2. Trends in Greenhouse Gas Emissions and Removals

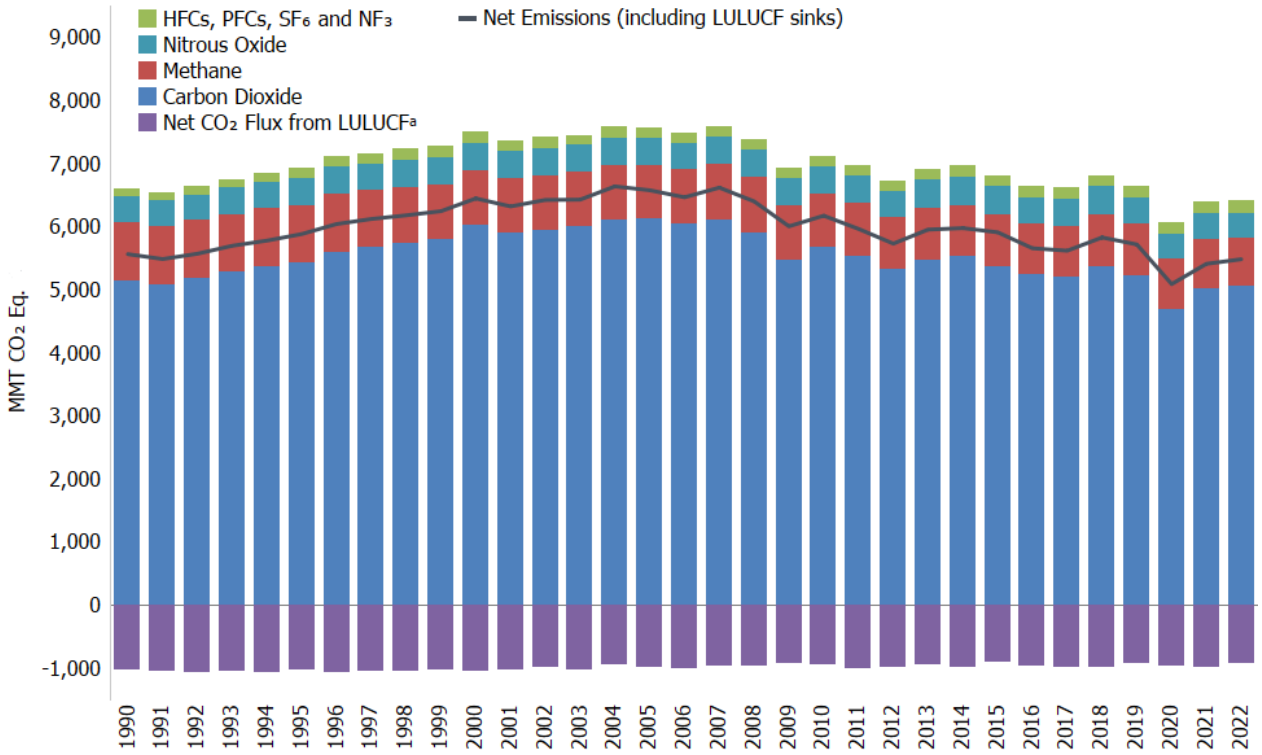
2.1 Overview of U.S. Greenhouse Gas Emissions and Sinks Trends

In 2022, total gross U.S. greenhouse gas emissions were 6,341.2 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.).[1] Total gross U.S. emissions decreased by 3.1 percent from 1990 to 2022, down from a high of 15.0 percent above 1990 levels in 2007. Gross emissions increased from 2021 to 2022 by 0.3 percent (16.4 MMT CO_2 Eq.). Net emissions (i.e., including sinks) were 5,487.0 MMT CO_2 Eq. in 2022. Overall, net emissions increased by 1.3 percent from 2021 to 2022 and decreased by 16.6 percent from 2005 levels, as shown in Table 2-1. Between 2021 and 2022, the increase in total greenhouse gas emissions was driven largely by an increase in CO_2 emissions from fossil fuel combustion across most end-use sectors due in part to increased energy use from the continued rebound of economic activity after the height of the COVID-19 pandemic. The CO_2 emissions from fossil fuel combustion increased by 1.0 percent from 2021 to 2022, including a 4.7 percent increase in residential sector emissions, a 3.0 percent increase in commercial sector emissions, 1.6 percent increase in transportation sector emissions, and 0.9 percent increase in industrial emissions. Electric power sector emissions decreased by 0.6 percent from 2021 to 2022 due largely to a 6.4 percent decrease in coal consumption for electricity generation. This corresponded with an increase in natural gas generation and renewable energy generation, largely from wind and solar energy. Electric power sector emissions decreased overall from 1990 through 2022, which reflects the combined impacts of long-term trends in many factors, including population, economic growth, energy markets, technological changes including energy efficiency, and the carbon intensity of energy fuel choices. Carbon sequestration in the Land Use, Land-Use Change, and Forestry (LULUCF) sector offset 14.5 percent of total emissions in 2022.

Figure 2-1 and Figure 2-2 illustrate the overall trend in total U.S. emissions and sinks since 1990, by gas and by annual percentage changes relative to the previous year.

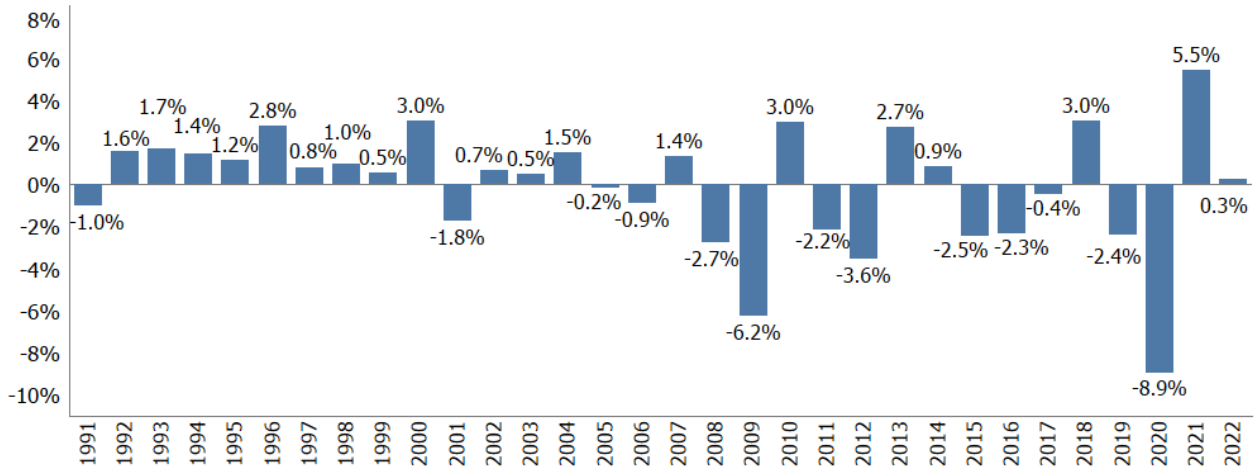
[1] The gross emissions total presented in this report for the United States excludes emissions and sinks from removals from LULUCF. The net emissions total presented in this report for the United States includes emissions and sinks from removals from LULUCF.

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



[a] The term "flux" is used to describe the exchange of CO_2 to and from the atmosphere, with net flux being either positive or negative depending on the overall balance. Removal and long-term storage of CO_2 from the atmosphere is also referred to as "carbon sequestration."

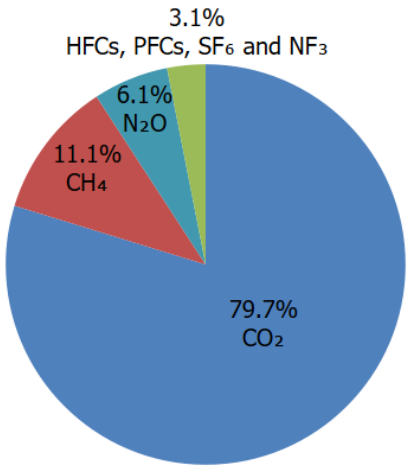
Figure 2-2: Annual Percentage Change in Gross U.S. Greenhouse Gas Emissions Relative to the Previous Year



Emissions and Sinks by Gas

Figure 2-3 illustrates the relative contribution of each gas to total gross U.S. greenhouse gas emissions in 2022, in CO_2 equivalents (i.e., weighted by global warming potential). The primary greenhouse gas emitted by human activities in the United States is CO_2, representing 79.7 percent of total greenhouse gas emissions. The largest source of CO_2—and of overall greenhouse gas emissions—is fossil fuel combustion, primarily from transportation and power generation. Methane (CH_4) emissions account for 11.1 percent of emissions. The major sources of methane include enteric fermentation associated with domestic livestock, natural gas systems, and decomposition of waste in landfills. Agricultural soil management, wastewater treatment, stationary sources of fuel combustion, and manure management are the major sources of N_2O emissions. Ozone depleting substance (ODS) substitute emissions were the primary contributor to aggregate hydrofluorocarbon (HFC) emissions. Perfluorocarbon (PFC) emissions were attributable primarily to electronics manufacturing and primary aluminum production. Electrical equipment accounted for most sulfur hexafluoride (SF_6) emissions. The electronics industry is the only source of nitrogen trifluoride (NF_3) emissions.

Figure 2-3: 2022 Gross Total U.S. Greenhouse Gas Emissions by Gas (Percentages based on MMT CO_2 Eq.)



Note: Emissions and removals from LULUCF are excluded from the figure above.

From 1990 to 2022, total emissions of CO_2 decreased by 75.6 MMT CO_2 Eq. (1.5 percent), total emissions of methane (CH_4) decreased by 169.1 MMT CO_2 Eq. (19.4 percent), and total emissions of nitrous oxide (N_2O) decreased by 21.6 MMT CO_2 Eq. (5.3 percent). During the same period, emissions of fluorinated gases including HFCs, PFCs, SF_6, and NF_3 rose by 63.5 MMT CO_2 Eq. (48.1 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, very long atmospheric lifetimes. 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 14.5 percent (921.8 MMT CO_2 Eq.) of total gross emissions in 2022.

Table 2-1 provides information on trends in emissions and sinks from all U.S. anthropogenic sources and sinks 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	2018	2019	2020	2021	2022
CO_2	**5,132.3**	**6,123.8**	**5,360.3**	**5,232.3**	**4,686.7**	**5,014.8**	**5,056.7**
Fossil Fuel Combustion	4,746.9	5,739.6	4,982.9	4,840.9	4,329.2	4,642.6	4,689.9
Transportation	*1,468.9*	*1,858.6*	*1,813.1*	*1,816.6*	*1,572.8*	*1,753.5*	*1,780.8*
Electric Power Sector	*1,820.0*	*2,400.1*	*1,753.4*	*1,606.7*	*1,439.6*	*1,540.9*	*1,531.7*
Industrial	*871.1*	*843.5*	*805.2*	*798.1*	*749.5*	*768.8*	*775.9*
Residential	*338.6*	*358.6*	*338.9*	*342.9*	*314.8*	*318.0*	*333.1*
Commercial	*228.3*	*227.0*	*246.3*	*251.7*	*229.3*	*237.5*	*244.7*
U.S. Territories	*20.0*	*51.9*	*25.9*	*24.8*	*23.3*	*23.8*	*23.8*
Non-Energy Use of Fuels	103.5	125.9	121.7	116.0	107.9	120.9	116.0
Cement Production	33.5	46.2	39.0	40.9	40.7	41.3	41.9
Iron and Steel Production & Metallurgical Coke Production	104.7	70.1	42.9	43.1	37.7	41.9	40.7
Natural Gas Systems	32.4	26.3	32.8	38.5	36.7	35.8	36.5
Petrochemical Production	21.6	27.4	27.2	28.5	27.9	30.7	28.8
Petroleum Systems	9.6	10.2	34.8	45.5	28.9	24.1	22.0
Ammonia Production	14.4	10.2	12.7	12.4	13.0	12.2	12.6
Incineration of Waste	12.9	13.3	13.3	12.9	12.9	12.5	12.4
Lime Production	11.7	14.6	13.1	12.1	11.3	11.9	12.2
Other Process Uses of Carbonates	7.1	8.5	7.9	9.0	9.0	8.6	10.4
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	6.1	6.2	5.8	6.6	7.1
Urea Fertilization	2.4	3.5	4.9	5.0	5.1	5.2	5.3
Carbon Dioxide Consumption	1.5	1.4	4.1	4.9	5.0	5.0	5.0
Liming	4.7	4.4	2.2	2.2	2.9	2.4	3.3
Coal Mining	4.6	4.2	3.1	3.0	2.2	2.5	2.5
Glass Production	2.3	2.4	2.0	1.9	1.9	2.0	2.0
Soda Ash Production	1.4	1.7	1.7	1.8	1.5	1.7	1.7
Titanium Dioxide Production	1.2	1.8	1.5	1.3	1.3	1.5	1.5
Aluminum Production	6.8	4.1	1.5	1.9	1.7	1.5	1.4
Ferroalloy Production	2.2	1.4	2.1	1.6	1.4	1.6	1.3
Zinc Production	0.6	1.0	1.0	1.0	1.0	1.0	0.9
Phosphoric Acid Production	1.5	1.3	0.9	0.9	0.9	0.9	0.8
Lead Production	0.5	0.6	0.5	0.5	0.5	0.4	0.4
Carbide Production and Consumption	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Abandoned Oil and Gas Wells	+	+	+	+	+	+	+
Substitution of Ozone Depleting Substances	+	+	+	+	+	+	+
Magnesium Production and Processing	0.1	+	+	+	+	+	+
Biomass and Biodiesel Consumption[a]	*237.9*	*245.4*	*336.0*	*333.1*	*295.7*	*303.0*	*305.4*
International Bunker Fuels[b]	*103.6*	*113.3*	*124.3*	*113.6*	*69.6*	*80.2*	*82.3*
CH_4 (excludes LULUCF sources)[c]	**871.6**	**795.4**	**771.5**	**754.3**	**735.3**	**720.6**	**702.5**
Enteric Fermentation	183.1	188.2	196.8	197.3	196.3	196.5	192.6
Natural Gas Systems	218.8	210.1	190.3	188.7	180.3	174.6	173.1
Landfills	197.8	147.7	126.3	128.7	124.1	122.0	119.8
Manure Management	39.1	55.0	67.7	66.7	66.9	66.4	64.7
Coal Mining	108.1	71.5	59.1	53.0	46.2	44.7	43.6
Petroleum Systems	49.4	48.2	59.0	52.2	53.3	48.6	39.6
Wastewater Treatment	22.7	22.7	21.4	21.1	21.0	20.7	20.8
Rice Cultivation	18.9	20.6	19.9	15.6	18.6	18.3	18.9
Stationary Combustion	9.6	8.8	9.6	9.8	8.0	8.0	8.7
Abandoned Oil and Gas Wells	7.8	8.2	8.4	8.5	8.5	8.6	8.5

