2. Trends in Greenhouse Gas Emissions

2.1 Recent Trends in U.S. Greenhouse Gas Emissions and Sinks

In 2018, total gross U.S. greenhouse gas emissions were 6,676.6 million metric tons carbon dioxide equivalent (MMT CO_2 Eq).[1] Total U.S. emissions have increased by 3.7 percent from 1990 to 2018, down from a high of 15.2 percent above 1990 levels in 2007. Emissions increased from 2017 to 2018 by 2.9 percent (188.4 MMT CO_2 Eq.). Net emissions (i.e., including sinks) were 5,903 MMT CO_2 Eq. Overall, net emissions increased 3.1 percent from 2017 to 2018 and decreased 10.2 percent from 2005 levels as shown in Table 2-1. The decline reflects many long-term trends, including population, economic growth, energy market trends, technological changes including energy efficiency, and energy fuel choices. Between 2017 and 2018, the increase in total greenhouse gas emissions was driven largely by an increase in CO_2 emissions from fossil fuel combustion. The increase in CO_2 emissions from fossil fuel combustion was a result of multiple factors, including increased energy consumption from greater heating and cooling needs due to a colder winter and hotter summer in 2018 compared to 2017.

Since 1990, U.S. emissions have increased at an average annual rate of 0.2 percent. Figure 2-1 through Figure 2-3 illustrate the overall trend in total U.S. emissions by gas, annual changes, and relative changes since 1990.

[1] The gross emissions total presented in this report for the United States excludes emissions and sinks from removals from Land Use, Land-Use Change, and Forestry (LULUCF). The net emissions total presented in this report for the United States includes emissions and sinks from removals from LULUCF.

Figure 2-1: Gross U.S. Greenhouse Gas Emissions by Gas

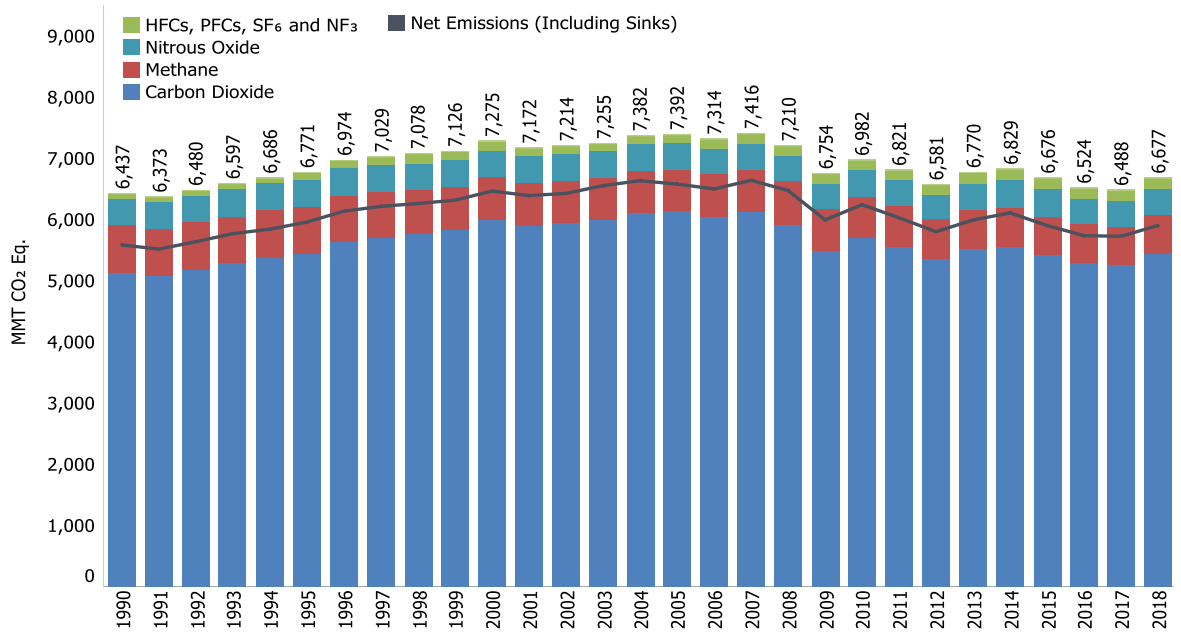


Figure 2-2: Annual Percent Change in Gross U.S. Greenhouse Gas Emissions Relative to the Previous Year

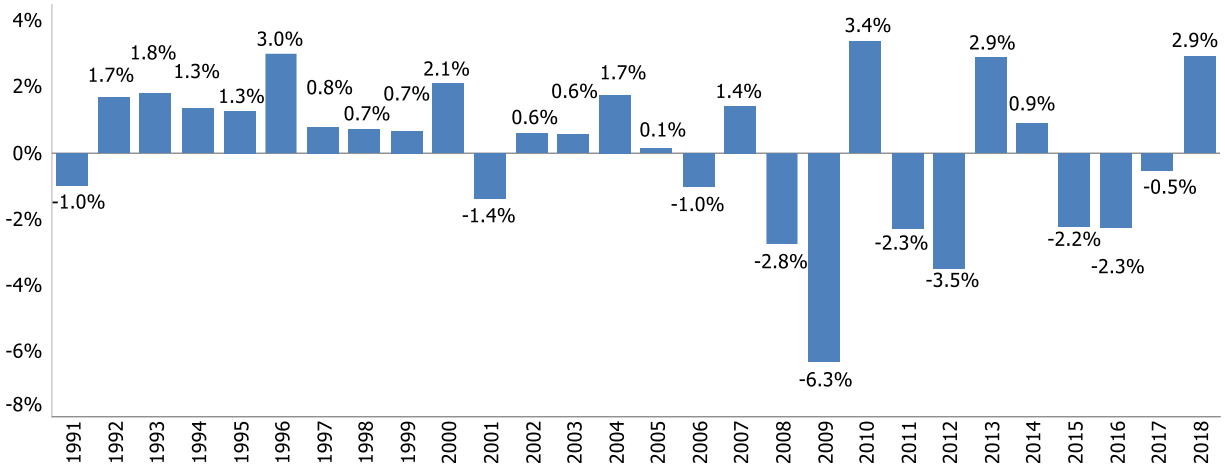
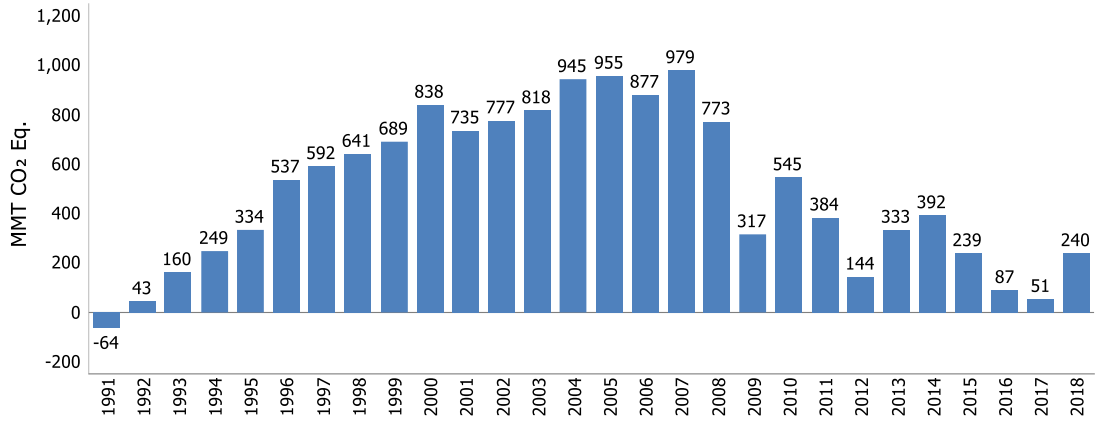


Figure 2-3: Change in Annual Gross U.S. Greenhouse Gas Emissions Relative to 1990 (1990=0, MMT CO_2 Eq.)



Overall, from 1990 to 2018, total emissions of CO_2 increased by 296.6 MMT CO_2 Eq. (5.8 percent), while total emissions of methane (CH_4) decreased by 140.0MMT CO_2 Eq. (18.1 percent), and total emissions of nitrous oxide (N_2O) remained constant despite fluctuations throughout the time series. During the same period, aggregate weighted emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) rose by 83.1 MMT CO_2 Eq. (83.4 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, SF_6, and NF_3 are significant because many of them have extremely high global warming potentials (GWPs), and, in the cases of PFCs, SF_6, and NF_3, long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by carbon (C) sequestration in managed forests, trees in urban areas, agricultural soils, landfilled yard trimmings, and coastal wetlands. These were estimated to offset 12.0 percent (799.6 MMT CO_2 Eq.) of total emissions in 2018.

Table 2-1 summarizes emissions and sinks from all U.S. anthropogenic sources in weighted units of MMT CO_2 Eq., while unweighted gas emissions and sinks in kilotons (kt) are provided in Table 2-2.

Table 2-1: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (MMT CO_2 Eq.)

Gas/Source	1990	2005	2014	2015	2016	2017	2018
CO_2	**5,128.3**	**6,131.9**	**5,561.7**	**5,412.4**	**5,292.3**	**5,253.6**	**5,424.9**
Fossil Fuel Combustion	4,740.0	5,740.7	5,184.8	5,031.8	4,942.4	4,892.2	5,031.8
Transportation	*1,469.1*	*1,856.1*	*1,713.7*	*1,725.3*	*1,765.3*	*1,787.3*	*1,820.7*
Electric Power	*1,820.0*	*2,400.0*	*2,037.1*	*1,900.6*	*1,808.9*	*1,732.0*	*1,752.8*
Industrial	*857.0*	*850.1*	*812.9*	*801.3*	*801.4*	*805.0*	*833.2*
Residential	*338.2*	*357.9*	*346.8*	*317.8*	*293.1*	*293.8*	*337.3*
Commercial	*228.2*	*226.9*	*232.8*	*245.4*	*232.3*	*232.8*	*246.5*
U.S. Territories	*27.6*	*49.7*	*41.4*	*41.4*	*41.4*	*41.4*	*41.4*
Non-Energy Use of Fuels	119.5	139.7	120.0	127.0	113.7	123.1	134.6
Iron and Steel Production & Metallurgical Coke Production	104.7	70.1	58.2	47.9	43.6	40.6	42.6
Cement Production	33.5	46.2	39.4	39.9	39.4	40.3	40.3
Petroleum Systems	9.6	12.2	30.5	32.6	23.0	24.5	36.8
Natural Gas Systems	32.2	25.3	29.6	29.3	29.9	30.4	35.0
Petrochemical Production	21.6	27.4	26.3	28.1	28.3	28.9	29.4
Ammonia Production	13.0	9.2	9.4	10.6	10.8	13.2	13.5
Lime Production	11.7	14.6	14.2	13.3	12.6	12.8	13.2
Incineration of Waste	8.0	12.5	10.4	10.8	10.9	11.1	11.1
Other Process Uses of Carbonates	6.3	7.6	13.0	12.2	10.5	9.9	10.0
Urea Fertilization	2.0	3.1	3.9	4.1	4.0	4.5	4.6

Carbon Dioxide Consumption	1.5	1.4	4.5	4.5	4.5	4.5	4.5
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	1.8	4.6	5.1	3.8	3.6
Liming	4.7	4.3	3.6	3.7	3.1	3.1	3.1
Ferroalloy Production	2.2	1.4	1.9	2.0	1.8	2.0	2.1
Soda Ash Production	1.4	1.7	1.7	1.7	1.7	1.8	1.7
Titanium Dioxide Production	1.2	1.8	1.7	1.6	1.7	1.7	1.5
Aluminum Production	6.8	4.1	2.8	2.8	1.3	1.2	1.5
Glass Production	1.5	1.9	1.3	1.3	1.2	1.3	1.3
Zinc Production	0.6	1.0	1.0	0.9	0.9	1.0	1.0
Phosphoric Acid Production	1.5	1.3	1.0	1.0	1.0	1.0	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2
Abandoned Oil and Gas Wells	+	+	+	+	+	+	+
Magnesium Production and Processing	+	+	+	+	+	+	+
Wood Biomass, Ethanol, and Biodiesel Consumption[a]	*219.4*	*230.7*	*323.2*	*317.7*	*317.2*	*322.2*	*328.9*
International Bunker Fuels[b]	*103.5*	*113.1*	*103.4*	*110.9*	*116.6*	*120.1*	*122.1*
CH_4[c]	**774.4**	**679.6**	**639.0**	**638.5**	**624.2**	**630.3**	**634.5**
Enteric Fermentation	164.2	168.9	164.2	166.5	171.8	175.4	177.6
Natural Gas Systems	183.3	158.1	141.1	141.9	135.8	139.3	140.0
Landfills	179.6	131.3	112.6	111.3	108.0	107.7	110.6
Manure Management	37.1	51.6	54.3	57.9	59.6	59.9	61.7
Coal Mining	96.5	64.1	64.6	61.2	53.8	54.8	52.7
Petroleum Systems	46.1	38.8	43.5	40.5	39.0	38.7	36.2
Wastewater Treatment	15.3	15.4	14.3	14.6	14.4	14.1	14.2
Rice Cultivation	16.0	18.0	15.4	16.2	13.5	12.8	13.3
Stationary Combustion	8.6	7.8	8.9	8.5	7.9	7.8	8.6
Abandoned Oil and Gas Wells	6.6	7.0	7.1	7.1	7.2	7.1	7.0
Abandoned Underground Coal Mines	7.2	6.6	6.3	6.4	6.7	6.4	6.2
Mobile Combustion	12.9	9.6	4.1	3.6	3.4	3.3	3.1
Composting	0.4	1.9	2.1	2.1	2.3	2.4	2.5
Field Burning of Agricultural Residues	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Petrochemical Production	0.2	0.1	0.1	0.2	0.2	0.3	0.3
Ferroalloy Production	+	+	+	+	+	+	+
Carbide Production and Consumption	+	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O[c]	**434.6**	**432.6**	**449.3**	**443.8**	**426.1**	**421.3**	**434.5**
Agricultural Soil Management	315.9	313.0	349.2	348.1	329.8	327.4	338.2
Stationary Combustion	25.1	34.3	33.0	30.5	30.0	28.6	28.4
Manure Management	14.0	16.4	17.3	17.5	18.1	18.7	19.4
Mobile Combustion	42.0	37.3	19.7	18.3	17.4	16.3	15.2
Adipic Acid Production	15.2	7.1	5.4	4.3	7.0	7.4	10.3
Nitric Acid Production	12.1	11.3	10.9	11.6	10.1	9.3	9.3
Wastewater Treatment	3.4	4.4	4.8	4.8	4.9	5.0	5.0
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Composting	0.3	1.7	1.9	1.9	2.0	2.2	2.2

Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.7	2.1	2.0	1.9	1.7	1.5	1.4
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
Electronics Industry	+	0.1	0.2	0.2	0.2	0.3	0.3
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Petroleum Systems	+	+	+	+	+	+	0.1
Natural Gas Systems	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.9*	*1.0*	*0.9*	*1.0*	*1.0*	*1.1*	*1.1*
HFCs	**46.5**	**128.7**	**166.3**	**170.5**	**170.5**	**172.5**	**171.6**
Substitution of Ozone Depleting Substances[d]	0.2	108.4	160.9	165.8	167.3	166.9	167.8
HCFC-22 Production	46.1	20.0	5.0	4.3	2.8	5.2	3.3
Electronics Industry	0.2	0.2	0.3	0.3	0.3	0.4	0.4
Magnesium Production and Processing	0.0	0.0	0.1	0.1	0.1	0.1	0.1
PFCs	**24.3**	**6.7**	**5.6**	**5.1**	**4.3**	**4.0**	**4.6**
Electronics Industry	2.8	3.2	3.1	3.0	2.9	2.9	3.0
Aluminum Production	21.5	3.4	2.5	2.0	1.4	1.0	1.6
Substitution of Ozone Depleting Substances[d]	0.0	+	+	+	+	+	0.1
SF_6	**28.8**	**11.8**	**6.5**	**5.5**	**6.1**	**5.9**	**5.9**
Electrical Transmission and Distribution	23.2	8.4	4.8	3.8	4.1	4.1	4.1
Magnesium Production and Processing	5.2	2.7	0.9	1.0	1.1	1.1	1.1
Electronics Industry	0.5	0.7	0.7	0.7	0.8	0.7	0.8
NF_3	**+**	**0.5**	**0.5**	**0.6**	**0.6**	**0.6**	**0.6**
Electronics Industry	+	0.5	0.5	0.6	0.6	0.6	0.6
Unspecified Mix of HFCs, PFCs, SF_6, and NF_3	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Electronics Industry	+	+	+	+	+	+	+
Total Emissions	**6,437.0**	**7,391.8**	**6,829.0**	**6,676.4**	**6,524.1**	**6,488.2**	**6,676.6**
LULUCF Emissions[c]	**7.4**	**16.3**	**16.6**	**27.4**	**12.8**	**26.1**	**26.1**
LULUCF CH_4 Emissions	4.4	8.8	9.5	16.1	7.3	15.2	15.2
LULUCF N_2O Emissions	3.0	7.5	7.0	11.2	5.5	10.8	10.9
LULUCF Carbon Stock Change[e]	**(860.7)**	**(831.0)**	**(739.6)**	**(802.9)**	**(801.7)**	**(790.0)**	**(799.6)**
LULUCF Sector Net Total[f]	**(853.4)**	**(814.7)**	**(723.0)**	**(775.5)**	**(788.9)**	**(763.9)**	**(773.5)**
Net Emissions (Sources and Sinks)	**5,583.6**	**6,577.1**	**6,106.0**	**5,900.8**	**5,735.1**	**5,724.3**	**5,903.2**

Notes: Total emissions presented without LULUCF. Net emissions presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Emissions from Wood Biomass, Ethanol, and Biodiesel Consumption are not included specifically in summing Energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for LULUCF.

[b] Emissions from International Bunker Fuels are not included in totals.

[c] LULUCF emissions of CH_4 and N_2O are reported separately from gross emissions totals. LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils. Refer to Table 2-8 for a breakout of emissions and removals for LULUCF by gas and source category.

[d] Small amounts of PFC emissions also result from this source.

[e] LULUCF Carbon Stock Change is the net C stock change from the following categories: *Forest Land Remaining Forest Land*, *Land Converted to Forest Land*, *Cropland Remaining Cropland*, *Land Converted to Cropland*, *Grassland Remaining Grassland*, *Land Converted to Grassland*, *Wetlands Remaining Wetlands*, *Land Converted to Wetlands*, *Settlements Remaining Settlements*, and *Land Converted to Settlements*. Refer to Table 2-8 for a breakout of emissions and removals for LULUCF by gas and source category.

