor. The resulting emissions are then converted from metric tons of SF_6 to metric tons of carbon equivalents (MTCE) and metric tons of carbon dioxide equivalents ($MTCO_2e$). The default assumption is that the emission factor is 1, i.e. all SF_6 consumed is used to replace SF_6 that was emitted. Default activity data for this sector equals national SF_6 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

$$\begin{array}{c} \text{Emissions} \\ (\text{MTCO}_2\text{E}) \end{array} = \begin{array}{c} \text{SF}_6\text{ Consumption} \\ (\text{metric tons SF}_6) \end{array} \text{ x } \begin{array}{c} \text{Emission Factor} \\ (\text{MT SF}_6/\text{MT Consumption}) \end{array} \text{ X } \text{GWP}_{\text{SF6}}$$

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 as: as refrigerants or working fluids in air conditioning and refrigeration equipment, as solvents in various industrial processes, and as blowing agents for making insulating foams.[1]

Emissions from HFCs, PFCs, and SF_6 from ODS substitute production are 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[2].

Emissions of HFCs, PFCs, and SF_6 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 CO_2 equivalents to metric tons of carbon equivalents (MTCE) and metric tons of carbon dioxide equivalents ($MTCO_{2e}e$).

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[1] Inventory of U.S. *Greenhouse Gases Emissions (1990-2016).*

[2] [2] U.S. Greenhouse Gas Inventory Report 1990 -2016
https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html

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

$$\text{Emissions } (\text{MTCO}_2\text{e}) = \text{National ODS Substitute Emissions } (\text{MTCO}_2\text{e}) \times \frac{\text{State Population}}{\text{National Population}}$$

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 6-1: Cement Industry Process CO_2 Emissions

Lehigh	Consumption	Units	% Biomass	CO_2 Emissions (metric tons)	CH_4 Emissions (metric tons CH_4)	N_2O Emissions (metric tons N_2O)	Source of Data
Kiln Emissions Captured Under Industrial Fossil Fuel Combustion Source Category Exhausted to CEM Stack							
-Coal	270,533	metric tons		587,726	66.71	9.74	MDE ECR
- DBS (Dry Bio-Solids) (Preheater/ Precalciner Kiln)	6,850	metric tons	**1.0%**	**19,292**	2.67	0.35	MDE ECR
- #2 Oil	315,658	Gallons		4,778	0.13	0.03	MDE ECR
- Fly Ash	4,335	metric tons		33,968	0.07	0.01	MDE ECR
Kiln Fossil Fuel Combustion (Calculation)				**645,765**	**69.58**	**10.13**	**Sum**
Kiln System Total CO_2 (CEM Measured)				**1,929,239**	69.58	10.13	CEM
Industrial Process Emissions = Total Emissions – Fossil Fuel Combustion Emissions							
Cement Production-Process CO_2 (metric tons) = Kiln System Total CO_2 - Kiln Fossil Fuel Combustion CO_2				**1,283,474**			Difference
Non-Kiln Emissions Captured Under Industrial Fossil Fuel Combustion Source Category							
Finish Mill (#2 Oil)	6,887	Gallons		738.44	0.0300	0.0060	MDE ECR
Total Facility CO_2= Kiln System CO_2 + Non-Kiln CO_2				1,929,977.44	69.61	10.1	**MDE ECR**
Kiln Fossil Fuel Combustion (short tons)				**711,955**	**76.71**	**11.17**	
Kiln System Total CO_2 (CEM Measured) (short tons)				**2,126,985**	76.71	11.17	
Cement Production-Process CO_2 (short tons) = Kiln System Total CO_2 - Kiln Fossil Fuel Combustion CO_2				**1,415,030**			**Conversion MT to Ton**
Total Facility CO_2 (short tons) = Kiln System CO_2 + Non-Kiln CO_2				2,127,798.91	76.73	11.2	MDE ECR

Holcim	**Consumption**	**Units**	**% Biomass**	**CO_2 Emissions (metric tons)**	**CH_4 Emissions (metric tons CH_4)**	**N_2O Emissions (metric tons N_2O)**	**Source of Data**
Kiln Emissions Captured Under Industrial Fossil Fuel Combustion Source Category Exhausted to CEM Stack							
-Coal	67,130	Short Tons		147,680.0	1.56	2.330	MDE ECR
- #2 Oil	197,684	Gallons		1,804.0	0.020	0.140	MDE ECR
- Tire	1,921	Short Tons		5,368.0	0.05	0.070	MDE ECR
Kiln Fossil Fuel Alone CO_2 (Calculation)				**154,852.0**	**1.63**	**2.44**	Sum
Non-Kiln Emissions Captured Under Industrial Fossil Fuel Combustion Source Category							
Raw Meal - # 2 Oil		Gallons					
Kiln System Total CO_2 (CEM Measured).				**383,002**	**16.88**	**0.00**	
Kiln Fossil Fuel Alone CO_2 (Calculation)				**154,852**	**1.63**	**2.44**	
Cement Process CO_2 (metric tons) = (Total Kiln CO_2) - (Kiln Fossil Fuel Alone CO_2)				**228,150**	**52**	**7.4**	
Total Facility CO_2 Emission = (Kiln System Total CO_2) + (Non Kiln CO_2)				**383,002**	**16.88**	**2.44**	
Kiln System Total CO_2 (CEM Measured) (short tons)				**422,188**	**18.61**	**0.00**	
Kiln Fossil Fuel Alone CO_2 (Calculated) (short tons)				**170,695.23**	**1.8**	**2.7**	
Cement Process CO_2 (short tons) = (Total Kiln CO_2) - (Kiln Fossil Fuel Alone CO_2)				**251,489.75**	**57**	**8.2**	
Total Facility CO_2 Emission(short tons) = (Kiln System Total CO_2) + (Non Kiln CO_2)				**422,183.10**	**18.61**	**2.69**	

MD TOTAL CEMENT GHG EMISSIONS (Lehigh + Holcim)	**CO_2 Emissions**
MD Summary Cement Process CO_2 Emissions (short tons)	**1,666,519**
MD Summary Cement Process CO_2 Emissions (metric tons)	**1,511,840**
MD Summary Cement Process CO_2 Emissions (MMTCO$_2$E)	**1.51**

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

Source	Pollutant	CO_2 Emissions (metric tons)	CO_2 Emissions (short tons)	Data Source
Bleeders	CO_2	0.0	0.0	MDE ECR
	CH_4	0.00	0.00	
	N_2O	0.00	0.00	
L Blast Furnace	CO_2	0.0	0.0	MDE ECR
	CH_4	0.0.	0.00	
	N_2O		-	
Sinter Plant	CO_2	0.0	0.0	MDE ECR
BOF	CO_2	0.0	0.0	MDE ECR
Total	CO_2	0.0	0.0	
	CH_4	0.0	0.0	
	N_2O	0.00	0.00	

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	95,344	0.4150	39,568	**0.040**

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	331,571	0.44	145,891	**0.146**

Table 6-6: 2017 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	2,013	0.73	1,469	0.001469

Table 6-7: SF_6 Emissions from Electrical T&D[1] System.

Total US SF_6 Emissions from Electric Power T & D ($MMTCO_2E$)	2.51E+06	A
SF_6 GWP	23,900	B
US Total SF_6 Consumed (metric tons)	105.09	'C = A/B
Total US Electric Sales (MWh) (2017)	3,681,995	D
MD Total Electric Sales (MWh) (2017)	59,174	E
MD Apportioned SF_6 Consumption (metric tons)	1.6890	F = C x E D
Emission Factor	1	G
SF_6 Emissions (metric tons)	1.6890	H= G*F
SF_6 Emissions ($MTCO_2E$)	40,367.04	I=H*B
SF_6 Emissions ($MMTCO_2E$)	**0.040367**	J=I/1E-06

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

Total US GHG 2017 Emissions from ODS substitute ($MMTCO_2E$)	159.10
MD 2017 Population	6,052,177
US 2017 Population	325,719,178
Apportioned State Emissions ($MMTCO_2E$)	**2.9566**

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[1] T&D: Transmission and Distribution

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 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 is 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.

