2020

Pennsylvania Greenhouse Gas Inventory Report

July 2020

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

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Greenhouse Gas Inventory Overview

Global climate is changing due to increased concentrations of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and Nitrous Oxide (N_2O) in Earth's atmosphere during the last century[1]. Pennsylvania's Climate Impacts Assessment report[2] states that the commonwealth's climate has undergone a long-term warming of more than 1° C (1.8° F) over the past 110 years, and provides details on how these changes impact Pennsylvanians. These changes in GHG concentrations and global climate have been linked to human activities and are long-lasting, as most GHGs take decades to break down and leave the atmosphere.

The Pennsylvania Climate Change Act (Act 70 of 2008, or Act) requires the Department of Environmental Protection (DEP) to:

- administer a Climate Change Advisory Committee[3];
- set up a voluntary registry of GHG emissions[4];
- prepare a Climate Change Impacts Assessment & provide an update once every three years;
- prepare a Climate Change Action Plan[5] and provide an update once every three years; and
- develop an inventory of GHGs and update this inventory annually.

Greenhouse gas emissions data presented in this inventory help track overall emissions reductions over time. Executive Order 2019-01, signed by Governor Wolf on January 8, 2019, sets GHG emissions reduction goals at 26 percent by 2025 from 2005 levels and 80 percent by 2050 from 2005 levels. The year 2005 is used as a reference point for emissions reductions in order to maintain consistency with U.S. Climate Alliance goals, and goals set forth in the Paris Climate Agreement. As of 2017, Pennsylvania has achieved a nearly 19 percent reduction in GHG emissions, compared to 2005, however, during the last reporting year GHG emissions rose slightly in the commonwealth, by 0.77 million metric tons of carbon dioxide equivalent ($MMTCO_2e$). A reduction of 20.98 $MMTCO_2e$ is required to reach the 2025 goal, and 175.84 $MMTCO_2e$ to reach the 2050 goal. This underscores the need for policies aimed at reducing Pennsylvania's GHG emissions.

Pennsylvania has several sectors which contribute to GHG emissions, and each of these sectors has undergone fluctuations since the year 2005. Changes in amount and type of fuel consumption, growth and contraction in the economy, and duration of severe weather events all have a role in the trends observed in the commonwealth's GHG emissions.

The following sectors emit GHGs in Pennsylvania: residential, commercial, industrial, transportation, electricity production, agriculture, waste management, and forestry and land use. Data for this inventory were primarily obtained from the United States Environmental Protection Agency (EPA) State Inventory Tool (SIT). SIT is an interactive spreadsheet model designed to help states develop GHG emissions inventories and provides a streamlined way to update an existing inventory or complete a new inventory.

The SIT consists of 11 estimation modules applying top-down approach to calculate GHG emissions, and one module to synthesize estimates across all modules. The default data are gathered by federal agencies and incorporate reported data from private, state, and local sources covering fossil fuels, electricity consumption,

[1] IPCC 2014: https://www.ipcc.ch/report/ar5/syr/
[2] Shortle et al. 2009, 2013, 2015 & 2020: https://www.dep.pa.gov/citizens/climate/Pages/impacts.aspx
[3] https://www.dep.pa.gov/Citizens/climate/Pages/CCAC.aspx
[4] https://www.theclimateregistry.org/
[5] https://www.dep.pa.gov/citizens/climate/Pages/PA-Climate-Action-Plan.aspx

agriculture, forestry, waste management, and industry. As is customary, the units for the GHG emissions are given in million metric tons of carbon dioxide equivalent ($MMTCO_2e$). A metric ton is equal to 2,204.6 pounds or approximately 1.1 short tons (US tons)[6]. The GHGs typically accounted for in the SIT are CO_2, CH_4, and N_2O. Each GHG has a different global warming potential (GWP), which is accounted for when converting emissions to $MMTCO_2e$. The default GWP used by the SIT for CO_2 is 1.0, CH_4 = 25, and N_2O = 298. The GWP of a GHG will vary depending on the time scale selected. The default time scale for the SIT is 100 years. In order to provide consistency with previous updates and other state inventories using the SIT, the default values were not changed in compiling the inventory. Where default data are not available, state-specific data is incorporated into the SIT modules, where it is available.

As shown in Table 1, the total statewide gross GHG emissions for Pennsylvania in 2017, the latest year with complete data available from the SIT, were 262.72 $MMTCO_2e$. This is a slight increase of 0.77 $MMTCO_2e$ from 2016. Pennsylvania's Forestry and Land Use sector provides a carbon sink for GHG emissions, absorbing 29.52 $MMTCO_2e$ in 2017, and lowering the commonwealth's net GHG emission for 2017 to 233.20 $MMTCO_2e$. Table 1 also shows a relative decrease of 18.2 percent in the gross emission and 18.7 percent in the net emission totals for 2017 relative to 2005.

Also shown in Table 1, the sectors with the largest contribution to the commonwealth's GHG emissions are the industrial, electricity production and transportation sectors. Emissions from the electricity production sector declined in 2017, continuing the trend observed over the past decade. Additionally, the industrial sector was the highest GHG producing sector in the state in 2017[7]. The relative change for each of these sectors between 2005 and 2017 was a decrease of 8.32 $MMTCO_2e$ (11.5 percent) for the transportation sector, an increase of 3.16 $MMTCO_2e$ (4.0 percent) for the industrial sector, and a decrease of 45.81 $MMTCO_2e$ (37.9 percent) for the electricity production sector. Together, these three sectors annually account for approximately 84 percent of Pennsylvania's gross GHG emissions.

The residential, and commercial sectors also experienced declines in GHG emissions during the time period from 2005 to 2017. The residential and commercial sectors had decreases in GHG emissions of 5.38, and 2.00 $MMTCO_2e$ (22.5 and 15.4 percent), respectively, during this time period. GHG emissions from the agricultural sector have increased slightly, 0.68 $MMTCO_2e$ (8.2 percent), between 2005 and 2017.

GHG emissions from the waste management sector experienced a 0.80 $MMTCO_2e$ (15.7 percent) decrease from 2005 to 2017. During this same period, the GHG emissions sequestered in the forest and land use sector have decreased by 4.95 $MMTCO_2e$ (14.4 percent).

A brief discussion of each individual sector will occur later in the document. The discussion will focus on the trends of various components within each sector, such as fuel mix or subgroups of the sector.