[f] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Table 2-2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (kt)

Gas/Source	1990	2005	2014	2015	2016	2017	2018
CO_2	**5,128,301**	**6,131,893**	**5,561,719**	**5,412,432**	**5,292,268**	**5,253,606**	**5,424,882**
Fossil Fuel Combustion	4,740,006	5,740,660	5,184,776	5,031,762	4,942,421	4,892,234	5,031,813
Transportation	*1,469,092*	*1,856,113*	*1,713,722*	*1,725,274*	*1,765,307*	*1,787,274*	*1,820,656*
Electric Power	*1,819,951*	*2,399,974*	*2,037,148*	*1,900,624*	*1,808,863*	*1,732,025*	*1,752,849*
Industrial	*857,009*	*850,072*	*812,899*	*801,260*	*801,422*	*805,006*	*833,207*
Residential	*338,209*	*357,934*	*346,811*	*317,798*	*293,148*	*293,818*	*337,251*
Commercial	*228,191*	*226,867*	*232,835*	*245,439*	*232,320*	*232,756*	*246,493*
U.S. Territories	*27,555*	*49,700*	*41,361*	*41,367*	*41,362*	*41,355*	*41,357*
Non-Energy Use of Fuels	119,530	139,707	120,030	127,027	113,651	123,133	134,576
Iron and Steel Production & Metallurgical Coke Production	104,734	70,081	58,187	47,944	43,624	40,576	42,600
Cement Production	33,484	46,194	39,439	39,907	39,439	40,324	40,324
Petroleum Systems	9,630	12,163	30,536	32,644	22,980	24,472	36,814
Natural Gas Systems	32,174	25,291	29,620	29,334	29,862	30,365	34,972
Petrochemical Production	21,611	27,383	26,254	28,062	28,310	28,910	29,424
Ammonia Production	13,047	9,196	9,377	10,634	10,838	13,216	13,532
Lime Production	11,700	14,552	14,210	13,342	12,630	12,833	13,223
Incineration of Waste	7,951	12,469	10,435	10,756	10,919	11,111	11,113
Other Process Uses of Carbonates	6,297	7,644	12,954	12,182	10,505	9,935	9,954
Urea Fertilization	2,011	3,150	3,923	4,082	4,041	4,514	4,598
Carbon Dioxide Consumption	1,472	1,375	4,471	4,471	4,471	4,471	4,471
Urea Consumption for Non-Agricultural Purposes	3,784	3,653	1,807	4,578	5,132	3,769	3,628
Liming	4,667	4,349	3,609	3,737	3,081	3,080	3,147
Ferroalloy Production	2,152	1,392	1,914	1,960	1,796	1,975	2,063
Soda Ash Production	1,431	1,655	1,685	1,714	1,723	1,753	1,714
Titanium Dioxide Production	1,195	1,755	1,688	1,635	1,662	1,688	1,541
Aluminum Production	6,831	4,142	2,833	2,767	1,334	1,205	1,451
Glass Production	1,535	1,928	1,336	1,299	1,241	1,296	1,263
Zinc Production	632	1,030	956	933	925	1,009	1,009
Phosphoric Acid Production	1,529	1,342	1,037	999	998	1,028	940
Lead Production	516	553	459	473	500	513	513
Carbide Production and Consumption	375	219	173	180	174	186	189
Abandoned Oil and Gas Wells	6	7	7	7	7	7	7
Magnesium Production and Processing	1	3	2	3	3	3	1
Wood Biomass, Ethanol, and Biodiesel Consumption[a]	*219,413*	*230,700*	*323,187*	*317,742*	*317,191*	*322,225*	*328,938*
International Bunker Fuels[b]	*103,463*	*113,139*	*103,400*	*110,887*	*116,594*	*120,107*	*122,088*
CH_4[c]	**30,976**	**27,182**	**25,560**	**25,539**	**24,970**	**25,212**	**25,378**
Enteric Fermentation	6,566	6,755	6,567	6,660	6,874	7,016	7,103
Natural Gas Systems	7,332	6,324	5,643	5,674	5,433	5,570	5,598
Landfills	7,182	5,253	4,503	4,452	4,322	4,308	4,422
Manure Management	1,485	2,062	2,172	2,316	2,385	2,395	2,467
Coal Mining	3,860	2,565	2,583	2,449	2,154	2,191	2,109

Petroleum Systems	1,844	1,553	1,739	1,622	1,559	1,548	1,449
Wastewater Treatment	614	618	573	583	575	566	569
Rice Cultivation	640	720	616	648	539	510	533
Stationary Combustion	344	313	355	340	318	312	346
Abandoned Oil and Gas Wells	263	278	284	286	289	282	281
Abandoned Underground Coal Mines	288	264	253	256	268	257	247
Mobile Combustion	518	383	166	146	138	131	126
Composting	15	75	84	85	91	98	98
Field Burning of Agricultural Residues	14	16	16	16	16	16	16
Petrochemical Production	9	3	5	7	10	10	12
Ferroalloy Production	1	+	1	1	1	1	1
Carbide Production and Consumption	1	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	1	1	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*7*	*5*	*3*	*4*	*4*	*4*	*4*
N_2O[c]	**1,458**	**1,452**	**1,508**	**1,489**	**1,430**	**1,414**	**1,458**
Agricultural Soil Management	1,060	1,050	1,172	1,168	1,107	1,099	1,135
Stationary Combustion	84	115	111	102	101	96	95
Manure Management	47	55	58	59	61	63	65
Mobile Combustion	141	125	66	62	58	55	51
Adipic Acid Production	51	24	18	14	23	25	35
Nitric Acid Production	41	38	37	39	34	31	31
Wastewater Treatment	11	15	16	16	16	17	17
N_2O from Product Uses	14	14	14	14	14	14	14
Composting	1	6	6	6	7	7	7
Caprolactam, Glyoxal, and Glyoxylic Acid Production	6	7	7	6	6	5	5
Incineration of Waste	2	1	1	1	1	1	1
Electronics Industry	+	+	1	1	1	1	1
Field Burning of Agricultural Residues	1	1	1	1	1	1	1
Petroleum Systems	+	+	+	+	+	+	+
Natural Gas Systems	+	+	+	+	+	+	+
International Bunker Fuels[b]	*3*	*3*	*3*	*3*	*3*	*4*	*4*
HFCs	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Substitution of Ozone Depleting Substances[d]	M	M	M	M	M	M	M
HCFC-22 Production	3	1	+	+	+	+	+
Electronics Industry	M	M	M	M	M	M	M
Magnesium Production and Processing	0	0	+	+	+	+	+
PFCs	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Electronics Industry	M	M	M	M	M	M	M
Aluminum Production	M	M	M	M	M	M	M
Substitution of Ozone Depleting Substances[d]	0	+	+	+	+	+	+
SF_6	**1**	**1**	**+**	**+**	**+**	**+**	**+**
Electrical Transmission and Distribution	1	+	+	+	+	+	+

Magnesium Production and Processing	+	+	+	+	+	+	+
Electronics Industry	+	+	+	+	+	+	+
NF_3	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Electronics Industry	+	+	+	+	+	+	+
Unspecified Mix of HFCs, PFCs, SF_6, and NF_3	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Electronics Industry	M	M	M	M	M	M	M

Notes: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.
+ Does not exceed 0.5 kt.
M - Mixture of multiple gases
[a] Emissions from Wood Biomass, Ethanol, and Biodiesel Consumption are not included specifically in summing Energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for LULUCF.
[b] Emissions from International Bunker Fuels are not included in totals.
[c] LULUCF emissions of CH_4 and N_2O are reported separately from gross emissions totals. Refer to Table 2-8 for a breakout of emissions and removals for LULUCF by gas and source category.
[d] Small amounts of PFC emissions also result from this source.

Emissions of all gases can be summed from each source category into a set of five sectors defined by the Intergovernmental Panel on Climate Change (IPCC). Figure 2-4 and Table 2-3 illustrate that over the twenty-nine-year period of 1990 to 2018, total emissions from the Energy, Industrial Processes and Product Use, and Agriculture sectors grew by 209.1 MMT CO_2 Eq. (3.9 percent), 30.9 MMT CO_2 Eq. (9.0 percent), and 64.1 MMT CO_2 Eq. (11.6 percent), respectively. Emissions from the Waste sector decreased by 64.6 MMT CO_2 Eq. (32.4 percent). Over the same period, total C sequestration in the Land Use, Land-Use Change, and Forestry (LULUCF) sector decreased by 61.1 MMT CO_2 (7.1 percent decrease in total C sequestration), and emissions from the LULUCF sector increased by 18.7 MMT CO_2 Eq. (254.2 percent).

Figure 2-4: U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (MMT CO_2 Eq.)

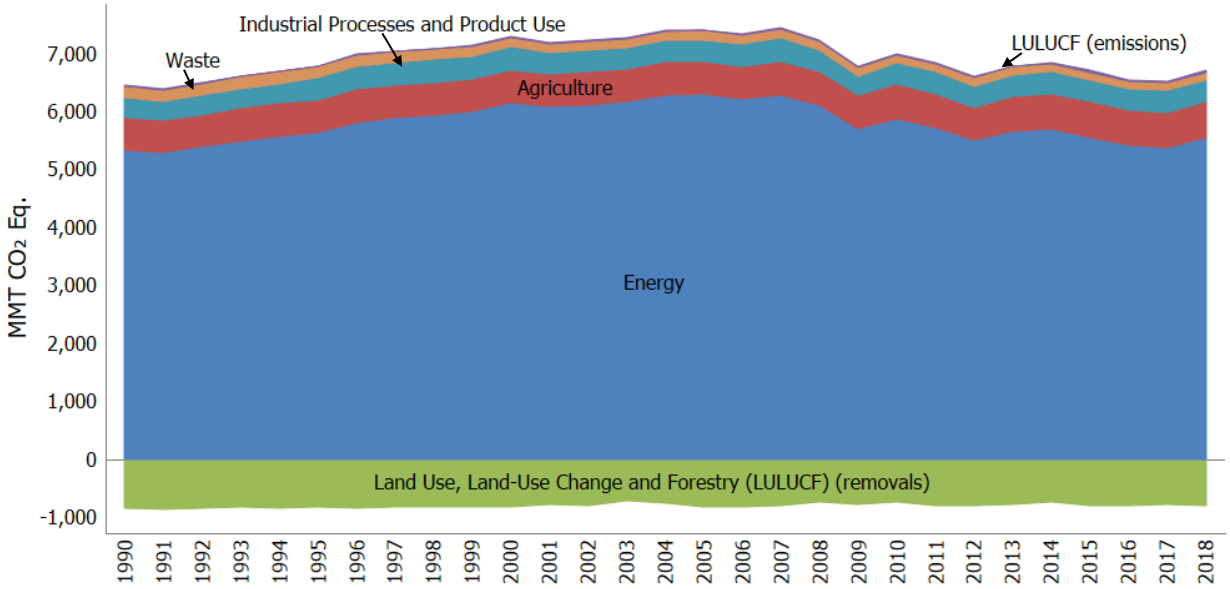


Table 2-3: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (MMT CO_2 Eq.)

Chapter/IPCC Sector	1990	2005	2014	2015	2016	2017	2018
Energy	**5,338.1**	**6,294.4**	**5,704.0**	**5,550.1**	**5,421.6**	**5,383.8**	**5,547.2**

Fossil Fuel Combustion	4,740.0	5,740.7	5,184.8	5,031.8	4,942.4	4,892.2	5,031.8
Natural Gas Systems	215.5	183.4	170.7	171.2	165.7	169.6	174.9
Non-Energy Use of Fuels	119.5	139.7	120.0	127.0	113.7	123.1	134.6
Petroleum Systems	55.7	51.0	74.0	73.2	62.0	63.2	73.1
Coal Mining	96.5	64.1	64.6	61.2	53.8	54.8	52.7
Stationary Combustion	33.7	42.1	41.8	39.0	38.0	36.4	37.0
Mobile Combustion	55.0	46.9	23.9	22.0	20.8	19.6	18.4
Incineration of Waste	8.4	12.9	10.7	11.1	11.2	11.4	11.4
Abandoned Oil and Gas Wells	6.6	7.0	7.1	7.2	7.2	7.1	7.0
Abandoned Underground Coal Mines	7.2	6.6	6.3	6.4	6.7	6.4	6.2
Industrial Processes and Product Use	**345.6**	**366.8**	**380.8**	**377.1**	**370.4**	**370.7**	**376.5**
Substitution of Ozone Depleting Substances	0.2	108.5	161.0	165.8	167.3	166.9	167.9
Iron and Steel Production & Metallurgical Coke Production	104.8	70.1	58.2	48.0	43.6	40.6	42.6
Cement Production	33.5	46.2	39.4	39.9	39.4	40.3	40.3
Petrochemical Production	21.8	27.5	26.4	28.2	28.6	29.2	29.7
Ammonia Production	13.0	9.2	9.4	10.6	10.8	13.2	13.5
Lime Production	11.7	14.6	14.2	13.3	12.6	12.8	13.2
Adipic Acid Production	15.2	7.1	5.4	4.3	7.0	7.4	10.3
Other Process Uses of Carbonates	6.3	7.6	13.0	12.2	10.5	9.9	10.0
Nitric Acid Production	12.1	11.3	10.9	11.6	10.1	9.3	9.3
Electronics Industry	3.6	4.8	4.9	5.0	5.0	4.9	5.1
Carbon Dioxide Consumption	1.5	1.4	4.5	4.5	4.5	4.5	4.5
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Electrical Transmission and Distribution	23.2	8.4	4.8	3.8	4.1	4.1	4.1
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	1.8	4.6	5.1	3.8	3.6
HCFC-22 Production	46.1	20.0	5.0	4.3	2.8	5.2	3.3
Aluminum Production	28.3	7.6	5.4	4.8	2.7	2.3	3.0
Ferroalloy Production	2.2	1.4	1.9	2.0	1.8	2.0	2.1
Soda Ash Production	1.4	1.7	1.7	1.7	1.7	1.8	1.7
Titanium Dioxide Production	1.2	1.8	1.7	1.6	1.7	1.7	1.5
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.7	2.1	2.0	1.9	1.7	1.5	1.4
Glass Production	1.5	1.9	1.3	1.3	1.2	1.3	1.3
Magnesium Production and Processing	5.2	2.7	1.0	1.1	1.2	1.2	1.2
Zinc Production	0.6	1.0	1.0	0.9	0.9	1.0	1.0
Phosphoric Acid Production	1.5	1.3	1.0	1.0	1.0	1.0	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2
Agriculture	**554.4**	**575.9**	**608.6**	**614.6**	**600.5**	**602.3**	**618.5**
Agricultural Soil Management	315.9	313.0	349.2	348.1	329.8	327.4	338.2
Enteric Fermentation	164.2	168.9	164.2	166.5	171.8	175.4	177.6
Manure Management	51.1	67.9	71.6	75.4	77.7	78.5	81.1
Rice Cultivation	16.0	18.0	15.4	16.2	13.5	12.8	13.3
Urea Fertilization	2.0	3.1	3.9	4.1	4.0	4.5	4.6
Liming	4.7	4.3	3.6	3.7	3.1	3.1	3.1
Field Burning of Agricultural Residues	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Waste	**199.0**	**154.7**	**135.6**	**134.7**	**131.6**	**131.4**	**134.4**
Landfills	179.6	131.3	112.6	111.3	108.0	107.7	110.6
Wastewater Treatment	18.7	19.8	19.1	19.3	19.2	19.1	19.2
Composting	0.7	3.5	4.0	4.0	4.3	4.6	4.7

Total Emissions[a]	**6,437.0**	**7,391.8**	**6,829.0**	**6,676.4**	**6,524.1**	**6,488.2**	**6,676.6**
Land Use, Land-Use Change, and Forestry	**(853.4)**	**(814.7)**	**(723.0)**	**(775.5)**	**(788.9)**	**(763.9)**	**(773.5)**
Forest land	(841.7)	(780.0)	(719.5)	(765.9)	(762.3)	(739.0)	(754.5)
Cropland	30.9	24.8	44.4	44.4	32.7	33.3	38.7
Grassland	2.6	(28.9)	(4.3)	(8.9)	(14.6)	(13.4)	(12.8)
Wetlands	(0.5)	(2.0)	(0.6)	(0.7)	(0.7)	(0.7)	(0.7)
Settlements	(44.7)	(28.5)	(43.0)	(44.5)	(44.1)	(44.3)	(44.2)
Net Emission (Sources and Sinks)[b]	**5,583.6**	**6,577.1**	**6,106.0**	**5,900.8**	**5,735.1**	**5,724.3**	**5,903.2**

Notes: Total emissions presented without LULUCF. Net emissions presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

[a] Total emissions without LULUCF.

[b] Net emissions with LULUCF.

Energy

Energy-related activities, primarily fossil fuel combustion, accounted for the vast majority of U.S. CO_2 emissions for the period of 1990 through 2018. Fossil fuel combustion is the largest source of energy-related emissions, with CO_2 being the primary gas emitted (see Figure 2-5). Due to their relative importance, fossil fuel combustion-related CO_2 emissions are considered in detail in the Energy chapter (see Energy chapter).

In 2018, approximately 80 percent of the energy consumed in the United States (on a Btu basis) was produced through the combustion of fossil fuels. The remaining 20 percent came from other energy sources such as hydropower, biomass, nuclear, wind, and solar energy. A discussion of specific trends related to CO_2 as well as other greenhouse gas emissions from energy use is presented here with more detail in the Energy chapter. Energy-related activities are also responsible for CH_4 and N_2O emissions (40 percent and 10 percent of total U.S. emissions of each gas, respectively). Table 2-4 presents greenhouse gas emissions from the Energy chapter, by source and gas.

Figure 2-5: 2018 Energy Chapter Greenhouse Gas Sources (MMT CO_2 Eq.)

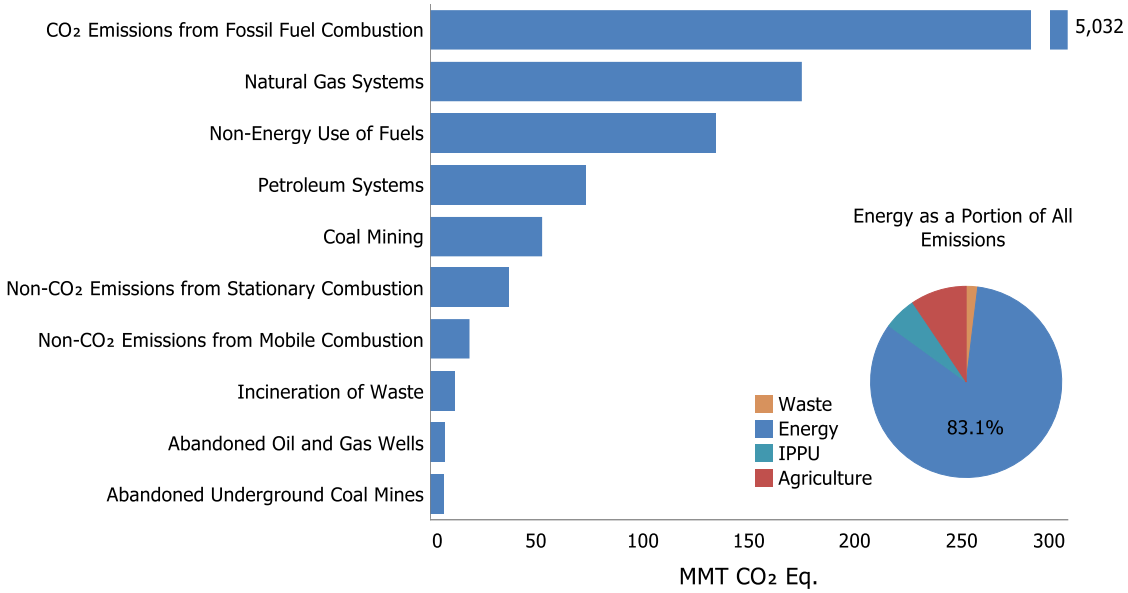


Table 2-4: Emissions from Energy (MMT CO_2 Eq.)