Abandoned Underground Coal Mines	8.1	7.4	6.9	6.6	6.5	6.4	6.4
Mobile Combustion	7.2	4.3	2.8	2.9	2.5	2.6	2.6
Composting	0.4	2.1	2.5	2.5	2.6	2.6	2.6
Field Burning of Agricultural Residues	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Anaerobic Digestion at Biogas Facilities	+	+	+	+	+	+	+
Carbide Production and Consumption	+	+	+	+	+	+	+
Ferroalloy Production	+	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+
Petrochemical Production	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O (excludes LULUCF sources)[c]	**408.1**	**419.2**	**439.4**	**416.4**	**391.1**	**398.1**	**386.5**
Agricultural Soil Management	288.8	294.1	333.4	315.6	292.1	298.0	290.8
Wastewater Treatment	14.8	18.1	21.2	21.6	22.3	22.1	21.9
Stationary Combustion	22.3	30.5	25.1	22.1	20.5	22.0	21.6
Manure Management	13.4	15.2	16.6	16.8	16.9	17.1	17.0
Mobile Combustion	38.4	37.0	17.7	19.1	16.1	16.8	16.6
Nitric Acid Production	10.8	10.1	8.5	8.9	8.3	7.9	8.6
N_2O from Product Uses	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Adipic Acid Production	13.5	6.3	9.3	4.7	7.4	6.6	2.1
Composting	0.3	1.5	1.8	1.8	1.8	1.8	1.8
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.5	1.9	1.3	1.2	1.1	1.2	1.3
Incineration of Waste	0.4	0.3	0.4	0.4	0.3	0.4	0.3
Electronics Industry	+	0.1	0.2	0.2	0.3	0.3	0.3
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Natural Gas Systems	+	+	+	+	+	+	0.2
Petroleum Systems	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.8*	*0.9*	*1.0*	*0.9*	*0.5*	*0.6*	*0.7*
HFCs	**48.2**	**121.2**	**162.9**	**167.2**	**169.6**	**176.3**	**181.4**
Substitution of Ozone Depleting Substances[d]	0.3	99.5	157.9	162.1	166.2	172.6	178.1
Fluorochemical Production	47.8	21.6	4.6	4.8	3.0	3.3	2.9
Electronics Industry	0.2	0.2	0.3	0.3	0.3	0.4	0.3
Magnesium Production and Processing	NO	NO	0.1	0.1	0.1	+	+
PFCs	**47.1**	**7.8**	**5.8**	**5.9**	**5.5**	**5.4**	**5.4**
Electronics Industry	2.5	3.0	2.9	2.6	2.6	2.7	2.7
Fluorochemical Production	25.2	1.6	1.3	1.7	1.3	1.6	1.8
Aluminum Production	19.3	3.1	1.4	1.4	1.4	0.9	0.8
SF_6 and PFCs from Other Product Use	0.1	0.1	0.2	0.2	0.2	0.1	0.2
Substitution of Ozone Depleting Substances[d]	NO	+	+	+	+	+	+
Electrical Equipment	+	+	NO	+	+	+	+
SF_6	**35.9**	**20.0**	**7.7**	**8.4**	**8.1**	**8.5**	**7.6**
Electrical Equipment	24.7	11.8	5.0	6.1	5.9	6.0	5.1
Magnesium Production and Processing	5.6	3.0	1.1	0.9	0.9	1.2	1.1
Electronics Industry	0.5	0.8	0.8	0.8	0.8	1.0	0.7
SF_6 and PFCs from Other Product Use	1.4	1.4	0.8	0.6	0.5	0.4	0.6

Fluorochemical Production	3.8	3.0	+	+	+	+	+
NF_3	**0.7**	**0.8**	**0.7**	**1.1**	**1.3**	**1.2**	**1.1**
Electronics Industry	+	0.4	0.6	0.5	0.6	0.7	0.6
Fluorochemical Production	0.7	0.4	0.1	0.6	0.7	0.5	0.5
Total Gross Emissions (Sources)	**6,544.0**	**7,488.2**	**6,748.2**	**6,585.6**	**5,997.6**	**6,324.9**	**6,341.2**
LULUCF Emissions[c]	**57.9**	**68.9**	**62.8**	**58.0**	**68.4**	**72.9**	**67.5**
CH_4	53.1	58.6	55.6	52.5	59.3	62.2	58.4
N_2O	4.8	10.4	7.2	5.5	9.1	10.8	9.1
LULUCF Carbon Stock Change[e]	**(1,034.7)**	**(976.6)**	**(978.3)**	**(921.6)**	**(972.8)**	**(983.4)**	**(921.8)**
LULUCF Sector Net Total[f]	**(976.7)**	**(907.6)**	**(915.5)**	**(863.6)**	**(904.4)**	**(910.5)**	**(854.3)**
Net Emissions (Sources and Sinks)	**5,567.3**	**6,580.5**	**5,832.7**	**5,722.0**	**5,093.2**	**5,414.4**	**5,487.0**

+ Does not exceed 0.05 MMT CO_2 Eq.

NO (Not Occurring)

[a] Emissions from biomass and biofuel consumption are not included specifically in 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, flooded land remaining flooded land, and land converted to flooded land; 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 from this source are included under HFCs due to confidential business information.

[e] LULUCF carbon stock change is the net carbon 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 LULUCF CH_4 and N_2O emissions to the atmosphere plus LULUCF net carbon stock changes.

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

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

Gas/Source	1990	2005	2018	2019	2020	2021	2022
CO_2	**5,132,272**	**6,123,753**	**5,360,271**	**5,232,302**	**4,686,665**	**5,014,814**	**5,056,712**
Fossil Fuel Combustion	4,746,911	5,739,557	4,982,940	4,840,949	4,329,241	4,642,645	4,689,883
Transportation	*1,468,944*	*1,858,552*	*1,813,135*	*1,816,636*	*1,572,820*	*1,753,546*	*1,780,763*
Electric Power Sector	*1,819,951*	*2,400,057*	*1,753,432*	*1,606,721*	*1,439,566*	*1,540,933*	*1,531,680*
Industrial	*871,148*	*843,503*	*805,214*	*798,125*	*749,518*	*768,833*	*775,859*
Residential	*338,568*	*358,609*	*338,940*	*342,905*	*314,795*	*318,034*	*333,100*
Commercial	*228,293*	*226,979*	*246,297*	*251,749*	*229,264*	*237,528*	*244,714*
U.S. Territories	*20,008*	*51,856*	*25,923*	*24,813*	*23,279*	*23,772*	*23,767*
Non-Energy Use of Fuels	103,496	125,948	121,723	115,974	107,922	120,856	116,027
Cement Production	33,484	46,194	38,971	40,896	40,688	41,312	41,884
Iron and Steel Production & Metallurgical Coke Production	104,740	70,082	42,863	43,095	37,724	41,873	40,672
Natural Gas Systems	32,442	26,324	32,768	38,525	36,719	35,780	36,466
Petrochemical Production	21,611	27,383	27,200	28,483	27,926	30,656	28,788
Petroleum Systems	9,585	10,202	34,777	45,498	28,937	24,140	21,971
Ammonia Production	14,404	10,234	12,669	12,401	13,006	12,192	12,610
Incineration of Waste	12,900	13,254	13,339	12,948	12,921	12,476	12,357
Lime Production	11,700	14,552	13,106	12,112	11,299	11,870	12,208
Other Process Uses of Carbonates	7,103	8,472	7,935	8,969	9,012	8,583	10,378

Gas/Source	1990	2005	2018	2019	2020	2021	2022
Urea Consumption for Non-Agricultural Purposes	3,784	3,653	6,113	6,150	5,805	6,600	7,053
Urea Fertilization	2,417	3,504	4,936	5,034	5,132	5,229	5,327
Carbon Dioxide Consumption	1,472	1,375	4,130	4,870	4,970	4,990	5,000
Liming	4,690	4,351	2,240	2,203	2,887	2,387	3,268
Coal Mining	4,606	4,169	3,139	2,992	2,197	2,455	2,474
Glass Production	2,263	2,402	1,989	1,940	1,858	1,969	1,956
Soda Ash Production	1,431	1,655	1,714	1,792	1,461	1,714	1,704
Titanium Dioxide Production	1,195	1,755	1,541	1,340	1,340	1,474	1,474
Aluminum Production	6,831	4,142	1,455	1,880	1,748	1,541	1,446
Ferroalloy Production	2,152	1,392	2,063	1,598	1,377	1,567	1,327
Zinc Production	632	1,030	999	1,026	977	1,007	947
Phosphoric Acid Production	1,529	1,342	937	909	901	874	840
Lead Production	516	553	527	531	450	439	428
Carbide Production and Consumption	243	213	184	175	154	172	210
Abandoned Oil and Gas Wells	7	7	8	8	8	8	8
Substitution of Ozone Depleting Substances	+	1	3	3	4	4	4
Magnesium Production and Processing	129	4	2	2	3	3	3
Biomass and Biofuel Consumption[a]	*237,946*	*245,421*	*335,971*	*333,057*	*295,695*	*303,014*	*305,417*
International Bunker Fuels[b]	*103,634*	*113,328*	*124,279*	*113,632*	*69,638*	*80,180*	*82,341*
CH_4 (excludes LULUCF sources)[c]	**31,130**	**28,408**	**27,553**	**26,940**	**26,262**	**25,734**	**25,091**
Enteric Fermentation	6,539	6,722	7,028	7,045	7,010	7,017	6,878
Natural Gas Systems	7,813	7,505	6,795	6,741	6,439	6,235	6,183
Landfills	7,063	5,275	4,512	4,595	4,431	4,359	4,277
Manure Management	1,398	1,964	2,418	2,382	2,390	2,373	2,312
Coal Mining	3,860	2,552	2,110	1,892	1,648	1,595	1,558
Petroleum Systems	1,764	1,723	2,108	1,865	1,904	1,737	1,415
Wastewater Treatment	811	809	763	755	748	738	743
Rice Cultivation	677	735	711	558	664	653	674
Stationary Combustion	344	313	344	351	285	286	311
Abandoned Oil and Gas Wells	279	294	301	302	303	306	303
Abandoned Underground Coal Mines	288	264	247	237	232	228	228
Mobile Combustion	258	154	101	102	91	92	93
Composting	15	75	90	91	92	92	92
Field Burning of Agricultural Residues	19	23	22	23	22	22	22
Iron and Steel Production & Metallurgical Coke Production	1	1	+	+	+	+	+
Anaerobic Digestion at Biogas Facilities	+	+	+	1	+	+	+
Carbide Production and Consumption	1	+	+	+	+	+	+
Ferroalloy Production	1	+	1	+	+	+	+
Petrochemical Production	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*7*	*5*	*4*	*4*	*3*	*3*	*3*
N_2O (excludes LULUCF sources)[c]	**1,540**	**1,582**	**1,658**	**1,571**	**1,476**	**1,502**	**1,459**
Agricultural Soil Management	1,090	1,110	1,258	1,191	1,102	1,124	1,097