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

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[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.

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 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.

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[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.

7.2 DATA SOURCES

- U.S Department of Transport, Office of Pipeline Safety (OPS). http://phmsa.dot.gov/pipeline/library/data-stats
- EIA's Number of Producing Wells. https://www.eia.gov/dnav/ng/NG_PROD_WELLS_S1_A.htm
- EIA States Energy Data- Maryland Natural Gas Consumption By End Use: https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SMD_a.htm
- Maryland Department of the Environment, Maryland Bureau of Mines Coal Division**.** https://mde.maryland.gov/programs/LAND/mining/Pages/BureauofMinesAnnualReports.aspx
- U.S Department of Transport, Office of Pipeline Safety (OPS). " Distribution and Transmission Annuals data: 2010 -Present" https://cms.phmsa.dot.gov/data-and-statistics/pipeline/annual-report-mileage-summary-statistics
- Emission Inventory Improvement Program (EIIP), *Volume VIII: Chapter 5.*[1]
- Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter 1.[2]
- Maryland Department of the Environment Bureau of Mines. https://mde.maryland.gov/programs/land/mining/pages/bureauofminesannualreports.aspx

7.3 GREENHOUSE GAS INVENTORY METHODOLOGY

2017 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[3]

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

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

[3] Energy Information Administration (EIA), State Energy Data, https://www.eia.gov/dnav/ng/ng_cons_sum_dcu_SMD_a.htm

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 2017 GHG emissions from pipeline natural gas consumption for compressor station were estimated using Equation 6.0. EIA State's natural gas pipeline and distribution use data (as pipeline natural gas) provided in Million cubic feet were multiplied by state specific natural gas heat content[1] to obtain State's Natural Gas Pipeline and Distribution Use in British thermal units (Btu). Btu data was multiply by emissions factors supplied by EPA in SIT to estimate emissions from pipeline natural combustion in 2017.

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 2017, no emission was estimated for this sub section of the inventory. The U.S. Energy Information Administration (EIA)[2] 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.[3] Maryland specific activity data in 2017 (see table 7.2) were multiplied by the respective EPA SIT default emissions factors to estimate

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[1] EIA State Energy Data System 2017 Production Technical Notes; https://www.eia.gov/state/seds/sep_prod/Prod_technotes.pdf

[2] EIA's Natural Gas Pipeline and Distribution Use (MMcf). https://www.eia.gov/dnav/ng/ng_sum_lsum_a_EPG0_vgp_mmcf_a.htm

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

emissions from natural gas systems. Similarly, CH_4 and N_2O emissions from coal mining operations were estimated using the EPA SIT and the EIIP guidance[1]. The year 2017 coal production data was obtained from the 2017 Maryland Bureau of Mines Annual Report[2].

Table 7-2: Natural Gas Activity Data.

	Activity Data and Emission factors Required	**Activity Data Sources**
Natural Gas – Production.	Number of Wells	EIA[3]
Natural Gas - Transmissions	Miles of transmission pipelines	OPS[4]
	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[5]
Coal Mining	Metric tons of coal produced	MDE

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

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[1] Emission Inventory Improvement Program (EIIP), *Volume VIII*: Chapter. 4. “Methods for Estimating Methane Emissions from Coal Mining”, March 2005.

[2] Maryland Bureau of Mines. Annual Report. https://mde.maryland.gov/programs/land/mining/pages/bureauofminesannualreports.aspx

[3] US Department of Energy, Energy Information Administration, “Natural Gas Navigation- Maryland Natural Gas Number of Gas and Gas Condensate Wells,” accessed from: http://www.eia.gov/dnav/ng/hist/na1170_smd_8a.htm.

[4] U.S Department of Transport, Office of Pipeline Safety, “2017 Distribution and Transmission Annuals Data” from:. https://cms.phmsa.dot.gov/data-and-statistics/pipeline/annual-report-mileage-natural-gas-transmission-gathering-systems

[5] US Department of Energy, Energy Information Administration, Natural Gas Pipeline and Distribution Use (MMcf). https://www.eia.gov/dnav/ng/ng_sum_lsum_a_EPG0_vgp_mmcf_a.htm

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.

Equation 6.2: Emission Equation for Natural Gas Production

Emissions (MTCO$_2$E)	=	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 source 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$_2$E)	=	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

Emissions (MTCO$_2$E)	=	Activity Data (BBtu)	x	Emission Factor (metric tons CH$_4$/ Activity data units)	x	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 2017, no emissions were estimated for this section in 2017

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.

Total Emissions	=	**Emissions from Underground Mines**	+	**Emissions from Surface Mines**	+	**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.

Surface Mining CH$_4$ Emissions (ft^3)	=	Coal Production (short tons)	x	Basin-Specific Emissions Factor (ft^3/ 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.

Underground Mining CH_4 Emissions (Mcf) = Measured Ventilation Emissions (Mcf) + Degasification System Emissions (Mcf) - 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 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.

Post-Mining Activities CH_4 Emissions (ft^3) = Coal Production (short tons) Basin/Mine -Specific Emissions Factor (ft^3/ 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: 2017 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)	8,342.5	8,342.5	8,342.5	
Combustion Efficiency (%)	100%	100%	100%	
Emissions ($MMTCO_2E$)	0.000442	0.0002456	0.000166	**0.000854**

Table 7.4: 2017 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	5	4.10	20.51	0.00043
Total			**20.51**	**0.00043**

Table 7.5: 2017 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	995	0.6185	616	0.01293
Number of gas transmission compressor stations	6	983.7	5,875	0.12338
Number of gas storage compressor stations	1	964.1	1,440	0.03023
Total			**7,931**	**0.16654**

Table 7.6: 2017 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	1,222	5.80	7,092.15	0.149
Miles of unprotected steel distribution pipeline	209	2.12	442	0.009
Miles of protected steel distribution pipeline	5,310	0.06	319	0.007
Miles of plastic distribution pipeline	8,243	0.37	3,064	0.064
Services				
Total number of services	1,043	0.02	16	0.00033
Number of unprotected steel services	75,380	0.03	2,469	0.052
Number of protected steel services	126,342	0.00	430	0.009
Total			**13,831**	**0.290**

Table 7.7: 2017 CH_4 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 ($MTCO_2E$)
1,070	119.0	127,341	2,445	51,344

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 ($MTCO_2E$)
1,382	45.0	62,180	1,194	25,071

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 ($MTCO_2E$)
1,070	19.3	20,693	397	8,343

Post Mining Activity – SubTotal		Emissions ('000 ft^3 CH_4)	Emissions ($MTCH_4$)	Emissions ($MTCO_2E$)
		82,873	1,591	33,414

Total Coal Mining Emissions ($MTCO_2e$)	**84,758**
Total Coal Mining Emissions ($MMTCO_2e$)	**0.84758**

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.

- Maryland Department of Agriculture, State Chemist Section-Product Registration. http://mda.maryland.gov/plants-pests/Pages/state_chemist.aspx.

- 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.[1]

- EIIP, *Volume VIII*: Chapter 10.[2]

- EIIP, *Volume VIII*: Chapter 11.[3]

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.[4] 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.

8.3.1 Carbon Dioxide (CO_2) 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.

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

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

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

[4] US Inventory of greenhouse Gas Emissions and Sinks: 1990 -2016, US Environmental Protection Agency, (2018). (http://epa.gov/climatechange/emissions/index.html)

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 fertilizer emissions were 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: 2017 MD Input Data - Animal Populations

	Number of Animals (thousand head)
Dairy Cattle	
Dairy Cows	53
Dairy Replacement Heifers	28
Beef Cattle	
Feedlot Heifers	4
Feedlot Steer	7
Bulls	4
Calves	36
Beef Cows	42
Beef Replacement Heifers	10
Steer Stockers	15
Heifer Stockers	7
Swine	
Breeding Swine	2
Market Under 60 lbs	9
Market 60-119 lbs	7
Market 120-179 lbs	4
Market over 180 lbs	4
Poultry	
Layers	
Hens > 1 yr	2,292
Pullets	184
Chickens	12
Broilers	53,073
Turkeys	704
Other	
Sheep on Feed	0
Sheep Not on Feed	24
Goats	12
Horses	79

Table 8.1: 2017 MD Input Data - Fertilizer Consumption.