Gas/Source	1990	2005	2014	2015	2016	2017	2018
CO_2	**4,909.3**	**5,930.3**	**5,375.4**	**5,231.5**	**5,119.8**	**5,081.3**	**5,249.3**
Fossil Fuel Combustion	4,740.0	5,740.7	5,184.8	5,031.8	4,942.4	4,892.2	5,031.8
Transportation	*1,469.1*	*1,856.1*	*1,713.7*	*1,725.3*	*1,765.3*	*1,787.3*	*1,820.7*
Electric Power Sector	*1,820.0*	*2,400.0*	*2,037.1*	*1,900.6*	*1,808.9*	*1,732.0*	*1,752.8*
Industrial	*857.0*	*850.1*	*812.9*	*801.3*	*801.4*	*805.0*	*833.2*
Residential	*338.2*	*357.9*	*346.8*	*317.8*	*293.1*	*293.8*	*337.3*
Commercial	*228.2*	*226.9*	*232.8*	*245.4*	*232.3*	*232.8*	*246.5*
U.S. Territories	*27.6*	*49.7*	*41.4*	*41.4*	*41.4*	*41.4*	*41.4*
Non-Energy Use of Fuels	119.5	139.7	120.0	127.0	113.7	123.1	134.6
Petroleum Systems	9.6	12.2	30.5	32.6	23.0	24.5	36.8
Natural Gas Systems	32.2	25.3	29.6	29.3	29.9	30.4	35.0
Incineration of Waste	8.0	12.5	10.4	10.8	10.9	11.1	11.1
Abandoned Oil and Gas Wells	+	+	+	+	+	+	+
Biomass-Wood[a]	*215.2*	*206.9*	*233.8*	*224.7*	*216.3*	*221.4*	*229.1*
International Bunker Fuels[b]	*103.5*	*113.1*	*103.4*	*110.9*	*116.6*	*120.1*	*122.1*
Biofuels-Ethanol[a]	*4.2*	*22.9*	*76.1*	*78.9*	*81.2*	*82.1*	*81.9*
Biofuels-Biodiesel[a]	*0.0*	*0.9*	*13.3*	*14.1*	*19.6*	*18.7*	*17.9*
CH_4	**361.2**	**292.0**	**275.6**	**269.3**	**253.9**	**257.3**	**253.9**
Natural Gas Systems	183.3	158.1	141.1	141.9	135.8	139.3	140.0
Coal Mining	96.5	64.1	64.6	61.2	53.8	54.8	52.7
Petroleum Systems	46.1	38.8	43.5	40.5	39.0	38.7	36.2
Stationary Combustion	8.6	7.8	8.9	8.5	7.9	7.8	8.6
Abandoned Oil and Gas Wells	6.6	7.0	7.1	7.1	7.2	7.1	7.0
Abandoned Underground Coal Mines	7.2	6.6	6.3	6.4	6.7	6.4	6.2
Mobile Combustion	12.9	9.6	4.1	3.6	3.4	3.3	3.1
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O	**67.6**	**72.1**	**53.1**	**49.2**	**47.8**	**45.2**	**44.0**
Stationary Combustion	25.1	34.3	33.0	30.5	30.0	28.6	28.4
Mobile Combustion	42.0	37.3	19.7	18.3	17.4	16.3	15.2
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
Petroleum Systems	+	+	+	+	+	+	0.1
Natural Gas Systems	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.9*	*1.0*	*0.9*	*1.0*	*1.0*	*1.1*	*1.1*
Total	**5,338.1**	**6,294.4**	**5,704.0**	**5,550.1**	**5,421.6**	**5,383.8**	**5,547.2**

Note: Totals may not sum due to independent rounding.

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Emissions from Wood Biomass and Biofuel Consumption are not included specifically in summing energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for LULUCF.

[b] Emissions from International Bunker Fuels are not included in totals.

CO_2 Emissions from Fossil Fuel Combustion

As the largest contributor to U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion has accounted for approximately 76 percent of GWP-weighted emissions across the time series Emissions from this source category grew by 6.2 percent (291.8 MMT CO_2 Eq.) from 1990 to 2018 and were responsible for most of the increase in national emissions during this period. Conversely, CO_2 emissions from fossil fuel combustion decreased by 708.8 MMT CO_2 Eq. from 2005 and by 319.2 MMT CO_2 Eq. from 2010, representing decreases of approximately 12.3 percent between 2005 and 2018 and 6.0 percent between 2010 and 2018. From 2017 to 2018, these emissions

increased by 2.9 percent (139.6 MMT CO_2 Eq.). Historically, changes in emissions from fossil fuel combustion have been the main factor influencing U.S. emission trends.

Changes in CO_2 emissions from fossil fuel combustion are affected by many long-term and short-term factors, including population and economic growth, energy price fluctuations and market trends, technological changes, energy fuel choices, and seasonal temperatures. On an annual basis, the overall consumption and mix of fossil fuels in the United States fluctuates primarily in response to changes in general economic conditions, overall energy prices, the relative price of different fuels, weather, and the availability of non-fossil alternatives. For example, coal consumption for electric power is influenced by a number of factors including the relative price of coal and alternative sources, the ability to switch fuels, and longer-term trends in coal markets. Likewise, warmer winters lead to a decrease in heating degree days and result in a decreased demand for heating fuel and electricity for heat in the residential and commercial sectors, which leads to a decrease in emissions from reduced fuel consumption.

Fossil fuel combustion CO_2 emissions also depend on the type of fuel consumed or energy used and its C intensity. Producing a unit of heat or electricity using natural gas instead of coal, for example, reduces CO_2 emissions because of the lower C content of natural gas (see Table A-42 in Annex 2.1 for more detail on the C Content Coefficient of different fossil fuels).

Trends in CO_2 emissions from fossil fuel combustion over the past five years have been strongly influenced by the electric power sector, which historically has accounted for the largest share of emissions from this source (see Figure 2-6). The types of fuel consumed to produce electricity have changed in recent years, impacting emission trends. Emissions increased 1.2 percent from 2017 to 2018 due to increasing electric power generation from natural gas and renewables and decreasing generation from coal. Carbon dioxide emissions from coal consumption for electric power generation decreased by 26.5 percent since 2014 and 42 percent since 2005, which can be largely attributed to a shift to the use of less-CO_2-intensive natural gas to generate electricity and a rapid increase in the use of renewable energy in the electric power sector in recent years. Electricity generation from renewable sources increased by 32.6 percent from 2014 to 2018 and natural gas generation increased by 32.2 percent over the same time period (see Table 3-12 for more detail on electricity generation by source). Total electric power generation decreased by 1.5 percent from 2014 to 2017 but increased by 3.4 percent from 2017 to 2018. The decrease in coal-powered electricity generation and increase in natural gas and renewable energy electricity generation have contributed to a 14.0 percent decrease in overall CO_2 emissions from electric power generation from 2014 to 2018 and a 27 percent decrease from 2005 to 2018 (see Figure 2-8).

The trends in CO_2 emissions from fossil fuel combustion over the past five years also follow changes in heating degree days. Emissions from natural gas consumption in the residential and commercial sectors increased by 13.4 percent and 11.2 percent from 2017 to 2018, respectively. This trend can be largely attributed to a 11.8 percent increase in heating degree days, which led to an increased demand for heating fuel in these sectors. Combined residential and commercial sector CO_2 emissions increased by 12.5 percent from 2017 to 2018.

Petroleum use is another major driver of CO_2 emissions from fossil fuel combustion, particularly in the transportation sector, which represents the largest source of CO_2 emissions from fossil fuel combustion in 2018. Emissions from petroleum consumption for transportation (including bunkers) have increased by 5.8 percent since 2014; this trend can be primarily attributed to a 7.1 percent increase in vehicle miles traveled (VMT) over the same time period. Fuel economy of light-duty vehicles is another important factor. The decline in new light-duty vehicle fuel economy between 1990 and 2004 reflected the increasing market share of light-duty trucks, which grew from about 30 percent of new vehicle sales in 1990 to 48 percent in 2004. Starting in 2005, average new vehicle fuel economy began to increase while light-duty VMT grew only modestly for much of the period and has slowed the rate of increase of CO_2 emissions.

Overall, across all sectors, there was a 2.9 percent increase in total CO_2 emissions from fossil fuel combustion from 2017 to 2018 and a 3.0 percent reduction since 2014. Carbon dioxide emissions from fossil fuel combustion, separated by end-use sector, are presented in Table 2-5 and Figure 2-6 based on the underlying U.S. energy consumer data collected by the U.S. Energy Information Administration (EIA). Figure 2-7 further describes direct and indirect CO_2 emissions from fossil fuel combustion, separated by end-use sector. Estimates of CO_2 emissions from fossil fuel combustion are calculated from these EIA "end-use sectors" based on total fuel consumption and

appropriate fuel properties described below. (Any additional analysis and refinement of the EIA data is further explained in the Energy chapter of this report.)

- *Transportation.* EIA's fuel consumption data for the transportation sector consists of all vehicles whose primary purpose is transporting people and/or goods from one physical location to another.
- *Industry.* EIA statistics for the industrial sector include fossil fuel consumption that occurs in the fields of manufacturing, agriculture, mining, and construction. EIA's fuel consumption data for the industrial sector consist of all facilities and equipment used for producing, processing, or assembling goods. (EIA includes generators that produce electricity and/or useful thermal output primarily to support on-site industrial activities in this sector.)
- *Electric Power.* EIA's fuel consumption data for the electric power sector are comprised of electricity-only and combined-heat-and-power (CHP) plants within the North American Industry Classification System (NAICS) 22 category whose primary business is to sell electricity, or electricity and heat, to the public. (Non-utility power producers are included in this sector as long as they meet the electric power sector definition.)
- *Residential.* EIA's fuel consumption data for the residential sector consist of living quarters for private households.
- *Commercial.* EIA's fuel consumption data for the commercial sector consist of service-providing facilities and equipment from private and public organizations and businesses. (EIA includes generators that produce electricity and/or useful thermal output primarily to support the activities at commercial establishments in this sector.)

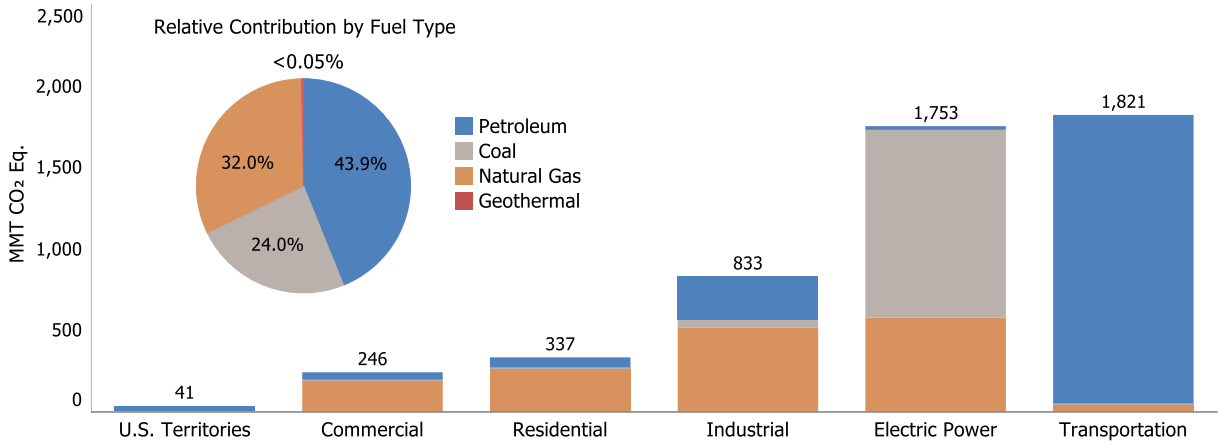
Table 2-5: CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector (MMT CO_2 Eq.)

End-Use Sector	1990	2005	2014	2015	2016	2017	2018
Transportation	**1,472.1**	**1,860.8**	**1,718.2**	**1,729.5**	**1,769.5**	**1,791.6**	**1,825.4**
Combustion	1,469.1	1,856.1	1,713.7	1,725.3	1,765.3	1,787.3	1,820.7
Electricity	3.0	4.7	4.4	4.3	4.2	4.3	4.7
Industrial	**1,543.4**	**1,586.4**	**1,405.9**	**1,350.8**	**1,319.0**	**1,309.4**	**1,320.4**
Combustion	857.0	850.1	812.9	801.3	801.4	805.0	833.2
Electricity	686.4	736.3	593.0	549.5	517.6	504.4	487.2
Residential	**931.0**	**1,213.9**	**1,080.9**	**1,001.6**	**946.6**	**910.9**	**986.7**
Combustion	338.2	357.9	346.8	317.8	293.1	293.8	337.3
Electricity	592.7	856.0	734.1	683.8	653.5	617.1	649.4
Commercial	**765.9**	**1,029.9**	**938.5**	**908.5**	**866.0**	**839.0**	**858.0**
Combustion	228.2	226.9	232.8	245.4	232.3	232.8	246.5
Electricity	537.7	803.0	705.6	663.0	633.6	606.2	611.5
U.S. Territories[a]	**27.6**	**49.7**	**41.4**	**41.4**	**41.4**	**41.4**	**41.4**
Total	**4,740.0**	**5,740.7**	**5,184.8**	**5,031.8**	**4,942.4**	**4,892.2**	**5,031.8**
Electric Power	**1,820.0**	**2,400.0**	**2,037.1**	**1,900.6**	**1,808.9**	**1,732.0**	**1,752.8**

Notes: Combustion-related emissions from electric power are allocated based on aggregate national electricity use by each end-use sector. Totals may not sum due to independent rounding.

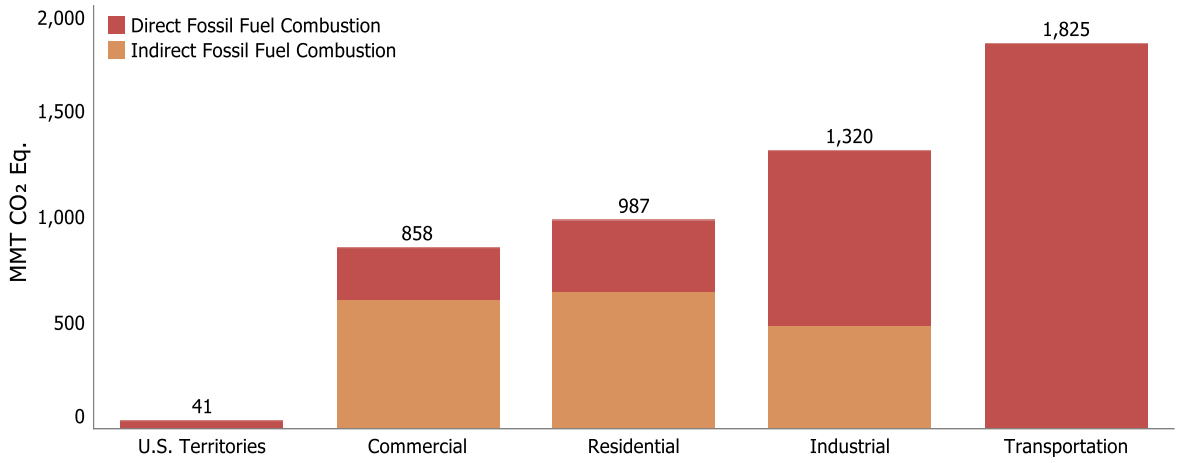
[a] Fuel consumption by U.S. Territories (i.e., American Samoa, Guam, Puerto Rico, U.S. Virgin Islands, Wake Island, and other U.S. Pacific Islands) is included in this report.

Figure 2-6: 2018 CO_2 Emissions from Fossil Fuel Combustion by Sector and Fuel Type (MMT CO_2 Eq.)



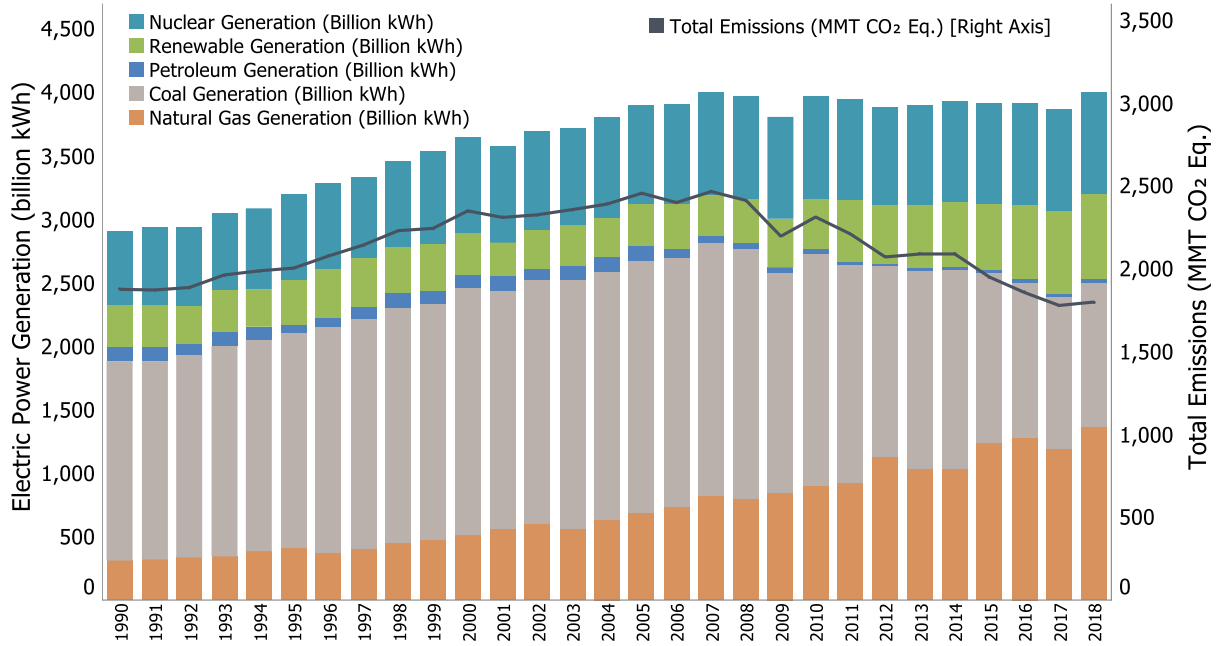
Note on Figure 2-6: Fossil Fuel Combustion for electric power also includes emissions of less than 0.5 MMT CO_2 Eq. from geothermal-based generation.

Figure 2-7: 2018 End-Use Sector Emissions of CO_2 from Fossil Fuel Combustion (MMT CO_2 Eq.)



Electric power was the second largest emitter of CO_2 in 2018 (surpassed by transportation); electric power generators used 32 percent of U.S. energy from fossil fuels and emitted 35 percent of the CO_2 from fossil fuel combustion in 2018. Changes in electricity demand and the carbon intensity of fuels used for electric power generation have a significant impact on CO_2 emissions. Carbon dioxide emissions from the electric power sector have decreased by approximately 3.7 percent since 1990, and the carbon intensity of the electric power sector, in terms of CO_2 Eq. per QBtu input, has significantly decreased by 13 percent during that same timeframe. This decoupling of electric power generation and the resulting CO_2 emissions is shown below in Figure 2-8.