Gas/Source	1990	2005	2018	2019	2020	2021	2022
Wastewater Treatment	56	68	80	81	84	83	83
Stationary Combustion	84	115	95	83	77	83	82
Manure Management	50	57	63	63	64	65	64
Mobile Combustion	145	140	67	72	61	63	63
Nitric Acid Production	41	38	32	34	31	30	33
N_2O from Product Uses	14	14	14	14	14	14	14
Adipic Acid Production	51	24	35	18	28	25	8
Composting	1	6	7	7	7	7	7
Caprolactam, Glyoxal, and Glyoxylic Acid Production	6	7	5	5	4	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
Natural Gas Systems	+	+	+	+	+	+	1
Petroleum Systems	+	+	+	+	+	+	+
International Bunker Fuels[b]	*3*	*3*	*4*	*3*	*2*	*2*	*3*
HFCs	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Substitution of Ozone Depleting Substances[d]	M	M	M	M	M	M	M
Fluorochemical Production	3	1	+	+	+	+	+
Electronics Industry	M	M	M	M	M	M	M
Magnesium Production and Processing	NO	NO	+	+	+	+	+
PFCs	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Electronics Industry	M	M	M	M	M	M	M
Fluorochemical Production	M	M	M	M	M	M	M
Aluminum Production	M	M	M	M	M	M	M
SF_6 and PFCs from Other Product Use	+	+	+	+	+	+	+
Substitution of Ozone Depleting Substances[d]	NO	+	+	+	+	+	+
Electrical Equipment	+	+	NO	+	+	+	+
SF_6	**2**	**1**	**+**	**+**	**+**	**+**	**+**
Electrical Equipment	1	1	+	+	+	+	+
Magnesium Production and Processing	+	+	+	+	+	+	+
Electronics Industry	+	+	+	+	+	+	+
SF_6 and PFCs from Other Product Use	+	+	+	+	+	+	+
Fluorochemical Production	+	+	+	+	+	+	+
NF_3	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Electronics Industry	+	+	+	+	+	+	+
Fluorochemical Production	+	+	+	+	+	+	+
CO	**130,178**	**67,491**	**33,399**	**32,975**	**30,983**	**31,901**	**31,172**
NO_x	**21,702**	**18,554**	**7,747**	**7,213**	**6,559**	**6,615**	**6,383**
SO_2	**20,935**	**13,193**	**2,210**	**1,798**	**1,615**	**1,706**	**1,706**
NMVOCs	**20,923**	**12,939**	**9,271**	**8,866**	**8,757**	**8,754**	**8,690**

Gas/Source	1990	2005	2018	2019	2020	2021	2022

+ Does not exceed 0.5 kt.
M (Mixture of multiple gases)
NO (Not Occurring)
[a] Emissions from biomass and biofuel consumption are not included specifically in 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 LULUCF 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 from this source are included under HFCs due to confidential business information.
Notes: Totals by gas may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Emissions and Sinks by IPCC Sector

Emissions and removals of all gases can be summed from each source and sink category into a set of five sectors defined by the Paris Agreement and UNFCCC reporting guidelines and methodological framework provided by the Intergovernmental Panel on Climate Change (IPCC). Figure 2-4 and Table 2-3 illustrate that over the 33-year period of 1990 to 2022, total emissions from the Energy and Waste sectors decreased by 3.3 percent (179.6 MMT CO_2 Eq.) and 29.3 percent (69.1 MMT CO_2 Eq.), respectively. Emissions from Industrial Processes and Product Use and Agriculture grew by 1.0 percent (3.6 MMT CO_2 Eq.) and 7.7 percent (42.2 MMT CO_2 Eq.), respectively. Over the same period, total carbon sequestration in the LULUCF sector decreased by 10.9 percent (112.9 MMT CO_2), and emissions from the LULUCF sector increased by 16.5 percent (9.6 MMT CO_2 Eq.).

Figure 2-4: U.S. Greenhouse Gas Emissions and Sinks by IPCC Sector

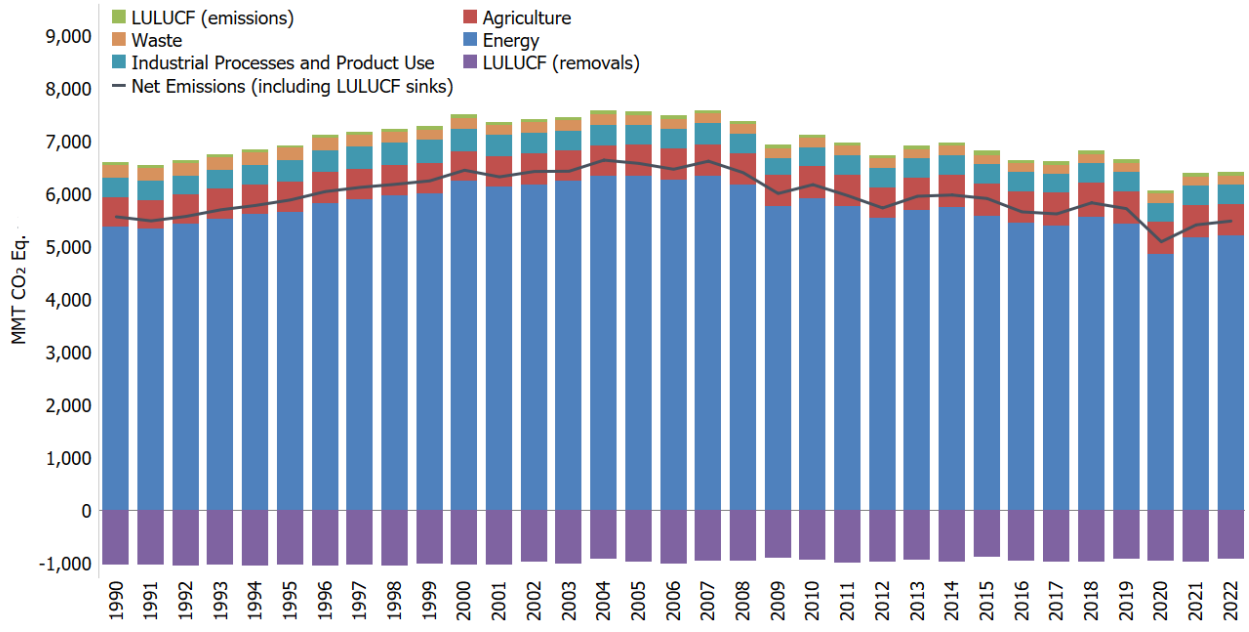


Table 2-3: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by IPCC Sector/Category (MMT CO_2 Eq.)

IPCC Sector/Category	1990	2005	2018	2019	2020	2021	2022
Energy	**5,380.1**	**6,345.9**	**5,568.1**	**5,420.2**	**4,860.2**	**5,171.0**	**5,200.5**
Fossil Fuel Combustion	4,746.9	5,739.6	4,982.9	4,840.9	4,329.2	4,642.6	4,689.9
Natural Gas Systems	251.2	236.5	223.0	227.3	217.0	210.4	209.7

IPCC Sector/Category	1990	2005	2018	2019	2020	2021	2022
Non-Energy Use of Fuels	103.5	125.9	121.7	116.0	107.9	120.9	116.0
Petroleum Systems	59.0	58.4	93.8	97.8	82.3	72.8	61.6
Coal Mining	112.7	75.6	62.2	56.0	48.3	47.1	46.1
Stationary Combustion[a]	32.0	39.3	34.7	31.9	28.5	30.0	30.3
Mobile Combustion	45.6	41.3	20.5	21.9	18.7	19.4	19.2
Incineration of Waste	13.3	13.6	13.7	13.3	13.3	12.8	12.7
Abandoned Oil and Gas Wells	7.8	8.2	8.4	8.5	8.5	8.6	8.5
Abandoned Underground Coal Mines	8.1	7.4	6.9	6.6	6.5	6.4	6.4
Biomass and Biodiesel Consumption[b]	*237.9*	*245.4*	*336.0*	*333.1*	*295.7*	*303.0*	*305.4*
International Bunker Fuels[c]	*104.6*	*114.3*	*125.3*	*114.6*	*70.3*	*80.9*	*83.2*
Industrial Processes and Product Use	**376.9**	**368.5**	**364.6**	**369.6**	**366.1**	**380.0**	**380.5**
Substitution of Ozone Depleting Substances	0.3	99.5	157.9	162.1	166.2	172.7	178.1
Cement Production	33.5	46.2	39.0	40.9	40.7	41.3	41.9
Iron and Steel Production & Metallurgical Coke Production	104.8	70.1	42.9	43.1	37.7	41.9	40.7
Petrochemical Production	21.6	27.4	27.2	28.5	27.9	30.7	28.8
Ammonia Production	14.4	10.2	12.7	12.4	13.0	12.2	12.6
Lime Production	11.7	14.6	13.1	12.1	11.3	11.9	12.2
Other Process Uses of Carbonates	7.1	8.5	7.9	9.0	9.0	8.6	10.4
Nitric Acid Production	10.8	10.1	8.5	8.9	8.3	7.9	8.6
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	6.1	6.2	5.8	6.6	7.1
Electrical Equipment	24.8	12.0	5.2	6.2	6.1	6.1	5.2
Fluorochemical Production	77.4	26.6	6.1	7.0	5.0	5.3	5.2
Carbon Dioxide Consumption	1.5	1.4	4.1	4.9	5.0	5.0	5.0
Electronics Industry	3.3	4.5	4.8	4.4	4.6	5.0	4.7
N_2O from Product Uses	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Aluminum Production	26.1	7.2	2.9	3.3	3.2	2.5	2.2
Adipic Acid Production	13.5	6.3	9.3	4.7	7.4	6.6	2.1
Glass Production	2.3	2.4	2.0	1.9	1.9	2.0	2.0
Soda Ash Production	1.4	1.7	1.7	1.8	1.5	1.7	1.7
Titanium Dioxide Production	1.2	1.8	1.5	1.3	1.3	1.5	1.5
Ferroalloy Production	2.2	1.4	2.1	1.6	1.4	1.6	1.3
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.5	1.9	1.3	1.2	1.1	1.2	1.3
Magnesium Production and Processing	5.7	3.0	1.1	1.0	0.9	1.2	1.2
Zinc Production	0.6	1.0	1.0	1.0	1.0	1.0	0.9
Phosphoric Acid Production	1.5	1.3	0.9	0.9	0.9	0.9	0.8
SF_6 and PFCs from Other Product Use	1.4	1.4	0.8	0.6	0.5	0.4	0.6
Lead Production	0.5	0.6	0.5	0.5	0.5	0.4	0.4
Carbide Production and Consumption	0.3	0.2	0.2	0.2	0.2	0.2	0.2
Agriculture	**551.1**	**581.8**	**642.4**	**620.0**	**599.6**	**604.8**	**593.4**
Agricultural Soil Management	288.8	294.1	333.4	315.6	292.1	298.0	290.8
Enteric Fermentation	183.1	188.2	196.8	197.3	196.3	196.5	192.6
Manure Management	52.5	70.2	84.3	83.5	83.8	83.6	81.7
Rice Cultivation	18.9	20.6	19.9	15.6	18.6	18.3	18.9
Urea Fertilization	2.4	3.5	4.9	5.0	5.1	5.2	5.3
Liming	4.7	4.4	2.2	2.2	2.9	2.4	3.3
Field Burning of Agricultural Residues	0.7	0.8	0.8	0.9	0.8	0.8	0.8
Waste	**235.9**	**192.0**	**173.2**	**175.8**	**171.7**	**169.2**	**166.9**
Landfills	197.8	147.7	126.3	128.7	124.1	122.0	119.8
Wastewater Treatment	37.5	40.7	42.5	42.7	43.2	42.7	42.7
Composting	0.7	3.6	4.3	4.3	4.4	4.4	4.4

IPCC Sector/Category	1990	2005	2018	2019	2020	2021	2022
Anaerobic Digestion at Biogas Facilities	+	+	+	+	+	+	+
Total Gross Emissions[d] (Sources)	**6,544.0**	**7,488.2**	**6,748.2**	**6,585.6**	**5,997.6**	**6,324.9**	**6,341.2**
LULUCF Sector Net Total[e]	**(976.7)**	**(907.6)**	**(915.5)**	**(863.6)**	**(904.4)**	**(910.5)**	**(854.3)**
Forest Land	(1,069.1)	(960.2)	(963.7)	(907.3)	(946.6)	(924.1)	(872.0)
Cropland	40.4	2.9	14.2	12.0	20.5	2.9	3.4
Grassland	59.8	46.7	54.9	54.3	45.8	36.0	39.6
Wetlands	44.0	41.2	38.9	38.9	38.8	38.8	38.8
Settlements	(51.9)	(38.1)	(59.7)	(61.4)	(63.0)	(64.1)	(64.1)
Net Emissions (Sources and Sinks)[f]	**5,567.3**	**6,580.5**	**5,832.7**	**5,722.0**	**5,093.2**	**5,414.4**	**5,487.0**

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Includes CH_4 and N_2O emissions from fuel combustion.