	Total Fertilizer Use (kg N)	**Total N (kg) in Fertilizers (Calendar Year)**
Synthetic	40,158,687	26,103,147
Organic	26,724,473	26,724,473
Dried Blood	-	-
Compost	-	-
Dried Manure	486,298	486,298
Activated Sewage Sludge	25,853,131	25,853,131
Other	385,044	385,044
Dried Manure (%)	2 %	2%
Non-Manure Organics	26,238,175	23,238,175
Manure Organics	486,298	486,298

Table 8.2: 2017 MD Input Data - Crop Productions.

Crop Type	**Units**	**Crop Production**	**Crop Production (metric tons)**
Alfalfa	'000 tons	140	127,008
Corn for Grain	'000 bushels	46,870	1,190,552
All Wheat	'000 bushels	12,540	341,282
Barley	'000 bushels	2,880	62,703
Soybeans	'000 bushels	17,903	487,243
TOTAL			**2,208,787**

Table 8.3: 2017 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	62,703	1.2	0.03	0.93	0.930	0.880	771
Corn	1,190,552	1.0	0.03	0.91	0.930	0.880	11,911
Peanuts	-	1.0	0.03	0.86	0.930	0.880	-
Rice	-	1.4		0.91	0.930	0.880	-
Soybeans	487,243	2.1	0.03	0.87	0.930	0.880	9,835
Sugarcane	-	0.8	0.03	0	0.930	0.880	-
Wheat	341,282	1.3	0.03	0.93	0.930	0.880	4,486

Table 8.4: 2017 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	53.0	680	10.0	130,365,037	0.24	0.118	3,697,660
Dairy Replacement Heifers	28.0	476	8.4	40,977,756	0.17	0.012	86,852
Beef Cattle							
Feedlot Heifers	3.9	420	4.4	2,668,401	0.33	0.013	11,556
Feedlot Steer	7.4	420	4.0	4,592,625	0.33	0.013	19,663
Bulls	4.0	750	5.2	6,613,800	0.17	0.011	12,368
Calves	36.0	118	6.4	9,938,833	0.17	0.011	18,586
Beef Cows	42.0	533	7.5	61,236,569	0.17	0.011	114,512
Beef Replacement Heifers	10	420	7.6	11,636,201	0.17	0.011	21,760
Steer Stockers	15.0	318	8.1	14,028,947	0.17	0.011	26,234
Heifer Stockers	7.0	420	8.6	9,111,271	0.17	0.011	17,038
Swine							
Breeding Swine	2.0	198	2.6	375,804	0.48	0.301	54,224
Market Under 60 lbs	9.00	16	8.8	459,059	0.48	0.300	66,142
Market 60-119 lbs	7.0	41	5.4	560,158	0.48	0.300	80,708
Market 120-179 lbs	4.0	68	5.4	534,693	0.48	0.300	77,039
Market over 180 lbs	4.0	91	5.4	715,473	0.48	0.300	103,086
Poultry							
Layers							
Hens > 1 yr	2,292.0	2	10.8	16,263,115	0.39	0.051	324,907
Pullets	184.0	2	9.7	1,172,614	0.39	0.051	23,427
Chickens	12.0	2	10.8	85,147	0.39	0.051	1,701
Broilers	53,072.7	1	15	261,515,729	0.36	0.015	1,412,185
Turkeys	704.0	7	9.7	16,949,082	0.36	0.015	91,525
Other							
Sheep on Feed	0	25	9.2	-	0.36	0.012	-
Sheep Not on Feed	24.0	80	9.2	6,451,200	0.19	0.011	13,481
Goats	12.0	64	9.5	2,672,640	0.17	0.011	4,997
Horses	80.0	450	10	129,921,750	0.33	0.011	472,429
TOTAL							**6,752,079**

Table 8.5: 2017 N_2O Generation from Manure Management.

	Number of Animals ('000 head)	Typical Animal Mass (TAM) (kg)	Total K-Nitrogen Excreted (kg)
Dairy			
Dairy Cows	53.0	680	7,852,125
Dairy Replacement Heifers	28.0	476	1,927,462
Beef Cattle			
Feedlot Heifers	3.9	420	218,344
Feedlot Steer	7.4	420	422,465
Swine			
Breeding Swine	2.0	198	29,269
Market Under 60 lbs	9.0	16	47,993
Market 60-119 lbs	7.0	41	56,016
Market 120-179 lbs	4.0	68	53,469
Market over 180 lbs	4.0	91	71,547
Poultry			
Layers			
Hens > 1 yr	2,292.0	2	1,189,617
Pullets	184.0	2	95,502
Chickens	12.0	2	8,672
Broilers	53,072.7	1	16,737,007
Turkeys	704.0	7	1,092,080
Other			
Sheep on Feed	0.0	25	-
Sheep Not on Feed	24.0	80	315,360
TOTAL			**30,118,367**

Table 8.6: 2017 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	127,008	0	0	0.85	NA	NA	0.03	3,238,704
Corn for Grain	1,190,552	1	0.9	0.91	0.0058	5,655,359		NA
All Wheat	341,282	1.3	0.9	0.93	0.0062	2,302,361		NA
Barley	62,703	1.2	0.9	0.93	0.0077	484,940		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	487,243	2.1	0.9	0.87	0.0230	18,426,977	0.03	39,422,794
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	**2,208,787**					**26,869,637**		**42,661,498**

8.4 GREENHOUSE GAS INVENTORY RESULTS

Table 8.7: 2017 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	53.0	144.5	7,658,500	0.0077	0.161
Dairy Replacement Heifers	28.0	66.0	1,848,000	0.0018	0.039
Beef Cattle					
Beef Cows	42.0	94.4	3,964,800	0.0040	0.083
Beef Replacement Heifers	10.0	66.7	667,000	0.0007	0.014
Heifer Stockers	10.0	60.1	601,000	0.0006	0.013
Steer Stockers	15.0	57.9	868,500	0.0009	0.018
Feedlot Heifers	3.9	43.2	168,998	0.0002	0.004
Feedlot Steer	7.4	42.0	310,590	0.0003	0.007
Bulls	4.0	97.6	390,400	0.0004	0.008
Other					
Sheep	24.0	8.0	192,000	0.0002	0.004
Goats	12.0	5.0	60,000	0.0001	0.001
Swine	23.0	1.5	34,500	0.0000	0.001
Horses	79.1	18.0	1,423,800	0.0014	0.030
TOTAL				**0.0182**	**0.382**

Table 8.8: 2017 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	3,697,660	2,448	0.002	0.051
Dairy Replacement Heifers	86,852	57	0.000	0.001
Beef Cattle				
Feedlot Heifers	11,556	8	0.000	0.000
Feedlot Steer	19,663	13	0.000	0.000
Bulls	12,368	8	0.000	0.000
Calves	18,586	12	0.000	0.000
Beef Cows	114,512	76	0.000	0.002
Beef Replacement Heifers	21,760	14	0.000	0.000
Steer Stockers	26,234	17	0.000	0.000
Heifer Stockers	17,038	11	0.000	0.000
Swine				
Breeding Swine	54,224	36	0.000	0.001
Market Under 60 lbs	66,142	44	0.000	0.001
Market 60-119 lbs	80,708	53	0.000	0.001
Market 120-179 lbs	77,039	51	0.000	0.001
Market over 180 lbs	103,086	68	0.000	0.001
Poultry				
Layers				
Hens > 1 yr	324,907	215	0.000	0.005
Pullets	23,427	16	0.000	0.000
Chickens	1,701	1	0.000	0.000
Broilers	1,412,185	935	0.001	0.020
Turkeys	91,525	61	0.000	0.001
Other				
Sheep on Feed	-	-	0.000	0.000
Sheep Not on Feed	13,481	9	0.000	0.000
Goats	4,997	3	0.000	0.000
Horses	472,429	313	0.000	0.007
TOTAL	**6,752,079**	**4,470**	**0.004**	**0.094**