Figure 2-8: Electric Power Generation (Billion kWh) and Emissions (MMT CO_2 Eq.)



Electric power CO_2 emissions can also be allocated to the end-use sectors that use electricity, as presented in Table 2-5. With electricity CO_2 emissions allocated to end-use sectors, the transportation end-use sector represents the largest source of fossil fuel combustion emissions accounting for 1,825.4 MMT CO_2 Eq. in 2018 or approximately 36 percent of total CO_2 emissions from fossil fuel combustion. The industrial end-use sector accounted for 26 percent of CO_2 emissions from fossil fuel combustion when including allocated electricity emissions. The residential and commercial end-use sectors accounted for 20 and 17 percent, respectively, of CO_2 emissions from fossil fuel combustion when including allocated electricity emissions. Both of these end-use sectors were heavily reliant on electricity for meeting energy needs, with electricity use for lighting, heating, air conditioning, and operating appliances contributing 66 and 71 percent of emissions from the residential and commercial end-use sectors, respectively.

Other Significant Trends in Energy

Other significant trends in emissions from energy source categories over the twenty-nine-year period from 1990 through 2018 included the following:

- Methane emissions from natural gas systems and petroleum systems (combined here) decreased 53.2 MMT CO_2 Eq. (23.2 percent decrease from 1990 to 2018) or from 229.4 MMT CO_2 Eq. in 1990 to 176.2 MMT CO_2 Eq. in 2018. Natural gas systems CH_4 emissions decreased by 43.4 MMT CO_2 Eq. (23.7 percent) since 1990, largely due to a decrease in emissions from distribution, transmission and storage, processing, and exploration. The decrease in distribution is largely due to decreased emissions from pipelines and distribution station leaks, and the decrease in transmission and storage emissions is largely due to reduced compressor station emissions (including emissions from compressors and leaks). Petroleum systems CH_4 emissions decreased by 9.9 MMT CO_2 Eq. (or 21.4 percent) since 1990. This decrease is due primarily to decreases in emissions from offshore platforms, tanks, and pneumatic controllers. Carbon dioxide emissions from natural gas and petroleum systems increased by 30.0 MMT CO_2 Eq. (71.7 percent) from 1990 to 2018. This increase is due primarily to increases in the production segment, where flaring emissions from associated gas flaring, tanks, and miscellaneous production flaring have increased over time.

- Methane emissions from coal mining decreased by 43.8 MMT CO_2 Eq. (45.4 percent) from 1990 through 2018, primarily due to a decrease in the number of active mines and annual coal production over the time period.
- Nitrous oxide emissions from mobile combustion decreased by 26.8 MMT CO_2 Eq. (63.7 percent) from 1990 through 2018, primarily as a result of N_2O national emission control standards and emission control technologies for on-road vehicles.
- Carbon dioxide emissions from non-energy uses of fossil fuels increased by 15.0 MMT CO_2 Eq. (12.6 percent) from 1990 through 2018. Emissions from non-energy uses of fossil fuels were 134.6 MMT CO_2 Eq. in 2018, which constituted 2.5 percent of total national CO_2 emissions, approximately the same proportion as in 1990.
- Nitrous oxide emissions from stationary combustion increased by 3.3 MMT CO_2 Eq. (13.1 percent) from 1990 through 2018. Nitrous oxide emissions from this source increased primarily as a result of an increase in the number of coal fluidized bed boilers in the electric power sector.
- Carbon dioxide emissions from incineration of waste (11.1 MMT CO_2 Eq. in 2018) increased by 3.2 MMT CO_2 Eq. (39.8 percent) from 1990 through 2018, as the volume of scrap tires and other fossil C-containing materials in waste increased.

Industrial Processes and Product Use

In many cases, greenhouse gas emissions are generated and emitted in two different ways. First, they are generated and emitted as the byproducts of many non-energy-related industrial activities. For example, industrial processes can chemically or physically transform raw materials, which often release waste gases such as CO_2, CH_4, N_2O, and fluorinated gases (e.g., HFC-23). In the case of byproduct emissions, the emissions are generated by an industrial process itself, and are not directly a result of energy consumed during the process.

Second, industrial manufacturing processes and use by end-consumers also release HFCs, PFCs, SF_6, and NF_3 and other fluorinated compounds. In addition to the use of HFCs and some PFCs as substitutes for ozone depleting substances (ODS), fluorinated compounds such as HFCs, PFCs, SF_6, NF_3, and others are also emitted through use by a number of other industrial sources in the United States. These industries include the electronics industry, electric power transmission and distribution, and magnesium metal production and processing. In addition, N_2O is used in and emitted by the electronics industry and anesthetic and aerosol applications. Figure 2-9 and Table 2-6 presents greenhouse gas emissions from industrial processes and product use by source category. Overall, emission sources in the Industrial Processes and Product Use (IPPU) chapter account for 5.6 percent of U.S. greenhouse gas emissions in 2018.

Figure 2-9: 2018 Industrial Processes and Product Use Chapter Greenhouse Gas Sources (MMT CO_2 Eq.)

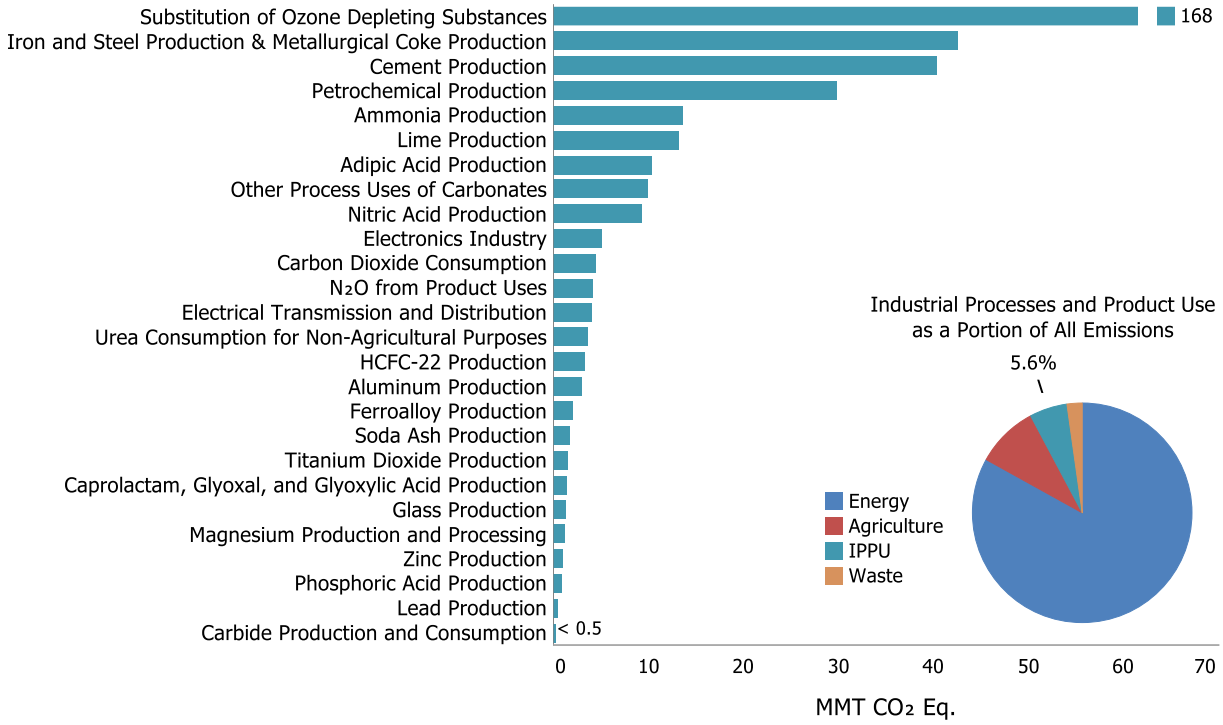


Table 2-6: Emissions from Industrial Processes and Product Use (MMT CO_2 Eq.)

Gas/Source	1990	2005	2014	2015	2016	2017	2018
CO_2	**212.3**	**194.1**	**178.8**	**173.1**	**165.3**	**164.7**	**167.8**
Iron and Steel Production & Metallurgical Coke Production	104.7	70.1	58.2	47.9	43.6	40.6	42.6
Iron and Steel Production	*99.1*	*66.2*	*54.5*	*43.5*	*41.0*	*38.6*	*41.3*
Metallurgical Coke Production	*5.6*	*3.9*	*3.7*	*4.4*	*2.6*	*2.0*	*1.3*
Cement Production	33.5	46.2	39.4	39.9	39.4	40.3	40.3
Petrochemical Production	21.6	27.4	26.3	28.1	28.3	28.9	29.4
Ammonia Production	13.0	9.2	9.4	10.6	10.8	13.2	13.5
Lime Production	11.7	14.6	14.2	13.3	12.6	12.8	13.2
Other Process Uses of Carbonates	6.3	7.6	13.0	12.2	10.5	9.9	10.0
Carbon Dioxide Consumption	1.5	1.4	4.5	4.5	4.5	4.5	4.5
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	1.8	4.6	5.1	3.8	3.6
Ferroalloy Production	2.2	1.4	1.9	2.0	1.8	2.0	2.1
Soda Ash Production	1.4	1.7	1.7	1.7	1.7	1.8	1.7
Titanium Dioxide Production	1.2	1.8	1.7	1.6	1.7	1.7	1.5
Aluminum Production	6.8	4.1	2.8	2.8	1.3	1.2	1.5
Glass Production	1.5	1.9	1.3	1.3	1.2	1.3	1.3
Zinc Production	0.6	1.0	1.0	0.9	0.9	1.0	1.0
Phosphoric Acid Production	1.5	1.3	1.0	1.0	1.0	1.0	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2
Magnesium Production and Processing	+	+	+	+	+	+	+
CH_4	**0.3**	**0.1**	**0.2**	**0.2**	**0.3**	**0.3**	**0.3**
Petrochemical Production	0.2	0.1	0.1	0.2	0.2	0.3	0.3
Ferroalloy Production	+	+	+	+	+	+	+

Carbide Production and Consumption	+	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+
N_2O	**33.3**	**24.9**	**22.8**	**22.2**	**23.3**	**22.7**	**25.5**
Adipic Acid Production	15.2	7.1	5.4	4.3	7.0	7.4	10.3
Nitric Acid Production	12.1	11.3	10.9	11.6	10.1	9.3	9.3
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.7	2.1	2.0	1.9	1.7	1.5	1.4
Electronics Industry	+	0.1	0.2	0.2	0.2	0.3	0.3
HFCs	**46.5**	**128.7**	**166.3**	**170.5**	**170.5**	**172.5**	**171.6**
Substitution of Ozone Depleting Substances[a]	0.2	108.4	160.9	165.8	167.3	166.9	167.8
HCFC-22 Production	46.1	20.0	5.0	4.3	2.8	5.2	3.3
Electronics Industry	0.2	0.2	0.3	0.3	0.3	0.4	0.4
Magnesium Production and Processing	0.0	0.0	0.1	0.1	0.1	0.1	0.1
PFCs	**24.3**	**6.7**	**5.6**	**5.1**	**4.3**	**4.0**	**4.6**
Electronics Industry	2.8	3.2	3.1	3.0	2.9	2.9	3.0
Aluminum Production	21.5	3.4	2.5	2.0	1.4	1.0	1.6
Substitution of Ozone Depleting Substances	0.0	+	+	+	+	+	0.1
SF_6	**28.8**	**11.8**	**6.5**	**5.5**	**6.1**	**5.9**	**5.9**
Electrical Transmission and Distribution	23.2	8.4	4.8	3.8	4.1	4.1	4.1
Magnesium Production and Processing	5.2	2.7	0.9	1.0	1.1	1.1	1.1
Electronics Industry	0.5	0.7	0.7	0.7	0.8	0.7	0.8
NF_3	**+**	**0.5**	**0.5**	**0.6**	**0.6**	**0.6**	**0.6**
Electronics Industry	+	0.5	0.5	0.6	0.6	0.6	0.6
Unspecified Mix of HFCs, NF_3, PFCs and SF_6	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Electronics Industry	+	+	+	+	+	+	+
Total	**345.6**	**366.8**	**380.8**	**377.1**	**370.4**	**370.7**	**376.5**

Note: Totals may not sum due to independent rounding.

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Small amounts of PFC emissions also result from this source.

Overall, emissions from the IPPU sector increased by 9.0 percent from 1990 to 2018. Significant trends in emissions from IPPU source categories over the twenty-nine-year period from 1990 through 2018 included the following:

- Hydrofluorocarbon and perfluorocarbon emissions resulting from the substitution of ODS (e.g., chlorofluorocarbons [CFCs]) have been increasing from small amounts in 1990 to 167.9 MMT CO_2 Eq. in 2018. This increase was in large part the result of efforts to phase out CFCs and other ODS in the United States. In the short term, this trend is expected to continue, and will likely continue over the next decade as hydrochlorofluorocarbons (HCFCs), which are in use as interim substitutes in many applications, are themselves phased-out.
- Combined CO_2 and CH_4 emissions from iron and steel production and metallurgical coke production increased by 5.0 percent to 42.6 MMT CO_2 Eq. from 2017 to 2018, but have declined overall by 62.1 MMT CO_2 Eq. (59.3 percent) from 1990 through 2018, due to restructuring of the industry. The trend in the United States has been a shift towards fewer integrated steel mills and more EAFs. EAFs use scrap steel as their main input and generally have less on-site emissions.
- Carbon dioxide emissions from ammonia production (13.5 MMT CO_2 Eq. in 2018) increased by 3.7 percent (0.5 MMT CO_2 Eq.) since 1990. Ammonia production relies on natural gas as both a feedstock and a fuel, and as such, market fluctuations and volatility in natural gas prices affect the production of ammonia from year to year. Recent low prices for natural gas and increased demand for ammonia use in nitrogen fertilizers has let to increases in ammonia production and emissions.
- Carbon dioxide emissions from cement production increased by 20.4 percent (6.8 MMT CO_2 Eq.) from 1990 through 2018. They rose from 1990 through 2006 and then fell until 2009 due to a decrease in

demand for construction materials during the economic recession. Since 2010, CO_2 emissions from cement production have risen 28.2 percent (8.9 MMT CO_2 Eq.).

- PFC emissions from aluminum production decreased by 92.6 percent (19.9 MMT CO_2 Eq.) from 1990 to 2018, due to both industry emission reduction efforts and lower domestic aluminum production.
- Nitrous oxide emissions from adipic acid production were 10.3 MMT CO_2 Eq. in 2018, and have decreased significantly (32.1 percent or 4.9 MMT CO_2 Eq.) since 1990 due to both the widespread installation of pollution control measures in the late 1990s and plant idling in the late 2000s.

Agriculture

Agricultural activities contribute directly to emissions of greenhouse gases through a variety of processes, including the following source categories: enteric fermentation in domestic livestock, livestock manure management, rice cultivation, agricultural soil management, liming, urea fertilization, and field burning of agricultural residues. Methane, N_2O, and CO_2 were the primary greenhouse gases emitted by agricultural activities.

In 2018, agricultural activities were responsible for emissions of 618.5 MMT CO_2 Eq., or 9.3 percent of total U.S. greenhouse gas emissions. Methane emissions from enteric fermentation and manure management represented approximately 28.0 percent and 9.7 percent of total CH_4 emissions from anthropogenic activities, respectively, in 2018. Agricultural soil management activities, such as application of synthetic and organic fertilizers, deposition of livestock manure, and growing N-fixing plants, were the largest contributors to U.S. N_2O emissions in 2018, accounting for 77.8 percent. Carbon dioxide emissions from the application of crushed limestone and dolomite (i.e., soil liming) and urea fertilization represented 0.1 percent of total CO_2 emissions from anthropogenic activities. Figure 2-10 and Table 2-7 illustrate agricultural greenhouse gas emissions by source.

Figure 2-10: 2018 Agriculture Chapter Greenhouse Gas Sources (MMT CO_2 Eq.)

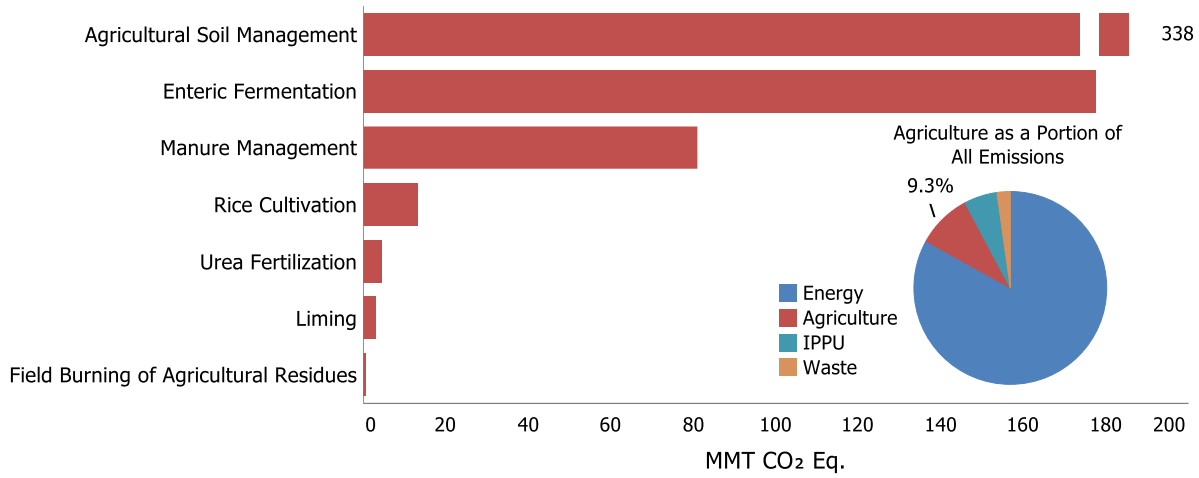


Table 2-7: Emissions from Agriculture (MMT CO_2 Eq.)

Gas/Source	1990	2005	2014	2015	2016	2017	2018
CO_2	**6.7**	**7.5**	**7.5**	**7.8**	**7.1**	**7.6**	**7.7**
Urea Fertilization	2.0	3.1	3.9	4.1	4.0	4.5	4.6
Liming	4.7	4.3	3.6	3.7	3.1	3.1	3.1
CH_4	**217.6**	**238.8**	**234.3**	**241.0**	**245.3**	**248.4**	**253.0**
Enteric Fermentation	164.2	168.9	164.2	166.5	171.8	175.4	177.6
Manure Management	37.1	51.6	54.3	57.9	59.6	59.9	61.7
Rice Cultivation	16.0	18.0	15.4	16.2	13.5	12.8	13.3
Field Burning of Agricultural Residues	0.3	0.4	0.4	0.4	0.4	0.4	0.4

N_2O	**330.1**	**329.6**	**366.7**	**365.8**	**348.1**	**346.2**	**357.8**
Agricultural Soil Management	315.9	313.0	349.2	348.1	329.8	327.4	338.2
Manure Management	14.0	16.4	17.3	17.5	18.1	18.7	19.4
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	**554.4**	**575.9**	**608.6**	**614.6**	**600.5**	**602.3**	**618.5**

Note: Totals may not sum due to independent rounding.

