Delaware's 2017 Greenhouse Gas Emissions Inventory

Prepared by:

Division of Air Quality

June 2020

Quick Summary

Economic Sector	2017 GHG Emissions[a]	Projection to 2030 (future)	Projection to 2050 (future)
Overall GHG Emissions	• Decrease by 0.80 $MmtCO_2e$ (5.1%) from 2016 GHG emissions	• Increase by 0.32 $MmtCO_2e$ (2.1%) from 2017 GHG emissions	• Increase by 1.39 $MmtCO_2e$ (9.3%) from 2017 GHG emissions
Electric Power	• Decrease of 0.64 $MmtCO_2e$ (17.8%) from 2016 GHG emissions • Third largest source of GHG emissions in DE	• Decrease by 0.16 $MmtCO_2e$ (5.4%) from 2017 GHG emissions • Third largest source of GHG emissions in DE	• Decrease by 0.21 $MmtCO_2e$ (7.0%) from 2017 GHG emissions • Third largest source of GHG emissions in DE
Transportation[b]	• Minor increase by 0.04 $MmtCO_2e$ (0.9%) from 2016 GHG emissions • Largest source of GHG emissions in DE	• Decrease by 0.44 $MmtCO_2e$ (9.1%) from 2016 GHG emissions • Largest source of GHG emissions in DE	• Decrease by 0.64 $MmtCO_2e$ (13.0%) from 2017 GHG emissions • Second largest source of GHG emissions in DE
Industrial	• Decrease by 0.26 $MmtCO_2e$ (6.1%) from 2016 GHG emissions • Second largest source of GHG emissions in DE	• Increase by 0.24 $MmtCO_2e$ (6.1%) from 2017 GHG emissions • Second largest source of GHG emissions in DE	• Increase by 1.27 $MmtCO_2e$ (32.0%) from 2017 GHG emissions • Largest source of GHG emissions in DE
Residential	• Minor decrease by 0.03 $MmtCO_2e$ (2.9%) from 2016 GHG emissions	• Increase by 0.34 $MmtCO_2e$ (36.8%) from 2017 GHG emissions • Large increase in HFC emissions	• Increase by 0.40 $MmtCO_2e$ (44.1%) from 2017 GHG emissions • HFC emissions continue to be significant
Commercial	• Negligible decrease by <0.01 $MmtCO_2e$ (0.3%) from 2016 GHG emissions	• Increase by 0.40 $MmtCO_2e$ (35.5%) from 2017 GHG emissions • Large increase in HFC emissions	• Increase by 0.57 $MmtCO_2e$ (50.3%) from 2017 GHG emissions • HFC emissions continue to be significant

Economic Sector	2017 GHG Emissions[a]	Projection to 2030 (future)	Projection to 2050 (future)
Agricultural	• Minor increase by 0.04 MmtCO_2e (7.4%) from 2014 GHG emissions	• Negligible increase by <0.01 MmtCO_2e (0.8%) from 2017 GHG emissions	• Minor increase by 0.01 MmtCO_2e (1.9%) from 2017 GHG emissions
Waste Management	• Minor increase by 0.04 MmtCO_2e (9.1%) from 2016 GHG emissions	• Decrease by 0.06 MmtCO_2e (12.5%) from 2017 GHG emissions	• Minor decrease by 0.03 MmtCO_2e (5.8%) from 2017 GHG emissions

[a] Gross GHG emissions; land-use, land-use change, forestry not included

[b] Projections do not consider Safer Affordable Fuel Economy Rule standards (85 FR 24174-25278)

INTRODUCTION

This emissions 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 2017 Greenhouse Gas (GHG) emissions inventory and account for GHG emissions and sinks[1] in the State of Delaware. The inventory includes Delaware GHG emissions from 1990 to 2017 as well as emission projections from 2018 to 2050 in business as usual (BAU) scenarios. In addition to the emissions data, this report provides information on emission sources and activities, as well as inventory methods.

Delaware's anthropogenic[2] GHG emissions were estimated 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).

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 2017 with projections from 2018 to 2050, emissions estimations were performed by using the U.S. EPA's State Inventory Tool (SIT) and projection tool (PT). The SIT and PT consist 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 that quantify emissions or removal per unit activity)[4] that are based on economic activities[5] in Delaware. Where applicable, Delaware specific data have been used to supplement the standard default data provided by the top-down approach of the EPA SIT sector modules. Projection of GHG emissions are estimated by utilizing the U.S. Energy Information Administration (EIA) Annual Energy Outlook (AEO) 2019[6] data as well as other economic data that are used to predict GHG emissions.

UPDATES FROM THE 2016 GHG INVENTORY REPORT

The U.S. EPA SIT and PT have now been updated to project GHG emissions through 2050 to consider the long-term trends of GHG emissions. All figures have been updated to provide such

[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
[6] Annual Energy Outlook 2019, U.S. Energy Information Administration; note: AEO 2019 data were used for energy-related projections in the EPA SIT and PT

trends throughout this report. The Quick Summary section compares the 2017 base year emissions to 2030 and 2050 GHG emission projections. This provides a quick insight to the base year comparison to a mid-term and long-term projection period.

The use of hydrofluorocarbons (HFC) in refrigeration, air-conditioning, and other applications has been rapidly increasing. HFCs are high-GWP GHGs that can have potent climate related effects in the atmosphere. In collaboration with the California Air Resources Board (CARB), the U.S. Climate Alliance (USCA) developed an emissions inventory tool for estimating HFC emissions at the state level. CARB estimated HFC emissions in California under a no policy, BAU scenario to determine end-use HFC emission estimates per person, per household, or per vehicle. The 2016 DE GHG inventory[7] report provides more detail on the HFC inventory tool and how it was used in that GHG inventory. The 2017 DE GHG inventory will use a hybrid approach to estimate HFC emissions by sector. The U.S. EPA SIT and PT provide estimates and projections for HFCs as ozone-depleting substances (ODS). This GHG inventory will use the estimates and projections of HFCs, but will apportion the emissions by sector using percentages calculated from the USCA/CARB HFC inventory tool. The USCA/CARB HFC inventory tool provides emissions projections through 2030. For projections for years 2031-2050, the sectoral breakdown percentages from 2030 have been held constant. HFC emissions are estimated and projected for the residential, commercial, industrial, and transportation sectors.

The agriculture sector has been updated to include Delaware specific data on liming of soils obtained from the Department of Agriculture, which included annual tonnage of liming materials from 2012 through 2019. The agriculture module of the SIT provides standard factors and ratios to estimate the amount of liming materials applied to soils. An emission factor is then used to estimate emissions based on the amount of liming materials applied to soils. The addition of these data no significant increase or decrease in agricultural GHG emissions. Projected GHG emissions associated with liming of soils were held constant from 2017 values.

Sources of GHG Emissions and Trends

The 2017 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.

[7] Delaware's 2016 Greenhouse Gas Inventory (2019); available: http://www.dnrec.delaware.gov/Air/Documents/2016-de-ghg-inventory.pdf

In 2017, Delaware's gross[8] total GHG emissions were equivalent to 14.97 $MmtCO_2e$, which represents approximately 0.2% of national gross GHG emissions (U.S. total was 6,457 $MmtCO_2e$ in 2017)[9]. Figure 1 shows the historical gross GHG emissions in Delaware from 1990 to 2017. Overall, gross GHG emissions have been trending downwards since 1990, and a decrease of roughly 0.78 $MmtCO_2e$ can be observed from 2016 to 2017. Gross GHG emissions in 2016 show a reduction of 23.8% relative to gross GHG emissions in 1990.

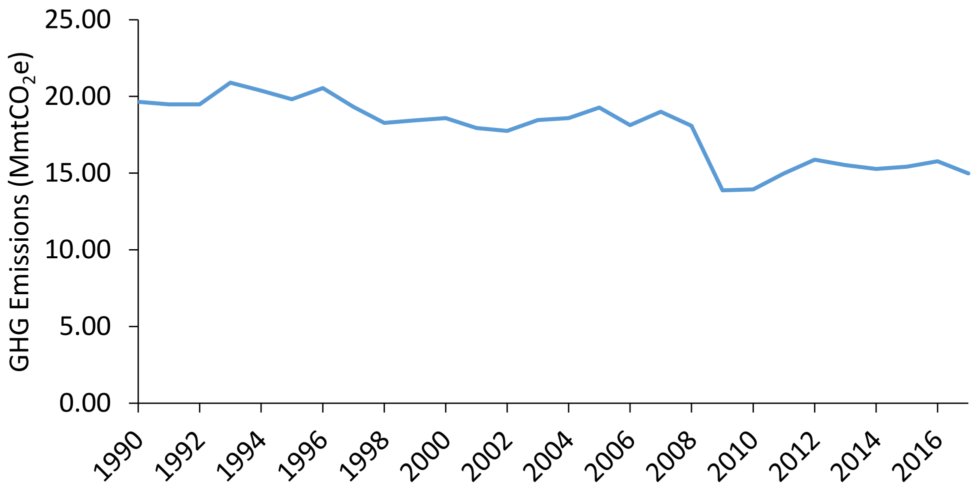

Figure 1. Gross GHG emissions from 1990 to 2016 in Delaware relative to the USCA GHG reduction target

Figure 2 presents a breakdown of GHG emissions (in $MmtCO_2e$) in 2017 by Delaware's economic sectors. The largest source of GHG emissions in 2017 was the transportation sector, which represented 33% of the gross GHG emissions. This was followed by the industrial sector with approximately 26%. The electric power sector was the third largest emitter of GHG emissions in 2017 representing approximately 20% of gross emissions, while all other sectors including residential, commercial, agriculture and waste management each represented approximately 6%, 8%, 4% and 2%, respectively.

