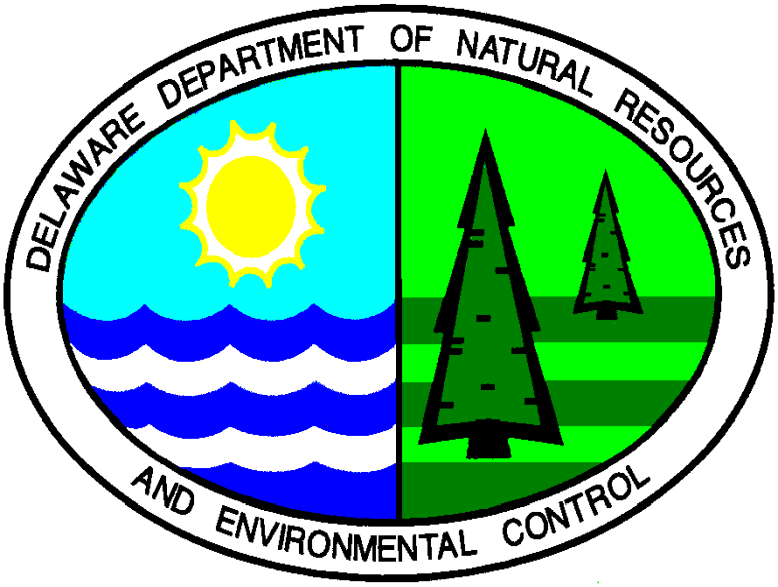


DELAWARE'S 2008 GREENHOUSE GAS EMISSIONS INVENTORY

PREPARED BY:

DIVISION OF AIR QUALITY

AUGUST 2012

EXECUTIVE SUMMARY

This report was prepared by the Department of Natural Resources and Environmental Control (DNREC), Division of Air Quality (DAQ) for Delaware to present the findings of the 2008 Greenhouse Gas (GHG) emissions inventory. The inventory was prepared to account for GHG emissions and sinks[1] in the State of Delaware. The inventory includes Delaware GHG emissions from1990 to 2008. In addition to emissions data, this report provides information on emission sources and activities, as well as inventory methods.

Delaware's anthropogenic[2] GHG emissions were developed using a set of generally accepted principles and guidelines as well as protocols for State GHG emissions inventories established by the U.S. Environmental Protection Agency (EPA) and International Organization for Standardization (ISO). The General Methodology and Assumptions section of this report describes the principles and general methods applied to this GHG inventory process.
GHG emissions from Delaware's sources are presented in this report by using a common metric, carbon dioxide equivalents (CO_2e), which accounts for the relative contributions of each gas to global average radiative forcing on a Global Warming Potential (GWP) weighted basis. The emissions estimates in this report are represented in million metric tons of CO_2 equivalents ($MmtCO_2e$).

To develop the annual emissions of GHGs from Delaware for the period of 1990 to 2008, emissions estimations were performed by using the U.S.EPA's State Inventory Tool (SIT). The SIT consists of MSExcel® spread sheets, which facilitate the collection of activity data (Information on the extent to which human activity takes place)[3] and emission factors (coefficients which quantify emissions or removal per unit activity)[4] that are based on economic activities[5] in Delaware.

[1] Sinks: Removal or sequestration of greenhouse gases from the atmosphere.
[2] The term "anthropogenic", in this context, refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities (IPCC/UNEP/OECD/IEA 1997)
[3] 2006 IPCC Guidelines for National Greenhouse Gas Inventories
[4] 2006 IPCC Guidelines for National Greenhouse Gas Inventories
[5] This includes fossil fuel combustion, industrial processes, agricultural activities and waste management

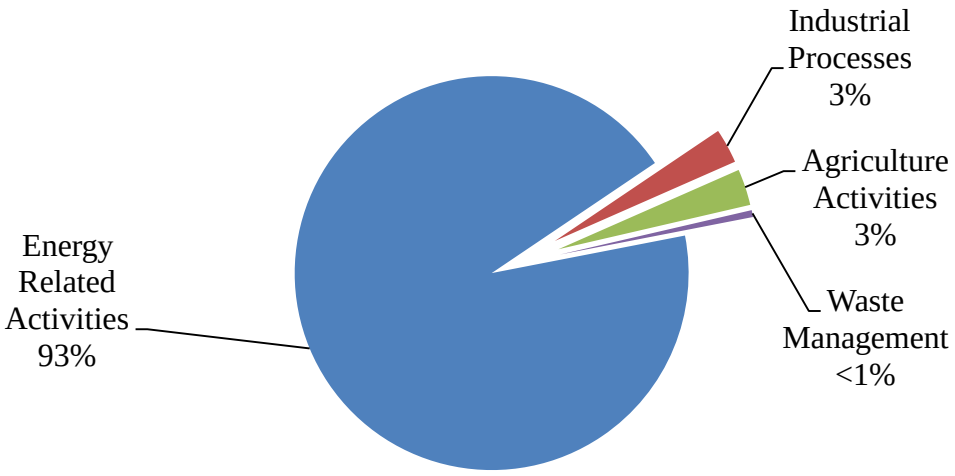
SOURCES OF GHG EMISSIONS

The 2008 GHG inventory estimated GHG emissions from various sources. Data collection was performed by characterizing the sources into four categories including energy related activities, non-energy related industrial processes, agricultural activities, land-use, land-use change & forestry (LULUCF) and waste management[6]. Each source category was subdivided based on economic activities, as well as methodologies for estimating emissions. In 2008, Delaware's gross[7] GHG emission was equivalent to 18.88 million metric tons of carbon dioxide equivalents ($MmtCO_2e$). Also in 2008, net[8] GHG emission was equivalent to 16.14 $MmtCO_2e$ emitted. This was approximately a 21% decrease when compared to 1990 net emission of 20.55 $MmtCO_2e$. Delaware's gross GHG emission in 2008 made up approximately 0.3% of gross U.S GHG emissions (7,048 $MmtCO_2e$)[9]. Figure ES-1 provides the breakdown[10] of the 2008 GHG emissions by Delaware source category.

As Figure ES-1 presents, GHG emissions from energy related activities in Delaware had the largest CO_2e contribution to gross GHG emissions with approximately 93%. This was followed by agricultural source categories with approximately 3%, non-energy related industrial process sources with approximately 3% and waste management sources with less than1% (approximately 0.58%).

[6] IPCC, 2006 Guidelines for National Greenhouse Gas Inventories, Vol. 1
[7] Gross GHG emissions excluded metric tons of CO_2e removed from the atmosphere (sink)
[8] The land-use category was a sink for the removal CO_2. This produced negative CO_2e in the inventory results.
[9] U.S. EPA: 2012 Inventory of U.S. Greenhouse Gas Emissions and Sinks:1990 -2008
[10] Figure 1 percentages are based on Delaware's gross emissions of 18.88 and not the net emissions of 16.14.

FIGURE ES-1. 2008 DELAWARE CO_2e EMISSIONS BY SOURCE CATEGORY



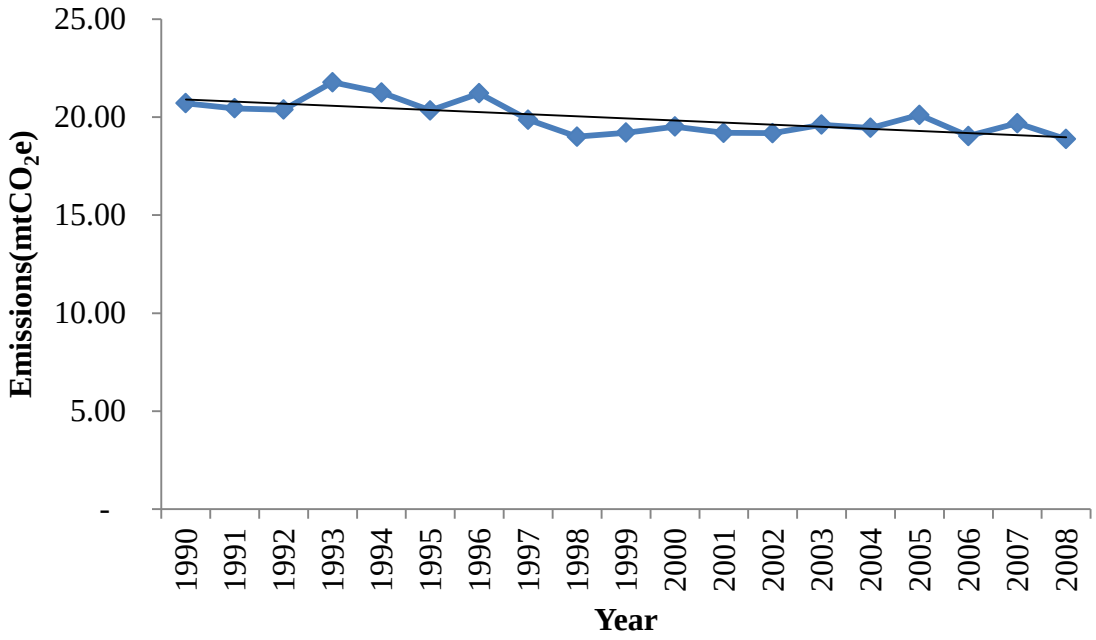
GROSS GHG EMISSION TREND

Delaware's gross GHG emissions trended down from 1990 to 2008 as shown in Figure ES-2. Gross GHG emissions decreased by approximately 8.8% from1990 to 2008. Though fluctuations where observed in the emissions trend as Figure ES-2 show, overall GHG emission levels declined from 1990 to 2008 at the rate of 0.11 $MmtCO_2e$ per year.

There were many factors that contributed to the downward trend of Delaware's gross GHG emissions. Energy related activities[11] affected all sectors of Delaware's economy and was the largest contributor to GHG emissions. Fossil fuel combustion was the greatest driver of GHG emissions from energy related activities. As the overall amount of fossil fuel combusted declined from 1990 to 2008, GHG emissions from energy related activities also declined. This decline in GHG emissions from energy related activities was the greatest driver of reductions in GHG emissions between 1990 and 2008.

11 Energy related activities are activities that involve fossil fuel combustion for energy use.

FIGURE ES-2. DELAWARE'S GROSS GHG EMISSION FROM 1990 TO 2008



Energy Related Activities

The GHG emission trends by source category in Figure ES-3 shows that emissions from the energy source category have the largest share in gross GHG emissions from 1990 to 2008. Energy related activities resulted in an average annual emission of 18.42 $MmtCO_2e$ from 1990 to 2008. As shown in Table ES-1, GHG emissions from energy related activities decreased from 1990 to 2008 due to decreased fossil fuel consumption.

Agricultural Activities

The agricultural activities[12] were a distant second with respect to overall GHG emissions from 1990 to 2008. It had an average annual emission of 0.62 $MmtCO_2e$. GHG emissions from agricultural activities decreased slightly from 1990 to 2008 as presented by Table ES-1. This decrease was partly due Delaware's shrinking agricultural base as a result of land development, as well as improved agricultural practices that minimize emissions as well as increase carbon storage and sequestration.

[12] Agricultural activities are activities that involve the cultivation of animals and plants for food.

Non-energy Related Activities

Emissions from agricultural activities were followed by non-energy related industrial processes, which resulted in an average emission of 0.43 $MmtCO_2e$ per year. Table ES-1 showed that GHG emissions from non-energy industrial process emissions increased emissions increased from 1990 to 2008. This increase was driven primarily by emissions from the consumption of substitutes of ozone depleting substances (ODS)[13]. Emissions from the consumption of ODS substitutes increased drastically by approximately 36,533% from 1990 to 2008, representing the largest emissions rate increase of any source category.

Waste management Activities[14]

Waste management had the least impact with an average emission of 0.31 $MmtCO_2e$ per year. On the other hand, land use, land-use change and forestry (LULUCF) had an opposite impact on gross GHG emissions because it was a major sink for CO_2, removing an average amount of 1.50 $MmtCO_2e$ per year from 1990 to 2008.

[13] Ozone depleting substances are gases that catalyzes the decomposition the ozone gas in the stratosphere

[14] Waste management activities are activities include recycling, combustion for energy recovery, treatment (treatment includes treatment for destruction and waste stabilization), and release, including disposal

FIGURE ES-3. GHG EMISSIONS BY SOURCE CATEGORIES

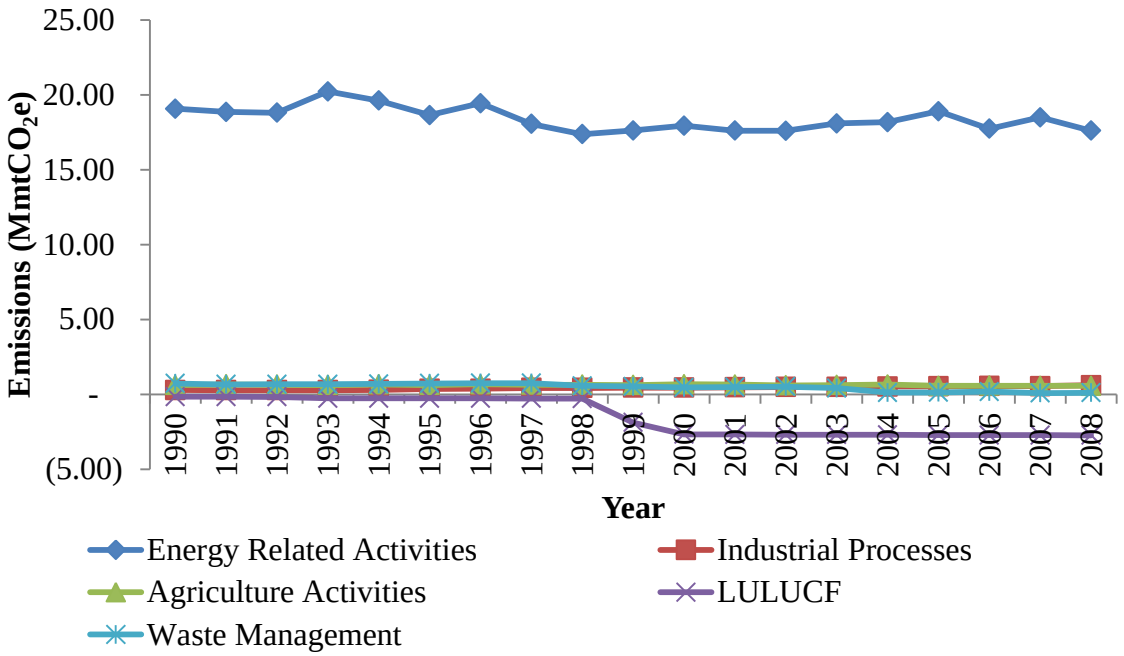


Table ES-1 provides a list of categories and sub-categories of sources with corresponding emissions estimates based on CO_2e. In 2008, energy related activities emitted 17.61 $MmtCO_2e$ into the atmosphere. This was followed by industrial processes with 0.60 $MmtCO_2e$, agricultural activities with 0.56 $MmtCO_2e$ and waste management with 0.11 $MmtCO_2e$. LULUCF removed 2.74 $MmtCO_2e$ from the atmosphere.

TABLE ES-1. GHG EMISSION ESTIMATES BY SOURCE CATEGORY

Source Categories	1990	1995	2000	2005	2008
Energy Related Activities	**19.08**	**18.64**	**17.94**	**18.90**	**17.61**
CO_2 from Fossil Fuel Combustion	18.78	18.30	17.62	18.66	17.43
Stationary Combustion	0.06	0.06	0.06	0.06	0.06
Mobile Combustion	0.24	0.28	0.27	0.19	0.12
Industrial Processes	**0.29**	**0.36**	**0.45**	**0.53**	**0.60**
Agriculture Activities	**0.62**	**0.61**	**0.67**	**0.57**	**0.56**

TABLE ES-1. GHG EMISSION ESTIMATES BY SOURCE CATEGORY					
Source Categories	**1990**	**1995**	**2000**	**2005**	**2008**
Enteric Fermentation	0.05	0.05	0.05	0.04	0.04
Manure Management	0.18	0.21	0.20	0.19	0.19
Agricultural Soil Management	0.38	0.35	0.42	0.33	0.32
Waste Management	**0.73**	**0.73**	**0.46**	**0.12**	**0.11**
Municipal Solid Waste	0.66	0.66	0.38	0.04	0.02
Wastewater	0.06	0.07	0.08	0.08	0.09
LULUCF	**(0.16)**	**(0.27)**	**(2.68)**	**(2.72)**	**(2.74)**
Gross Emissions	**20.71**	**20.34**	**19.52**	**20.12**	**18.88**
Sinks	**(0.16)**	**(0.27)**	**(2.68)**	**(2.72)**	**(2.74)**
Net Emissions	**20.55**	**20.07**	**16.84**	**17.40**	**16.14**
Indirect CO_2 from Electricity Consumption	**0.00**	**0.00**	**6.26**	**6.74**	**6.55**

NET GHG EMISSIONS TREND

In addition to estimating GHG emissions from various sources, DAQ also estimated the amount of GHGs in metric tons sequestered or removed from the atmosphere by sinks. The land-use, land-use change and forestry (LULUCF) category was identified as a sink. LULUCF mitigates the atmospheric build-up of GHGs by removing CO_2 from the atmosphere and then storing it in forest at a rate greater than emission back to the atmosphere through human and natural disturbances. The GHG emissions removed as a result of LULUCF from 1990 to 2008 were subtracted from gross GHG emissions to obtain net GHG emissions as presented in Figure ES-4.

FIGURE ES-4. NET GHG EMISSION FROM DELAWARE

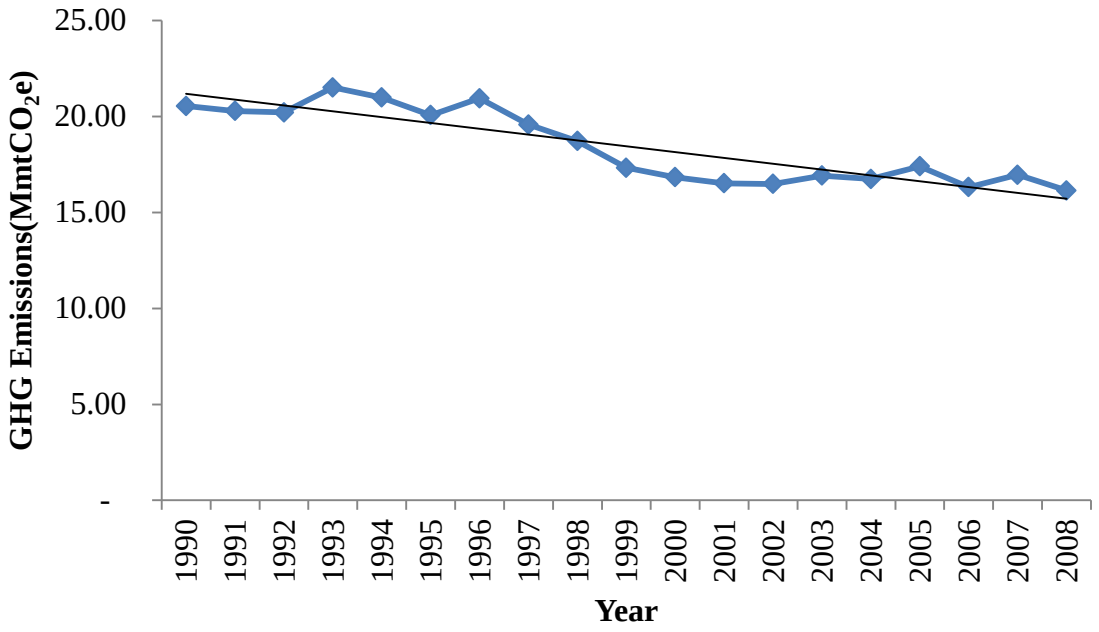


Table ES-1 shows that net GHG emissions decreased from 20.55 $MmtCO_2e$ in 1990 to 16.14 $MmtCO_2e$ in 2008. This was a decrease of approximately 21%. The overall decrease in net GHG emissions was at the rate of 0.30 $MmtCO_2e$ per year.

According to Table ES-1, indirect CO_2 emission from electricity consumption resulted in the emission of 6.55 $MmtCO_2e$. Indirect CO_2 emission is CO_2 emission that is estimated based on the amount of kilowatt-hour consumed by end-users of electricity. Estimates of indirect CO_2 emissions do not include electricity generated from fossil combustion. Indirect CO_2 estimates were included in the 2008 GHG inventory to show how electricity demand in Delaware impacts CO_2 emissions. Indirect CO_2 emissions were estimated from 2000 to 2008 because the available data was limited to those years. Direct CO_2 emissions from electricity generation were separated from indirect CO_2 emissions to avoid the double counting of emissions estimates. According to the 2008 GHG inventory, overall indirect CO_2 emissions increased as electricity demands increased from 2000 to 2008.

GHG EMISSIONS BY GAS

The 2008 GHG inventory estimated emissions for the six Kyoto GHGs. They include carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).

FIGURE ES-5. 2008 DELAWARE'S GHG EMISSIONS BY GAS

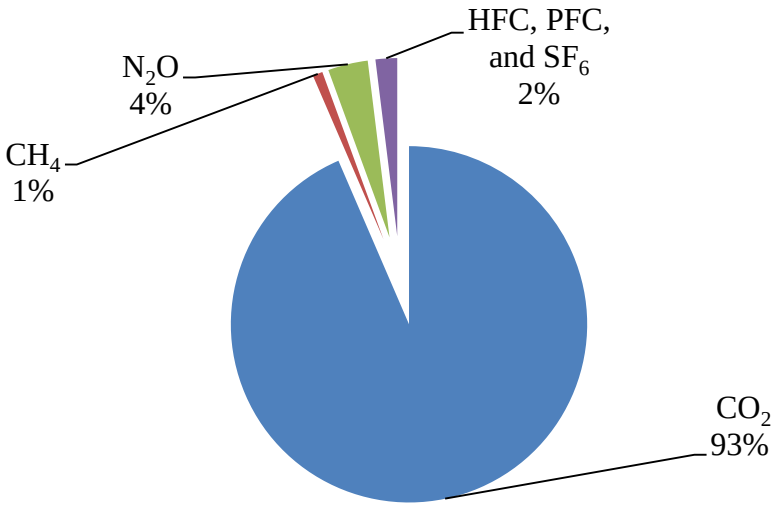


Figure ES-5 provides the percent breakdown for each GHG emitted in 2008. According to Figure ES-5, CO_2 emission represented the largest share of gross GHG emissions in 2008 with approximately 93% of the emissions. N_2O emission was a distant second representing only 4% of gross emissions. The combined emission of SF_6, HFC and PFC represented 2% of gross emissions, while CH_4 emission represented 1% in 2008.

Carbon Dioxide: The emission of CO_2 was driven by fossil fuel combustion in all sectors of Delaware's economy. As Table ES-2 provides CO_2 emissions in Delaware decreased slightly by approximately 8% from 1990 to 2008.

Methane: Based on estimates provided by Table ES-2, CH_4 emissions decreased drastically by approximately 64% from 1990 to 2008. This decrease in CH_4 emissions

was driven by landfill gas recovery activities that mitigate the impact of CH_4 emissions. These activities included flaring and landfill gas conversion to electricity.

Nitrous Oxide: Based on estimates provided by Table ES-2, N_2O emissions decreased gradually by approximately 16% from 1990 to 2008. This decrease in N_2O was driven by improved farming activities as well as Delaware shrinking agricultural base due to land use change.

Hydrofluorocarbons), Perfluorocarbons and Sulfur hexafluoride: The combined emission of HFC, PFC and SF_6 increased drastically by approximately 363% from 1990 to 2008. This increase was driven by the increasing consumption of ODS substitutes. Though there was a significant increase in the emission of ODS substitutes, its impact to Delaware's gross GHG emissions was minimal because it was approximately only 2 % of total GHG emissions.

TABLE ES-2. GHG EMISSION ESTIMATES BY GAS ($MMTCO_2e$)

	1990	**1995**	**2000**	**2005**	**2008**
Gross CO_2	**19.12**	**18.60**	**17.81**	**18.84**	**17.59**
Net[15] CO_2	18.95	18.31	15.12	16.11	14.85
CO_2 from FFC	18.78	18.30	17.62	18.66	17.43
Industrial Processes	0.20	0.20	0.19	0.18	0.16
Waste	0.14	0.09	0	0	0
LULUCF	(0.17)	(0.28)	(2.69)	(2.72)	(2.75)
CH_4	**0.69**	**0.75**	**0.56**	**0.21**	**0.25**
Stationary Combustion	0.02	0.02	0.02	0.02	0.02
Mobile Combustion	0.02	0.02	0.02	0.01	0.01
Oil Refining	0.01	0.01	0.01	0.01	0.01

[15] Net CO_2 is determined by subtracting total CO_2 removed from the atmosphere by LULUCF (sink).

TABLE ES-2. GHG EMISSION ESTIMATES BY GAS (MMTCO_2e)					
	1990	**1995**	**2000**	**2005**	**2008**
Enteric Fermentation	0.05	0.05	0.05	0.04	0.04
Manure Management	0.03	0.03	0.03	0.03	0.03
MSW	0.52	0.56	0.38	0.04	0.02
Wastewater Treatment	0.05	0.05	0.05	0.06	0.06
N_2O	**0.82**	**0.86**	**0.90**	**0.74**	**0.68**
Stationary Combustion	0.04	0.04	0.04	0.04	0.04
Mobile Combustion	0.21	0.26	0.25	0.18	0.11
Manure Management	0.15	0.17	0.16	0.16	0.16
Agricultural Soil Management	0.38	0.35	0.42	0.33	0.32
Burning of Ag Crop Residue	0.00	0.00	0.00	0.00	0.00
N_2O from Settlement Soils	0.01	0.01	0.01	0.01	0.01
MSW	0.01	0.00	0	0	0
Wastewater Treatment	0.02	0.02	0.02	0.02	0.03
HFC, PFC, and SF_6	**0.08**	**0.15**	**0.26**	**0.34**	**0.37**
Industrial Processes	0.08	0.15	0.26	0.34	0.37
Gross Emissions	**20.71**	**20.34**	**19.52**	**20.12**	**18.88**
Sinks	**(0.17)**	**(0.28)**	**(2.69)**	**(2.72)**	**(2.75)**
Net Emissions (Sources and Sinks)	**20.55**	**20.35**	**16.84**	**17.40**	**16.14**
Indirect CO_2 from Electricity Consumption	**0**	**0**	**6.26**	**6.74**	**6.55**

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ACRONYMS AND KEY TERMS

AFV– Alternative Fuel Vehicle

B_o is the maximum CH4 producing capacity

BOD – Biochemical Oxygen Demand

BOF – Basic Oxygen Furnace

BBtu– Billion British thermal unit

C – Carbon

CFCs – Chlorofluorocarbons

CH_4 – Methane

CH_3COOH – Acetic Acid

CH3OH - Methanol

CO_2 – Carbon Dioxide

CO_2e – Carbon Dioxide equivalent

COD - Chemical oxygen demand

DAQ – Division of Air Quality

EAF – Electric Arc Furnace

EF – Emission Factors

EPA – U.S. Environmental Protection Agency

EIA – US DOE Energy Information Administration

EIIP – Emissions Inventory Improvement Program

FFC- Fossil Fuel Combustion

FHWA – Federal Highway Administration

GHGs – Greenhouse Gases

GWP – Global Warming Potential

HCOOH - Formic Acid

HFCs – Hydrofluorocarbons

IPCC – Intergovernmental Panel on Climate Change

1b – pound

ISO – International Organization for Standardization

Kg - Kilogram

LFGTE - Landfill Gas-to-Energy

LPG – Liquefied Petroleum Gas

LULUCF- Land Use, Land-use Change and Forestry

MCF **–** methane conversion factors

MMBtu – Million British thermal units

MMt – Million Metric tons

MTCE – Metric Ton of Carbon Equivalent

$MMTCO_2eq$ – Million Metric tons of Carbon Dioxide equivalent

Mt – Metric ton (equivalent to 1.102 short tons)

MSW – Municipal Solid Waste

N – Nitrogen

NASS – National Agricultural Statistics Service

N_2O – Nitrous Oxide

NO_2 – Nitrogen Dioxide

ODS – Ozone-Depleting Substances

OHF – Open Heat Furnace

PFCs – Perfluorocarbons

SEDS – State Energy Data System

SF_6 – Sulfur Hexafluoride

SIT – EPA's State Inventory Tool

T&D – Transmission & Distribution

USDA – U.S. Department of Agriculture

USDS – U.S. Department of State

UNFCCC or FCCC - United Nations Framework Convention on Climate Change

VBC – Vacuum Circuit Breaker

VMT – Vehicle Miles Traveled

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1.0 INTRODUCTION AND BACKGROUND

Delaware's 2008 greenhouse gas inventory accounted for the annual amount of anthropogenic[16] greenhouse gases (GHG) emitted to or removed from the atmosphere between 1990 and 2008. The Division of Air Quality (DAQ) has prepared this GHG inventory report to characterize Delaware's 2008 GHG emissions, compare 2008 GHG emissions to historical GHG emissions, and thereby inform the policy option development process. This GHG inventory report provides information on the activities that caused emissions and removals, as well as background information on the methods used to estimate the emissions. The 2008 GHG emissions inventory had five key objectives:

- Identify and Characterize GHG emissions sources and sinks
- Quantify GHG emissions and removal from sources and sinks
- Characterize GHG emission trends for the period from 1990 to 2008
- Document the emission inventory data and analytical results, and
- Document the GHG inventory data sources.

GREENHOUSE GASES

This 2008 GHG inventory report presents data and analyses on the six greenhouse gasses listed in the Kyoto protocol. The Kyoto Protocol is a protocol to the United Nations Framework Convention on Climate Change (UNFCCC or FCCC), an international environmental treaty with the goal of achieving the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[17] The six GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O),

[16] The "term anthropogenic" refers to greenhouse gas emissions and removal that are a direct result of human activities, or are a result of natural processes that have been affected by human activities (IPCC/UNEP/OECD/IEA 1997.

[17] Kyoto Protocol." *United Nations Framework Convention on Climate Change"*. Web. 18 April 2011. Web site: http://unfccc.int/resource/docs/convkp/kpeng.pdf

hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The following are descriptions of each of the GHGs:

Carbon Dioxide: Carbon dioxide (CO_2) is an odorless and colorless gas at low concentrations. Anthropogenic sources of CO_2 include fossil fuel combustion, industrial processes and waste management. Carbon dioxide is also removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle.

Methane: Methane (CH_4) is a colorless gas, which is lighter than air. Anthropogenic sources of methane in Delaware include oil refining, decay of organic waste in municipal solid waste landfills, livestock and other agricultural practices and wastewater treatment. Methane is also a primary constituent of natural gas, losses occur during the production, processing, storage, transmission, and distribution of natural gas.

Nitrous Oxide: Nitrous oxide (N_2O) is a colorless non-flammable gas with a slightly sweet smelling odor and taste. It is manufactured for use as oxidizers in rockets and race cars, as an anesthetic or analgesic (pain killer) in the medical field, as an aerosol propellant and as a food preservative. Sources of nitrous oxide in Delaware include bacterial breakdown of nitrogen in soils and water, agricultural soil management, animal manure management, sewage treatment, and mobile and stationary combustion of fossil fuel.

Hydrofluorocarbon: Hydrofluorocarbons (HFCs) were developed as alternatives to ozone-depleting substances (ODS) for industrial, commercial, and consumer products (U.S. EPA). Hydrofluorocarbons (HFCs) are used primarily as alternatives to several classes of ODS that are being phased out under the terms of the Montreal Protocol and the Clean Air Act Amendments of 1990. ODSs, which include chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and hydrochlorofluorocarbons (HCFCs), are used in a variety of industrial applications including refrigeration and air conditioning equipment, aerosols, solvent cleaning, fire extinguishing, foam blowing, and

sterilization. Although their substitutes, HFCs, are not harmful to the stratospheric ozone layer, they are powerful GHGs.

Perfluorocarbons: The two most important perfluorocarbons (PFCs) are CF_4 (tetrafluoromethane) and C_2F_6 (hexafluoroethane). Aluminum production and semiconductor manufacturing are the largest known man-made sources of perfluorocarbons and are not located in Delaware at this time.

Sulfur Hexafluoride: Sulfur Hexafluoride (SF_6) is a colorless, odorless, nontoxic, nonflammable gas with dielectric properties. SF_6 is used for insulation and current interruption in electric power transmission and distribution equipment, in the magnesium industry to protect molten magnesium from oxidation and potentially violent burning, in semiconductor manufacturing to create circuitry patterns on silicon wafers, and as a tracer gas for leak detection. In Delaware, SF_6 emissions are attributed to the electric power transmission and distribution equipment.

SOURCE CATEGORIES

There are two sources of GHG emissions: biogenic and anthropogenic. Biogenic sources of GHGs result from natural processes. Examples of such include the carbon cycle, nitrogen cycle, underground deposits of natural gas (i.e., permafrost[18]) and decomposition of organic materials. Anthropogenic sources, on the other hand, include human activities such as fossil fuel combustion, chemical processes and agricultural activities. This 2008 GHG emission inventory analyzes emissions only from anthropogenic sources.

For this inventory, the anthropogenic emission sources are divided into five categories including

- Energy Related Activities,
- Industrial processes (Non-energy related),

[18] Is a soil at or below the freezing point of water 0 °C (32°F) for two or more years

- Agriculture
- Land-use, and Forestry
- Waste management.

GHG emissions from these source categories are provided in Sections 4.0 through 4.7 of this report. This GHG inventory also identified potential carbon sinks (artificial or natural reservoirs that accumulate and store carbon compounds) based on carbon emission savings in Delaware. The sinks include land-use forests, soils and artificial carbon sequestration.

NOTE: The following Source Category descriptions are excerpts from the USEPA / NACAA Emissions Inventory Improvement Program Guidelines (Vol. I – XIV) for the State Inventory Tool. (U.S. EPA 2005).

Energy Related Activities

Energy-related activities are the most significant contributor to U.S. greenhouse gas emissions, accounting for nearly 94 percent of total emissions in 2008. Emissions from fossil fuel combustion comprise the vast majority of these energy-related emissions.

Fossil Fuel Combustion. Fossil fuel is combusted to heat residential and commercial buildings, to generate electricity, to produce steam for industrial processes, and to power automobiles and other vehicles. As fossil fuels burn, they emit carbon dioxide (CO_2) as a result of oxidation of the carbon in the fuel.

Other gases that are precursors of CO_2, such as carbon monoxide and non-methane volatile organic compounds, are emitted as by-products of incomplete combustion. These gases are then oxidized to CO_2 over periods ranging from a few days to 10 years or more. For purposes of most greenhouse gas inventories, emissions of these other gases are counted as CO_2 emissions. That is, all carbon emitted to the atmosphere (except for

that emitted in the form of methane) is reported as CO_2 emissions, even though a very small portion of the carbon will be emitted as these other gases.[19] By reporting emissions in this fashion, the inventory emission estimates of CO_2 will reflect total loadings of carbon to the atmosphere.

Stationary Combustion Sources[20]. In addition to carbon dioxide, combustion of fuels at stationary sources results in emissions of five greenhouse gases: methane (CH_4), nitrous oxide (N_2O), carbon monoxide, nitrogen oxides, and non-methane volatile organic compounds. For the first two of these greenhouse gases (CH_4 and N_2O), global warming potential values have been developed, which allow for normalization of all emissions to a common unit of metric tons of carbon equivalent. No Global Warming Potential values have yet been developed for the other three types of gases (carbon monoxide, nitrogen oxides, and non-methane volatile organic compounds); thus, they cannot be included in this greenhouse gas inventory. Consequently, this inventory only describes emissions of CH_4 and N_2O from fuel combustion at stationary sources.

Mobile Combustion Sources[21]. Although there is virtually no methane (CH_4) in either gasoline or diesel fuel, CH_4 is emitted as by-products of fuel combustion that is influenced by fuel composition, combustion conditions, and control technologies. Depending on the emission control technologies used, CH_4 emissions may also result from hydrocarbons passing unburned or partially burned through the engine, and then affected by any post-combustion control of hydrocarbon emissions, such as catalytic converters.

Nitrous oxide (N_2O) formation in internal combustion engines is not yet well understood, and data on these emissions are scarce. It is believed that N_2O emissions

[19] Methane emitted from combustion of fossil fuels in stationary and mobile sources is addressed in the section covering non-energy related industrial processes.

[20] Stationary combustion sources are fixed sources that emit of GHGs as a result of fuel combustion.

[21] Mobile combustion sources are sources that emit of GHGs as a result of fuel combustion while moving from one point to another.

come from two distinct processes. In the first process, during combustion in the cylinder, N_2O is formed as nitrogen oxide interacts with combustion intermediates such as NH and NCO. The second N_2O forming process occurs during catalytic after treatment of exhaust gases.

Emissions of CH_4 and N_2O from non-highway mobile sources have received relatively little study. These sources include jet aircraft, gasoline-fueled piston aircraft, agricultural and construction equipment, railway locomotives, boats, and ships. Except for gasoline-fueled aircraft, all of these sources are typically equipped with diesel engines

The GHG emissions associated with energy related activities is found in Section 4.2 of this report.

Non-energy Related Industrial Processes

Emissions are often produced as a by-product of various non-energy related industrial activities. Emissions of carbon dioxide (CO_2) from fossil fuel combustion to produce energy for industrial processes are described under energy related activities in Section 4.2 of this report; other emissions that result from industrial processes are described here and in section 4.3.

In some industrial sectors, raw materials are chemically transformed from one state to another. This transformation often results in the release of greenhouse gases such as CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorinated carbons (PFC), and sulfur hexafluoride (SF_6). The production processes addressed in this section are oil refining, iron and steel production, titanium dioxide manufacturing, soda ash consumption and use, the use of substitutes for ozone-depleting substances, and sulfur hexafluoride use in electrical power systems.

The GHG emissions from non-energy related Industrial Sources are provided in Section 4.3.

Agricultural

Soil Management: Various agricultural soil management practices contribute to greenhouse gas emissions. The use of synthetic and organic fertilizers adds nitrogen to soils, resulting in emissions of nitrous oxide (N_2O). Other agricultural soil management practices, such as irrigation, tillage practices, or the fallowing of land, can also affect fluxes of greenhouse gases to and from the soil.

N_2O is produced naturally in soils through the microbial processes of denitrification and nitrification.[22] A number of anthropogenic activities add nitrogen to soils, thereby increasing the amount of nitrogen available for nitrification and denitrification, and ultimately the amount of N_2O emitted. These activities include application of fertilizers, animal production, cultivation of nitrogen-fixing crops, and incorporation of crop residues. Another agricultural activity that leads to N_2O emissions, through the mineralization of old nitrogen-rich organic matter, is the cultivation of histosols[23] (highly organic soils). In addition, applied nitrogen (i.e., from animal wastes or fertilizer) contributes indirectly to emissions from agricultural soils through volatilization, leaching, and runoff. The sources of N_2O described here are divided into three categories: (1) direct emissions from agricultural soils due to cropping practices; (2) direct emissions from agricultural soils due to animal production; and (3) emissions from soils indirectly induced by agricultural applications of nitrogen.

Emissions from soil management are presented under the Section 4.4.1

[22] Denitrification, the process by which nitrates or nitrites are reduced by bacteria, results in the release of nitrogen into the air. Nitrification is the process by which bacteria and other microorganisms oxidize ammonium salts to nitrites, and further oxidize nitrites to nitrates.

[23] A histosol is a soil consisting primarily of organic materials.

Livestock Manure Management: Manure decomposition is a process in which microorganisms derive energy and material for cellular growth by metabolizing organic material in manure. When decomposition occurs without oxygen (i.e., anaerobic decomposition), methane (CH_4) is produced. In addition to CH_4, nitrous oxide (N_2O) is produced during the manure decomposition process. Estimation of N_2O emissions from animal waste is divided into three methodologies in this report. Emissions from animal waste during storage in a management system are accounted. It is assumed that the manure from these waste management systems is ultimately applied to soils, where further emissions take place. These emissions, as well as the third emission type, manure managed through daily spread, are considered to be emissions from agricultural soils, and are presented under the Section 4.4.2 for agricultural soil management.

Enteric Fermentation: Methane (CH_4) is a natural by-product of animal digestion. During digestion, CH_4 is produced through a process referred to as enteric fermentation, in which microbes that reside in animal digestive systems break down feed consumed by the animal. Ruminants, which include cattle, sheep, and goats, have higher CH_4 emissions than other types of animals because of their unique digestive system. Ruminants possess a rumen, or large "fore-stomach," in which a significant amount of CH_4-producing fermentation occurs. Non-ruminant domestic animals, such as swine and horses, have much lower CH_4 emissions than ruminants because much less CH_4-producing fermentation takes place in their digestive systems. CH_4 emissions are counted only for domesticated animals; emissions from wild animals are not considered, because such emissions are not the result of human activity.

CH_4 produced as part of the normal digestive processes of animals result in emissions that account for a significant portion of CH_4 emissions in the United States, approximately 5.4 million metric tons annually, or 19 percent of total U.S. CH_4 emissions (U.S. EPA 2004). Approximately 200 species and strains of microorganisms

are present in the digestive system of ruminant[24] animals, although only a small portion, about 10 to 20 species, are believed to play an important role in ruminant digestion (Baldwin and Allison 1983). The microbial fermentation that occurs in the rumen enables ruminant animals to digest coarse plant material that non- ruminant animals cannot digest.

CH_4 is produced in the rumen by bacteria as a by-product of the fermentation process. This CH_4 is exhaled or eructated by the animal and accounts for the majority of emissions from ruminants. CH_4 is also produced in the large intestines of ruminants and is excreted. Non-ruminant herbivores have a limited amount of fermentation in the large intestines or ceca. The CH_4 produced in this manner is quite small compared to the amount produced by ruminant animals.

The GHG emissions associated with Enteric Fermentation are provided in Section 4.4.3

Agricultural Residue Burning: In Delaware, agricultural residue burning falls under the category of prescribed fire. Prescribed fire or controlled burn is any fire intentionally ignited to meet specific land management objectives such as land clearing for agricultural purposes. Agricultural residue burning is not considered a net source of CO_2, because the carbon released into the atmosphere during burning is reabsorbed during the next growing season. However, agricultural residue is net source of CH_4 and N_2O, which are released during combustion and are not reabsorbed during the growing season. Crops that are grown in Delaware and may undergo agricultural residue burning include corn, barley and soy beans.

The GHG emissions associated with Solid Waste Disposal are provided in Section 4.4.4

[24] A ruminant is a mammal that digests plant-based food by initially softening it within the animal's first compartment of the stomach, principally through bacterial actions, then regurgitating the semi-digested mass, now known as cud, and chewing it again.

Waste Management

Solid Waste Disposal. In landfills, methane (CH_4) and carbon dioxide (CO_2) are produced from anaerobic decomposition of organic matter by methanogenic bacteria. Organic waste first decomposes aerobically (in the presence of oxygen) and is then decomposed by anaerobic non-methanogenic bacteria, which convert organic material to simpler forms like cellulose, amino acids, sugars, and fats. These simple substances are further broken down to gases and short-chain organic compounds (H_2, CO_2, CH_3COOH, HCOOH, and CH_3OH), which support the growth of methanogenic bacteria. The bacteria further metabolize these fermentation products into stabilized organic materials and "biogas," which consists of approximately 50 percent CO_2 and 50 percent CH_4 by volume.

Neither the CO_2 emitted directly as biogas nor the CO_2 emitted from combusting CH_4 at flares is counted as an anthropogenic greenhouse gas emission. The source of the CO_2 is primarily the decomposition of organic materials derived from biomass sources (e.g., crops, forests), and in the United States these sources are grown and harvested on a sustainable basis. Sustainable harvesting implies that photosynthesis (which removes CO_2 from the atmosphere) is equal to decomposition (which adds CO_2 to the atmosphere).

Much of the carbon in landfills that is not converted to CO_2 or CH_4 is stored indefinitely and removed from the pool of carbon available to cycle to the atmosphere, i.e., it is sequestered. In accordance with the Intergovernmental panel on Climate Change (IPCC) guidelines on greenhouse gas accounting (IPCC/UNEP/OECD/IEA 1997), only biogenic carbon (i.e., carbon from plant or animal matter) is counted as sequestered. Plastics that are landfilled represent a transfer of carbon from one long-term carbon pool (oil or natural gas reserves) to another (landfills), and thus are not counted as incremental carbon sequestered.

The GHG emissions associated with Solid Waste Disposal are provided in Section 4.5.1.

Wastewater Treatment. Disposal and treatment of industrial and municipal wastewater often result in methane emissions. Wastewater may be treated using aerobic and/or anaerobic technologies, or if untreated, may degrade under either aerobic or anaerobic conditions. Methane is produced when organic material in treated and untreated wastewater degrades anaerobically, i.e., in the absence of oxygen.

Municipal wastewater is treated primarily through either septic tank systems or sewage treatment plants. Septic tanks, common in low population density areas, collect wastewater onsite in an underground tank; since the tank's contents are not exposed to the air, the waste is decomposed anaerobically. In more populated areas, domestic wastewater is treated at a large central facility. Such treatment plants service approximately 75 percent of American households (U.S. EPA 2001). At these facilities, the wastewater undergoes a multi-step treatment process in which waste may be decomposed both aerobically and anaerobically.

In highly organic wastewater streams, e.g., streams from food processing plants or pulp and paper plants, the available oxygen in the water is rapidly depleted as the organic matter decomposes. The organic content (sometimes known as "loading") of these wastewater streams is expressed in terms of biochemical oxygen demand, or BOD. BOD represents the amount of oxygen taken up by the organic matter in the wastewater during decomposition. Alternatively, the chemical oxygen demand (COD) is often used to characterize industrial wastewater. COD refers to the amount of oxygen consumed during the oxidation of both organic matter and oxidizable *in*organic matter. Under the same conditions, wastewater with a higher BOD or COD will produce more methane than wastewater with a lower BOD/COD.

Nitrous oxide is emitted from both domestic and industrial wastewater containing nitrogen-rich organic matter. Nitrous oxide is produced through the natural processes of nitrification and denitrification. Nitrification occurs aerobically and converts ammonia into nitrate, whereas denitrification occurs anaerobically, and converts nitrate to nitrous oxide. Human sewage is believed to constitute a significant portion of the material responsible for nitrous oxide emissions from wastewater (Spector 1997).

The GHG emissions associated with Wastewater Treatment are provided in Section 4.5.2.

Land Use, Land Use Change and Forestry

When humans use and alter the biosphere through land-use change and forest management activities, the balance between the emission and uptake of greenhouse gases (GHGs) changes, affecting their atmospheric concentration; this balance between emission and uptake is known as net GHG flux. Such activities can include clearing an area of forest to create cropland, restocking a logged forest, draining a wetland, or allowing a pasture to revert to grassland. 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, 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 soils.

The GHG emissions associated with Land Use, Land Use Change and Forestry are provided in Section 4.6.

2.0 GLOBAL WARMING POTENTIAL

The global warming potential (GWP) of a gas is a number that compares its potential to trap heat in the atmosphere relative to another gas. In technical terms, the GWP of a gas is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kilogram (kg) of a trace substance relative to that of 1 kg of a reference gas[25]. The reference gas used for this report is CO_2 because it has the least potential to trap heat in the atmosphere; and therefore, GWP weighted emissions are measured in CO_2 equivalents (CO_2e).

The GWP is calculated over a period of time. A longer period of time yields a lower GWP. For instance, the GWP for CH_4 is 72 over a 20-year period, but 25 over a 100-year period. This 2008 GHG emissions inventory uses the GWPs listed in Table 1 below for estimating the relative contribution of each GHG to global warming. These GWP values were calculated based on a 100-year period.

TABLE 1. GWP OF GHGS CALCULATED OVER A 100-YR PERIOD

GHG	GWP
CO_2	1
CH_4	21
N_2O	310
PFCs	5,400
HFCs	11,700
SF_6	23,900

IPCC (1996)

[25] IPCC 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the IPCC.

3.0 GENERAL METHODOLOGY

The methodologies used in the development of this 2008 GHG emissions inventory are based on the emissions accounting methodologies presented by the US EPA Emissions Inventory Improvement Program (EIIP), and its national GHG emissions inventory guidelines[26] for States (*based, in turn, on the 2006 emissions inventory guidelines from the Intergovernmental Panel on Climate Change (IPCC), the international organization responsible for developing coordinated methods for national GHG inventories*). For the most part, the activity data utilized in the development of this 2008 GHG inventory was collected via the EPA's State Inventory Tool (SIT) Model.

3.1 STATE INVENTORY TOOL

The 2008 State Inventory Tool (SIT) Model is a collection of Excel® spreadsheets designed by the EPA to assist states in developing GHG emissions inventories. The SIT model provides a streamlined approach for states to use in order to update an existing inventory or complete a new inventory. The SIT model provides the ability to apply state-specific data or use default data. The default data gathered by federal agencies and other sources covering fossil fuels, agriculture, forestry, waste management, and industry and provided in the model.

While the SIT provides overall emissions estimates for states, it does not provide emission estimates for individual facilities or sources. This is because the SIT model follows a top-down approach to calculating greenhouse gas emissions at the state level. For example, tons of coal burned times an emissions factor. It gives an aggregated total for each sector at the state level, but does not include emissions for specific power plants, industrial facilities, or other point sources. The methods used and the sources covered are the same as those in the U.S. GHG Inventory, and as described in the Emissions Inventory Improvement Tool of The EPA, Volume

[26] US EPA 2007, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990 to 2005*

III on emission estimation methods[27].Table 2 provides a summary of modules and economic sectors included in the SIT.

TABLE 2. MODULES AND SECTORS INCLUDED IN THE STATE INVENTORY TOOL

Modules	Sub-Sectors	
Carbon Dioxide from Fossil Fuel Combustion (CO_2)	• Residential • Commercial • Transportation	• Electric Power • Bunker Fuels • Industrial
Stationary Combustion (CH_4 & N_2O)	• Residential • Commercial	• Electric Power • Industrial
Mobile Combustion (CH_4 & N_2O)	• Highway Vehicles • Aviation • Boats & Vessels	• Locomotives • Other Non-Highway Sources • Alternative Fuel Vehicles
Industrial Processes (CO_2,CH_4, & N_2O)	• Cement Production • Lime Manufacture • Limestone and Dolomite Use • Soda Ash Manufacture and Consumption • Iron and Steel Production • Ammonia Manufacture* • Nitric Acid Production • Adipic Acid Production	• Aluminum Production • HCFC-22 Production • Consumption of Substitutes for Ozone-Depleting Substances • Semiconductor Manufacture • Electric Power Transmission and Distribution • Magnesium Production and Processing
Coal (CH_4)	• Coal Mining	• Abandoned Underground Coal Mines

[27] US EPA 2006, Emissions Inventory Improvement Program Volume VIII

TABLE 2. MODULES AND SECTORS INCLUDED IN THE STATE INVENTORY TOOL		
Modules	**Sub-Sectors**	
Natural Gas and Oil (CO_2 & CH_4)	• Natural Gas - Production • Natural Gas - Transmission • Natural Gas - Distribution	• Natural Gas - Venting & Flaring • Petroleum Systems
Agriculture (CH_4 & N_2O)	• Enteric Fermentation • Manure Management • Agricultural Soil Management	• Rice Cultivation • Agricultural Residue Burning
Land-Use Change and Forestry (CO_2,CH_4, & N_2O)	• Forest Carbon Flux • Liming of Agricultural Soils • Urban Trees • N_2O from Settlement Soils	• Non-CO_2 Emissions from Forest Fires • Landfilled Yard Trimmings and Food Scraps
Solid Waste (CO_2 & CH_4)	• Landfills	• Waste Combustion
Wastewater (CH_4 & N_2O)	• Municipal Wastewater	• Industrial Wastewater - Fruits & Vegetables, Red Meat, Poultry, Pulp & Paper
Synthesis Tool	• Gathers emissions from all modules into one summary table	
Projection Tool	• Projects emissions estimates into the future	

3.2 DATA COLLECTION APPROACH

The data collection approach used in this 2008 GHG emissions inventory was based on the IPCC guidelines[28] and combines both top-down and bottom-up approaches (hybrid approach)[29].

[28] IPCC, 2006 Guidelines for National Greenhouse Gas Inventories, Vol. 2, Section 2.2

[29] EPA, Developing a Greenhouse Gas Inventory Web, 18 April 2011 http://www.epa.gov/statelocalclimate/local/activities/ghg-inventory.html

The top-down approach involved the collection of economic data from Federal databases to estimate GHG emissions. For instance, the amount of GHG emissions from fossil fuel combustion in each economic sector of Delaware was estimated by collecting activity data on various fuel types from the Energy Information Administration (EIA). Table 3 provides a summary of data sources used in the collection of activity data. The bottom-up approach involves the collection of end-use data directly from various sources. The hybrid approach is the preferred approach because it allows for flexibility in inventory development. The hybrid approach also improves the accuracy of the inventory results by characterizing individual sources as well as aggregate sources. The hybrid approach in this 2008 GHG inventory was especially necessary due to missing or unreliable data in the SIT. For instance, DAQ collected activity data from some industrial facilities including Delaware City Refinery (barrels of refined oil), Evraz Claymont Steel (metric tons of steel production) and DuPont Edge Moor titanium dioxide facility. An additional source of activity data was Delaware Solid Waste Authority (DSWA), which submitted landfill data from three of its municipal landfills including Cherry Island Landfill, Central Solid Waste Management Center and Southern Solid Waste Management Center.

TABLE 3. SUMMARY OF INVENTORY DATA SOURCES

Sources	Information provided	Use of Information in this Analysis
US EPA State Inventory Tool (SIT) – http://www.epa.gov/statelocalclimate/resources/tool.html	US EPA SIT is a collection of linked spreadsheets designed to help users develop State GHG inventories for historical emissions as well as projections. The SIT contains default data for each State for most of the information	Where not indicated otherwise, SIT default data is used to calculate emissions from Delaware sources.

TABLE 3. SUMMARY OF INVENTORY DATA SOURCES		
Sources	**Information provided**	**Use of Information in this Analysis**
	required for an inventory.	
US Energy Information Administration (EIA) State Energy Data System(SEDS) - http://www.eia.gov/state/seds/	EIA SEDS provides energy use data in each State, annually for all fuels to 2008.	EIA SEDS is the source for energy use data. Emission factors from the SIT are used to calculate energy-related emissions.
EIA State Electricity Profiles - http://www.eia.gov/electricity/	EIA provides information on the electric power industry generation by primary energy source for 1990 – 2008.	EIA State Electricity Profiles were used to determine the mix of in-state electricity generation by fuel.
USDS National Agricultural Statistics Service (NASS) – http://www.nass.usda.gov/	USDA NASS provides data on crops and livestock.	Crop production data used to estimate agricultural residue and agricultural soils emissions; livestock population data used to estimate manure and enteric fermentation emissions.

3.3 GENERAL PRINCIPLES AND GUIDELINES

This 2008 GHG emissions inventory was performed according to the following generally accepted GHG emissions accounting principles[30] for evaluating historical and projected GHG emissions:

- ***Transparency***: the inventory report included data sources, methods, and key uncertainties to allow for open review and opportunities for additional revisions based on input from others.
- ***Consistency****:* The 2008 GHG emissions inventory was designed to be externally consistent with current emission reporting of GHG emissions for other States, and also to meet national and international standards. The 2008 GHG emissions inventory utilized the State Inventory Tool (SIT) from the EPA for estimating historical emissions as a starting point. These initial estimates will be refined and updated periodically to conform with State-based inventory and base-case projection needs.
- ***Priority of Significant Emissions Sources***: More effort was spent on analyzing and reporting larger emissions from each of the source categories than those with relatively small emission levels in order to characterize more fully the major sources of emissions in Delaware.
- ***Use of Consumption-Based Emissions Estimates***: The inventory will also account for emissions associated with electricity consumed in Delaware but not produced in Delaware. The emissions in this category will be reported separately to avoid double counting.