Some significant trends in U.S. emissions from Agriculture source categories include the following:

- Agricultural soils are the largest anthropogenic source of N_2O emissions in the United States, accounting for approximately 77.8 percent of N_2O emissions in 2018 and 5.1 percent of total emissions in the United States in 2018. Estimated emissions from this source in 2018 were 338.2 MMT CO_2 Eq. Annual N_2O emissions from agricultural soils fluctuated between 1990 and 2018, although overall emissions were 22.2 MMT CO_2 Eq. or 7.0 percent higher in 2018 than in 1990. Year-to-year fluctuations are largely a reflection of annual variation in weather patterns, synthetic fertilizer use, and crop production.
- Enteric fermentation is the largest anthropogenic source of CH_4 emissions in the United States. In 2018, enteric fermentation CH_4 emissions were 28.0 percent of total CH_4 emissions (177.6 MMT CO_2 Eq.), which represents an increase of 13.4 MMT CO_2 Eq. (8.2 percent) since 1990. This increase in emissions from 1990 to 2018 in enteric fermentation generally follows the increasing trends in cattle populations. From 1990 to 1995, emissions increased and then generally decreased from 1996 to 2004, mainly due to fluctuations in beef cattle populations and increased digestibility of feed for feedlot cattle. Emissions increased from 2005 to 2007, as both dairy and beef populations increased. Research indicates that the feed digestibility of dairy cow diets decreased during this period. Emissions decreased again from 2008 to 2014 as beef cattle populations again decreased. Emissions increased from 2014 to 2018, consistent with an increase in beef cattle population over those same years.
- Overall, emissions from manure management increased 58.7 percent between 1990 and 2018. This encompassed an increase of 66.1 percent for CH_4, from 37.1 MMT CO_2 Eq. in 1990 to 61.7 MMT CO_2 Eq. in 2018; and an increase of 39.0 percent for N_2O, from 14.0 MMT CO_2 Eq. in 1990 to 19.4 MMT CO_2 Eq. in 2018. The majority of the increase observed in CH_4 resulted from swine and dairy cattle manure, where emissions increased 42.8 and 119.2 percent, respectively, from 1990 to 2018. From 2017 to 2018, there was a 3.0 percent increase in total CH_4 emissions from manure management, mainly due to minor shifts in the animal populations and the resultant effects on manure management system allocations.
- Liming and urea fertilization are the only sources of CO_2 emissions reported in the Agriculture sector. Estimated emissions from these sources were 3.1 and 4.6 MMT CO_2 Eq., respectively. Liming emissions increased by 2.2 percent relative to 2017 and decreased 1.5 MMT CO_2 Eq. or 32.6 percent relative to 1990, while urea fertilization emissions increased by 1.9 percent relative to 2017 and 2.6 MMT CO_2 Eq. 128.7 percent relative to 1990.

Land Use, Land-Use Change, and Forestry

When humans alter the terrestrial biosphere through land use, changes in land use, and land management practices, they also influence the carbon (C) stock fluxes on these lands and cause emissions of CH_4 and N_2O. Overall, managed land is a net sink for CO_2 (C sequestration) in the United States. The primary drivers of fluxes on managed lands include, for example, forest management practices, tree planting in urban areas, the management of agricultural soils, the landfilling of yard trimmings and food scraps, and activities that cause changes in C stocks in coastal wetlands. The main drivers for net forest sequestration include net forest growth, increasing forest area, and a net accumulation of C stocks in harvested wood pools. The net sequestration in *Settlements Remaining Settlements,* is driven primarily by C stock gains in urban forests through net tree growth and increased urban area, as well as long-term accumulation of C in landfills from additions of yard trimmings and food scraps.

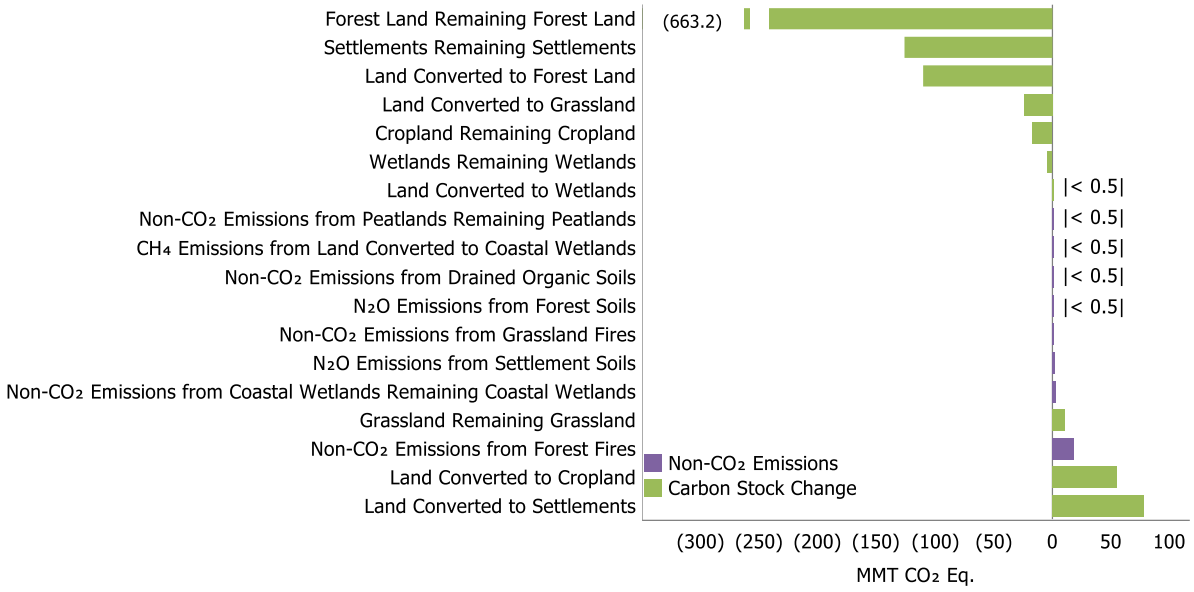
The LULUCF sector in 2018 resulted in a net increase in C stocks (i.e., net CO_2 removals) of 799.6 MMT CO_2 Eq. (Table 2-8).[2] This represents an offset of approximately 11.9 percent of total (i.e., gross) greenhouse gas emissions in 2018. Emissions of CH_4 and N_2O from LULUCF activities in 2018 were 26.1 MMT CO_2 Eq. and represent 0.4 percent of total greenhouse gas emissions.[3] Between 1990 and 2018, total C sequestration in the LULUCF sector decreased by 7.1 percent, primarily due to a decrease in the rate of net C accumulation in forests and *Cropland Remaining Cropland*, as well as an increase in CO_2 emissions from *Land Converted to Settlements*.

Forest fires were the largest source of CH_4 emissions from LULUCF in 2018, totaling 11.3 MMT CO_2 Eq. (452 kt of CH_4). *Coastal Wetlands Remaining Coastal Wetlands* resulted in CH_4 emissions of 3.6 MMT CO_2 Eq. (144 kt of CH_4). Grassland fires resulted in CH_4 emissions of 0.3 MMT CO_2 Eq. (12 kt of CH_4). *Land Converted to Wetlands*, *Drained Organic Soils, and Peatlands Remaining Peatlands* resulted in CH_4 emissions of less than 0.05 MMT CO_2 Eq. each.

Forest fires were also the largest source of N_2O emissions from LULUCF in 2018, totaling 7.5 MMT CO_2 Eq. (25 kt of N_2O). Nitrous oxide emissions from fertilizer application to settlement soils in 2018 totaled to 2.4 MMT CO_2 Eq. (8 kt of N_2O). Additionally, the application of synthetic fertilizers to forest soils in 2018 resulted in N_2O emissions of 0.5 MMT CO_2 Eq. (2 kt of N_2O). Grassland fires resulted in N_2O emissions of 0.3 MMT CO_2 Eq. (1 kt of N_2O). *Coastal Wetlands Remaining Coastal Wetlands* and *Drained Organic Soils* resulted in N_2O emissions of 0.1 MMT CO_2 Eq. each (less than 0.5 kt of N_2O). *Peatlands Remaining Peatlands* resulted in N_2O emissions of less than 0.05 MMT CO_2 Eq.

Carbon dioxide removals from C stock changes are presented (green) in Figure 2-11 and Table 2-8 along with CH_4 and N_2O emissions (purple) for LULUCF source categories.

Figure 2-11: 2018 LULUCF Chapter Greenhouse Gas Sources and Sinks (MMT CO_2 Eq.)



[2] LULUCF Carbon Stock Change is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements,* and *Land Converted to Settlements.*

[3] LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.

Table 2-8: U.S. Greenhouse Gas Emissions and Removals (Net Flux) from Land Use, Land-Use Change, and Forestry (MMT CO_2 Eq.)

Gas/Land-Use Category	1990	2005	2014	2015	2016	2017	2018
Carbon Stock Change[a]	**(860.7)**	**(831.0)**	**(739.6)**	**(802.9)**	**(801.7)**	**(790.0)**	**(799.6)**
Forest Land Remaining Forest Land	(733.9)	(678.6)	(618.8)	(676.1)	(657.9)	(647.7)	(663.2)
Land Converted to Forest Land	(109.4)	(110.2)	(110.5)	(110.6)	(110.6)	(110.6)	(110.6)
Cropland Remaining Cropland	(23.2)	(29.0)	(12.2)	(12.8)	(22.7)	(22.3)	(16.6)
Land Converted to Cropland	54.1	53.8	56.7	57.2	55.5	55.6	55.3
Grassland Remaining Grassland	9.1	10.7	19.7	13.6	9.6	10.9	11.2
Land Converted to Grassland	(6.7)	(40.3)	(24.9)	(23.2)	(24.8)	(24.9)	(24.6)
Wetlands Remaining Wetlands	(4.0)	(5.7)	(4.3)	(4.4)	(4.4)	(4.4)	(4.4)
Land Converted to Wetlands	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Settlements Remaining Settlements	(109.6)	(116.6)	(126.6)	(126.8)	(125.7)	(125.9)	(125.9)
Land Converted to Settlements	62.9	85.0	81.4	80.1	79.4	79.3	79.3
CH_4	**4.4**	**8.8**	**9.5**	**16.1**	**7.3**	**15.2**	**15.2**
Forest Land Remaining Forest Land: Forest Fires[b]	0.9	5.0	5.6	12.2	3.4	11.3	11.3
Wetlands Remaining Wetlands: Coastal Wetlands Remaining Coastal Wetlands	3.4	3.5	3.6	3.6	3.6	3.6	3.6
Grassland Remaining Grassland: Grassland Fires[c]	0.1	0.3	0.4	0.3	0.3	0.3	0.3
Land Converted to Wetlands: Land Converted to Coastal Wetlands	+	+	+	+	+	+	+
Forest Land Remaining Forest Land: Drained Organic Soils[d]	+	+	+	+	+	+	+
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
N_2O	**3.0**	**7.5**	**7.0**	**11.2**	**5.5**	**10.8**	**10.9**
Forest Land Remaining Forest Land: Forest Fires[b]	0.6	3.3	3.7	8.1	2.2	7.5	7.5
Settlements Remaining Settlements: Settlement Soils[e]	2.0	3.1	2.2	2.2	2.2	2.3	2.4
Forest Land Remaining Forest Land: Forest Soils[f]	0.1	0.5	0.5	0.5	0.5	0.5	0.5
Grassland Remaining Grassland: Grassland Fires[c]	0.1	0.3	0.4	0.3	0.3	0.3	0.3
Wetlands Remaining Wetlands: Coastal Wetlands Remaining Coastal Wetlands	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Forest Land Remaining Forest Land: Drained Organic Soils[d]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wetlands Remaining Wetlands: Peatlands Remaining Peatlands	+	+	+	+	+	+	+
LULUCF Emissions[g]	**7.4**	**16.3**	**16.6**	**27.4**	**12.8**	**26.1**	**26.1**
LULUCF Carbon Stock Change[a]	**(860.7)**	**(831.0)**	**(739.6)**	**(802.9)**	**(801.7)**	**(790.0)**	**(799.6)**
LULUCF Sector Net Total[h]	**(853.4)**	**(814.7)**	**(723.0)**	**(775.5)**	**(788.9)**	**(763.9)**	**(773.5)**

Notes: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.

[a] LULUCF Carbon Stock Change is the net C stock change from the following categories: *Forest Land Remaining Forest Land, Land Converted to Forest Land, Cropland Remaining Cropland, Land Converted to Cropland, Grassland Remaining Grassland, Land Converted to Grassland, Wetlands Remaining Wetlands, Land Converted to Wetlands, Settlements Remaining Settlements,* and *Land Converted to Settlements.*

[b] Estimates include emissions from fires on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land.*

[c] Estimates include emissions from fires on both *Grassland Remaining Grassland* and *Land Converted to Grassland*.

[d] Estimates include emissions from drained organic soils on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land.*

[e] Estimates include emissions from N fertilizer additions on both *Settlements Remaining Settlements* and *Land Converted to Settlements.*

[f] Estimates include emissions from N fertilizer additions on both *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*.

[g] LULUCF emissions include the CH_4 and N_2O emissions reported for *Peatlands Remaining Peatlands*, Forest Fires, Drained Organic Soils, Grassland Fires, and *Coastal Wetlands Remaining Coastal Wetlands*; CH_4 emissions from *Land Converted to Coastal Wetlands*; and N_2O emissions from Forest Soils and Settlement Soils.

[h] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Other significant trends from 1990 to 2018 in emissions from LULUCF categories include:

- Annual C sequestration by forest land (i.e., annual C stock accumulation in the five C pools and harvested wood products for *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*) has decreased by approximately 8.2 percent since 1990. This is primarily due to decreased C stock gains in *Land Converted to Forest Land* and the harvested wood products pools within *Forest Land Remaining Forest Land*.
- Annual C sequestration from *Settlements Remaining Settlements* (which includes organic soils, settlement trees, and landfilled yard trimmings and food scraps) has increased by 14.9 percent over the period from 1990 to 2018. This is primarily due to an increase in urbanized land area in the United States with trees growing on it.
- Annual emissions from *Land Converted to Settlements* increased by approximately 26.1 percent from 1990 to 2018 due primarily to C stock losses from *Forest Land Converted to Settlements* and mineral soils C stocks from *Grassland Converted to Settlements*.

Waste

Waste management and treatment activities are sources of greenhouse gas emissions (see Figure 2-12). In 2018, landfills were the third-largest source of U.S. anthropogenic CH_4 emissions, generating 110.6 MMT CO_2 Eq. and accounting for 17.4 percent of total U.S. CH_4 emissions.[4] Additionally, wastewater treatment generates emissions of 19.2 MMT CO_2 Eq. and accounts for 14.3 percent of waste emissions, 2.2 percent of U.S. CH_4 emissions, and 1.2 percent of U.S. N_2O emissions. Emissions of CH_4 and N_2O from composting are also accounted for in this chapter, generating emissions of 2.5 MMT CO_2 Eq. and 2.2 MMT CO_2 Eq., respectively. Overall, emission sources accounted for in the Waste chapter generated 134.4 MMT CO_2 Eq., or 2.0 percent of total U.S. greenhouse gas emissions in 2018. A summary of greenhouse gas emissions from the Waste chapter is presented in Table 2-9.

[4] Landfills also store carbon, due to incomplete degradation of organic materials such as wood products and yard trimmings, as described in the Land Use, Land-Use Change, and Forestry chapter.

Figure 2-12: 2018 Waste Chapter Greenhouse Gas Sources (MMT CO_2 Eq.)

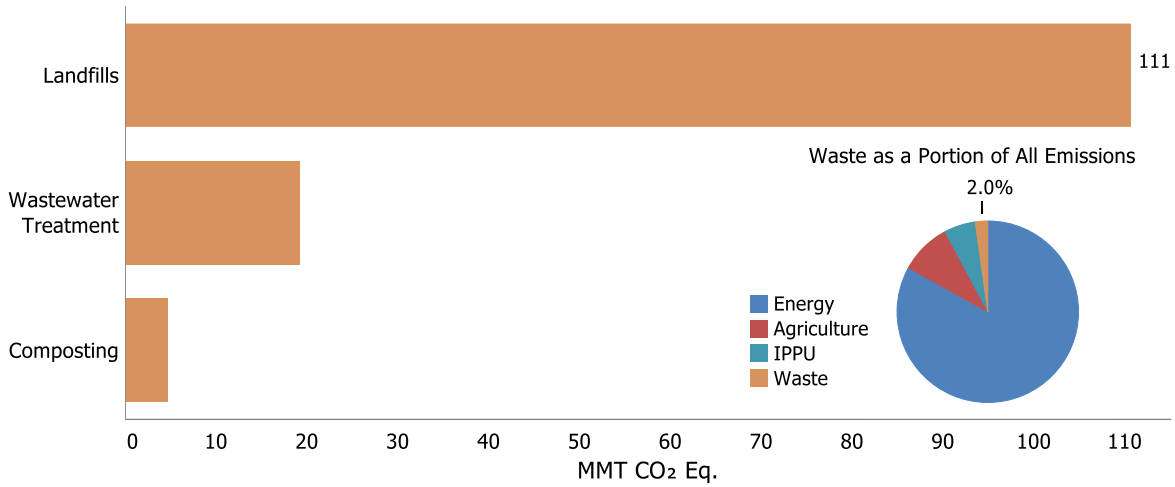


Table 2-9: Emissions from Waste (MMT CO_2 Eq.)

Gas/Source	1990	2005	2014	2015	2016	2017	2018
CH_4	**195.3**	**148.6**	**129.0**	**128.0**	**124.7**	**124.3**	**127.2**
Landfills	179.6	131.3	112.6	111.3	108.0	107.7	110.6
Wastewater Treatment	15.3	15.4	14.3	14.6	14.4	14.1	14.2
Composting	0.4	1.9	2.1	2.1	2.3	2.4	2.5
N_2O	**3.7**	**6.1**	**6.6**	**6.7**	**6.9**	**7.2**	**7.2**
Wastewater Treatment	3.4	4.4	4.8	4.8	4.9	5.0	5.0
Composting	0.3	1.7	1.9	1.9	2.0	2.2	2.2
Total	**199.0**	**154.7**	**135.6**	**134.7**	**131.6**	**131.4**	**134.4**

Note: Totals may not sum due to independent rounding.

Some significant trends in U.S. emissions from waste source categories include the following:

- From 1990 to 2018, net CH_4 emissions from landfills decreased by 69.0 MMT CO_2 Eq. (38.4 percent), with small increases occurring in interim years. This downward trend in emissions coincided with increased landfill gas collection and control systems, and a reduction of decomposable materials (i.e., paper and paperboard, food scraps, and yard trimmings) discarded in municipal solid waste (MSW) landfills over the time series.
- Combined CH_4 and N_2O emissions from composting have generally increased approximately 3.9 MMT CO_2 Eq. since 1990, from 0.7 MMT CO_2 Eq. to 4.7 MMT CO_2 Eq. in 2018, which represents more than a five-fold increase over the time series. The growth in composting since the 1990s is attributable to primarily four factors: (1) the enactment of legislation by state and local governments that discouraged the disposal of yard trimmings and food waste in landfills; (2) yard trimming collection and yard trimming drop off sites provided by local solid waste management districts; (3) an increased awareness of the environmental benefits of composting; and (4) loans or grant programs to establish or expand composting infrastructure.
- From 1990 to 2018, CH_4 and N_2O emissions from wastewater treatment decreased by 1.1 MMT CO_2 Eq. (7.4 percent) and increased by 1.6 MMT CO_2 Eq. (48.0 percent), respectively. Methane emissions from domestic wastewater treatment have decreased since 1999 due to decreasing percentages of wastewater being treated in anaerobic systems, including reduced use of on-site septic systems and central anaerobic treatment systems. Nitrous oxide emissions from wastewater treatment processes gradually increased across the time series as a result of increasing U.S. population and protein consumption.