[b] Emissions from 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.

[c] Emissions from international bunker fuels are not included in totals.

[d] Total emissions without LULUCF.

[e] 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, flooded land remaining flooded land, and land converted to flooded land; 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.

[f] Net emissions with LULUCF.

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

Energy

Emissions from energy-related activities come from two main categories: 1) direct emissions associated with fuel use (i.e., fossil fuel combustion, non-energy use of fossil fuels and waste combustion), and 2) fugitive emissions mainly from coal, natural gas, and oil production. Energy emissions also include some categories that are not added to Energy sector totals but are instead presented as memo items, including international bunker fuels and biomass emissions. Energy-related activities, primarily fossil fuel combustion, accounted for the vast majority of U.S. CO_2 emissions from 1990 through 2022. 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 Chapter 3).

In 2022, 83.0 percent of the energy used in the United States on a Btu basis was produced through the combustion of fossil fuels. The remaining 17.0 percent came from other energy sources such as hydropower, biomass, nuclear, wind, and solar energy. A discussion of specific trends related to CO_2 and 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 (40.2 percent and 10.0 percent of gross total U.S. emissions of each gas, respectively).[2] Table 2-4 presents greenhouse gas emissions from the Energy chapter by source and gas.

[2] The contribution of energy non-CO_2 emissions is based on gross totals so excludes LULUCF methane (CH_4) and nitrous oxide (N_2O) emissions. The contribution of energy-related CH_4 and N_2O including LULUCF non-CO_2 emissions, is 37.1 percent and 9.8 percent, respectively.

Figure 2-5: Trends in Energy Sector Greenhouse Gas Sources

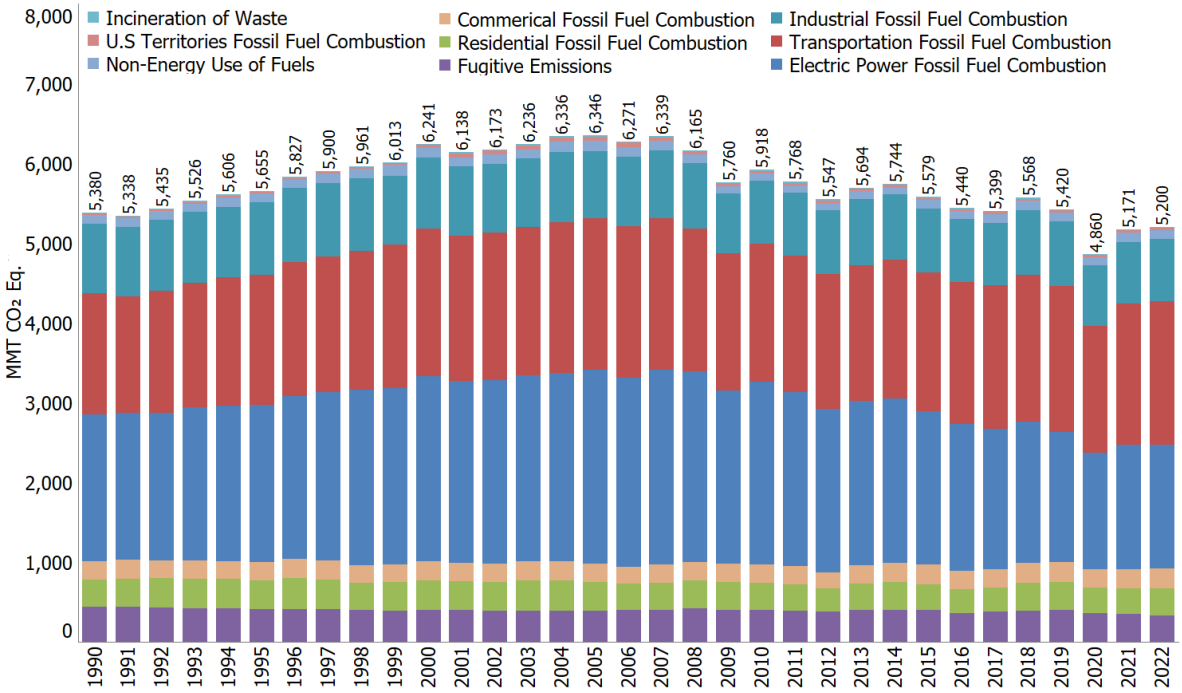


Table 2-4: Emissions from Energy (MMT CO_2 Eq.)[3]

Gas/Source	1990	2005	2018	2019	2020	2021	2022
CO_2	4,909.9	5,919.5	5,188.7	5,056.9	4,517.9	4,838.4	4,879.2
Fossil Fuel Combustion	4,746.9	5,739.6	4,982.9	4,840.9	4,329.2	4,642.6	4,689.9
Transportation	*1,468.9*	*1,858.6*	*1,813.1*	*1,816.6*	*1,572.8*	*1,753.5*	*1,780.8*
Electricity Generation	*1,820.0*	*2,400.1*	*1,753.4*	*1,606.7*	*1,439.6*	*1,540.9*	*1,531.7*
Industrial	*871.1*	*843.5*	*805.2*	*798.1*	*749.5*	*768.8*	*775.9*
Residential	*338.6*	*358.6*	*338.9*	*342.9*	*314.8*	*318.0*	*333.1*
Commercial	*228.3*	*227.0*	*246.3*	*251.7*	*229.3*	*237.5*	*244.7*
U.S. Territories	*20.0*	*51.9*	*25.9*	*24.8*	*23.3*	*23.8*	*23.8*
Non-Energy Use of Fuels	103.5	125.9	121.7	116.0	107.9	120.9	116.0
Natural Gas Systems	32.4	26.3	32.8	38.5	36.7	35.8	36.5
Petroleum Systems	9.6	10.2	34.8	45.5	28.9	24.1	22.0
Incineration of Waste	12.9	13.3	13.3	12.9	12.9	12.5	12.4
Coal Mining	4.6	4.2	3.1	3.0	2.2	2.5	2.5
Abandoned Oil and Gas Wells	+	+	+	+	+	+	+
Biomass-Wood[a]	*215.2*	*206.9*	*220.0*	*217.7*	*190.6*	*192.5*	*195.3*
International Bunker Fuels[b]	*103.6*	*113.3*	*124.3*	*113.6*	*69.6*	*80.2*	*82.3*
Biofuels-Ethanol[a]	*4.2*	*22.9*	*81.9*	*82.6*	*71.8*	*79.1*	*79.6*
Biofuels-Biodiesel[a]	*0.0*	*0.9*	*17.9*	*17.1*	*17.7*	*16.1*	*15.6*
Biomass-MSW[a]	*18.5*	*14.7*	*16.1*	*15.7*	*15.6*	*15.3*	*14.9*
CH_4	**409.0**	**358.5**	**336.2**	**321.7**	**305.3**	**293.4**	**282.6**
Natural Gas Systems	218.8	210.1	190.3	188.7	180.3	174.6	173.1
Coal Mining	108.1	71.5	59.1	53.0	46.2	44.7	43.6

[3] The full time series data is available in Common Reporting Tables (CRTs) included in the U.S. Paris Agreement and UNFCCC submission and in CSV format available at https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Gas/Source	1990	2005	2018	2019	2020	2021	2022
Petroleum Systems	49.4	48.2	59.0	52.2	53.3	48.6	39.6
Stationary Combustion	9.6	8.8	9.6	9.8	8.0	8.0	8.7
Abandoned Oil and Gas Wells	7.8	8.2	8.4	8.5	8.5	8.6	8.5
Abandoned Underground Coal Mines	8.1	7.4	6.9	6.6	6.5	6.4	6.4
Mobile Combustion	7.2	4.3	2.8	2.9	2.5	2.6	2.6
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O	**61.2**	**67.9**	**43.2**	**41.6**	**37.0**	**39.2**	**38.7**
Stationary Combustion	22.3	30.5	25.1	22.1	20.5	22.0	21.6
Mobile Combustion	38.4	37.0	17.7	19.1	16.1	16.8	16.6
Incineration of Waste	0.4	0.3	0.4	0.4	0.3	0.4	0.3
Natural Gas Systems	+	+	+	+	+	+	0.2
Petroleum Systems	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.8*	*0.9*	*1.0*	*0.9*	*0.5*	*0.6*	*0.7*
Total	**5,380.1**	**6,345.9**	**5,568.1**	**5,420.2**	**4,860.2**	**5,171.0**	**5,200.5**

+ Does not exceed 0.05 MMT CO_2 Eq.

[a] Emissions from biomass and biofuel consumption are not included specifically in 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. These values are presented for informational purposes only, in line with the *2006 IPCC Guidelines*, the Paris Agreement and the UNFCCC reporting obligations.

purposes only, in line with the *2006 IPCC Guidelines*, the Paris Agreement and the UNFCCC reporting obligations.

Note: Totals may not sum due to independent rounding.

Fossil Fuel Combustion CO_2 Emissions

As the largest contributor to U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion has accounted for approximately 74.0 percent of CO_2-equivalent total gross emissions on average across the time series. Within the United States, fossil fuel combustion accounted for 92.7 percent of CO_2 emissions in 2022. Emissions from this source category include CO_2 associated with the combustion of fossil fuels (coal, natural gas, and petroleum) for energy use. Fossil fuel combustion CO_2 emissions decreased by 1.2 percent (57.0 MMT CO_2 Eq.) from 1990 to 2022 and were responsible for most of the decrease in national emissions during this period. Similarly, CO_2 emissions from fossil fuel combustion have decreased by 18.3 percent (1,049.7 MMT CO_2 Eq.) since 2005. From 2021 to 2022, these emissions increased by 1.0 percent (47.2 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 since 1990 are affected by many long-term and short-term factors, including population and economic growth, energy price fluctuations and market trends, technological changes, carbon intensity of energy fuel choices, and seasonal temperatures. On an annual basis, the overall consumption and mix of fossil fuels in the United States fluctuates 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 factors such as the relative price of coal and alternative sources, the ability to switch fuels, and longer-term trends in coal markets. Fossil fuel combustion CO_2 emissions also depend on the type of fuel consumed or energy used and its carbon intensity. Producing a unit of heat or electricity using natural gas instead of coal, for example, reduces CO_2 emissions because of the lower carbon content of natural gas (see Table 3-12 in Chapter 3 for more detail on electricity generation by source and see Table A-19 in Annex 2.1 for more detail on the carbon content coefficient of different fossil fuels).

Overall CO_2 emissions from electric power generation decreased by 36.2 percent from 2005 to 2022 (see Figure 2-7), reflecting the continued shift in the share of electric power generation from coal to natural gas and renewables since 2005. Carbon dioxide emissions from coal combustion gradually increased between 1990 and 2007, then began to decrease at a faster rate from 2008 to 2022. Carbon dioxide emissions from natural gas combustion remained relatively constant, with a slight increase between 1990 and 2009, then began to consistently increase between 2010 and 2022.

Petroleum use is another major driver of CO_2 emissions from fossil fuel combustion, particularly in the transportation sector, which has represented the largest source of CO_2 emissions from fossil fuel combustion since 2017. Emissions from petroleum consumption for transportation increased by 2.1 percent from 2021 to 2022. This trend can be primarily attributed to a 0.9 percent increase in vehicle miles traveled (VMT) from 2021 to 2022. 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 29.6 percent of new vehicle sales in 1990 to 48.0 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.