[6] 1 short ton = .90718474 metric tons

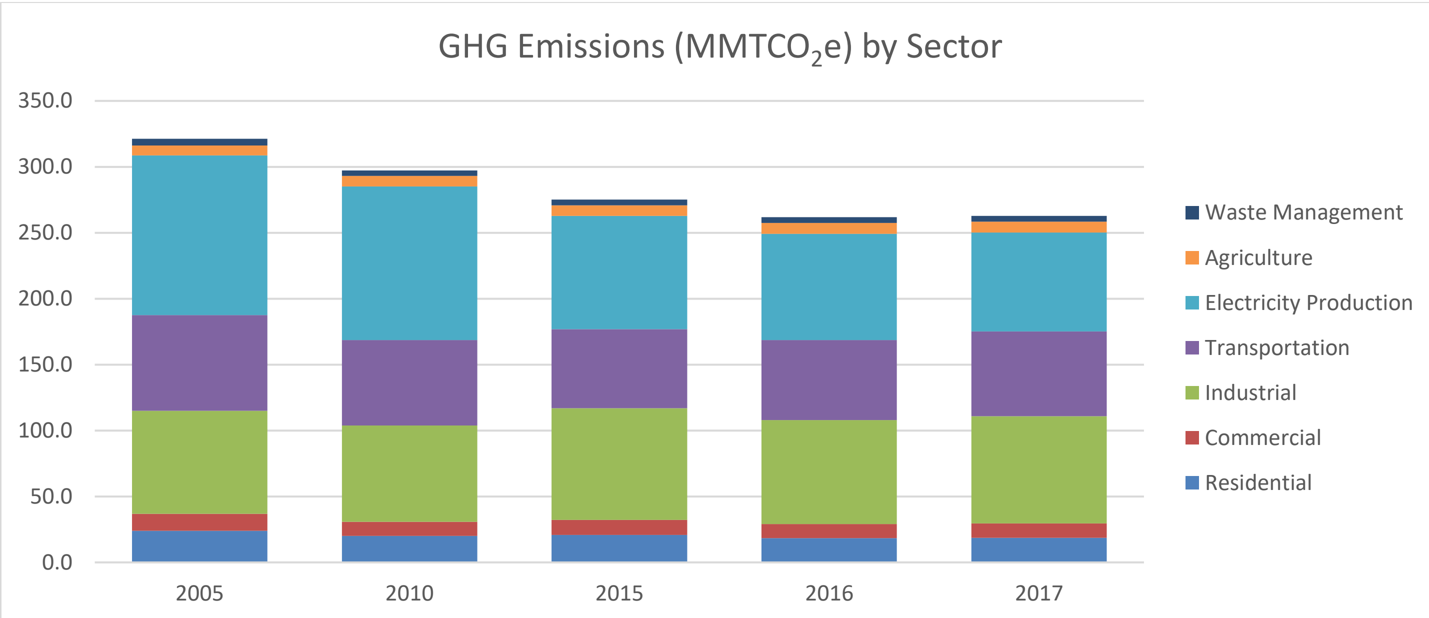
[7] Previous reports indicated that the industrial sector was the greatest contributor to GHG emissions in Pennsylvania since 2015, updated data in the current SIT, and corrections to natural gas distribution pipeline miles revises those estimated emissions downward for previous years.

Table 1 - GHG Emissions by Sector

Sector / Emission Sources (MMTCO$_2$e)	2005	2010	2015	2016	2017
Residential	**23.91**	**20.21**	**20.75**	**18.48**	**18.53**
Commercial	**12.94**	**10.57**	**11.47**	**10.60**	**10.94**
Industrial	**78.20**	**73.16**	**84.62**	**78.87**	**81.35**
Combustion of Fossil Fuels	46.33	39.97	50.49	45.86	47.78
Industrial Process	13.78	13.16	13.54	13.39	13.24
Coal Mining and Abandoned Mines	10.71	12.80	10.70	9.88	10.68
Natural Gas and Oil Systems	7.38	7.23	9.89	9.74	9.65
Transportation	**72.61**	**64.68**	**59.93**	**60.73**	**64.28**
Petroleum	70.89	62.05	57.50	58.48	61.88
Natural Gas	1.71	2.63	2.42	2.26	2.40
Electricity Production	**120.97**	**116.59**	**86.03**	**80.50**	**75.15**
Coal	112.34	102.70	61.38	52.65	46.02
Petroleum	4.19	0.51	0.44	0.25	0.22
Natural Gas	4.43	13.38	24.20	27.59	28.91
Agriculture	**7.57**	**7.97**	**8.03**	**8.29**	**8.19**
Enteric Fermentation	3.37	3.44	3.44	3.52	3.59
Manure Management	1.34	1.33	1.35	1.38	1.36
Agricultural Soil Management	2.81	2.79	3.12	3.18	3.04
Liming of Soils	0.03	0.38	0.08	0.16	0.16
Urea Fertilization	0.02	0.03	0.04	0.04	0.04
Burning of Agricultural Crop Waste	0.00	0.00	0.00	0.00	0.00
Waste Management	**5.06**	**4.03**	**4.25**	**4.32**	**4.27**
Solid Waste and Combustion	3.37	2.25	2.45	2.46	2.46
Waste Water	1.69	1.78	1.80	1.87	1.81
Total Statewide Gross Emissions (Prod.)	**321.26**	**297.20**	**275.09**	**261.79**	**262.72**
Change relative to 2005		*-7.5%*	*-14.4%*	*-18.5%*	*-18.2%*
Forestry and Land Use	-34.47	-31.07	-29.63	-29.36	-29.52
Total Statewide Net Emissions (Prod w/ Sinks)	**286.78**	**266.13**	**245.46**	**232.43**	**233.20**
Change relative to 2005		*-7.2%*	*-14.4%*	*-19.0%*	*-18.7%*

Figure 1 displays the total contribution to the commonwealth's GHG emissions for the residential, commercial, industrial, transportation, electricity production, agriculture, and waste management sectors.

