DELAWARE'S 2016 GREENHOUSE GAS EMISSIONS INVENTORY

PREPARED BY:

DIVISION OF AIR QUALITY

JULY 2019

QUICK SUMMARY

Economic Sector	2016 GHG Emissions[a]	Projection to 2030 (future)
Overall GHG Emissions	• Increase by 0.50 $MmtCO_2e$ (3.3%) from 2014 GHG emissions	• Increase by 0.42 $MmtCO_2e$ (2.6%) from 2016 GHG emissions • Not on track to achieve 2025 reduction goal (minimum emissions gap of 1.9 $MmtCO_2e$ in 2025)
Electric Power	• Insignificant decrease of 0.03 $MmtCO_2e$ (0.8%) from 2014 GHG emissions • Third largest source of GHG emissions in DE	• Decrease by 0.20 $MmtCO_2e$ (5.5%) from 2016 GHG emissions • Third largest source of GHG emissions in DE
Transportation[b]	• Increase by 0.42 $MmtCO_2e$ (9.6%) from 2014 GHG emissions • Largest source of GHG emissions in DE	• Decrease by 0.54 $MmtCO_2e$ (11.1%) from 2016 GHG emissions • Second largest source of GHG emissions in DE
Industrial	• Increase by 0.15 $MmtCO_2e$ (3.7%) from 2014 GHG emissions • Second largest source of GHG emissions in DE	• Increase by 0.60 $MmtCO_2e$ (14.1%) from 2016 GHG emissions • Largest source of GHG emissions in DE
Residential	• Decrease by 0.16 $MmtCO_2e$ (14.8%) from 2014 GHG emissions	• Increase by 0.20 $MmtCO_2e$ (21.7%) from 2016 GHG emissions • Large increase in HFC emissions
Commercial	• Increase by 0.14 $MmtCO_2e$ (13.5%) from 2014 GHG emissions	• Increase by 0.25 $MmtCO_2e$ (22.2%) from 2016 GHG emissions • Large increase in HFC emissions
Agricultural	• Insignificant decrease by 0.02 $MmtCO_2e$ (3.2%) from 2014 GHG emissions	• Insignificant increase by 0.03 $MmtCO_2e$ (4.7%) from 2016 GHG emissions
Waste Management	• Insignificant decrease by >0.01 $MmtCO_2e$ (0.5%) from 2014 GHG emissions	• Insignificant increase by 0.03 $MmtCO_2e$ (7.0%) from 2016 GHG emissions

[a] Gross GHG emissions; land-use, land-use change, forestry not included
[b] Projections do not consider proposed fuel economy standards (83 FR 42986-43500)

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 2016 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 2016 as well as emission projections from 2017 to 2030 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 2016 with projections from 2017 to 2030, 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 Annual Energy Outlook data as well as other economic data that are used to predict GHG emissions.

KEY UPDATES FROM THE 2014 GHG INVENTORY REPORT

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

[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

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 HFC emissions per unit were applied to Delaware specific data for population, households with air-conditioning (A/C), and number of vehicles. The inventory tool allows for HFC emissions to be separated by economic sector, as shown in Table 1. Each sector is broken down into aggregated end uses, which are comprised of collections of end uses identified in the CARB F-Gas model[6].

Table 1. End uses by economic sector for HFC emissions

Economic Sector	Aggregated End Uses	End Uses (per CARB model)
Residential	Refrigeration	Household refrigerator freezer
	Stationary A/C	Stationary A/C heat pumps Stationary central A/C Stationary room unit A/C
Commercial	Refrigeration	Commercial systems (>50lbs refrigerant) Vending machines Stand-alone units
	Stationary A/C (>50lbs refrigerant)	Centrifugal chillers (>200lbs refrigerant) Packaged chillers (200-2,000lbs refrigerant) Unitary A/C (50-200lbs refrigerant)
	Stationary A/C (<50lbs refrigerant)	Unitary A/C (<50lbs refrigerant) Window A/C units
Industrial	Refrigeration	Cold Storage Industrial process cooling
	Foam Aerosol Propellants Solvents and Fire Suppressant	
Transportation	Light-duty motor vehicle A/C Heavy-duty motor vehicle A/C Transportation Refrigeration	

*A/C: air-conditioning

Emissions estimates and projections from the agricultural sector have been updated to include the liming of soils and urea fertilization. This update has been performed for the national GHG inventory produced by the U.S. EPA. The update was provided to states in the user's guide document for the agricultural sector[7].

Historical emissions and sequestration estimates and projections for the land-use, land-use change, and forestry sector have been updated. Carbon data for the forestry sector are sourced from the U.S. Forest Service (USFS) Forest Inventory and Analysis (FIA). In a report from the

[6] California's High Global Warming Potential Gases Emissions Inventory – Emission Inventory Methodology and Technical Support Document (2015 Edition), California Air Resources Board

[7] User's Guide for Estimating Carbon Dioxide, Methane, and Nitrous Oxide Emissions from Agriculture Using the State Inventory Tool

USFS, the agency describes that a new modeling approach was used to estimate forest carbon both historically (dating back to 1990) and for 2016 estimates[8]. This effort included re-measuring forest plot locations to achieve better accuracy for forest carbon stocks and changes.

SOURCES OF GHG EMISSIONS AND TRENDS

The 2016 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.

GHG emission reductions in Delaware are guided by the state's commitment as a member of the USCA[9]. Delaware aims to reduce overall gross GHG emissions by at least 26-28% below 2005 levels by 2025. Gross emissions in Delaware in 2005 were estimated at 19.3 MmtCO_2e. To achieve a reduction of 26-28% gross GHG emissions from 2005, gross GHG emissions in Delaware must total between 13.9 and 14.3 MmtCO_2e by 2025.

In 2016, Delaware's gross[10] total GHG emissions were equivalent to 15.75 MmtCO_2e, which represents approximately 0.2% of national gross GHG emissions (U.S. total was 6,511 MmtCO_2e in 2016)[11]. Figure 1 shows the historical gross GHG emissions in Delaware from 1990 to 2016, as well as the USCA reduction target. Overall, gross GHG emissions have been trending downwards since 1990; however, an increase of roughly 0.50 MmtCO_2e can be observed from 2014 to 2016. Gross GHG emissions in 2016 show a reduction of 18.3% relative to the 2005 baseline. Further reductions of 1.45 – 1.85 MmtCO_2e would be required by 2025 to achieve the target set by the USCA goal, which is approximately 9.2 to 11.7% of the total 2016 gross GHG emissions.

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[8] The U.S. Forest Carbon Accounting Framework: Stocks and Stock Change, 1990-2016, U.S. Forest Service
[9] "Delaware Joins U.S. Climate Alliance to Uphold Goals of Paris Agreement," Delaware.gov, June 2017
[10] Gross GHG emissions accounts for only positive emissions and excluded metric tons of CO_2e removed from the atmosphere (sink)
[11] U.S. EPA: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 -2016

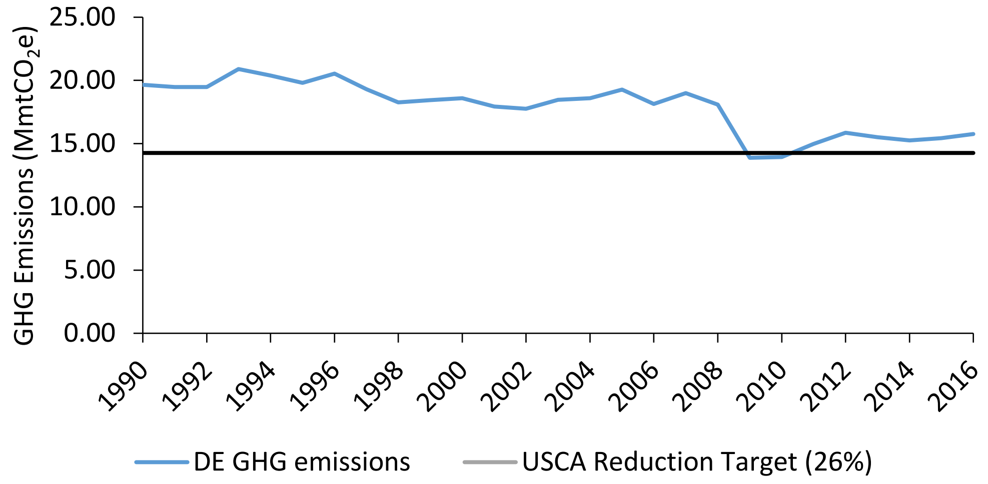

Figure 1. Gross GHG emissions from 1990 to 2016 in Delaware relative to the USCA GHG reduction target