[30] 2006 IPCC Guidelines for National Greenhouse Inventories

4.0 EMISSIONS INVENTORY OVERVIEW

4.1 EMISSION INVENTORY BY SOURCE CATEGORY

In 2008, Delaware's gross (total CO_2e emissions excluding sinks) GHG amount emitted was 18.88 million metric tons of CO_2 equivalent ($MmtCO_2e$). Delaware's gross GHG emission represents approximately 0.3% of U.S. gross GHG emissions in 2008, which was 7,048 $MmtCO_2e$. However, the amount of CO_2 removed from the atmospheres due to sinks totaled 2.74 $MmtCO_2e$. The removal of CO_2 was attributed to the land use change/forestry[31]. When the amount of CO_2e associated with sinks is subtracted from the total CO_2e emissions from Delaware, the result is a net CO_2e emission of 16.14 $MmtCO_2e$.

The source categories that were covered in this 2008 GHG inventory included energy related activities, agriculture, non-energy related industrial processes and waste management. Figure 1 provides the breakdown[32] of the 2008 GHG emissions by Delaware source category in percent CO_2e.

Emissions from energy related activities in Delaware had the largest CO_2e contribution to gross GHG emissions with 93%. This was followed by agricultural source categories with 3%, non-energy related industrial process sources with 3% and waste management sources with less than 1% (approximately 0.58%).

[31] The land-use, land-use change and forestry source category was a sink for the removal CO_2 and thereby resulted in negative CO_2e inventory results.

32 Figure 1 percentages are based on Delaware's gross emissions of 18.88 and not the net emissions of 16.14.

FIGURE 1. 2008 PERCENT CO_2e EMISSIONS BY SOURCE CATEGORY

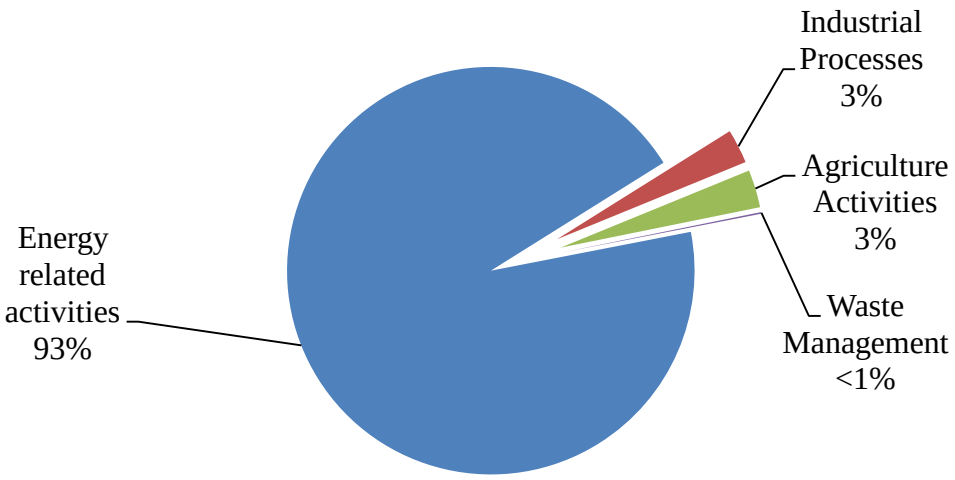
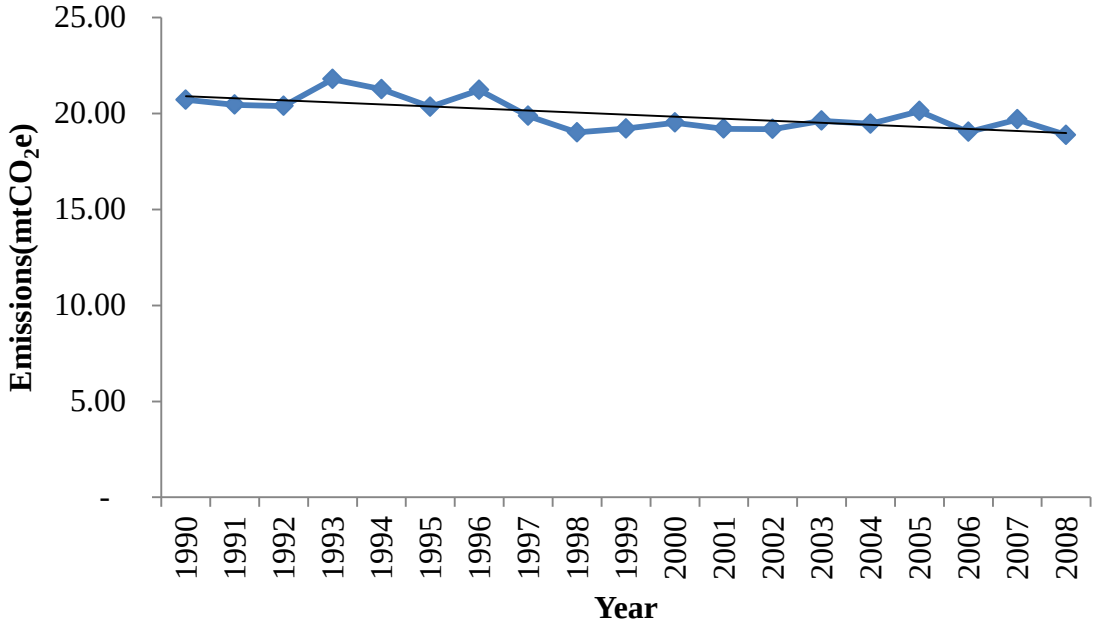


FIGURE 2. DELAWARE'S GROSS GHG EMISSIONS FROM 1990 TO 2008



The emission results provided by Figure 2 show that the general trend for gross GHG emissions in Delaware was downward with fluctuations. As figure 2 shows, GHG emission levels where generally higher in the 1990s. Emissions levels spiked to 21.78 $MmtCO_2e$ in 1993, after which emission declined to 18.88 $MmtCO_2e$ in 2008. An analysis of the emissions results revealed a 13% reduction in gross GHG emissions from1990 to 2008. Significant fluctuations were observed in Delaware's gross GHG emissions from 1990 to 2008 as presented in Figure 2. The fluctuations in GHG emissions levels were a function of Delaware's fluctuating energy profile as presented in Figure 8.

Overall, energy related activities had the most impact on gross GHG emissions from Delaware when compared to other source categories that make up Delaware's gross GHG emissions as Figure 3 presents. This is because emissions from energy related activities are primarily due to fossil fuel combustion, which is the single most important driver of GHG emissions. Energy related activities released an average CO_2 amount of 18.42 $MmtCO_2e$ into the atmosphere per year between 1990 and 2008.

Fossil fuel combustion encompasses all sectors of Delaware's economy. The agricultural activities were a distant second with respect to overall GHG emissions between 1990 and 2008. Agriculture represent had an average emission of 0.62 $MmtCO_2e$ per year. This was followed by non-energy related industrial processes with an average emission of 0.43 $MmtCO_2e$ per year. Waste management had the least impact with an average emission of 0.31 $MmtCO_2e$ per year. On the other hand, land use, land-use change and forestry (LULUCF) had the opposite impact on gross GHG emissions because it was a major sink for CO_2, absorbing an average amount of 1.50 $MmtCO_2e$ per year from 1990 to 2008.

Section 4.2 to 4.6 of this report provides information on each of the Source categories that make up Delaware's gross GHG emissions and their impact on gross GHG emissions from the State.

FIGURE 3. DELAWARE'S GHG EMISSIONS BY SOURCE CATEGORY

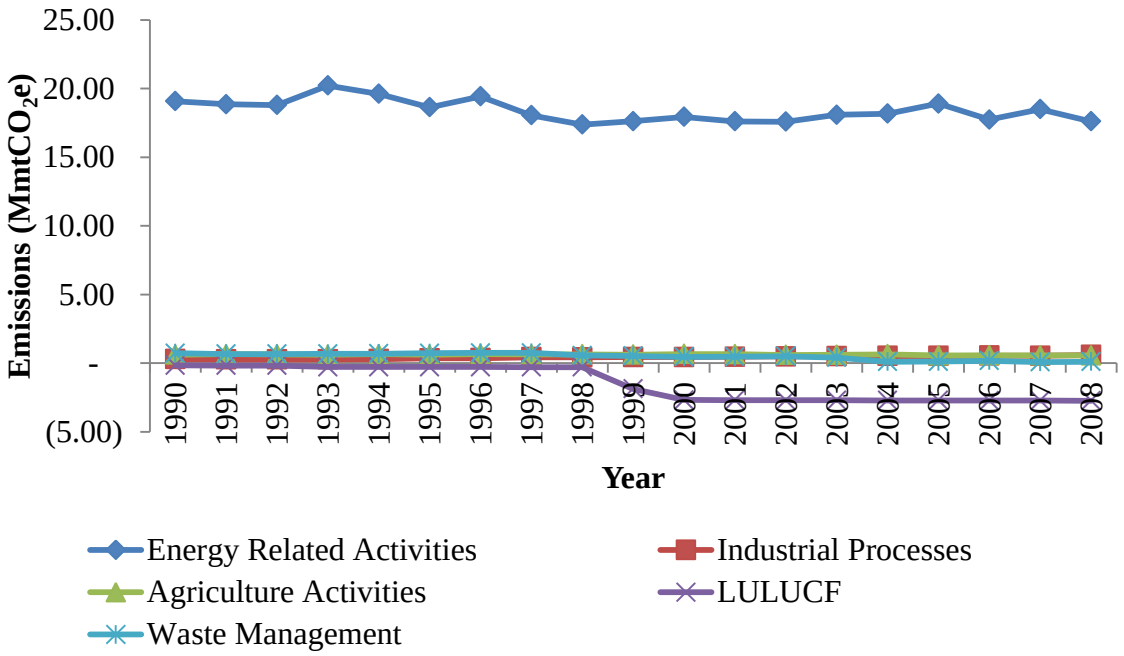


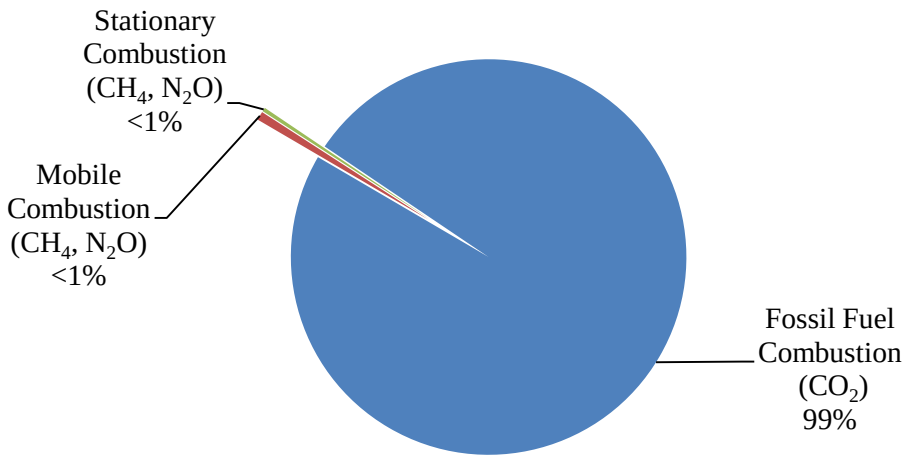
TABLE 4. GHG EMISSIONS ESTIMATES BY SOURCE CATEGORIES ($MmtCO_2e$)					
Source Categories	**1990**	**1995**	**2000**	**2005**	**2008**
Energy	19.08	18.64	17.94	18.90	17.61
Industrial processes	0.29	0.36	0.45	0.53	0.60
Agricultural	0.62	0.61	0.67	0.57	0.56
Waste management	0.73	0.73	0.46	0.12	0.11
Gross Emissions	**20.71**	**20.34**	**19.52**	**20.12**	**18.88**

See appendix A for details

4.2 ENERGY RELATED ACTIVITIES

Energy related activities produced GHG emissions in all the economic sectors of Delaware including electricity generation (power plants), transportation, residential, industrial, commercial and the agricultural sector. Energy-related sources were the primary sources of Delaware anthropogenic greenhouse gas emissions in 2008, accounting for approximately 95% of total GHG emissions from Delaware according to Figure 1. In 2008, the total GHG emission that came from energy related activities was 17.62 $MmtCO_2e$.

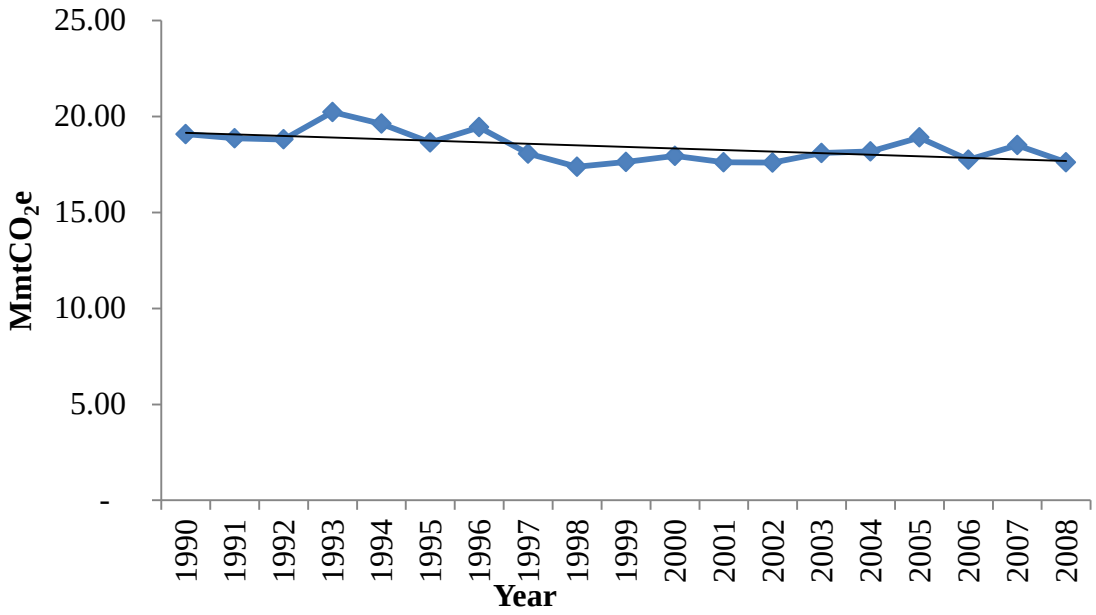
FIGURE 4. 2008 PERCENT CO_2e OF GHG EMISSIONS BY ENERGY SOURCES



As Figure 4 presents, CO_2 emissions from fossil fuel combustion represented 99% of total emissions from energy related activities in 2008. Methane and N_2O emissions from both stationary and mobile fossil fuels combustion where each less than 1% of total GHG emissions from energy related activities.

Figure 5 shows a chart of annual GHG emissions form energy related activities between 1990 and 2008. As the chart shows, slight fluctuation of annual emissions was observed. Emissions reached their highest level in 1993 at 20.23 $MmtCO_2e$ and bottomed in 1998 at 17.38 $MmtCO_2e$. In general, GHG emissions from this source category decreased at the rate of 7.7% since 1990.

FIGURE 5. TOTAL GHG EMISSIONS FROM ENERGY RELATED ACTIVITIES



Greenhouse gas emissions from energy-related activities occur as a result of fuel combustion. The greenhouse gases of concern to this 2008 GHG inventory, relative to energy-related activities, include CO_2, CH_4 and N_2O. Of the three, CO_2 is the most commonly emitted.

Table 5 below shows estimates of annual GHG emissions. As the table shows, GHG emissions from fossil fuel combustion were consistently higher than GHG emissions from other energy related activities.

TABLE 5. GHG EMISSIONS ESTIMATES BY ENERGY SUBCATEGORIES ($MMTCO_2e$)

Sources	1990	1995	2000	2005	2008
FFC[33]	18.78	18.30	17.62	18.66	17.43
Mobile Combustion	0.24	0.28	0.27	0.19	0.12
Stationary combustion	0.063	0.063	0.057	0.058	0.055
Total Emissions	**19.08**	**18.64**	**17.94**	**18.90**	**17.61**

[33] Fossil Fuel Combustion

***4.2.1 CO_2 emissions from Fossil Fuel Combustion*:** Fossil fuels are combusted for the purpose of producing energy for heating, power and transportation. During the combustion process, the carbon contained in the fossil fuel is oxidized and emitted as CO_2 as well as CH_4 and N_2O in lesser amounts. This section only considers CO_2 emissions from fossil fuel combustion. Section 4.2.2 and 4.2.3 will discuss the emission of CH_4 and N_2O from fossil fuel combustion. The amount of GHG emissions released from Fossil fuel combustion (FFC) depends on the type of fossil fuel, amount of fuel consumed, carbon content of the fuel, type of combustion activity and rate of oxidation. There is uncertainty associated with each of these factors.

Carbon dioxide emissions generated from the combustion of fossil fuels were counted in all energy related activities of the economy including electric power generation, commercial, residential, transportation, and industrial sectors of the economy. FFC was the largest source of GHG emissions in 2008 with approximately 99% of GHG emissions from the energy related activities.

There are three primary fuel types consumed in Delaware, which are petroleum, natural gas and coal. Of the three fuel types, petroleum is the most widely consumed. Table 6 provides a list of fuels consumed by fossil fuel combustion in Delaware. Data[34] on these fuels were imported into the state inventory tool in order to estimate GHGs emissions due to combustion.

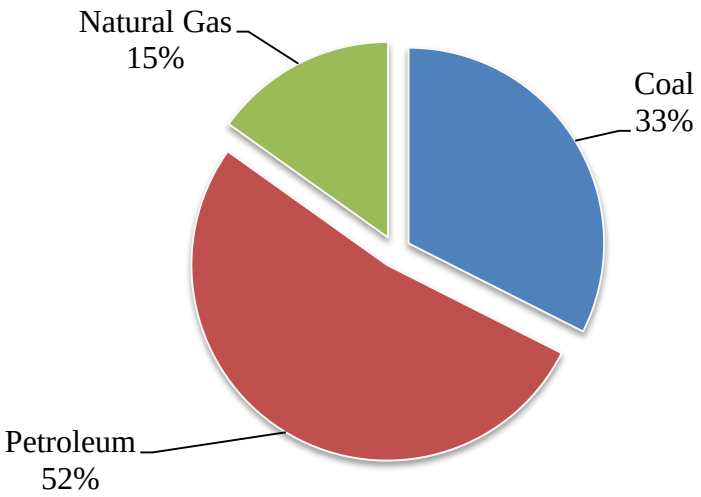
Figure 6 provides the percent contribution of each fuel type to overall GHG emissions from FFC. Petroleum had the largest share of CO_2e emissions at 52%[35], while coal and natural gas accounted for 33% and 15% respectively.

[34] Default data was collected from the Energy Information Administration website: http://www.eia.doe.gov/emeu/states/_seds.htm

[35] Transportation related activities accounts for a large portion of the petroleum fuel based emissions.

Table 6[36]. Fossil Fuels Consumed by the Delaware's Economic Sector				
Residential	**Commercial**	**Industrial**	**Transportation**	**Electric Power Generation**
				Coal
Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Petroleum: Distillate Fuel Kerosene LPG	Petroleum: Distillate Fuel Kerosene Motor Gasoline LPG Residual Fuel	Petroleum: Asphalt & Road Oil Crude Oil Feed Stocks Petroleum Products Petroleum Coke Pentanes Plus Still Gas Special Naphthas Unfinished Oils Waxes Gasoline Blending Components Motor Gasoline Blending	Petroleum: Jet Fuel,Kerosene Jet Fuel,Naphtha Aviation gasoline Distillate Fuel Residual Fuel LPG Motor Gasoline Diesel	Petroleum: Distillate Fuel Petroleum Coke Residual Fuel

FIGURE 6. 2008 CO_2 EMISSIONS FROM FFC BY FUEL TYPES



[36] Data source: The list of Delaware fuels is taken from U.S. EPA's State inventory tool.

Methodology

The general formula used to estimate the emissions from the fossil fuel combustion subcategory is as follows:

EQUATION 1. GENERAL EMISSION EQUATION FOR FFC

$$Emissions = \Sigma (Activity\ data \times Emission\ factor)$$

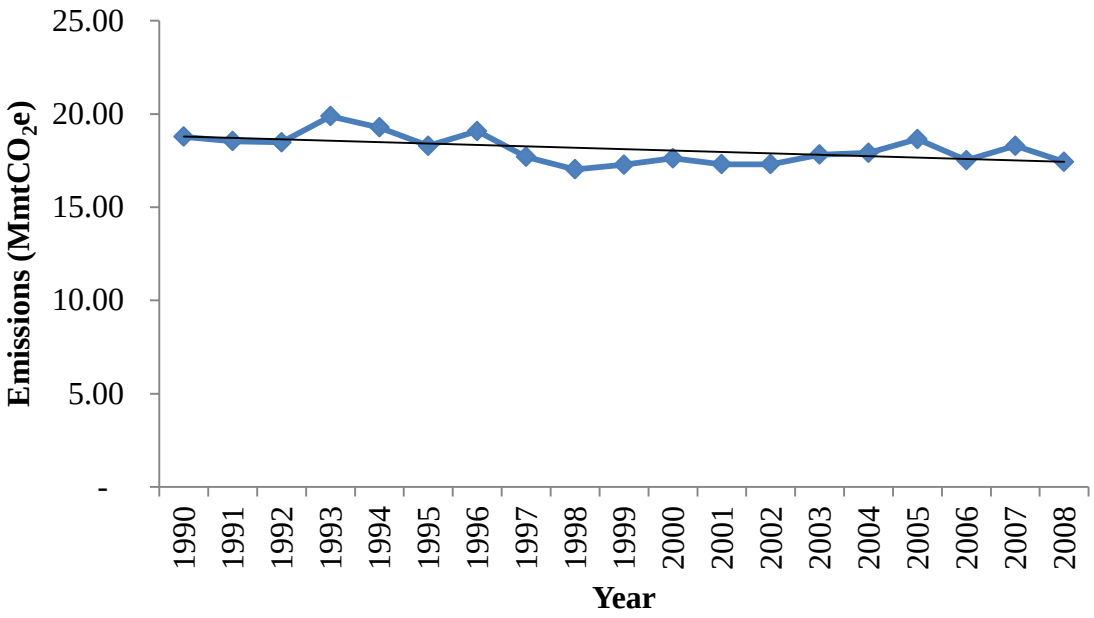
Activity data required in this case was the quantity of fossil fuel consumed in Delaware. DAQ used default activity data on all the fuels consumed in Delaware[37] between 1990 and 2008 as listed in Table 6.

Analysis of FFC Emissions

This 2008 GHG inventory shows that emissions have been fluctuating downward since 1990, with a decrease of approximately 7.2% between 1990 and 2008. Figure 7 provides historical CO_2 emissions in $MmtCO_2e$ from FFC sources. Emissions peaked in 1993 with 19.88 $MmtCO_2e$ and reached its lowest point in 1998 with 17.03 $MmtCO_2e$. . Analysis of the FFC data results revealed that from 1990 to 2008, the annual rate of decrease of CO_2 emission was 0.08 $MmtCO_2e$ per year.

[37] Data source: Default state-level data derived from EIA's *State Energy Consumption, Price, and Expenditure Estimates (SEDS) 2008: Consumption Estimates* (EIA 2010). http://www.eia.doe.gov/emeu/states/_seds.htm Default state synthetic natural gas data obtained from Table 12 of EIA's *Historical Natural Gas Annual* (EIA 2009), and Table 8 for Natural Gas Annual publications from: http://www.eia.doe.gov/oil_gas/natural_gas/data_publications/natural_gas_annual/nga.html

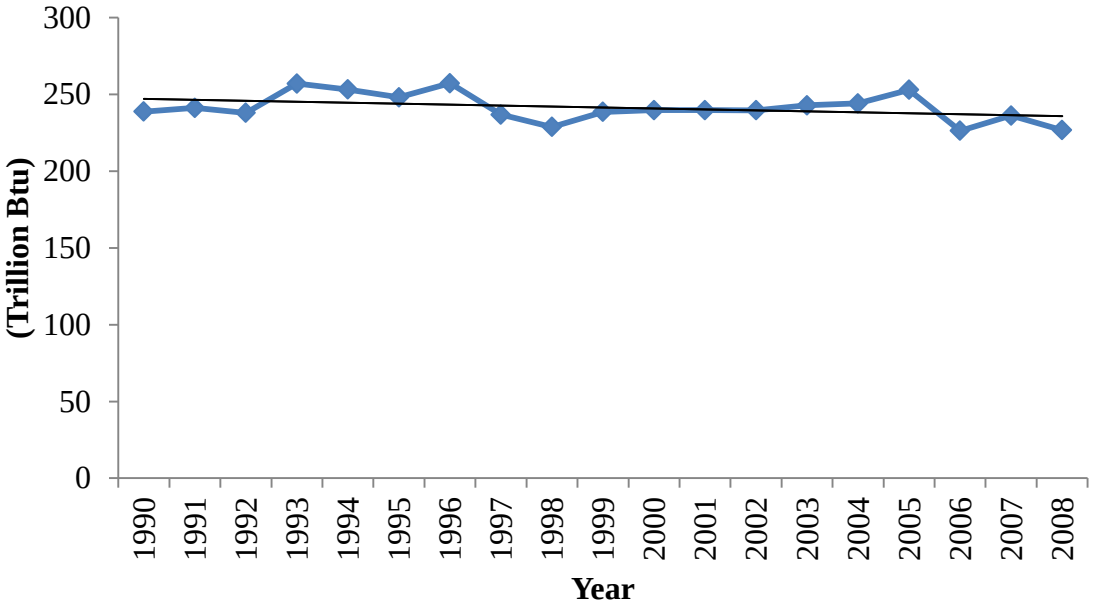
FIGURE 7. DELAWARE'S CO_2 EMISSIONS FROM FOSSIL FUEL COMBUSTION



Fossil fuel consumption in Delaware is directly proportional to CO_2 emissions. Figure 8 shows that fossil fuel consumption in Delaware trended downward between 1990 and 2008. Similar fluctuations observed in Delaware's energy consumption data were also observed in Delaware's GHG emission levels as presented Figure 7. This shows that the changing energy consumption pattern in Delaware was a major factor in GHG emissions. As energy consumption decreased, GHG emissions also decreased.

According to the Energy Information Administration (EIA), Delaware's annual energy consumption decreased by 5.1% from 1990 to 2008. The annual rate of decrease was determined to be 0.6 MmtCO2e per year.

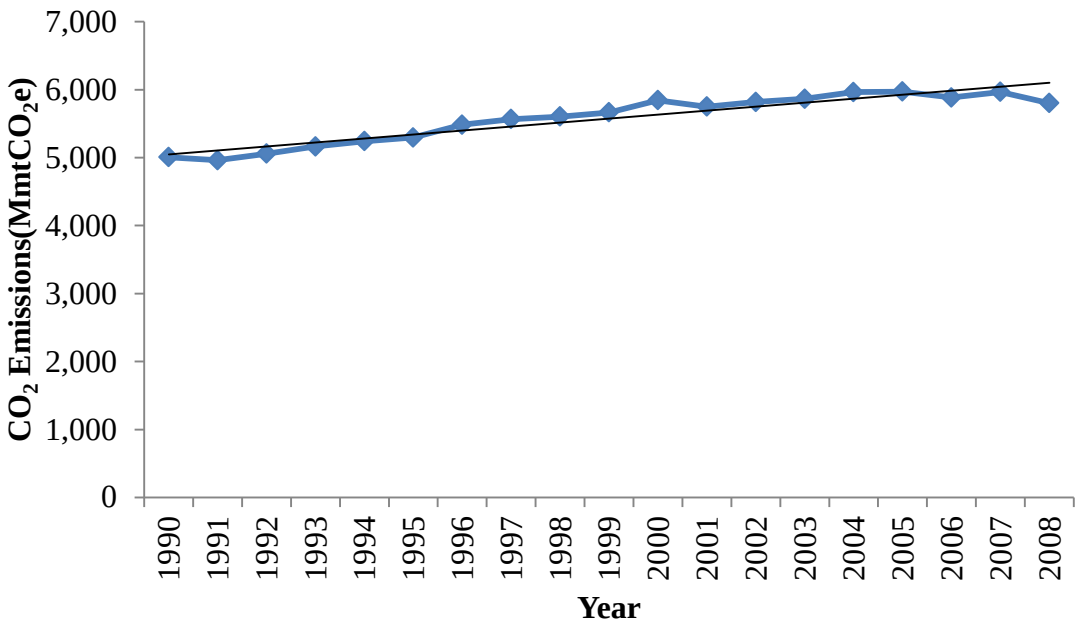
FIGURE 8. DELAWARE'S FOSSIL FUEL CONSUMPTION PROFILE[38]



A number of factors may have contributed to the fluctuations observed in Delaware's energy consumption profile presented in Figure 8.These include fluctuating energy prices, fluctuating seasonal temperatures, fuel switching and changes in economic outlook, which may affect energy demand. In general, CO_2 emissions from FFC trended downward from 1990 to 2008.

[38] Source: EIA – SEDS: tp://www.eia.gov/state/seds/hf.jsp?incfile=sep_use/total/use_tot_DEcb.html&mstate

FIGURE 9. U.S. CO_2 EMISSIONS FROM FOSSIL FUEL COMBUSTION



Data Source: 2009 Energy Information Administration Estimates

Figure 9 is a chart of United States (U.S.) historical CO_2 emissions[39] from fossil fuel combustion between 1990 and 2008. The chart shows that CO_2 emissions from the FFC in the U.S. trended upward between 1990 and 2008. Emissions increased between 1990 and 2008 by approximately 16%. The annual rate of increase was determined to be approximately 58.5 $mtCO_2e$ per year.

The increasing U.S. CO_2 emissions between 1990 and 2008 that was observed in Figure 9, contradicts the downward trend of Delaware's CO_2 emissions that was observed in Figure 7. This shows that while Delaware's CO_2 emissions from FFC trended downward between 1990 and 2008, CO_2 emissions in the U. S. trended upward during the same period. Factors that impact CO_2 emission from FFC differ from state to state, so Delaware's CO_2 emission from FFC is not expected to have the same trend as U.S. CO_2 emissions from FFC.

[39] EIA data: http://www.eia.gov/oiaf/1605/flash/flash.html

FFC Emissions by Fuel type: Figure 10 shows the historical emissions by fuel type between 1990 and 2008. Emissions from petroleum, sources were consistently larger than emissions from coal and natural gas. Fluctuations in the annual emissions of the three fuel types were observed as demonstrated by Figure 10.

TABLE 7. CO_2e EMISSIONS FROM FFC BY FUEL TYPE IN $MMTCO_2e$					
Fuel types	**1990**	**1995**	**2000**	**2005**	**2008**
Petroleum	11.07	10.04	10.30	10.81	9.14
Coal	5.58	4.93	4.66	5.27	5.66
Natural Gas	2.13	3.33	2.66	2.58	2.64
Total	**18.78**	**18.30**	**17.62**	**18.66**	**17.43**

Overall carbon dioxide emissions from petroleum decreased from 1990 at 11.07 $MmtCO_2e$ to 2008 at 9.14 $MmtCO_2e$, by 17%. The annual rate of decrease was determined to be 0.09 $MmtCO_2e$ per year. Carbon dioxide emissions from coal decreased slightly as well, at the rate of 0.002 $MmtCO_2e$ per year. Conversely, Figure 10 shows that natural gas emissions increased slightly between 1990 and 2008 at a rate of 0.014 $MmtCO_2e$ per year. Petroleum CO_2 emissions exceed CO_2 emissions from coal and natural gas because, petroleum was consumed in larger quantities than the other two fuel types and was consumed in all economic sectors of Delaware from 1990 to 2008[40] as shown in Figure 11.

[40]See Table 8.

FIGURE 10. DELAWARE CO_2 EMISSIONS FROM FFC TREND BY FUEL TYPES

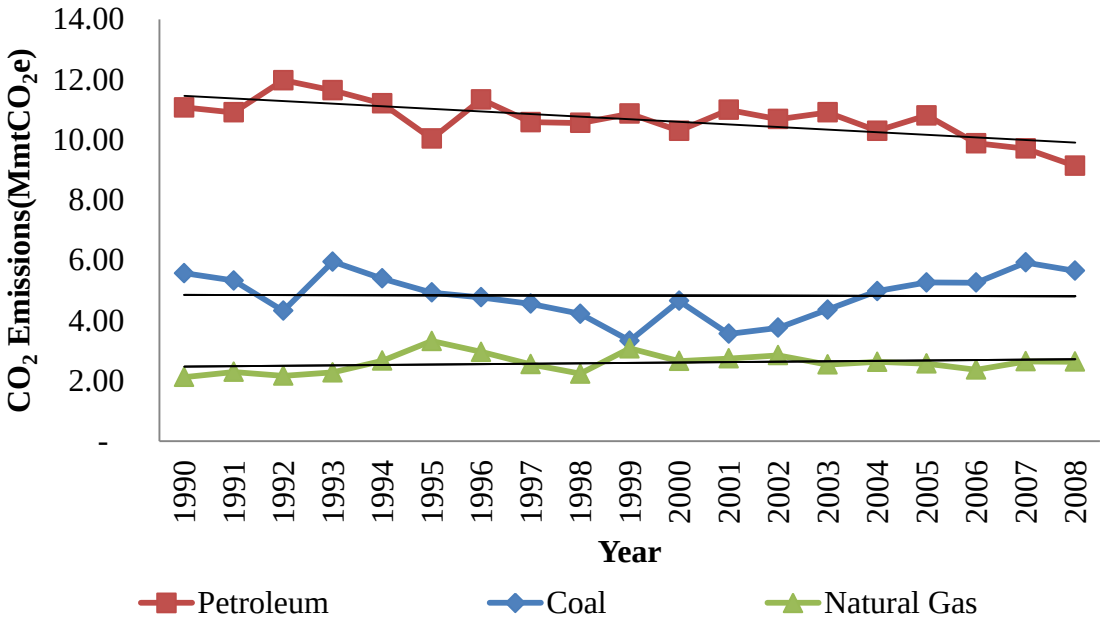
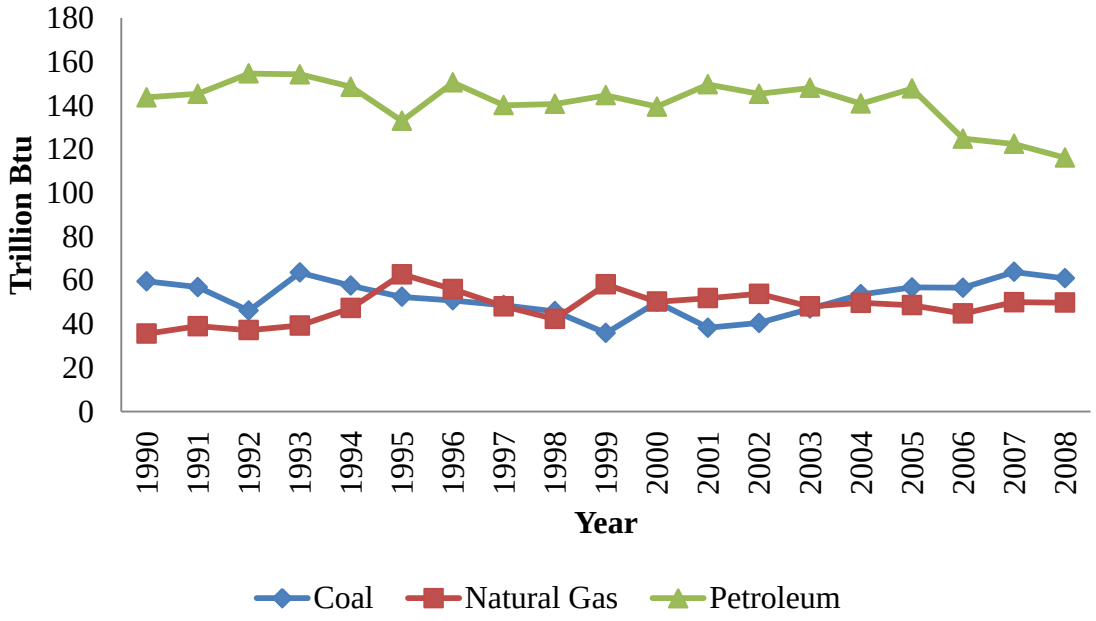


FIGURE 11. DELAWARE'S FOSSIL FUELS CONSUMPTION BY FUEL TYPE



Petroleum was particularly consumed in the electric power generation, transportation and industrial sectors which, when combined, make 91% of total CO_2 emissions from FFC sources as Figure 13 indicates. On the other hand, coal consumption was limited to electric power generation as indicated in Table 6. However, CO_2 emission from coal combustion still exceeded emissions from natural gas as shown in Figure 10.

As Figure 11 shows, the decreasing fossil fuel consumption in Delaware was a factor in the downward trend of CO_2 emissions. The demand for petroleum fuel in Delaware between 1990 and 2008 was higher than coal and natural gas with an average of 142 trillion British thermal units (Btu). The consumption of both coal and natural gas averaged 52 and 48 trillion Btu respectively. When Figure 10 is compared to Figure 11, we observe consistency in the relationship between fuel consumption and CO_2 emissions.

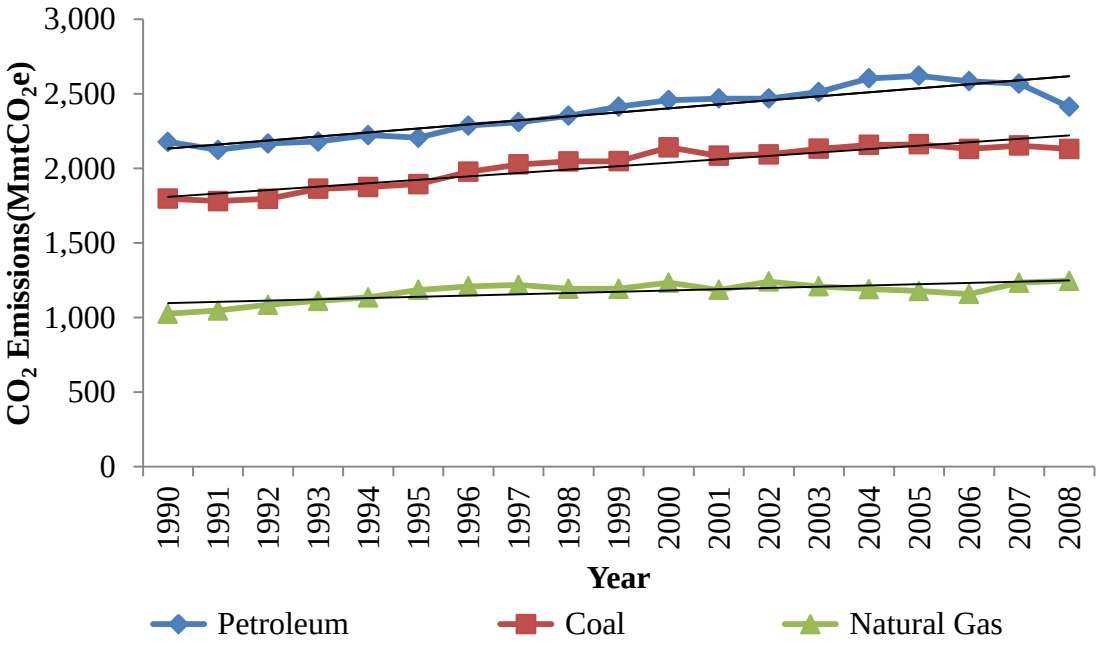
As petroleum consumption decreased in Delaware, CO_2 emissions from petroleum consumption also decreased. The figure also shows that as coal and natural gas consumption remained relatively flat, so does the CO_2 emission from both fuels . In the case of petroleum, high levels of annual CO_2 emissions observed in Figure 10 corresponded with higher fuel consumption observed in Figure 11. CO_2 emissions for coal in Figure10 were higher than that of natural gas. Because the carbon content of natural gas is approximately 55%[41]of that for coal (the carbon content of coal is approximately 26 metric tons per billion Btu, while natural gas is approximately 15 metric tons per billion Btu), more CO_2 is generated from the combustion of coal than natural gas even though consumption levels for both fuels were close as presented in Figure 11.

Figure 12 provides the historical emissions for U.S. CO_2 emissions by fuel types from 1990 to 2008. Comparing CO_2 emissions from Delaware in Figure 10 to U.S. CO_2 emissions in Figure 12, we observe opposing trends. Delaware's CO_2 emissions from

[41] EIA: http://www.eia.gov/oiaf/kyoto/fossil.html

petroleum combustion as shown in Figure 10 decreased by approximately 17% from 1990 to 2008, while U.S. CO_2 emissions increased by 11% from 1990 to 2008 as Figure 12 shows. United States CO_2 emissions increased at the rate of 26.9 $MmtCO_2em$ per year. In the same period, coal and natural gas increased at the rate of 22.9 $MmtCO_2em$ per year and 8.5 $MmtCO_2em$ per year respectively.

FIGURE 12. U.S. CO_2 EMISSIONS FROM FFC TREND BY FUEL TYPES



Data Source: 2009 Energy Information Administration Estimates

FFC Emissions by Economic Sectors: Figure 13 shows GHG emissions the relative contribution of each economic sector in the FFC subcategory. The top three economic sectors that had the most CO_2 emissions from FFC in 2008 were the electric power, transportation and industrial sectors. The electric power sector had the largest contribution of CO_2 emissions from FFC with approximately 35% followed by the transportation sector with approximately 29% and the industrial sector with approximately 27%. All three sectors combined consume the most energy in Delaware,

which contributes approximately 91% of the emissions in CO_2e. Table 8 provides estimates of CO_2 emissions by sector.

FIGURE 13. 2008 CO_2 EMISSIONS FROM FFC BY ECONOMIC SECTORS

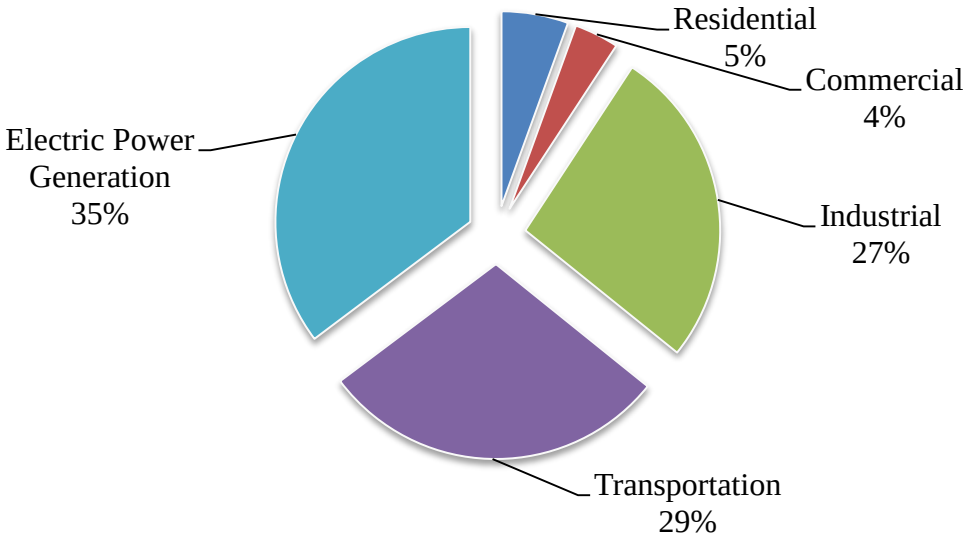


Figure 15 shows EIA estimates of U.S. CO_2 emissions from FFC by sector. Carbon dioxide emissions from FFC in all sectors continued to increase from 1990 to 2008 with one exception, the industrial sector. Industrial sector CO_2 emissions from FFC increased from 1,583 MmtCO2e in 1990 to 1,828 MmtCO_2 in 1999, but later decreased to 1,588 MmtCO_2 in 2008, below electric power and transportation CO_2 emissions. This was a reduction of approximately 13% at the rate of 3.44 MmCO_2e per year. Conversely, between 1990 and 2008, emissions from the power sector increased by approximately 30%, transportation by 21%, residential by 26% and commercial by approximately 37%.

FIGURE 14. DELAWARE'S CO_2 EMISSIONS FROM FFC BY ECONOMIC SECTORS

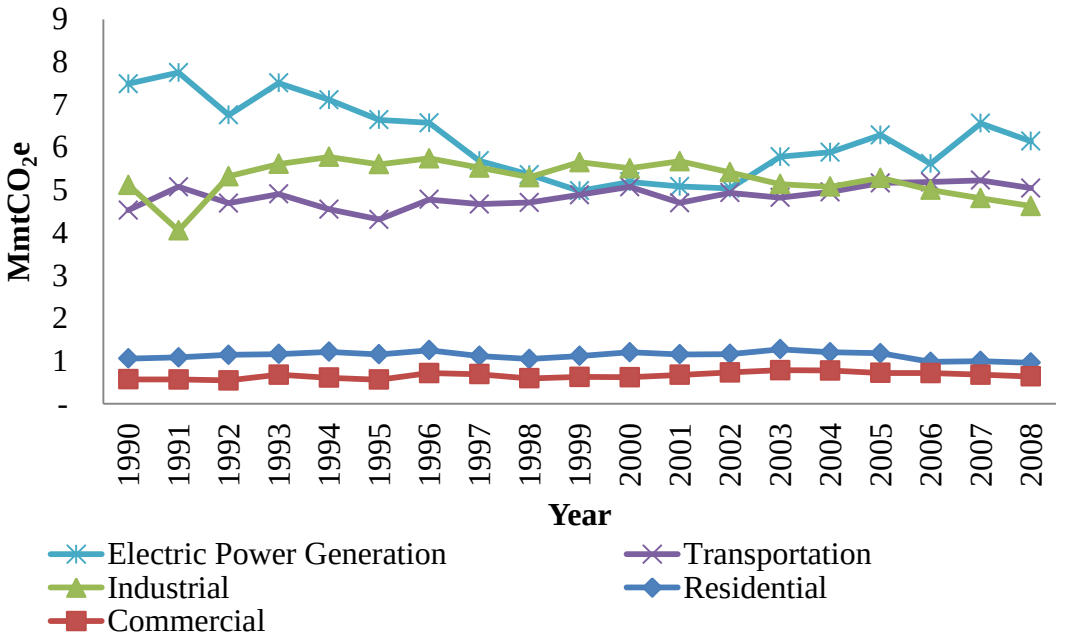
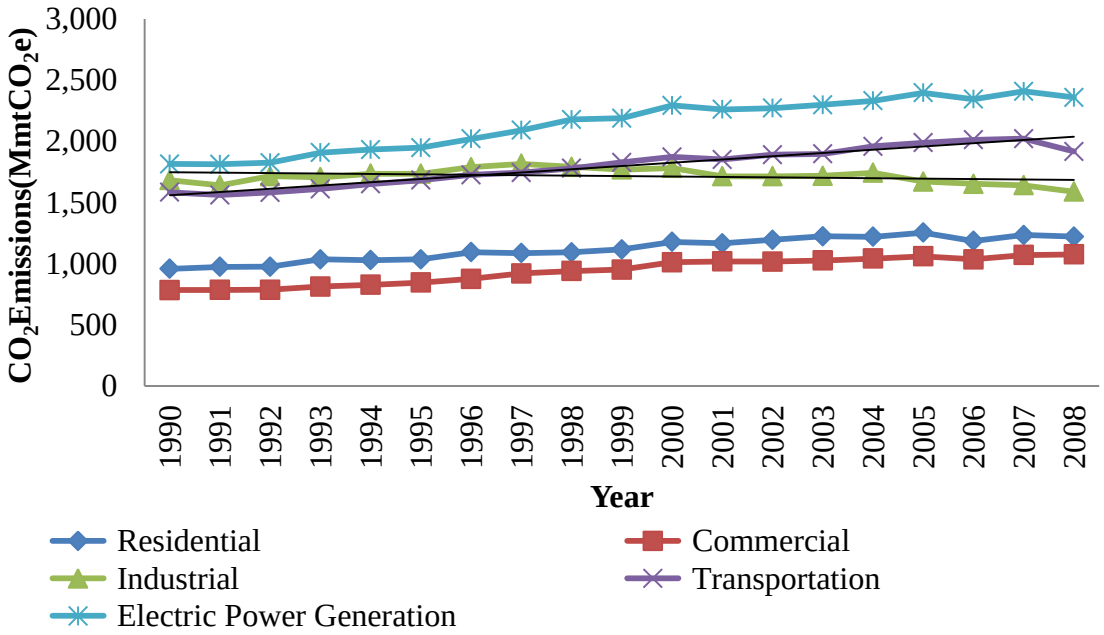


FIGURE 15. U.S. CO_2 EMISSIONS FROM FFC BY SECTOR



When U.S. CO_2 emissions in Figure 15 are compared to Delaware's emissions from FFC by sector in Figure 14, we observe a difference in trend for all the economic sectors. However, decreasing CO_2 emissions from industrial sector FFC is more than likely due to the economic downturn that was experience during that period, which also affected Delaware's industrial base.

TABLE 8. TOTAL CO_2 EMISSIONS FROM FFC
($MmtCO_2e$)

Fuel Type/Vehicle Type	1990	1995	2000	2005	2008
Residential	**1.06**	**1.16**	**1.21**	**1.18**	**0.97**
Coal	0.01	0.00	0.00	0.0	0.0
Petroleum	0.66	0.69	0.68	0.62	0.42
Natural Gas	0.39	0.47	0.52	0.57	0.54
Commercial	**0.57**	**0.57**	**0.62**	**0.72**	**0.64**
Coal	0.04	0.00	0.00	0.0	0.0
Petroleum	0.32	0.25	0.34	0.26	0.16
Natural Gas	0.22	0.32	0.28	0.46	0.49
Industrial	**5.12**	**5.61**	**5.51**	**5.29**	**4.63**
Coal	0.50	0.46	0.44	0.29	0.21
Petroleum	3.71	4.08	3.68	4.16	3.43
Natural Gas	0.91	1.06	1.40	0.84	1.00
Transportation	**4.53**	**4.32**	**5.08**	**5.17**	**5.05**
Coal	0.0	0.0	0.0	0.0	0.0
Petroleum	4.53	4.32	5.07	5.16	5.05
Natural Gas	0.00	0.00	0.01	0.00	0.00
Electric Utilities	**7.49**	**6.65**	**5.20**	**6.29**	**6.14**
Coal	5.02	4.47	4.22	4.98	5.45
Petroleum	1.85	0.70	0.52	0.60	0.08

TABLE 8. TOTAL CO_2 EMISSIONS FROM FFC ($MmtCO_2e$)					
Natural Gas	0.61	1.48	0.45	0.71	0.61
TOTAL	**18.78**	**18.30**	**17.62**	**18.66**	**17.43**
Coal	5.58	4.93	4.66	5.27	5.66
Petroleum	11.07	10.04	10.30	10.81	9.14
Natural Gas	2.13	3.33	2.66	2.58	2.64

See Appendix B for details.

Electric Power: There were 15 electric generation plants in Delaware between 1990 and 2008 as Table 9 provides. Carbon dioxide emissions[42] from all the power plants in Delaware were estimated using fossil fuel data from the EIA. Carbon dioxide emission from electric power generation was at its highest in 1991 at 7.75$MmtCO_2e$ as shown by Figure 16 and later decreased to 4.89 $MmtCO_2e$ in 1999 and rose to 6.14 $MmtCO_2e$ in 2008. Carbon dioxide emissions from electric power generation declined at the rate of 0.09 $MmtCO_2e$ per year.

In addition, CO_2 emissions decreased by 18% from 1990 to 2008. Table 9 shows estimates of CO_2 emissions from petroleum, coal, and natural gas by economic sectors from 1990 to 2008. As the Table 8 provides, the CO_2 emissions from electric power generation was largely driven by coal combustion, followed by petroleum.

[42] Note: The 2008 GHG Inventory report did not separate CO_2 emission from the electric power sector by power plants. Instead, the sum total of fossil fuels consumed in this sector was used to estimate CO_2 emissions.

TABLE 9. LIST OF POWER PLANTS IN DELAWARE		
Plant name	**County**	**Capacity MW**
Christiana	New Castle	56
Delaware City 10	New Castle	18.5
Edge Moor	New Castle	710.3
R Madison*	New Castle	12
West Station	New Castle	20
Hay Road	New Castle	1193
Delaware City Plant	New Castle	417.2
McKee Run	Kent	151.2
Van Sant Station	Kent	45.1
Warren F Sam Beasley Generation Station	Kent	45
NRG Energy Center Dover	Kent	118
Indian River Operations	Sussex	799.4
Seaford Delaware Plant	Sussex	30
Lewes	Sussex	2
Seaford	Sussex	7.8

*R. Madison power plant was retired in 2004

Figure 16 shows that between 1996 (6.58 MmtCO_2e) and 2003 (5.78 MmtCO_2e), there was a decrease in CO_2 emissions, which may be attributed to a decline in the combustion of fossil fuels to generate electricity between 1996 and 2003. The decline in electricity generation may have been the result of declining electricity demand in the industrial sector due to Delaware's shrinking industrial base.

FIGURE 16. CO_2 EMISSIONS FROM FFC IN THE POWER SECTOR

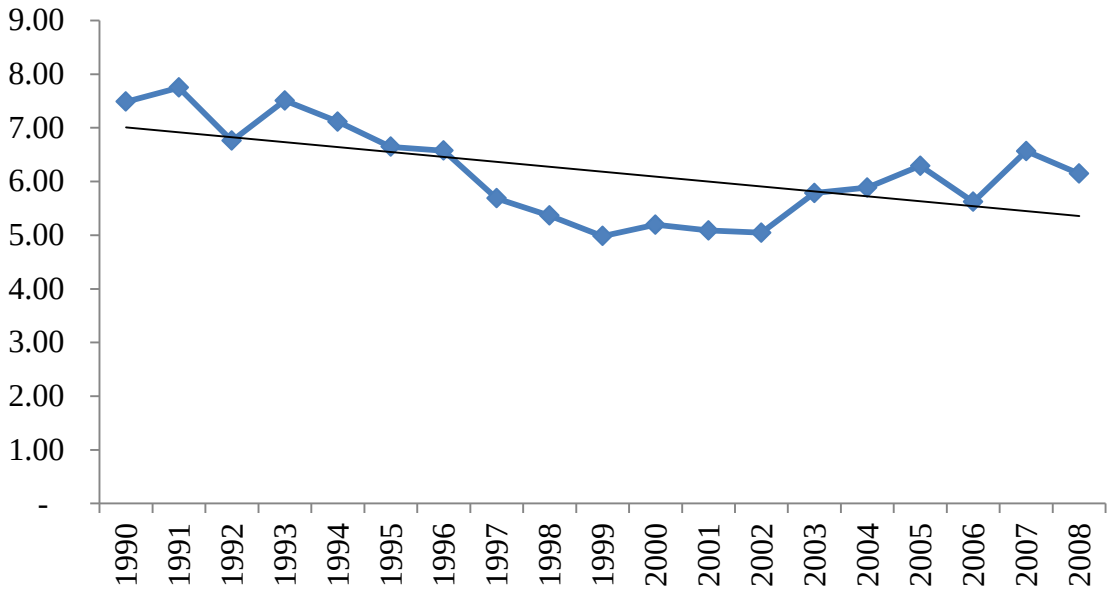
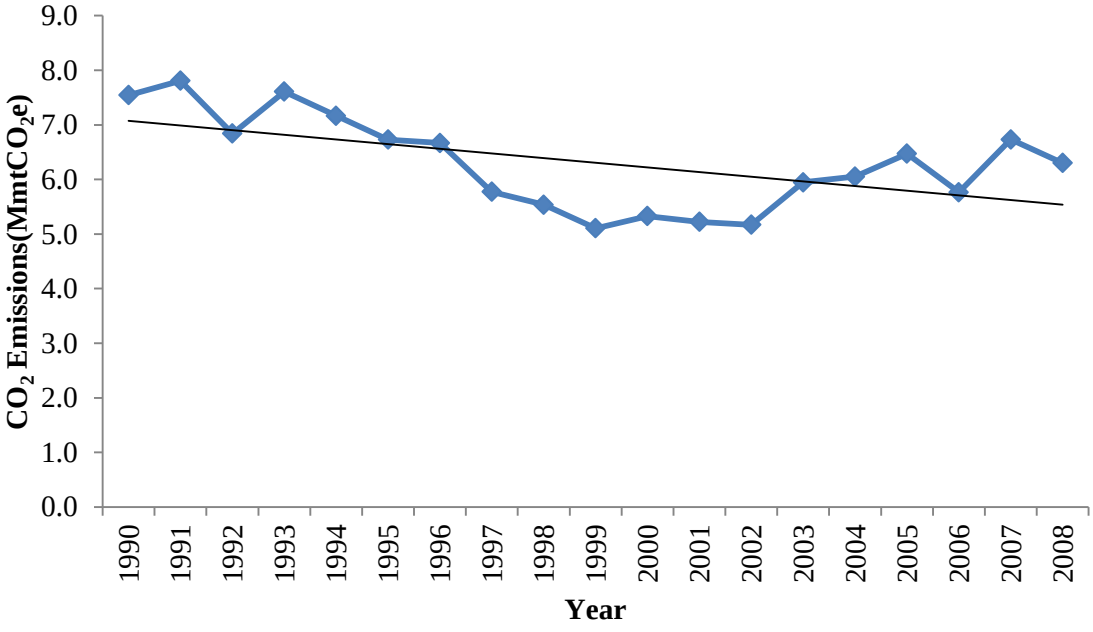


FIGURE 17. CO_2 EMISSIONS FROM FFC IN THE POWER SECTOR BASED ON EIA ESTIMATES



The dip in CO_2 emissions from electric power generation may also be the result of fluctuating seasonal temperatures, which could have affected electricity demand in

the residential and commercial sectors during that period[43]. Figure 17 shows that the Energy Information Administration also observed a similar dip in CO_2 emissions for that period. Section 4.7 addresses CO_2 emissions from electricity consumption under indirect CO_2 emissions from electricity consumption.