[8] Gross GHG emissions accounts for only positive emissions and excluded metric tons of CO_2e removed from the atmosphere (sink)
[9] U.S. EPA: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 -2017

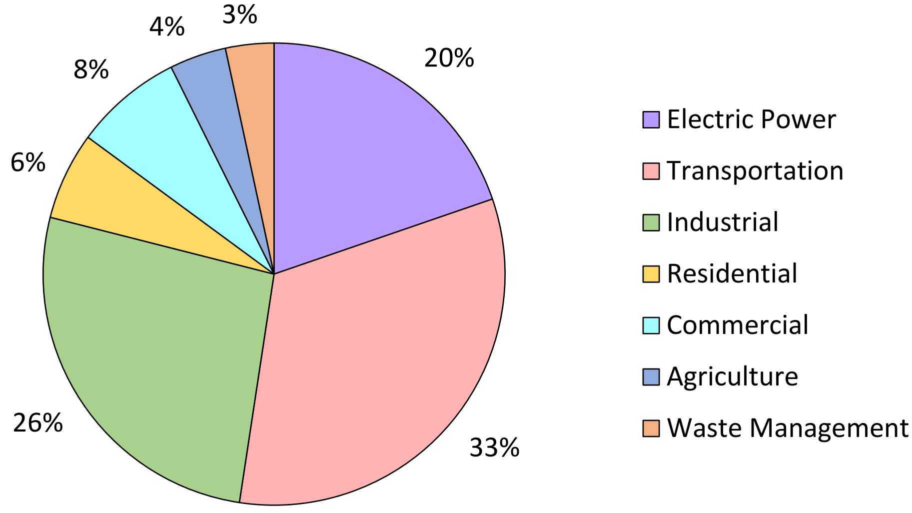

Figure 2. Breakdown of gross GHG emissions in Delaware by sector in 2017

Figure 3 presents the trends of gross GHG emissions by economic sector. As can be seen, the electric power, transportation, and industrial sectors have consistently generated the majority of gross GHG emissions in Delaware. In this report, the collection of these three sectors is known as the *Big Three* because their combined GHG emissions have represented at least 75% of Delaware's GHG emissions since 1990. The transportation sector has been the greatest source of GHG emissions in Delaware since 2013. HFC emissions have been parsed out to relevant sectors, as described in the Updates section of this report. The industrial sector has been the second highest source of GHG emissions in Delaware since 2013. The electric power had generally been the greatest source of GHG emissions in Delaware from 1990 to 2008 but has been the third greatest source since 2013. All other sectors have gone through minor fluctuations in emissions. The residential and commercial sectors continue to trend upwards with the increasing amount of HFC emissions in each sector.

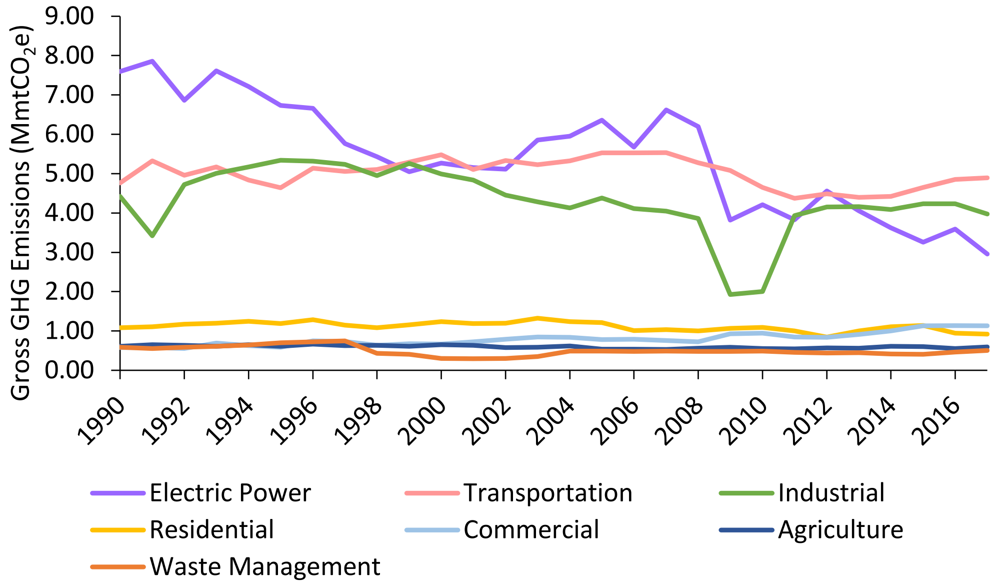

Figure 3. Gross GHG emissions in Delaware by economic sector from 1990 to 2017

As the analysis indicates, the driving force for GHG emissions is largely energy consumption in all economic sectors.[10] Energy related activities – specifically fossil fuel combustion – were the largest source of GHG emissions in 2017 as they represented 88% of gross GHG emissions in Delaware. Downward emission trends are observed since overall fuel consumption in Delaware has declined in 2017 relative to 1990. In addition, the electric power generation fuel mix shifted more towards natural gas and away from coal; as such, gross GHG emissions decreased.

Net GHG emissions are calculated by including the LULUCF sector to the total emissions. The LULUCF sector acts as a sink for CO_2 emissions; i.e. it estimates the removal of CO_2 emissions from the atmosphere by the land sector. In this analysis, the LULUCF sector is actually a source of emissions between 1990 and 1998 (excluding 1997), as shown in Figure 4. Further assessment of the LULUCF sector and associated uncertainty is provided later in this report.

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

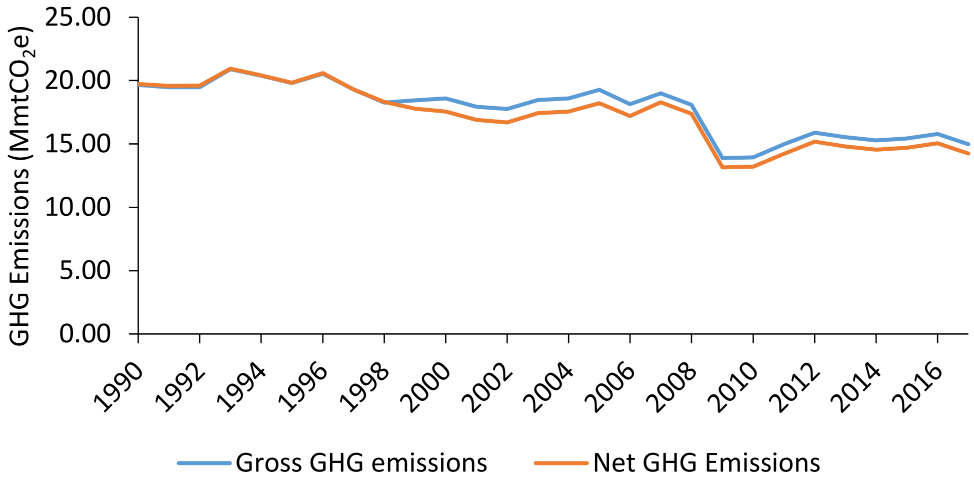

Figure 4. Comparison of gross and net GHG emissions in Delaware from 1990 to 2017

Reference Case GHG Emissions projections

The overall decline in historical GHG emissions is not projected to continue over time. Projection analysis shows that gross GHG emissions from Delaware are expected to increase slightly and flat-line over time. Figure 5 presents the gross GHG emissions that are projected in Delaware from 2018 to 2050. It can be seen that the GHG emission projections are generally flat, with an increase through 2050. Total gross GHG emissions are projected to increase from 2017 by 2.1% in 2030 (15.29 $MmtCO_2e$) and by 9.3% in 2050 (16.36 $MmtCO_2e$). While total gross GHG emissions and projections are shown in Figure 5, emissions and projections are broken out by sector in the following sections.

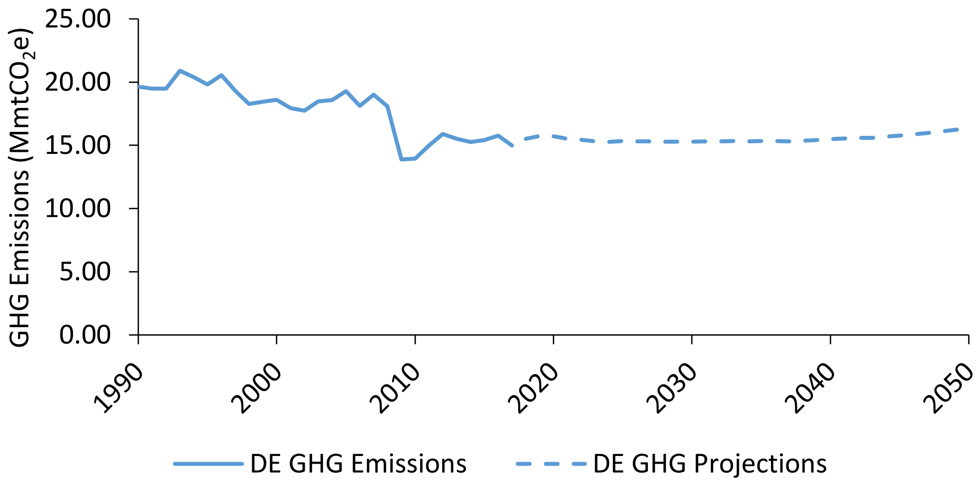

Figure 5. Delaware gross GHG emissions and projections from 1990 to 2050

The breakdown of gross GHG emissions (in $MmtCO_2e$) in Delaware in 2030, shown in Figure 6, displays some shifts in relative sectoral contribution. The *Big Three* continue to contribute a high majority of all GHG emissions at 75%. The transportation sector remains as the largest source of GHG emissions; however, its overall share of gross GHG emissions has decreased. The industrial sector is the second largest source and saw an increase in relative percentage of the total GHG emissions in 2030. The electric power sector has declined in its portion Delaware's gross GHG emissions in 2030 to 21%. The contribution of GHG emissions from the residential and commercial sectors each increased by 2% from 2017. The increasing amount of HFC emissions in these sectors is a main component to the overall GHG emissions observed. The agriculture and waste management sectors did not change in their relative contribution to total GHG emissions in 2030.

