DELAWARE DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENTAL CONTROL

DELAWARE'S 2010 GREENHOUSE GAS EMISSIONS INVENTORY

FINAL REPORT

PREPARED BY:

DIVISION OF AIR QUALITY

FEBRUARY 2014

EXECUTIVE SUMMARY

This inventory 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 2010 Greenhouse Gas (GHG) emissions inventory. This inventory report was prepared to account for GHG emissions and sinks[1] in the State of Delaware. The inventory includes Delaware GHG emissions from1990 to 2010 as well as emission projections from 2011 to2030. 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 2010 with projections, emissions estimations were performed by using the U.S.EPA's State Inventory Tool (SIT) as well as the projection tool (PT). The SIT and the PT 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. Projection of GHG emissions are estimated by utilizing the U.S. Energy Information Administration Annual Energy Outlook data as well as other economic data that are used to predict GHG emissions.

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[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 AND TRENDS

The 2010 GHG inventory estimated GHG emissions from various sources. Data collection was performed by characterizing the sources into eight economic sectors of Delaware including electric power, transportation, industrial, residential, commercial, agricultural, waste management and land-use, land-use change & forestry (LULUCF). To estimate GHG emissions, each economic sector was subdivided based on subsectors and economic activities, as well as methodologies.

Between 1990 and 2010, GHG emissions from Delaware added a cumulative amount of 386.99 million metric tons of carbon dioxide equivalents (MmtCO$_2$e) to the atmosphere. In 2010, Delaware's gross[6] GHG emission was equivalent to 13.60 MmtCO$_2$e. Also in 2010, Delaware's net[7] GHG emission was equivalent to 12.48 MmtCO$_2$e. From 1990 to 2010, gross GHG emissions decreased by approximately 31%, while net emissions decreased by approximately 37%[8]. Delaware's gross GHG emission in 2010 made up approximately 0.2% of gross U.S GHG emissions (6,821.8 MmtCO$_2$e)[9].

Figure ES-1 presents a breakdown[10] of GHG emissions in 2010 by Delaware's economic sectors. The largest source of GHG emissions in 2010 was the transportation sector. The transportation sector represented 34% of gross GHG emissions in 2010 as presented in Figure ES-1. This was followed by the electric power sector with approximately 31%.The industrial sector was the third largest emitter of GHG emissions in 2010 representing approximately 16% of gross emissions that year, while all other sectors including residential, commercial, agriculture and waste management all represented approximately 8%, 6%, 4% and 1% respectively as presented in Figure ES-1.

Figure ES-2 presents Delaware's gross[11] GHG emissions profile from 1990 to 2010. It shows that in general, GHG emissions in Delaware's economic sectors trended downwards from 1990

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[6] Gross GHG emissions excluded metric tons of CO$_2$e removed from the atmosphere (sink)

[7] The land-use category was a sink for the removal CO$_2$ from 1999 to 2010 because it generated negative CO$_2$ emission.

[8] In 1990, gross emission was equivalent to net emission (19.78MmtCO$_2$e) because there was no negative emission.

[9] U.S. EPA: 2012 Inventory of U.S. Greenhouse Gas Emissions and Sinks:1990 -2010

[10] Figure 1 percentages are based on Delaware's gross emissions of 13.60 MmtCO$_2$e and not the net emissions of 12.48 MmtCO$_2$e.

[11] Gross emissions included all positive emissions includes all positive emissions and excludes all negative emissions from 1990 to 2010

to 2010 with some fluctuations. Greenhouse gas emissions decreased from 19.78 MmtCO_2e in 1990 to 13.60 MmtCO_2e in 2010, a decrease of approximately 31%. This decrease occurred at the annual rate of 0.24 MmtCO_2e per year with GHG emissions peaking at 20.95 MmtCO_2e.

FIGURE ES-1. 2010 DELAWARE GHG EMISSIONS BY ECONOMIC SECTOR

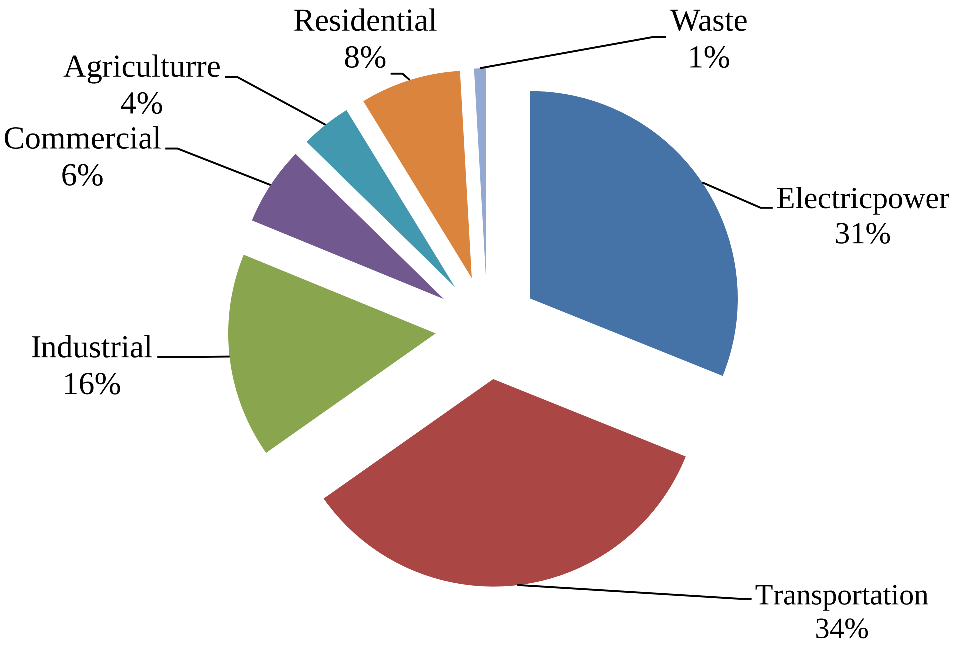

FIGURE ES-2.DELAWARE'S GROSS GHG EMISSION FROM 1990 TO 2010

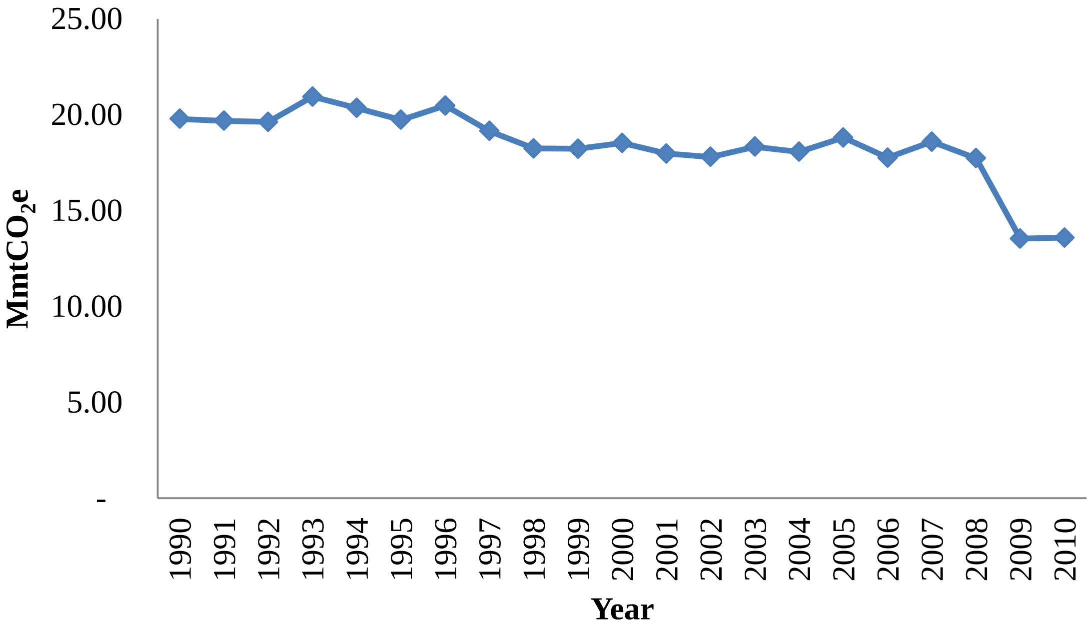

Figure ES-3 presents net[12] GHG emissions from 1990 to 2010. Emissions decreased from 19.78 MmtCO$_2$e in 1990 to 12.48 MmtCO$_2$e in 2010 as presented by Figure ES-3. This was a decrease of approximately 37% at the rate 0.32 MmtCO$_2$e per year.

FIGURE ES-3. DELAWARE'S NET GHG EMISSIONS FROM 1990 TO 2010

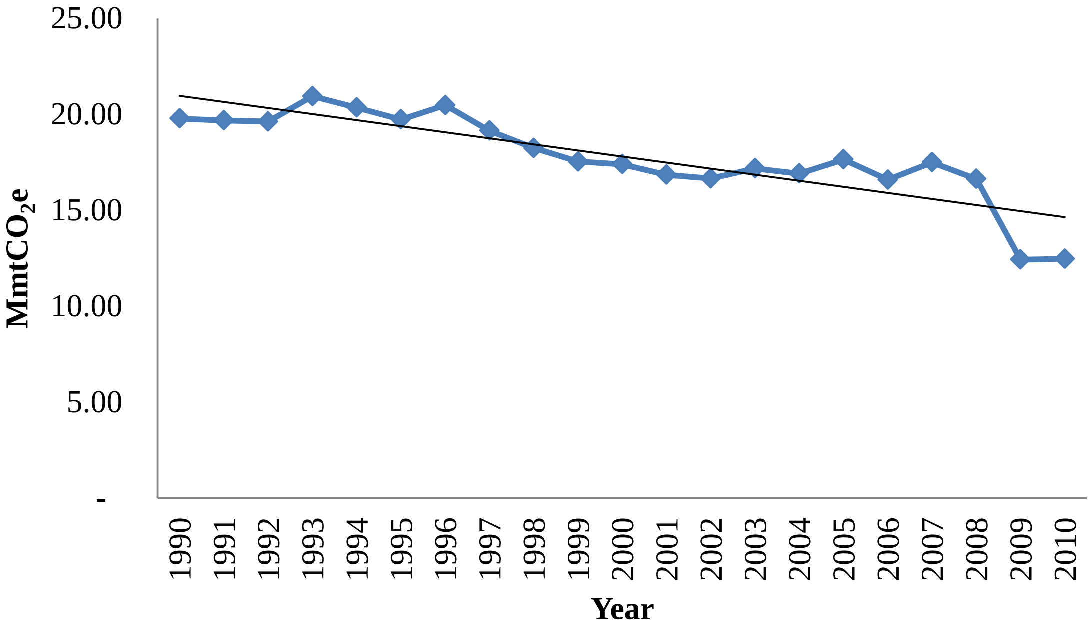

Figure ES-4 presents GHG emissions by economic sectors. Figure ES-4 shows that the largest emissions sources in Delaware included the electric power, residential and industrial sectors. In this report, all three sectors are known as the *Big Three* because their combined GHG emissions represented approximately 81% of Delaware's emissions in 2010. As Figure ES-4 presents, GHG emissions from the *Big Three* intersected between1998 and 2002. For most of the years between 1990 and 2010, electric power GHG emissions exceeded emissions from the other two sectors.

However, in 1999, GHG emissions from the industrial sector was the largest, while transportation was second followed by electric power GHG emissions. And in 2010, the transportation sector GHG emissions again exceeded the electric power sector GHG emissions,

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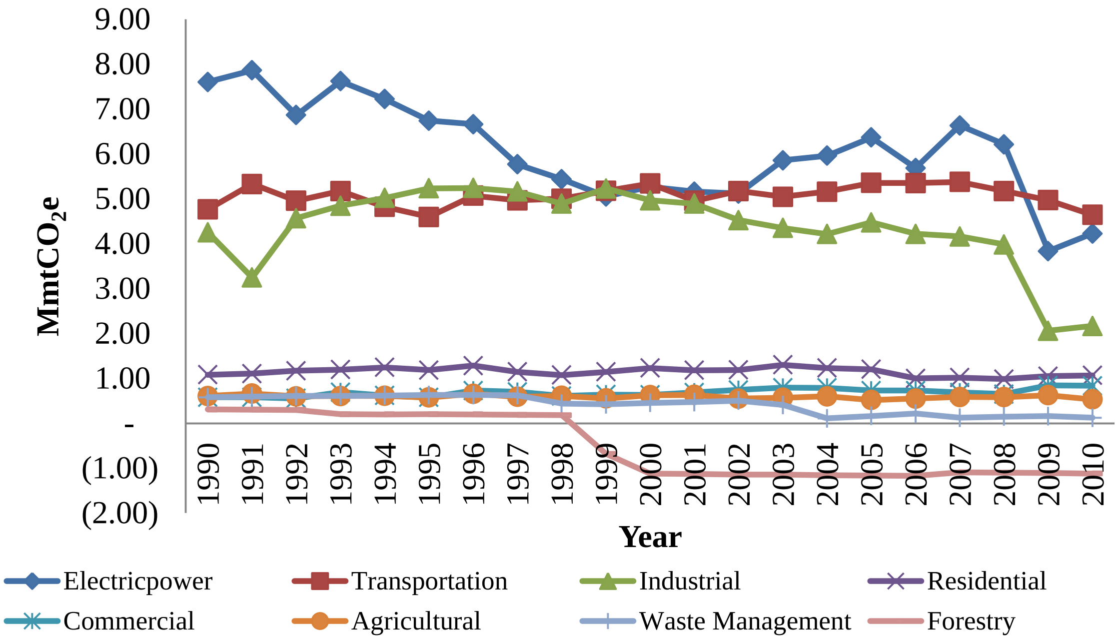
[12] Net GHG emissions include all emissions including negative and positive emissions from 1990 to 2010.

while industrial sector GHG emissions decreased significantly from 2009 to 2010 as Figure ES-4 shows.

FIGURE ES-4. DELAWARE'S GHG EMISSIONS BY ECONOMIC SECTOR



As the analysis indicates, the driving force for GHG emissions is largely energy consumption in all economic sectors.[13] Energy related activities specifically fossil fuel combustion, was the largest source of GHG emissions because in 2010, it represented approximately 90% of gross GHG emissions from Delaware. In addition, CO_2 emission from this source makes up approximately 90% gross emissions. As the overall amount of fossil fuel combusted decreased from 1990 to 2010, gross GHG emissions from Delaware also decreased.

Reference Case GHG Emissions projections

The overall decline in historical GHG emissions is not projected to continue over time. Projection analysis[14] shows that gross GHG emissions from Delaware is expected to trend upwards overtime. Gross Figure ES-5 presents projected GHG emissions by economic sectors in 2030. Greenhouse gas emissions from the transportation sector are projected to be approximately 36% in 2030. This will be a 2 % increase from 2010. The Electric power sector is projected to be

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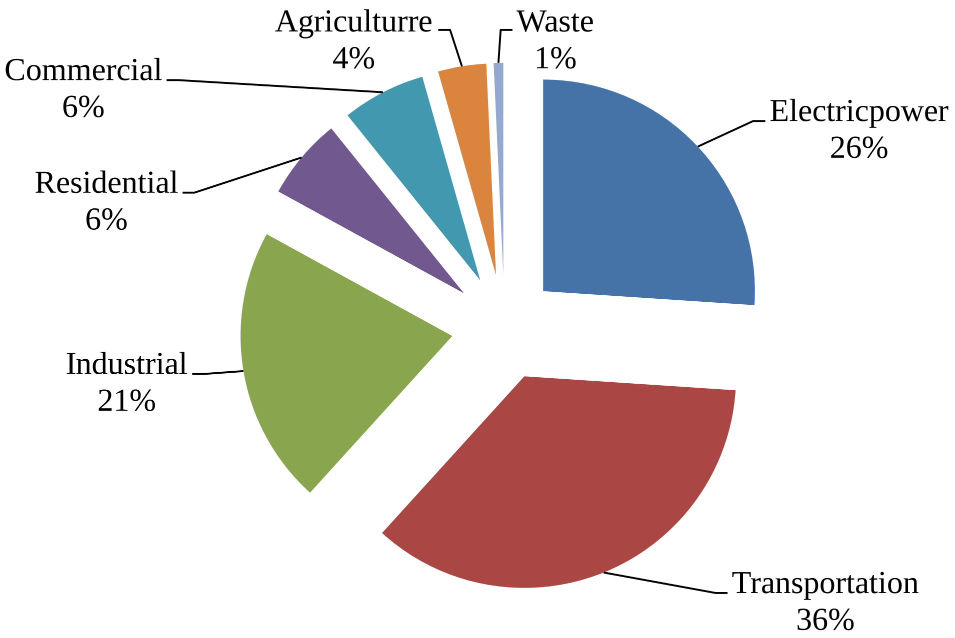
[13] Energy related activities are activities that involve fossil fuel combustion for energy use.

[14] Projection analyses for all economic sectors are discussed in from Section 4.1 through 4.7.

the second largest emitter of GHGs representing approximately 26% in 2030 as Figure ES-5 presents. This will be a decrease of 5% from 2010. Conversely, industrial GHG emission is projected increase by 5% from 2010, representing approximately 21% in 2030. Residential sector GHG emission is projected to represent approximately 6%, a decrease of 2% from 2010. However, GHG emissions from commercial, agricultural and waste management sectors of the economy are all projected to represent approximately 6%, 4% and 1% respectively in 2030.

FIGURE ES-5. DELAWARE'S 2030 GHG EMISSIONS BY ECONOMIC SECTOR



Greenhouse gas emissions from Delaware are projected to add approximately 292.83 MmtCO$_2$e to the atmosphere between 2011 and 2030. Figure ES-6 presents projected gross GHG emissions from Delaware from 2011 to 2030. Greenhouse gas emissions are projected to increase from 13.29 MmtCO$_2$e in 2011 to 15.37 MmtCO$_2$e in 2030. This will be an increase of approximately 16% at the rate of 0.092 MmtCO$_2$e per year.

Cumulative net GHG emission between 2011 and 2030 is projected to be 282.79 MmtCO$_2$e. Figure ES-7 presents projected net GHG emissions from 2011 to 2030. Greenhouse gas emissions are projected to increase from 12.98 MmtCO$_2$e in 2011 to14.68 MmtCO$_2$e in 2030. This will be an increase of approximately 13% at the rate of 0.073 MmtCO$_2$e per year.

FIGURE ES-6. DELAWARE'S PROJECTED GROSS GHG EMISSIONS FROM 2011TO2030

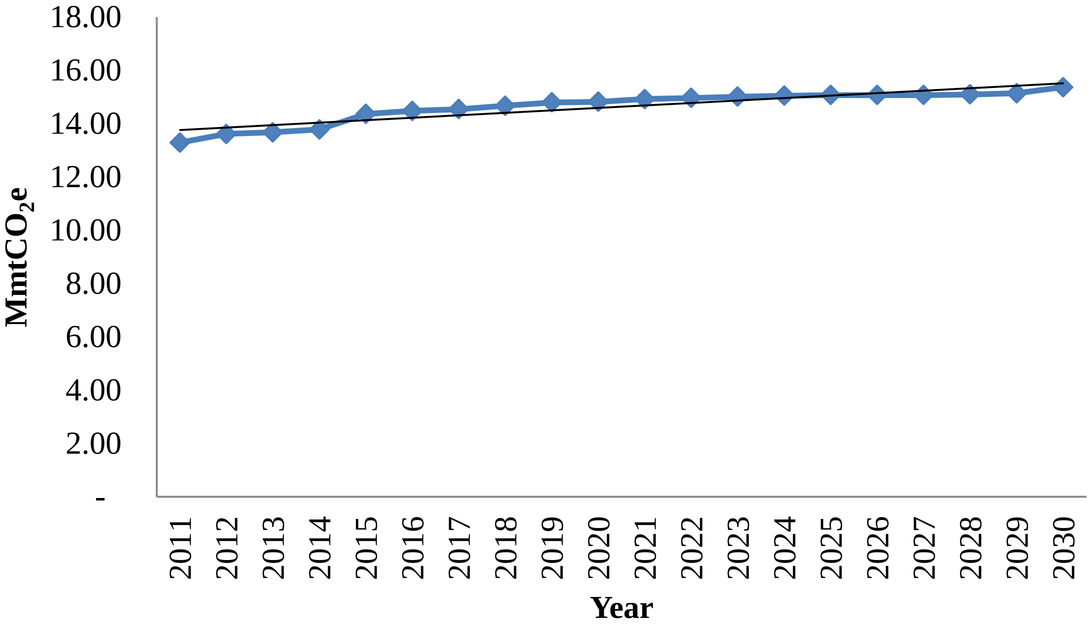


FIGURE ES-7. DELAWARE'S PROJECTED NET GHG EMISSIONS FROM 2011TO2030

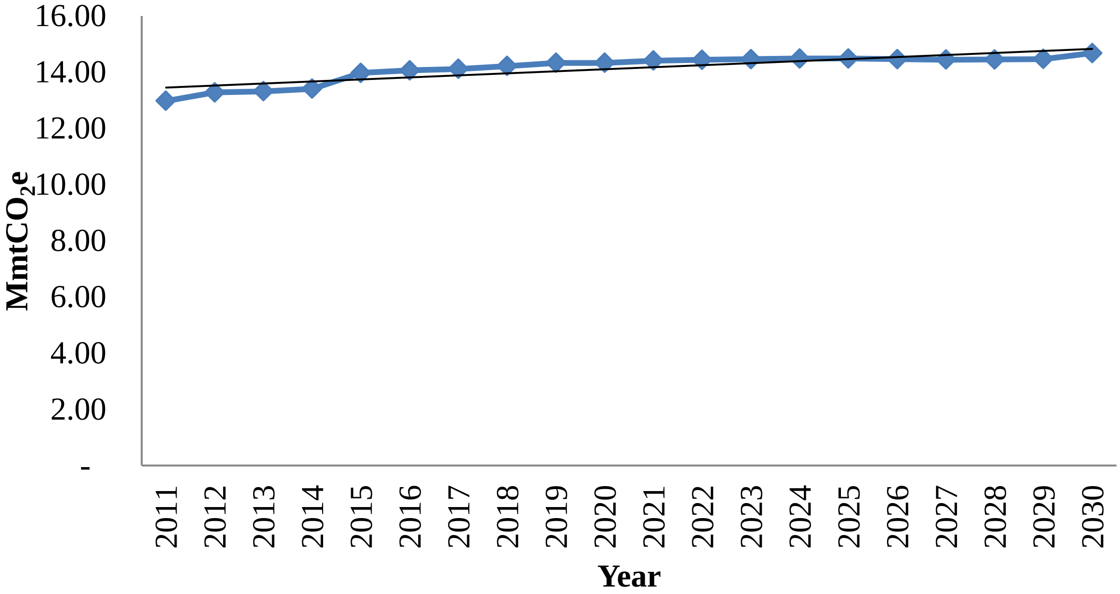
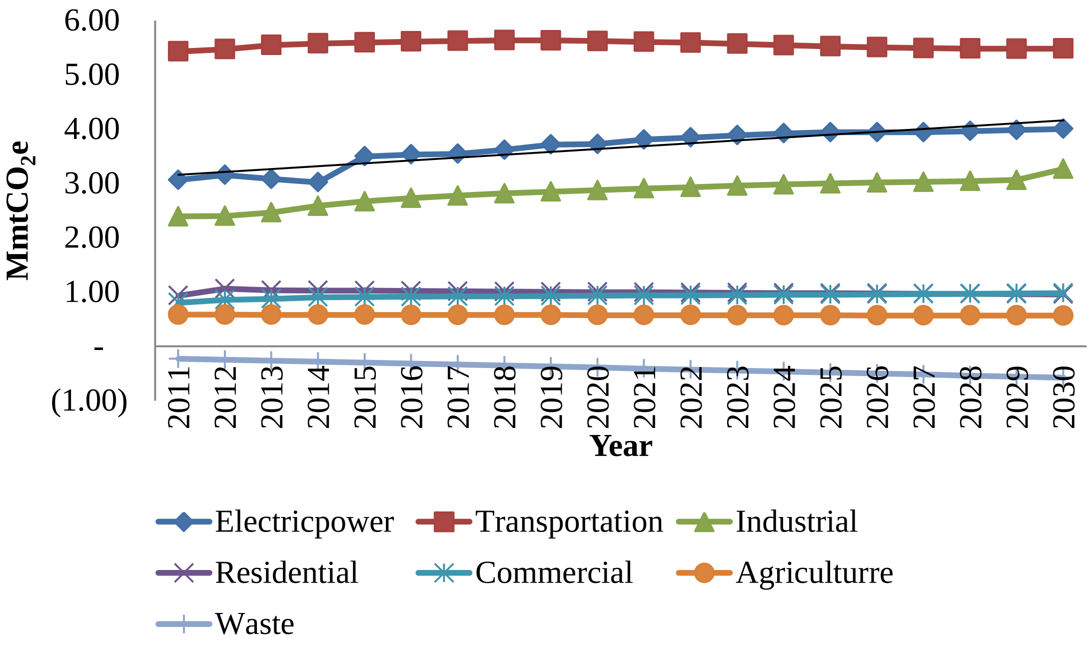


Figure ES-8 presents projected GHG emissions by sector from 2011 to 2030. Projection analysis shows that most of the economic sector emissions are projected to increase over time as. As Figure ES-8 presents, the *Big Three* sectors are expected to continue to exceed all other sectors in terms of GHG emissions. The transportation sector is projected to be largest source of GHG emissions from 2011 to 2030. This will be followed by the electric power sector and industrial sector as shown in Figure ES-8. Other sectors such as residential, commercial, as well as agricultural are projected to have lower emission over time. However, the waste management sector is expected to have negative GHG emissions from 2011 to 2030.

FIGURE ES-8. DELAWARE'S PROJECTED GHG EMISSIONS BY SECTOR



GHG Emission Trends by Economic sectors

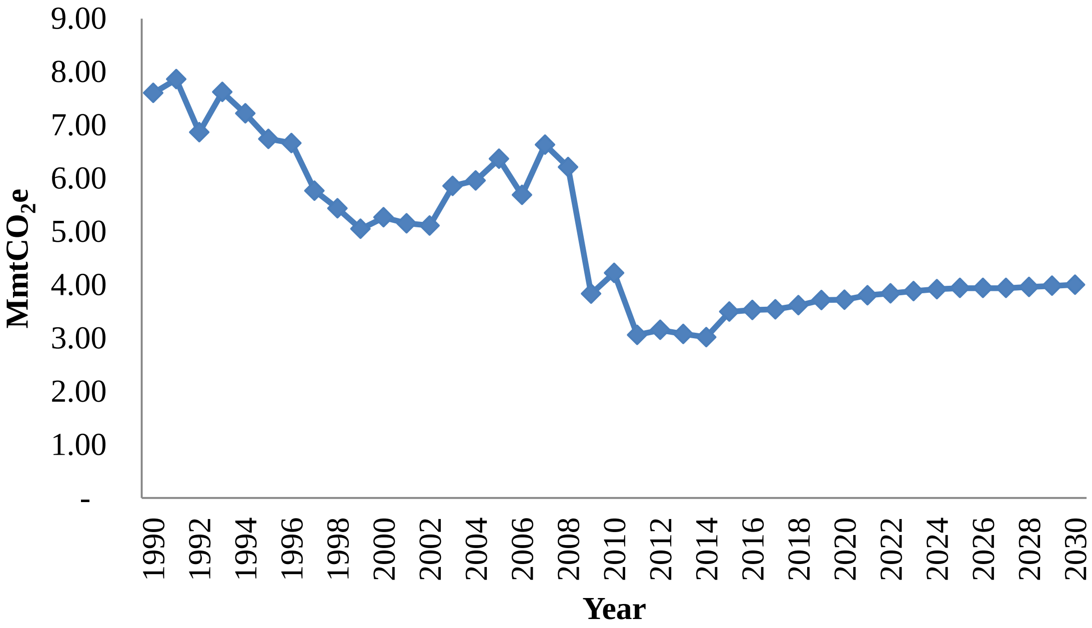
The 2010 GHG emisssions inventory characterized GHG emissions into eight econmic sectors of Delaware. The emssion trends and analytical findings of those sectors are summerized below:

Electric Power Sector

The electric power sector added a cumulative amount of approximately 127 MmtCO$_2$e in GHG emissions to the atmosphere between 1990 and 2010. The emission of GHGs in this sector was driven primarily by the combustion of fossil fuels such as coal, natural gas and petroleum products in order to generate electricity. In 2010, the electric power sector represented approximately 31%, the second largest source of emissions as Figure ES-1 presents. Figure ES-9 shows that emissions decreased significantly from 7.60 MmtCO$_2$e in 1990 to 4.23 MmtCO$_2$e in 2011, a decrease of approximately 44% at the rate of .123

$MmtCO_2e$ per year. Projection analysis shows that this sector is expected to add an additional 73 $MmtCO_2e$ in GHG emissions from 2011 to 2030. Electric power GHG emission is expected to stabilize with slight increases between 2011 and 2030 as Figure ES-9 shows. Annual emissions are projected to increase by approximately 30% from 2011(3.06 $MmtCO_2e$) to 2030 (3.98 $MmtCO_2e$) at the rate of 0.05 $MmtCO_2e$ per year. Decreasing emissions in the electric power sector were attributed to decreasing consumption of electricity due to a diminished industrial base.

FIGURE ES-9. ELECTRIC POWER SECTOR GHG EMISSIONS FROM 1990 TO 2030

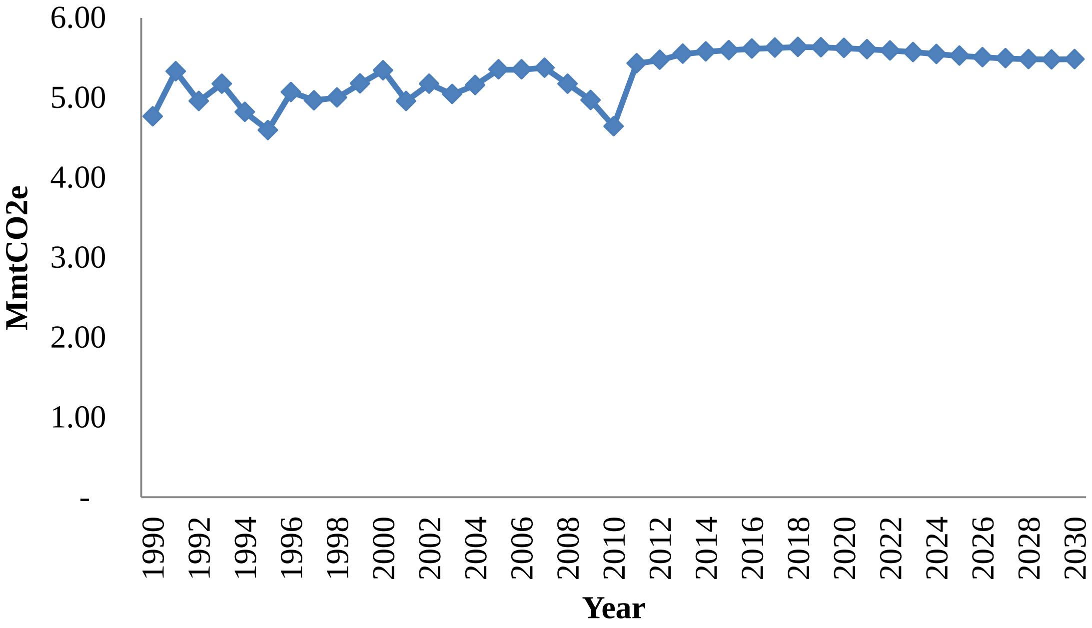


Transportation Sector

Between 1990 and 2010, the transportation sector added approximately 106 $MmtCO_2e$ to the atmosphere. Approximately 98% of GHG emission was CO_2 emission from gasoline combustion in automobiles. In 2010, the transportation sector represented the largest source of GHG emissions with approximately 34% as Figure ES-1 presents. Figure ES-10 shows that GHG emission from the transportation sector trended downwards with major fluctuations. GHG emissions decreased from 4.76 $MmtCO_2e$ in 1990 to 4.64 $MmtCO_2e$ in 2010, a decrease of approximately 2.5% at the rate of 0.008 $MmtCO_2e$ per year.

Projected transportation sector GHG emission shows that a cumulative amount of approximately 111 MmtCO$_2$e in GHG emissions is expected to be added to the atmosphere from 2011 to 2030. Projection analysis shows that emissions are expected to stabilize with a slight decrease from 2011 to 2030 as Figure ES-10 presents. Emissions are projected to average approximately 5.55MmtCO$_2$e annually between 2011 and 2030. The projected rise in GHG emissions presented in Figure ES-10 was attributed a steady increase in Delaware's population, which was projected to continue into the future.

FIGURE ES-10. TRANSPORTATION SECTOR GHG EMISSIONS FROM 1990 TO 2030

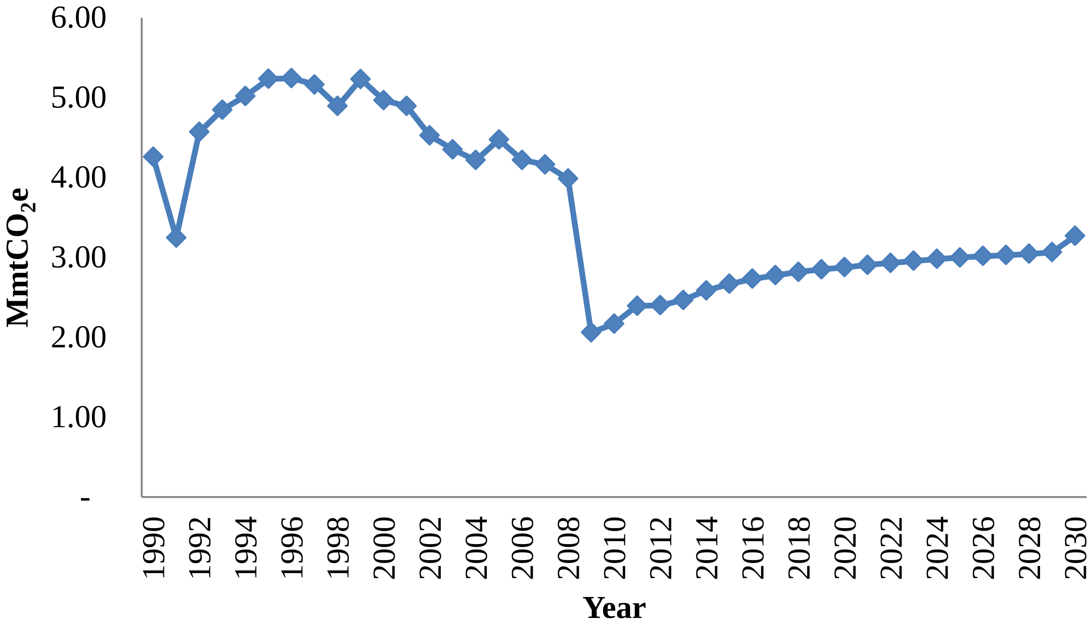


Industrial Sector

The industrial sector added a cumulative amount of approximately 92 MmtCO$_2$e in GHG emissions to the atmosphere between 1990 and 2010.In 2010, GHG emissions from this sector represented 16% of gross GHG emissions in 2010. As Figure ES-11 presents, GHG emissions from this sector had a concave profile peaking at 5.23 MmtCO$_2$e in 1995 and decreasing significantly to 2.17 MmtCO$_2$e in 2010, a decrease of approximately 60%. This decrease in industrial sector emissions was influenced by declining productivity in this sector due to a slowing economy and loss of heavy industry as represented by the significant decrease from 2008 to 2009 presented in Figure ES-1. Emissions analysis shows that GHG emissions deceased at the rate of 0.074 MmtCO$_2$e per year.

Cumulative GHG emission from this sector is projected to add up to 57 MmtCO$_2$e from 2010 to 2030. Projected emissions presented in Figure ES-11 predict a steadily increasing annual GHG emission from this sector. Emissions are projected to increase from 2.39 MmtCO$_2$e in 2011 to 3.27 MmtCO$_2$e in 2030, an increase of approximately 37% at the annual rate of 0.038 MmtCO$_2$e per year.

FIGURE ES-11. INDUSTRIAL SECTOR GHG EMISSIONS FROM 1990 TO 2030

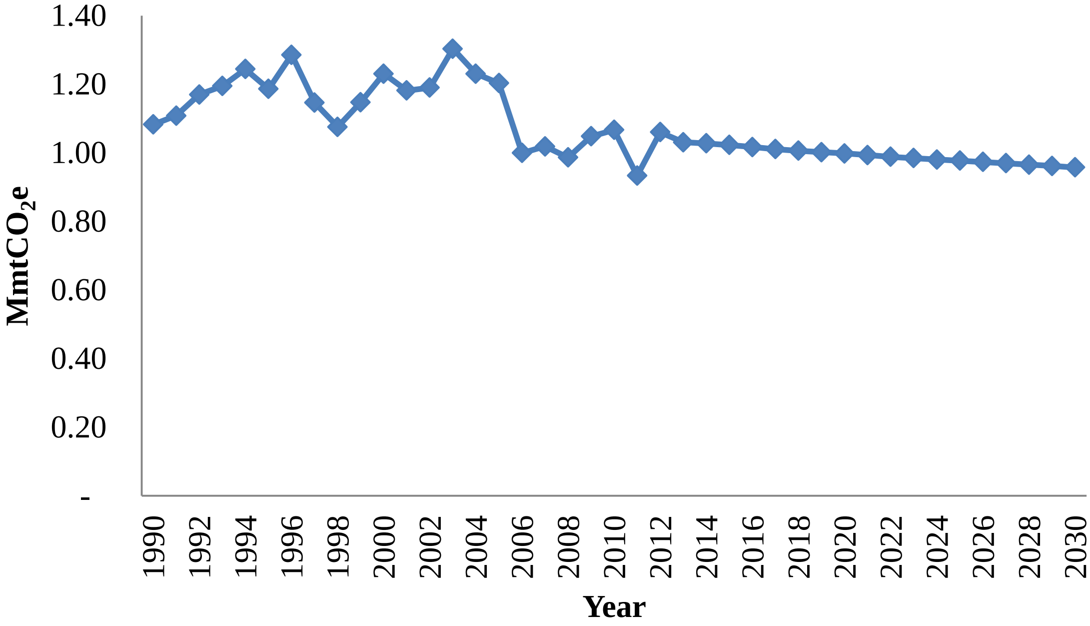


Residential Sector

The residential sector added a cumulative amount of approximately 24 MmtCO$_2$e in GHG emissions to the atmosphere from 1990 to 2030. GHG emissions in this sector were driven by fossil fuel combustion for heating. In 2010, GHG emissions from the residential sector represented approximately 8%. As Figure ES-12, historical emissions from 1990 to 2010 show major fluctuations. Emissions peaked at 1.30 MmtCO$_2$e in 2003 and it fluctuated downward to 1.07 MmtCO$_{2e}$ in 2010, a decrease of approximately 18%. Cumulative GHG emission from this sector is expected add 20 MmtCO$_2$e to the atmosphere from 2011 to 2030. As Figure ES-5 present, GHG emission from this sector is projected to represent approximately 6% of gross GHG emissions from Delaware.

Projected emissions show that from 2011 to 2030, GHG emission is expected to stabilize decreasing steadily but only slightly from 1.06 $MmtCO_{2e}$ in 2012 to 0.96 in 2030, a decrease of approximately 9%. Over time, GHG emissions form the residential sector is not expected to decrease significantly but remain stable with minor fluctuations depending on future weather patterns.

FIGURE ES-12. RESIDENTIAL SECTOR GHG EMISSIONS FROM 1990 TO 2030

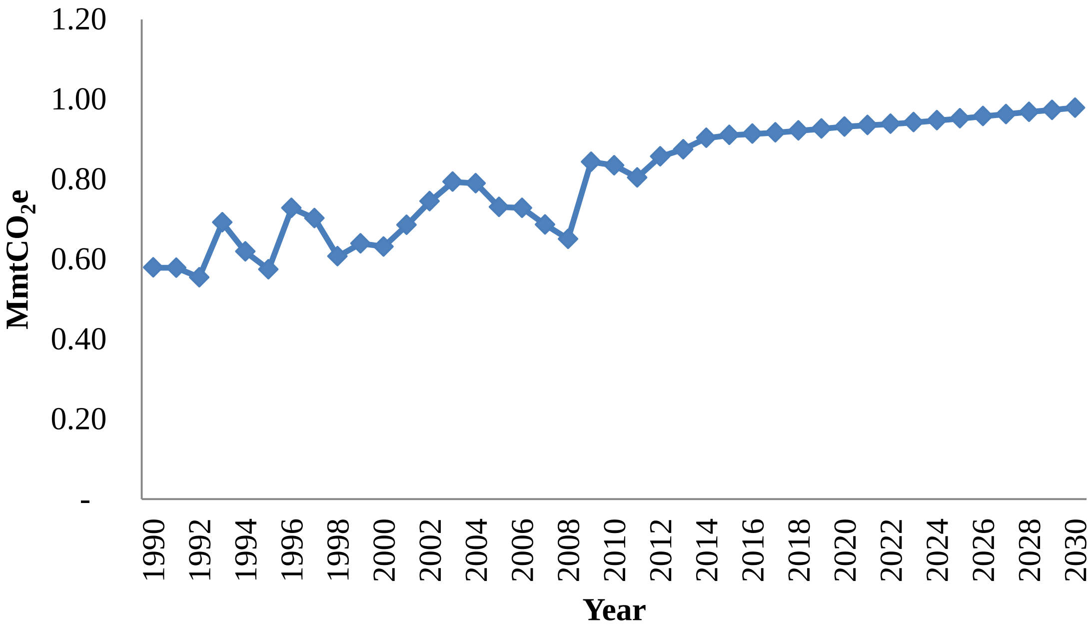


Commercial Sector

The commercial sector added approximately 14 $MmtCO_2e$ in GHG emissions to the atmosphere from 1990 to 2030. Like the residential sector, commercial sector GHG emissions are driven primarily by fossil fuel combustion for heating purposes. In 2010, commercial sector GHG emissions represented approximately 6% of gross GHG emissions from Delaware as presented in Figure ES-1. As Figure ES-13 presents, historical GHG emissions fluctuated upwards from 1990 to 2010, GHG emissions from this sector increased from 0.58 $MmtCO_2e$ in 1990 to 0.84 $MmtCO_2e$ in 2010, an increase of approximately 45% at the rate of 0.01 $MmtCO_2e$ per year.

Projected emissions show that between 2011 and 2030, the commercial sector is expected to add a total of approximately 19 MmtCO$_2$e to the atmosphere. In 2030, commercial sector GHG emission is expected to remain 6% of gross GHG emissions from Delaware as presented in Figure ES-5. As Figure ES-13 presents, GHG emissions are projected to increase from 0.80 MmtCO$_2$e in 2011 to 0.98 MmtCO$_2$e in 2030, an increase of approximately 23%. The projection profile in Figure ES-13 shows that emissions from this sector are projected to rise steadily at the rate of 0.007 MmtO$_2$e per year.

FIGURE ES-13. COMMERCIAL SECTOR GHG EMISSIONS FROM 1990 TO 2030

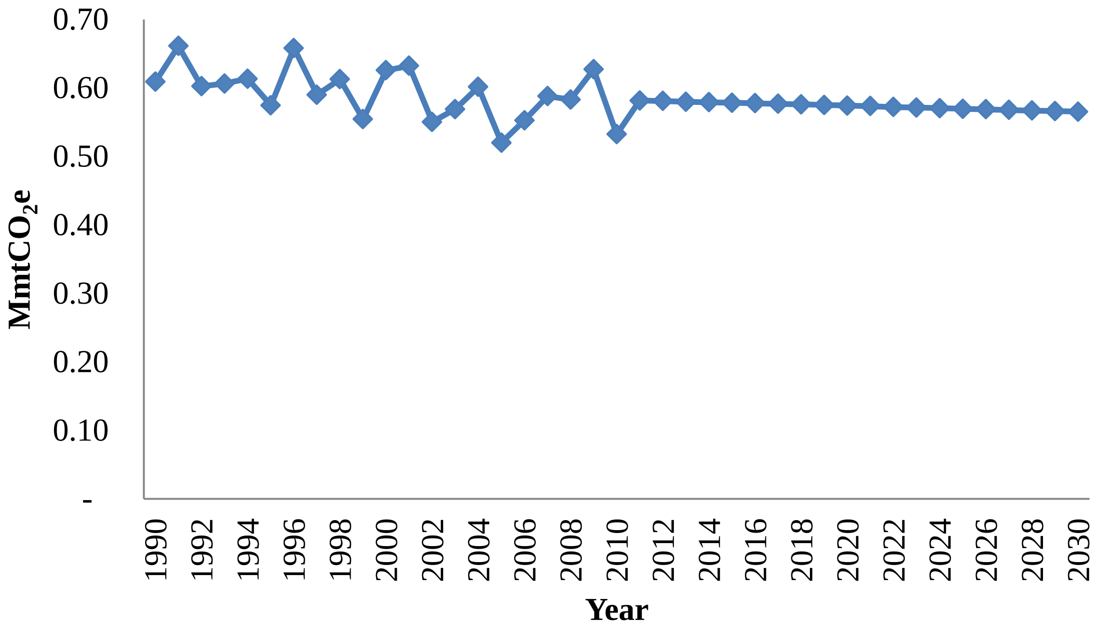


Agricultural Sector

Agricultural sector GHG emissions added a total of 12.47MmtCO$_2$e in GHG emissions to the atmosphere from 1990 to 2010.Figure ES-1 shows that GHG emissions represented only approximately 4% of gross GHG emissions in 2010. The GHG emissions from this sector fluctuated downward from 0.60 MmtCO$_2$e in 1990 to 0.53 MmtCO$_2$e in 2010, a decrease of approximately 11%. This decrease was partly due to 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.

Figure ES-14 shows that GHG emission from the agricultural sector is projected to basically remain stable with a slight decrease from 2011 to 2030. The cumulative GHG emissions projected to be added to the atmosphere is 11.47 $MmtCO_2e$ between 2011 and 2030. Greenhouse emission from the agricultural sector is projected to remain at 4% of gross GHG emissions from Delaware as Figure ES-5 presents. Average annual emissions is projected to be 0.57 $MmtCO_2e$

FIGURE ES-14. AGRICULTURAL SECTOR GHG EMISSIONS FROM 1990 TO 2030

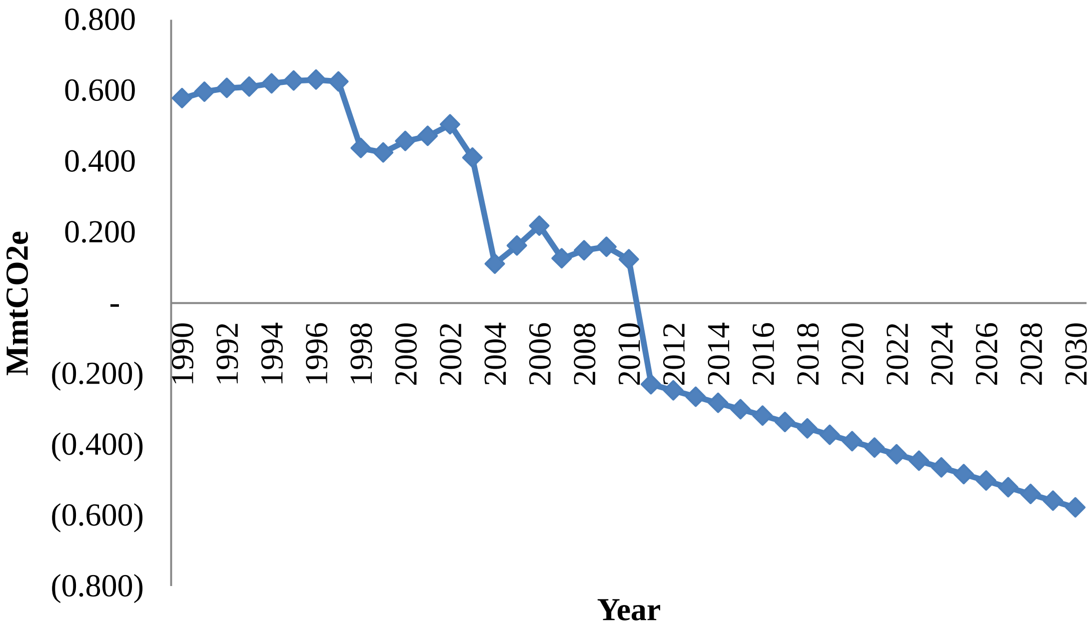


Waste Management Sector

Greenhouse gas emission from the waste management sector includes municipal solid waste (landfills) and wastewater treatment methane emissions. This sector added a total of approximately 9 $MmtCO_2e$ in GHG emissions to the atmosphere from 1990 to 2010. The waste management sector represented only approximately one percent of gross GHG emissions according to Figure ES-1. As Figure ES-15 presents, emissions decreased sharply by approximately 79% from 1990 to 2010. This sharp decrease in GHG emissions from this sector was driven mainly by sharp decreases in methane emissions from landfill activities. Activities such as flaring and landfill gas to energy conversion (energy recycling) served as emission sinks for CH_4 emissions in the waste management sector.

Projection analysis as presented in Figure ES-15 shows that the waste management sector is expected to continue to be a major sink for methane emissions from Delaware landfills. Landfill activities in the waste management sector are projected to remove a cumulative amount of 8.03 $MmtCO_2e$ in GHG emissions from 2011 to 2030. The removal of GHG emissions from this sector is expected to increase steadily at the rate of .001 $MmtCO_2e$ per year as presented in Figure ES-15.

FIGURE ES-15. WASTE MANAGEMENT SECTOR GHG EMISSIONS FROM 1990 TO 2030



Land-use, Land Use Change and Forestry Emission Analysis

The 2010 GHG emissions inventory identified the land-use sector as a major sink[15] for GHG emissions in Delaware. Between 1990 and 1998, the land use sector had positive emissions totaling 2.09 $MmtCO_2e$. The emission of GHGs in this sector was driven by the decay of dead biomass materials and forest fires. According to Figure ES-16, net GHG emission from this sector was negative from 1999 to 2010. The removal of GHGs

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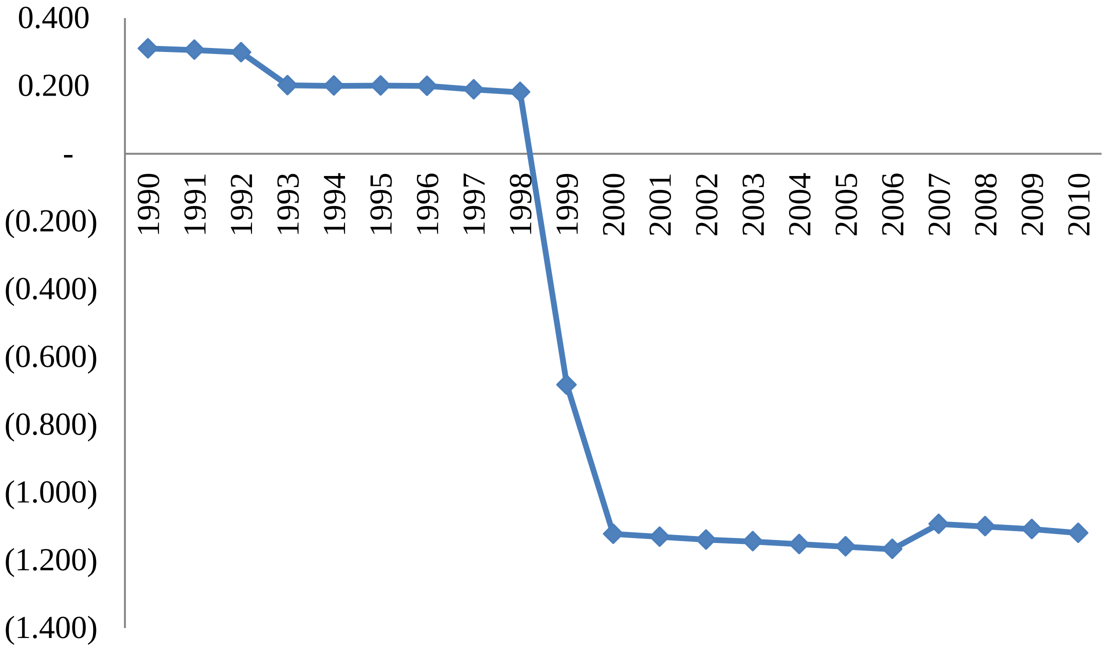
[15] A sink is the removal of GHG from the atmosphere

in this sector peaked in 2006 with a net GHG removal of 1.17 MmtCO$_2$e as indicated in Figure ES-16. Net GHG removed from the land use sector totaled 11.04 MmtCO$_2$e from 1990 and 2010.

The analysis of the land use sector highlights the potential for carbon sequestration projects in Delaware as part of a statewide GHG emissions reduction strategy. The IPCC identified two types of GHG emission reduction opportunities in this sector, which includes changing the use of land and changing land management practices. IPCC's Fourth Assessment Report on climate change (2007)[16] included example of how land use change can reduce emissions or sinks can be enhanced.

FIGURE ES-16. LAND-USE GHG SEQUESTRATION



Indirect GHG Emissions from Electricity Consumption

Indirect GHG are emissions associated with consuming electricity that is produced in Delaware as well as imported. This source category describes the electric power consumption pattern of Delawareans in terms of GHG emissions. Indirect CO$_2$ emission is CO$_2$ emission that is estimated based on the amount of kilowatt-hour consumed by

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[16] IPCC Fourth Assessment Rep IPCC Fourth Assessment Report: Climate Change 2007

end-users of electricity. Estimates of indirect GHG emissions do not include electricity generated from fossil combustion. Indirect GHG estimates were included in the 2010 GHG inventory to show how electricity demand in Delaware impacts GHG emissions. Direct GHG emissions from electricity generation were separated from indirect CO_2 emissions to avoid the double counting of emissions estimates.

Between 1990 and 2010, the total indirect GHG emission from Delaware was estimated at approximately 118 $MmtCO_2e$. As Figure ES-17 presents, indirect GHG emissions increased from 4.40 $MmtCO_2e$ in 1990 to 6.00 $MmtCO_2e$ in 2010, an increase of approximately 36%. The rate of annual increase was determined to be 0.095 $MmtCO_2e$ per year.

Indirect GHG emissions are expected to continue to increase linearly as Figure ES-17 shows. Projected indirect GHG emissions are expected to increase from 6.92 $MmtCO_2e$ in 2011 to 8.53 $MmtCO_2e$ in 2030, an increase of approximately 23%. The rate of annual increase was determined to be 0.091 $MmtCO_2e$ per year.

FIGURE ES-17. INDIRECT GHG EMISSIONS FROM 1990 TO 2030

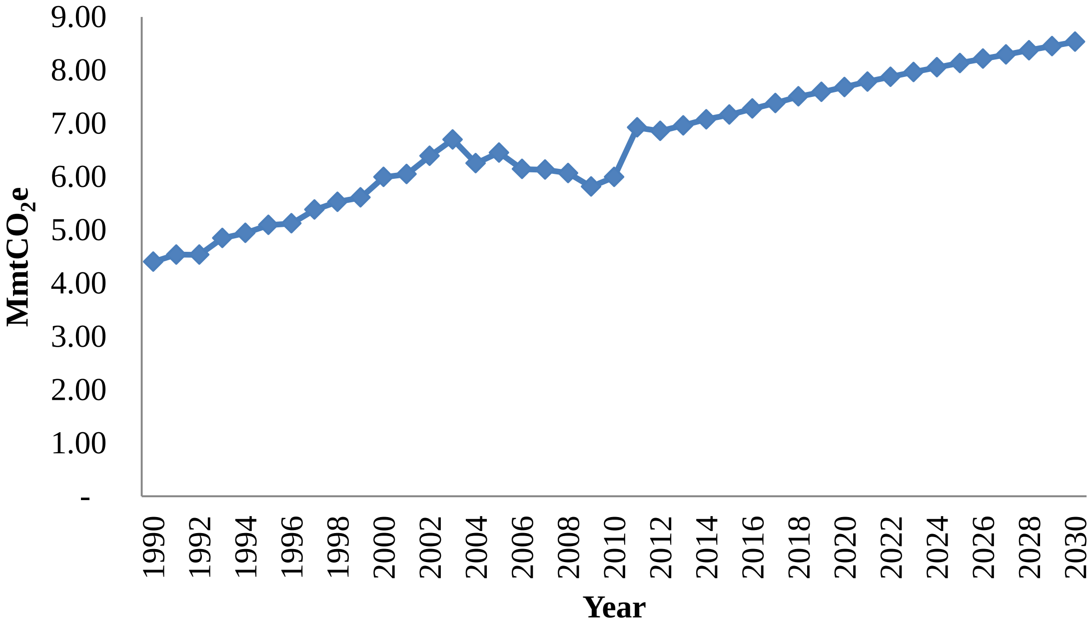


TABLE ES-1. GHG EMISSION ESTIMATES BY SECTORS

Economic Sectors	**1990**	**2000**	**2010**	**2020**	**2030**
Electric Power	**7.60**	**5.27**	**4.23**	**3.72**	**4.00**
CO2 from FFC	7.49	5.20	4.17	3.70	3.99
CH4&N2O from FFC	0.03	0.02	0.02	0.02	0.02
SF6 from T&D	0.08	0.05	0.04	0.01	0
Transportation	**4.76**	**5.34**	**4.64**	**5.62**	**5.48**
CO2 from FFC	4.53	5.08	4.55	5.55	5.41
CH4&N2O from FFC	0.23	0.27	0.09	0.07	0.07
Industrial	**4.26**	**4.97**	**2.17**	**2.88**	**3.27**
CO2 From FFC	4.04	4.58	1.55	2.12	2.34
CH4&N2O from FFC	0.01	0.01	0.00	0.00	0.00
CH4 from IP	0.01	0.01	0.09	0.10	0.11
CO2 from IP	0.20	0.16	0.20	0.12	0.09
HFC, PFC Emissions	0.00	0.21	0.33	0.54	0.73
Residential	**1.08**	**1.23**	**1.07**	**1.00**	**0.96**
CO2 from FFC	1.07	1.22	1.06	0.99	0.95
CH4&N2O from FFC	0.01	0.02	0.01	0.00	0.00
Commercial	**0.58**	**0.63**	**0.84**	**0.93**	**0.98**
CO2 from FFC	0.58	0.63	0.83	0.93	0.98
CH4&N2O from FFC	0.00	0.00	0.00	0.00	0.00
Agricultural	**0.61**	**0.63**	**0.53**	**0.57**	**0.57**
Enteric Fermentation	0.05	0.05	0.04	0.04	0.04
Manure Management	0.19	0.20	0.19	0.23	0.24
Ag Soils	0.37	0.38	0.30	0.30	0.28
Agricultural Residue Burning	0.00	0.00	0.00	0.00	0.00
Waste Management	**0.578**	**0.457**	**0.123**	**(0.391)**	**(0.578)**
Wastewater Treatment	0.063	0.076	0.088	0.100	0.112
MSW	0.515	0.381	0.035	(0.491)	(0.690)
Total GHG	**19.47**	**18.52**	**13.60**	**14.33**	**14.68**
Land Use/Forestry	**0.31**	**(1.12)**	**(1.12)**	**0**	**0**
Total GHG with Land Use	**19.78**	**17.40**	**12.48**	**14.82**	**15.37**
Electricity Consumption	4.40	5.99	6.00	7.68	8.53

GHG EMISSIONS BY GAS

The 2010 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-18. 2010 DELAWARE'S GHG EMISSIONS BY GAS

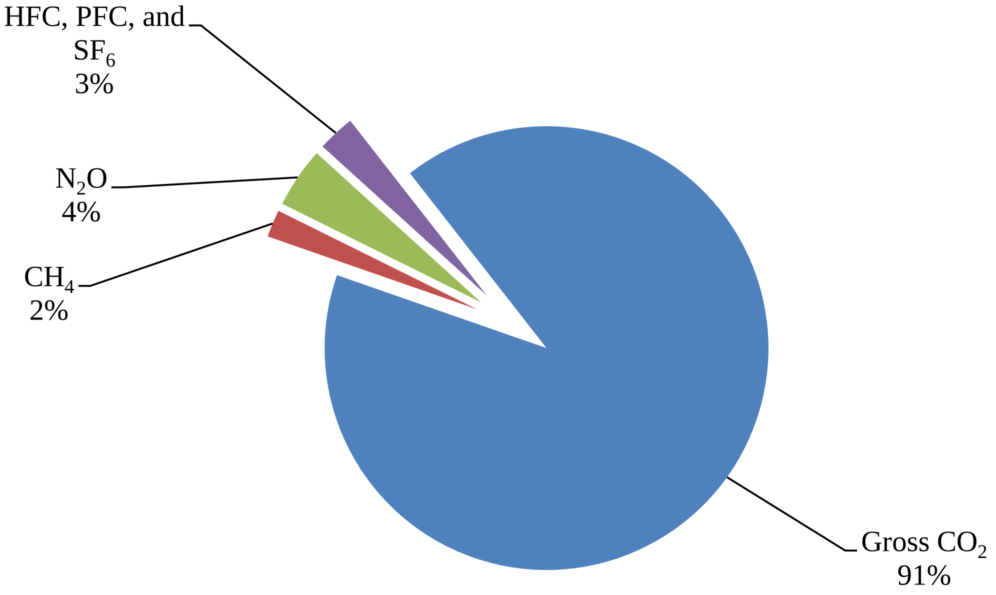


FIGURE ES-19. 2030 DELAWARE'S GHG EMISSIONS BY GAS

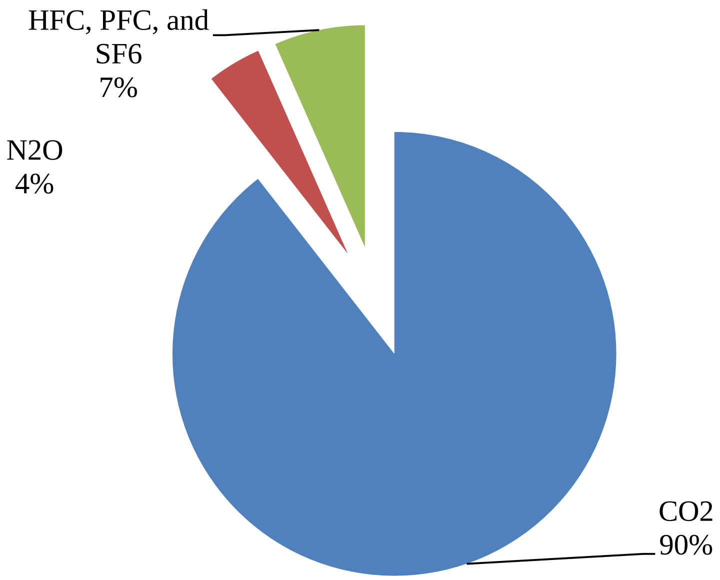
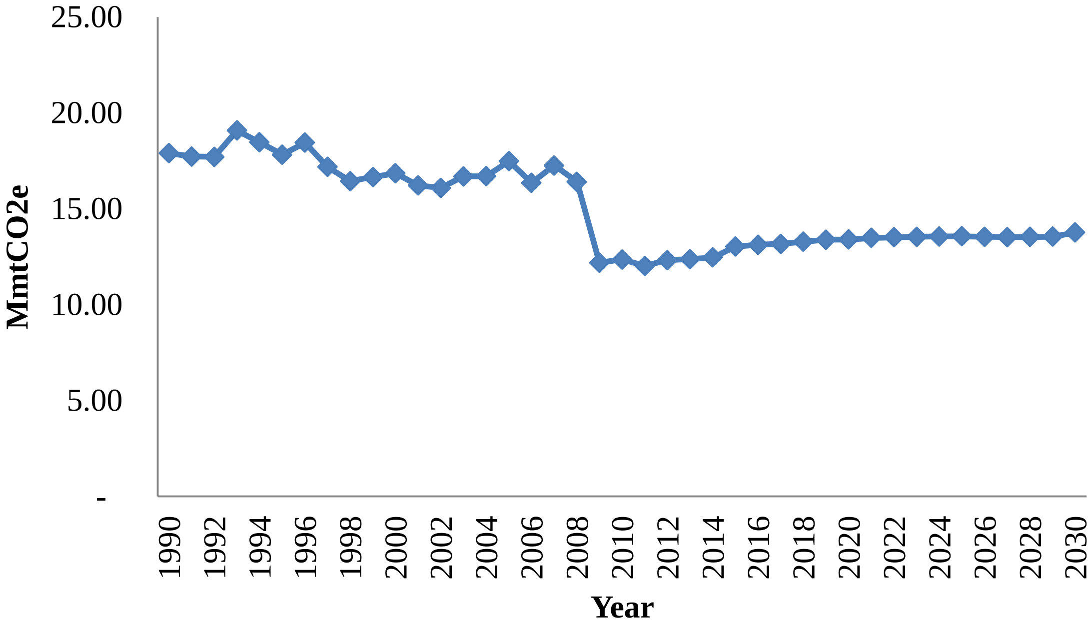


Figure ES-18 presents a breakdown of emissions by GHGs in 2010. Carbon dioxide emissions represented the largest emissions of GHGs with approximately 91% of gross emissions from Delaware. This was followed N_2O representing approximately 4%. The combined emission of HCF, PFC and SF_6 represented approximately 3%, while CH_4 represented 2% of gross GHG emissions from Delaware.

Figure ES-19 presents a breakdown of GHG emissions by GHGs in 2030. Carbon dioxide is projected to remain the most emitted GHG representing approximately 90 % of gross GHGs emitted in 2030. The combined emissions of HFC, PFC and SF_6 is projected to be as distant 2nd representing approximately 7% of gross emissions, followed by N_2O emissions, which is projected to represent approximately 4%. Methane emission was not represented in Figure ES-19 because it was projected to be negative emissions in 2030.

> ***Carbon Dioxide:*** The emission of CO_2 was driven by fossil fuel combustion in all sectors of Delaware's economy. Between 1990 and 2010, approximately 351MmtCO_2e in CO_2 emissions as added to the atmosphere. Carbon dioxide was the largest contributor to GHG emissions representing approximately 91% in 2010, and projected to represent approximately 90% in 2030. Most of the CO_2 emissions, approximately 98% came from fossils fuel combustion. Carbon dioxide emissions trended downwards with major fluctuations.
>
> As Figure ES-20 presents CO_2 emissions in decreased from 17.90 MmtCO_2e in 1990 to 12.36 MmtCO_2e in 2010, a decrease of approximately 31%. However, gross CO_2 emission is projected to increase steadily from 12.02 MmtCO_2e in 2011 to 13.55 MmtCO_2e in 2030, a decrease of approximately 13%. Economic activities in Delaware are projected to add 264 MmtCO_2e to the atmosphere from 2011 to 2030.

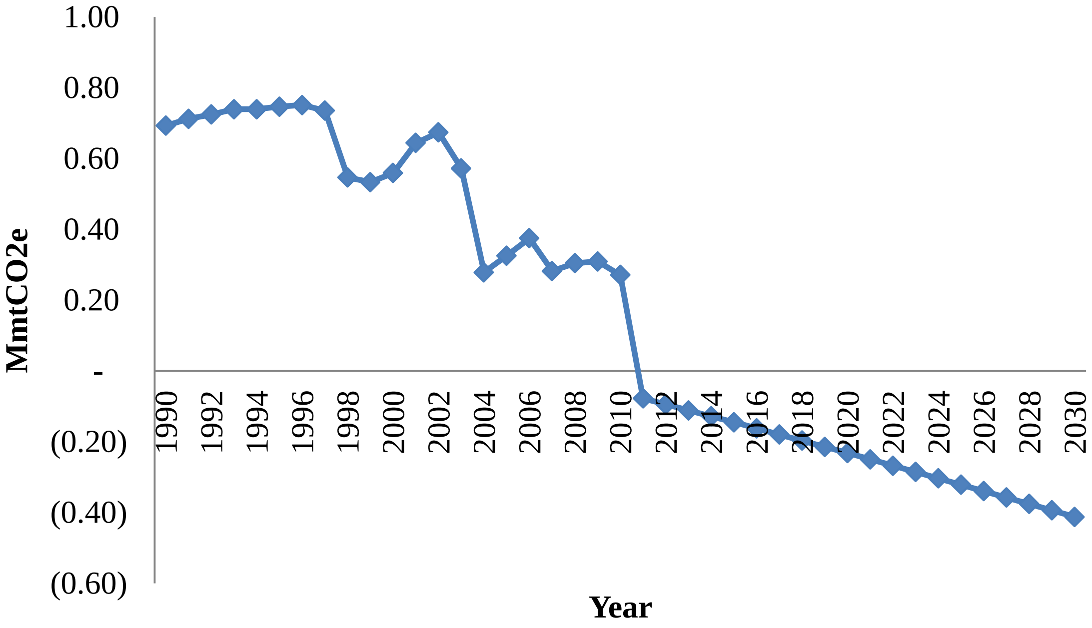
FIGURE ES-20. CO_2 EMISSIONS FROM 1990 TO 2030.



Methane: From 1990 to 2030, approximately 12 $MmtCO_2e$ in CH_4 emissions was added to the atmosphere. Figure ES-21 shows that CH_4 emissions decreased significantly from 0.69 $MmtCO_2e$ in 1990 to 0.27 $MmtCO_2e$ in 2030, a decrease of approximately 61%. 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.

Methane emissions are projected to decrease significantly from -0.08 $MmtCO_2e$ in 2011 to -0.41 $MmtCO_2e$, a decrease of approximately 612%. Cumulatively, a total of approximately 5$MmtCO_2e$ is projected to be removed from Delaware's economic sectors between 2011 and 2030.

FIGURE ES-21. CH_4 EMISSIONS FROM 1990 TO 2030.



Nitrous Oxide: From 1990 to 2010, approximately 16 $MmtCO_2e$ in N_2O emissions was added to the atmosphere.

FIGURE ES-22. N_2O EMISSIONS FROM 1990 TO 2030.

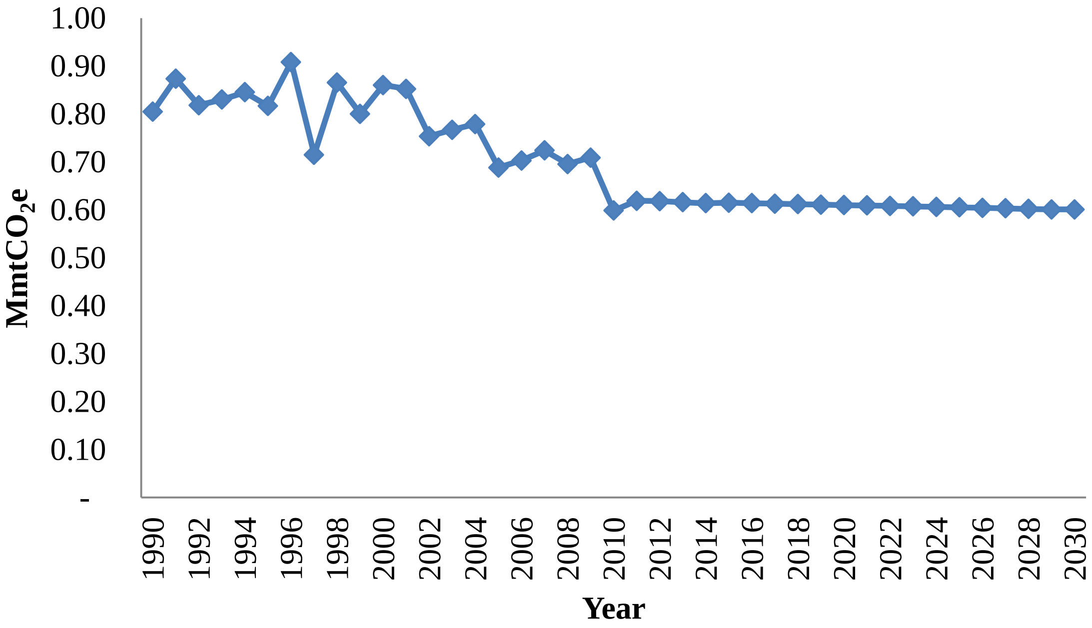


Figure ES-22 shows that N_2O emissions decreased gradually from 0.80 $MmtCO_2e$ in 1990 to 0.60 $MmtCO_2e$ in 2010, a decrease of approximately 25% .This decrease in N_2O was driven by improved farming activities as well as Delaware shrinking agricultural base due to land use change.