Transportation CO_2 emissions from the transportation sector averaged 4.86 $MmtCO_2$ from 1990 to 2008. As demonstrated by Figure 18, Transportation related CO_2 emissions from FFC continued to increase at the rate of 0.03 $MmtCO_2e$ per year from 1990 to 2008. Emissions increased from 4.53 in 1990 to 5.05 in 2008, an increase of 12%.

The upward trend of CO_2 emissions from FFC in the transportation sector is consistent with the Delaware's vehicle miles traveled (VMT) data from 1990 to 2008 as presented by Figure 19. As vehicle mile increased, the amount of gasoline fuel consumed in the transportation sector also increased from 1990 to 2008 as provided by Figure 20.

The consumption of Gasoline fuel was a major factor in CO_2 emissions from the transportation sector. Table 8 shows that CO_2 emissions from the transportation sector resulted largely from the consumption of petroleum. CO_2 emissions from natural gas consumption were minimal (0.01 $MmtCO_2e$).

[43] See Figure 24 for fluctuating seasonal temperatures

FIGURE 18. CO_2 EMISSIONS FROM FFC IN THE TRANSPORTATION SECTOR

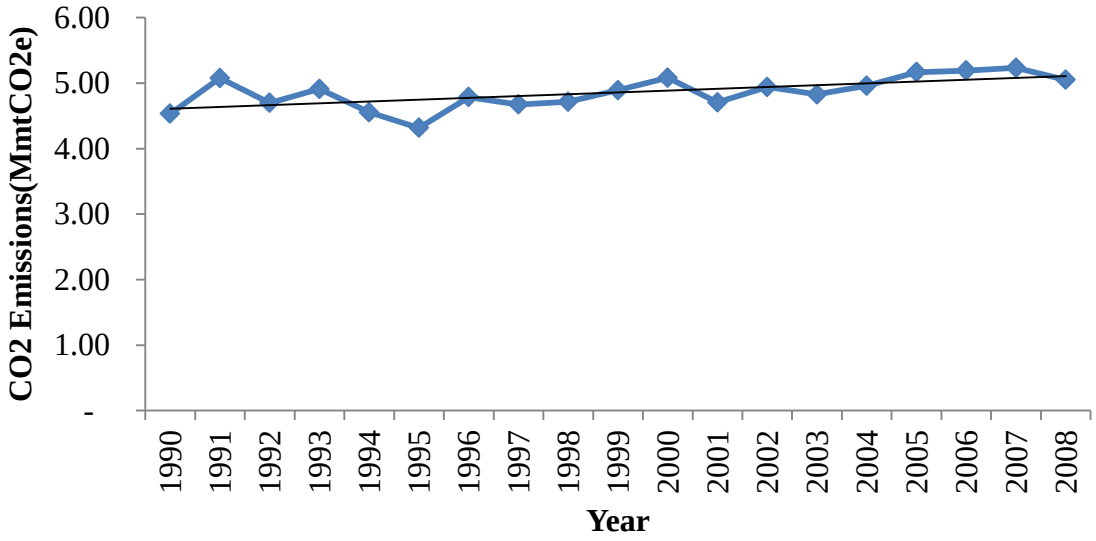


FIGURE 19. DELAWARE'S VEHICLE MILES TRAVELED

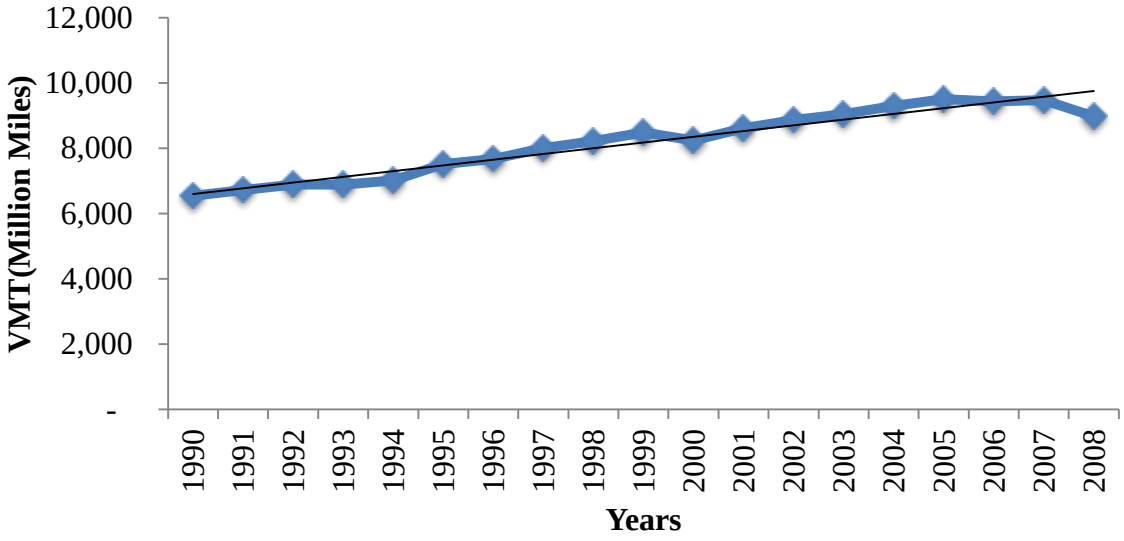
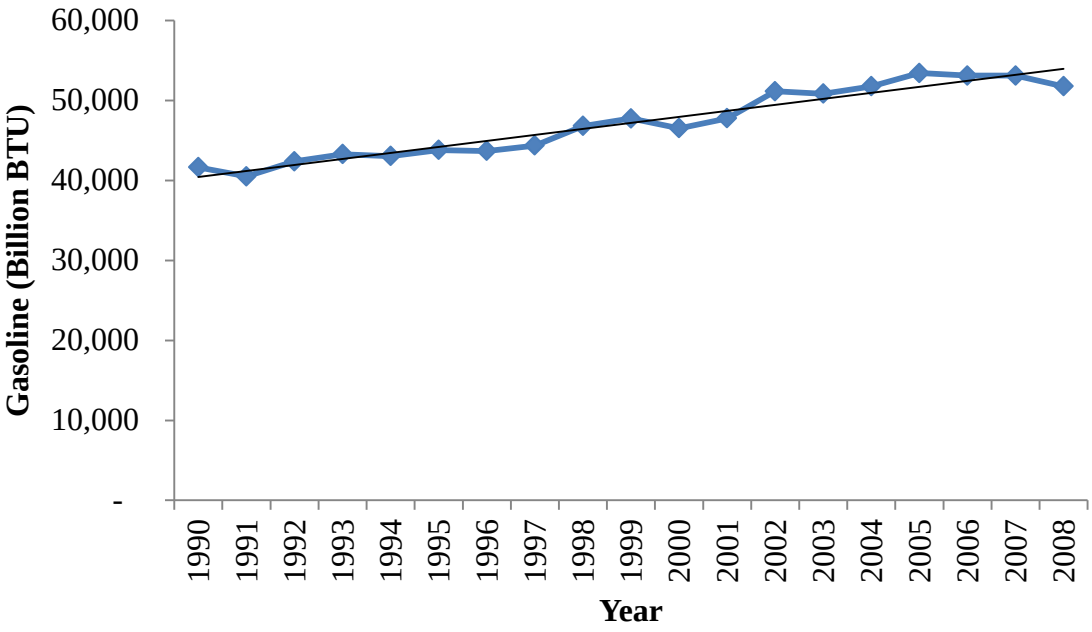


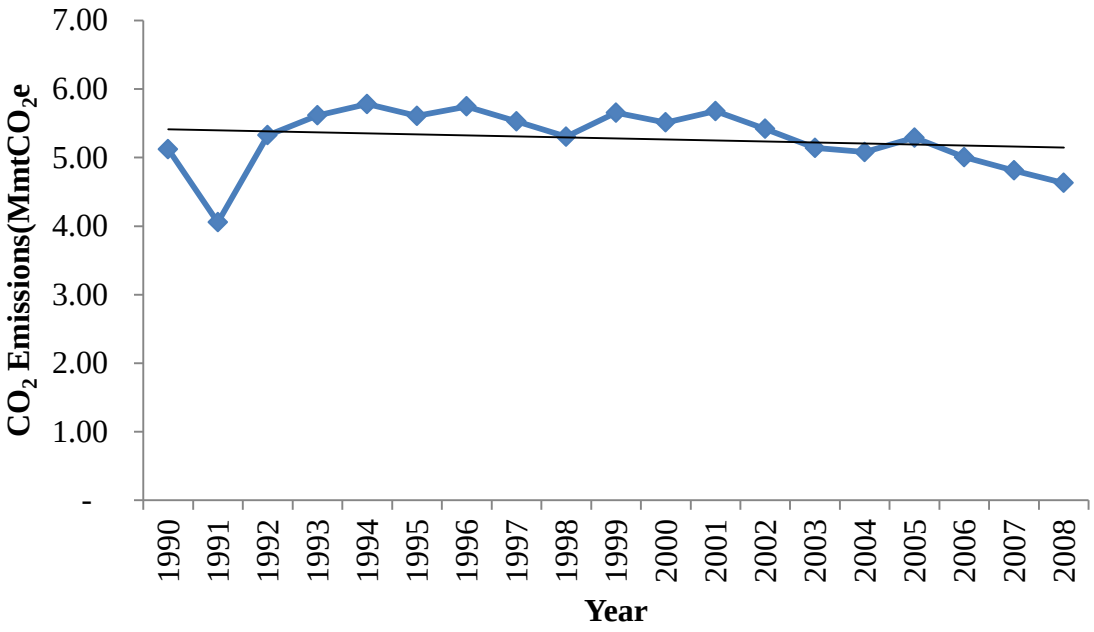
FIGURE 20. GASOLINE CONSUMPTION IN DELAWARE'S TRANSPORTATION SECTOR



Industrial: Figure 21 shows that that industrial sector CO_2 emissions decreased slightly from 1990 to 2008 by 9.6%. Trendline analysis revealed that CO_2 emissions decreased at the rate of 0.015 MmtCO_2e per year. Between 1998 and 2002, industrial sector CO_2 emissions exceeded both electric power and transportation sectors. However, emissions remained relatively flat when compared to the electric power sector.

Industrial sector emissions resulted from petroleum consumption, as well the consumption of natural gas. As petroleum consumption decreased slightly from 1990 to 2008 as Figure 21 shows, industrial CO_2 emissions from FFC also decreased.

FIGURE 21. CO_2 EMISSIONS FROM FFC IN THE INDUSTRIAL SECTOR



Residential and Commercial: As Figure 22 shows, both residential and commercial sector CO_2 emissions had fluctuations from 1990 to 2008. The FFC CO_2 emissions from both sectors fluctuated. The residential and commercial sectors had average CO_2 emissions of 1.13 $MmtCO_2e$ and 0.66 $MmtCO_2e$ respectively. However, a slight decrease of 8.5% was calculated for the residential sector emissions and an increase of 12.3% was calculated for commercial sector emissions from 1990 to 2008. From 1990 to 2008, carbon dioxide emission from FFC in the residential sector decreased at the rate of 0.004 $MmtCO_2e$ per year, while increasing at the rate of 0.008 $MmtCO_2e$ per year in the commercial sector.

Fluctuating seasonal temperatures contributed to fluctuating emissions levels observed in Figure 22. Figure 23 presents, Delaware's average minimum and maximum temperatures from 1990 to 2008. Lower average temperatures lead to increased energy consumption for heating purposes when compared to higher

average minimum temperature for the month of January. As Figure 23 indicates, a drop in the average minimum temperature of Delaware to 18.9 ^{o}F in 1994 corresponded to CO_2 emissions rising to 1.22 MmtCO_2e in the residential sector that same year. Another factor that may affects CO_2 emissions form the residential and commercial sector is the fluctuating price of energy including fossil fuels and electricity. The price of energy affects the demand for energy and ultimately the CO_2 emissions from consuming energy.

As Table 8 provides, CO_2 emissions from the residential and commercial sectors were driven by petroleum and natural gas consumption for heating purposes. Figure 24 shows that the direction fossil fuel consumption in all the economic sectors from 1990 to 2008 was consistent with CO_2 emissions from the FFC sectors.

FIGURE 22. EMISSIONS FROM FFC IN THE RESEDENTIALN AND COMERCIAL SECTORS

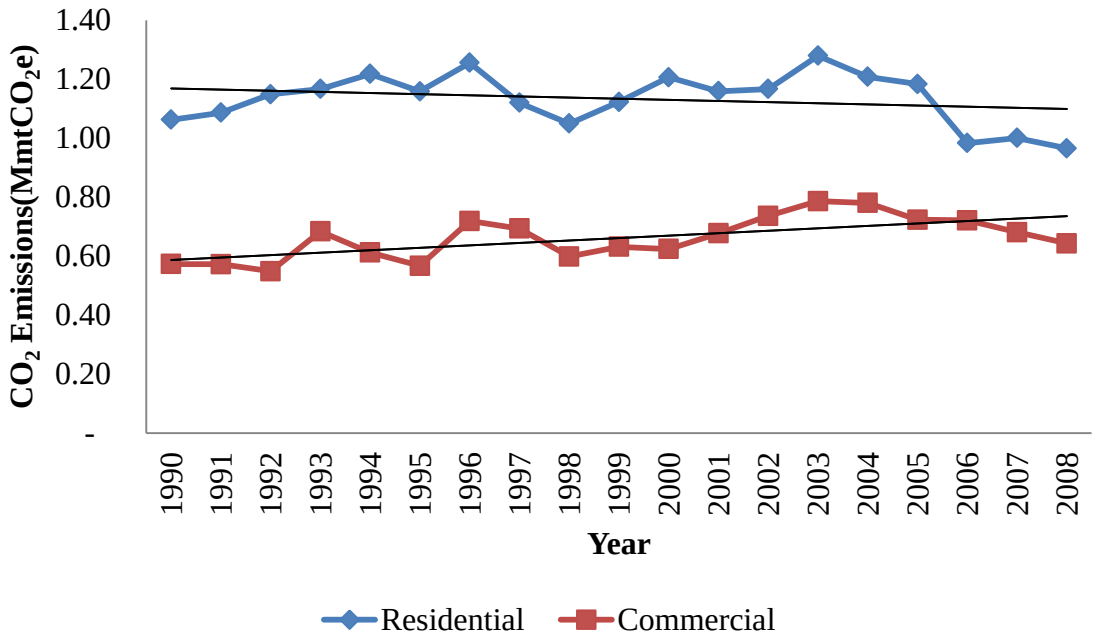


FIGURE 23. DELAWARE'S AVERAGE MINIMUM TEMPERATURES FOR JANUARY

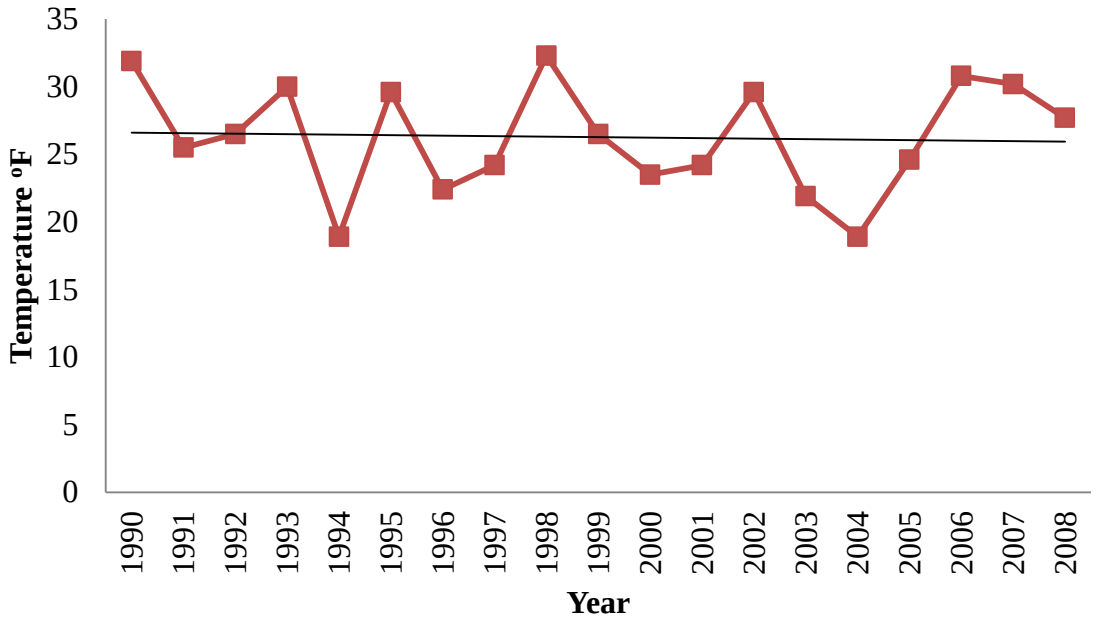
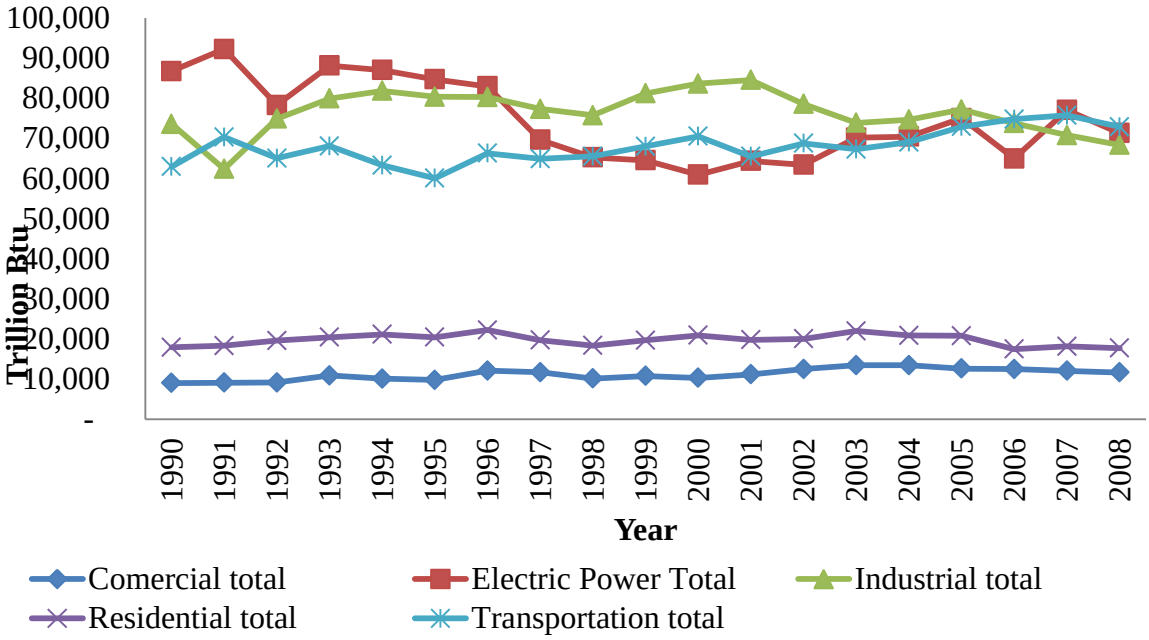


FIGURE 24. FOSSIL FUEL CONSUMPTION BY ECONOMIC SECTORS



4.2.2 Mobile Combustion of Fossil Fuels (CH_4 and N_2O): In addition to CO_2 emissions, the combustion of fossil fuels produces CH_4 and N_2O. GHG emission from the mobile combustion of fossil fuels applies primarily to transportation, which includes both on-road and non-road vehicles. Also included in this category are farm and construction equipment, which apply to the agricultural and industrial sectors respectively.

Nitrous oxide is formed by the catalytic processes used to control NO_x, CO, and hydrocarbon emissions in vehicles[44]. On the other hand, CH_4 emissions in mobile combustion occur as result of the incomplete combustion of CH_4 and other hydro carbons in vehicle engines[45]. The methods for estimating CH_4 and N_2O from mobile combustion do not include CO_2 emissions. All CO_2 emission estimates from mobile combustion were included in section 4.2.1 under Fossil Fuel Combustion.

Methodology

Estimates of CH_4 and N_2O emissions were developed by collecting activity data for mobile sources based on vehicle mile traveled, the combustion technologies (types of vehicles) used, and the types of emission control technologies employed during and after combustion (operating conditions during combustion is also a factor in mobile combustion emissions, and are reflected in the emission factors). The basic approach for estimating the emissions of CH_4 and N_2O is presented in the following equation:

[44] EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks:1990-2004

[45] 2012 U.S. EPA inventory report: http://www.epa.gov/climatechange/emissions/usinventoryreport.html

EQUATION 2. NON-ENERGY RELATED MOBILE COMBUSTION EMISSIONS

Emissions	=	*Σ (EFabc x Activityabc)*
Where EF	=	*emissions factor (e.g., grams/kilometer traveled);*
Activity	=	*activity level measured in the units appropriate to the emission factor (e.g., miles);*
a	=	*fuel type (e.g., diesel or gasoline);*
b	=	*vehicle type (e.g., passenger car, light duty truck, etc.);*
c	=	*emission control type.*

The SIT categorized emissions from mobile combustion into the following sources:

- On-road gasoline vehicles include passenger cars, light-duty trucks heavy-duty vehicles and motorcycles that use gasoline.
- On-road diesel vehicles include passenger cars, light-duty trucks, heavy-duty vehicles that use diesel.
- Non-road vehicles and engines include aircrafts, boats, trains, farm and construction equipment.
- Alternative Fuel Vehicles that use fuels such as biodiesel, liquefied petroleum gas (LPG), liquefied natural gas (LNG) and compressed natural gas (CNG)

GHG emission estimates for on-road gasoline and diesel vehicles[46] were based on vehicle miles traveled (VMT) and emission factors (EF) by vehicle type, fuel type, and control

[46] The Federal Highway Administration (FHWA), in FHWA's Highway Statistics report (Table VM-1), available online at: http://www.fhwa.dot.gov/policy/ohpi/hss/index.cfm

technology and model year. Also, emission estimates from alternative fuel vehicles[47] were based on VMT and EF by vehicle and fuel type. Fuel consumption data were used as a measure of activity for non-road[48] vehicles and engines in conjunction with fuel Emissions Factors (EFs).

FIGURE 25. 2008 GHG EMISSIONS BY CO_2e FROM MOBILE COMBUSTION BY VEHICLE TYPE

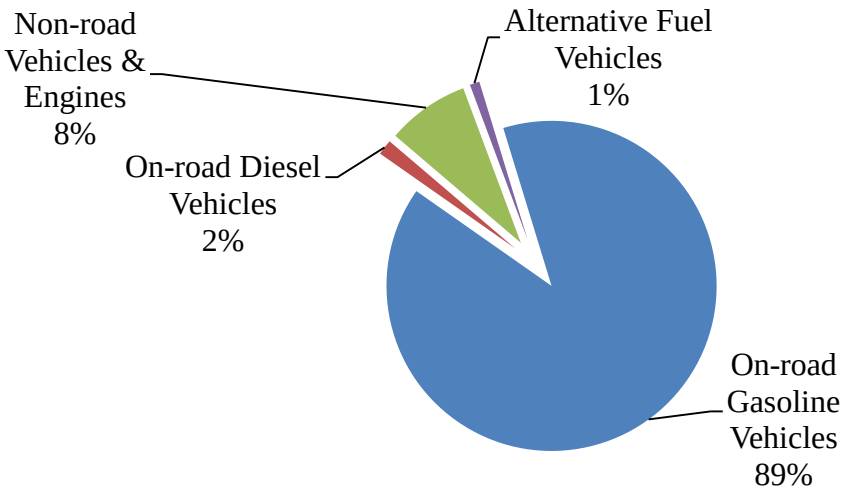


Figure 25 shows the percent contribution of each vehicle type to Delaware's total mobile combustion emissions in 2008. On-road gasoline vehicles had the largest contribution with approximately 89% of total mobile combustion emissions. Emissions from non-road vehicles were approximately 8%, while emissions from on-road diesel vehicles and alternative fuels vehicles were 2% and 1% respectively.

[47] The Federal Highway Administration (FHWA), in FHWA's Highway Statistics report (Table VM-2), available online at: http://www.fhwa.dot.gov/policy/ohpi/hss/index.cfm

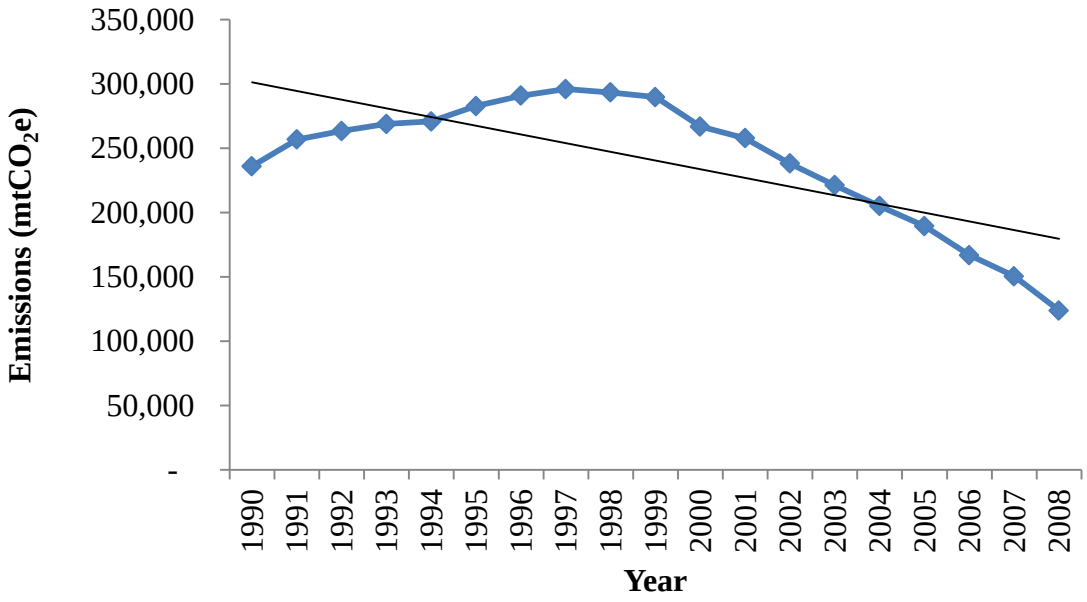
[48] -EIA's *Petroleum Sales and Consumption: Fuel Oil and Kerosene Sales*, Table 16. Available online at: http://tonto.eia.doe.gov/dnav/pet/pet_cons_821dsta_dcu_nus_a.htm

- U.S. Department of Energy publication *State Energy Data System* (EIA 2010) for data on aviation gasoline consumption. http://www.eia.doe.gov/states/_seds.html

Analysis of Mobile Combustion Emissions

Figure 26 presents a chart of the combined emission of N_2O and CH_4 from the mobile combustion of fossils fuels. As Figure 24 shows, GHG [49] emissions from mobile combustion peaked in 1997 at 295,909 $mtCO_2e$ (0.296 $MmtCO_2e$). In 2008, the total GHG emission from mobile combustion was 123,808 $mtCO_2e$ (0.124 $MmtCO_2e$), a 48% decrease from 1990. Emissions decreased at the rate of 6,569 $mtCO_2e$ per year based on trendline analysis. Table 10 provides GHG emission estimates from mobile combustion sources by vehicle types.

FIGURE 26. N_2O & CH_4 FROM MOBILE COMBUSTION SOURCES



[49] Combined N_2O and CH_4 in CO_2e, not including CO_2

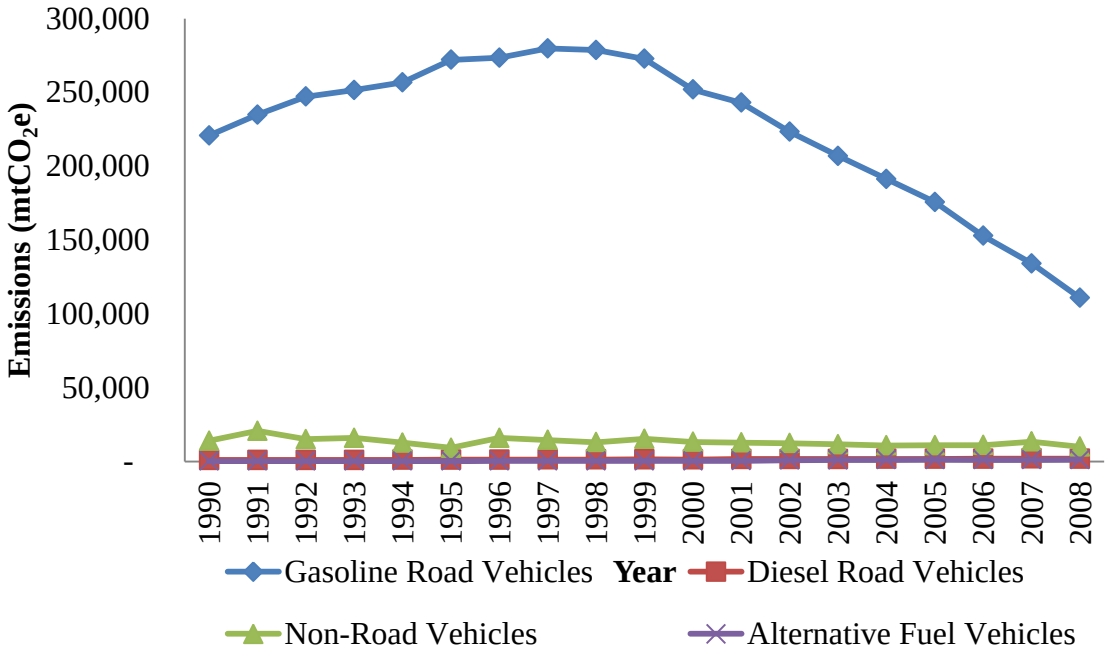
TABLE 10. TOTAL N_2O & CH_4 EMISSIONS FROM MOBILE SOURCE COMBUSTION (MTCO_2e)					
Fuel Type/Vehicle Type	**1990**	**1995**	**2000**	**2005**	**2008**
Gasoline Road	**220,879**	**272,108**	**251,960**	**175,720**	**110,753**
Passenger Cars	138,866	146,653	130,275	96,725	60,650
Light-Duty Trucks	77,145	119,507	115,379	73,605	48,632
Heavy-Duty Vehicles	4,673	5,725	6,107	5,198	1,215
Motorcycles	196	223	199	193	255
Non-Road	**13,951**	**9,203**	**13,182**	**10,935**	**10,010**
Boats	5,718	6,760	10,401	7,111	7,597
Locomotives	170	46	19	26	119
Farm Equipment	733	455	869	884	607
Construction Equipment	1,251	958	850	817	874
Aircraft	5,996	717	585	1,733	0
Other[50]	83	267	458	365	814
Diesel Road	**918**	**1,152**	**1,308**	**1,721**	**1,863**
Passenger Cars	24	19	15	15	13
Light-Duty Trucks	39	55	64	74	104
Heavy-Duty Vehicles	855	1,079	1,229	1,632	1,746
Alternative Fuel Vehicles	**209**	**240**	**350**	**1,173**	**1,183**
Light Duty Vehicles	50	60	115	358	376
Heavy Duty Vehicles	149	161	210	713	701
Buses	10	19	25	103	105
Total	**235,957**	**282,703**	**266,800**	**189,550**	**123,808**

See Appendix C for details.

[50] "Other" includes small gasoline powered utility equipment, heavy-duty gasoline powered utility equipment, and heavy-duty diesel powered utility equipment.

GHG Emissions from On-road Gasoline Vehicles: As shown in Figure 27, on-road gasoline vehicles emissions from 1990 to 2008 were higher than emissions from all other mobile combustion sources, reaching its highest level in 1998 with 278,744 $mtCO_2e$. The annual rate of decrease for GHG emissions from on-road gasoline vehicles as determined by trendline analysis was 6,583 $mtCO_2e$ per year. GHG emissions from other vehicle types appeared to be minimal when compared to GHG emissions from on-road gasoline vehicles. The average CO_2e emissions for all three (diesel road, non-road and alternative fuel vehicles) were 1,382 $mtCO_2e$, 13,274 $mtCO_2e$ and 565 $mtCO_2e$ respectively.

FIGURE 27. CO_2e FROM MOBILE COMBUSTION BY VEHICLE TYPE

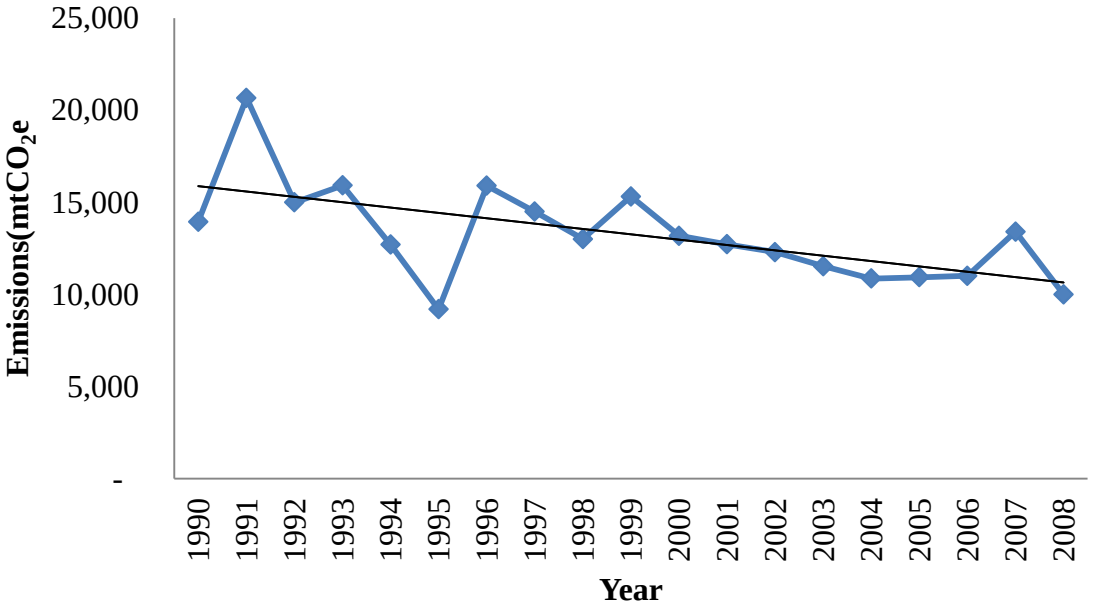


GHG Emissions from Non-road Engines and Vehicles: This category includes boats and other marine vessels, aviation, locomotive, construction and farm equipment. Factors that affect the amount emissions include fossil fuel consumption and level of activity (frequency of operation). Fossil fuel

consumption as well as activity levels in this category declined between 1990 and 2008.

As Figure 28 shows, GHG emissions from non-road engines and vehicles trended downward with larger fluctuations from 1990 to 1998. Its lowest point was in 1995 with 9,203 $mtCO_2e$ and its highest point was in 1991 with 20,674 $mtCO_2e$. From 1990 to 2008, emissions decreased by 28% at the rate of 290 $mtCO_2e$ per year as determined by trendline analysis.

FIGURE 28. GHG EMISSIONS FROM NON-ROAD ENGINES AND VEHICLES

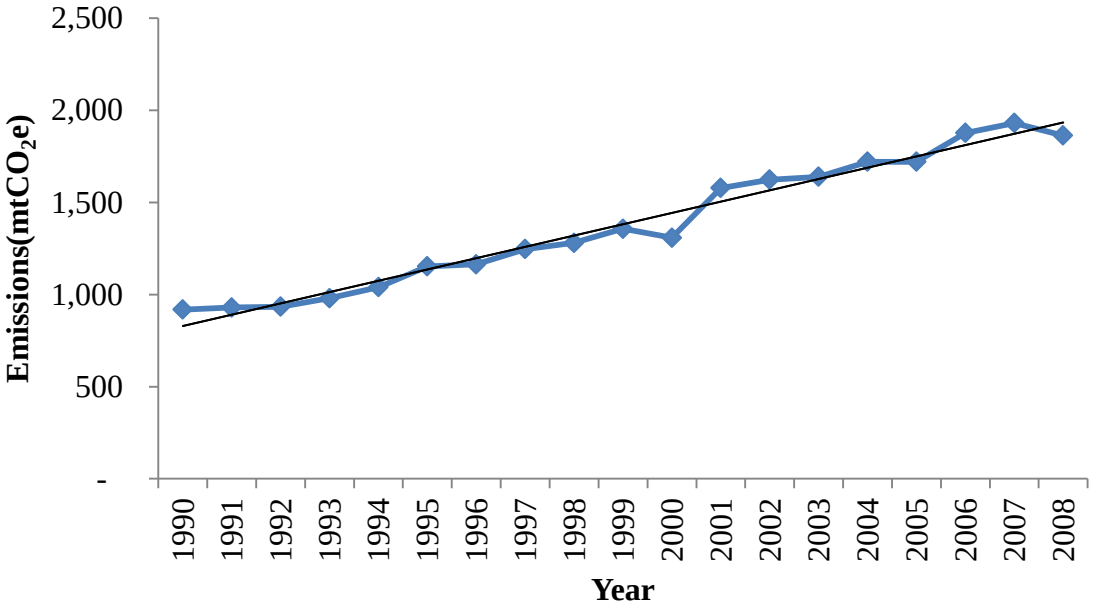


***GHG Emissions from On-road Diesel Vehicles**:* Figure 29 shows that GHG emission from on-road diesel vehicles, which continued to increase from 1990 to 2008 by 96% at the rate of 61 $mtCO_2e$ per year. This major increase in emissions could be the result of an increase in the on-road diesel vehicle population from 1990 to 2008. Diesel fueled engines have always been available in heavy-duty trucks, but automakers are expanding customer options include compact and midsize sedans, as well as SUVs. This expansion of customer options could have

increased the number of diesel vehicles on the road thereby leading to increased emissions..

This report does not include data on the number of diesel vehicles on Delaware roads. However in future reports, DAQ will fully characterize the relationship between N_2O and CH_4 emissions from on-road diesel vehicles and the number of diesel vehicles as well as other factors that contribute to increasing emissions from this vehicle type.

FIGURE 29. GHG EMISSIONS FROM ON-ROAD DIESEL VEHICLES



GHG Emissions from Alternative Fuel Vehicles: Alternative fuel vehicle (AFV) are vehicles that runs on fuels other than traditional petroleum fuels (gasoline or diesel); and also refers to any technology of powering an engine that does not involve solely petroleum

Because of a combination of factors, such as rising oil prices environmental concerns, and, government policies (fuel efficiency, energy sustainability and

security), there is increasing demand for cleaner alternative fuels vehicles. According to the U.S. Department of Energy, there were 8[51] AFV fuel sites in Delaware as of 2011. These AFV fuel sites include Biodiesel, Compressed Natural Gas (CNG), Ethanol (E85), Electric Charging Stations, Hydrogen, and Liquefied Propane Gas (LPG).

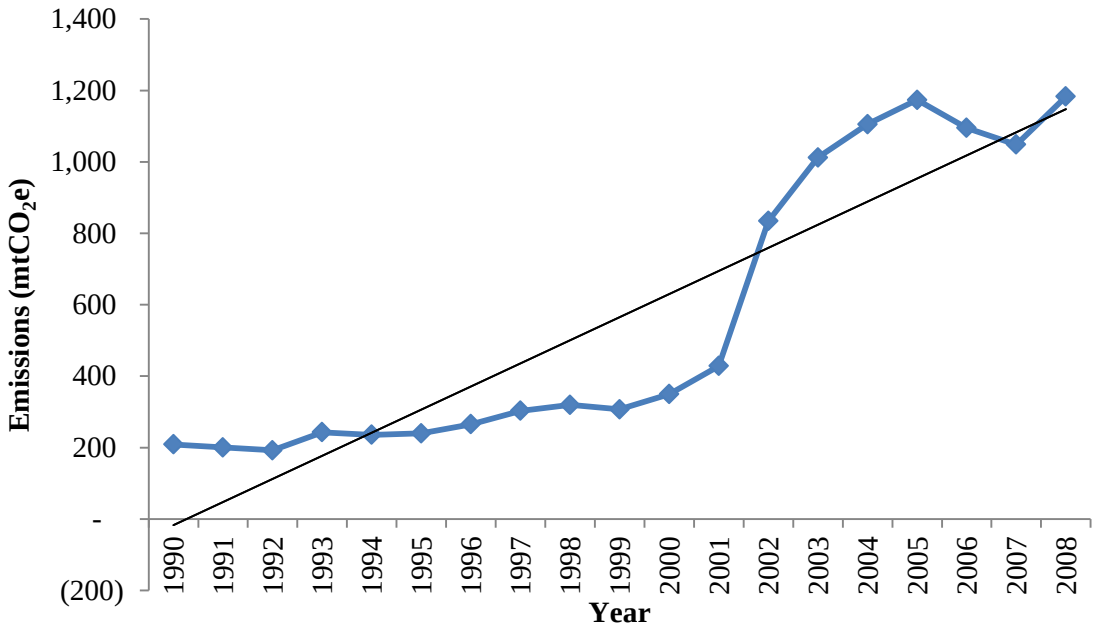
The emissions of CH_4 and N_2O from these AFV fuels can contribute significantly to gross GHG emissions from the lifecycle of conventional and alternative transportation fuels and technologies. For example, CH_4 and N_2O together account for about 15% of the lifecycle GHG emissions impact of conventional gasoline vehicles, and up to 43% of the lifecycle GHG impact of some AFV fuel types (Lipman and Mark)[52]. Some AFV fuels contain hydrocarbons, which can produce CH_4.as a result of incomplete combustion or N_2O as a result the catalytic process.

The rate of increase was 65 mtCO2e per year as determined by trendline analysis. In 2008, total GHG emission from AFV fuel types was only 1% of total GHG emissions from the mobile combustion source category.

[51] www.eere.energy.gov/afdc/fuels/stations_counts.html, February 2011.

[52] Lipman, Timothy E. and Delucchi Mark A. 2002. "Emission of Nitrous Oxide and Methane Conventional and Alternative Fuels Motor Vehicles" *Energy and Resources Group, University of California, RAEL and Institute of Transportation Studies, University of California,*

FIGURE 30. GHG EMISSIONS FROM ALTERNATIVE FUEL VEHICLES

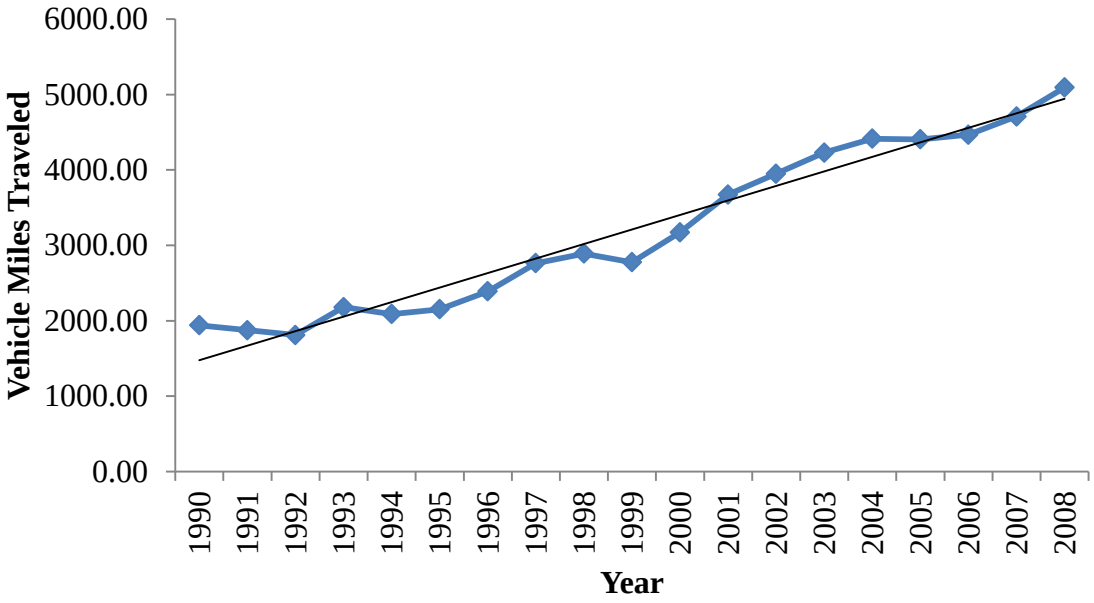


As Figure 30 shows, GHG (combined emission of N_2O and CH_4) emissions from AFVs increased from 209 $mtCO_2e$ in 1990 to 1,183 $mtCO_2e$ in 2008, an increase of approximately 466%. Figure 30 also shows that initially, emissions slowly increased from 1990 to 2000, and then rapidly increased by approximately 238% from 2000 to 2008. This increase in GHG emissions was due to the increasing vehicle miles traveled by AFVs as the number of vehicles in Delaware increase.

Though, the percent increase in GHG emissions from the combustion of AVF fuels between 1990 and 2008 was considerably high, GHG emissions from this source pales in comparison to Delaware's overall GHG emissions and is not considered to be a major source.

As Figure 31 presents, between 1990 and 2008, VMT increased from 1,940 miles traveled to 5,093 miles traveled, an increase of 163%. This increase was enough to produce a 466% increase in GHG emissions. The rate of increase was 193 miles traveled per year.

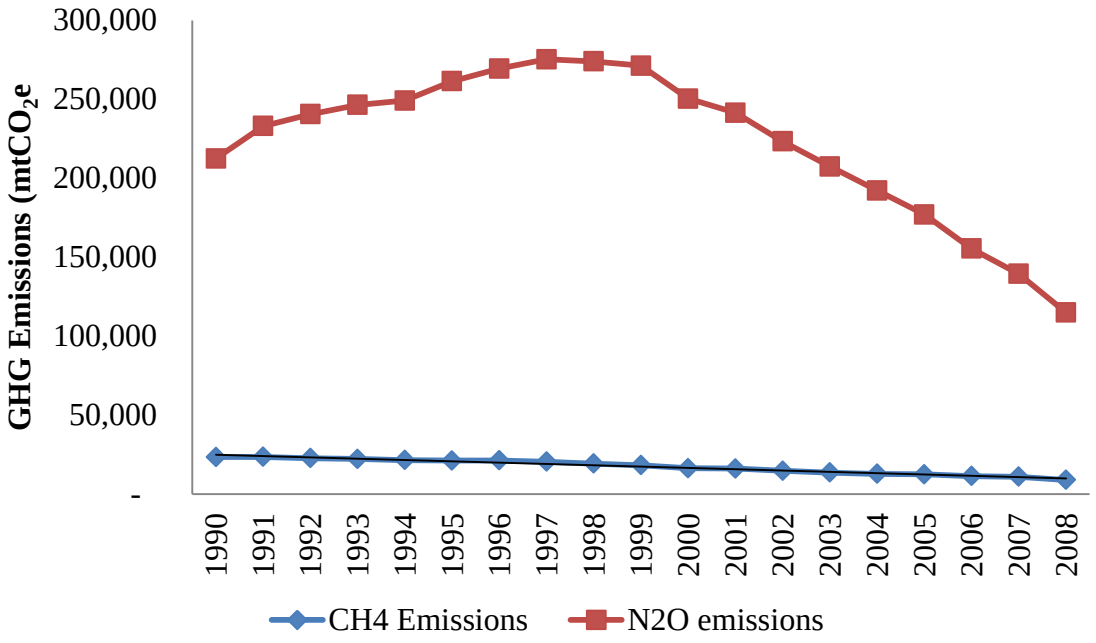
FIGURE 31. DELAWARE'S VMT DATA FOR ALTERNATIVE FUEL VEHICLES



Mobile Source Combustion Emissions by Gas:

Figure 32 presents emissions from mobile source combustion from 1990 to 2008 from by gas. The figure shows that from 1990 to 2008, N_2O emissions were significantly larger than CH_4 emissions since N_2O has a larger GWP than CH_4. The minimum emission for both N_2O and CH_4 occurred in 2008 with 114,933 $mtCO_2$eand 8,876 $mtCO_2e$ respectively as Figure 32 indicates.

FIGURE 32. N_2O AND CH_4 EMISSIONS FROM MOBILE COMBUSTION



Nitrous Oxide: Table 11 provides CO_2e estimates of N_2O emissions by vehicle type. As observed in the Figure 33, N_2O emission from mobile combustion increased gradually from 1990 at 212,561 $mtCO_2e$ and peaking in 1997 at 262,189 $mtCO_2e$, an increase of 31%. From 1997 to 2008, the emission of N_2O from mobile source combustion experienced a downward trend. N_2O emissions from mobile combustion have decreased at a rate of 5,916 $mtCO_2e$ per year.

TABLE 11. TOTAL N_2O EMISSIONS FROM MOBILE SOURCE COMBUSTION ($MTCO_2E$) BY VEHICLE TYPE

Fuel Type/Vehicle Type	1990	1995	2000	2005	2008
Gasoline Road Vehicles	**199,680**	**252,761**	**238,093**	**166,097**	**103,989**
Passenger Cars	125,889	135,897	122,368	91,136	56,776
Light-Duty Trucks	70,316	112,187	110,190	70,109	45,938
Heavy-Duty Vehicles	3,360	4,546	5,416	4,737	1,121

TABLE 11. TOTAL N_2O EMISSIONS FROM MOBILE SOURCE COMBUSTION ($MTCO_2e$) BY VEHICLE TYPE					
Fuel Type/Vehicle Type	**1990**	**1995**	**2000**	**2005**	**2008**
Motorcycles	115	131	119	115	153
Diesel Road Vehicles	**859**	**1,077**	**1,223**	**1,608**	**1,741**
Passenger Cars	23	19	15	15	12
Light-Duty Trucks	37	52	61	71	99
Heavy-Duty Vehicles	798	1,006	1,146	1,522	1,629
Non-Road Vehicles	**11,827**	**7,459**	**10,921**	**8,483**	**8,360**
Boats	4,786	5,658	8,706	5,952	6,358
Locomotives	140	38	16	21	98
Farm Equipment	531	330	629	640	440
Construction Equipment	1,086	832	737	709	758
Aircraft	5,212	370	436	844	0.0
Other[53]	72	232	397	317	706
Alternative Fuel Vehicles	**195**	**212**	**281**	**880**	**843**
Light Duty Vehicles	45	50	85	269	285
Heavy Duty Vehicles	144	151	182	552	497
Buses	6	11	14	58	60
Total	**212,561**	**252,761**	**250,518**	**177,068**	**114,933**

See Appendix D for details.

[53] "Other" includes small gasoline powered utility equipment, heavy-duty gasoline powered utility equipment, and heavy-duty diesel powered utility equipment.

FIGURE 33. N_2O EMISSIONS FROM MOBILE SOURCE COMBUSTION

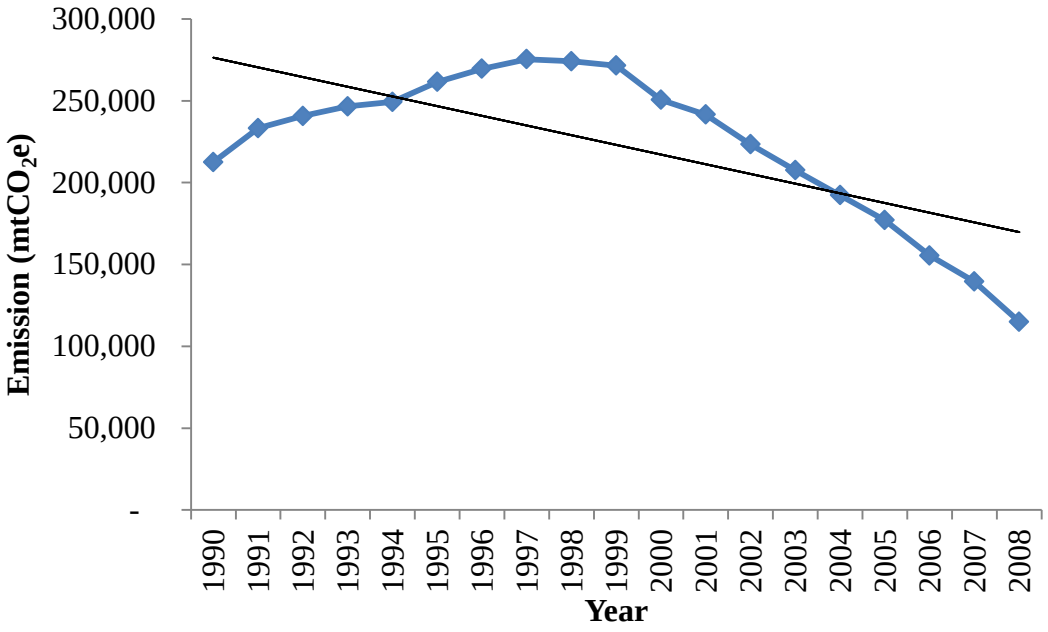
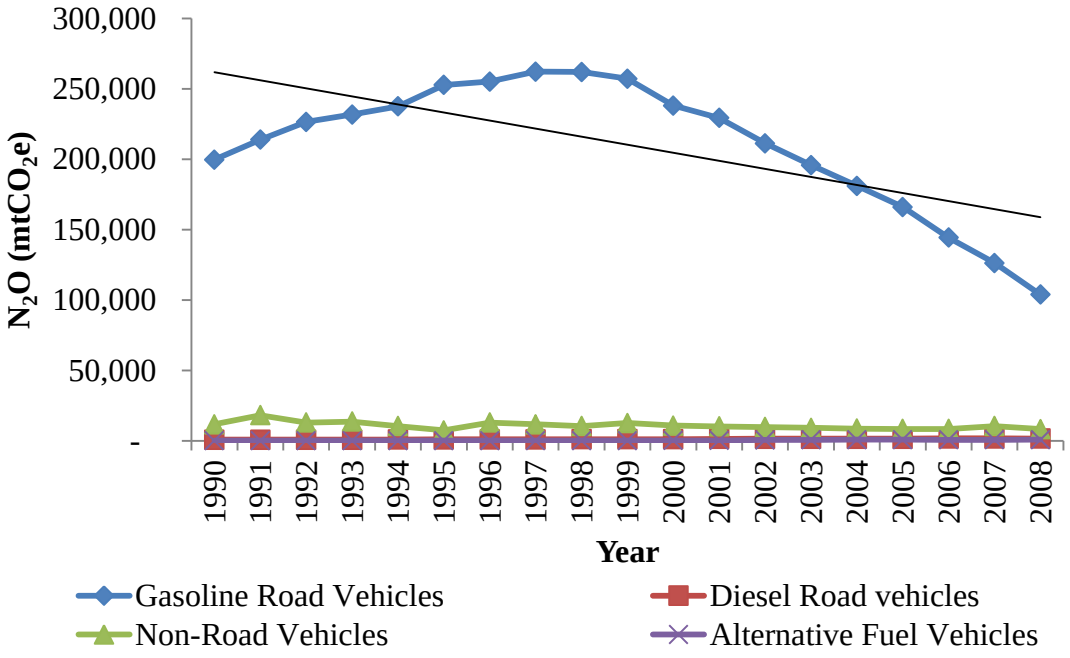


Figure 34 provides N_2O emissions from the mobile source combustion of fossil fuels by vehicles type from 1990 to 2008. As shown by the chart, N_2O emissions from gasoline road vehicles were the largest. Nitrous oxide emissions from gasoline road vehicles peaked in 1997, with a total of 262,189 $mtCO_2e$ (0.26 $MmtCO_2e$), an increase of approximately 31% from 199,680 $mtCO_2e$ (0.20 $MmtCO_2e$) in 1990. Nitrous oxide emissions from gasoline road vehicles later decreased drastically to 103, 989 $mtCO_2e$ (0.10 $MmtCO_2e$) in 2008, a decrease of approximately 60%. Overall, N_2O emissions from gasoline road vehicles decreased at the rate of 5, 916 $mtCO_2e$ per year.