Table 8.9: 2017 CH_4 from Agricultural Residue Burning

Crop	Crop Production (metric tons)	C Content (m- tons C/m-tons dm)	Total C Released (metric tons C)	CH_4 - C Emission Ratio	CH_4 Emissions (metric tons CH_4)	CH_4 GWP	CH_4 Emissions ($MMTCO_2E$)
Barley	62,703	0.4485	771	0.007	5.14	21	0.000011
Corn	1,190,552	0.4478	11911	0.007	79.41	21	0.001668
Peanuts	-	0.45	-	0.007	-	21	-
Rice	-	0.3806	-	0.007	-	21	-
Soybeans	487,243	0.45	9835	0.007	65.57	21	0.001377
Sugarcane	-	0.4235	-	0.007	-	21	-
Wheat	341,282	0.4428	4486	0.007	29.9	21	0.000628
Total CH_4 from Agriculture Residue Burning ($MMTCO_2E$)							**0.003683**

Table 8.10: 2017 N_2O from Agricultural Residue Burning

Crop	Crop Production (metric tons)	N Content (m- tons N/m-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	62,703	0.0077	13.23	0.007	0.09	0.146	310	0.000045
Corn	1,190,552	0.0058	154.28	0.007	1.39	1.697	310	0.000526
Peanuts	-	0.0106	-	0.007	-	0	310	-
Rice	-	0.0072	-	0.007	-	0	310	-
Soybeans	487,243	0.023	502.69	0.007	3.11	5.53	310	0.001714
Sugarcane	-	0.004	-	0.007	-	0	310	-
Wheat	341,282	0.0062	62.81	0.007	0.3	0.691	310	0.000214
Total N_2O from Agriculture Residue Burning ($MMTCO_2E$)								**0.002500**

Table 8.11: 2017 N_2O Emissions from Manure Management

	Number of Animals ('000 head)	Total K-Nitrogen Excreted (kg)	Unvolatilized N from Manure in Anaerobic Lagoons and Liquid Systems (kg)	Unvolatilized N from Manure in Solid Storage, Drylot & Other Systems (kg)	Emissions from Anaerobic Lagoons and Liquid Systems (kg N2O-N)	Emissions from Solid Storage, Drylot, & Other Systems (kg N2O-N)	Total N_2O Emissions (kg N_2O)	Emissions (MTCE)	Emissions (MMTCE)	Emissions (MMTCO$_2$E)
Dairy										
Dairy Cows	53.0	7,852,125	2,125,872	1,831,372	2,126	36,627	60,898	5,149	0.00515	0.01888
Dairy Replacement Heifers	28.0	1,927,462	521,838	944,902	522	18,898	29,697	2,511	0.00251	0.00921
Beef Cattle										
Feedlot Heifers	3.9	218,344	NA	218,344	NA	4,367	6,862	580	0.00058	0.00213
Feedlot Steer	7.4	422,465	NA	422,465	NA	8,449	13,277	1,123	0.00112	0.00412
Swine										
Breeding Swine	2.0	29,269	22,577	1,198	23	24	73	6	0.00001	0.00002
Market Under 60 lbs	9.0	47,993	37,020	1,964	37	39	120	10	0.00001	0.00004
Market 60-119 lbs	7.0	56,016	43,208	2,293	43	46	140	12	0.00001	0.00004
Market 120-179 lbs	4.0	53,469	41,244	2,188	41	44	134	11	0.00001	0.00004
Market over 180 lbs	4.0	71,547	55,189	2,928	55	59	179	15	0.00002	0.00006
Poultry										
Layers										
Hens > 1 yr	2,292.0	1,189,617	59,481	1,130,136	59	5,651	8,973	759	0.00076	0.00278
Pullets	184.0	95,502	4,775	90,726	5	454	720	61	0.00006	0.00022
Chickens	12.0	8,672	434	8,239	0	41	65	5	0.00001	0.00002
Broilers	53,072.7	16,737,007	NA	16,737,007	NA	334,740	526,020	44,473	0.04447	0.16307
Turkeys	704.0	1,092,080	NA	1,092,080	NA	21,842	34,323	2,902	0.00290	0.01064
Other										
Sheep on Feed	0.0	-	NA	-	NA	-	-	-	-	-
Sheep Not on Feed	24.0	315,360	NA	213,844	NA	4,277	6,721	568	0.00057	0.00208
TOTAL		**30,118,367**	**2,911,638**	**22,699,687**	**2,912**	**435,557**	**688,202**	**58,184**	**0.05818**	**0.21334**

Table 8.12: 2017 Direct N_2O Emissions from Fertilizer Application (Agriculture Soils).

	Synthetic Fertilizer	**Organic Fertilizer**
Total Fertilizer Use (kg N)	40,158,687	26,724,473
Total N in Fertilizers (Calendar Year)	26,103,147	26,238,175
Volatilization Rate	10%	20%
Nitrogen Content of Fertilizer	0	4.10%
Unvolatized N (kg)	23,492,832	860,612.14
Unvolatized N (metric tons)	23,493	860.61
Direct Emission factor (N_20 -N)	0.01	0.0125
Direct Emission (metric) (N_20 - N)	234.93	10.76
Ratio N_2O-N_2	1.57	1.57
Direct Emission (metric) (N_20)	369.17	16.90
N_2O GWP	310	310
Direct Emission (MMTCO$_2$E)	0.114443654	0.003334872
Total Direct Emission (MMTCO$_2$E)	**0.1178**	

Table 8.13: 2017 Indirect N_2O Emissions from Fertilizer Application (Released to Atmosphere)

	Synthetic Fertilizer	**Organic Fertilizer**
Total Fertilizer Use (kg N)	40,158,687	26,724,473
Total N in Fertilizers (Calendar Year)	26,103,147	26,238,175
Volatilization Rate	10%	20%
Nitrogen Content of Fertilizer	0	4.10%
Volatized N (kg)	2,610,315	215,153.04
Volatized N (metric tons)	2,610	215.15
N_2O from Volatilization - Emission Factor (N_20 -N)	0.01	0.0125
Indirect Emission (metric) (N_20 -N)	26.10	2.69
Ratio N_2O-N_2	1.57	1.57
Indirect Emission (metric) (N_20)	41.02	4.23
N_2O GWP	310	310
Indirect Emission (MMTCO$_2$E)	0.0127	0.0013
Total Indirect Emission (MMTCO$_2$E)	**0.0140**	

Table 8.14: 2017 Indirect N_2O Emissions from Fertilizer Application (Runoff /Leaching)

	Synthetic Fertilizer	**Organic Fertilizer**	**Manure Excreted**
Total Fertilizer Use (kg N)	40,158,687	26,724,473	
Total N in Fertilizers-kg (Calendar Year)	26,103,147	26,238,175	38,991,102
Volatilization Rate	10%	20%	0%
Nitrogen Content of Fertilizer	100%	4.10%	1.0%
Unvolatized N (kg)	23,492,832	860,612	
Leached / Runoff Rate	30%	30%	30%
Leached / Runoff N (kg)	7,047,849.69	258,183.64	11,697,330.60
Leached / Runoff N (metric tons)	7,048	258	11,697
Indirect Emission factor (N_20 -N)	0.0075	0.0075	0.0075
Indirect Emission (metric tons) (N_20 -N)	52.86	1.94	87.73
Ratio N_2O-N_2	1.57	1.57	1.57
Indirect Emission (metric tons) (N_20)	83.06	3.04	137.86
N_2O GWP	310	310	310
Leached /Runoff Emission (MMTCO$_2$E)	0.03	0.0009	0.04
Total Leached /Runoff Emission (MMTCO$_2$E)	**0.06943**		

Table 8.15: 2017 Direct N_2O Emissions from Agriculture Crop Residue

	Crop Residues	**Legumes**
	N Returned to Soils	**N-Fixed by Crops**
	(kg)	**(kg)**
	26,869,637	42,661,498
Direct N_2O Emissions Factor	0.01	0.01
Direct N_2O Emission kg (N_2O -N)/ Yr	268,696.37	426,614.98
Ratio N_2O- N	1.571428571	1.571428571
Direct N_2O Emission (kg N_2O)	422,237.15	670,394.97
Direct N_2O Emission (metric tons)	422.2371529	670.3949686
Direct N_2O Emission (MMT)	0.000422237	0.000670395
GWP	310	310
Direct Emissions (MMTCO$_2$E)	0.130893517	0.20782244
Total N_2O Emission from Residue (MMTCO$_2$E)	**0.338715958**	