Figure 1– GHG Emissions by Sector ($MMTCO_2e$)



Greenhouse Gas Emissions by Sector

Residential Sector

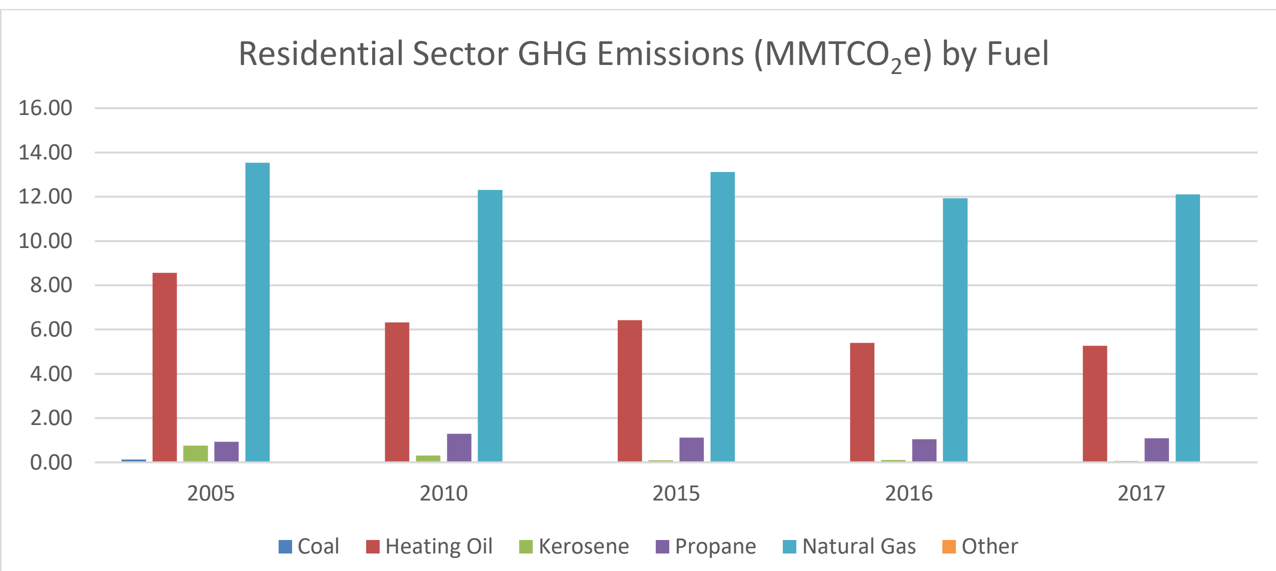
The emissions attributed to the residential sector result from fuels combusted to provide heat and hot water to residential homes within the commonwealth. These fuels, in order of decreasing use in 2017, are natural gas, heating oil, propane, and kerosene. Table 2 shows the amount of each fuel used (BBtu, or billion British thermal units) in residential homes within the commonwealth. Several factors influence the amount of a fuel being used; including the severity of the weather, efficiency of the heating/hot water system, and the price/availability of a particular fuel. No electricity consumption is included in these values.

Table 2– Residential Sector Fuel Consumption (BBtu) by Year

	2005	2010	2015	2016	2017
Coal[8]	1,253	0	0	0	0
Heating Oil	115,753	85,432	86,789	73,049	71,250
Kerosene	10,330	4,211	1,350	1,513	921
Propane	15,122	20,812	18,230	16,909	17,668
Natural Gas	255,038	231,854	247,059	224,764	228,174

Each fuel used in residential homes will emit GHGs at different rates. Figure 2 shows the GHG emission ($MMTCO_2e$) attributed to each fuel used in the residential sector. The emissions from burning firewood to heat residential homes are accounted for in the land use change sector. The emissions related to electricity use for residential homes using electricity for heating or cooling purposes are accounted for in the electricity production sector.

Figure 2 - Residential Sector GHG Emissions by Fuel Type ($MMTCO_2e$)



[8] The U.S. Energy Information Administration, which is the source of default fuel consumption data used in the SIT, assumes that coal use for residential heating is zero from 2008 on.

Commercial Sector

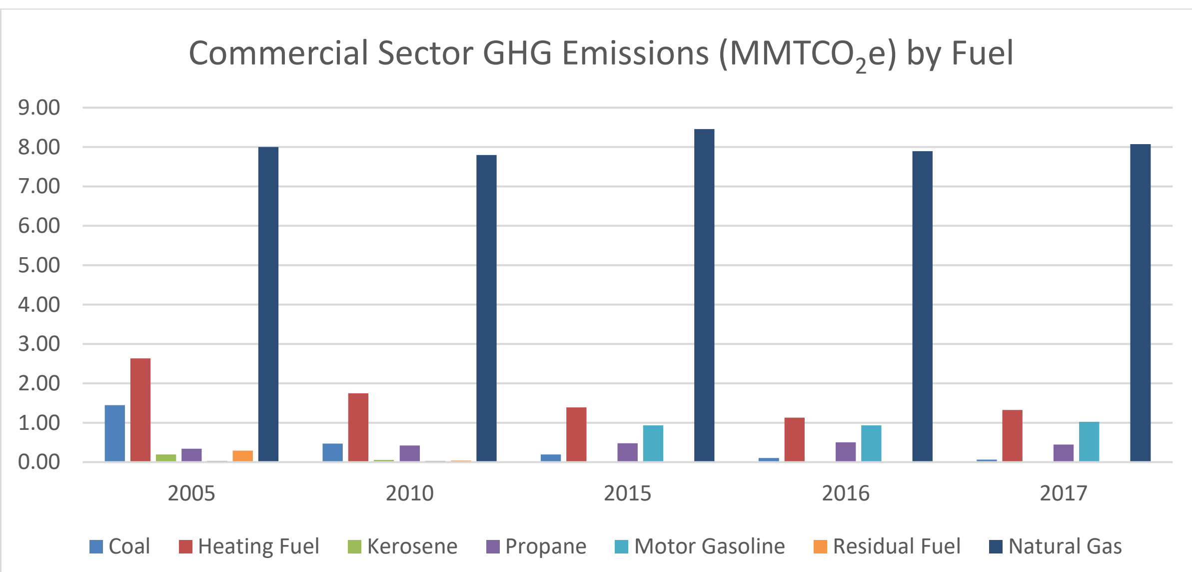
The emissions attributed to the commercial sector result from fuels combusted to provide heat and hot water to commercial buildings within the commonwealth. These fuels, in order of decreasing use in 2017, are natural gas, heating oil, gasoline, propane, coal, kerosene, and residual oil. Table 3 shows the amount of each fuel used (billion Btu) in commercial buildings within the commonwealth. Several factors will influence the amount of a fuel being used; including the severity of the weather, efficiency of the heating/hot water system, and the price/availability of a particular fuel. No electricity consumption is included in these values.

Table 3- Commercial Sector Fuel Consumption (BBtu)

	2005	2010	2015	2016	2017
Coal	14,407	4,729	1,963	1,031	645
Heating Oil	35,632	23,625	18,765	15,272	17,907
Kerosene	2610	755	144	222	143
Propane	5,480	6,853	7,829	8,135	7,225
Motor Gasoline[9]	462	428	13,062	13,142	14,305
Residual Fuel	3,934	570	53	127	3
Natural Gas	150,849	146,902	159,442	148,851	152,218

As in the residential sector, each fuel used in commercial buildings will have different rates of GHG emissions. Figure 3 shows the GHG emissions ($MMTCO_2e$) attributed to each fuel used in the commercial sector. The emissions from burning firewood to heat commercial buildings are accounted for in the forestry and land use sector. The emissions related to electricity use for commercial buildings using electricity for heating or cooling purposes are accounted for in the electricity production sector.