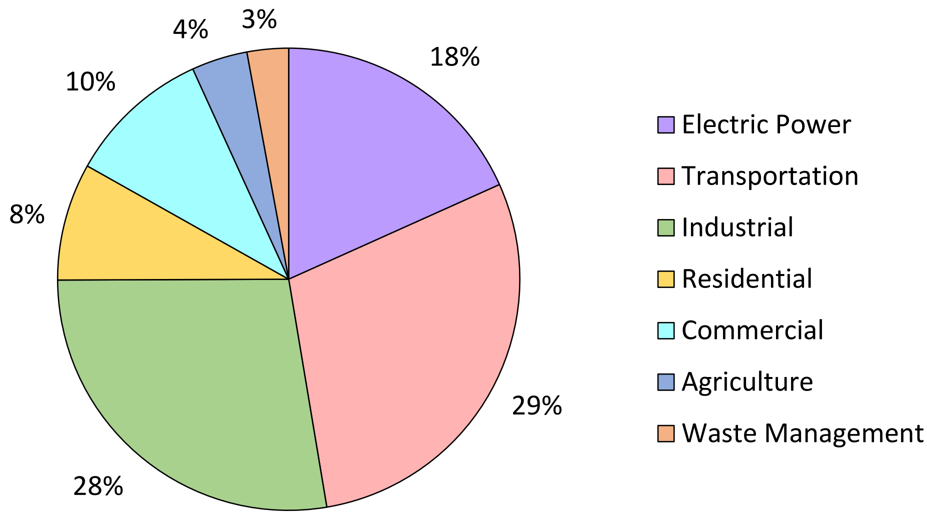

Figure 6. Breakdown of gross GHG emissions in Delaware by sector in 2030

Figure 7 shows the breakdown of gross GHG emissions (in $MmtCO_2e$) in Delaware in 2050. It can be seen that a shift in the top contributor of GHG emissions in Delaware has occurred from the transportation sector (26%) to the industrial sector (32%). A preliminary assessment would suggest that improvements in fuel economy would account for the projected lower overall GHG emissions in the transportation sector[11]. The electric power sector saw a decline in relative contribution to total GHG emissions in 2050. However, the industrial, transportation, and electric power sectors remain as the *Big Three* sectors in 2050. The remaining economic sectors

[11] As stated in the Quick Summary section, the GHG projections do not account for the changes in fuel economy standards as promulgated in the Safer Affordable Fuel Economy Rule in April 2020.

each held constant in their relative contributions (as compared to 2030) to the total gross GHG emissions in Delaware in 2050.

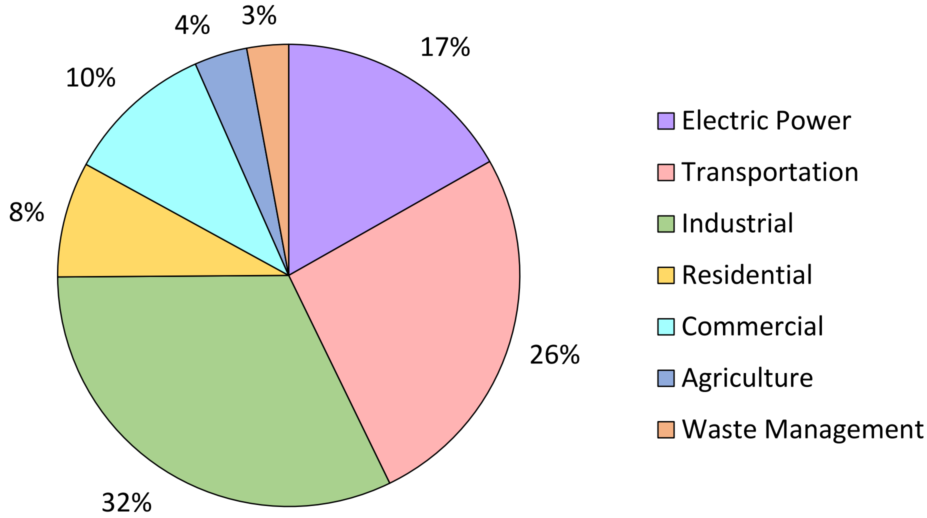

Figure 7. Breakdown of gross GHG emissions in Delaware by sector in 2050

Figure 8 presents the GHG emissions and projections by sector from 1990 to 2050. As expected, the *Big Three* sectors make up the majority of GHG emissions over the projection period. Notably, there is a decline in GHG emissions in projected for the transportation sector, and it is no longer the largest source of GHG emissions after 2033. The estimated projected fuel use in the transportation from the U.S. EIA AEO 2019 shows a decline caused by increases in fuel economy standards[12]. It may be expected that GHG emission projections for the transportation sector could be higher with the federal proposal of a fuel economy freeze[13].

[12] Annual Energy Outlook 2019, U.S. Energy Information Administration; note: AEO 2019 data were used for energy-related projections in the EPA SIT and PT

[13] The Safer Affordable Fuel Efficient (SAFE) Vehicles Proposed Rule for Model Years 2021-2026, U.S. Environmental Protection Agency

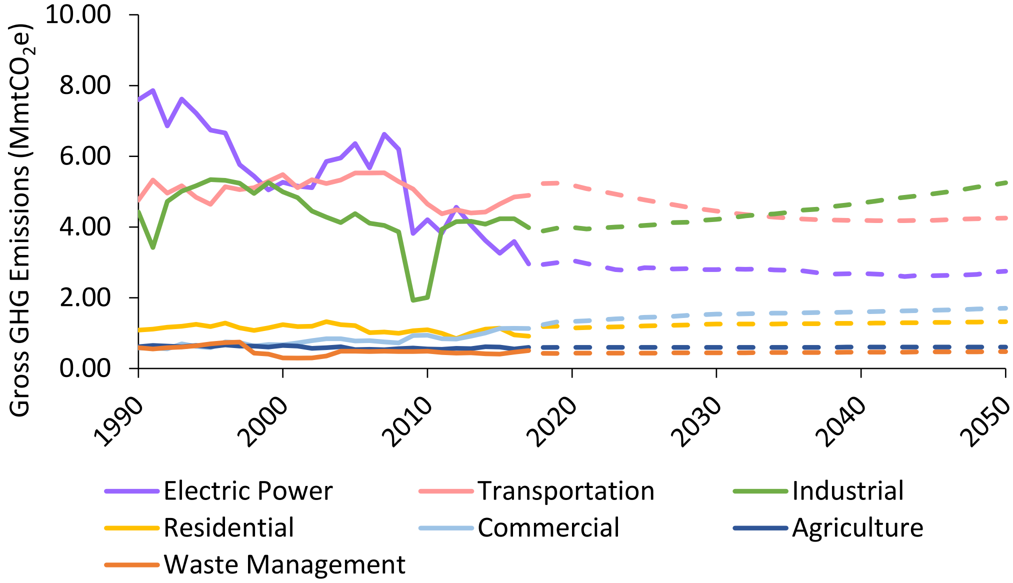

Figure 8. Gross GHG emissions and projections in Delaware by economic sector from 1990 to 2050

The industrial sector is projected to overtake the transportation sector as the largest source of GHG emissions from 2033 to 2050. As shown in Figure 8, steady increases in GHG emissions are projected in the industrial sector from 2017 through 2050. Each other sector, including the electric power sector, is projected to have to remain relatively constant as compared to 2017 levels of GHG emissions in Delaware. The residential and commercial sectors see a fair increase in projected emissions, which, again, is most likely as a result of increased HFC emissions.

GHG Emissions Trends by Economic Sectors

The 2017 GHG emisssions inventory characterized GHG emissions into eight economic sectors of Delaware. A summary table of GHG emission estimates and projections is provided as Table 1. The emssion trends and analytical findings of those sectors are summarized below.

Table 1. Summary table of GHG emission estimates and projections

	1990	2000	2017	2030	2050
Electric Power	**7.60**	**5.27**	**2.95**	**2.81**	**2.75**
CO_2 from FFC	7.49	5.20	2.94	2.80	2.74
N_2O from FFC	0.03	0.02	0.00	0.00	0.00
CH_4 from FFC	<0.01	<0.01	<0.01	<0.01	<0.01
SF_6 from T&D	0.08	0.05	0.01	0.01	0.01
Transportation	**4.76**	**5.48**	**4.89**	**4.40**	**4.25**
CO_2 from FFC	4.53	5.08	4.70	4.24	4.09
N_2O from FFC	0.20	0.24	0.05	0.06	0.06
CH_4 from FFC	0.03	0.02	0.01	0.01	0.01