Table 8.16: 2017 N_2O Emissions from Manure Application

	Livestock Emissions (metric tons N_2O)	**N_2O GWP**	**Livestock Emissions** (MMT CO$_2$E)
Indirect N_2O Emissions	123.0	310	**0.03799**
Direct N_2O Emissions -Manure Applied to Soil	755	310	0.23395
Direct N_2O Emissions -Pasture, Range and Paddock	309.0	310	0.09568
Sum Direct N_2O Emissions	**1,063**		**0.32964**
Total Animal N_2O Emisssions (MMTCO$_2$E)	**0.37763**		

Table 8.17: 2017 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$_2$E)
Dairy Cattle								
Dairy Cows	53	5,788,024	20%	1%	11.58	0.1819093	310	5.63919E-05
Dairy Replacement Heifers	28	1,508,063	20%	1%	3.02	0.0473962	310	1.46928E-05
Beef Cattle								
Feedlot Heifers	3.9	179,913	20%	1%	0.36	0.0056544	310	1.75287E-06
Feedlot Steer	7.4	340,096	20%	1%	0.68	0.0106887	310	3.31351E-06
Bulls	4	339,450	20%	1%	0.68	0.0106684	310	3.30721E-06
Calves	36	465,156	20%	1%	0.93	0.0146191	310	4.53195E-06
Beef Cows	42	2,696,394	20%	1%	5.39	0.0847438	310	2.62706E-05
Steer Stockers	15	539,726	20%	1%	1.08	0.0169628	310	5.25847E-06
Total Beef Heifers	17	807,891	20%	1%	1.62	0.0253908	310	7.87117E-06
Swine								
Breeding Swine	2	33,967	20%	1%	0.07	0.0010675	310	3.30935E-07
Market Under 60 lbs	9	31,299	20%	1%	0.06	0.0009836	310	3.04946E-07
Market 60-119 lbs	7	43,568	20%	1%	0.09	0.0013692	310	4.24475E-07
Market 120-179 lbs	4	41,587	20%	1%	0.08	0.0013070	310	4.05178E-07
Market over 180 lbs	4	55,648	20%	1%	0.11	0.0017489	310	5.4217E-07
Poultry								
Layers						0		
Hens > 1 yr	2,292.0	1,249,851	20%	1%	2.50	0.0392810	310	1.21771E-05
Pullets	184	74,951	20%	1%	0.15	0.0023555	310	7.30233E-07
Chickens	12	6,544	20%	1%	0.01	0.0002056	310	6.37545E-08
Broilers	53,072.	19,177,82	20%	1%	38.36	0.6027314	310	0.00018684
Turkeys	704	1,293,023	20%	1%	2.59	0.0406378		0
Other								
Sheep on Feed	-	-			0.00	0		
Sheep Not on Feed	24	294,336	20%	1%	0.59	0.00925056	310	2.86767E-06
Goats	12	126,144	20%	1%	0.25	0.0039645	310	1.229E-06
Horses	80	3,897,653	20%	1%	7.80	0.1224976	310	3.79743E-05
TOTAL		**38,991,102**			**77.98**	**1.2254346**		**0.00036728**

Table 8.18: 2017 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	53.0	2,837,470	20%	0.0125		54	1.06194	310	0.0248
Dairy Replacement Heifers	28.0	739,300	20%	0.0125		14	0.27669	310	0.0063
Beef Cattle									
Feedlot Heifers	3.9	179,913	20%	0.0125		2	0.03534	310	0.0000
Feedlot Steer	7.4	340,096	20%	0.0125		3	0.066805	310	0.0015
Bulls	4.0	NA	20%						-
Calves	36.0	NA	20%						-
Beef Cows	42.0	NA	20%						-
Steer Stockers	15.0	NA	20%						-
Total Beef Heifers	17.0	NA	20%						-
Swine									
Breeding Swine	2.0	26,786	20%	0.0125		0.0	0.005262	310	0.0000
Market Under 60 lbs	9.0	24,683	20%	0.0125		0.0	0.004848	310	0.0000
Market 60-119 lbs	7.0	34,357	20%	0.0125		0.0	0.006749	310	0.0000
Market 120-179 lbs	4.0	32,795	20%	0.0125		0.0	0.006442	310	0.0000
Market over 180 lbs	4.0	43,884	20%	0.0125		0.0	0.008620	310	0.0000
Poultry									
Layers									
Hens > 1 yr	2,292.0	1,249,851	20%	0.0125	4.20%	12	0.235196	310	0.0059
Pullets	184.0	74,951	20%	0.0125	4.20%	1	0.014104	310	0.0000
Chickens	12.0	6,544	20%	0.0125	4.20%	0	0.001232	310	0.0000
Broilers	53,072.7	19,177,820	20%	0.0125	4.20%	181	3.608855	310	0.0882
Turkeys	704.0	1,293,023	20%			12	0.243319		0.0015
Other									
Sheep on Feed	-	-							
Sheep Not on Feed	24.0	-	20%					310	-
Goats	12.0	NA	20%					310	-
Horses	79.0	NA	20%					310	-
TOTAL						**284**	**5.5754**		**0.00165**

Table 8.19: 2017 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	53.0	5,788,024	7.64	0.14998	310	0.000046
Dairy Replacement Heifers	28.0	1,508,063	1.99	0.03908	310	0.000012
Beef Cattle						
Feedlot Heifers	3.9	NA				
Feedlot Steer	7.4	NA				
Bulls	4.0	339,450	6.79	0.13336	310	0.000041
Calves	36.0	465,156	9.30	0.182740	310	0.000057
Beef Cows	42.0	2,696,394	53.93	1.059300	310	0.000328
Steer Stockers	15.0	539,726	10.79	0.212035	310	0.000066
Total Beef Heifers	17.0	807,891	16.16	0.31739	310	0.000098
Swine						
Breeding Swine	2.0	33,967	0.14	0.00282	310	0.000001
Market Under 60 lbs	9.0	31,299	0.13	0.002599	310	0.000001
Market 60-119 lbs	7.0	43,568	0.18	0.0036184	310	0.000001
Market 120-179 lbs	4.0	41,587	0.18	0.003454	310	0.000001
Market over 180 lbs	4.0	55,648	0.24	0.004622	310	0.000001
Poultry						
Layers						
Hens > 1 yr	2,292.0	NA				
Pullets	184.0	NA				
Chickens	12.0	NA				
Broilers	53,072.7	NA				
Turkeys	704.0	1,293,023	2.59	0.05080		0.00000
Other						
Sheep on Feed	-	-				
Sheep Not on Feed	24.0	294,336	5.89	0.11563	310	0.000036
Goats	12.0	126,144	2.52	0.04956	310	0.000015
Horses	79.1	3,897,653	77.95	1.531221	310	0.000475
TOTAL			**196.42**			**0.00118**

9.0 Waste Management

9.1 OVERVIEW

Greenhouse gas (GHG) emissions from waste management include:

- Solid waste management
    - methane (CH4) and carbon dioxide (CO_2) emissions from waste decomposition at municipal and industrial solid waste landfills, accounting for both fugitive and flared GHG from 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/CO_2 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.

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

For the 2017 periodic emissions inventory, 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 2017, there were 42 active sites in Maryland. Four of these sites are controlled by flares, eleven were landfill- gas- to- energy (LFGTE) plants, the rest (27) 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.

Landfill Gas (LFG) Generation

Landfill gas is generated by the decomposition of organic municipal solid waste by bacteria naturally present in the waste dumped in the landfill and in the soil used to cover the landfill. Organic waste includes food, garden waste, street sweepings, textiles, wood and paper products.