Figure 3– Commercial Sector GHG Emissions by Fuel Type ($MMTCO_2e$)



[9] Beginning in 2015, the Federal Highway Administration (FHWA) has revised its methods of estimating non-highway use of motor gasoline, therefore estimates for motor gasoline consumption by sector from 2015 forward are not compatible with data before 2015.

Industrial Sector

Greenhouse gas emissions from the industrial sector differ from the residential and commercial sectors in that the emissions come from four separate sub-groups: combustion of fossil fuels, the industrial process, activities involving coal mining and abandoned coal mines, and activities involving natural gas and oil systems. Within the four sub-groups, combustion of fossil fuels consistently accounts annually for over 50 percent of the GHG emissions from the industrial sector.

Combustion of Fossil Fuels in the Industrial Sector

The emissions attributed to the industrial sector result from fuels combusted to heat and cool industrial buildings and equipment within the commonwealth. These fuels, in order of decreasing use in 2017, are natural gas, coal/coke, heating oil, and various other fuels. Table 4 shows the amount of each fuel used (BBtu) in the industrial sector within the commonwealth. Several factors will influence the amount of a fuel being used, including the severity of the weather, efficiency of the heating/cooling system, and the price/availability of a particular fuel.

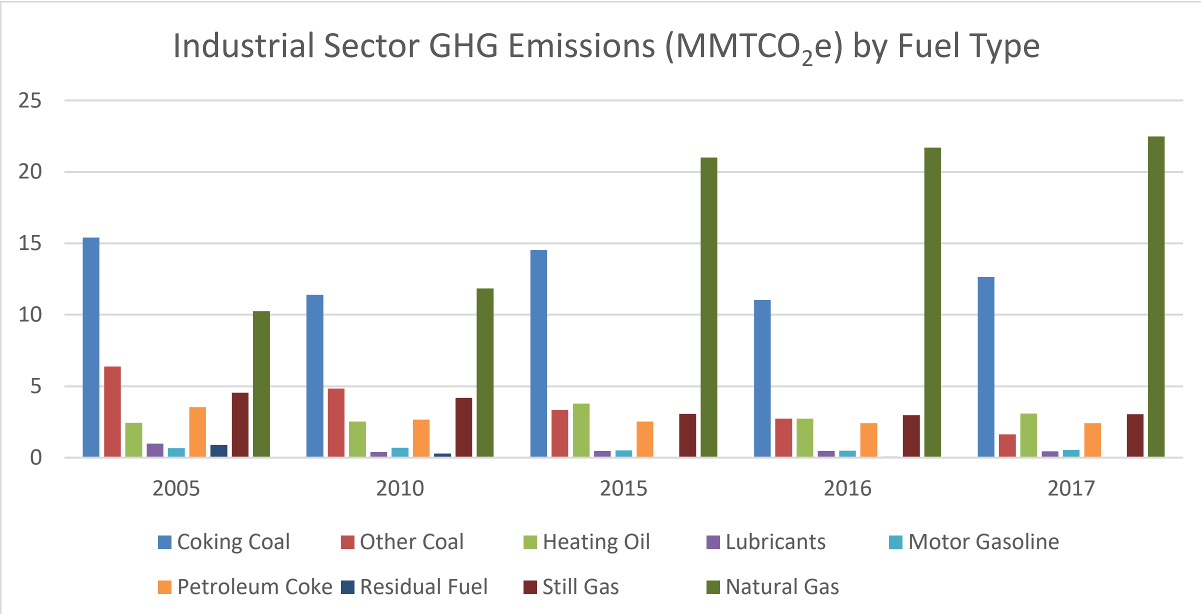
Table 4 – Industrial Sector Fuel Consumption (BBtu)

	2005	2010	2015	2016	2017
Coking Coal	182,475	134,939	172,216	130,860	149,838
Other Coal	67,654	51,240	35,377	28,876	17,257
Heating Oil	33,055	34,088	51,101	36,780	41,820
Propane	23,620	26,755	19,312	19,312	19,312
Lubricants[10]	14,716	5,910	7,064	7,077	6,540
Petroleum Coke	36,889	26,859	25,424	24,379	24,432
Residual Fuel	12,039	4,272	565	770	598
Still Gas	70,200	67,173	49,515	47,789	48,896
Natural Gas	197,525	228,806	404,961	418,060	433,128

As in the residential and commercial sectors, each fuel used in the industrial sector emits GHGs at different rates. Figure 4 shows the GHG emissions (MMTCO_2e) attributed to each fuel used in the industrial sector. The emissions related to electricity within the industrial sector are accounted for in the electricity production sector.

[10] EIA's State Energy Data System (SEDS) modified the methodology for deriving lubricants consumption in data year 2016. https://www.eia.gov/state/seds/seds-data-changes.php?sid=US#2016

Figure 4– Industrial Sector GHG Emissions by Fuel Type ($MMTCO_2e$)



Industrial Process

Some of the industrial processes that are accounted for in this group include: cement manufacturing, lime manufacturing, limestone and dolomite use, iron and steel production, substitutes for ozone-depleting substances (ODS), and electric power transmission and distribution systems. Table 5 shows the GHG emissions ($MMTCO_2e$) attributed to each of the processes included within the industrial sector.

Table 5– Industrial Sector Process Emissions ($MMTCO_2e$)

	2005	2010	2015	2016	2017
Cement Manufacture	3.13	1.65	1.85	1.78	1.77
Lime Manufacture	0.85	0.85	0.73	0.69	0.69
Limestone and Dolomite Use	0.57	0.87	0.95	0.84	0.69
Iron & Steel Production	4.48	3.80	3.80	3.80	3.80
ODS Substitutes	4.27	5.65	5.95	6.00	6.01
Electric Power Transmission and Distribution Systems	0.34	0.23	0.16	0.17	0.17
Other	0.15	0.11	0.11	0.11	0.11
Total	**13.78**	**13.16**	**13.54**	**13.39**	**13.24**

Coal Mining and Abandoned Coal Mines

The GHG emissions associated with coal mining, both underground and surface mines, and processing coal are accounted for in this section. The GHG emissions coming from abandoned coal mines are also included. The majority of emissions come from underground mining activity. The results are determined by measurements of ventilation air from underground mines and by applying emission factors for surface mines, abandoned mines, and for coal processing. Table 6 shows the GHG emissions ($MMTCO_2e$) attributed to underground and surface coal mining, coal processing, and abandoned underground mines.