Figure 2 presents a breakdown of GHG emissions (in $MmtCO_2e$) in 2016 by Delaware's economic sectors. The largest source of GHG emissions in 2016 was the transportation sector, which represented 31% of the gross GHG emissions. This was followed by the industrial sector with approximately 27%. The electric power sector was the third largest emitter of GHG emissions in 2016 representing approximately 23% of gross emissions, while all other sectors including residential, commercial, agriculture and waste management each represented approximately 6%, 7%, 4% and 2%, respectively.

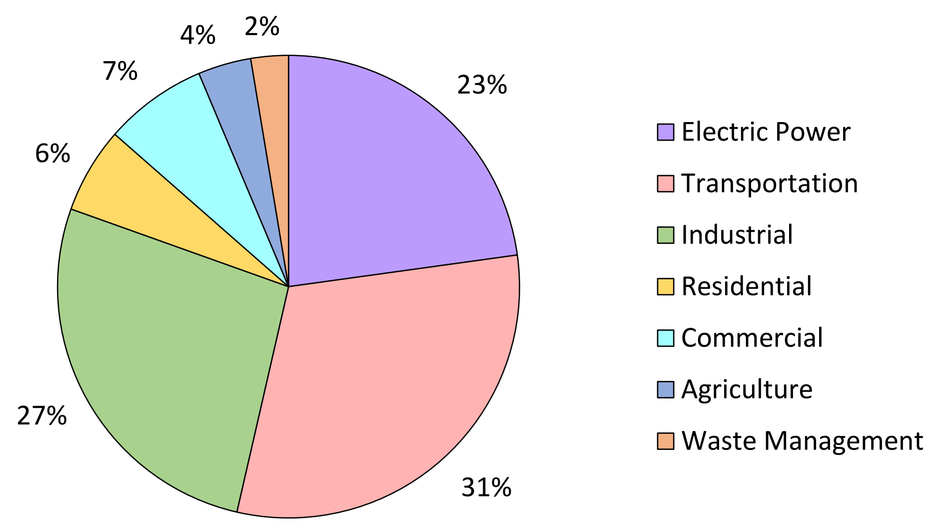

Figure 2. Breakdown of gross GHG emissions in Delaware by sector in 2016

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. It is important to observe that this contradicts a previous version of this report, in which the industrial sector was the greatest source of GHG emissions in 2013 and 2014[12]. In this updated GHG emissions inventory report for Delaware, HFC emissions have been parsed out to relevant sectors, as described in the Key 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 traditionally 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. Notably, the residential and commercial sectors have seen a fair increase caused by assigning the increasing amount of HFC emissions in Delaware to each sector as appropriate.

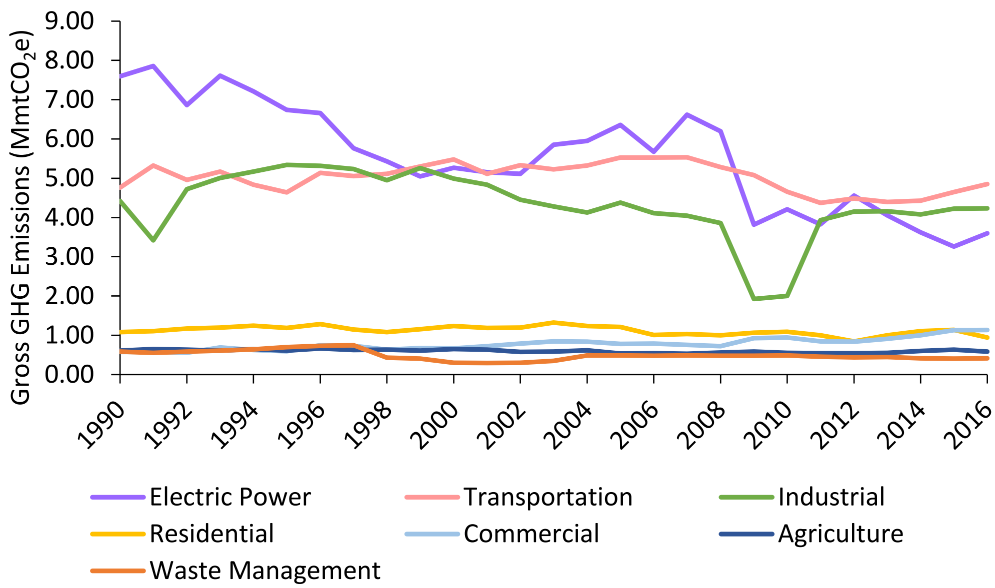

Figure 3. Gross GHG emissions in Delaware by economic sector from 1990 to 2016

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 – were the largest source of GHG emissions in 2016 as they represented 89% of gross GHG emissions in Delaware. Downward emission trends are observed since overall fuel consumption in Delaware

[12] Delaware's 2014 Greenhouse Gas Emissions Inventory, DNREC, January 2019
[13] Energy related activities are activities that involve fossil fuel combustion for energy use.

has declined in 2016 relative to 1990. In addition, the fuel mix shifted more towards natural gas and away from coal; as such, gross GHG emissions decreased.

Net GHG emissions are included here for reference but are not used to assess Delaware's progress toward achieving the emission reduction goal set forth by the commitment to the USCA. 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 land sector is actually a source of emissions between 1990 and 1998 (excluding 1997), as shown in Figure 4. Further assessment of the LULUCF sector is provided later in this report.

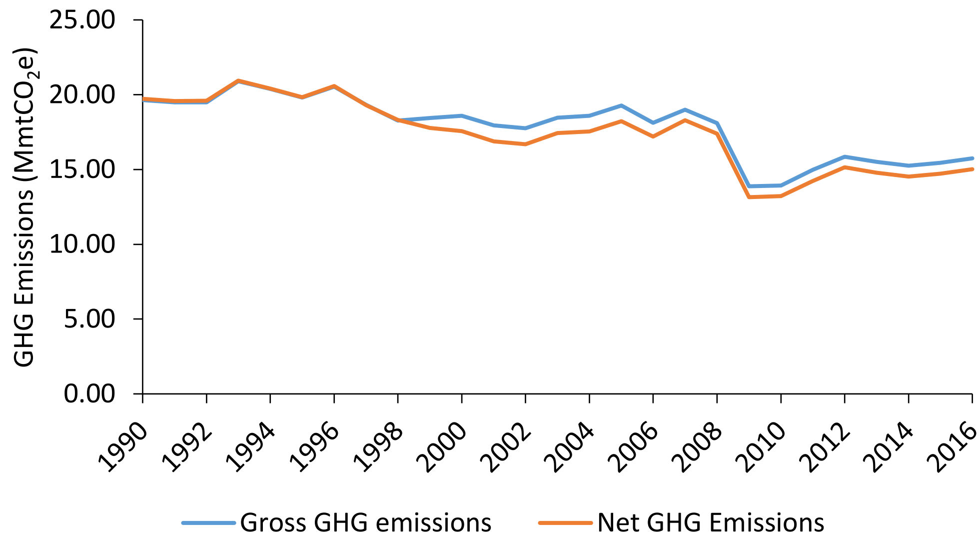

Figure 4. Comparison of gross and net GHG emissions in Delaware from 1990 to 2016

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 2017 to 2030, while providing the minimum USCA target as reference. Delaware is currently not on track to achieve the GHG emissions reduction goal set forth by the USCA target in 2025. In fact, gross GHG emissions are projected to increase in 2025 relative to 2016. The red arrow depicts the projection path for emissions reductions that would be needed to reach the minimum of 26% reduction from 2005 by 2025. The projected GHG emissions in 2025 are 16.2 $MmtCO_2e$, which is a reduction of 16% from 2005. An emissions gap of about 1.9 $MmtCO_2e$ exists that must be reduced to achieve the minimum USCA target for Delaware.