From 1990 to 2008, N_2O emissions from diesel road and alternative fuel vehicles increased by approximately 103% and 332% respectively. The rate of increase of N2O emissions from both diesel road and alternative fuel vehicles were approximately 57 $mtCO_2e$ per year and 45 $mtCO_2e$ per year respectively. Conversely, N_2O emissions from non-road vehicles decreased from 11,827

$mtCO_2e$ in 1990 to 8,360 $mtCO_2e$ in 2008, a decrease of approximately 30%. The rate of decrease was approximately 297 $mtCO_2e$ per year.

FIGURE 34. N_2O EMISSIONS FROM MOBILE SOURCE COMBUSTION BY VEHICLE TYPES



Methane: As observed in Figure 35, CH_4 emissions from mobile combustion decreased from1990 at 23,397 $mtCO_2e$ to 2008 at 8,876 $mtCO_2e$ by approximately 62%. Trendline analysis determined that the rate of decrease was 831 $mtCO_2e$. Table 12 provides estimates of CH_4 emissions by vehicle types.

Figure 36 provides the CH_4 emissions by vehicle type between 1990 and 2008. Methane emissions from gasoline road vehicles dropped from 21,199 $mtCO_2e$ in 1990 to 6,764 $mtCO_2e$ in 2008, a significant decrease of 68%. The rate of decrease was determined to be 862 $mtCO_2e$ per year. Emissions from the other vehicles vehicle types (non-road, diesel road and alternative fuel) were minimal with averages of 2,313 $mtCO_2e$, 123 $mtCO_2e$ and 90 $mtCO_2e$ respectively.

TABLE 12. TOTAL CH_4 EMISSIONS FROM MOBILE SOURCE COMBUSTION ($MTCO_2e$) BY VEHICLE TYPE					
Fuel Type/Vehicle Type	**1990**	**1995**	**2000**	**2005**	**2008**
Gasoline Road	**21,199**	**19,347**	**13,867**	**9,623**	**6,764**
Passenger Cars	12,977	10,756	7,907	5,590	3,874
Light-Duty Trucks	6,829	7,320	5,189	3,495	2,694
Heavy-Duty Vehicles	1,313	1,179	691	461	93
Motorcycles	80	91	81	77	102
Diesel Road	**60**	**75**	**86**	**113**	**122**
Passenger Cars	1	1	0	0	0
Light-Duty Trucks	2	2	3	3	4
Heavy-Duty Vehicles	57	72	82	110	117
Non-Road	**2,124**	**1,745**	**2,261**	**2,453**	**1,650**
Boats	932	1,102	1,695	1,159	1,238
Locomotives	30	8	3	5	21
Farm Equipment	202	126	240	244	167
Construction Equipment	166	127	112	108	116
Aircraft	784	347	149	889	-
Other	11	35	61	48	108
Alternative Fuel Vehicles	**14**	**27**	**68**	**294**	**340**
Light Duty Vehicles	5	10	30	88	91
Heavy Duty Vehicles	5	10	28	161	204
Buses	4	8	11	44	45
Total	**23,397**	**21,194**	**16,282**	**12,482**	**8,876**

See Appendix E for details

FIGURE 35. CH_4 EMISSIONS FROM MOBILE SOURCE COMBUSTION

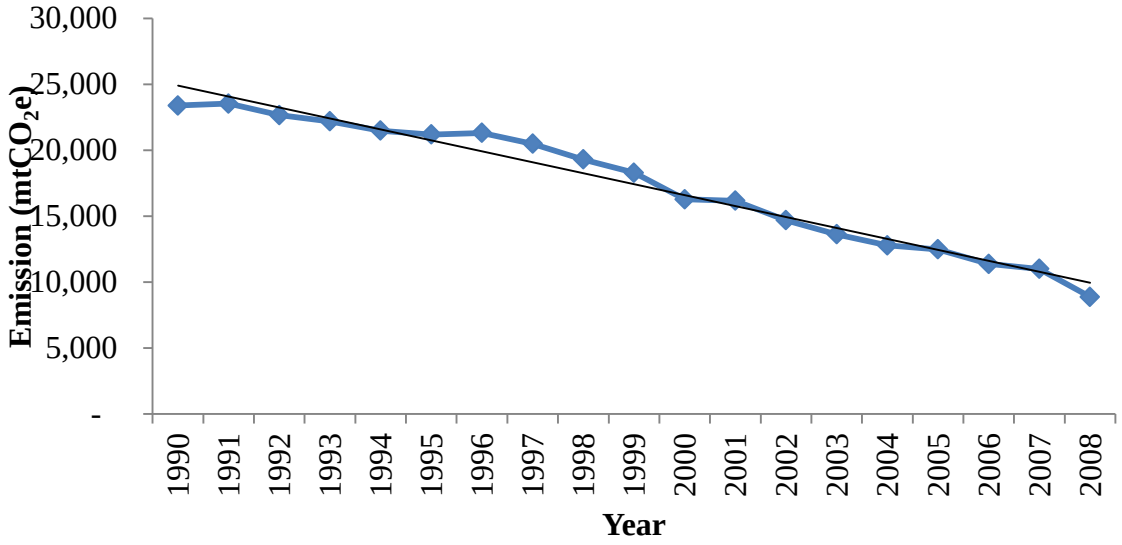


FIGURE 36. CH_4 EMISSIONS FROM MOBILE COMBUSTION BY VEHICLE TYPES

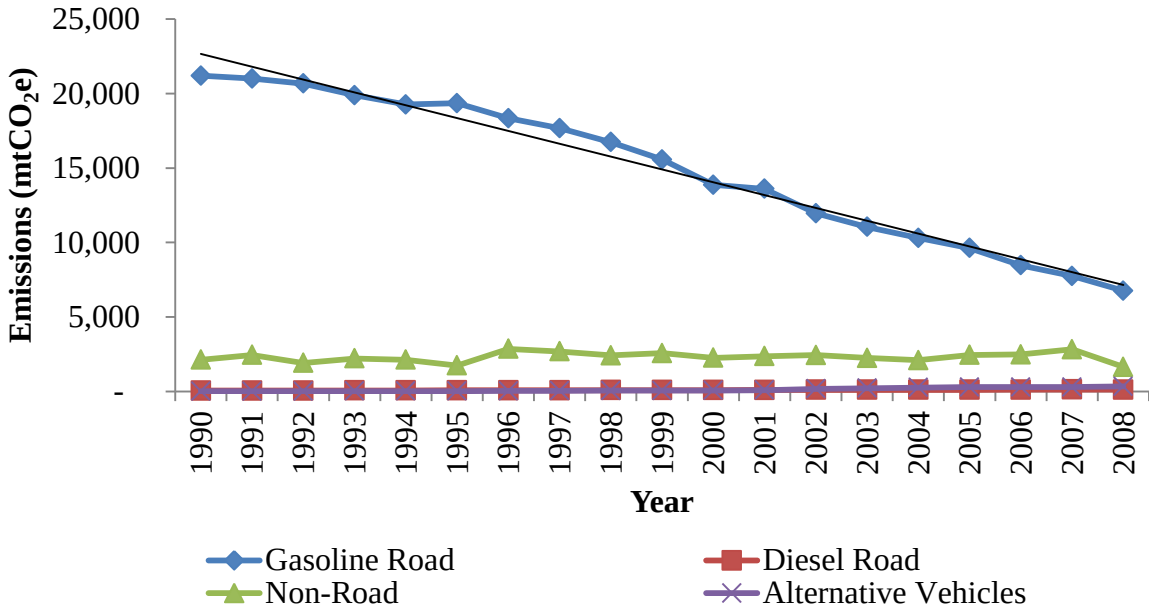
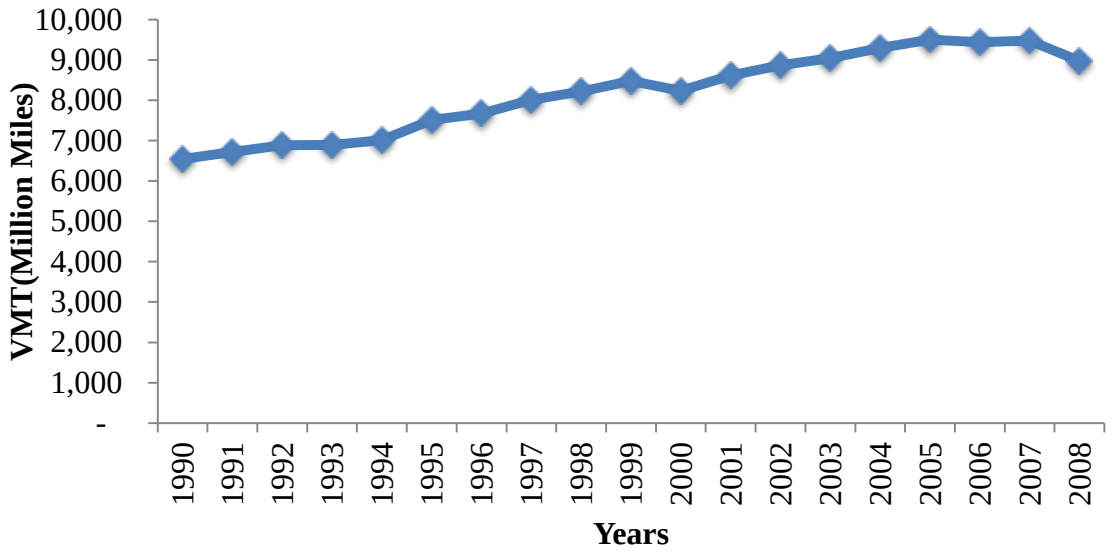


FIGURE 37. VEHICLE MILES TRAVELED (MILLION MILES)



As observed in Figure 32, the downward trend of N_2O and CH_4 emissions from the mobile source combustion category between 1990 and 2008 contradicts the upward trend of the vehicle miles traveled (VMT)[54] data as presented in Figure 37. Emissions were expected to increase with VMT. However, the contradiction in trends suggests that the relationship between VMT and CH_4 and N_2O emissions from mobile combustion is more complex.

The counter intuitiveness of the results points to other factors affecting emissions from mobile combustion sources.N_2O is a product of the catalytic process in vehicles and not a function VMT, while CH_4 is a product of incomplete fuel combustion. The emission of both gases is dependent on the amount of fuel consumed which in turn depends on vehicle miles traveled. Yet as the trends shows N_2O and CH_4 are declining while VMT is

[54] The Federal Highway Administration (FHWA), in FHWA's Highway Statistics report (Table VM-2), available online at: http://www.fhwa.dot.gov/policy/ohpi/hss/index.cfm.

increasing. This decline in emissions could be a attributed to engine efficiency, which has been steadily improved with better engine design, more precise ignition timing, and computerized engine management. These improvements in motor vehicles have minimized fuel consumption by improving efficiency, which subsequently reduces N_2O and CH_4 emissions. In addition, the introduction of improved emission control technologies[55] and the introduction of high efficiency vehicles such as hybrids have contributed to reductions in emissions.

4.2.3 Stationary Source Combustion (CH_4 and N_2O): This subcategory involves the stationary combustion of fuels that lead to the emissions of CH_4 or N_2O, but not CO_2[56]. The sources characterized in this subcategory according to the Emissions Inventory Improvement Program guidance[57] were stationary combustion sources that emitted CH_4 and N_2O. Carbon dioxide emission estimates from stationary combustion sources were included in the FFC subcategory. The estimation of emissions from stationary combustion using the IPCC tier 1 approach[58] was employed, which included the following basic formula: total emissions for Delaware State equals the sum of emissions for both CH_4 and N_2O across sectors and fuel types. Stationary combustion sources in the 2008 GHG inventory included electric power, residential, industrial, commercial and industrial sectors of Delaware's economy. In general, emissions of CH_4 and N_2O will vary with the type of fuel combusted, the size and vintage of the combustion technology, the maintenance and operation of the combustion equipment, and the type of pollution control technology used.

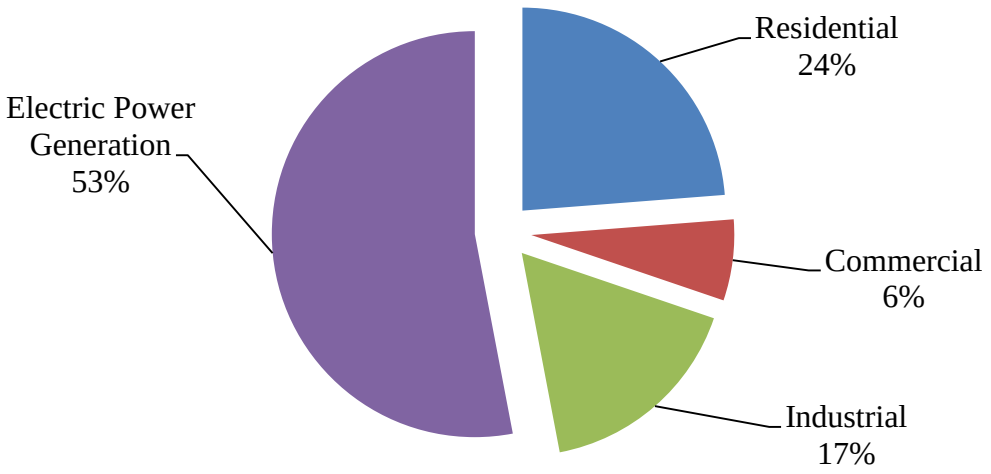
[55] OBDII (On Board Diagnostics II) systems are required by Federal law on all passenger cars and light trucks manufactured since 1996. It is a computer on board the vehicle that monitors the engine and emission control equipment to verify that all systems are working properly. If the monitor detects a fault, a code is stored in the computer, and the malfunction indicator lamp (MIL) is illuminated.
http://www.catalyticconverter.org/obd_II/index.htm

[56] Carbon dioxide emissions from the stationary combustion of fuels is covered under section 4.2.1under FFC

[57] 2004 U.S. EPA's Emissions Inventory Improvement Plan Volume VIII Chapter 2.
[58] 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

In 2008, emissions from stationary combustion sources were a miniscule 0.003% of the total GHG emissions (based on CO_2e) from energy related activities with a total of 0.055 $MmtCO_2e$ (55,380 $mtCO_2e$). The stationary combustion category covered Delaware's economic sectors including residential, commercial, industrial and electric power generation. As Figure 38 shows, electric power generation had the largest share of emissions in 2008 with approximately 53% followed by residential, which was approximately 24%. The industrial and commercial sectors were approximately 17% and 6% respectively. Table 13 provides a list of fuel types that were analyzed in the 2008 GHG emissions inventory.

FIGURE 38. CH_4 & N_2O EMISSIONS FROM STATIONARY COMBUSTION BY SECTORS



The general equation used to calculate CH_4 and N_2O emissions from fossil fuel combustion in the residential, commercial, and electric power sectors is shown in Equation 3. The equation used for estimating emissions in the industrial sector is also similar to Equation 4, but includes the non-energy use of fuels, as shown in Equation 5.

EQUATION 3. GENERAL EQUATION FOR STATIONARY COMBUSTION EMISSIONS

Emissions	=	*Σ (Activityab x EFab)*
Where: Activity	=	*Energy input [59](BBtu);*
EF	=	*Emission factor[60](mt/BBtu);*
a	=	*Primary fuel type; and*
b	=	*Source*

EQUATION 4. GENERAL EMISSION EQUATION

Emissions ($MmtCO_{2e}$) = Consumption (BBtu) × Emission Factor (mt/BBtu) × GWP ÷ 1,000,000 (to yield $MmtCO_2e$)

EQUATION 5. EMISSION EQUATION FOR THE INDUSTRIAL SECTOR

Emissions ($MmtCO_2e$) = [Total Consumption (BBtu) – Non-Energy Consumption (BBtu)] × Emission Factor (mt/BBtu) × GWP ÷ 1,000,000 (to yield $MmtCO_2e$)

[59] Default state-level data derived from EIA's State Energy Data 2007: Consumption Estimates. (EIA 2009) Appendix B: Thermal Conversion Factors.

[60] Default emission factors are provided in the Stationary Combustion module for all fuel types and sectors and are available from IPCC (2006).

TABLE 13. STATIONARY COMBUSTION FUEL TYPES				
Residential	**Commercial**	**Industrial**	**Transportation**	**Electric Utilities**
				Coal
Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Petroleum: Fuel oil	Petroleum: Diesel Fuel oil	Petroleum: Asphalt & Road Oil Feed stocks Misc. Petroleum Products Petroleum Coke Pentanes Plus Still Gas Special Naphthas Unfinished Oils Waxes Aviation Gasoline Blending Components Motor Gasoline	Petroleum: Jet Fuel, Kerosene Jet Fuel, Naphtha Gasoline Diesel	Petroleum: Petroleum Fuel Oil petrol

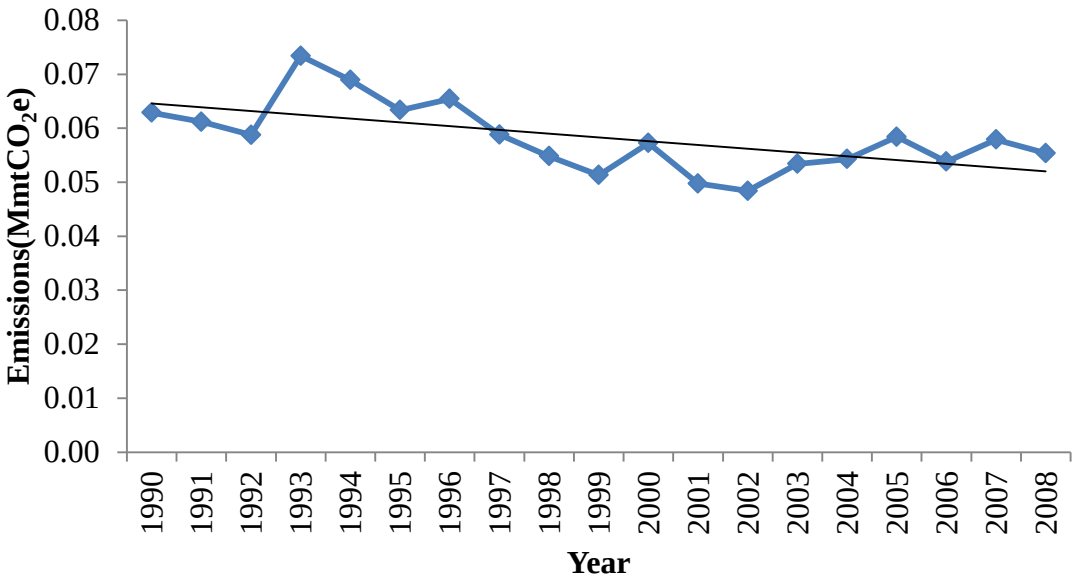
EPA's State Inventory Tool 2008 updates

Analysis of Historical Stationary Source Combustion Emissions

Figure 39 presents emissions of N_2O and CH_4 from stationary source combustion of fossil fuels. Annual emissions fluctuate from 1990 to 2008, with the highest point in 1993 at 0.073 $MmtCO_2e$ (73,409 $mtCO_2e$), and lowest in 2002 at 0.048 $MmtCO_2e$ (48,398 $mtCO_2e$). The total GHG emission realized in 2008 was 0.055 $MmtCO_2e$ (55,380 $mtCO_2e$). From 1990 (0.063$MmtCO_2e$) to 2008 N_2O and CH_4 emissions from stationary combustion dropped by 13%. The rate of decrease was determined to be 0.001 $MmtCO_2e$ per year

Figure 38 shows that both N_2O and CH_4 emissions fluctuate from 1990 to 2008. Nitrous oxide emissions were consisitently higher than CH_4 emissions between 1990 and 2008. Nitrous oxide emissions varied between 0.044 $MmtCO_2e$ (43,590 $mtCO_2e$) to 0.038 $MmtCO_2e$ (38,433$mtCO_2e$), while the average CH_4 emission was approximately 0.02 $MmtCO_2e$ (19,280 $mtCO_2e$).

FIGURE 39. N_2O & CH_4 EMISSIONS FROM STATIONARY COMBUSTION



Both N_2O and CH_4 emissions trend down from1990 to 2008. Nitrous oxide emissions decreased by approximately 14% from from 1990 to 2008.

Methane emissions remained relatively flat as Figure 40. demonstratesThe reduction N_2O and CH_4 can be tied to decreasing amounts of fossil fuels consumed during this period as observed in the fossil fuel consumption data. Table 14 provides estimates of N_2O and CH_4 emissions by economic sector.

FIGURE 40. HISTORICAL STATIONARY COMBUSTION EMISSIONS BY GHGS

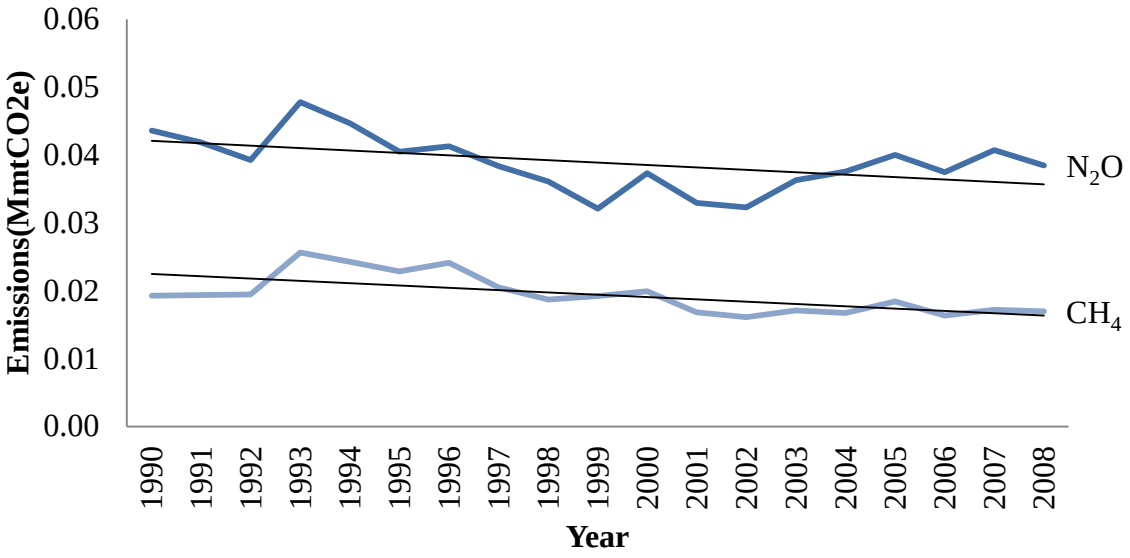
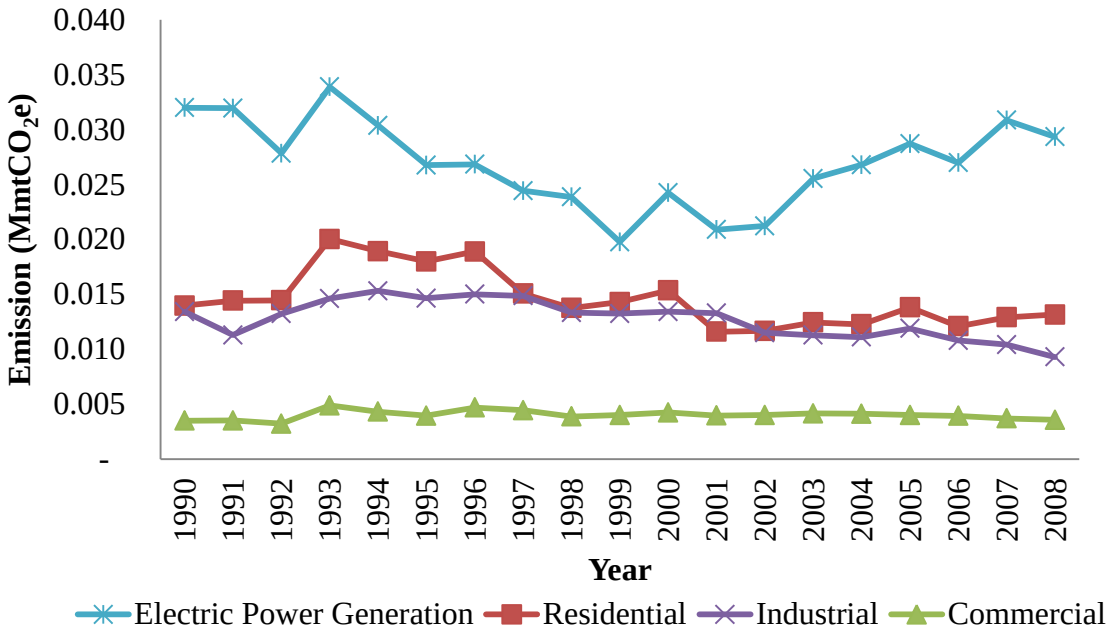


TABLE 14. GHG EMISSIONS FROM STATIONARY COMBUSTION EMISSIONS BY SECTORS ($MMTCO_2e$)					
Sectors	**1990**	**1995**	**2000**	**2005**	**2008**
Electric Power	**0.032**	**0.018**	**0.015**	**0.014**	**0.029**
N_2O	0.029	0.004	0.004	0.003	0.028
CH_4	0.003	0.014	0.012	0.010	0.002
Residential	**0.014**	**0.004**	**0.004**	**0.004**	**0.013**
N_2O	0.003	0.001	0.001	0.001	0.003
CH_4	0.011	0.003	0.003	0.003	0.010
Commercial	**0.003**	**0.015**	**0.013**	**0.012**	**0.004**
N_2O	0.001	0.011	0.010	0.009	0.001
CH_4	0.002	0.004	0.004	0.003	0.003
Industrial	**0.013**	**0.027**	**0.024**	**0.029**	**0.009**
N_2O	0.010	0.025	0.023	0.027	0.007
CH_4	0.004	0.002	0.002	0.002	0.003

TABLE 14. GHG EMISSIONS FROM STATIONARY COMBUSTION EMISSIONS BY SECTORS ($MMTCO_2e$)					
Sectors	**1990**	**1995**	**2000**	**2005**	**2008**
TOTAL	**0.063**	**0.063**	**0.057**	**0.058**	**0.055**
N_2O	0.044	0.040	0.037	0.040	0.038
CH_4	0.019	0.02	0.02	0.02	0.017

See Appendix F for details.

FIGURE 41 STATIONARY COMBUSTION GHG EMISSIONS BY SECTORS



As Figure 41 presents, GHG[61] emissions from electric power generation exceeded all other sectors from 1990 to 2008. Emissions dipped in 1999 with 0.02 $MmtCO_2e$, but increased to 0.029 $MmtCO_2e$ in 2008. GHG emissions amounts from the residential and industrial sectors were equivalent, while the commercial sector was slightly lower than all the other sectors with and average amount 0.004 $MmtCO_2e$.

[61] GHG emissions include N_2O and CH_4

Variations in N_2O and CH_4 emissions from stationary fossil fuel combustion that were observed in Figure 41, were consistent with the variations observed in fossil fuel consumption in Delaware as provided by Figure 14. This consistency in variations observed between Figure 41 and Figure 14 suggests that GHG emissions from the stationary combustion of fossil fuels are directly proportional to fossil fuel consumption.

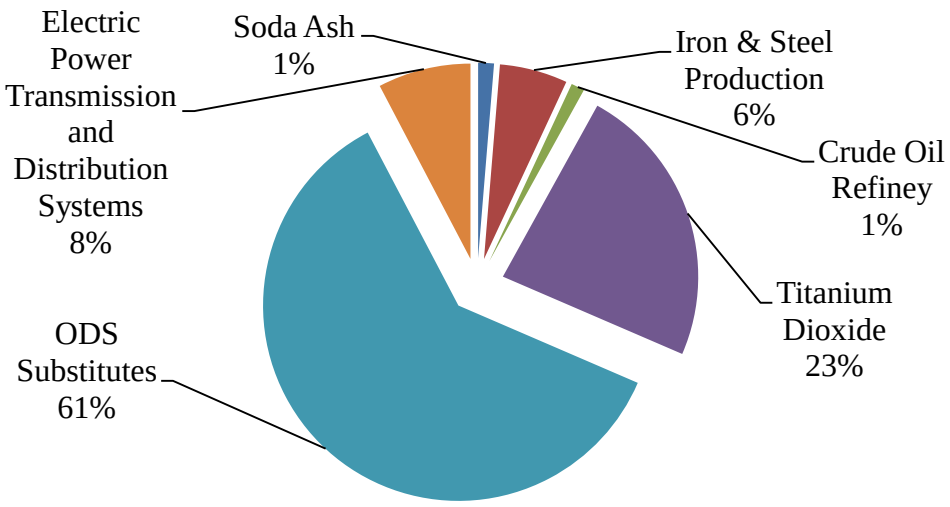
4.3 NON-ENERGY RELATED EMISSIONS FROM INDUSTRIAL PROCESSES

The GHG emissions that were accounted for in the industrial process source category were from non-energy related industrial activities. In 2008, the total emission from non-energy related industrial processes was 534,676 $mtCO_2e$, (0.53 $MmtCO_2e$) which was 3% of Delaware's gross emissions. Delaware's industrial process sources and associated GHGs emitted include:

- Ozone Depleting Substances (ODS)
- Titanium Dioxide Production (CO_2)
- Transmission and Distribution Systems (SF_6)
- Iron and Steel production (CO_2)
- Oil Refining (CH_4)
- Soda Ash Consumption (CO_2)

Figure 42 presents the CO_2e emissions (non-combustion) from the industrial process sources. Ozone depleting substitutes had the largest contribution to industrial process category with 61% of total CO_2e emissions, followed by CO_2 emission from titanium dioxide (TiO_2) production with 23%, transmissions & distribution with 8%, iron and steel production with 6%, soda ash consumption and oil refining with 1% each.

FIGURE 42. CO_2e EMISSIONS BY NON-ENERGY RELATED INDUSTRIAL PROCESS SOURCES



Analysis of Historical Non-Energy Related Industrial Emissions

Figure 43 provides the CO_2e emissions from the non-energy related industrial processes in Delaware from 1990 to 2008. CO_2e Emissions increased from 290,480 $mtCO_2e$ in 1990 to 534,676 $mtCO_2e$ in 2008, an increase of approximately 84%. The rate of increase between 1990 and 2008 was determined to be 17,292 $mtCO_2e$ per year. Table 15 provides estimates of GHG emissions from subcategories of non-energy related industrial process emissions.

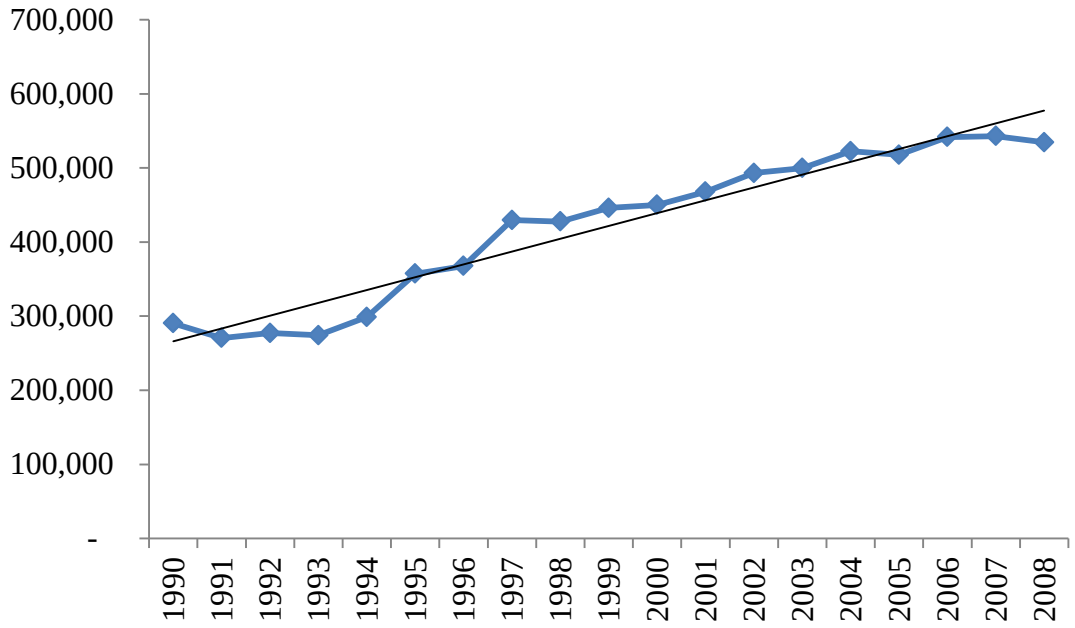
TABLE 15. GHG EMISSION ESTIMATES FROM NON-ENERGY RELATED INDUSTRIAL EMISSIONS

Fuel Type/Vehicle Type	1990	1995	2000	2005	2008
ODS Substitutes	888	79,181	207,076	292,843	325,251
Titanium Dioxide Production	194,218	196,844	152,623	137,753	125,347
Transmission & Distribution	81,313	68,022	49,514	46,287	41,117
Iron & Steel Production	0	0	26,306	26,484	30,065
Oil Refinery	6,753	5,834	7,209	7,080	5,926
Soda Ash	7,308	7,402	7,416	7,350	6,971

TABLE 15. GHG EMISSION ESTIMATES FROM NON-ENERGY RELATED INDUSTRIAL EMISSIONS					
Fuel Type/Vehicle Type	**1990**	**1995**	**2000**	**2005**	**2008**
Total Emissions	**290,480**	**357,284**	**450,144**	**517,798**	**534,676**

See Appendix G for details.

FIGURE 43. CO_2E EMISSIONS FROM NON-ENERGY RELATED INDUSTRIAL PROCESSES



Methodologies for Estimating Non-energy Related Industrial Process Emissions

Estimating GHG emissions from the non-energy related industrial process sources followed the general method of calculating GHG emissions. Data was collected on the various industrial process activities required for the calculation (i.e., production and/or consumption data) and then multiplied by their respective emission factors. The general equation used to estimate emission from the non-energy related industrial process is provided by Equation 6:

EQUATION 6. GENERAL EMISSION EQUATION FOR NON-ENERGY INDUSTRIAL PROCESSES

$$Emissions = Activity\ Level \times Emission\ Factor$$

Section 4.3.1 to 4.3.6 provides information on all the sources analyzed in the non-energy related industrial processes.

4.3.1 Ozone Depleting Substance Substitutes: The GHGs associated with this source includes hydrofluorocarbons (HFCs) and Perfluorocarbons (PFCs). Hydro fluorocarbons (HFCs) are used primarily as alternatives to several classes of ozone depleting substances (ODSs) including chlorofluorocarbons, halons, carbon tetrachloride and methyl chloroform, which are being phased out under the terms of the Montreal Protocol and the Clean Air Act Amendments of 1990.

Ozone depleting substances, which include chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and hydro chlorofluorocarbons (HCFCs), are used in a variety of applications including refrigeration and air conditioning equipment, aerosols, solvent cleaning, fire extinguishing, foam blowing, and sterilization.

In 2008, gross ODS related GHG emission from this source were 61% of total emissions from the non-energy related industrial processes. Although their substitutes, HFCs, are not harmful to the stratospheric ozone layer, they are powerful greenhouse gases. These gases are used in Delaware industries for refrigeration, air conditioning equipment, solvent cleaning, sterilization and aerosol.

Methodology

Delaware state level emissions for ODS substitutes were estimated based on national emissions[62]. State-level emissions of HFCs used as ODS substitutes were estimated by calculating per-capita emissions of HFCs used as ODS substitutes and then multiplying per-capita emissions by state population.

EQUATION 7. GENERAL EMISSION EQUATION FOR ODS

Per-Capita Emissions (MTCE/person)	=	*National Emissions (MTCE) /national Population*
State-Level Emissions (MTCE)	=	*Per-Capita Emissions (MTCE/person) x State Population*

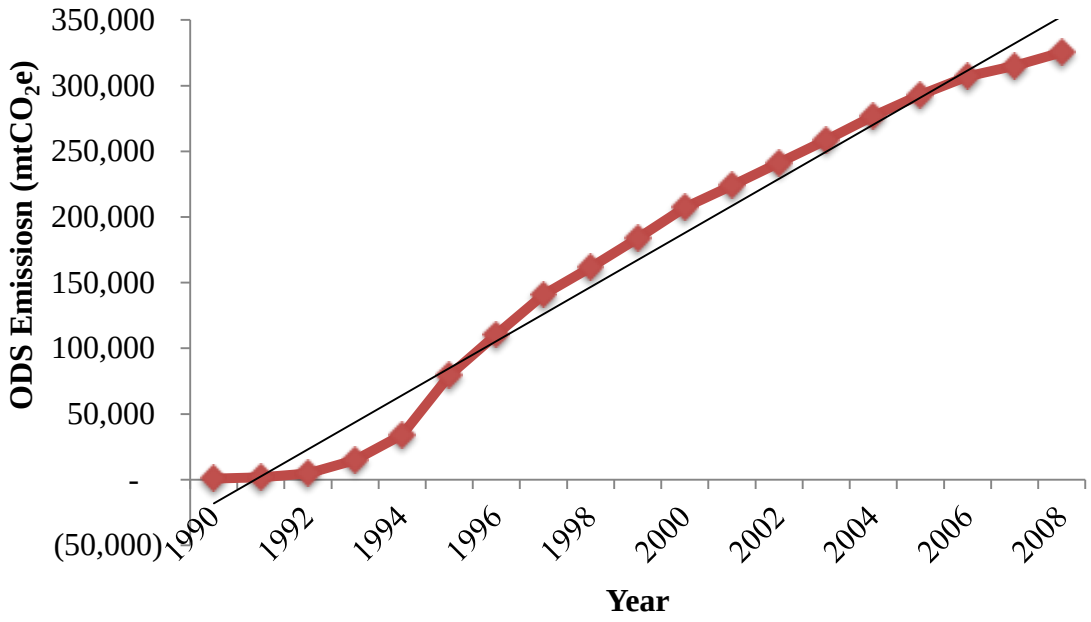
ODS substitute emissions accounted for 7% of all GHG emissions in the industrial process subcategory in 2008. The total amount of ODS emission in 2008 was 325,251 $mtCO_2e$. The emission of ODS substitutes come from many point sources, which makes the estimation of emissions difficult.

ODS Emission Analysis

Figure 44 shows that ODS substitute emissions from this subcategory increased from 888 $mtCO_2e$ in 1990 to 325,251 $mtCO_2e$ (0.33 $MmtCO_2e$) in 2008, an increase of approximately 36,533%. The rate of annual increase was determined to be 20,606 $mtCO_2e$ per year. This drastic rise in ODS substitutes emissions could be attributed to the increased application of ODS substitutes in many household products since 1990.

[62]The Chemical Manufacturers Association (Washington, D.C.), Alliance for Responsible CFC Policy (Arlington, VA) Grant Thornton Consulting (Washington, D.C.)

FIGURE 44. HISTORICAL ODS SUBSTITUTES EMISSIONS



4.3.2 CO_2 Emissions from the Production of Titanium Dioxide

Titanium Oxide (TiO_2) is a metal oxide commonly used as white pigment in paint manufacturing, paper, food coloring, plastics, sunscreen and ceramic applications[63]. The DuPont Edgemoor facility in Delaware is the only producer of TiO_2 in the State. The facility has the production capacity of 154,000 Metric Tons per year[64]. Titanium Oxide is produced through two processes from titanium ore: 1) chloride process and 2) sulfate process. The chloride process uses petroleum coke and chlorine as raw materials, which leads to CO_2 emissions. The sulfate process does not use petroleum coke or any other forms of carbon as a raw material, and does not emit process related CO_2. The DuPont Edgemoor facility uses the chloride process to produce TiO_2[65]. During the chloride

[63] EPA's Technical Support Document for Titanium Dioxide: Proposed rule for Mandatory Reporting of GHGs 2009

[64] USGS 2009 estimates for Delaware: http://minerals.usgs.gov/minerals/pubs/commodity/titanium/

[65] The sulfate process is not used for TiO_2 production in Delaware

process, petroleum coke is oxidized as the reducing agent in the first reaction in the presence of chlorine and crystallized titanium oxide ($FeTiO_3$) to form CO_2. Calcinated[66] petroleum coke, (CPC) is used for the chloride process. The chloride process is based on the following chemical reaction:

EQUATION 8. GENERAL EMISSION EQUATION FOR ODS

Step 1: $2FeTiO_3 + 7Cl_2 + 3C => 2TiCl_4 + 2FeCl_3 + 3CO_2$

Step 2: $2TiCl_4 + 2O_2 => 2TiO_2 + 4Cl_2$

The carbon (C) in the first chemical reaction is provided by petroleum coke, which is oxidized in the presence of the chlorine and FeTiO3 (the Ti-containing ore) to form CO_2. The $TiCl_4$ produced in the first reaction is oxidized at 1,000 ^oC and the resulting TiO_2 is calcinated to remove residual chlorine and any hydro chloric acid that may have formed in the reaction.

Methodology

The Division of Air Quality (DAQ) requested facility data from DuPont Edgemoor to calculate CO_2 emissions from the facility. DuPont Edgemoor submitted TiO_2 production data from 2005 and 2010 as provided in Table 16. The CO_2 emissions in Table 16 were obtained by direct measurement using a continuous emissions monitoring system (CEMS). The CEMS is a device that continuously withdraws and analyzes samples of stack gas and measures the GHG concentration and flow rate of the gas.

[66] A thermal treatment process in presence of air applied to ores and other solid materials to bring about a thermal decomposition or removal of a volatile fraction.

TABLE 16. FACILITY LEVEL PRODUCTION DATA FROM DUPONT EDGEMOOR		
Year	TiO_2 Production (short tons)	CO_2 Emissions (short tons) from CEM
2005	103,572	95,792
2006	105,428,	103,781
2007	93,594	110,617
2008	89,572	103,061
2009	97,572	108,343
2010	106,639	127,916

*DuPont Edgemoor Facility Data reported to EPA

The facility level data provided by DuPont Edgemoor covered 2005 and 2010 production years. To estimate the amount of CO_2 emitted from TiO_2 production, the 2009 U.S. EPA technical document[67] for titanium dioxide production was followed, which was based 2006 IPCC guidelines[68]. The method that was used was consistent with the IPCC Tier 1 method, which determined process related CO_2 emissions based on production activity data. A default emission factor of 0.4 metric ton C/metric ton TiO_2[69] was applied to the estimated chloride process production. The emission factor was taking from U.S. EPA's GHG inventory for 2012.

[67] EPA's Technical Support Document for Titanium Dioxide: Proposed rule for Mandatory Reporting of GHGs 2009

[68] IPCC 2006 Guidelines for National Greenhouse gas Inventories vol.1

[69] 2012 US EPA's US-GHG-Inventory-2012: http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-Chapter-4-Industrial-Processes.pdf

EQUATION 9. CO_2 EMISSION EQUATION FOR TITANIUM DIOXIDE

$$CO_{2\ emissions} = TiO_{2\ Production} \times Emissions\ Factor$$

Based the above equation, DuPont Edgemoore produced 85,479 metric tons (mt) of TiO_2, (94,244 short tons) in 2008. The production data was used to estimate the CO_2 emissions by applying it to the above equation, the result was 125,347 metric tons of CO_2 ($mtCO_2e$) emitted in 2008, which represented approximately 23% of the total Industrial CO_2e emissions. Table 17 provides the results of the CO_2 emission estimates from TiO_2 production.

TABLE 17. CO_2 EMISSION ESTIMATES FROM TiO_2 PRODUCTION

Year	TiO_2 production [70] (mt*)	C[71] (mt)	CO_2 (mt)
1990	132,446	52,978	194,218
1991	120,334	48,134	176,458
1992	123,006	49,203	180,377
1993	113,781	45,513	166,849
1994	120,778	48,311	177,109
1995	134,236	53,694	196,844
1996	124,229	49,692	182,170
1997	130,252	52,101	191,002

[70] Data based on the Annual Air Emission Inventory and Emission Statement Facility Report submitted to DAQ by DuPont Edgemoor.

[71] Using equation 6, carbon generated from TIO2 production is calculated. Then CO2 emissions are calculated using the ratio of the molecular weight of CO_2 (m.w. 44) to the molecular weight of carbon (m.w.12): 44/12.

TABLE 17. CO_2 EMISSION ESTIMATES FROM TiO_2 PRODUCTION			
Year	**TiO_2 production [70] (mt*)**	**C[71] (mt)**	**CO_2 (mt)**
1998	120,778	48,311	177,109
1999	119,964	47,986	175,916
2000	104,080	41,632	152,623
2001	104,854	41,941	153,758
2002	110,649	44,259	162,255
2003	103,858	41,543	152,297
2004	105,765	42,306	155,094
2005	93,940	37,576	137,753
2006	101,333	40,533	148,594
2007	96,342	38,537	141,277
2008	85,479	34,192	125,347

* mt: metric tons,

Titanium Dioxide CO_2 Emission Analysis

As Figure 45 presents, the CO_2 emissions from TiO_2 production had a downward trend from 1990 to 2008. Carbon dioxide emissions went from 194,218 $mtCO_2e$ (0.19 $MmtCO_2e$) in 1990 to 125,347 $mtCO_2e$ (0.12 $MmtCO_2e$) in 2008, a decrease of approximately 35%. The rate of decrease from 1990 to 2008 was 3,062 $mtCO_2e$ per year.

Comparing the results of the estimated CO_2 emissions from TiO_2 production with the DuPont Edgemoore facility CO_2 emissions data, we observe an average difference of 34,930 $mtCO_2e$ as Table 18 shows.

FIGURE 45. DELAWARE CO_2 EMISSION FROM TiO_2 PRODUCTION

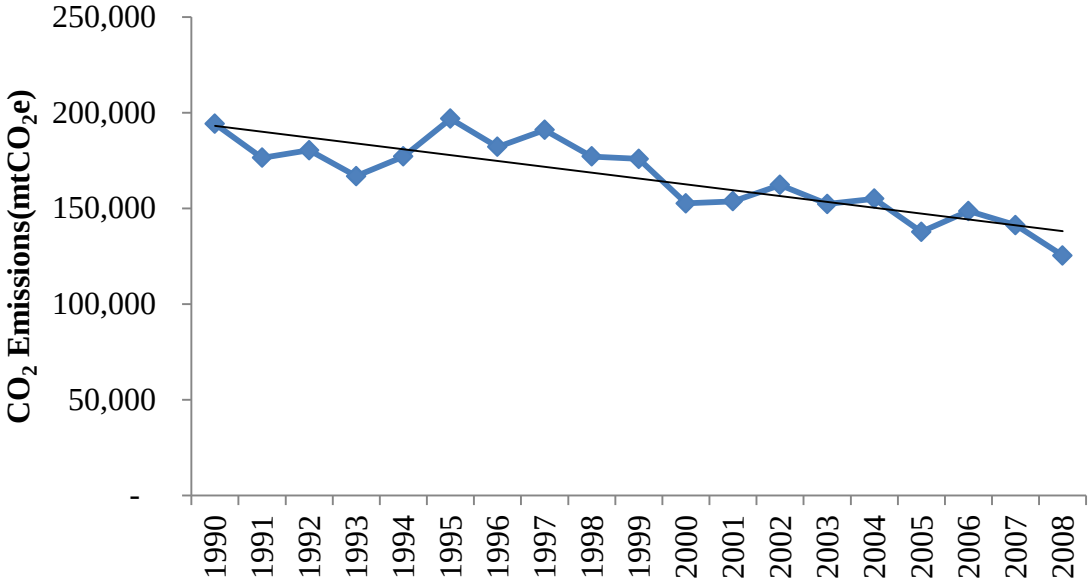


TABLE 18. ESTIMATED CO_2 EMISSIONS COMPARED WITH FACILITY CO_2 DATA IN MTCO_2E				
Year	**Estimated**	**DuPont**	**Difference**	**%Difference**
2005	137,753	95792	41,961	30
2006	148,594	103781	44,813	30
2007	141,277	110617	30,660	22
2008	125,347	103061	22,286	18
Average Difference			34,930	25

Figure 46 show that the difference between the two data sets gets smaller as we approach 2008. In the future inventories DAQ will explore the relationship between estimated CO_2 emissions and measure facility CO_2 emissions.

FIGURE 46. ESTIMATED CO_2 EMISSIONS VS FACILITY CO_2 EMISSIONS DATA

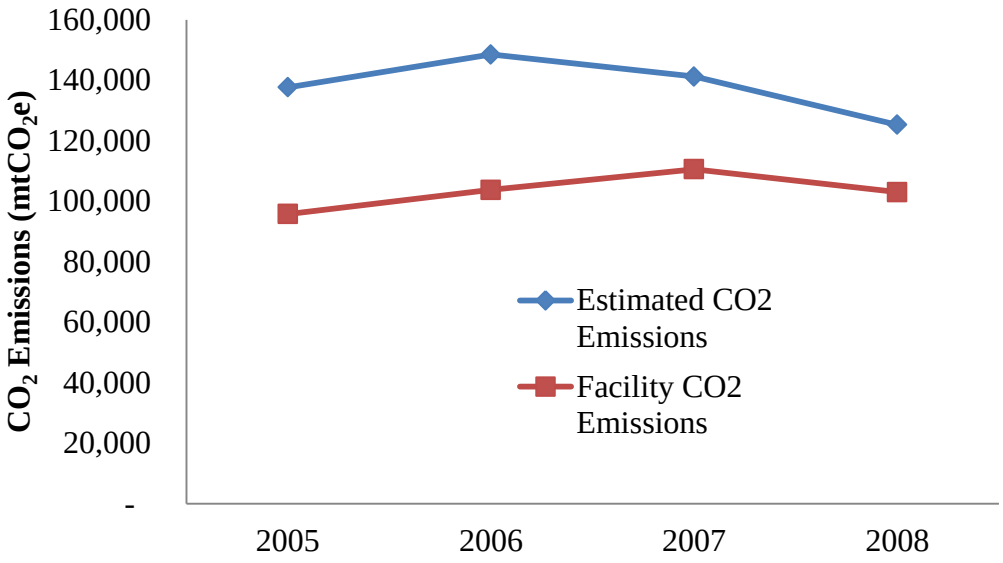
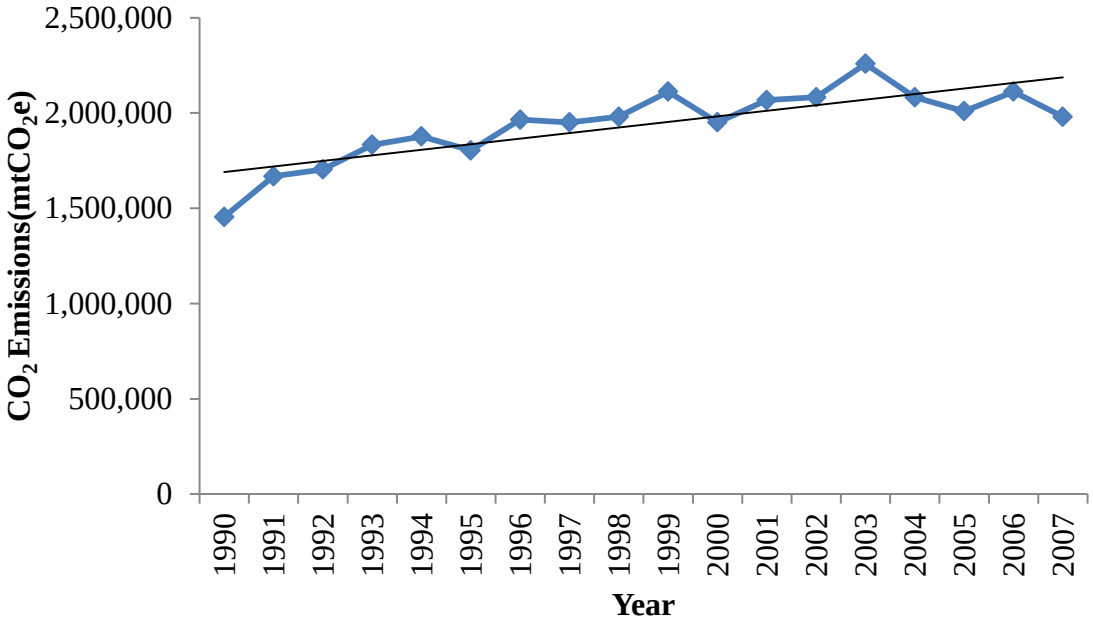


Figure 46 presents CO_2 emissions from the production of TiO_2 in the United States. As the figure shows, annual CO_2 emission from 1990 to 2008 increased slightly by 36%. The annual rate of increase was determined to be approximately 80.1 $MmtCO_2e$ per year.

When Figure 45, Delaware's emissions from TiO_2, is compared to Figure 47, U.S. CO_2 emissions from TiO_2 production, both emission trends are in different directions. The primary reason for this is because TiO_2 production at DuPont Edgemoor facility declined, while overall U.S. TiO_2 production increased between 1990 and 2008. DAQ's contact at the DuPont Edgemoor facility explained that the demand for TiO_2 from the facility gradually declined between 1990 and 2008 due to a downturn in the economy. In addition, DuPont has other facilities in Mississippi, Tennessee, Taiwan and Mexico. Production may have shifted to any of these other facilities based on considerations such as production cost effectiveness. Shifting TiO_2 production to other U.S. facilities would increase to U.S CO_2 emissions from TiO_2 production.

FIGURE 47. U.S. CO_2 EMISSIONS FROM TiO_2 PRODUCTION



4.3.3 Electric Power Transmission and distribution (T&D) systems

The GHG associated with this subcategory is sulfur hexafluoride (SF_6). The primary use of SF_6 is as an electric insulator and interrupter in the transmission and distribution of electricity due to its dielectric properties[72]. It is used in equipment such as circuit breakers and switch gears, replacing flammable insulating oils in many applications. Emission of SF_6 can be caused by fugitive emissions, and during the manufacture and installation of the equipment. Fugitive emission occurs in switch gears through seals, especially in older equipment.