Table 6– Coal Mining-Related Process Emissions ($MMTCO_2e$)

	2005	2010	2015	2016	2017
Underground Mining	6.64	9.48	8.00	7.38	8.09
Surface Mining	0.73	0.61	0.35	0.24	0.31
Underground Processing	1.16	1.01	0.93	0.88	0.93
Surface Processing	0.12	0.10	0.06	0.04	0.05
Abandoned Mines[11]	2.06	1.59	1.36	1.33	1.31
Total	**10.71**	**12.80**	**10.70**	**9.88**	**10.68**

Natural Gas and Oil Systems

The GHG emissions associated with natural gas production, transmission, and distribution are accounted for in this section. Emission factors are used in determining the total GHG emissions based on the number of natural gas wells, miles of transmission pipeline, and the number and types of services used for distribution in the commonwealth[12]. The natural gas transmission data became available in 2001. An emission factor is also used to determine the GHG emissions based on the total oil production within the commonwealth. Table 7 shows the GHG emissions ($MMTCO_2e$) attributed to natural gas production, transmission, and distribution, and oil production.

Table 7 – Natural Gas Production Process Emissions ($MMTCO_2e$)

	2005	2010	2015	2016	2017
Natural Gas Production	4.78	4.56	7.18	7.01	6.89
Natural Gas Transmission	1.92	1.97	1.98	2.00	2.02
Natural Gas Distribution[13]	0.64	0.65	0.66	0.66	0.67
Oil Production	0.04	0.05	0.07	0.07	0.07
Total	**7.38**	**7.23**	**9.89**	**9.74**	**9.65**

Transportation Sector

The emissions attributed to the transportation sector result from fuels combusted to provide transportation for various types of vehicles within the commonwealth. These fuels, in order of decreasing use in 2017, are gasoline, diesel, jet fuel, and natural gas. Several factors will influence the amount of a fuel being used; including the mode of transportation, efficiency of the vehicle, and the price/availability of a particular fuel. The emissions related to electricity use in transportation are accounted for in the electricity production sector.

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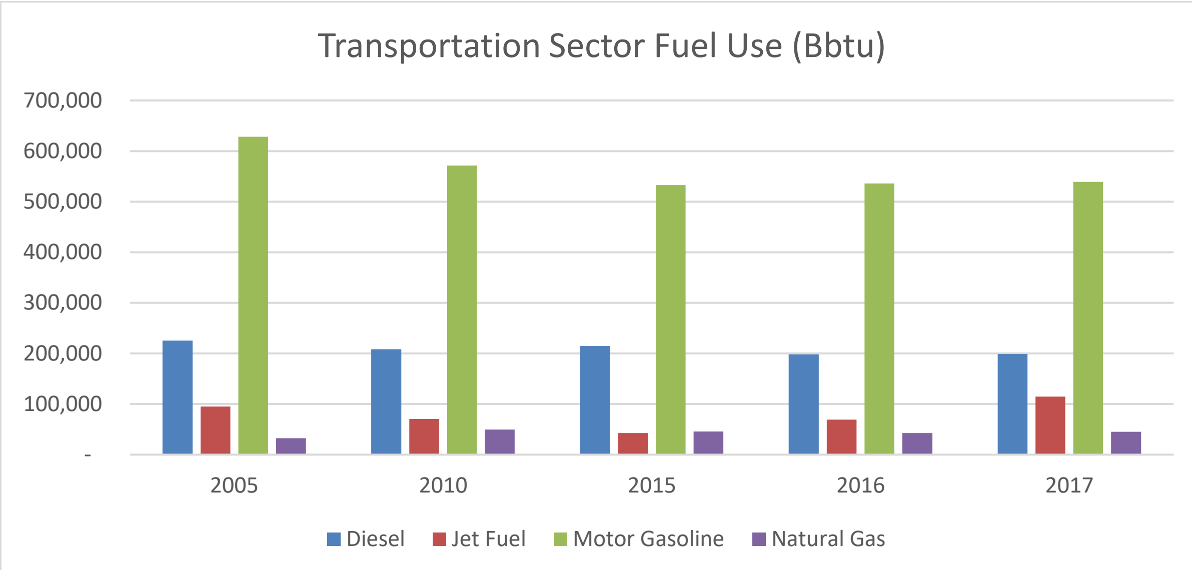
[11] The SIT was updated in 2018 to include data from five additional abandoned mines with closure dates beginning in 2000.

[12] Transmission and distribution pipeline data from the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administrations. https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids

[13] Emissions for natural gas distribution were over-estimated in previous inventories due to a calculation error. This has been corrected, thus the apparent reduction in emissions from this source.

Figure 5– Transportation Sector Fuel Use (BBtu)



As in the previous sectors, each fuel used in transportation will have different rates of GHG emissions. Table 8 shows the GHG emission ($MMTCO_2e$) attributed to each fuel used in the transportation sector. Greenhouse gas emissions from the transportation sector have increased primarily from an increase in air travel and jet fuel use. This continues the trend observed over recent years.

Table 8– Transportation Sector Emissions by Fuel Consumption ($MMTCO_2e$)

	2005	**2010**	**2015**	**2016**	**2017**
Diesel	16.69	15.40	15.86	14.66	14.69
Jet Fuel	6.89	5.10	3.08	5.00	8.28
Motor Gasoline	44.60	40.78	38.01	38.24	38.47
Natural Gas	1.71	2.63	2.42	2.26	2.40
Other	2.73	0.79	0.58	0.58	0.46
Total	**72.63**	**64.70**	**59.94**	**60.75**	**64.30**