The composition, quantity and rate of landfill gas generation are dependent on the types of waste that are decomposing and the level of microbial activity within the wastes. By volume, at near steady- state, LFG is typically composed of approximately 55 percent CH_4, 40 percent CO_2, 5 percent N_2, and smaller amounts of NMOCs such as benzene, vinyl chloride, chloroform, 1,1-dichloroethene, carbon tetrachloride, and other Non-Methane-Organic-Compounds (NMOCs)[1]. In addition, non-organic species such as hydrogen sulfide and vapor phase mercury are often found in LFG.

Bacteria decompose landfill waste in four phases[2]. The composition of the gas produced changes with each of the four phases of decomposition. Landfills often accept waste over a 20- to 30-year period, so waste in a landfill may be undergoing several phases of decomposition at once.
This means that older waste in one area might be in a different phase of decomposition than more recently buried waste in another area.

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[1] EPA: Guidance For Evaluating Landfill Gas emissions From Closed or Abandoned Facilities. http://www.cluin.org/download/char/epa-600-r-05-123.pdf

[2] ATSDR, 2001a. *Landfill Gas Primer – An Overview for Environmental Health Professionals, Chapter 2: Landfill Gas Basics.* Agency for Toxic Substances and Disease Registry (ATSDR). November 2001. http://www.atsdr.cdc.gov/hac/landfill/html/ch2.html

Phase I

During the first phase of decomposition, aerobic bacteria—bacteria that live only in the presence of oxygen—consume oxygen while breaking down the long molecular chains of complex carbohydrates, proteins, and lipids that comprise organic waste. The primary byproduct of this process is carbon dioxide. Nitrogen content is high at the beginning of this phase, but declines as the landfill moves through the four phases. Phase I continues until available oxygen is depleted. Phase I decomposition can last for days or months, depending on how much oxygen is present when the waste is disposed of in the landfill. Oxygen levels will vary according to factors such as how loose or compressed the waste was when it was buried.

Phase II

Phase II decomposition starts after the oxygen in the landfill has been used up. Using an anaerobic process (a process that does not require oxygen), bacteria convert compounds created by aerobic bacteria into acetic, lactic, and formic acids and alcohols such as methanol and ethanol. The landfill becomes highly acidic. As the acids mix with the moisture present in the land-fill, they cause certain nutrients to dissolve, making nitrogen and phosphorus available to the increasingly diverse species of bacteria in the landfill. The gaseous byproducts of these processes are carbon dioxide and hydrogen. If the landfill is disturbed or if oxygen is somehow introduced into the landfill, microbial processes will return to Phase I.

Phase III

Phase III decomposition starts when certain kinds of anaerobic bacteria consume the organic acids produced in Phase II and form acetate, an organic acid. This process causes the landfill to become a more neutral environment in which methane-producing bacteria begin to establish themselves. Methane-and acid-producing bacteria have a symbiotic, or mutually beneficial, relationship. Acid-producing bacteria create compounds for the methanogenic bacteria to consume. Methanogenic bacteria consume the carbon dioxide and acetate, too much of which would be toxic to the acid-producing bacteria.

Phase IV

Phase IV decomposition begins when both the composition and production rates of landfill gas remain relatively constant. Phase IV landfill gas usually contains approximately 45% to 60% methane by volume, 40% to 60% carbon dioxide, and 2% to 9% other gases, such as sulfides. Gas is produced at a stable rate in Phase IV, typically for about 20 years; however, gas will continue to be emitted for 50 or more years after the waste is placed in the landfill. Gas production might last longer, for example, if greater amounts of organics are present in the waste, such as at a landfill receiving higher than average amounts of domestic animal waste.

For cellulose, the principal sources of gas from landfill waste, typical conversion reactions can be represented by the following three reactions:

Aerobic Oxidation

$$C_6H_{12}O_6 \quad + \quad O_2 \quad \xrightarrow{\text{Aerobic bacterial}} \quad CO_2 \quad + \quad H_2O \quad + \quad \text{Biomass} \quad + \quad \text{Heat (I)}$$

Anaerobic Oxidation

$$C_6H_{12}O_6 \quad \xrightarrow{\text{Anaerobic bacterial}} \quad CH_4 + CO_2 + \text{Biomass} \quad + \quad \text{Heat} \quad \text{(II)}$$

Methanogenesis Reaction

$$\text{Acetic Acid :} \quad (CH_3COO^-) \quad + \quad H_2O \quad \xrightarrow{\text{Methanogenic bacterial}} \quad CH_4 \quad + \quad HCO_3^- \quad \text{(III)}$$

$$4H_2O \quad + \quad CO_2 \quad \xrightarrow{\text{Methanogenic bacterial}} \quad CH_4 \quad + \quad 2H_2O \quad \text{(IV)}$$

As the LFG gases rises to the surface of the landfill, some oxidation of CH_4 to CO_2 occurs near the soil surface, where aerobic degraders persist. In landfills with active gas collection system, the LFG is collected prior to reaching this aerobic soil layer, along with some infiltration air.

9.3.1 Carbon Dioxide (CO_2) Direct Emissions.

9.3.1.1 Carbon Dioxide Emissions from Landfill Gas

Carbon dioxide (CO_2) emissions from municipal solid waste (MSW) landfills were estimated from the Landfill's cumulative and annual MSW tonnage report collected by MDE's Solid Waste Program and the annual emission certificate report from MDE's Air Quality Program. The landfills specific placement data were applied as the input data to EPA's Landfill Gas Emissions Model (LandGEM) to estimate the CO_2 emissions generation rate of each of the landfills.

The total CO_2 gas generated from all the Landfills were summed and estimated to be the CO_2 emissions from Maryland in 2017 since there is no feasible control technology to control the emission of the CO_2 emissions.

MDE calculated the 2017 carbon dioxide (CO_2) 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 CO_2 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. Applied the annual waste accepted data from the opening year to current year or closure to the EPA LandGEM Model.

6. Extract the CO_2 generation rate data (LandGEM Output) from each of the landfills.

7. Summed all the CO_2 generation rate data to estimate Maryland 2017 carbon dioxide emission from Landfills.

9.3.1.2 Carbon Dioxide Emissions from Landfill Gas Flaring/Energy Conversion.

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.

$$CH_4 + 2O_2 \Rightarrow CO_2 + 2H_2O \quad \text{…………….. (Equation 1)}$$

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

9.3.1.3 Carbon Dioxide Emissions (CO_2) from 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 2017 by the default EPA Municipal Solid Waste heat value and CO_2 emission factor[1].

9.3.1.4 Carbon Dioxide Emissions (CO_2) from 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.

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[1] Table C -1 To Subpart C of Part 98- Default CO_2 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.

9.3.2 Additional Direct Emissions (CH_4 and N_2O)

9.3.2.1 Methane Gas Emissions from Landfill Gas

Emissions from municipal solid waste landfills and combustion were calculated using site specific data collected by the MDE's solid waste and air quality programs. Throughput data reported on individual facility's air emission inventories were used to tabulate the total quantity of landfill gas flared, landfill gas collected in landfill-to-gas-energy projects, and municipal solid waste combusted. The total quantity of municipal solid waste landfill was tabulated from individual landfill reporting to the solid waste program. Emissions were also refined by using state-specific proportions of discards that are plastics, synthetic rubbers, and synthetic instead of SIT default values to calculate CO_2 emissions from municipal solid waste combustion.

MDE calculated the 2017 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. Applied CH_4 GWP to CH_4 generated (metric tons) to estimate **MSW CH_4 generation** ($MTCO_2E$).

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

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

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

11. Applied Landfills specific LFG collection efficient to CH_4 generated to estimate amount of **CH_4 collected.**
12. 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.

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

14. 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**.

15. Apply EPA default surface oxidation factor (10%) to **Uncollected CH_4** to estimate Municipal Landfills **fugitive CH_4 emission.**

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

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

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

19. 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 9.1: SIT Key Default Values for Municipal Wastewater Treatment.