Projected emissions of N_2O from Delaware's economy are projected to stay relatively flat with a slight decrease of approximately 3% from 2011 to 2030 as Figure ES-22 shows. Economic activities in Delaware are projected to add approximately 11 $MmtCO_2e$ in N_2O emissions to the atmosphere from 2011 to 2030.

Hydrofluorocarbons), Perfluorocarbons and Sulfur hexafluoride: The combined emission of HFC, PFC and SF_6 added approximately 5$MmtCO_2e$ to the atmosphere from 1990 to 2010. 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 3% of total GHG emissions in 2010 as Figure ES-18 presents. However, it is projected to represent approximately 7% of gross GHG emissions in 2030[17] as FigureES-19 presents. The emissions this class of GHGs increased significantly from .0.08 $MmtCO_2e$ in 1990 to 0.37 $MmtCO_2e$ in 2010. This was an increase of approximately 362% overtime.

The increasing emissions of this class of GHGs in Delaware was driven primarily by increasing consumption of ODS substitutes such as HFCs and PFCs. However, SF_6 emissions from power transmission distribution in Delaware and actually declined by approximately 54% from 1990 to 2010, and is projected to continue to decline in the future. Projection analyses show that this class of GHGs is expected to add approximately 11 $MmtCO_2e$ to the atmosphere from 2011 to 2030. Emissions have been projected to increase from 0.41 $MmtCO_2e$ in 2011 to 0.73 $MmtCO_2e$ in 2030, a significant increase of approximately 78%.

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[17] Methane emission was excluded from the projection because it had a negative emissions estimate in 2030.

FIGURE ES-23. HFC, PFC AND SF_6 EMISSIONS FROM 1990 TO 2030.

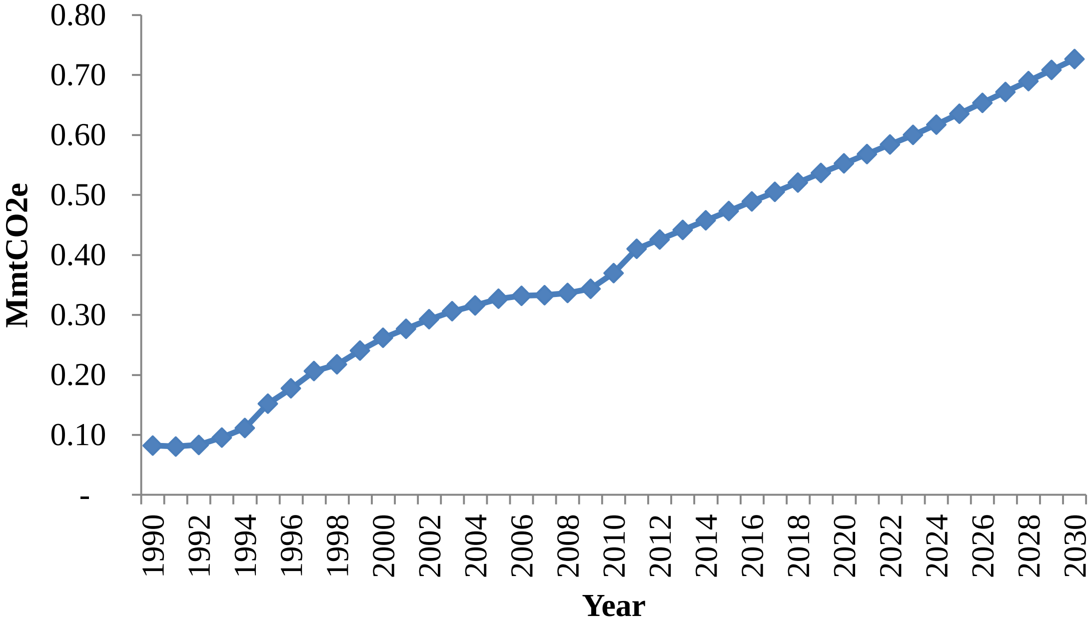

TABLE ES-2. GHG EMISSION ESTIMATES BY GAS ($MMTCO_2e$)

GHGs by Sources	1990	2000	2010	2020	2030
CO2	**17.90**	**16.85**	**12.36**	**13.40**	**13.77**
CO2 from Fossil Fuel Combustion	17.70	16.69	12.16	13.29	13.68
Industrial Processes	0.21	0.16	0.20	0.12	0.09
CH4	**0.69**	**0.56**	**0.27**	**(0.23)**	**(0.41)**
Stationary Combustion	0.02	0.02	0.01	0.01	0.01
Mobile Combustion	0.02	0.02	0.01	0.01	0.01
Natural Gas and Oil Systems	0.01	0.01	0.09	0.10	0.11
Enteric Fermentation	0.05	0.05	0.04	0.04	0.04
Manure Management	0.03	0.03	0.03	0.04	0.04
Burning of Agricultural Crop Waste	0.00	0.00	0.00	0.00	0.00
Waste	0.51	0.38	0.03	(0.49)	(0.69)
Wastewater	0.05	0.05	0.06	0.07	0.08
N2O	**0.80**	**0.86**	**0.60**	**0.61**	**0.60**
Stationary Combustion	0.04	0.04	0.02	0.02	0.02
Mobile Combustion	0.21	0.25	0.08	0.07	0.06
Manure Management	0.15	0.16	0.16	0.19	0.20
Agricultural Soil Management	0.37	0.38	0.30	0.30	0.28

TABLE ES-2. GHG EMISSION ESTIMATES BY GAS (MMTCO$_2$e)					
GHGs by Sources	**1990**	**2000**	**2010**	**2020**	**2030**
Burning of Agricultural Crop Waste	0.00	0.00	0.00	0.00	0.00
Wastewater	0.02	0.02	0.03	0.03	0.04
HFC, PFC, and SF6	**0.08**	**0.26**	**0.37**	**0.55**	**0.73**
Industrial Processes	0.08	0.26	0.37	0.55	0.73
Total GHG	**19.47**	**18.52**	**13.60**	**14.33**	**14.68**
Land Use/Forestry	**0.31**	**(1.12)**	**(1.12)**	**0**	**0**
Total GHG with Land Use	**19.78**	**17.40**	**12.48**	**14.82**	**15.37**

GHG EMISSIONS PER PERSON

Another way to analyze GHG emissions is to divide them by state population and examine them on a per capita basis. This will be useful in state to state comparison of GHG emissions. Many factors contribute to the amount of emissions per capita. According to the EPA[18], factors such as climate, the structure of the economy, population density, energy sources, building standards and explicit state policies to reduce emissions can impact GHG emissions. In 2010, Delaware was 39th in GHG emissions per capita in the United States. As Figure ES-24 presents, per capita GHG emissions decreased from 29.57mtCO$_2$e in 1990 to 13.89 mtCO$_2$e in 2010, a decrease of approximately 53%. Annual rate of decrease from 1990 to 2010 was determined by trend line analysis to be 0.75mtCO$_2$e. The significant decrease in per capita GHG emissions from 1990 to 2010 can be attributed to a number of factors including; the economic recession, which lead to a decline in the industrial sector emissions; energy efficiency in the power, commercial and residential sectors; and switching from a more carbon intensive fuel such as coal to a less carbon intensive fuel such as natural gas.

However, in spite of the decrease in historic GHG emissions, Delaware's population growth is expected to stabilize GHG emissions. Figure ES-24 shows that GHG emission per person is expected to be stable between 2011 and 2030. Delaware's per capita GHG emission is projected

---

[18] State-Level Energy-Related Carbon Dioxide Emissions, 2000-2010

to increase from 14.71 mtCO$_2$e in 2011 to 15.18 mtCO$_2$e in 2030, a slight increase of approximately 3%.

FIGURE ES-24. GHG EMISSIONS PER PERSON IN DELAWARE FROM 1990 TO 2030

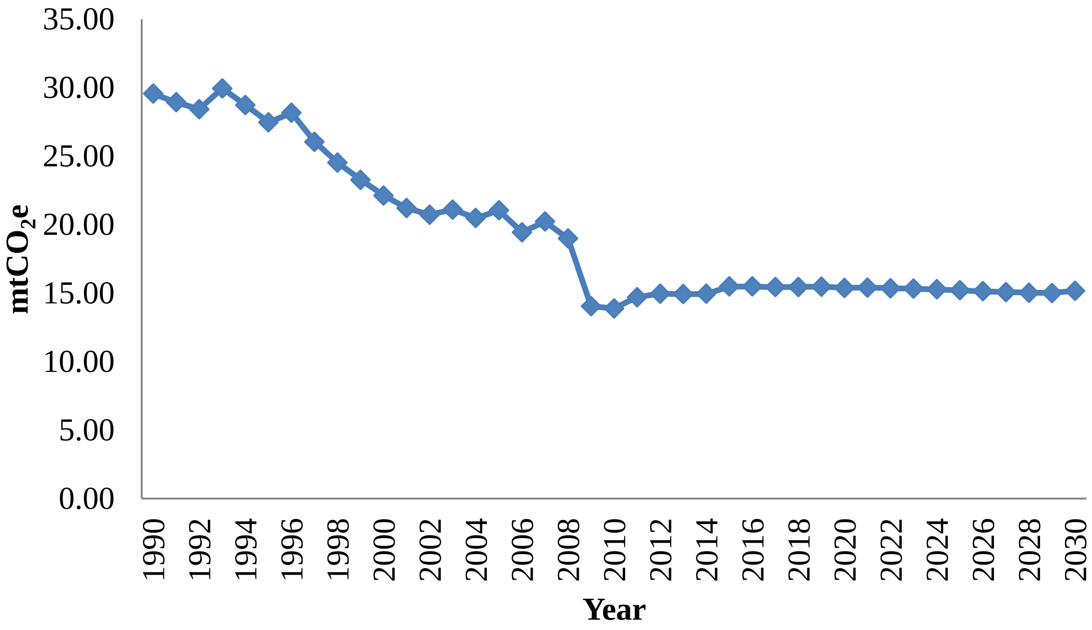

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TABLE OF CONTENTS

EXECUTIVE SUMMARY ____ I

ACRONYMS AND KEY TERMS ____ XXXV

INTRODUCTION AND BACKGROUND ____ 1

GREENHOUSE GASSES ____ 1

SOURCE OF GHGS ____ 3

GLOBAL WARMING POTENTIAL ____ 11

GENERAL METHODOLOGY ____ 12

STATE INVENTORY TOOL ____ 13

DATA COLLECTION APPROACH ____ 15

GENERAL PRINCIPLES AND GUIDELINES ____ 16

EMISSIONS INVENTORY OVERVIEW BY ECONOMIC SECTORS ____ 17

ELECTRIC POWER SECTOR ____ 17

GHG Emissions from Interstate Generation of Electricity ____ 18

GHG Emissions Associated with Electricity Consumption ____ 27

Emissions of SF_6 from Transmissions and Distribution of Electricity ____ 35

TRANSPORTATION ____ 39

CO_2 Emissions from the Transportation Sector ____ 42

N_2O nand CH_4 Emissiosn from the Transportation Sector ____ 43

Reference Projection of CO_2 Emissions from the Transportation Sector ____ 48

Projected CO2 Emissions from Transportation Sector ____ 50

Projected Mobile Source Emissions ____ 53

INDUSTRIAL SECTOR ____ 56

Energy Related Industrial Sector Emissions ____ 58

Non-Energy Related Industril Sector Emissions ____ 65

RESIDENTIAL SECTOR ____ 89

COMMERCIAL SECTOR ____ 98

AGRICULTURAL SECTOR ____ 104

Agricultural Soil Management ____ 109

Manure Management ____ 112

Enteric Fermentation ____ 115

Agricultural Residue Burning ____ 117

WASTE MANAGEMENT SECTOR ____ 120

Landfill Activities ____ 124

Waste Water Treatment ____ 140

LAND-USE, LAND-USE CHANGE AND FORESTRY ____ 149

EMISSIONS INVENTORY RESULTS BY GHG ____ 153

Carbondioxide Emissions ____ 156

Methane Emissions ____ 160

Nitrous Oxide Emissions ____ 163

Ozone Depleteing Substance Substitute *167*
Sulfur Hexaflouride Emissions *169*

SUMMARY OF FINDINGS **172**

REFERENCE **174**

LIST OF TABLES

Table ES-1. GHG Emissions Estimates by Sector xviii

Table ES-2. GHG Emissions Estimates by Gas xxiv

Table 1. GWP of GHGs calculated over a 100-yr period 12

Table 2. Modules and Sectors Included in the State Inventory Tool 13

Table 3. Summary of Inventory Data Sources 15

Table 4. Estimates of Emissions by Fuel Type 23

Table 5. Estimates of Indirect GHG Emissions by Fuel Type 27

Table 6. Estimates of Indirect GHG Emissions by Sector 31

Table 7. Projected Estimates of Indirect GHG Emissions by Sector 35

Table 8. Estimate of CO_2 Emissions from Transportation 38

Table 9. Estimates of N_2O and CH_4 Emissions by Vehicle Type 47

Table 10. Projected Estimates of N_2O and CH_4 Emissions by Vehicle Ttpe 55

Table 11. Estimates of GHG Emissions from Industrial 62

Table 12. CO_2 Emissions from TiO_2 Production 74

Table 13. Estimates of CO_2 from Iron and Steel production 85

Table 14. GHG Emissions from Residential Sector FFC 92

Table 15. GHG Emission from Residential Sector FFC 97

Table 16. GHG Emissions from Residential Sector FFC 101

Table 17. GHG Emissions from Agricultural Activities 107

Table 18. GHG Emissions from Waste management Sector 122

Table 19. CH_4 Emissions from Landfills 132

Table 20. Projected CH4 Emissions from Landfills 133

Table 21. CH_4 Emissions from Landfills 136

Table 22. Projected CH4 Recovered from Landfills 138

Table 23. CH_4 Oxidized at MSW and Industrial Landfills 140

Table 24. List of Municipal Wastewater Treatment Plants in Delaware 141

Table 25. Wastewater Emissions by Source 143

Table 26. Sink Estimates for Land Use, Land use Change and Forestry Sector 151

Table 27. Estimates of Emissions by GHG 154
Table 28. Projected Estimates of Emissions by GHG 156

LIST OF FIGURES

Figure ES-1. 2010 Delaware GHG Emission by Economic Sectors iii
Figure ES-2. Delaware's Gross GHG Emissions from 1990 to 2010 iii
Figure ES-3. Delaware's Net GHG Emissions from 1990 to 2010 vi
Figure ES-4. Delaware's GHG Emission by Economic Sector v
Figure ES-5. Delaware's 2030 GHGs Emissions by Economic Sector vi
Figure ES-6. Delaware's Projected Gross GHG Emissions from 2011 to 2030 vii
Figure ES-7. Delaware's Projected Net GHG Emissions from 2011 to 2030 vii
Figure ES-8. Delaware's Projected GHG Emissions by Sector viii
Figure ES-9. Electric Power Sector GHG Emissions from 1990 to 2030 ix
Figure ES-10. Transportation Sector GHG Emissions from 1990 to 2030 x
Figure ES-11. Industrial Sector GHG Emissions from 1990 to 2030 xi
Figure ES-12. Residential Sector GHG Emissions from 1990 to 2030 xii
Figure ES-13. Commercial Sector GHG Emissions from 1990 to 2030 xiii
Figure ES-14. Agricultural Sector GHG Emissions from 1990 to 2030 xiv
Figure ES-15. Waste Management Sector GHG Emissions from 1990 to 2030 xv
Figure ES-16. Land Use Sequestration xvi
Figure ES-17. Indirect GHG Emissions from 1990 to 2030 xvii
Figure ES-18. 2010 Delaware's GHG Emissions by Gas xix
Figure ES-19. 2030 Delaware's GHGs Emissions by Gas xix
Figure ES-20. CO_2 Emissions from 1990 to 2030 xxi
Figure ES-21. CH_4 Emissions from 1990 to 2030 xxii
Figure ES-22. N_2O Emissions from 1990 to 2030 xxii
Figure ES-23. HFC, PFC and SF_6 Emissions from 1990 to 2030 xxiv
Figure ES-24. GHG Emissions per Person in Delaware from 1990 to 2030 xxvi
Figure 1. Gross GHG Emissions from Electric Power Sector 20
Figure 2. 2010 GHG Emissions by Fuel Type 21
Figure 3. Fossil Fuel Consumption in 2010 21
Figure 4. GHG Emissions by Fuel Type 22
Figure 5. CO_2 Emissions from Power Sector FFC 23
Figure 6. N_2O and CH_4 Emissions from Power Sector FFC 24

Figure 7. GHG Emissions from In-State Power Generation from 2011 to 2013 ____________________ 25
Figure 8. GHG Emission by Fuel Type from Power Generation 2011 to 2030 ____________________ 26
Figure 9. 2030 Emissions by Fuel Type____________________26
Figure 10. Fuel Consumption by Fuel Type in the Electric Power Sector ____________________ 27
Figure 11. Indirect GHG Emissions by Sector____________________29
Figure 12. Indirect GHG Emission from Electricity Consumption____________________ 30
Figure 13. Indirect GHG Emissions by Sector ____________________31
Figure 14. Projected Indirect Emissions from 2011 to 2030____________________ 32
Figure 15. 2030 Indirect Emissions from Electricity Consumption____________________33
Figure 16. Projected Indirect GHG Emissions by Sector from 2011 to 2030____________________34
Figure 17. SF_6 Emissions from T&D ____________________37
Figure 18. Projected Emissions SF_6 Emissions____________________38
Figure 19. GHG Emissions from Transportation Sector____________________ 41
Figure 20. GHG Emissions from Transportation Sector ____________________ 41
Figure 21. Gross CO_2 Emissions from the Transportation Sector____________________ 43
Figure 22. N_2O and CH_4 Emissions from the Transportation Sector____________________45
Figure 23. Vehicle Miles Traveled from 1990 to 2010____________________46
Figure 24. N_2O and CH_4 Emissions by Vehicle Type____________________ 47
Figure 25. Projected GHG Emissions from Transportation ____________________49
Figure 26. 2030 Emissions from the Transportation Sector by GHG ____________________ 49
Figure 27. Projected CO_2 Emissions from Transportation____________________ 51
Figure 28. . Projected CO_2 Emissions by Fuel Type____________________51
Figure 29. Projected N_2O and CH_4 Emissions from the Transportation Sector____________________53
Figure 30. N_2O and CH_4 Emissions by Vehicle Type____________________54
Figure 31. Gross Industrial Sector Emissions from 1990 to 2010____________________57
Figure 32. Gross Industrial Sector Emissions from 2011 to 2030____________________58
Figure 33. Energy Related Industrial Sector Emissions____________________59
Figure 34. 2010 Energy Related Industrial Sector Emissions by Fuel____________________60
Figure 35. GHG Emissions from Industrial Sector FFC by Fuel Type____________________61
Figure 36. 2030 Energy Related Industrial Sector Emissions____________________ 63
Figure 37. Projected Energy Related Industrial Sector Emissions____________________64
Figure 38. Energy Related Industrial Sector Emissions by Fuel Type____________________64
Figure 39. Non-energy Related Industrial Sector Emissions____________________66
Figure 40. 2010 Industrial Process Emissions____________________67

Figure 41 CO_2e Emissions by Non-Energy Related Industrial Processes 67
Figure 42. Historical ODS Substitutes Emissions 70
Figure 43. Projected GHG Emissions from ODS substitutes 71
Figure 44. Historical Emissions from Titanium Production 78
Figure 45. Projected GHG Emissions fromTiO_2 Production 76
Figure 46. Methane Emissions from Natural Gas Transmissions and Oil Refining 77
Figure 47. Methane Emissions from Natural Gas T&D 79
Figure 48. Methane Emissions from Oil Refining and Transportation 82
Figure 49. Projected Methane Emissions from Oil Refining and Transportation 83
Figure 50. Historical CO_2 Emissions from Iron and Steel Production 85
Figure 51. CO_2 Emissions from Soda Ash Consumption 88
Figure 52. Projected CO_2 Emissions Soda Ash Consumption 89
Figure 53. Gross GHG Emissions from Fossil Fuel Combustion 90
Figure 54. Delaware's Average Maximum Temperature for January 91
Figure 55. GHG Emissions from Residential Sector by Fuel 92
Figure 56. Emissions from Commercial Sector by GHGs 93
Figure 57. Projected GHG Emissions from the Residential Sector 94
Figure 58. Projected GHG Emissions from the Residential Sector by Fuel 95
Figure 59. 2030 GHG Emissions from Residential Sector by Fuel 96
Figure 60. 2030 GHG Emissions from the Residential Sector by GHG 96
Figure 61. GHG Emissions from Commercial Sector 98
Figure 62. GHG Emissions from Commercial Sector by Fuel Type 62
Figure 63. 2010 GHG Emissions from Commercial Sector by Fuel Type 100
Figure 64. 2010 Emissions from Commercial Sector by GHG 101
Figure 65. Projected Gross GHG Emissions from Commercial Sector FFC 102
Figure 66. Projected Gross GHG Emissions from Commercial Sector by Fuel Type 103
Figure 67. GHG Emissions by Fuel from the Commercial Sector in 2030 104
Figure 68. GHG Emissions from Agriculture 105
Figure 69. Gross GHG Emissions from Agricultural Sector 106
Figure 70. GHG Emissions by Agricultural Activities 106
Figure 71. Projected Gross Emissions from the Agricultural Sector 108
Figure 72. 2030 Emissions by Agricultural Activities 109
Figure 73. Emissions by Agricultural Activities 109
Figure 74. N_2O Emissions from Agricultural Soil Management 111

Figure 75. Projected N_2O Emissions from Agricultural Soil management 112
Figure 76 GHG Emissions from Manure Management 113
Figure 77. Projected GHG Emissions from Manure Management 115
Figure 78 CH_4 Emissions from Enteric Fermentation 116
Figure 79. Projected GHG Emissions from Enteric Fermentation 117
Figure 80. Emissions from Agriculture Residue Burning 118
Figure 81. Projected Emissions from Agriculture Residue Burning 119
Figure 82. Net GHG Emissions from Waste Management 121
Figure 83. Historical GHG Emissions by Waste management Sources 121
Figure 84. Projected Emissions from Waste management 122
Figure 85. Projected Emissions by Waste management and MSW 123
Figure 86. Net GHG Emissions from Landfill Activities 125
Figure 87. Projected Net CH_4 Emissions from Landfills 126
Figure 88 Gross CH_4 Emission from Landfill Activities 128
Figure 89. Gross CH_6 Emissions from MSW and Industrial Landfills 129
Figure 90. Gross CH_4 Emissions from MSW Landfills 130
Figure 91. Gross CH_4 Emissions from Industrial Landfills 132
Figure 92. Projected CH_4 Emissions by Landfill Type 133
Figure 93. Amount of CH_4 Emissions Recovered 134
Figure 94. Methane Recovered by LFGTE 135
Figure 95. Methane Recovered by Flaring 136
Figure 96. Methane Recovery from Delaware Landfills 137
Figure 97. Projected Methane Recovery from Flaring and LFGTE 138
Figure 98. Methane Oxidized at Landfill Facilities 139
Figure 99. Gross GHG Emission from Wastewater Treatment 142
Figure 100. GHG Emission from Wastewater Treatment Subcategories 142
Figure 101. GHG Emissions by Municipal Wastewater Treatment 145
Figure 102. CH_4 Emissions from Industrial Wastewater Treatment 146
Figure 103. Delaware's Population Growth from 1990 to 2010 147
Figure 104. Projected Gross GHG Emissions from Wastewater Treatment 148
Figure 106. Historical Land use CO_2 Sequestration t 151
Figure 107. 2010 Emissions by GHG 153
Figure 108. Emissions by Gas 155
Figure 109. 2010 Gross CO_2 Emissions from FFC by Economic Sector 157

Figure 110. Historical CO_2 Emissions 158
Figure 111. Projected CO_2 Emissions 159
Figure 112. 2030 CO_2 Emissions by Sector 159
Figure 113. 2010 Gross CH_4 Emissions by Source Category 161
Figure 114. Net Historical CH_4 Emissions 161
Figure 115. Projected Gross CH_4 Emissions from Delaware 162
Figure 116. 2030 CH_4 Emissions by Sources 163
Figure 117. 2010 N_2O Emissions by Sources 164
Figure 118. Delaware's N2O Emissions from 1990 to 2010 165
Figure 119. 2030 N_2O Emissions by Sources 166
Figure 120. Delaware's N2O Emissions from 2011 to 2030 166
Figure 121. Delaware's ODS Substitute Emissions 168
Figure 122. Projected Emissions of ODS Substitute 169
Figure 123. Delaware's SF_6 Emissions 170
Figure 124. Projected SF_6 Emissions 171

LIST OF EQUATIONS

Equation 1. General Emission Equation for the Electric Power Sector 19
Equation 2. Estimating Indirect Emissions from Electricity Consumption 28
Equation 3. Estimating SF6 Emissions from Transmissions and Distribution 36
Equation 4. GHG Emissions from the Transportation Sector 42
Equation 5. Energy Related Industrial Sector Emissions 62
Equation 6. Emissions Equation for ODS Substitutes 69
Equation 7. General Emission Equation for ODS 72
Equation 8. CO_2 Emissions Equation for Titanium Dioxide 73
Equation 9. Equation for Natural Gas Transmissions 79
Equation 10. Emissions Equation for Petroleum Systems 81
Equation 11. General Equation for Estimating CO2 from Steel Production 84
Equation 12. General Equation for CO2 Emissions from Soda Ash Consumption 87
Equation 13. Methane Emissions Equation for Solid Waste 126
Equation 14. First Order Decay of Waste to Generate CH4 127
Equation 15 CH_4 Emissions Equation for Municipal Wastewater Treatment 144
Equation 16. N_2O Emissions Equation for Municipal Wastewater Treatment 144
Equation 17 CH_4 Emissions Equation for Industrial Wastewater Treatment 145

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 – Liquified 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

1.0 INTRODUCTION AND BACKGROUND

Delaware’s 2010 greenhouse gas emissions inventory accounted for the annual amount of anthropogenic[19] greenhouse gases (GHG) emitted to or removed from the atmosphere between 1990 and 2010. The inventory also estimated projected emissions over a 20 year period from 2011 to 2030. The Division of Air Quality (DAQ) has prepared this GHG inventory report to characterize Delaware’s historical as well as projected 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 2010 GHG emissions inventory had four key objectives:

- Identify and Characterize GHG emissions sources and sinks
- Quantify GHG emissions and removal from sources and sinks
- Document the emission inventory data and analytical results, and
- Document the GHG inventory data sources.

1.1 GREENHOUSE GASES

This 2010 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."[20] The six GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), 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

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[19] 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.

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

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.

1.2 SOURCE OF GHGS

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[21]) and decomposition of organic materials. Anthropogenic sources, on the other hand, include human activities such as fossil fuel combustion, chemical processes and agricultural activities. The U.S. EPA categorizes GHG sources[22] into five source categories based on the methods of estimating the GHG emissions from the sources. Based on the U.S. EPA's Emissions Inventory Improvement Program (EIIP), the following source categories were described in this report:

- Energy Related Activities,
- Non-energy related Industrial processes ,
- Agriculture Activities
- Waste management.
- Land Use, Land Use Change and Forestry

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

[22] USEPA / NACAA EIIP Guidelines (Vol. I – XIV) for the State Inventory Tool

Energy Related Activities

Energy-related activities are the most significant contributor to Delaware's greenhouse gas emissions, accounting for approximately 92 percent of total emissions in 2010. Emissions from fossil fuel combustion comprise the vast majority of these energy-related emissions.

CO_2 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 the purpose of this greenhouse gas inventory, 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.[23] By reporting emissions in this fashion, the inventory emission estimates of CO_2 will reflect total loadings of carbon to the atmosphere.

N_2O and CH_4 Stationary Fossil Fuel Combustion Sources[24]. In addition to carbon dioxide, combustion of fuels at stationary sources results in the emission of methane (CH_4) and nitrous oxide (N_2O). Stationary combustion sources of CO_2 and N_2O 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. In this report, N_2O and CH_4 emissions from stationary fuel combustion was

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

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

separated from CO_2 emissions from stationary fossil fuel combustion because the methodology for calculating both types of emissions are different.

N_2O and CH_4 Mobile Fossil Fuel Combustion Sources[25]. Although there is virtually no methane (CH_4) in either gasoline or diesel fuel, CH_4 is emitted as a by-product of fuel combustion. Methane emission 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 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 2010 GHG inventory report characterizes emissions associated with energy related activities according to Delaware's economic sectors as described in section 4.0. The economic sectors include electric power, transportation, industrial, residential, commercial, agricultural and waste management.

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

Non-energy Related Industrial Processes

Greenhouse gas emissions from the non-energy related industrial processes accounted nearly three percent of total GHG emissions in 2010. Emissions are often produced as a by-product of various non-energy related industrial activities. 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 2010 GHG inventory report characterizes emissions associated with non-energy related industrial processes under the industrial sector as described in section 4.3.

Agricultural Activities

Greenhouse gas emissions from the agricultural activities accounted for nearly four percent of total GHG emissions in 2010. Emissions from this category came from the following sources:

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.[26] A number of anthropogenic activities add nitrogen to soils, thereby

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[26] 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.

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[27] (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.

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. 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.

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-

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

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[28] 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.

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

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[28] 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.

season. Crops that are grown in Delaware and may undergo agricultural residue burning include corn, barley and soy beans.

The 2010 GHG inventory report characterizes emissions associated with agricultural activities under the agricultural sector as described in section 4.6.

Waste Management

Greenhouse gas emissions from the waste management category accounted for nearly one percent of total emissions in 2010. Emissions from this category came from the following sources:

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.

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 2010 GHG inventory report characterizes emissions associated with waste management under the waste management sector as described in section 4.7.

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 2010 GHG inventory report characterizes emissions associated with land use under the Land Use, Land Use Change and Forestry sector as described in section 4.8.

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[29]. 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)

3.0 GENERAL METHODOLOGY

The methodologies used in the development of this 2010 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 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

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

development of this 2010 GHG inventory was collected via the EPA's State Inventory Tool (SIT) Model.

3.1 State Inventory Tool

The 2010 State Inventory Tool (SIT) Model is a collection of Excel® spreadsheets designed by the U.S.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 Program of The EPA, Volume III on emission estimation methods[30].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

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

TABLE 2. MODULES AND SECTORS INCLUDED IN THE STATE INVENTORY TOOL		
Modules	**Sub-Sectors**	
Mobile Combustion (CH4 & 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 & Distribution • Magnesium Production and Processing
Coal (CH_4)	• Coal Mining	• Abandoned Underground Coal Mines
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 2010 GHG emissions inventory was based on the IPCC guidelines[31] and combines both top-down and bottom-up approaches (hybrid approach)[32].

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 2010 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	Where not indicated otherwise, SIT default data is used to calculate emissions from Delaware sources.

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

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

TABLE 3. SUMMARY OF INVENTORY DATA SOURCES

Sources	Information provided	Use of Information in this Analysis
	contains default data for each State for most of the information 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 2010.	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 – 2010.	EIA State Electricity Profiles were used to determine the mix of in-state electricity generation by fuel.
USDA 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 2010 GHG emissions inventory was performed according to the following generally accepted GHG emissions accounting principles[33] 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 2010 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 2010 GHG emissions

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[33] 2006 IPCC Guidelines for National Greenhouse Inventories

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.

4.0 EMISSIONS INVENTORY OVERVIEW BY ECONOMIC SECTOR

4.1 ELECTRIC POWER SECTOR

The electric power sector is categorized as one of the big three[34] sources of GHG emissions in Delaware. In 2010, the electric power sector of Delaware represented approximately 31% gross GHG emission in Delaware. Greenhouse gas emissions associated with Delaware's electricity sector was characterized into two types of emissions namely direct and indirect GHG emissions. Direct GHG emissions come from in-state generation of electricity as a result of fossils fuel combustion and transmissions and distribution (T&D) of electricity. The sources of this type of emissions are owned and controlled within the Delaware's borders.

This inventory report categorizes direct emissions under *GHG emissions associated with in-state generation of electricity* as described in section 4.1.1. And GHG emissions associated with T&D, which is a minor source of GHG (specifically sulfur hexafluoride emissions), is categorized under *Emission of* SF_6 *from T&D* as described in section 4.1.3. Indirect GHG emissions are emissions associated with the consumption of purchased electricity in

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[34] The big three sources of GHG emissions in Delaware are economic sectors including electric power, transportation and industrial sectors.

Delaware and not generation by fossils fuel combustion. The sources of indirect GHG emissions go beyond Delaware's borders. This inventory report categorizes indirect emissions under *GHG Emissions associated with electricity consumption* as described in section 4.1.2.

There is an overlap between direct and indirect GHG emission associated with Delaware's electric power sector because indirect emissions accounts for both instate and out of state generation, and adding both emissions estimates can lead to double counting[35]. To avoid double counting, this report separates indirect emissions from gross emissions from all other sources.

4.1.1 GHG Emissions associated with In-state Generation of Electricity

Greenhouse gases are emitted when electric generators are fired using fossil fuels such as coal, natural gas or petroleum. Delaware's electricity output has relatively small compared to other states in the U.S. According to the U.S. EIA, Delaware ranked 50th in net electricity generation in 2013 with an output of 509,000 MWh. In-state electric power generations has generally been the largest source of Gross GHG emissions in Delaware. The electric power generation emitted approximately 126.00 $MmtCO_2e$ into the atmosphere between 1990 and 2010. However in 2010, GHG emissions from the transportation sector exceeded GHG emissions from the electric power sector. Electric power generation contributed 4.19 $MmtCO_2e$ into the atmosphere, while the transportation sector contributed 4.64 $MmtCO_2e$. Emissions from electric power generation represented approximately 31% of Delaware's total GHG emissions in 2010.

Methodology

GHG emissions from in-state electric power generation were estimated using the U.S. EPA SIT. The SIT was populated with fossils fuel consumption data collected from the U.S Energy Information Administration (EIA). The general formula used to estimate the emissions is as follows:

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

EQUATION 1. GENERAL EMISSION EQUATION FOR ELECTRIC POWER SECTOR

$$\text{Emissions} \quad = \quad \Sigma\ (\text{Activity data x Emission factor})$$

Activity data[36] required in this case was the quantity of fossil fuel consumed for in-state generation of electricity. The EIA publishes emission factors for three major GHGs including Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_20), which are released when fuels are burned to generate electricity.

In-State Electric Power Generation Emissions

Figure 1 shows the GHG emissions from the electric power generation from 1990 to 2010. GHG emissions dropped from 7.52 $MmtCO_2e$ in 1990 to 4.19 $MmtCO_2e$ in in 2010, a decrease of approximately 44%. In spite of the increase of GHG emissions from 2002 to 2008 as observed in Figure 1, the general trend of emissions has been downward with an average decrease of 0.12 $MtCO_2e$ per year.

Figure 1 also shows that from 1990 to 2002, GHG emissions decreased from 7.52 $MmtCO_2e$ to 5.07 $MmtCO_2e$. This decrease in emissions can be partly attributed to a decline in overall electricity demand during that period. The decline in GHG emissions from electricity generation as represented in Figure 1 is the result of a decrease in electricity consumption particularly in the industrial sector due to Delaware's shrinking industrial base during that period. Closures of facilities such as General Motors, and decline in manufacturing with high electricity demand lead to reduction in the annual electricity consumption and subsequently GHG emissions from Delaware's power sector. In addition to the recession, fuel switching (coal to natural gas) and energy efficiency initiatives in Delaware's power sector such as the installation of combined cycle units contributed to the decline in GHG emissions.

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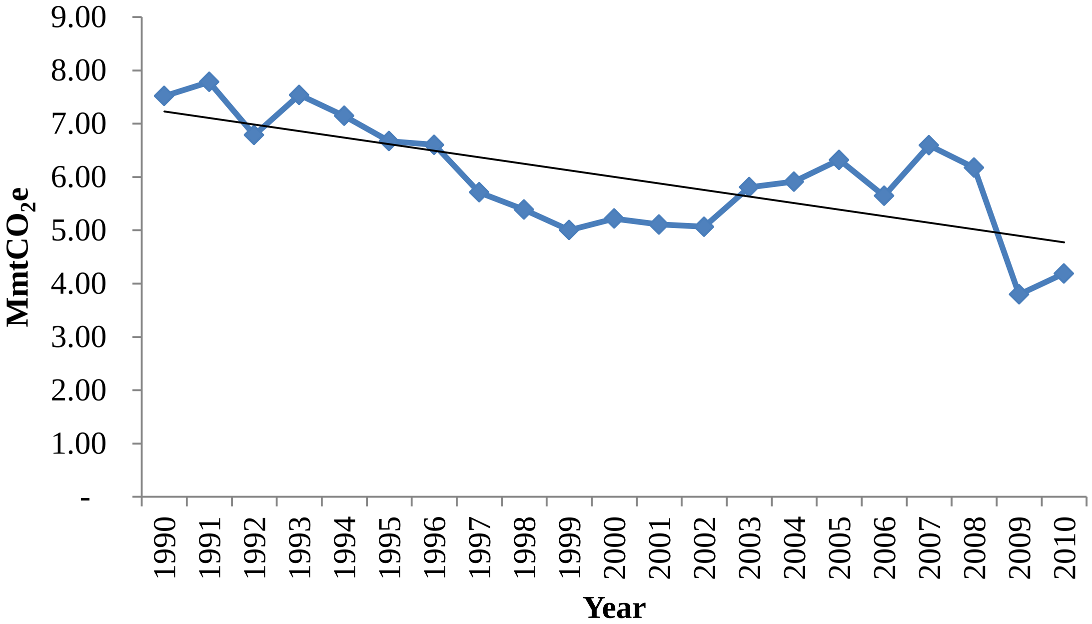
[36] Data source: Default state-level data derived from EIA's *State Energy Consumption, Price, and Expenditure Estimates (SEDS) 2010: Consumption Estimates* (EIA 2012). http://www.eia.gov/state/seds/sed-data-fuel-prev,cfm. Default state synthetic natural gas data obtained from Table 12 of EIA's *Historical Natural Gas Annual* (EIA 2012), and Table 8 for Natural Gas Annual publications from: 2001-2010 http://www.eia.doe.gov/oil_gas/natural_gas/data_publications/natural_gas_annual/nga.html

FIGURE 1. GROSS GHG EMISSION FROM ELECTRIC POWER GENERATION



GHG Emissions by Fuel Type

Delaware's electric power sector GHG emissions are driven primarily by the combustion of fossil fuels such as coal, natural gas and petroleum. Coal is generally more carbon intensive than natural gas or petroleum. Figure 2 presents the percentage of emissions by fuel type in 2010.

Coal combustion for in-state generation of electricity contributed 2.82 MmtCO$_2$e in to the atmosphere in 2010. This represented 67% the GHG emissions from this sector. Natural gas combustion contributed 1.32 MmtCO$_2$e to the atmosphere, which represented approximately 32% of GHG emissions from the power sector Natural gas emissions from the power sector. However, the combustion of petroleum to generate electric only contributed of 0.05 MmtCO$_2$e in 2010. This represented approximately 1% of gross GHG emissions from the electric power sector.

FIGURE 2. 2010 GHG EMISSIONS BY FUEL TYPE

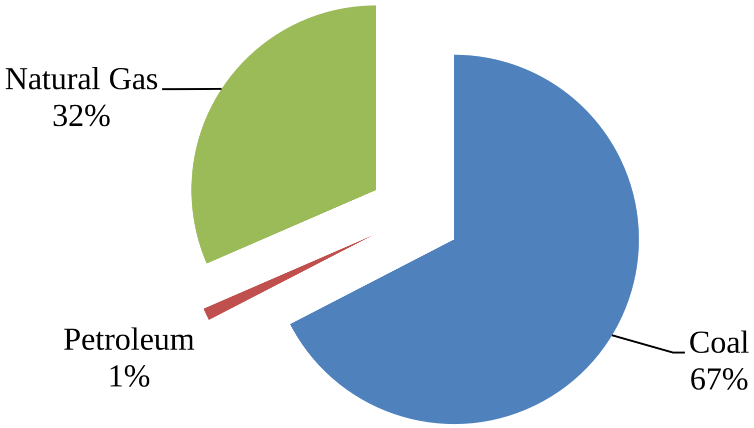


FIGURE 3. FOSSIL FUEL CONSUMPTION IN 2010

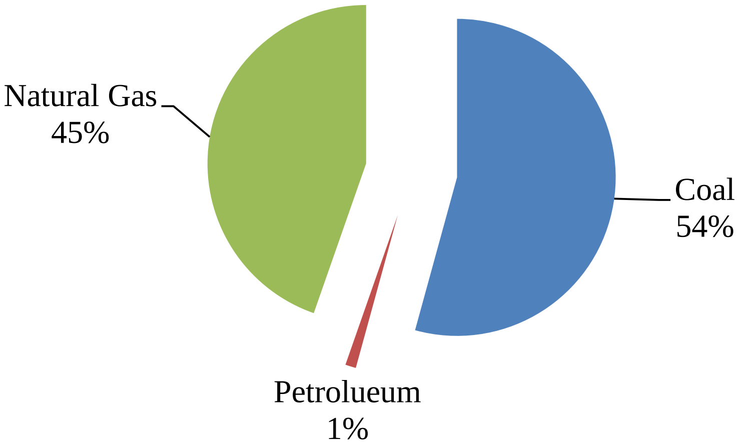
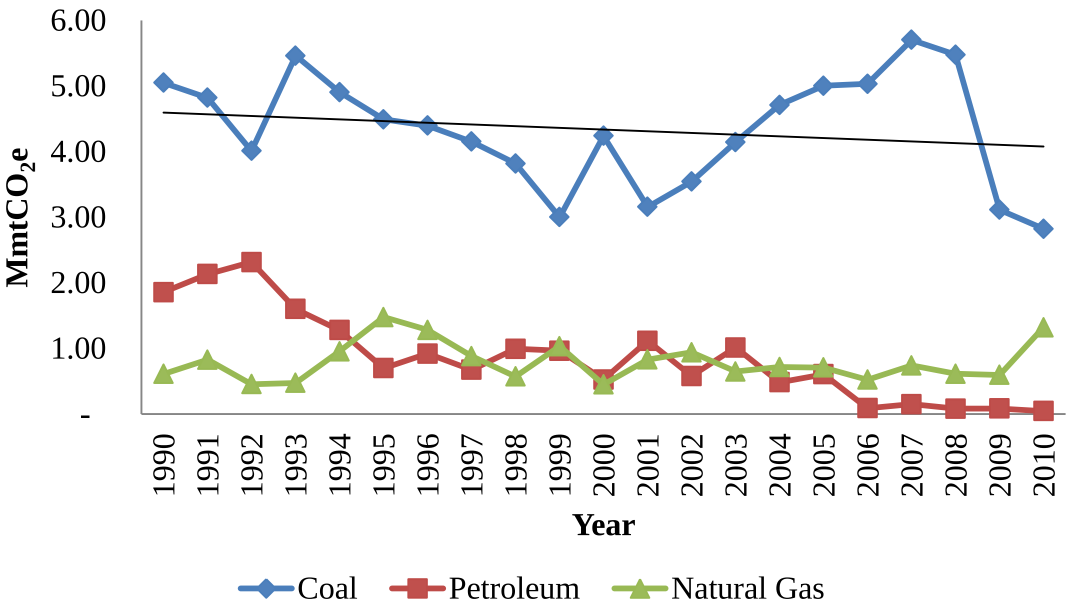


Figure 3 presents fossil fuel consumption for in-state generation of electricity by fuel type. Compared to the other two fuel types, coal is very carbon intensive. Although coal-fired power generation accounted for approximately 67% of GHG emissions from the electric power sector in 2010, it represents approximately 54% of fossil fuels consumed as Figure 3 present. Conversely, emissions from natural gas consumption was approximately 32% of GHG emissions from in-state generation of electricity, whereas natural gas represented 45% fuels consumed in Delaware for in-state generation of electricity. Coal-fired emissions are higher than natural gas fired generation because the carbon content of natural gas is approximately 55%[37]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). Figure 2 shows that petroleum consumption in the electric power sector was approximately 1%, which is consistent with its percent GHG emissions as presented in Figure 3.

Figure 4 shows that emissions from coal fired electricity exceeded all other sources of emission between1990 and 2010. Emissions had a steep decline in the 1990s but rebounded in the 2000s with a sharp drop from 5.48 $MmtCO_2e$ in 2008 to 2.82 $MmtCO_2e$ in 2010. Table 4 provides emission estimates by fuel type.

FIGURE 4. GHG EMISSIONS BY FUEL TYPE



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

TABLE 4. ESTIMATES OF EMISSIONS BY FUEL TYPE					
$MmtCO_2e$	**1990**	**1995**	**2000**	**2005**	**2010**
Coal	5.05	4.49	4.24	5.01	2.82
Natural Gas	0.61	1.48	0.45	0.71	1.32
Petroleum	1.86	0.70	0.53	0.61	0.05
TOTAL	7.52	6.67	5.22	6.32	4.19

Types of GHGs from In-State Power Generation

Carbon dioxide (CO_2) emission represents the largest emission of greenhouse gas from in-state generation of electricity. In 2010, CO_2 emissions from the power sector represented approximately 99% of all GHG emissions from the power sector with 4.17 $MmtCO_2e$. Figure 5 presents CO_2 emissions from in-state power generation. Historically, CO_2 emissions from the in-state generation of electricity have been decreasing since 1990. Trendline analysis shows that CO_2 emissions decreased at the rate of 0.122 $MmtCO_2e$ per year between 1990 and 2010.

Methane (CH_4) and nitrous oxide (N_2O) emissions both represented approximately less than 0.5% of GHG emissions from the in-state generation.

FIGURE 5. CO_2 EMISSIONS FROM POWER SECTOR FFC

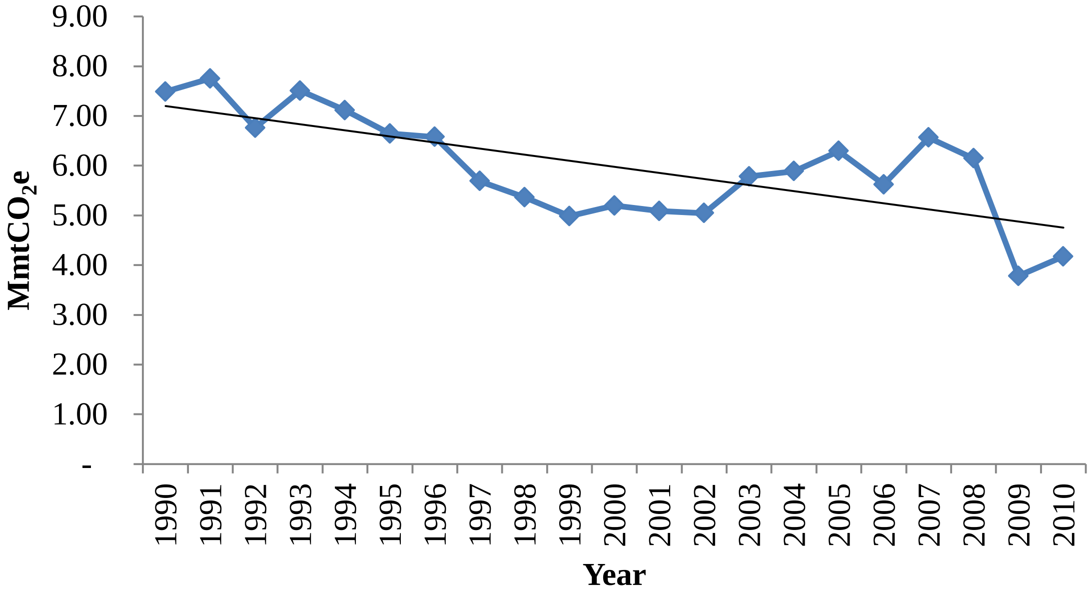
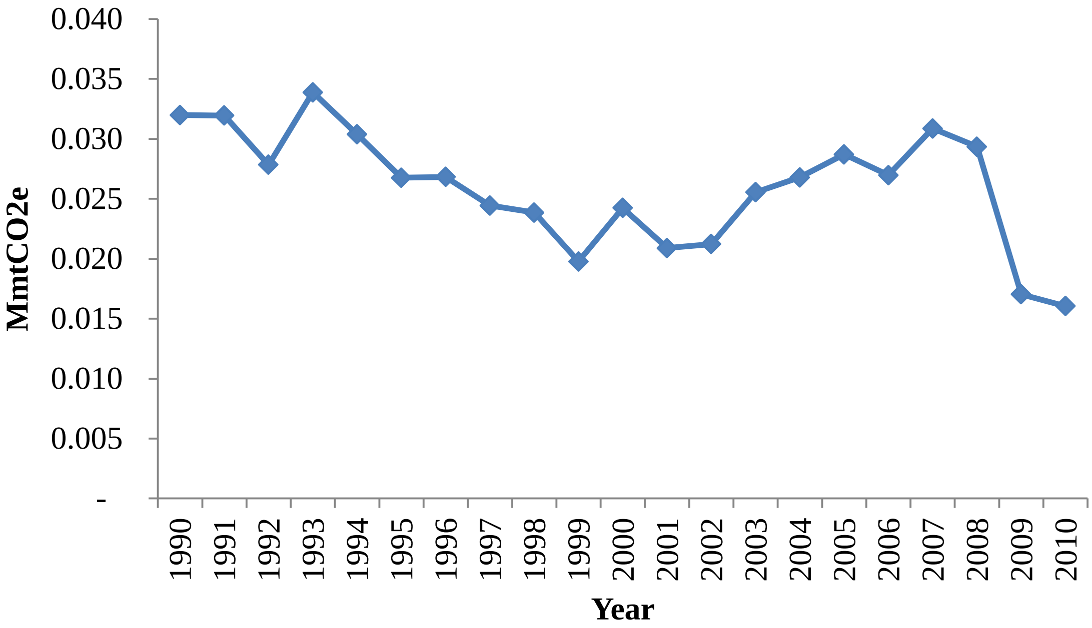


FIGURE 6. N_2O AND CH_4 EMISSIONS FROM POWER SECTOR FFC



Reference case Projections - GHG Emission from In-State Power Generation

Projections of GHG emissions from in-state electric power generation were estimated using U.S. EPA's projection tool. Energy consumption data based on U.S. EIA energy outlook was multiplied by fuel-specific carbon coefficient and combustion efficiency. The annual variable carbon coefficient and combustion efficiencies were based U.S. EIA data. The results of the projected emissions were categorized into fuel types including coal, natural gas and petroleum.

Figure 7 presents the projected annual emissions from in-state electric power generation from 2011 to 2030. Based on the EPA's emission data, gross GHG emissions from power generation in Delaware are projected to increase at a rate of 0.055MmtCO_2e per year form 3.03 MmtCO_2e in 2011 to 4.00 MmtCO_2e in 2030.This is an increase of approximately 32%. Figure 8 presents reference case projected emissions from 2011 to 2030 by fuel type.

Based on EIA projections, emissions from coal fired power generation is expected to continue to exceed emissions from both natural gas and petroleum fired power generation. Emissions from coal-fired power generation in Delaware are projected to increase steadily at a rate of 0.051 $MmtCO_2e$ per year from 2.14 $MmtCO_2e$ in 2011 to 3.07 $MmtCO_2e$ in 2030 as Figure 8 presents. GHG emissions from natural gas and petroleum fired power generation are projected to hold steady at averages of 0.84 $MmtCO_2e$ and 0.04 $MmtCO_2e$ respectively.

Figure 9 presents the reference case projection of GHG emissions by fuel type in 2030. The GHG emission from coal-fired power generation in Delaware is projected to increase from approximately 67% in 2010 as presented by Figure 2 to approximately 77% in 2030 as presented by Figure 9. Conversely, GHG emission from natural gas fired power generation will decrease from approximately 32% in 2010 as presented in Figure 2 to approximately 22% in 2030 as presented by Figure 9. GHG emissions from Petroleum-fired power generation are projected to remain the same.

FIGURE 7. GHG EMISSIONS FROM IN-STATE POWER GENERATION FROM 2011 TO 2013

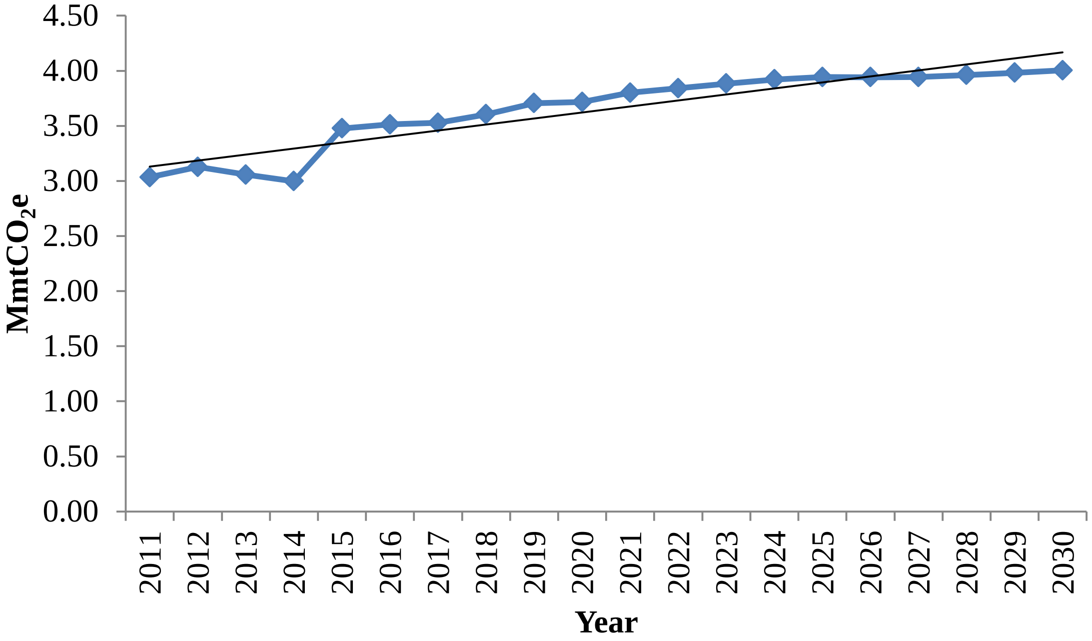


FIGURE 8. GHG EMISSIONS BY FUEL TYPE FROM POWER GENERATION 2011 TO 2030

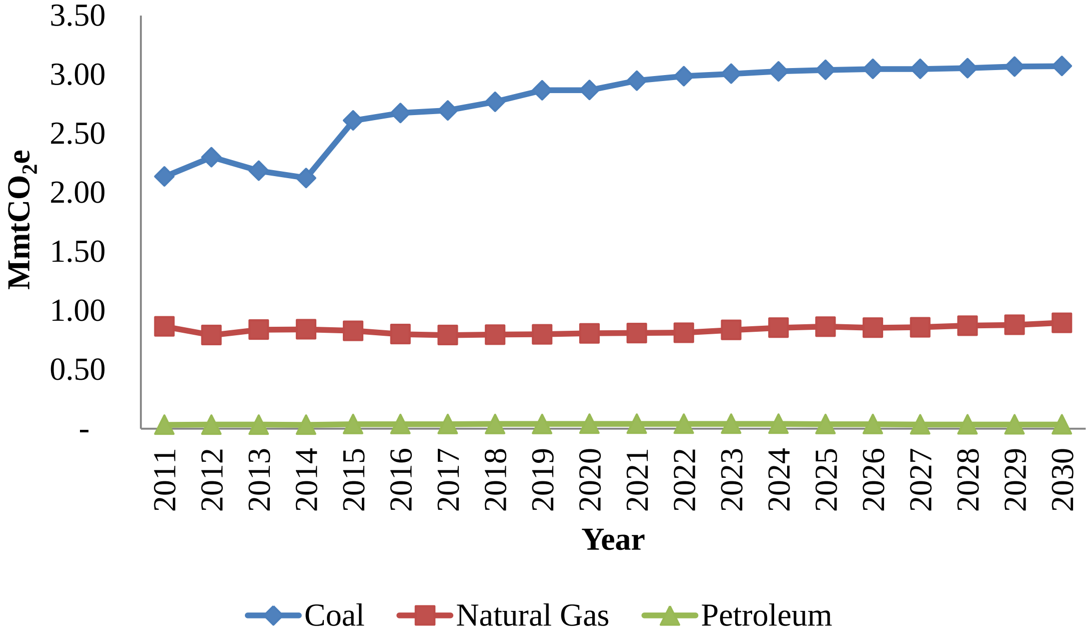
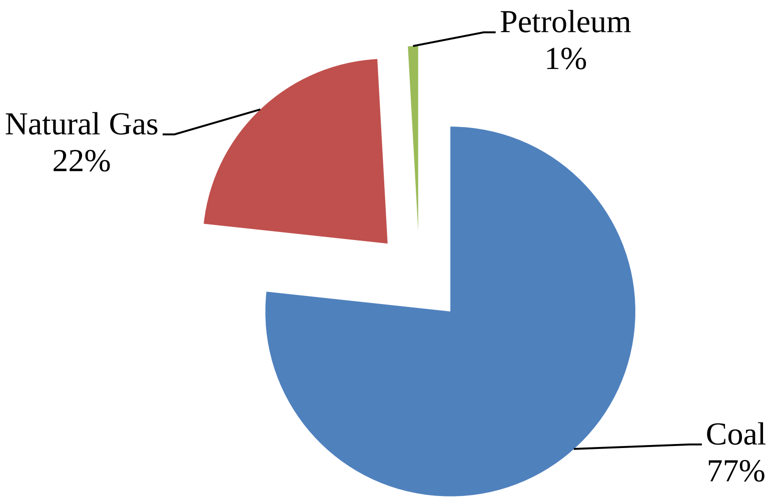


FIGURE 9. 2030 EMISSIONS BY FUEL TYPE

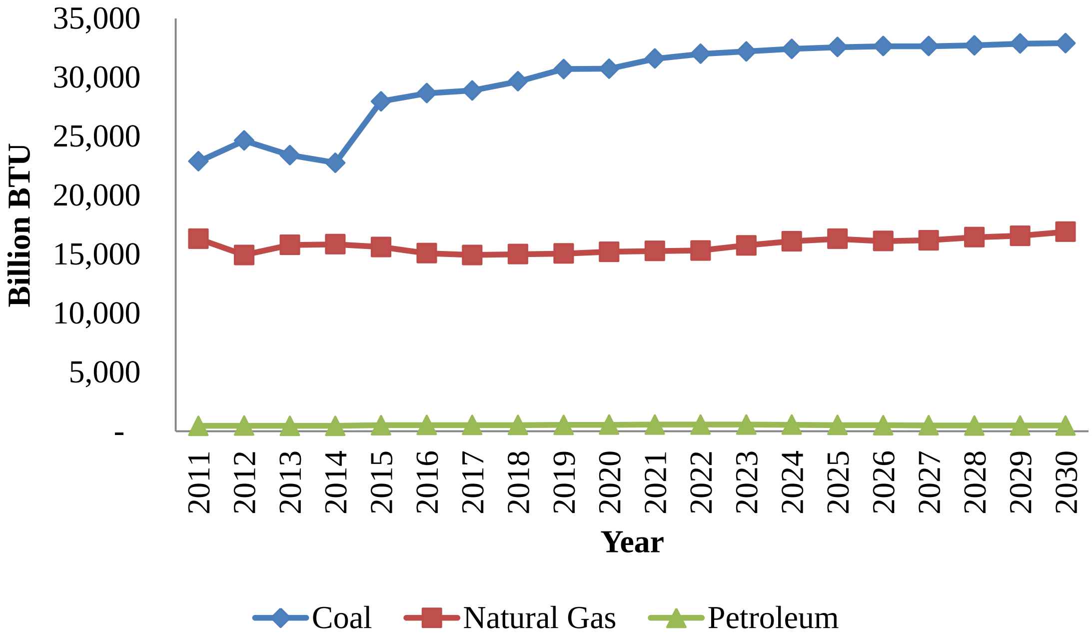


The projected significant increase in GHG emissions from coal-fired generation is the result of a projected increase in coal consumption in the power sector of Delaware. Figure 10 presents projected data on the consumption of fossil fuels in the electric power sector. Natural gas and petroleum consumption will remain flat as presented in Figure 10. The reference case projection of fossil fuel consumption in Delaware suggests that substituting coal-fired units with natural gas fired units will reduce GHG emissions from the Delaware's power sector. Table 5 provides GHG emissions data on projected emissions from 2011 to 2030.

TABLE 5. ESTIMATES OF INDIRECT GHG EMISSIONS BY FUEL TYPE

MmtCO$_2$e	**2011**	**2015**	**2020**	**2025**	**2030**
Coal	2.14	2.61	2.87	3.04	3.07
Natural Gas	0.87	0.83	0.81	0.86	0.90
Petroleum	0.03	0.04	0.04	0.04	0.04
TOTAL	**3.03**	**3.48**	**3.72**	**3.94**	**4.00**

FIGURE 10. CONSUMPTION BY FUEL TYPE IN THE ELECTRIC POWER SECTOR



4.1.2 *GHG Emissions Associated with Electricity Consumption*

The purpose of this section is to characterize GHG emissions associated with electricity consumption in Delaware also known as indirect GHG emissions[38]. Indirect GHG

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[38] This report quantifies CO$_2$e only, because it is difficult to separate emissions associated with electricity consumption by individual GHGs that are normally associated electricity generation such as CO2, CH4 and N2O.

emissions are estimated based on the amount of kilowatt-hour (kWh) consumed by electricity end-users. The electricity consumed by end-users includes in-state generated electricity as well as imported electricity. According to the EIA, Delaware generates less than one-half of the electricity sold to customers. Although generation is increasing, the state remains a net recipient of electricity. Less than one-third of Delaware households use electricity as their primary source for home heat.

Estimates of indirect GHG emissions do not include direct[39] emissions associated with in-state electric power generation. Indirect emissions estimates were included in the 2010 GHG inventory to show how electricity demand and consumption patterns of Delawareans impacts GHG emissions. Because there is an overlap between indirect and direct GHG emissions, indirect GHG emissions were separated from Direct GHG emissions in the 2010 GHG inventory to avoid double counting.

Methodology

The Electricity Consumption module of the SIT was used to estimate indirect GHG emissions. Indirect GHG emissions from electricity consumption were categorized into the three main end-use sectors including industrial, residential, and commercial. Electricity is consumed in these sectors primarily for lighting, heating, operating appliances, electronics, heating and air conditioning. The electricity consumption module calculates CO_2 equivalent emissions for each of these sectors by multiplying the 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 GHG emissions from electricity consumption is shown in Equation 2.

EQUATION 2. ESTIMATING INDIRECT EMISSIONS FROM ELECTRICITY CONSUMPTION

$$\textit{Indirect Electricity Emissions} = \textit{Total Consumption in Sector (kWh)} \times \textit{End-Use Equipment Consumption (\%)} \times [\textit{Emission Factor (lbs } CO_2e\textit{/kWh)} \times (1+\textit{Transmission Loss Factor (\%)})]$$

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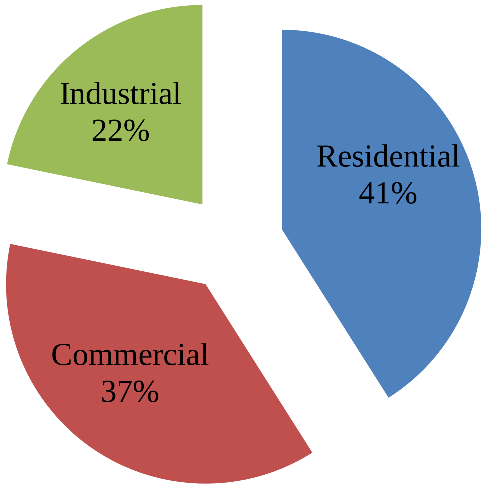
[39] Direct emissions estimate were addressed under in-state generation.

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 (6.41%) to estmate indirect GHG emissions. Indirect emissions from electricity consumption in the sectors were calculated by multiplying state energy consumption (total kWh consumed in the sector) by the percentage of sector end-use consumption. The resulting consumption values (kWh) are multiplied by a state-specific emission factor (lbs CO_2e/kWh) and transmission line losses (1+Tranmissions loss factor). The resulting emissions values, in pounds of carbon, are converted to short tons of carbon, million metric tons of carbon equivalent (MmtCe), and then to million metric tons of carbon dioxide equivalent ($MmtCO_2e$).

Indirect GHG Emissions from 1990 to 2010

The primary sources of indirect GHG emissions in Delaware include residential, commercial and industrial. Indirect GHG emissions from the residential sector were the largest representing approximately 41% of total indirect emissions in Delaware. This was followed by the commercial sector, which represented approximately 37% of gross indirect emissions. Indirect emissions from the industrial sector represented lowest emission of the sources with approximately 22% as presented in Figure 11.

FIGURE 11. INDIRECT GHG EMISSIONS BY SECTOR



From 1990 to 2010, indirect GHG emissions increased by 36 %. This increase can be attributed to increasing demand for electricity in the economic sectors due to steady growth in Delaware's population, which increased by approximately 34% between 1990 and 2010. Indirect emissions from the consumption of electricity in Delaware generated a total of 118 $MmtCO_2e$ in emissions from 1990 to 2010. As Figure 12 presents, indirect emissions in Delaware peaked in 2003 at 6.70 $MmtCO_2e$ and decreased to 6.00 MmtCO2e in 2010. Indirect emissions increased at an annual rate of 0.95 $MmtCO_2e$ per year.

FIGURE 12. INDIRECT GHG EMISSIONS FROM ELECTRICITY CONSUMPTION

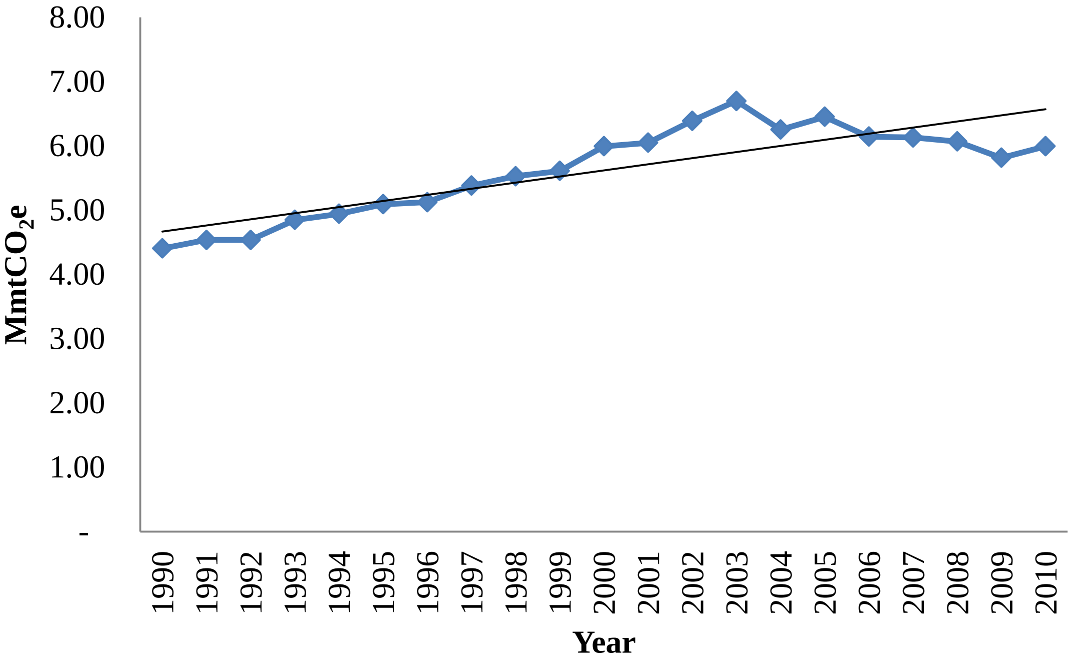


Table 6 provides a summary of indirect emissions from electricity consumption by Delaware's economic sector. The table shows that generally, indirect emissions from all sectors trended upwards. However, indirect emissions from the industrial sector peaked in 2003 at 2.40 $MmtCO_2e$ and decreased significantly to 1.30 $MmtCO_2e$ in 2010, a decrease of 46 %.

The decrease in industrial indirect GHG emissions can be partly attributed to a decline in the industrial sector due to the economy. The closure of facilities such as General Motors and Chrysler, and decline in other industries, which have higher demand for electricity contributed to the decrease in electricity consumption in the industrial sector, leading to a decline indirect GHG emissions from 2003 to 2010. Figure 13 presents indirect GHG emissions from electricity consumption. Indirect emissions from residential increased from 1.41MmtCO$_2$e in 1990 to 2.46 MmtCO$_2$e in 2010 as presented in Figure 13. This was an increase of approximately 74 %. While indirect emission from the commercial sector increased from 1.26 MmtCO$_2$e in 1990 to 2.23 MmtCO$_2$e in 2010, an increase of approximately 77 % as indicated in Figure 13.