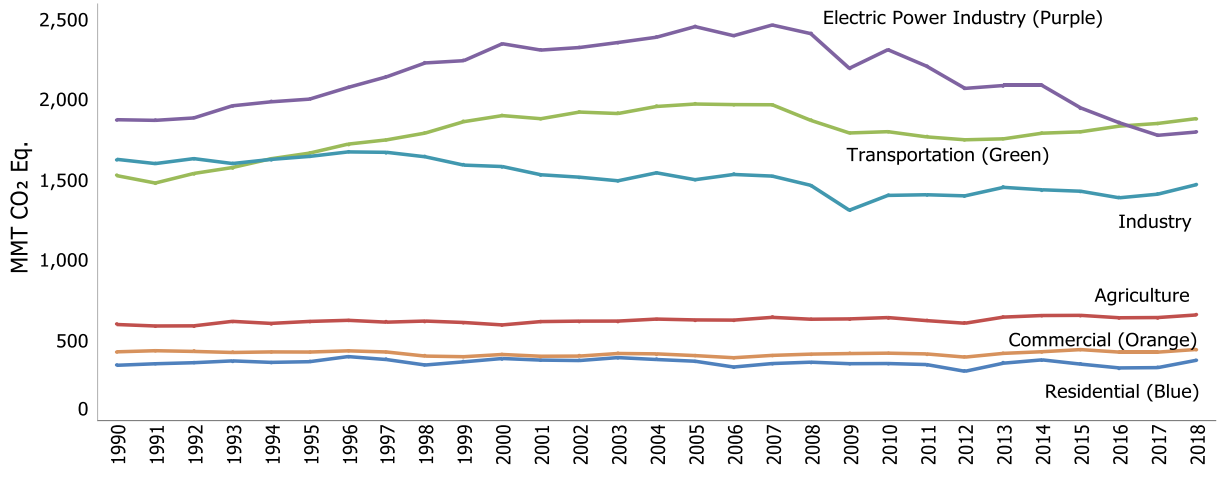
2.2 Emissions by Economic Sector

Throughout this report, emission estimates are grouped into five sectors (i.e., chapters) defined by the IPCC and detailed above: Energy, IPPU, Agriculture, LULUCF, and Waste. While it is important to use this characterization for consistency with United Nations Framework Convention on Climate Change (UNFCCC) reporting guidelines and to promote comparability across countries, it is also useful to characterize emissions according to commonly used economic sector categories: residential, commercial, industry, transportation, electric power, and agriculture. Emissions from U.S. Territories are reported as their own end-use sector due to a lack of specific consumption data for the individual end-use sectors within U.S. Territories. See Box 2-1 for more information on how economic sectors are defined. For more information on trends in the Land Use, Land Use Change, and Forestry sector, see section 2.1.

Using this categorization, transportation activities, in aggregate, accounted for the largest portion (28.2 percent) of total U.S. greenhouse gas emissions in 2018. Emissions from electric power accounted for the second largest portion (26.9 percent), while emissions from industry accounted for the third largest portion (22.0 percent) of total U.S. greenhouse gas emissions in 2018. Emissions from industry have in general declined over the past decade due to a number of factors, including structural changes in the U.S. economy (i.e., shifts from a manufacturing-based to a service-based economy), fuel switching, and efficiency improvements.

The remaining 22.8 percent of U.S. greenhouse gas emissions were contributed by, in order of magnitude, the agriculture, commercial, and residential sectors, plus emissions from U.S. Territories. Activities related to agriculture accounted for roughly 9.9 percent of emissions; unlike other economic sectors, agricultural sector emissions were dominated by N_2O emissions from agricultural soil management and CH_4 emissions from enteric fermentation, rather than CO_2 from fossil fuel combustion. An increasing amount of carbon is stored in agricultural soils each year, but this CO_2 sequestration is assigned to the LULUCF sector rather than the agriculture economic sector. The commercial and residential sectors accounted for roughly 6.6 percent and 5.6 percent of emissions, respectively, and U.S. Territories accounted for 0.7 percent of emissions; emissions from these sectors primarily consisted of CO_2 emissions from fossil fuel combustion. Carbon dioxide was also emitted and sequestered (in the form of C) by a variety of activities related to forest management practices, tree planting in urban areas, the management of agricultural soils, landfilling of yard trimmings, and changes in C stocks in coastal wetlands. Table 2-10 presents a detailed breakdown of emissions from each of these economic sectors by source category, as they are defined in this report. Figure 2-13 shows the trend in emissions by sector from 1990 to 2018.

Figure 2-13: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (MMT CO_2 Eq.)



Note: Emissions and removals from Land Use, Land Use Change, and Forestry are excluded from figure above. Excludes U.S. Territories.

Table 2-10: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (MMT CO_2 Eq. and Percent of Total in 2018)

Sector/Source	1990	2005	2014	2015	2016	2017	2018	Percent[a]
Transportation	**1,527.1**	**1,973.4**	**1,791.6**	**1,800.2**	**1,835.6**	**1,852.3**	**1,882.6**	**28.2%**
CO_2 from Fossil Fuel Combustion	1,469.1	1,856.1	1,713.7	1,725.3	1,765.3	1,787.3	1,820.7	27.3%
Substitution of Ozone Depleting Substances	+	69.3	48.8	46.3	43.3	40.1	38.5	0.6%
Mobile Combustion	46.1	37.9	19.1	17.7	16.6	15.3	14.2	0.2%
Non-Energy Use of Fuels	11.8	10.2	10.0	11.0	10.4	9.6	9.3	0.1%
Electric Power Industry	**1,875.6**	**2,455.9**	**2,089.1**	**1,949.2**	**1,856.8**	**1,778.4**	**1,798.9**	**26.9%**
CO_2 from Fossil Fuel Combustion	1,820.0	2,400.0	2,037.1	1,900.6	1,808.9	1,732.0	1,752.8	26.3%
Stationary Combustion	20.9	30.9	29.9	27.7	27.4	25.9	25.6	0.4%
Incineration of Waste	8.4	12.9	10.7	11.1	11.2	11.4	11.4	0.2%
Other Process Uses of Carbonates	3.1	3.8	6.5	6.1	5.3	5.0	5.0	0.1%
Electrical Transmission and Distribution	23.2	8.4	4.8	3.8	4.1	4.1	4.1	0.1%
Industry	**1,628.7**	**1,501.7**	**1,438.8**	**1,429.8**	**1,388.8**	**1,411.5**	**1,470.7**	**22.0%**
CO_2 from Fossil Fuel Combustion	813.6	799.7	767.4	760.6	761.7	765.6	793.8	11.9%
Natural Gas Systems	215.5	183.4	170.7	171.2	165.7	169.6	174.9	2.6%
Non-Energy Use of Fuels	102.0	121.4	104.9	111.0	98.2	108.5	120.2	1.8%
Petroleum Systems	55.7	51.0	74.0	73.2	62.0	63.2	73.1	1.1%
Coal Mining	96.5	64.1	64.6	61.2	53.8	54.8	52.7	0.8%
Iron and Steel Production	104.8	70.1	58.2	48.0	43.6	40.6	42.6	0.6%
Cement Production	33.5	46.2	39.4	39.9	39.4	40.3	40.3	0.6%
Substitution of Ozone Depleting Substances	+	9.8	27.0	29.8	32.1	33.9	35.3	0.5%
Petrochemical Production	21.8	27.5	26.4	28.2	28.6	29.2	29.7	0.4%
Ammonia Production	13.0	9.2	9.4	10.6	10.8	13.2	13.5	0.2%
Lime Production	11.7	14.6	14.2	13.3	12.6	12.8	13.2	0.2%
Adipic Acid Production	15.2	7.1	5.4	4.3	7.0	7.4	10.3	0.2%
Nitric Acid Production	12.1	11.3	10.9	11.6	10.1	9.3	9.3	0.1%
Abandoned Oil and Gas Wells	6.6	7.0	7.1	7.2	7.2	7.1	7.0	0.1%
Abandoned Underground Coal Mines	7.2	6.6	6.3	6.4	6.7	6.4	6.2	0.1%
Electronics Industry	3.6	4.8	4.9	5.0	5.0	4.9	5.1	0.1%
Other Process Uses of Carbonates	3.1	3.8	6.5	6.1	5.3	5.0	5.0	0.1%
Carbon Dioxide Consumption	1.5	1.4	4.5	4.5	4.5	4.5	4.5	0.1%
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2	0.1%
Stationary Combustion	4.8	4.6	4.2	4.2	4.1	4.2	4.2	0.1%
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	1.8	4.6	5.1	3.8	3.6	0.1%
Mobile Combustion	7.6	7.8	4.0	3.7	3.6	3.6	3.6	0.1%
HCFC-22 Production	46.1	20.0	5.0	4.3	2.8	5.2	3.3	+%
Aluminum Production	28.3	7.6	5.4	4.8	2.7	2.3	3.0	+%
Ferroalloy Production	2.2	1.4	1.9	2.0	1.8	2.0	2.1	+%
Soda Ash Production	1.4	1.7	1.7	1.7	1.7	1.8	1.7	+%
Titanium Dioxide Production	1.2	1.8	1.7	1.6	1.7	1.7	1.5	+%
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.7	2.1	2.0	1.9	1.7	1.5	1.4	+%
Glass Production	1.5	1.9	1.3	1.3	1.2	1.3	1.3	+%
Magnesium Production and Processing	5.2	2.7	1.0	1.1	1.2	1.2	1.2	+%

Zinc Production	0.6	1.0	1.0	0.9	0.9	1.0	1.0	+%
Phosphoric Acid Production	1.5	1.3	1.0	1.0	1.0	1.0	0.9	+%
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5	+%
Carbide Production and Consumption	0.4	0.2	0.2	0.2	0.2	0.2	0.2	+%
Agriculture	**599.0**	**627.5**	**654.9**	**656.0**	**641.0**	**642.4**	**658.6**	**9.9%**
N_2O from Agricultural Soil Management	315.9	313.0	349.2	348.1	329.8	327.4	338.2	5.1%
Enteric Fermentation	164.2	168.9	164.2	166.5	171.8	175.4	177.6	2.7%
Manure Management	51.1	67.9	71.6	75.4	77.7	78.5	81.1	1.2%
CO_2 from Fossil Fuel Combustion	43.4	50.4	45.5	40.7	39.7	39.4	39.4	0.6%
Rice Cultivation	16.0	18.0	15.4	16.2	13.5	12.8	13.3	0.2%
Urea Fertilization	2.0	3.1	3.9	4.1	4.0	4.5	4.6	0.1%
Liming	4.7	4.3	3.6	3.7	3.1	3.1	3.1	+%
Mobile Combustion	1.2	1.2	0.8	0.6	0.6	0.6	0.6	+%
Field Burning of Agricultural Residues	0.5	0.6	0.6	0.6	0.6	0.6	0.6	+%
Stationary Combustion	0.1	+	0.1	0.1	0.1	0.1	0.1	+%
Commercial	**428.7**	**405.1**	**429.4**	**442.5**	**427.0**	**426.8**	**443.3**	**6.6%**
CO_2 from Fossil Fuel Combustion	228.2	226.9	232.8	245.4	232.3	232.8	246.5	3.7%
Landfills	179.6	131.3	112.6	111.3	108.0	107.7	110.6	1.7%
Substitution of Ozone Depleting Substances	+	22.1	59.5	60.8	61.5	61.0	60.8	0.9%
Wastewater Treatment	15.3	15.4	14.3	14.6	14.4	14.1	14.2	0.2%
Human Sewage	3.4	4.4	4.8	4.8	4.9	5.0	5.0	0.1%
Composting	0.7	3.5	4.0	4.0	4.3	4.6	4.7	0.1%
Stationary Combustion	1.5	1.4	1.4	1.6	1.5	1.5	1.6	+%
Residential	**344.7**	**370.1**	**378.6**	**352.0**	**328.3**	**330.2**	**375.9**	**5.6%**
CO_2 from Fossil Fuel Combustion	338.2	357.9	346.8	317.8	293.1	293.8	337.3	5.1%
Substitution of Ozone Depleting Substances	0.2	7.2	25.8	28.9	30.4	31.8	33.2	0.5%
Stationary Combustion	6.3	4.9	6.0	5.3	4.7	4.6	5.4	0.1%
U.S. Territories	**33.3**	**58.0**	**46.6**	**46.6**	**46.6**	**46.6**	**46.6**	**0.7%**
CO_2 from Fossil Fuel Combustion	27.6	49.7	41.4	41.4	41.4	41.4	41.4	0.6%
Non-Energy Use of Fuels	5.7	8.1	5.1	5.1	5.1	5.1	5.1	0.1%
Stationary Combustion	0.1	0.2	0.2	0.2	0.2	0.2	0.2	+%
Total Emissions	**6,437.0**	**7,391.8**	**6,829.0**	**6,676.4**	**6,524.1**	**6,488.2**	**6,676.6**	**100.0%**
LULUCF Sector Net Total[b]	**(853.4)**	**(814.7)**	**(723.0)**	**(775.5)**	**(788.9)**	**(763.9)**	**(773.5)**	**(11.6%)**
Net Emissions (Sources and Sinks)	**5,583.6**	**6,577.1**	**6,106.0**	**5,900.8**	**5,735.1**	**5,724.3**	**5,903.2**	**88.4%**

Notes: Total emissions presented without LULUCF. Total net emissions presented with LULUCF. Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

+ Does not exceed 0.05 MMT CO_2 Eq. or 0.05 percent.

[a] Percent of total (gross) emissions excluding emissions from LULUCF for 2018.

[b] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Box 2-1: Methodology for Aggregating Emissions by Economic Sector

In presenting the Economic Sectors in the annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks*, the Inventory expands upon the standard IPCC sectors common for UNFCCC reporting. Discussing greenhouse gas emissions relevant to U.S.-specific economic sectors improves communication of the report's findings.

The *Electric Power* economic sector includes CO_2 emissions from the combustion of fossil fuels that are included in the EIA electric power sector. Stationary combustion emissions of CH_4 and N_2O are also based on the EIA electric power sector. Additional sources include CO_2, CH_4, and N_2O from waste incineration, as the majority of municipal solid waste is combusted in plants that produce electricity. The Electric Power economic sector also

includes SF_6 from Electrical Transmission and Distribution, and a portion of CO_2 from Other Process Uses of Carbonates (from pollution control equipment installed in electric power plants).

The *Transportation* economic sector includes CO_2 emissions from the combustion of fossil fuels that are included in the EIA transportation fuel-consuming sector. (Additional analyses and refinement of the EIA data are further explained in the Energy chapter of this report.) Emissions of CH_4 and N_2O from mobile combustion are also apportioned to the Transportation economic sector based on the EIA transportation fuel-consuming sector. Substitution of Ozone Depleting Substances emissions are apportioned to the Transportation economic sector based on emissions from refrigerated transport and motor vehicle air-conditioning systems. Finally, CO_2 emissions from Non-Energy Uses of Fossil Fuels identified as lubricants for transportation vehicles are included in the Transportation economic sector.

The *Industry* economic sector includes CO_2 emissions from the combustion of fossil fuels that are included in the EIA industrial fuel-consuming sector, minus the agricultural use of fuel explained below. The CH_4 and N_2O emissions from stationary and mobile combustion are also apportioned to the Industry economic sector based on the EIA industrial fuel-consuming sector, minus emissions apportioned to the Agriculture economic sector. Substitution of Ozone Depleting Substances emissions are apportioned based on their specific end-uses within the source category, with most emissions falling within the Industry economic sector.

Additionally, all process-related emissions from sources with methods considered within the IPCC IPPU sector are apportioned to the Industry economic sector. This includes the process-related emissions (i.e., emissions from the actual process to make the material, not from fuels to power the plant) from activities such as Cement Production, Iron and Steel Production and Metallurgical Coke Production, and Ammonia Production. Additionally, fugitive emissions from energy production sources, such as Natural Gas Systems, Coal Mining, and Petroleum Systems are included in the Industry economic sector. A portion of CO_2 from Other Process Uses of Carbonates (from pollution control equipment installed in large industrial facilities) is also included in the Industry economic sector. Finally, all remaining CO_2 emissions from Non-Energy Uses of Fossil Fuels are assumed to be industrial in nature (besides the lubricants for transportation vehicles specified above) and are attributed to the Industry economic sector.

The *Agriculture* economic sector includes CO_2 emissions from the combustion of fossil fuels that are based on supplementary sources of agriculture fuel use data, because EIA does not include an agriculture fuel-consuming sector. Agriculture equipment is included in the EIA industrial fuel-consuming sector. Agriculture fuel use estimates are obtained from U.S. Department of Agriculture survey data, in combination with separate EIA fuel sales reports (USDA 2019; EIA 2020). These supplementary data are subtracted from the industrial fuel use reported by EIA to obtain agriculture fuel use. CO_2 emissions from fossil fuel combustion, and CH_4 and N_2O emissions from stationary and mobile combustion, are then apportioned to the Agriculture economic sector based on agricultural fuel use.

The other IPCC Agriculture emission source categories apportioned to the Agriculture economic sector include N_2O emissions from Agricultural Soils, CH_4 from Enteric Fermentation, CH_4 and N_2O from Manure Management, CH_4 from Rice Cultivation, CO_2 emissions from Liming and Urea Application, and CH_4 and N_2O from Field Burning of Agricultural Residues.

The *Residential* economic sector includes CO_2 emissions from the combustion of fossil fuels that are included in the EIA residential fuel-consuming sector. Stationary combustion emissions of CH_4 and N_2O are also based on the EIA residential fuel-consuming sector. Substitution of Ozone Depleting Substances are apportioned to the Residential economic sector based on emissions from residential air-conditioning systems. Nitrous oxide emissions from the application of fertilizers to developed land (termed “settlements” by the IPCC) are also included in the Residential economic sector.

The *Commercial* economic sector includes CO_2 emissions from the combustion of fossil fuels that are included in the EIA commercial fuel-consuming sector. Emissions of CH_4 and N_2O from Mobile Combustion are also apportioned to the Commercial economic sector based on the EIA commercial fuel-consuming sector. Substitution of Ozone Depleting Substances emissions are apportioned to the Commercial economic sector based on emissions from commercial refrigeration/air-conditioning systems. Public works sources, including

direct CH_4 from Landfills, CH_4 and N_2O from Wastewater Treatment, and Composting, are also included in the Commercial economic sector.

Emissions with Electricity Distributed to Economic Sectors

It is also useful to view greenhouse gas emissions from economic sectors with emissions related to electric power distributed into end-use categories (i.e., emissions from electric power are allocated to the economic sectors in which the electricity is used).