	1990	2000	2017	2030	2050
HFCs	<0.01	0.14	0.13	0.09	0.09
Industrial	**4.42**	**4.99**	**3.98**	**4.26**	**5.25**
CO_2 from FFC	4.04	4.58	3.68	3.91	4.86
N_2O from FFC	0.01	0.01	0.01	0.01	0.01
CH_4 from FFC	<0.01	<0.01	<0.01	<0.01	<0.01
CO_2 from IP	0.20	0.16	0.01	0.01	0.01
CH_4 from IP	0.17	0.21	0.22	0.23	0.27
HFC/PFCs	0.00	0.03	0.05	0.10	0.10
Residential	**1.08**	**1.24**	**0.92**	**1.26**	**1.32**
CO_2 from FFC	1.07	1.22	0.83	0.92	0.99
N_2O from FFC	<0.01	<0.01	<0.01	<0.01	<0.01
CH_4 from FFC	0.01	0.01	0.01	<0.01	<0.01
HFCs	<0.01	0.01	0.08	0.33	0.33
Commercial	**0.58**	**0.67**	**1.13**	**1.54**	**1.70**
CO_2 from FFC	0.58	0.63	0.95	1.04	1.20
N_2O from FFC	<0.01	<0.01	<0.01	<0.01	<0.01
CH_4 from FFC	<0.01	<0.01	<0.01	<0.01	<0.01
HFCs	<0.01	0.04	0.18	0.50	0.50
Agricultural	**0.61**	**0.65**	**0.59**	**0.60**	**0.61**
Enteric Fermentation	0.06	0.06	0.04	0.04	0.04
Manure Management	0.19	0.19	0.19	0.22	0.25
Ag Soils	0.36	0.40	0.36	0.33	0.31
Ag Residue Burning	<0.01	<0.01	<0.01	<0.01	<0.01
Liming and Urea	<0.01	<0.01	0.01	0.01	0.01
Waste Management	**0.59**	**0.30**	**0.51**	**0.44**	**0.48**
Wastewater Treatment	0.11	0.14	0.19	0.22	0.27
Landfill Activities	0.33	0.17	0.31	0.22	0.21
Waste Incineration	0.15	N/A	N/A	N/A	N/A
Land Use/Forestry	**0.09**	**-1.04**	**-0.73**	**-0.73**	**-0.73**
Gross GHG Emissions	**19.64**	**18.60**	**14.97**	**15.29**	**16.36**
Net GHG Emissions	**19.73***	**17.56**	**14.25**	**14.57**	**15.64**
Electricity Consumption	8.10	11.03	4.70	5.27	6.13

*Net GHG emissions are greater than gross because the LULUCF sector was estimated to have positive emissions in 1990

Electric Power Sector

The emission of GHGs in the electric power sector was driven primarily by the combustion of fossil fuels such as coal, natural gas, and petroleum products to generate electricity. Figure 9 shows that emissions decreased significantly from 7.60 MmtCO_2e in 1990 to 2.95 MmtCO_2e in 2017, a decrease of approximately 61.2%. Figure 9 also shows the contribution towards the total emissions by each fuel consumed for electricity generation as well as SF_6 emissions associated with transmission and distribution (T&D). Fuel shifting away from coal to natural gas as a combustion fuel for electricity generation is a large contributor to the decrease in GHG emissions from the electric power sector that is observed. In addition, there have been no significant increases in electricity demand in Delaware, and demand has been trending downwards slightly since 2003[14]. 2017 GHG emissions in the electric power sector have decreased by about 5% from 2016 levels, likely caused by a decline in in-state electric power generation[15]. Projected emissions in the electric power sector in Delaware have generally flat-lined at 2017 GHG emissions levels. This trend is similar to that projected in the 2017 load forecast by PJM, which shows minor increases in load for the DPL zone[16].

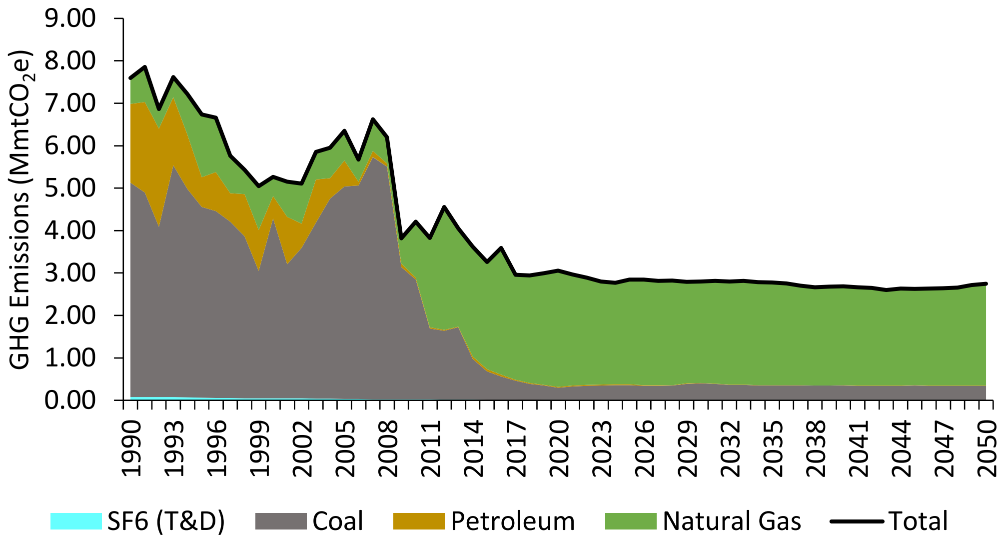

Figure 9. Gross GHG emissions and projections in the electric power sector, including contribution by fuel combustion/transmission and distribution (T&D)

Transportation Sector

GHG emissions in the transportation sector are overwhelmingly sourced from the combustion of fossil fuels, particularly the combustion of petroleum products. A minor amount of GHG emissions are sourced from alternate fuel vehicles, which use natural gas as a fuel. Fossil fuel combustion is the source of at least 97% of all GHGs in the transportation sector for on-road and non-road vehicles. HFC emissions from motor vehicle air conditioning systems make up the balance for the total GHG emissions each year. In 2017, GHG emissions in transportation sector increased from 2016 and remain at their highest value since 2009. Emissions are projected to increase in 2018, then decrease from 2019 to 2042, and will flat-line with a minimal increase

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[14] Detailed State Data, "Retail Sales of Electricity by State by Sector by Provider (EIA-86), U.S. Energy Information Administration

[15] In-state electric power generation decreased by about 16% in 2017 relative to 2016 per the U.S. Energy Information Administration

[16] PJM Load Forecast Report January 2017; DPL zone also includes parts of Maryland and Virginia.

from 2043-2050. As previously explained, the decrease in emissions is projected from fuel consumption estimates modeled with increasing fuel economy standards.

Figure 10 shows the annual GHG emissions and projections of the transportation sector, as well as contribution by fossil fuel type (HFC emissions also shown but are not a combustion fuel). GHG emissions from the transportation sector were relatively constant between 1990 and 2007, but saw a decrease from 2008 to 2011, which could be attributed to the economic recession and rising gas prices[17]. GHG emissions in the transportation sector include CO_2, N_2O, CH_4, and HFCs. CO_2 is a combustion byproduct that makes up the majority (≥92% each year) of emissions in the transportation sector. Further, CO_2 emissions from only gasoline and diesel combustion make-up at least 83% of all transportation sector GHG emissions in a given year. N_2O and CH_4 are also formed during the combustion of fossil fuels, while N_2O may also be generated during catalytic after-treatment of exhaust gases[18]. As stated above, HFC emissions are sourced from air-conditioning systems in motor vehicles. Emissions associated with jet fuel provided a considerable amount of GHG emissions through 1994; however, the total jet fuel emissions included naphtha-type jet fuel until 1994.

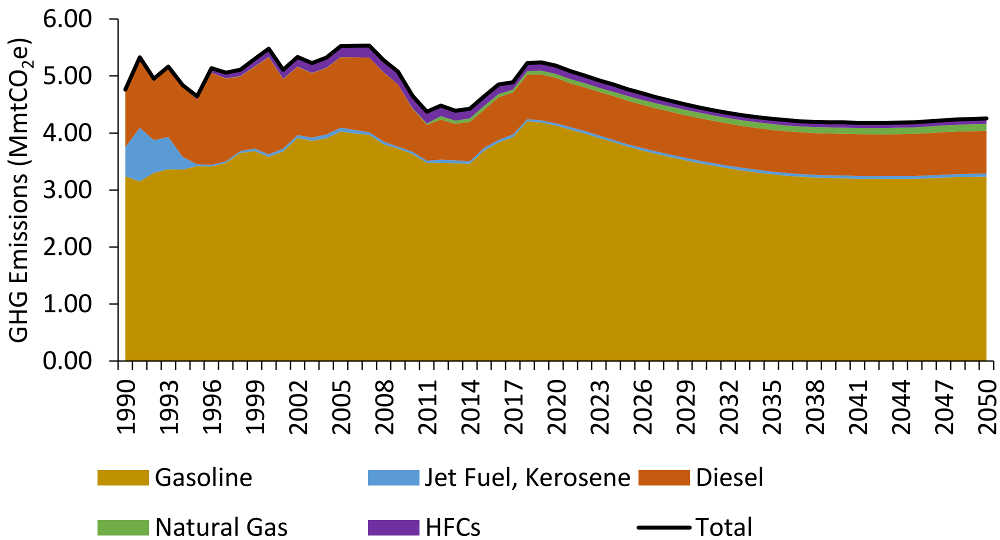

Figure 10. Gross GHG emissions and projections for the transportation sector, including contributions per fossil fuel combusted and total HFC emissions from motor vehicle air conditioning units

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[17] EIA State Energy Data System (SEDS) 1960-2016

[18] User's Guide for Estimating Methane and Nitrous Oxide emissions from Mobile Combustion Using the State Inventory Tool, U.S. Environmental Protection Agency

Industrial Sector

The industrial sector was the second largest source of GHG emissions in Delaware in 2017, contributing to 26% of the state total. Industrial sector GHG emissions in Delaware are sourced from energy and non-energy related activities. Energy related activities are those involving fossil fuel combustion, while non-energy related activities are those associated with industrial processes. The majority of industrial sector GHG emissions in Delaware are from energy related activities, shown in Figure 11. GHG emissions from energy related activities (i.e. fossil fuel combustion) were 93% of the total industrial sector in 2017, and typically are about 90% each year. Wood burning for energy related activities contributes to <<1% of annual industrial GHG emissions. The combustion of natural gas and petroleum products are the major sources of GHG emissions in the industrial sector in Delaware. Non-energy related activities include HFC use and fugitive emissions associated with refinery operations, natural gas transmission and distribution pipelines, and more.