Trends in CO_2 emissions from fossil fuel combustion 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 trends in direct and indirect CO_2 emissions from fossil fuel combustion 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.[4]

- *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.
- *Electric Power.* EIA's fuel consumption data for the electric power sector are composed 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.)
- *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.)
- *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	2018	2019	2020	2021	2022
Transportation	**1,472.0**	**1,863.3**	**1,817.9**	**1,821.4**	**1,576.9**	**1,758.6**	**1,786.8**
Combustion	1,468.9	1,858.6	1,813.1	1,816.6	1,572.8	1,753.5	1,780.8
Electricity	3.0	4.7	4.8	4.8	4.1	5.0	6.1
Industrial	**1,557.6**	**1,579.8**	**1,306.6**	**1,263.6**	**1,159.3**	**1,213.9**	**1,213.8**
Combustion	871.1	843.5	805.2	798.1	749.5	768.8	775.9
Electricity	686.4	736.3	501.3	465.5	409.8	445.1	437.9
Residential	**931.3**	**1,214.6**	**981.2**	**926.7**	**860.1**	**890.3**	**897.9**
Combustion	338.6	358.6	338.9	342.9	314.8	318.0	333.1
Electricity	592.7	856.0	642.3	583.7	545.3	572.3	564.8
Commercial	**766.0**	**1,030.0**	**851.3**	**804.4**	**709.6**	**756.1**	**767.6**
Combustion	228.3	227.0	246.3	251.7	229.3	237.5	244.7
Electricity	537.7	803.0	605.0	552.7	480.3	518.6	522.8

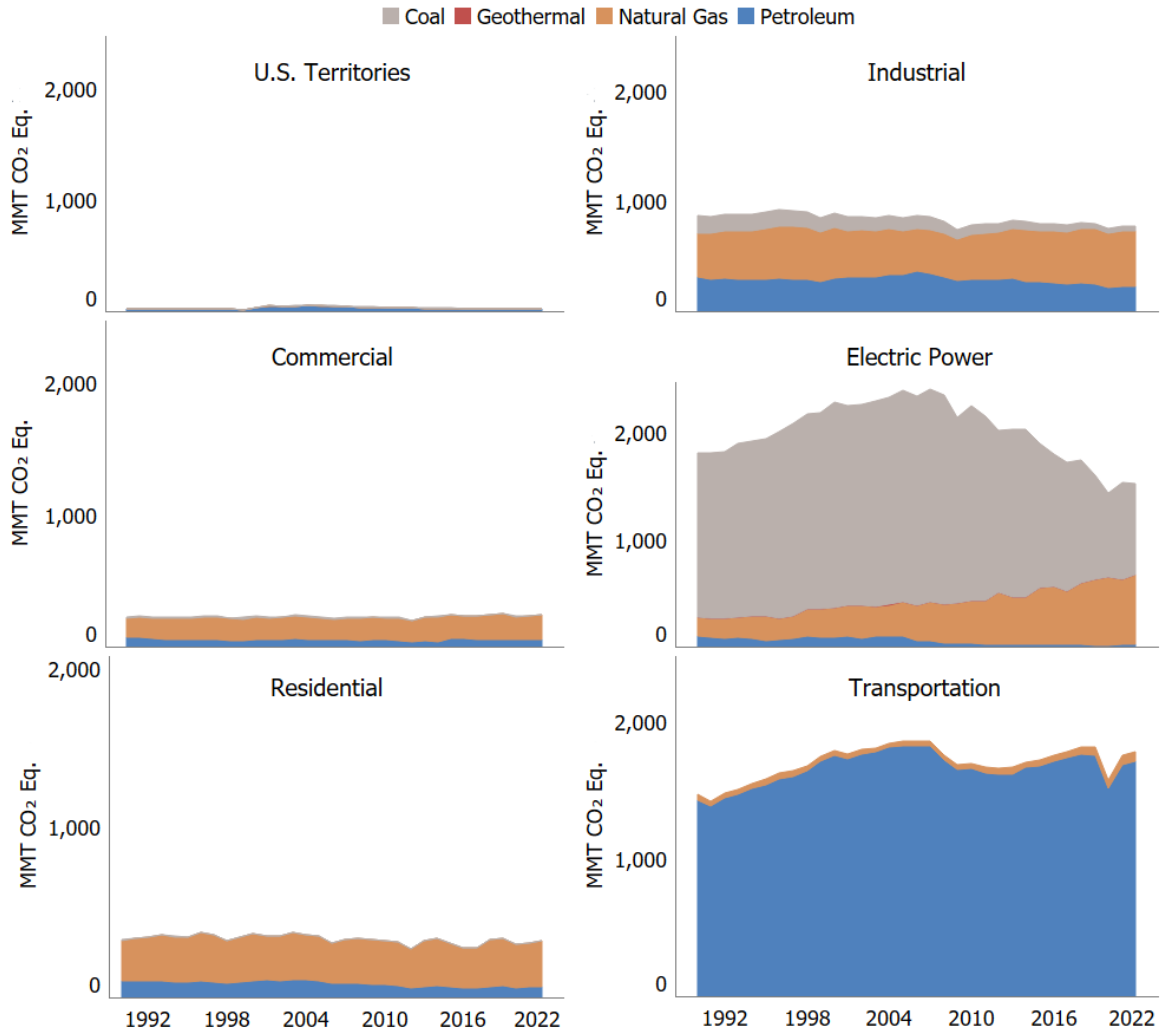
[4] Additional analysis and refinement of the EIA data is further explained in the Energy chapter of this report.

U.S. Territories[a]	**20.0**	**51.9**	**25.9**	**24.8**	**23.3**	**23.8**	**23.8**
Total	**4,746.9**	**5,739.6**	**4,982.9**	**4,840.9**	**4,329.2**	**4,642.6**	**4,689.9**
Electric Power	**1,820.0**	**2,400.1**	**1,753.4**	**1,606.7**	**1,439.6**	**1,540.9**	**1,531.7**

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

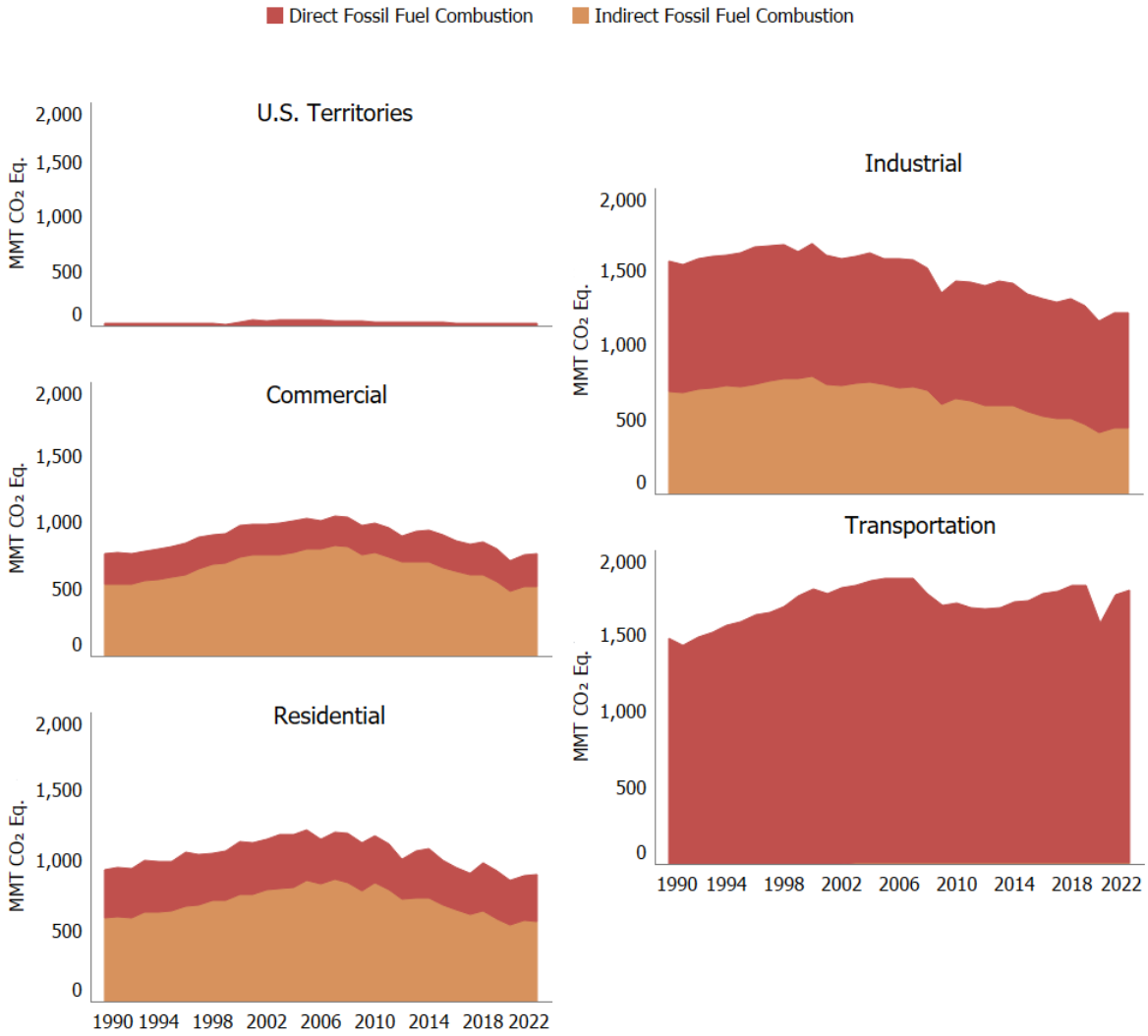
Notes: Combustion-related emissions from electric power are allocated based on aggregate national electricity use by each end-use sector. Totals may not sum due to independent rounding.

Figure 2-6: Trends in CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector and Fuel Type



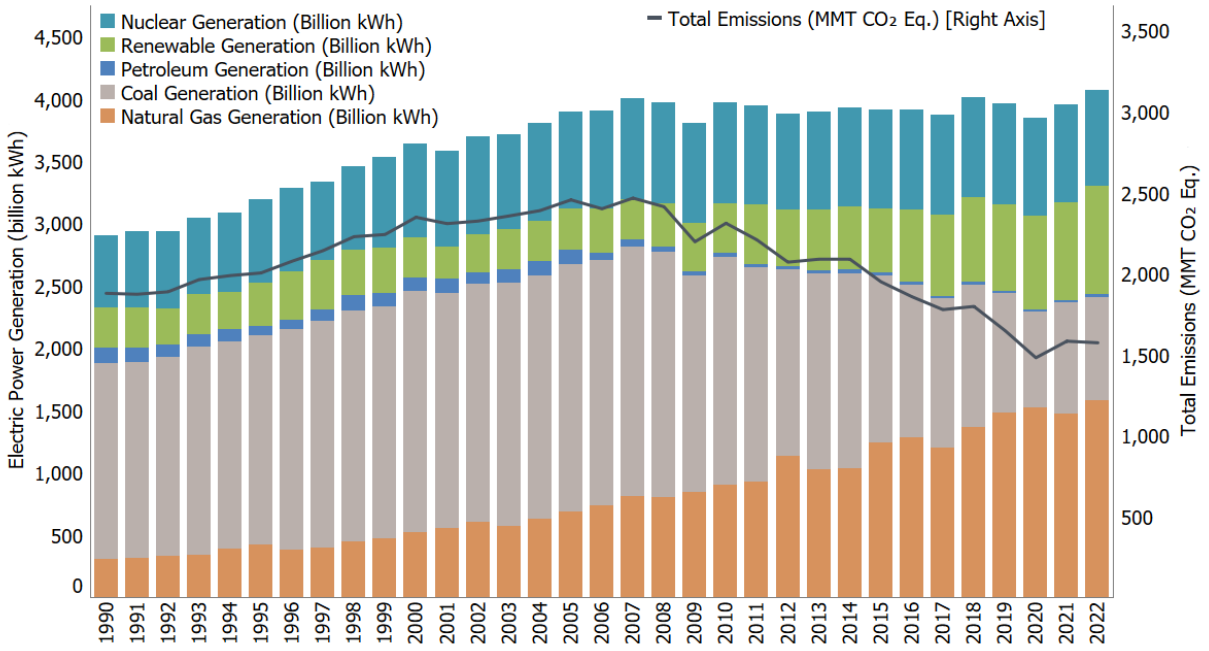
Note: Fossil fuel combustion for electric power also includes emissions of less than 0.5 MMT CO_2 Eq. from geothermal-based generation. Although not technically a fossil fuel, geothermal energy-related CO_2 emissions are included for reporting purposes. The source of CO_2 is non-condensable gases in subterranean heated water.

Figure 2-7: Trends in End-Use Sector Emissions of CO_2 from Fossil Fuel Combustion



Electric power was the second largest end-use emitter of CO_2 in 2022 (surpassed by transportation in 2017); electric power generators used 30.6 percent of U.S. energy from fossil fuels and emitted 32.7 percent of the CO_2 from fossil fuel combustion in 2022. 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 fossil fuel combustion from the electric power sector have decreased by 15.8 percent since 1990, and the carbon intensity of the electric power sector, in terms of CO_2 Eq. per QBtu input, has decreased by 27.6 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 1,786.8 MMT CO_2 Eq. in 2022 or 38.1 percent of total CO_2 emissions from fossil fuel combustion. The industrial end-use sector accounted for 25.9 percent of CO_2 emissions from fossil fuel combustion when including allocated electricity emissions. The residential and commercial end-use sectors accounted for 19.1 and 16.4 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 62.9 and 68.1 percent of emissions from the residential and commercial end-use sectors, respectively.