FIGURE 13 . INDIRECT EMISSIONS BY SECTOR

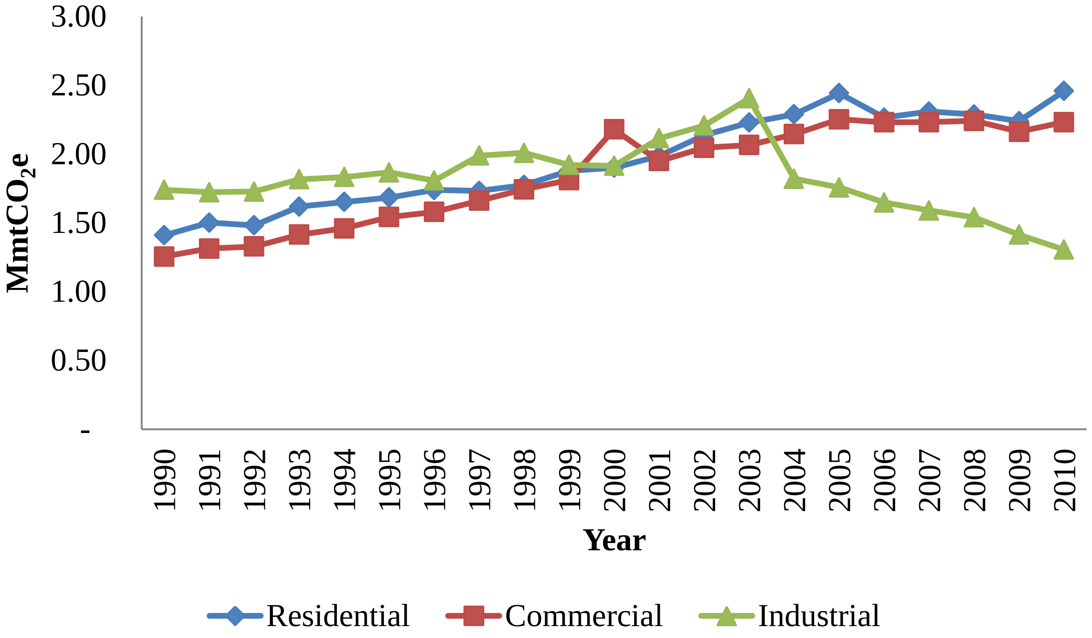
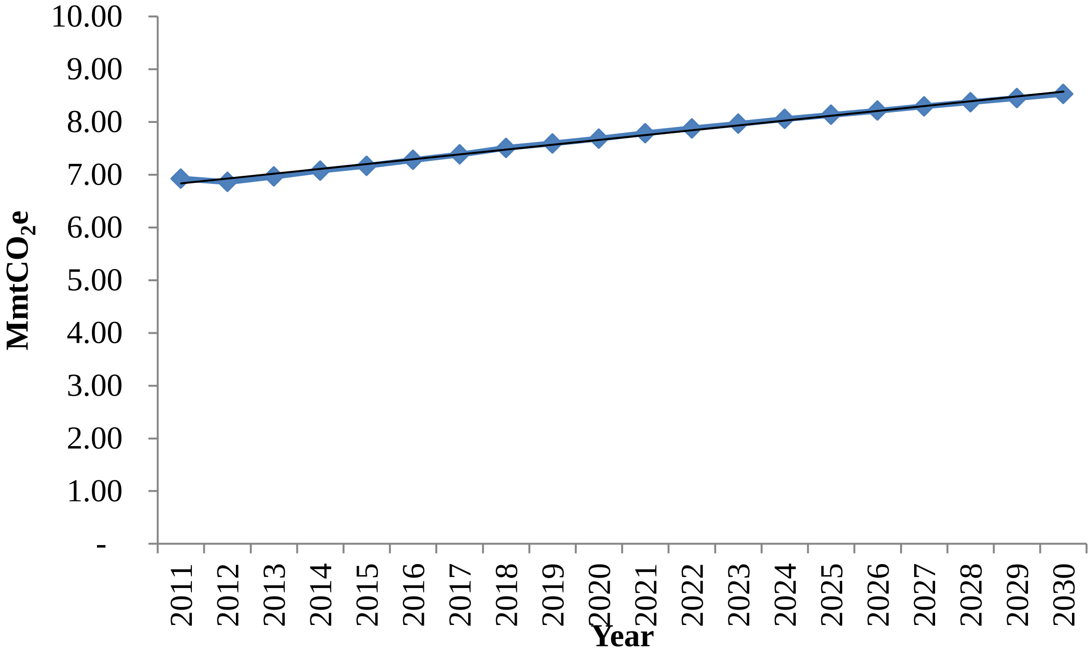


TABLE 6. ESTIMATES OF INDIRECT GHG EMISSIONS BY SECTOR					
MmtCO$_2$e	**1990**	**1995**	**2000**	**2005**	**2010**
Residential	1.41	1.68	1.90	2.44	2.46
Commercial	1.26	1.54	2.18	2.25	2.23
Industrial	1.74	1.87	1.91	1.76	1.30
TOTAL	4.40	5.09	5.99	6.45	6.00

Reference case Projections for Indirect Emissions (Business as Usual[40])

Equation 2 was utilized to estimate projected indirect GHG emissions from electricity consumption. Emissions and transmission factors were derived from eGRID 2012 version1.0 estimates. Projected regional estimates of electricity consumption through 2030 are from EIA's Annual Energy Outlook. Projected regional consumption was disaggregated to state-level estimates by applying the proportion of electricity consumption in 2010 from EIA's State Energy Data 2010 Consumption tables (EIA 2012).

FIGURE 14. PROJECTED INDIRECT EMISSIONS FROM 2011 TO 2030



Based on SIT projections, Delaware is projected to emit gross amount of 154 MmtCO$_2$e between 2011 and 20130 following a business as usual (BAU) scenario. Indirect GHG emissions are projected to continue to increase steadily at a rate of 0.092 MmtCO$_2$e per year from 6.92 MmtCO$_2$e in 2011 to 8.53 MmtCO$_2$e in 2030 as represented by Figure 14. This will be an increase of approximately 23%. The increase in indirect emissions is

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[40] Business as Usual includes the impacts of federal and state programs such as Renewable Fuel Standard (RFS) and Regional Greenhouse Gas Initiative (RGGI)

linked to projected increase in the amount of electricity consumed between 2011 and 2030. According to the EIA, Delaware's annual Electricity consumption will increase from 13,404,182 MWh in 2011 to 16,516,623 MWh in 2030.

Figure 15 breaks down the projected 2030 emission of 8.53 MmtCO$_2$e by sector. The residential sector is projected to emit the largest share of indirect GHG emissions representing approximately 38%. This will be followed by the commercial sector with approximately 37%, and lastly, the industrial sector, which represented approximately 25%.

FIGURE 15. 2030 INDIRECT EMISSIONS FROM ELECTRICITY CONSUMPTION

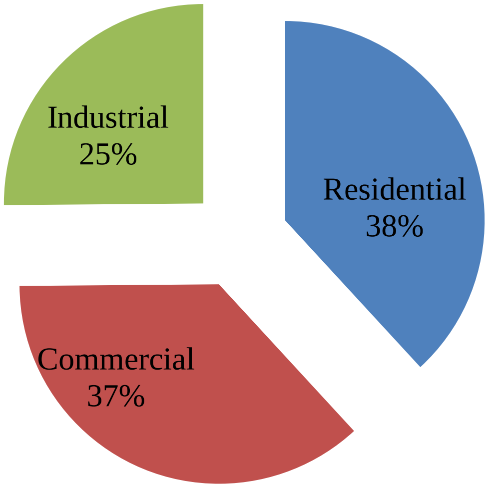
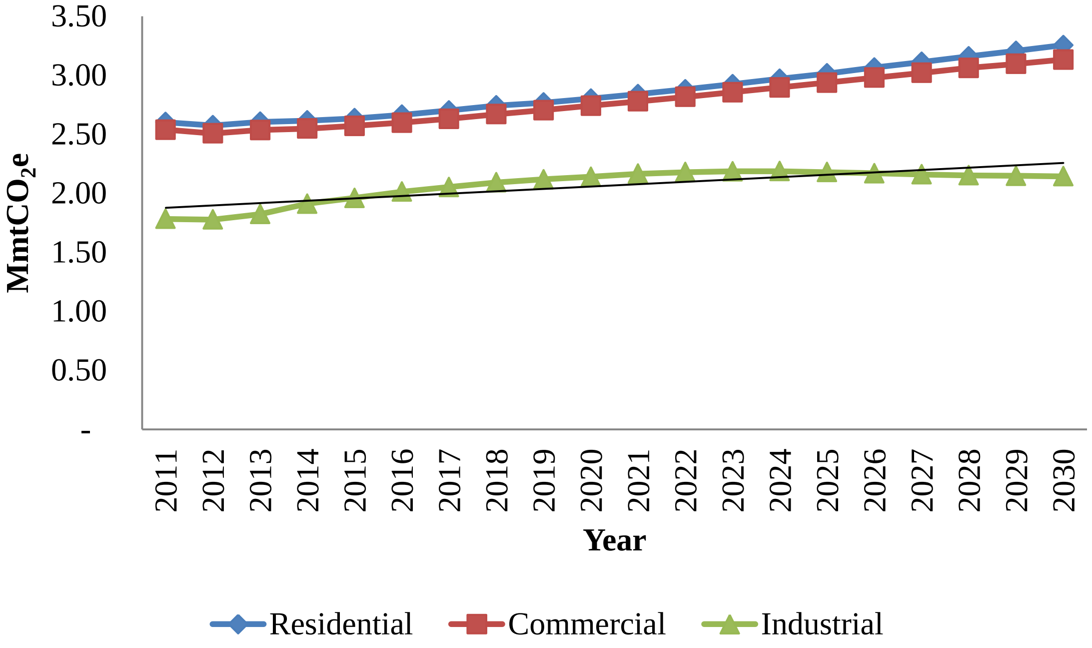


Figure 16 present the projected emissions for all three sectors. As presented, the residential and the commercial sector indirect GHG emissions are projected to rise steadily from 2011 to 2030. Indirect GHG emissions from the residential sector are projected to increase from 2.60 MmtCO$_2$e in 2011 to 3.26 MmtCO$_2$e in 2030. This will be an increase of approximately 25% at a steady rate of 0.0368 MmtCO$_2$e per year. Indirect emissions from the commercial sector are projected to increase from 2.54 MmtCO$_2$e in 2011 to 3.13 MmtCO$_2$e in 2030, an increase of approximately 23%. Commercial sector indirect GHG emissions are projected to increase by 0.0346

$MmtCO_2e$ per year. However, industrial sector indirect GHG emissions are projected to increase at a slower rate of 0.0201 $MmtCO_2e$ per year. Indirect emissions from the commercial sector will increase from 1.78 $MmtCO_2e$ in 2011 to 2.14 $MmtCO_2e$ in 2030, an increase of approximately 20% as Figure 16 indicates.

In addition, Figure 16 indicates that electricity consumption from the residential and commercial sectors will increase steadily from 2011 to 2030 due to steady growth in Delaware's population, as well as growth in economy. However, indirect GHG emissions in the industrial sector will peak in 2023 and decrease slightly to 2.19 $MmtCO_2e$ in 2030.

FIGURE 16. PROJECTED INDIRECT GHG EMISSIONS BY SECTOR FROM 2011 TO 2030



The downward trend of industrial indirect GHG emissions when compared to residential and commercial indirect emissions is in response to historical emissions. As observed in Figure 13, indirect GHG emission from industrial sector had a sharp decrease of 46% between 2003 and 2010. The decrease was in response to a decline in Delaware's industrial sector. The closure of facilities such as General Motors, and decline in other industries, which have high electricity demand, caused a reduction in Delaware's indirect GHG emissions. Though projected indirect GHG emissions from the industrial sector is expected to slow down from 2023 to 2030 based on the reference case projection (BAU) as presented in Figure 16, Delaware's electricity consumption is expected to continue to increase steadily with population. Table 7 provides estimates of indirect GHG emissions from electricity consumption.

TABLE 7. ESTIMATES OF INDIRECT GHG EMISSIONS BY SECTOR

MmtCO$_2$e	**2011**	**2015**	**2020**	**2025**	**2030**
Residential	2.60	2.64	2.80	3.02	3.26
Commercial	2.54	2.57	2.74	2.94	3.13
Industrial	1.78	1.96	2.14	2.18	2.14
TOTAL	**6.92**	**7.17**	**7.68**	**8.13**	**8.53**

4.1.3 Emission of SF$_6$ from T&D

In addition to the combustion of fossil fuels including coal, petroleum, and natural gas in the electric power sector as a source of GHG emissions from in Delaware, another source of GHGs is the transmissions and distribution of electricity (T&D). Sulfur hexafluoride emission is a GHG that comes from T&D. It is typically used for insulating electric power transmission and distribution equipment due to its dielectric[41] properties. Some those properties include high dielectric strength, arc-quenching ability thermal stability and thermal conductivity. Due to its dielectric properties, SF$_6$ is suitable for insulating electrical equipment such as switch gears, circuit breaker and other equipment used for T&D.

Sulfur hexafluoride emissions may occur when there is a leak in any of the equipment. Sulfur hexafluoride represents less than 1% of greenhouse gas emissions from this sector. Sulfur Hexafluoride is considered to be a fully fluorinated compound (FFC) with an atmospheric lifetimes of up to 50,000 years. This makes it a very potent GHG, with significant and permanent contributions to global warming.

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[41] A poor conductor of electricity, but an efficient supporter of electrostatic field. A nonconductor of electricity, especially a substance with electrical conductivity of less than a millionth (10^{-6}) of a siemens

Methodology

Emissions from electric power transmission and distribution are calculated by multiplying the quantity of SF_6 consumed by an emission factor. The resulting emissions are then converted from metric tons of SF_6 to metric tons of carbon dioxide equivalents ($mtCO_2e$) as shown in Equation 3. The default assumption is that the emission factor is 1 (all SF_6 consumed is used to replace SF_6 that was emitted). The global warming potential of SF_6 is 23,900 as provided by Table 8.Default activity data for this sector equals national SF_6 emissions apportioned by state electricity sales divided by national electricity sales.

EQUATION 3. ESTIMATING SF_6 EMISSIONS FROM TRANSMISSION AND DISTRIBUTION SYSTEMS

$$\text{Emissions } (mtCO_2e) = SF_6 \text{ Consumption (metric tons of } SF_6) \times \text{Emission Factor (mt of } SF_6 \text{ in / mt of Consumption in) x GWP of } SF_6$$

As Figure 17 presents, SF_6 emissions from T&D decreased from 0.08 $MmtCO_2e$ in 1990 to approximately 0.04 $MmtCO_2e$ in 2010, a decrease of approximately 50%. Analysis of SF_6 data emissions shows that SF_6 emission has been decreasing at the rate of 0.002 $MmtCO_2e$ per year.

The decline in SF_6 emissions from T&D systems can be partly attributed to increases in the price of SF_6. The increased implementation of 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 of the environmental impacts of $SF_{6.}$ These practices have been promoted by the U.S. EPA[42] 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 SF_6, are now available to the electric power industry.

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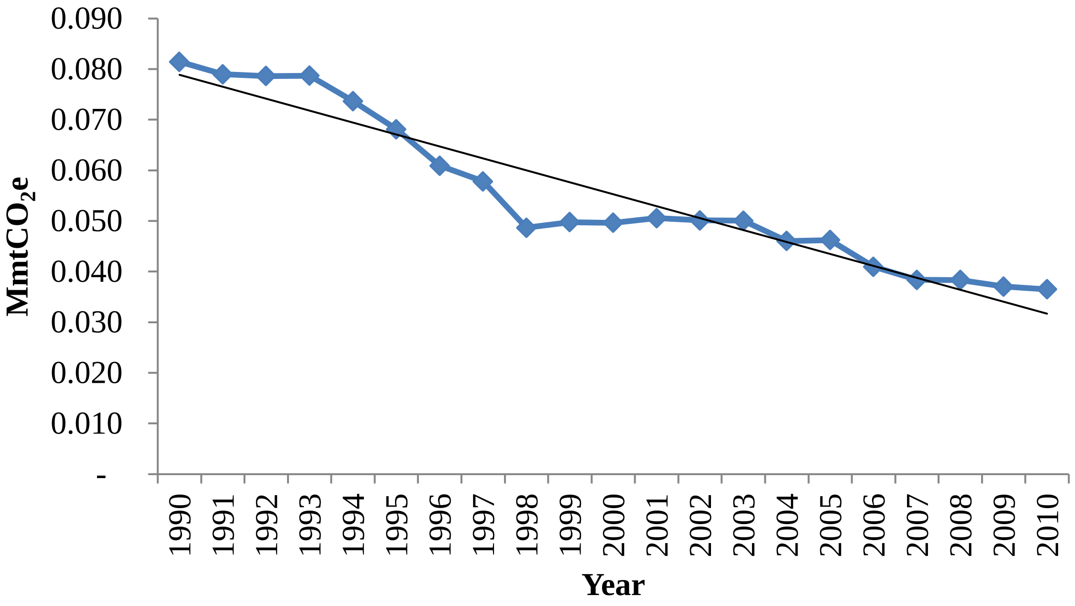
[42] http://www.epa.gov/electricpower-sf6

FIGURE 17. SF_6 EMISSIONS FROM T&D SYSTEMS

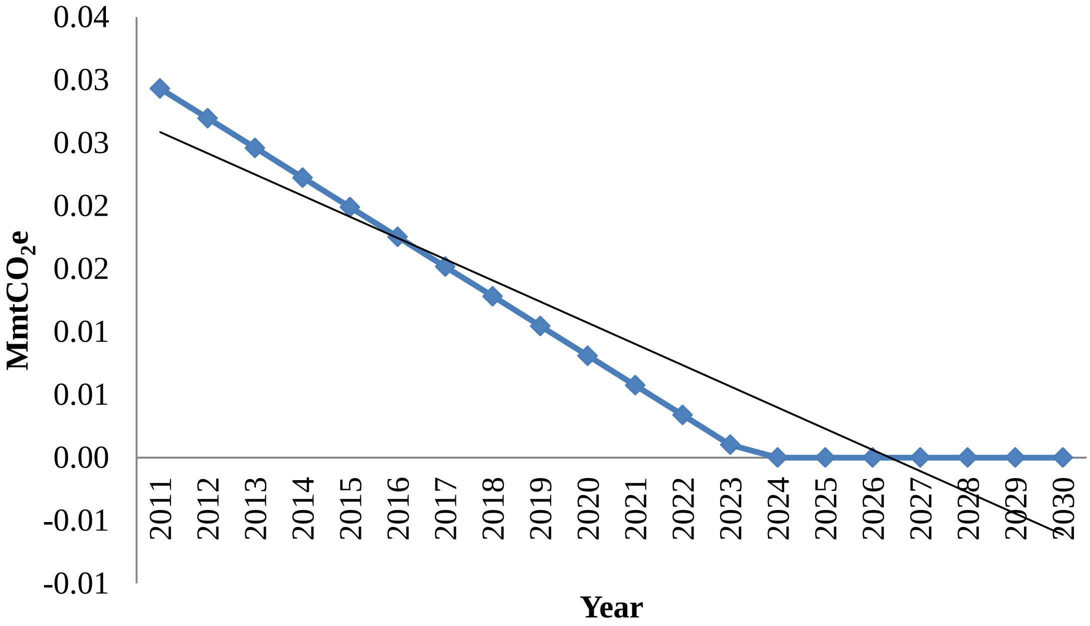


Reference case projection for SF_6

SF_6 emissions are expected to continue to decrease into the future. Figure 18 presents projected emissions for SF_6. Projection analysis shows that SF_6 emission from the transmissions and distribution of electricity in the power sector is expected to diminish in to the future. Sulfur hexafluoride emissions from transmissions and distribution lines in Delaware were projected by using national projection estimates. National emissions from Electric Power Transmission and Distribution Systems were provided by U.S. EPA and were apportioned to states by electricity consumption (Electric Power Annual, EIA, Volumes 1994-2010).

Figure 18 provides projected SF_6 emissions from 2011 to 2030. Gross SF_6 emissions are projected decreased from 0.03 $MmtCO_2e$ in 2011 to 0.001 $MmtCO_2e$ in 2023 as presented by Figure 18.This is a decrease of approximately 97 % at the rate of 0.002 $MmtCO_2e$ per year. Sulfur hexafluoride emissions are projected to diminish to zero starting from 2024 as presented in Figure 18. Diminishing SF_6 emissions can be linked to the use of VBCs, which replaces SF_6 as insulator, as well other SF_6 reduction practices.

FIGURE 18. PROJECTED SF_6 EMISSIONS



Conclusion of Power Sector GHG Emissions Analysis

Analysis of GHG emissions in the electric power sector shows that overall emissions are expected to continue to increase[43]. The EPA's state inventory tool shows that increasing GHG emissions from this sector will be driven primarily by coal consumption as well as increasing electricity consumption. Coal-fired units in Delaware have the largest GHG emissions when compared to other fuels and is expected to continue to grow. However, emissions from coal-fired units are projected

According to the U.S EIA, coal consumption in Delaware's power sector[44] is projected to grow from 22,878 Billion Btus in 2011 to 32,905 Billion Btus, an increase of approximately 44%. In spite of coal's larger share of the electricity market, electricity generation from natural gas is the favored source of new generation capacity due to relatively low cost and high efficiency. However coal is expected to retain its

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[43] Direct GHG emissions from electricity generation is projected to be 4.00 $MmtCO_2e$ in 2030, while indirect emissions is projected to be 8.53 $MmtCO_2e$ the same year.

[44] EIA 2012, Projected Regional Consumption data. http://www.eia.doe.gov/states/_seds.html.

competitiveness due to favorable fuel prices when compared to natural gas. Natural gas prices are expected to rise faster due to demand. As long as coal remains competitive, GHG emissions from coal will continue to increase over the time. Substituting coal generation with natural gas (fuel switching) could reduce gross GHG emissions from electricity generation[45]. In addition, the New Source Performance Standard (111d) proposed by the EPA, will require the deployment carbon capture and sequestration technology to reduce GHG emissions from fossil fuel-fired electric generating units. Carbon content of natural gas is approximately 60%[46] of coal per unit of primary energy content (kg/GJ). Factoring the higher efficiency of electricity production from natural gas turbines over the average efficiency for coal-fired generation, CO_2 emissions per unit gas-fired electricity are an additional 30% lower than emissions from coal-fired generation.

In addition, GHG emissions data indicates an upward trend in electricity consumption. This projected increase in electricity us can be attributed to increasing population as well as a positive economic outlook. Emissions from the residential sector are expected to increase with Delaware's population, which will increase electricity demand and consumption overtime. As the economy improves, there will be an expansion in the industrial and commercial sectors. To meet the demand for electricity that results from future economic expansion, in-state generated of electricity as well as imported electricity is expected to increase, which will increase associated GHG emissions.

4.2 TRANSPORTATION SECTOR

The transportation sector is categorized as one of the big three sources of GHG emissions in Delaware. Historically, the transportation sector is second to the electric power sector in terms of GHG emissions. However, in 2009, transportation sector GHG emissions exceeded the electric power sector emissions. The transportation sector emitted 4.97 $MmtCO_2e$ to the atmosphere compared to the power sector contribution of 3.83 $MmtCO_2e$ in 2009. Greenhouse gas emissions from transportation sector also exceeded emission from the

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[45] Currently, there are no natural gas pipelines to switch Indian River power plant from coal to natural gas.

[46] Katharine Hayhoe etal 2002, Substitution of Natural Gas for Coal: Climatic Effects of Utility Sector Emission

electric power sector in 2010. The transportation sector emitted 4.64 MmtCO$_2$e, compared to 4.23 MmtCO$_2$e[47] emitted by the electric power sector in 2010. In 2010, the transportation sector represented 34% of Delaware's gross GHG emissions, and it has emitted a cumulative amount of 106.40 MmtCO$_2$e between 1190 and 2010.

Figure 19 presents historical gross emissions from the transportation sector. Emissions decreased from 4.76 MmtCO$_2$e in 1990 to 4.6.4 MmtCO$_2$e in 2010, which was a slight decrease of approximately 2.5 %. The decline in emissions occurred at a slow rate of 0.008 MmtCO$_2$e per year. Transportation sector GHG emissions reached a peak of 5.38 MmtCO$_2$e in 2007 and declined slowly to 4.64 MmtCO$_2$e in 2010. However emissions are expected to continue to increase. The analysis of historical emissions from the transportation sector indicate that emissions in this sector show no sign of significant decreases in response to factors such as the economy or rising gas prices. The primary GHG emitted from the transportation sector is CO$_2$, which in 2010 represented approximately 98% of gross GHG emissions from this sector according to Figure 20. Carbon dioxide emissions in the transportation sector come from fuel combustion in internal combustion engines (ICE)[48] of automobiles.

Carbon dioxide is a byproduct of the combustion fossil fuels such as gasoline, diesel gas and to a lesser extent natural gas. These fossil fuels are called hydrocarbons because they poses hydrogen and carbon molecules. When these fuels undergo oxidation during combustion, the result is the emissions of CO$_2$ and other GHGs. Gasoline combustion is the largest source of CO$_2$ from the transportation sector because it's the most widely consumed fossil fuel. In addition to CO$_2$ emissions, the combustion of fossil fuels produces CH$_4$ and N$_2$O. Greenhouse gas 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. Figure 20 shows that CO$_2$ emissions was the largest GHG emitted in

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[47] Gross emissions includes sulfur hexafluoride emissions from the transmissions and distribution of electricity.

[48] The internal combustion engine is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit.

2010 representing approximately 98%, followed by N_2O representing approximately 2% and CH_4 representing less than one percent.

FIGURE 19. GHG EMISSIONS FROM TRANSPORTATION SECTOR

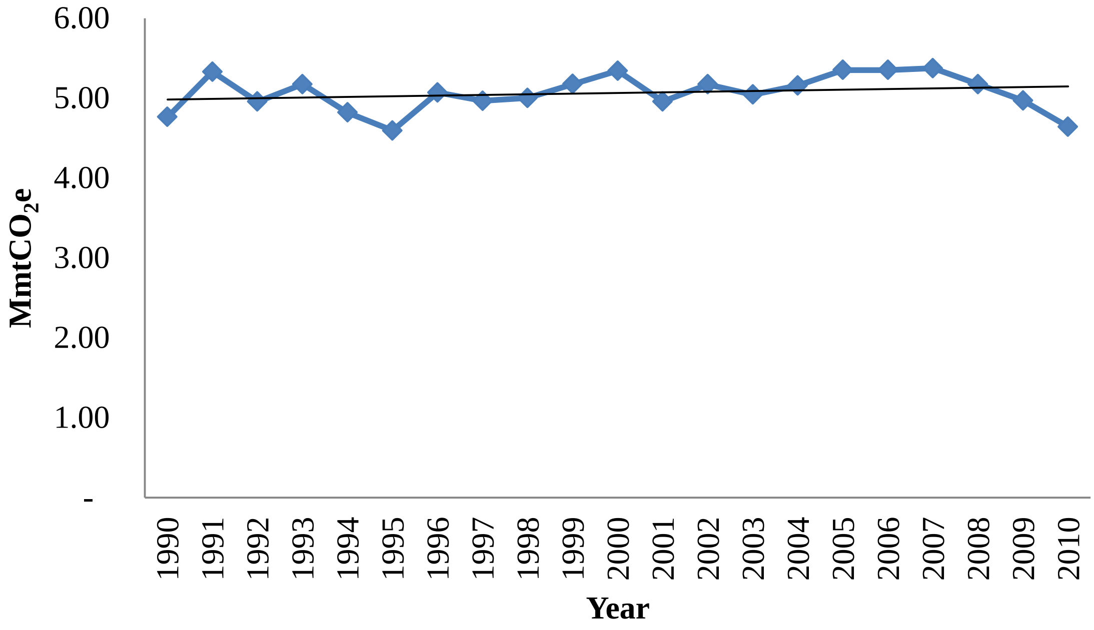
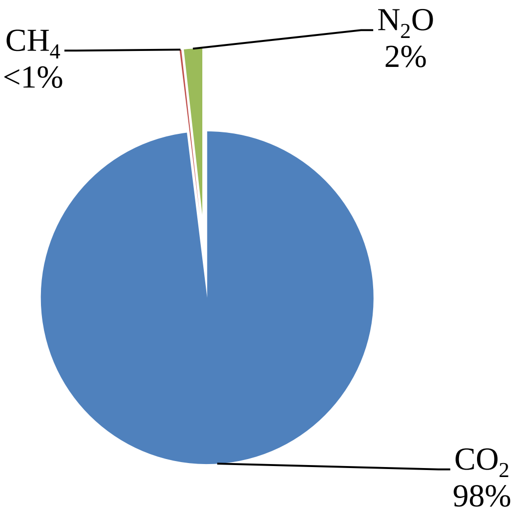


FIGURE 20. GHG EMISSIONS FROM THE TRANSPORTATION SECTOR



Methodology

The GHGs of concern are CO_2, N_2O and CH_4 emissions from fossil fuel combustion (FFC) in the transportation sector. The U.S. EPA’s EIIP categorizes CO_2 emissions from FFC separately from N_2O and CH_4 emissions because their methodologies for estimating the emissions are different. In the SIT, CO_2 emissions from fossil fuel combustion were categorized under *energy related activities* emissions, while N_2O and CH_4 emissions are categorized under *mobile source* emissions. The methods for estimating both categories are described in Equation 4. This equation describes the general method for estimating the emissions using the activity data and the emissions factor.

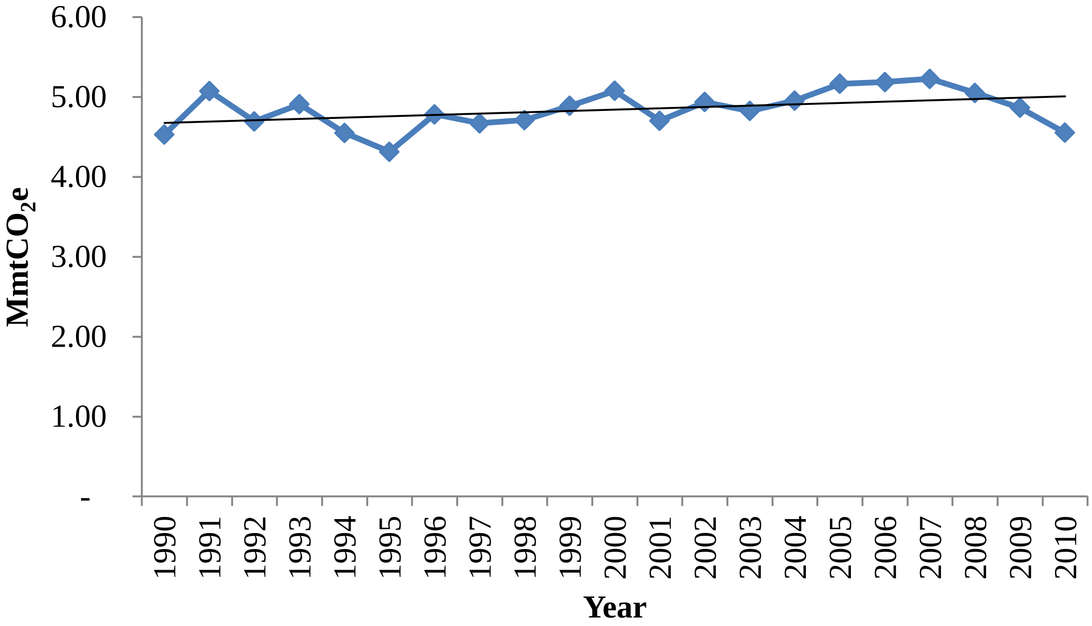
EQUATION 4. GHG EMISSIONS FROM TRANSPORTATION SECTOR

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,
c = emission control type.

4.2.1 CO_2 Emissions from Transportation Sector

The SIT was used to estimate CO_2 from *energy related activities* in all economic sectors of Delaware. Transportation sector emissions were categorized separately. Carbon dioxide emissions were estimated by multiplying energy consumption (in the transportation sector) by emission factors for each fuel. These results were then multiplied by fuel-specific percentages of carbon during combustion ("combustion efficiency"). The non-energy consumption of lubricants multiplied by its carbon storage factor was subtracted from its energy consumption before carrying out the above calculations. The resulting fuel emissions, in pounds of carbon, were then converted to short tons of carbon and million metric tons of carbon equivalent (MmtCe), then to million metric tons of carbon dioxide equivalent ($MmtCO_2e$), and summed.

Figure 21. Gross CO_2 Emissions from Transportation Sector



A cumulative total of 101.7 $MmtCO_2e$ in GHG emissions was emitted from the transportation sector between 1990 and 2010. As demonstrated by Figure 21, transportation related CO_2 emissions from FFC has remained relatively stable fluctuating between 5.50 $MmtCO_2e$ and 4.50$MmtCO_2e$. The consumption of gasoline fuel, which is a petroleum product, was a major factor in CO_2 emissions from the transportation sector. The fluctuations in emission observed in Figure 21 were possibly the result fluctuating gasoline price over the years. Table 8 provides CO_2 emissions from petroleum.

TABLE 8. ESTIMATES OF CO_2 EMISSIONS FROM TRANSPORTATION

$MmtCO_2e$	1990	1995	2000	2005	2010
Petroleum	4.53	4.31	5.07	5.16	4.54

4.2.2 N_2O and CH_4 Emissions from Transportation Sector

Nitrous oxide is formed by the catalytic processes used to control NOx, CO, and hydrocarbon emissions in vehicles[49]. On the other hand, CH_4 emissions in mobile combustion occur as result of the incomplete combustion of CH_4 and other hydro carbons

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

in automobile engines[50]. The methods for estimating CH_4 and N_2O emission from mobile combustion are different from that of CO_2 emissions. All CO_2 emission estimates from fossil fuel combustion in the transportation sector were included under *CO_2 Emissions from the Transportation Sector* as described in section 4.2.1.

Estimates of CH_4 and N_2O emissions from *mobile sources* were developed by collecting activity data for *mobile sources* based on vehicle mile traveled (VMT), the combustion technologies (types of vehicles) used, and the types of emission control technologies employed in fuel 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 Equation 4. The SIT categorized emissions from *mobile sources* into the following vehicle types:

- On-road gasoline vehicles including passenger cars, light-duty trucks heavy-duty vehicles and motorcycles that use gasoline.
- On-road diesel vehicles including passenger cars, light-duty trucks, heavy-duty vehicles that use diesel.
- Non-road vehicles and engines including aircrafts, boats, trains, farm and construction equipment that use fuels such as kerosene, residual, distillate and aviation gasoline.
- 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[51] were based on VMT and emission factors by vehicle type, fuel type, and control technology and model year. Also, emission estimates from alternative fuel vehicles[52] were based on VMT and emission factors by vehicle and fuel type. Fuel consumption data were used as a measure

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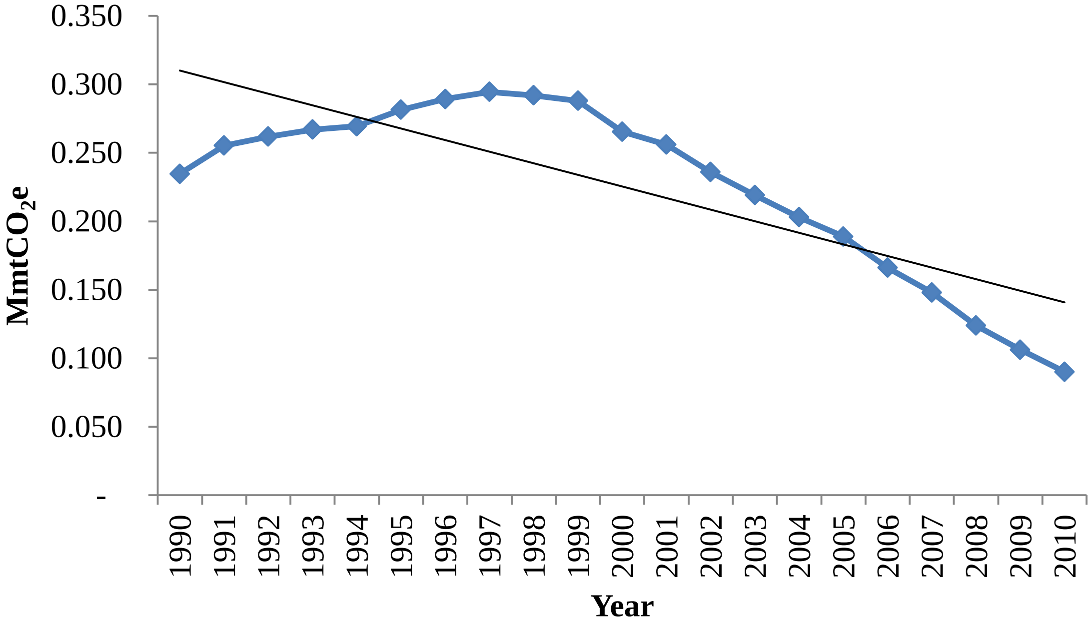
[50] 2012 U.S. EPA inventory report: http://www.epa.gov/climatechange/emissions/usinventoryreport.html

[51] 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

[52] 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

of activity for non-road[53] vehicles and engines in conjunction with fuel emission factors. Analysis shows that cumulatively, the transportation sector has emitted about 4.74 $MmtCO_2e$ into the atmosphere between 1990 and 2010. According to Figure 22, N_2O and CH_4 emissions from the transportation sector peaked at 0.295 $MmtCO_2e$ in 1997. Emissions subsequently decreased significantly to 0.09 $MmtCO_2e$ in 2010, a decrease of approximately 70%. Overall, emissions decreased at a slow rate of 0.009 $MmtCO_2e$ per year. The downward trend of N_2O and CH_4 emissions from the transportation sector observed in Figure 22 is in contrast with the upward trend of VMT[54] observed in Figure 23. The contrast in trends suggests a complex relationship between VMT and historical GHG emissions from *mobile sources*.

FIGURE 22. N_2O AND CH_4 EMISSION FROM THE TRANSPORTATION SECTOR



The analysis of the results points to other factors affecting emissions from the *mobile sources*. N_2O is a product of the catalytic process in vehicles, while CH_4 is a product of

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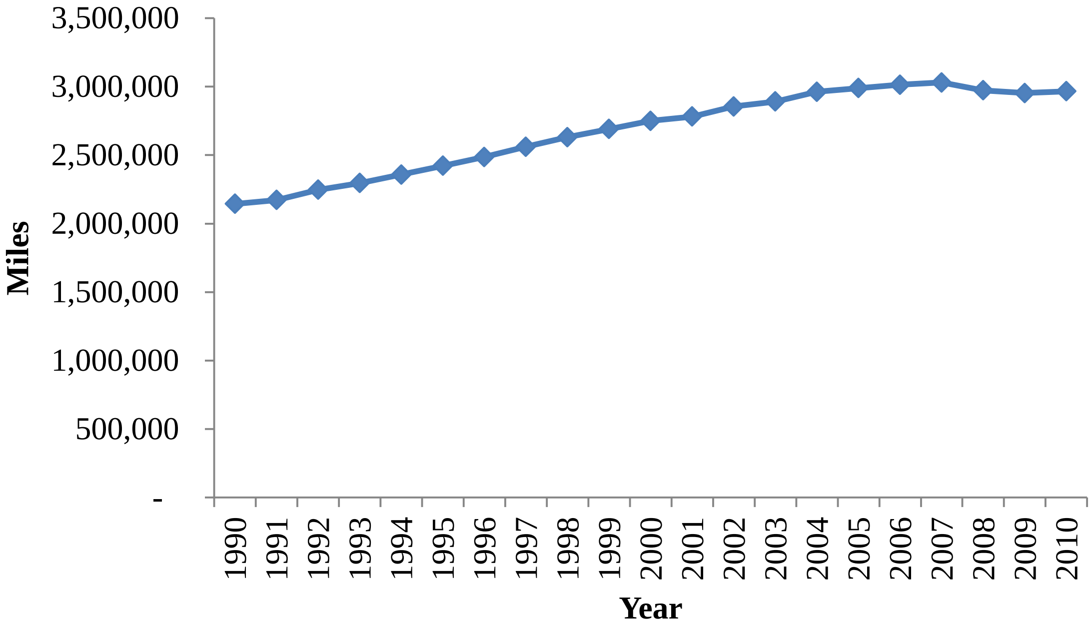
[53] -EIA's *Petroleum Sales and Consumption: Fuel Oil and Kerosene Sales*, Table 16. Available online at: http://tonto.eia.doe.gov/dnav/pet/pet_cons_821dsta_dcu_nus_a.htm - U.S. Department of Energy publication *State Energy Data System* (EIA 2010) for data on aviation gasoline consumption. http://www.eia.doe.gov/states/_seds.html

[54] Provided by 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.

incomplete fuel combustion. The emission of both gases is dependent on the amount of fuel consumed which in turn depends on VMT. Yet as the emission trend in Figure 22 indicate N_2O and CH_4 emissions are declining while VMT is increasing according to Figure 23.

FIGURE 23. VEHICLE MILE TRAVELED FROM 1990 TO 2010



This decline in emissions can be attributed to increased energy efficiency in the transportation sector. The efficiency of auto vehicles has been steadily improving with better engine design, more precise ignition timing, and computerized engine management. These improvements have minimized fuel consumption, which subsequently reduces N_2O and CH_4 emissions. In addition, the introduction of improved emission control technologies[55] and the introduction of higher energy efficiency vehicles such as hybrids have contributed to significant reductions in GHG emissions from *mobile sources*.

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[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

FIGURE 24. N_2O AND CH_4 EMISSIONS BY VEHICLE TYPE

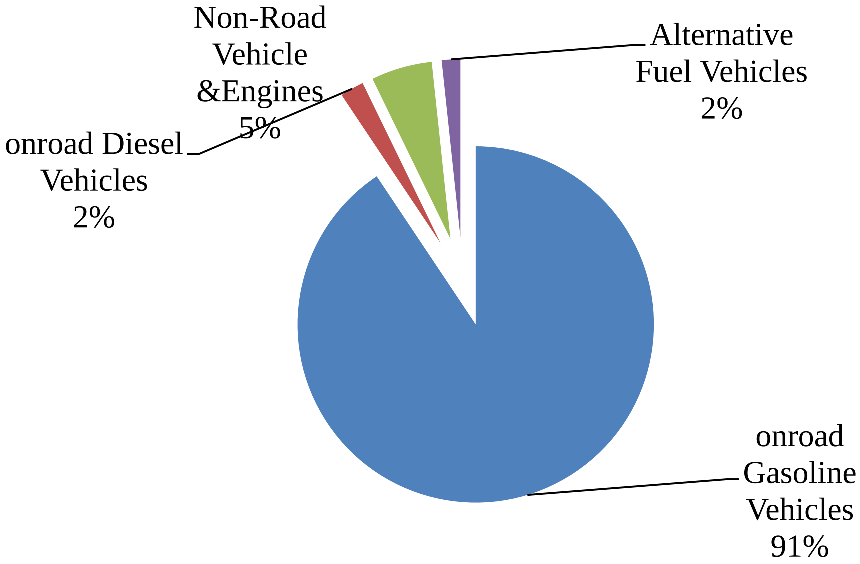


Figure 24 present 2010 N_2O and CH_4 emissions by vehicle type. On-road gasoline vehicles had the largest emissions of N_2O and CH_4 representing approximately 91% in 2010. Greenhouse gas emissions from non-road vehicles were a distant second representing approximately 5% of gross N_2O and CH_4 emissions from the transportation sector. Nitrous oxide and CH_4 Emissions from diesel and alternative fuel vehicles both represented approximately 2 % of gross emissions from *mobile sources* as Figure 24 presents. Table 9 provides N_2O and CH_4 emissions by vehicle type from the transportation sector. As the analytical data show, gasoline vehicles are the primary sources of N_2O and CH_4 emissions in the transportation sector.

TABLE 9. ESTIMATES OF N_2O AND CH_4 EMISSIONS BY VEHICLE TYPE

$MmtCO_2e$	**1990**	**1995**	**2000**	**2005**	**2010**
Gasoline Vehicle	**0.221**	**0.272**	**0.252**	**0.176**	**0.082**
Passenger Cars	0.139	0.147	0.130	0.097	0.059
Light-Duty Trucks	0.077	0.120	0.115	0.074	0.021
Heavy-Duty Vehicles	0.005	0.006	0.006	0.005	0.002
Motorcycles	0.000	0.000	0.000	0.000	0.000
Diesel Vehicle	**0.001**	**0.001**	**0.001**	**0.002**	**0.002**
Passenger Cars	0.000	0.000	0.000	0.000	0.000
Light-Duty Trucks	0.000	0.000	0.000	0.000	0.000
Heavy-Duty	0.001	0.001	0.001	0.002	0.002

TABLE 9. ESTIMATES OF N_2O AND CH_4 EMISSIONS BY VEHICLE TYPE					
$MmtCO_2e$	**1990**	**1995**	**2000**	**2005**	**2010**
Vehicles					
Non-Road vehicle	**0.013**	**0.008**	**0.012**	**0.010**	**0.005**
Boats	0.006	0.007	0.010	0.007	0.003
Locomotives	0.000	0.000	0.000	0.000	0.000
Farm Equipment	0.001	0.000	0.001	0.001	0.001
Aircraft	0.006	0.001	0.001	0.002	0.001
Alternative Fuel Vehicles	**0.000**	**0.000**	**0.000**	**0.002**	**0.002**
Light Duty Vehicles	0.000	0.000	0.000	0.000	0.000
Heavy Duty Vehicles	0.000	0.000	0.000	0.001	0.001
Buses	0.000	0.000	0.000	0.000	0.000
Total	**0.235**	**0.281**	**0.265**	**0.189**	**0.090**

4.2.3 Reference Case Projections of GHG Emissions from Transportation

The projected emissions of GHG from the transportation sector was determined by using the general methodology discussed above, energy outlook data from the EIA as well as VMT data from the Federal Highway Administration (FHWA). The State Inventory Tool was used to determine emissions by state for 2010. Projections were then apportioned to states based on the ratio of state emissions to national emissions in 2010.

Greenhouse gas emissions from the transportation sector are projected to stabilize in the future as presented in Figure 25. GHG Emissions is expected to range between 5.43 $MmtCO_2e$ to 5.64 $MmtCO_2e$. As Figure 25 presents, GHG emission from the transportation sector is projected to be 5.48 $MmtCO_2e$ in 2030. This is a slight increase from 5.43 $MmtCO_2e$ in 2011. Projected GHG emissions from the transportation sector will be driven primarily by CO_2 emissions from fossils fuel combustion.

Figure 26 presents projected emissions from the transportation sector by GHGs in 2030. Carbon dioxide emissions from fossils fuel combustion are projected to represent approximately 99% of gross GHG emissions from the transportation sector in 2030.

Nitrous oxide emissions, on the other hand, are projected to represent only approximately 1%, while CH_4 will represent less than1% as presented in Figure 26.

FIGURE 25 PROJECTED GHG EMISSIONS FROM TRANSPORTATION

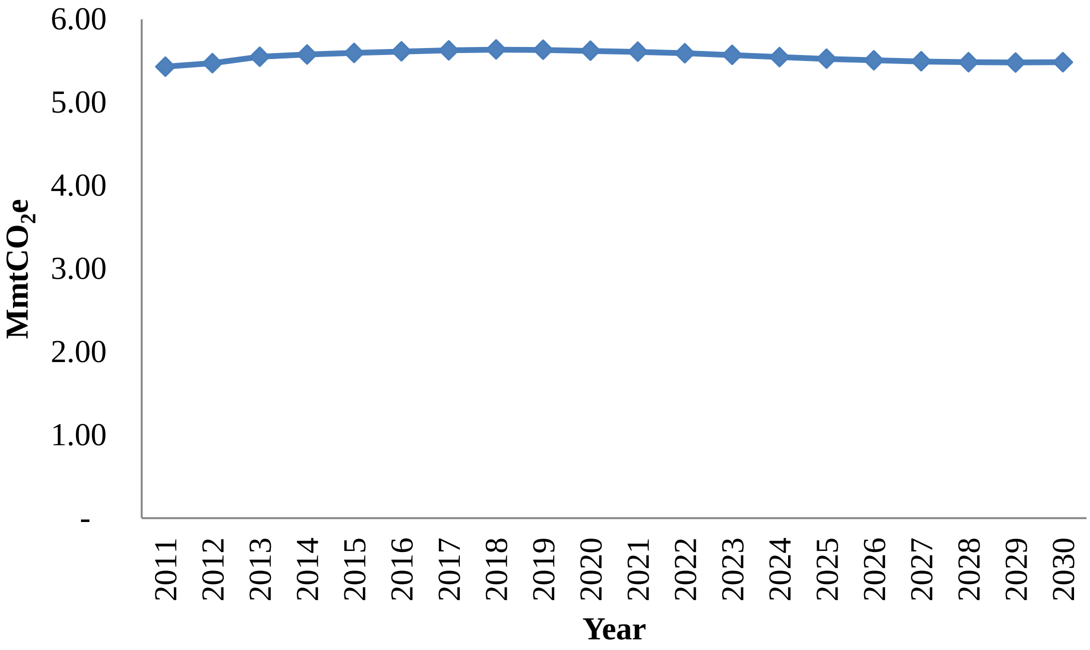
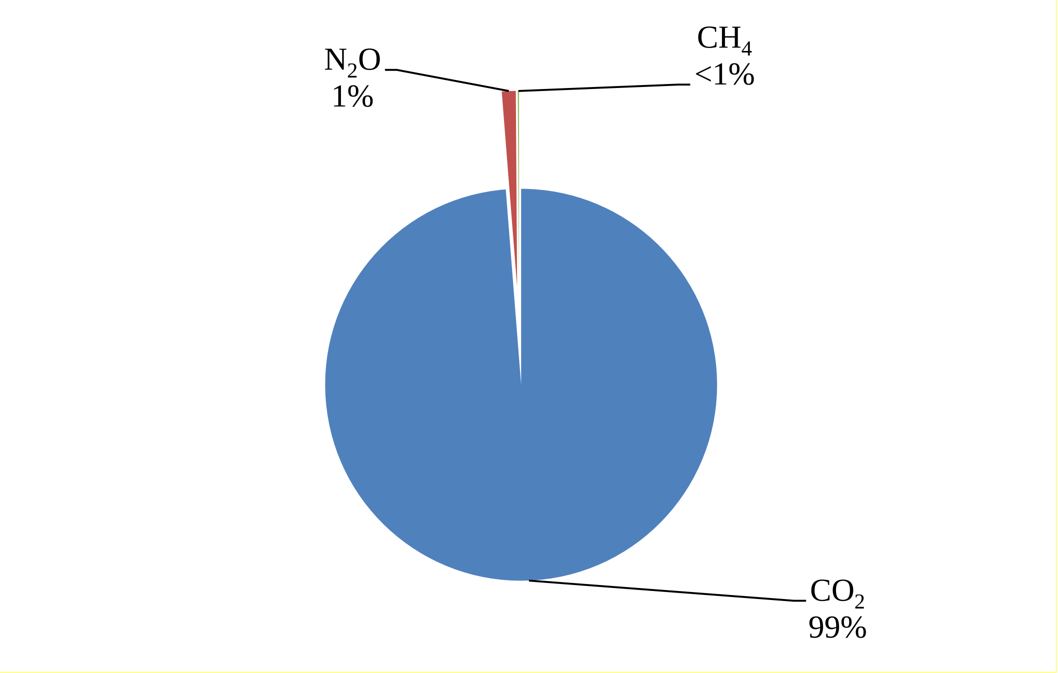


FIGURE 26. 2030 EMISSIONS FROM THE TRANSPORTATION SECTOR BY GHG



Carbon dioxide emissions from fossils fuels is expected to remain the GHG of concern in to the future as the reference case projections show. Comparing percent CO_2 emissions from the transportation sector presented in Figure 20 to projected CO_2 emissions, we observe a slight increase in the percent of CO_2 emission from 98% in 2010 to 99% in 2030.

4.2.4 Projected CO_2 Emissions from Transportation Sector:

Figure 27 presents projected CO_2 emissions from the transportation sector. Overall, projected emissions are expected to stabilize from 2011 to 2030 as Figure 27 presents. Carbon dioxide emissions are expected to average 5.48 $MmtCO_2e$ annually between 2011 and 2030. Carbon dioxide emissions are projected to be 5.41 $MmtCO_2e$ in 2030, which is only a slight increase from 5.35 $MmtCO_2e$ in 2011.

Figure 28 breaks down projected CO_2 emissions by fuel type. While CO_2 emissions from gasoline fuel consumption is projected to decline gradually, CO_2 emissions from distillate and residual fuel are projected rise gradually as presented by Figure 28.

The emissions projection analyses show that of GHG emissions from gasoline is expected to decrease from 3.72 $MmtCO_2e$ in 2011 to 3.29 $MmtCO_2e$ in 2030 at the rate of 0.021 $MmtCO_2e$ per year. This will be a decrease of approximately 12%. Conversely, distillate fuel GHG emissions are projected to increase from 0.65 $MmtCO_2e$ in 2011 to 0.92 $MmtCO_2e$ in 2030 at the rate of 0.012 $MmtCO_2e$ per year. This will be an increase of approximately 41%. And residual fuel GHG emissions are projected to increase from 0.88 $MmtCO_2e$ in 2011 to 1.08 $MmtCO_2e$ in 2030 at the rate of 0.006 $MmtCO_2e$ per year. This will be an increase of approximately 22%.

The projected decline in CO_2 emissions from the consumption gasoline as presented in Figure 28 reflects the impact of improving fuel efficiency in the transportation sector, as well the expansion of low carbon fuel markets.

FIGURE 27. PROJECTED CO_2 EMISSIONS FROM TRANSPORTATION

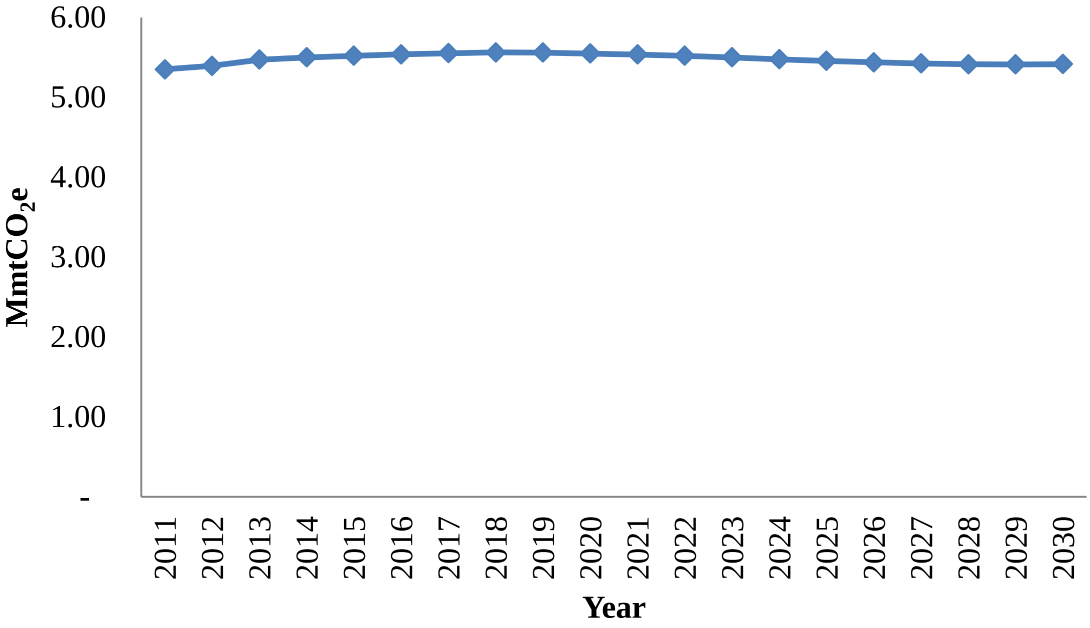
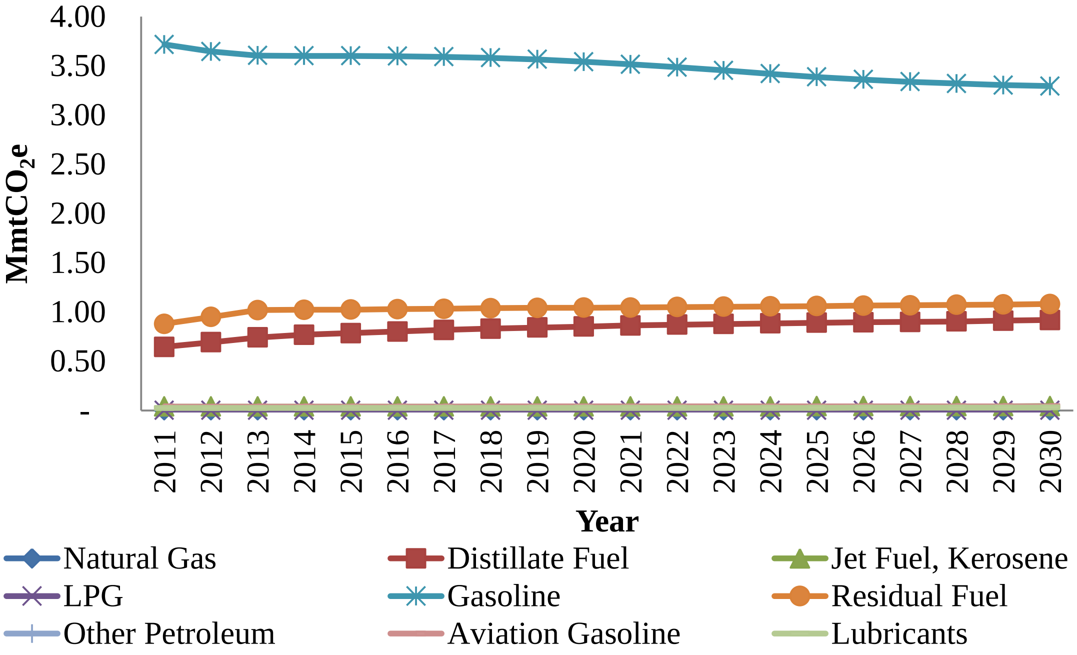


FIGURE 28. PROJECTED CO_2 EMISSIONS BY FUEL TYPE



The introduction of the Corporate Average Fuel Economy (CAFE) standard in 1975 has led to improved fuel efficiency in automobiles. The CAFE standards set fuel economy requirements for various types of automobiles in miles per gallon. The result has been decreased consumption and demand for gasoline fuel and relative price stability. According to the National Academy of Science, fuel consumption would have been 14% higher absent the CAFE standard[56]. By reducing gasoline fuel consumption, the CAFÉ standard contributes to not only reductions in historical CO_2 emissions, but also future CO_2 emissions form gasoline combustion in Delaware.

In addition, projected decline in CO_2 emissions can also be linked to the positive outlook on alternative vehicles and fuels. The effort to transition from light-duty vehicles (LDVs) powered by internal combustion engines driven by gasoline fuel has been motivated by energy security concerns about petroleum imports and the effect of greenhouse gas (GHG) emissions on global climate. Alternative vehicles include electric cars, hybrids and cars that use alternative fuel such as biofuels and hydrogen fuel cells. According to the EIA, there are 5,277 alternative vehicles in Delaware as of 2011, which is only 0.4% of the national number. As the numbers of these cars grow[57] in Delaware, gasoline consumption may decrease gradually, which will lead to decreasing CO_2 emissions.

Increasing emissions from distillate and residual fuel as presented in Figure 28 can be linked to a number of factors such as the improving economy and fuel efficiency requirements. Distillate and residual fuels are used in non-road vehicles like marine vessels and locomotives. The consumption of both fuels is expected to increase with economic activities that involve shipping and locomotives in Delaware. Therefore, CO_2 emissions from both fuels are projected to increase with time. In addition, there are currently no fuel efficiency/economy requirements for most non-road vehicles such as marine vessels and locomotives unlike gasoline vehicles, which further contribute to the increasing CO_2 emissions associated with residual and distillate fuels.

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[56] Board On Energy and Environmental Systems (2002). *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards (2002)*. The National Academies.

[57] U.S. EIA projects that new light-duty alternative vehicles will grow from 13 percent of the U.S. automobile sales market in 2008 to 49 percent in 2035 due to rising oil prices and federal renewable fuel and fuel-economy standards.

4.2.5 Projected mobile source Emissions: Emissions of N_2O and CH_4 from the transportation sector are projected to continue to decline as Figure 29 presents. Emissions will decrease from 0.08 $MmtCO_2e$ in 2011 to 0.07 $MmtCO_2e$ in 2030. This will be a decrease of approximately 12.5%, at the gradual rate of 0.0006 $MmtCO_2e$ per year.

Decreasing N_2O and CH_4 emissions is expected to slow down significantly. This is observed when comparing historical emissions in Figure 22, which decreased significantly by approximately 70% at the rate 0.009 $MmtCO_2e$ per year, to projected emissions in Figure 29, which is decrease by approximately 12.5% at the slow rate of 0.0006 $MmtCO_2e$ per year. The slowdown in the decreasing N_2O and CH_4 emissions is due to diminishing returns of existing emission control technologies. This reference case projection does not include future emission control technologies as well as state and federal regulations that may contribute to further reductions in N_2O & CH_4 emissions in the future.

FIGURE 29. PROJECTED N_2O AND CH_4 EMISSIONS FROM THE TRANSPORTATION SECTOR

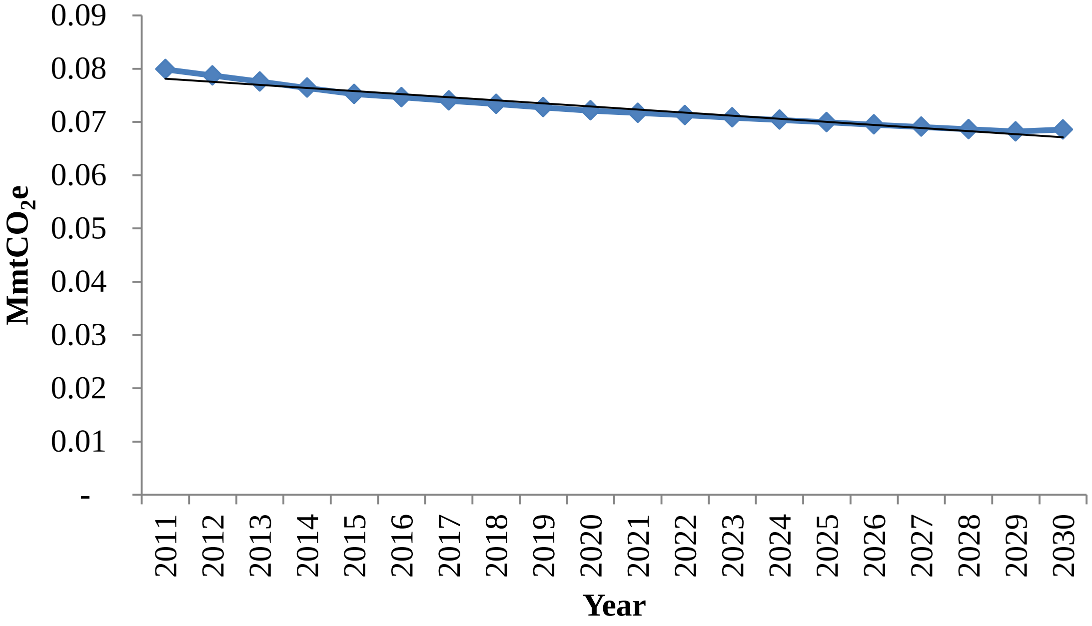


FIGURE 30. 2030 N_2O AND CH_4 EMISSIONS BY VEHICLE TYPE

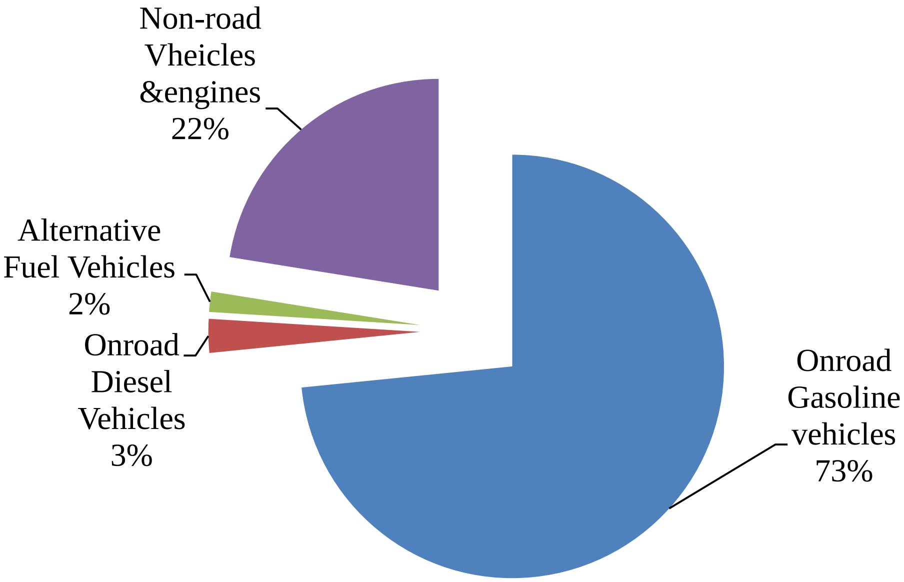


Figure 30 presents GHG emissions from the transportation sector distributed by vehicle types. Greenhouse gas emissions from on-road gasoline vehicles are projected to be the largest in 2030 representing approximately 73% of gross emissions from *mobile sources*. This is followed by non-road vehicles GHG emissions representing approximately 22%, and diesel vehicles GHG emissions representing approximately 3% and alternative fuel vehicles representing approximately 2%.

Figure 30 indicates that gasoline vehicles are expected to remain the primary source of N_2O & CH_4 emissions from *mobile sources* in the transportation sector. However emissions from non-road vehicles and engines had a significant increase from approximately 5 % of gross emissions from the transportation sector as presented in Figure 24 to a projected 22% of gross emissions as presented in Figure 30. The projected increase in non-road vehicle & engine emissions is linked to the absence of federal or state regulations limiting N_2O and CH_4 emissions from non-road vehicles and engines. Based on this reference case scenario, GHG emissions from non-road vehicles and engines in Delaware is projected to increase with increasing number non-road vehicles and engines, as well as increasing fossil fuel consumption by this GHG emissions source. Table 10 provides estimates on projected N_2O and CH_4 emissions from the transportation sector by vehicle type.

TABLE 10. PROJECTED ESTIMATES OF N_2O AND CH_4 EMISSIONS BY VEHICLE TYPE

$MmtCO_2e$	**2011**	**2015**	**2020**	**2025**	**2030**
Gasoline Vehicle	**0.07**	**0.06**	**0.06**	**0.05**	**0.05**
Passenger Cars	0.04	0.03	0.03	0.03	0.03
Light-Duty Trucks	0.03	0.03	0.02	0.02	0.02
Heavy-Duty Vehicles	0.00	0.00	0.00	0.00	0.00
Motorcycles	0.00	0.00	0.00	0.00	0.00
Diesel Vehicle	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Passenger Cars	0.00	0.00	0.00	0.00	0.00
Light-Duty Trucks	0.00	0.00	0.00	0.00	0.00
Heavy-Duty Vehicles	0.00	0.00	0.00	0.00	0.00
Non-Road vehicle	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Boats	0.01	0.01	0.01	0.01	0.02
Locomotives	0.00	0.00	0.00	0.00	0.00
Farm Equipment	0.00	0.00	0.00	0.00	0.00
Aircraft	0.00	0.00	0.00	0.00	0.00
Alternative Fuel Vehicles	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Light Duty Vehicles	0.00	0.00	0.00	0.00	0.00
Heavy Duty Vehicles	0.00	0.00	0.00	0.00	0.01
Buses	0.08	0.08	0.07	0.07	0.07
Total	**0.07**	**0.06**	**0.06**	**0.05**	**0.05**

Conclusion from the Analysis of GHG Emissions from the Transportation Sector

Carbon dioxide emissions is the primary GHG concern representing approximately 98% of the GHG emissions in 2010, and it's expected to represent approximately 99% in 2030. The primary source of CO_2 emissions in the transportation sector is petroleum combustion, and a gross CO_2 emission is expected to remain stable overtime. However, the reference case projection shows that CO_2 emissions from gasoline combustion is expected to decline overtime due to decreasing gasoline consumption while other sources of CO_2 such as distillate and residual fuels are expected to increase overtime.

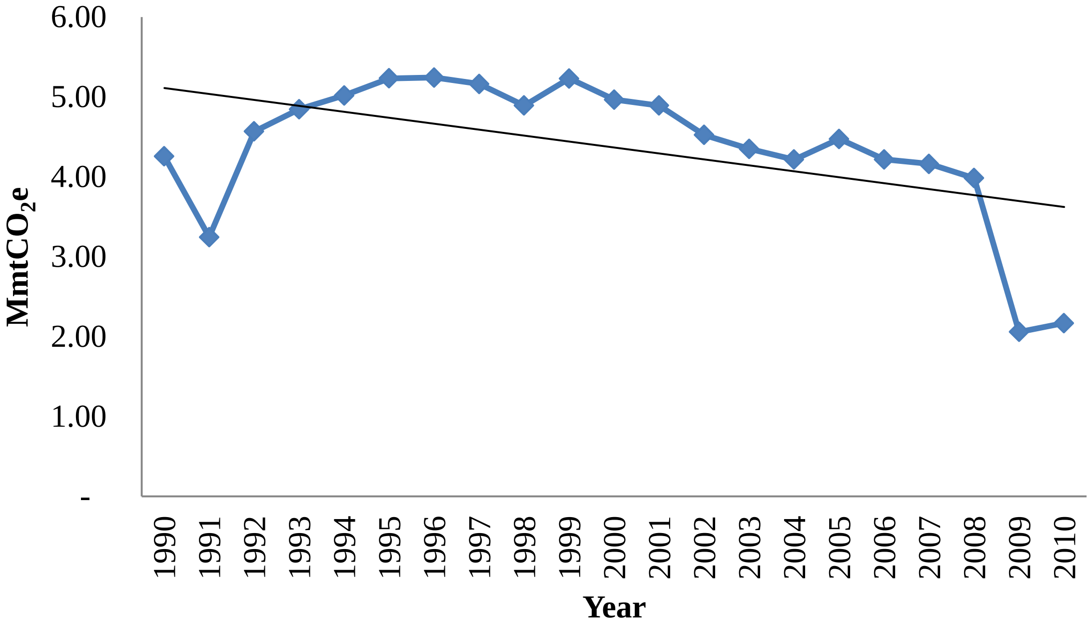
In addition, there are currently no fuel efficiency/economy requirements for most non-road vehicles such as boats and locomotives unlike gasoline motor vehicles, which further contribute to the increasing CO_2 emissions from the residual and distillate fuels. To incentivize reductions in CO_2 emissions from the transportation sector, CO_2 emissions from non-road sources will have to be addressed. This may require exploring and developing fuel efficiency programs that apply to engines that use residual and distillate fuels in Delaware.

4.3 INDUSTRIAL SECTOR

Emissions from the industrial sector as described in this report consist of GHG emissions from energy related activities such as fossil fuel combustion as well as GHG emissions associated with non-energy related industrial processes. The industrial sector is categorized as one of the big three sources of GHG emissions in Delaware. In 2010, GHG emissions from the industrial sector were 2.17 $MmtCO_2e$, making the industrial sector the 3rd largest emitter of GHGs representing approximately 16% of gross GHG emissions in Delaware. Cumulatively, the industrial sector added 91.72 $MmtCO_2e$ in GHG emissions to the atmosphere between 1990 and 2011.

Between 1990 and 2010, the industrial sector contributed approximately 91.72 $MmtCO_2e$ to the atmosphere. Figure 31 presents historical GHG emissions from the industrial sector from 1990 to 2010. Emissions peaked in 1999 at 5.23 $MmtCO_2e$, but decreased to 2.17 $MmtCO_2e$ in 2010, a decrease of approximately 58%. Overall emissions decreased by approximately 50% from 1990 to 2010. The rate of decrease was determined to be 0.07 $MmtCO_2e$ per year.

FIGURE 31. GROSS INDUSTRIAL SECTOR EMISSION FROM 1990 TO 2010



Industrial sector emissions in the 2010 GHG emissions inventory were categorized into two types namely *energy* and *non-energy related industrial sector emissions*. *Energy related industrial sector emissions* come from fossils fuel combustion in the industrial sector for purposes including electric power, heating, manufacturing and industrial equipment operation. While *non-energy related industrial sector emissions* are by-products of industrial and chemical processes. The industrial and chemical processes included in this report include titanium oxide as well as iron & steel production. Other sources of non-energy related industrial sector emissions include soda ash consumption as well as the use of ozone depleting substance (ODS) substitutes.

Reference Case Projection of GHG emissions from Industrial Sector

In addition to estimating historical GHG emissions, future GHG emissions were also estimated for sources within the industrial sector. Gross GHG emission from Delaware's industrial sector is expected to continue to increase based on a positive economic outlook.