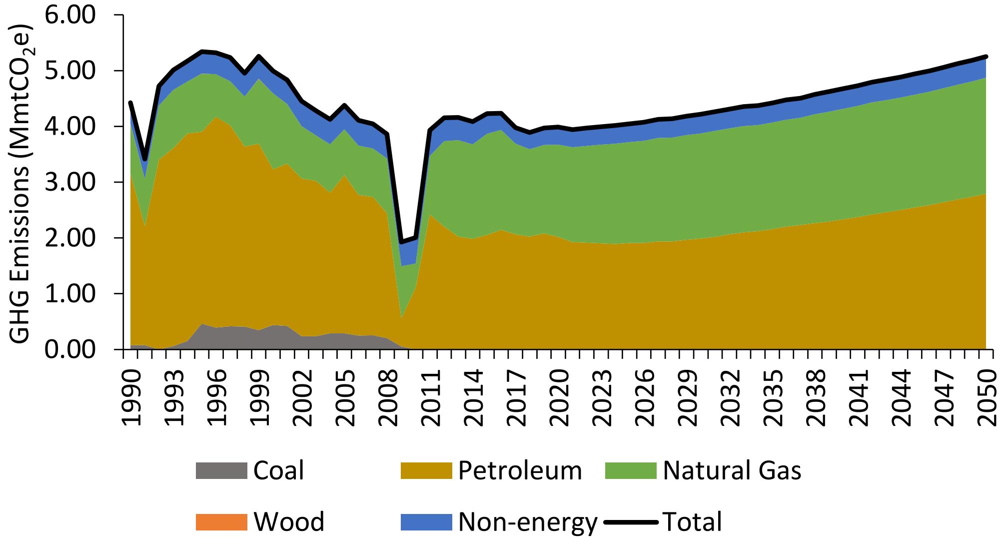

Figure 11. Gross GHG emissions and projections for the industrial sector, including contributions per fossil fuel combusted (energy related) and total non-energy related activity GHG emissions

A significant decrease in GHG emissions in the industrial sector can be observed between 2009 and 2010. This decrease was most likely influenced by a slowing economy, loss of heavy industry, and, most notably, the shut-down of operations at the Delaware City Refinery from the end of 2009 through the end of 2011[19].

GHG emissions in the industrial sector are projected to follow an upward trend post-2017. By 2030, total industrial sector GHG emissions are projected to increase by approximately 6.1%.

[19] "PBF Celebrates Successful Restart of its Delaware City Refinery" Delaware News, Office of the Governor, October 2011

The increasing trend is mainly the result of increasing energy related GHG emissions, which are projected using modeled fuel consumption. Total GHG emissions in the industrial sector are projected to further increase through 2050. In 2050, it is projected that total industrial sector GHG emissions will be 5.25 $MmtCO_2e$, which is a 32% increase from 2017. Again, increasing projected fuel consumption from the US EIA AEO 2019 is resulting in increased energy-related GHG emissions in the industrial sector.

Residential Sector

Residential sector GHG emissions are estimated using energy consumption data and carbon content of each fuel type used. In addition, HFC emissions are estimated from residential refrigeration and air-conditioning. It should be noted that emissions associated with electricity consumption are not accounted for. Emissions associated with electricity are accounted for in the electric power sector; however, a discussion on electricity consumption-based emissions can be found in the indirect GHG emissions section of this report.

The primary fuel type in the residential sector in 2017 and more recent years is natural gas, for which it is mainly used in heating and other appliances. As Figure 12 shows, historical emissions from 1990 to 2017 show some fluctuations that can be attributed to weather and fuel shifting. For example, a local peak in the emissions data in 1996 can be linked to temperature data at the Dover station. The year 1996 had the most days with a maximum temperature below 32°F between 1990 and 2016[20]. A sharp decrease in emissions was observed from 2005 to 2006, as natural gas became the major type of fuel used over petroleum. Petroleum use in the residential sector decreased even more from 2010 to 2012, thus, further reductions in emissions. However, residential sector emissions increased in 2013 and 2014 as petroleum use increased due to high natural gas prices during the December of 2013 through February of 2014[21]. Further, increased use of HFCs in refrigeration and air-conditioning caused greater GHG emissions in 2014 and 2015. Residential sector GHG emissions decreased slightly in 2017, as compared to 2016. Temperature data from the Dover station show that 2017 had a similar amount of cooling degree days compared to 2014 and 2015, but had nearly 1,000 fewer heating degree days than each of 2014 and 2015.

[20] National Oceanic and Atmospheric Administration, National Centers for Environmental Information – Climate Data Online
[21] U.S. Energy Information Administration, Henry Hub Natural Gas Spot Price

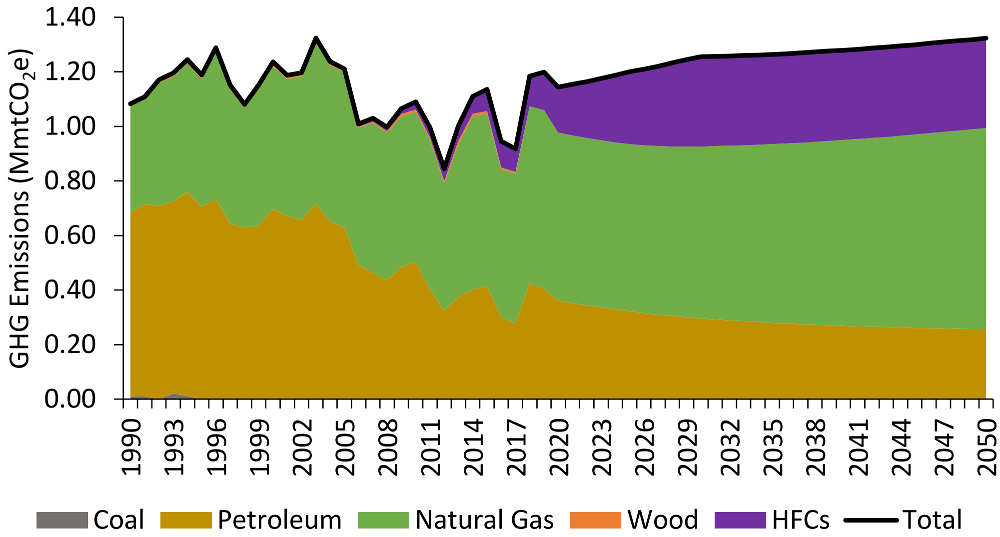

Figure 12. Gross GHG emissions and projections for the residential sector, including contributions per fossil fuel combusted and total HFC emissions from residential refrigeration and air conditioning units

GHG emissions in the residential sector are projected to increase from 2018 to 2050, primarily caused by increases in HFC emissions. GHG emissions from petroleum products combustion in the residential sector is projected to have a slight decrease through 2050, while emissions associated with natural gas combustion are projected to slightly increase. It is expected that electrification and increased availability and use of energy efficiency innovations have helped to curtail fossil fuel needs for cooling and heating purposes.

Commercial Sector

Commercial sector GHG emissions are associated with fossil fuel combustion and HFC use among various applications such as heating, cooling, ventilation, lighting, and refrigeration. Like the residential sector, natural gas[22] is the most used fuel type in the commercial sector. As Figure 13 presents, historical GHG emissions fluctuated and trended upwards from 1990 to 2016. The combustion of natural gas for energy is the greatest source of GHG emissions in the commercial sector. Projections of GHG emissions related to petroleum products combustion appear to be constant from 2018 to 2050; however, an increase in GHG emissions from natural gas combustion by 21% in the same period can be observed. Increasing HFC emissions cause total commercial sector GHG emissions to rise further through 2050. HFCs are used for commercial refrigeration and air conditioning applications, including cold storage, refrigerated

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[22] As stated in the residential sector section, indirect emissions associated with electricity use are not accounted for, but are discussed in the indirect GHG emissions section of this report.

retail spaces, and more. Total commercial sector GHG emissions are projected to increase by about 50% in 2050 compared to 2017, while HFC emissions are projected to increase by a factor of 2.7 in that same time period.

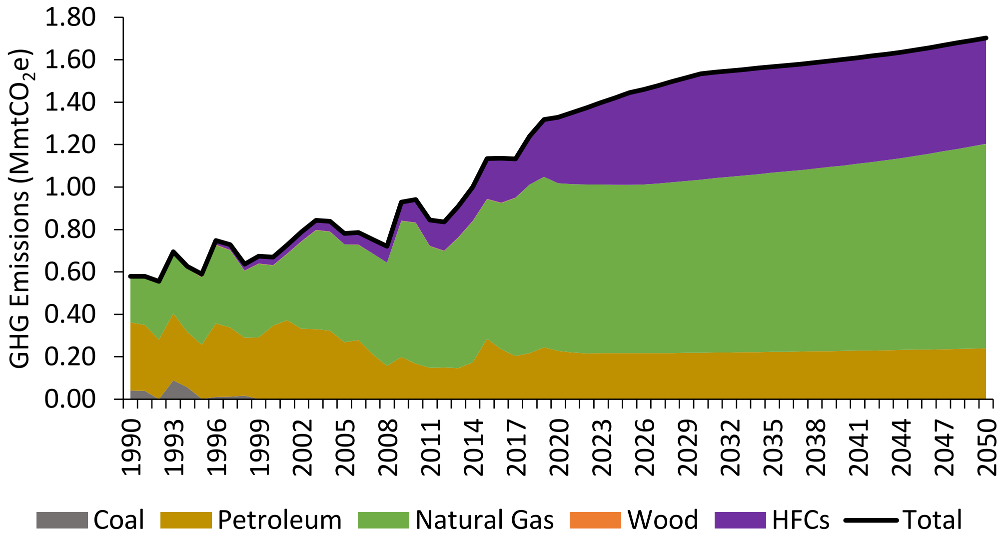

Figure 13. Gross GHG emissions and projections for the commercial sector, including contributions per fossil fuel combusted and total HFC emissions

Agricultural Sector

Agricultural sector GHG emissions represented approximately 4% of the total gross GHG emissions in Delaware in 2016. GHG emissions from the agricultural sector have been essentially constant since 1990, as shown in Figure 14. GHG emissions are projected to remain constant in the agricultural sector through 2050. GHG emissions associated with liming of soils was updated for this report, as explained in the Updates section. As stated, Delaware specific liming tonnage data were provided by the Department of Agriculture. Standard ratios and factors from the US EPA SIT for agricultural applications of liming materials to soils compared to other agricultural uses were used to estimate the GHG emissions associated with liming of soils. Data were available annually from 2012 and on. It can be seen that the contribution from liming of soils relative to the overall GHG emissions in the agriculture sector is minimal. The major sources of GHG emissions in the agriculture sector are associated with agricultural soil management and manure management.