Default Values for Municipal Wastewater Treatment Variables [1]	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: 2017 CO_2 and N_2OEmissions from MSW Combustion

MSW Processed (tons)	**1,298,472**
CO_2 Emissions	
Default high Heat Value (MMBtu/S tons)	9.95
Default CO_2 Emission factor (kg /MMBtu)	90.7
CO_2 Emissions (tons/yr)	1,308,965
CO_2 Emissions (metric tons/yr)	**1,187,472**
CO_2 Emissions (million metric tons/yr)	1.187472
N_2O Emissions	
Default N_2O Emission factor (kg /MMBtu)	4.20E-03
N_2O Emissions (metric tons/yr)	54.26
N_2O GWP	310
N_2O Emissions ($MMTCO_2E$)	**0.01016**

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

Table 9.3: 2017GHG Emissions from Landfills

MSW CH_4 Generation (short ton CH_4)	(A)	101,154
CH_4 GWP	(B)	21
MSW Generation (MTCO$_2$E)	(C) = (A) x (B) x 0.9071847	1,927,062
Industrial Generation (MTCO$_2$E)	(D) = (C) *7%	134,894
Potential CH_4 (MTCO$_2$E)	(E) = (C) +(D)	562,352
Flared CH_4 (tons)	(F)	18,219
Flared CH_4 (MTCO$_2$E)	(G) = (F) *(B)	347,094
Landfill Gas-to-Energy (tons)	(H)	39,579
Landfill Gas-to-Energy (MTCO$_2$E)	(I) = (H)*(B)	754,017
CH_4 Avoided (MTCO$_2$E)	(J) =(I) +(G)	**1,101,111**
Oxidation at MSW Landfills (tons)	(K)	32,208
Oxidation at MSW Landfills (MTCO$_2$E)	(L) =(K) *(B)	613,587
Oxidation at Industrial Landfills (MTCO$_2$E)	(M) =(L) *7%	**42,951**
Total CH_4 Emissions (MTCO$_2$E)	(N) =(E)- (J)-(L) -(M)	**334,255**
CO_2 Emission from (Flaring + LFGTE) (MMTCO$_2$E)	**(O)**	**0.1230**
CO_2 Emissions From Landfill Gas (MMTCO$_2$E)		**0.3682**

Table 9.4: 2017 CH_4 Emissions Calculation for Municipal Wastewater Treatment.

State Population		A	6,052,177
Per Capita BOD_5	(kg/day)	B	0.0900
Days per Year	(days)	C	365
Unit Conversion	(metric tons/kg)	D	0.001
Emission Factor	(Gg CH_4/Gg BOD_5)	E	0.6000
WW BOD_5 anaerobically digested	(percent)	F	16.25%
Emissions	(metric tons CH_4)	G= A x B x C x D x E x F	19,384.4
CH_4 GWP	(CO_2 Eq.)	H	21
Unit Conversion	(MMT/MT)	I	0.000001
C/CO_2		J= (12/44)	0.27
Emissions	(MMTCE)	K= G x H x I x J	0.111
Emissions	(MMTCO_2E)	'L = K* (44/12)	0.4071

Table 9.5: 2017 N_2O Emissions from Municipal Wastewater Treatment.

State Population		A	6,052,177
Fraction of Population not on Septic		B	81%
Direct N_2O Emissions from Wastewater Treatment	(g N_2O/person/year)	C	4.0
Unit Conversion	(g/metric ton)	D	1E-06
Emissions	(Metric Tons N_2O)	E=A*B*C*D	19.71
N_2O GWP	(CO_2 Eq.)	F	310
Unit Conversion	(MMT/MT)	G	0.000001
C/CO_2		H	0.27
Emissions	(MMTCE)	I =E*F*G*H	0.002
Emissions	(MMTCO$_2$E)	J = I* (44/12)	0.0061

Table 9.6: 2017 N_2O Emissions from Biosolids Fertilizers.

	Formula	Result
Population (person – 2017)	A	6,052,177
Per Capital Protein Consumption (kg / capital/day)	B = 41.90	45.2
Protein Consumed (kg)	C = A * B	273,558,400
Fraction of Nitrogen in Protein (FRAC $_{NPR}$)	D = 16%	16%
Nitrogen Consumed (kg)	E = C *D	43,769,344.06
Fraction of Non Consumption Nitrogen	F = 1.75	1.75
Total Nitrogen in Domestic Wastewater (kg)	G = E * F	76,596,352.11
Total Nitrogen in Domestic Wastewater (metric tons)	**H = G / 1,000**	76,596.35
Direct N_2O Emission from Wastewater Treatment (metric tons N_2O)	I	19.65
Biosolids Available N (metric tons)	**J = (H – I)**	**76,577**
Percentage Biosolids used as Fertilizer	K= 0%	0%
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	**601.67**
N_2O GWP	P	310
MMT/MT Conversion	Q= 1/1E+06	0.00
C/CO_2 Conversion	R =12/44	0.2727
Emissions from Biosolids (MMTCE)	S=O*P*Q*R	0.050869
Direct N_2O Emission from Wastewater Treatment (MMTCE)	T=I*P*Q*R	0.001661
Total Emission Biosolids (MMTCE)	U=S+T	0.0525
C/CO_2 Conversion	V=44/12	3.67
N_2O Emissions from Biosolids Fertilizer (MMTCO_2E)	**V = U*V**	**0.1926**

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 2017 were calculated using the EPA SIT software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[1] However, the SIT only contains default activity data for year 2013. MDE was not able to obtain the default year 2017 input data required by the SIT software to estimate the GHG emission. MDE is applying the year 2013 data as surrogate for the periodic year 2017 and will continue evaluating information as it becomes available, and will update year 2017 data when available.

In general, the SIT methodology applies emission factors developed for the US to activity data for the land use and forestry sectors.

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

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

- 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

- Urban Forest Data.
  Forester Rob Feldt of Maryland Forest Services, Maryland Department of Natural Resources.

- 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 (2014) Commercial Fertilizers 2014.
  Association of American Plant Food Control Officials. University of Kentucky, Lexington, KY.

- Maryland Solid Waste Management and Diversion Report (2017) ; Input Data to EPA WARM Model

  http://www.mde.state.md.us/programs/LAND/RecyclingandOperationsprogram/Pages/index.aspx

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 1990-2009. 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. Forest Carbon stocks and net annual Carbon stock change were determined according to a stock-difference method, which involves applying Carbon estimation factors to forest inventory data and interpolating between successive inventory-based estimates of Forest Carbon stocks.

Stock-difference method
The stock-difference method involves the measurement of carbon stocks in relevant pools at 2 points in time to assess carbon stock changes. The following equation is applied:

$$\Delta C = \frac{(Ct_2 - Ct_1)}{(t_2 - t_1)}$$

Where:
ΔC annual change in carbon stocks in the pool, tC/yr
Ct_1 carbon stocks in the pool at time t_1, tC
Ct_1 carbon stocks in the pool at time t_2, tC

EPA has updated this source category many times since the 2006 base year inventory was produced. Each time the forest carbon flux emission/sink calculation was influenced by:

- New updated models and model output data
- New sources of input data such as time intervals

When the model is updated or the inputs are changed, the emission/sink values change not only for future years but for the 2006 base year as well. MDE has decided to keep the forest carbon flux emission/sink calculation at the 2006 base year level for future year in order to maintain a constant 2006 base year inventory and to allow for accurate evaluations between future year anthropogenic greenhouse gas emission inventories and the base year.

(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

$$\text{Emissions or Sequestration (MMTCO}_2\text{e)} = \text{Aboveground Biomass Carbon Flux} + \text{Belowground Biomass Carbon Flux} + \text{Dead Wood Carbon Flux} + \text{Litter Carbon Flux} + \text{Soil Organic Carbon Flux} + \text{Wood Products Carbon Flux} + \text{Landfills Carbon Flux}$$

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)[1].

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

No default data on the application of limestone and dolomite to Agriculture soil could be found for the State of Maryland. Therefore, national percent limestone applied to Agriculture soil were multiplied by Maryland total limestone consumption to estimate the amount of limestone applied to agriculture soil.