FIGURE 32. GROSS INDUSTRIAL SECTOR EMISSION FROM 2011 TO 2030

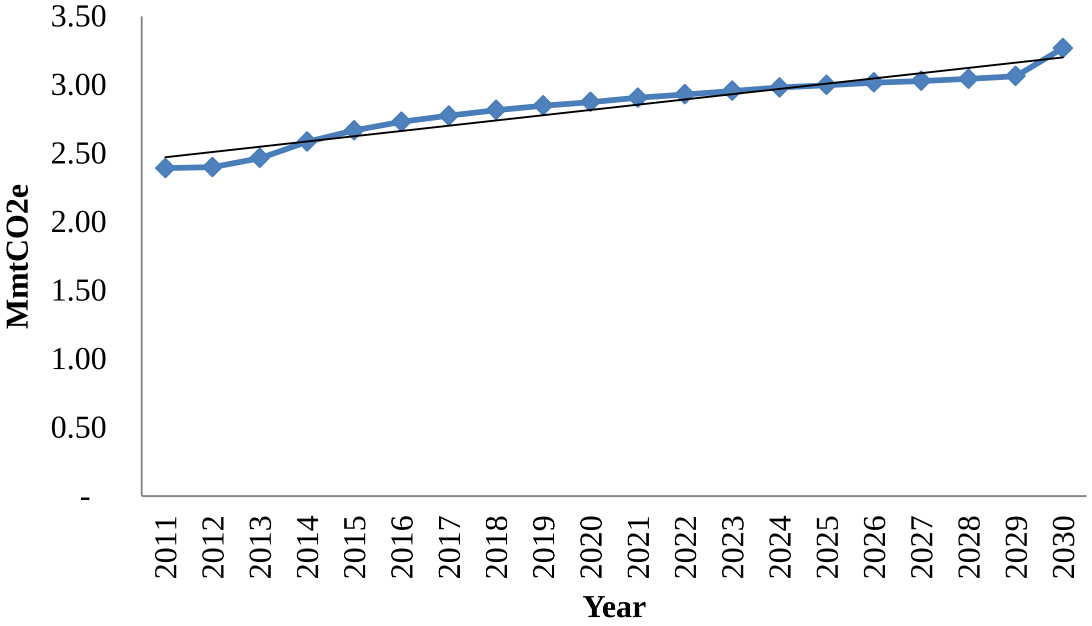
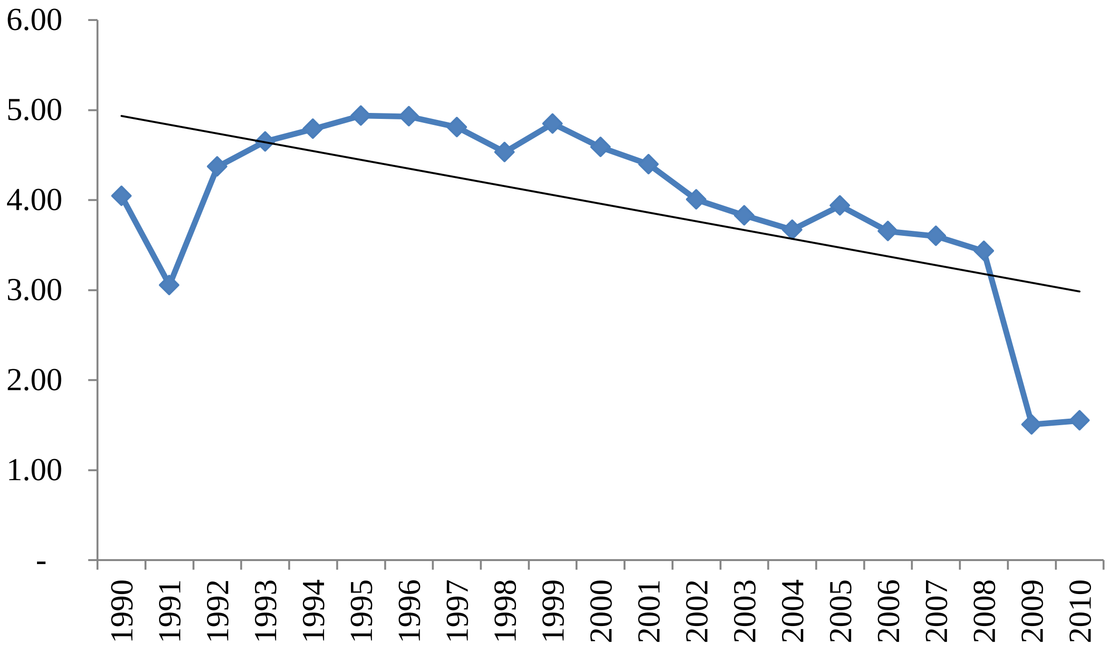


Figure 32 presents gross GHG emissions from the industrial sector activities from 2011 to 2030. Emissions are projected to increase from 2.39 MmtCO$_2$e in 2011 to 3.27 MmtCO$_2$e. This is a projected increase of approximately 37% at the 0.04 MmtCO$_2$e per year.

4.3.1 Energy related Industrial Sector Emissions

Energy related industrial sector emissions added a cumulative amount of 83.14 MmtCO$_2$e in GHG emissions into the atmosphere between 1990 and 2010. Figure 33 present's emission estimates for energy related industrial sector activities that require fossil fuel combustion. Industrial emission from this category trended downward with fluctuations from 4.05 MmtCO$_2$e in 1990, to 1.55 MmtCO$_2$e in 2010 at the rate of 0.098 MmtCO$_2$e per year. This was a decrease of approximately 62%. Emissions peaked in 1995 at 4.94 MmtCO$_2$e, and decreased to 2008 at 3.43 MmtCO$_2$e. This was followed by a significant decrease to 1.55 MmtCO$_2$e in 2010, a decrease of approximately 55%. This decrease in emissions correlates with significant decline in petroleum fuel usage in the industrial sector due to the closure of major industrial facilities including Delaware's refinery[58], Chrysler as well as General Motors.

FIGURE 33. ENERGY RELATED INDUSTRIAL SECTOR EMISSIONS



Methodology

The primary GHG of concern from *energy-related industrial sector emissions* are CO_2, N_2O and CH_4 from fossils fuel combustion. Greenhouse gas emissions from fossil fuel combustion in the industrial sector are calculated by first subtracting non-energy consumption multiplied by carbon storage factors from the energy consumption for each fuel type. The resulting combustible consumption for each fuel is then multiplied by a carbon content coefficient and by the percentage of carbon oxidized during combustion ("combustion efficiency"). The resulting fuel emissions, in pounds of carbon, are converted to short tons of carbon and million metric tons of carbon equivalent (MmtCE), then to $MmtCO_2e$. Equation 5 provides the basic method for estimating the emissions from the combustion of fossil fuels in the industrial sector.

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[58] The refinery, under the Valero Energy Corporation was shutdown in 2009 but later reopened in the spring of 2011 under new management, PBF Energy Partners.

EQUATION 5. ENERGY RELATED INDUSTRIAL SECTOR EMISSIONS

Emissions = Total Consumption – [Non Energy Consumption x Carbon storage Factor] × Emission Factor × Combustion Efficiency

FIGURE 34. 2010 ENERGY RELATED INDUSTRIAL SECTOR EMISSIONS BY FUEL

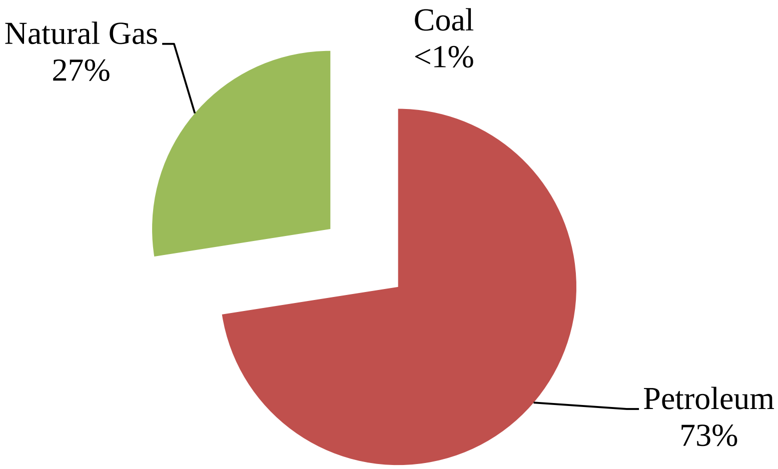
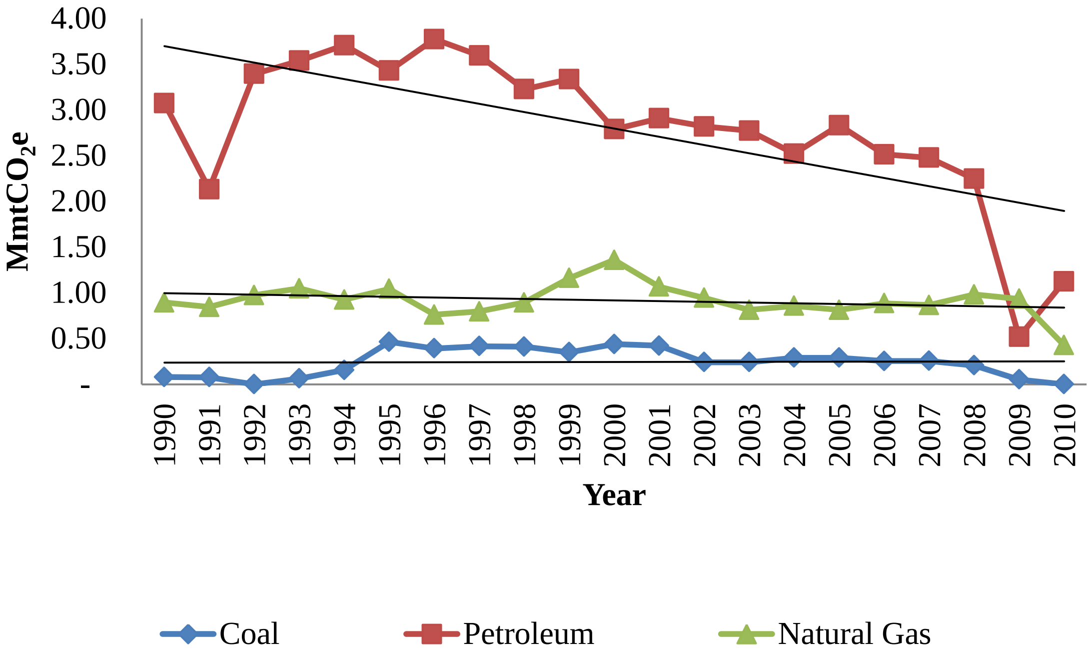


Figure 34 breaks down the energy related industrial sector emissions in 2010 by fuel type. The chart shows petroleum combustion is the largest source of GHG emissions representing approximately 73% of gross energy related industrial sector emissions. This was followed by natural gas, which represented approximately 27%, and coal with less than 1%.

Figure 35 breaks down the non-energy related industrial sector emissions from 1990 to 2010 by fuel type. Emissions form petroleum combustion in the industrial sector has been the largest source of GHG emissions from this industrial sector. Figure 35 shows that emissions declined with fluctuations from 1990 to 2010. Carbon dioxide emissions from petroleum peaked in 1996 at 3.78 $MmtCO_2e$, but decreased significantly with fluctuations to 2.25 $MmtCO_2e$ in 2008, a decrease of approximately 40%.

There was a sharp decrease in emissions from petroleum fuels from to 2.25 MmtCO$_2$e in 2008 to 0.52 MmtCO$_2$e In 2009 as Figure 35 presents. However, in 2010, GHG emissions later increased to 1.13 MmtCO$_2$e as Figure 35 presents.

FIGURE 35. GHG EMISSIONS FROM INDUSTRIAL SECTOR FFC BY FUEL TYPE



In general, GHG emissions from petroleum fuel use in *energy-related industrial sector activities* declined by approximately 63% from 1990 to 2010. The sharp decline in petroleum emissions corresponds with the economic recession, which started in 2007. The impact of the recession on Delaware's industrial sector contributed to industrial facility closures such as Valero, Chrysler and General motors. This led to sharp decreases in petroleum consumption in the industrial sector, thereby reducing GHG emissions. The rate of decrease in GHG emissions from petroleum consumption was determined to be 0.09 MmtCO$_2$e per year.

As presented in Figure 35, natural gas combustion was the second largest source in the industrial sector. While emissions fluctuated between 2.0 MmtCO$_2$e and 0.40 MmtCO$_2$e, but remained relatively flat. Emissions decreased from 0.89 in 1990 to 0.43 in 2010, a decrease of approximately 52%. The rate of decrease in GHG emissions from natural gas consumption in the industrial sector was determined to be 0.01 MmtCO$_2$e per year. Emissions were expected to rise again from the 2010 estimate. Greenhouse gas emissions from coal combustion in the industrial sector were the lowest because coal was the least consumed fuel in the industrial sector. Emission fluctuated between 0.50 and 0.00 from 1990 to 2010. In 1992 and 2010, emissions estimates for GHG emission from coal combustion were zero according to the SIT. Table11 provides estimates for energy related industrial sector emissions by GHG and fuel type. As the table shows, petroleum consumption was the largest source of GHG emissions from the industrial sector, and CO$_2$ was the largest GHG emitted.

TABLE 11. ESTIMATES OF GHG EMISSIONS FROM INDUSTRIAL MmtCO$_2$e

Fuel Type	1990	1995	2000	2005	2010
Petroleum	**3.07**	**3.43**	**2.79**	**2.83**	**1.13**
CO_2	3.07	3.42	2.78	2.82	1.12
N_2O	0.006	0.007	0.006	0.006	0.002
CH_4	0.002	0.002	0.002	0.002	0.001
Natural gas	**0.89**	**1.04**	**1.36**	**0.81**	**0.43**
CO_2	0.89	1.04	1.36	0.81	0.43
N_2O	0.000	0.001	0.001	0.00	0.00
CH_4	0.002	0.002	0.002	0.002	0.00
Coal	**0.08**	**0.46**	**0.44**	**0.29**	**0.00**
CO_2	0.08	0.46	0.44	0.29	0.00
N_2O	0.000	0.002	0.002	0.001	0.00
CH_4	0.000	0.002	0.002	0.001	0.00
Total	**4.05**	**4.94**	**4.59**	**3.94**	**1.55**

Reference Case Projection of GHG Emissions from Energy-related Industrial Sector Emissions: Projected *energy-related industrial sector emissions* were estimated by the basic methodology described in Equation 5. The projected estimates were calculated using the EPA's projection tool based on historical emissions[59]. The activity data used was based on the EIA's energy outlook data, and the emissions factors used were EPA's default emissions factors.

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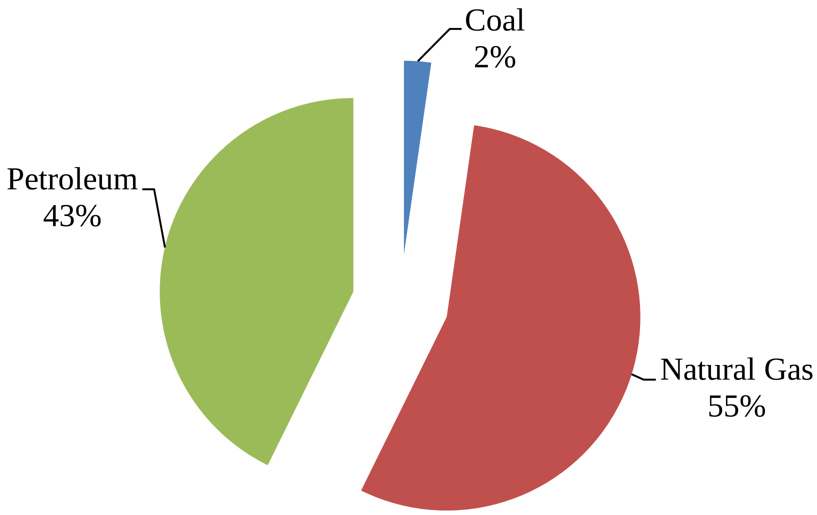
[59] Historical emissions were imported from the EPA's state inventory tool.

FIGURE 36. 2030 ENERGY-RELATED INDUSTRAIL SECTOR EMISSIONS



Between 2011 and 2030, cumulative *energy-related industrial sector emission is projected to be* 41.45 MmtCO$_2$e, with a projected emission of 2.35 MmtCO$_2$e in 2030. Figure 36 presents a breakdown of 2030 GHG emissions from *energy-related industrial sector emissions* by fuel type. Greenhouse gas emissions associated with natural gas consumption in the industrial sector is projected to represent approximately 55% in 2030. This will be followed by GHG emissions from petroleum consumption, which will represent approximately 43%, and GHG emissions from coal, a distant third with 2% as presented in Figure 36.

Figure 37 presents *energy-related industrial sector emissions* from 2011 to 2030. The data shows that emissions from this source category are projected to maintain an upward trend in the future. Emissions are projected to increase from 1.78 MmtCO$_2$e in 2011 to 2.35 MmtCO$_2$e in 2030, an increase of approximately 32%. The rate of increase was determined by trend line analysis to be 0.022 MmtCO$_2$e per year.

FIGURE 37. PROJECTED ENERGY RELATED INDUSTRIAL SECTOR EMISSIONS

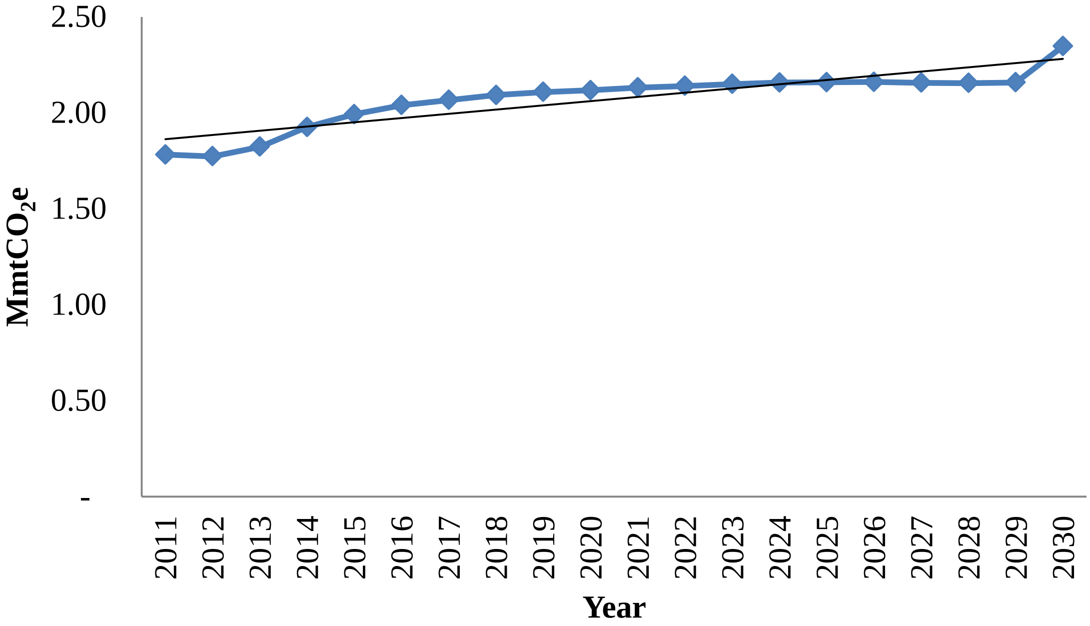


FIGURE 38. ENERGY RELATED INDUSTRIAL EMISSIONS BY FUEL TYPE

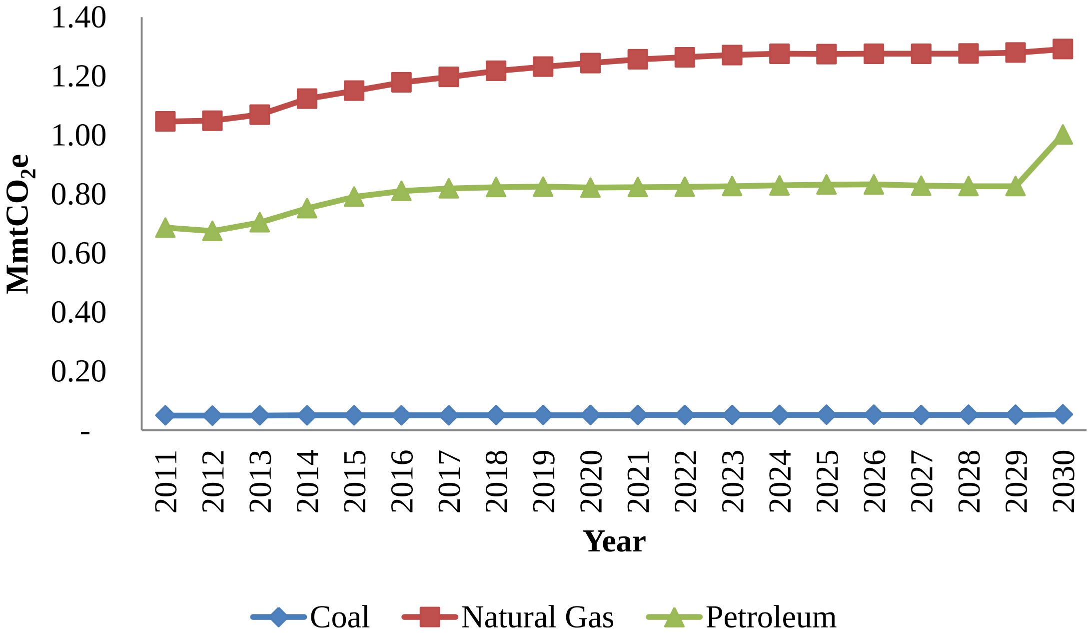


Figure 38 presents a breakdown of *energy-related industrial sector emissions* by fuel type. Natural gas emission is expected to contribute the largest share of GHG emissions in this source category. Greenhouse gas emissions from natural gas consumption in the industrial sector will increase from 1.05 $MmtCO_2e$ in 2011 to 1.29 $MmtCO_2e$ in 2030, an increase of approximately 23%.

The projected increase of natural gas emissions from the industrial sector is based on the growing demand for natural gas, which was reflected in the EIA's Annual Energy Outlook 2013. According to the EIA, natural gas consumption in the industrial sector is projected to increase by an average of 0.5 percent per year from 2011 to 2040. Industrial output is expected to grow as the energy-intensive industries take advantage of relatively low natural gas prices, particularly through 2025. After 2025, growth in the industrial sector is expected to slowdown in response to rising prices and increased international competition[60]. This is why natural gas emissions as Figure 38 levels off in 2025, but still continues to increase modestly.

Greenhouse gas emission from petroleum consumption in this source category is also projected to increase. As Figure 38 presents, emissions data projects a modest increase from 2011 to 2015 of 0.1 $MmtCO_2e$. Petroleum emissions are expected to remain flat from 2016 through 2029, and then there will be an increase from 0.83 $MmtCO_2e$ in 2029 to 1.0 $MmtCO_2e$ in 2030. On the other hand, coal is not projected to have any significant impact on *energy-related industrial sector emissions*. As Figure 38 presents, the SIT projects that GHG emissions from coal combustion in this sector is expected to remain flat, with an average of 0.05 $MmtCO_2e$ from 2011 to 2030.

4.3.2 Non-energy related Industrial Sector Emissions

The GHG emissions that were estimated under n*on-energy related industrial sector emissions* included GHG emissions from industrial processes that did not include fossil fuel combustion. From 1990 to 2010, emissions from industrial processes released approximately 8.58 $MmtCO_2e$ into the atmosphere, which is significantly lower when

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[60] 2013 EIA Annual Energy Outlook: http://www.eia.gov/forecasts/aeo/pdf/0383(2013).pdf

compared to *energy related industrial sector emissions,* with an amount of 83.14 $MmtCO_2e$. Figure 39 present gross GHG emissions from combined industrial process sources. Gross emissions increased from 0.21 $MmtCO_2e$ in 1990 to 0.62 $MmtCO_2e$ in 2010, an increase of approximately 195%. The rate of increase in GHG emissions from industrial processes was determined to be 0.02 $MmtCO_2e$ per year.

Delaware's *non-energy related industrial sector emission* sources and associated GHGs categorized in the 2010 GHG emission inventory include:

- Ozone Depleting Substances (ODS)
- Titanium Dioxide Production (CO_2)
- Iron and Steel production (CO_2)
- Oil Refining (CH_4) and Natural Gas transmission (CH_4)
- Soda Ash Consumption (CO_2)

FIGURE 39. NON-ENERGY RELATED INDUSTRIAL SECTOR EMISSIONS

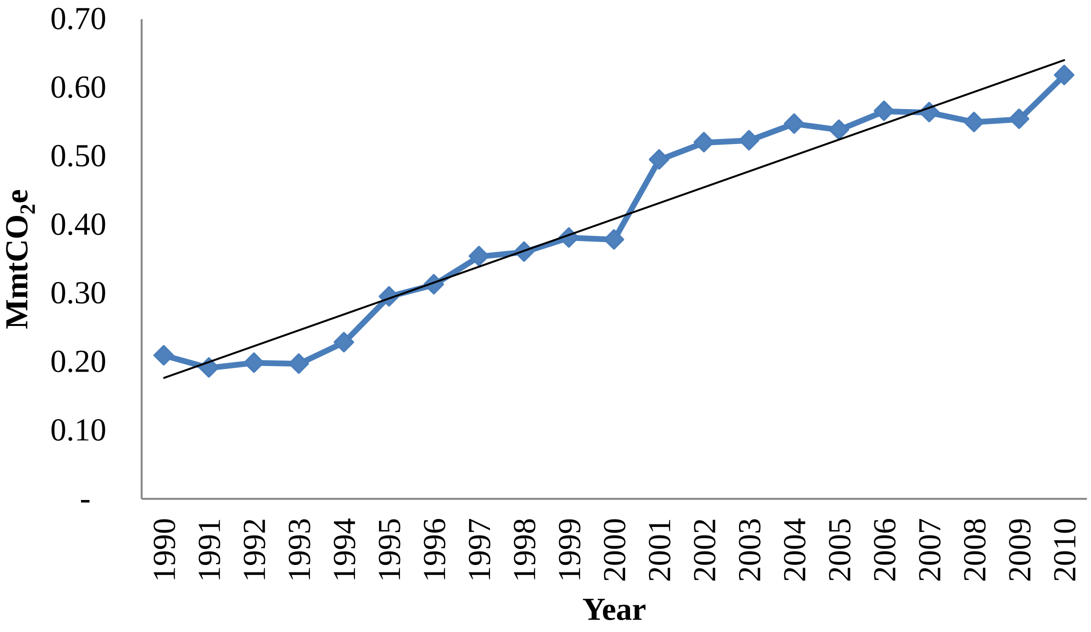

FIGURE 40. 2010 INDUSTRIAL PROCESS EMISSIONS

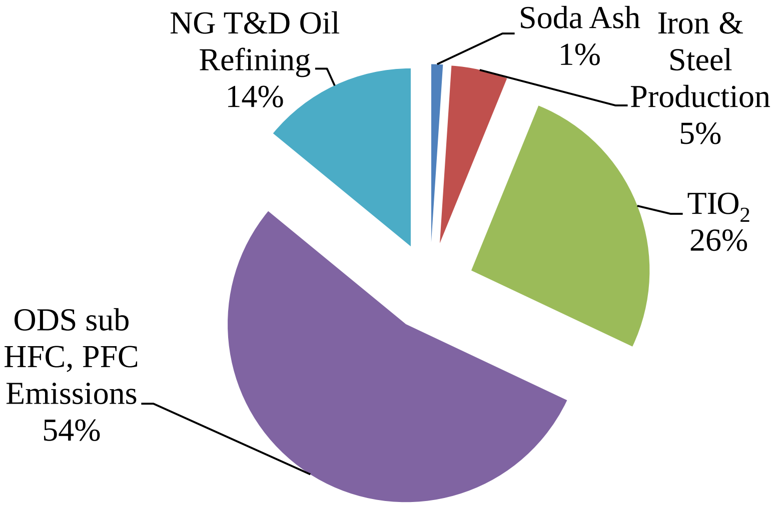

FIGURE 41. CO$_2$e EMISSIONS BY NON-ENERGY RELATED INDUSTRIAL PROCESSES

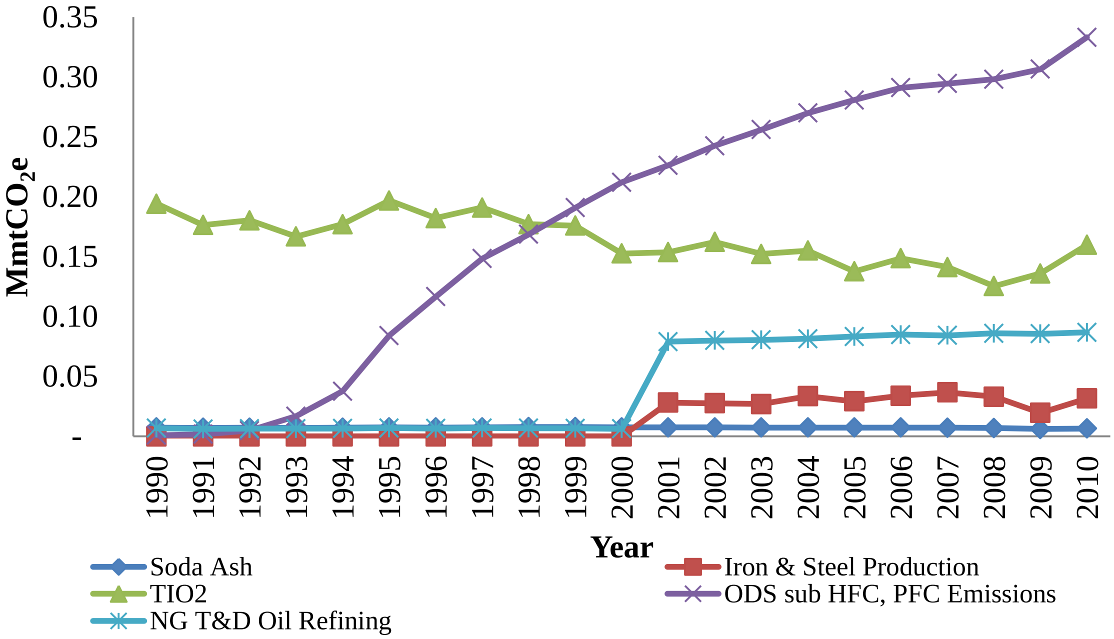

Figure 40 presents the GHG emissions (non-combustion) from the industrial process in 2010. Ozone depleting substance (ODS) substitutes had the largest contribution to industrial process emissions representing approximately 54% of total CO$_2$e emissions.

This is followed by CO_2 emissions from titanium dioxide (TiO_2) production, which represented approximately 26%, CH_4 emissions from oil refining, represented approximately 14% of gross GHG emissions from *non-energy related industrial sector emissions*. Methane emissions from oil refining and natural gas T&D represented approximately 5% and CO_2 emissions from soda ash consumption were the lowest with approximately 1%. Historically emissions for ODS consumption exceeded all other emissions in 1998 when it surpassed emissions from TiO_2 production as Figure 41 shows.

4.3.2.2 Ozone Depleting Substance Substitutes: The GHGs associated with ozone depleting substances (ODSs) substitute emissions include hydro fluorocarbons (HFCs) and perfluorocarbons (PFCs). Hydro fluorocarbons (HFCs) are used primarily as alternatives to several classes of ozone depleting substances. 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. Ozone depleting substances are being phased-out according to the Clean Air Act (CAA) consistent with the 1990 Montreal Protocol.

The U.S. phase-out has operated by reducing in stages the amount of ODS that may be legally produced or imported into the U.S. The Parties to the Montreal Protocol have changed the phase-out schedule over time, through adjustments and amendments, and EPA has also accelerated the phase-out under its Clean Air Act authority. As the phasedown of virgin ODS continues, ODS uses will increasingly resort to reclaimed material or alternatives.

Although their substitutes, HFCs and PFCs, are not harmful to the stratospheric ozone layer, they are powerful greenhouse gases. These substitutes are also 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[61]. 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. The emission of ODS substitutes come from many point sources, which makes the estimation of emissions difficult.

EQUATION 6. EMISSION EQUATION FOR ODS SUBTITUTES

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

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

In 2010, gross ODS substitute GHG emission from this source represented approximately 54% of *non-energy related industrial sector emissions* as Figure 40 presents. Between 1990 and 2010, ODS substitute added a cumulative amount of 3.78 $MmtCO_2e$ in GHGs emissions to the atmosphere. Figure 42 shows that ODS substitute emissions from this subcategory increased from $8.7x10^{-4}$ $MmtCO_2e$ (888 $mtCO_2e$) in 1990 to 0.33 $MmtCO_2e$ (333,211 $mtCO_2e$) in 2010, an increase of approximately 37,424%.

ODS substitute emission started slowly from $8.7x10^{-4}$ $MmtCO_2e$ in 1990 to 0.04 $MmtCO_2e$ 1994. ODS substitute emissions then picked up between 1995 and 2006, rising from 0.08 $MmtCO_2e$ in 1995 to 0.29 $MmtCO_2e$ in 2006 as represented by the concave profile in Figure 42. This indicated an increase in the consumption of ODS substitutes due to economic growth during that period. A slowdown in emissions is observed between 2007 and 2010, with emissions increasing from 0.29 in 2007 to 0.33 in 2010. This may be a result of declining economic growth during that period.

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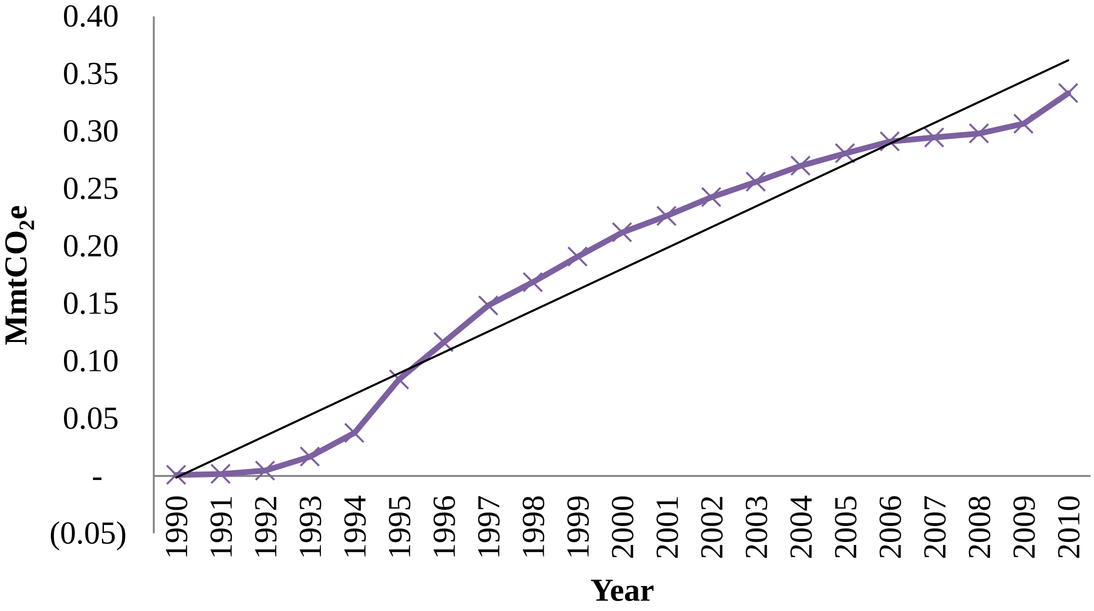
[61] The Chemical Manufacturers Association (Washington, D.C.), Alliance for Responsible CFC Policy (Arlington, VA) Grant Thornton Consulting (Washington, D.C.)

FIGURE 42. HISTORICAL ODS SUBSTITUTES EMISSIONS



The rate of annual increase was determined to 0.0182 $MmtCO_2e$ per year. This significant increase in ODS substitutes emissions can be attributed to the increased application of ODS substitutes in many household products since 1990. As Delaware's population steadily increased between, the number of households that us products that contain ODS substitutes also increased. Delaware's ODS emissions trend as provided in Figure 42 is consistent with the National GHG emissions trend from the consumption of ODS substitutes. According to the U.S EPA 2011 GHG inventory, ODS substitute emissions increased by 38,100% from 1990 to 2010.

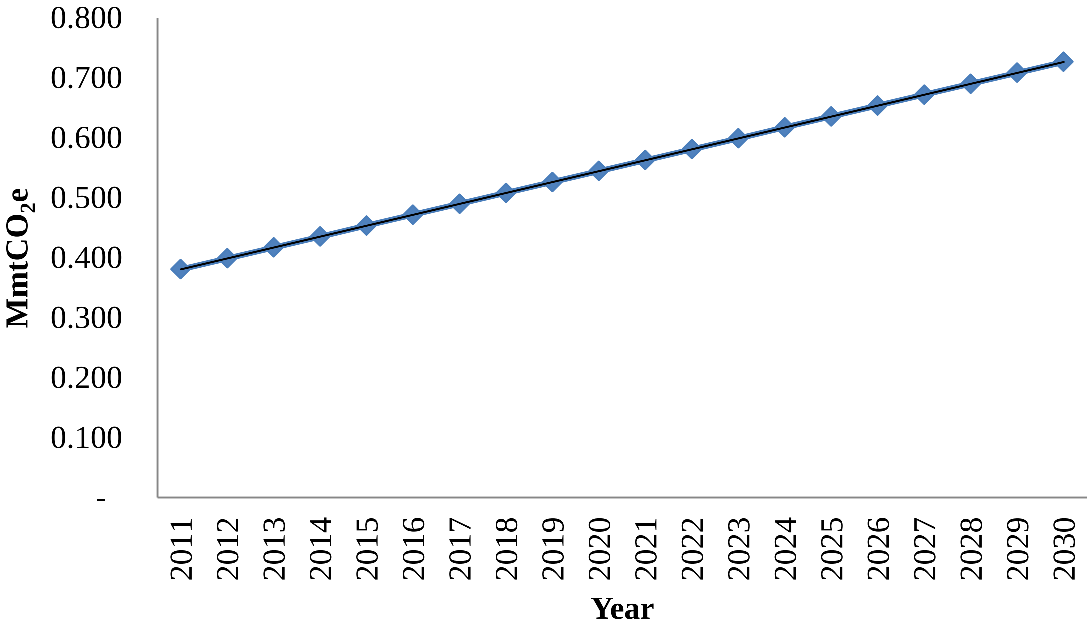
Reference Case Projections for ODS Substitutes Emissions

Projection emissions for ODS substitutes were estimated based on historical emission trends. This is because projected emissions could not be calculated using the EPA's projection tool due to a glitch in the tool. Using the trend line equation of ODS substitutes historical emissions, GHG emission from this source category was projected from 2011 through 2030. The trend line equation, with its slope as the annual rate of emission, allows the incremental estimation of annual emissions over a time horizon of 20 years.

Cumulative GHG emissions from ODS substitutes is projected to be 11.07 $MmtCO_2e$. Figure 43 presents projected emissions from ODS substitutes from 2011 to 2030. Projection analysis shows that the emissions trend for ODS substitutes is expected to have a linear trajectory as represented in Figure 43.

Emissions from this sources category are projected to increase from 0.381$MmtCO_2e$ in 2011 to 0.727 $MmtCO_2e$ in 2030, an increase of approximately 91%. The annual rate of increase is projected to be 0.0182 $MmtCO_2e$ per year. Projection analysis for this source category indicate that as long as consumption levels for ODS substitute in applications such as refrigeration and air conditioning equipment, aerosols, solvent cleaning, fire extinguishing, foam blowing, and sterilization remain the same, GHG emissions will continue to increase. To reduce emissions, ODS substitutes that have no greenhouse gas effects are needed.

FIGURE 43. PROJECTED GHG EMISSIONS FROM ODS SUBSTITUTES



4.3.2.3 CO_2 Emissions from the Production of Titanium Dioxide

Titanium dioxide (TiO_2) is a metal oxide commonly used as white pigment in paint manufacturing, paper, food coloring, plastics, sunscreen and ceramic applications[62]. 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[63]. Titanium dioxide 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 is a source of 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[64]. In the chloride 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[65] petroleum coke, (CPC) is used for the chloride process. The chloride process is based on the following chemical reaction:

EQUATION 7. GENERAL EMISSION EQUATION FOR ODS

Step 1: $2FeTiO_3 + 7Cl_2 + 3C \Rightarrow 2TiCl_4 + 2FeCl_3 + 3CO_2$

Step 2: $2TiCl_4 + 2O_2 \Rightarrow 2TiO_2 + 4Cl_2$

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 ^{o}C and the resulting TiO_2 is calcinated to remove residual chlorine and any hydro chloric acid that may have formed in the reaction.

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

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

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

[65] 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.

Methodology

The Division of Air Quality (DAQ) collected data[66] on Delaware's TiO_2 production capacity from the U.S Geological Survey to calculate CO_2 emissions from TiO_2 production in the DuPont Edge more facility. The data was based on 2009 USGS estimates. 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 EPA's GHG inventory for 2012.

EQUATION 8. CO_2 EMISSION EQUATION FOR TITANIUM DIOXIDE

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

Based the above equation, DuPont Edgemoore produced 109,049 metric tons (mt) of TiO_2 in 2010, which corresponds to 159,909 $mtCO_2e$ (0.16 $MmtCO_2e$). The amount of CO2 emissions generated from TiO_2 production in Delaware was approximately 19% of gross GHG emissions from industrial processes. Table 12 provides the results of the CO_2 emission estimates from TiO_2 production.

The production of TiO_2 in Delaware led to the emission of approximately 3.5 $MmtCO_2e$ into the atmosphere between 1990 and 2010. Overall, CO_2 emissions from TiO_2 production trended downward with minor fluctuations from 1990 to 2010 as Figure 44 presents.

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[66] 2009 USGS TIO2 Production Capacity Data

[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

TABLE 12. 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
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
2009	92,676	37,071	135,901
2010	109,049	43,619	159,909

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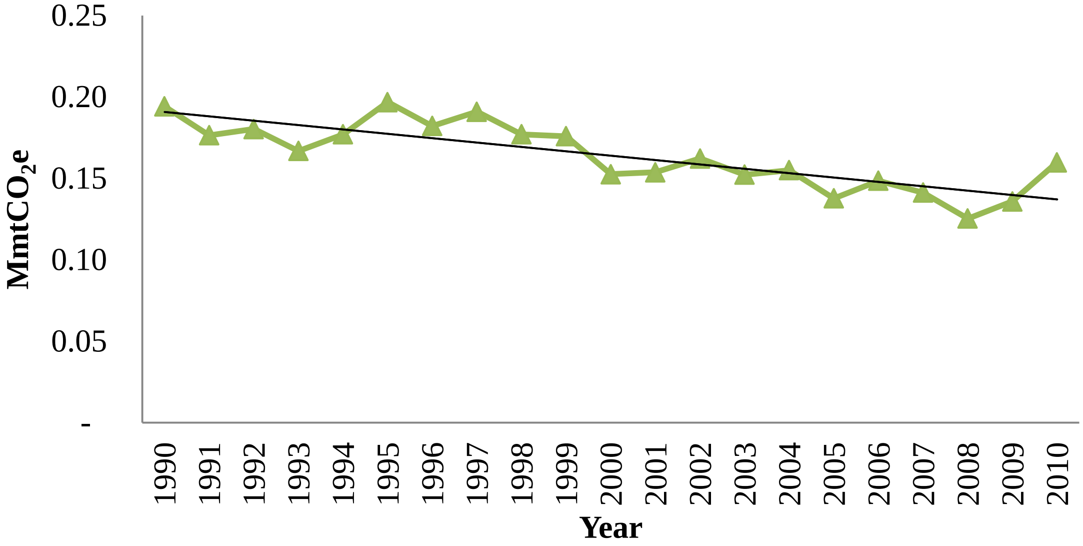
[70] Data based on the Annual Air Emission Inventory and Emission Statement Facility Report submitted to DAQ by DuPont Edgemoor.

[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.

FIGURE 44. HISTORICAL EMISSIONS FROM TITANIUM DIOXIDE PRODUCTION.

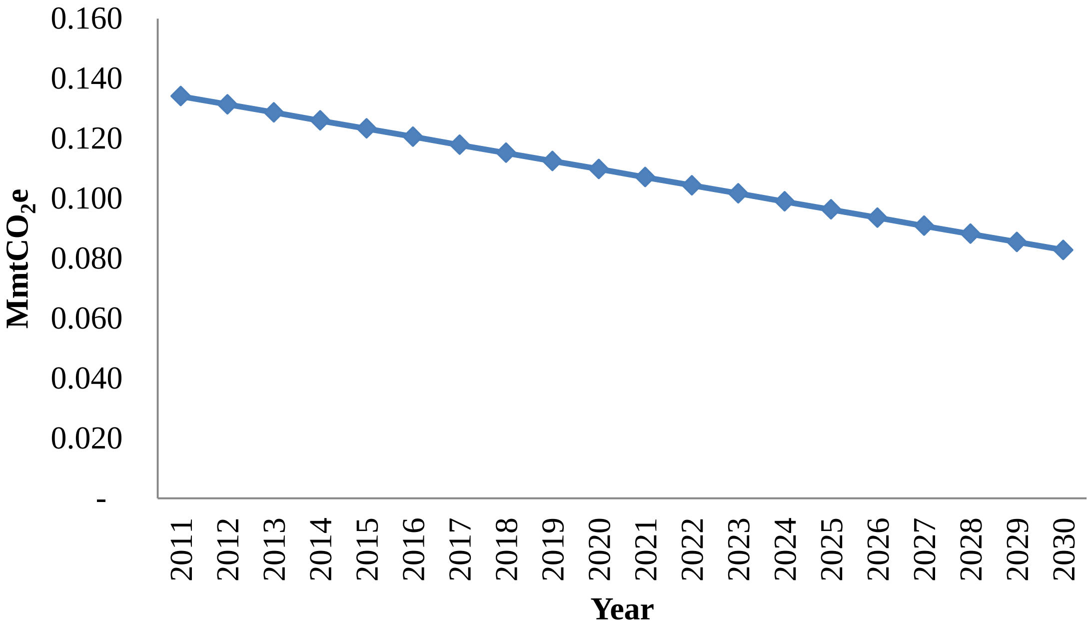


Carbon dioxide emissions went from 0.19 $MmtCO_2e$ (194,218 $mtCO_2e$) in 1990 to 0.16 $MmtCO_2e$ (159,909 $mtCO_2e$) in 2010, a decrease of approximately 18% at a rate of decrease 0.003 $MmtCO_2e$ (30,000$mtCO_2e$) per year.

Reference case projection of GHG Emissions from Titanium Dioxide Production: Projection GHG emissions for titanium dioxide (TiO2) production were estimated based on historical emission trends. As stated in section 4.3.2.2 under the reference case projection of ODS substitutes GHG emissions, projected emissions could not be calculated using the EPA's projection tool due to a glitch in the tool. Using the trend line equation of TiO2 historical emissions, GHG emission from this source category was projected from 2011 through 2030. The trend line equation, with its slope as the annual rate of emission, allows the incremental estimation of annual emissions over a time horizon of 20 years. The projection of GHG emissions from TiO2 production was based on the assumption that production will continue to decrease over time as historical data in Table 12 shows..

Greenhouse gas emissions from TiO2 production added a cumulative amount of 2.17 $MmtCO_2e$ between 2011 and 2030. Figure 45 presents projected GHG emissions from TiO2 production from 2011 to 2030. As observed, GHG emissions are projected to decrease from 0.134 $MmtCO_2e$ in 2011 to 0.083 $MmtCO_2e$ in 2003, a decrease of approximately 38%. The rate of annual decrease in emissions is projected to be 0.003 $MmtCO_2e$ per year.

FIGURE 45. PROJECTED GHG EMISSIONS FROM TIO2 PRODUCTION



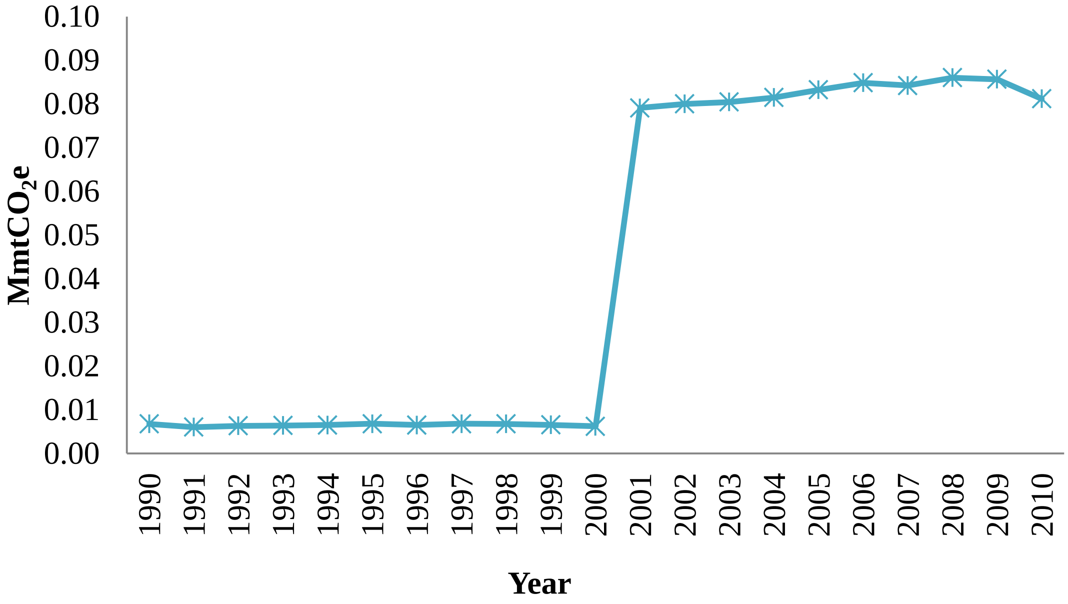
4.3.2.4. Methane Emissions from Natural Gas T&D and Oil Refining

The SIT groups emissions from natural gas transmission and oil refining under natural gas and oil systems. Natural gas emissions come from natural gas transmissions and distribution (T&D) lines, while oil refining emissions come from Delaware City refinery, the only refinery in Delaware.

Cumulatively, this source category added 0.90 $MmtCO_2e$ to the atmosphere between 1990 and 2010. According to Figure 40, the emissions from oil refining and natural gas T&D represented approximately 14% of gross emissions from industrial processes with a combined emission of 0.09 $MmtCO_2e$ (86,818$mtCO_2e$). Figure 46 present the historical emissions from natural gas T&D and oil refining in Delaware. Methane emission from these sources jumped from 0.01 in 2000 to 0.08 as shown by Figure 46 because there was no emission data reported for natural gas T&D in

Delaware by the SIT from 1990 to 2000. As a result, zero emission for natural gas transmissions were reported for those years.

FIGURE 46. METHANE EMISSIONS FROM NATURAL GAS TRANSMISSIONS AND OIL REFINING



The following sections summarize the GHG emissions associated with both oil and natural gas emissions sources in Delaware.

Natural Gas Transmissions and Distribution: Methane emissions from natural gas T&D comes from leaks in natural gas transmissions and distribution piping systems. These T&D systems have operated and maintained by four utilities in Delaware over the last 10 years. The utilities include Chesapeake Utilities Corporation, Delmarva Power & Light Company, Eastern Shore Natural Gas Company and Delaware Solid Waste Authority (DSWA)[72]. The natural gas pipeline systems were characterized into two:

- *Local distribution lines*: These lines include service and main lines. They are distribution pipelines that are used by local distribution companies to transmit

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[72] As of 2011, only Delmarva Power & light Company and Chesapeake Utilities Corporation operate and maintain transmissions lines in Delaware (based on data submitted by Pipeline and Hazardous Material safety Administration).

natural gas to end-users. The pipelines are extensive networks of 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. According to the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA)[73] , Delaware currently, has approximately 3,069 miles of main lines (280 miles are regulated by the Federal Energy Regulatory Commission), as well as 161,801 service lines with average service lengths 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. According to the PHMSA, Delaware currently has approximately 411 miles of transmission lines for natural gas running through the State.

Methodology

Emissions from Natural Gas T&D are calculated as the sum of emissions from transmissions and distribution pipelines and end services. The activity data for each

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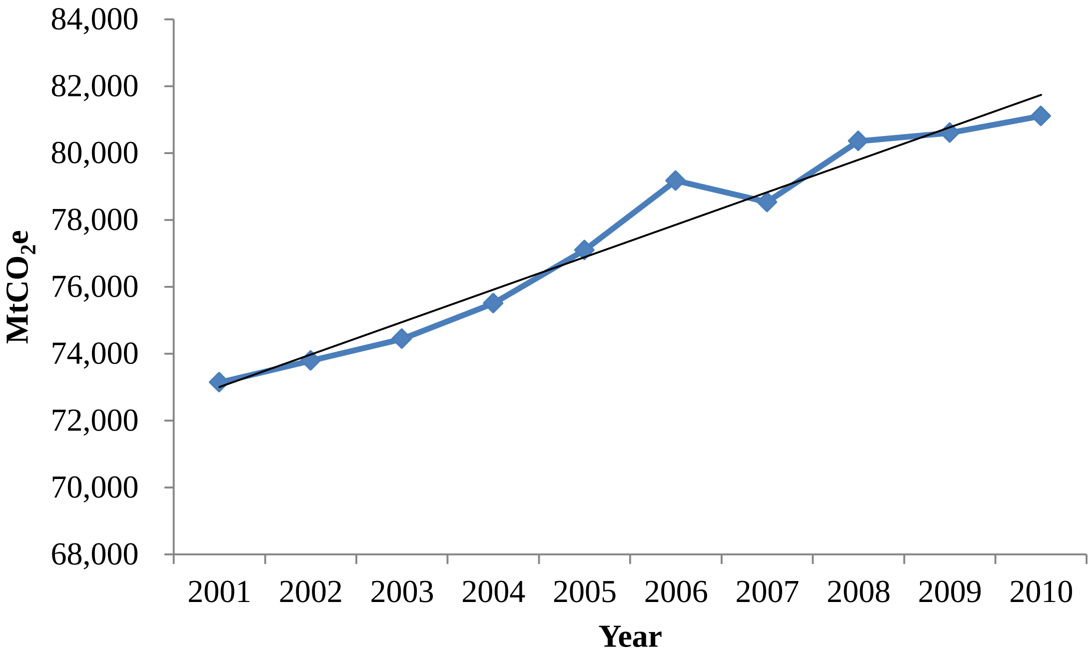
[73] http://www.phmsa.dot.gov/pipeline/library/data-stats

type of pipeline (miles of pipeline) is multiplied by the corresponding emission factor. The number of services is multiplied by a general emission factor and type-specific emission factors. Pipeline and service emissions are then converted to metric tons of CO_2 equivalent and metric tons of carbon equivalent, and summed. Equation 9 provided the general method of estimation.

EQUATION 9. EQUATION FOR NATURAL GAS TRANSMISSION

Emissions ($MmtCO_2e$) = Activity Data (Miles of Transmission Lines) × Emission Factor (mt CH_4/miles)

FIGURE 47. METHANE EMISSIONS FROM NATURAL GAS T&D



The activity data was requested from the Pipeline and Hazardous Material Safety Administration (PHMA). The PHMSA submitted miles of T&D pipeline in Delaware from 2001 to 2010. Natural gas T&D has released a total 904,000 $mtCO_2e$ (0.904 $MmtCO_2e$) of CH_4 into the atmosphere between 2001 and 2010. Figure 47 presents the emissions from natural gas distribution from 2001 to 2010. As Figure 47 presents, CH_4 emissions trended upward from 2001 to 2010 at the rate of 970 $mtCO_2e$ per year.

Emissions increased from 73,143 mtCO_2e in 2001 to 81,107 mtCO_2e in 2010, which was a 10% increase. Methane emissions from natural gas T&D in Delaware has been increasing in line with increasing miles of T&D pipelines. According to data received from the PHMSA, total T&D miles increased from 2,761 miles in 2001 to approximately 3,480 miles in 2011, an increase of approximately 26%.

Oil Refining and Transportation: Methane emissions from the refining of crude oil are the focus in this source category. Delaware City Refinery is the only source of CH_4 in this source category. 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 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.

Methane emissions within the refinery occur due to venting, fugitive and combustion emissions. Refinery systems blow-downs[74] 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 2010, CH_4 emissions from Delaware City Oil refinery released approximately 5,712 mtCO_2e (>0.01MmtCO_2e)[75] of CH_4 into the atmosphere.as a result oil refining operations. The CH_4 emission amount in 2010 was estimated based data collected from the Petroleum Administration for Defense District 1 (PADD1).

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[74] 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.

[75] 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

Methodology

The activity factor (number of barrels of oil) for each sector is multiplied by the sector-specific emission factor. These emissions are then converted to metric tons of CO_2 equivalent and metric tons of carbon equivalent, and summed. Note that default emission factors are available through 2010. Methane emissions from crude oil refining in Delaware was estimated using Equation 10, the general emission equation for petroleum systems. In addition to accounting for CH_4 emissions associated with refining crude oil, the 2010 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.

EQUATION 10. EMISSION EQUATION FOR PETROLEUM SYSTEMS

$$\text{Emissions (MmtCO}_2\text{e)} = \text{Activity Data ('000 barrels)} \times \text{Emission Factor (kg CH}_4\text{/'000 barrels)} \div 1{,}000 \text{ (kg/mt)} \times 21 \text{ (GWP)} \div 106 \text{ (mt/Mmt)}$$

The activity data used was barrels of oil refined in the State. The activity data was based on DAQ calculated the amount of oil refined in Delaware by using data collected from the PADD 1[76].

Figure 48 present CH_4 emissions from oil refining and transportation. Emissions trended downward with slight fluctuations from 6,791 $mtCO_2e$ in 1990 to 5,036 $mtCO_2e$ in 2009. This was a decrease of approximately 26% at the rate of approximately 60.0 $mtCO_2e$ per year. In 2010, CH_4 emission from the refinery was zero due to the shot down in operations. In 2009, the refinery was shut down permanently as part of cost-cutting measures by Valero Energy Corporation. However in 2010 the Refinery was purchased by PBF Energy[77].

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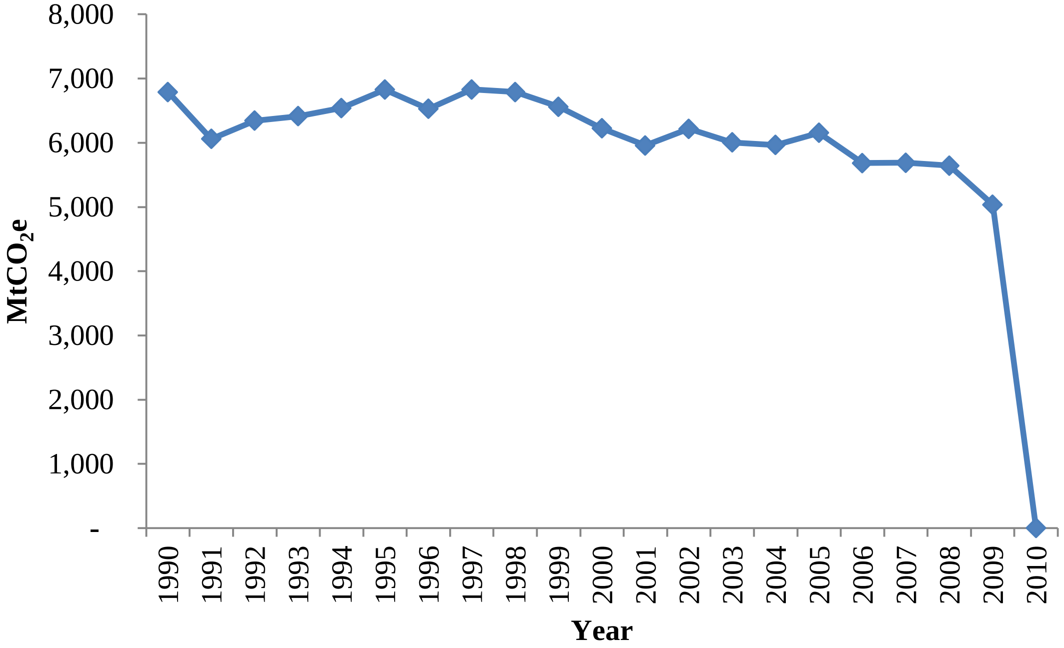
[76] The PADDs were created during World War II under the Petroleum Administration for War to help organize the allocation of fuels derived from petroleum products, including gasoline and diesel (or "distillate") fuel. They are currently used mainly to collect oil production and refining data in the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

[77] The refinery was expected to reopen in PBF Energy the restarted refinery operations 2011, processes heavy sour crude.

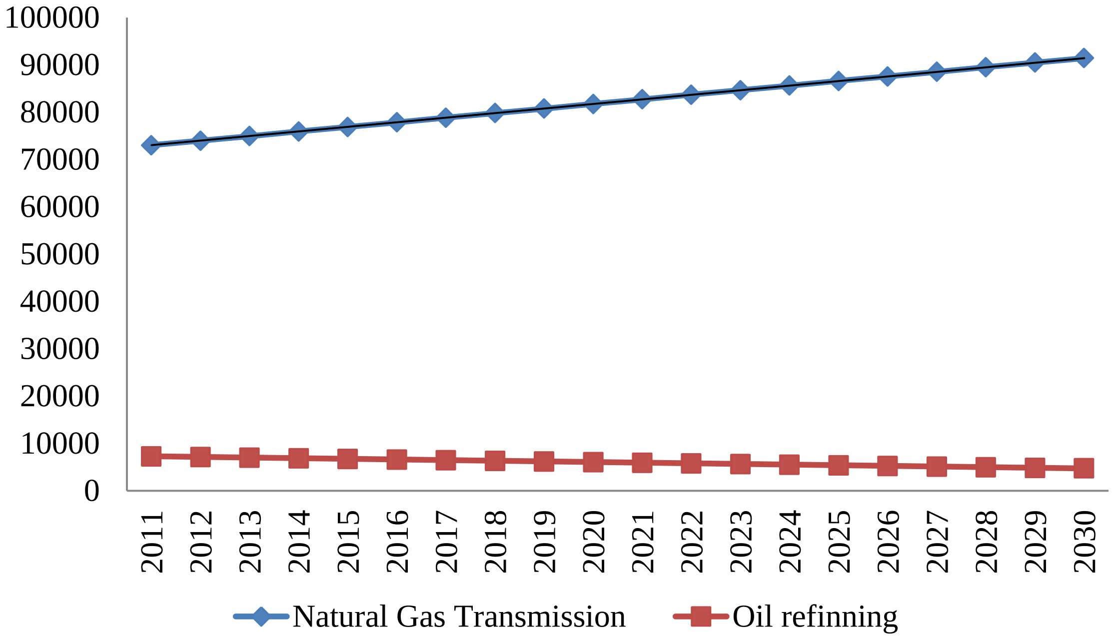
FIGURE 48. METHANE EMISSIONS FROM OIL REFINING AND TRANSPORTATION IN DELAWARE



Reference Case Projection for Natural Gas Transmissions and Oil Refining GHG Emissions: The Projection GHG emissions from natural gas transmissions and oil refining were estimated based on historical emissions. Using the trend line equation of historical emissions, GHG emission from this source category was projected from 2011 through 2030. The trend line equation, with its slope as the annual rate of emission, allows the incremental estimation of annual emissions over a time horizon of 20 years.

Between 2011 and 2030, this source category is projected to add 0.90 MmtCO$_2$e to the atmosphere Figure 49 presents projected GHG emissions from natural gas transmissions and oil refining. As observed, projection analysis projects an upward trend that is linear for GHG emissions from natural gas transmissions. Natural gas GHG emission is projected to increase from approximately 73,008 mtCO$_2$e in 2011 to approximately 91,447 mtCO$_2$e in 2030, an increase of approximately 25%. Conversely, emission from the refining process is expected to diminish with time based on historic emission. Figure 49 presents projected GHG emission from oil refining. Oil refining emissions is projected to decrease from approximately 7,253 mtCO$_2$e in 2011 to 4,716 mtCO$_2$e in 2030, a decrease of approximately 35%. However, the downward trend future GHG emissions from oil refining are expected to mirror closely historic emissions as presented in Figure 48 because the amount of oil refined fluctuates annually.

FIGURE 49. PROJECTED METHANE EMISSIONS FROM OIL REFINING AND TRANSPORTATION



4.3.2.5 Iron & Steel production

Steel is produced 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 owned by Evraz Claymont Steel, 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[78] 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 2010, the CO_2 emission from Evraz was 31,564 $mtCO_2e$; this was only 5% of non-energy related industrial process emissions as shown in Figure 40.

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 [79] 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 2001 to 2010 only. The data was imported into the SIT to estimate CO_2 emissions. The following general equation was applied to estimate CO_2 emissions:

EQUATION 11. GENERAL EQUATION FOR ESTIMATING CO_2 FROM STEEL PRODUCTION

$$CO_2\ emission = Steel\ Production \times Emissions\ Factor$$

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[78] 2006 IPCC Guidelines for National Greenhouse Gas Inventories 4.1

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

Analysis of Historical Iron and Steel Production Emissions

Figure 50 presents the GHG emissions from 2001 to 2010. GHG emission from the Evraz facility peaked increased from 28,112 mtCO$_2$e in 2001 to 31,564 mtCO$_2$e in 2010, an increase of approximately 12%. Trendline analysis estimated the annual rate of increase to be approximately 124 mtCO$_2$e per year. In 2009, there was dip in emissions to 19,637 mtCO$_2$e from 33,141 mtCO$_2$e in 2008. Emissions later increased to 31,564 in 2010.

FIGURE 50. HISTORICAL CO$_2$ EMISSIONS FROM IRON AND STEEL PRODUCTION

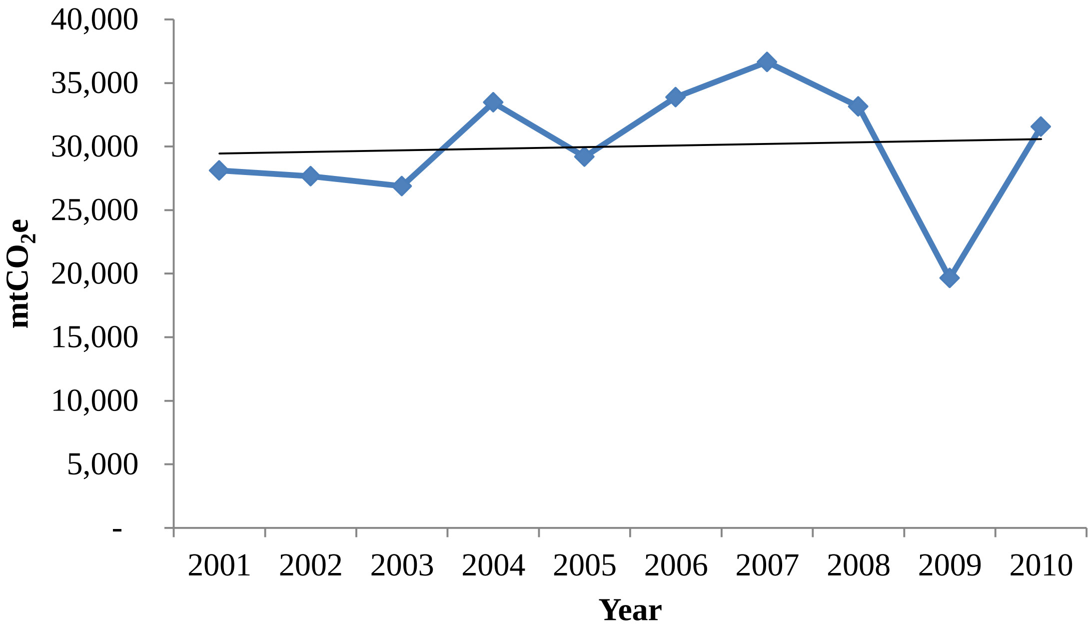

Table 13. Estimates of CO2 Emissions from Iron & Steel Production			
Years	**Facility Steel Production Data (Metric Tons)**	**Carbon Equivalents (mtCe)**	**CO2 Emissions (mtCO2e)**
2001	318,783	6,955	25,503
2002	313,619	6,843	25,090
2003	304,846	6,651	24,388
2004	379,485	8,280	30,359
2005	331,053	7,223	26,484

Table 13. Estimates of CO2 Emissions from Iron & Steel Production			
Years	**Facility Steel Production Data (Metric Tons)**	**Carbon Equivalents (mtCe)**	**CO2 Emissions (mtCO2e)**
2006	384,169	8,382	30,734
2007	415,606	9,068	33,248
2008	375,818	8,200	30,065
2009	245,457	5,355	19,637
2010	394,552	8,608	31,564

Reference case Projections for GHG Emissions from Iron and Steel Production

A projection analysis was not performed for GHG emissions from iron and steel production in Delaware. This is because as of December 13, 2013, Evraz is shutting down all steel production operations in Delaware. This action was in response to reduced market demand and the high volume of imports According to Evraz. However, GHG emissions from iron and steel production for the last 3 years were calculated based on steel production outputs. Carbon dioxide emissions from Evra steel production in 2011, 2012 and 2013 were estimated to be 9,130 mtCO_2e, 8,561 mtCO_2e, 7,794 mtCO_2e respectively. This indicates a downward trend in emissions that can be attributed to a slowdown in production activities.

4.3.2.6 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 2010 GHG emission inventory estimates CO_2 emissions from soda ash consumption.

Cumulatively, soda ash consumption is Delaware added 0.15 MmtCO_2e to the atmosphere between 1990 and 2010. In 2010, Delaware consumed 15,327 metric ton of soda ash according to the U.S geological Survey (USGS). The total CO_2 emission from soda ash consumption in 2010 was 6,361 $mtCO_2e$. This source contributed 0.1% of gross GHG emissions from the *non-energy related industrial process emissions* as shown by Figure 40.

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[80]. The activity data for this subsector was the annual amount of soda ash consumed in Delaware. The SIT default activity data[81] was multiplied with the SIT's default emission factor for soda ash consumption to estimate the emission amount.

EQUATION 12. GENERAL EQUATION FOR CO_2 EMISSIONS FROM SODA ASH CONSUMPTION

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

Figure 51 presents CO_2 emissions from soda ash consumption in Delaware from 1990 to 2010. As observed in Figure 51, CO_2 emissions from soda ash consumption in Delaware generally remained flat from 1995 to 2007. However from, emissions decreased from 7,268 $mtCO_2e$ in 1990 to 6,361 $mtCO_2e$ in 2010, which was a decrease of approximately 12%. Emissions decreased at the rate of approximately 26 $mtCO_2e$ per year according to trendline analysis. There was also a slight dip in emissions from 6,810 $mtCO_2e$ in 2008 to 6,006 $mtCO_2e$ in 2009. However, emissions increased to 6,361 $mtCO_2e$ from in 2010.