Electricity Production Sector

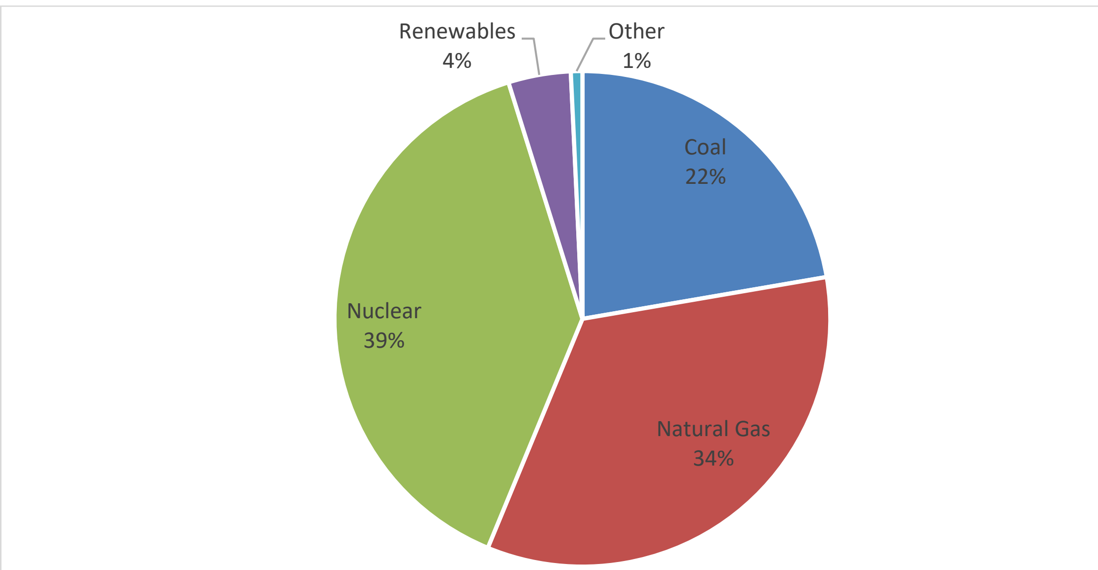
The emissions attributed to the electricity production sector result from fuels combusted to generate electricity within the commonwealth. The electricity production sector has historically been the largest contributor of GHG emissions, however, in 2017 the industrial sector became the largest contributor of GHG emissions. Nearly one third of the statewide gross emissions in 2017 came from the electricity production sector, however, a sizable percentage of these emissions are associated with electricity that is produced and exported to meet the needs of surrounding states. Electricity is produced several different ways within the commonwealth. The three primary forms of electricity generation in Pennsylvania are nuclear, natural gas, and coal. Figure 6 shows the electricity generation in Pennsylvania by fuel for 2017.

The largest changes in the production of electricity since 2005 have occurred in the use of coal and natural gas. From 2016 to 2017, electricity generation from coal continued its decline from 25.4 percent of total generation to 22.3 percent, while electricity generation from natural gas increased from 31.6 percent of total generation to 33.9 percent. Table 9 gives the relative percentages of each fuel used to generate electricity in Pennsylvania.

Table 9– Electricity Generation by Fuel Type (%)[14]

	2005	2010	2015	2016	2017
Coal	55.5%	48.0%	35.7%	25.4%	22.3%
Hydroelectric	1.0%	1.0%	0.9%	0.8%	1.5%
Natural Gas	5.0%	14.7%	24.0%	31.6%	33.9%
Nuclear	35.0%	33.9%	35.6%	38.6%	38.9%
Other	0.3%	0.4%	0.0%	0.4%	0.4%
Biomass	0.6%	0.7%	1.1%	1.1%	0.9%
Other Fossil	0.3%	0.2%	0.6%	0.2%	0.2%
Oil	2.3%	0.3%	0.4%	0.2%	0.2%
Solar	0.0%	0.0%	0.0%	0.0%	0.0%
Wind	0.1%	0.8%	1.6%	1.6%	1.7%

Figure 6– Electricity Generation by Type (%) for 2017



Since electricity produced from nuclear fuel, hydroelectric, solar, and wind creates no direct GHG emissions, the primary fuels associated with GHG emissions from electricity production are coal and natural gas. Table 10 shows the amount of each of these fuels consumed (BBtu) for electricity generation in Pennsylvania.

[14] U.S. Energy Information Administration (EIA). 2018. Net Generation by State by Type of Producer by Energy Source (EIA-906, EIA-920, and EIA-923). Accessed 12/19/2018. https://www.eia.gov/electricity/data/state/

Table 10– Fuel Use for Electricity Generation (BBtu)

	2005	2010	2015	2016	2017
Coal	1,224,911	1,119,758	669,244	574,070	501,784
Natural Gas	83,531	252,182	456,219	520,118	544,924
Oil	51,783	6,812	6,014	3,375	2,985
Total	1,360,225	1,378,752	1,131,477	1,097,563	1,049,693

As in the previous sectors, each fuel used in electricity production emits GHGs at different rates. Figure 7 shows the GHG emission ($MMTCO_2e$) attributed to the three primary fuels used in the electricity production sector.

Figure 7– GHG Emissions by Fuel Type

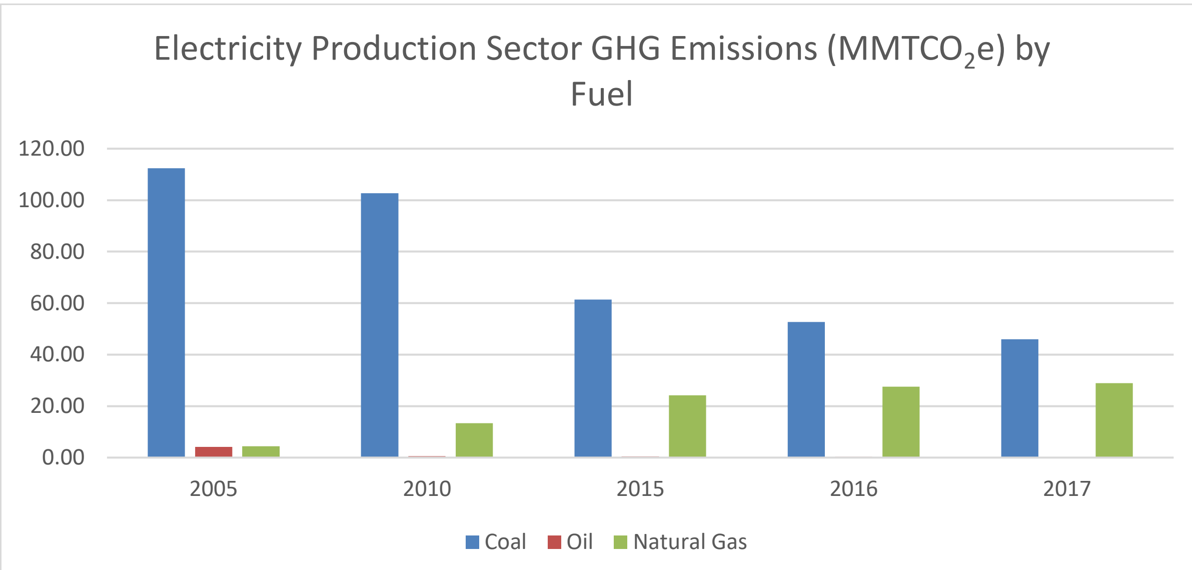


Table 11 gives the relative percentage of GHG emissions attributed to the three primary fuels used in the electricity production sector.