The generation, transmission, and distribution of electricity accounted for 26.9 percent of total U.S. greenhouse gas emissions in 2018. Electric power-related emissions decreased by 4.1 percent since 1990 but increased by 1.2 percent from 2017 to 2018, primarily due to a significantly colder winter and a hotter summer in 2018 compared to 2017, which increased the amount of energy required for heating and cooling. Between 2017 to 2018, the consumption of natural gas and petroleum for electric power generation increased by 14.2 and 19.6 percent, respectively, while the consumption of coal decreased by 4.5 percent, reflecting a continued shift from coal to natural gas for electricity generation.

From 2017 to 2018, electricity sales to the residential and commercial end-use sectors increased by 6.6 percent and 2.1 percent, respectively. Electricity sales to the industrial sector increased by approximately 1.8 percent. Overall, from 2017 to 2018, the amount of electricity retail sales (in kWh) increased by 3.7 percent. Table 2-11 provides a detailed summary of emissions from electric power-related activities.

Table 2-11: Electric Power-Related Greenhouse Gas Emissions (MMT CO_2 Eq.)

Gas/Fuel Type or Source	1990	2005	2014	2015	2016	2017	2018
CO_2	**1,831.0**	**2,416.3**	**2,054.1**	**1,917.5**	**1,825.0**	**1,748.1**	**1,768.9**
Fossil Fuel Combustion	1,820.0	2,400.0	2,037.1	1,900.6	1,808.9	1,732.0	1,752.8
Coal	*1,546.5*	*1,982.8*	*1,568.6*	*1,351.4*	*1,242.0*	*1,207.1*	*1,152.9*
Natural Gas	*175.4*	*318.9*	*442.9*	*525.2*	*545.0*	*505.6*	*577.4*
Petroleum	*97.5*	*97.9*	*25.3*	*23.7*	*21.4*	*18.9*	*22.2*
Geothermal	*0.5*	*0.5*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
Incineration of Waste	8.0	12.5	10.4	10.8	10.9	11.1	11.1
Other Process Uses of Carbonates	3.1	3.8	6.5	6.1	5.3	5.0	5.0
CH_4	**0.4**	**0.9**	**1.1**	**1.2**	**1.2**	**1.1**	**1.2**
Stationary Sources[a]	0.4	0.9	1.1	1.2	1.2	1.1	1.2
Incineration of Waste	+	+	+	+	+	+	+
N_2O	**21.0**	**30.4**	**29.2**	**26.8**	**26.5**	**25.1**	**24.7**
Stationary Sources[a]	20.5	30.1	28.9	26.5	26.2	24.8	24.4
Incineration of Waste	0.5	0.4	0.3	0.3	0.3	0.3	0.3
SF_6	**23.2**	**8.4**	**4.8**	**3.8**	**4.1**	**4.1**	**4.1**
Electrical Transmission and Distribution	23.2	8.4	4.8	3.8	4.1	4.1	4.1
Total	**1,875.6**	**2,455.9**	**2,089.1**	**1,949.2**	**1,856.8**	**1,778.4**	**1,798.9**

Note: Totals may not sum due to independent rounding.

+ Does not exceed 0.05 MMT CO_2 Eq.

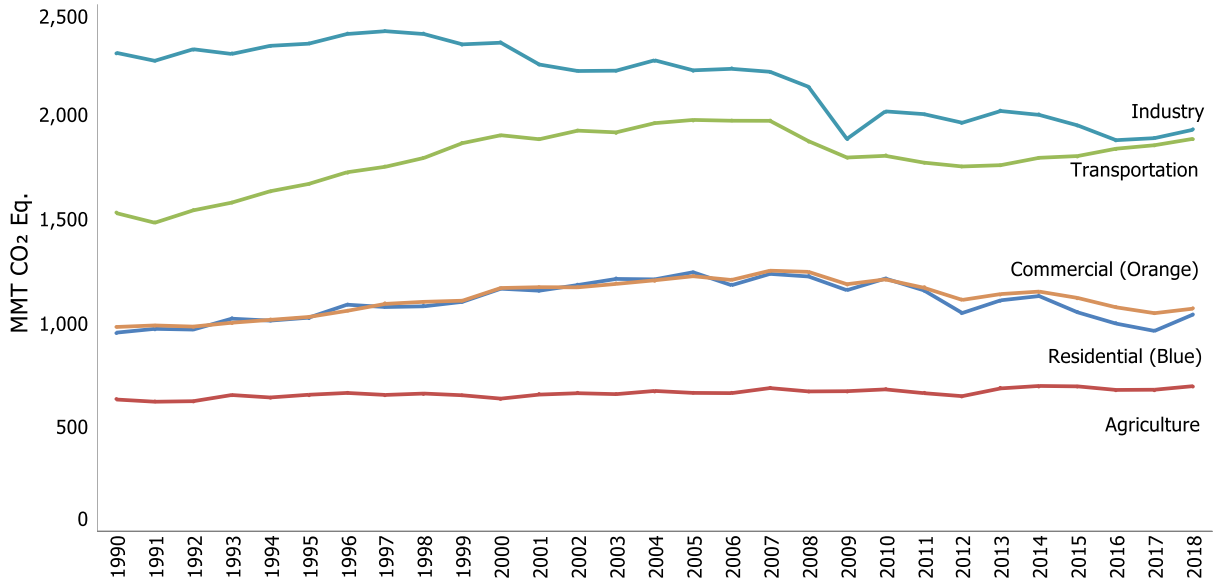
[a] Includes only stationary combustion emissions related to the generation of electricity.

To distribute electricity emissions among economic end-use sectors, emissions from the source categories assigned to the electric power sector were allocated to the residential, commercial, industry, transportation, and agriculture economic sectors according to each economic sector's share of retail sales of electricity (EIA 2019; Duffield 2006). These source categories include CO_2 from Fossil Fuel Combustion, CH_4 and N_2O from Stationary Combustion, Incineration of Waste, Other Process Uses of Carbonates, and SF_6 from Electrical Transmission and

Distribution Systems. Note that only 50 percent of the Other Process Uses of Carbonates emissions were associated with electric power and distributed as described; the remainder of Other Process Uses of Carbonates emissions were attributed to the industrial processes economic end-use sector.[5]

When emissions from electricity use are distributed among these economic end-use sectors, industrial activities account for the largest share of total U.S. greenhouse gas emissions (28.9 percent), followed closely by emissions from transportation (28.3 percent). Emissions from the commercial and residential sectors also increase substantially when emissions from electricity are included (16.0 and 15.6 percent, respectively). In all economic end-use sectors except agriculture, CO_2 accounts for more than 80.6 percent of greenhouse gas emissions, primarily from the combustion of fossil fuels. Table 2-12 presents a detailed breakdown of emissions from each of these economic sectors, with emissions from electric power distributed to them. Figure 2-11 shows the trend in these emissions by sector from 1990 to 2018.

Figure 2-14: U.S. Greenhouse Gas Emissions with Electricity-Related Emissions Distributed to Economic Sectors (MMT CO_2 Eq.)



Note: Emissions and removals from Land Use, Land Use Change, and Forestry are excluded from figure above. Excludes U.S. Territories.

Table 2-12: U.S. Greenhouse Gas Emissions by Economic Sector and Gas with Electricity-Related Emissions Distributed (MMT CO_2 Eq.) and Percent of Total in 2018

Sector/Gas	1990	2005	2014	2015	2016	2017	2018	Percent[a]
Industry	**2,301.0**	**2,216.8**	**2,002.6**	**1,952.1**	**1,881.0**	**1,890.7**	**1,931.0**	**28.9%**
Direct Emissions	**1,628.7**	**1,501.7**	**1,438.8**	**1,429.8**	**1,388.8**	**1,411.5**	**1,470.7**	**22.0%**
CO_2	1,166.7	1,148.8	1,104.7	1,100.5	1,072.7	1,088.6	1,148.7	17.2%
CH_4	348.1	282.4	266.5	260.9	246.2	249.8	245.7	3.7%
N_2O	37.6	29.7	27.3	26.5	27.7	27.2	30.2	0.5%
HFCs, PFCs, SF_6, and NF_3	76.3	40.7	40.2	41.8	42.2	45.9	46.2	0.7%
Electricity-Related	**672.3**	**715.2**	**563.8**	**522.4**	**492.2**	**479.2**	**460.3**	**6.9%**
CO_2	656.4	703.6	554.3	513.8	483.8	471.0	452.6	6.8%
CH_4	0.2	0.3	0.3	0.3	0.3	0.3	0.3	+%

[5] Emissions were not distributed to U.S. Territories, since the electric power sector only includes emissions related to the generation of electricity in the 50 states and the District of Columbia.

N_2O	7.5	8.9	7.9	7.2	7.0	6.8	6.3	0.1%
SF_6	8.3	2.4	1.3	1.0	1.1	1.1	1.0	+%
Transportation	**1,530.2**	**1,978.3**	**1,796.2**	**1,804.6**	**1,839.9**	**1,856.7**	**1,887.4**	**28.3%**
Direct Emissions	**1,527.1**	**1,973.4**	**1,791.6**	**1,800.2**	**1,835.6**	**1,852.3**	**1,882.6**	**28.2%**
CO_2	1,480.9	1,866.3	1,723.8	1,736.2	1,775.7	1,796.8	1,829.9	27.4%
CH_4	5.9	3.0	1.7	1.6	1.5	1.5	1.4	+%
N_2O	40.2	34.8	17.4	16.0	15.1	13.9	12.8	0.2%
HFCs[b]	+	69.3	48.8	46.3	43.3	40.1	38.5	0.6%
Electricity-Related	**3.1**	**4.8**	**4.6**	**4.4**	**4.3**	**4.4**	**4.9**	**0.1%**
CO_2	3.1	4.8	4.5	4.3	4.2	4.4	4.8	0.1%
CH_4	+	+	+	+	+	+	+	+%
N_2O	+	0.1	0.1	0.1	0.1	0.1	0.1	+%
SF_6	+	+	+	+	+	+	+	+%
Commercial	**982.8**	**1,226.8**	**1,153.0**	**1,122.5**	**1,077.4**	**1,049.2**	**1,070.9**	**16.0%**
Direct Emissions	**428.7**	**405.1**	**429.4**	**442.5**	**427.0**	**426.8**	**443.3**	**6.6%**
CO_2	228.2	226.9	232.8	245.4	232.3	232.8	246.5	3.7%
CH_4	196.4	149.7	130.1	129.2	125.9	125.5	128.5	1.9%
N_2O	4.1	6.4	7.0	7.0	7.2	7.5	7.5	0.1%
HFCs	+	22.1	59.5	60.8	61.5	61.0	60.8	0.9%
Electricity-Related	**554.2**	**821.7**	**723.6**	**680.0**	**650.4**	**622.4**	**627.5**	**9.4%**
CO_2	541.0	808.4	711.5	668.9	639.3	611.8	617.1	9.2%
CH_4	0.1	0.3	0.4	0.4	0.4	0.4	0.4	+%
N_2O	6.2	10.2	10.1	9.4	9.3	8.8	8.6	0.1%
SF_6	6.8	2.8	1.7	1.3	1.4	1.4	1.4	+%
Residential	**955.6**	**1,246.0**	**1,131.4**	**1,053.3**	**999.1**	**963.9**	**1,042.4**	**15.6%**
Direct Emissions	**344.7**	**370.1**	**378.6**	**352.0**	**328.3**	**330.2**	**375.9**	**5.6%**
CO_2	338.2	357.9	346.8	317.8	293.1	293.8	337.3	5.1%
CH_4	5.2	4.1	5.0	4.5	3.9	3.8	4.5	0.1%
N_2O	1.0	0.9	1.0	0.9	0.8	0.8	0.9	+%
HFCs	0.2	7.2	25.8	28.9	30.4	31.8	33.2	0.5%
Electricity-Related	**610.9**	**875.9**	**752.8**	**701.3**	**670.8**	**633.6**	**666.5**	**10.0%**
CO_2	596.4	861.8	740.2	689.9	659.3	622.8	655.4	9.8%
CH_4	0.1	0.3	0.4	0.4	0.4	0.4	0.4	+%
N_2O	6.8	10.9	10.5	9.7	9.6	8.9	9.2	0.1%
SF_6	7.5	3.0	1.7	1.4	1.5	1.5	1.5	+%
Agriculture	**634.0**	**665.8**	**699.2**	**697.2**	**680.1**	**681.1**	**698.3**	**10.5%**
Direct Emissions	**599.0**	**627.5**	**654.9**	**656.0**	**641.0**	**642.4**	**658.6**	**9.9%**
CO_2	50.1	57.9	53.1	48.5	46.9	47.0	47.1	0.7%
CH_4	218.3	239.4	234.5	241.1	245.5	248.6	253.1	3.8%
N_2O	330.6	330.2	367.4	366.4	348.7	346.8	358.3	5.4%
Electricity-Related	**35.1**	**38.3**	**44.3**	**41.2**	**39.1**	**38.7**	**39.7**	**0.6%**
CO_2	34.2	37.7	43.6	40.6	38.4	38.1	39.1	0.6%
CH_4	+	+	+	+	+	+	+	+%
N_2O	0.4	0.5	0.6	0.6	0.6	0.5	0.5	+%
SF_6	0.4	0.1	0.1	0.1	0.1	0.1	0.1	+%
U.S. Territories	**33.3**	**58.0**	**46.6**	**46.6**	**46.6**	**46.6**	**46.6**	**0.7%**
Total Emissions	**6,437.0**	**7,391.8**	**6,829.0**	**6,676.4**	**6,524.1**	**6,488.2**	**6,676.6**	**100.0%**
LULUCF Sector Net Total[c]	**(853.4)**	**(814.7)**	**(723.0)**	**(775.5)**	**(788.9)**	**(763.9)**	**(773.5)**	**(11.6%)**
Net Emissions (Sources and Sinks)	**5,583.6**	**6,577.1**	**6,106.0**	**5,900.8**	**5,735.1**	**5,724.3**	**5,903.2**	**88.4%**

Notes: Total emissions presented without LULUCF. Net emissions presented with LULUCF. Emissions from electric power are allocated based on aggregate electricity use in each end-use sector. Totals may not sum due to independent rounding.

+ Does not exceed 0.05 MMT CO_2 Eq. or 0.05 percent.

[a] Percent of total (gross) emissions excluding emissions from LULUCF for year 2018.

[b] Includes primarily HFC-134a.

[c] The LULUCF Sector Net Total is the net sum of all CH_4 and N_2O emissions to the atmosphere plus net carbon stock changes.

Industry

The industry end-use sector includes CO_2 emissions from fossil fuel combustion from all manufacturing facilities, in aggregate, and with the distribution of electricity-related emissions, accounts for 28.9 percent of U.S. greenhouse gas emissions in 2018. This end-use sector also includes emissions that are produced as a byproduct of the non-energy-related industrial process activities. The variety of activities producing these non-energy-related emissions includes CH_4 emissions from petroleum and natural gas systems, fugitive CH_4 emissions from coal mining, byproduct CO_2 emissions from cement manufacture, and HFC, PFC, SF_6, and NF_3 byproduct emissions from the electronics industry, to name a few.

Since 1990, industrial sector emissions have declined by 16.1 percent. The decline has occurred both in direct emissions and indirect emissions associated with electricity use. Structural changes within the U.S. economy that led to shifts in industrial output away from energy-intensive manufacturing products to less energy-intensive products (e.g., from steel to computer equipment) have had a significant effect on industrial emissions.

Transportation

When electricity-related emissions are distributed to economic end-use sectors, transportation activities accounted for 28.3 percent of U.S. greenhouse gas emissions in 2018. The largest sources of transportation greenhouse gas emissions in 2018 were passenger cars (41.2 percent); freight trucks (23.2 percent); light-duty trucks, which include sport utility vehicles, pickup trucks, and minivans (17.4 percent); commercial aircraft (6.9 percent); pipelines (2.6 percent); other aircraft (2.4 percent); rail (2.3 percent); and ships and boats (2.2 percent). These figures include direct CO_2, CH_4, and N_2O emissions from fossil fuel combustion used in transportation, indirect emissions from electricity use and emissions from non-energy use (i.e., lubricants) used in transportation, as well as HFC emissions from mobile air conditioners and refrigerated transport allocated to these vehicle types.

In terms of the overall trend, from 1990 to 2018, total transportation emissions increased due, in large part, to increased demand for travel. The number of VMT by light-duty motor vehicles (passenger cars and light-duty trucks) increased 46.1 percent from 1990 to 2018, as a result of a confluence of factors including population growth, economic growth, urban sprawl, and periods of low fuel prices.

The decline in new light-duty vehicle fuel economy between 1990 and 2004 reflected the increasing market share of light-duty trucks, which grew from about 30 percent of new vehicle sales in 1990 to 48 percent in 2004. Starting in 2005, average new vehicle fuel economy began to increase while light-duty VMT grew only modestly for much of the period. Light-duty VMT grew by less than one percent or declined each year between 2005 and 2013,[6] then grew at a faster rate until 2016 (2.6 percent from 2014 to 2015, and 2.5 percent from 2015 to 2016). Since 2016, the rate of light-duty VMT growth has slowed to less than one percent each year. Average new vehicle fuel economy has increased almost every year since 2005, while light-duty truck market share decreased to about 33 percent in 2009 and has since varied from year to year between 36 and 48 percent. Light-duty truck market share was about 48 percent of new vehicles in model year 2018 (EPA 2019a).

Table 2-13 provides a detailed summary of greenhouse gas emissions from transportation-related activities with electricity-related emissions included in the totals. Historically, the majority of electricity use in the transportation sector was for rail transport. However, more recently there has been increased electricity use in on-road electric and plug-in hybrid vehicles. For a more detailed breakout of emissions by fuel type by vehicle see Table A-121 in Annex 3.

[6] VMT estimates are based on data from FHWA Highway Statistics Table VM-1 (FHWA 1996 through 2017). In 2007 and 2008 light-duty VMT decreased 3.0 percent and 2.3 percent, respectively. Note that the decline in light-duty VMT from 2006 to 2007 is due at least in part to a change in FHWA's methods for estimating VMT. In 2011, FHWA changed its methods for estimating VMT by vehicle class, which led to a shift in VMT and emissions among on-road vehicle classes in the 2007 to 2018 time period. In absence of these method changes, light-duty VMT growth between 2006 and 2007 would likely have been higher.

Almost all of the energy used for transportation was supplied by petroleum-based products, with more than half being related to gasoline consumption in automobiles and other highway vehicles. Other fuel uses, especially diesel fuel for freight trucks and jet fuel for aircraft, accounted for the remainder. The primary driver of transportation-related emissions was CO_2 from fossil fuel combustion, which increased by 24 percent from 1990 to 2018.[7] This rise in CO_2 emissions, combined with an increase in HFCs from close to zero emissions in 1990 to 38.5 MMT CO_2 Eq. in 2018, led to an increase in overall greenhouse gas emissions from transportation activities of 23 percent.[8]

Table 2-13: Transportation-Related Greenhouse Gas Emissions (MMT CO_2 Eq.)