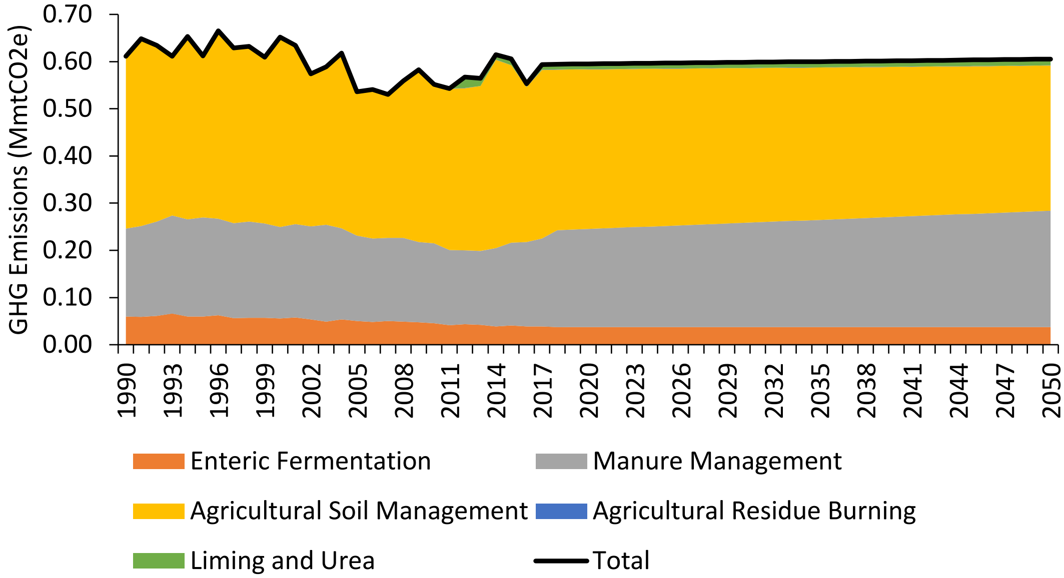

Figure 14. Gross GHG emissions and projections from the agricultural sector in Delaware

Waste Management Sector

GHG emissions from the waste management sector include wastewater treatment methane (CH_4) and nitrous oxide (N_2O) emissions and municipal solid waste (landfills) CH_4 emissions. GHG emissions from wastewater treatment were fairly constant from 1990 to 2017 and are based mainly on municipal wastewater and industrial wastewater generated from poultry processing. However, the majority of emissions in this sector are fugitive methane emissions from municipal solid waste landfills. For completeness, historical GHG emissions associated with municipal waste combustion were included, but the practice was banned in 2000.

As Figure 15 presents, emissions fluctuated from 1990 to 2017. Fluctuations in the waste management sector are largely based on changes in operation in the municipal solid waste sector. The first major change in emissions occurred between 1997 and 1998, when flaring began each of the three major landfills. In addition, land fill gas recovery for energy generation (landfill gas to energy, or LFGTE) started in 1997 at the Cherry Island Landfill site. LFTGE began in 2007 at the Central and Southern Solid Waste Management Centers; however, additional decreases in emissions were not observed because processes simply shifted from flaring to LFGTE. A moderate increase in emissions can be observed in 2017, due to a lower collection efficiency at one of the municipal solid waste landfill sites. GHG emissions in the waste management sector are projected to remain constant from 2018 to 2050, assuming collection rates and efficiencies remain constant through 2050. Nominal landfill gas collection rates were provided by the Delaware Solid Waste Authority, and collection efficiencies were obtained from reported data to the U.S. EPA GHG Reporting Program.

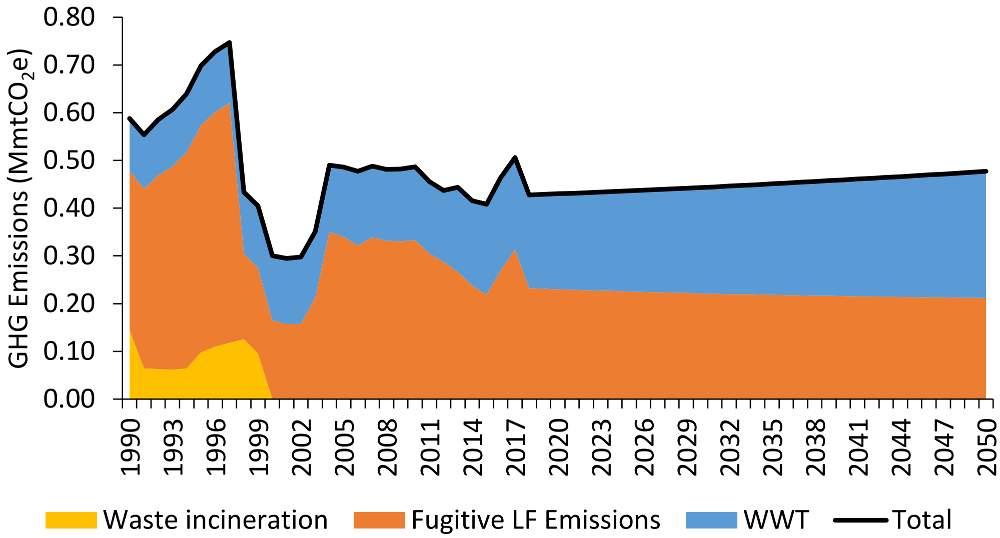

Figure 15. Gross GHG emissions and projections of the waste management sector in Delaware; LF: landfill

Land-use, Land Use Change and Forestry Emission Analysis

The 2017 GHG emissions inventory identified the land-use sector as a sink[23] for GHG emissions in Delaware. Carbon emissions and/or sequestration in the land-use sector is calculated as the annual change in carbon storage among different carbon pools of Delaware's forest and croplands, as well as harvested wood products. Between 1990 and 1998, estimated emissions from the land use sector were positive. However, despite some losses in forest acreage, increased forest management practices and trees reaching maturity have enhanced carbon sequestration from 1999 to the present[24, 25]. In 2016, total GHG emissions for land-use were -0.73 $MmtCO_2e$; meaning, 0.73 $MmtCO_2e$ in GHG emissions were sequestered from the atmosphere as a result of Delaware's land sector. This would be equivalent to offsetting about 4.6% of Delaware's gross GHG emissions in 2016. The removal of GHGs in this sector peaked in 2005 with a net GHG removal of 1.05 $MmtCO_2e$ as indicated in Figure 16. Since it is difficult to project sequestration of carbon and there is a significant amount of uncertainty, the projection analysis for this sector was based on the assumption that Delaware's change in carbon storage will remain constant from 2018 to 2050 at 0.73 $MmtCO_2e$.

[23] A sink is the removal of GHG from the atmosphere
[24] Delaware Forest Resource Assessment, Delaware Forest Service, 2010
[25] Delaware Forests 2013, United States Forest Service, 2017

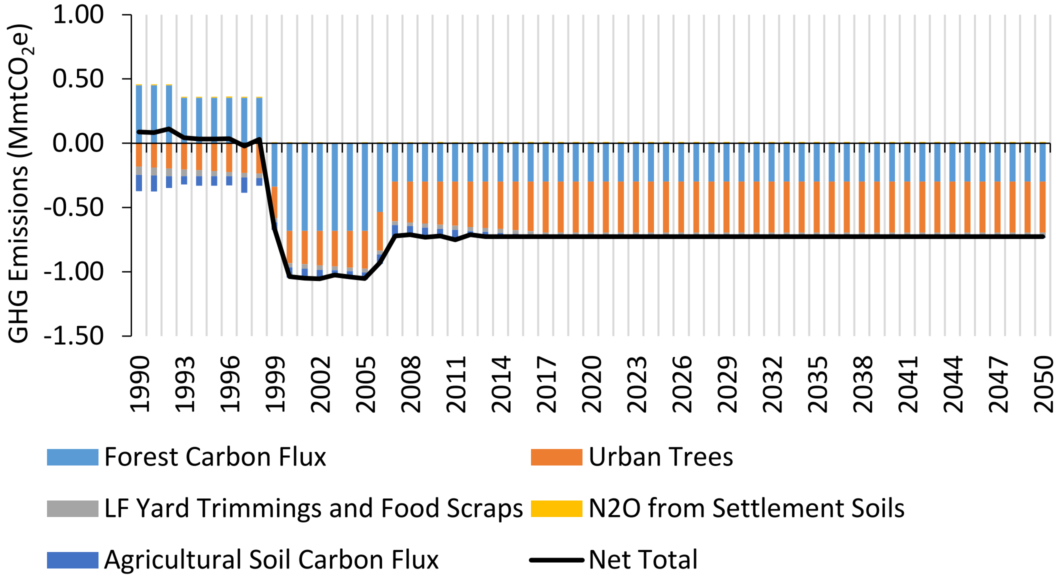

Figure 16. Emissions and sequestration (represented as negative emissions) of carbon (in $MmtCO_2e$) in the LULUCF sector; LF: landfill

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 emissions are CO_2 emissions that are estimated based on the amount of kilowatt-hours consumed by end-users of electricity. Indirect GHG estimates were included in the 2017 GHG inventory to show how electricity demand in Delaware impacts GHG emissions. This section describes GHG emissions associated with all electricity consumed by Delawareans, whether generated in-state or out-of-state. GHG emissions from in-state electricity generation sources are detailed in the electric power sector section of this report. This section provides estimates and projections on a consumption basis, and is accounted separately from to avoid the double counting of electric power sector GHG emissions. Note that only emissions accounted in the electric power sector are included in the state's total emissions.