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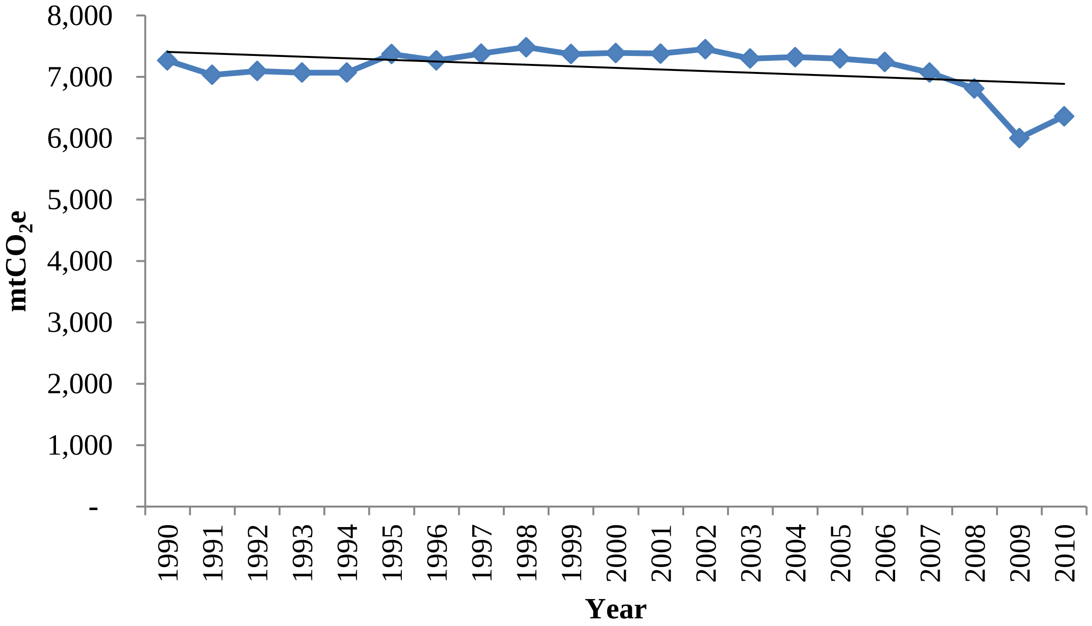
[80] EPA 2004 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004

[81] 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

FIGURE 51. CO_2 EMISSIONS FROM SODA ASH COSUMPTION

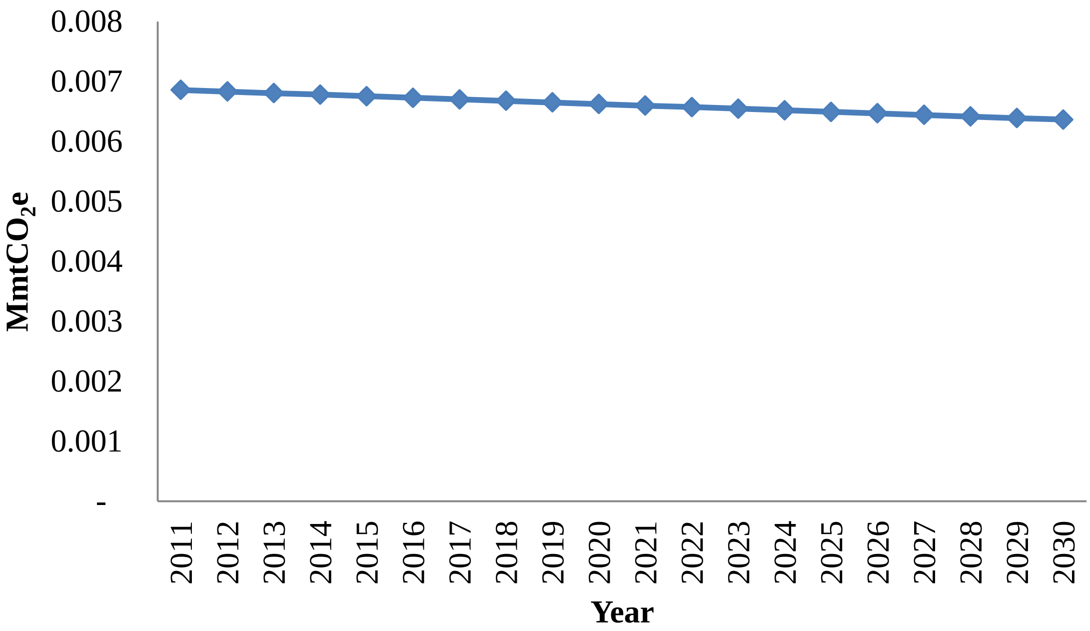


Reference Case Projection for GHG Emissions from Soda Ash Consumption

The Projection GHG emissions from soda ash consumption were estimated based on historical emissions. Using the trend line equation of soda ash historical emissions, GHG emission from this source category was projected from 2011 through 2030. The trend line equation, with its slope as the annual rate of emission, allows the incremental estimation of annual emissions over a time horizon of 20 years.

Cumulatively, soda ash consumption is projected to add a total of 0.13 $MmtCO_2e$ in GHG emissions to the atmosphere. This source category is projected to represent approximately one percent of non-energy related industrial sector emissions in 2030 as Figure 40 presents. Figure 52 presents projected GHG emissions from soda ash consumption. Figure 52 shows that GHG emissions are projected to decrease from 0.007 $MmtCO_2e$ in 2011 to 0.006 $MmtCO_2e$ to 2030. This will be a decrease of approximately 14%.

FIGURE 52. PROJECTED CO_2 EMISSION FROM SODA ASH CONSUMPTION



4.4 RESIDENTIAL SECTOR

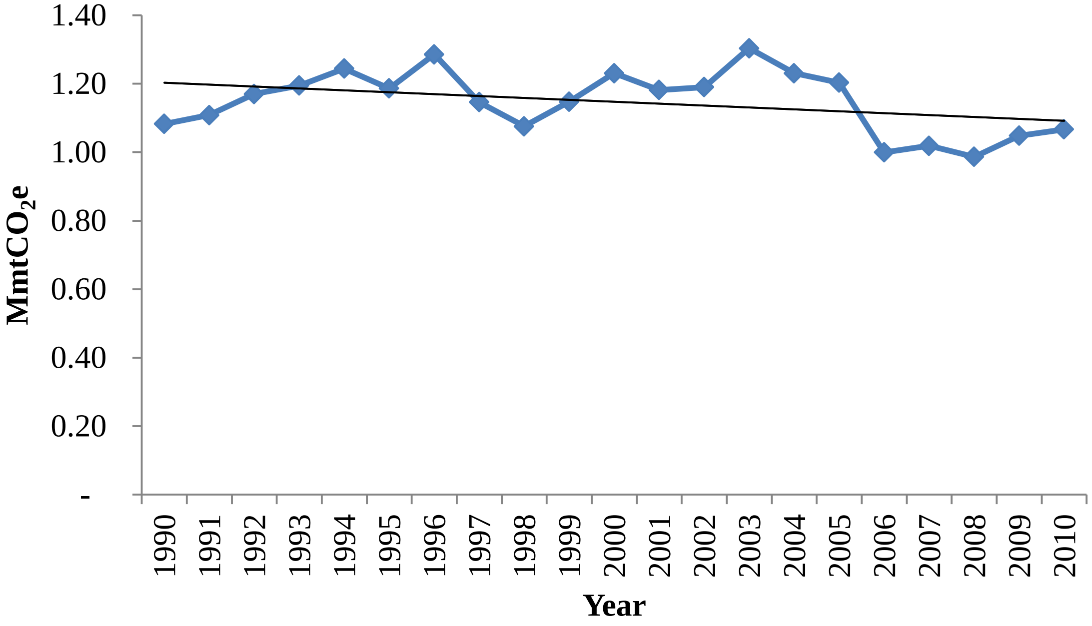
Emissions from the residential sector as described in this report consist of direct emissions from fossil fuel combustion for heating purposes as well indirect emissions associated electricity consumption. To avoid double counting emissions, this section focuses only direct emissions. In direct emissions associated with electricity consumption are covered under section 4.1.2, GHG emissions associated with electricity consumption.

Cumulatively, GHG emission from the residential sector has added approximately 24 $MmtCO_2e$ to the atmosphere from 1990 to 2010. In 2010, the residential sector represented approximately 8% of gross GHG emissions in Delaware. Emissions have been driven primarily by CO_2 emissions from fossils fuel combustion in the residential sector. Fossil fuel consumed in the residential sector between 1990 and 2010 include petroleum, natural gas, wood and to lesser extent coal.

Figure 53 shows that GHG emissions from the residential sector fluctuated downward from 1990 to 2010. Emissions fluctuated between 1.00 $MmtCO_2e$ and 1.30 $MmtCO_2e$ as presented in Figure 53. Emissions slightly decreased from 1.08 $MmtCO_2e$ in 1990 to 1.07 $MmtCO_2e$ in

2010, which was approximately 1% decrease in emissions. Emissions decreased at a rate of 0.0055 $MmtCO_2e$ per year.

Figure 53. Gross GHG Emissions from Fossil fuel combustion



Fluctuating seasonal temperatures contributed to fluctuating emissions levels observed in Figure 53. Figure 54 presents, Delaware's average minimum and maximum temperatures in January from 1990 to 2008[82]. 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 54 indicates, similar spikes and dips in temperature are observed in the emissions trend presented in Figure 53. 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.

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[82] Weather Warehouse: Past Monthly Weather Data for Wilmington, Delaware ("Wilmington New Castle County Arpt") : JULY, 1948 - 2013

FIGURE 54. DELAWARE'S AVERAGE MAXIMUM TEMPERATURE FOR JANUARY

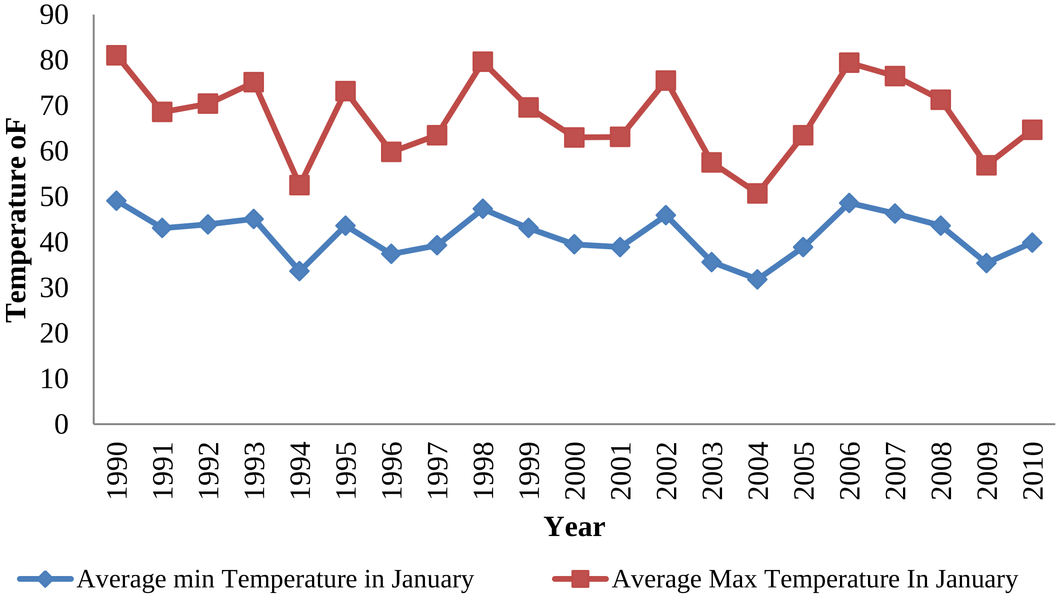

Figure 55 resents emissions from the residential sector by fossils fuels. From 1990 to 2006, GHG emissions from petroleum combustion in the residential sector exceeded GHG emissions from natural gas combustion. Natural gas GHG emissions exceeded petroleum GHG emissions in 2006, at 0.50 MmtCO$_2$e and petroleum at 0.49 MmtCO$_2$e.

Greenhouse gas emissions from natural gas increased from 1990 to 2010 because natural gas became more competitive due to decreasing prices. Demand and consumption for petroleum decreased gradually to 0.44 MmtCO$_2$e in 2008, but increased to 0.51 MmtCO$_2$e in 2010 as natural gas emissions remained flat between 2007 and 2010. Figure 55 indicates that fuel switching in the residential sector from petroleum products to natural gas for heating contributed to the slight leveling of GHG emissions from the sector.

As Table 14 provides, CO$_2$ emissions from the residential sector were driven by petroleum and natural gas consumption for heating purposes from 1990 to 2010. Coal was consumed to a lesser extent. In 2010, zero GHG emissions came from coal consumption because the amount of coal consumed in 2005 and 2010 years were reported to be zero as Table 14 provides.

Figure 55. GHG Emissions from Residential Sector by Fuel

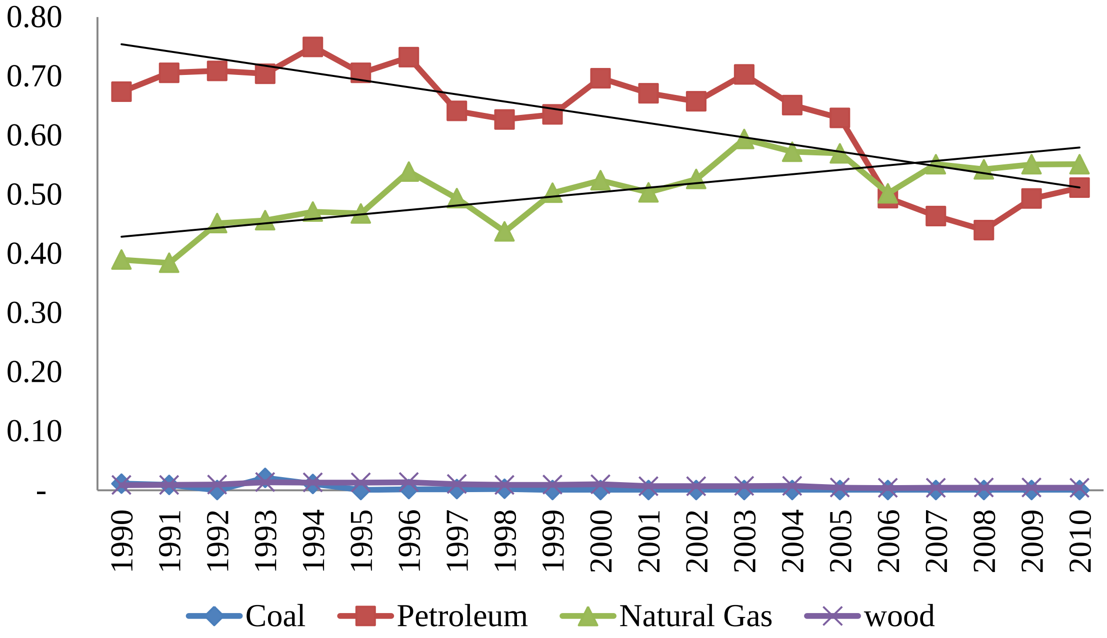

Table 14. GHG Emissions From Residential Sector FFC

MmtCO$_2$e	1990	1995	2000	2005	2010
Coal	**0.01**	**0.00**	**0.00**	**-**[83]	**-**
CO$_2$	0.01	0.00	0.00	-	-
N$_2$O	0.000	0.000	0.000	-	-
CH$_4$	0.001	0.000	0.000	-	-
Petroleum	**0.67**	**0.71**	**0.70**	**0.63**	**0.51**
CO$_2$	0.67	0.70	0.69	0.63	0.51
N$_2$O	0.002	0.002	0.002	0.002	0.001
CH$_4$	0.002	0.002	0.002	0.002	0.002
Natural Gas	**0.39**	**0.47**	**0.52**	**0.57**	**0.55**
CO$_2$	0.39	0.47	0.52	0.57	0.55
N$_2$O	0.000	0.000	0.000	0.000	0.000
CH$_4$	0.001	0.001	0.001	0.001	0.001
Wood	**0.01**	**0.01**	**0.01**	**0.00**	**0.00**
N$_2$O	0.001	0.002	0.002	0.001	0.001
CH$_4$	0.007	0.011	0.008	0.004	0.003
Total	**1.08**	**1.19**	**1.23**	**1.20**	**1.07**

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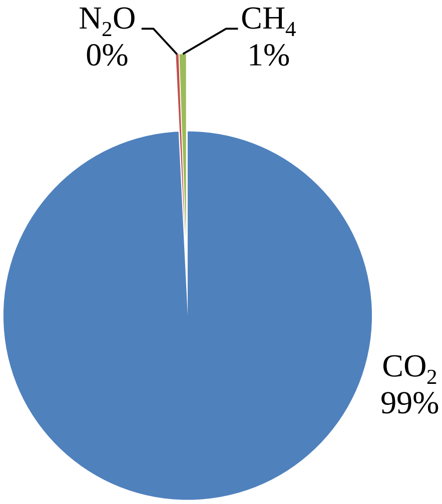
[83] The above dashes indicate GHG emissions were zero because no amount of coal was consumed in the residential sector that year.

Figure 56 shows that in 2010, CO_2 emissions from fossils fuel combustion in the commercial sector was the largest with approximately 99.61%, while the combined emissions of both N_2O and CH_4 were both less than 1% (approximately 0.11% and 0.28% respectively).

FIGURE 56. EMISSIONS FROM COMMERCIAL SECTOR BY GHGS



Reference Case Projection of GHG Emissions from the Residential Sector

The GHG inventory analysis shows that GHG emissions from the residential sector are expected to decrease from 1.07 $MmtCO_2e$ in 2010 to 0.93 $MmtCO_2e$ in 2011. Figure 57 also shows that GHG emissions from the residential sector increased from 0.93 $MmtCO_2e$ in 2011 to 1.06 $MmtCO_2e$ in 2012, and decrease gradually to 0.96 $MmtCO_2e$ (approximately 9% decrease) in 2030 as Figure 57 presents. Greenhouse gas emissions will decrease at the rate of 0.003 $MmtCO_2e$ per year based on trendline analysis.

Analysis of estimated future GHG emissions from the residential sector of Delaware indicates that decline in petroleum consumption will contribute to the projected decrease in gross GHG emissions from the residential sector.

FIGURE 57. PROJECTED GHG EMISSIONS FROM THE RESIDENTIAL SECTOR

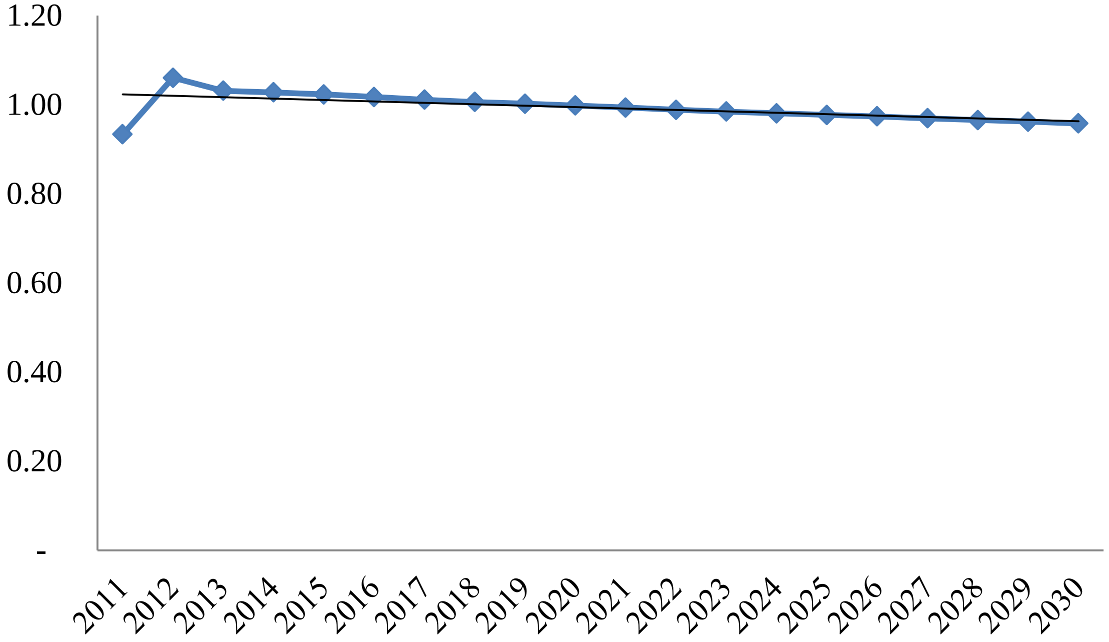


Figure 58 presents a breakdown of projected GHG emissions by fuel. Greenhouse gas emissions from natural gas from the residential sector are projected to continue to increase gradually from 2011 to 2030, while GHG emissions from petroleum consumption will continue to decrease.

As shown, annual GHG emissions from natural gas consumption in the residential sector is projected to increase from 0.48 $MmtCO_2e$ in 2011 to 0.56 $MmtCO_2e$ in 2030, a modest increase of approximately 8%. Trendline analysis projects the annual rate of increase to be 0.002 $MmtCO_2e$ per year. Conversely, GHG emissions from petroleum consumption in the residential sector increased sharply from 0.45 $MmtCO_2e$ in 2011 to 0.52 $MmtCO_2e$ in 2012. However, GHG emissions are projected to decrease from 0.52 $MmtCO_2e$ in 2012 to 0.40 $MmtCO_2e$ in 2030 according to Figure 58. The decrease was approximately 7%, at the rate of 0.005 $MmtCO_2e$ per year. Greenhouse gas emissions from wood and coal were not included in the analysis because the consumption of both fuels is expected to be negligible.

FIGURE 58. PROJECTED GHG EMISSIONS FROM THE RESIDENTIAL SECTOR BY FUEL

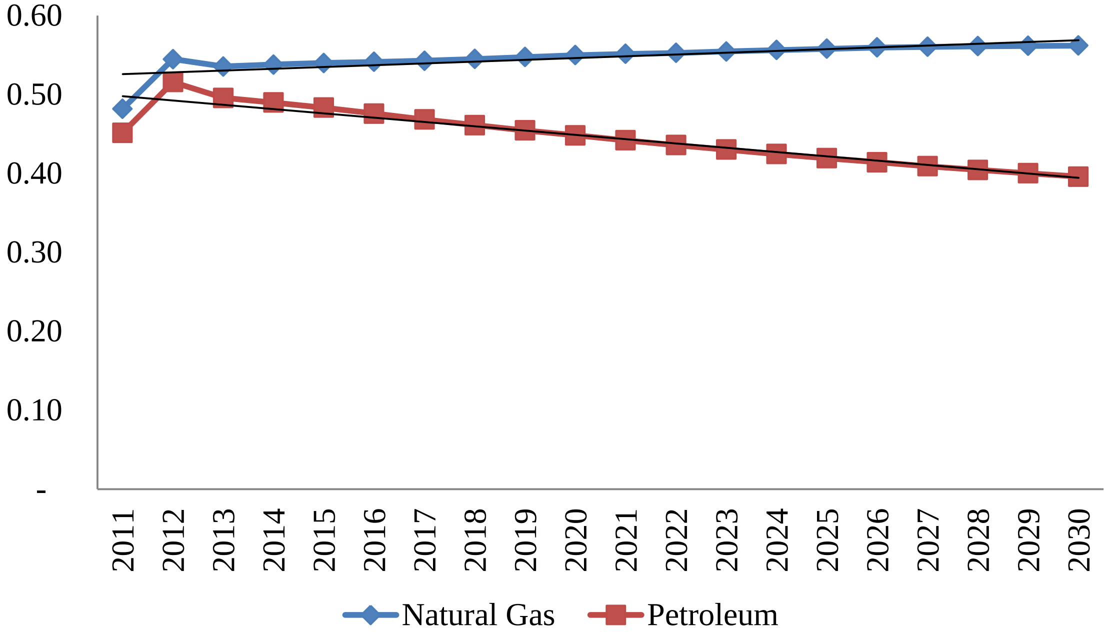


Figure 59 presents the breakdown of GHG emissions by fuel in 2030. Greenhouse gas emissions from natural gas consumption is projected to be approximately 59 % of gross GHG emissions from the residential sector, while GHG emissions from petroleum consumption is projected to be approximately 41% as presented by Figure 59.

In addition, CO_2 is projected to remain the GHG of concern in residential sector emissions as the residential sector emissions analysis indicates. Figure 60 presents emissions from the residential in 2030 by GHG. The analysis shows that CO_2 emissions from the residential sector is projected to be approximately 99.6% of gross GHG emissions, while the combined emissions of N_2O and CH_4 are projected to be less that 1% (approximately 0.15% and 0.24 % respectively). Table 15 provides a summary of emissions by GHGs and fuel types from residential sector consumption of fossil fuels. It shows that GHG emissions from natural gas consumption will be consistently higher than petroleum emissions from 2011 to 2030. It also shows that CO_2 emissions will be consistently higher than all other GHGs.

FIGURE 59. 2030 GHG EMISSIONS FROM RESIDENTIAL SECTOR BY FUEL

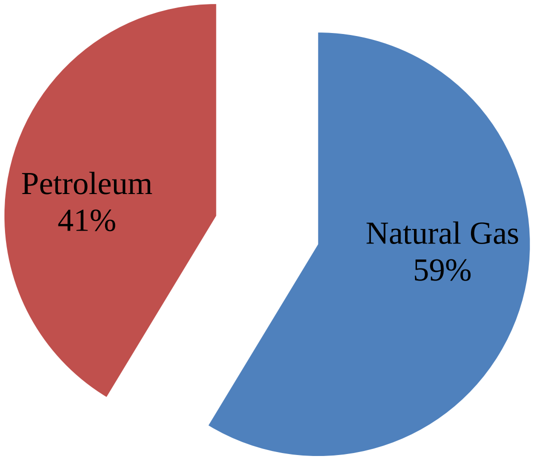


FIGURE 60. 2030 GHG EMISSIONS FROM THE RESIDENTIAL SECTOR BY GHG

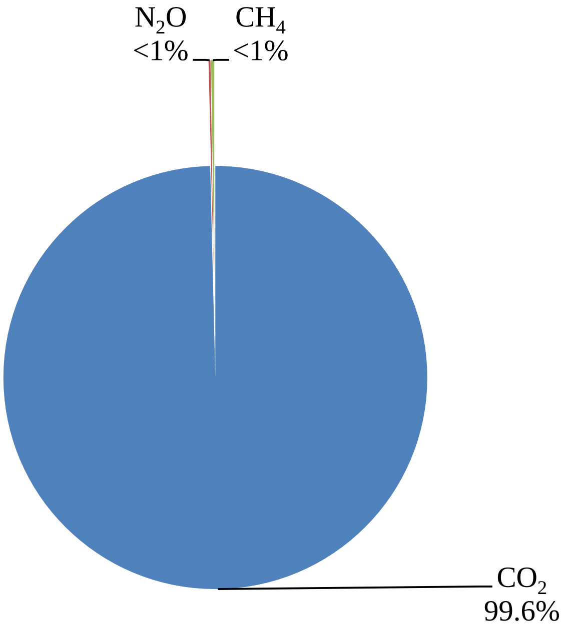


TABLE 15. GHG EMISSIONS FROM RESIDENTIAL SECTOR FFC

$MmtCO_2e$	2011	2015	2020	2025	2030
Natural Gas	**0.48**	**0.54**	**0.55**	**0.56**	**0.56**
CO_2	0.48	0.54	0.55	0.56	0.56
N_2O	0.000	0.000	0.000	0.000	0.000
CH_4	0.001	0.001	0.001	0.001	0.001
Petroleum	**0.45**	**0.48**	**0.45**	**0.42**	**0.40**
CO_2	0.45	0.48	0.45	0.42	0.39
N_2O	0.001	0.001	0.001	0.001	0.001
CH_4	0.001	0.001	0.001	0.001	0.001
Total	**0.93**	**1.02**	**1.00**	**0.98**	**0.96**

Conclusion of Residential Sector GHG Emissions Analysis

There is an indirect correlation between temperature and GHG emission in the residential sector. Fluctuations observed in historical GHG emissions from the residential sector are attributed to fluctuating historical temperatures[84] from 1990 to 2010. When seasonal temperatures are low, fossil fuel consumption increases, which leads to an increase in gross GHG emissions. While higher seasonal temperature leads to a decrease in the consumption. However, similar fluctuations in historical GHG emissions are not observed in projected GHG emission is because seasonal temperature is not factored in the projection model. As a result, gross GHG emission projections appear to be linear as presented in Figure 57 presents.

In addition, the projected decrease in GHG emissions from residential sector is driven by primarily by fuel switching from petroleum to natural gas. Emissions from natural gas consumption will continue to exceed emissions from petroleum consumption in the residential sector because the demand for natural gas is expected increase due to decreasing price. This makes natural gas more competitive than petroleum in the fossil fuel market and a viable substitute for petroleum products in the residential sector. However, as Figure 58 presents, GHG emissions from natural gas appears to be almost flat with slight increases as GHG emissions from petroleum decreases over time. This is because natural gas consumption is projected to exceed petroleum consumption well into the future.

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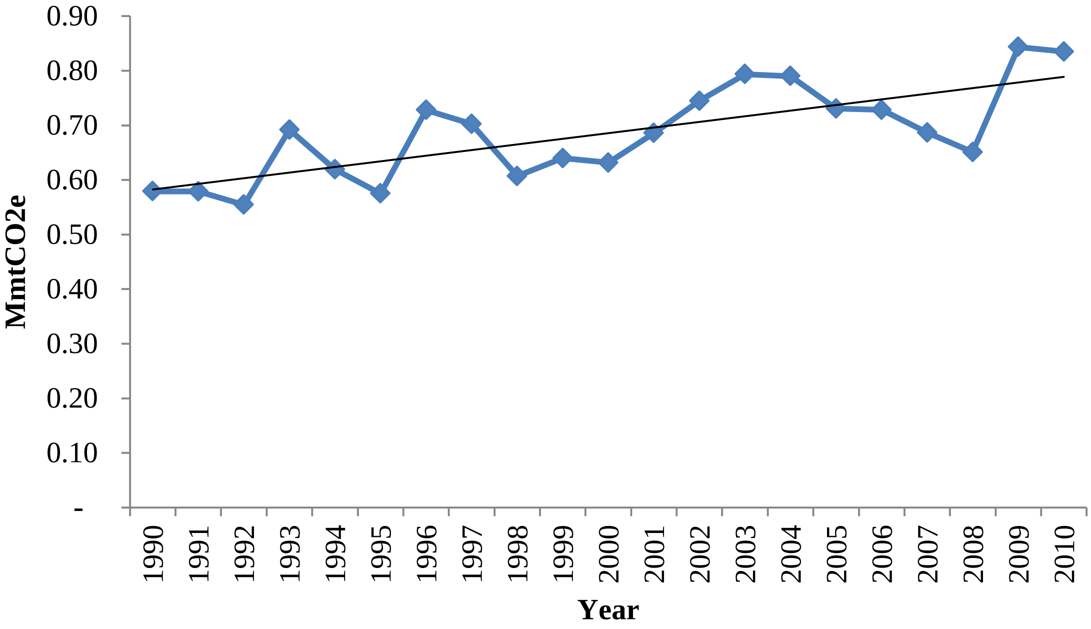
[84] What causes fluctuations in seasonal temperatures is beyond the scope of this report.

4.5 COMMERCIAL SECTOR

Emissions from the commercial sector as described in this report consist of direct emissions from fossil fuel combustion for heating purposes as well indirect emissions associated electricity consumption. However, to avoid double counting emissions, this section focuses only direct emissions. In direct emissions associated with electricity consumption are covered under section 4.1.2, GHG emissions associated with electricity consumption. The commercial sector emitted a total amount of 14.4 MmtCO_2e into the atmosphere from1990 to 2010. Greenhouse gas emissions from the commercial sector were driven primarily by CO_2 emissions from fossil fuel combustion for heating purposes.

FIGURE 61. GHG EMISSIONS FROM COMMERCIAL SECTOR



GHG emissions from the commercial sector represented approximately 6% of o gross GHG emissions in 2010. Figure 61 shows that GHG emissions from the commercial sector fluctuated upward at the rate of 0.01 MmtCO_2e from 1990 to 2010. Emissions increased from 0.58 MmtCO_2e in 1990 to 0.84 MmtCO_2e in 2010, an increase of approximately 45%.

Figure 62 presents GHG emissions from the commercial sector by fuel type. As in the residential sector, wood was also used for heating in the commercial sector between 1990 and 2010 as presented in Figure 62. However, the largest source of GHG emissions was natural gas combustion. From 1990 to 2001, emissions from natural gas combustion were close to emissions from petroleum combustion in the commercial sector as Figure 62 shows. However, in between 2002 and 2010, annual emissions for natural gas exceeded annual emission for petroleum great as Figure 62 shows. In 2010, natural gas emissions were 0.66 $MmtCO_2e$, while petroleum emissions were 0.17 $MmtCO_2e$ as indicated in Figure 62. Emissions from natural gas were larger than emissions from petroleum during the period of 2002 and 2010 due to fuel switching from heating oil, a derivative of petroleum, to natural gas. As prices declined for natural gas, it became more completive, which led to increasing GHG emission. Petroleum GHG emissions declined in response to less demand.

Annual GHG emissions from coal and wood remained very low between 1990 and 2010 as presented in Figure 62. This is because the consumption of coal and wood in commercial sector heating is not as considerable when compared to natural gas and petroleum consumption. Also, coal and wood emissions also decreased significantly due to the increasing demand for natural gas.

Figure 63 presents gross GHG emissions from the commercial sector by fuel type in 2010. Greenhouse gas emissions natural gas was the largest with approximately 80% of gross emission, while emissions from petroleum consumption were a distant second with approximately 20%. Emissions from wood consumption were less than 1% (0.1%) while emissions from coal consumption were zero because coal was not consumed in 2010.

Figure 64 shows that CO_2 emissions from fossils fuel combustion in the commercial sector was the largest with approximately 99.61%, while the combined emissions of both N_2O and CH_4 were both less than 1% (approximately 0.11% and 0.28% respectively).

FIGURE 62 GHG EMISSIONS FROM COMMERCIAL SECTOR BY FUEL TYPE

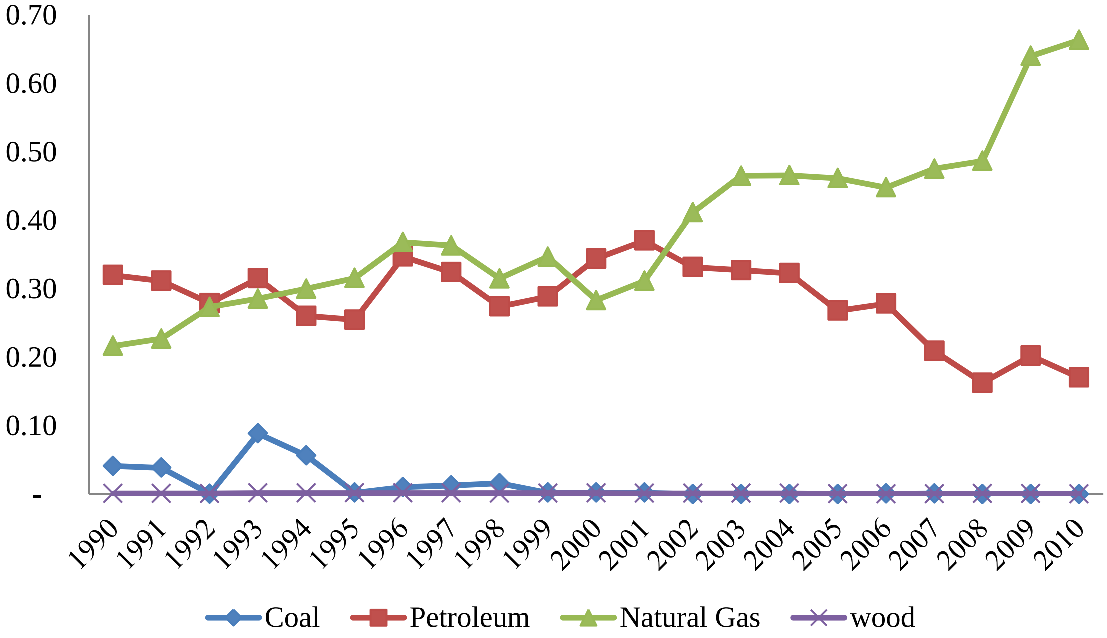


FIGURE 63 2010 GHG EMISSIONS FROM COMMERCIAL SECTOR BY FUEL TYPE

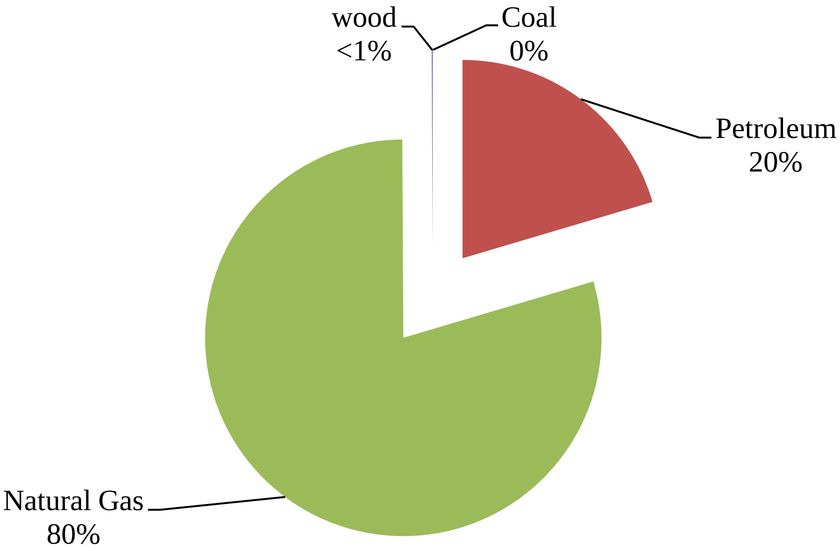


FIGURE 64. 2010 EMISSIONS FROM COMMERCIAL SECTOR BY GHGS

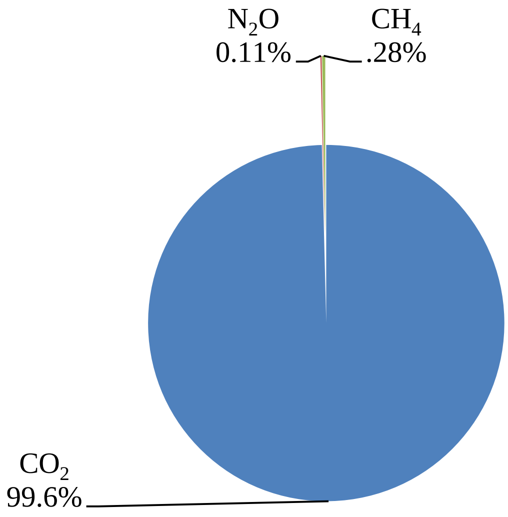


Table 16 provides a summary of emissions estimates based on fuel and GHG. The table also shows that GHG emissions natural gas consumption continued to increase from 0.22 MmtCO$_2$e in 1990 to 0.66 MmtCO$_2$e in 2010. In general, natural gas consumption was the largest source of GHG emissions, followed by petroleum consumption, which decreased in GHG emissions from 0.32 MmtCO$_2$e in 1990 to 0.17 MmtCO$_2$e in 2010.

TABLE 16. GHG EMISSIONS FROM RESIDENTIAL SECTOR FFC

MmtCO$_2$e	**1990**	**1995**	**2000**	**2005**	**2010**
Coal	**0.04**	**0.00**	**0.00**	**-**	**-**
CO_2	0.04	0.00	0.00	-	-
N_2O	0.000	0.000	0.000	-	-
CH_4	0.000	0.000	0.000	-	-
Petroleum	**0.32**	**0.25**	**0.34**	**0.27**	**0.17**
CO_2	0.32	0.25	0.34	0.27	0.17
N_2O	0.001	0.001	0.001	0.001	0.000
CH_4	0.001	0.000	0.001	0.001	0.001
Natural Gas	**0.22**	**0.32**	**0.28**	**0.46**	**0.66**
CO_2	0.22	0.32	0.28	0.46	0.66
N_2O	0.000	0.000	0.000	0.000	0.000
CH_4	0.000	0.001	0.001	0.001	0.001
Wood	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
N_2O	0.000	0.000	0.000	0.000	0.000

Table 16. GHG Emissions From Residential Sector FFC

$MmtCO_2e$	**1990**	**1995**	**2000**	**2005**	**2010**
CH_4	0.001	0.001	0.001	0.001	0.001
Total	**0.58**	**0.57**	**0.63**	**0.73**	**0.84**

Reference Case Projection of GHG Emissions from the Commercial Sector

Delaware's commercial sector is expanding slowly, and the expansion expected to continue due to the economic recovery. As a result, GHG emissions in this sector are projected to increase slightly or stabilize with fossil fuel consumption. Figure 65 presents projected GHG emissions from the commercial sector. Gross GHG emission from the commercial sector is projected to increase from 0.80 $MmtCO_2e$ in 2011 to 0.98 $MmtCO_2e$ in 2030, an increase of approximately 23%. The rate of annual increase was determined to be 0.007 $MmtCO_2e$ per year. Unlike historical emissions, Figure 65 does not show significant fluctuations because seasonal fluctuations in temperature were not factored in GHG emission projection model.

Figure 65. Projected Gross GHG Emissions from Commercial Sector

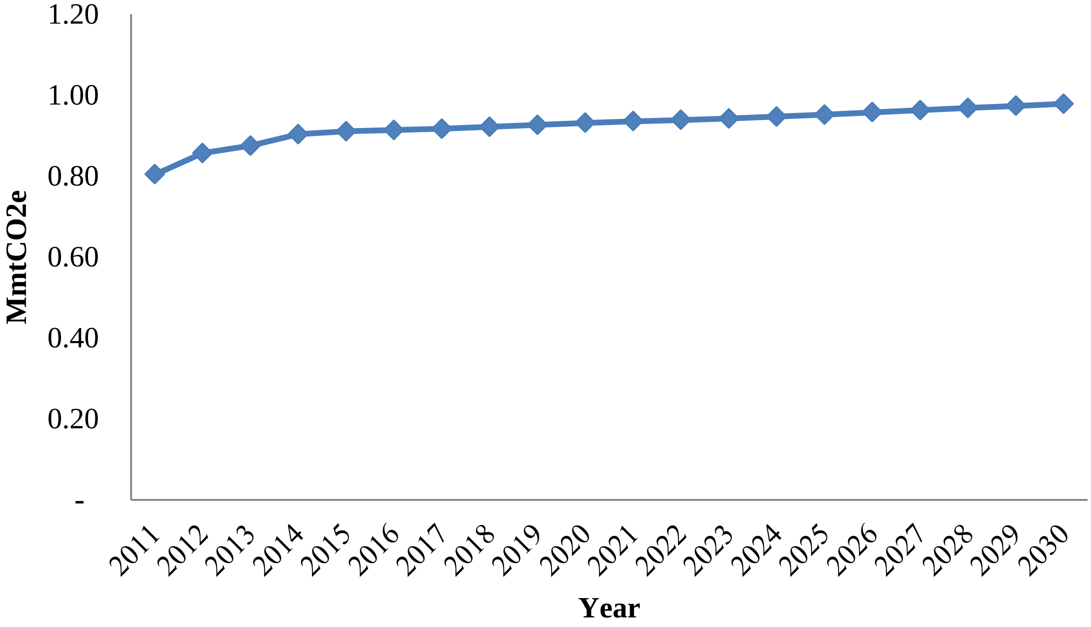


FIGURE 66. PROJECTED GHG EMISSIONS FROM THE COMMERCIAL SECTOR BY FUEL

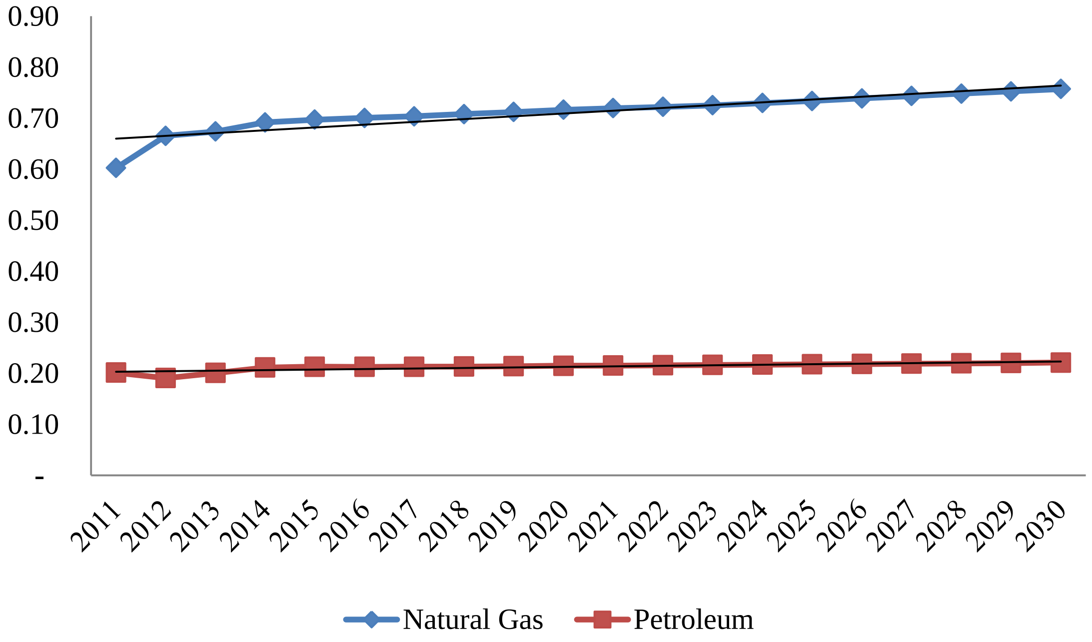
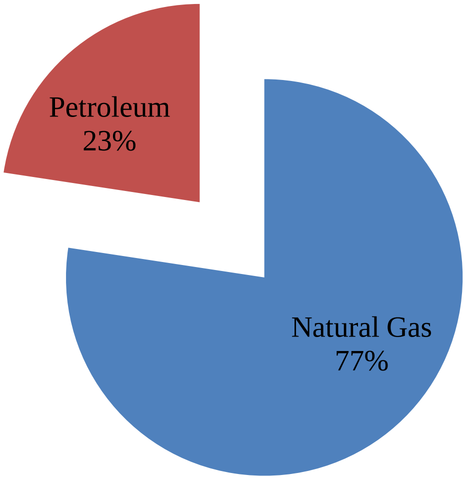


Figure 66 presents projected gross GHG emissions by fuel. It shows that projected GHG emissions from natural gas consumption are expected to exceed GHG emissions from petroleum consumption from 2011 to 2030. This is based on the assumption that natural gas consumption in this sector will continue to replace petroleum consumption. Greenhouse gas emission from natural gas consumption is projected to increase from 0.60 $MmtCO_2e$ in 2011 to 0.76 $MmtCO_2e$ in 2030 at the rate of 0.006 $MmtCO_2e$ per year. This will be an increase of approximately 27%. Projected GHG emissions from petroleum consumption will remain relatively flat with slight increase of approximately 10% from 2011 to 2030.

Figure 67 presents the projected percent contribution of each fuel to gross GHG emissions from the commercial sector in 2030. Natural gas is projected to be approximately 77% of gross contribution from the commercial sector while petroleum is projected to be approximately 23%.

FIGURE 67. GHG EMISSIONS BY FUEL FROM THE COMMERCIAL SECTOR IN 2030



Conclusion of Commercial Sector GHG Emissions Analysis

Natural gas consumption in the commercial sector is the most significant source of GHGs based on historical data. Projected data also shows that natural gas consumption will be the most significant source of GHGs in this sector. Historical GHG emissions from natural gas increased significantly and are projected to continue to increase slightly. Gross GHG emissions from petroleum consumption in the commercial sector decreased and are projected to stabilize in the future. In order to achieve reduction in emissions from natural gas and petroleum consumption, energy efficiency in the consumption fuel will have to be a priority.

4.6 AGRICULTURE SECTOR

According the 2010 GHG inventory, the agriculture sector represented only approximately 4% of gross GHG emissions from economic sectors of Delaware with a total of 0.429 $MmtCO_2e$ (429,000 $mtCO_2e$) . Sources of GHGs emissions in the agriculture sector of Delaware consist of agricultural activities including enteric fermentation, manure management, agricultural soil management and agricultural residue burning. Figure 68 presents the total GHG emissions from the agricultural sector from 1990 to 2010. Emissions fluctuated from year to year while dec

reasing from 0.471M mtCO$_2$e in 1990 to 0.429 MmtCO$_2$e in 2010. Emissions peaked in 1991 at 0.525 MmtCO$_2$e, and reached its lowest point in 2005 at 0.425 MmtCO$_2$eThis was a decrease of approximately 9.1%. The annual rate of decrease was 0.0027 MmtCO$_2$e per year. Factors that significantly impacts agricultural sector emissions include the population of livestock, fertilizer applications and crop production.

Figure 69 present GHG emissions by agricultural activities in 2010. Greenhouse gas emissions from agricultural soil management represented the largest emissions from the agricultural sector with approximately 56%. This was followed by manure management representing approximately 36% of gross GHG emissions from the agricultural sector as presented in Figure 69. Greenhouse gas emissions from enteric fermentation represented approximately 9%, and it was flowed by agricultural residue burning, which represented approximately 1%.

FIGURE 68. GHG EMISSIONS FROM AGRICULTURE

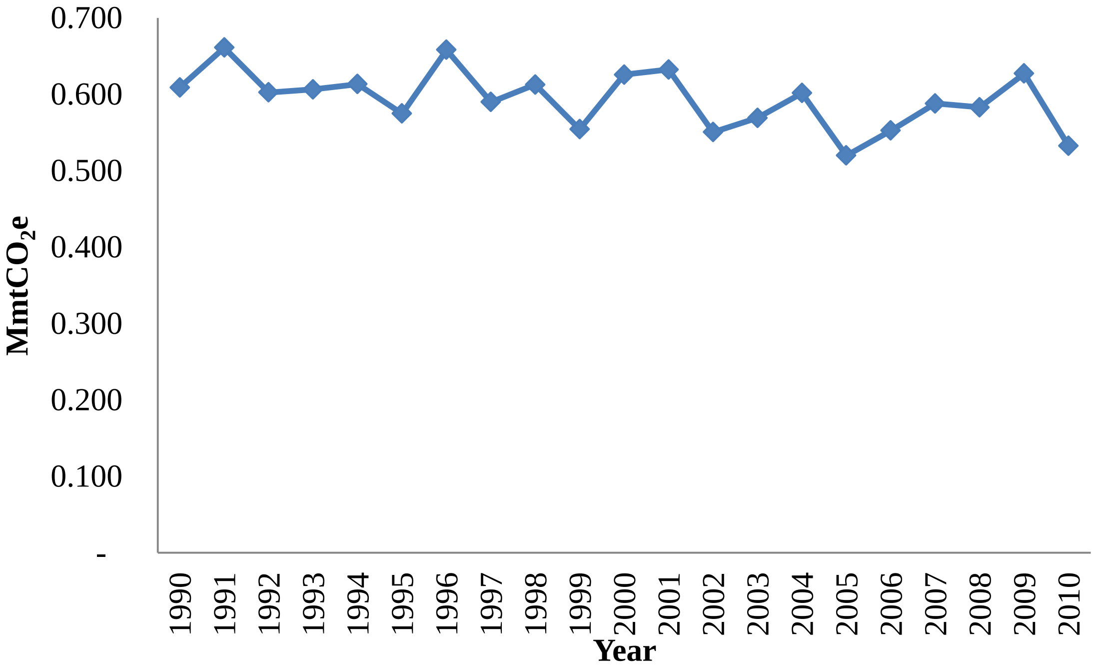


FIGURE 69. GROSS GHG EMISSIONS FROM THE AGRICULTURAL SECTOR IN 2030

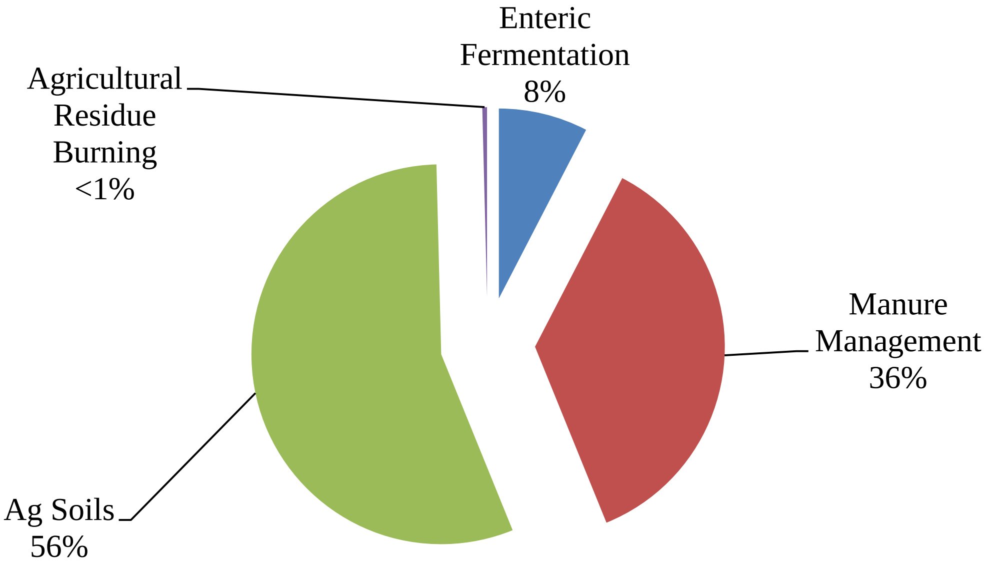


FIGURE 70. GHG EMISSIONS BY AGRICULTURAL ACTIVITIES

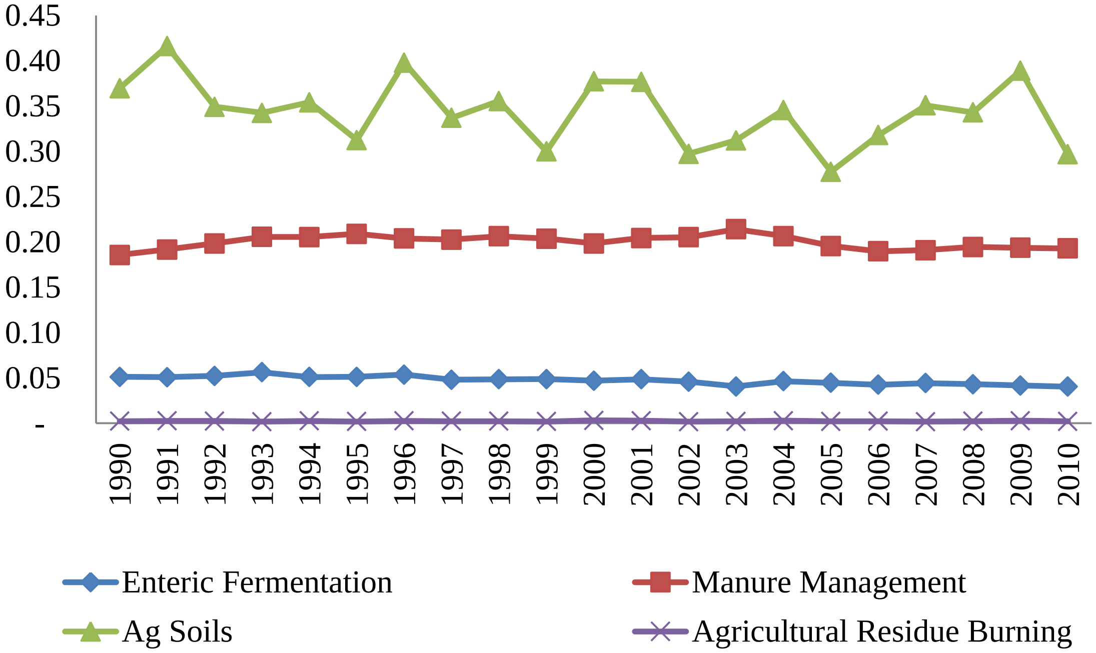


Figure 70 presents GHG emissions from the agricultural sector by activity from 1990 to 2010. Historical GHG emissions from agricultural soil management and manure management remained the largest of the four activities from 1990 to 2010 as shown by Figure 70.

Emissions from enteric fermentation stayed relatively flat at approximately 0.52 $MmtCO_2e$, and emissions from agricultural residue remained the lowest emissions at approximately 0.002 $MmtCO_2e$ from 1990 to 2010. Table 17 provides a summary of estimates of emissions by agricultural activities.

TABLE 17. GHG EMISSIONS FROM AGRICULTURAL ACTIVITIES

Emissions($mtCO_2e$)	**1990**	**1995**	**2000**	**2005**	**2010**
Enteric Fermentation	0.05	0.05	0.05	0.04	0.04
Manure Management	0.19	0.21	0.20	0.20	0.19
Agricultural Soil Management	0.37	0.31	0.38	0.28	0.30
Agricultural Residue Burning	0.00[85]	0.00	0.00	0.00	0.00
Total	**0.609**	**0.575**	**0.626**	**0.520**	**0.532**

Reference Case Projection of GHG Emissions from the Agricultural Sector

Figure 71 presents future gross GHG emissions from the agricultural sector based on projected estimates. Gross missions from the agricultural sector will remain relatively flat from 2011 to 2030. 1n 2011, gross emissions were 0.58 $MmtCO_2e$, and projected to decrease slightly to 0.57 $MmtCO_2e$, a decrease of approximately 2%. The rate of decrease was projected to be a slight 0.0005 $MmtCO_2e$ per year.

Figure 72 presents GHG emissions by agricultural activities in 2030. Manure management emissions are projected to represent the largest share of emissions from the agricultural sector with approximately 49%. This will be followed by GHG emissions from agricultural soil management which is projected to represent approximately 37%. Emissions from enteric fermentation and the burning of agricultural crop waste were the lowest representing 9% and 1% respectively.

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[85] Emissions estimates were rounded to 2 decimal places.

FIGURE 71. PROJECTED GROSS EMISSIONS FROM THE AGRICULTURAL SECTOR

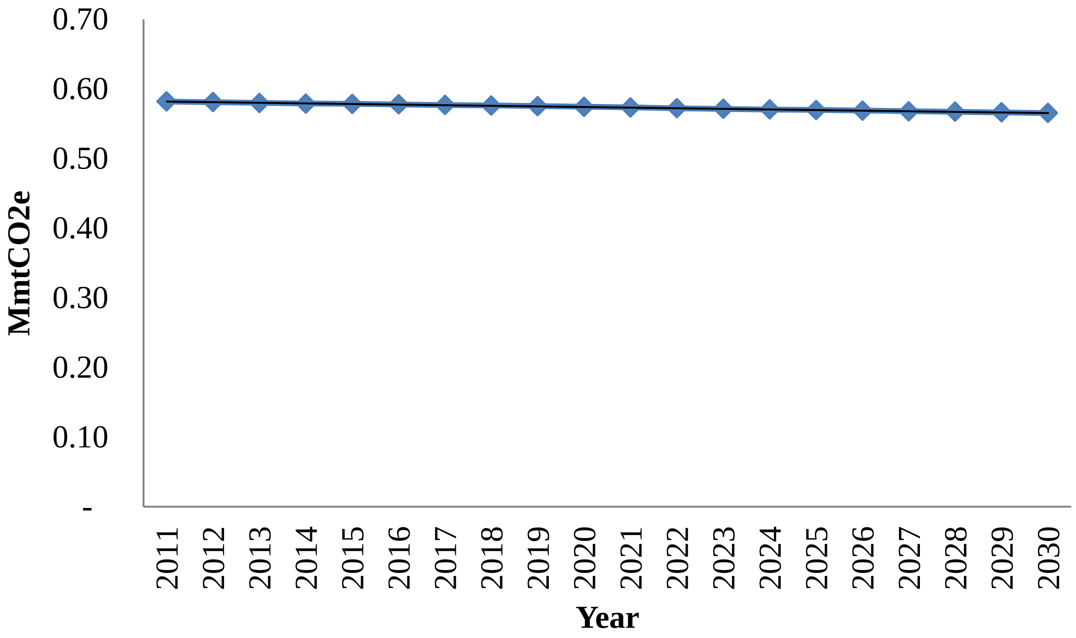

FIGURE 72. 2030 EMISSIONS BY AGRICULTURAL ACTIVITIES

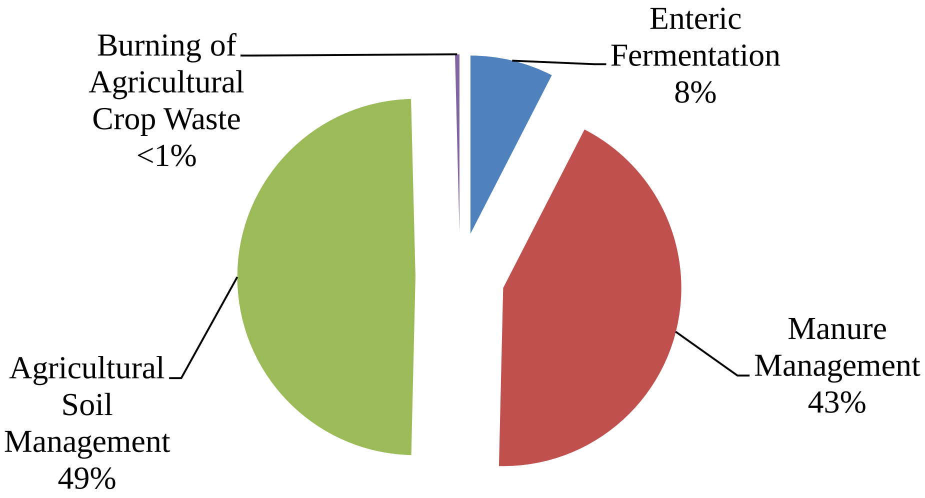

FIGURE 73. EMISSIONS BY AGRICULTURAL ACTIVITIES

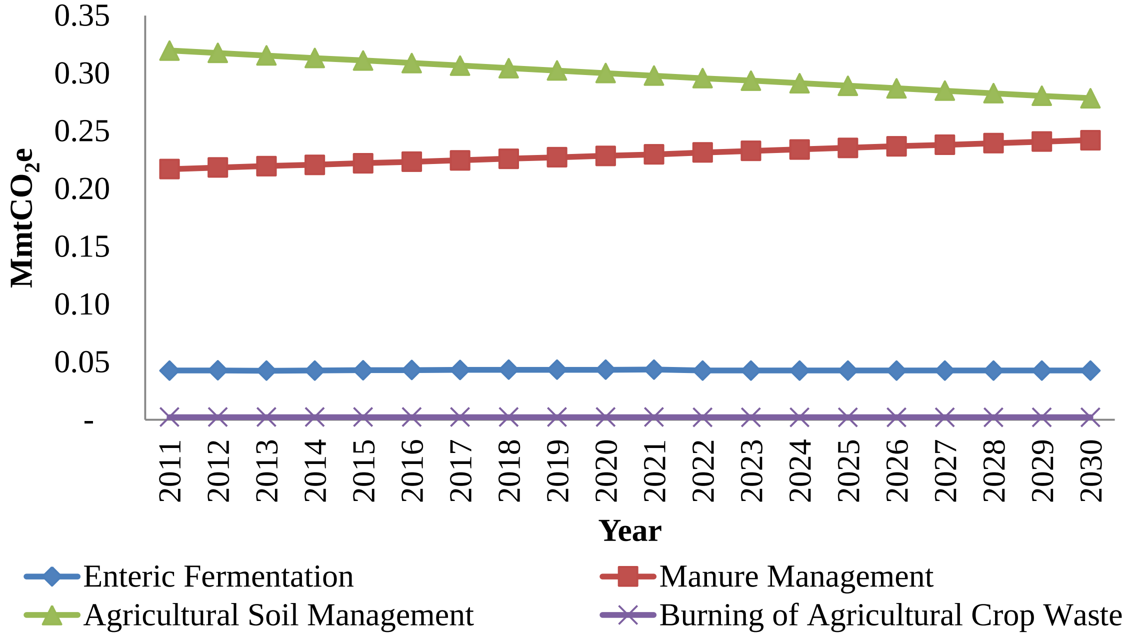

Figure 73 presents projected GHG emissions from the agricultural sector by agricultural activities from 2011 to 2030. Emissions levels from agricultural soil management is projected to be greater than all agricultural activities followed by emissions manure management, enteric fermentation and burning of agricultural crop waste as Figure 73 shows. Figure 73 also shows that the difference between agricultural soil management and manure management emissions is projected to narrow towards 2030, and emissions from enteric fermentation is projected to remain parallel with emissions from agricultural waste burning.

4.6.1 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[86]. The method of estimating N_2O emissions from these sources was based IPCC’s method[87]. Nitrous oxide emissions from agricultural soil management are

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[86] The act of plowing land and leaving it unseeded.

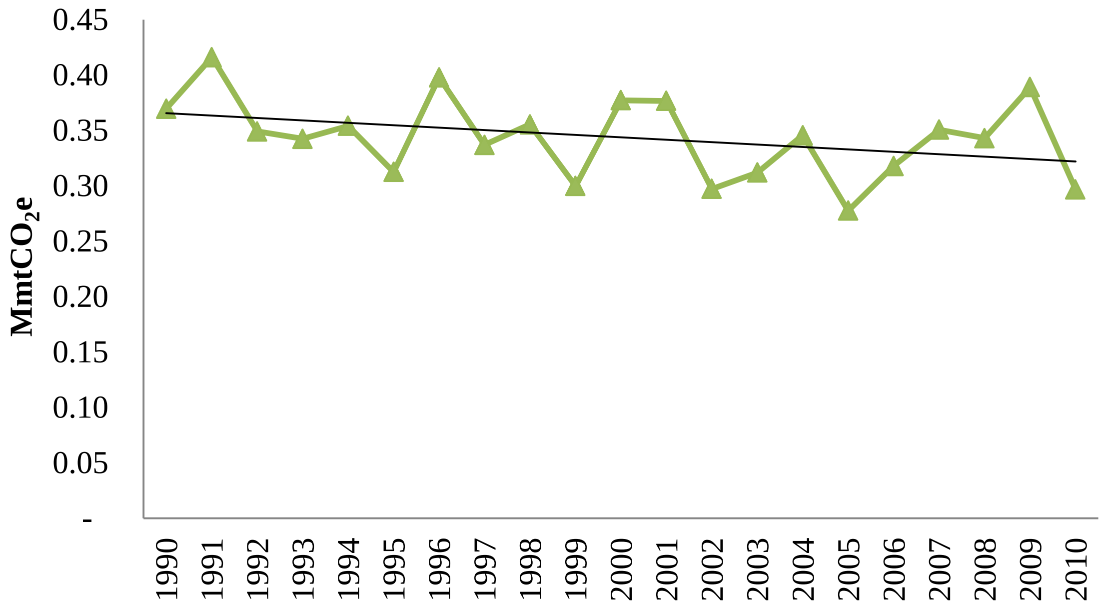
[87] EPA’s Emissions Inventory Improvement Plan Volume III

categorized into direct and indirect N_2O emissions due to the addition of fertilizers and deposition of manure to agricultural soil. In 2010, agricultural soil management generated 0.194 $MmtCO_2e$ as Table 13 provides.

Historical Emission of GHG Emissions from Agriculture Soil Management

Historically, agricultural soil management GHG emissions were the largest of all agricultural activities with a total of 7.22 $MmtCO_2e$ between 1990 and 2010. In 2010, N_2O emissions from agricultural soil management represented the larges emissions from the agricultural sector with 56% as Figure 69 presents. Nitrous oxide emissions fluctuated between 0.25 $MmtCO_2e$ and 0.45 $MmtCO_2e$, peaking in 1991 at 0.41 $MmtCO_2e$ and reaching its lowest point in 2005 at 0.28 $MmtCO_2e$. Between 1990 and 2010, N_2O decreased from zero M $mtCO_2e$ in 1990 to 0.194 $MmtCO_2e$ in 2010, a decrease of approximately 16%. Nitrous oxide emissions decreased by 0.002 $MmtCO_2e$ per year as determined by trendline analysis.

FIGURE 74. N_2O EMISSIONS FROM AGRICULTURAL SOIL MANAGEMENT

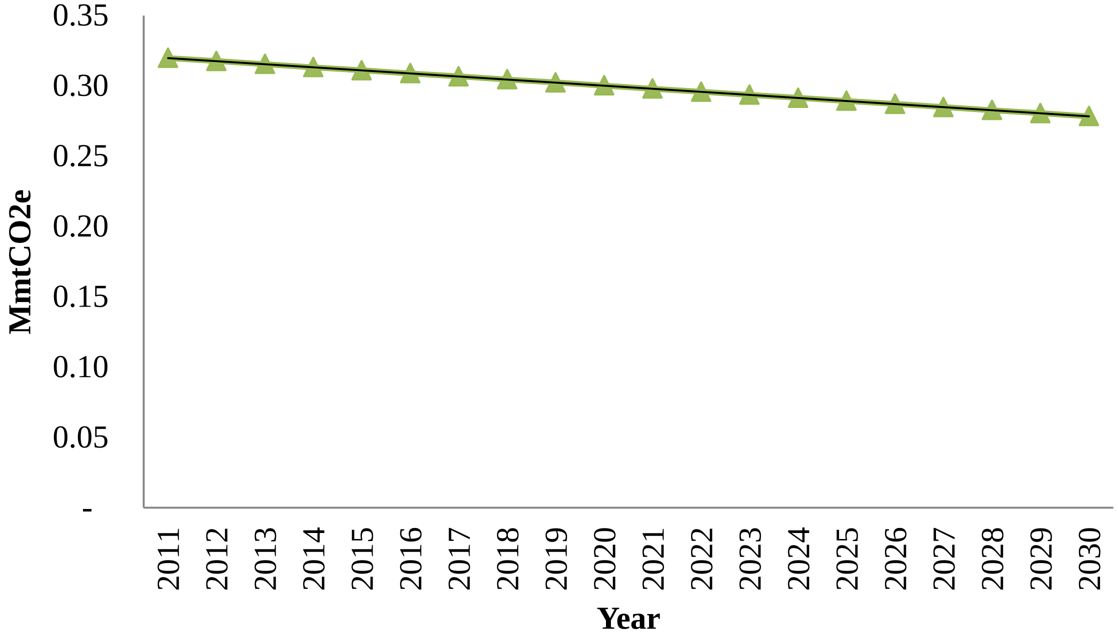


Reference Case projection of GHG emissions from Agricultural Soil Management

Figure 75 presents projected N_2O emissions from Agricultural soil management. Projected emissions estimates for this subsector were based on historic N_2O emissions from 1990 to 2010. The SIT utilized the trend line equation of the historical emissions to predict future emissions.

Nitrous oxide emissions from agricultural soil management were projected to represent approximately 49 % of gross emission from the agricultural sector as presented in Figure 72. This is because N_2O emissions are expected to decrease by 12.5 % from 0.32 MmtCO$_2$e in 2011 to 0.28 MmtCO$_2$e in 2030 as Figure 75 indicates. Emissions are projected to decrease at the rate of 0.002 MmtCO$_2$e per year. The total N_2O emissions projected to be released into the atmosphere 2011 to 203 is 5.98 MmtCO$_2$e.

FIGURE 75. PROJECTED N_2O EMISSIONS FROM AGRICULTURAL SOIL MANAGEMENT



4.6.2 Manure Management:

Greenhouse gas emissions from manure management stayed relatively flat at approximately 0.200 MmtCO_2e every year 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 2010 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 69, manure management was the second largest source in the agricultural sector, emitting approximately 36% of total emission from the sector in 2010. 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[88].

Analysis of Manure Management Emissions

As Figure 76 shows, fluctuations were observed in emissions from manure management sources of GHGs in Delaware. The highest point was in 2003 with 0.21 MmtCO_2e and the lowest point in 1990 with 0.19 MmtCO_2e. Emissions increased by approximately 10.5% between 1990 and 1995 (0.21MmtCO_2e). On the other hand, emissions decreased by 9.5% between 2003 (0.21MmtCO_2e) and 2010 (0.19MmtCO_2e). An analysis of the data show the emissions decreased by 0.0002 MmtCO_2e per year between 1990 and 2010. The slight fluctuations in emissions from manure management can be attributed to changes in livestock population. According to the animal livestock data in EPA's state inventory tool, animal livestock in Delaware decreased by approximately 6.5% from 2002 to 2010, which contributed to decrease in emissions observed in Figure 76.