Other Energy Sector Trends

Energy sector emissions increased by 0.6 percent since 2021 and decreased by 3.3 percent since 1990. Other notable trends in emissions from energy source categories (Figure 2-6 and Figure 2-7) over the 33-year period from 1990 through 2022 included the following:

- Emissions (CH_4, CO_2, and N_2O) from oil and gas systems decreased by 13 percent (38.9 MMT CO_2 Eq.) since 1990 and decreased by 4.2 percent (11.8 MMT CO2 Eq.) from 2021 to 2022. Natural gas systems CH_4 emissions have decreased by 20.9 percent (45.7 MMT CO_2 Eq.) since 1990, due to a decrease in emissions from the distribution, transmission and storage, processing, and exploration segments. The decrease in distribution emissions is due mainly to reduced emissions from pipeline and distribution station leaks, and the decrease in transmission and storage emissions is due mainly to reduced compressor station emissions (including emissions from compressors and leaks). Over the same time period (i.e., since 1990), methane emissions from the natural gas production segment increased due to increased gathering and boosting emissions. Between 2021 and 2022, methane emissions from natural gas systems decreased 0.8 percent, due to a decrease in emissions from production segment pneumatic controllers. Petroleum systems CH_4 emissions decreased by 19.8 percent (9.8 MMT CO_2 Eq.) since 1990 and 18.5 percent between 2021 and 2022. 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 39 percent (16.4 MMT CO_2) from 1990 to 2022 and decreased by 2.5 percent between 2021 and 2022. This increase since 1990 is due primarily to increases in the production segment, where emissions from associated gas flaring, tanks, and miscellaneous production flaring have increased over time. The decrease in emissions between 2021 and 2022 and is also due primarily to the production segment, where flaring emissions decreased for associated gas and tanks.

- Methane emissions from coal mining decreased by 59.6 percent (64.4 MMT CO_2 Eq.) from 1990 through 2022 and by 2.3 percent between 2021 and 2022 primarily due to a decrease in the number of active mines and annual coal production over this time period.
- Nitrous oxide emissions from mobile combustion decreased by 56.8 percent (21.8 MMT CO_2 Eq.) from 1990 through 2022 and by 1.3 percent (0.2 MMT CO_2 Eq.) between 2021 and 2022, primarily as a result of national vehicle criteria pollutant emissions standards and emission control technologies for on-road vehicles.
- Nitrous oxide emissions from stationary combustion were the third largest source of anthropogenic N_2O emissions in 2022, accounting for 5.6 percent of N_2O emissions and 0.3 percent of total gross U.S. greenhouse gas emissions in 2022. Stationary combustion emissions peaked in 2007 and have steadily decreased since then.
- Carbon dioxide emissions from non-energy uses of fossil fuels increased by 12.5 MMT CO_2 Eq. (12.1 percent) from 1990 through 2022 but decreased by 4.8 MMT CO_2 Eq. (4.0 percent) between 2021 and 2022. Emissions from non-energy uses of fossil fuels were 116.0 MMT CO_2 Eq. in 2022, which constituted 2.3 percent of total national CO_2 emissions, approximately the same proportion as in 1990.
- Carbon dioxide emissions from incineration of waste decreased slightly by 0.5 MMT CO_2 Eq. (4.2 percent) from 1990 through 2022, as the volume of scrap tires and other fossil carbon-containing materials in waste decreased. Emissions decreased 0.1 MMT CO_2 Eq. (0.9 percent) between 2021 and 2022, consistent with trends across the time series.

Industrial Processes and Product Use

Greenhouse gases can be generated and emitted by industry 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 man-made 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, electrical equipment, and magnesium metal production and processing. In addition, N_2O is used in and emitted by the electronics industry and anesthetic and aerosol applications, PFCs and SF_6 are emitted from other product use, and CO_2 is consumed and emitted through various end-use applications.

Emission sources in the Industrial Processes and Product Use (IPPU) chapter accounted for 6.0 percent of U.S. greenhouse gas emissions in 2022. Emissions from the IPPU sector increased by 1.0 percent from 1990 to 2022. The use of HFCs and PFCs as substitutes for ODS is the largest source of emissions in this sector, contributing 46.8 percent of IPPU emissions in 2022. Total emissions from IPPU increased 0.1 percent between 2021 and 2022. Despite the sectoral increase in emissions, emissions from aluminum production, ferroalloy production, adipic acid production, and electrical equipment all decreased by over 10 percent, and emissions from petrochemical production, zinc production, and the electronics industry decreased over by 5 percent from 2021 to 2022. Figure 2-9 presents greenhouse gas emissions from IPPU by source category.

Figure 2-9: Trends in Industrial Processes and Product Use Sector Greenhouse Gas Sources

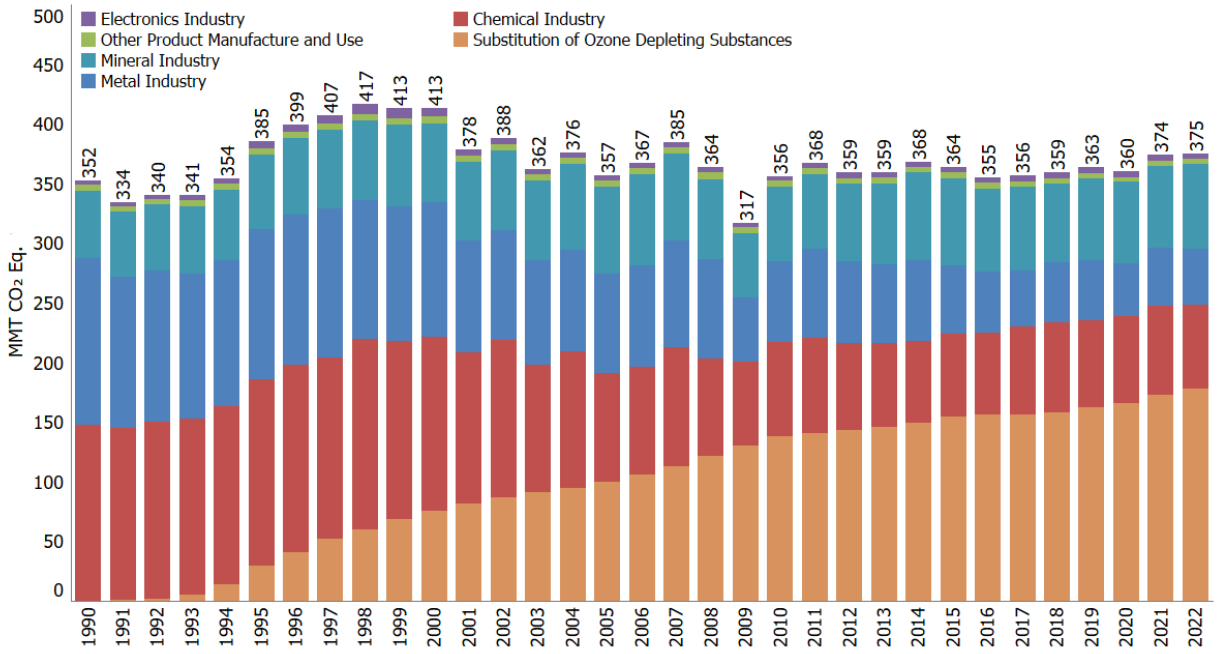


Table 2-6: Emissions from Industrial Processes and Product Use (MMT CO_2 Eq.)

Gas/Source	1990	2005	2018	2019	2020	2021	2022
CO_2	**215.2**	**196.4**	**164.4**	**168.2**	**160.7**	**168.8**	**168.9**
Cement Production	33.5	46.2	39.0	40.9	40.7	41.3	41.9
Iron and Steel Production & Metallurgical Coke Production	104.7	70.1	42.9	43.1	37.7	41.9	40.7
Iron and Steel Production	*99.1*	*66.2*	*41.6*	*40.1*	*35.4*	*38.6*	*37.7*
Metallurgical Coke Production	*5.6*	*3.9*	*1.3*	*3.0*	*2.3*	*3.2*	*3.0*
Petrochemical Production	21.6	27.4	27.2	28.5	27.9	30.7	28.8
Ammonia Production	14.4	10.2	12.7	12.4	13.0	12.2	12.6
Lime Production	11.7	14.6	13.1	12.1	11.3	11.9	12.2
Other Process Uses of Carbonates	7.1	8.5	7.9	9.0	9.0	8.6	10.4
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	6.1	6.2	5.8	6.6	7.1
Carbon Dioxide Consumption	1.5	1.4	4.1	4.9	5.0	5.0	5.0
Glass Production	2.3	2.4	2.0	1.9	1.9	2.0	2.0
Soda Ash Production	1.4	1.7	1.7	1.8	1.5	1.7	1.7
Titanium Dioxide Production	1.2	1.8	1.5	1.3	1.3	1.5	1.5
Aluminum Production	6.8	4.1	1.5	1.9	1.7	1.5	1.4
Ferroalloy Production	2.2	1.4	2.1	1.6	1.4	1.6	1.3
Zinc Production	0.6	1.0	1.0	1.0	1.0	1.0	0.9
Phosphoric Acid Production	1.5	1.3	0.9	0.9	0.9	0.9	0.8
Lead Production	0.5	0.6	0.5	0.5	0.5	0.4	0.4
Carbide Production and Consumption	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Substitution of Ozone Depleting Substances[a]	+	+	+	+	+	+	+
Magnesium Production and Processing	0.1	+	+	+	+	+	+
CH_4	**0.1**	**+**	**+**	**+**	**+**	**+**	**+**
Carbide Production and Consumption	+	+	+	+	+	+	+
Ferroalloy Production	+	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+

Petrochemical Production	+	+	+	+	+	+	+
N_2O	**29.6**	**22.2**	**23.1**	**18.8**	**20.8**	**19.7**	**16.1**
Nitric Acid Production	10.8	10.1	8.5	8.9	8.3	7.9	8.6
N_2O from Product Uses	*3.8*	*3.8*	*3.8*	*3.8*	*3.8*	*3.8*	*3.8*
Adipic Acid Production	13.5	6.3	9.3	4.7	7.4	6.6	2.1
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.5	1.9	1.3	1.2	1.1	1.2	1.3
Electronics Industry	+	0.1	0.2	0.2	0.3	0.3	0.3
HFCs	**48.2**	**121.2**	**162.9**	**167.3**	**169.6**	**176.3**	**181.4**
Substitution of Ozone Depleting Substances[a]	0.3	99.5	157.9	162.1	166.2	172.6	178.1
Fluorochemical Production	47.8	21.6	4.6	4.8	3.0	3.3	2.9
Electronics Industry	0.2	0.2	0.3	0.3	0.3	0.4	0.3
Magnesium Production and Processing	0.0	0.0	0.1	0.1	0.1	+	+
PFCs	**47.1**	**7.8**	**5.8**	**5.9**	**5.5**	**5.4**	**5.4**
Electronics Industry	2.5	3.0	2.9	2.6	2.6	2.7	2.7
Fluorochemical Production	25.2	1.6	1.3	1.7	1.3	1.6	1.8
Aluminum Production	19.3	3.1	1.4	1.4	1.4	0.9	0.8
SF_6 and PFCs from Other Product Use	0.1	0.1	0.2	0.2	0.2	0.1	0.2
Substitution of Ozone Depleting Substances[a]	NO	+	+	+	+	+	+
Electrical Equipment	+	+	*0.0*	+	+	+	+
SF_6	**35.9**	**20.0**	**7.7**	**8.4**	**8.1**	**8.5**	**7.6**
Electrical Equipment	24.7	11.8	5.0	6.1	5.9	6.0	5.1
Magnesium Production and Processing	5.6	3.0	1.1	0.9	0.9	1.2	1.1
Electronics Industry	0.5	0.8	0.8	0.8	0.8	1.0	0.7
SF_6 and PFCs from Other Product Use	1.4	1.4	0.8	0.6	0.5	0.4	0.6
Fluorochemical Production	3.8	3.0	+	+	+	+	+
NF_3	**0.7**	**0.8**	**0.7**	**1.1**	**1.3**	**1.2**	**1.1**
Electronics Industry	+	0.4	0.6	0.5	0.6	0.7	0.6
Fluorochemical Production	0.7	0.4	0.1	0.6	0.7	0.5	0.5
Total	**376.9**	**368.5**	**364.6**	**369.6**	**366.1**	**380.0**	**380.5**

+ Does not exceed 0.05 MMT CO_2 Eq.
NO (Not Occurring)
[a] Small amounts of PFC emissions from this source are included under HFCs due to confidential business information.
Note: Totals may not sum due to independent rounding.