In 2008, Delaware's SF_6 emissions were 41,117 $mtCO_2e$, from electric power transmission and distribution systems. Total GHG emission from this subcategory was approximately 8% of total CO_2e emissions from non-energy related industrial processes as shown in Figure 42.

[72] US EPA Inventory of U.S Greenhouse Gas Emissions 1990 to 2004

Methodology

The required activity[73] data for this subsector were 1) total national emissions of SF_6 from the electric utility sector in $mtCO_2e$, 2) the state's electricity consumption in million kilowatt hours, and 3) national electricity consumption in million kilowatt hours. The annual SF_6 emissions for Delaware were estimated using the following equation:

EQUATION 10. GENERAL EMISSION EQUATION FOR SF_6

Total State SF_6 Emissions (MTCE) = National SF_6 Emissions (MTCE) x State Electricity Consumption (million kWh) / National Electricity Consumption (million kWh)

The resulting emissions were converted to $mtCO_2e$. The default assumption was all SF_6 consumed was counted as emissions[74].

Analysis of Historical T&D Emissions

Figure 48 shows that there has been a steady decline in the emission of SF_6 from the power transmission and distribution systems in Delaware. Sulfur hexafluoride emissions dropped by approximately 50% from 1990 level of 81,313 $mtCO_2e$ to 2008 level of 41,117 $mtCO_2e$. The annual rate of decrease in SF_6 emissions was approximately 2,417 $mtCO_2e$ per year. The significant drop in the SF_6 emissions from power transmission and distribution systems is partly attributed to increases in the price of SF_6. In addition, the increased implementation SF_6 reduction practices in the transmission and distribution of electricity has also contributed to the rapid decline in SF_6 emissions. These practices include detection and repair of SF_6 leaks, SF_6 recycling and also increasing awareness on

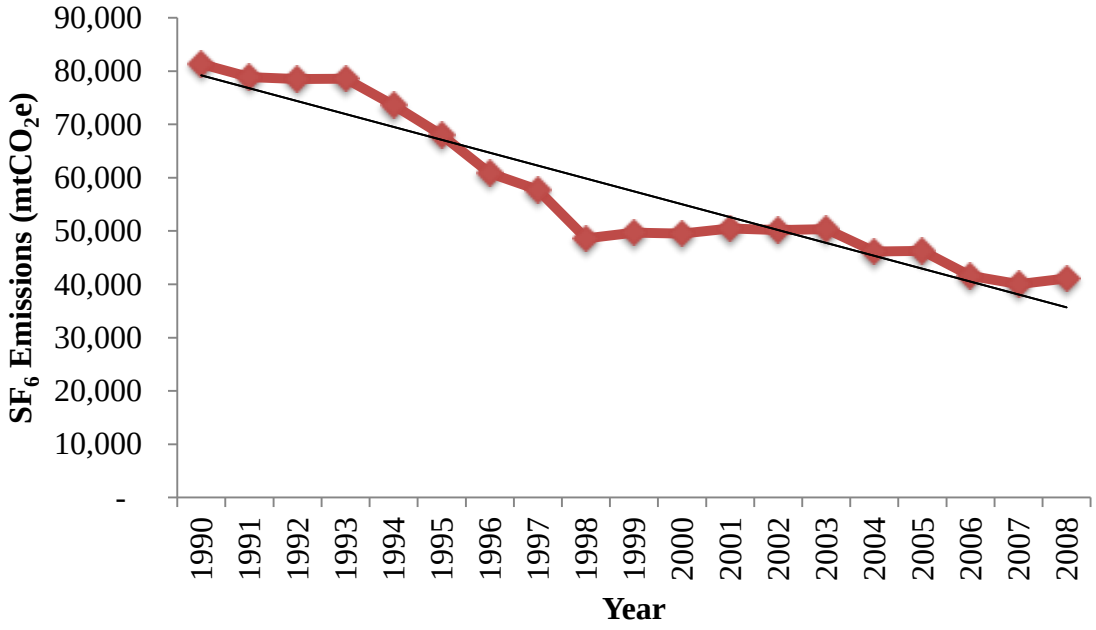
[73] Data source: State and national electricity consumption U.S. Department of Energy, Energy Information Administration report, Electric Power Annual 2008 Vol. I (EIA 2010) (Electricity Consumption data)

[74] US EPA State Inventory Tool, 2010. Industrial Process, Iron and Steel methodology.

the environmental impacts of SF_6. These practices have been promoted by the U.S. EPA[75] in partnership with the electric power industry to reduce SF_6 emissions.

In addition to these SF_6 reduction practices, new technology such as vacuum circuit breakers (VBCs), which replaces the need for SF6, are now available to the electric power industry.

FIGURE 48. SF_6 EMISSIONS FROM ELECTRIC POWER TRANSMISSIONS & DISTRIBUTION



4.3.4. Methane Emissions from Crude Oil Transportation and Refining

Crude Oil Refining: Methane emissions from the refining of crude oil are the focus in this source category. Delaware City Refinery is the only source. Crude oil is delivered to the refinery where it is temporarily stored before it undergoes fractional distillation and treatment. The fractions are reformed or cracked and

[75] http://www.epa.gov/electricpower-sf6

then blended into consumer petroleum products. Crude oil refining processes account for slightly over 2% of methane emissions from the oil industry because of the CH_4 in crude oil is removed or escapes before the crude oil is delivered to the refinery.

Refined products have insignificant (less than 1%) amounts of CH_4 emissions. CH_4 emissions within the refinery occur due to venting, fugitive and combustion emissions. Refinery systems blow-downs[76] for maintenance and the process for asphalt blowing, with air to harden asphalt, are the primary venting contributors. Most fugitive emissions occur due to leaks in the fuel gas system. Refinery combustion emissions include small amounts of unburned CH_4 in process heater stack and emissions as well as unburned CH_4 from engine exhaust and flares.

In 2008, Delaware City Oil Refinery released 5,926 $mtCO_2e$ ($>0.01MmtCO_2e$)[77] of CH_4 into the atmosphere. The CH_4 emission amount in 2008 was estimated based data collected from the Petroleum Administration for Defense District 1 (PADD1). The emissions total was 1% of GHG emissions in CO_2e from the industrial processes source category as presented by Figure 40.

Methodologies

Methane emissions from crude oil refining in Delaware was estimated using Equation 11, the general emission equation for petroleum systems.

[76] A blow-down is a vertical stack that is used to vent the pressure of components of a refinery or other process if there is a process problem or emergency.

[77] The emission amount was based on Petroleum Administration for Defense District 1 (PADD1) data. Methane emissions estimated based on facility data was 4,575 $mtCO_2e$ in 2008

EQUATION 11. GENERAL EMISSION EQUATION FOR PETROLEUM SYSTEMS

$$Emissions\ (MmtCO_2e) = Activity\ Data\ (\text{'}000\ barrels) \times Emission\ Factor\ (kg\ CH_4/\text{'}000\ barrels) \div 1{,}000\ (kg/mt) \times 21\ (GWP) \div 106\ (mt/Mmt)$$

The activity data used was barrels of oil refined in the State. The activity data was collected in two ways: 1) DAQ requested the facility data on the annual amount of refined crude oil from Delaware City Refinery, and 2) DAQ calculated the amount of oil refined in Delaware by using data collected from the PADD 1[78].

Methane emissions Based on facility Data

Delaware City refinery submitted to the DAQ oil refining data based barrels per day from 1999 to 2010. DAQ converted the data to barrels per year and the CH_4 emissions were estimated using annual emission factors. The CH_4 emissions were then converted to CO_2 equivalents using a GWP of 21[79]. Table 19 summarizes the results of the calculations. The average CH_4 emission was determined to be 5,978 $mtCO_2e$ from 1999 to 2008.

[78] The PADDs were created during World War II under the Petroleum Administration for War to help organize the allocation of fuels derived from petroleum products, including gasoline and diesel (or "distillate") fuel. They are currently used mainly to collect oil production and refining data in the oil industry.

79 Methane's global warming potential (IPCC 2007)

TABLE 19. TOTAL CH4 EMISSIONS FROM OIL REFINING ($mtCO_2E$) BASED ON DATA FROM DELAWARE CITY REFINERY			
Years	**Data from Delaware City Refinery (Crude refined Annually 1000 bbl)**	**Emissions[80] Factors (Kg CH_4/year/ 1000bbl)**	**CO_2e Emissions (Metric Tons)**
1999	58,400	5.01	6,144
2000	57,305	5.04	6,065
2001	57,670	4.89	5,922
2002	62,415	4.94	6,475
2003	57,305	4.90	5,897
2004	60,225	4.93	6,235
2005	59,130	4.97	6,171
2006	60,590	4.95	6,298
2007	59,495	4.80	5,997
2008	46,355	4.70	4,575

Analysis of Historical Crude Oil Refining Emissions (Facility Data)

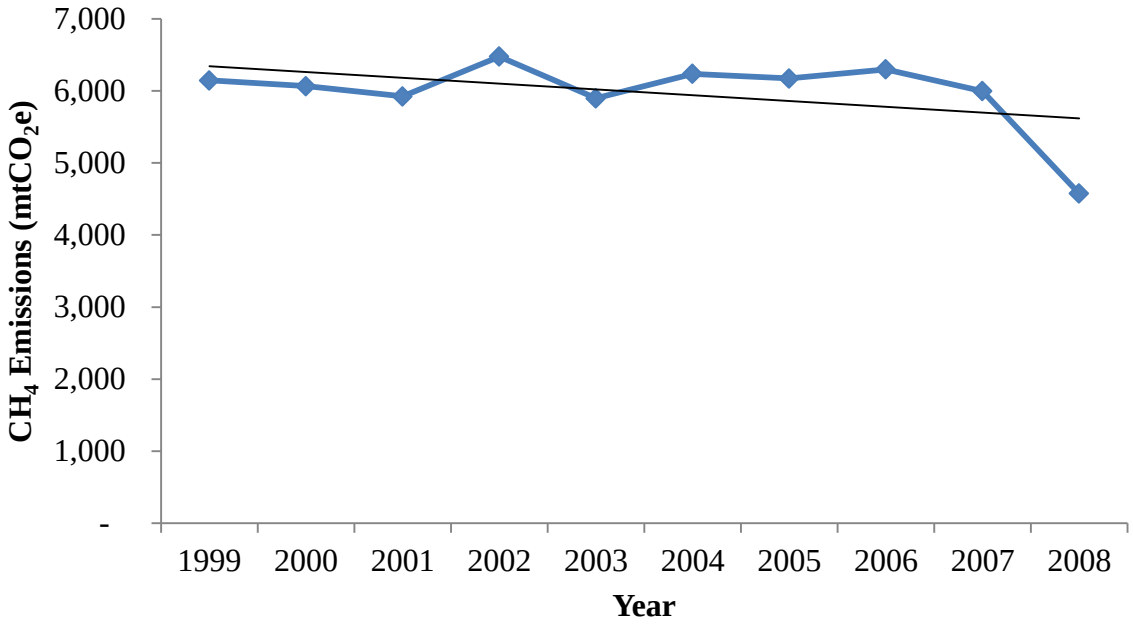
As Figure 49 shows, between 1999 and 2007 CH_4 emissions stayed relatively flat even though there was a spike in 2002 of 6,475 $mtCO_2e$, which corresponded to increased production of. Methane emissions dropped sharply from 2007 at 5,997 $mtCO_2e$ to 4,575 $mtCO_2e$ in 2008, a decrease of 24% (1,422 $mtCO_2e$).

This sharp decrease resulted from a slowdown in production output in 2008, which eventually lead to the plant shutting down. Delaware City refinery had a production output of 46,355,000 bbl of refined oil in 2008 as provided by Table

[80] Data source: Default emissions factors are provided in the U.S. EPA State Inventory Tool.

19 above, but the output dropped to 37,960 in 2009, and in 2010[81] production was zero. Overall, there was a decrease of approximately 26% from the 1999 emission amount of 6,144 $mtCO_2e$. The annual rate of decrease was 0.22 $mtCO_2e$ per year.

FIGURE 49. CH_4 FROM OIL REFINING BASED ON FACILITY DELAWARE CITY DATA



Methane emissions Based on PADD 1

The facility data used to calculate CH_4 emissions from oil refining was considered to be incomplete because there was no data prior to 1999. This meant that CH_4 emissions from crude oil refining prior to 1999 could not be estimated. To correct this issue, DAQ collected PADD 1 data from the Energy Information Administration on annual crude oil refined in the East coast between 1990 and 2008. The ratio of Delaware's annual operating capacity (191,000 bbl/day) to PADD 1 annual operating capacity (1,414 bbl/day) was determined to be 0.14. The amount of crude oil refined in Delaware on annual bases was then estimated

[81] Plant Shutdown commences in 2010

by multiplying the data the by the calculated ratio. The results[82] calculations based on PADD 1 crude oil estimates were then imported into the SIT to estimate the CH_4 emissions. The average CH_4 emission from 1990 to 2008 was 6,734 $mtCO_2e$. Table 20 summarizes the data based on PADD 1 data and the corresponding emission estimates.

TABLE 20. TOTAL CH_4 EMISSIONS FROM OIL REFINING ($MTCO_2E$) BASED ON DATA FROM DELAWARE CITY REFINERY

Years	Daily Gross Crude Input into Refinery 1000 bbl Based on PADD1 data	Estimated Crude Refined Annually 1000 bbl	Emissions[83] Factors (Kg CH_4/year/ 1000bbl)	CO_2e Emissions (Metric Tons)
1990	1,284	63,306	5.08	6,753
1991	1,241	60,927	5.02	6,423
1992	1,273	61,802	4.95	6,424
1993	1,357	63,237	5.03	6,680
1994	1,365	65,674	4.99	6,882
1995	1,478	69,107	4.02	5,834
1996	1,331	67,288	4.94	6,980
1997	1,483	69,621	4.97	7,266
1998	1,569	70,297	4.97	7,337
1999	1,548	67,534	5.01	7,105
2000	1,571	68,111	5.04	7,209
2001	1,499	65,273	4.89	6,703
2002	1,541	67,313	4.94	6,983

[82] The results annual crude oil refined in Delaware from 1990 to 2008 was close in magnitude to the facility data that was submitted by Delaware City refinery.

[83] Data source: Default emissions factors are provided in the U.S. EPA State Inventory Tool.

TABLE 20. TOTAL CH_4 EMISSIONS FROM OIL REFINING ($mtCO_2E$) BASED ON DATA FROM DELAWARE CITY REFINERY				
Years	**Daily Gross Crude Input into Refinery 1000 bbl Based on PADD1 data**	**Estimated Crude Refined Annually 1000 bbl**	**Emissions[83] Factors (Kg CH_4/year/ 1000bbl)**	**CO_2e Emissions (Metric Tons)**
2003	1,605	66,563	4.90	6,849
2004	1,597	64,355	4.93	6,663
2005	1,627	67,839	4.97	7,080
2006	1,512	62,744	4.95	6,522
2007	1,513	62,450	4.80	6,295
2008	1,421	60,039	4.70	5,926

This 2008 GHG inventory included the results of the PADD 1 CH_4 emission estimations in the analysis of gross CH_4 emissions from oil refining due to the availability data using this approach.

Analysis of Historical Crude Oil Refining Emissions (PADD1 data)

As Figure 50 shows, the CH_4 emissions from the refinery remained flat with slight fluctuations from 1990 to 2008. There was a dip in CH_4 emissions in 1995. Methane emissions dropped from 6,882 $mtCO_2e$ in 1994 to 5,834 $mtCO_2e$ in 1995 and increased back to 6,980 $mtCO_2e$ in 1996. This dip in emission corresponded with a change in production equipment. In 1995, the crude unit atmospheric heater was changed from a 456 MBtu fired heater to a 425 MBtu gas fired heater. This lead to interruptions in production, and subsequently reduced emissions.

FIGURE 50. CH_4 EMISSIONS FROM OIL REFINING

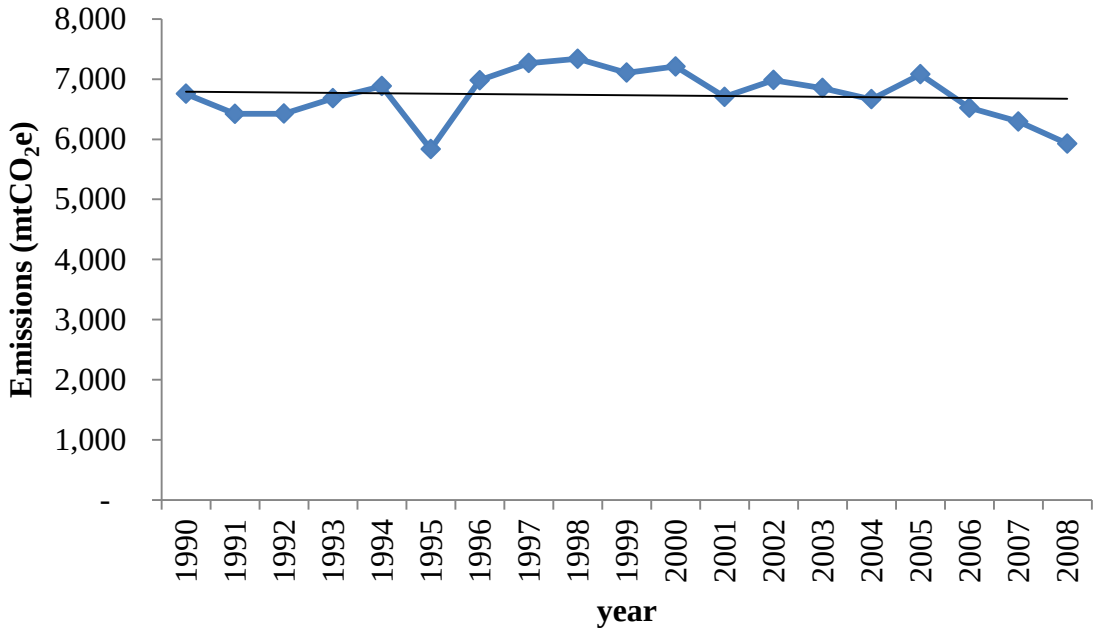
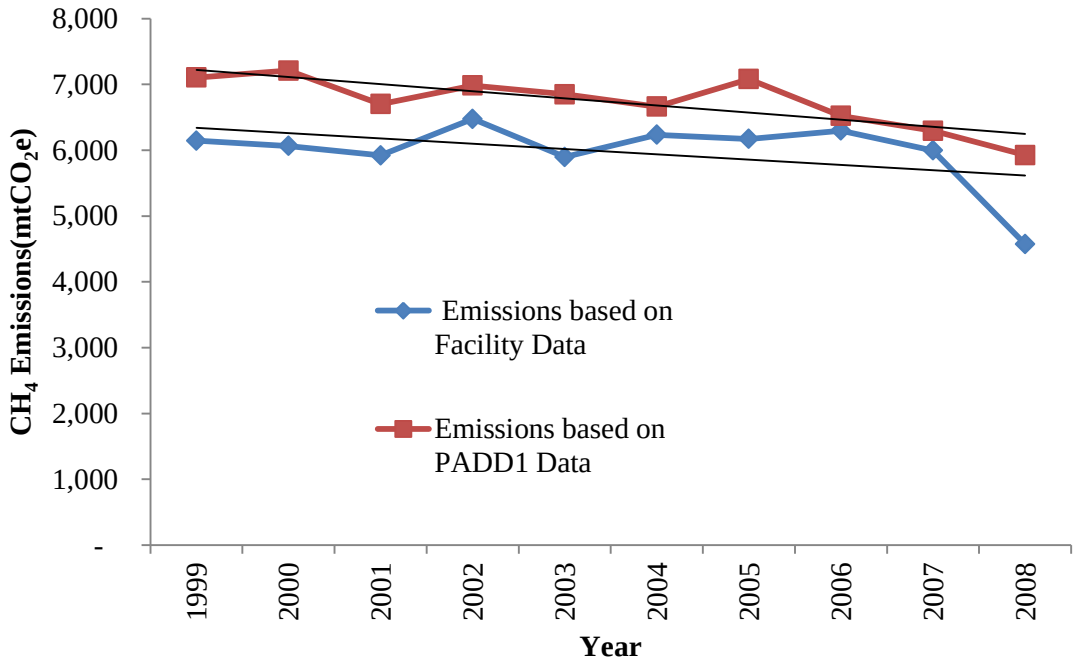


FIGURE 51. CH_4 FROM OIL REFINING BASED FACILITY &PADD1 DATA



From 2005 to 2008, emissions dropped by approximately 16% due to decreasing production output until the refinery closed in 2010. Further analysis of the results

as provided by Figure 51 shows that when PADD1 and Facility CH_4 emissions estimates are compared, a downward trend is observed.

Crude Oil Transportation: In addition to accounting for CH_4 emissions associated with refining crude oil, the 2008 GHG inventory also included the emissions associated with transporting the crude oil to the refinery for processing. Methane emission can occur due to venting from tanks and vessels loading operations.

Methane emission from the transportation of crude oil is a very small portion of overall CH_4 emission from the oil industry, accounting for only one percent. In 2008, crude oil transportation accounted for 17% of CH_4 emissions with just 924 $mtCO_2e$ CH_4 emitted. Table 21 provides estimates of CH_4 emissions in CO_2 equivalents, based on facility as well as PADD1 data from 1999 to 2008. The 2008 emission estimate based on PADD1 data was 1197 $mtCO_2e$ as provided by Table 19.

TABLE 21. CH_4 EMISSIONS FROM THE TRANSPORTATION OF CRUDE OIL TO THE REFINERY

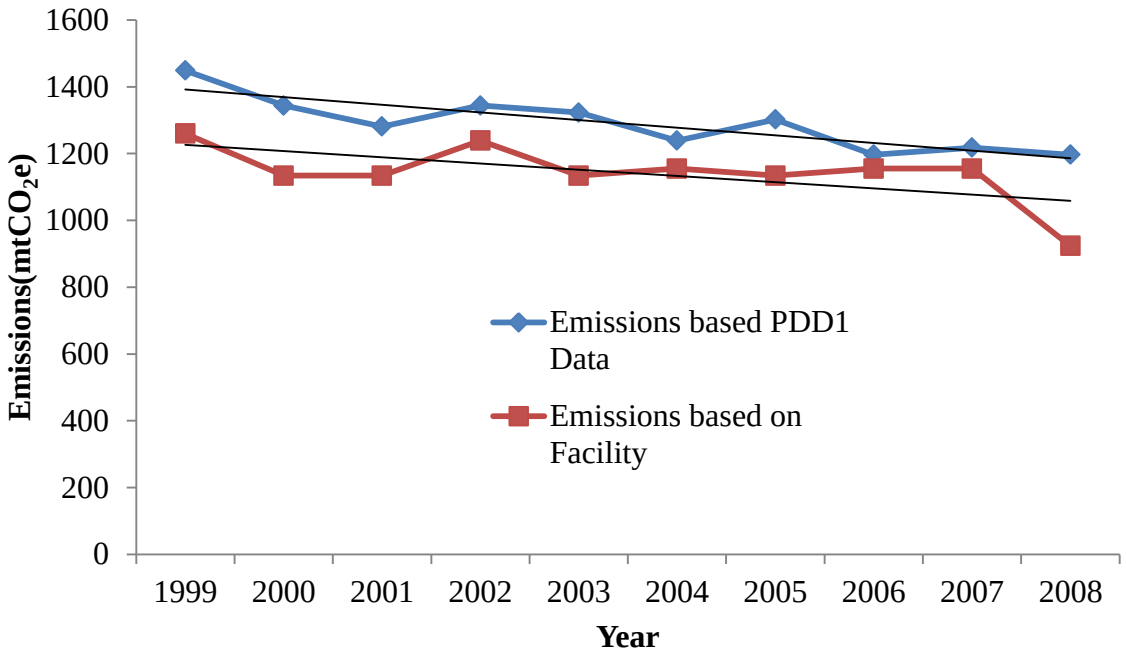
Years	Data from Delaware City Refinery (Crude refined Annually '000 bbl)	Estimated Crude Refined Annually 1000 bbl	CH_4 Emissions from Crude Transportation ($mtCO_{2e}$) based on facility data	CH_4 Emissions from Crude transportation ($mtCO_2e$) based on PADD1 data
1999	58,400	67,534	1260	1449
2000	57,305	68,111	1134	1344
2001	57,670	65,273	1134	1281
2002	62,415	67,313	1239	1344

TABLE 21. CH_4 EMISSIONS FROM THE TRANSPORTATION OF CRUDE OIL TO THE REFINERY				
Years	**Data from Delaware City Refinery (Crude refined Annually '000 bbl)**	**Estimated Crude Refined Annually 1000 bbl**	**CH_4 Emissions from Crude Transportation ($mtCO_{2e}$) based on facility data**	**CH_4 Emissions from Crude transportation ($mtCO_2e$) based on PADD1 data**
2003	57,305	66,563	1134	1323
2004	60,225	64,355	1155	1239
2005	59,130	67,839	1134	1302
2006	60,590	62,744	1155	1197
2007	59,495	62,450	1155	1218
2008	46,355	60,039	924	1197

Figure 52 provides a comparison between CH_4 emissions estimates from the transportation of crude oil based on facility data and CH_4 emissions estimates from the transportation of crude oil based on PADD1 from 1999 to 2008.

Methane emissions estimates from PADD1 averaged approximately 1,289 $mtCO_2e$, while emissions based on facility data averaged 1142 $mtCO_2e$. This gave an average difference of 147 $mtCO_2e$. The emissions based on facility data deviated slightly in 2008 emission for the facility

FIGURE 52. CH_4 FROM OIL TRANSPORTATION BASED ON FACILITY &PADD1 DATA



The 2008 GHG inventory also considered CH_4 emission from natural gas transmission, and distribution in Delaware. However, due to the lack of sufficient historical data to properly characterize the CH_4 emissions from the transmission and distribution of natural gas, emissions estimates from this source category was not e included in the 2008 GHG inventory. Emissions from natural gas transmission and distribution in Delaware will be accounted for in the next GHG inventory[84].

The primary natural gas transmission and distribution lines in Delaware include:

- *Local distribution lines*: these lines include service and main lines. They are distribution pipelines that are used by local distribution companies to transmit natural gas to end-users. The pipelines are extensive networks of

[84] 2009 GHG Emissions Inventory

generally small diameter and low-pressure. Gas enters distribution networks from transmission systems at various stations, where the pressure is reduced for distribution within cities or towns. Major CH_4 emission sources are chronic leaks, meters, regulators, and mishaps. Currently, Delaware has 2,777 miles of main lines, as well as 161,801 service lines with an average service length of 70 feet.

- *Transmission lines:* Transmission lines are large diameter, high-pressure pipelines that transport gas from production fields, processing plants, storage facilities, and other sources of supply over long distances to local distribution companies or to large volume customers. A variety of facilities support the overall system, including metering stations, maintenance facilities, and compressor stations located along pipeline routes. Compressor stations, which maintain the pressure in the 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. Major CH_4 emission sources are chronic leaks, compressor fugitives, compressor exhaust, vents, and pneumatic devices. Delaware currently has seven miles transmission lines for natural gas running through the State.

4.3.5 Iron & Steel production

Steel production can occur at integrated facilities from iron ore, or at secondary facilities, which produce steel mainly from recycled steel scrap. Integrated facilities typically include coke production, blast furnaces, and basic oxygen steelmaking furnaces (BOFs) or in some cases open hearth furnaces (OHFs), raw steel is produced using a basic oxygen furnace from pig iron produced by the blast furnace and then processed into

finished steel products. Pig iron may also be processed directly into iron products. Secondary steelmaking most often occurs in electric arc furnaces (EAFs). The BOF is typically used for high-tonnage production of carbon steels, while the EAF is used to produce carbon steels and low tonnage specialty steels.

Delaware has one secondary facility that produces iron and steel namely Evraz, which is located in Claymont, Delaware. The Evraz facility utilizes the EAF process for its steel production and relies on mainly scrap metal as it raw material. Steel production in the EAF[85] is performed by charging 100 percent recycled steel scrap, which is melted using electrical energy imparted to the charge through carbon electrodes and then refined and alloyed to produce the desired grade of steel. Since the EAF process is mainly one of melting scrap and not reducing oxides, carbon's role is not as dominant as it is in the blast furnace/BOF process. In a majority of scrap-charged EAF, CO_2 emissions are associated with consumption of the carbon electrodes. In 2008, the CO_2 emission from Evraz was 30,065 mtCO_2e, this was only 6% of non-energy related industrial process emissions as shown in Figure 40 above.

Methodology

The iron and steel subcategory focuses on CO_2 emissions and the activity data required for this subsector are the quantity of crude steel [86] produced. CO_2 emissions were estimated by multiplying the activity data with the appropriate emission factors. State-specific data was required to estimate the CO_2 emissions for this source because SIT default values were based on national averages, and data was not available for all years, and may be inaccurate for Delaware. DAQ requested annual steel production output from Evraz in order to estimate CO_2 emissions from the EAF process. The Evraz data, when received, included production outputs from 1997 to 2010 only.

[85] 2006 IPCC Guidelines for National Greenhouse Gas Inventories 4.1

[86] Crude steel is defined as the first cast product suitable for sale or further processing.

EQUATION 12. GENERAL EQUATION FOR ESTIMATING CO_2 FROM STEEL PRODUCTION

$$CO_2 \text{ emission} = \text{Steel Production} \times \text{Emissions Factor}$$

Analysis of Historical Iron and Steel Emissions

Figure 53 shows the GHG emissions from 1997 to 2008. GHG emission from the Evraz facility peaked in 2007 at 33,248 $mtCO_2e$, and dropped to 30,065 $mtCO_2e$ in 2008. Overall, CO_2 emissions increased from by approximately 19% from 1997 to 2005 as the figure indicates. The annual rate of increase was determined to be 694.8 $mtCO_2$ per year. Carbon dioxide emissions from iron and steel production in Delaware were directly proportional to the amount of steel produced. As Table 22 indicates, steel production outputs from Delaware between 1997 and 2008 increased with minor fluctuations.

FIGURE 53. HISTORICAL CO_2 EMISSIONS FROM IRON AND STEEL PRODUCTION

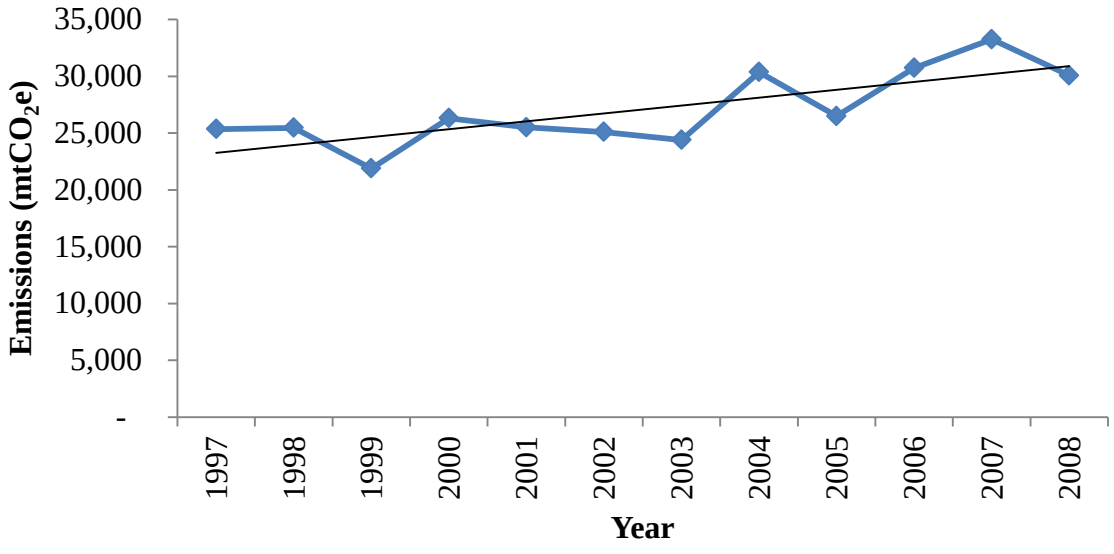


TABLE 22. ESTIMATES OF CO_2 EMISSIONS FROM IRON & STEEL PRODUCTION			
Years	**Facility Steel Production Data (Metric Tons)**	**Carbon Equivalents (mtCe)**	**CO_2 Emissions ($mtCO_2e$)**
1997	316,821	6,912	25,346
1998	318,291	6,945	25,463
1999	273,488	5,967	21,879
2000	328,828	7,174	26,306
2001	318,783	6,955	25,503
2002	313,619	6,843	25,090
2003	304,846	6,651	24,388
2004	379,485	8,280	30,359
2005	331,053	7,223	26,484
2006	384,169	8,382	30,734
2007	415,606	9,068	33,248
2008	375,818	8,200	30,065

4.3.6 Soda Ash Consumption

Soda Ash is a white crystalline solid that is readily soluble in water and strongly alkaline. Delaware is not a source of natural or synthetic soda ash. However soda ash is used domestically as a cleaning agent. It is used as a raw material in the production of glass, soap, detergents, or simply as an alkali to neutralize acids. It is also used to treat hardness in drinking water as well as wastewater treatment. This 2008 GHG emission inventory estimates CO_2 emissions from soda ash consumption.

In 2008, Delaware consumed 16,495 metric ton of soda ash according to the U.S geological Survey (USGS). The total CO_2 emission from soda ash consumption in 2008

was 6,845 $mtCO_2e$ as provided by Table 23. This source contributed 0.1% of gross GHG emissions from the non-energy related industrial process source category as shown by Figure 42 above.

Methodology

To estimate CO_2 emissions from soda ash consumption, it is assumed that one mole of carbon is released for every one mole of soda ash used. Approximately 0.113 metric tons of carbon (0.415 metric tons of CO_2) is released for every metric ton of soda ash consumed[87]. The activity data for this subsector was the annual amount of soda ash consumed in Delaware. The SIT default activity data[88] was multiplied with the SIT's default emission factor for soda ash consumption to estimate the emission amount.

EQUATION 13. GENERAL EQUATION FOR CO_2 EMISSIONS FROM SODA ASH CONSUMPTION

$$CO_2 \text{ emission} = \text{Soda ash Consumed} \times \text{Emissions Factor}$$

Analysis of Soda Ash Emissions

Figure 54 provides a chart of CO_2 emissions from soda ash consumption in Delaware from 1990 to 2008. Figure 52 provides the CO_2 emissions from soda ash consumption from 1990 to 2008. From 1990 to 2008, CO_2 emissions from soda ash consumption in Delaware decreased by approximately 5.8%. CO_2 emission peaked in 1998 at 7,484 $mtCO_2e$ and trended down to 7,301 in 2003, a decrease of approximately 2.4%. In 2008, emission decreased to 6,845 $mtCO_2e$ from 2003, a decrease of approximately 6.2%.

[87] EPA 2004 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004

[88] U.S. Geological Survey (USGS) in Soda Ash: Minerals Yearbook Annual Report (for trona production and soda ash consumption by state) http://www.census.gov/cir/www

Table 23 provides estimates of emissions. Figure 53 shows the consumption of soda ash is the main factor in soda ash CO_2 emissions in Delaware.

FIGURE 54. CO_2 EMISSIONS FROM SODA ASH COSUMPTION

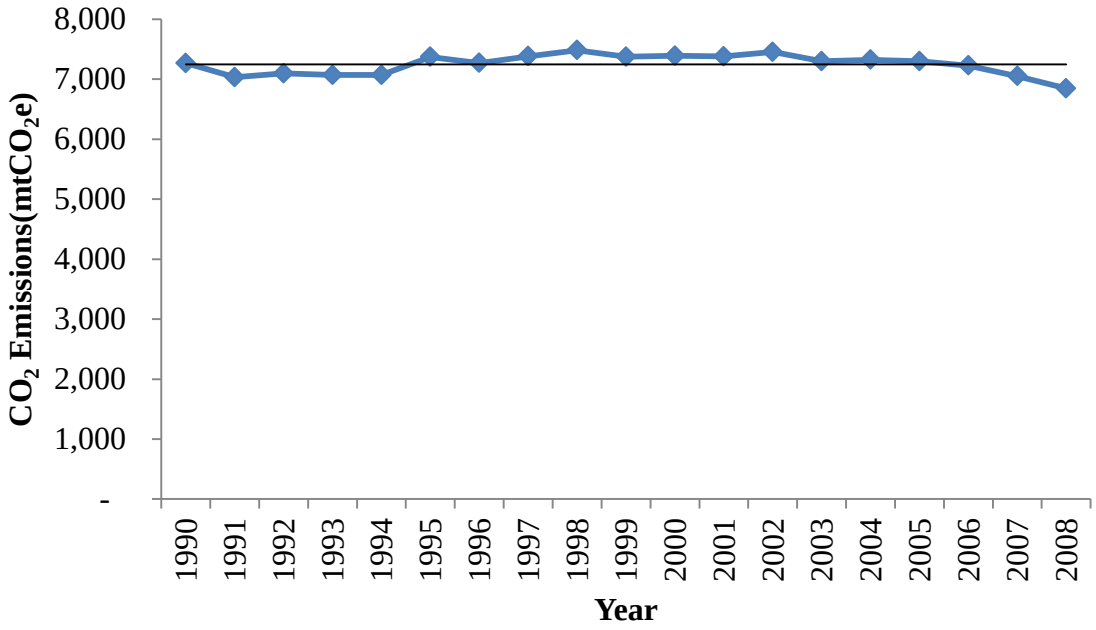
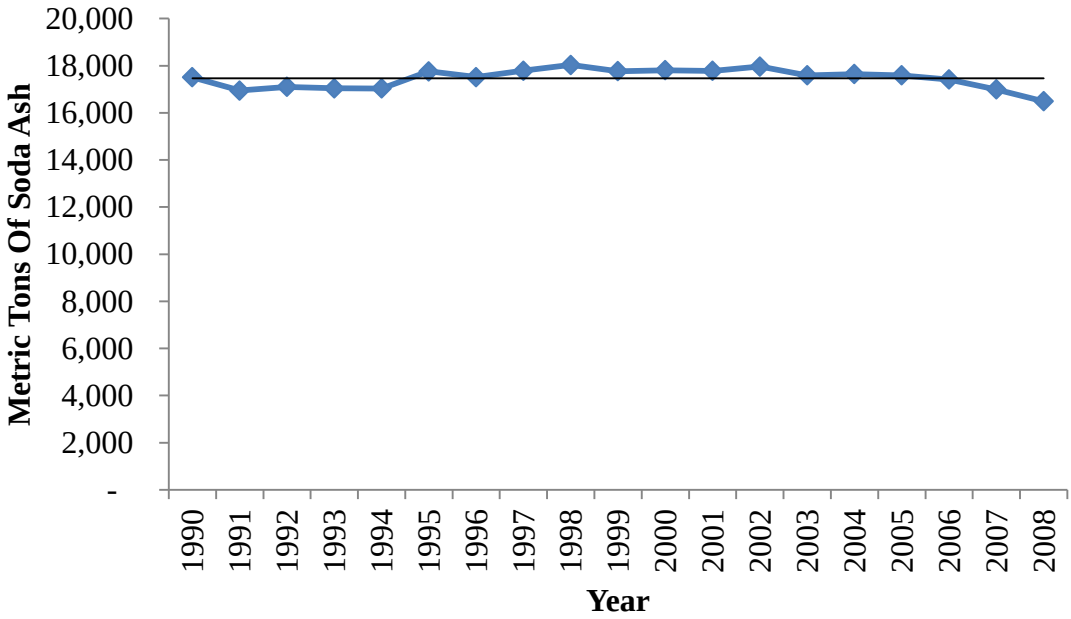


FIGURE 55. SODA ASH CONSUMPTION



As Figure 55 present, the decline in CO_2 emissions from the consumption soda ash is directly linked to declining soda ash consumption between 1990 and 2008.

TABLE 23. CO_2 EMISSION ESTIMATES FROM SODA ASH CONSUMPTION		
Year	**Soda Ash Consumed (Metric Tons)**	**CO_2 emissions ($mtCO_2e$)**
1990	17,513	7,268
1991	16,948	7,033
1992	17,103	7,098
1993	17,040	7,072
1994	17,035	7,070
1995	17,765	7,373
1996	17,517	7,270
1997	17,787	7,381
1998	18,034	7,484
1999	17,768	7,374
2000	17,809	7,391
2001	17,783	7,380
2002	17,962	7,454
2003	17,592	7,301
2004	17,647	7,324
2005	17,590	7,300
2006	17,414	7,227
2007	16,994	7,052
2008	16,495	6,845

4.4 AGRICULTURAL

This 2008 GHG emissions inventory includes the emission of CH_4 and N_2O from the Agricultural sector of Delaware. In 2008, the total GHG emission from the agricultural sector was approximately 3% of Delaware's gross GHG emissions with an amount of 560,222 $mtCO_2e$. Emissions came primarily from enteric fermentation, manure management and agricultural soil management. Figure 56 present GHG emissions by agricultural activity. Table 24 provides estimates of emissions for all the subcategories of agricultural sources.

FIGURE 56. GHG EMISSIONS BY AGRICULTURAL ACTIVITY

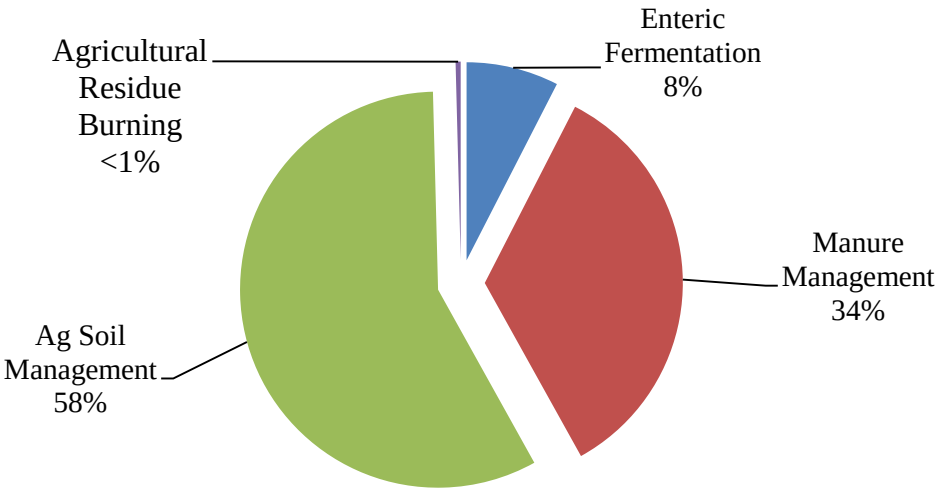


Figure 57 shows the total GHG emissions from the agricultural sector from 1990 to 2008. Emissions fluctuated from year to year, decreasing from 615,534 mtCO2e in 1990 to 560,222 mtCO2e in 2008. This was a decrease of approximately 9.1%. The annual rate of decrease was 3,848 mtCO2e per year. Factors that significantly impacts agricultural sector emissions include the population of livestock, fertilizer applications and crop production.

FIGURE 57. TOTAL N_2O AND CH_4 EMISSIONS FROM THE AGRICULTURAL SECTOR

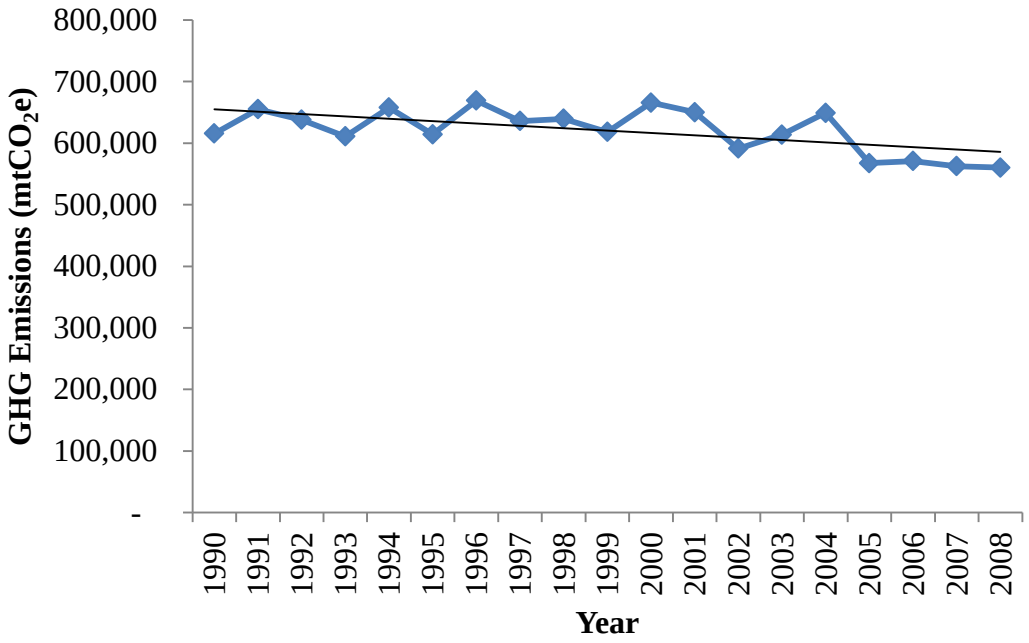


TABLE 24. GHG EMISSIONS FROM AGRICULTURAL ACTIVITIES					
Emissions($mtCO_2e$)	1990	1995	2000	2005	2008
Ag Soil Management	50,692	51,264	46,898	43,870	42,237
Manure Management	184,155	207,339	196,412	193,589	192,622
Enteric Fermentation	378,287	353,774	419,183	327,884	323,055
Agricultural Residue Burning	2,400	1,962	3,156	2,204	2,308
Total	**615,534**	**614,340**	**665,650**	**567,547**	**560,222**

See Appendix H for details.

Methodologies

4.4.1 Agricultural Soil management:

Nitrous oxide is generated from agricultural soil management due of nitrification and denitrification in the soils. Soil management activities include the application of fertilizers, the application of managed livestock manure, irrigation, tillage and land

fallowing[89]. The method of estimating N_2O emissions from these sources was based IPCC's method[90]. Nitrous oxide emissions from agricultural soil management are categorized into direct and indirect N_2O emissions due to the addition of fertilizers and deposition of manure to agricultural soil. In 2008, agricultural soil management generated 1,042 mt N_2O which was equivalent to 323,000 $mtCO_2e$. It was the largest contribution to GHG emissions from the agricultural activities in Delaware with approximately 58% according to Figure 56. It was also the largest source of N_2O emissions in the State.

Analysis of N_2O Emissions from Agriculture Soil Management

Between 1990 and 2008, N_2O decrease from 378,287 $mtCO_2e$ in 1990 to 323,055 in 2008, a decrease of approximately 15%. Nitrous oxide emissions increased by 3,108 $mtCO_2e$ per year as determined by trendline analysis.

As Figure 58 shows, fluctuations were observed in emissions between 1990 and 2008. The largest emission was in 2000 with 419,183 $mtCO_2e$ and the smallest was in 2008 with 323,055 $mtCO_2e$.

Table 25 shows emission estimates of direct and indirect N_2O from agricultural soil management. The results show that between 1990 and 2008, direct N_2O emissions exceeded indirect N_2O emissions. The largest direct N_2O emissions came from livestock management, followed by fertilizers and N-fixing crops. Over the years, reductions in fertilizers application, livestock and cultivation of nitrogen fixing crops have contributed to the decrease in N_2O emissions observed. Figure 59 provides information on the amount of fertilizers applied to Delaware farms in metric tons of nitrogen. As observed in Figure 59, the application of fertilizers on Delaware farms follows the same trend as Figure 58 above showing that as the application of fertilizers decrease, N_2O emissions

89

[90] EPA's Emissions Inventory Improvement Plan Volume III

declines. The reduction in N_2O emissions from agricultural soil management can be attributed to improved farming practices recommended by the EPA including conservation or riparian buffers, conservation tillage on croplands and grazing land management. These practices not only help to minimize GHG emissions from agricultural activities, they also increase carbon storage and sequestration.

FIGURE 58. N_2O EMISSIONS FROM AGRICULTURAL SOIL MANAGEMENT.

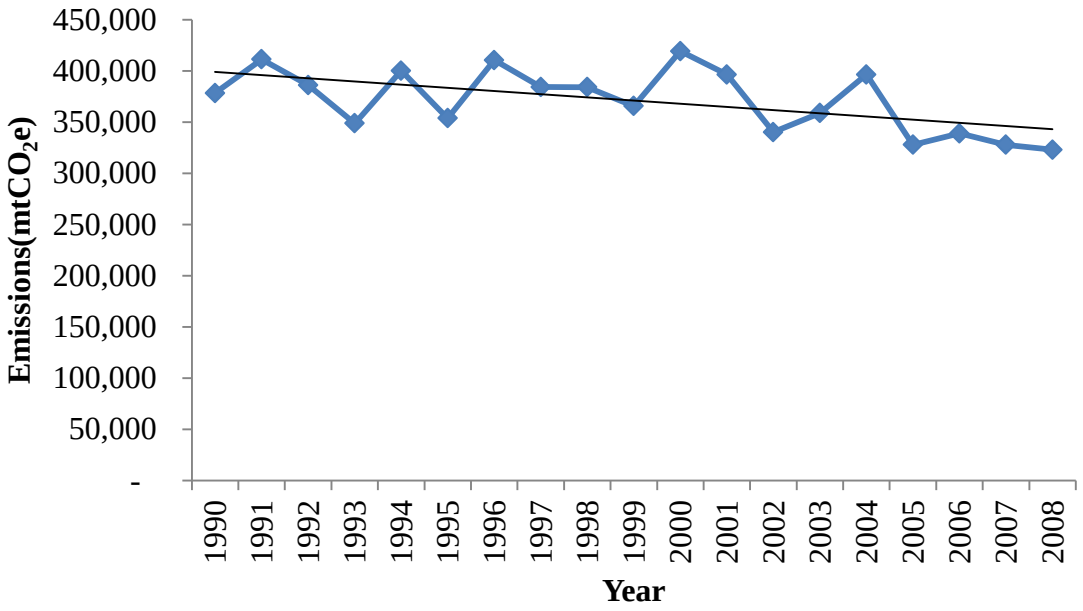


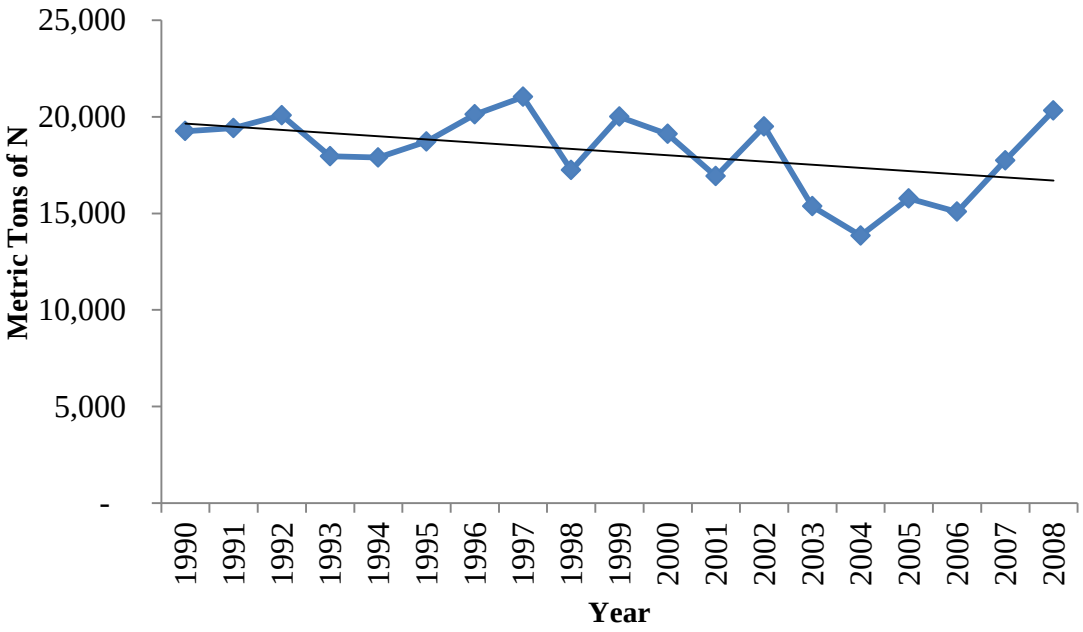
TABLE 25. N2O EMISSIONS FROM AGRICULTURAL SOIL MANAGEMENT (MTN2O)[91]					
N_2O Sources	**1990**	**1995**	**2000**	**2005**	**2008**
Direct	**1,007**	**916**	**1,137**	**858**	**854**
Fertilizers	273	271	259	219	187
Crop Residues	161	124	215	134	144
N-Fixing Crops[92]	246	167	331	170	191
Livestock	328	353	332	334	333

[91] Emissions are in metric tons of nitrous oxide

[92] Crops that convert nitrogen (N_2) in the atmosphere to ammonium (NH4+).

TABLE 25. N2O EMISSIONS FROM AGRICULTURAL SOIL MANAGEMENT (MTN2O)91					
N_2O Sources	**1990**	**1995**	**2000**	**2005**	**2008**
Indirect	**213**	**225**	**215**	**199**	**188**
Fertilizers	30	30	29	24	21
Livestock	57	63	60	59	59
Leaching/Runoff	126	132	126	116	108
TOTAL	**1,220**	**1,141**	**1,352**	**1,058**	**1,042**

FIGURE 59. AMOUNT OF FERTILIZERS APPLIED IN METRIC TONS OF NITROGEN



4.4.2 Manure Management:

CH_4 and N_2O were generated by livestock manure management in the agricultural sector of Delaware. CH_4 is produced by the anaerobic decomposition of manure, while N_2O is produced by the nitrification and denitrification of nitrogen in livestock manure and urine. The 2008 GHG Emissions inventory estimated the CH_4 emissions from each animal by estimating the quantity of volatile solids produced by each animal type and converting it to metric tons of carbon emitted.

As shown by Figure 56, manure management was the second largest source in the agricultural sector, emitting approximately 34% of total emission from the sector with an amount of 193 $mtCO_2e$ in 2008. Emissions from manure management are dependent on animal population which fluctuates throughout the year and makes it hard to get accurate estimates for each year. Therefore, using single point estimates (horses and sheep), multiple point estimates (cattle and swine), or periodic estimates (goat), introduces uncertainties into the emission estimates[93].

Analysis of Manure Management Emissions

As Figure 60 shows, significant fluctuations were observed in emissions from manure management sources of GHGs in Delaware. The highest point was in 2003 with 212,365 $mtCO_2e$ and the lowest point in 1990 with 184,155 mCO_2e. Emissions increased by approximately 12.5% between 1990 and 1995 (207,339 $mtCO_2e$). On the other hand, emissions decreased by 9.3% between 2003 (212,365 $mtCO_2e$) and 2008 (192,622 $mtCO_2e$. An e analysis of the data show the emissions decreased by 51 $mtCO_2e$ per year between 1990 and 2008. Figure 61 shows that the number of livestock in Delaware fluctuated slightly between 1990 and 2008. Livestock amounts peaked in 1998 with a total of 48,672. When comparing manure management emissions in Figure 60 with the livestock population data in Figure 61 similarities in the trends of both charts were observed. In Figure 61, livestock population increased from 43,309 in 1990 to 48,672 in 1995, an increase of approximately 12%, which is close to the 12.5% increase in emissions observed above.