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[1] West, T.O.; McBride, A.C. "The contribution of agricultural lime to carbon dioxide emissions in the United States: dissolution, transport, and net emissions," Agricultural Ecosystems & Environment. 2005, 108, 145-154.

$$\text{MD Limestone applied to Agric Soil} = (\text{National \% Limestone Applied to Agricultural Soil}) \times (\text{Total MD Limestone Consumption})$$

Equation 1.3.2: Liming Emissions Equation

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

10.3.3 Urea Fertilization

The use of urea as a fertilizer results in CO_2 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 CO2 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 (2014) Commercial Fertilizers 2014. 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

$$\textbf{Emissions (MMTCO}_2\textbf{e)} = \frac{\textbf{Total Urea Applied to Soil (metric tons)} \ \textbf{X} \ \textbf{Emission Factor (tons C/ton urea)} \ \textbf{X} \ \textbf{44/12 (ratio of CO}_2\textbf{ to C)}}{\textbf{1,000,000 (MT/MMTCO}_2\textbf{e)}}$$

Where:

Emissions = Amount of carbon dioxide emitted from urea fertilization ($MMTCO_2E$)
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)
44/12 = 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 ground 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 2017 periodic 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 obtained the updated periodic year 2017 Total Urban Area (km^2) data and the percent Urban Area coverage from the Maryland Forest Services. Periodic Year 2014 Sequestration was estimated from Urban Tree with the equation below, using SIT default C sequestration factor.

Equation 1.3.4: Urban Trees Equation

$$\text{Sequestration } (\text{MMTCO}_2\text{e}) = \frac{\text{Total Urban Area } (\text{km}^2) \times \text{Urban Area with Tree Cover } (\%) \times \text{100 } (\text{ha/km}^2) \quad \text{Carbon Sequestration Factor (metric tons C/ha/yr)} \times \text{44/12 (ratio of CO}_2\text{ to C)}}{\text{1,000,000 } (\text{MT/MMTCO}_2\text{e})}$$

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

$$\text{Sequestration (MMTCO}_2\text{e)} = \frac{\text{Total Synthetic Fertilizer (metric ton N)} \times \text{Emission Factor (percent)} \times 0.01\ \text{(metric tons N}_2\text{0-N/ metric ton N)} \times \text{GWP (310)} \times 44/28\ \text{(ratio of N}_2\text{O to N}_2\text{O -N)}}{1{,}000{,}000\ \text{(MT/MMTCO}_2\text{e)}}$$

Where:

Sequestration = Amount of carbon removed (MMTCO$_2$e)
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 N_2O-N to metric tons N (0.01)
GWP = Global Warming Potential, N_20 to CO_2 (310)
44/28 = Conversion Factor - converts N_2O-N to N_20 (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 2017 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 ($MMTCO_2e$)	=	**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)	Combusti on 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
Other temperate forests	480	152,440	45%	8.1	0.11	21	310
Shrublands	436	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 for periodic year 2017 was extracted from the Maryland Solid Waste Management and Diversion Report (Input Data to WARM Model)

.

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 2006 in short tons of wet weight is provided within the module and was used by MDE. MDE updated the default data with Maryland specific annual landfilled yard trimmings and food scraps from year 2007 to date, with certified reported landfilled data submitted to the MDE Solid Waste Program.

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 10.2

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

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 stock 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: 2017 Summary of Land Use, Land –Use Change, and Forestry Emissions and Sequestration in Maryland. (MMTCO$_2$e)

	2017
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	**0.0315228**
Limestone	0.0315228
Dolomite	0.00000
Urea Fertilization	**0.01067**
Urban Trees	**(1.09292)**
Landfilled Yard Trimmings and Food Scraps	**(0.16864)**
Grass	(0.00955)
Leaves	(0.04901)
Branches	(0.04428)
Landfilled Food Scraps	(0.06579)
Forest Fires	**0.01650**
CH_4	0.01375
N_2O	0.00276
N_2O from Settlement Soils	**0.02110**
Total	**(11.67987)**

Table10.8: 2017 CO$_2$ Emissions from Urea Fertilizer Use

	Total Urea Applied to Soil		**Emission Factor**		**Carbon Emissions**		**Carbon Dioxide-to -Carbon Ratio (44/12)**		**Carbon Dioxide Emissions**	**Carbon Dioxide Emissions**
Year	**(Metric Tons)**		**(Ton C/Ton urea)**		**(MT)**				**(MTCO$_2$E)**	**(MMTCO$_2$E)**
2017	14,547	x	0.2	=	2,909	x	3.66667	=	10,668	0.01067

Table 10.9: 2017 CO_2 Emissions from Liming of Soil

Year		Total Applied to Soil ('000 Metric Tons)		Emission Factor (Ton C/Ton limestone)		Emissions (Ton C)		C-CO_2 Ratio	Carbon Dioxide Emissions ($MTCO_2E$)		Total Carbon Dioxide Emissions ($MMTCO_2E$)
2017	Limestone	145,713.80	x	0.059	=	8,597	x	(44/12)	31,523	=	0.031522752
2017	Dolomite	0	x	0.064	=	0			0	=	0
											0.031522752

Table 10.10: 2017 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	480	152,440	45%	8.1	480	21	0.0056
Shrublands	436	152,440	72%	8.1	436	21	0.0081
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							**0.0137**

Table 10.11: 2017 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 ($MMTCO_2E$)
2017	4,336	1%	1.57	68.1	310	21,111	0.02110

Table 10.12: 2017 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	480	152,440	45%	0.11	3.6202	310	0.0011
Scrublands	436	152,440	72%	0.11	5.2692	310	0.0016
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							**0.0028**

Table 10.13: 2017 C- Storage in Urban Trees.

Year	**2017**
Total Urban Area (km^2)	4,773.70
Urban Area with Tree Cover(Percent)	28%
Total Area of Urban Tree Cover (km^2)	1,538.32
Hectare/ km^2	100
Total Area of Urban Tree Cover (ha)	153,832
Carbon Sequestration Factor (metric tons C /hectare/year)	2.23
Carbon Sequested (metric tons)	343,045.36
Carbon dioxide-to-Carbon Ratio (44/12)	3.67
Carbon Dioxide Removed (metric tons)	1,092,920
Carbon Sequested ($MMTCO_2E$)	**-1.09292**

Table 10.14: Net Sequestrations/ Emissions (MMTCO$_2$e) - Landfilled Yard Trimmings and Food Scraps (2011 -2017).

	2011	2012	2013	2014	2015	2016	2017
Grass	-0.0069	-0.0091	-0.0137	-0.0127	-0.0127	-0.0127	-0.00955
Leaves	-0.0481	-0.057	-0.0778	-0.0709	-0.0709	-0.0709	-0.04901
Branches	-0.0431	-0.0515	-0.0711	-0.0646	-0.0646	-0.0646	-0.04428
Food Scraps	-0.0615	-0.0501	-0.0619	-0.0701	-0.0701	-0.0701	-0.06579
Total	(0.1595)	(0.1678)	(0.2246)	(0.2182)	(0.2182)	(0.2182)	(0.16864)

Table 10.15: -Net Séquestration/ Emissions (MMTCO$_2$e)- Forest Carbon Flux (2011 -2017).

	2011	2012	2013	2014	2015	2016	2017
Aboveground Biomass	-7.4829	-7.4829	-7.4829	-7.4829	-7.4829	-7.4829	-7.4829
Belowground Biomass	-1.4221	-1.4221	-1.4221	-1.4221	-1.4221	-1.4221	-1.4221
Dead Wood	-0.5848	-0.5848	-0.5848	-0.5848	-0.5848	-0.5848	-0.5848
Litter	-0.232	-0.232	-0.232	-0.232	-0.232	-0.232	-0.232
Soil Organic Carbon	-0.0514	-0.0514	-0.0514	-0.0514	-0.0514	-0.0514	-0.0514
Total	(10.498)	(10.498)	(10.498)	(10.498)	(10.498)	(10.498)	(10.498)

Table 10.16: Net Sequestrations/ Emissions (MMTCO$_2$e) - Wood Products and Landfills (2011 -2017).

	2011	2012	2013	2014	2015	2016	2017
Total wood products and landfills	(0.7248)	(0.7248)	(0.7248)	(0.7248)	(0.7248)	(0.7248)	(0.7248)