Figure 17 shows that indirect GHG emissions from electricity consumption peaked in 2003 and have been declining through 2017. Fuel switching from more carbon intensive fuels (e.g. coal) to less carbon intensive fuels (e.g. natural gas), or zero-emitting sources (i.e. renewable energy) have pushed this trend. Another contributing factor is the overall declining trend of electricity demand as improvements in energy efficiency become more cost effective and widely available. The projections of indirect GHG emissions from 2018 to 2050 show a gradual increase. These projections provide a representation of indirect GHG emissions based on projected electricity consumption. From the projections, that electricity demand is shown to likely increase; however, technological gains in energy efficiency and renewable energy occur rapidly which may reduce demand and emissions intensity of electricity generation.

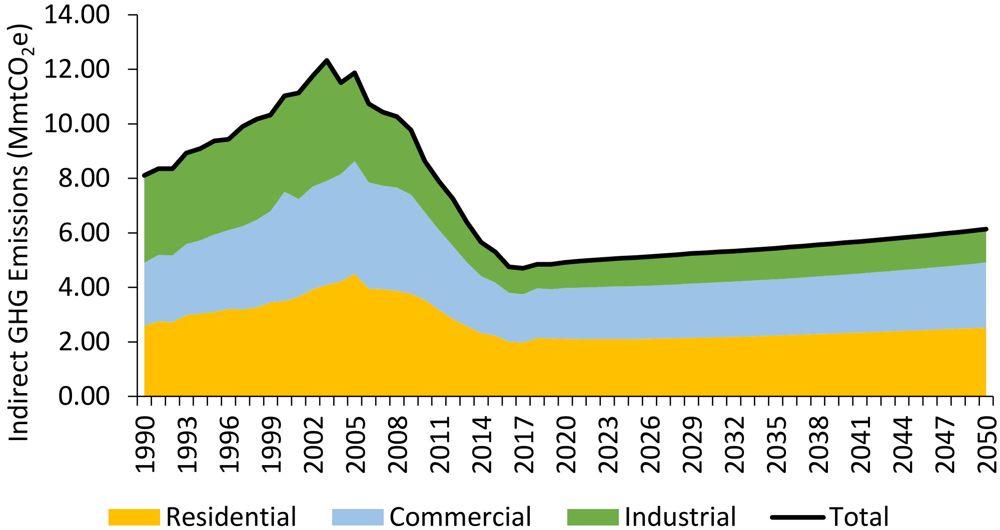

Figure 17. Indirect GHG emissions associated with electricity consumption, per sector, in Delaware

GHG Emissions By Gas

The 2017 GHG inventory estimated emissions for the following GHGs, per the Greenhouse Gas Protocol[26]: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFC), perfluorocarbons (PFC), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

Figure 18 presents gross GHG emissions by gas in 2017. Carbon dioxide emissions represent the most abundant type of GHGs with approximately 88% of gross emissions in Delaware which is followed by N_2O and CH_4, representing approximately 4% and 5%, respectively. The combined emission of HFC/PFC/NF_3 and SF_6 represent approximately 3% of gross GHG emissions from Delaware.

[26] Greenhouse Gas Protocol, February 2013, Required Greenhouse Gases in Inventories

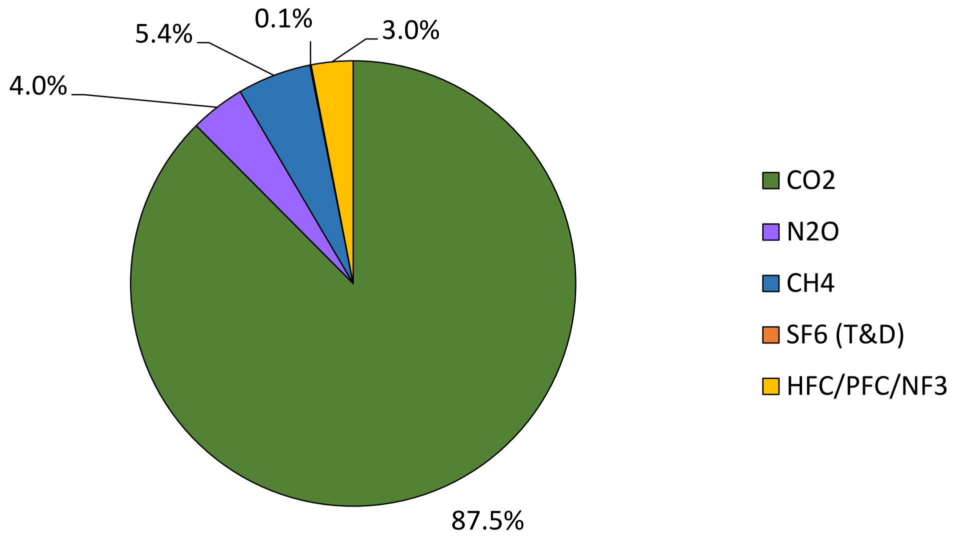

Figure 18. GHG emissions by gas type in 2017 in Delaware (in MmtCO_2e)

Figure 19 presents gross GHG emissions by gas in 2030. Carbon dioxide is projected to remain the most emitted GHG representing approximately 84% of gross GHGs emitted in 2030. CH_4 emissions are projected to be 5% of the total gross GHG emissions in 2030. The combined emissions of HFC/PFC/NF_3 7% of gross emissions. This group of emissions has grown in relative contribution from 2017, mainly caused by an increase in projected HFC emissions. N_2O emissions are projected to represent approximately 4% of gross GHG emissions in 2030. SF_6 emissions remain low and represent less that 0.1% of gross GHG emissions in 2030.

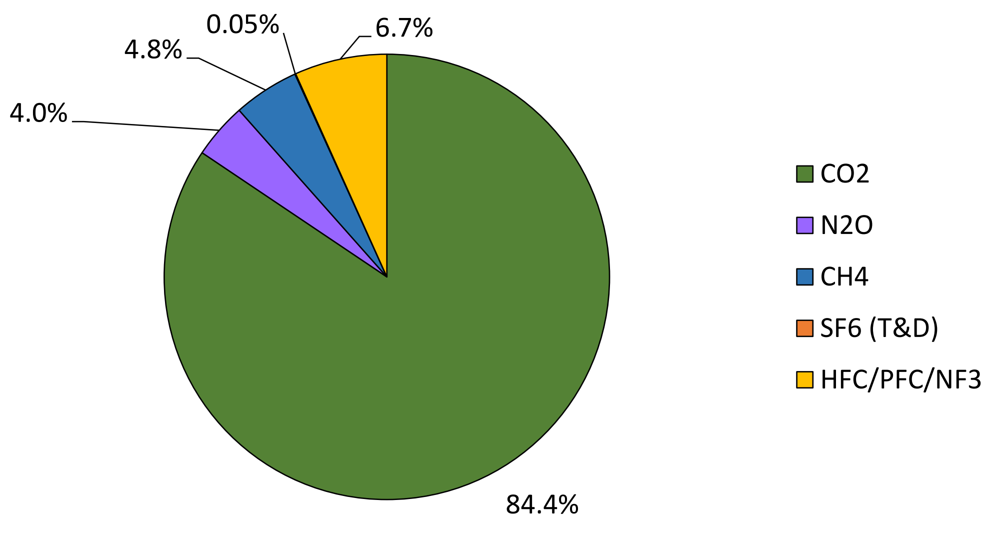

Figure 19. GHG emissions by gas type in 2030 in Delaware (in MmtCO_2e)

Figure 20 presents the gross GHG emissions projected in Delaware by gas in 2050. In can be seen that CO_2 is projected as the most abundant GHG at about 85% of the total. N_2O and CH_4 remain consistent in relative percentages from 2017 at about 4% and 5%, respectively. SF_6 emissions remain as a near negligible percentage of gross GHG emissions in 2050. HFC/PFC/NF_3 emissions decrease from 2030 to about 6% of the total gross GHG emissions in 2050.