Table 11– Contribution to GHG Emissions, Fuel Type, in the Electricity Sector (%)

	2005	2010	2015	2016	2017
Coal	92.9%	88.1%	71.3%	65.4%	61.2%
Oil	3.5%	0.4%	0.5%	0.3%	0.3%
Natural Gas	3.7%	11.5%	28.1%	34.3%	38.5%

As noted in Tables 9 and 11, for Pennsylvania's electricity generation sector in 2017 coal produced over 61 percent of the GHG emissions while producing approximately 22 percent of the electricity, natural gas produced approximately 39 percent of the GHG emissions while producing approximately 34 percent of the electricity, oil resources produced just over a third of one percent of the GHG emissions while producing about two tenths of one percent of all electricity generated in the commonwealth. Nuclear fuel, which produces no GHG emissions, was responsible for generating nearly 39 percent of the electricity.

As has been noted in previous inventory reports, Pennsylvania has historically been, and is projected to remain, an exporter of electricity to neighboring states. Table 12 shows the total consumption of electricity (TWh) within the residential, commercial, industrial, and transportation sectors.

Table 12 – Electricity Consumption by Sector (TWh)

	2005	2010	2015	2016	2017
Residential	53.66	55.25	54.42	53.88	51.72
Commercial	45.78	47.37	43.75	43.54	42.62
Industrial	47.95	45.46	47.40	47.13	47.89
Transportation	0.88	0.89	0.78	0.79	0.75
Line Loss	6.41%	5.82%	4.73%	4.49%	4.49%
Total	**157.77**	**157.64**	**153.27**	**151.87**	**149.40**

Table 13 gives the total amount of electricity (TWh) consumed in Pennsylvania and the total amount of electricity (TWh) generated. The difference between the two values is the total amount of electricity (TWh) exported from Pennsylvania.

Table 13– Electricity Generated, Consumed and Exported (TWh)

	2005	2010	2015	2016	2017
Electricity Consumed	151.56	151.75	150.67	150.53	148.33
Electricity Generated	218.09	229.75	214.57	215.07	213.64
Electricity Exported	52.86	68.25	54.93	55.74	56.61

Agriculture Sector

At consistently less than eight MMTCO$_2$e annually, the GHG emissions from the agriculture sector are significantly lower than emission from the industrial, transportation, and electricity production sectors. Like the industrial sector, GHG emissions in the agriculture sector are broken down into smaller groups: enteric fermentation, manure management, and soil management. Table 14 lists the number (1,000 head) of each type of farm animal accounted for in the SIT.

Table 14– Animal Populations Contributing to GHG Emissions (1,000 Head)

	2005	2010	2015	2016	2017
Dairy Cows	566	540	530	530	525
Dairy Replacement Heifers	275	300	305	325	315
Beef Cows	154	160	150	170	185
Beef Replacement Heifers	40	40	55	60	65
Heifer Stockers	55	50	55	55	60
Steer Stockers	170	150	145	140	160
Feedlot Heifers	24	24	24	24	24
Feedlot Steer	44	46	46	46	46
Bulls	25	25	25	25	25
Sheep	100	94	86	94	93
Goats	52	54	45	43	41
Swine	1,088	1,133	1,165	1,163	1,200
Horses	115	118	122	123	123

The enteric fermentation group includes animals that produce methane emissions as a result of their unique digestive process. Each type of farm animal has an associated methane emission factor associated with the enteric fermentation process. The total estimated GHG emissions from enteric fermentation then is a summation of the product of the size of the statewide herd of each particular farm animal and the emission factor for that animal. Table 15 shows the GHG emissions (MMTCO$_2$e) attributed to each animal in the agriculture sector due to enteric fermentation.

Table 15– GHG Emissions, by Livestock Type, from Enteric Fermentation (MMTCO$_2$e)

	2005	2010	2015	2016	2017
Dairy Cows	1.936	1.950	1.932	1.934	1.935
Dairy Replacement Heifers	0.440	0.495	0.503	0.536	0.519
Beef Cows	0.357	0.377	0.354	0.401	0.436
Beef Replacement Heifers	0.065	0.071	0.098	0.107	0.116
Heifer Stockers	0.082	0.075	0.083	0.083	0.091
Steer Stockers	0.245	0.217	0.210	0.203	0.232
Feedlot Heifers	0.024	0.026	0.026	0.026	0.026
Feedlot Steer	0.042	0.048	0.048	0.048	0.048
Bulls	0.060	0.061	0.061	0.061	0.061
Sheep	0.020	0.019	0.017	0.019	0.019
Goats	0.006	0.007	0.006	0.005	0.005
Swine	0.041	0.042	0.044	0.044	0.045
Horses	0.052	0.053	0.055	0.055	0.056
Total	**3.370**	**3.442**	**3.436**	**3.523**	**3.589**

The second sub-group of the agriculture sector is the manure management group. As with the enteric fermentation sub-group, each type of farm animal has an associated emission factor for the GHG emission (CH_4 and N_2O) based on the amount of manure that the animal produces. The total GHG emissions from manure management are equal to the summation of the product of the statewide livestock herd size, by animal and the emission factor for that animal. Table 16 shows the GHG emission ($MMTCO_2e$) attributed to each animal in the agriculture sector due to manure management. The "other" category includes sheep, goats, and horses.

Table 16 – GHG Emissions, by Livestock Type, from Manure Management ($MMTCO_2e$)

	2005	2010	2015	2016	2017
Dairy Cattle	0.767	0.764	0.765	0.783	0.762
Beef Cattle	0.054	0.056	0.057	0.059	0.059
Swine	0.301	0.314	0.304	0.311	0.308
Poultry	0.208	0.189	0.215	0.219	0.220
Other	0.012	0.011	0.011	0.011	0.011
Total	**1.343**	**1.334**	**1.352**	**1.382**	**1.361**

The third sub-group of the agriculture sector is the soil management group. GHG emissions (N_2O) from agricultural soils are calculated from the direct and indirect biochemical interactions of fertilizers, livestock, and crop residue with the soil. Table 17 below shows the estimated GHG emissions ($MMTCO_2e$) resulting from agriculture soils management.