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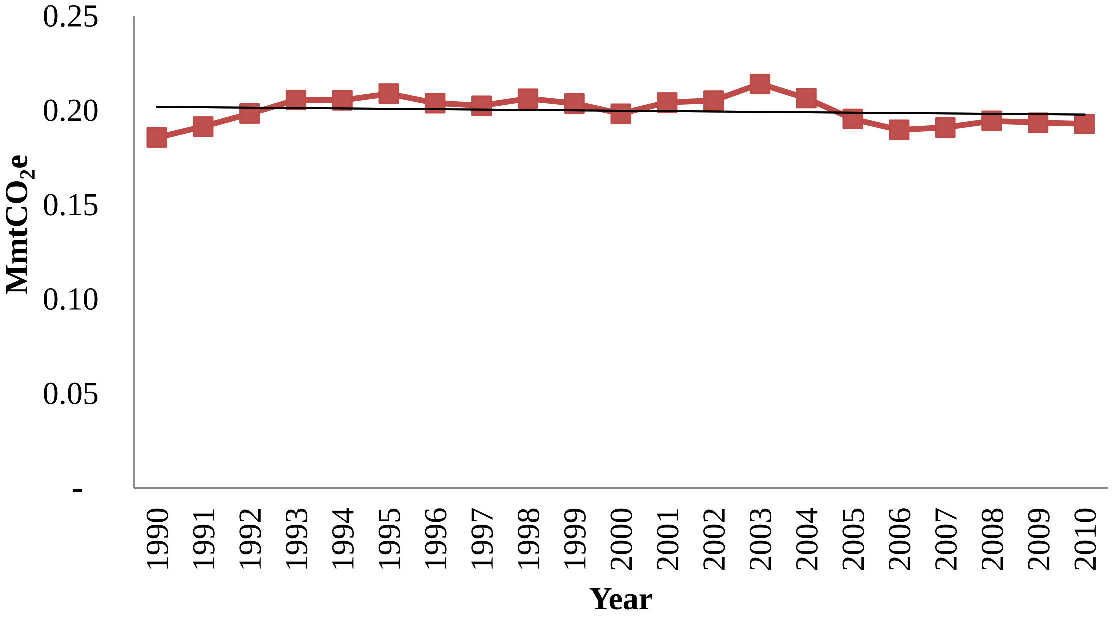
[88] U.S. EPA State Inventory Tool Methane and Nitrous Oxide from Agriculture Module

FIGURE 76. GHG EMISSIONS FROM MANURE MANAGEMENT



Delaware's livestock population decrease was mostly due to farmland conversion pressure[89]. 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[90], 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 of farmlands to residential use and other issues.

In spite of the conversion farmlands to residential use, 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

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

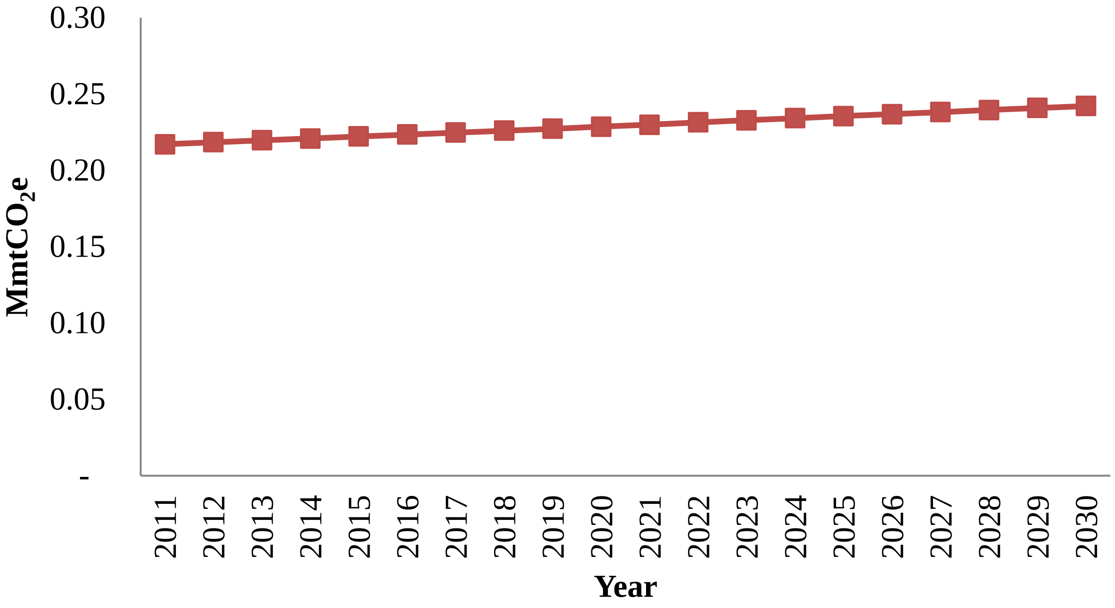
[90] http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/landuse/rangepasture

permanently preserved 89,692 acres of agricultural land and an additional 2,131 acres of forestland (eighteen percent of the total)[91]. 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.

Reference Case projection of GHG Emissions from Manure Management

Figure 77 presents projected manure management GHG emissions from 2011 to 2030. The SIT utilized the projected population of animal livestock to predict future GHG emissions from this subsector. Delaware's animal livestock population is expected to increase by approximately 7% from 2011 to 2030.

FIGURE 77. PROJECTED GHG EMISSIONS FROM MANURE MANAGEMENT



Greenhouse gas emissions from manure management are projected to represent 43% of gross emissions from the agricultural sector in 2030 as represented in Figure 72. Emissions are projected to increase from 0.22 $MmtCO_2e$ in 2011 to 0.24 $MmtCO_2e$ in 2030 as indicated in Figure 77. This will be an increase of approximately 9%.

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[91] Delaware's department of Agriculture :http://dda.delaware.gov/pressrel/2009

4.6.3 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 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[92]. The U.S Department of Agriculture (USDA) provided data on emission factors. In 2010, GHG[93] emission from this sub-category was 8% of gross emissions from the agricultural sector as shown by Figure 69. This was a contribution of 0.04 $MmtCO_2e$ to gross agricultural sector emissions.

Analysis of Enteric Fermentation GHG Emissions

As Figure 78 presents, emissions from enteric fermentation fluctuated downward from 1990 to 2010. The Emissions decreased from 0.05 $MmtCO_2e$ in 1990 to 0.04$MmtCO_2e$ in 2010, a decrease of approximately 20%. Emissions decreased at a rate of 0.0006 $MmtCO_2e$ per year. Methane emissions reached a maximum amount of 0.06 $MmtCO_2e$ in 1993 and reached dipped to 0.04 $MmtCO_2e$ in 2003 as shown in Figure 78.

Decreasing emissions from enteric fermentation could also be attributed to decreasing livestock population in Delaware. 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 enteric fermentation is by the use anaerobic manure digesters. Anaerobic digesters produce methane gas that may be used for heating and generating electricity.

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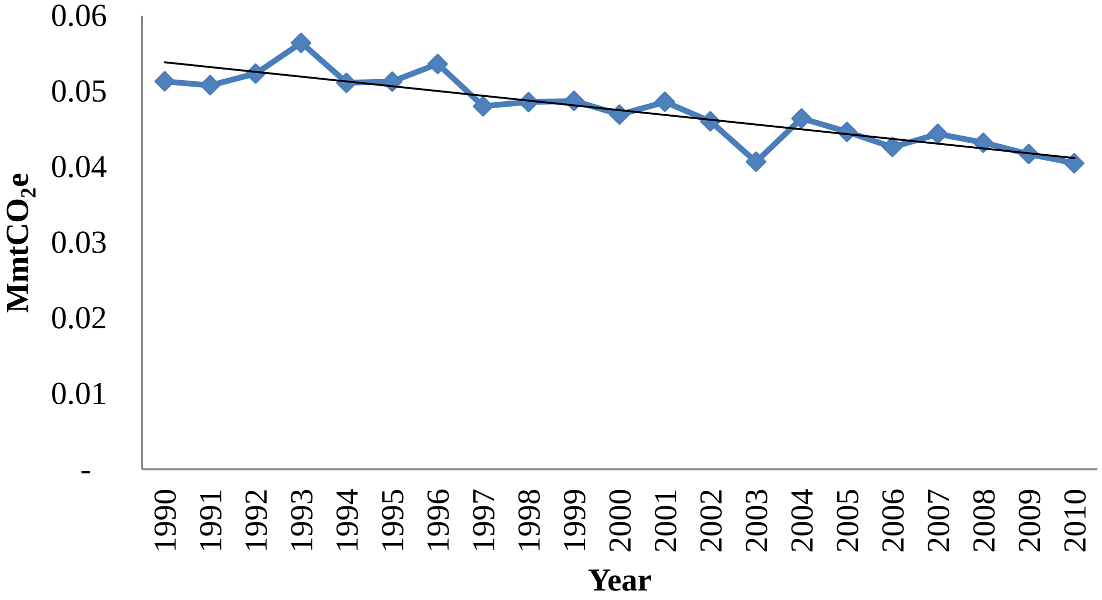
[92] 2010 Greenhouse Gas Emissions Inventory Development Plan-page 29

[93] GHG emissions include N_2O and CH_4

FIGURE 78. CH_4 EMISSIONS FROM ENTERIC FERMENTATION

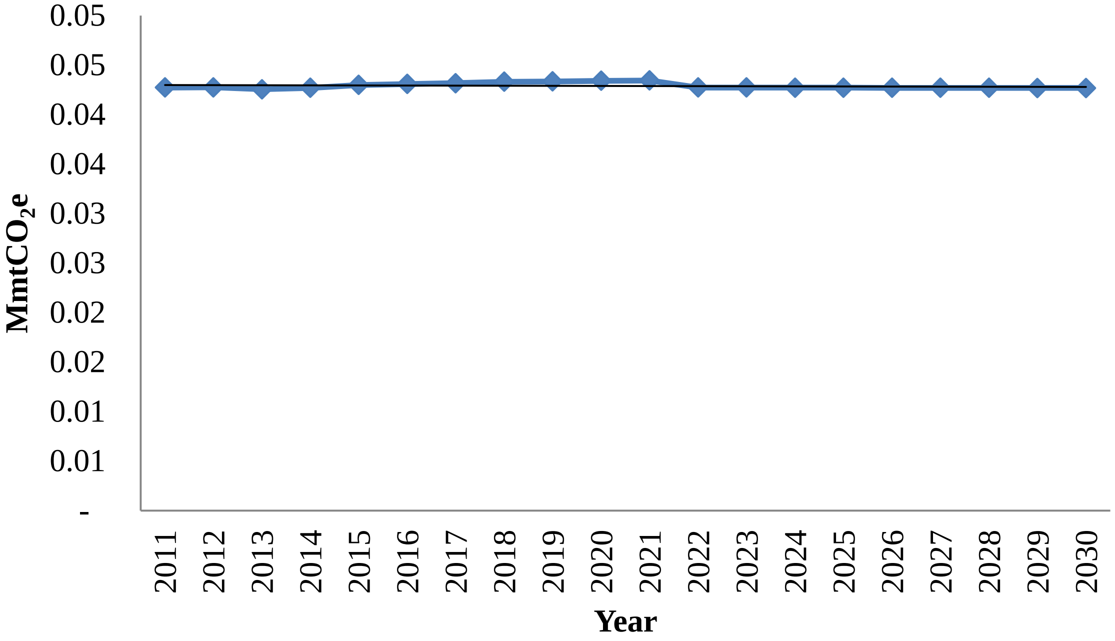


Reference Case projection of CH_4 Emissions from Enteric Fermentation

Methane emissions from enteric fermentation are projected to represent 8% of gross GHG emissions from the agricultural sector with a total of 0.04MmtCO$_2$e in 2030. Cumulative emissions from enteric fermentation from 2011 to 2030 are projected to be 0.85MmtCO$_2$e.

As Figure 79 presents, CH_4 emissions are not expected to change much, remaining flat from 2011 to 2030. However, if Delaware's livestock population continues to decline based on historical CH_4 emissions similar to the trend presented in Figure 78, projected emissions will also diminish with time.

FIGURE 79. PROJECTED CH_4 EMISSIONS FROM ENTERIC FERMENTATION



4.6.4 Agricultural Residue Burning:

In addition to the above sources of GHG emission in the agricultural sector, this 2010 GHG emissions inventory also identifies a minor source of N_2O and CH_4. Agricultural residue burning in Delaware falls under the category of prescribed[94] 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 2010, this source represented approximately 0.4% of agricultural sector GHG emissions, with an amount of 0.002 $MmtCO_2e$ (2,000 $mtCO_2e$).

Analysis of Total GHG Emissions from Agricultural Source Category

As Figure 80 presents, GHG emissions from agricultural residue burning fluctuated between 0.0035$MmtCO_2e$ and 0.0015$MmtCO_2e$ between 1990 and 2010 as Figure 80 indicates. Average emissions were approximately 0.002 $MmtCO_2e$ and cumulative

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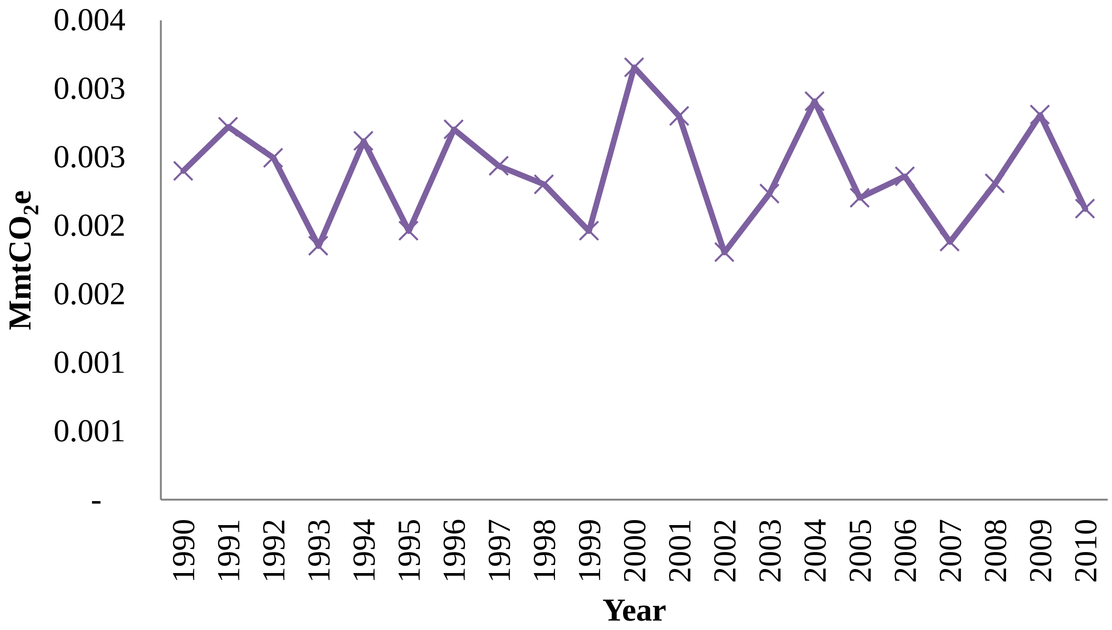
[94] Information on prescribed burns:http://www.dnrec.delaware.gov/whs/awm/Info/Pages/OBPrescribedBurns.aspx

emissions from 1990 to 2010 totaled 0.004 $MmtCO_2e$. The highest point was in 2000 with 0.0031$MmtCO_2e$ (3,156 $mtCO_2e$) and the lowest point was in 2002 with 0.0018 $MmtCO_2e$ (1,806 $mtCO_2e$).

FIGURE 80. EMISSIONS FROM AGRICULTURAL RESIDUE BURNING

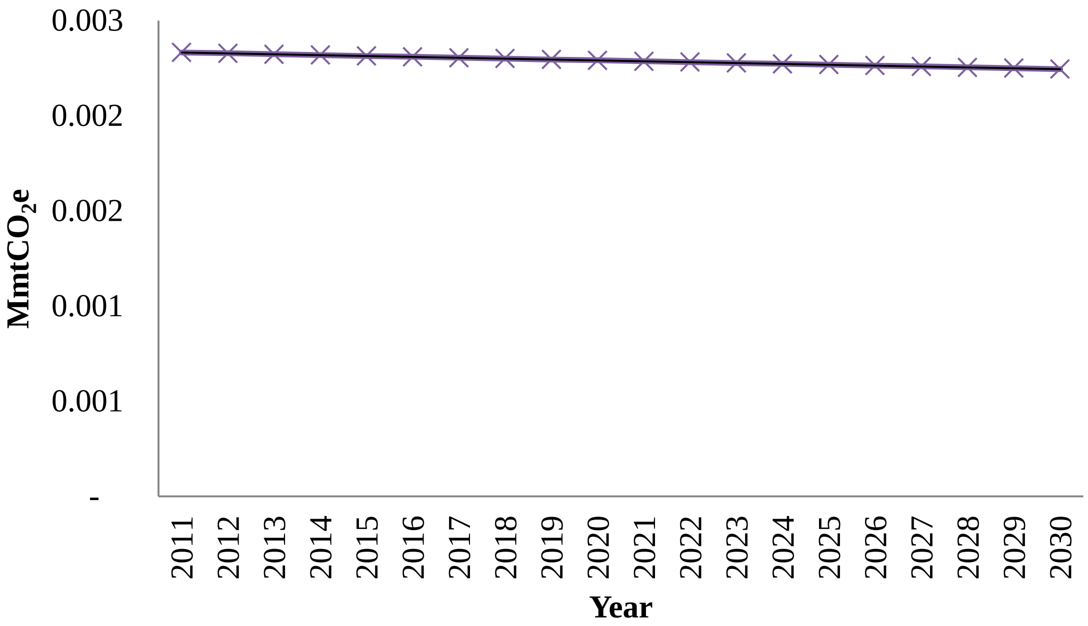


Reference Case projection of GHG Emissions from Agriculture Residue Burning

Cumulative GHG emissions from agriculture residue burning between 2011 and 2030 are projected to be 0.05$MmtCO_2e$. GHG emissions are projected to represent approximately less than 1% (0.4%) of gross GHG emissions from the agricultural sector as Figure 72 presents. Figure 81 shows that projected emissions will stabilize at approximately 0.002 $MmtCO_2e$ as indicated by the straight line. GHG emissions will decrease slightly by approximately 4%.

However, historical emissions from agricultural residue burning show significant fluctuations from 1990 to 2010 as presented in Figure 80. Likewise, actual future emissions estimates for agricultural residue burning are expected to reflect similar fluctuations observed in the historical GHG emissions from this source as opposed to the linear trajectory observed in Figure 81.

FIGURE 81. PROJECTED EMISSIONS FROM AGRICULTURAL RESIDUE BURNING



Conclusion of Agricultural Sector GHG Emissions Analysis

In spite of significant fluctuations observed in gross historical GHG emissions from the agricultural sector, overtime emissions remained stable with only a slight decrease. Projected GHG emissions from the agricultural sector also remained stable with slight decrease overtime. Based on historic and projected emissions data, gross GHG emissions from the agricultural sector is not expected to change significantly overtime, so gross GHG emissions from this sector will not trend upwards in the nearest future.

Projected reductions in GHG emissions were observed in none livestock activities such as agricultural soil management and emissions in agricultural residue burning. Both activities provide opportunities for potential additional reductions in overall GHG emissions from the agricultural sector by producing healthier crops, (which trap more GHG) reducing tillage and minimizing residue burning. If the livestock population in Delaware continues to decrease, then GHG emissions from the other agricultural activities will also continue to decrease as well.

4.7 WASTE MANAGEMENT SECTOR

In 2010, GHG emissions from the waste management source category represented approximately 1% of total emissions from Delaware. The primary GHGs of concern from Delaware's waste management sector were CH_4, and N_2O 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 2010 was approximately 0.12 MmtCO$_2$e. Total emissions were estimated by adding up GHG emissions from both wastewater treatment and MSW. Between 1990 and 2010, the waste management sector released 8.65 MmtCO$_2$e in to the atmosphere. Figure 82 presents historical emissions from the waste management sector. From 1990 to 2010, GHG emissions from the waste management sector decreased by approximately 79% in emissions as Figure 82 indicate.

According to Figure 82, GHG emissions from waste management sector had a significant decrease 1990 to 2010. This decrease was primarily influenced by significant reductions in GHG emissions from landfill activities as shown in Figure 83. Landfill emission reductions resulted from changes made to landfill practices including methane recovery[95] 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 reductions GHG emission from the waste management sector observed in Figure 82. As Figure 83 shows, GHG emissions from wastewater treatment increased steadily between 1990 and 2010. In 2004, landfill emissions dropped below emissions from wastewater treatment. Table 18 provides estimates of total GHG emissions from landfill activities and wastewater treatment.

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

FIGURE 82. NET GHG EMISSIONS FROM WASTE MANAGEMENT

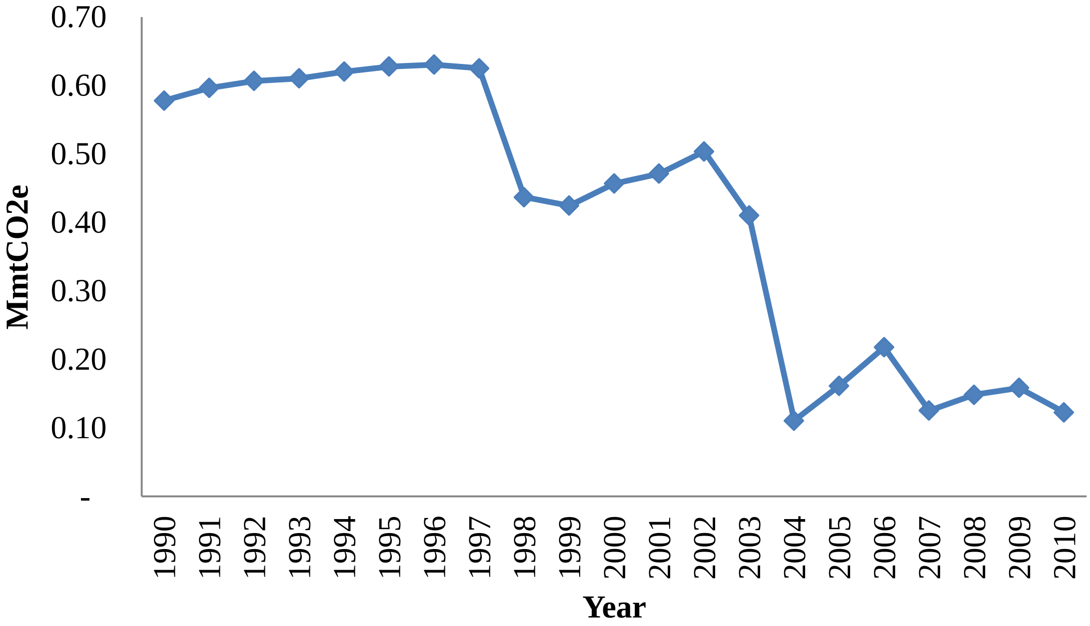


FIGURE 83. HISTORICAL GHG EMISSIONS BY WASTE MANAGEMENT SOURCES

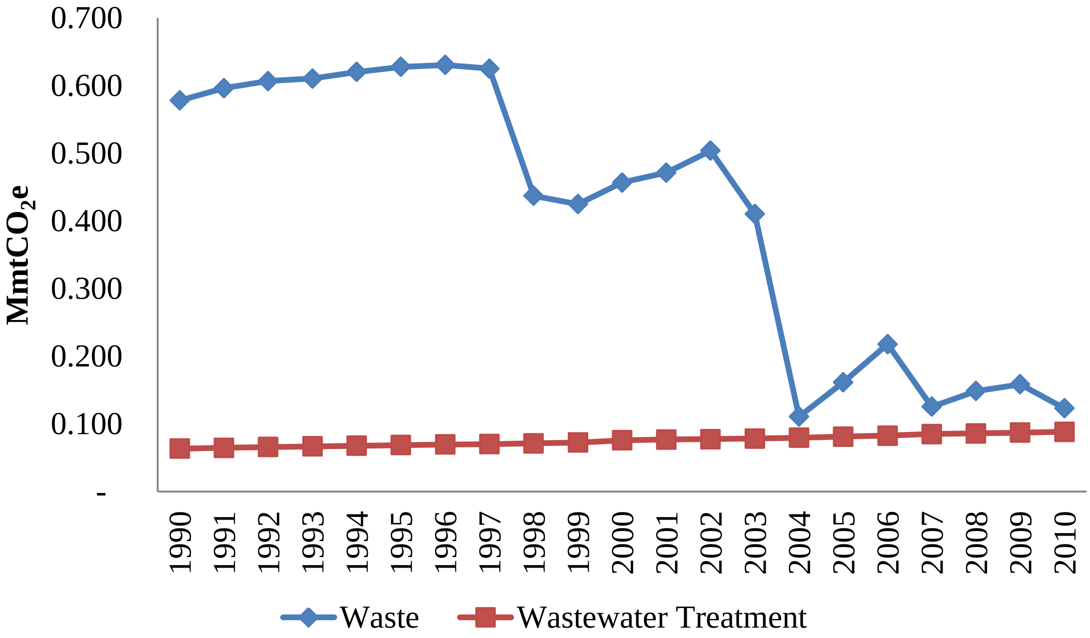


TABLE 18. GHG EMISSIONS FROM THE WASTE MANAGEMENT SECTOR IN MMTCO$_2$E					
Sources	**1990**	**1995**	**2000**	**2005**	**2010**
Landfill	0.06	0.07	0.08	0.08	0.09
Wastewater Treatment	0.51	0.56	0.38	0.08	0.03
Total Emissions	**0.58**	**0.63**	**0.46**	**0.16**	**0.12**

Reference Case Projection of Waste management GHG Emissions

The waste management sector is projected to represent approximately 6% of gross GHG emissions in 2030. Figure 84 presents gross GHG emissions from the waste management sector from 2011 to 2030. Greenhouse gas emissions from this sector are expected to diminish significantly due to sinks in the waste management sector such as landfill gas flaring and recycling for energy uses. Emissions are projected to decrease from -0.23 MmtCO$_2$e in 2011 to -0.58 MmtCO$_2$e in 2030 as presented in Figure 84. This is a decrease of approximately 152%. The rate at which GHGs will be removed from the waste management sector was determined by trend line analysis to be 0.02 MmtCO$_2$e per year.

FIGURE 84. PROJECTED EMISSIONS FROM WASTE MANAGEMENT

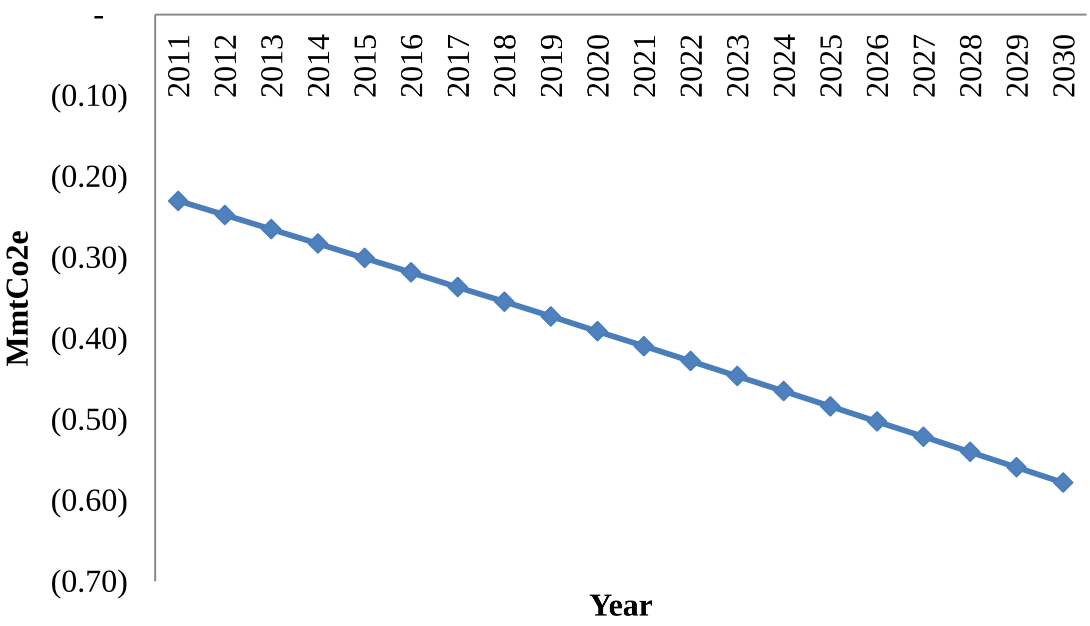
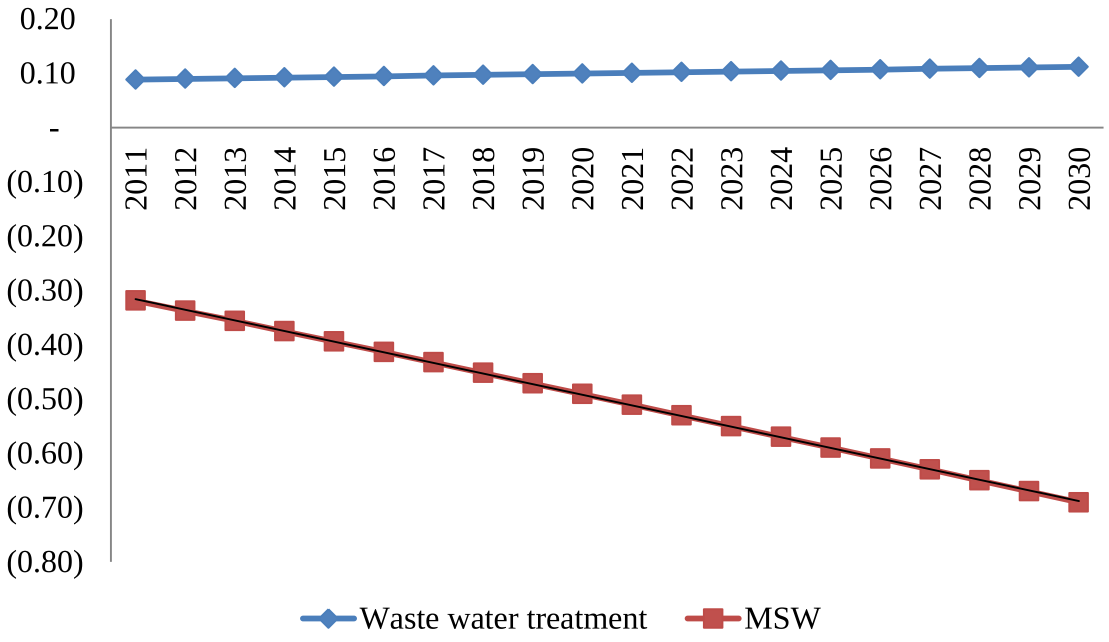


Figure 85 breaks down projected GHG emissions from the waste management sector by sources including wastewater treatment and landfills. Figure 85 shows that GHG emissions from the waste management sector will be primarily driven by emissions from landfills. Greenhouse gas emissions from MSW are projected to decrease from -0.32 $MmtCO_2e$ in 2011 to -0.690 $MmtCO_2e$ in 2030 as presented in Figure 85. This will be a decrease of approximately 116%. Emissions will be removed from this sector at the rate of 0.02 $MmtCO_2e$ per year.

According to projection analysis, MSW activities are projected to remove a total of 10.04 $MmtCO_2e$ in GHG emissions between 2011 and 2030. Conversely, GHG emissions from waste water treatment is projected to remain flat as presented in Figure 85 with a slight increase from 0.09 $MmtCO_2e$ in 2011 to 0.11 $MmtCO_2e$ in 2030. Cumulative emission from wastewater treatment between 2011 and 2030 is projected to be 2.01 $MmtCO_2e$

FIGURE 85. PROJECTED EMISSIONS FOR WASTEWATER AND MSW



4.7.1 Landfill Activities

Greenhouse gas emissions from landfill activities include primarily $CH_{4,}$ 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 (Bingemer and Crutzen)[96].

Landfills are artificial sinks because landfill covers contain microbes that allow for the microbial oxidation of methane that is generated from biodegradable organic matter. This process is known as methanotrophy[97]

In 2010, the total GHG emissions from landfills were approximately 0.12 $MmtCO_2e$. This represented approximately a 79% decrease in emissions from 1990, which was 0.578 MmtCO2e. There was a sharp decrease in CH_4 Emissions from 0.625 $MmtCO_2e$ in 1997 to 0.437 $MmtCO_2e$ in 1998. Methane emissions also decreased sharply from 0.504 $MmtCO_2e$ in 2002 to 0.111 $MmtCO_2e$ in 2004.

Methane emissions fluctuated downward from 2004 to 2010 as presented in Figure 86. The rate of decrease in emissions was determined to be 0.03 $MmtCO_2e$ per year. The decline in CH_4 emissions from landfill sources in Delaware accelerated in 1997 due to the introduction of CH_4 recovery in at the landfill sites. In Delaware, CH_4 was recovered using two methods, flaring and landfill gas-to-energy conversion[98]. Sections 4.7.1.3 and 4.7.1.4 discuss CH_4 recovery in detail.

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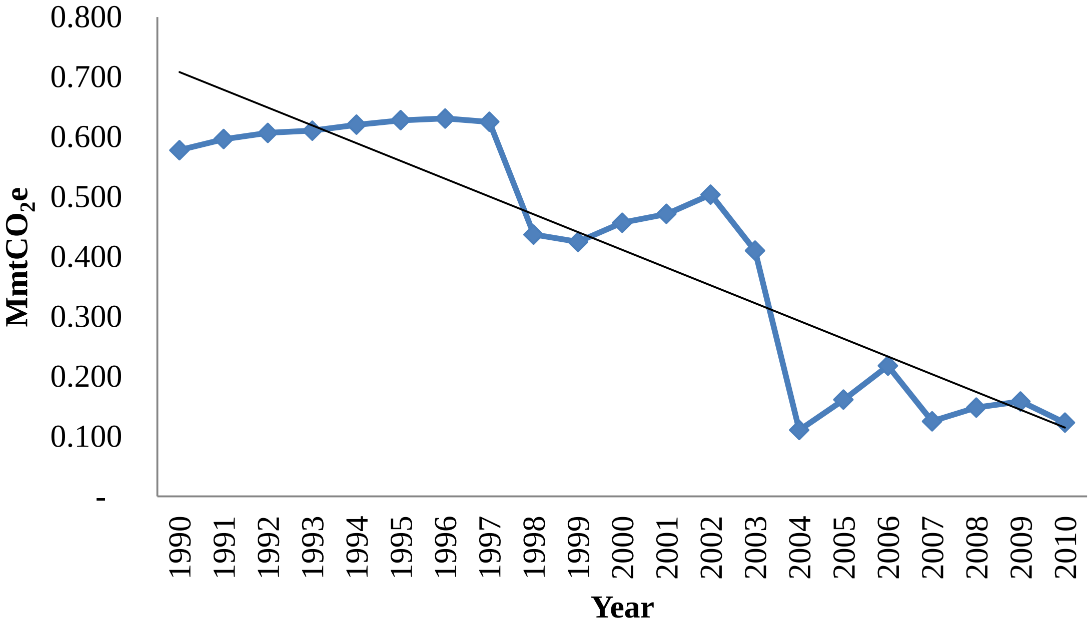
[96] Bingemer, H. and P. Crutzen. 1987. “The Production of Methane from Solid Waste.” Journal of Geophysical research 92: 2181-2187.

[97] Alex Visscher et al. 2007. “Greenhouse Gas Sinks-Artificial Methane Sinks”.

[98] Methane gas from landfill emissions used as fuel.

FIGURE 86. NET GHG EMISSIONS FROM LANDFILL ACTIVITIES

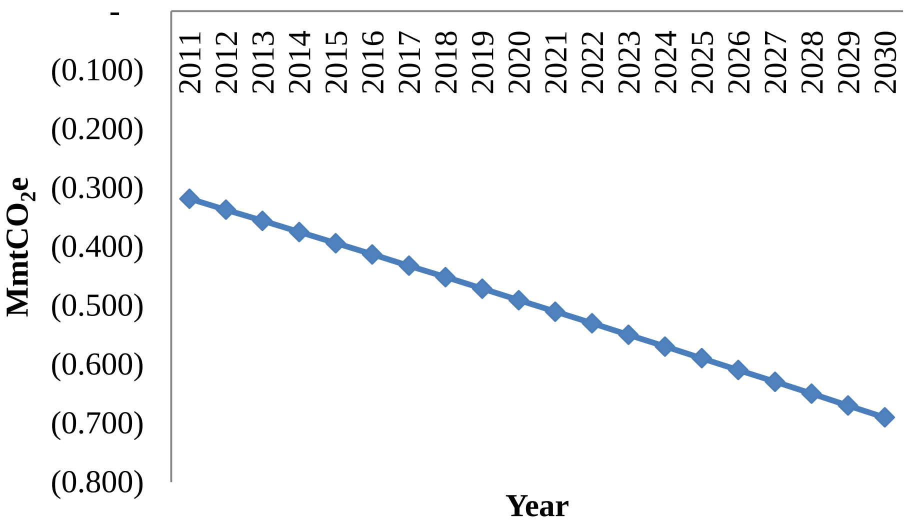


Reference Case Projections for GHG Emissions from Waste Management

According to the 2010 GHG emissions results, net CH_4 emissions from Delaware landfills are projected to be in the negative values.

Figure 87 presents projected net CH_4 emissions from industrial and municipal landfills. Net CH_4 emission from landfills was - 0.319 $MmtCO_2e$ in 2011, and is projected to decrease to -0.690 $MmtCO_2e$ in 2030. This was a decrease of approximately 116 % at the rate of 0.02 $MmtCO_2e$ per year. This means that between 2011 and 2030, the annual absorption of CH_4 by landfill activities will increase by 116% at the rate of 0.02 $MmtCO_2e$ per year making landfill activities in Delaware a major potential sink for CH_4. The linear projection represented in Figure 87 is based on the assumption that annual methane recovery and oxidation will increase with the amount of methane generated from industrial, municipal landfills as well as Delaware population between 2011 and 2030.

FIGURE 87. PROJECTED NET CH4 EMISSIONS FROM LANDFILLS



Methodology

This 2010 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 13 is the general equation used to estimate net methane emissions from landfill activities.

EQUATION 13. METHANE EMISSIONS EQUATION FOR SOLID WASTE

Net CH_4 Emissions = *Municipal Landfill CH_4 Generation – Municipal Landfill CH_4 Recovery - CH_4 Oxidation by Soil at MSW Landfills + Industrial Landfill CH_4 Generation*[99] *- CH_4 Oxidation by Soil at Industrial Landfill*

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

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[100] because the average rainfall in Delaware is 45.68 inches[101]. 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 14:

EQUATION 14 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 from Delaware landfills increased steadily from 1990 to 2010.

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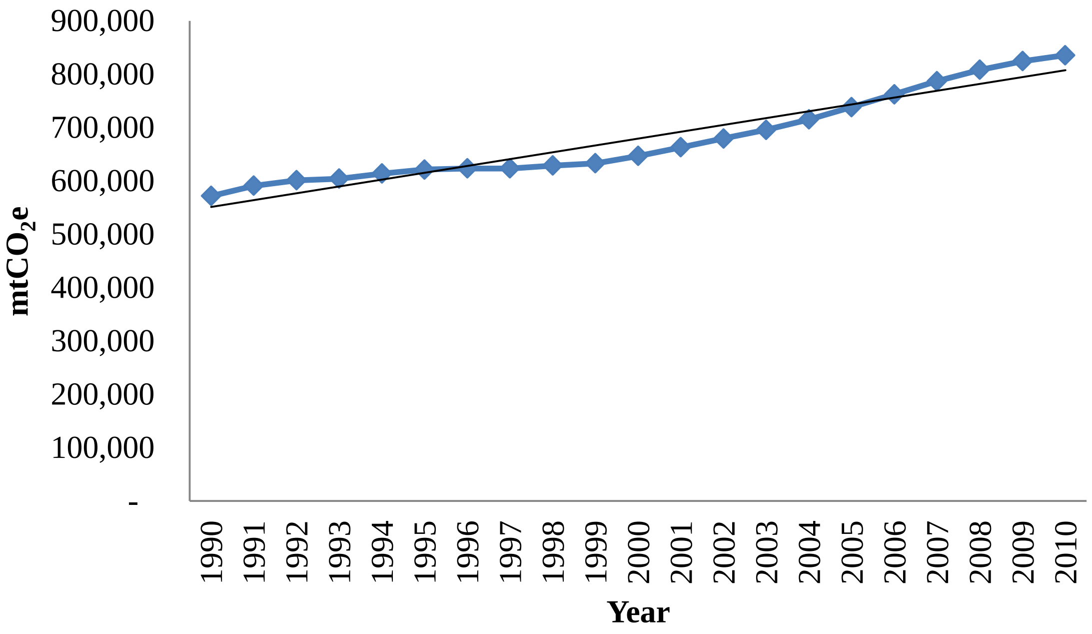
[100] States in non-arid climates have average annual rainfall that is greater than 25 inches.

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

4.7.1.1 Gross Methane Emissions from municipal and Industrial landfills: Landfills were the largest source of anthropogenic CH_4 emissions in this 2010 GHG emission inventory. Gross CH_4 emission[102] from Delaware landfills totaled 0.84 $MmtCO_2e$ (835,702 $mtCO_2e$) in 2010. Gross CH_4 emissions increased at the rate of 0.013 $MmtCO_2e$ (12,816 $mtCO_2e$) per year as represented by Figure 88. Gross CH_4 emissions from landfill increased from 0.57 $MmtCO_2e$ (571,859 $mtCO_2e$) in 1990 to 0.84 $MmtCO_2e$ (835,702 $mtCO_2e$) in 2010. This is an increase of approximately 47%. Gross CH_4 emissions increased at the rate of 0.001 $MmtCO_2e$ per year. Methane emissions from landfills increased steadily with Delaware's solid waste disposal at landfills also increased.

FIGURE 88. GROSS CH_4 EMISSIONS FROM LANDFILL ACTIVITIES



Gross CH_4 emissions from landfills came from two source types: municipal solid waste (MSW) landfill emissions and industrial landfills. Figure 89 presents historical emissions of Industrial and MSW landfills as determined by the FOD model. As Figure 89 shows, annual CH_4 emissions from MSW landfills exceeded annual CH_4

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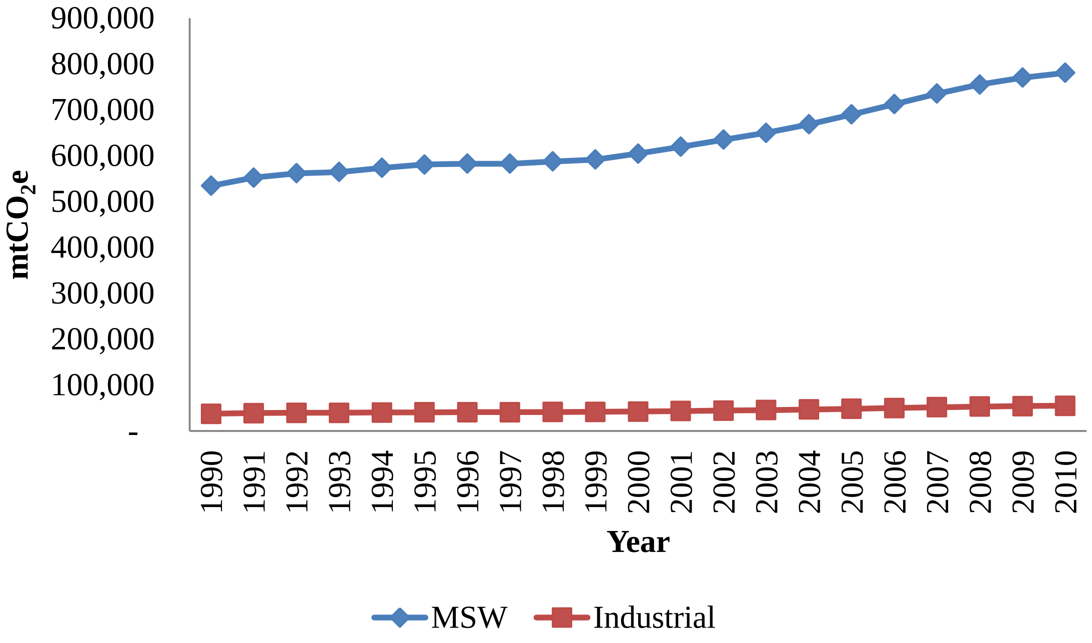
[102] With the exclusion of Methane recovered by flaring and landfill gas converted for energy use.

emissions from industrial landfills by an order of magnitude. Between 1990 and 2010, MSW landfills released approximately 13.3 MmtCO$_2$e into the atmosphere, while industrial landfill released approximately 0.93 MmtCO$_2$e into the atmosphere during the same period.

FIGURE 89. GROSS CH$_4$ EMISSIONS FROM MSW AND INDUSTRIAL LANDFILLS

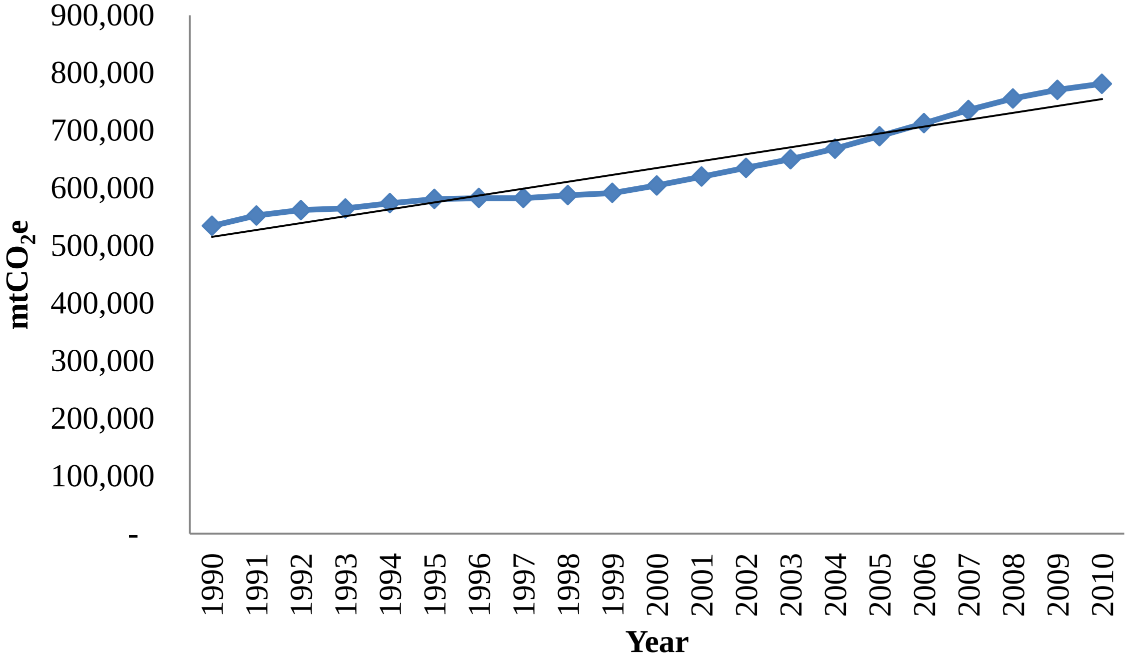


4.7.1.1.2 Gross CH$_4$ Emissions from MSW Landfills: Three MSW landfills in Delaware were surveyed to estimate CH$_4$ emissions for this source category. The Cherry Island Landfill (CIL) located in Wilmington, Central Solid Waste Management Center (CSWMC) located in Felton and Southern Solid Waste Management 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.

Between 1990 and 2010, cumulative CH$_4$ emissions from MSW landfills in Delaware were approximately 13.3 MmCO$_2$e. Methane emissions from MSW landfills in Delaware increased from 0.53 MmtCO$_2$e (534,448 mtCO$_2$e) in 1990 to

0.78 $MmtCO_2e$ (781,030 $mtCO_2e$) in 2010 as Figure 90 present. This was an increase of approximately 47%. Emissions increased at the rate of 0.012 $MmtCO_2e$ per year according to trendline analysis. Methane emissions from landfills increase with Delaware's population, which is projected to increase by approximately 12% from 2011 to 2030.

FIGURE 90. GROSS CH_4 EMISSIONS FROM MSW LANDFILLS



4.7.1.1.2 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 2010 include Delaware Recyclable Product Inc. (DRPI), which is a construction and demolition material landfill. Industrial landfills in Delaware between 1990 and 2010 also include DuPont Hay Road and Motiva Industrial Waste Landfill.

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 landfill 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[103], 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%[104] of the MSW landfill CH_4 generation prior to adjusting for flaring and recovery or oxidation. This 7% value was applied to estimate Delaware's industrial landfills CH_4 emissions in this 2010 GHG inventory.

Between 1990 and 2010, cumulative CH_4 emissions from industrial landfills in Delaware were approximately 0.93 $MmCO_2e$. Figure 91 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 91 shows that CH_4 emissions from industrial landfills in Delaware increased steadily from 0.037 $MmtCO_2e$ (37,411 $mtCO_2e$) in 1990 to 0.055 $MmtCO_2e$ (54,672 $mtCO_2e$) in 2010. This was an increase of approximately 49% at the rate of 0.001$MmtCO_2e$ per year as determined by trendline analysis. Table 19 provides estimates of CH_4 emissions from MSW and industrial landfills.

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

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

FIGURE 91. GROSS CH_4 EMISSIONS FROM INDUSTRIAL LANDFILLS

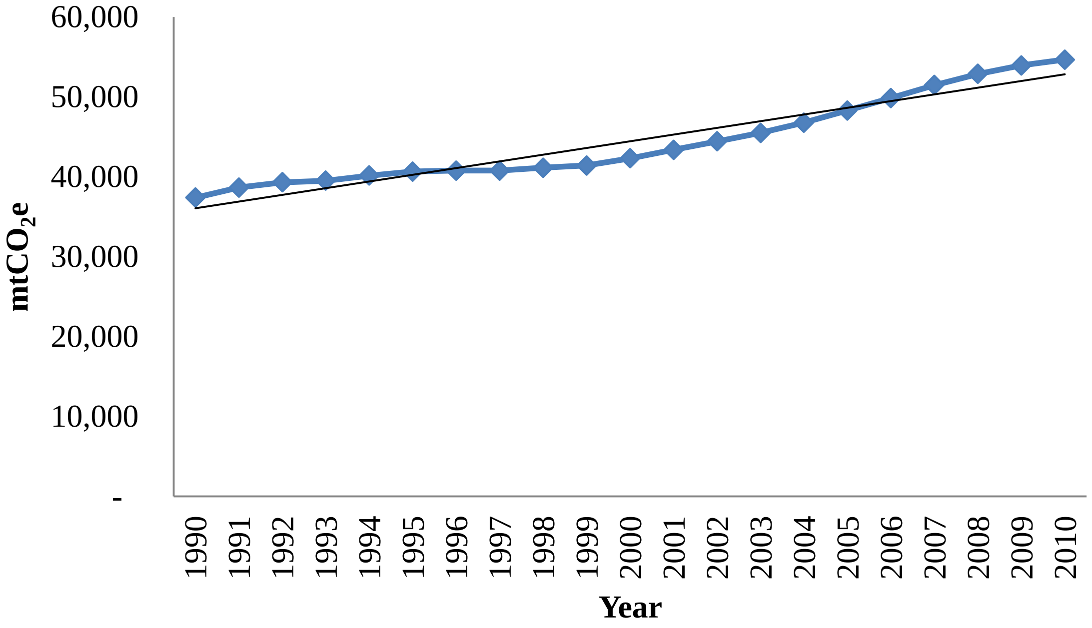


TABLE 19. CH_4 EMISSIONS FROM LANDFILLS

Landfills	1990	1995	2000	2005	2010
MSW	534,448	580,840	604,667	690,120	781,030
Industrial	37,411	40,659	42,327	48,308	54,672
Total CH_4 ($mtCO_2e$)	**571,859**	**622,504**	**646,994**	**738,428**	**835,702**

4.7.1.2 Reference Case Projections for GHG Emissions from Waste Management: The State Inventory Tool was modified to include state population forecasts and projected per capita waste generation estimates, and then calculate future emissions using the first-order decay model (FOD), the same methodology as historical emissions are currently calculated in the state inventory tool for waste. As Figure 92 presents, emissions from municipal solid waste (MSW) landfills are projected to be much larger than emissions from industrial landfills. As Delaware population continues to rise steadily, municipal landfill waste will also increase, which in turn increases MSW emission.

As Figure 92 indicates, CH_4 emissions from MSW is projected to increase from 0.6 $MmtCO_2e$ (555,997 $mtCO_2e$) in 2011 to 1.1 $MmtCO_2e$ (1,150,338 $mtCO_2e$) in 2030. This will be an increase of approximately 83% at the rate of 0.03 $MmtCO_2e$ per year.

FIGURE 92. PROJECTED CH_4 EMISSIONS BY LANDFILL TYPE

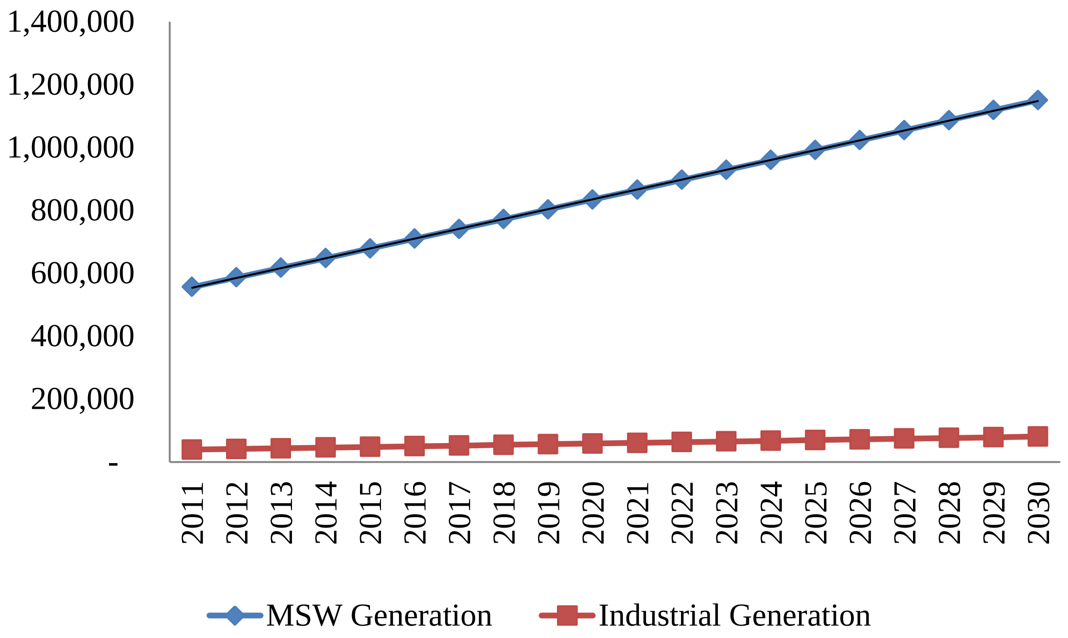


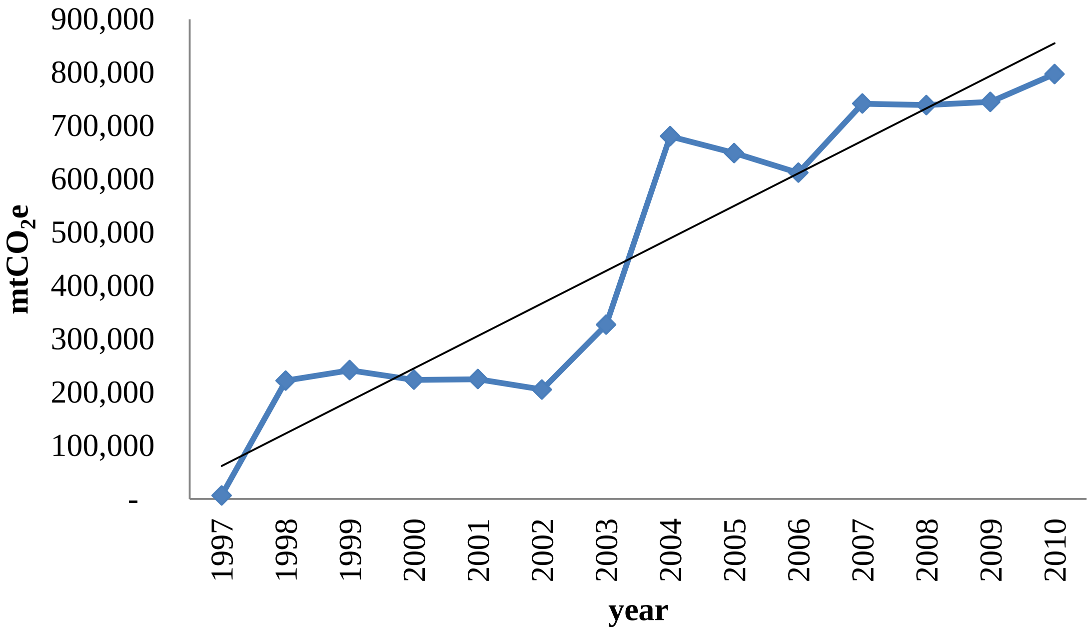
TABLE 20. PROJECTED CH_4 EMISSIONS FROM LANDFILLS					
Landfills	**2011**	**2015**	**2020**	**2025**	**2030**
MSW	555,977	678,732	834,189	991,503	1,150,338
Industrial	38,918	47,511	58,393	69,405	80,524
Total CH_4 ($mtCO_2e$)	**594,895**	**726,243**	**892,582**	**1,060,909**	**1,230,862**

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

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

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 2010. The recovery data was only available from 1997 according to DSWA. Figure 93 presents the CH_4 emissions recovered from Delaware landfill from 1997 to 2010.

FIGURE 93. AMOUNT OF CH_4 EMISSIONS RECOVERED



Between 1997 and 2010, a cumulative amount of 6.4 million metric ton of methane has been flared or recycled for energy use. As Figure 93 shows, CH_4 emissions avoided increased from 6,668 $mtCO_2e$ in 1997 to 797,237 $mtCO_2e$ in 2010. The rate of growth was 0.061 $MmtCO_2e$ (60,987 $mtCO_2e$) per year as determined by trendline analysis. This increase in CH_4 emissions was primarily 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[105] began in 2007.

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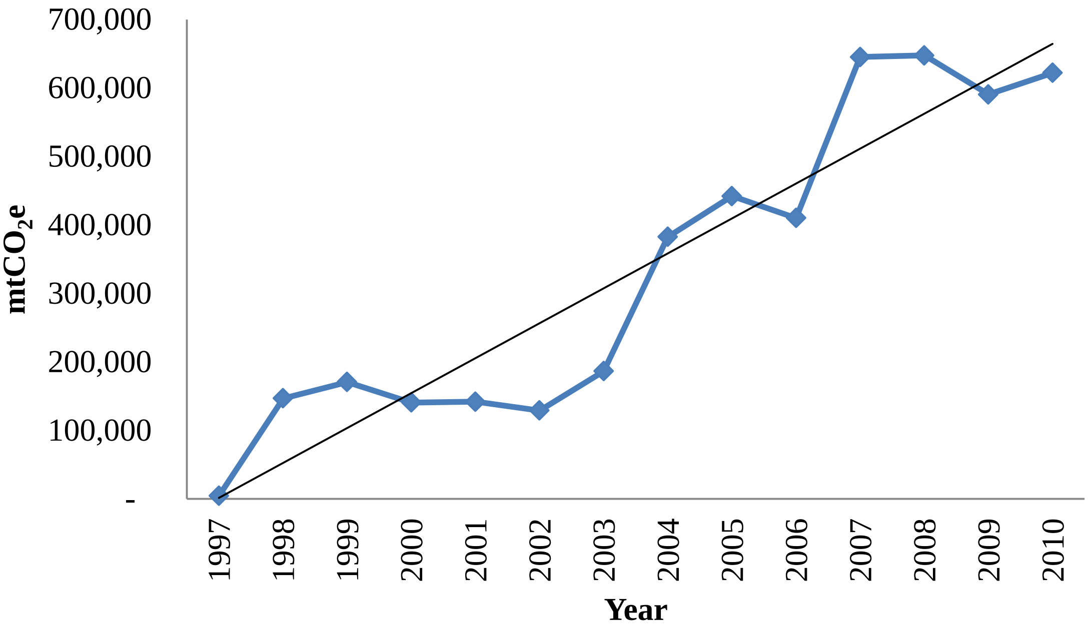
[105] Delaware's Public Service Commission Web Site: http://depsc.delaware.gov/electric/delrps.shtml

4.7.1.3 Methane Emissions Recovered from LFGTE: Between 1997 and 2010, a cumulative amount of 4.6 million metric ton of landfill gas has been recycled for energy use. Figure 94 presents the annual amount of CH_4 collected for LFGTE. The figure shows an increase from 1997 to 2010. LFGTE amounts increased from 4,553 $mtCO_2e$ in 1997 to 622,065 $mtCO_2e$ in 2010. This was an increase of approximately 13,600% at the rate of 51,007 $mtCO_2e$ per year.

FIGURE 94. METHANE RECOVERED BY LFGTE



4.7.1.4 Methane Emissions Recovered from Flaring: Figure 95 presents the amount of CH_4 recovered annually due to 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 2,115 $mtCO_2e$ in 1997 to 297,916 $mtCO_2e$ in 2004, an increase of approximately 13,986%. However, the amount of CH_4 flared decreased significantly to 91,368 $mtCO_2e$ in 2008, a decrease of approximately 69%.

Table 21 provides a summary of annual estimates of recovered CH_4 from flaring as well as LFGTE. There were no CH_4 recovered inform 1990 through 1996 as indicated in Table 21 by zero estimates in 1990 and 1995. However, CH_4 recovery began in 1997, which led to a gross CH_4 recovery of 223,599 $mtCO_2e$ in 2000, 648,965 $mtCO_2e$ in 2005 and 797,237 $mtCO_2e$ in 2010. Table 22 provides a summary estimated CH_4 amounts recovered annually between 1990 and 2010.

FIGURE 95 METHANE RECOVERED BY FLARING

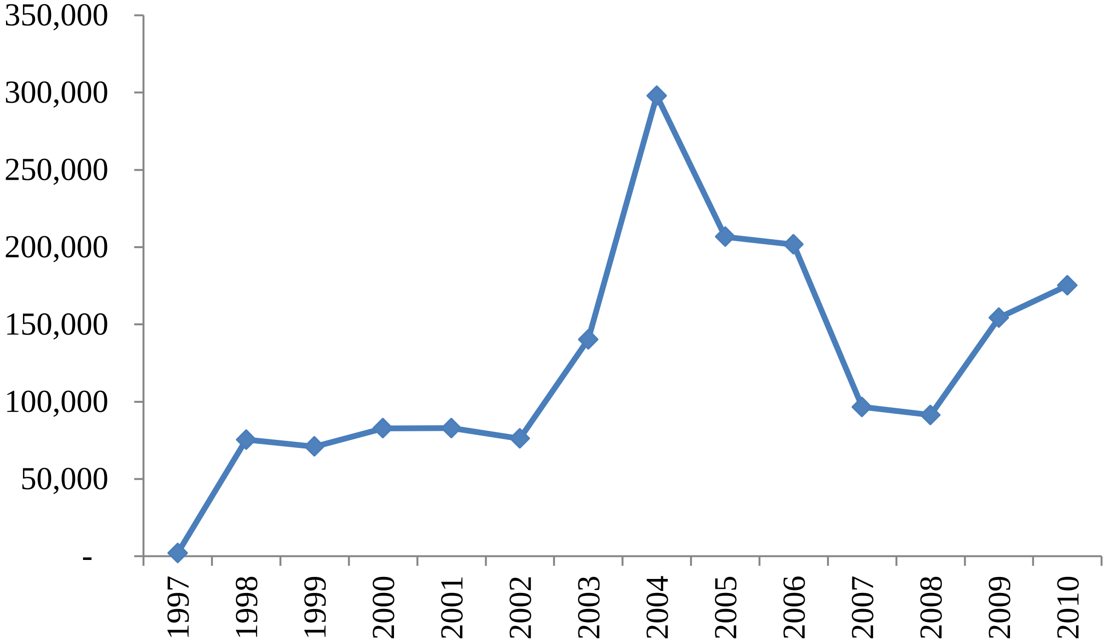
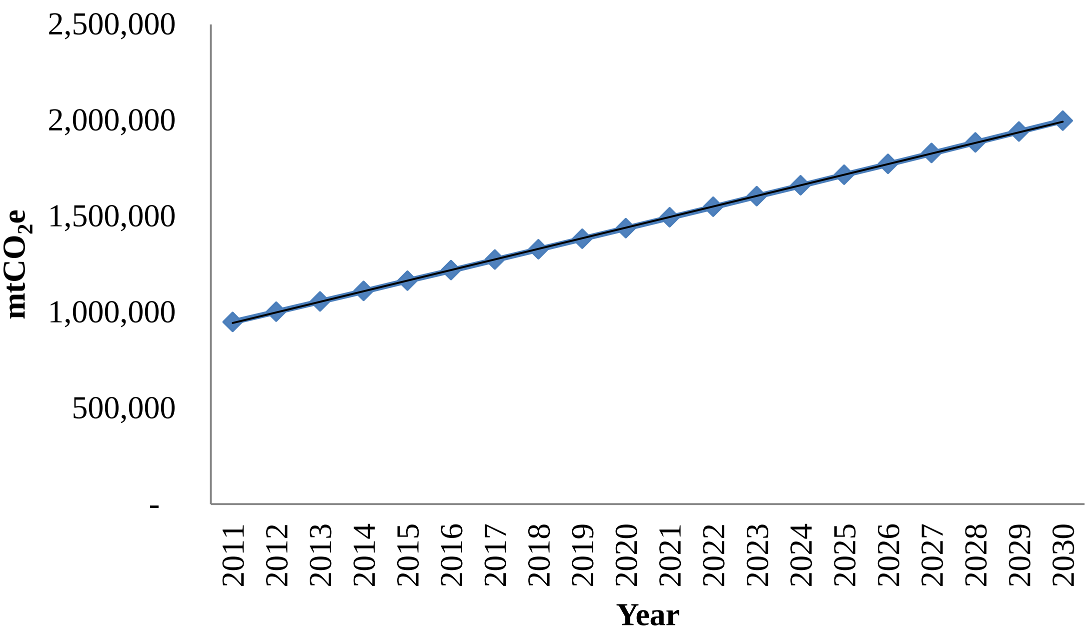


TABLE 21. CH_4 RECOVERED FROM LANDFILLS					
Recovery	**1990**	**1995**	**2000**	**2005**	**2010**
Flare	0	0	82,776	206,682	175,172
LFGTE	0	0	140,823	442,283	622,065
Total CH_4 Recovered	**0**	**0**	223,599	648,965	797,237

Reference Case Projection of CH_4 Recovered from Delaware Landfills

Projected estimates for flaring and LFGTE rates through 2030 are based on the reported/default 2009 value. This approach allows for state specific activity data to be utilized for estimating GHG emissions, which is the most accurate methodology possible. Limitations can be found in the per capita landfilling rate and landfill gas collection projection factors. Nonetheless, this projection approach is the most accurate method available based on current landfill characteristic projections.

FIGURE 96. METHANE RECOVERY FROM DELAWARE LANDFILLS



Methane recovery from Delaware landfills is expected to continue increase through 2030. The projected cumulative CH_4 recovery between 2011 and 2030 is approximately 29.4 $MmtCO_2e$. Annual methane recovered through flaring and recycling (LFGTE) is projected to increase from 0.9 $MmtCO_2e$ (948,947 $mtCO_2e$) in 2011 to 1.2 $MmtCO_2e$ (1, 997,739 $mtCO_2e$) in 2030 as Figure 96 indicates. This is an increase of approximately 110% at the rate of 0.055 $MmtCO_2e$ per year.

Figure 97 presents CH_4 recovery data for both landfill gas flaring and LFGTE. The data shows that the cumulative CH_4 recovered from LFGTE between 2011 and 2030 is projected to be approximately 25.4 $MmtCO_2e$. This will significantly be larger than the CH_4 recovery due to flaring at Delaware landfills, which projected to be approximately 4.0 $MmtCO_2e$. As Figure 97 indicates, emissions are projected to increase from 0.82 $MmtCO_2e$ (820,173 $mtCO_2e$) in 2011 to 1.7 $MmCO_2e$ (1,726,643 $mtCO_2e$) in 2030. This is a projected increase of approximately 110% at the rate of 0.048 $MmtCO_2e$ per year.

Methane emissions from flaring are projected to increase from 0.13 $MmtCO_2e$ (128,773 $mtCO_2e$) in 2011 to 0.27 $MmtCO_2e$ (271,096 $mtCO_2e$) in 2030. This is a projected increase of approximately 108% at the rate of 0.01 $MmtCO_2e$ per year. Table 22 provides a summary of CH_4 amounts recovered annually between 2011 and 2030.

FIGURE 97. METHANE RECOVERY FROM FLARING AND LFGTE

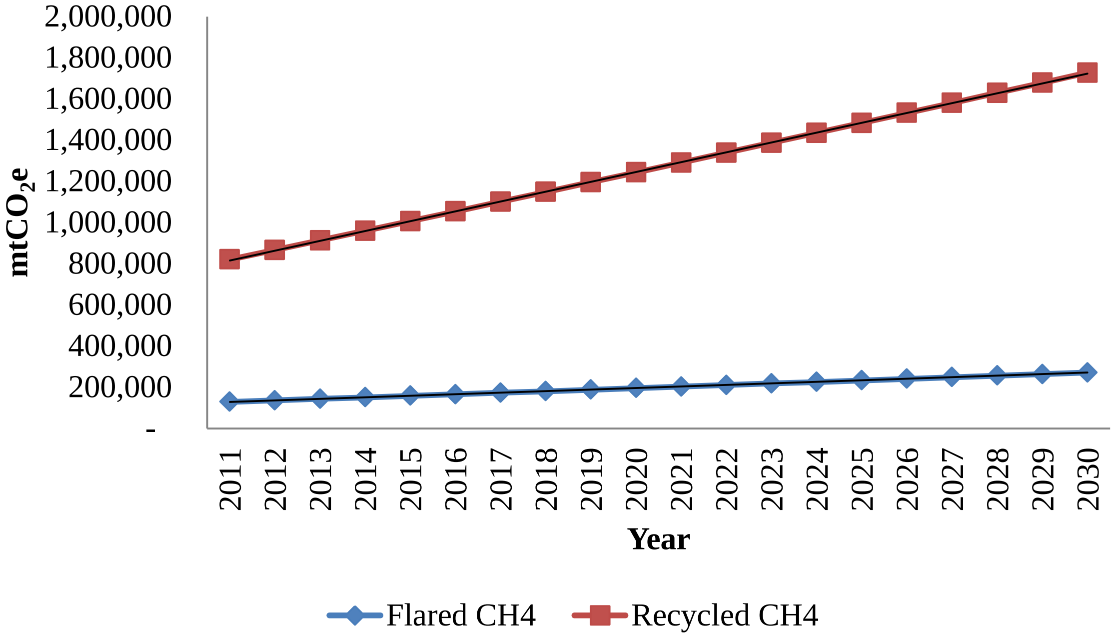
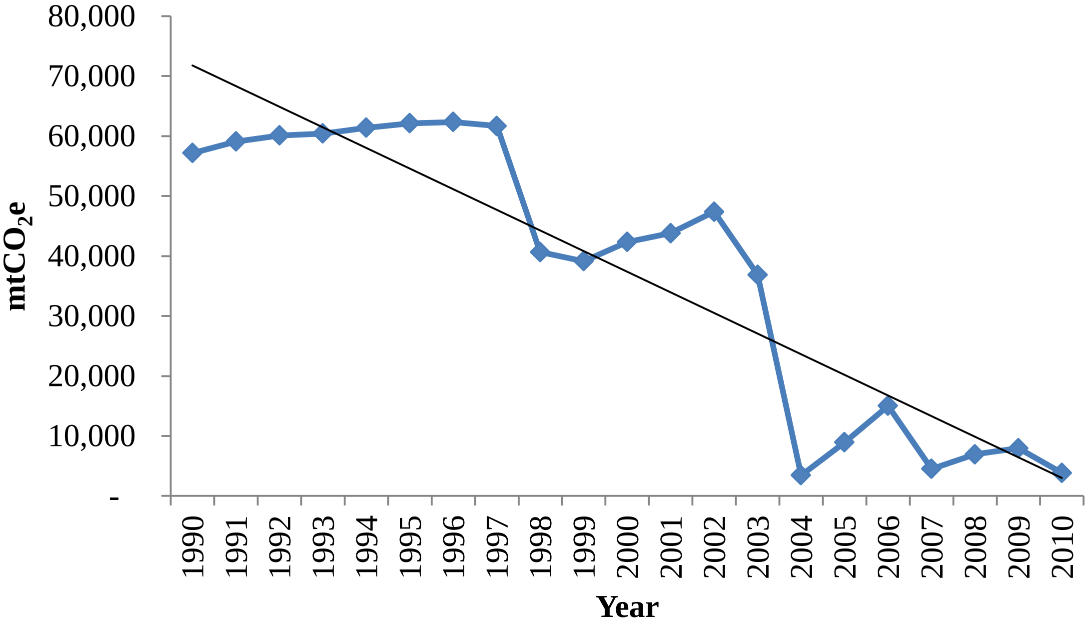


TABLE 22. PROJECTED CH_4 RECOVERED FROM LANDFILLS					
Recovery	**2011**	**2015**	**2020**	**2025**	**2030**
Flare	128,773	157,981	195,131	232,872	271,096
LFGTE	820,173	1,006,202	1,242,815	1,483,189	1,726,643
Total CH_4	**948,947**	**1,164,183**	**1,437,946**	**1,716,061**	**1,997,739**

4.7.1.5 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 98 presents data on the amount of CH_4 oxidized at Delaware landfills.