IPPU sector emissions increased 0.1 percent since 2021 and 1.0 percent since 1990. Some significant trends in U.S. emissions from IPPU source categories over the 33-year period from 1990 through 2022 included the following:

- HFC and PFC emissions resulting from the substitution of ODS (e.g., chlorofluorocarbons [CFCs]) increased from small amounts in 1990 to 178.1 MMT CO_2 Eq. in 2022 (an increase of 70,364.6 percent).
- Combined CO_2 and CH_4 emissions from iron and steel production and metallurgical coke production decreased by 2.9 percent from 2021 to 2022 to 40.7 MMT CO_2 Eq. and declined overall by 61.2 percent (64.1 MMT CO_2 Eq.) from 1990 through 2022, due to restructuring of the industry. The trend in the United States has been a shift toward fewer integrated steel mills and more electric arc furnaces (EAFs). EAFs use scrap steel as their main input and generally have lower on-site emissions.
- Carbon dioxide emissions from petrochemical production increased by 33.2 percent between 1990 and 2022, from 21.6 MMT CO_2 Eq. to 28.8 MMT CO_2 Eq. The increase in emissions is largely driven by a doubling of production of ethylene over that period.
- Carbon dioxide emissions from ammonia production have decreased by 12.5 percent (1.8 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. Emissions from ammonia production have increased since 2016, due to the addition of new ammonia production facilities and new production units at existing facilities. Agricultural demands continue to drive demand for nitrogen fertilizers and the need for new ammonia production capacity.

- Carbon dioxide emissions from cement production increased by 25.1 percent (8.4 MMT CO_2 Eq.) from 1990 through 2022. 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 by 33.2 percent.
- HFC, PFC, SF_6, and NF_3 emissions from fluorochemical production decreased by 93.3 percent (72.3 MMT CO_2 Eq.) from 1990 to 2022 due to a reduction in the HFC-23 emission rate from HCFC-22 production (kg HFC-23 emitted/kg HCFC-22 produced), the imposition of emissions controls at production facilities, and a decrease in SF_6 production due to the cessation of production at the major SF_6 production facility in 2010.
- PFC emissions from aluminum production decreased by 96.1 percent (18.5 MMT CO_2 Eq.) from 1990 to 2022, due to both industry emission reduction efforts and lower domestic aluminum production.
- SF_6 emissions from electrical equipment decreased by 79.4 percent (19.6 MMT CO_2 Eq.) from 1990 to 2022 due to a sharp increase in the price of SF_6 during the 1990s and industry emission reduction efforts.

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 and N_2O are the primary greenhouse gases emitted by agricultural activities, with small amounts of CO_2 also emitted.[5] Carbon stock changes from agricultural soils are included in the LULUCF sector.

In 2022, agricultural activities were responsible for emissions of 593.4 MMT CO_2 Eq., or 9.4 percent of total U.S. greenhouse gas emissions. Agricultural soil management activities, such as the application of synthetic and organic fertilizers, deposition of livestock manure, and growing N-fixing plants, were the largest contributors to agricultural-related emissions (49.0 percent) and were the largest source of U.S. N_2O emissions in 2022, accounting for 75.2 percent. Methane emissions from enteric fermentation and manure management represented 27.4 percent and 9.2 percent of total CH_4 emissions from anthropogenic activities, respectively, in 2022. Carbon dioxide emissions from the application of crushed limestone and dolomite (i.e., soil liming) and urea fertilization represented 0.2 percent of total CO_2 emissions from anthropogenic activities. Figure 2-10 and Table 2-7 illustrate agricultural greenhouse gas emissions by source and gas.

[5] The contribution of agriculture non-CO_2 emissions is based on gross totals and excludes LULUCF methane (CH_4) and nitrous oxide (N_2O) emissions. The contribution of agriculture CH_4 and N_2O including LULUCF non-CO_2 emissions, is 40.5 percent and 48.7 percent, respectively.

Figure 2-10: Trends in Agriculture Sector Greenhouse Gas Sources

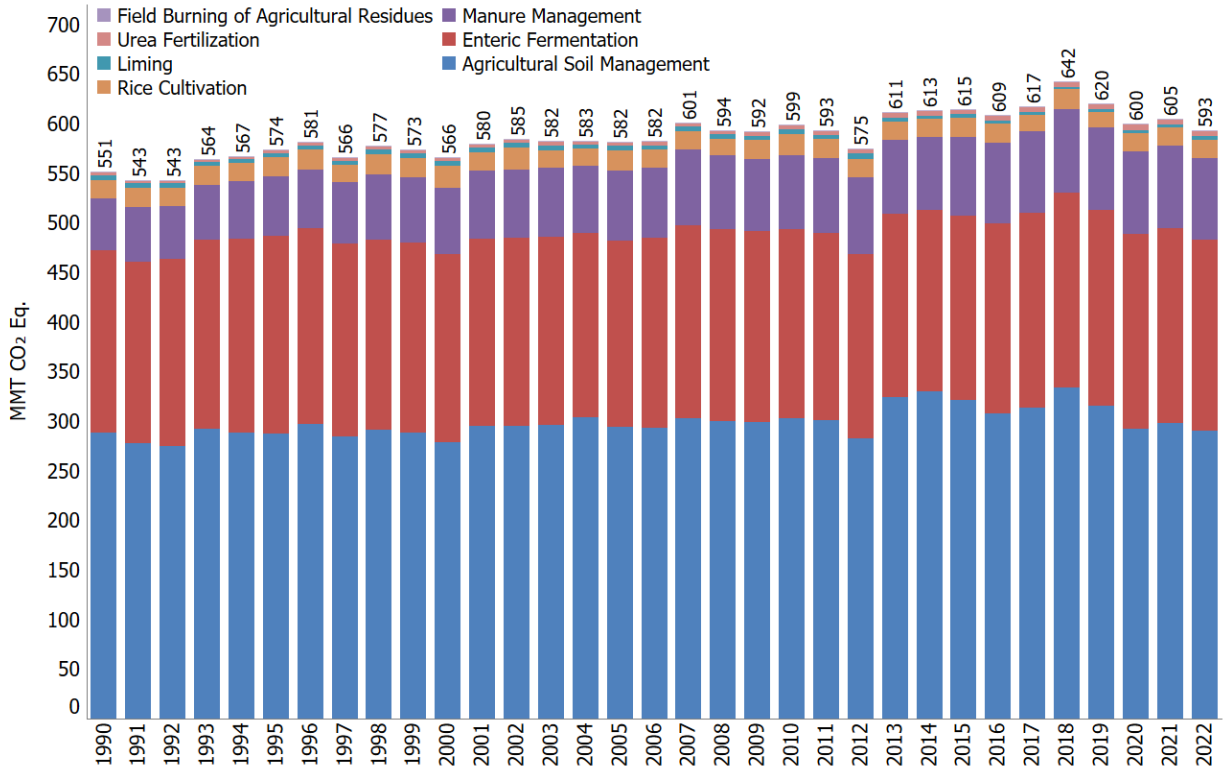


Table 2-7: Emissions from Agriculture (MMT CO_2 Eq.)

Gas/Source	1990	2005	2018	2019	2020	2021	2022
CO_2	**7.1**	**7.9**	**7.2**	**7.2**	**8.0**	**7.6**	**8.6**
Urea Fertilization	2.4	3.5	4.9	5.0	5.1	5.2	5.3
Liming	4.7	4.4	2.2	2.2	2.9	2.4	3.3
CH_4	**241.7**	**264.4**	**285.0**	**280.2**	**282.4**	**281.8**	**276.8**
Enteric Fermentation	183.1	188.2	196.8	197.3	196.3	196.5	192.6
Manure Management	39.1	55.0	67.7	66.7	66.9	66.4	64.7
Rice Cultivation	18.9	20.6	19.9	15.6	18.6	18.3	18.9
Field Burning of Agricultural Residues	0.5	0.6	0.6	0.6	0.6	0.6	0.6
N_2O	**302.3**	**309.5**	**350.2**	**332.6**	**309.2**	**315.3**	**308.0**
Agricultural Soil Management	288.8	294.1	333.4	315.6	292.1	298.0	290.8
Manure Management	13.4	15.2	16.6	16.8	16.9	17.1	17.0
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	**551.1**	**581.8**	**642.4**	**620.0**	**599.6**	**604.8**	**593.4**

Note: Totals may not sum due to independent rounding.

Agriculture sector emissions decreased by 1.9 percent since 2021 and increased by 7.7 percent since 1990. Some significant trends in U.S. emissions from Agriculture source categories (Figure 2-10) over the 33-year time series from 1990 through 2022 included the following:

- Agricultural soils are the largest anthropogenic source of agriculture-related emissions and of N_2O emissions in the United States, accounting for 75.2 percent of N_2O emissions and 4.6 percent of total emissions in the United States in 2022. Annual N_2O emissions from agricultural soils fluctuated between 1990 and 2022, and overall emissions were 0.7 percent (2.0 MMT CO_2 Eq.) higher in 2022 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 2022, enteric fermentation CH_4 emissions were 27.4 percent of total CH_4 emissions, which represents an increase of 5.2 percent (9.5 MMT CO_2 Eq.) since 1990. This increase in emissions from enteric fermentation from 1990 to 2022 generally follows the increasing trends in cattle populations. For example, 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 2022, consistent with an increase in beef cattle population over those same years. CH_4 emissions from enteric fermentation decreased by 2.0 percent (3.9 MMT CO_2 Eq.) from 2021 to 2022, however, largely driven by a decrease in beef cattle populations.
- Manure management is the fourth largest anthropogenic source of CH_4 and N_2O emissions in the United States and accounted for 13.8 percent of Agriculture sector emissions in 2022. Emissions from manure management increased by 55.6 percent between 1990 and 2022. This includes an increase of 65.3 percent (25.6 MMT CO_2 Eq.) for CH_4 and an increase of 27.2 percent (3.6 MMT CO_2 Eq.) for N_2O. The majority of the increase observed in CH_4 emissions resulted from swine and dairy cattle manure, where emissions increased by 37.2 and 108.7 percent, respectively, from 1990 to 2022. From 2021 to 2022, CH_4 emissions from manure management decreased by 2.6 percent, 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. All other CO_2 emissions and removals (e.g., carbon stock changes from the management of croplands) are included in the LULUCF sector. Liming emissions increased by 36.9 percent relative to 2021 and decreased by 30.5 percent (1.4 MMT CO_2 Eq.) relative to 1990, while urea fertilization emissions increased by 1.9 percent relative to 2021 and 120.4 percent (2.9 MMT CO_2 Eq.) 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 stock fluxes on these lands and cause emissions of CH_4 and N_2O. Overall, managed land is a net sink for CO_2 (carbon sequestration) in the United States. The primary driver of fluxes on managed lands is from management of forest lands, but also includes trees in settlements (i.e., urban areas), afforestation, conversion of forest lands to settlements and croplands, the management of croplands and grasslands, flooded lands, and the landfilling of yard trimmings and food scraps. The main drivers for net forest sequestration include net forest growth, increasing forest area, and a net accumulation of carbon stocks in harvested wood pools. The net sequestration in settlements remaining settlements is driven primarily by carbon stock gains in urban forests (i.e., settlement trees) through net tree growth and increased urban area, as well as long-term accumulation of carbon in landfills from additions of yard trimmings and food scraps.

The LULUCF sector in 2022 resulted in a net increase in carbon stocks (i.e., net CO_2 removals) of 921.8 MMT CO_2 Eq. (Table 2-8).[6] This represents an offset of 14.5 percent of total (i.e., gross) greenhouse gas emissions in 2022. Emissions of CH_4 and N_2O from LULUCF activities in 2022 were 67.5 MMT CO_2 Eq. and represented 1.2 percent of

[6] LULUCF carbon stock change is the net carbon 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.

net greenhouse gas emissions.[7] Between 1990 and 2022, total net carbon sequestration in the LULUCF sector decreased by 10.9 percent, primarily due to a decrease in the rate of net carbon accumulation in forests and cropland remaining cropland, as well as an increase in CO_2 emissions from land converted to settlements.

Flooded land remaining flooded land was the largest source of CH_4 emissions from LULUCF and the fifth largest source overall of net CH_4 emissions in 2022, totaling 44.2 MMT CO_2 Eq. (1,579 kt of CH_4). Forest fires were the second largest source of CH_4 emissions from LULUCF in 2022, totaling 9.1 MMT CO_2 Eq. (325 kt of CH_4). Forest fires were the largest source of N_2O emissions from LULUCF in 2022, totaling 5.7 MMT CO_2 Eq. (22 kt of N_2O). Figure 2-11 and Table 2-8 illustrate LULUCF emissions and removals by land-use category and gas.