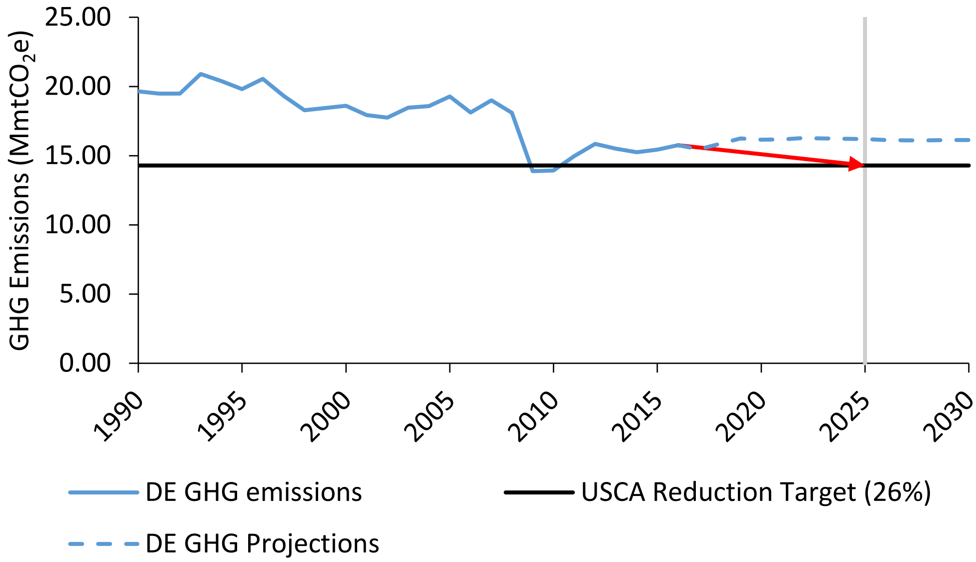

Figure 5. Delaware gross GHG emissions and projections from 1990 to 2030

The breakdown of gross GHG emissions (in $MmtCO_2e$) in Delaware in 2025, shown in Figure 6, is relatively unchanged compared to that of 2016. The *Big Three* continue to contribute a high majority of all GHG emissions at 78%. 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 2025. The electric power sector has declined in its portion Delaware's gross GHG emissions in 2025 to 21%. The contribution of GHG emissions from the residential and commercial sectors each increased by 1% from 2016. This is most likely caused by the increasing amount of HFC emissions in these sectors. The agriculture sector did not change in its contribution to total GHG emissions in 2025, while the waste management sector increased by 1%. The increase for the waste management sector is most likely a facet of increasing relative percentage when other sectors decline (actual GHG emissions from the waste management sector were relatively constant between 2016 and 2025).

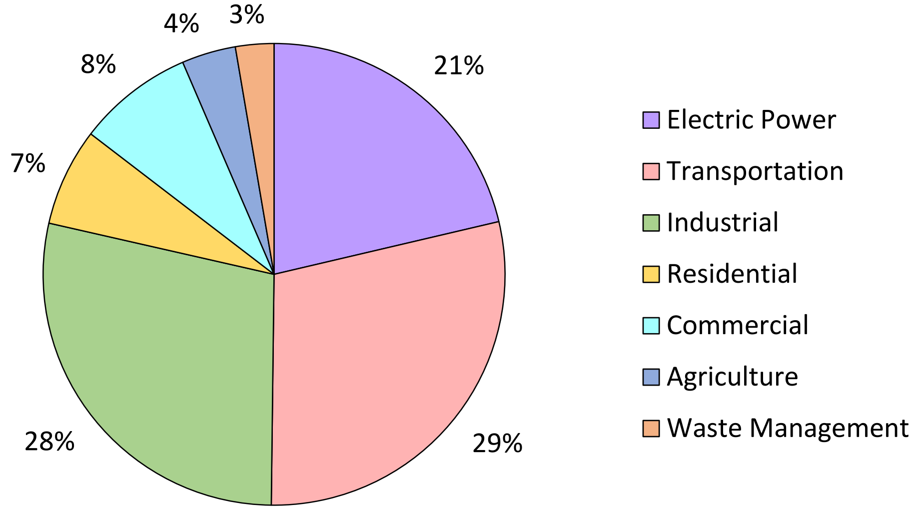

Figure 6. Breakdown of gross GHG emissions in Delaware by sector in 2025

Figure 7 presents the GHG emissions and projections by sector from 1990 to 2030. As expected, the *Big Three* sectors make up the majority of GHG emissions over the projection period. Notably, a decline in GHG emissions in projected for the transportation sector, and it is no longer the largest source of GHG emissions after 2025. The estimated projected fuel use in the transportation from the U.S. Energy Information Administration (EIA) Annual Energy Outlook (AEO) 2018 shows a decline caused by increases in fuel economy standards[14]. It may be expected that GHG emission projections for the transportation sector could be higher with the federal proposal of a fuel economy freeze[15].

[14] Annual Energy Outlook 2018, U.S. Energy Information Administration
[15] The Safer Affordable Fuel Efficient (SAFE) Vehicles Proposed Rule for Model Years 2021-2026, U.S. Environmental Protection Agency

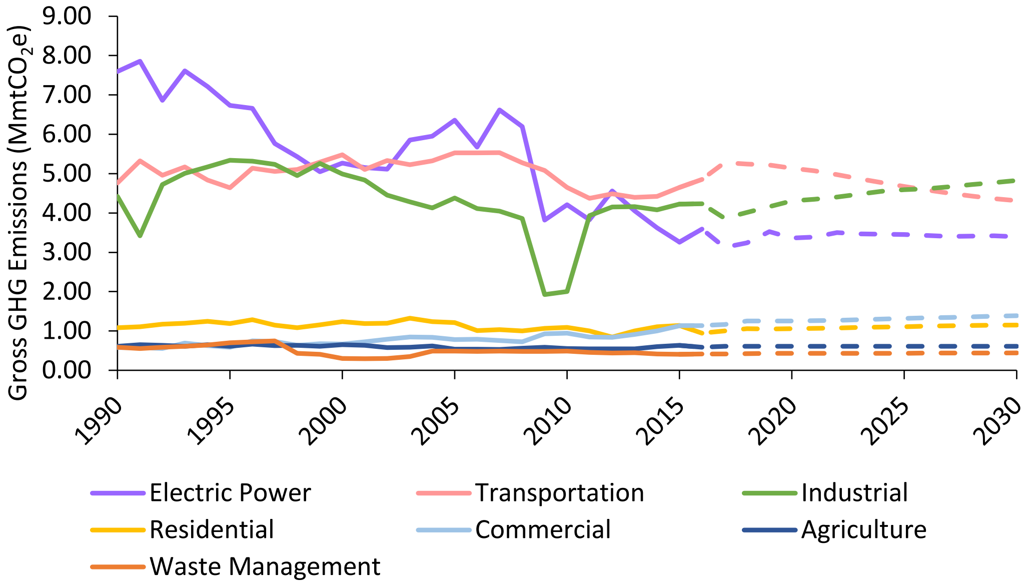

Figure 7. Gross GHG emissions and projections in Delaware by economic sector from 1990 to 2030

The industrial sector is projected to overtake the transportation sector as the largest source of GHG emissions from 2026 to 2030. As shown in Figure 7, steady increases in GHG emissions are projected in the industrial sector from 2017 to 2030. Each other sector, including the electric power sector, is projected to have to relatively constants as compared to 2016 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 2016 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 2. The emssion trends and analytical findings of those sectors are summarized below.