[93] U.S. EPA State Inventory Tool Methane and Nitrous Oxide from Agriculture Module

FIGURE 60. N_2O AND CH_4 EMISSIONS FROM MANURE MANAGEMENT

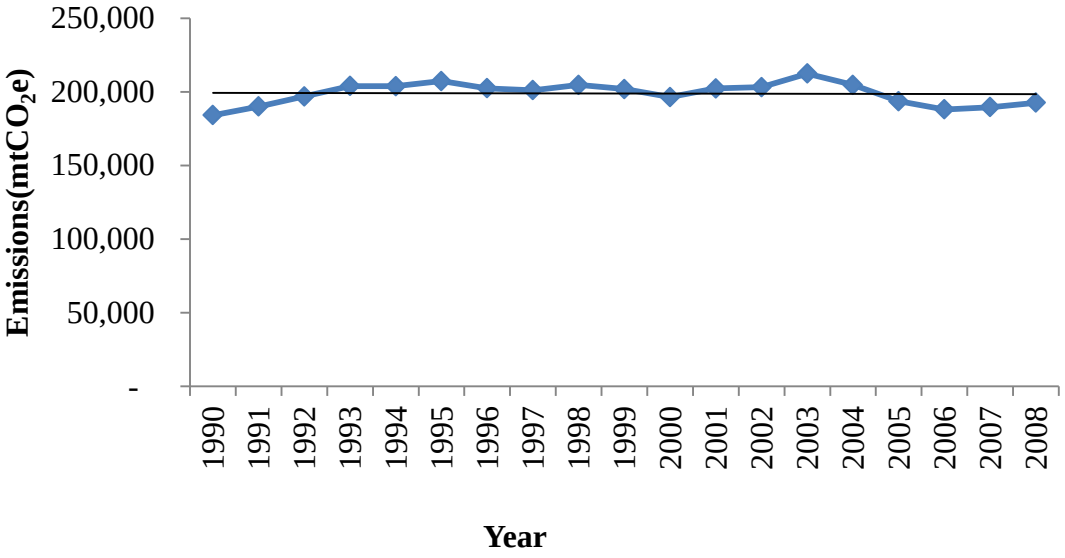
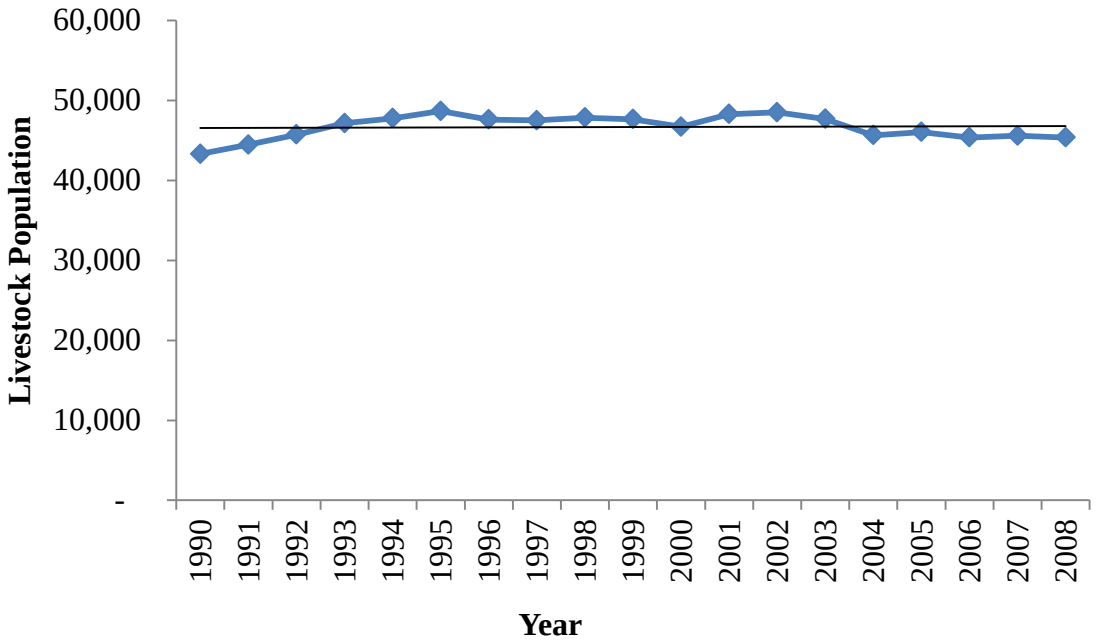


FIGURE 61. DELAWARE'S LIVESTOCK POPULATION



Delaware's livestock population decreased by 6.5% between 2002 and 2008, which also contributed to decrease in emissions observed in Figure 60.

Delaware's livestock population decrease was mostly due to farmland conversion pressure[94]. Farmlands, including pasture and range lands, are necessary for grazing animal livestock. The decline in these types of land will continue to impact livestock population in Delaware. According to the National Resource Inventory (NRI) conducted by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) since 1982[95], Delaware has lost 14.3% of its agricultural land, which includes pasture and range, crop and conservation reserve program land, between 1982 and 2007. In addition, Delaware's Department of Agriculture released statistics showing that since 2002, Delaware has lost approximately 30,000 acres of farmland, due to conversion pressure and other issues.

In spite of the conversion pressure farmlands in Delaware are facing, the NRI showed that Delaware protected 1.06 acres of agricultural land for every acre developed. In addition, Delaware still has more than 510,000 acres of agricultural land, which is 40% of the State's total land area. The Delaware Agricultural Lands Preservation Foundation and DDA have permanently preserved 89,692 acres of agricultural land and an additional 2,131 acres of forestland (eighteen percent of the total)[96]. Delaware preserves more farm land than any other state in the nation. The preservation of agricultural land will slow the decline in livestock population, which will in turn slow decreasing emissions from manure management sources in Delaware.

4.4.3 Enteric Fermentation:

Enteric fermentation is the microbial fermentation of digested food in animal livestock. The by-product of this process is CH_4, which can be exhaled or eructated (belched) by the animal. The amount of CH_4 the animals produce depends on the digestive systems of the animals. Delaware's animal included cattle, goats and swine. The amounts of the

94 Conversion of farmlands to developed lands (industrial, residential and commercial real estate)

95 http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/landuse/rangepasture

96 Delaware's department of Agriculture :http://dda.delaware.gov/pressrel/2009

various types of animals were multiplied by the respective emission factors. Total CH_4 emission from livestock was estimated by multiplying the population of different types of livestock with respective emission factors[97]. The U.S Department of Agriculture (USDA) provided data on emission factors. In 2008, GHG[98] emission from this sub-category was 7.5% of gross emissions from the agricultural sector as shown by Figure 56 above. This was a contribution of 42,000 $mtCO_2e$ to gross agricultural sector emissions.

Analysis of Enteric Fermentation GHG Emissions

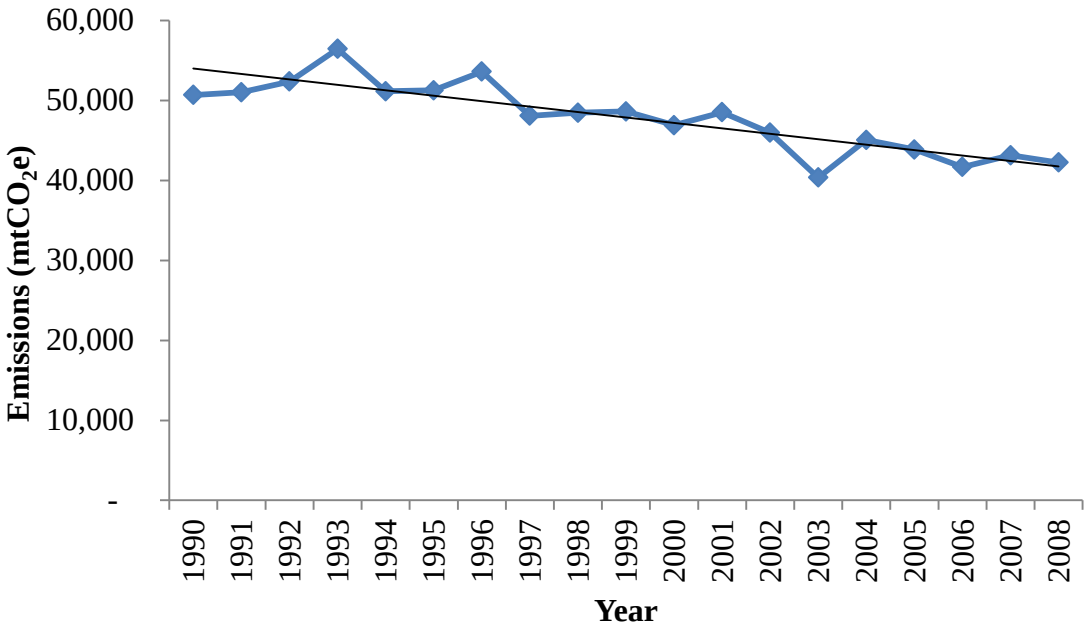
As Figure 62 provides, emissions from enteric fermentation decreased from 1990 to 2008. The Emissions decreased from 50,692 $mtCO_2e$ in to 42,237 $mtCO_2e$ in 2008, a decrease of 18%. Emissions decreased at a rate of 679 $mtCO_2e$ per year.

Decreasing emissions from enteric fermentation could also be attributed to decreasing livestock population as shown in Figure 59. The declining populations of ruminant animals that produce methane from the microbial fermentation of digested food lead to reductions enteric fermentation emissions. Another way in which CH_4 emissions are reduced from agricultural activities is by the use anaerobic manure digesters. Anaerobic digesters produce methane gas that may be used for heating and generating electricity.

[97] 2008 Greenhouse Gas Emissions Inventory Development Plan-page 29

[98] GHG emissions include N_2O and CH_4

FIGURE 62. CH_4 EMISSIONS FROM ENTERIC FERMENTATION



4.4.4 Agricultural Residue Burning:

In addition to the above sources of GHG emission in the agricultural sector, this 2008 GHG emissions inventory also identifies a minor source of N_2O and CH_4 emissions from the agricultural sector. Agricultural residue burning in Delaware falls under the category of prescribed[99] burns and cannot be performed without a permit. They are conducted for land clearing and field maintenance purposes.

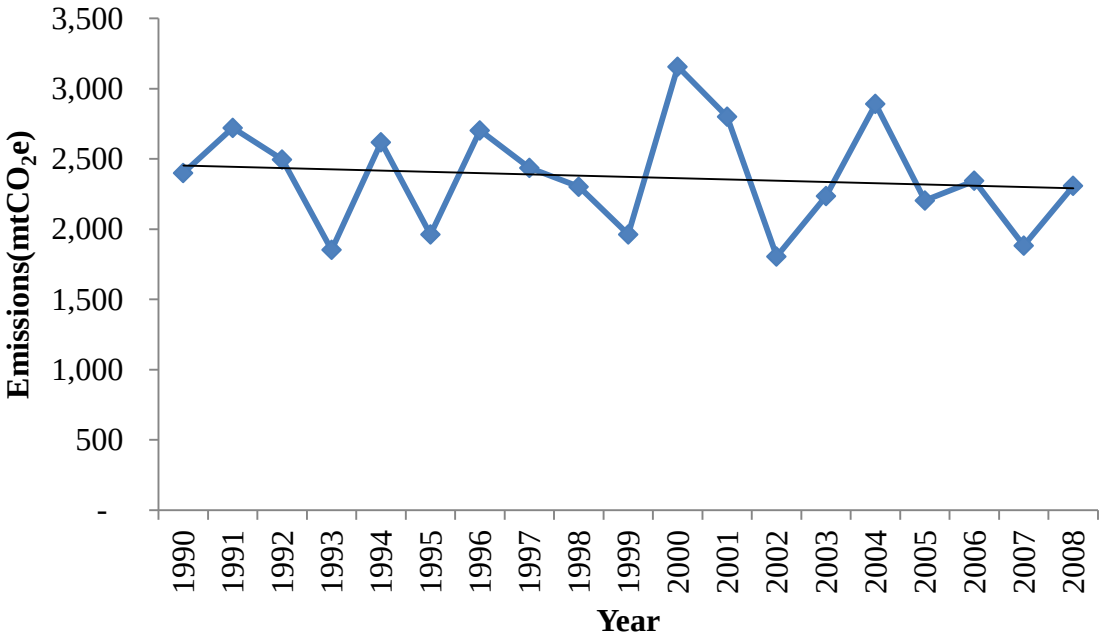
The emissions from agricultural residue burning were estimated by multiplying crop production by emissions factors including residue crop ratio and combustion efficiency. In 2008, this source made up 0.4% of agricultural sector GHG emissions, with an amount of 2,000 $mtCO_2e$.

[99] Information on prescribed burns:http://www.dnrec.delaware.gov/whs/awm/Info/Pages/OBPrescribedBurns.aspx

Analysis of Total GHG Emissions from Agricultural Source Category

As Figure 63 shows, GHG emissions from agricultural residue burning fluctuated significantly between 3,156 $mtCO_2e$ and 1,806 $mtCO_2e$ between 1990 and 2008. Generally, emissions stayed basically stayed flat according to trendline analysis (rate of decrease was 9 $mtCO_2e$ per year). The highest point was in 2000 with 3,156 $mtCO_2e$ and the lowest point was in 2002 with 1,806 $mtCO_2e$.

FIGURE 63. EMISSIONS FROM AGRICULTURAL RESIDUE BURNING



4.5 WASTE MANAGEMENT

In 2008, CO_2e emissions from the waste management source category represented approximately 0.57% of total emissions from Delaware. The primary GHGs of concern from Delaware's waste management sector were CH_4, N_2O and CO_2 emissions. Emissions from the waste management sector came primarily from two sources: landfills facilities and wastewater treatment plants.

The total GHG emission in CO_2e from the waste management sector in 2008 was approximately 0.11 MmtCO_2e (106,572 mtCO_2e). Total emissions are the sum of CO_2e emissions from both wastewater treatment and MSW. Figure 62 presents historical emissions from the waste management sector. From 1990 to 2008, there was a significant decrease of approximately 85% in emissions from the waste management sector.

According to Figure 64, GHG emissions from waste management dropped from 725,492 mtCO_2e in 1990 to 106,572 mtCO_2e in 2008. This decrease was primarily influenced by significant reductions in GHG emissions from landfill activities as shown in Figure 65. Landfill emission reductions resulted from changes made to landfill practices including methane recovery [100] by flaring and landfill gas recycle for energy use. In addition to these changes, the prohibition on waste incineration in Delaware enacted in 2000 also contributed to the landfill emission reductions observed in the 2008 GHG inventory.

According to Figure 65, total GHG emissions from landfills decreased drastically from 1990 to 2008, while GHG emissions from wastewater treatment increased steadily during the same period. In 2004, landfill emissions dropped below emissions from wastewater treatment. Section 4.5.1 and Section 4.5.2 presents information on emission from landfill activities and wastewater treatment respectively. Table 26 provides estimates of total GHG emissions from landfill activities and wastewater treatment.

[100] Methane recovery includes captured methane that is destroyed by flaring or converted for energy use.

FIGURE 64. NET GHG EMISSIONS FROM WASTE MANAGEMENT

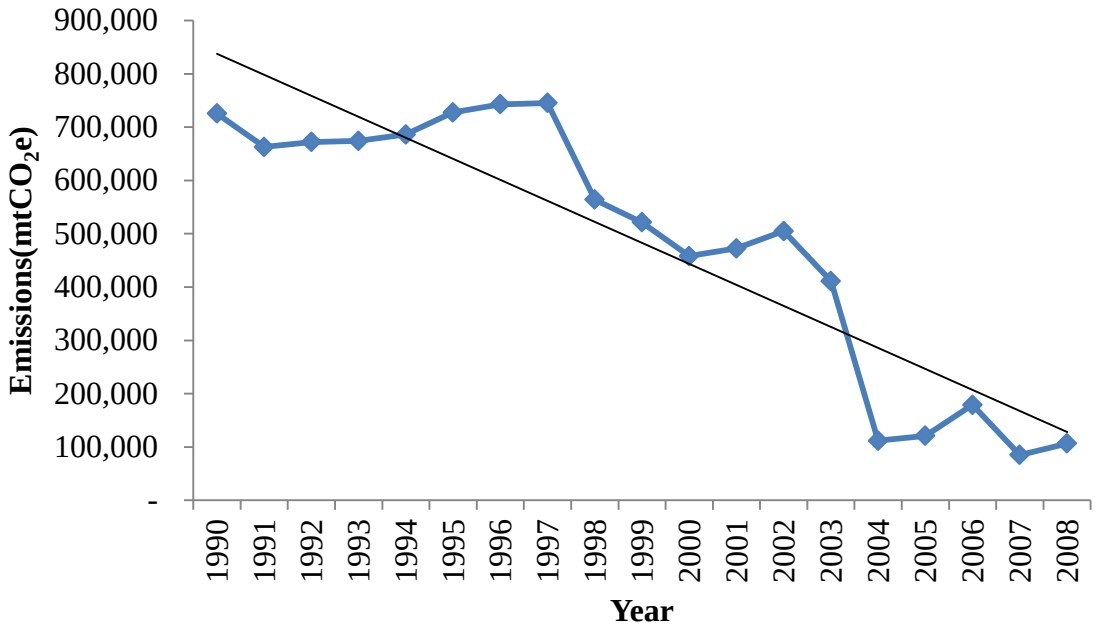


FIGURE 65. HISTORICAL GHG EMISSIONS BY WASTE MANAGEMENT SUBSECTORS

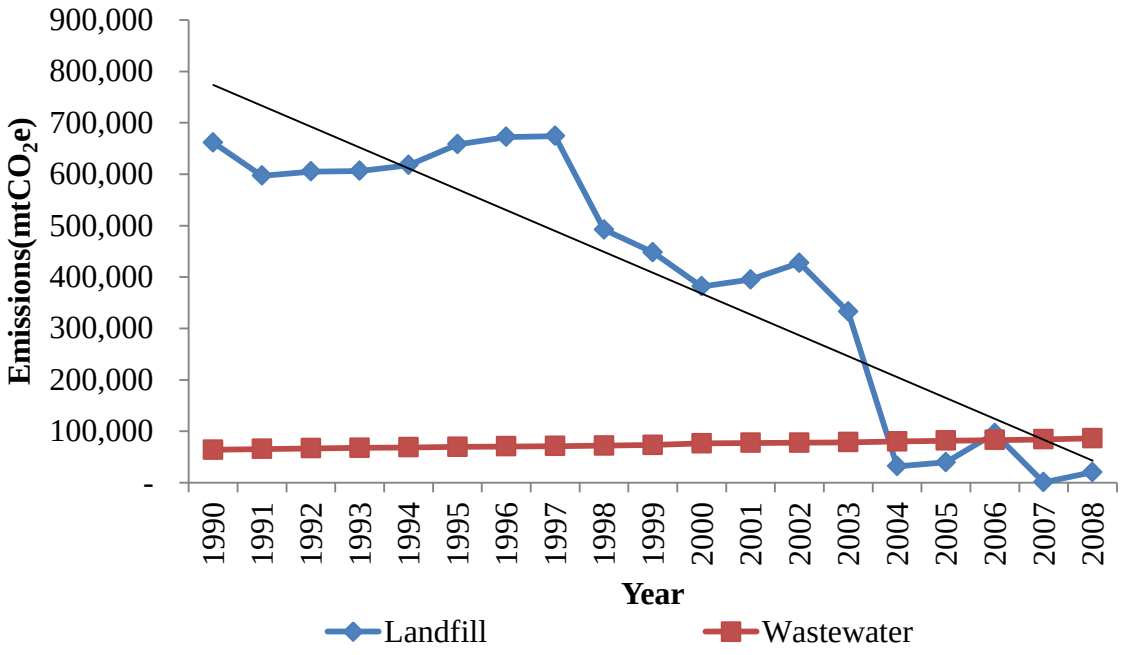


TABLE 26 GHG EMISSIONS FROM THE WASTE MANAGEMENT SECTOR IN $MTCO_2E$					
Sources	**1990**	**1995**	**2000**	**2005**	**2008**
Landfill	661,492	658,029	381,805	39,565	20,298
Wastewater Treatment	64,000	69,454	76,337	81,544	86,274
Total Emissions	**725,492**	**727,483**	**458,142**	**121,109**	**106,572**

4.5.1 Landfill Activities

Greenhouse gas emissions from landfill activities include CH_4, CO_2 and N_2O emission from municipal and industrial landfill activities. Methane is generated in landfills when organic waste materials decompose. Decomposition first takes place aerobically, and then the organic waste materials were converted to simpler forms such as cellulose, sugars, amino acids and fats by anaerobic processes. These substances are further broken down through fermentation into intermediate organic compounds. Methane producing bacteria then converts these compounds into stabilized organic materials and biogases consisting of mostly CH_4 and also CO_2 gases (Bingemer and Crutzen)[101].

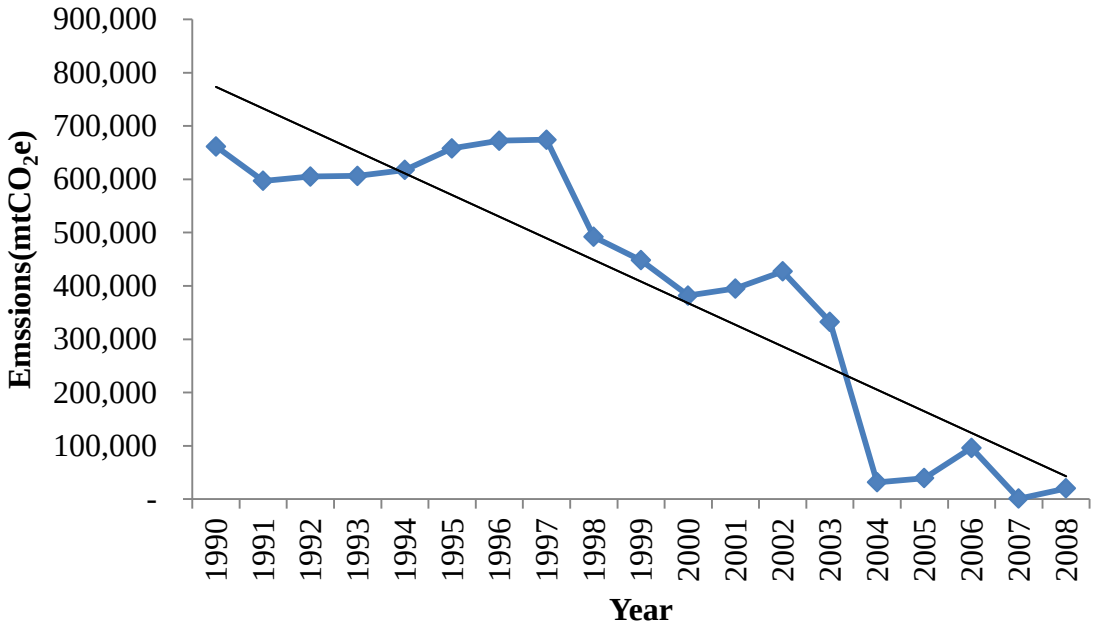
Methane, CO_2 and N_2O are also by-products of waste combustion at landfills. Waste combustion emission data were available between 1990 and 1999 only. This was because in 2000, an amendment to the statutes was passed by Delaware's legislative branch to prevent solid waste incineration near to public areas. The amendment was made under Chapter 60 (Environmental Control), Title 7 of the Delaware code. The amendment prohibits the permitting of any incinerator located within three miles of any residential community, church, school, hospital or park. As a result of the amendment, landfill waste incineration in Delaware has not been practiced since 2000..

In 2008, the total GHG emissions from landfills were approximately 20,298 $mtCO_2e$ according to Table 26 above. This represented 19% of GHG emissions from waste

[101] Bingemer, H. and P. Crutzen. 1987. "The Production of Methane from Solid Waste." Journal of Geophysical research 92: 2181-2187.

management. In 1990 however, total GHG emission from landfill activities was 661,492 $mtCO_2e$ according to Table 26, which represented 91% of GHG emissions from waste management. From 1990 to 2008, GHG emissions from landfill activities dropped by 87% as indicated by Figure 66. The rate of decrease was 40,595 $mtCO_2e$ per year.

FIGURE 66. NET GHG EMISSIONS FROM LANDFILL ACTIVITIES



Methodology

This 2008 GHG emissions inventory characterized CH_4 emissions from landfills by estimating CH_4 generation at municipal landfills, CH_4 generation at industrial landfills, CH_4 recovery, and CH_4 oxidation. Equation 14 is the general equation used to estimate net methane emissions from landfill activities.

EQUATION 14. METHANE EMISSIONS EQUATION FOR SOLID WASTE

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*[102] *- CH_4 Oxidation by Soil at Industrial Landfill*

Gross Methane Emissions from Landfills using First Order Decay:

To determine the amount of CH_4 emitted at landfills, the SIT's first order decay (FOD) model was used to estimate CH_4 generation. Methane emission estimates from the FOD model are based on waste deposited at landfills over the past thirty years. These emissions vary not only by the amount of waste present in the landfill, but also by the CH_4 generation rate (k).

The CH_4 generation rate varies according to the climate in which the landfill is located. Delaware landfills are located in a non-arid climate[103] because the average rainfall in Delaware is 45.68 inches[104]. The "k" value of 0.04 for landfills in non-arid climates was applied to Delaware in the U.S. EPA's SIT model for landfill CH_4 generation.

A value of 100 m^3/metric ton was applied to the CH_4 generation potential (L_o). The first order decay model was based on Equation 15:

[102] The U. EPA assumes that methane generation from industrial landfills is approximately 7% of methane generation from MSW landfills.

[103] States in non-arid climates have average annual rainfall that is greater than 25 inches.

[104] **Data sources:** National Climatic Data Center, severe thunderstorm / tornado watch data period is 1999 - 2008, NOAA Storm Prediction Center

EQUATION 15 FIRST ORDER DECAY OF WASTE TO GENERATE CH_4

$$Q_{tx} = A * k * Rx * Lo * e^{-k(T - x)}$$

Where, $Q_{T,x}$ = Amount of CH_4 generated in year T by the waste Rx,

T = Current year

x = Year of waste input,

A = Normalization factor, $(1-e^{-k})/k$

k = CH_4 generation rate (yr^{-1})

R_x = Amount of waste landfilled in year x

L_o = CH_4 generation potential

Based on the results of the FOD modeling, gross emissions increased steadily from 1990 to 2008 as Figure 65 shows. However, other factors caused net CH_4 emissions to decrease drastically as Figure 64 shows. Those factors include CH_4 recovery and oxidation.

Gross Methane Emissions from MSW and Industrial landfills: Landfills were the largest source of anthropogenic CH_4 emissions in this 2008 GHG emission inventory. Gross[105] GHG emission from MSW landfills totaled 761,468 $mtCO_2e$ in 2008. As Figure 67 presents, CH_4 emissions increased from 573,087 $mtCO_2e$ in 1990 to 761, 468 $mtCO_2e$ in 2008, which was an increase of 33%. The CH_4 emissions increased at the rate of 9,310 $mtCO_2e$ per year. The observed increase in gross emissions from landfill activities between 1990 and 2008 is expected to continue. This is because gross CH_4 emission is proportional to population growth. As Delaware's population increases, the amount of solid waste disposal at landfills will also increase.

[105] With the exclusion of Methane avoided by flaring and landfill gas converted for energy use.

FIGURE 67. GROSS CH_4 EMISSIONS FROM LANDFILL ACTIVITIES

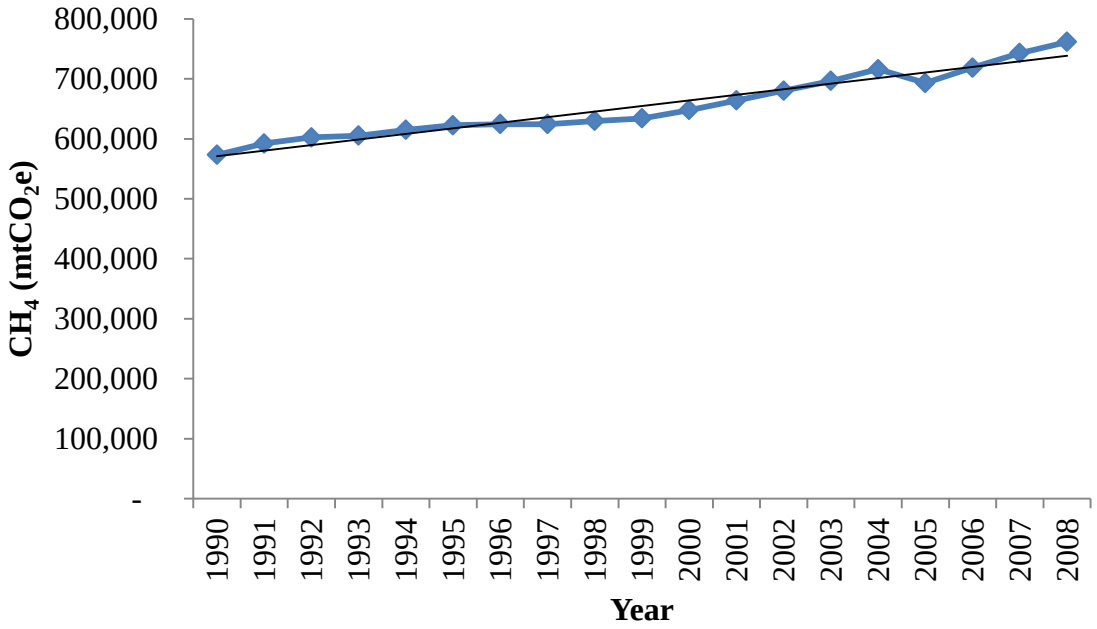
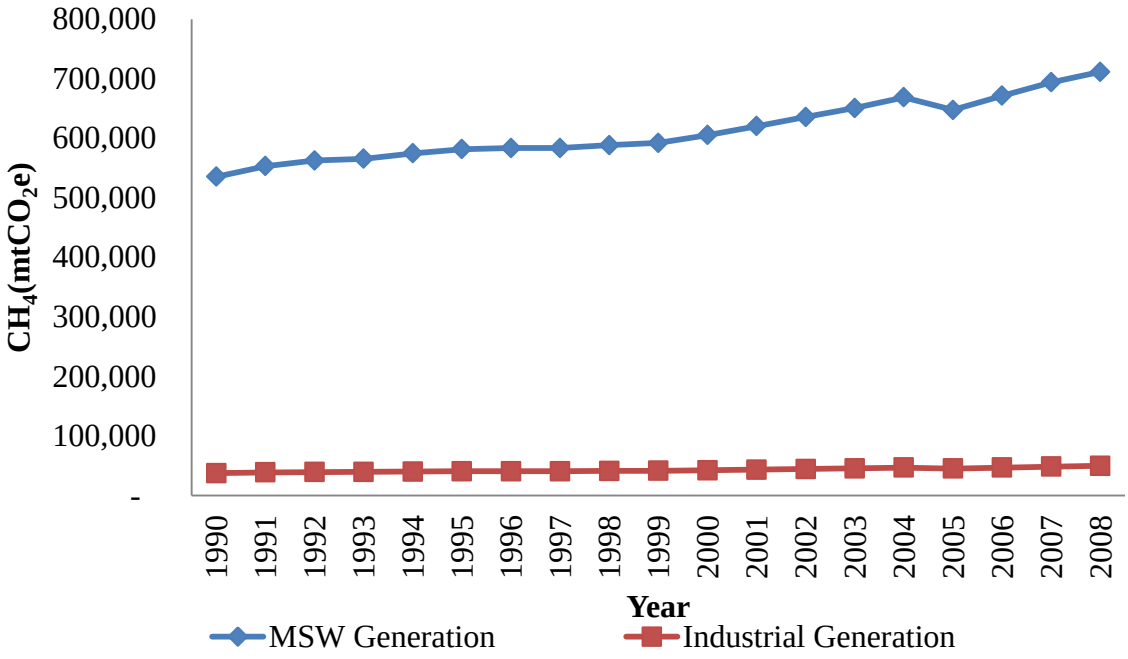


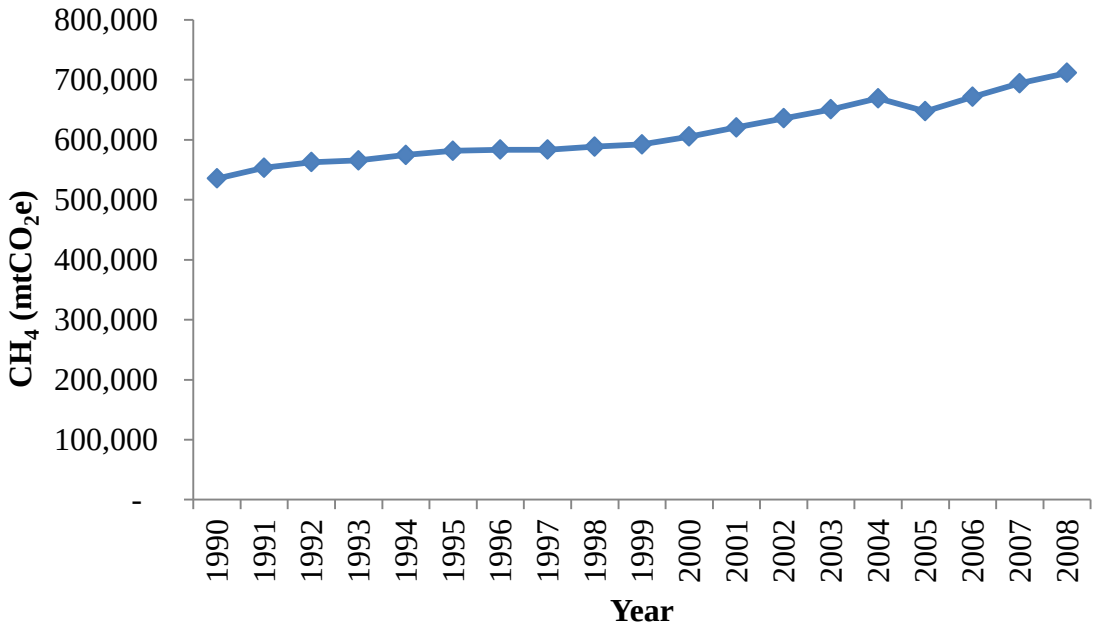
FIGURE 68. GROSS CH_4 EMISSIONS FROM MSW AND INDUSTRIAL LANDFILLS



In the 2008 GHG inventory, CH_4 emissions from landfills were divided into two types: municipal solid waste (MSW) landfill emissions and industrial landfill emissions. Figure 68 presents historical emissions of Industrial and MSW landfills as determined by the FOD model.

Gross CH_4 Emissions from MSW Landfills: Three MSW landfills in Delaware were surveyed to estimate CH_4 emissions for this source category. The Cherry Island Landfill (CIL) located in Wilmington, Central Solid Waste Management Center (CSWMC) located in Felton and Southern Solid Waste Management Center (SSWMC) located in Georgetown. All three landfills are under the jurisdiction of Delaware Solid Waste Administration (DSWA). To estimate the amount of CH_4 emissions from these MSW landfill, data on the amount of waste disposed at the landfills were collected from DSWA. GHG emission from MSW landfills in 2008 was 711,652 $mtCO_2e$.

FIGURE 69. GROSS CH_4 EMISSIONS FROM MSW LANDFILLS



Gross CH_4 Emissions from Industrial Landfills: CH_4 emission from industrial landfills does not include CH_4 generation from industrial waste disposed of into MSW landfills. This CH_4 generation is already accounted for under MSW landfills Industrial landfills that were operational in Delaware between 1990 and 2008 include Delaware Recyclable Product Inc. (DRPI), which is a construction and demolition material landfill. Industrial landfills in Delaware between 1990 and 2008 also include DuPont Hay Road and Motiva Industrial Waste Landfill (IWL).

The DuPont Hay Road landfill is located on the Delaware River in Wilmington. The DuPont Company used the site for sludge drying and disposal of byproduct material from the company's titanium dioxide pigment made at its Edgemoor facility which is located further upstream. The DuPont Hay Road was landfill was closed in 1997.

The Motiva IWL was used by the Delaware City Refinery for disposal of refinery wastes. Petroleum coke (a byproduct of oil refinery coke units and cracker processes) and fly ash[106], from the Delaware City Refinery's wastewater treatment plant from 1994 to 2004.

Other industrial landfills include fly ash landfills such as Invista, conectiv, NRG and Motiva ash landfill. Ash landfills generate very little greenhouse gases because all of their organics are well broken down. Based on estimates of the quantity of solid waste in place at industrial landfills and on the estimated organic content of industrial landfills, as compared to MSW landfills, the U.S. EPA estimates that CH_4 generation from industrial landfills in the United States is approximately 7%[107] of the MSW landfill CH_4 generation prior to adjusting for

[106] Fly ash is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases

[107] U.S. EPA's 2008 Emissions Inventory Improvement Program and State Inventory Tool

flaring and recovery or oxidation. This 7% value was applied to estimate Delaware's industrial landfills CH_4 emissions in this 2008 GHG inventory.

Figure 70 presents gross CH_4 emissions from industrial landfills estimated by using the U.S. EPA's assumption that CH_4 emission from industrial landfills equals 7% of CH_4 emission from MSW landfills. Figure 70 shows that CH_4 emissions from industrial landfills in Delaware increased steadily from 37,492 $mtCO_2e$ in 1990 to 49,816 $mtCO_2e$ in 2008. This was an increase of 33% at the rate of 609 $mtCO_2e$ per year as determined by trendline analysis.

FIGURE 70. GROSS CH_4 EMISSIONS FROM INDUSTRIAL LANDFILLS

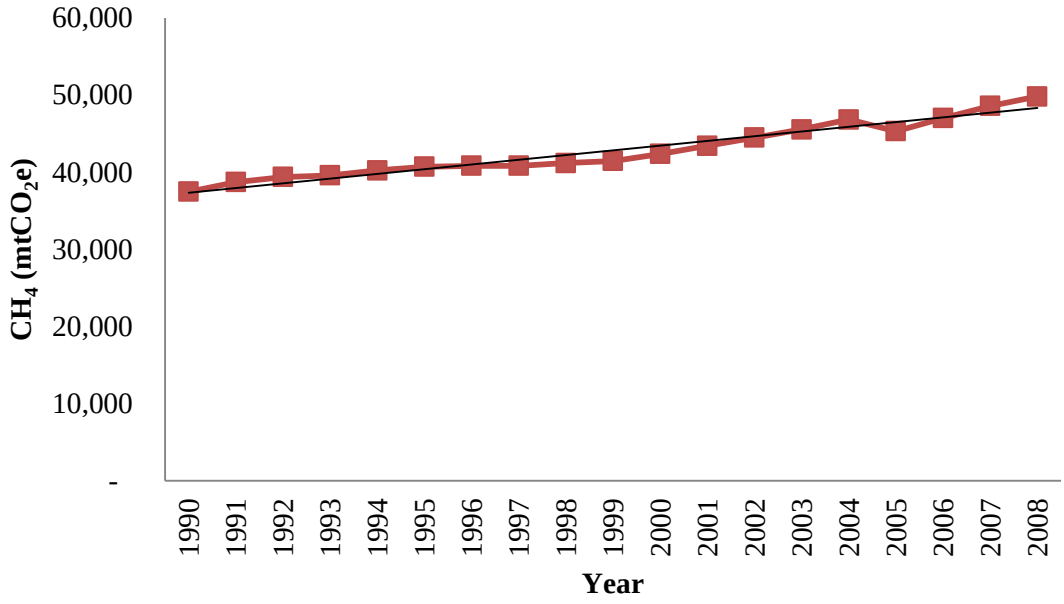


Table 27 provides estimates of CH_4 emissions from MSW and industrial landfills.

TABLE 27. CH_4 EMISSIONS FROM LANDFILLS

Landfills	1990	1995	2000	2005	2008
MSW Generation	535,595	581,780	605,436	647,599	711,652
Industrial Generation	37,492	40,725	42,381	45,332	49,816
Total CH_4	**573,087**	**622,504**	**647,817**	**692,931**	**761,468**

See Appendix I for details.

Gross GHG Emissions from Waste Combustion: Carbon dioxide emission estimates were calculated for three waste combustion categories including plastics, synthetic fibers and synthetic rubber[108]. The U.S. EPA SIT contained information on the typical composition of discards in Delaware's solid waste stream to estimate the mass of each of these waste types that is combusted, and then estimates the proportion of each material that comprises fossil carbon. An assumption was made that 98% of the fossil carbon is converted to CO_2 in the combustion process as recommended in the U.S. EPA's EIIP.

Nitrous oxide and methane emissions were estimated from MSW combustion by multiplying the amount of MSW combusted by the respective emissions factors of N_2O (0.00005 ton N_2O/ ton MSW) and CH_4 (0.00002 ton CH_4/ ton MSW). The results were then multiplied by the GWP of the respective GHGs.

Figure 71 presents the gross GHG[109] emissions of from MSW combustion. As the figure, emissions dipped between 1991 and 1994 with an average emission of 60,000 mtCO_2e. However, in 1995 emissions increased from 97,775 mtCO_2e to its peak point of 125, 296 mtCO_2e in 199. Emissions dropped to zero in 2000 due to the prohibition on waste combustion that took effect in 2000.

[108] U.S EPA's 2004 Emissions Inventory Implementation Program (EIIP) Vol. VIII

[109] GHG include CO_2, N_2O and CH_4

FIGURE 71. GROSS GHG EMISSIONS FROM MSW COMBUSTION

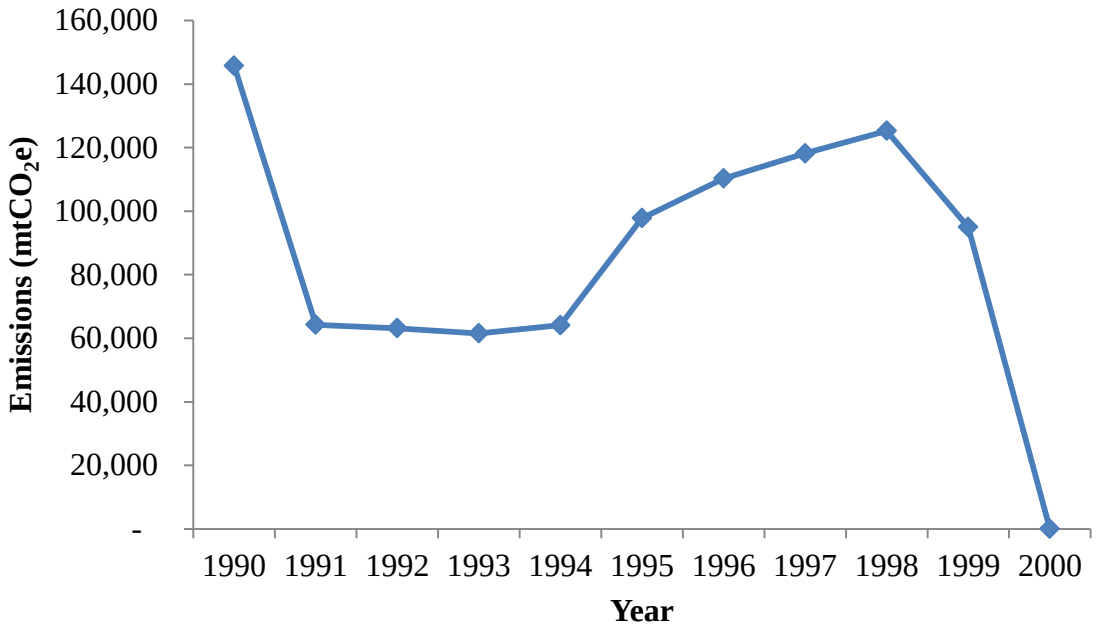


FIGURE 72 CO_2, N_2O AND CH_4 EMISSIONS FROM WASTE COMBUSTION

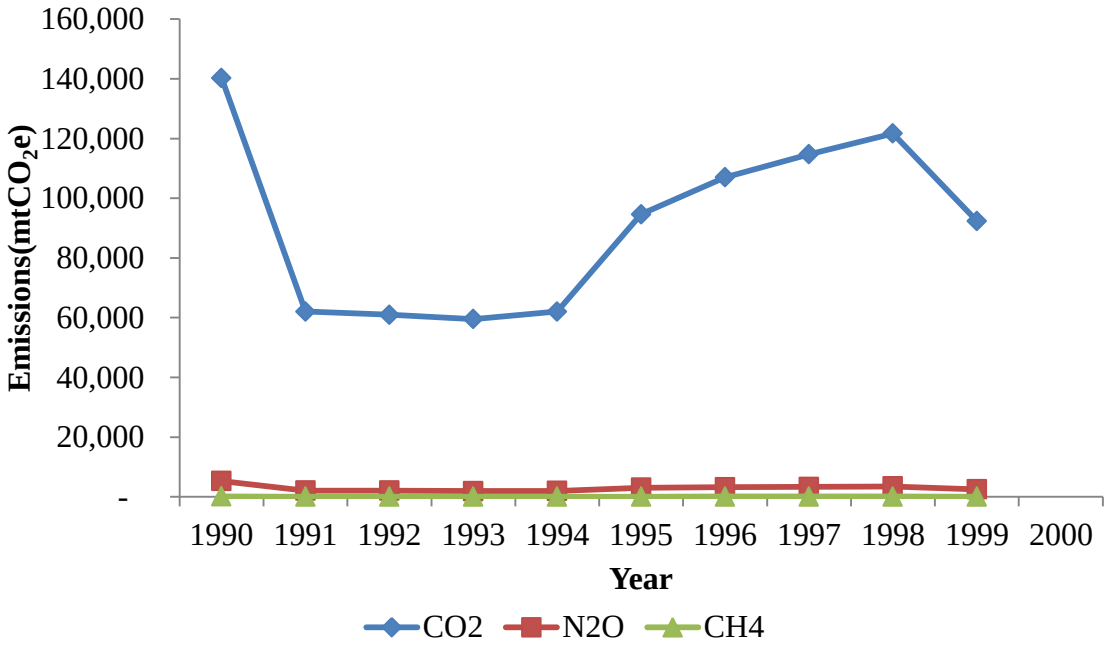


Figure 72 breaks down emissions from waste combustion by gas. As the figure shows, a CO_2 emission from waste combustion was by far greater than N_2O and

CH_4 emission. In 1999, CO_2 emission was 92,379 $mtCO_2e$, while N_2O and CH_4 emissions were 2,531 $mtCO_2e$ and 69 $mtCO_2e$ respectively.

FIGURE 73. 1999 GHG EMISSIOSN FROM WASTE COMBUSTION BY GHG

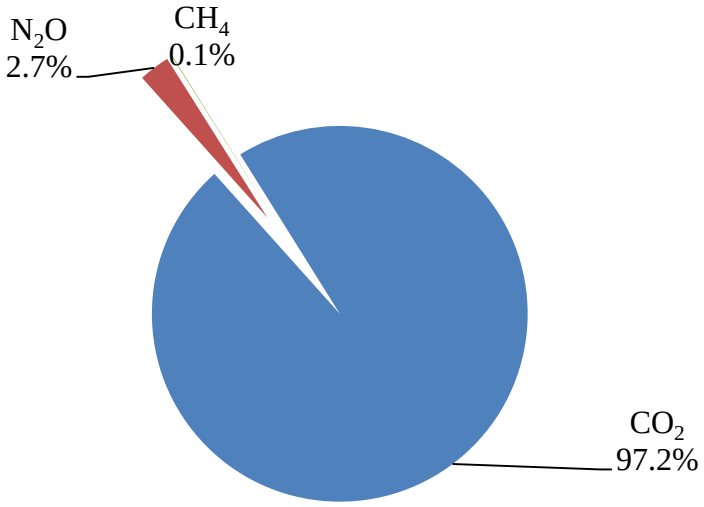


TABLE 28. CO_2, N_2O, AND CH_4 EMISSIONS FROM WASTE COMBUSTION* ($mtCO_2e$)					
GHG s	**1990**	**1995**	**2000**	**2005**	**2008**
CO_2	140,279	94,655	0	0	0
Plastics	94,078	63,118	0	0	0
Synthetic Rubber	20,491	11,254	0	0	0
Synthetic Fibers	25,711	20,283	0	0	0
N_2O	5,291	3,037	0	0	0
CH_4	143	82	0	0	0
Total CO_2, N_2O, CH_4	**145,713**	**97,775**	**0**	**0**	**0**

See Appendix I for details.

* The waste combustion emissions estimates were calculated by using Delaware's % MSW combustion data, which was provided by the U.S. EPA's State Inventory Tool (2008 updates). DAQ could not validate the MSW combustion data, which presents an uncertainty in the waste combustion emission estimates. DAQ is working with U.S. EPA and their consultants to validate the data in the 2009 inventory

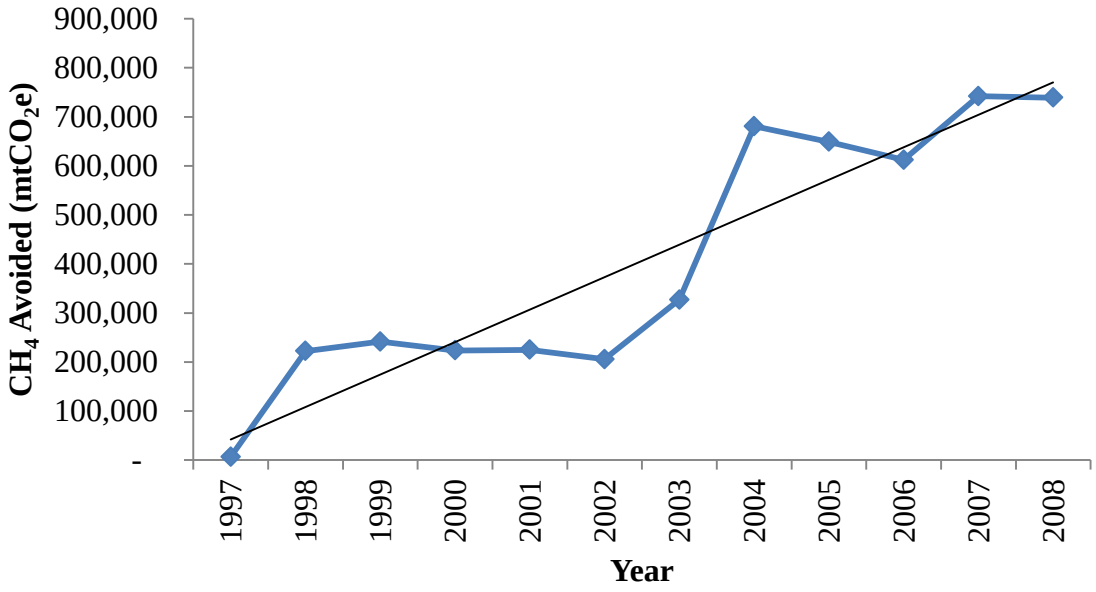
According to Figure 73, CO_2 emission represented approximately 97.2% of waste combustion emissions in 1999, while N_2O and CH_4 represented approximately 2.7% and 0.1% respectively.

Methane Recovery: Methane recovery at Delaware landfills occurs in two ways:

1) Flaring landfill gas
2) Recycling landfill gas for energy use, which is called Landfill Gas-to-Energy (LFGTE).

The total amount of CH_4 recovered is the sum of the amount of flared gas and the amount of LFGTE. Data was collected from DSWA to estimate the total CH_4 emissions avoided annually. DSWA submitted flaring and LFGTE data for the period of 1997 to 2008. The recovery data was only available from 1997 according to DSWA. Figure 74 presents the CH_4 emissions avoided at MSW landfills in Delaware from 1997 to 2008.

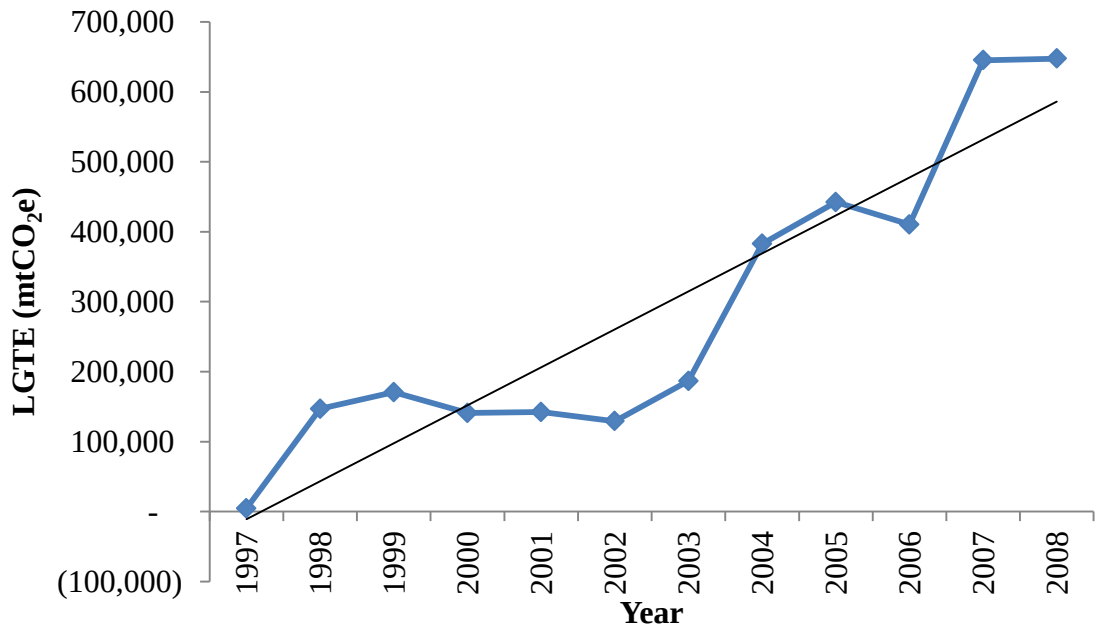
FIGURE 74. AMOUNT OF CH_4 EMISSIONS AVOIDED FROM 1997 TO 2008



As Figure 74 shows, CH_4 emissions avoided increased from 6,671 $mtCO_2e$ in 1997 to 738,914 in 2008. This was a drastic increase of approximately 10,977% from 1997 to 2008. The rate of growth was 66,218 $mtCO_2e$ per year as determined by trendline analysis. This increase in CH_4 emissions was in part because due to the recycling of CH_4 for energy use.

In the late 1990's, there was an increased effort to convert landfill gas to electrical power as the electric power market in Delaware expanded and became more competitive. In addition, Delaware's renewable portfolio standard (RPS)requiring power providers to have 10% of their power come from renewable resources by 2019[110] began in 2007.

FIGURE 75. METHANE RECOVERED BY LFGTE



[110] Delaware's Public Service Commission Web Site: http://depsc.delaware.gov/electric/delrps.shtml

Figure 75 presents the annual amount of CH_4 collected for LFGTE. The figure shows an increase from 1997 to 2008. LFGTE amounts increased from 4,548 $mtCO_2e$ in 1997 to 647,558 $mtCO_2e$ in 2008. This was an increase of approximately 14,138% at the rate of 54,276 $mtCO_2e$ per year.

FIGURE 76 METHANE RECOVERED BY FLARING

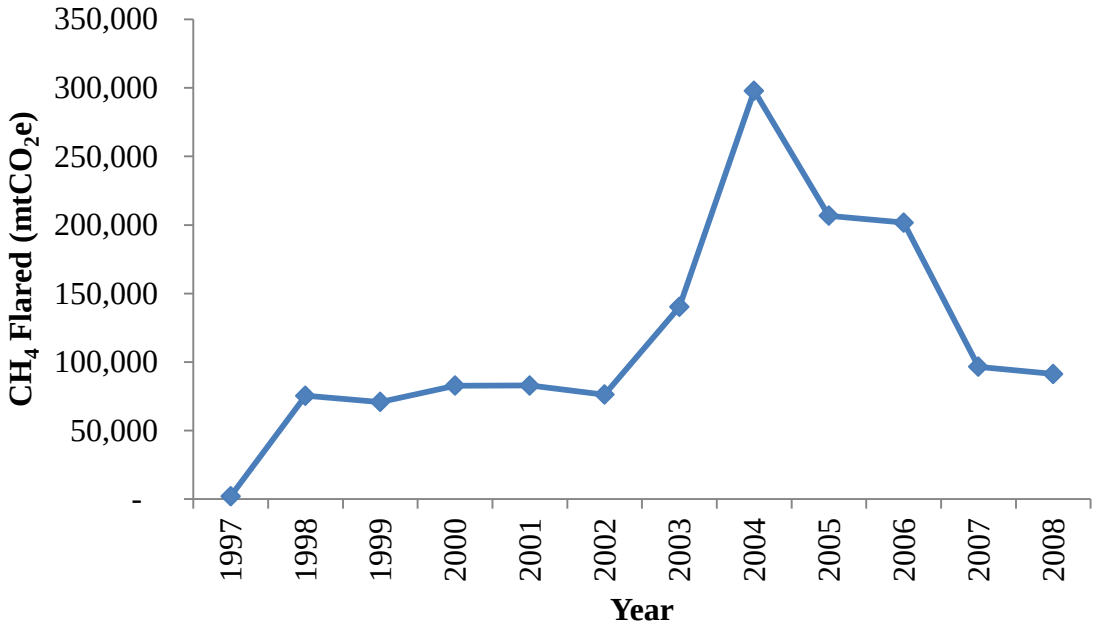


Figure 76 presents the amount of CH_4 avoided each year by flaring landfill gas. As the chart shows, there was a spike in the amount of CH_4 flared in 2004. This was due to the expansion of the flaring system. DSWA installed additional flaring units between 2003 and 2004 to collect and flare excess CH_4, which resulted in odor issues at that Cherry Island landfill.