Table 17 – GHG Emissions from the Management of Agricultural Soils ($MMTCO_2e$)

	2005	2010	2015	2016	2017
Direct	2.32	2.31	2.57	2.62	2.54
Indirect	0.21	0.21	0.23	0.24	0.22
Leaching and Runoff	0.27	0.27	0.32	0.32	0.28
Total	**2.81**	**2.79**	**3.12**	**3.18**	**3.04**

Waste Management Sector

GHG emissions in the waste management sector primarily come from three sub-groups; landfill gas, solid waste combustion, and wastewater treatment. Landfill gas, which is approximately 50 percent methane, is generated by the decomposition of solid waste within a landfill. Some solid waste in the commonwealth is combusted in waste-to-energy plants, avoiding the production of methane that would otherwise be produced in a landfill, but also results in the release of carbon dioxide. Both municipal wastewater treatment and industrial wastewater treatment are accounted for in the third sub-group.

Data in the SIT regarding the amount of landfilled solid waste in the commonwealth was used to calculate the potential landfill methane emissions. The methane avoided value in Table 18 was calculated using data in the SIT and reflects the amount of methane that otherwise could have entered the atmosphere, but instead was combusted in either a flare or a landfill gas to energy project. A small amount (10 percent) of oxidation occurs in landfills each year, reducing the amount of methane emitted. Table 18 shows the GHG emissions ($MMTCO_2e$) attributable to the potential landfill gas, the avoided methane emissions, and the avoided emissions due to solid waste oxidation.

Table 18– GHG Emissions Associated with Landfilling Operations ($MMTCO_2e$)

	2005	2010	2015	2016	2017
Potential Landfill CH_4	8.81	9.78	9.93	9.97	10.01
CH_4 Avoided	-6.85	-8.89	-9.02	-9.06	-9.10
Oxidation	-0.20	-0.09	-0.09	-0.09	-0.09
Total CH_4 Emissions (Landfills)[15]	**1.76**	**0.80**	**0.81**	**0.82**	**0.82**

The GHG emissions in the solid waste combustion sub-group result from the combustion of certain types of solid waste (plastics, synthetic rubber, and synthetic fibers). To avoid the potential for double counting, the emissions from the combustion of natural or biogenic materials, such as cotton, paper, etc. are omitted because these items would decompose naturally and therefore, no additional CO_2 is emitted from the combustion of these materials. This section also accounts for N_2O and CH_4 gases that are generated in the waste combustion process. Data from the SIT for total solid waste combusted and the relative percentage of each of the materials listed previously was used in the calculation. Table 19 shows the GHG emissions ($MMTCO_2e$) attributable to the combustion of plastics, synthetic rubber, and synthetic fibers of the waste combustion portion of the waste management sector.

Table 19– GHG Emissions Associated with Waste Combustion ($MMTCO_2e$)

	2005	2010	2015	2016	2017
CO_2	1.58	1.42	1.61	1.61	1.61
N_2O	0.03	0.03	0.03	0.03	0.03
CH_4	0.00	0.00	0.00	0.00	0.00
Total CO_2, N_2O, CH_4 Emissions (Waste Combustion)	**1.62**	**1.45**	**1.64**	**1.64**	**1.64**

The GHG emissions from the wastewater portion of the waste management sector are a combination of municipal wastewater treatment (CH_4 and N_2O) and some types of industrial wastewater treatment (red meat, poultry, pulp and paper, and fruit and vegetable production). The SIT was used to calculate the municipal and industrial wastewater GHG emissions. Production data was collected from the United States Department of Agriculture's National Agricultural Statistics Service for the poultry, and fruit and vegetable industrial wastewater treatment sector and multiplied by the SIT-supplied emission factors to determine the total GHG emissions. Table 20 shows the GHG emissions ($MMTCO_2e$) attributed to the treatment of wastewater from municipal and industrial sources in the waste management sector.

Table 20 – GHG Emissions Associated with Wastewater Treatment ($MMTCO_2e$)

	2005	2010	2015	2016	2017
Municipal CH_4	0.99	1.02	1.02	1.02	1.02
Municipal N_2O	0.38	0.38	0.38	0.38	0.38
Industrial CH_4	0.32	0.38	0.39	0.46	0.40
Total	**1.69**	**1.78**	**1.79**	**1.86**	**1.80**

[15] The methodology used in the SIT to determine municipal solid waste generation was changed in 2018. This caused the default data to change for all years between 2009 and 2017. Prior to 2018, these values were held constant at 2008 levels.

Table 21 shows the GHG emissions (MMTCO_2e) totals for the solid waste and wastewater treatment portions of the waste management sector.

Table 21– Total GHG Emissions from the Waste Management Sector (MMTCO_2e)

	2005	2010	2015	2016	2017
Solid Waste	3.37	2.25	2.45	2.46	2.46
Wastewater	1.69	1.78	1.79	1.86	1.80
Total	**5.06**	**4.03**	**4.24**	**4.32**	**4.26**

Forestry and Land Use Sector

The forestry and land use sector is very important in its ability to sequester (absorb) carbon dioxide, reducing the net GHG emission in the commonwealth. In 2017, 29.52 MMTCO_2 of GHG was sequestered in the forestry and land use sector, more than the GHG emissions from the residential and commercial sectors combined. This sector includes forested lands and soils, trees located in urban settings, yard waste, and forest fires. Prior to the 2018 release of the SIT, liming and fertilization of agricultural soils was included in this sector, but those sources are now accounted for in the agricultural sector. Data from the SIT was the primary source of information for this section, however, forest fire acreage is collected from the National Interagency Fire Center[16]. Table 22 shows the total GHG emissions produced (positive values) and emissions sequestered (negative values) (MMTCO_2e) totals for the forestry and land use sector.

Table 22– Total GHG Emissions from the Forestry and Land Use Sector (MMTCO_2e)

	2005	2010	2015	2016	2017
Forest Carbon Flux	-29.32	-27.06	-27.06	-27.06	-27.06
Urban Trees	-3.15	-3.31	-3.46	-3.49	-3.52
Landfilled Yard Trimmings and Food Scraps	-0.38	-0.43	-0.40	-0.39	-0.39
Forest Fires	0.05	0.23	0.95	1.09	0.81
N_2O from Settlement Soils	0.04	0.04	0.06	0.06	0.06
Agricultural Soil Carbon Flux	-1.71	-0.55	0.27	0.43	0.58
Total	**-34.47**	**-31.07**	**-29.63**	**-29.36**	**-29.52**

It is important to note that the EPA's SIT is updated and re-released annually, and as methods for compiling GHG emissions data are refined, estimates for previous years may change with each iteration of the inventory.

[16] https://www.nifc.gov/fireInfo/fireInfo_statistics.html