Table 2. Summary table of GHG emission estimates and projections

	1990	2000	2016	2025	2030
Electric Power	7.60	5.27	3.59	3.45	3.40
CO_2 from FFC	7.49	5.20	3.58	3.44	3.38
N_2O from FFC	0.03	0.02	0.00	0.00	0.00
CH_4 from FFC	0.00	0.00	0.00	0.00	0.00
SF_6 from T&D	0.08	0.05	0.01	0.01	0.01
Transportation	4.76	5.48	4.85	4.67	4.31
CO_2 from FFC	4.53	5.08	4.63	4.51	4.17
N_2O from FFC	0.20	0.24	0.04	0.06	0.06
CH_4 from FFC	0.03	0.02	0.01	0.01	0.01

	1990	2000	2016	2025	2030
HFCs	0.00	0.14	0.17	0.10	0.07
Industrial	4.42	4.99	4.23	4.59	4.83
CO_2 from FFC	4.04	4.58	3.93	4.28	4.50
N_2O from FFC	0.01	0.01	0.01	0.01	0.01
CH_4 from FFC	0.00	0.00	0.00	0.00	0.00
CO_2 from IP	0.20	0.16	0.01	0.01	0.01
CH_4 from IP	0.17	0.21	0.23	0.23	0.23
HFC/PFCs	0.00	0.03	0.06	0.07	0.08
Residential	1.08	1.24	0.95	1.11	1.15
CO_2 from FFC	1.07	1.22	0.84	0.89	0.89
N_2O from FFC	0.00	0.00	0.00	0.00	0.00
CH_4 from FFC	0.01	0.01	0.01	0.01	0.01
HFCs	0.00	0.01	0.10	0.21	0.25
Commercial	0.58	0.67	1.14	1.32	1.39
CO_2 from FFC	0.58	0.63	0.92	0.97	1.00
N_2O from FFC	0.00	0.00	0.00	0.00	0.00
CH_4 from FFC	0.00	0.00	0.00	0.00	0.00
HFCs	0.00	0.04	0.21	0.34	0.38
Agricultural	0.61	0.65	0.59	0.61	0.61
Enteric Fermentation	0.06	0.06	0.04	0.04	0.04
Manure Management	0.19	0.19	0.18	0.21	0.21
Ag Soils	0.36	0.40	0.33	0.33	0.32
Ag Residue Burning	0.00	0.00	0.00	0.00	0.00
Liming and Urea	0.00	0.00	0.04	0.04	0.04
Waste Management	**0.59**	**0.30**	**0.41**	**0.44**	**0.44**
Wastewater Treatment	0.11	0.14	0.20	0.21	0.22
Landfill Activities	0.33	0.17	0.22	0.23	0.22
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**	**15.75**	**16.19**	**16.13**
Net GHG Emissions	**19.73***	**17.56**	**15.03**	**15.47**	**15.40**
Electricity Consumption	8.10	11.03	4.76	5.01	5.19

*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 8 shows that emissions decreased significantly from 7.60 $MmtCO_2e$ in 1990 to 3.59 $MmtCO_2e$ in 2016, a decrease of approximately 52.8%. Figure 8 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). The decrease in GHG emissions from the electric power sector is expected to be a result of fuel shifting away from coal to natural gas as a combustion fuel for electricity generation. In addition, there have been no increases in electricity demand in Delaware, and demand has been trending downwards slightly since 2003[16]. Projected emissions in the electric power sector in Delaware flat-line at 2016 GHG emissions levels. This trend is similar to that projected in the 2016 load forecast by PJM, which shows minor increases in load for the DPL zone[17].

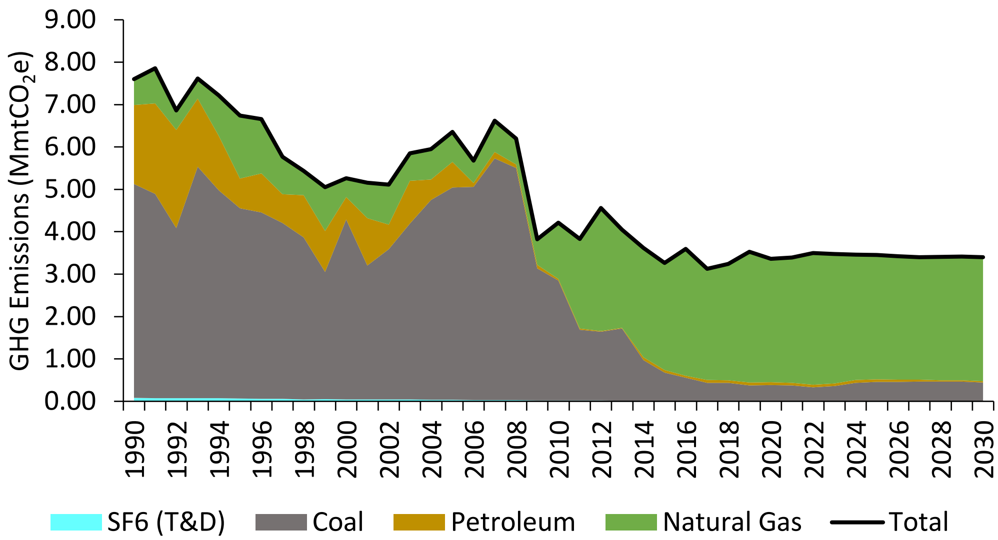

Figure 8. Gross GHG emissions and projections in the electric power sector, including contribution by fuel combustion/transmission and distribution (T&D)

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 96% 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 2016, GHG emissions in transportation sector reached their highest value since 2009. Emissions are projected to increase in 2017, but ultimately decrease from 2018 to 2030. As previously explained, the decrease in emissions is projected from fuel consumption estimates modeled with increasing fuel economy standards.

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

[17] PJM Load Forecast Report January 2016; DPL zone also includes parts of Maryland and Virginia.

Figure 9 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[18]. 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[19]. As stated above, HFC emissions are sourced from A/C 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.

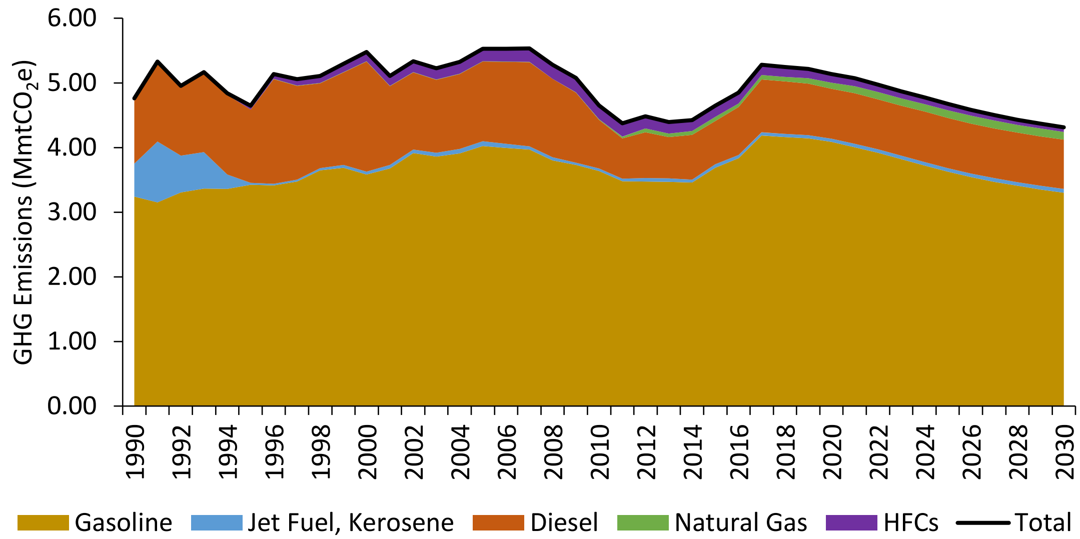

Figure 9. Gross GHG emissions and projections for the transportation sector, including contributions per fossil fuel combusted and total HFC emissions from motor vehicle air conditioning units