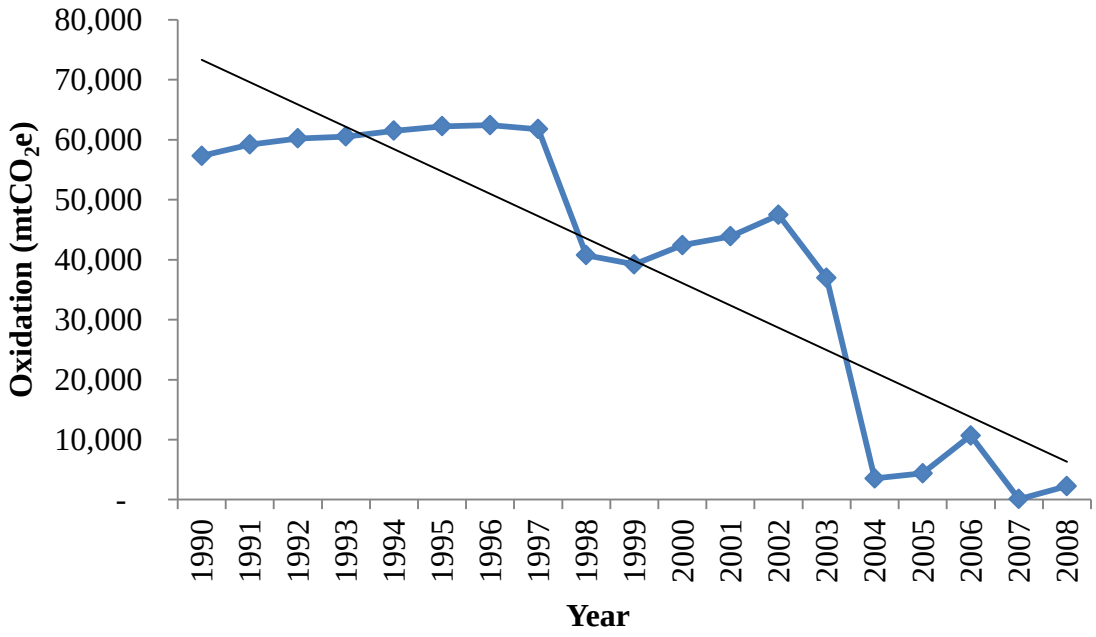
From 1997 to 2004 the amount of CH_4 flared increased rapidly from 2,124 $mtCO_2e$ to 297,924 $mtCO_2e$, an increase of approximately 13,927%. However, the amount of CH_4 flared dropped to 91,359 $mtCO_2e$ in 2008, a decrease of approximately 69%.

TABLE 29. CH_4 RECOVERED FROM LANDFILLS					
Recovery	**1990**	**1995**	**2000**	**2005**	**2008**
Flare	0	0	82,773	206,688	91,359
LFGTE	0	0	140,816	442,282	647,555
Total CH_4 Recovered	**0**	**0**	**223,589**	**648,970**	**738,914**

See Appendix I for details.

Methane Oxidized: The oxidation of CH_4 at landfills is a natural process by which landfill gas that is not collected passes through landfill cover soils on the way to being released to the environment. Bacteria in the soil consume methane and other volatile hydrocarbons that are produced by decomposition in the underlying waste by reacting it with oxygen.

FIGURE 77. METHANE OXIDIZED AT LANDFILL FACILITIES



The amount of CH_4 oxidized by the landfill cover at both municipal and industrial landfills was assumed to be 10% of the CH_4 generated that is not recovered[111]. To

[111] IPCC 2006, Mancinelli and McKay 1985, Czepiel et al. 1996

calculate net CH_4 emissions, both recovered and oxidized CH_4 were subtracted from the amount of CH_4 generated at municipal and industrial landfills.

The amount of CH_4 oxidized increased from 57,309 $mtCO_2e$ in 1990 to 61,779 $mtCO_2e$ in 1997, but later dropped to 2,255 $mtCO_2e$ in 2008 as Figure 77 presents. The overall reduction in the amount of CH_4 oxidized was approximately 96%. The rate of decrease was 3,723 $mtCO_2e$ per year. This decrease was primarily the result of the increased CH_4 recovery activities at Delaware landfills from 1997 to 2008.

Table 30 provides a summary of CH_4 oxidized at Delaware landfills between 1990 and 2008.

TABLE 30. CH_4 OXIDIZED AT MSW AND INDUSTRIAL LANDFILLS ($mtCO_2e$)

CH_4 Oxidized	**1990**	**1995**	**2000**	**2005**	**2008**
Oxidation at MSW Landfills	53,560	58,178	38,185	(137)	(2,726)
Oxidation at Industrial Landfills	3,749	4,072	4,238	4,533	4,982
Total CH_4 Oxidized	**57,309**	**62,250**	**42,423**	**4,396**	**2,256**

See appendix I for detail

4.5.2 Wastewater Treatment:

GHGs emitted from the wastewater sector in Delaware included CH_4 and N_2O. Both GHGs are emitted from the disposal and treatment of industrial[112], as well as municipal[113] wastewater. Methane is produced when organic material in treated and untreated wastewater degrades in the absence of oxygen. Nitrous oxide is emitted from both

[112] Default factors for wastewater outflow, industry-specific COD, and the fraction of industrial wastewater that is anaerobically treated that are used to estimate emissions from industrial wastewater in the Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. EPA 2010) are provided in the control sheet.

[113]EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. EPA 2010) Table 8-13, for data on annual per capita protein consumed

domestic and industrial wastewater containing nitrogen-rich organic matter. Nitrous oxide is produced through the natural processes of nitrification and denitrification.

Delaware has 19 wastewater treatment facilities. The facilities include major and minor[114] wastewater treatment plants. Table 31 provides a list of minor and major wastewater treatment facilities in Delaware:

TABLE 31 . LIST OF WASTEWATER TREATMENT PLANTS IN DELAWARE

Facilities	Major/Minor	Discharge flow (MGD)[115]
Bridgeville	Major	0.8
Delaware City	Minor	0.57
Greenville Country Club	Minor	0.015
Harrington	Minor	0.75
Kent County	Major	16.3
Laurel	Minor	0.7
Lewes	Major	1.5
Lums Pond State Park Minor	Minor	0.105
Middletown-Odessa-Townsends	Minor	2.5
Millsboro	Minor	0.55
Milton	Minor	0.35
Mobile Gardens Trailer Park	Minor	0.06
Port Penn	Minor	0.05
Rehoboth Beach	Major	3.4
Seaford	Major	2
Selbyville	Major	1.25
South Coastal Region l	Major	9
Wilmington	Major	134
Winterthur	Minor	0.025

Data source: Division of Water Resources

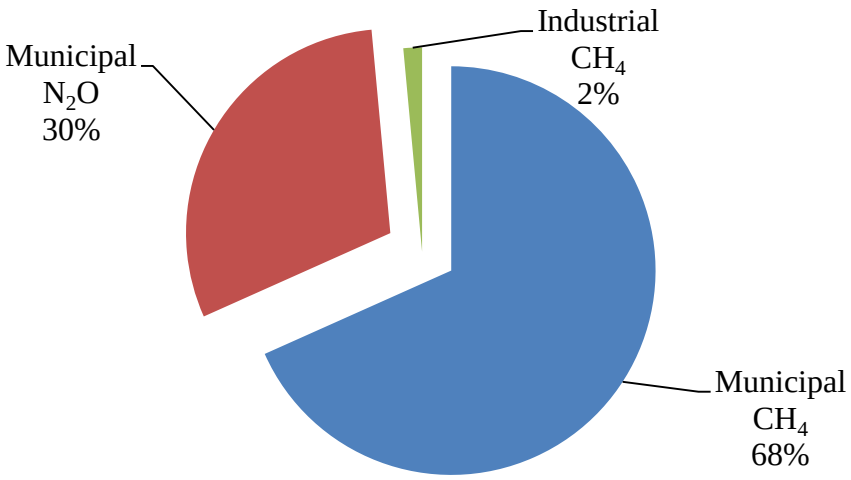
Figure 78 provides the breakdown of GHG emissions in $mtCO_2e$ from each of the types of emission sources above. In 2008, gross GHG emission from wastewater treatment was

[114] Wastewater Treatment Plants with flow discharges less than 0.8 MGD is considered minor.

[115] MGD: million gallons per day

86,274 $mtCO_2e$. Methane from municipal wastewater treatment was the largest contributor to gross GHG emissions from the wastewater treatment sources representing approximately 68%. This was followed by N_2O from municipal wastewater treatment representing approximately 30% and CH_4 from industrial wastewater treatment representing approximately 2%.

FIGURE 78 CO_2e EMISSIONS BY WASTEWATER TREATMENT SUBCATEGORIES



From 1990 to 2008, gross GHG emissions from wastewater treatment increased annually as Figure79 shows. From 1990 to 2008, GHG emissions increased by approximately 35%. Methane emission was 6,400 $mtCO_2e$ in 1990 and 86,274 in 2008 $mtCO_2e$. The annual rate of increase was approximately 1,184 $mtCO_2e$ per year. Delaware's population growth is proportional to the growth of GHG emissions from wastewater treatment. Between 1990 and 2008, Delaware's population grew by approximately 32%.

TABLE 32. WASTEWATER EMISSIONS BY SOURCE ($MTCO_2e$)

Wastewater treatment Sources	1990	1995	2000	2005	2008
Municipal CH_4	44,807	48311	52,894	56,399	58,934
Municipal N_2O	18,227	20189	22,887	24,664	26,072
Industrial CH_4	966	955	556	481	1,268

TABLE 32. WASTEWATER EMISSIONS BY SOURCE ($MTCO_2e$)					
Wastewater treatment Sources	**1990**	**1995**	**2000**	**2005**	**2008**
Total	**64,000**	**69,454**	**76,337**	**81,544**	**86,274**

See Appendix J for details.

FIGURE 79. GHG EMISSIONS FROM WASTEWATER TREATMENT

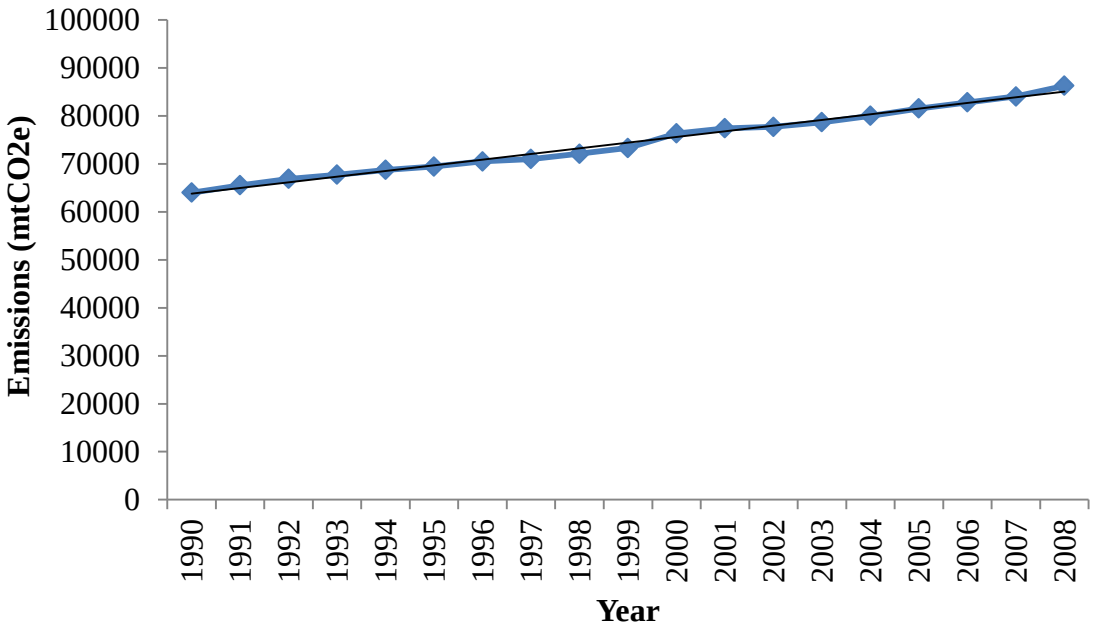


Table 32 provides estimates of GHG emissions from wastewater treatment sourceses.

GHG emissions were categorized into three sources including:

- Methane emissions from municipal waste water treatment,
- Nitrous Oxide from municipal wastewater treatment
- Methane Emissions from industrial wastewater treatment.

Methodologies

The following subsections describe the methodologies used to estimate GHG emissions from each source type:

A. ***Methane Emissions from Municipal Wastewater Treatment***: Methane from Municipal wastewater treatment came from organic materials in municipal solid waste treatment. Methane emissions were estimated using the biochemical oxygen demand (BOD) in the wastewater based on Emissions Inventory Improvement Program (EIIP) method. To calculate methane emissions from municipal wastewater treatment, the total annual BOD_5 production in metric tons was multiplied by the fraction that is treated anaerobically and by the CH_4 produced per metric ton of BOD_5, converted to metric tons carbon equivalent (mtCe), and converted to metric tons carbon dioxide equivalent ($mtCO_2e$). Equation 16 describes the method for estimating CH_4 emissions from municipal wastewater treatment:

EQUATION 16. METHANE EMISSIONS EQUATION FOR MUNICIPAL SOLID WASTE

CH_4 Emissions (kg CH_4)	=	*BOD5 Treated Anaerobically (kg BOD_5/yr) x CH_4 EF(kg CH_4/kg BOD_5)*

Analysis of CH_4 Emissions from Municipal Wastewater Treatment: As observed in Figure 80, CH_4 emissions from municipal wastewater treatment increased from 44,807 $mtCO_2e$ in 1990 to 58,934 $mtCO_2e$ in 2008. This was an increase of 33% during that period. Methane emissions increased annually by approximately 786 $mtCO_2e$. This trend is expected to continue as Delaware's population increases due to the linear relationship that exist between CH_4 emissions from municipal waste water treatment and Delaware's population as shown by Figure 81.

FIGURE 80. CH_4 EMISSIONS FROM MUNICIPAL WASTEWATER TREATMENT

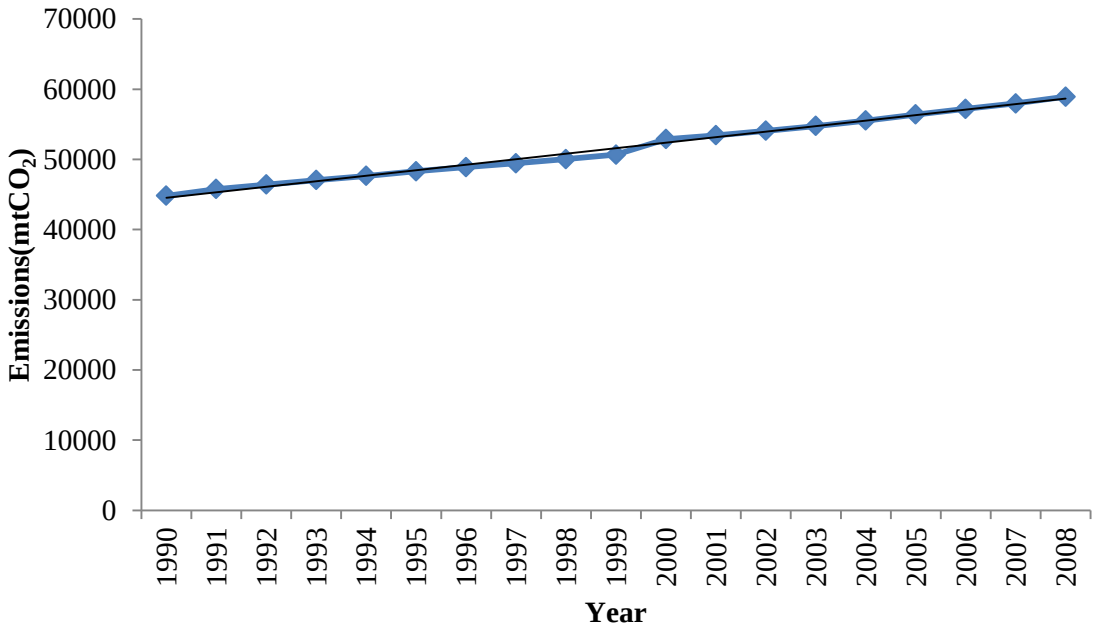
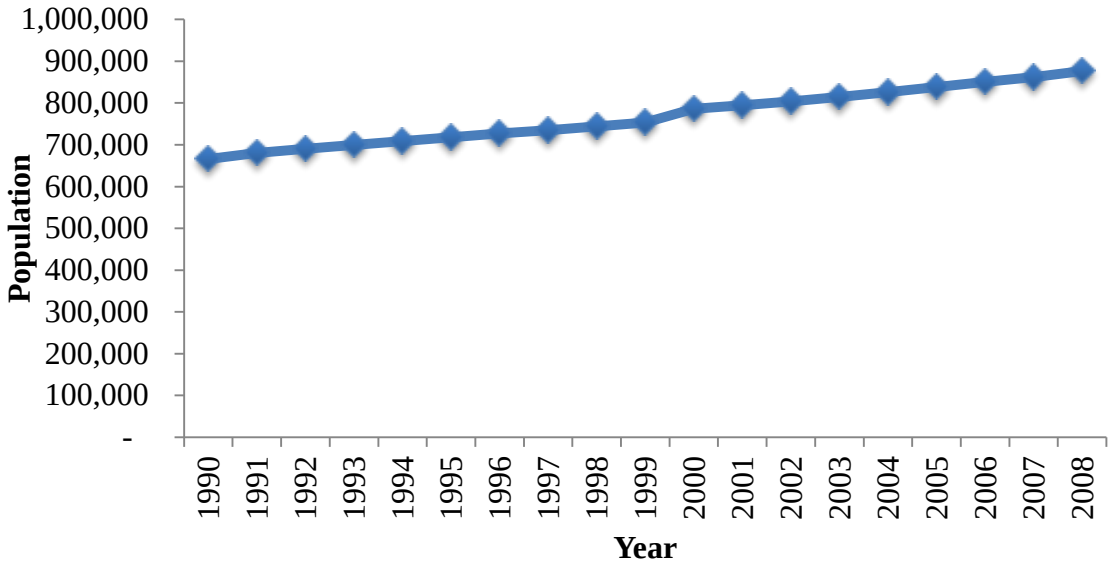


FIGURE 81. DELAWARE'S POPULATION FROM 1990 TO 2008



B. ***Nitrous Oxide Emissions from Municipal Wastewater Treatment:***

The general equation for estimating N_2O from wastewater treatment is described in Equation 17:

EQUATION 17 METHANE EMISSIONS EQUATION FOR MUNICIPAL WASTEWATER TREATMENT

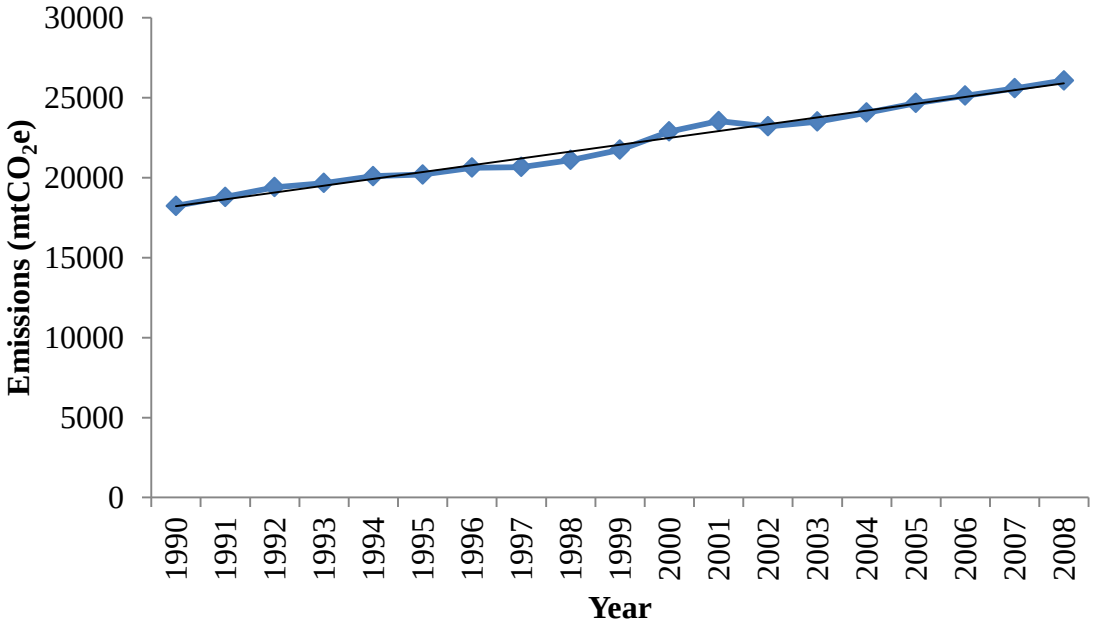
Annual Emissions of N_2O from Wastewater (kg N_2O)	=	*Annual Total N in Wastewater (kg N) x EF (kg N_2O-N/kg N) x 44/28*

There are two types of N_2O emissions from wastewater treatment: 1) Direct N_2O from municipal wastewater treatment, and 2) N_2O emissions from human sewage waste treatment. Direct N_2O emissions from municipal wastewater treatment were calculated by multiplying total population served by an N_2O emission factor per person per year, converted to metric tons carbon equivalent (mtCe), and converted to metric tons carbon dioxide equivalent ($mtCO_2e$). Municipal wastewater N_2O emissions from biosolids (human sewage) were estimated by multiplying the total annual protein consumption by the nitrogen content of protein and fraction of nitrogen not consumed, an N_2O emission factor per metric ton of nitrogen treated, subtracting direct emissions, converted to million metric tons carbon equivalent (MmtCe), and converted to million metric tons carbon dioxide equivalent ($MmtCO_2e$). Direct and biosolids N_2O emissions were then added to produce an estimate of total municipal wastewater treatment N_2O emissions.

Analysis of Municipal N_2O Emissions

Figure 82 shows that between 1990 and 2008, N_2O emissions increased from 18,227 in 1990 to 26,072 in 2008. This was an increase of 43%. The rate of N_2O emissions increase was determined by trendline analysis to be 427 $mtCO_2e$ per year.

FIGURE 82. N_2O EMISSIONS FROM MUNICIPAL WASTEWATER TREATMENT



C. ***Methane Emissions from Industrial Wastewater Treatment*:** To estimate emissions from industrial CH_4 sources, annual wastewater productions were multiplied by the industry-specific Chemical (COD), fraction of COD treated anaerobically, and the industry-specific emission factor.

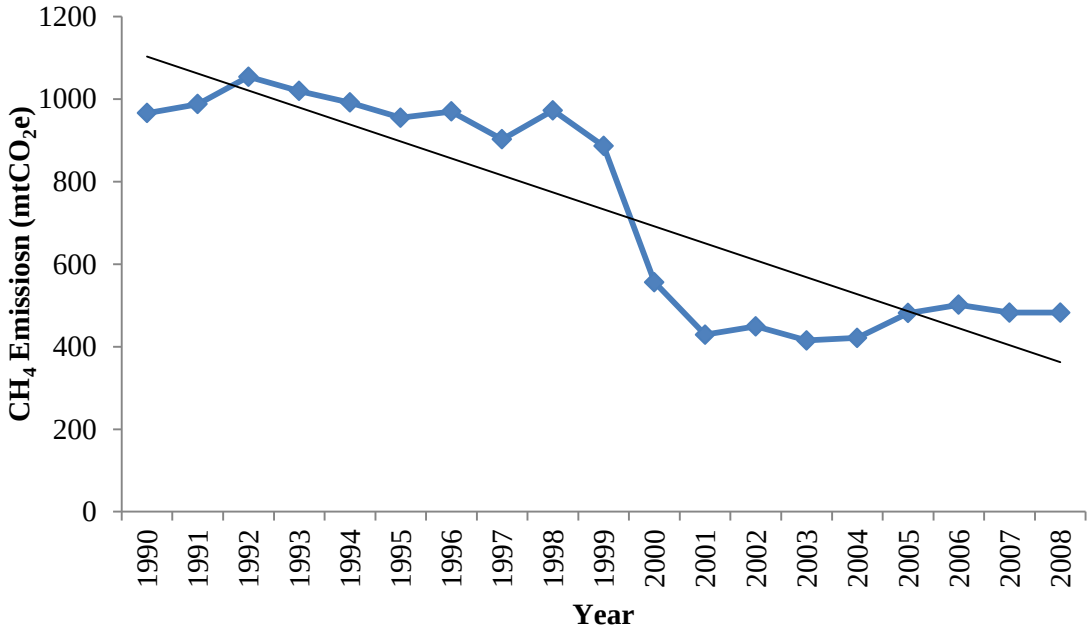
EQUATION 18. CH_4 EMISSIONS EQUATION FOR MUNICIPAL WASTEWATER TREATMENT

CH_4 Emissions (g CH_4)	=	*Wastewater Production (l) x COD (g COD/l) x Fraction of COD Anaerobically Treated (%) x Emission Factor (g CH_4/g COD)*

Analysis of CH_4 Emissions from Wastewater Treatment

Figure 83 presents CH_4 emissions from industrial waste water treatment. Figure 83 shows that from 1990 to 2008, CH_4 emissions from industrial wastewater treatment in Delaware declined from 966 $mtCO_2e$ in 1990 to 482 $mtCO_2e$ in 2008. This was a decrease of approximately 50% in CH_4 emissions from industrial wastewater treatment.

FIGURE 83. CH_4 EMISSIONS FROM INDUSTRIAL WASTEWATER TREATMENT



4.6 LAND –USE, LAND-USE CHANGE AND FORESTRY:

The 2008 GHG emissions inventory identified the land-use source category as a major sink for GHG emissions in Delaware. Through the process of photosynthesis, carbon dioxide is absorbed by trees and plants and converted to carbon in biomass. Carbon dioxide emissions occur due to dead biomass decay as well as forest fires. Carbon is stored for long time periods when forest biomass is harvested for use in durable wood products. Carbon is also stored in soil. Carbon

dioxide flux is the net balance of carbon dioxide removals from, and emissions to the atmosphere from the processes described above.

GHG emissions from the land-use sector are estimated by calculating the greenhouse gas flux from land-use sources. The greenhouse gas net flux from forest pools were derived from inventories of forest stock. Emissions from harvested wood were determined by accounting for the variable rate of decay of harvested wood. The following GHG emissions estimates were included in this sector: forest carbon flux, soils fertilization, urban trees, landfill yard trimmings, and forest fires[116].

Land-use Emission Analysis

The 2008 GHG emissions inventory identified the land-use sector as a major sink[117] for CO_2 emissions in Delaware. According to Figure 84, net CO_2 emission from this sector has been negative since 1990. Its removal of CO_2 from the atmosphere peaked in 2008 with a net GHG removal of 2.74 $MmtCO_2e$. As Table 33 below shows, from 1990 to 1998, the forest carbon flux had positive emissions with an average of 0.04 $MmtCO_{2e}$ (40,000 $mtCO_2e$). However, in 1999, the net emission from this source was -1.57 $MmtCO_2e$ (1.57 $MmtCO_2e$ sequestered

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[116] Data source: State Inventory Tool default date.

[117] A sink is the removal of GHG from the atmosphere

FIGURE 84. HISTORICAL LAND-USE CO_2 SEQUESTRATION

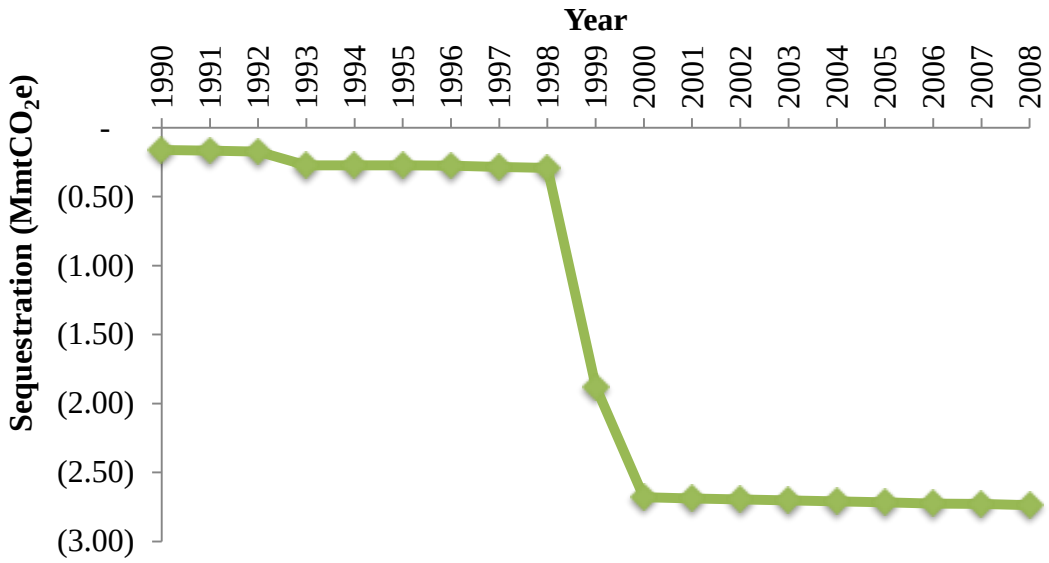


TABLE 33. SINK ESTIMATES FOR THE LAND-USE, LAND-USE CHANGE AND FORESTRY SECTOR

($MmtCO_2e$)*	**1990**	**1998**	**1999**	**2005**	**2008**
Forest Carbon Flux	**0.11**	**0.01**	**(1.57)**	**(2.36)**	**(2.36)**
Aboveground Biomass	(0.31)	(0.31)	(1.11)	(1.51)	(1.51)
Belowground Biomass	(0.05)	(0.05)	(0.21)	(0.28)	(0.28)
Dead Wood	(0.03)	(0.03)	(0.14)	(0.19)	(0.19)
Litter	0.15	0.15	0.05	(0.00)	(0.00)
Soil Organic Carbon	0.35	0.35	(0.07)	(0.28)	(0.28)
Total wood products	0.00	(0.09)	(0.09)	(0.09)	(0.09)
Liming of Agricultural Soils	**(0.22)**	**(0.28)**	**(0.29)**	**(0.34)**	**(0.36)**
Urea Fertilization	0.00	0.00	0.00	0.00	0.00
Urban Trees	(0.22)	(0.28)	(0.29)	(0.34)	(0.36)
Landfilled Yard Trimmings and Food Scraps	**(0.06)**	**(0.04)**	**(0.03)**	**(0.03)**	**(0.03)**

TABLE 33. SINK ESTIMATES FOR THE LAND-USE, LAND-USE CHANGE AND FORESTRY SECTOR					
($MmtCO_2e$)*	**1990**	**1998**	**1999**	**2005**	**2008**
Grass	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)
Leaves	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)
Branches	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)
Landfilled Food Scraps	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)
N_2O from Settlement Soils	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Total	**(0.16)**	**(0.29)**	**(1.88)**	**(2.72)**	**(2.74)**

See Appendix K for more details.

* The parenthesis indicate negative numbers or sequestration

As Table 34 shows, net emission estimates from landfill yard trimmings also show CO_2 removal from Delaware's atmosphere from 1990 to 2008.

4.7 EMISSION INVENTORY RESULTS BY GHGS

Figure 85 shows the percent emissions by GHGs in 2008. Of all the GHGs, CO_2 had the largest contribution to gross GHG emissions. Table 34 provides estimates of emissions by GHGs.

FIGURE 85. 2008 PERCENT CO_2E EMISSIONS BY GHGS

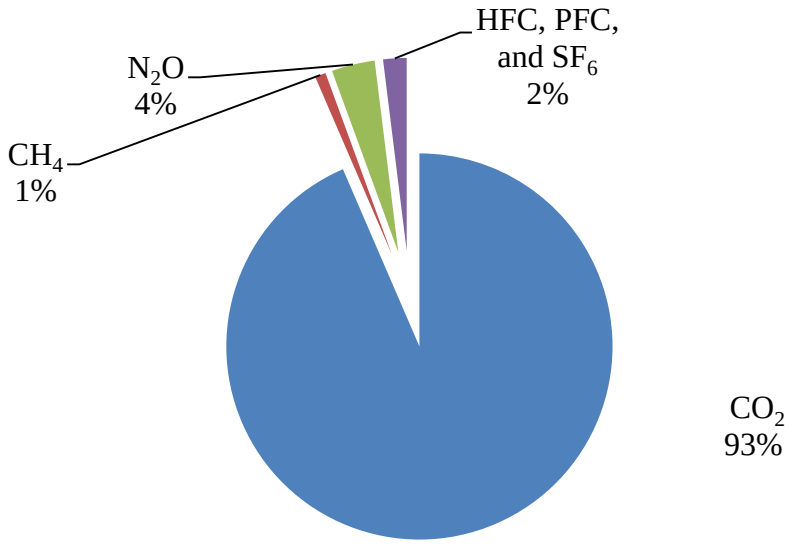


TABLE 34. ESTIMATES OF EMISSIONS BY GHGS ($MTCO_2e$)					
	1990	**1995**	**2000**	**2005**	**2008**
Gross CO2	**19.12**	**18.60**	**17.81**	**18.84**	**17.59**
Net[118] CO_2	18.95	18.31	15.12	16.11	14.85
CO_2 from FFC	18.78	18.30	17.62	18.66	17.43
Industrial Processes	0.20	0.20	0.19	0.18	0.16
Waste	0.14	0.09	0	0	0
LULUCF*	(0.17)	(0.28)	(2.69)	(2.72)	(2.75)
CH_4	**0.69**	**0.75**	**0.56**	**0.21**	**0.25**
Stationary Combustion	0.02	0.02	0.02	0.02	0.02
Mobile Combustion	0.02	0.02	0.02	0.01	0.01
Oil Refining	0.01	0.01	0.01	0.01	0.01
Enteric Fermentation	0.05	0.05	0.05	0.04	0.04
Manure Management	0.03	0.03	0.03	0.03	0.03
Burning of Ag Crop Residue	0.00	0.00	0.00	0.00	0.00
MSW	0.52	0.56	0.38	0.04	0.02
Wastewater Treatment	0.05	0.05	0.05	0.06	0.06
N_2O	**0.82**	**0.86**	**0.90**	**0.74**	**0.68**
Stationary Combustion	0.04	0.04	0.04	0.04	0.04
Mobile Combustion	0.21	0.26	0.25	0.18	0.11
Industrial Processes	-	-	-	-	-
Manure Management	0.15	0.17	0.16	0.16	0.16
Agricultural Soil Management	0.38	0.35	0.42	0.33	0.32
Burning of Ag Crop Residue	0.00	0.00	0.00	0.00	0.00
N_2O from Settlement Soils	0.01	0.01	0.01	0.01	0.01
MSW	0.01	0.00	0	0	0
Wastewater Treatment	0.02	0.02	0.02	0.02	0.03
HFC, PFC, and SF_6	**0.08**	**0.15**	**0.26**	**0.34**	**0.37**
Industrial Processes	0.08	0.15	0.26	0.34	0.37
Gross Emissions	**20.71**	**20.34**	**19.52**	**20.12**	**18.88**
Sinks	**(0.17)**	**(0.28)**	**(2.69)**	**(2.72)**	**(2.75)**
Net Emissions (Sources and Sinks)	**20.55**	**20.35**	**16.84**	**17.40**	**16.14**
Indirect CO_2 from Electricity Consumption	**0**	**0**	**6.26**	**6.74**	**6.55**

See Appendix L for details. *Land –Use, Land-Use Change and Forestry

[118] Net CO_2 is the result of applying CO_2 sink by subtracting CO_2 removal by LULUCF from the atmosphere.

4.7.1 Carbon dioxide (CO_2)

Carbon dioxide (CO_2) is an odorless and colorless gas at low concentrations. Anthropogenic sources of CO_2 include fossil fuel combustion, industrial processes and waste management. Because of its low global warming potential (GWP) CO_2 is used as the reference gas, for which the GWP of all other gases are based on. The anthropogenic sources of CO_2 in Delaware include fossil fuel combustion (FFC), industrial processes and waste combustion.

In 2008, CO_2 emissions represented approximately 93% gross CO_2e emissions from Delaware, which was a total of 17.59MmtCO_2e. Approximately 99% of CO_2 emissions from Delaware come from FFC, while the rest came from industrial processes and waste management. Figure 86 provides a breakdown of gross CO_2 emissions by economic sector. In 2008, electric power generation represented the largest CO_2 emission with approximately 34%. This was followed by industrial CO_2 emissions with 29%, transportation CO_2 emission with 28%, Residential CO_2 emission with 5%, commercial CO_2 emission with 4% and waste CO_2 emission with less than 1% (approximately 0.5%)

FIGURE 86. 2008 GROSS CO_2 EMISSIONS FROM FFC BY ECONOMIC SECTOR

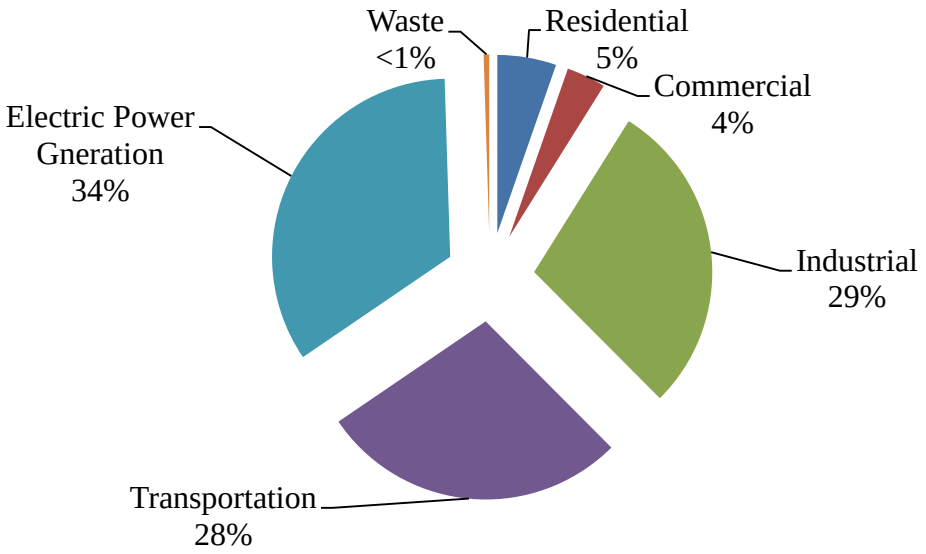
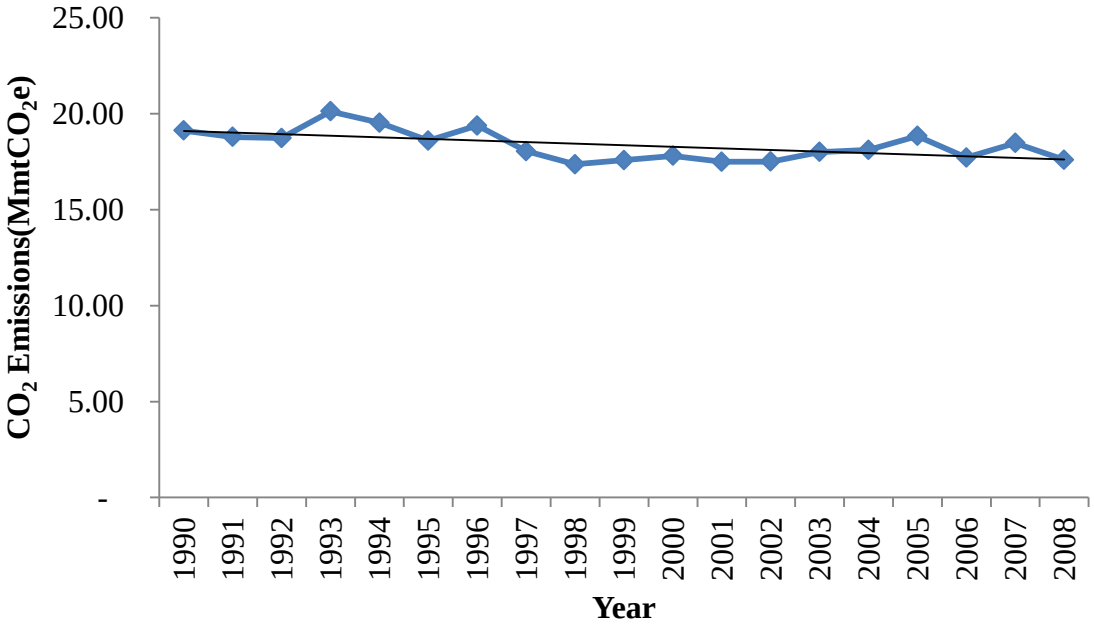


Figure 87 shows that from 1990 to 2008, CO_2 emissions had a downward trend. Carbon dioxide emissions peaked in 1993 with 20.12 $MmtCO_2e$ and reached its lowest point in 1998 with 17.36 $MmtCO_2e$. Carbon dioxide emissions decreased annually at the rate of 0.0821 $MmtCO_2e$ per year. This downward trend was primarily caused by the decline in fossil fuel consumption in all sectors of Delaware's economy from 1990 to 2008.

FIGURE 87. DELAWARE'S CO_2 EMISSION TREND

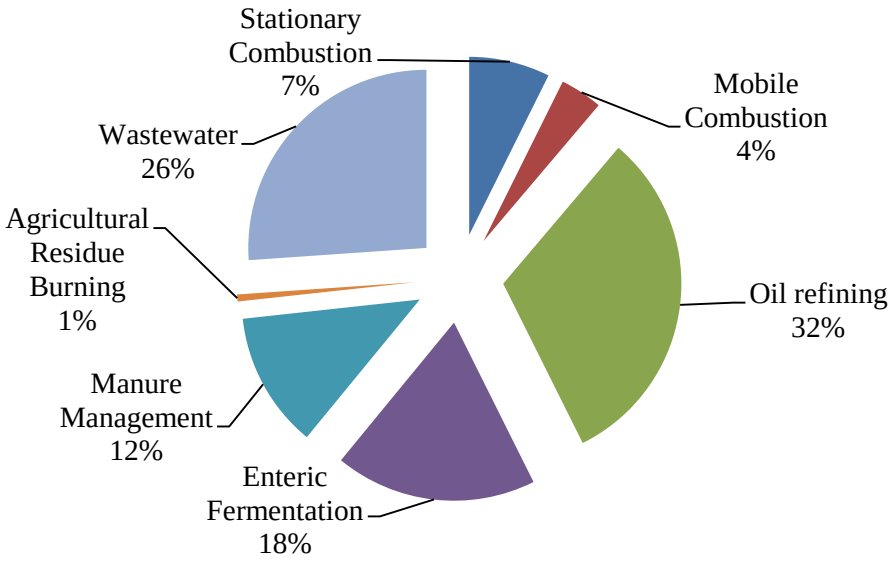


4.7.2 Methane (CH_4)

Methane (CH_4) is a colorless gas, which is lighter than air.CH_4 is 25 (GWP) times as effective as CO_2 at trapping heat in the atmosphere (IPCC 1996). Over the last two hundred and fifty years, the concentration of CH_4 in the atmosphere increased by 148 percent (IPCC 2007). Anthropogenic sources of CH_4 in Delaware include oil refining, agricultural activities, landfills, wastewater treatment, and stationary and mobile combustion.

In 2008, CH_4 emissions represented approximately 1% of gross CO_2e emissions from Delaware. Figure 88 shows of CH_4 emission from various economic sectors in 2008. Emissions from oil refining represented the largest source of CH_4 emission in 2008 with 32% of gross CH_4 emissions.

FIGURE 88. 2008 GROSS CH_4 EMISSIONS BY SOURCE CATEGORY

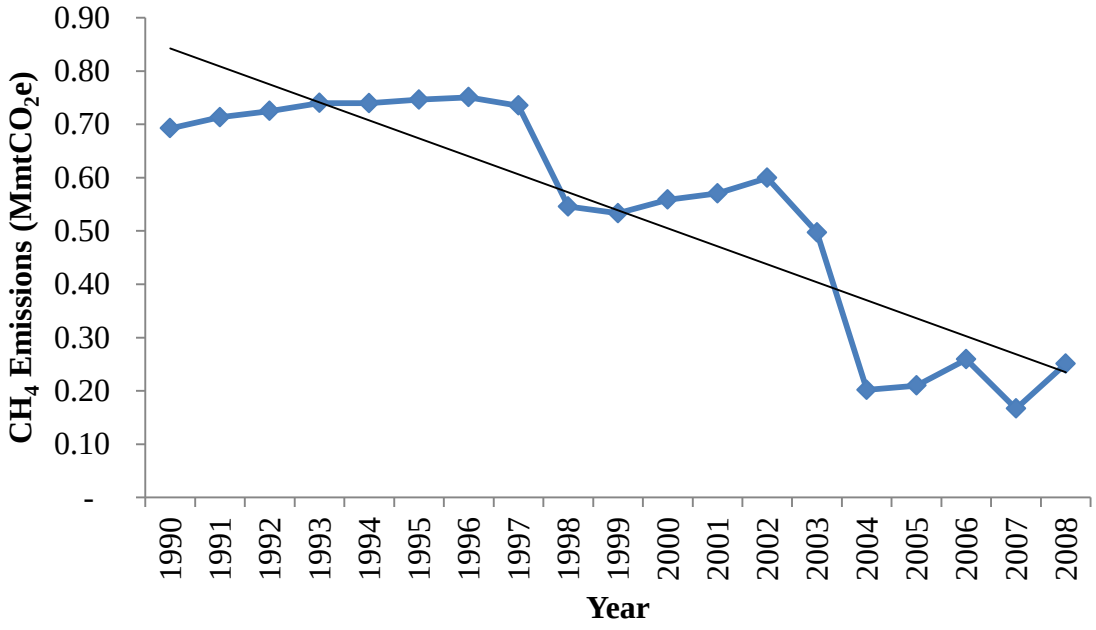


This was followed by wastewater treatment with 26%, followed by enteric fermentation which was approximately 18%, manure management with approximately 12%, stationary combustion with approximately 7%, mobile combustion with approximately 4% and agricultural residue burning with approximately 1%. Total methane emission in 2008 was 0.25 $MmtCO_2e$.

Figure 89 presents CH_4 emissions from 1990 to 2008 from the various sectors of Delaware. Similarities are observed when overall CH_4 emissions, as depicted by Figure 89 is compared to waste management emissions as depicted by Figure 77. This indicates that overall CH_4 emissions is driven largely emissions from the waste management sector.

According to Figure 89, CH_4 emissions increased steadily from 1990 (0.69 $MmtCO_2e$) to 1997 (0.74 $MmtCO_2e$) by 7.2%. Emissions then decreased from 1997 to 2008 with fluctuations. Overall, emissions decreased 0.25 $MmtCO_2e$ in 2008, a decrease of 66%. The lowest point of emissions was 0.20 $MmtCO_2e$ in 2004 with. The rate of decrease was determined to be 0.034 $MmtCO_2e$ per year.

FIGURE 89. DELAWARE'S NET CH_4 EMISSIONS TREND

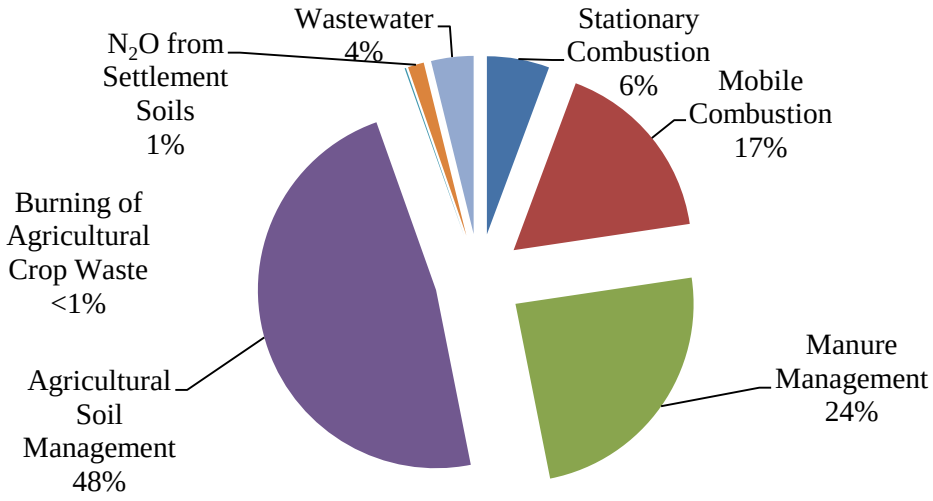


4.7.3 Nitrous Oxide (N_2O)

Nitrous oxide is a colorless non-flammable gas with a slightly sweet smelling odor and taste. N_2O is produced by biological processes that occur in soil and water and by a variety of anthropogenic activities in the agricultural, energy-related, industrial, and waste management sources in Delaware. Other sources of N_2O in Delaware also include use as oxidizers in race cars, as an anesthetic or analgesic (pain killer) in the medical field, as an aerosol propellant and as food preservative. While N_2O emissions are usually lower than CO_2 emissions, N_2O is approximately 300 times more powerful than CO_2 at

trapping heat in the atmosphere (IPCC 1996). Since 1750, the global atmospheric concentration of N_2O has risen by approximately 18% (IPCC 2007).

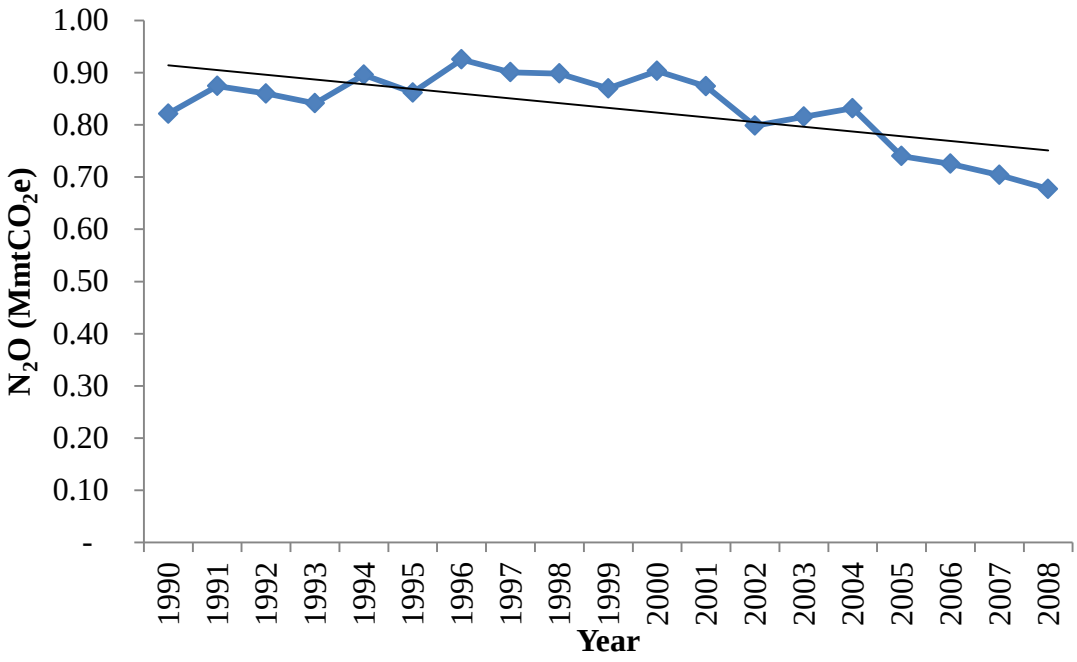
FIGURE 90. 2008 PERCENT CO_2e OF N_2O EMISSIONS FROM SOURCE CATEGORY



In 2008, N_2O accounted for 4% of gross CO_2e emissions in Delaware with a total amount of 0.68 $MmtCO_2e$. As Figure 90 shows, agricultural soil management represented the largest source of N_2O, with approximately 48% of gross N_2O. This was followed by manure management with approximately 24% and mobile combustion with approximately 17%. Other sources included stationary combustion (6%), wastewater treatment (4%) and emissions from settlement soils (1%). The lowest N_2O emission came from the burning agricultural crop with less than 1% of gross N_2O emissions in 2008.

Figure 91 shows that N_2O emissions have been decreasing since its highest level in 1996 with 0.93$MmtCO_2e$. The 2008 emission level was 0.68$MmtCO_2e$, which is a 17% decrease in emissions when compared to the 1990 estimate of 0.82$MmtCO_2e$. The N_2O emissions results revealed that emissions have been declining at the rate 0.009 $MmtCO_2e$ per year from 1990 to 2008.

FIGURE 91. DELAWARE'S N_2O EMISSIONS FROM 1990 TO 2008



4.7.4 Ozone Depleting Substance (ODS) Substitutes (Hydro-fluorocarbons (HFC), Perflourocarbons (PFC)

HFCs and PFCs are families of synthetic chemicals that are used as alternatives to ODS, which are being phased out under the Montreal Protocol and Clean Air Act Amendments of 1990 but are still used in some end-use products. GWP for HFCs and PFCs are 14,800 and 5,400 respectively. HFCs and PFCs do not deplete the stratospheric ozone layer, and are therefore acceptable alternatives under the Montreal Protocol, but due to their global warming potential are considered air pollutants.

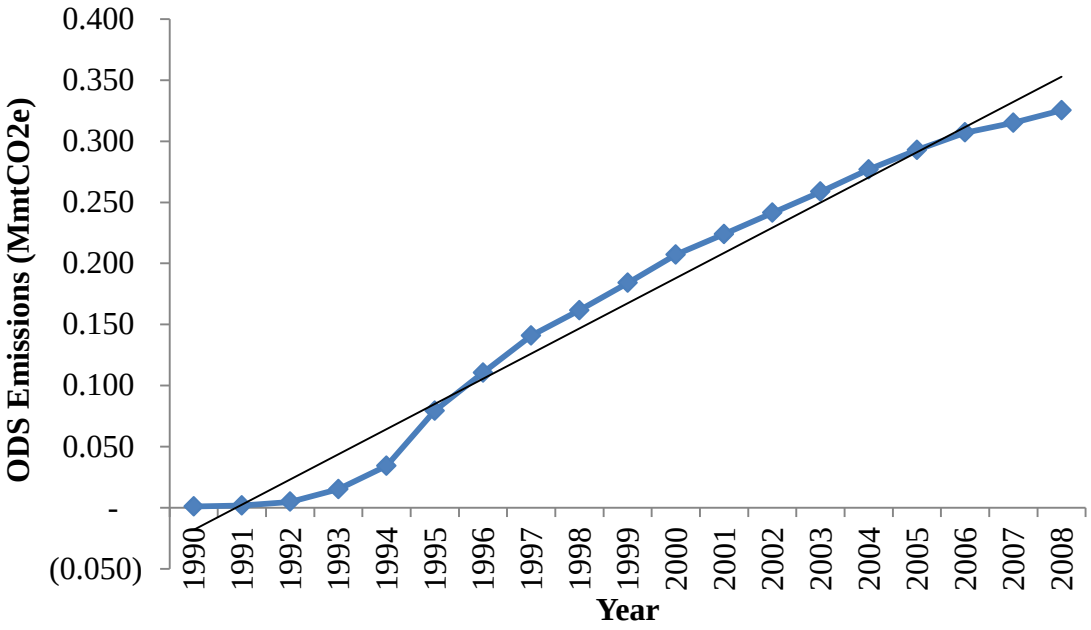
The use of ODS substitutes in Delaware are applied to mostly end-use products, which include:

- Refrigeration, air conditioning, chillers, and other cooling equipment (CFCs and HCFCs)
- Fire extinguishers (halons)

- Solvents for cleaning printed circuit boards and precision parts and degreasing metal parts (CFCs, HCFCs, methyl chloroform, and CTC)
- Fumigant (methyl bromide).
- Propellants in aerosols (CFCs and HCFCs)

Emission estimates for ODS substitutes in the 2008 GHG emissions inventory were determined by apportioning national emissions to each states based on population. In 2008, the GHG emissions from HFCs and PFCs were 2% of gross GHG emissions from Delaware according to Figure 85.