Gas/Vehicle	1990	2005	2014	2015	2016	2017	2018
Passenger Cars	**639.6**	**693.1**	**760.3**	**760.2**	**770.6**	**767.3**	**777.5**
CO_2	612.2	642.8	734.7	736.8	749.8	749.2	761.5
CH_4	3.2	1.3	0.7	0.6	0.6	0.5	0.5
N_2O	24.1	17.3	9.1	8.1	7.1	6.1	5.1
HFCs	0.0	31.7	15.8	14.7	13.2	11.4	10.4
Light-Duty Trucks	**326.7**	**538.5**	**334.7**	**323.7**	**332.8**	**326.8**	**328.3**
CO_2	312.2	490.7	305.9	297.2	308.7	305.0	308.0
CH_4	1.7	0.8	0.3	0.3	0.2	0.2	0.2
N_2O	12.8	13.6	3.9	3.2	2.9	2.4	2.0
HFCs	0.0	33.3	24.7	23.0	21.1	19.2	18.1
Medium- and Heavy-Duty Trucks	**230.3**	**400.1**	**402.5**	**410.1**	**414.2**	**427.6**	**437.9**
CO_2	229.3	395.4	394.8	402.1	406.0	419.0	428.9
CH_4	0.3	0.1	0.1	0.1	0.1	0.1	0.1
N_2O	0.7	1.2	2.3	2.4	2.6	2.8	3.0
HFCs	0.0	3.4	5.3	5.5	5.5	5.7	5.9
Buses	**8.5**	**12.2**	**19.0**	**19.4**	**19.0**	**20.4**	**21.9**
CO_2	8.4	11.6	18.3	18.7	18.3	19.7	21.1
CH_4	+	0.2	0.2	0.2	0.2	0.2	0.2
N_2O	+	+	0.1	0.1	0.1	0.1	0.1
HFCs	0.0	0.3	0.4	0.4	0.4	0.4	0.4
Motorcycles	**1.7**	**1.6**	**3.8**	**3.7**	**3.9**	**3.8**	**3.9**
CO_2	1.7	1.6	3.8	3.7	3.8	3.7	3.8
CH_4	+	+	+	+	+	+	+
N_2O	+	+	+	+	+	+	+
Commercial Aircraft[a]	**110.9**	**134.0**	**116.3**	**120.1**	**121.5**	**129.2**	**130.8**
CO_2	109.9	132.7	115.2	119.0	120.4	128.0	129.6
CH_4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N_2O	1.0	1.2	1.1	1.1	1.1	1.2	1.2
Other Aircraft[b]	**78.3**	**59.7**	**35.0**	**40.4**	**47.5**	**45.6**	**44.7**
CO_2	77.5	59.1	34.7	40.0	47.0	45.2	44.3
CH_4	0.1	0.1	+	+	+	+	+
N_2O	0.7	0.5	0.3	0.4	0.4	0.4	0.4
Ships and Boats[c]	**47.4**	**45.7**	**29.2**	**33.8**	**40.9**	**44.0**	**41.2**
CO_2	46.3	44.2	26.2	30.5	37.1	39.9	36.8
CH_4	0.6	0.5	0.3	0.3	0.3	0.3	0.3
N_2O	0.6	0.6	0.3	0.4	0.5	0.5	0.5
HFCs	0.0	0.5	2.3	2.6	2.9	3.3	3.6
Rail	**39.0**	**50.9**	**45.9**	**43.7**	**39.9**	**41.1**	**42.9**
CO_2	38.5	50.3	45.2	43.0	39.3	40.5	42.3
CH_4	0.1	0.1	0.1	0.1	0.1	0.1	0.1

[7] See previous footnote.

[8] See previous footnote.

N_2O	0.3	0.4	0.4	0.4	0.3	0.4	0.4
HFCs	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Other Emissions from Electric Power[d]	0.1	+	+	+	+	0.1	0.1
Pipelines[e]	**36.0**	**32.4**	**39.4**	**38.5**	**39.2**	**41.3**	**49.2**
CO_2	36.0	32.4	39.4	38.5	39.2	41.3	49.2
Lubricants	**11.8**	**10.2**	**10.0**	**11.0**	**10.4**	**9.6**	**9.3**
CO_2	11.8	10.2	10.0	11.0	10.4	9.6	9.3
Total Transportation	**1,530.2**	**1,978.3**	**1,796.2**	**1,804.6**	**1,839.9**	**1,856.7**	**1,887.4**
International Bunker Fuels[f]	*54.8*	*44.7*	*28.7*	*31.6*	*35.0*	*34.6*	*32.5*
Ethanol CO_2[g]	*4.1*	*21.6*	*74.0*	*74.2*	*76.9*	*77.7*	*78.6*
Biodiesel CO_2[g]	*0.0*	*0.9*	*13.3*	*14.1*	*19.6*	*18.7*	*17.9*

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Consists of emissions from jet fuel consumed by domestic operations of commercial aircraft (no bunkers).

[b] Consists of emissions from jet fuel and aviation gasoline consumption by general aviation and military aircraft.

[c] Fluctuations in emission estimates are associated with fluctuations in reported fuel consumption and may reflect issues with data sources.

[d] Other emissions from electric power are a result of waste incineration (as the majority of municipal solid waste is combusted in "trash-to-steam" electric power plants), electrical transmission and distribution, and a portion of Other Process Uses of Carbonates (from pollution control equipment installed in electric power plants).

[e] CO_2 estimates reflect natural gas used to power pipelines, but not electricity. While the operation of pipelines produces CH_4 and N_2O, these emissions are not directly attributed to pipelines in the Inventory.

[f] Emissions from International Bunker Fuels include emissions from both civilian and military activities; these emissions are not included in the transportation totals.

[g] Ethanol and biodiesel CO_2 estimates are presented for informational purposes only. See Section 3.11 and the estimates in Land Use, Land-Use Change, and Forestry (see Chapter 6), in line with IPCC methodological guidance and UNFCCC reporting obligations, for more information on ethanol and biodiesel.

Notes: Passenger cars and light-duty trucks include vehicles typically used for personal travel and less than 8,500 lbs; medium- and heavy-duty trucks include vehicles larger than 8,500 lbs. HFC emissions primarily reflect HFC-134a. Totals may not sum due to independent rounding.

Commercial

The commercial end-use sector, with electricity-related emissions distributed, accounts for 16.0 percent of U.S. greenhouse gas emissions in 2018 and is heavily reliant on electricity for meeting energy needs, with electricity use for lighting, heating, air conditioning, and operating appliances. The remaining emissions were largely due to the direct consumption of natural gas and petroleum products, primarily for heating and cooking needs. Energy-related emissions from the commercial sector have generally been increasing since 1990, and annual variations are often correlated with short-term fluctuations in energy use caused by weather conditions, rather than prevailing economic conditions. Decreases in energy-related emissions in the commercial sector in recent years can be largely attributed to an overall reduction in energy use driven by a reduction in heating degree days and increases in energy efficiency.

Landfills and wastewater treatment are included in the commercial sector, with landfill emissions decreasing since 1990 and wastewater treatment emissions decreasing slightly.

Residential

The residential end-use sector, with electricity-related emissions distributed, accounts for 15.6 percent of U.S. greenhouse gas emissions in 2018 and similarly, is heavily reliant on electricity for meeting energy needs, with electricity use for lighting, heating, air conditioning, and operating appliances. The remaining emissions were largely due to the direct consumption of natural gas and petroleum products, primarily for heating and cooking needs. Emissions from the residential sector have generally been increasing since 1990, and annual variations are

often correlated with short-term fluctuations in energy use caused by weather conditions, rather than prevailing economic conditions. In the long term, the residential sector is also affected by population growth, migration trends toward warmer areas, and changes in housing and building attributes (e.g., larger sizes and improved insulation). A shift toward energy-efficient products and more stringent energy efficiency standards for household equipment has also contributed to recent trends in energy demand in households (EIA 2018).

Agriculture

The agriculture end-use sector accounts for 10.5 percent of U.S. greenhouse gas emissions in 2018 when electricity-related emissions are distributed, and includes a variety of processes, including enteric fermentation in domestic livestock, livestock manure management, and agricultural soil management. In 2018, agricultural soil management was the largest source of N_2O emissions, and enteric fermentation was the largest source of CH_4 emissions in the United States. This sector also includes small amounts of CO_2 emissions from fossil fuel combustion by motorized farm equipment such as tractors.

Box 2-2: Recent Trends in Various U.S. Greenhouse Gas Emissions-Related Data

Total greenhouse gas emissions can be compared to other economic and social indices to highlight changes over time. These comparisons include: (1) emissions per unit of aggregate energy use, because energy-related activities are the largest sources of emissions; (2) emissions per unit of fossil fuel consumption, because almost all energy-related emissions involve the combustion of fossil fuels; (3) emissions per unit of total gross domestic product as a measure of national economic activity; and (4) emissions per capita.

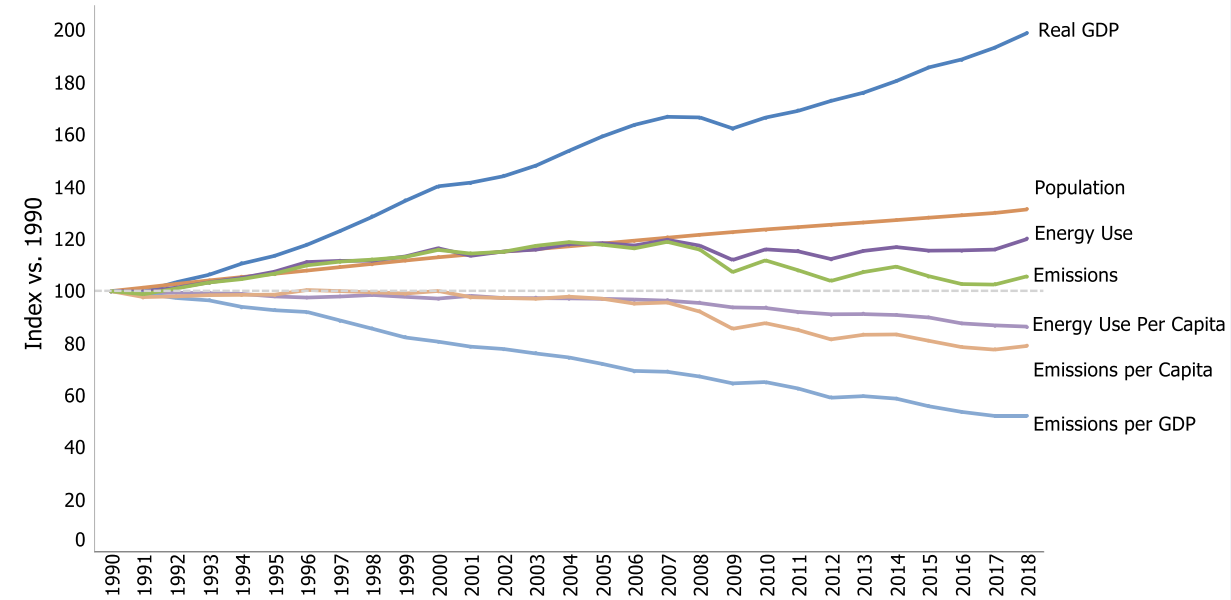
Table 2-14 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. These values represent the relative change in each statistic since 1990. Greenhouse gas emissions in the United States have grown at an average annual rate of 0.2 percent since 1990, although changes from year to year have been significantly larger. This growth rate is slightly slower than that for total energy use, overall gross domestic product (GDP) and national population (see Table 2-14 and Figure 2-15). The direction of these trends started to change after 2005, when greenhouse gas emissions, total energy use and associated fossil fuel consumption began to peak. Greenhouse gas emissions in the United States have decreased at an average annual rate of 0.7 percent since 2005. Fossil fuel consumption has also decreased at a slower rate than emissions since 2005, while total energy use, GDP, and national population continued to increase.

Table 2-14: Recent Trends in Various U.S. Data (Index 1990 = 100)

Variable	1990	2005	2014	2015	2016	2017	2018	Avg. Annual Change Since 1990[a]	Avg. Annual Change Since 2005[a]
Greenhouse Gas Emissions[b]	100	115	106	104	101	101	104	0.2%	-0.7%
Energy Use[c]	100	118	117	116	116	116	120	0.7%	0.1%
GDP[d]	100	159	181	186	189	193	199	2.5%	1.7%
Population[e]	100	118	127	128	129	130	131	1.0%	0.8%

[a] Average annual growth rate.
[b] GWP-weighted values.
[c] Energy-content-weighted values (EIA 2019).
[d] GDP in chained 2009 dollars (BEA 2020).
[e] U.S. Census Bureau (2020).

Figure 2-15: U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product



Source: BEA (2020), U.S. Census Bureau (2020), and emission estimates in this report.

2.3 Precursor Greenhouse Gas Emissions (CO, NO_x, NMVOCs, and SO_2)

The reporting requirements of the UNFCCC[9] request that information be provided on precursor greenhouse gases, which include carbon monoxide (CO), nitrogen oxides (NO_x), non-CH_4 volatile organic compounds (NMVOCs), and sulfur dioxide (SO_2). These gases are not direct greenhouse gases, but indirectly affect terrestrial radiation absorption by influencing the formation and destruction of tropospheric and stratospheric ozone, or, in the case of SO_2, by affecting the absorptive characteristics of the atmosphere. Additionally, some of these gases may react with other chemical compounds in the atmosphere to form compounds that are greenhouse gases. Carbon monoxide is produced when carbon-containing fuels are combusted incompletely. Nitrogen oxides (i.e., NO and NO_2) are created by lightning, fires, fossil fuel combustion, and in the stratosphere from N_2O. Non-methane volatile organic compounds—which include hundreds of organic compounds that participate in atmospheric chemical reactions (i.e., propane, butane, xylene, toluene, ethane, and many others)—are emitted primarily from transportation, industrial processes, and non-industrial consumption of organic solvents. In the United States, SO_2 is primarily emitted from coal combustion for electric power generation and the metals industry. Sulfur-containing compounds emitted into the atmosphere tend to exert a negative radiative forcing (i.e., cooling) and therefore are discussed separately.

One important indirect climate change effect of NMVOCs and NO_x is their role as precursors for tropospheric ozone formation. They can also alter the atmospheric lifetimes of other greenhouse gases. Another example of

[9] See <http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf>.

indirect greenhouse gas formation into greenhouse gases is the interaction of CO with the hydroxyl radical—the major atmospheric sink for CH_4 emissions—to form CO_2. Therefore, increased atmospheric concentrations of CO limit the number of hydroxyl molecules (OH) available to destroy CH_4.

Since 1970, the United States has published estimates of emissions of CO, NO_x, NMVOCs, and SO_2 (EPA 2019b),[10] which are regulated under the Clean Air Act. Table 2-15 shows that fuel combustion accounts for the majority of emissions of these indirect greenhouse gases. Industrial processes—such as the manufacture of chemical and allied products, metals processing, and industrial uses of solvents—are also significant sources of CO, NO_x, and NMVOCs.

Table 2-15: Emissions of NO_x, CO, NMVOCs, and SO_2 (kt)

Gas/Activity	1990	2005	2014	2015	2016	2017	2018
NO_x	**21,738**	**17,338**	**10,797**	**10,286**	**9,572**	**9,293**	**8,892**
Mobile Fossil Fuel Combustion	10,862	10,295	6,138	5,740	5,413	5,051	4,689
Stationary Fossil Fuel Combustion	10,023	5,858	3,313	3,036	2,876	2,757	2,719
Oil and Gas Activities	139	321	650	650	650	650	650
Industrial Processes and Product Use	592	572	414	414	414	414	414
Forest Fires	22	127	142	312	87	289	289
Waste Combustion	82	128	97	97	97	97	97
Grassland Fires	5	21	27	21	19	21	20
Agricultural Burning	12	14	14	13	13	13	13
Waste	+	2	2	2	2	2	2
CO	**130,943**	**71,745**	**47,328**	**52,310**	**41,871**	**47,438**	**45,749**
Mobile Fossil Fuel Combustion	119,360	58,615	34,135	33,159	30,786	29,112	27,438
Forest Fires	801	4,507	5,055	11,125	3,092	10,314	10,314
Stationary Fossil Fuel Combustion	5,000	4,648	3,686	3,686	3,686	3,686	3,686
Waste Combustion	978	1,403	1,776	1,776	1,776	1,776	1,776
Industrial Processes and Product Use	4,129	1,557	1,251	1,251	1,251	1,251	1,251
Oil and Gas Activities	302	318	637	637	637	637	637
Grassland Fires	84	358	442	356	324	345	331
Agricultural Burning	287	332	338	311	310	308	308
Waste	1	7	8	8	8	8	8
NMVOCs	**20,930**	**13,154**	**11,130**	**10,965**	**10,718**	**10,513**	**10,307**
Industrial Processes and Product Use	7,638	5,849	3,815	3,815	3,815	3,815	3,815
Mobile Fossil Fuel Combustion	10,932	5,724	3,754	3,589	3,342	3,137	2,931
Oil and Gas Activities	554	510	2,853	2,853	2,853	2,853	2,853
Stationary Fossil Fuel Combustion	912	716	497	497	497	497	497
Waste Combustion	222	241	143	143	143	143	143
Waste	673	114	68	68	68	68	68
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA
SO_2	**20,935**	**13,196**	**4,240**	**3,342**	**2,685**	**2,548**	**2,481**
Stationary Fossil Fuel Combustion	18,407	11,541	3,532	2,635	1,978	1,841	1,774
Industrial Processes and Product Use	1,307	831	497	497	497	497	497
Oil and Gas Activities	390	180	94	94	94	94	94
Mobile Fossil Fuel Combustion	793	619	88	87	87	87	87
Waste Combustion	38	25	27	27	27	27	27
Waste	+	1	1	1	1	1	1
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA

Note: Totals may not sum due to independent rounding.
+ Does not exceed 0.5 kt.

[10] NO_x and CO emission estimates from Field Burning of Agricultural Residues were estimated separately, and therefore not taken from EPA (2019b).

NA (Not Available)
Source: (EPA 2019b) except for estimates from Forest Fires, Grassland Fires, and Field Burning of Agricultural Residues.

Box 2-3: Sources and Effects of Sulfur Dioxide

Sulfur dioxide (SO_2) emitted into the atmosphere through natural and anthropogenic processes affects the earth's radiative budget through its photochemical transformation into sulfate aerosols that can:

(1) scatter radiation from the sun back to space, thereby reducing the radiation reaching the earth's surface;
(2) affect cloud formation; and
(3) affect atmospheric chemical composition (e.g., by providing surfaces for heterogeneous chemical reactions).

The indirect effect of sulfur-derived aerosols on radiative forcing can be considered in two parts. The first indirect effect is the aerosols' tendency to decrease water droplet size and increase water droplet concentration in the atmosphere. The second indirect effect is the tendency of the reduction in cloud droplet size to affect precipitation by increasing cloud lifetime and thickness. Although still highly uncertain, the radiative forcing estimates from both the first and the second indirect effect are believed to be negative, as is the combined radiative forcing of the two (IPCC 2013).

Sulfur dioxide is also a major contributor to the formation of regional haze, which can cause significant increases in acute and chronic respiratory diseases. Once SO_2 is emitted, it is chemically transformed in the atmosphere and returns to the earth as the primary source of acid rain. Because of these harmful effects, the United States has regulated SO_2 emissions in the Clean Air Act.

Electric power is the largest anthropogenic source of SO_2 emissions in the United States, accounting for 47.8 percent in 2018. Coal combustion contributes nearly all of those emissions (approximately 92 percent). Sulfur dioxide emissions have decreased in recent years, primarily as a result of electric power generators switching from high-sulfur to low-sulfur coal and installing flue gas desulfurization equipment.