Industrial Sector

The industrial sector was the second largest source of GHG emissions in Delaware in 2016, contributing to 27% 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

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

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

processes. The majority of industrial sector GHG emissions in Delaware are from energy related activities, shown in Figure 10. GHG emissions from energy related activities (i.e. fossil fuel combustion) were 93% of the total industrial sector in 2016, and typically are about 90%. Wood burning for energy related activities contributes to <<1% of 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, pipelines, and more.

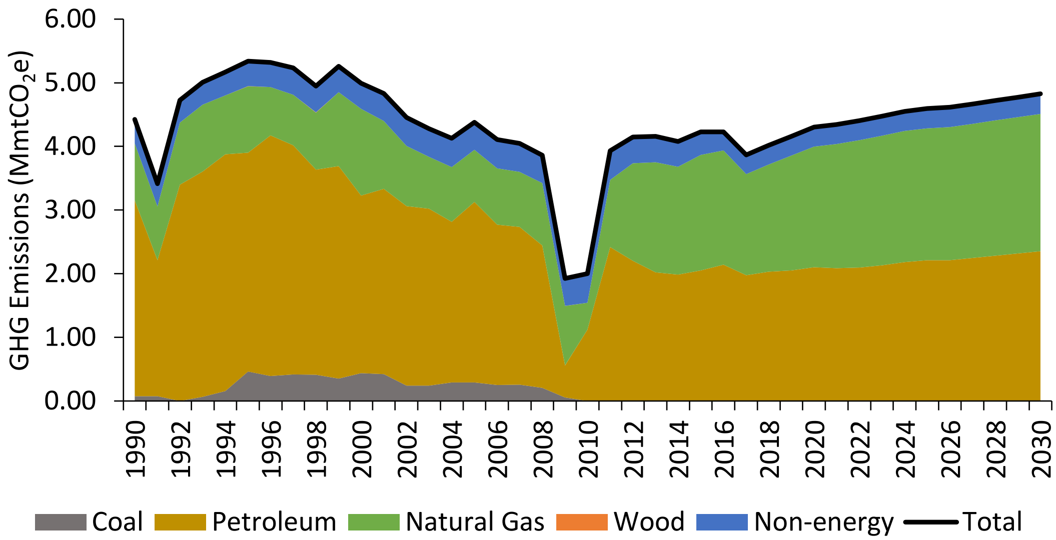

Figure 10. Gross GHG emissions and projections for the industrial sector, including contributions per fossil fuel combusted (energy related) and total non-energy related activity GHG emissions

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[20].

GHG emissions in the industrial sector are projected to follow an upward trend post-2016. By 2025, total industrial sector GHG emissions are projected to increase by approximately 8.5%. The increasing trend is mainly the result of increasing energy related GHG emissions, which are projected using modeled fuel consumption through 2030.

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

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

refrigeration and A/C. The primary fuel type in the residential sector in 2016 and more recent years is natural gas, for which it is mainly used in heating and cooling applications. As Figure 11 shows, historical emissions from 1990 to 2016 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[21]. 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[22]. Further, increased use of HFCs in refrigeration and air-conditioning caused greater GHG emissions in 2014 and 2015. Residential sector GHG emissions decreased again in 2016. Temperature data from the Dover station show that 2016 had nearly 1,000 fewer heating degree days than each of 2014 and 2015.

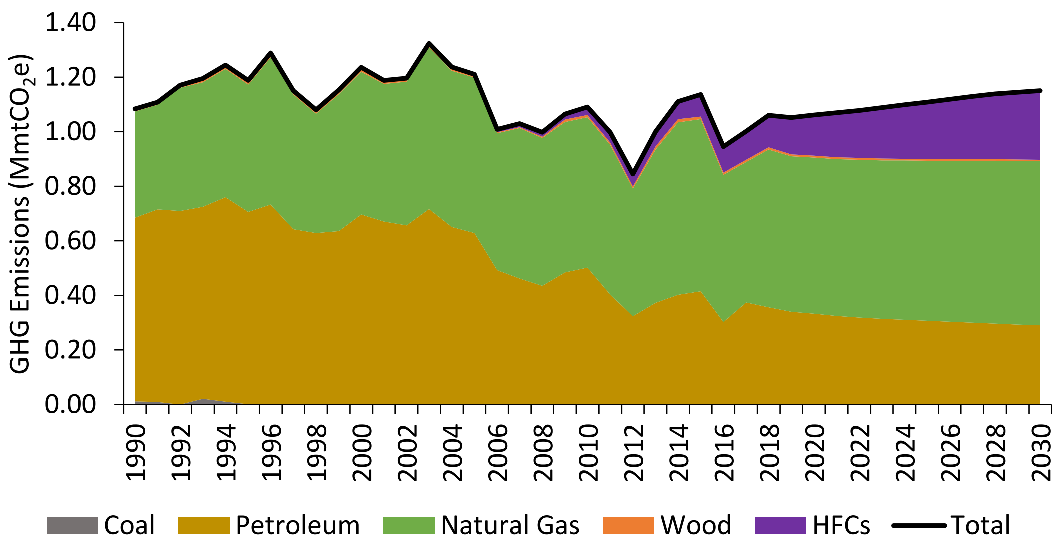

Figure 11. Gross GHG emissions and projections for the residential sector, including contributions per fossil fuel combusted and total HFC emissions from residential refrigeration and air conditioning units

GHG emissions in the residential sector are projected to increase from 2017 to 2030, primarily caused by increases in HFC emissions. Fossil fuel combustion in residential sector is projected to remain constant with a slight decrease. The increased availability and use of energy efficiency innovations have helped to reduce further fossil fuel needs for cooling and heating purposes.

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

Commercial Sector

Commercial sector GHG emissions are associated with fuel use and HFC use among various applications such as heating, cooling, ventilation, lighting, and refrigeration. Like the residential sector, natural gas is the most used fuel type in the commercial sector. As Figure 12 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 fossil fuel combustion appear to be constant from 2017 to 2030; however, significant increases in HFC emissions can be observed. HFCs are used for commercial refrigeration and air conditioning applications, including cold storage, refrigerated retail spaces, and more. Total commercial sector GHG emissions are projected to increase by about 16% in 2025 compared to 2016, while HFC emissions are projected to increase by 64% in that same time period.