FIGURE 92. DELAWARE'S ODS SUBSTITUTES EMISSIONS



The total emissions were 0.325 $MmtCO_2e$. Historical emissions presented in Figure 92 show an upward trend in the emissions of ODS substitutes. Emissions of ODS substitutes increased by 324,000% from 1990 to 2008. This increase in ODS substitute

emissions may be attributed to the increased use of ODS substitutes since 1990 where emissions were only 0.001mtCO_2e.

4.6.5 Sulfur Hexafluoride (SF_6)

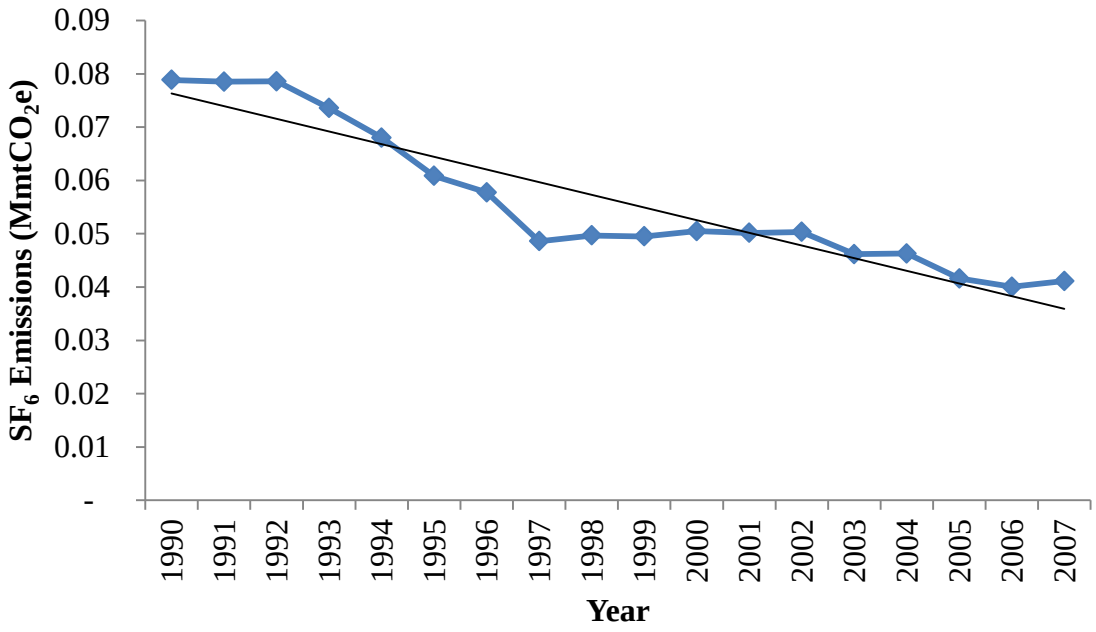
Sulfur Hexafluoride (SF_6) is a colorless, odorless, nontoxic, nonflammable gas with dielectric properties. SF_6 is used for insulation and current interruption in electric power transmission and distribution equipment, in the magnesium industry to protect molten magnesium from oxidation and potentially violent burning, in semiconductor manufacturing to create circuitry patterns on silicon wafers, and as a tracer gas for leak detection.

SF_6 is the most potent of all the GHGs analyzed in this report. It has a GWP of 22,800. Its high GWP is due to its extremely long atmospheric lifetime, resulting in its irreversible accumulation in the atmosphere once emitted.

In 2008, SF_6 was approximately 0.24% of gross GHG emissions. The total amount of SF_6 emitted from Delaware was 0.40 MmtCO_2e. Unlike HFCs and PFCs, SF_6 emissions had a downward trended according to Figure 93. From 1990 to 2008, the emission of SF_6 decreased by 50%. This rapid decrease may be attruibuted to the implementation of SF_6 reduction practices in the electri power industry[119], availability of new technology such as vacuum circuit breakers and increases in the price of SF_6.

[119] See section 4.3.3 under Electric Power Transmission and distribution (T&D) systems

FIGURE 93. DELAWARE'S SF_6 EMISSIONS



4.8 INDIRECT CO_2 EMISSIONS FROM ELECTRICITY CONSUMPTION

The purpose of this section is to characterize the indirect CO_2 emissions that come from electricity consumption in Delaware. Indirect CO_2 emission is CO_2 emission that is estimated based on the amount of kilowatt-hour consumed by end-users of electricity. Estimates of indirect CO_2 emissions do not come from electricity generated from fossil combustion. Indirect CO_2 estimates were included in the 2008 GHG inventory to show how electricity demand in Delaware impacts CO_2 emissions. Indirect CO_2 emissions were estimated from 2000 to 2008 because the available data was limited to those years. Indirect CO_2 emissions were separated from Direct CO_2 emissions in the 2008 GHG inventory to avoid the double counting of emissions estimates.

Approximately 45% of electricity consumed in Delaware is imported, while the remaining 55% is generated within the State. Table 35 provides a list of power plants that generate electricity in

Delaware. Indirect CO_2 emissions from the electricity consumption source category were not included in Delaware's total CO_2e emissions, in order to avoid double counting.[120]

TABLE 35. LIST OF POWER PLANTS IN DELAWARE		
Facility Name	**County**	**Capacity**
Hay Road Calpine	New Castle	1193
Indian River NRG	Sussex	799.4
Edge Moor Calpine	New Castle	710.3
Delaware City Plant	New castle	417.2
McKee Run	Kent	151.2
NRG Energy Center Dover	Kent	118
Christiana	New castle	56
Van Sant Station	Kent	45.1
Warren Beasley	Kent	45
Seaford Delaware Plant	Sussex	30
West Station	New Castle	20
Delaware City 10	New Castle	18.5
R Madison*	New Castle	12
Invista	Sussex	7.8
City of Lewes	Sussex	2
Ameresco LFG		

- R. Madison was Closed in

In 2008, the total indirect CO_2 emission from electricity consumption was 6.55 $MmtCO_2e$. Indirect CO_2 emission from electricity consumption came from three sectors, which include residential, commercial and industrial. Figure 94 shows the breakdown of indirect CO_2 emissions by sector. The residential and commercial sectors had the largest share indirect CO_2 emissions with approximately 37% each, while the industrial sector represented approximately 26% of the total indirect emission from electricity consumption.

[120] Accounting for emissions from a source or source category more than once.

FIGURE 94. PERCENTAGE OF INDIRECT CO_2 BY SECTOR

FIGURE 95. INDIRECT CO_2 EMISSIONS FROM ELECTRICITY CONSUMPTION

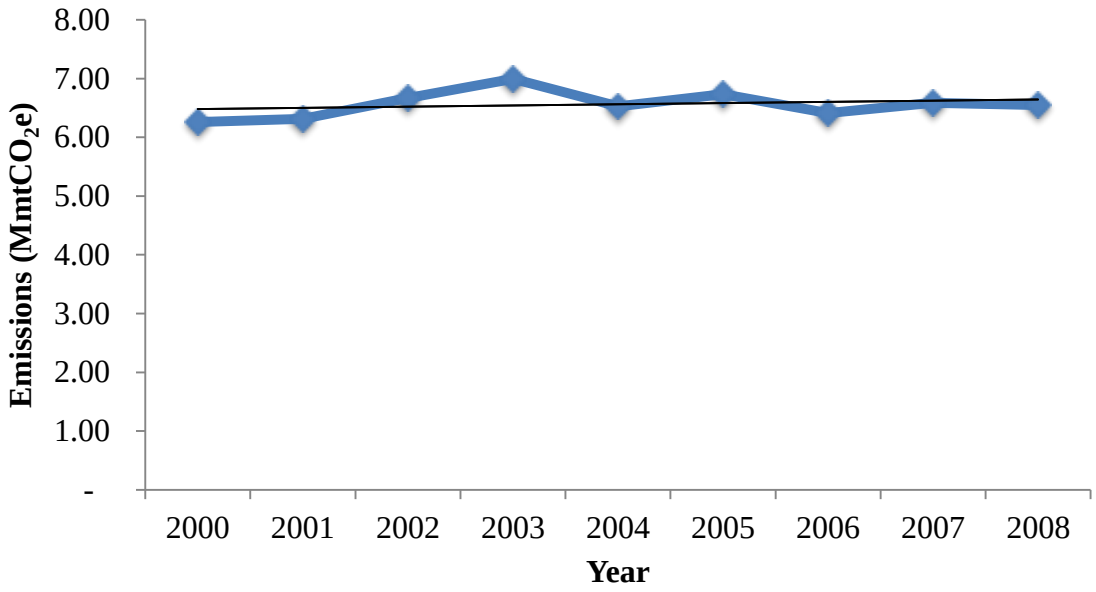


Figure 95 shows indirect CO_2 emissions from 2000 to 2008. The SIT was used to estimate indirect CO_2 emissions based on default data. Emissions estimates are limited to 2000 because

activity data in kilowatt-hour were not available in the SIT beyond 2000. In the future, DAQ will collect additional data to estimate emissions from 1990 to 2000.

Figure 95 also shows that indirect CO_2 emissions fluctuated slightly from 2000 to 2008. The highest point was in 2003 with 6.99 $MmtCO_2e$, and the lowest point was in 2000 with 6.26 $MmtCO_2e$. From 2000 to 2008, indirect CO_2 emissions increased by approximately 4.6%, at a rate of 0.02 $MmtCO_2e$ per year.

Methodology

The SIT's Electricity Consumption module was used to estimate indirect CO_2 emissions. Emissions from electricity consumption are categorized into the four main end-use sectors used to measure and analyze energy use: industrial, residential, and commercial. Electricity is consumed in these sectors primarily for lighting, heating, appliances, electronics, and air conditioning. The electricity consumption module calculates CO_2 equivalent emissions for each of these sectors by multiplying electricity consumption of end-use equipment in each sector by emission factors, while taking into account electricity losses resulting from the transmission and distribution of electricity.

The general equation used by the SIT module to calculate indirect CO_2 emissions from electricity consumption is shown in Equation 19.

EQUATION 19. EQUATION FOR ESTIMATING INDIRECT CO_2 EMISSIONS FROM ELECTRICITY CONSUMPTION

Indirect Electricity Emissions = Total State Consumption (kWh) × End-Use Equipment Consumption (%) × [Emission Factor (lbs CO_2e/kWh) × (1+Transmission Loss Factor (%))]

Using this equation as a guide, the following sections describe the state electricity consumption data, end-use equipment percentages, and transmission loss and emission factors used to estimate indirect greenhouse gas emissions from electricity consumption for each sector.

The activity data used for this source category was the total State electricity consumption in kilowatt hour (kWh). Default activity data was used in conjunction with the emission factor (1.10 lbs CO_2e/kWh) and transmission loss (6.4%) to estmate the indirect emissions. Indirect CO_2 emissions from electricity consumption in the sectors are calculated by multiplying state energy consumption (total kWh consumed in the residential sector) by the percentage of state consumption by electricity consumed. The resulting sub-sector consumption values (kWh) are then multiplied by a state-specific emission factor (lbs CO_2e/kWh) and transmission line losses. The resulting emissions values, in pounds of carbon, are converted to short tons of carbon, million metric tons of carbon equivalent (MmtCe), then to million metric tons of carbon dioxide equivalent (MmtCO_2e).

Indirect CO_2 emissions from 2000 to 2008

The results presented in Figure 96, between 2000 and 2008, indirect CO_2 emissions from the residential sector, which increased at the rate of approximately 0.06 MmtCO_2e per year, while the commercial indirect CO_2 emissions increased at the rate of approximately 0.04 MmtCO_2e per year. On the other hand, industrial sector indirect CO_2 emissions decreased at a rate of 0.08MmtCO_2e per year. Also, indirect CO_2 from the industrial sector spiked in 2003 with approximate 2.51MmtCO_2e, but decreased by 33% between 2003 and 2008. Commercial indirect CO_2 emissions rose steadily from 2001to 2008 by approximately 18%, while emissions from the residential sector increased by approximately 24% from 2000.

In general, the increased demand for electricity in the residential and commercial sectors, due to steady growth in Delaware's population, lead to increased indirect CO_2 emissions. However, indirect CO_2 emissions in the industrial sector decreased from 2003 to 2008. The decrease in industrial indirect CO_2 emissions could be attributed to industrial sector decline due to the economic recession. The closure of facilities such as General Motors, and decline in other

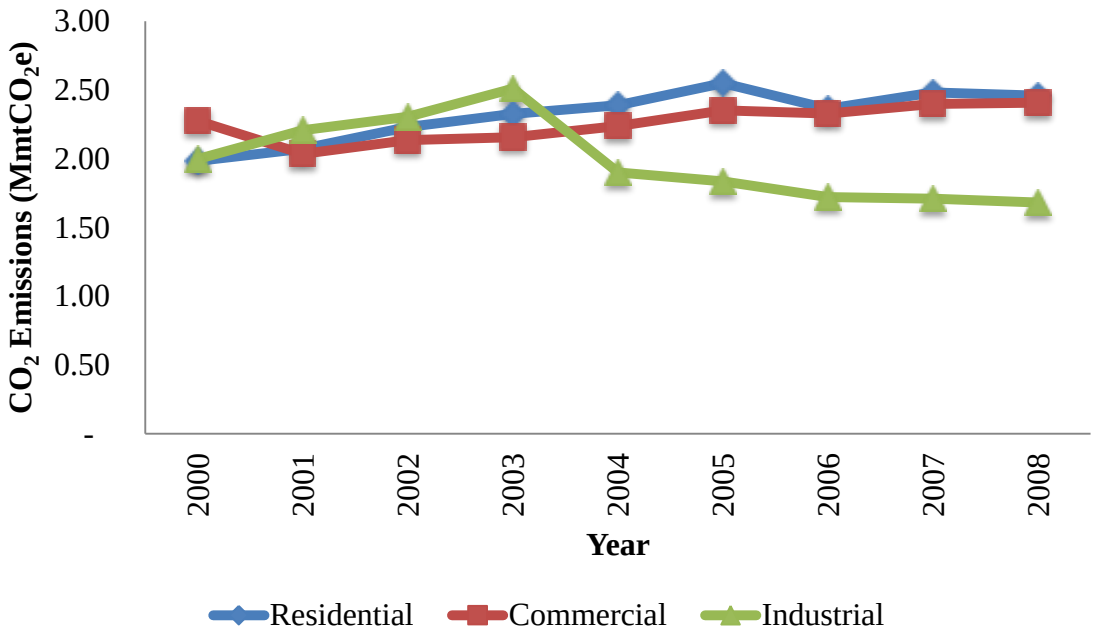
industries, which have a high demand for electricity has contributed to the decline in indirect CO_2 emissions. Table 36 provides estimates of indirect CO_2 emissions from electricity consumption.

TABLE 36. ESTIMATES OF INDIRECT CO_2 EMISSIONS BY SECTOR

$MmtCO_2e$	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Residential	1.98	2.07	2.23	2.33	2.39	2.55	2.36	2.48	2.46
Commercial	2.27	2.04	2.14	2.16	2.24	2.35	2.33	2.40	2.41
Industrial	2.00	2.21	2.30	2.51	1.90	1.83	1.72	1.71	1.68
TOTAL	**6.26**	**6.32**	**6.67**	**6.99**	**6.53**	**6.74**	**6.41**	**6.59**	**6.55**

See Appendix M for details.

FIGURE 96. CO_2e INDIRECT EMISSIONS BY SECTORS



4.9 SUMMARY OF THE 2008 GHG INVENTORY FINDINGS

The 2008 GHG emission inventory reports overall decreasing GHG emissions from 1990 to 2008. Based on emission estimates from 1990 to 2008, Delaware's gross GHG emissions declined mainly as a result of decreasing CO_2 emission from fossil fuel combustion. The emission of CO_2 from fossil fuel combustion made up the largest share of gross GHG emissions with approximately 93%. .

In addition, the 2008 GHG emissions inventory identified the land-use, land-use change and forestry (LULUCF) sector as a sink for CO_2. LULUCF mitigates the atmospheric build-up of GHGs by removing CO_2 from the atmosphere and then storing it in forest at a rate greater than emission back to the atmosphere through human and natural disturbances. Between 1990 and 2008, the LULUCF sector removed an average of 1.50 million metric tons of CO_2 from Delaware's atmosphere each year. The estimated amount of CO_2 removed from the atmosphere each year from 1990 to 2008 were subtracted from gross GHG emissions to obtain net GHG emissions. LULUCF provides a great opportunity to minimize the impact of Delaware's gross GHG emissions to the climate.

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APPENDIX A

Source Category Emissions ($MmtCO_2e$)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Energy Related Activities	19.08	18.86	18.80	20.23	19.62	18.64	19.44	18.06	17.38	17.62	17.94	17.61	17.59	18.09	18.17	18.90	17.74	18.50	17.61
CO_2 from Fossil Fuel Combustion	18.78	18.54	18.48	19.88	19.28	18.30	19.08	17.70	17.03	17.28	17.62	17.31	17.31	17.82	17.91	18.66	17.52	18.29	17.43
Stationary Combustion	0.06	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.06	0.05	0.06	0.06
Mobile Combustion	0.24	0.26	0.26	0.27	0.27	0.28	0.29	0.30	0.29	0.29	0.27	0.26	0.24	0.22	0.21	0.19	0.17	0.15	0.12
Industrial Processes	0.29	0.27	0.28	0.27	0.30	0.36	0.37	0.43	0.43	0.45	0.45	0.47	0.49	0.50	0.52	0.53	0.55	0.54	0.60
Agriculture Activities	0.62	0.66	0.64	0.61	0.66	0.61	0.67	0.64	0.64	0.62	0.67	0.65	0.59	0.61	0.65	0.57	0.57	0.56	0.56
Enteric Fermentation	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.04
Manure Management	0.18	0.19	0.20	0.20	0.20	0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.21	0.20	0.19	0.19	0.19	0.19
Agricultural Soil Management	0.38	0.41	0.39	0.35	0.40	0.35	0.41	0.38	0.38	0.37	0.42	0.40	0.34	0.36	0.40	0.33	0.34	0.33	0.32
Burning of Agricultural Crop Waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste Management	0.73	0.66	0.67	0.67	0.69	0.73	0.74	0.75	0.56	0.52	0.46	0.47	0.50	0.41	0.11	0.12	0.18	0.08	0.11
Municipal Solid Waste	0.66	0.60	0.61	0.61	0.62	0.66	0.67	0.67	0.49	0.45	0.38	0.40	0.43	0.33	0.03	0.04	0.10	0.00	0.02
Wastewater	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09
LULUCF	(0.16)	(0.17)	(0.17)	(0.27)	(0.27)	(0.27)	(0.27)	(0.29)	(0.29)	(1.88)	(2.68)	(2.69)	(2.70)	(2.70)	(2.71)	(2.72)	(2.72)	(2.73)	(2.74)
Gross Emissions	**20.71**	**20.45**	**20.39**	**21.78**	**21.26**	**20.34**	**21.22**	**19.87**	**19.01**	**19.21**	**19.52**	**19.20**	**19.18**	**19.62**	**19.46**	**20.12**	**19.04**	**19.69**	**18.88**
Sinks	**(0.16)**	**(0.17)**	**(0.17)**	**(0.27)**	**(0.27)**	**(0.27)**	**(0.27)**	**(0.29)**	**(0.29)**	**(1.88)**	**(2.68)**	**(2.69)**	**(2.70)**	**(2.70)**	**(2.71)**	**(2.72)**	**(2.72)**	**(2.73)**	**(2.74)**
Net Emissions	**20.55**	**20.28**	**20.21**	**21.51**	**20.99**	**20.07**	**20.94**	**19.58**	**18.71**	**17.33**	**16.84**	**16.51**	**16.49**	**16.91**	**16.75**	**17.40**	**16.31**	**16.96**	**16.14**
Indirect CO_2 from Electricity Consumption	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.26	6.32	6.67	6.99	6.53	6.74	6.41	6.59	6.55

APPENDIX B

FFC Emissions ($MMTCO_2$ Eq.)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Residential	1.06	1.09	1.15	1.17	1.22	1.16	1.26	1.12	1.05	1.12	1.21	1.16	1.17	1.28	1.21	1.18	0.98	1.00	0.97
Coal	0.01	0.01	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.66	0.69	0.70	0.69	0.74	0.69	0.72	0.63	0.61	0.62	0.68	0.66	0.64	0.69	0.64	0.62	0.48	0.45	0.42
Natural Gas	0.39	0.38	0.45	0.46	0.47	0.47	0.54	0.49	0.44	0.50	0.52	0.50	0.52	0.59	0.57	0.57	0.50	0.55	0.54
Commercial	0.57	0.57	0.55	0.68	0.61	0.57	0.72	0.69	0.60	0.63	0.62	0.68	0.74	0.79	0.78	0.72	0.72	0.68	0.64
Coal	0.04	0.04	0.00	0.09	0.06	0.00	0.01	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Petroleum	0.32	0.31	0.28	0.31	0.26	0.25	0.34	0.32	0.27	0.28	0.34	0.36	0.33	0.32	0.32	0.26	0.27	0.21	0.16
Natural Gas	0.22	0.23	0.27	0.29	0.30	0.32	0.37	0.36	0.31	0.35	0.28	0.31	0.41	0.46	0.46	0.46	0.45	0.48	0.49
Industrial	5.12	4.06	5.33	5.62	5.78	5.61	5.75	5.53	5.30	5.65	5.51	5.68	5.42	5.14	5.08	5.29	5.01	4.81	4.63
Coal	0.50	0.49	0.34	0.41	0.45	0.46	0.39	0.41	0.41	0.35	0.44	0.42	0.24	0.24	0.29	0.29	0.25	0.25	0.21
Petroleum	3.71	2.71	4.00	4.13	4.39	4.08	4.58	4.30	3.98	4.11	3.68	4.16	4.21	4.07	3.91	4.16	3.85	3.68	3.43
Natural Gas	0.91	0.86	0.99	1.07	0.95	1.06	0.78	0.81	0.92	1.19	1.40	1.10	0.97	0.83	0.88	0.84	0.90	0.88	1.00
Transportation	4.53	5.08	4.70	4.91	4.55	4.32	4.78	4.67	4.71	4.89	5.08	4.70	4.94	4.83	4.96	5.17	5.19	5.23	5.05
Petroleum	4.53	5.08	4.70	4.91	4.55	4.32	4.78	4.67	4.71	4.89	5.07	4.70	4.93	4.82	4.95	5.16	5.19	5.23	5.05
Natural Gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00
Electric Utilities	7.49	7.75	6.76	7.51	7.12	6.65	6.58	5.69	5.36	4.98	5.20	5.09	5.04	5.78	5.89	6.29	5.62	6.57	6.14
Coal	5.02	4.80	3.99	5.44	4.88	4.47	4.38	4.13	3.80	2.99	4.22	3.14	3.53	4.13	4.69	4.98	5.01	5.67	5.45
Petroleum	1.85	2.13	2.31	1.60	1.28	0.70	0.92	0.67	0.99	0.96	0.52	1.11	0.58	1.01	0.48	0.60	0.09	0.15	0.08
Natural Gas	0.61	0.83	0.46	0.47	0.96	1.48	1.28	0.88	0.57	1.03	0.45	0.83	0.94	0.65	0.72	0.71	0.52	0.74	0.61
TOTAL	**18.78**	**18.54**	**18.48**	**19.88**	**19.28**	**18.30**	**19.08**	**17.70**	**17.03**	**17.28**	**17.62**	**17.31**	**17.31**	**17.82**	**17.91**	**18.66**	**17.52**	**18.29**	**17.43**
Coal	**5.58**	**5.33**	**4.33**	**5.96**	**5.40**	**4.93**	**4.78**	**4.56**	**4.23**	**3.34**	**4.66**	**3.56**	**3.77**	**4.37**	**4.98**	**5.27**	**5.26**	**5.93**	**5.66**
Petroleum	**11.07**	**10.91**	**11.98**	**11.64**	**11.21**	**10.04**	**11.34**	**10.59**	**10.56**	**10.87**	**10.30**	**11.00**	**10.69**	**10.91**	**10.30**	**10.81**	**9.89**	**9.71**	**9.14**
Natural Gas	**2.13**	**2.30**	**2.17**	**2.28**	**2.67**	**3.33**	**2.96**	**2.55**	**2.24**	**3.08**	**2.66**	**2.75**	**2.85**	**2.54**	**2.64**	**2.58**	**2.37**	**2.65**	**2.64**

APPENDIX C

Total CH_4 and N_2O Emissions from Mobile Sources ($MTCO_2E$)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Gasoline Road Vehicles	**220,879**	**234,927**	**247,211**	**251,607**	**256,786**	**272,108**	**273,509**	**279,863**	**278,744**	**272,726**	**251,960**	**243,008**	**223,325**	**206,947**	**191,381**	**175,720**	**152,851**	**134,111**	**110,753**
Passenger Cars	138,866	137,962	140,136	138,752	140,397	146,653	145,056	145,341	144,365	141,805	130,275	125,281	119,311	111,217	104,650	96,725	83,707	73,618	60,650
Light-Duty Trucks	77,145	91,512	101,694	107,491	110,876	119,507	122,308	127,937	127,388	123,883	115,379	111,964	97,955	89,522	80,717	73,605	67,511	58,920	48,632
Heavy-Duty Vehicles	4,673	5,252	5,175	5,158	5,304	5,725	5,931	6,374	6,786	6,819	6,107	5,579	5,877	6,027	5,825	5,198	1,405	1,323	1,215
Motorcycles	196	201	206	206	210	223	214	210	205	218	199	184	182	181	189	193	229	250	255
Diesel Road Vehicles	**918**	**930**	**934**	**980**	**1,039**	**1,152**	**1,164**	**1,246**	**1,280**	**1,357**	**1,308**	**1,579**	**1,624**	**1,639**	**1,721**	**1,721**	**1,877**	**1,931**	**1,863**
Passenger Cars	24	22	21	20	19	19	18	18	17	17	15	14	15	15	15	15	14	14	13
Light-Duty Trucks	39	43	47	50	51	55	56	61	62	65	64	65	67	70	71	74	84	108	104
Heavy-Duty Vehicles	855	865	865	910	969	1,079	1,090	1,167	1,201	1,275	1,229	1,499	1,542	1,554	1,634	1,632	1,779	1,809	1,746
Non-Road Vehicles	**13,951**	**20,674**	**15,005**	**15,923**	**12,708**	**9,203**	**15,906**	**14,497**	**13,012**	**15,318**	**13,182**	**12,728**	**12,300**	**11,540**	**10,871**	**10,935**	**11,019**	**13,415**	**10,010**
Boats	5,718	8,172	6,563	7,138	7,922	6,760	12,938	11,569	9,822	12,152	10,401	9,101	7,917	7,352	6,720	7,111	7,287	7,947	7,597
Locomotives	170	88	117	148	59	46	45	46	47	57	19	25	89	123	78	26	111	146	119
Farm Equipment	733	893	633	540	556	455	743	727	925	883	869	853	972	829	792	884	804	835	607
Construction Equipment	1,251	1,386	1,471	1,476	1,100	958	1,267	1,106	978	936	850	1,419	1,795	1,726	1,646	817	831	2,129	874
Aircraft	5,996	10,054	6,144	6,352	2,776	717	655	792	776	548	585	1,008	1,203	1,192	1,257	1,733	1,663	1,522	-
Other*	83	80	77	270	295	267	258	257	465	742	458	323	323	318	377	365	323	837	814
Alternative Fuel Vehicles	**209**	**200**	**192**	**243**	**236**	**240**	**265**	**303**	**319**	**307**	**350**	**428**	**834**	**1,012**	**1,105**	**1,173**	**1,095**	**1,048**	**1,183**
Light Duty Vehicles	50	50	50	53	51	60	71	92	98	100	115	124	249	303	323	358	350	341	376
Heavy Duty Vehicles	149	139	129	172	167	161	174	190	199	183	210	274	530	647	689	713	650	616	701
Buses	10	11	13	17	18	19	20	21	23	24	25	30	56	62	93	103	96	92	105
Total	**235,957**	**256,731**	**263,342**	**268,753**	**270,769**	**282,703**	**290,844**	**295,909**	**293,356**	**289,708**	**266,800**	**257,743**	**238,083**	**221,137**	**205,078**	**189,550**	**166,842**	**150,505**	**123,808**

* "Other" includes snowmobiles, small gasoline powered utility equipment, heavy-duty gasoline powered utility equipment, and heavy-duty diesel powered utility equipment.

APPENDIX D

N_2O Emissions from Mobile Sources ($MTCO_2E$)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Gasoline Highway	**199,680**	**213,919**	**226,538**	**231,716**	**237,520**	**252,761**	**255,165**	**262,189**	**262,004**	**257,156**	**238,093**	**229,408**	**211,362**	**195,902**	**181,073**	**166,097**	**144,379**	**126,359**	**103,989**
Passenger Cars	125,889	125,824	128,444	127,677	129,642	135,897	134,886	135,591	135,069	132,945	122,368	117,834	112,363	104,842	98,641	91,136	78,763	69,123	56,776
Light-Duty Trucks	70,316	84,079	94,041	99,926	103,590	112,187	115,319	121,097	120,934	118,109	110,190	106,465	93,575	85,454	76,993	70,109	64,192	55,869	45,938
Heavy-Duty Vehicles	3,360	3,898	3,932	3,991	4,164	4,546	4,833	5,376	5,880	5,972	5,416	4,999	5,315	5,498	5,326	4,737	1,288	1,217	1,121
Motorcycles	115	118	121	121	124	131	127	125	122	129	119	110	109	108	113	115	137	150	153
Diesel Highway	**859**	**869**	**873**	**916**	**972**	**1,077**	**1,088**	**1,165**	**1,197**	**1,268**	**1,223**	**1,475**	**1,517**	**1,531**	**1,608**	**1,608**	**1,754**	**1,805**	**1,741**
Passenger Cars	23	21	21	20	19	19	18	18	17	16	15	14	14	14	15	15	14	13	12
Light-Duty Trucks	37	41	45	48	49	52	54	58	59	62	61	62	64	67	68	71	80	103	99
Heavy-Duty Vehicles	798	807	807	849	904	1,006	1,016	1,089	1,121	1,189	1,146	1,399	1,438	1,450	1,525	1,522	1,660	1,688	1,629
Non-Highway	**11,827**	**18,226**	**13,090**	**13,704**	**10,583**	**7,459**	**13,043**	**11,805**	**10,595**	**12,746**	**10,921**	**10,359**	**9,854**	**9,296**	**8,773**	**8,483**	**8,533**	**10,584**	**8,360**
Boats	4,786	6,840	5,493	5,975	6,630	5,658	10,829	9,683	8,221	10,171	8,706	7,617	6,627	6,154	5,625	5,952	6,099	6,652	6,358
Locomotives	140	73	96	122	48	38	37	38	38	47	16	21	74	101	65	21	92	120	98
Farm Equipment	531	647	458	391	403	330	538	526	670	639	629	618	704	600	574	640	582	604	440
Construction Equipment	1,086	1,203	1,276	1,280	955	832	1,099	960	848	813	737	1,231	1,557	1,498	1,429	709	721	1,847	758
Aircraft	5,212	9,394	5,699	5,702	2,290	370	316	375	415	432	436	592	612	667	755	844	759	634	-
Other*	72	70	67	234	256	232	224	223	403	644	397	280	281	276	327	317	280	726	706
Alternative Fuel Vehicles	195	**186**	**177**	**223**	**215**	**212**	**229**	**254**	**265**	**248**	**281**	**338**	**659**	**793**	**842**	**880**	**806**	**758**	**843**
Light Duty Vehicles	45	45	45	48	45	50	58	70	73	72	85	92	185	227	242	269	263	258	285
Heavy Duty Vehicles	144	134	124	165	159	151	159	173	179	162	182	229	443	530	548	552	489	448	497
Buses	6	7	7	10	11	11	12	12	13	14	14	17	32	35	53	58	54	52	60
Total	**212,561**	**233,200**	**240,678**	**246,560**	**249,289**	**261,509**	**269,525**	**275,414**	**274,061**	**271,419**	**250,518**	**241,580**	**223,392**	**207,521**	**192,296**	**177,068**	**155,473**	**139,506**	**114,933**

* "Other" includes snowmobiles, small gasoline powered utility equipment, heavy-duty gasoline powered utility equipment, and heavy-duty diesel powered utility equipment.

APPENDIX E

CH_4 Emissions from Mobile Sources ($MTCO_2E$)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Gasoline Road	**21,199**	**21,008**	**20,673**	**19,891**	**19,266**	**19,347**	**18,344**	**17,674**	**16,740**	**15,569**	**13,867**	**13,601**	**11,963**	**11,045**	**10,309**	**9,623**	**8,472**	**7,751**	**6,764**
Passenger Cars	12,977	12,138	11,692	11,075	10,755	10,756	10,170	9,750	9,297	8,860	7,907	7,447	6,948	6,374	6,010	5,590	4,944	4,495	3,874
Light-Duty Trucks	6,829	7,433	7,653	7,564	7,285	7,320	6,989	6,840	6,455	5,774	5,189	5,500	4,380	4,068	3,724	3,495	3,319	3,051	2,694
Heavy-Duty Vehicles	1,313	1,354	1,243	1,167	1,141	1,179	1,097	999	906	847	691	579	562	530	499	461	117	106	93
Motorcycles	80	83	85	85	86	91	88	86	83	88	81	74	73	73	76	77	92	100	102
Diesel Road	**60**	**60**	**61**	**64**	**68**	**75**	**76**	**81**	**84**	**89**	**86**	**104**	**107**	**108**	**113**	**113**	**123**	**126**	**122**
Passenger Cars	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
Light-Duty Trucks	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	4
Heavy-Duty Vehicles	57	58	58	61	65	72	73	78	81	86	82	101	103	104	110	110	119	121	117
Non-Road	**2,124**	**2,448**	**1,915**	**2,219**	**2,125**	**1,745**	**2,863**	**2,692**	**2,416**	**2,572**	**2,261**	**2,369**	**2,446**	**2,244**	**2,098**	**2,453**	**2,486**	**2,832**	**1,650**
Boats	932	1,332	1,070	1,164	1,291	1,102	2,109	1,886	1,601	1,981	1,695	1,484	1,291	1,199	1,095	1,159	1,188	1,295	1,238
Locomotives	30	15	20	26	10	8	8	8	8	10	3	4	16	21	14	5	19	25	21
Farm Equipment	202	246	175	149	153	126	205	201	255	244	240	235	268	229	219	244	222	230	167
Construction Equipment	166	183	195	195	146	127	168	146	129	124	112	188	237	228	218	108	110	282	116
Aircraft	784	660	445	650	486	347	339	417	361	116	149	416	592	525	502	889	904	888	-
Other*	11	11	10	36	39	35	34	34	61	98	61	43	43	42	50	48	43	111	108
Alternative Fuel	**14**	**15**	**16**	**20**	**21**	**27**	**36**	**49**	**54**	**59**	**68**	**90**	**175**	**220**	**263**	**294**	**289**	**290**	**340**
Light Duty Vehicles	5	5	5	6	6	10	13	23	25	28	30	32	64	76	81	88	86	83	91
Heavy Duty Vehicles	5	5	5	7	7	10	14	17	20	21	28	45	87	117	141	161	161	167	204
Buses	4	5	5	7	8	8	8	9	10	10	11	13	24	27	40	44	41	40	45
Total	**23,397**	**23,531**	**22,664**	**22,194**	**21,480**	**21,194**	**21,319**	**20,496**	**19,295**	**18,289**	**16,282**	**16,163**	**14,692**	**13,616**	**12,782**	**12,482**	**11,370**	**10,999**	**8,876**

* "Other" includes snowmobiles, small gasoline powered utility equipment, heavy-duty gasoline powered utility equipment, and heavy-duty diesel powered utility equipment.

APPENDIX F

Stationary Combustion MMTCO$_2$E	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Residential	0.014	0.014	0.014	0.020	0.019	0.018	0.019	0.015	0.014	0.014	0.015	0.012	0.012	0.012	0.012	0.014	0.012	0.013	0.013
N_2O	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
CH_4	0.011	0.011	0.011	0.016	0.015	0.014	0.014	0.011	0.010	0.011	0.012	0.008	0.009	0.009	0.009	0.010	0.009	0.010	0.010
Commercial	0.003	0.004	0.003	0.005	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
N_2O	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
CH_4	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Industrial	0.013	0.011	0.013	0.015	0.015	0.015	0.015	0.015	0.013	0.013	0.013	0.013	0.011	0.011	0.011	0.012	0.011	0.010	0.009
N_2O	0.010	0.008	0.010	0.011	0.011	0.011	0.011	0.011	0.010	0.010	0.010	0.010	0.008	0.008	0.008	0.009	0.008	0.008	0.007
CH_4	0.004	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.003	0.003	0.003
Electric Power Generation	0.032	0.032	0.028	0.034	0.030	0.027	0.027	0.024	0.024	0.020	0.024	0.021	0.021	0.026	0.027	0.029	0.027	0.031	0.029
N_2O	0.029	0.029	0.025	0.031	0.028	0.025	0.025	0.023	0.022	0.018	0.023	0.019	0.020	0.024	0.025	0.027	0.026	0.029	0.028
CH_4	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002
TOTAL	**0.063**	**0.061**	**0.059**	**0.073**	**0.069**	**0.063**	**0.065**	**0.059**	**0.055**	**0.051**	**0.057**	**0.050**	**0.048**	**0.053**	**0.054**	**0.058**	**0.054**	**0.058**	**0.055**

APPENDIX G

Industrial Processes ($MTCO_2$ Eq.)	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Carbon Dioxide Emissions	208,280	189,933	193,924	180,621	191,095	210,080	196,467	231,032	217,563	212,565	193,554	193,365	201,809	190,864	199,475	178,668	193,125	187,957	168,309
Soda Ash	7,308	7,052	7,123	7,093	7,104	7,402	7,317	7,418	7,654	7,665	7,416	7,401	7,481	7,330	7,359	7,350	7,275	7,137	6,971
Soda Ash	7,268	7,033	7,098	7,072	7,070	7,373	7,270	7,381	7,484	7,374	7,391	7,380	7,454	7,301	7,324	7,300	7,227	7,052	6,845
Ammonia & Urea	40	19	25	21	35	30	47	36	170	291	25	21	27	29	36	50	48	84	125
Iron & Steel Production	0	0	0	0	0	0	0	25,346	25,463	21,879	26,306	25,503	25,090	24,388	30,359	26,484	30,734	33,248	30,065
Oil Refinery	6,753.4	6,422.9	6,424.3	6,680	6,882	5,834	6,980	7,266	7,337	7,105	7,209	6,703	6,983	6,849	6,663	7,080	6,522	6,295	5,926
Titanium Dioxide	194,218	176,458	180,377	166,849	177,109	196,844	182,170	191,002	177,109	175,916	152,623	153,758	162,255	152,297	155,094	137,753	148,594	141,277	125,347
HFC, PFC, and SF_6 Emissions	82,200	80,586	83,204	93,581	107,706	147,203	171,251	198,624	210,155	233,547	256,590	274,438	291,412	308,984	322,986	339,130	348,685	355,144	366,367
ODS Substitutes	888	1,727	4,691	15,007	34,139	79,181	110,414	140,879	161,556	183,861	207,076	223,933	241,254	258,632	276,815	292,843	307,084	315,100	325,251
Electric Power Transmission and Distribution Systems	81,313	78,859	78,513	78,574	73,568	68,022	60,837	57,744	48,599	49,686	49,514	50,505	50,158	50,351	46,171	46,287	41,601	40,044	41,117
Total Emissions	290,480	270,519	277,128	274,202	298,802	357,284	367,718	429,656	427,719	446,112	450,144	467,803	493,221	499,848	522,461	517,798	541,810	543,101	534,676

APPENDIX H

Emissions Agricultural Activities ($MmtCO_2e$)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Enteric Fermentation	0.051	0.051	0.052	0.056	0.051	0.051	0.054	0.048	0.048	0.049	0.047	0.049	0.046	0.040	0.045	0.044	0.042	0.043	0.042
Manure Management	0.184	0.190	0.197	0.204	0.204	0.207	0.202	0.201	0.205	0.202	0.196	0.202	0.203	0.212	0.205	0.194	0.188	0.190	0.193
Agricultural Soil Management	0.378	0.411	0.386	0.349	0.400	0.354	0.410	0.384	0.384	0.366	0.419	0.396	0.340	0.359	0.396	0.328	0.339	0.328	0.323
Burning of Agricultural Crop Waste	0.002	0.003	0.002	0.002	0.003	0.002	0.003	0.002	0.002	0.002	0.003	0.003	0.002	0.002	0.003	0.002	0.002	0.002	0.002
TOTAL	**0.616**	**0.655**	**0.638**	**0.611**	**0.658**	**0.614**	**0.669**	**0.636**	**0.639**	**0.618**	**0.666**	**0.650**	**0.591**	**0.614**	**0.649**	**0.568**	**0.571**	**0.562**	**0.560**

APPENDIX I

Total Emissions from Landfills and Waste Combustion ($MMTCO_2E$)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CH_4	0.516	0.533	0.542	0.545	0.554	0.560	0.562	0.556	0.367	0.353	0.382	0.395	0.427	0.333	0.032	0.040	0.096	0.001	0.020
CO_2	0.140	0.062	0.061	0.060	0.062	0.095	0.107	0.115	0.122	0.092	0	0	0	0	0	0	0	0	0
N_2O	0.005	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0	0	0	0	0	0	0	0	0
Total	0.661	0.597	0.605	0.606	0.618	0.658	0.672	0.674	0.492	0.448	0.382	0.395	0.427	0.333	0.032	0.040	0.096	0.001	0.020

CH_4 Emissions from Landfills ($MTCO_2E$)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Potential CH_4	573,087	592,097	602,240	605,337	614,966	622,504	624,462	624,461	629,760	633,913	647,817	664,017	680,257	696,422	715,870	692,931	718,684	742,838	761,468
MSW Generation	535,595	553,362	562,841	565,736	574,734	581,780	583,609	583,608	588,561	592,442	605,436	620,577	635,755	650,862	669,038	647,599	671,667	694,241	711,652
Industrial Generation	37,492	38,735	39,399	39,602	40,231	40,725	40,853	40,853	41,199	41,471	42,381	43,440	44,503	45,560	46,833	45,332	47,017	48,597	49,816
CH_4 Avoided	0	0	0	0	0	0	0	(6,671)	(222,324)	(241,589)	(223,589)	(224,996)	(205,497)	(326,922)	(680,598)	(648,970)	(611,982)	(741,844)	(738,914)
Flare	0	0	0	0	0	0	0	(2,124)	(75,495)	(70,940)	(82,773)	(82,882)	(76,224)	(140,253)	(297,924)	(206,688)	(201,732)	(96,544)	(91,359)
Landfill Gas-to-Energy	0	0	0	0	0	0	0	(4,548)	(146,829)	(170,649)	(140,816)	(142,114)	(129,273)	(186,669)	(382,673)	(442,282)	(410,250)	(645,300)	(647,555)
Oxidation at MSW Landfills	53,560	55,336	56,284	56,574	57,478	58,173	58,361	57,694	36,624	35,085	38,185	39,558	43,026	32,394	(1,156)	(137)	5,969	(4,760)	(2,726)
Oxidation at Industrial Landfills	3,749	3,874	3,940	3,960	4,023	4,072	4,085	4,085	4,120	4,147	4,238	4,344	4,450	4,556	4,683	4,533	4,702	4,860	4,982
Total CH_4 Emissions	515,778	532,887	542,016	544,804	553,469	560,254	562,016	556,011	366,693	353,092	381,805	395,119	427,285	332,551	31,745	39,565	96,032	895	20,298

CO_2 and N_2O Emissions from Waste Combustion ($MTCO_2E$)

Gas/Waste Product	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
CO_2	140,279	62,075	60,961	59,555	62,034	94,655	106,992	114,744	121,722	92,379	0	0	0	0	0	0	0	0	0
Plastics	94,078	41,726	40,733	39,915	41,096	63,118	71,356	77,408	82,164	63,249	0	0	0	0	0	0	0	0	0
Synthetic Rubber in MSW	20,491	8,825	8,349	7,962	8,189	11,254	12,548	12,950	13,524	9,742	0	0	0	0	0	0	0	0	0
Synthetic Fibers	25,711	11,525	11,879	11,678	12,749	20,283	23,089	24,386	26,033	19,388	0	0	0	0	0	0	0	0	0
N_2O	5,291	2,109	2,111	1,919	2,011	3,037	3,192	3,344	3,480	2,531	0	0	0	0	0	0	0	0	0
CH_4	143	57	57	52	54	82	86	91	94	69	0	0	0	0	0	0	0	0	0
Total CO_2, N_2O, CH_4 Emissions	145,713	64,242	63,129	61,527	64,099	97,775	110,270	118,178	125,296	94,978	0	0	0	0	0	0	0	0	0

APPENDIX J

Emissions From Waste water treatment ($MMTCO_2E$)	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Municipal CH_4	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06
Municipal N_2O	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03
Industrial CH_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Emissions	**0.06**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.09**

APPENDIX K

Emissions* From LULUF ($MMTCO_2E$)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Forest Carbon Flux	0.11	0.11	0.11	0.01	0.01	0.01	0.01	0.01	0.01	(1.57)	(2.36)	(2.36)	(2.36)	(2.36)	(2.36)	(2.36)	(2.36)	(2.36)	(2.36)
Aboveground Biomass	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(0.31)	(1.11)	(1.51)	(1.51)	(1.51)	(1.51)	(1.51)	(1.51)	(1.51)	(1.51)	(1.51)
Belowground Biomass	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.21)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)
Dead Wood	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.14)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)
Litter	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.05	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Soil Organic Carbon	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	(0.07)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)
Total wood products and landfills	0.00	0.00	0.00	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
Liming of Agricultural Soils	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urea Fertilization	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Urban Trees	(0.22)	(0.22)	(0.23)	(0.24)	(0.25)	(0.26)	(0.27)	(0.27)	(0.28)	(0.29)	(0.30)	(0.31)	(0.31)	(0.32)	(0.33)	(0.34)	(0.35)	(0.35)	(0.36)
Landfilled Yard Trimmings and Food Scraps	(0.06)	(0.06)	(0.06)	(0.05)	(0.05)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Grass	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Leaves	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Branches	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Landfilled Food Scraps	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
N_2O from Settlement Soils	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Total	**(0.16)**	**(0.17)**	**(0.17)**	**(0.27)**	**(0.27)**	**(0.27)**	**(0.27)**	**(0.29)**	**(0.29)**	**(1.88)**	**(2.68)**	**(2.69)**	**(2.70)**	**(2.70)**	**(2.71)**	**(2.72)**	**(2.72)**	**(2.73)**	**(2.74)**

*** Note that parentheses indicate net sequestration.**

APPENDIX L

Emissions By Gas ($MmtCO_2e$)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Gross CO2	19.12	18.79	18.73	20.12	19.53	18.60	19.38	18.04	17.36	17.58	17.81	17.49	17.50	18.00	18.11	18.84	17.71	18.47	17.59
Net CO2	18.95	18.61	18.54	19.84	19.24	18.31	19.09	17.75	17.06	15.69	15.12	14.80	14.80	15.29	15.39	16.11	14.98	15.73	14.85
CO2 from Fossil Fuel Combustion	18.78	18.54	18.48	19.88	19.28	18.30	19.08	17.70	17.03	17.28	17.62	17.31	17.31	17.82	17.91	18.66	17.52	18.29	17.43
Industrial Processes	0.20	0.18	0.19	0.17	0.18	0.20	0.19	0.22	0.21	0.21	0.19	0.19	0.19	0.18	0.19	0.18	0.19	0.18	0.16
Waste	0.14	0.06	0.06	0.06	0.06	0.09	0.11	0.11	0.12	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LULUCF	(0.17)	(0.18)	(0.18)	(0.28)	(0.28)	(0.28)	(0.28)	(0.29)	(0.30)	(1.89)	(2.69)	(2.70)	(2.71)	(2.71)	(2.72)	(2.72)	(2.73)	(2.74)	(2.75)
CH_4	0.69	0.71	0.72	0.74	0.74	0.75	0.75	0.74	0.55	0.53	0.56	0.57	0.60	0.50	0.20	0.21	0.26	0.17	0.25
Stationary Combustion	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mobile Combustion	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Oil refining	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.07
Enteric Fermentation	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.04
Manure Management	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Burning of Agricultural Crop Waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Waste	0.52	0.53	0.54	0.54	0.55	0.56	0.56	0.56	0.37	0.35	0.38	0.40	0.43	0.33	0.03	0.04	0.10	0.00	0.02
Wastewater	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06
N_2O	0.82	0.87	0.86	0.84	0.90	0.86	0.93	0.90	0.90	0.87	0.90	0.87	0.80	0.82	0.83	0.74	0.73	0.70	0.68
Stationary Combustion	0.04	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.04	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04
Mobile Combustion	0.21	0.23	0.24	0.25	0.25	0.26	0.27	0.28	0.27	0.27	0.25	0.24	0.22	0.21	0.19	0.18	0.16	0.14	0.11
Manure Management	0.15	0.16	0.16	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.16	0.17	0.17	0.18	0.17	0.16	0.16	0.16	0.16
Agricultural Soil Management	0.38	0.41	0.39	0.35	0.40	0.35	0.41	0.38	0.38	0.37	0.42	0.40	0.34	0.36	0.40	0.33	0.34	0.33	0.32
Burning of Agricultural Crop Waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX L

N_2O from Settlement Soils	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Waste	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wastewater	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03
HFC, PFC, and SF_6	0.08	0.08	0.08	0.09	0.11	0.15	0.17	0.20	0.21	0.23	0.26	0.27	0.29	0.31	0.32	0.34	0.35	0.36	0.37
Industrial Processes	0.08	0.08	0.08	0.09	0.11	0.15	0.17	0.20	0.21	0.23	0.26	0.27	0.29	0.31	0.32	0.34	0.35	0.36	0.37
Indirect CO2 from Electricity Consumption*	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6.26	6.32	6.67	6.99	6.53	6.74	6.41	6.59	6.55
Gross Emissions	**20.71**	**20.45**	**20.39**	**21.78**	**21.26**	**20.34**	**21.22**	**19.87**	**19.01**	**19.21**	**19.52**	**19.20**	**19.18**	**19.62**	**19.46**	**20.12**	**19.04**	**19.69**	**18.88**
Sinks	**(0.17)**	**(0.18)**	**(0.18)**	**(0.28)**	**(0.28)**	**(0.28)**	**(0.28)**	**(0.29)**	**(0.30)**	**(1.89)**	**(2.69)**	**(2.70)**	**(2.71)**	**(2.71)**	**(2.72)**	**(2.72)**	**(2.73)**	**(2.74)**	**(2.75)**
Net Emissions (Sources and Sinks)	**20.55**	**20.28**	**20.21**	**21.51**	**20.99**	**20.07**	**20.94**	**19.58**	**18.71**	**17.33**	**16.84**	**16.51**	**16.49**	**16.91**	**16.75**	**17.40**	**16.31**	**16.96**	**16.14**

APPENDIX M

Indirect CO_2 Emissions ($MMTCO_2$ Eq.)	2000	2001	2002	2003	2004	2005	2006	2007	2008
Residential	1.98	2.07	2.23	2.33	2.39	2.55	2.36	2.48	2.46
Space Heating	0.21	0.22	0.22	0.21	0.20	0.19	0.18	0.18	0.18
Air-conditioning	0.44	0.46	0.53	0.58	0.62	0.70	0.65	0.68	0.67
Water Heating	0.21	0.22	0.25	0.26	0.27	0.29	0.27	0.29	0.28
Refrigeration	0.24	0.25	0.26	0.25	0.24	0.24	0.23	0.24	0.23
Other Appliances and Lighting	0.87	0.91	0.98	1.02	1.05	1.13	1.04	1.10	1.09
Commercial	2.27	2.04	2.14	2.16	2.24	2.35	2.33	2.40	2.41
Space Heating	0.08	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08
Cooling	0.44	0.40	0.42	0.42	0.44	0.46	0.45	0.47	0.47
Ventilation	0.26	0.23	0.25	0.25	0.26	0.27	0.27	0.28	0.28
Water Heating	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Lighting	0.80	0.72	0.75	0.76	0.79	0.83	0.82	0.84	0.85
Cooking	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Refrigeration	0.25	0.22	0.23	0.23	0.24	0.25	0.25	0.26	0.26
Office Equipment	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Computers	0.09	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09
Other	0.24	0.22	0.23	0.23	0.24	0.25	0.25	0.25	0.26
Industrial	2.00	2.21	2.30	2.51	1.90	1.83	1.72	1.71	1.68
Indirect Uses-Boiler Fuel	0.01	0.01	0.01	0.01	0.01	0.01	0.07	0.06	0.06
Conventional Boiler Use	0.01	0.01	0.01	0.01	0.01	0.01	0.07	0.06	0.06
CHP and/or Cogeneration Process	0.00	0.00	0.00	0.00	0.00	0.00	-	-	-
Direct Uses-Total Process	1.60	1.77	1.85	2.01	1.52	1.47	1.38	1.37	1.35
Process Heating	0.23	0.25	0.27	0.29	0.22	0.21	0.17	0.17	0.16
Process Cooling and Refrigeration	0.14	0.16	0.17	0.18	0.14	0.13	0.12	0.11	0.11
Machine Drive	1.03	1.13	1.18	1.29	0.98	0.94	0.89	0.89	0.87
Electro-Chemical Processes	0.20	0.22	0.23	0.25	0.19	0.18	0.18	0.18	0.18
Other Process Use	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Direct Uses-Total Nonprocess	0.33	0.36	0.38	0.41	0.31	0.30	0.26	0.26	0.25
Facility HVAC	0.18	0.20	0.20	0.22	0.17	0.16	0.13	0.13	0.13
Facility Lighting	0.12	0.13	0.14	0.15	0.11	0.11	0.09	0.09	0.09
Other Facility Support	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03

APPENDIX M

Indirect CO_2 Emissions ($MMTCO_2$ Eq.)	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Onsite Transportation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.06	0.06	0.07	0.07	0.06	0.05	0.02	0.02	0.02
TOTAL	**6.26**	**6.32**	**6.67**	**6.99**	**6.53**	**6.74**	**6.41**	**6.59**	**6.55**
Residential	1.98	2.07	2.23	2.33	2.39	2.55	2.36	2.48	2.46
Commercial	2.27	2.04	2.14	2.16	2.24	2.35	2.33	2.40	2.41
Industrial	2.00	2.21	2.30	2.51	1.90	1.83	1.72	1.71	1.68