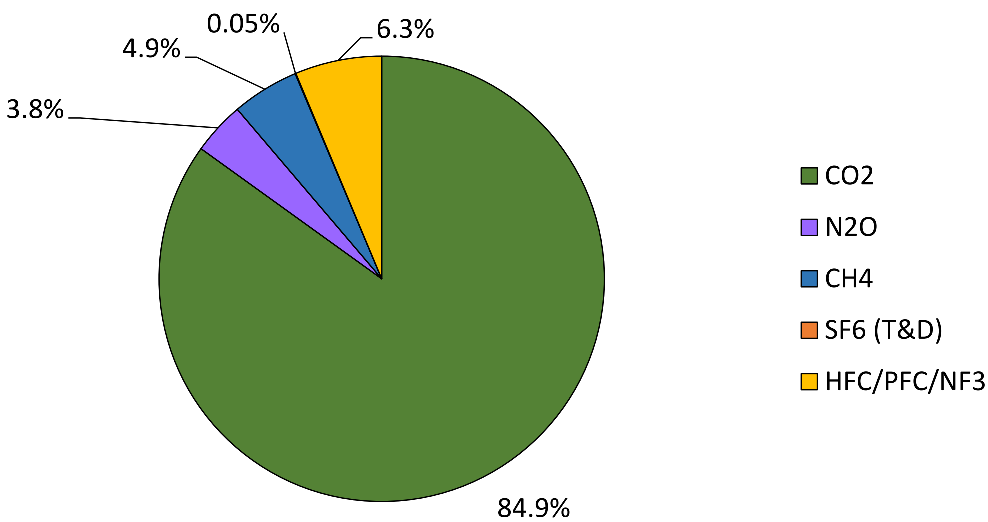

Figure 20. GHG emissions by gas type in 2050 in Delaware (in MmtCO$_2$e)

The emission of CO_2 was driven by fossil fuel combustion in all sectors of Delaware's economy. Nearly all (>99%) of CO_2 emissions came from fossil fuel combustion in 2017. As stated, CO_2 was the largest contributor to GHG emissions representing approximately 88% in 2017. Historical CO_2 emissions continue to trend downwards from 1990 levels with a minor increase as the economy rebounded from the 2008 recession as Figure 21 demonstrates. Gross CO_2 emissions are projected to remain essentially constant through the late 2030s until a slight increasing trend is projected towards 2050.

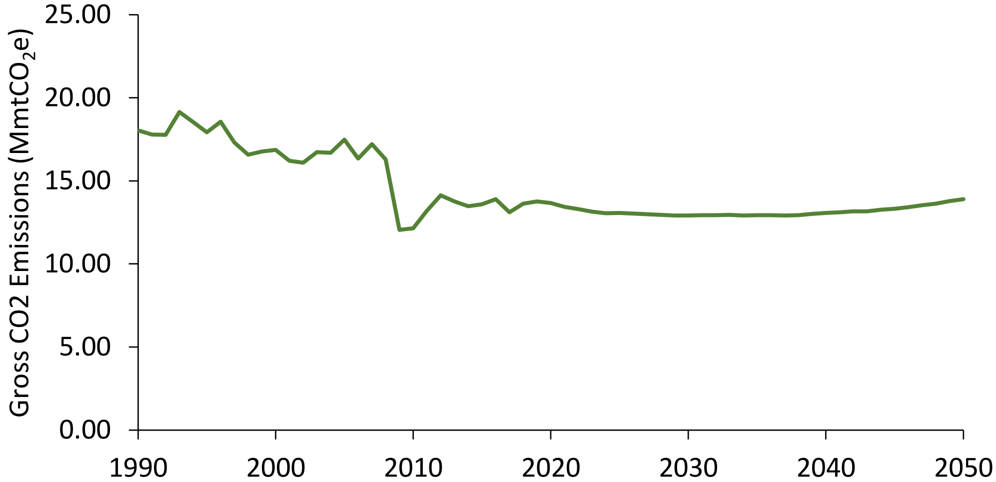

Figure 21. Gross CO_2 emission estimates and projections in Delaware from 1990 to 2050

The remaining GHGs that were identified in the Kyoto Protocol represent at most roughly 16% of the total gross GHG emissions in a given year between 1990 and 2050. Figure 22 shows emission estimates and projections of each of these non-CO_2 GHGs from 1990 to 2050. It can be seen that there is a significant increase in HFC/PFC/NF_3 emissions from 1990 to 2050[27]. The rapid increase in emissions of these high-GWP GHGs brings a concern for their growing uses in refrigeration, air-conditioning, and other applications in the various economic sectors. Methane emissions include emissions from fossil fuel combustion, agricultural processes, industrial processes, and waste management. Within waste management, methane recovered for energy use or that is flared are subtracted from the overall landfill emissions. The commencement of such landfill gas recovery operations can be noted by the sharp decrease in CH_4 emissions in 1998. The decrease in N_2O emissions can be attributed to increased emission standards for vehicles and improved farming activities. Current projections of economic activities such as agriculture, transportation, and wastewater treatment in Delaware cause a nearly constant amount of N_2O emissions through 2050. SF_6 emissions from power transmission and distribution in Delaware have declined by approximately 83% from 1990 to 2017 and are projected to continue to decrease with time.

[27] HFC emissions are the dominant gas type in this grouping of GHGs. The US EPA Projection Tool holds HFC emissions constant from 2030-2050. A decrease in HFC emissions is noted in 2017 due to the change in methodology described in the Updates section of this report.

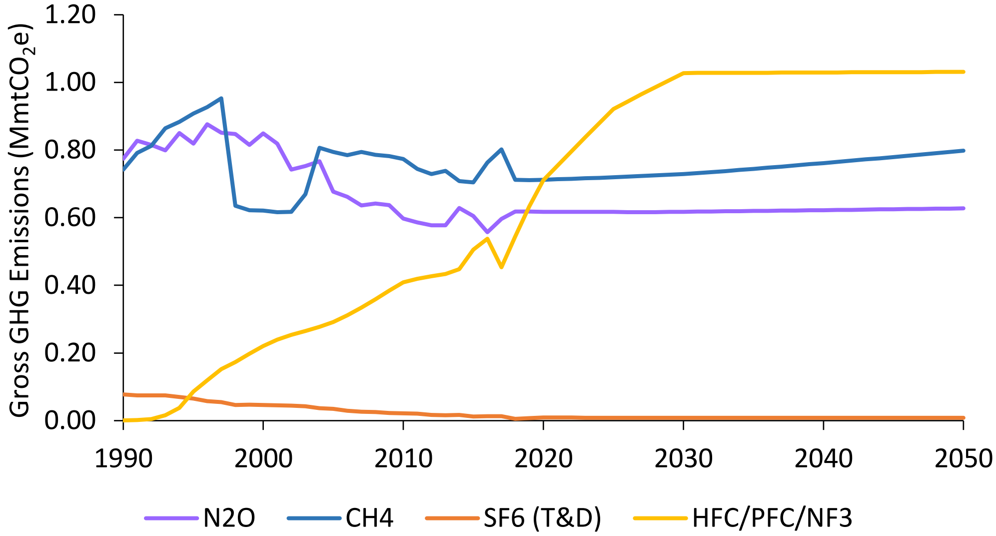

Figure 22. Gross emission estimates and projections of non-CO_2 GHGs in Delaware from 1990 to 2050

GHG Emissions per Person

Another way to present Delaware's GHG emissions is to analyze the data by state population and a per capita basis. This is useful when comparing emissions from one state to another. Many factors contribute to the amount of emissions per capita. According to the US EIA[28], 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 2017, Delaware ranked 30th in (energy-related) CO_2 emissions per capita according to the U.S Energy Information Administration[29]. As Figure 23 presents, per capita GHG emissions decreased from 29.36 mtonCO_2e/person in 1990 to 15.57 mtonCO_2e/person in 2017, a decrease of approximately 47%. The significant decrease in per capita GHG emissions from 1990 to 2017 can be attributed to a number of factors including; the economic recession, which lead to a significant decline in the industrial sector emissions that never fully rebounded; energy efficiency in multiple economic sectors; and switching from a more carbon intensive fuel such as coal to a less carbon intensive fuel such as natural gas.

Projected GHG emissions per capita are expected to have a slight decline from 16.05 mtonCO_2e/person in 2018 to 14.64 mtonCO_2e/person in 2050. Even though a moderate increase in total gross GHG emissions is projected through 2050, population growth slightly outpaces GHG emissions through 2050. Thus, an overall decrease in GHG emissions per capita is observed.

[28] State-Level Energy-Related Carbon Dioxide Emissions, 2000-2010
[29] Energy-Related Carbon Dioxide Emissions by State, 2005-2016

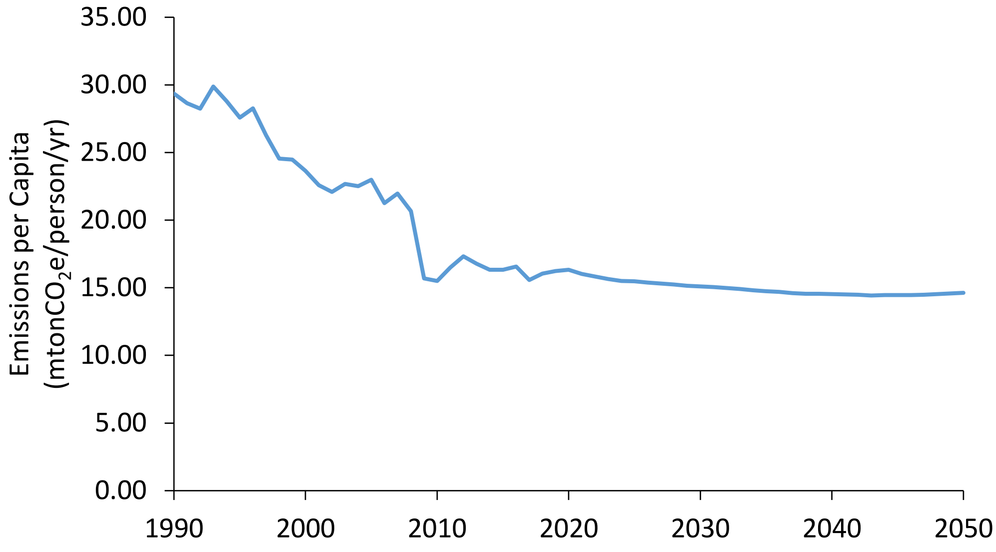

Figure 23. Gross GHG emissions per capita in Delaware