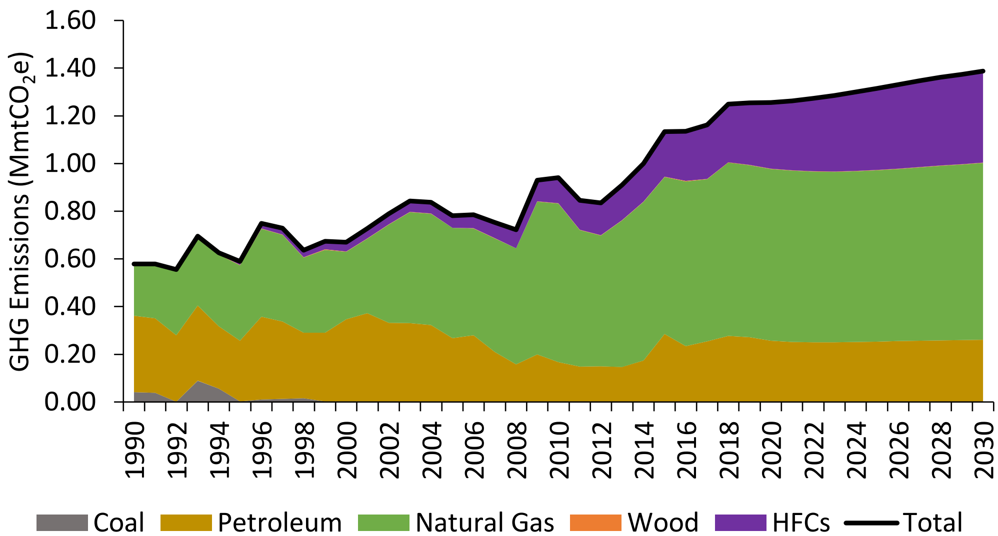

Figure 12. Gross GHG emissions and projections for the commercial sector, including contributions per fossil fuel combusted and total HFC emissions

Agricultural Sector

Agricultural sector GHG emissions represented approximately 4% of the total gross GHG emissions in Delaware in 2016. Per a change in national GHG inventory reporting, GHG emissions associated with liming of soils and urea fertilization are now included in this sector, rather than the LULUCF sector[23]. GHG emissions from the agricultural sector have been essentially constant since 1990, as shown in Figure 13. GHG emissions are projected to remain constant in the agricultural sector through 2030. Liming of soils was estimated and projected

[23] Id 7

based on default data available in the SIT module for the agricultural sector. No data were available for 2014 and prior. The default data for 2015 and 2016 were estimated from an even distribution of agricultural use of limestone from all states that have withheld information in the U.S. Geological Survey (USGS) "Stone, Crushed" Mineral Yearbook (2015 edition, Table 11)[24]. Projections assumed that use and, thus, emissions were constant.

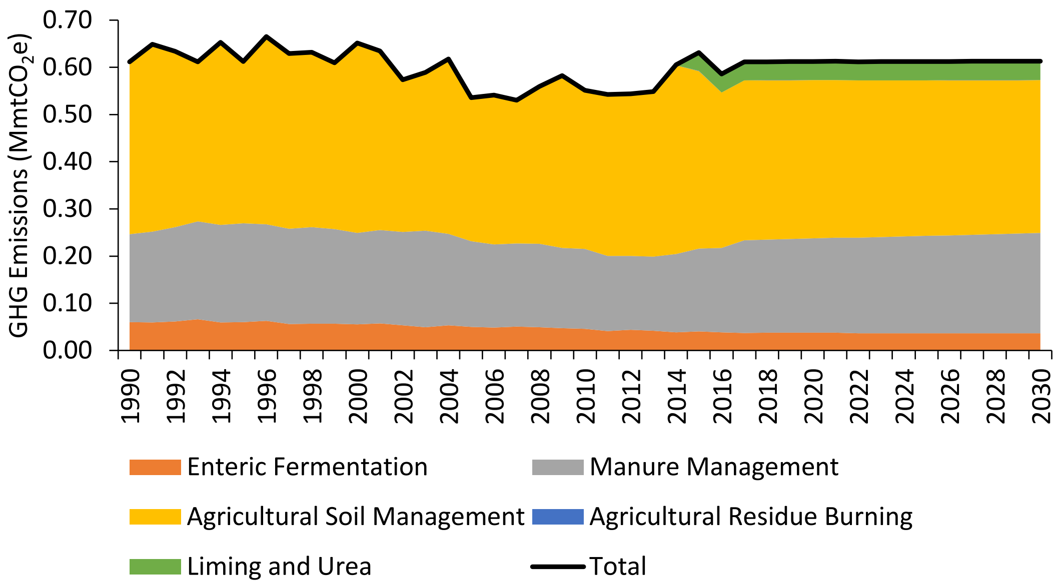

Figure 13. Gross GHG emissions and projections from the agricultural sector in Delaware

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 2016 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 14 presents, emissions fluctuated from 1990 to 2016. 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

[24] 2015 Minerals Yearbook – Stone, Crushed, U.S. Geological Survey; data withheld to avoid disclosing proprietary information

emissions were not observed because processes simply shifted from flaring to LFGTE. GHG emissions in the waste management sector are projected to remain constant from 2017 to 2030, assuming collection rates and efficiencies remain constant through 2030. 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.

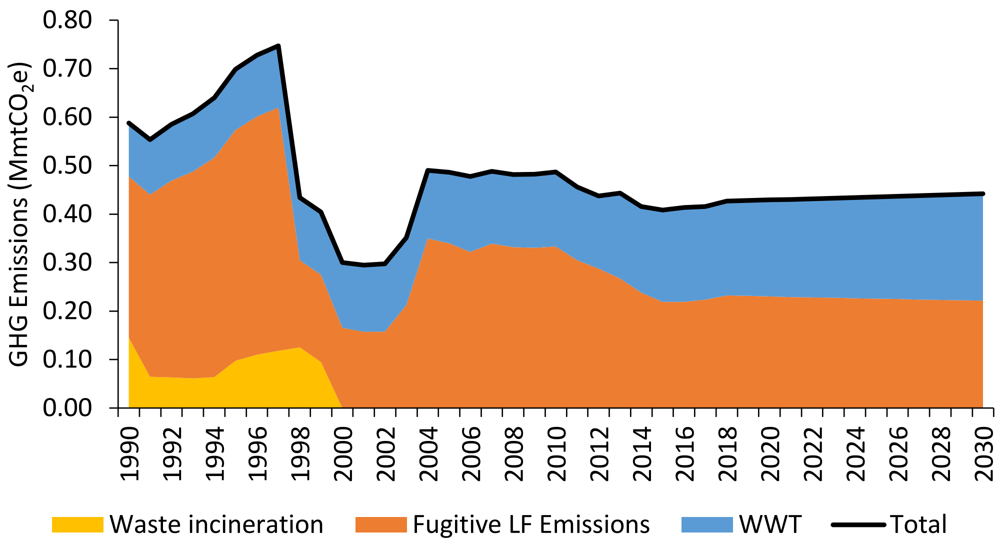

Figure 14. Gross GHG emissions and projections of the waste management sector in Delaware; LF: landfill

Land-use, Land Use Change and Forestry Emission Analysis

The 2016 GHG emissions inventory identified the land-use sector as a major sink[25] 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[26, 27]. In 2016, total GHG emissions for land-use were -0.73 MmtCO$_2$e; meaning, 0.73 MmtCO$_2$e 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$_2$e as indicated in Figure 15. Since it is difficult to project sequestration of carbon, the projection analysis for this sector was based on the

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

assumption that Delaware's change in carbon storage will remain constant from 2017 to 2030. Therefore, the sequestration of 0.73 $MmtCO_2e$ in 2016 is assumed constant from 2017 to 2030.