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[106]. To 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.

FIGURE 98. METHANE OXIDIZED AT LANDFILL FACILITIES



The amount of CH_4 oxidized increased from 57,186 $mtCO_2e$ in 1990 to 61,687 $mtCO_2e$ in 1997, but later decreased to 40,655 $mtCO_2e$ in 1998 and continued fluctuating downwards as Figure 98 shows. The overall reduction in the amount of CH_4 oxidized was approximately 93%. The rate of decrease was 3,437 $mtCO_2e$ per

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

year. This decrease was primarily the result of the increased CH_4 recovery activities at Delaware landfills from 1997 to 2010. Table 23 provides a summary of CH_4 oxidized at Delaware landfills between 1990 and 2010.

TABLE 23. CH_4 OXIDIZED AT MSW AND INDUSTRIAL LANDFILLS ($mtCO_2e$)

CH_4 Oxidized	**1990**	**1995**	**2000**	**2005**	**2010**
Oxidation at MSW Landfills	53,445	58,084	38,107	4,116	(1,621)
Oxidation at Industrial Landfills	3,741	4,066	4,233	4,831	5,467
Total CH_4 Oxidized	57,186	62,150	42,339	8,946	3,846

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[107], as well as municipal[108] wastewater. Methane is produced when organic material in treated and untreated wastewater degrades in the absence of oxygen. 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. Factors that affect wastewater treatment emissions include population growth, cheimical and biochemical oxygen demand. These factors were incoporated in the methodology for estimating the emissions.

Delaware has 19 municipal wastewater treatment facilities. The facilities include major and minor[109] wastewater treatment plants. Table 24 provides a list of minor and major wastewater treatment facilities in Delaware:

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[107] 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.

[108] 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.

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

TABLE 24. LIST OF MUNICIPAL WASTEWATER TREATMENT PLANTS IN DELAWARE		
Facilities	Major/Minor	Discharge flow (MGD)[110]
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

Between 1990 and 2010, wastewater treatment released approximately 2.08 MmtCO$_2$e into Delaware's atmosphere. Greenhouse gas emissions increased from 0.08 in 1990 to 0.11 in 2010. This was an increase of approximately 38%. The annual rate of increase was determined to be approximately 0.002MmtCO$_2$e per year. Delaware's population growth is proportional to the growth of GHG emissions from wastewater treatment. Between 1990 and 2010, Delaware's population grew by approximately 34%.

Emissions from wastewater treatment were divided into two sub-categories in the 2010 GHG emissions inventory. They included emissions from municipal and industrial wastewater treatment. Figure 100 provides the breakdown of GHG emissions in 2010 from each type of emission sources in the wastewater management sector. Municipal

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[110] MGD: million gallons per day

wastewater treatment was the largest contributor to gross GHG emissions from the wastewater treatment sources representing approximately 99%. Emissions from industrial wastewater treatment were only approximately 1% as Figure 100 presents.

FIGURE 99. GROSS GHG EMISSIONS FROM WASTEWATER TREATMENT

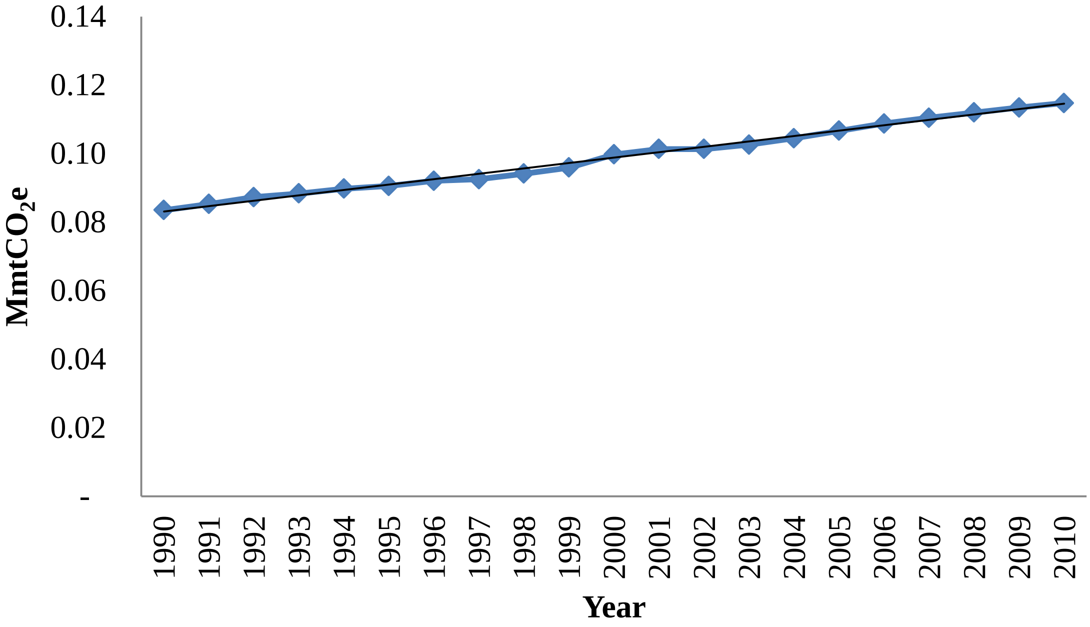


FIGURE 100. GHG EMISSIONS BY WASTEWATER TREATMENT SUBCATEGORIES

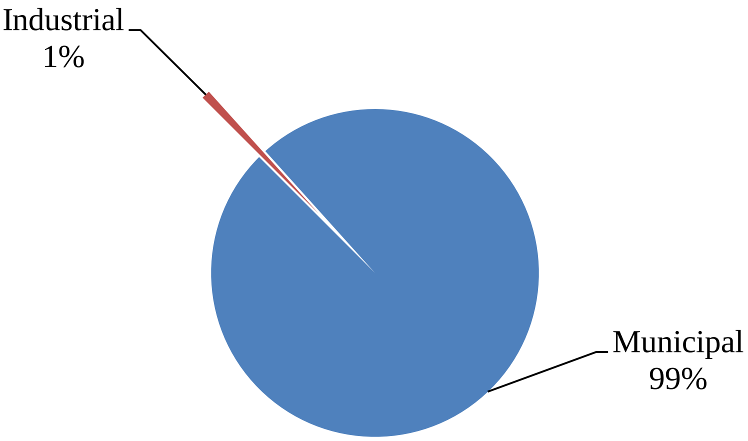


TABLE 25. WASTEWATER EMISSIONS BY SOURCE ($mtCO_2e$)					
Wastewater treatment Sources	**1990**	**1995**	**2000**	**2005**	**2010**
Municipal CH_4	81,614	88,689	98,669	105,728	113,816
Industrial CH_4	1,932	1,909	1,112	962	967
Total	83,546	90,598	99,781	106,690	114,783

See Appendix J for details.

Table 25 provides estimates of GHG emissions from wastewater treatment sourceses including GHG emissions from .

Methodologies

The methods for estimating CH_4 and N_2O from municipal wastewater treatment are different. Therefore, the 2010 GHG emissions inventory included two methodologies in order to estimate gross GHG emissions from municipal wastewater treatment sources. 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 15 describes the method for estimating CH_4 emissions from municipal wastewater treatment:

EQUATION 15. CH_4 EMISSIONS EQUATION FOR MUNICIPAL WASTEWATER TREATMENT

$$CH_4\ Emissions\ (kg\ CH_4) = BOD_5\ Treated\ Anaerobically\ (kg\ BOD_5/yr) \times CH_4\ EF(kg\ CH_4/kg\ BOD_5)$$

B. ***Nitrous Oxide Emissions from Municipal Wastewater Treatment****:*
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. The general equation for estimating N_2O from wastewater treatment is described in Equation 16:

EQUATION 16 N_2O EMISSIONS EQUATION FOR MUNICIPAL WASTEWATER TREATMENT

$$Annual\ Emissions\ of\ N_2O\ from\ Wastewater\ (kg\ N_2O) = Annual\ Total\ N\ in\ Wastewater\ (kg\ N) \times EF\ (kg\ N_2O\text{-}N/kg\ N) \times 44/28$$

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.

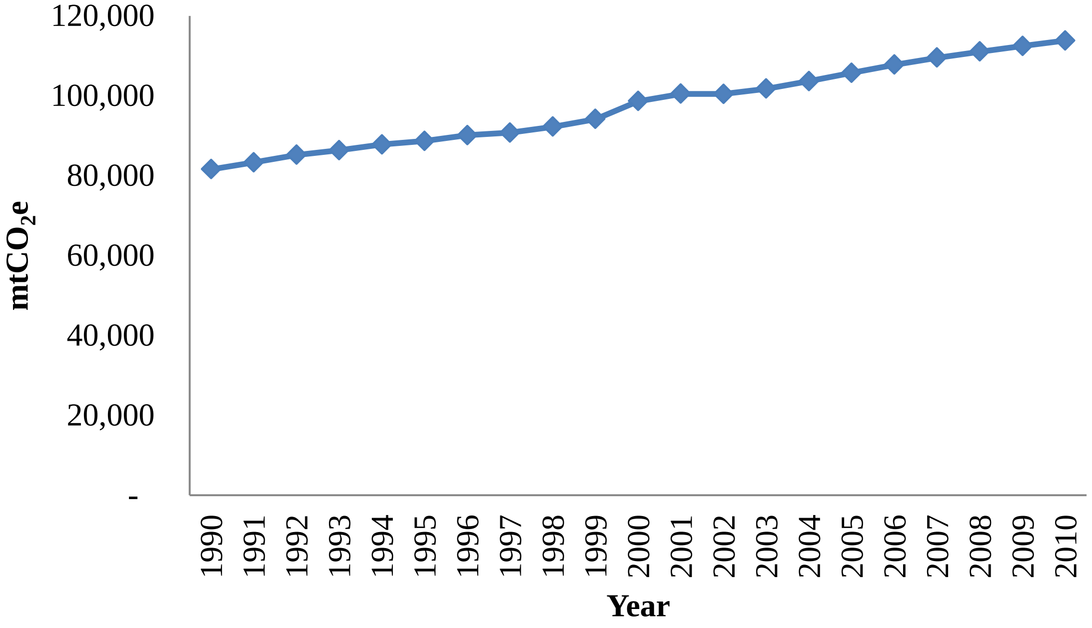
EQUATION 17. CH_4 EMISSIONS EQUATION FOR INDUSTRIAL WASTEWATER TREATMENT

$$CH_4 \text{ Emissions (g } CH_4) = \text{Wastewater Production (l)} \times \text{COD (g COD/l)} \times \text{Fraction of COD Anaerobically Treated (\%)} \times \text{Emission Factor (g } CH_4\text{/g COD)}$$

Analysis of GHG Emissions from Municipal Wastewater Treatment: Using the above methods, CH_4 and N_2O emissions from municipal wastewater treatment were estimated and the results were added to provide gross GHG emissions from wastewater treatment.

As observed in Figure 101, GHG emissions from municipal wastewater treatment increased from 0.082 $MmtCO_2e$ (81,614 $mtCO_2e$) in 1990 to 0.114 $MmtCO_2e$ (113,816 $mtCO_2e$) in 2010. This was an increase of approximately 39% during that period at an annual rate of emissions increased annually by approximately 1,647 $mtCO_2e$ per year. This trend is expected to continue with Delaware's population due to the linear relationship between population growth and GHG emissions from wastewater treatment as presented by Figure 103.

FIGURE 101. GHG EMISSIONS FROM MUNICIPAL WASTEWATER TREATMENT



Analysis of CH_4 Emissions from Industrial Wastewater Treatment: Using the above method for estimating CH_4 emissions from industrial wastewater treatment, emissions in this subsector were estimated and the results were added to provide gross GHG emissions from wastewater treatment

As observed in Figure 102, CH_4 emissions from industrial wastewater treatment decreased from 0.002 $MmtCO_2e$ (1,932 $mtCO_2e$) in 1990 to 0.0001 $MmtCO_2e$ (967 $mtCO_2e$) in 2010. This was a decrease of approximately 50% during that period at an annual rate of emissions increased annually by approximately 73.04 $mtCO_2e$ per year. The largest decrease observed was from 1,772 $mtCO_2e$ in 1999 to 1,112 $mtCO_2e$ in 2000, a decrease of approximately 37%. The overall decrease in CH_4 emissions from industrial wastewater treatment in Delaware can be partly attributed to decreasing wastewater treatment activities in the industrial sector due to the economic recession.

FIGURE 102. CH_4 EMISSIONS FROM INDUSTRIAL WASTEWATER TREATMENT

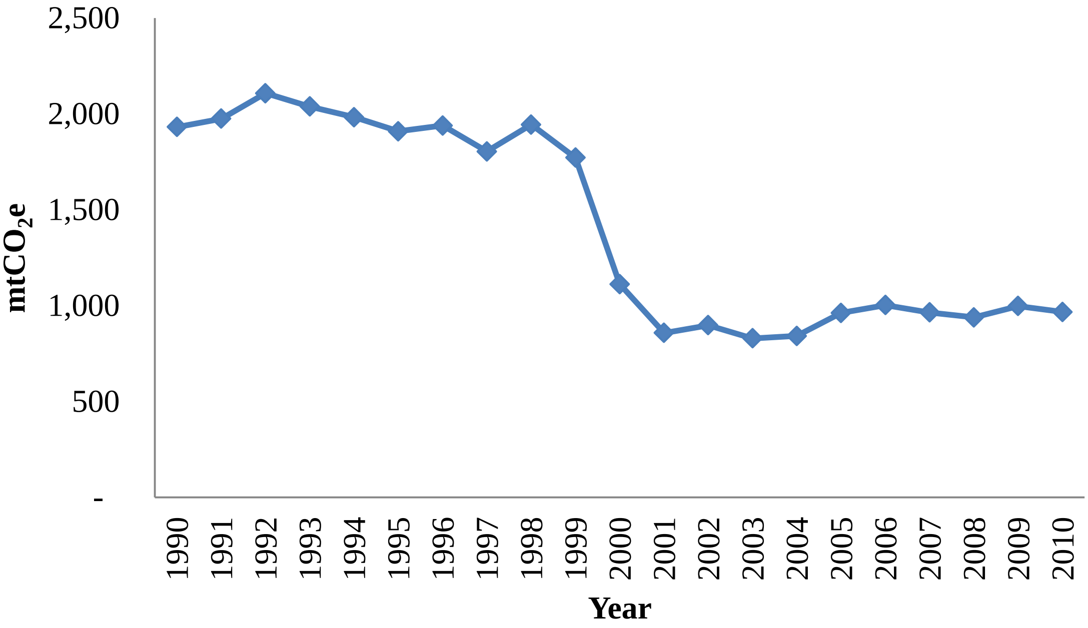
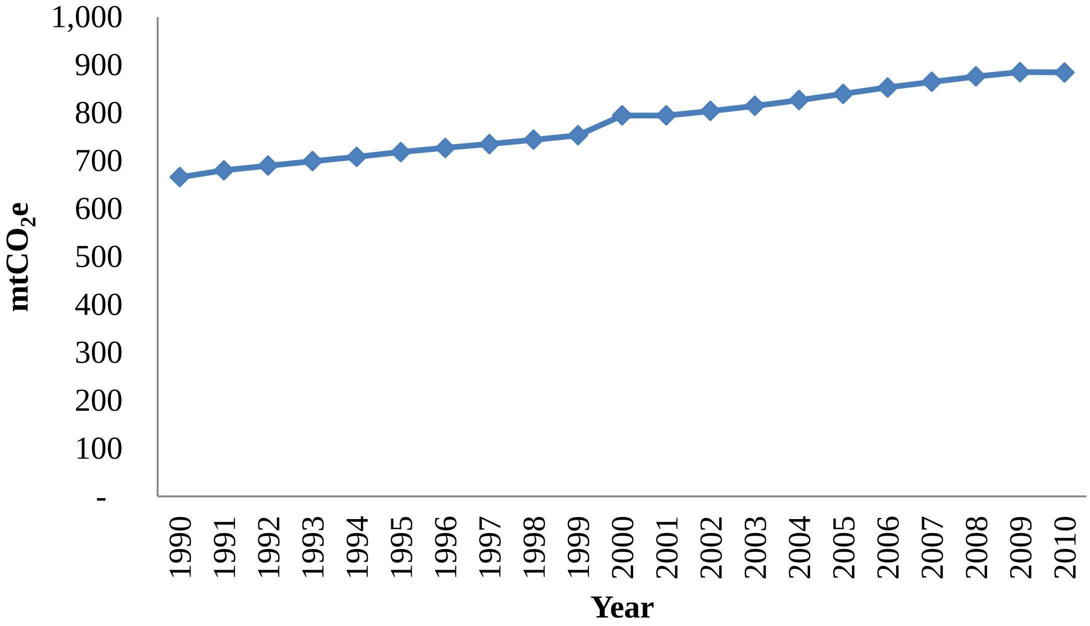


FIGURE 103. DELAWARE'S POPULATION GROWTH FROM 1990 TO 2010



Reference Case Projection of GHG Emissions from Municipal Wastewater Treatment

Wastewater emissions projections were calculated by multiplying national emissions with Delaware State's percentage of national population. The projected emission was based on historic data. The trend observed indicates a linear relationship between population growth and wastewater treatment emissions from Delaware. Cumulative greenhouse house gas emissions from wastewater treatment are projected to be 2.09 $MmtCO_2e$ between 2011 and 2030.

As Figure 104 presents, gross GHG emissions from wastewater treatment is projected to increase from 0.09 $MmtCO_2e$ in 2011 to 0.11$MmtCO_2e$ in 2030. This is an increase of approximately 22% at the rate of 0.001 $MmtCO_2e$ per year.

Figure 105 presents projected emissions from wastewater treatment by the municipal and industrial sources of wastewater treatment. The results show that emissions from municipal wastewater treatment are projected to be greater than industrial emissions, and are expected to continue to increase into the future.

FIGURE 104. PROJECTED GROSS GHG EMISSIONS FROM WASTEWATER TREATMENT

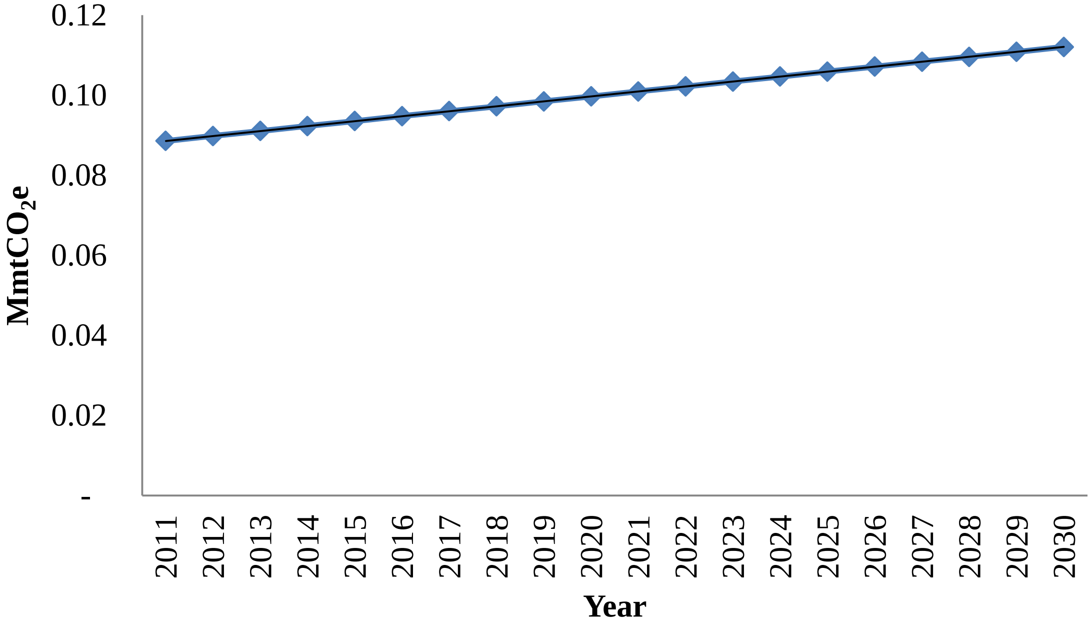
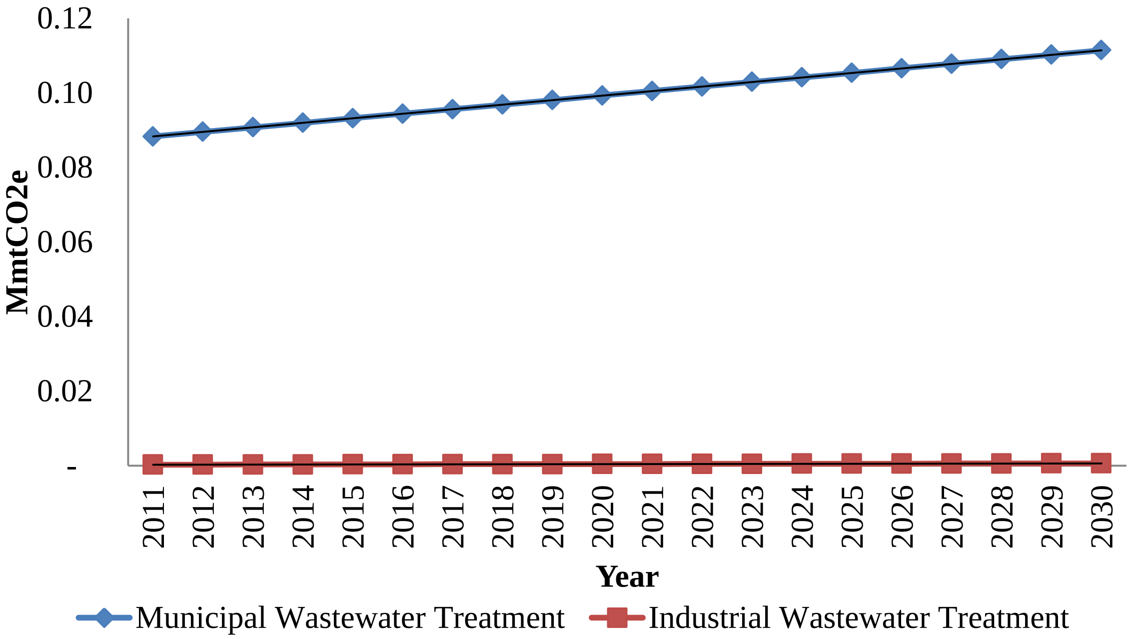


FIGURE 105. PROJECTED GROSS GHG EMISSIONS FROM MUNICIPAL AND INDUSTRIAL WASTEWATER TREATMENT



Greenhouse gas emissions from municipal wastewater treatment are projected to increase from 0.09 MmtCO$_2$e in 2011 to 011MmtCO$_2$e in 2030. This will be an increase of approximately 22% at the rate of 0.0012 MmtCO$_2$e per year. While GHG emissions from industrial wastewater treatment are projected to increase from 0.0003 MmtCO$_2$e in 2011 to 0.0006 MmtCO$_2$e in 2030, an increase of approximately 100%.

Conclusion of Waste Management Sector GHG Emissions Analysis

As a result current waste management activities, historical GHG emissions from Delaware's waste management sector decreased significantly. Also, GHG emissions from waste management sources are projected to generate negative emissions from 2011 to 2030. This is due to the significant reductions in GHG emissions from both industrial and municipal landfill as a result landfill gas recovery. However, wastewater treatment emissions increased gradually with population growth and projected to increase gradually.

Historical and projected emission data shows that Delaware's waste management sector is a carbon sink for GHG emissions. Municipal landfill activities such as flaring and conversion of landfill gas to energy (LFGTE) have removed significant amounts of GHG emissions from Delaware landfills. In addition, methane oxidation at landfill covers contributed to methane emission reductions and is expected to be a significant factor in landfill emissions reduction in the future. Overall, approximately 7.2 MmtCO$_2$e was removed from Delaware landfills between 1990 and 2010 due to landfill activities and processes.

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

The 2010 GHG emissions inventory identified the land-use source sector as a major sink for GHG emissions in Delaware. The GHGs associated with this sector are CO_2 and N_2O. 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. Nitrous oxide emission from land use sector is generated when fertilizers are applied to soils including lawns, golf courses, and other landscaping within settled areas.

Methodology

The CO_2 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 land use module also estimates N_2O emissions from the application of fertilizers to settlement soils. The following GHG emissions estimates were included in this sector: forest carbon flux, urea fertilization, urban trees, landfill yard trimmings, landfill food scraps and N_2O from settlement soils[111]. Projection analysis for land-use sector GHG emissions was not included in the SIT. As a result, the 2010 GHG emissions report did not include projection in its analysis for land use emissions.

Land-use Emission Analysis

The 2010 GHG emissions inventory identified the land-use sector as a major sink[112] for GHG emissions in Delaware. According to Figure 106, net GHG emission from this sector has been negative since 1999. The removal of GHGs from this sector peaked in 2006 with a net GHG removal of 1.17 $MmtCO_2e$ as indicated in Figure 106. Between 1990 and 1998, the land use sector had positive emissions totaling 2.09 $MmtCO_2e$. Net emissions removed from the land use sector totaled 11.04 $MmtCO_2e$ between 1990 and 2010.

Table 26 provides estimates of GHG emissions from the land use sector. Carbon dioxide emissions estimates associated with forest carbon flux was the largest source of GHG emissions as Table 26 provides. This was largely due to CO_2 emissions from soil organic

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[111] Data source: State Inventory Tool default data.
[112] A sink is the removal of GHG from the atmosphere

carbon (carbon stored in soils due to biomass decay in the forests). As provided by Table 26, positive emissions were also generated by N_2O from settlement soils. On average N_2O emissions from settlement soils were estimated at 0.01MmtCO$_2$e annually from 1990 to 2010. All other categories presented in Table 26 generated negative to negligible GHG emissions.

FIGURE 106. HISTORICAL LAND-USE CO_2 SEQUESTRATION

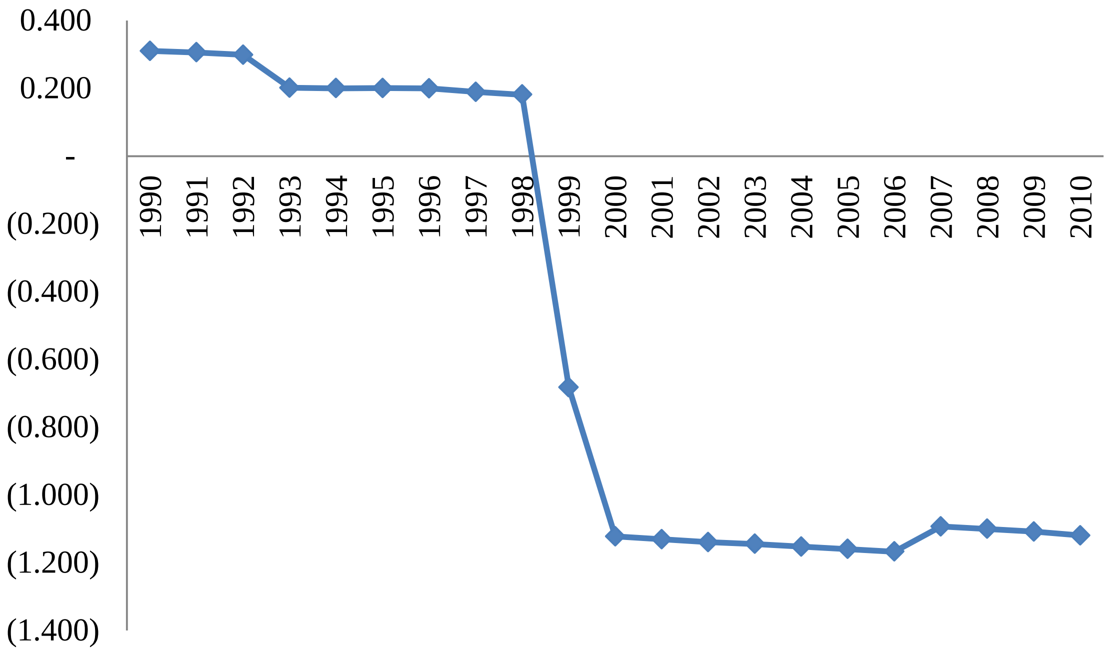

TABLE 26. SINK ESTIMATES FOR THE LAND-USE, LAND-USE CHANGE AND FORESTRY SECTOR

(MmtCO$_2$e)*	1990	1995	2000	2005	2010
Forest Carbon Flux	0.550	0.453	(0.834)	(0.834)	(0.754)
Aboveground Biomass	(0.072)	(0.072)	(0.682)	(0.682)	(0.671)
Belowground Biomass	(0.009)	(0.009)	(0.128)	(0.128)	(0.127)
Dead Wood	0.099	0.099	(0.155)	(0.155)	(0.086)
Litter	0.094	0.094	0.024	0.024	0.024
Soil Organic Carbon	0.436	0.436	0.201	0.201	0.201

TABLE 26. SINK ESTIMATES FOR THE LAND-USE, LAND-USE CHANGE AND FORESTRY SECTOR					
($MmtCO_2e$)*	**1990**	**1995**	**2000**	**2005**	**2010**
Total wood products	0.002	(0.095)	(0.095)	(0.095)	(0.095)
Urea Fertilization	0.000	0.000	0.000	0.000	0.001
Urban Trees	(0.217)	(0.257)	(0.298)	(0.339)	(0.379)
Landfilled Yard Trimmings and Food Scraps	(0.032)	(0.004)	0.001	0.005	0.006
Grass	(0.001)	0.002	0.002	0.002	0.001
Leaves	(0.013)	(0.002)	0.003	0.005	0.004
Branches	(0.015)	(0.003)	0.002	0.004	0.003
Landfilled Food Scraps	(0.004)	(0.001)	(0.006)	(0.006)	(0.003)
N_2O from Settlement Soils	0.01	0.01	0.01	0.01	0.01
Total	0.310	0.200	(1.122)	(1.160)	(1.120)

See Appendix K for more details.

* The parenthesis indicate negative numbers or sequestration

Conclusion of Land-Use, Land Use Change and Forestry GHG Emissions Analysis

The land use sector is a larger carbon sinks than the waste management sector because its net GHG generation between 1990 and 2010 was -11.04 $MmtCO_2e$. Between 1999 and 2010, the land use sector removed a total of 13.12 $MmtCO_2e$ from the atmosphere. Though no projection analysis was performed, GHG emissions from this sector are expected to remain negative in the future.

The analysis of the land use sector highlights the potential for carbon sequestration projects in Delaware as part of a statewide GHG emissions reduction strategy. The IPCC identified two types of GHG emission reduction opportunities in this sector, which includes changing the use of land and changing land management practices. IPCC's Fourth Assessment Report on climate change (2007)[113] included example of how land use change can reduce emissions or sinks can be enhanced. They include encouraging the transformation of cropland to forest

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[113] IPCC Fourth Assessment Rep IPCC Fourth Assessment Report: Climate Change 2007

and avoiding the conversion of forest land to settlements. On the other hand, changes to land management practices could be achieved by improving land management practices on existing land-use types. Reducing soil erosion to minimize losses in soil carbon storage can be employed to accomplish this. Another way is by planting after natural or human-induced forest disturbances to accelerate vegetation growth and minimize soil carbon losses.

4.9 EMISSION INVENTORY RESULTS BY GHGS

Figure 107 presents a breakdown of 2010 emissions by GHGs. Carbon dioxide emissions represented the largest emissions of GHGs with approximately 91% of gross emissions from Delaware. This was followed N_2O representing approximately 4%. The combined emission of HCF, PFC and SF_6 represented approximately 3%, while CH_4 represented 2% of gross GHG emissions from Delaware as Figure 106 presents.

FIGURE 107. 2010 EMISSIONS BY GHG

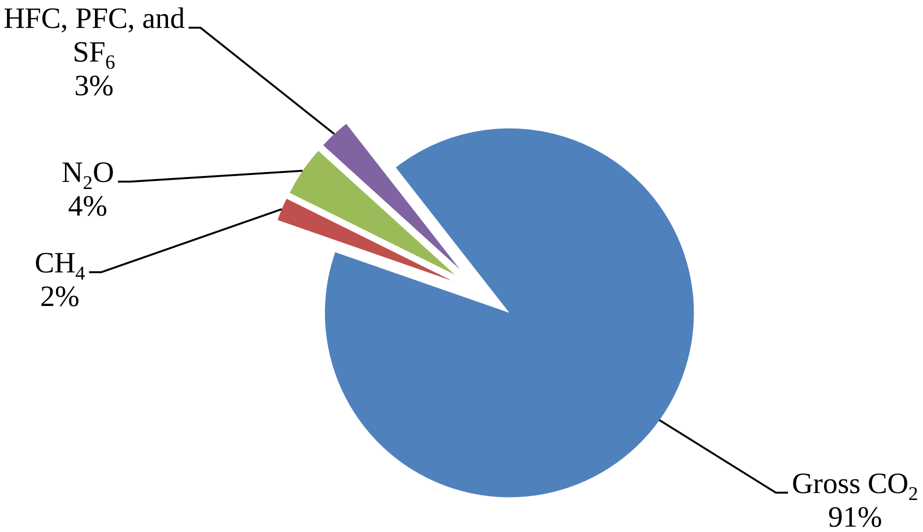

Table 27 provides a summary of historical emission estimates from 1990 to 2010. Carbon dioxide emissions from all sectors of Delaware's economy had the largest contribution to gross GHG emissions. Historically CO_2 emissions exceeded other GHGs from 1990 to 2010 as summarized by Table 27.

TABLE 27. ESTIMATES OF EMISSIONS BY GHG (MTCO_2e)

GHG Sources	1990	1995	2000	2005	2010
Gross CO_2	**18.01**	**17.82**	**16.70**	**17.35**	**12.20**
Net[114] CO_2	18.01	17.82	15.57	16.18	11.08
CO_2 from FFC	17.70	17.62	16.69	17.30	12.16
Industrial Processes	0.20	0.20	0.16	0.18	0.20
LULUCF*	0.30	0.19	(1.13)	(1.17)	(1.13)
CH_4	**0.69**	**0.75**	**0.56**	**0.33**	**0.27**
Stationary Combustion	0.02	0.02	0.02	0.01	0.01
Mobile Combustion	0.02	0.02	0.02	0.01	0.01
Oil Refining	0.01	0.01	0.01	0.08	0.09
Enteric Fermentation	0.05	0.05	0.05	0.04	0.04
Manure Management	0.03	0.04	0.03	0.03	0.03
Burning of Ag Crop Residue	0.00	0.00	0.00	0.00	0.00
MSW	0.51	0.56	0.38	0.08	0.03
Wastewater Treatment	0.05	0.05	0.05	0.06	0.06
N_2O	**0.80**	**0.82**	**0.86**	**0.69**	**0.60**
Stationary Combustion	0.04	0.04	0.04	0.04	0.02
Mobile Combustion	0.21	0.26	0.25	0.18	0.08
Manure Management	0.15	0.17	0.16	0.16	0.16
Agricultural Soil Management	0.37	0.31	0.38	0.28	0.30
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
Wastewater Treatment	0.02	0.02	0.02	0.02	0.03
HFC, PFC, and SF_6	**0.08**	**0.15**	**0.26**	**0.33**	**0.37**
Industrial Processes	0.08	0.15	0.26	0.33	0.37
Gross Emissions	**19.47**	**19.53**	**18.52**	**18.81**	**13.60**
Sinks	**0.31**	**0.20**	**(1.12)**	**(1.16)**	**(1.12)**
Net Emissions (Sources and Sinks)	**19.78**	**19.73**	**17.40**	**17.65**	**12.48**
Indirect CO_2 from Electricity Consumption	**4.40**	**5.09**	**5.99**	**6.45**	**6.00**

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

The cumulative amount of CO_2 emitted from Delaware sources between 1990 and 2010 was estimated to be 351.66 MmtCO$_2$e. This was followed by N_2O with a cumulative emission of 16.41 MmtCO$_2$e. Methane was third with a cumulative emission of 11.52 MmtCO$_2$e. Sulfur Hexafluoride, HCF as well as PFC had a combined cumulative emission of 5.94 MmtCO$_2$e.

Reference Case projection Estimates

Figure 108 presents a breakdown of projected emission estimates for 2030. Carbon dioxide is projected to remain the most emitted GHG representing approximately 90 % of gross GHGs emitted in 2030. The combined emissions of HFC, PFC and SF_6 is projected to be as distant 2nd representing approximately 7% of gross emissions, followed by N_2O emissions, which is projected to represent approximately 4% as presented in Figure 108.

FIGURE 108. 2030 PROJECTED GHG EMISSIONS BY GAS

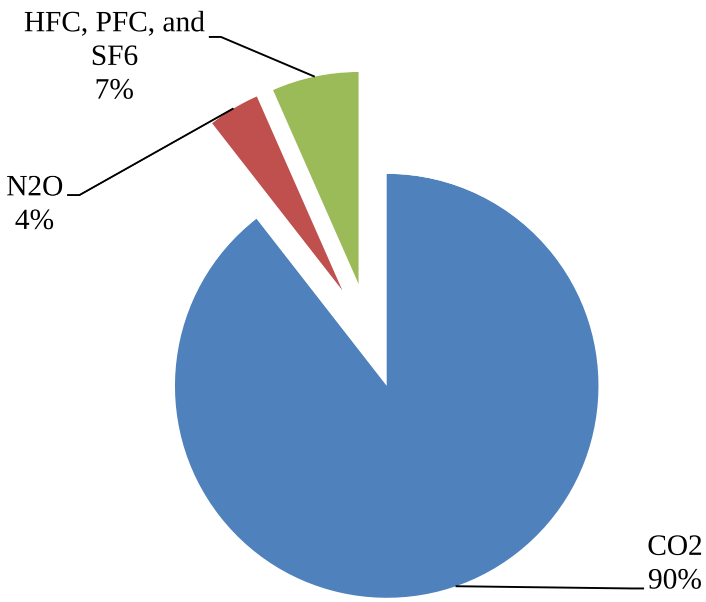


Table 28 provides a summary of projected emission estimates from 2011 to 2030. Carbon dioxide emission from all sectors of Delaware's economy is projected to have the largest contribution to gross GHG emissions. The cumulative CO_2 emission from Delaware sources between 2011 and 2030 is projected to be 262.09 MmtCO$_2$e. Cumulative N_2O emissions are projected to be a distant second with 12.19 MmtCO$_2$e and the combined cumulative emissions of SF$_6$, HCF as well as PFC are projected to be 15.58 MmtCO$_2$e. Cumulative methane emissions have the lowest projection with 0.02MmtCO$_2$e. As Table 28 provides, gross CH$_4$ emission is expected to diminish over as a result of CH$_4$ sinks in the waste management sector.

TABLE 28. PROJECTED ESTIMATES OF EMISSIONS BY GHG (MTCO$_2$e)

GHG Sources	2011	2015	2020	2025	2030
CO$_2$	**12.02**	**13.03**	**13.41**	**13.56**	**13.77**
CO2 from Fossil Fuel Combustion	11.88	12.90	13.29	13.46	13.68
Industrial Processes	0.14	0.13	0.12	0.10	0.09
CH$_4$	**(0.08)**	**0.09**	**0.01**	**(0.06)**	**(0.15)**
Stationary Combustion	0.01	0.01	0.01	0.01	0.01
Mobile Combustion	0.01	0.01	0.01	0.01	0.01
Oil Refining	0.09	0.33	0.34	0.36	0.36
Enteric Fermentation	0.04	0.04	0.04	0.04	0.04
Manure Management	0.04	0.04	0.04	0.04	0.04
Agricultural Waste Burn	0.00	0.00	0.00	0.00	0.00
MSW	(0.32)	(0.39)	(0.49)	(0.59)	(0.69)
Wastewater Treatment	0.06	0.06	0.07	0.07	0.08
N$_2$O	**0.62**	**0.61**	**0.61**	**0.61**	**0.60**
Stationary Combustion	0.02	0.02	0.02	0.02	0.02
Mobile Combustion	0.07	0.07	0.07	0.06	0.06
Manure Management	0.18	0.19	0.19	0.20	0.20
Ag Soil Management	0.32	0.31	0.30	0.29	0.28
Agricultural Waste Burn	0.00	0.00	0.00	0.00	0.00
Wastewater Treatment	0.03	0.03	0.03	0.03	0.04
HFC, PFC, and SF$_6$	**0.41**	**0.63**	**0.75**	**0.89**	**1.01**
Industrial Processes	0.41	0.63	0.75	0.89	1.01
Total Emissions	**13.23**	**14.24**	**14.67**	**14.91**	**15.15**

4.9.1 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 2010, CO_2 emissions represented approximately 90% gross CO_2e emissions from Delaware according to Figure 108, which was a total of 12.36 MmtCO_2e. Approximately 98% of CO_2 emissions from Delaware come from FFC, while the rest came from industrial processes and waste management. Figure 109 provides a breakdown of gross CO_2 emissions by economic sector. In 2010, CO_2 emissions in the transportation sector represented the largest CO_2 emission from fossil fuel combustion in Delaware with approximately 37%. This was followed by CO_2 emissions from electric power generation with 34%, CO_2 emission from the Industrial sector with 13%, CO_2 emissions from the residential sector represented 9%, and CO_2 emissions from the commercial sector represented 4% of gross CO_2 emissions from fossil fuel combustion.

FIGURE 109. 2010 GROSS CO_2 EMISSIONS FROM FFC BY ECONOMIC SECTOR

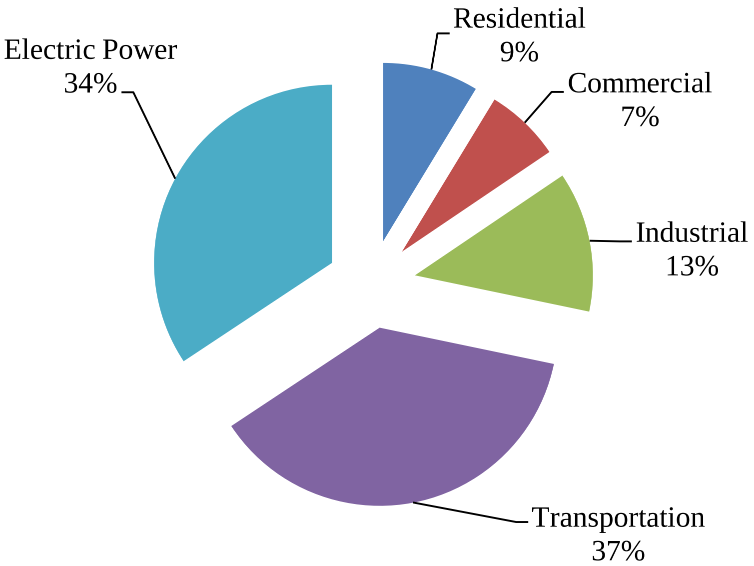
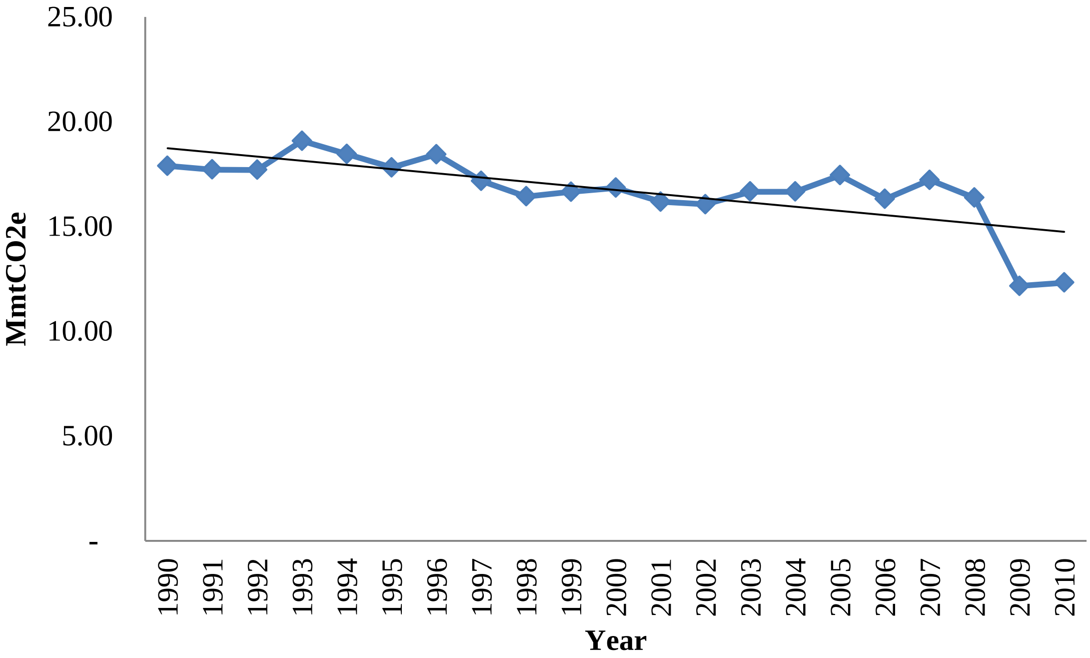


Figure 110 presents gross CO_2 emissions from Delaware economic sectors from 1990 to 2010. Carbon dioxide emissions decreased gradually as Figure 110 shows. Carbon dioxide emissions decreased by approximately 31% from 17.89 MmtCO_2e 1990 to 12.32

$MmtCO_2e$ in 2010. Emissions peaked in 1993 with 19.08 $MmtCO_2e$ and reached its lowest point in 2010 with 12.32 $MmtCO_2e$. Between 1990 and 2010, CO_2 emissions decreased annually at the rate of 0.20 $MmtCO_2e$ 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 110. HISTORICAL CO_2 EMISSIONS



Reference case Projection for CO_2 Emissions

Figure 111 presents projected CO_2 emissions from 2011 to 2030. Carbon dioxide emissions are projected to increase from 11.89 $MmtCO_2e$ in 2011 to 13.69 $MmtCO_2e$ in 2030, an increase of approximately 15 %.

Carbon dioxide emissions will increase at the rate of 0.08 $MmtCO_2e$ per year. This projection is based on the assumption that CO_2 emissions from all sectors of Delaware's economy will continue to increase with population and as well as economic growth.

FIGURE 111. PROJECTED CO_2 EMISSIONS

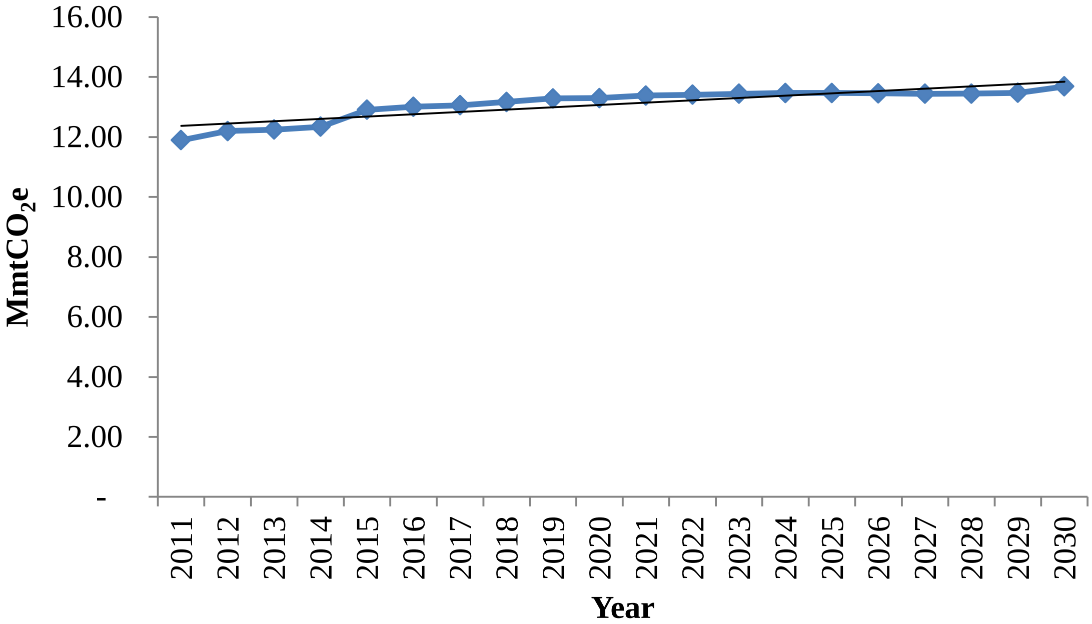


FIGURE 112. 2030 CO_2 EMISSIONS BY SECTOR

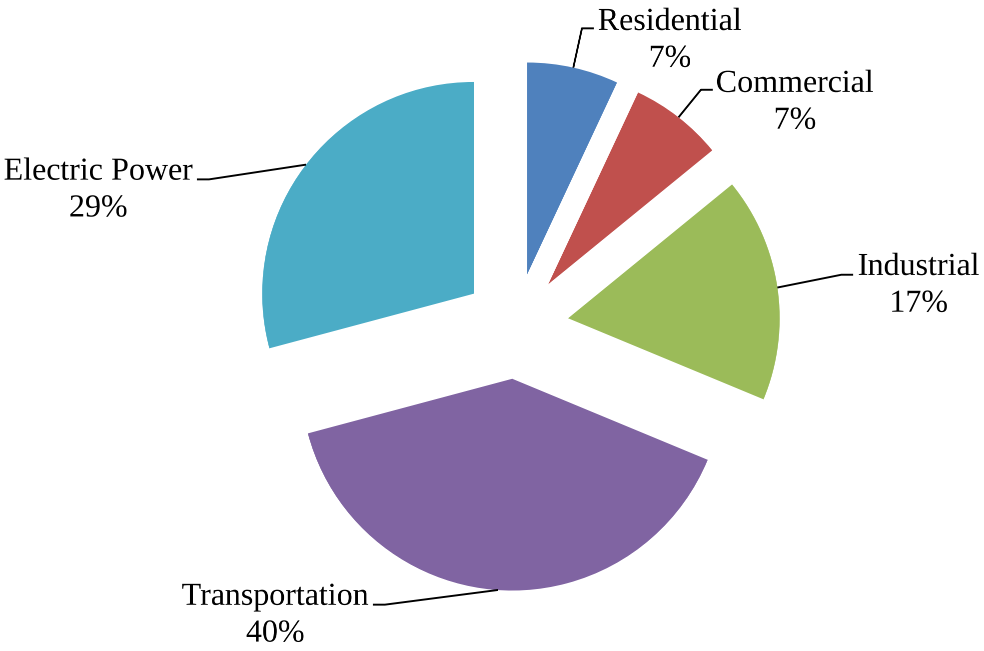


Figure 112 presents a breakdown of CO_2 emissions form fossils fuel combustion (FFC) in 2030. Carbon dioxide emission from the transportation sector is projected to represent the largest share with approximately 40% of gross CO_2 emissions from FFC as presented on Figure 112. This will be followed by CO_2 emissions from electric power generation representing approximately 29 %. The industrial sector CO_2 emissions will represent the third largest with approximately 17%. Emissions from residential and commercial are both projected to represent 7% of gross CO_2 emissions.

4.9.2 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 2010, gross methane emission was 0.27 $MmtCO_2e$. This represented approximately 2% of gross CO_2 emissions from Delaware. Figure 113 shows of CH_4 emission from various sources in 2010. Emissions from oil refining in the industrial sector represented the largest source of CH_4 emission in 2010 with 32% of gross CH_4 emissions.

Other sources included wastewater treatment with 26%, followed by agricultural sector sources including enteric fermentation and manure management with approximately 15% and 11% respectively. Stationary combustion such as the residential, commercial and power sectors contributed approximately 4%, while mobile combustion in the transportation sector contributed approximately 4%. Agricultural residue burning in the agricultural sector contributed the list amount, which was less than 1%.

Figure 114 presents CH_4 emissions from 1990 to 2010 from the various sectors of Delaware. Similarities are observed when overall CH_4 emissions, as depicted by Figure 114 is compared to waste management emissions as depicted by Figure 76. This is because overall CH_4 emissions were driven largely by emissions from the waste management sector.

FIGURE 113. 2010 GROSS CH_4 EMISSIONS BY SOURCE CATEGORY

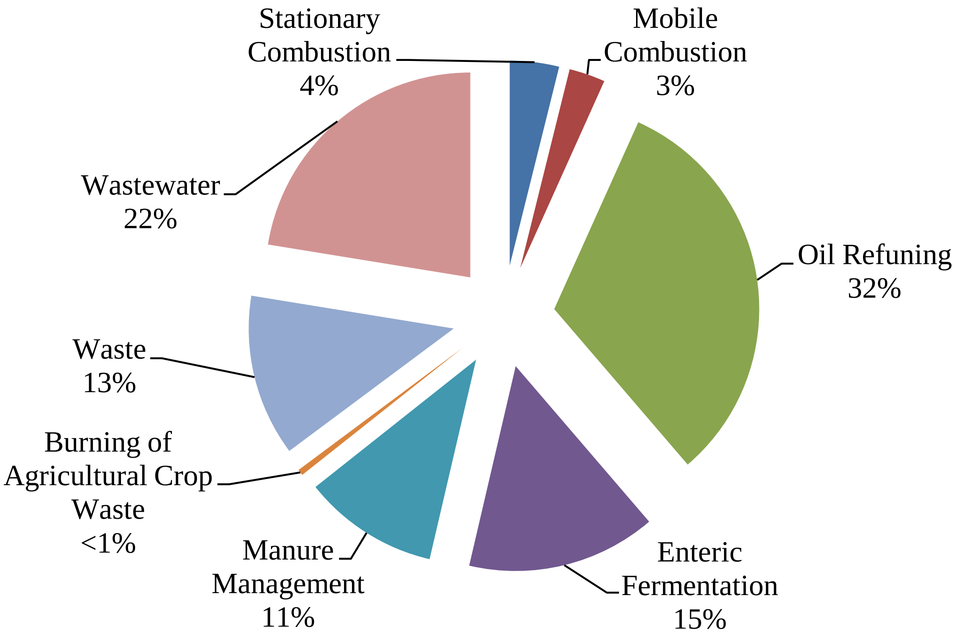
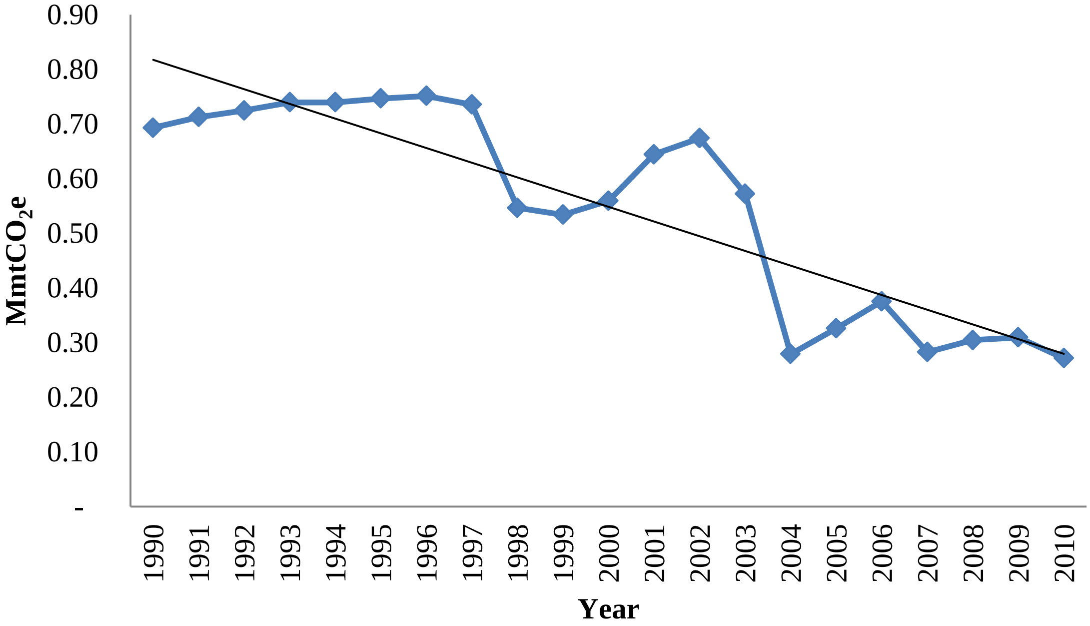


FIGURE 114. NET HISTORICAL CH_4 EMISSIONS



As shown by 114, CH_4 emissions increased steadily from 0.69 $MmtCO_2e$ in 1990 to 0.74 $MmtCO_2e$ in 1997 by 7.2%. Emissions then decreased from 1997 to 2010 with fluctuations. Overall, emissions decreased 0.27 $MmtCO_2e$ in 2010, a decrease of 63%. The rate of decrease was determined to be 0.030 $MmtCO_2e$ per year.

Reference case Projection for CH_4 Emissions

Projected CH_4 emissions from waste management, oil refining and agricultural activities in Delaware are projected to decrease significantly as Figure 115 presents. Methane emissions are expected decline from 0.13 $MmtCO_2e$ in 2011 to -0.15 $MmtCO_2e$ in 2030, a decline of approximately 215%. The decline in CH_4 emissions will be at the rate of 0.015 $MmtCO_2e$ per year. Also, as presented in Figure 115, CH_4 emissions will become negative in 2021 with -0.003 $MmtCO_2e$, and is expected to be negative through 2030. Between 2021 and 2030, Delaware's net removal CH_4 emissions from economic activities will total 0.73 $MmtCO_2e$.

FIGURE 115. PROJECTED GROSS CH_4 EMISSIONS FROM DELAWARE

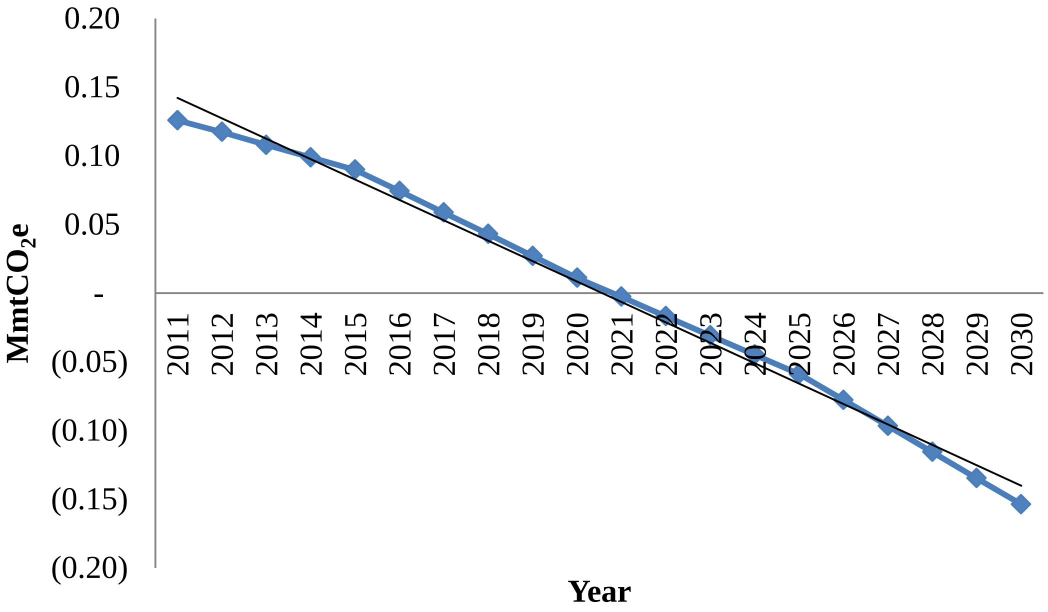
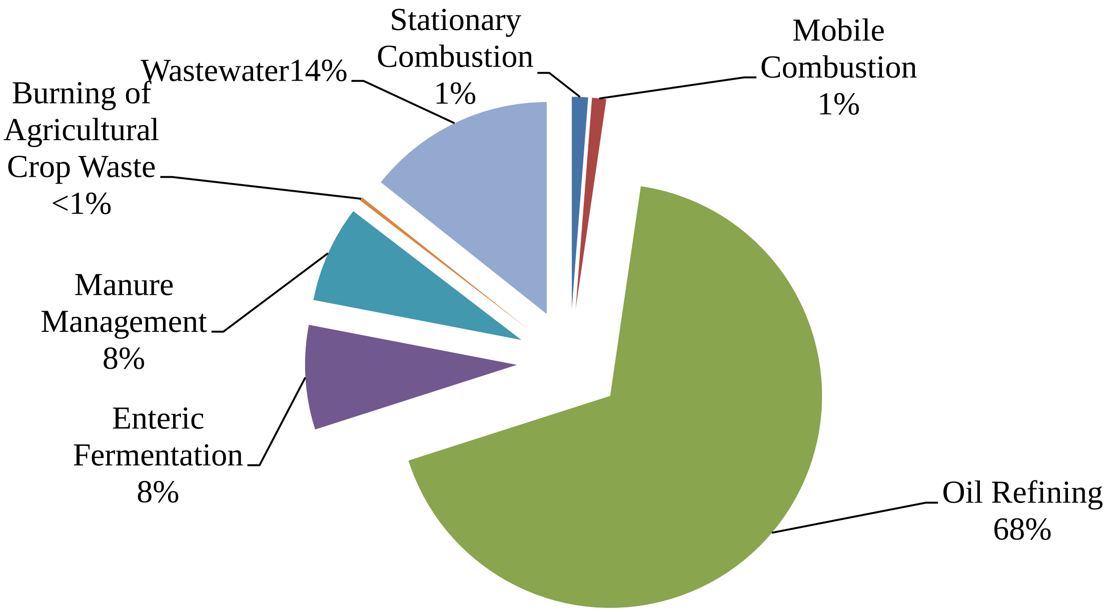


Figure 116 presents projected of CH_4 emissions by sources in 2030. The largest emissions source for CH_4 is expected to be oil refining with 68% of gross methane emissions. This will be followed by wastewater treatment, a distant second with approximately 14%. Enteric fermentation and manure management are projected to be in third place with approximately 8%, while stationary and mobile combustion sources are each projected to be 1% according to Figure 116. Agricultural crop waste burning is expected to have the smallest contribution to gross CH_4 emissions in 2030 with emissions less than one percent as Figure 116 presents.

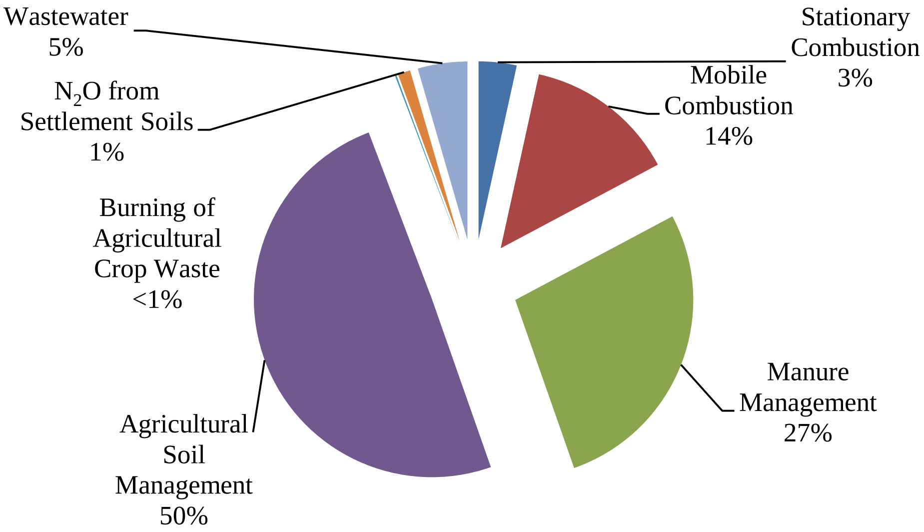
FIGURE 116. 2030 CH_4 EMISSIONS BY SOURCES



4.9.3 *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 117 presents a breakdown of N_2O emissions in 2010 by sources in Delaware.

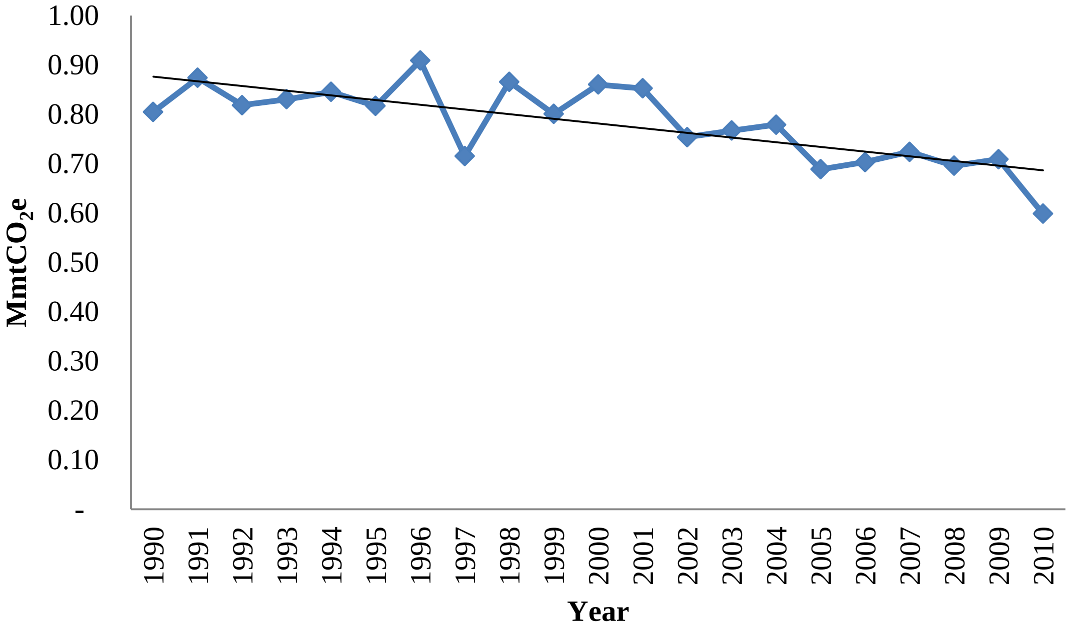
FIGURE 117. 2010 N_2O EMISSIONS BY SOURCES



In 2010, N_2O accounted for 4% of gross CO_2e emissions in Delaware with a total amount of 0.60 $MmtCO_2e$. As Figure 117 shows, N_2O emissions from agricultural soil management represented the largest source of N_2O, with approximately 50% of gross N_2O. This was followed by N_2O emissions from manure management with approximately 27% and mobile combustion emissions with approximately 14%. Other sources included stationary combustion with approximately 3%, wastewater treatment with approximately 5% and emissions from settlement soils with approximately 1%. The lowest N_2O emission came from the burning agricultural crop waste, which was less than 1% of gross N_2O emissions.

Figure 118 presents N_2O emissions from Delaware sources from 1990 to 2010. Nitrous oxide emissions decreased from 0.80 $MmtCO_2e$ in 1990 to 0.60 $MmtCO_2e$ in 2010, which was a reduction of approximately 25%. The emissions results revealed that N_2O emissions declined at the rate 0.01 $MmtCO_2e$ per year from 1990 to 2010.

FIGURE 118. DELAWARE'S N_2O EMISSIONS FROM 1990 TO 2010



Reference case Projection for N_2O Emissions

Gross N_2O emissions from all sources in Delaware are projected to be 0.60 $MmtCO_2e$ in 2030. Nitrous oxide emissions are expected to be driven primarily by emissions from the agricultural sector.

Figure 119 presents a breakdown of gross N_2O emissions in 2030. Agricultural soil management emission is expected to be the largest source of N_2O in 2030 with approximately 46%. This will be followed by manure management with approximately 34%. Mobile sources in the transportation sector are expected to emit approximately 10% of gross N_2O emissions. Wastewater treatment sources and stationary combustion of fuels for energy use are expected to emit approximately 6% and 4% respectively. The burning of agricultural waste is expected to contribute the list amount of N_2O emissions in 2030 with less than 1% as presented by Figure 119.

FIGURER 119. 2030 N_2O EMISSIONS BY SOURCES

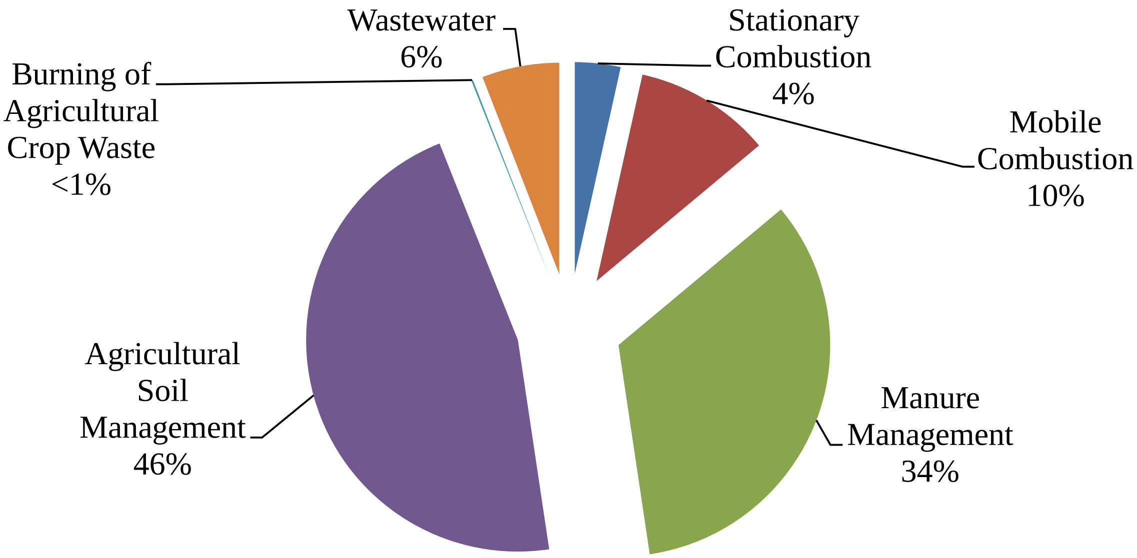


FIGURE 120. DELAWARE'S N_2O EMISSIONS FROM 2011 TO 2030

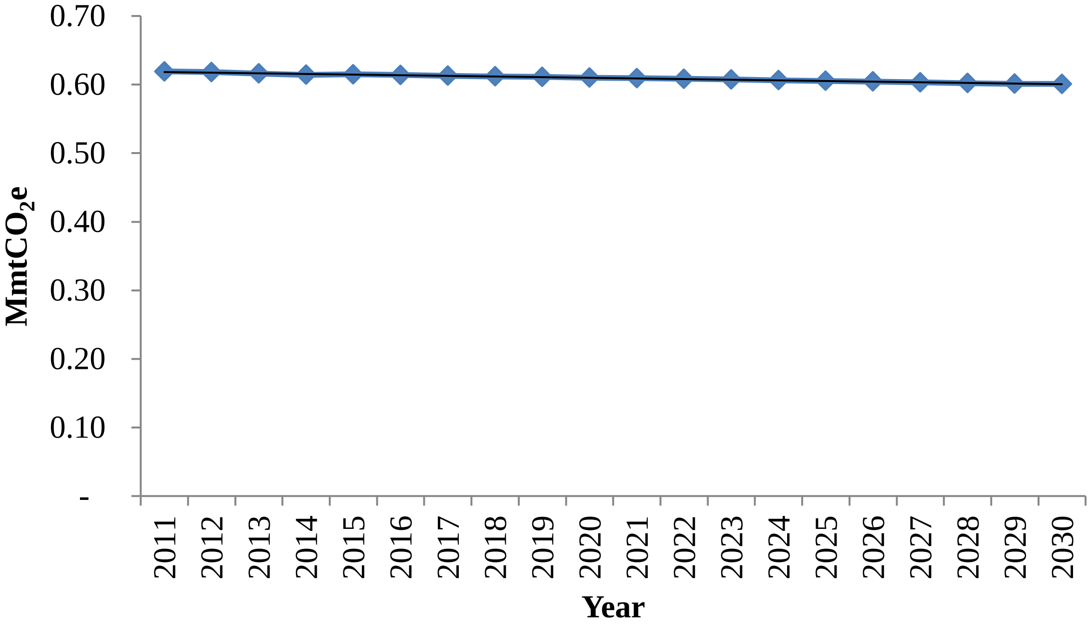


Figure 120 presents projected N_2O emissions from 2011 to 2030. In general, gross N_2O emissions are projected to trend flat with a slight decline as Figure 120 presents. Nitrous oxide emissions from all economic sources are projected to decrease from 0.62 $MmtCO_2e$ in 2011 to 0.60 $MmtCO_2e$ in 2030. This will be a slight decrease of approximately 3% at the rate of 0.001 $MmtCO_2e$ per year according to trend line analysis.

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

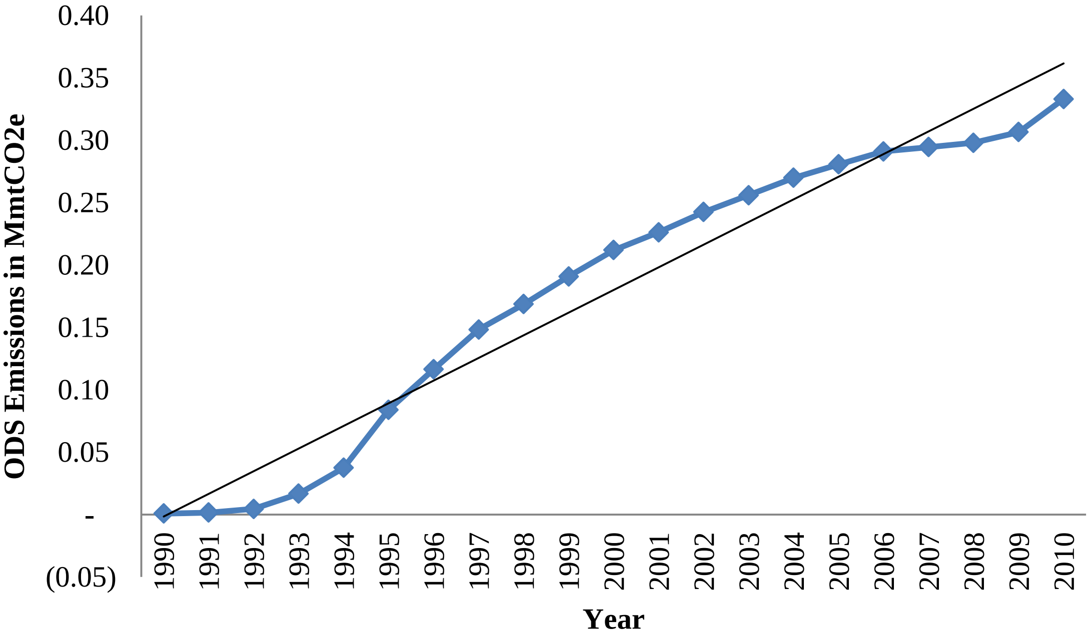
HFCs and PFCs are families of synthetic chemicals that are used as alternatives to ODS, which are being phased out under the Montreal Protocol and Clean Air Act Amendments of 1990 but are still used in some end-use products. GWP for HFCs and PFCs are 14,800 and 5,400 respectively. HFCs and PFCs do not 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 2010 GHG emissions inventory were determined by apportioning national emissions to each states based on population.
In 2010, the GHG emissions from HFCs and PFCs were 2.4% of gross GHG emissions from Delaware.

FIGURE 121. DELAWARE'S ODS SUBSTITUTES EMISSIONS

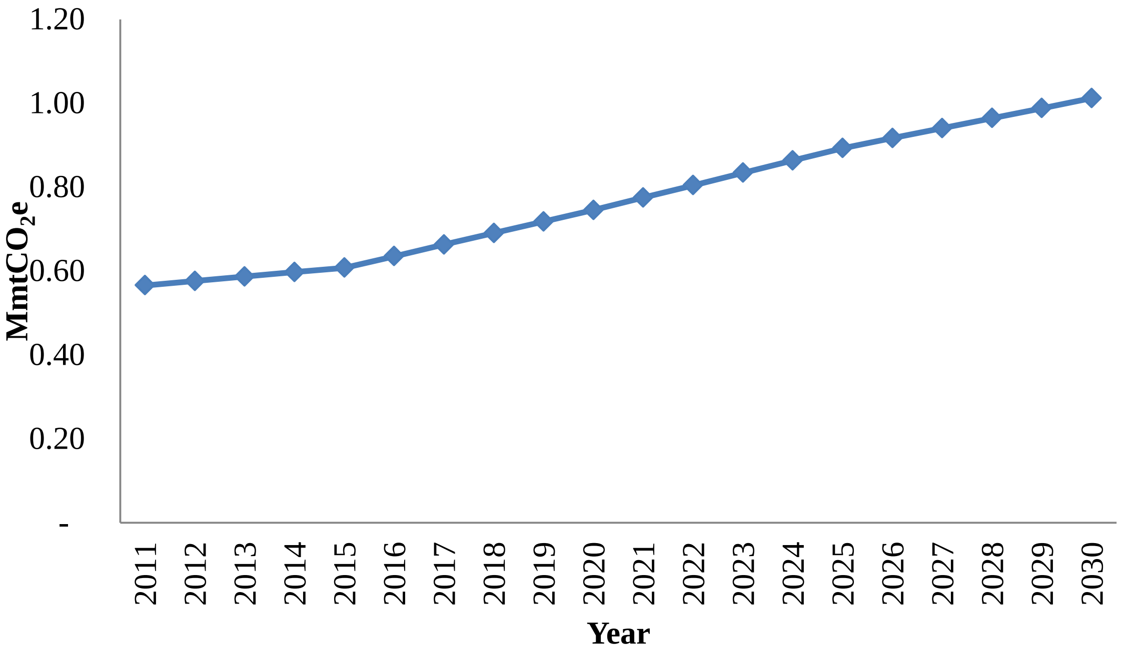


The total emissions were 0.333 MmtCO_2e. Historical emissions presented in Figure 121 show an upward trend in the emissions of ODS substitutes. Emissions of ODS substitutes increased by 374,000% from 1990 to 2010. Emissions increased from 888 mtCO_2e in 1990 to 333,211 mtCO_2e in 2010. Analysis of historical data shows that ODS emissions increased at the rate of 0.0182 mtCO_2e per year. This increase in ODS substitute emissions may be attributed to the increased use of ODS substitutes since 1990 where emissions were only 888 mtCO_2e.

Reference case projection for ODS Substitutes

This subsection discusses emissions projections for ozone delpleting substance (ODS) subtitutes including HFC and PFC. Figure 122 presents the emissions trend for HFC and PFC. The gross emission of both GHGs where combined and presented in Figure 122. The gross emission of ODS subtitutes is projected to increase from 0.60 MmtCO_2e in 2011 to 1.01 MmtCO_2e in 2030. This is projected to be an increase of approximately 77% at the rate of 0.025 MmtCO_2e per year.

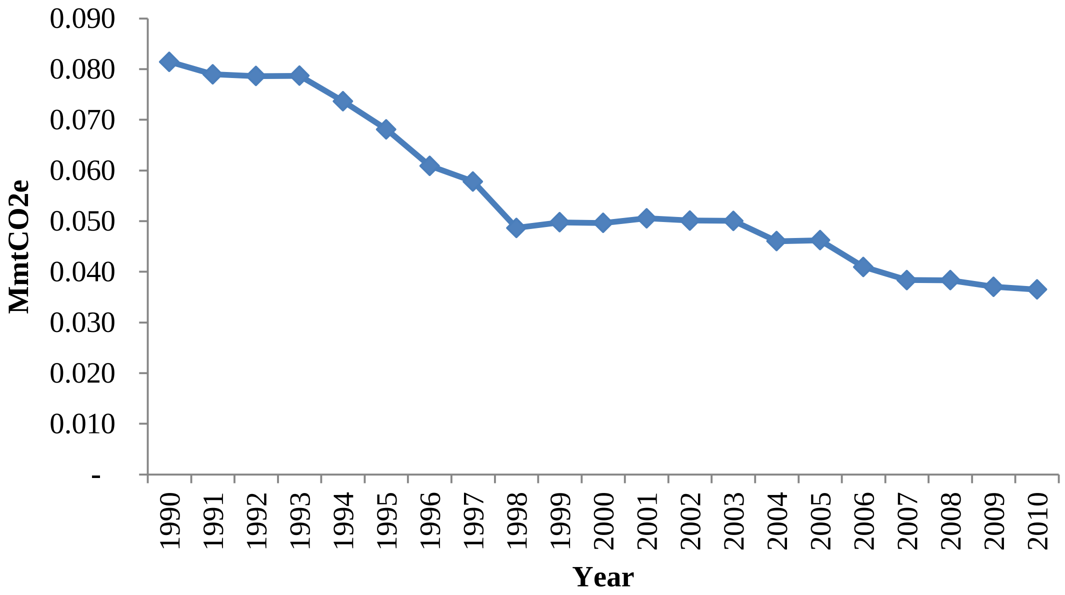
FIGURE122. PROJECTED EMISSIONS OF ODS SUBSTITUTES



4.9.5 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. Applications for SF_6 include gas insulated transmission lines, switchgears and gas insulated power distribution substations. The transmission and distribution (T&D) of electricity are minor sources of GHG emissions.

FIGURE 123. DELAWARE'S SF_6 EMISSIONS



In 2010, SF_6 was approximately 0.3% of gross GHG emissions. The total amount of SF_6 emitted from Delaware was 0.040 $MmtCO_2e$ in 2010. Unlike HFCs and PFCs, SF_6 emissions had a downward trend. According to Figure 123, SF_6 emissions of decreased by approximately 54% from 1990 to 2010. This rapid decrease may be attruibuted to the implementation of SF_6 reduction practices in the electri power industry[115], availability of new technology such as vacuum circuit breakers and increases in the price of SF_6.

Reference case projection for SF_6

Figure 123 presents projected emissions for SF_6. Projection analysis shows that SF_6 emission from the transmissions and ditribution of electricity in the power sector is expected to diminish in to the future. Figure 124 provides projected SF_6 emissions from 2011 to 2030. Gross SF6 emissions is projected decreased from 0.03 $MmtCO_2e$ in 2011 to 0.001 $MmtCO_2e$ in 2023 as presented by Figure 124. This is a decrease of approximately 97 % at the rate of 0.002 $MmtCO_2e$ per year. Sulfur hexaflouride emissions is projected to diminsh to zero starting from 2024 as presented in Figure 124.

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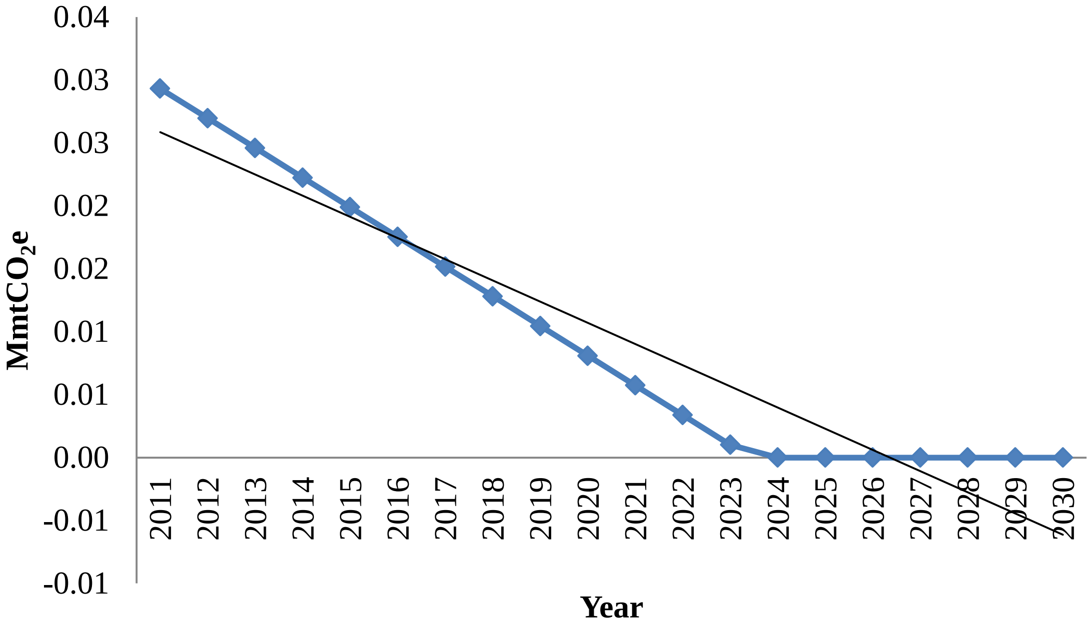
[115] See section 4.3.3 under Electric Power Transmission and distribution (T&D) systems

FIGURE 124. PROJECTED SF$_6$ EMISSIONS



SUMMARY OF THE 2010 GHG INVENTORY FINDINGS

The 2010 GHG emission inventory reports overall decreasing GHG emissions from 1990 to 2010. Based on emission estimates from 1990 to 2010, Delaware's gross GHG emission declined by approximately 30%. The decline in gross GHG emissions from Delaware's economic sectors is primarily the result of decrease in gross CO_2 emissions from fossil fuel combustion in all economic sectors between 1990 and 2010. The emission of CO_2 from fossil fuel combustion made up the largest share of gross GHG emissions in 2010 with approximately 91%.

This decreases in CO_2 emissions occurred overtime in part due to downturns in the economy. The economic downturns lead to a decline in the amount of fossils fuels consumed in Delaware. Another reason for the decline in CO_2 emissions due to fossil fuel consumption is fuel switching. Many of the electric generating facilities in Delaware (with the exception of Indian River power plant) have switched their fuels from coal, a high carbon intensity fuels to natural gas, a lower carbon intensity fuels. This has led to on-system reduction in GHG emissions as well as co-benefits in air pollutant emission rates. Another basis for the decline in CO_2 emissions associated with fossil fuel combustion in Delaware is energy efficiency. In addition to fuel switching at electric generating facilities in Delaware, which also improves efficiency, the facilities have adopted energy efficiency installations and programs to increase energy efficiency. Also, Delawareans have more access to energy efficient appliances.

Though, historical GHG emissions declined over time, gross GHG emissions are expected to increase steadily between 2011 and 2030. Gross GHG emissions are projected to be 15.15 $MmtCO_2e$ in 2030, an increase of approximately 15 % from 2011. The emission of CO_2 from fossil fuel combustion presents the greatest challenge to Delaware's overall GHG reduction objectives because projection analyses show that CO_2 will continue to be the most emitted GHG into the future. The share of CO_2 emissions in 2030 is projected to be 91%, one percent decrease compared to 2010.

The projected increase in GHG emissions from 2011 was based on the assumption of continuous growth in Delaware's economy and population. Projected GHG emissions will be primarily driven by increasing CO_2 emissions from fossils fuel combustion in all economic sectors. The consumption of fossils fuels, particularly in the power, industrial and commercial sectors of Delaware is expected to increase as Delaware's economy expands. Fossil fuel consumption particularly in the residential sector will also increase as Delaware's population grows.

In addition, the 2010 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 1999 and 2010, the land use sector removed a total of 13.12 $MmtCO_2e$ from Delaware. The estimated amount of CO_2 removed from the atmosphere was 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

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Electric Power	**7.60**	**7.86**	**6.87**	**7.62**	**7.22**	**6.74**	**6.66**	**5.77**	**5.44**	**5.05**	**5.27**	**5.16**	**5.12**	**5.86**	**5.96**	**6.37**	**5.69**	**6.63**	**6.21**	**3.83**	**4.23**
CO2 from FFC	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	3.78	4.17
CH4&N2O from FFC	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02
SF6 from T&D	0.08	0.08	0.08	0.08	0.07	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04
Transportation	**4.76**	**5.33**	**4.96**	**5.18**	**4.82**	**4.60**	**5.07**	**4.97**	**5.00**	**5.18**	**5.34**	**4.96**	**5.17**	**5.04**	**5.16**	**5.35**	**5.35**	**5.38**	**5.17**	**4.97**	**4.64**
CO2 from FFC	4.53	5.08	4.70	4.91	4.55	4.31	4.78	4.67	4.71	4.89	5.08	4.70	4.94	4.83	4.96	5.16	5.19	5.23	5.05	4.87	4.55
CH4&N2O from FFC	0.23	0.26	0.26	0.27	0.27	0.28	0.29	0.29	0.29	0.29	0.27	0.26	0.24	0.22	0.20	0.19	0.17	0.15	0.12	0.11	0.09
Industrial	**4.26**	**3.25**	**4.57**	**4.85**	**5.02**	**5.23**	**5.24**	**5.16**	**4.89**	**5.23**	**4.97**	**4.89**	**4.52**	**4.35**	**4.22**	**4.48**	**4.22**	**4.16**	**3.98**	**2.06**	**2.17**
CO2 From FFC	4.04	3.05	4.36	4.64	4.78	4.92	4.91	4.80	4.52	4.84	4.58	4.38	3.99	3.82	3.66	3.93	3.64	3.59	3.42	1.50	1.55
CH4&N2O from FFC	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	0.00	0.00
CH4 from IP	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09
CO2 from IP	0.20	0.18	0.19	0.17	0.18	0.20	0.19	0.20	0.18	0.18	0.16	0.19	0.20	0.19	0.20	0.17	0.19	0.19	0.17	0.16	0.20
HFC, PFC Emissions	0.00	0.00	0.00	0.02	0.04	0.08	0.12	0.15	0.17	0.19	0.21	0.23	0.24	0.26	0.27	0.28	0.29	0.29	0.30	0.31	0.33
Residential	**1.08**	**1.11**	**1.17**	**1.19**	**1.24**	**1.19**	**1.29**	**1.15**	**1.08**	**1.15**	**1.23**	**1.18**	**1.19**	**1.30**	**1.23**	**1.20**	**1.00**	**1.02**	**0.99**	**1.05**	**1.07**
CO2 from FFC	1.07	1.09	1.16	1.17	1.23	1.17	1.27	1.13	1.06	1.13	1.22	1.17	1.18	1.29	1.22	1.19	0.99	1.01	0.98	1.04	1.06
CH4&N2O from FFC	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Commercial	**0.58**	**0.58**	**0.55**	**0.69**	**0.62**	**0.57**	**0.73**	**0.70**	**0.61**	**0.64**	**0.63**	**0.69**	**0.74**	**0.79**	**0.79**	**0.73**	**0.73**	**0.69**	**0.65**	**0.84**	**0.84**
CO2 from FFC	0.58	0.58	0.55	0.69	0.61	0.57	0.72	0.70	0.60	0.64	0.63	0.68	0.74	0.79	0.79	0.73	0.73	0.68	0.65	0.84	0.83
CH4&N2O from FFC	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	0.00	0.00
Agricultural	**0.61**	**0.66**	**0.60**	**0.61**	**0.61**	**0.57**	**0.66**	**0.59**	**0.61**	**0.55**	**0.63**	**0.63**	**0.55**	**0.57**	**0.60**	**0.52**	**0.55**	**0.59**	**0.58**	**0.63**	**0.53**
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	0.04	0.04
Manure Management	0.19	0.19	0.20	0.21	0.21	0.21	0.20	0.20	0.21	0.20	0.20	0.20	0.21	0.21	0.21	0.20	0.19	0.19	0.19	0.19	0.19
Ag Soils	0.37	0.42	0.35	0.34	0.35	0.31	0.40	0.34	0.36	0.30	0.38	0.38	0.30	0.31	0.35	0.28	0.32	0.35	0.34	0.39	0.30
Agricultural Residue Burning	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	0.00	0.00
Waste Management	**0.578**	**0.596**	**0.607**	**0.611**	**0.620**	**0.628**	**0.631**	**0.625**	**0.437**	**0.425**	**0.457**	**0.471**	**0.504**	**0.410**	**0.111**	**0.162**	**0.218**	**0.125**	**0.149**	**0.159**	**0.123**
Wastewater Treatment	0.063	0.065	0.066	0.067	0.068	0.068	0.070	0.070	0.071	0.072	0.076	0.077	0.077	0.078	0.080	0.081	0.083	0.085	0.086	0.087	0.088
MSW	0.515	0.532	0.541	0.544	0.553	0.559	0.561	0.555	0.366	0.352	0.381	0.394	0.427	0.332	0.031	0.081	0.135	0.041	0.063	0.072	0.035
Gross GHG Emissions	**19.78**	**19.69**	**19.62**	**20.95**	**20.36**	**19.73**	**20.48**	**19.15**	**18.25**	**18.23**	**18.52**	**17.98**	**17.80**	**18.33**	**18.07**	**18.81**	**17.76**	**18.59**	**17.74**	**13.54**	**13.60**
Forestry	**0.31**	**0.31**	**0.30**	**0.20**	**0.20**	**0.20**	**0.20**	**0.19**	**0.18**	**(0.68)**	**(1.12)**	**(1.13)**	**(1.14)**	**(1.14)**	**(1.15)**	**(1.16)**	**(1.17)**	**(1.09)**	**(1.10)**	**(1.11)**	**(1.12)**
Net GHG Emissions	**19.78**	**19.69**	**19.62**	**20.95**	**20.36**	**19.73**	**20.48**	**19.15**	**18.25**	**17.54**	**17.40**	**16.85**	**16.66**	**17.19**	**16.92**	**17.65**	**16.59**	**17.50**	**16.64**	**12.43**	**12.48**

APPENDIX B

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Electricpower	**3.06**	**3.15**	**3.08**	**3.02**	**3.50**	**3.53**	**3.54**	**3.62**	**3.72**	**3.72**	**3.81**	**3.84**	**3.88**	**3.92**	**3.94**	**3.94**	**3.94**	**3.96**	**3.98**	**4.00**
CO2 from FFC	3.02	3.11	3.04	2.99	3.46	3.50	3.51	3.59	3.69	3.70	3.78	3.82	3.87	3.90	3.93	3.92	3.93	3.95	3.97	3.99
CH4&N2O from FFC	0.01	0.01	0.01	0.01	0.01	0.01	0.01	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
SF6 from T&D	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	-	-	-	-	-	-	-
Transportation	**5.43**	**5.47**	**5.55**	**5.58**	**5.59**	**5.61**	**5.63**	**5.64**	**5.63**	**5.62**	**5.61**	**5.59**	**5.57**	**5.55**	**5.52**	**5.51**	**5.49**	**5.48**	**5.48**	**5.48**
CO2 from FFC	5.35	5.39	5.47	5.50	5.52	5.54	5.55	5.56	5.56	5.55	5.54	5.52	5.50	5.48	5.45	5.44	5.42	5.41	5.41	5.41
CH4&N2O from FFC	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Industrial	**2.39**	**2.40**	**2.47**	**2.59**	**2.67**	**2.73**	**2.78**	**2.82**	**2.85**	**2.88**	**2.91**	**2.93**	**2.96**	**2.98**	**3.00**	**3.02**	**3.03**	**3.04**	**3.06**	**3.27**
CO2 From FFC	1.78	1.77	1.82	1.92	1.99	2.04	2.06	2.09	2.11	2.12	2.13	2.14	2.15	2.16	2.16	2.16	2.15	2.15	2.16	2.34
CH4&N2O from FFC	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	0.00
CH4from IP	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11
CO2 from IP	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09
HFC, PFC Emissions	0.38	0.40	0.42	0.44	0.45	0.47	0.49	0.51	0.53	0.54	0.56	0.58	0.60	0.62	0.64	0.65	0.67	0.69	0.71	0.73
Residential	**0.93**	**1.06**	**1.03**	**1.03**	**1.02**	**1.02**	**1.01**	**1.01**	**1.00**	**1.00**	**0.99**	**0.99**	**0.98**	**0.98**	**0.98**	**0.97**	**0.97**	**0.97**	**0.96**	**0.96**
CO2 from FFC	0.93	1.06	1.03	1.02	1.02	1.01	1.01	1.00	1.00	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.97	0.96	0.96	0.95
CH4&N2O from FFC	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	0.00
Commercial	**0.80**	**0.86**	**0.87**	**0.90**	**0.91**	**0.91**	**0.92**	**0.92**	**0.93**	**0.93**	**0.94**	**0.94**	**0.94**	**0.95**	**0.95**	**0.96**	**0.96**	**0.97**	**0.97**	**0.98**
CO2 from FFC	0.80	0.85	0.87	0.90	0.91	0.91	0.91	0.92	0.92	0.93	0.93	0.94	0.94	0.94	0.95	0.95	0.96	0.97	0.97	0.98
CH4&N2O from FFC	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	0.00
Agriculturre	**0.58**	**0.58**	**0.58**	**0.58**	**0.58**	**0.58**	**0.58**	**0.58**	**0.58**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**
Enteric Fermentation	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Manure Management	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.24	0.24	0.24	0.24	0.24	0.24
Ag Soils	0.32	0.32	0.32	0.31	0.31	0.31	0.31	0.30	0.30	0.30	0.30	0.30	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28
Agricultural Residue Burning	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	0.00
Waste	**(0.230)**	**(0.248)**	**(0.265)**	**(0.283)**	**(0.301)**	**(0.319)**	**(0.337)**	**(0.355)**	**(0.373)**	**(0.391)**	**(0.409)**	**(0.428)**	**(0.446)**	**(0.465)**	**(0.484)**	**(0.502)**	**(0.521)**	**(0.540)**	**(0.559)**	**(0.578)**
Wastewater Treatment	0.089	0.090	0.091	0.092	0.094	0.095	0.096	0.097	0.098	0.100	0.101	0.102	0.103	0.105	0.106	0.107	0.108	0.110	0.111	0.112
MSW	(0.319)	(0.337)	(0.356)	(0.375)	(0.394)	(0.413)	(0.433)	(0.452)	(0.471)	(0.491)	(0.510)	(0.530)	(0.550)	(0.570)	(0.590)	(0.610)	(0.630)	(0.650)	(0.670)	(0.690)
Net GHG emissions	**12.98**	**13.28**	**13.32**	**13.41**	**13.97**	**14.07**	**14.11**	**14.22**	**14.33**	**14.33**	**14.41**	**14.44**	**14.46**	**14.48**	**14.48**	**14.46**	**14.44**	**14.45**	**14.47**	**14.68**
Gross GHG emissions	**13.29**	**13.61**	**13.67**	**13.78**	**14.37**	**14.48**	**14.55**	**14.67**	**14.80**	**14.82**	**14.92**	**14.97**	**15.01**	**15.05**	**15.07**	**15.07**	**15.07**	**15.10**	**15.14**	**15.37**

APPENDIX C

Emissions (MMTCO2E)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Gross CO2	18.01	17.85	17.82	19.12	18.48	17.82	18.46	17.17	16.44	16.49	16.70	16.06	15.93	16.54	16.55	17.35	16.21	17.12	16.29	12.05	12.20
Net CO2	18.01	17.85	17.82	19.12	18.48	17.82	18.46	17.17	16.44	15.79	15.57	14.92	14.78	15.39	15.39	16.18	15.04	16.02	15.18	10.94	11.08
CO2 from Fossil Fuel Combustion	17.70	17.54	17.52	18.92	18.28	17.62	18.26	16.98	16.26	16.48	16.69	16.03	15.89	16.51	16.51	17.30	16.17	17.08	16.25	12.03	12.16
Industrial Processes	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.04	0.03	0.04	0.05	0.05	0.04	0.04	0.03	0.04
LULUCF	0.30	0.30	0.29	0.19	0.19	0.19	0.19	0.18	0.17	(0.69)	(1.13)	(1.14)	(1.15)	(1.15)	(1.16)	(1.17)	(1.18)	(1.10)	(1.11)	(1.12)	(1.13)
CH4	0.69	0.71	0.72	0.74	0.74	0.75	0.75	0.74	0.55	0.53	0.56	0.64	0.67	0.57	0.28	0.33	0.38	0.28	0.30	0.31	0.27
Stationary 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	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
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	0.01	0.01
Natural Gas and Oil Systems	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09
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	0.04	0.04
Manure Management	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.04	0.03	0.03	0.04	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	0.00	0.00
Waste	0.51	0.53	0.54	0.54	0.55	0.56	0.56	0.56	0.37	0.35	0.38	0.39	0.43	0.33	0.03	0.08	0.14	0.04	0.06	0.07	0.03
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	0.06	0.06
N2O	0.80	0.87	0.82	0.83	0.85	0.82	0.91	0.72	0.87	0.80	0.86	0.85	0.75	0.77	0.78	0.69	0.70	0.72	0.70	0.71	0.60
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	0.02	0.02
Mobile Combustion	0.21	0.23	0.24	0.25	0.25	0.26	0.27	0.27	0.27	0.27	0.25	0.24	0.22	0.21	0.19	0.18	0.15	0.14	0.11	0.10	0.08
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	0.16	0.16
Agricultural Soil Management	0.37	0.42	0.35	0.34	0.35	0.31	0.40	0.20	0.36	0.30	0.38	0.38	0.30	0.31	0.35	0.28	0.32	0.35	0.34	0.39	0.30
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	0.00	0.00
N2O 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	0.01	0.01
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	0.03	0.03
HFC, PFC, and SF6	0.08	0.08	0.08	0.10	0.11	0.15	0.18	0.21	0.22	0.24	0.26	0.28	0.29	0.31	0.32	0.33	0.33	0.33	0.34	0.34	0.37
Industrial Processes	0.08	0.08	0.08	0.10	0.11	0.15	0.18	0.21	0.22	0.24	0.26	0.28	0.29	0.31	0.32	0.33	0.33	0.33	0.34	0.34	0.37
Indirect CO2 from Electricity Consumption*	4.40	4.54	4.54	4.85	4.94	5.09	5.13	5.38	5.53	5.61	5.99	6.05	6.39	6.70	6.25	6.45	6.14	6.13	6.07	5.82	6.00
Gross Emissions	**19.59**	**19.51**	**19.45**	**20.78**	**20.18**	**19.54**	**20.30**	**18.83**	**18.07**	**18.06**	**18.38**	**17.84**	**17.65**	**18.19**	**17.92**	**18.69**	**17.62**	**18.46**	**17.62**	**13.42**	**13.44**
Sinks	**0.31**	**0.31**	**0.30**	**0.20**	**0.20**	**0.20**	**0.20**	**0.19**	**0.18**	**(0.69)**	**(1.13)**	**(1.14)**	**(1.15)**	**(1.15)**	**(1.16)**	**(1.17)**	**(1.18)**	**(1.10)**	**(1.11)**	**(1.12)**	**(1.13)**
Net Emissions (Sources and Sinks)	**19.59**	**19.51**	**19.45**	**20.78**	**20.18**	**19.54**	**20.30**	**18.83**	**18.07**	**17.37**	**17.25**	**16.70**	**16.50**	**17.03**	**16.76**	**17.52**	**16.45**	**17.36**	**16.51**	**12.30**	**12.32**
TiO2 CO2	0.19	0.18	0.18	0.17	0.18	0.20	0.18	0.19	0.18	0.18	0.15	0.15	0.16	0.15	0.16	0.14	0.15	0.14	0.13	0.14	0.16
Total GHG Emissions	19.78	19.69	19.63	20.95	20.36	19.74	20.48	19.02	18.25	18.24	18.53	17.99	17.81	18.34	18.08	18.83	17.77	18.60	17.75	13.55	13.60
Net Emissions (Sources and Sinks)	19.78	19.69	19.63	20.95	20.36	19.74	20.48	19.02	18.25	17.54	17.40	16.85	16.66	17.19	16.92	17.66	16.60	17.50	16.64	12.43	12.48

APPENDIX D

MMTCO2E	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO2	12.02	12.33	12.37	12.47	13.03	13.13	13.18	13.28	13.40	13.40	13.49	13.51	13.54	13.56	13.56	13.55	13.53	13.53	13.55	13.77
CO2 from Fossil Fuel Combustion	11.88	12.19	12.24	12.33	12.90	13.00	13.05	13.16	13.28	13.29	13.37	13.40	13.43	13.46	13.46	13.45	13.43	13.44	13.46	13.68
Industrial Processes	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09
CH4	(0.08)	(0.09)	(0.11)	(0.13)	(0.14)	(0.16)	(0.18)	(0.20)	(0.21)	(0.23)	(0.25)	(0.27)	(0.29)	(0.30)	(0.32)	(0.34)	(0.36)	(0.38)	(0.39)	(0.41)
Stationary Combustion	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	0.01
Mobile Combustion	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	0.01
Natural Gas and Oil Systems	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11
Enteric Fermentation	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Manure Management	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
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	0.00
Waste	(0.32)	(0.34)	(0.36)	(0.38)	(0.39)	(0.41)	(0.43)	(0.45)	(0.47)	(0.49)	(0.51)	(0.53)	(0.55)	(0.57)	(0.59)	(0.61)	(0.63)	(0.65)	(0.67)	(0.69)
Wastewater	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08
N2O	0.62	0.62	0.62	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.60	0.60	0.60	0.60	0.60
Stationary 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	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Mobile Combustion	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Manure Management	0.18	0.18	0.18	0.18	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Agricultural Soil Management	0.32	0.32	0.32	0.31	0.31	0.31	0.31	0.30	0.30	0.30	0.30	0.30	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28
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	0.00
Wastewater	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	0.03	0.03	0.03	0.04	0.04
HFC, PFC, and SF6	0.41	0.43	0.44	0.46	0.47	0.49	0.51	0.52	0.54	0.55	0.57	0.58	0.60	0.62	0.64	0.65	0.67	0.69	0.71	0.73
Industrial Processes	0.41	0.43	0.44	0.46	0.47	0.49	0.51	0.52	0.54	0.55	0.57	0.58	0.60	0.62	0.64	0.65	0.67	0.69	0.71	0.73
Total Emissions	**12.98**	**13.28**	**13.32**	**13.41**	**13.97**	**14.07**	**14.11**	**14.22**	**14.33**	**14.33**	**14.41**	**14.44**	**14.46**	**14.48**	**14.48**	**14.46**	**14.45**	**14.45**	**14.47**	**14.68**
Electricity Consumption Emissions	**6.92**	**6.86**	**6.97**	**7.08**	**7.17**	**7.28**	**7.38**	**7.51**	**7.59**	**7.68**	**7.79**	**7.88**	**7.97**	**8.05**	**8.13**	**8.21**	**8.29**	**8.37**	**8.45**	**8.53**
Gross without MSW	13.30	13.62	13.68	13.7852	14.3668	14.48	14.55	14.67	14.80	14.82	14.92	14.97	15.01	15.05	15.07	15.07	15.07	15.10	15.14	15.37

APPENDIX E

MMTCO$_2$E	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Electric Power CO$_2$	**7.49**	**7.75**	**6.76**	**7.51**	**7.12**	**6.65**	**6.58**	**5.69**	**5.36**	**4.98**	**5.2**	**5.09**	**5.04**	**5.78**	**5.89**	**6.29**	**5.62**	**6.57**	**6.14**	**3.78**	**4.17**
Coal	5.02	4.8	3.99	5.44	4.88	4.47	4.38	4.13	3.8	2.99	4.22	3.14	3.53	4.13	4.69	4.98	5.01	5.67	5.45	3.1	2.81
Petroleum	1.85	2.13	2.31	1.6	1.28	0.7	0.92	0.67	0.99	0.96	0.52	1.11	0.58	1.01	0.48	0.6	0.09	0.15	0.08	0.08	0.04
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	0.6	1.32
N20																					
Electric Power	0.029	0.029	0.025	0.031	0.028	0.025	0.025	0.023	0.022	0.018	0.023	0.019	0.02	0.024	0.025	0.027	0.026	0.029	0.028	0.016	0.015
Coal	0.025	0.024	0.02	0.027	0.024	0.022	0.022	0.02	0.019	0.015	0.021	0.016	0.018	0.021	0.023	0.025	0.025	0.028	0.027	0.016	0.014
Petroleum	0.004	0.005	0.005	0.004	0.003	0.002	0.002	0.002	0.002	0.002	0.001	0.003	0.001	0.003	0.001	0.002	0	0	0	0	0
Natural Gas	0	0	0	0	0.001	0.001	0.001	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0.001
CH4																					
Electric Power	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	0.001	0.001
Coal	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	0.001	0.001	0.001	0.001	0.001	0.001
Petroleum	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0	0.001	0	0.001	0	0.001	0	0	0	0	0
Natural Gas	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SF$_6$from T&D	**0.081**	**0.079**	**0.079**	**0.079**	**0.074**	**0.068**	**0.061**	**0.058**	**0.049**	**0.05**	**0.05**	**0.051**	**0.05**	**0.05**	**0.046**	**0.046**	**0.041**	**0.038**	**0.038**	**0.037**	**0.037**
Total Electric	**7.6**	**7.86**	**6.87**	**7.62**	**7.22**	**6.74**	**6.66**	**5.77**	**5.44**	**5.05**	**5.27**	**5.16**	**5.12**	**5.86**	**5.96**	**6.37**	**5.69**	**6.63**	**6.21**	**3.83**	**4.23**

APPENDIX F

CO2 Projection	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Electric Power Projection	**3.02**	**3.11**	**3.04**	**2.99**	**3.46**	**3.5**	**3.51**	**3.59**	**3.69**	**3.7**	**3.78**	**3.82**	**3.87**	**3.9**	**3.93**	**3.92**	**3.93**	**3.95**	**3.97**	**3.99**
Coal	2.12	2.29	2.17	2.11	2.6	2.66	2.68	2.75	2.85	2.85	2.93	2.97	2.99	3.01	3.02	3.03	3.03	3.04	3.05	3.06
Natural Gas	0.86	0.79	0.84	0.84	0.83	0.8	0.79	0.8	0.8	0.81	0.81	0.81	0.83	0.85	0.86	0.85	0.86	0.87	0.88	0.9
Distillate Fuel	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Residual Fuel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

N2O projection	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Electric Power Projection	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Coal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distillate Fuel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Residual Fuel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petroleum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

CH4 projection	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Electric Power Projection	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distillate Fuel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Residual Fuel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petroleum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CH4&N2O total	0.01	0.01	0.01	0.01	0.01	0.01	0.01	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
SF_6 from T&D	**0.029**	**0.027**	**0.025**	**0.022**	**0.02**	**0.018**	**0.015**	**0.013**	**0.01**	**0.008**	**0.006**	**0.003**	**0.001**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total Electric power	**3.03**	**3.13**	**3.06**	**3**	**3.48**	**3.51**	**3.53**	**3.6**	**3.71**	**3.72**	**3.8**	**3.84**	**3.88**	**3.92**	**3.94**	**3.94**	**3.94**	**3.96**	**3.98**	**4**

APPENDIX G

CO2MMTCO$_2$E	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Transportation	4.53	5.08	4.7	4.91	4.55	4.31	4.78	4.67	4.71	4.89	5.08	4.7	4.94	4.83	4.96	5.16	5.19	5.23	5.05	4.87	4.55
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Petroleum	4.53	5.07	4.69	4.91	4.55	4.31	4.78	4.67	4.71	4.88	5.07	4.7	4.93	4.82	4.95	5.16	5.19	5.23	5.05	4.86	4.54
Natural Gas	0.0002	0	0	0	0	0	0	0	0	0	0.01	0	0.01	0	0.01	0	0	0	0	0	0.01

Total CH4 and N2O Emissions from Mobile Sources (MmtCO2E)

Fuel Type/Vehicle Type	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Gasoline Highway	**0.22**	**0.23**	**0.25**	**0.25**	**0.26**	**0.27**	**0.27**	**0.28**	**0.28**	**0.27**	**0.25**	**0.24**	**0.22**	**0.21**	**0.19**	**0.18**	**0.15**	**0.13**	**0.11**	**0.09**	**0.08**
Passenger Cars	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.14	0.14	0.13	0.13	0.12	0.11	0.1	0.1	0.08	0.07	0.06	0.07	0.06
Light-Duty Trucks	0.08	0.09	0.1	0.11	0.11	0.12	0.12	0.13	0.13	0.12	0.12	0.11	0.1	0.09	0.08	0.07	0.07	0.06	0.05	0.02	0.02
Heavy-Duty Vehicles	0	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	0	0	0	0
Motorcycles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel Highway	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Passenger Cars	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Light-Duty Trucks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heavy-Duty Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-Highway	**0.01**	**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**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0**
Boats	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	0.01	0
Locomotives	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Farm Equipment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aircraft	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alternative Fuel Vehicles	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Light Duty Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heavy Duty Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Buses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total CH4 and N2O	**0.23**	**0.26**	**0.26**	**0.27**	**0.27**	**0.28**	**0.29**	**0.29**	**0.29**	**0.29**	**0.27**	**0.26**	**0.24**	**0.22**	**0.2**	**0.19**	**0.17**	**0.15**	**0.12**	**0.11**	**0.09**
Total Transportation	**4.76**	**5.33**	**4.96**	**5.18**	**4.82**	**4.6**	**5.07**	**4.97**	**5**	**5.18**	**5.34**	**4.96**	**5.17**	**5.04**	**5.16**	**5.35**	**5.35**	**5.38**	**5.17**	**4.97**	**4.64**

APPENDIX H

Transportation CO2	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Sources	**5.35**	**5.39**	**5.47**	**5.5**	**5.52**	**5.54**	**5.55**	**5.56**	**5.56**	**5.55**	**5.54**	**5.52**	**5.5**	**5.48**	**5.45**	**5.44**	**5.42**	**5.41**	**5.41**	**5.41**
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Distillate Fuel	0.65	0.69	0.74	0.77	0.79	0.8	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.89	0.9	0.9	0.9	0.91	0.92
Jet Fuel, Kerosene	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
LPG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gasoline	3.72	3.65	3.61	3.6	3.6	3.6	3.59	3.58	3.57	3.54	3.51	3.49	3.45	3.42	3.39	3.36	3.34	3.32	3.3	3.29
Residual Fuel	0.88	0.95	1.02	1.02	1.02	1.03	1.03	1.04	1.04	1.04	1.05	1.05	1.05	1.06	1.06	1.06	1.07	1.07	1.08	1.08
Aviation Gasoline	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Lubricants	0.03	0.02	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	0.03	0.03	0.03

N_2O and CH_4 emissions from Mobile Sources

Sources	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Gasoline Highway	**0.07**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**
Passenger Cars	0.04	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	0.03	0.03	0.03
Light-Duty Trucks	0.03	0.03	0.03	0.03	0.03	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
Heavy-Duty Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Motorcycles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel Highway	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Passenger Cars	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Light-Duty Trucks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heavy-Duty Vehicles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alternative Fuel Vehicles	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Non-Highway	**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**	**0.02**	**0.02**
Marine vessels	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Locomotives	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Farm Equipment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction Equipment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aircraft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**	**0.07**

APPENDIX I

MMTCO$_2$E	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Industrial CO$_2$	**4.04**	**3.05**	**4.36**	**4.64**	**4.78**	**4.92**	**4.91**	**4.8**	**4.52**	**4.84**	**4.58**	**4.38**	**3.99**	**3.82**	**3.66**	**3.93**	**3.64**	**3.59**	**3.42**	**1.5**	**1.55**
Coal	0.08	0.08	-	0.06	0.15	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	0.2	0.05	-
Petroleum	3.07	2.13	3.39	3.53	3.7	3.42	3.76	3.59	3.22	3.33	2.78	2.9	2.81	2.77	2.51	2.82	2.51	2.47	2.24	0.52	1.12
Natural Gas	0.89	0.84	0.97	1.05	0.93	1.04	0.76	0.79	0.89	1.16	1.36	1.07	0.94	0.81	0.86	0.81	0.88	0.86	0.98	0.93	0.43
CH$_4$ and N$_2$O	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Industrial N$_2$O	**0.008**	**0.006**	**0.008**	**0.009**	**0.009**	**0.01**	**0.011**	**0.011**	**0.01**	**0.009**	**0.009**	**0.009**	**0.008**	**0.008**	**0.008**	**0.008**	**0.007**	**0.007**	**0.007**	**0.002**	**0.002**
Coal	0	0	0	0	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0	-
Petroleum	0.006	0.005	0.007	0.008	0.008	0.007	0.008	0.008	0.007	0.007	0.006	0.007	0.006	0.006	0.006	0.006	0.006	0.006	0.005	0.001	0.002
Natural Gas	0	0	0.001	0.001	0	0.001	0	0	0	0.001	0.001	0.001	0	0	0	0	0	0	0.001	0	0
Wood	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial CH$_4$	**0.003**	**0.002**	**0.003**	**0.003**	**0.003**	**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**	**0.001**	**0.001**
Coal	0	0	-	0	0	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	0	-
Petroleum	0.002	0.002	0.002	0.003	0.003	0.002	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	0.001
Natural Gas	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0
Wood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial Processes	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Sources	**0.21**	**0.19**	**0.2**	**0.2**	**0.23**	**0.3**	**0.31**	**0.35**	**0.36**	**0.38**	**0.38**	**0.49**	**0.52**	**0.52**	**0.55**	**0.54**	**0.57**	**0.56**	**0.55**	**0.55**	**0.62**
Soda Ash	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	0.01	0.01
Iron & Steel Production	-	-	-	-	-	-	-	-	-	-	-	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.02	0.03
TIO2	0.19	0.18	0.18	0.17	0.18	0.2	0.18	0.19	0.18	0.18	0.15	0.15	0.16	0.15	0.16	0.14	0.15	0.14	0.13	0.14	0.16
HFC, PFC Emissions	0	0	0	0.02	0.04	0.08	0.12	0.15	0.17	0.19	0.21	0.23	0.24	0.26	0.27	0.28	0.29	0.29	0.3	0.31	0.33
NG T&D Oil Refining	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09
Total Industrial	**4.26**	**3.25**	**4.57**	**4.85**	**5.02**	**5.23**	**5.24**	**5.16**	**4.89**	**5.23**	**4.97**	**4.89**	**4.52**	**4.35**	**4.22**	**4.48**	**4.22**	**4.16**	**3.98**	**2.06**	**2.17**

APPENDIX J

Emissions (MmTCO2E)	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Industrial	**1.78**	**1.77**	**1.82**	**1.93**	**1.99**	**2.04**	**2.07**	**2.09**	**2.11**	**2.12**	**2.13**	**2.14**	**2.15**	**2.16**	**2.16**	**2.16**	**2.16**	**2.16**	**2.16**	**2.35**
Coal	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**
Coking Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other Coal	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Natural Gas	**1.05**	**1.05**	**1.07**	**1.12**	**1.15**	**1.18**	**1.2**	**1.22**	**1.23**	**1.24**	**1.26**	**1.26**	**1.27**	**1.28**	**1.28**	**1.28**	**1.28**	**1.28**	**1.28**	**1.29**
Natural Gas	1.05	1.05	1.07	1.12	1.15	1.18	1.2	1.22	1.23	1.24	1.26	1.26	1.27	1.28	1.27	1.28	1.28	1.28	1.28	1.29
Petroleum	**0.69**	**0.67**	**0.7**	**0.75**	**0.79**	**0.81**	**0.82**	**0.82**	**0.83**	**0.82**	**0.82**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	**1**
Distillate Fuel	0.12	0.13	0.12	0.13	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.25
LPG	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04
Motor Gasoline	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Residual Fuel	0.12	0.12	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Asphalt and Road Oil	0.32	0.3	0.33	0.35	0.38	0.39	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.41	0.41	0.41	0.41	0.41	0.41	0.43
Lubricants	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Misc. Petro Products	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	0.03	0.03	0.03	0.03

Emissions (MmTCO2E)	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Carbon Dioxide Emissions	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
Limestone and Dolomite Use																				
Soda Ash	**0.007**	**0.007**	**0.007**	**0.007**	**0.007**	**0.007**	**0.007**	**0.007**	**0.007**	**0.007**	**0.007**	**0.007**	**0.007**	**0.007**	**0.006**	**0.006**	**0.006**	**0.006**	**0.006**	**0.006**
Ammonia & Urea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Urea Consumption	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ODS Substitutes	**0.381**	**0.399**	**0.417**	**0.435**	**0.454**	**0.472**	**0.49**	**0.508**	**0.526**	**0.545**	**0.563**	**0.581**	**0.599**	**0.617**	**0.636**	**0.654**	**0.672**	**0.69**	**0.708**	**0.727**
Semiconductor Manufacturing																				
Electric Power Transmission and Distribution Systems	**0.029**	**0.027**	**0.025**	**0.022**	**0.02**	**0.018**	**0.015**	**0.013**	**0.01**	**0.008**	**0.006**	**0.003**	**0.001**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
HCFC-22 Production																				
TIO2	**0.134**	**0.131**	**0.129**	**0.126**	**0.123**	**0.121**	**0.118**	**0.115**	**0.113**	**0.11**	**0.107**	**0.104**	**0.102**	**0.099**	**0.096**	**0.094**	**0.091**	**0.088**	**0.086**	**0.083**
NG and Oil refinery	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.11**
Total Emissions	0.639	0.653	0.667	0.681	0.695	0.709	0.723	0.737	0.751	0.765	0.779	0.793	0.808	0.823	0.839	0.856	0.872	0.888	0.905	0.921
projected emissions without SF6 =	0.61	0.626	0.643	0.659	0.675	0.692	0.708	0.725	0.741	0.757	0.774	0.79	0.806	0.823	0.839	0.856	0.872	0.888	0.905	0.921
HFC, PFC, and SF6 Emissions	0.41	0.43	0.44	0.46	0.47	0.49	0.51	0.52	0.54	0.55	0.57	0.58	0.6	0.62	0.64	0.65	0.67	0.69	0.71	0.73
projected gross industrial sector	**2.39**	**2.4**	**2.47**	**2.59**	**2.67**	**2.73**	**2.78**	**2.82**	**2.85**	**2.88**	**2.91**	**2.93**	**2.96**	**2.98**	**3**	**3.02**	**3.03**	**3.04**	**3.06**	**3.27**

APPENDIX K

CO2 emissions from FFC

MMTCO$_2$E	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Residential	1.07	1.09	1.16	1.17	1.23	1.17	1.27	1.13	1.06	1.13	1.22	1.17	1.18	1.29	1.22	1.19	0.99	1.01	0.98	1.04	1.06
Coal	0.01	0.01	0	0.02	0.01	0	0	0	0	0	0	0	-	-	-	-	0	0	-	-	-
Petroleum	0.67	0.7	0.71	0.7	0.75	0.7	0.73	0.64	0.62	0.63	0.69	0.67	0.65	0.7	0.65	0.63	0.49	0.46	0.44	0.49	0.51
Natural Gas	0.39	0.38	0.45	0.46	0.47	0.47	0.54	0.49	0.44	0.5	0.52	0.5	0.52	0.59	0.57	0.57	0.5	0.55	0.54	0.55	0.55

N2O stationary emissions by fuel type

MMTCO2E	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Residential	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	0.002	0.002	0.002	0.002	0.002
Coal	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	0	0	-	-	-
Petroleum	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

CH4 Stationary emissions by fuel type

Residential	0.011	0.011	0.011	0.016	0.015	0.014	0.015	0.011	0.01	0.011	0.011	0.009	0.009	0.009	0.009	0.006	0.006	0.006	0.006	0.006	0.006
Coal	0.001	0.001	0	0.001	0.001	0	0	0	0	0	0	0	-	-	-	-	0	0	-	-	-
Petroleum	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.002	0.002
Natural Gas	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	0.001	0.001	0.001	0.001	0.001	0.001
Wood	0.007	0.008	0.008	0.011	0.011	0.011	0.011	0.009	0.008	0.008	0.008	0.006	0.006	0.006	0.006	0.004	0.003	0.003	0.004	0.004	0.003
Total Residential	**1.08**	**1.11**	**1.17**	**1.19**	**1.24**	**1.19**	**1.29**	**1.15**	**1.08**	**1.15**	**1.23**	**1.18**	**1.19**	**1.3**	**1.23**	**1.2**	**1**	**1.02**	**0.99**	**1.05**	**1.07**

APPENDIX L

CO2 Emissions, MMTCO2E

Sector/Fuel	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Residential	**0.93**	**1.06**	**1.03**	**1.02**	**1.02**	**1.01**	**1.01**	**1.00**	**1.00**	**0.99**	**0.99**	**0.98**	**0.98**	**0.98**	**0.97**	**0.97**	**0.97**	**0.96**	**0.96**	**0.95**
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural Gas	0.48	0.54	0.53	0.54	0.54	0.54	0.54	0.54	0.55	0.55	0.55	0.55	0.55	0.55	0.56	0.56	0.56	0.56	0.56	0.56
Distillate Fuel	0.22	0.26	0.24	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.15
Kerosene	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	0.01	0.01	0.01
LPG	0.21	0.24	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
petroleum	0.45	0.51	0.49	0.49	0.48	0.47	0.47	0.46	0.45	0.45	0.44	0.43	0.43	0.42	0.42	0.41	0.41	0.40	0.40	0.39

N2O Emissions, MMTCO2E

Sector/Fuel	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Residential	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural Gas	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Distillate Fuel	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kerosene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LPG	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	0.001	0.001	0.001	0.001	0.001
Petroleum	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	0.00

CH4 Emissions, MMTCO2E

Sector/Fuel	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Residential	**0.002**	**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**	**0.002**	**0.002**	**0.002**	**0.002**
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural Gas	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	0.001	0.001	0.001	0.001	0.001
Distillate Fuel	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	0.000	0.000	0.000	0.000	0.000	0.000
Kerosene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LPG	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	0.001	0.001	0.001	0.001	0.001
Petroleum	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	0.00
CH4&N2O	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	0.00
Total s	**0.93**	**1.06**	**1.03**	**1.03**	**1.02**	**1.02**	**1.01**	**1.01**	**1.00**	**1.00**	**0.99**	**0.99**	**0.98**	**0.98**	**0.98**	**0.97**	**0.97**	**0.97**	**0.96**	**0.96**

APPENDIX M

MMTCO2E	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Commercial	0.58	0.58	0.55	0.69	0.61	0.57	0.72	0.70	0.60	0.64	0.63	0.68	0.74	0.79	0.79	0.73	0.73	0.68	0.65	0.84	0.83
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	-	-	-
Petroleum	0.32	0.31	0.28	0.31	0.26	0.25	0.35	0.32	0.27	0.29	0.34	0.37	0.33	0.33	0.32	0.27	0.28	0.21	0.16	0.20	0.17
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	0.47	0.49	0.64	0.66
N2O Stationary emissions by Fuel type																					
Commercial	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	0.001	0.001
Coal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	0.000	0.000	-	-	-
Petroleum	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	0.001	0.001	0.001	0.000	0.001	0.000
Natural Gas	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wood	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CH4 Stationary Emissions by fuel type																					
Commercial	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	0.002	0.002	0.002	0.002	0.002	0.002
Coal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-	-	-	-	0.000	0.000	-	-	-
Petroleum	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	0.001	0.001	0.001	0.000	0.001	0.001
Natural Gas	0.000	0.000	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	0.001	0.001	0.001	0.001
Wood	0.001	0.001	0.001	0.002	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
Total Commercial	**0.58**	**0.58**	**0.55**	**0.69**	**0.62**	**0.57**	**0.73**	**0.70**	**0.61**	**0.64**	**0.63**	**0.69**	**0.74**	**0.79**	**0.79**	**0.73**	**0.73**	**0.69**	**0.65**	**0.84**	**0.84**

APPENDIX N

Sector/Fuel	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CO2 Stationary																				
Commercial	**0.80**	**0.85**	**0.87**	**0.90**	**0.91**	**0.91**	**0.91**	**0.92**	**0.92**	**0.93**	**0.93**	**0.94**	**0.94**	**0.94**	**0.95**	**0.95**	**0.96**	**0.97**	**0.97**	**0.98**
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural Gas	0.60	0.66	0.67	0.69	0.70	0.70	0.70	0.71	0.71	0.72	0.72	0.72	0.72	0.73	0.73	0.74	0.74	0.75	0.75	0.76
Distillate Fuel	0.10	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Kerosene	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	0.00
LPG	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Motor Gasoline	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	0.00
Residual Fuel	-	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
Petroleum	0.20	0.19	0.20	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22

N2OStationary	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Commercial	**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**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural Gas	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Distillate Fuel	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kerosene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LPG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Motor Gasoline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Residual Fuel	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Petroleum	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	0.001	0.001	0.001	0.001	0.001
CH4 Stationary																				
Commercial	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**	**0.002**
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Natural Gas	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	0.001	0.001	0.001	0.001	0.001
Distillate Fuel	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Kerosene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LPG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Motor Gasoline	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Residual Fuel	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Petorleum	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	0.001	0.001	0.001	0.001	0.001
CH4&N2O	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	0.003	0.003	0.003	0.003
Total	**0.80**	**0.86**	**0.87**	**0.90**	**0.91**	**0.91**	**0.92**	**0.92**	**0.93**	**0.93**	**0.94**	**0.94**	**0.94**	**0.95**	**0.95**	**0.96**	**0.96**	**0.97**	**0.97**	**0.98**

APPENDIX O

CH4 Emissions (MMTCO2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Enteric Fermentation	0.051	0.051	0.052	0.056	0.051	0.051	0.054	0.048	0.049	0.049	0.047	0.049	0.046	0.041	0.046	0.045	0.043	0.044	0.043	0.042	0.040
Manure Management	0.031	0.034	0.035	0.037	0.035	0.035	0.033	0.033	0.035	0.036	0.034	0.034	0.035	0.033	0.033	0.033	0.030	0.030	0.030	0.030	0.029
Rice Cultivation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Agricultural Residue Burning	0.001	0.002	0.002	0.001	0.002	0.001	0.002	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.002	0.001
Total	**0.084**	**0.086**	**0.089**	**0.095**	**0.087**	**0.088**	**0.089**	**0.083**	**0.085**	**0.086**	**0.083**	**0.084**	**0.082**	**0.075**	**0.081**	**0.079**	**0.074**	**0.076**	**0.075**	**0.073**	**0.071**

N2O Emissions (MMTCO2 Eq.)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Manure Management	0.154	0.158	0.164	0.169	0.171	0.174	0.171	0.170	0.171	0.167	0.164	0.170	0.170	0.182	0.173	0.163	0.160	0.161	0.164	0.164	0.164
Ag Soils	0.232	0.280	0.224	0.207	0.246	0.188	0.255	0.218	0.233	0.188	0.261	0.255	0.185	0.217	0.255	0.182	0.208	0.191	0.193	0.236	0.194
Agricultural Residue Burning	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	0.001	0.001	0.001	0.001	0.001	0.001
Total	**0.387**	**0.439**	**0.389**	**0.376**	**0.418**	**0.363**	**0.426**	**0.388**	**0.405**	**0.356**	**0.427**	**0.426**	**0.356**	**0.399**	**0.430**	**0.346**	**0.369**	**0.353**	**0.359**	**0.402**	**0.359**
TOTAL	**0.609**	**0.661**	**0.603**	**0.607**	**0.613**	**0.575**	**0.658**	**0.590**	**0.613**	**0.554**	**0.626**	**0.632**	**0.551**	**0.569**	**0.602**	**0.520**	**0.553**	**0.588**	**0.583**	**0.627**	**0.532**

Total CO_2e Emissions

Emissions (MMTCO2 Eq.)

Source	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
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	0.04	0.04
Manure Management	0.19	0.19	0.20	0.21	0.21	0.21	0.20	0.20	0.21	0.20	0.20	0.20	0.21	0.21	0.21	0.20	0.19	0.19	0.19	0.19	0.19
Ag Soils	0.37	0.42	0.35	0.34	0.35	0.31	0.40	0.34	0.36	0.30	0.38	0.38	0.30	0.31	0.35	0.28	0.32	0.35	0.34	0.39	0.30
Agricultural Residue Burning	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	0.00	0.00
TOTAL	**0.609**	**0.661**	**0.603**	**0.607**	**0.613**	**0.575**	**0.658**	**0.590**	**0.613**	**0.554**	**0.626**	**0.632**	**0.551**	**0.569**	**0.602**	**0.520**	**0.553**	**0.588**	**0.583**	**0.627**	**0.532**

APPENDIX P

CO$_2$e (MmtCO2e)	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Agriculture																				
Enteric Fermentation	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Manure Management	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.24	0.24	0.24	0.24	0.24	0.24
Agricultural Soil Management	0.32	0.32	0.32	0.31	0.31	0.31	0.31	0.30	0.30	0.30	0.30	0.30	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28
Burning of Agricultural Crop Waste	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Total Agricultural Emissions	**0.58**	**0.58**	**0.58**	**0.58**	**0.58**	**0.58**	**0.58**	**0.58**	**0.58**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**	**0.57**

APPENDIX Q

Waste Water Emissions

Emissions (MMTCO2E)	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Municipal CH4	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Municipal N2O	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	0.03	0.03
Human sewage	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	0.03	0.03
Industrial CH4	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	0.00	0.00
Total Emissions	**0.08**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.09**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**	**0.11**

APPENDIX R

Municipal wastewater treatment Emission

Sources	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
municipal	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08
Human sewage	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	0.03	0.03	0.03	0.03	0.03	0.04
	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11
Industrial wastewater treatment																					
Industrial	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	0.00	0.00
Total	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11

APPENDIX S

Total Emissions from Landfills and Waste Combustion (MMTCO$_2$E)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
CH$_4$	0.51	0.53	0.54	0.54	0.55	0.56	0.56	0.56	0.37	0.35	0.38	0.39	0.43	0.33	0.03	0.08	0.14	0.04	0.06	0.07	0.03
CO$_2$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N$_2$O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**0.51**	**0.53**	**0.54**	**0.54**	**0.55**	**0.56**	**0.56**	**0.56**	**0.37**	**0.35**	**0.38**	**0.39**	**0.43**	**0.33**	**0.03**	**0.08**	**0.14**	**0.04**	**0.06**	**0.07**	**0.03**

CH$_4$ Emissions from Landfills (MTCO$_2$E)

Potential CH$_4$	**571,859**	**590,917**	**601,107**	**604,248**	**613,919**	**621,499**	**623,496**	**623,533**	**628,868**	**633,056**	**646,994**	**663,227**	**679,497**	**695,692**	**715,169**	**738,428**	**762,397**	**786,974**	**808,451**	**824,508**	**835,702**
MSW Generation	534,448	552,259	561,782	564,718	573,756	580,840	582,707	582,741	587,727	591,642	604,667	619,838	635,044	650,180	668,382	690,120	712,521	735,490	755,562	770,568	781,030
Industrial Generation	37,411	38,658	39,325	39,530	40,163	40,659	40,789	40,792	41,141	41,415	42,327	43,389	44,453	45,513	46,787	48,308	49,876	51,484	52,889	53,940	54,672
CH$_4$ Avoided	-	-	-	-	-	-	-	**(6,668)**	**(222,323)**	**(241,602)**	**(223,599)**	**(225,009)**	**(205,501)**	**(326,911)**	**(680,589)**	**(648,965)**	**(611,987)**	**(741,856)**	**(738,923)**	**(744,962)**	**(797,237)**
Flare	-	-	-	-	-	-	-	(2,115)	(75,498)	(70,945)	(82,776)	(82,890)	(76,222)	(140,252)	(297,916)	(206,682)	(201,729)	(96,549)	(91,368)	(154,368)	(175,172)
Landfill Gas-to-Energy	-	-	-	-	-	-	-	(4,553)	(146,824)	(170,657)	(140,823)	(142,119)	(129,279)	(186,660)	(382,673)	(442,283)	(410,259)	(645,307)	(647,555)	(590,593)	(622,065)
Oxidation at MSW Landfills	**53,445**	**55,226**	**56,178**	**56,472**	**57,376**	**58,084**	**58,271**	**57,607**	**36,540**	**35,004**	**38,107**	**39,483**	**42,954**	**32,327**	**(1,221)**	**4,116**	**10,053**	**(637)**	**1,664**	**2,561**	**(1,621)**
Oxidation at Industrial Landfills	**3,741**	**3,866**	**3,932**	**3,953**	**4,016**	**4,066**	**4,079**	**4,079**	**4,114**	**4,141**	**4,233**	**4,339**	**4,445**	**4,551**	**4,679**	**4,831**	**4,988**	**5,148**	**5,289**	**5,394**	**5,467**
Total CH$_4$ Emissions	**514,673**	**531,825**	**540,996**	**543,823**	**552,527**	**559,349**	**561,146**	**555,179**	**365,891**	**352,309**	**381,055**	**394,396**	**426,597**	**331,903**	**31,122**	**80,517**	**135,369**	**40,606**	**62,576**	**71,592**	**34,618**

APPENDIX T

Total Emissions from Landfills and Waste Combustion (MMTCO2E)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
CH4	(0.32)	(0.34)	(0.36)	(0.38)	(0.39)	(0.41)	(0.43)	(0.45)	(0.47)	(0.49)	(0.51)	(0.53)	(0.55)	(0.57)	(0.59)	(0.61)	(0.63)	(0.65)	(0.67)	(0.69)
CO2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**(0.32)**	**(0.34)**	**(0.36)**	**(0.38)**	**(0.39)**	**(0.41)**	**(0.43)**	**(0.45)**	**(0.47)**	**(0.49)**	**(0.51)**	**(0.53)**	**(0.55)**	**(0.57)**	**(0.59)**	**(0.61)**	**(0.63)**	**(0.65)**	**(0.67)**	**(0.69)**

CH4 Emissions from Landfills (MTCO2E)

	2,011	2,012	2,013	2,014	2,015	2,016	2,017	2,018	2,019	2,020	2,021	2,022	2,023	2,024	2,025	2,026	2,027	2,028	2,029	2,030
Potential CH4	**594,895**	**627,573**	**660,359**	**693,251**	**726,243**	**759,332**	**792,514**	**825,785**	**859,143**	**892,582**	**926,101**	**959,696**	**993,364**	**1,027,103**	**1,060,909**	**1,094,779**	**1,128,713**	**1,162,706**	**1,196,756**	**1,230,862**
MSW Generation	555,977	586,517	617,158	647,898	678,732	709,656	740,667	771,762	802,937	834,189	865,515	896,912	928,378	959,909	991,503	1,023,158	1,054,872	1,086,641	1,118,464	1,150,338
Industrial Generation	38,918	41,056	43,201	45,353	47,511	49,676	51,847	54,023	56,206	58,393	60,586	62,784	64,986	67,194	69,405	71,621	73,841	76,065	78,292	80,524
CH4 Recovered	**(948,947)**	**(1,002,407)**	**(1,056,106)**	**(1,110,034)**	**(1,164,183)**	**(1,218,544)**	**(1,273,109)**	**(1,327,869)**	**(1,382,818)**	**(1,437,946)**	**(1,493,249)**	**(1,548,718)**	**(1,604,347)**	**(1,660,130)**	**(1,716,061)**	**(1,772,134)**	**(1,828,344)**	**(1,884,685)**	**(1,941,151)**	**(1,997,739)**
Flare	(128,773)	(136,028)	(143,315)	(150,633)	(157,981)	(165,358)	(172,763)	(180,194)	(187,650)	(195,131)	(202,636)	(210,163)	(217,712)	(225,282)	(232,872)	(240,481)	(248,109)	(255,754)	(263,417)	(271,096)
Landfill Gas-to-Energy	(820,173)	(866,379)	(912,791)	(959,401)	(1,006,202)	(1,053,186)	(1,100,346)	(1,147,676)	(1,195,167)	(1,242,815)	(1,290,613)	(1,338,555)	(1,386,635)	(1,434,848)	(1,483,189)	(1,531,653)	(1,580,235)	(1,628,930)	(1,677,734)	(1,726,643)
Oxidation at MSW Landfills	**(39,297)**	**(41,589)**	**(43,895)**	**(46,214)**	**(48,545)**	**(50,889)**	**(53,244)**	**(55,611)**	**(57,988)**	**(60,376)**	**(62,773)**	**(65,181)**	**(67,597)**	**(70,022)**	**(72,456)**	**(74,898)**	**(77,347)**	**(79,804)**	**(82,269)**	**(84,740)**
Oxidation at Industrial Landfills	**3,892**	**4,106**	**4,320**	**4,535**	**4,751**	**4,968**	**5,185**	**5,402**	**5,621**	**5,839**	**6,059**	**6,278**	**6,499**	**6,719**	**6,941**	**7,162**	**7,384**	**7,606**	**7,829**	**8,052**
Total CH4 Emissions	**(318,646)**	**(337,351)**	**(356,172)**	**(375,105)**	**(394,146)**	**(413,291)**	**(432,535)**	**(451,876)**	**(471,307)**	**(490,828)**	**(510,433)**	**(530,120)**	**(549,885)**	**(569,725)**	**(589,637)**	**(609,619)**	**(629,668)**	**(649,781)**	**(669,955)**	**(690,189)**

Emissions (MMTCO2E)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Forest Carbon Flux	**0.55**	**0.55**	**0.55**	**0.45**	**0.45**	**0.45**	**0.45**	**0.45**	**0.45**	**(0.41)**	**(0.83)**	**(0.83)**	**(0.83)**	**(0.83)**	**(0.83)**	**(0.83)**	**(0.83)**	**(0.75)**	**(0.75)**	**(0.75)**	**(0.75)**
Aboveground Biomass	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.48)	(0.68)	(0.68)	(0.68)	(0.68)	(0.68)	(0.68)	(0.68)	(0.67)	(0.67)	(0.67)	(0.67)
Belowground Biomass	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.09)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
Dead Wood	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	(0.07)	(0.16)	(0.16)	(0.16)	(0.16)	(0.16)	(0.16)	(0.16)	(0.09)	(0.09)	(0.09)	(0.09)
Litter	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.05	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Soil Organic Carbon	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.28	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
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)	(0.09)	(0.09)
Liming of Agricultural Soils	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Limestone	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dolomite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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**	**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)**	**(0.37)**	**(0.38)**
Landfilled Yard Trimmings and Food Scraps	**(0.03)**	**(0.03)**	**(0.03)**	**(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**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Grass	(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	0.00	0.00
Leaves	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Branches	(0.01)	(0.01)	(0.01)	(0.01)	(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
Landfilled Food Scraps	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.01)**	**(0.01)**	**(0.01)**	**(0.01)**	**(0.01)**	**(0.01)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**	**(0.00)**
Forest Fires	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CH4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N2O 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	0.01	0.01
Total Forestry	**0.31**	**0.31**	**0.30**	**0.20**	**0.20**	**0.20**	**0.20**	**0.19**	**0.18**	**(0.68)**	**(1.12)**	**(1.13)**	**(1.14)**	**(1.14)**	**(1.15)**	**(1.16)**	**(1.17)**	**(1.09)**	**(1.10)**	**(1.11)**	**(1.12)**