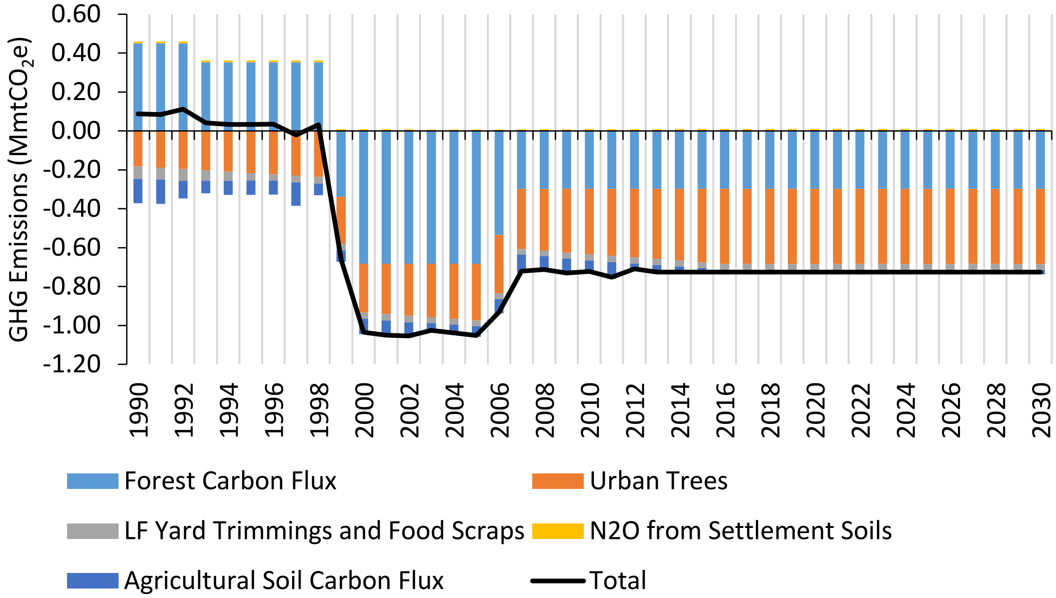

Figure 15. Emissions and sequestration (represented as negative emissions) of carbon (in $MmtCO_2e$) in the LULUCF sector; LF: landfill

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 2016 GHG inventory to show how electricity demand in Delaware impacts GHG emissions. Direct GHG emissions from in-state electricity generation were separated from indirect CO_2 emissions to avoid the double counting of emissions estimates.

Figure 16 shows that indirect GHG emissions from electricity consumption peaked in 2003 and have been declining through 2016. 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 2017 to 2030 show a slight increase. These projections may provide a fair representation of indirect GHG emissions, though they may vary since technological gains in energy efficiency and renewable energy occur rapidly.

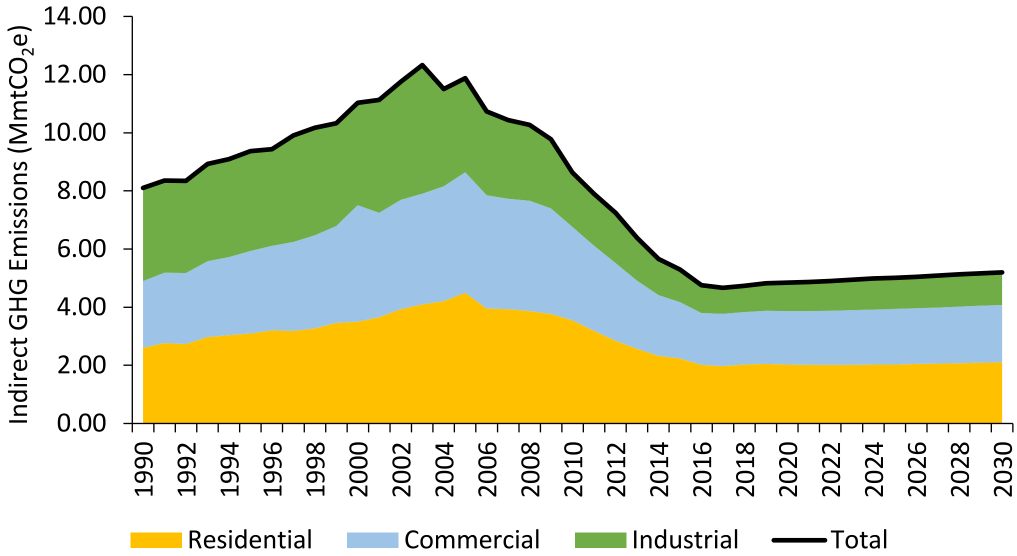

Figure 16. Indirect GHG emissions associated with electricity consumption, per sector, in Delaware

GHG Emissions By Gas

The 2016 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 17 presents gross GHG emissions by gas in 2016. 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 5% and 4%, respectively. The combined emission of HFC, PFC and SF_6 represent approximately 3% of gross GHG emissions from Delaware.

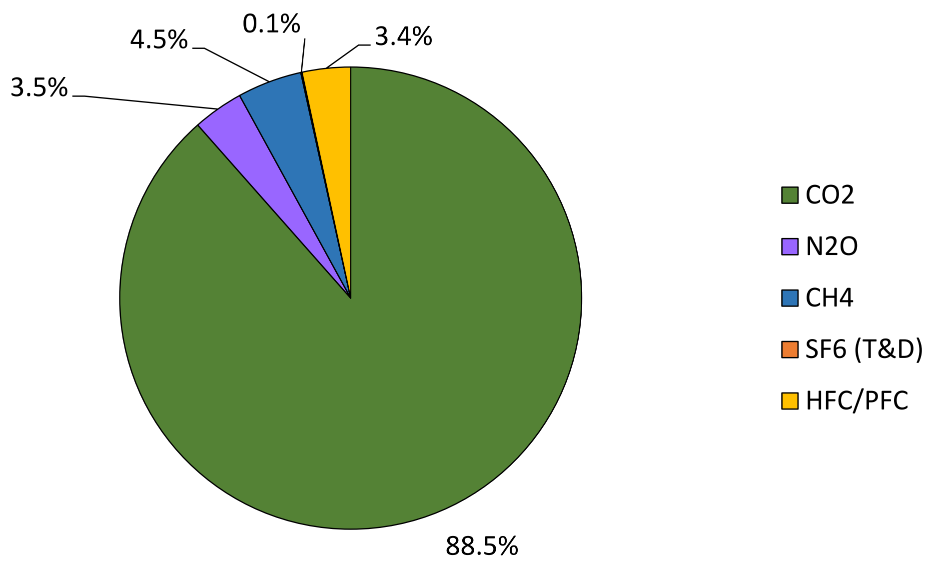

Figure 17. GHG emissions by gas type in 2016 in Delaware (in $MmtCO_2e$)

Figure 19 presents gross GHG emissions by gas in 2025. Carbon dioxide is projected to remain the most emitted GHG representing approximately 87% of gross GHGs emitted in 2025. CH_4 emissions are projected to be 5% of the total gross GHG emissions in 2025. The combined emissions of HFC, PFC and SF_6 is projected to be approximately 5% of gross emissions. N_2O emissions are projected to represent approximately 4% of gross GHG emissions in 2025.

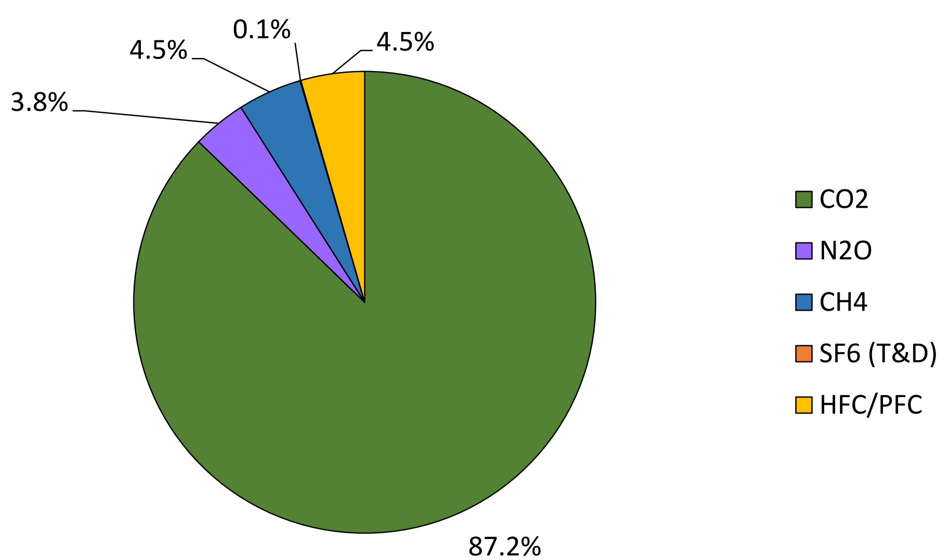

Figure 18. GHG emissions by gas type in 2025 in Delaware (in $MmtCO_2e$)

The emission of CO_2 was driven by fossil fuel combustion in all sectors of Delaware's economy. Approximately 98% of CO_2 emissions came from fossil fuel combustion in 2016. CO_2 was the largest contributor to GHG emissions representing approximately 88% in 2016, and is projected to represent approximately 87% in 2025. 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 19 demonstrates. Gross CO_2 emissions have shown a decreasing trend from 1990 to 2016; however, they are projected to increase slightly in 2017 and remain constant.

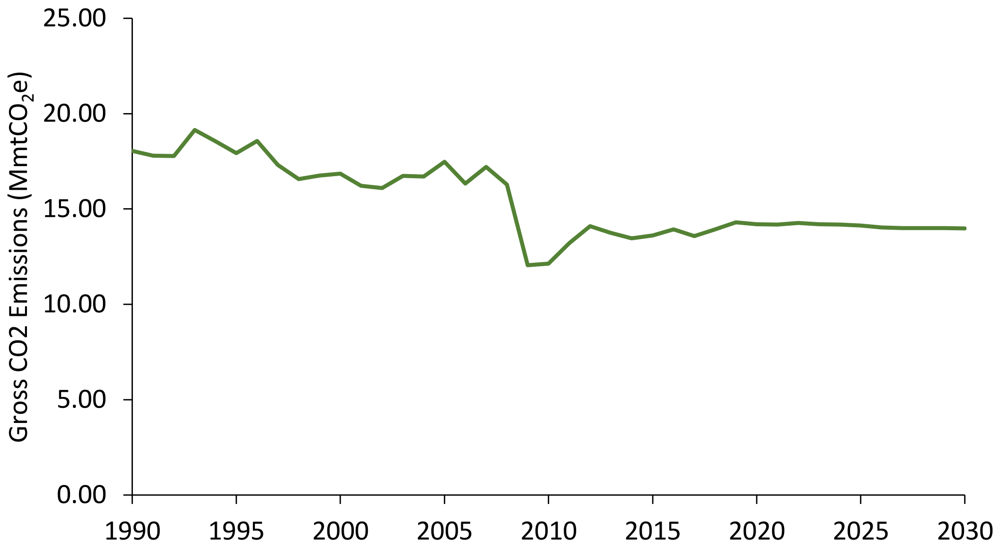

Figure 19. Gross CO_2 emission estimates and projections in Delaware from 1990 to 2030

The remaining five GHGs that were identified in the Kyoto Protocol represent at most 14% of the total gross GHG emissions in a given year between 1990 and 2030. Figure 20 shows emission estimates and projections of each of these non-CO_2 GHGs from 1990 to 2030. It can be seen that there is a significant increase in HFC/PFC emissions (represented only as HFC emissions) from 1990 to 2030. 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 constant amount of N_2O emissions through 2030. SF_6 emissions from power transmission and distribution in Delaware have declined by approximately 83% from 1990 to 2016 and are projected to continue to decrease with time.

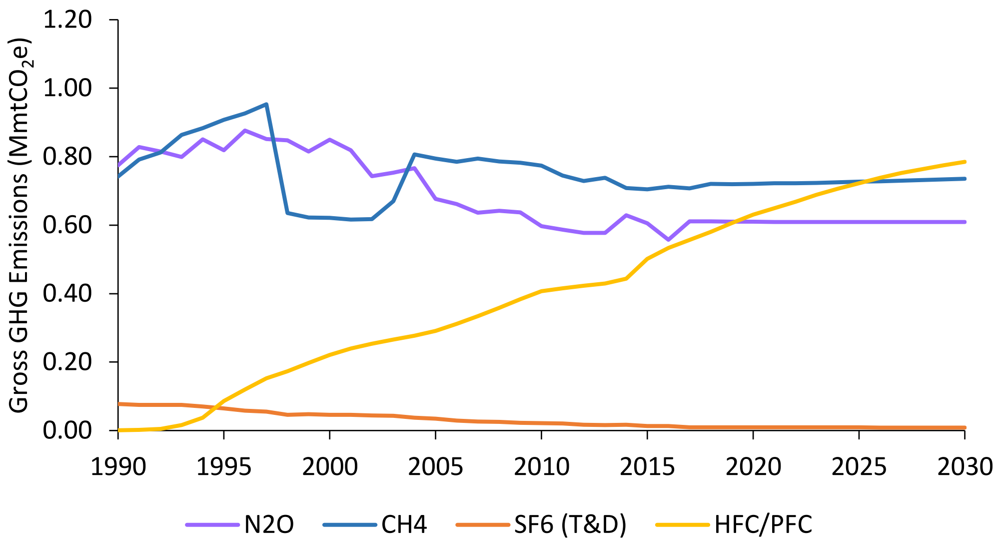

Figure 20. Gross emission estimates and projections of non-CO_2 GHGs in Delaware from 1990 to 2030

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 EPA[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 2016, Delaware ranked 30th in (energy related) GHG emissions per capita according to the U.S Energy Information Administration[29]. As Figure 21 presents, per capita GHG emissions decreased from 29.36 mtonCO_2e/person in 1990 to 16.54 mtonCO_2e/person in 2016, a decrease of approximately 44%. The significant decrease in per capita GHG emissions from 1990 to 2016 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 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 remain essentially constant from 16.07 mtonCO_2e/person in 2017 to 15.93 mtonCO_2e/person in 2030. GHG emissions and population

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

increases are projected to occur at similar rates, which explains why there is not a significant decrease or increase in emissions per capita through 2030.

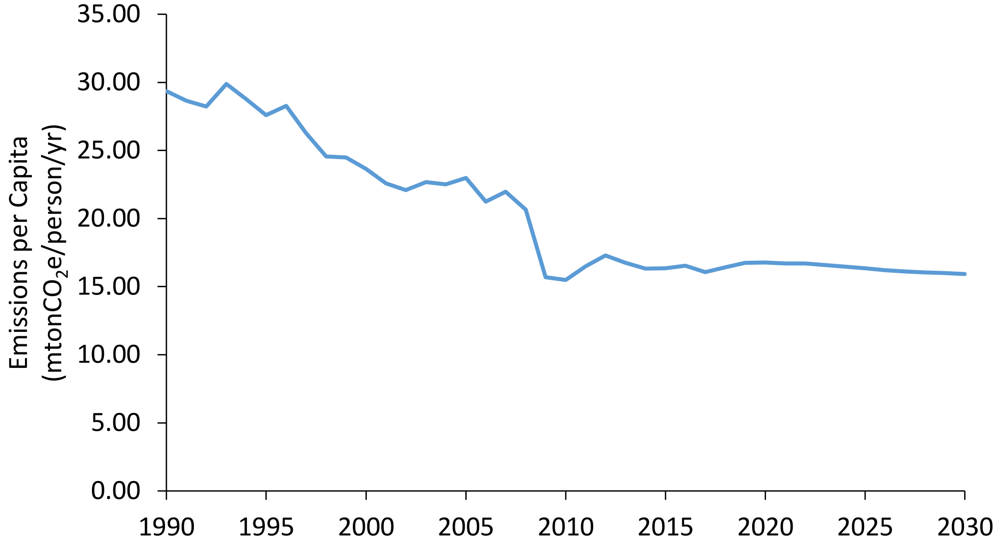

Figure 21. Gross GHG emissions per capita in Delaware