Figure 2-11: Trends in Emissions and Removals (Net CO_2 Flux) from Land Use, Land-Use Change, and Forestry

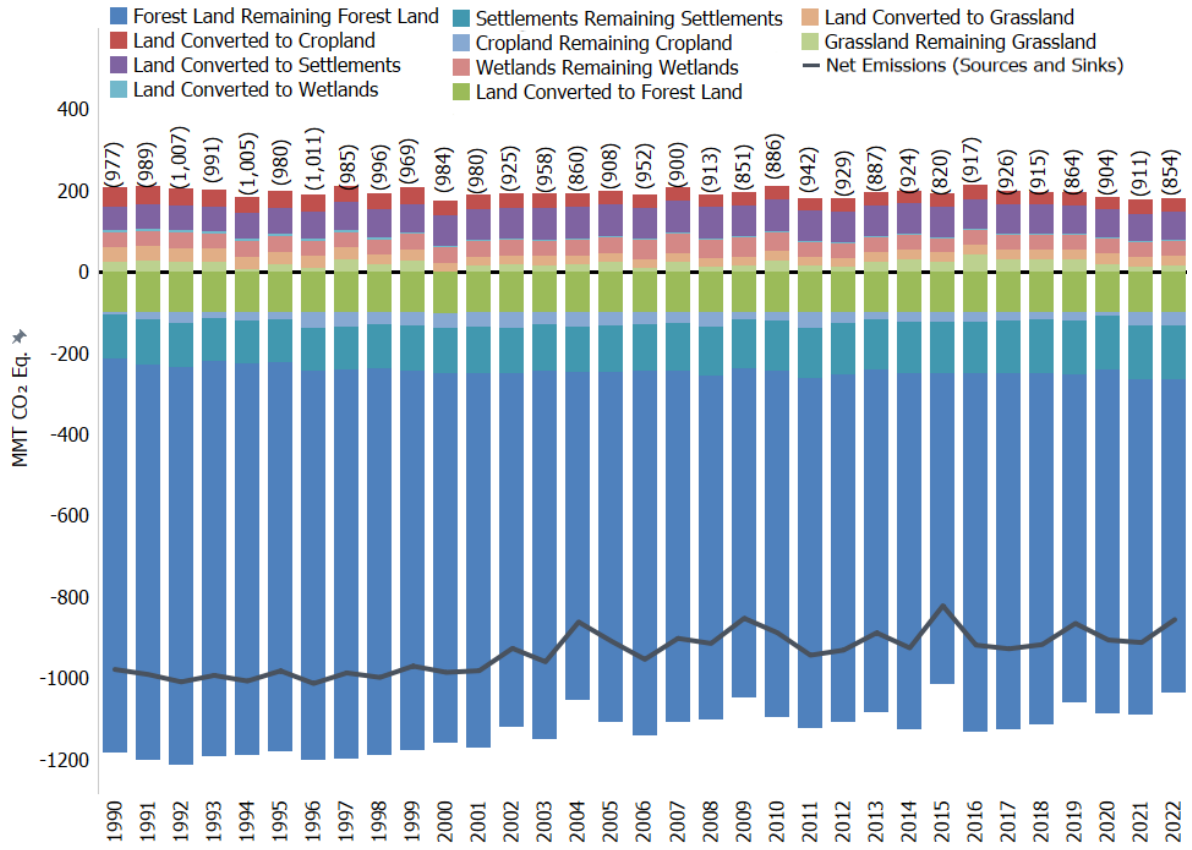


Table 2-8: U.S. Greenhouse Gas Emissions and Removals (Net Flux) from Land Use, Land-Use Change, and Forestry (MMT CO_2 Eq.)

Land-Use Category	1990	2005	2018	2019	2020	2021	2022
Forest Land Remaining Forest Land	**(968.8)**	**(860.0)**	**(863.3)**	**(807.0)**	**(846.3)**	**(823.8)**	**(771.7)**
Changes in Forest Carbon Stocks[a]	(974.8)	(876.0)	(873.5)	(813.2)	(862.0)	(844.2)	(787.0)

[7] 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 flooded land remaining flooded land, land converted to flooded land, and land converted to coastal wetlands; and N_2O emissions from forest soils and settlement soils.

Non-CO_2 Emissions from Forest Fires[b]	5.8	15.5	9.7	5.7	15.3	19.9	14.8
N_2O Emissions from Forest Soils[c]	0.1	0.4	0.4	0.4	0.4	0.4	0.4
Non-CO_2 Emissions from Drained Organic Soils[d]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Land Converted to Forest Land	**(100.2)**	**(100.2)**	**(100.4)**	**(100.3)**	**(100.3)**	**(100.3)**	**(100.3)**
Changes in Forest Carbon Stocks[e]	(100.2)	(100.2)	(100.4)	(100.3)	(100.3)	(100.3)	(100.3)
Cropland Remaining Cropland	**(5.0)**	**(31.6)**	**(17.8)**	**(19.4)**	**(8.8)**	**(32.0)**	**(31.7)**
Changes in Mineral and Organic Soil Carbon Stocks	(5.0)	(31.6)	(17.8)	(19.4)	(8.8)	(32.0)	(31.7)
Land Converted to Cropland	**45.4**	**34.5**	**31.9**	**31.4**	**29.3**	**34.9**	**35.1**
Changes in all Ecosystem Carbon Stocks[f]	45.4	34.5	31.9	31.4	29.3	34.9	35.1
Grassland Remaining Grassland	**24.6**	**24.9**	**29.7**	**28.9**	**17.1**	**11.5**	**14.0**
Changes in Mineral and Organic Soil Carbon Stocks	24.4	24.1	28.6	28.5	16.1	10.6	13.4
Non-CO_2 Emissions from Grassland Fires[g]	0.2	0.8	1.1	0.3	1.1	0.9	0.6
Land Converted to Grassland	**35.3**	**21.8**	**25.2**	**25.4**	**28.7**	**24.5**	**25.6**
Changes in all Ecosystem Carbon Stocks[f]	35.3	21.8	25.2	25.4	28.7	24.5	25.6
Wetlands Remaining Wetlands	**36.8**	**39.4**	**38.2**	**38.1**	**38.1**	**38.1**	**38.1**
Changes in Organic Soil Carbon Stocks in Peatlands	1.1	1.1	0.7	0.6	0.6	0.5	0.6
Non-CO_2 Emissions from Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Changes in Biomass, DOM, and Soil Carbon Stocks in Coastal Wetlands	(10.8)	(10.1)	(11.1)	(11.1)	(11.1)	(11.1)	(11.1)
CH_4 Emissions from Coastal Wetlands Remaining Coastal Wetlands	4.2	4.2	4.3	4.3	4.3	4.3	4.3
N_2O Emissions from Coastal Wetlands Remaining Coastal Wetlands	0.1	0.2	0.1	0.1	0.1	0.1	0.1
CH_4 Emissions from Flooded Land Remaining Flooded Land	42.3	44.0	44.2	44.2	44.2	44.2	44.2
Land Converted to Wetlands	**7.2**	**1.8**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**
Changes in Biomass, DOM, and Soil Carbon Stocks in Land Converted to Coastal Wetlands	0.5	0.5	(+)	(+)	(+)	(+)	(+)
CH_4 Emissions from Land Converted to Coastal Wetlands	0.3	0.3	0.2	0.2	0.2	0.2	0.2
Changes in Land Converted to Flooded Land	3.6	0.6	0.3	0.3	0.3	0.3	0.3
CH_4 Emissions from Land Converted to Flooded Land	2.9	0.4	0.2	0.2	0.2	0.2	0.2
Settlements Remaining Settlements	**(109.1)**	**(115.2)**	**(131.0)**	**(131.5)**	**(131.8)**	**(132.3)**	**(132.3)**
Changes in Organic Soil Carbon Stocks	9.9	10.1	14.4	14.6	15.1	15.4	15.4
Changes in Settlement Tree Carbon Stocks	(96.6)	(117.0)	(134.4)	(135.6)	(136.7)	(137.8)	(138.5)
N_2O Emissions from Settlement Soils[h]	2.1	3.1	2.4	2.5	2.5	2.5	2.5
Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills	(24.5)	(11.4)	(13.4)	(13.1)	(12.8)	(12.5)	(11.8)
Land Converted to Settlements	**57.2**	**77.1**	**71.4**	**70.2**	**68.8**	**68.2**	**68.2**
Changes in all Ecosystem Carbon Stocks[f]	57.2	77.1	71.4	70.2	68.8	68.2	68.2
LULUCF Carbon Stock Change[j]	**(1,034.7)**	**(976.6)**	**(978.3)**	**(921.6)**	**(972.8)**	**(983.4)**	**(921.8)**
LULUCF Emissions[i]	**57.9**	**68.9**	**62.8**	**58.0**	**68.4**	**72.9**	**67.5**
CH_4	53.1	58.6	55.6	52.5	59.3	62.2	58.4
N_2O	4.8	10.4	7.2	5.5	9.1	10.8	9.1
LULUCF Sector Net Total[k]	**(976.7)**	**(907.6)**	**(915.5)**	**(863.6)**	**(904.4)**	**(910.5)**	**(854.3)**

+ Absolute value does not exceed 0.05 MMT CO_2 Eq.

[a] Includes the net changes to carbon stocks stored in all forest ecosystem pools (estimates include carbon stock changes from drained organic soils from both forest land remaining forest land and land converted to forest land) and harvested wood products.

[b] Estimates include emissions from fires on both forest land remaining forest land and land converted to forest land.

[c] Estimates include emissions from N fertilizer additions on both forest land remaining forest land and land converted to forest land.

[d] Estimates include CH_4 and N_2O emissions from drained organic soils on both forest land remaining forest land and land converted to forest land. Carbon stock changes from drained organic soils are included with the forest land remaining forest land forest ecosystem pools.

[e] Includes the net changes to carbon stocks stored in all forest ecosystem pools.

[f] Includes changes in mineral and organic soil carbon stocks for all land use conversions to cropland, grassland, and settlements. Also includes aboveground/belowground biomass, dead wood, and litter carbon stock changes for conversion of forest land to cropland, grassland, and settlements.

[g] Estimates include CH_4 and N_2O emissions from fires on both grassland remaining grassland and land converted to grassland.

[h] Estimates include N_2O emissions from N fertilizer additions on both settlements remaining settlements and land converted to settlements because it is not possible to separate the activity data at this time.

[i] LULUCF emissions subtotal includes 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 flooded land remaining flooded land, and land converted to flooded land, and land converted to coastal wetlands; and N_2O emissions from forest soils and settlement soils. Emissions values are included in land-use category rows.

[j] LULUCF carbon stock change includes any carbon stock gains and losses from all land use and land-use conversion categories.

[k] The LULUCF sector net total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus LULUCF net carbon stock changes in units of MMT CO_2 Eq.

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

Overall CH_4 and N_2O emissions from LULUCF decreased 7.4 percent from 2021 and 16.5 percent since 1990 while total net sequestration decreased 10.9 percent since 1990 and 6.3 percent from 2021. Other trends from 1990 to 2022 in emissions from LULUCF categories (Figure 2-11) over the 33-year period included the following:

- Annual carbon sequestration by forest land (i.e., annual carbon stock accumulation in the five ecosystem carbon pools and harvested wood products for forest land remaining forest land and land converted to forest land) has decreased by 17.5 percent since 1990. This is primarily due to decreased carbon stock gains in land converted to forest land and the harvested wood products pools within forest land remaining forest land.
- Annual carbon sequestration from settlements remaining settlements (which includes organic soils, settlement trees, and landfilled yard trimmings and food scraps) has increased by 21.2 percent over the period from 1990 to 2022. 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 19.1 percent from 1990 to 2022 due primarily to carbon stock losses from forest land converted to settlements and mineral soils carbon stocks from grassland converted to settlements.

Waste

Waste management and treatment activities are sources of CH_4 and N_2O emissions (see Figure 2-12 and Table 2-9). Overall, emission sources accounted for in the Waste chapter generated 166.9 MMT CO_2 Eq., or 2.6 percent of total U.S. greenhouse gas emissions in 2022. In 2022, landfills were the largest source of waste emissions, accounting for 71.8 percent of waste-related emissions. Landfills are also the third-largest source of U.S. anthropogenic CH_4 emissions, generating 119.8 MMT CO_2 Eq. and accounting for 17.0 percent of total U.S. CH_4 emissions in 2022.[8] Additionally, wastewater treatment generated emissions of 42.7 MMT CO_2 Eq. and accounted for 25.6 percent of waste emissions, 3.0 percent of U.S. CH_4 emissions, and 5.7 percent of U.S. N_2O emissions in 2022. Emissions of CH_4 and N_2O from composting are also accounted for in this chapter, generating emissions of 2.6 MMT CO_2 Eq. and 1.8 MMT CO_2 Eq., accounting for 1.5 and 1.1 percent of Waste sector emissions, respectively. Anaerobic digestion

[8] 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.

at biogas facilities generated CH_4 emissions of less than 0.05 MMT CO_2 Eq., accounting for less than 0.05 percent of emissions from the Waste sector.

Figure 2-12: Trends in Waste Sector Greenhouse Gas Sources

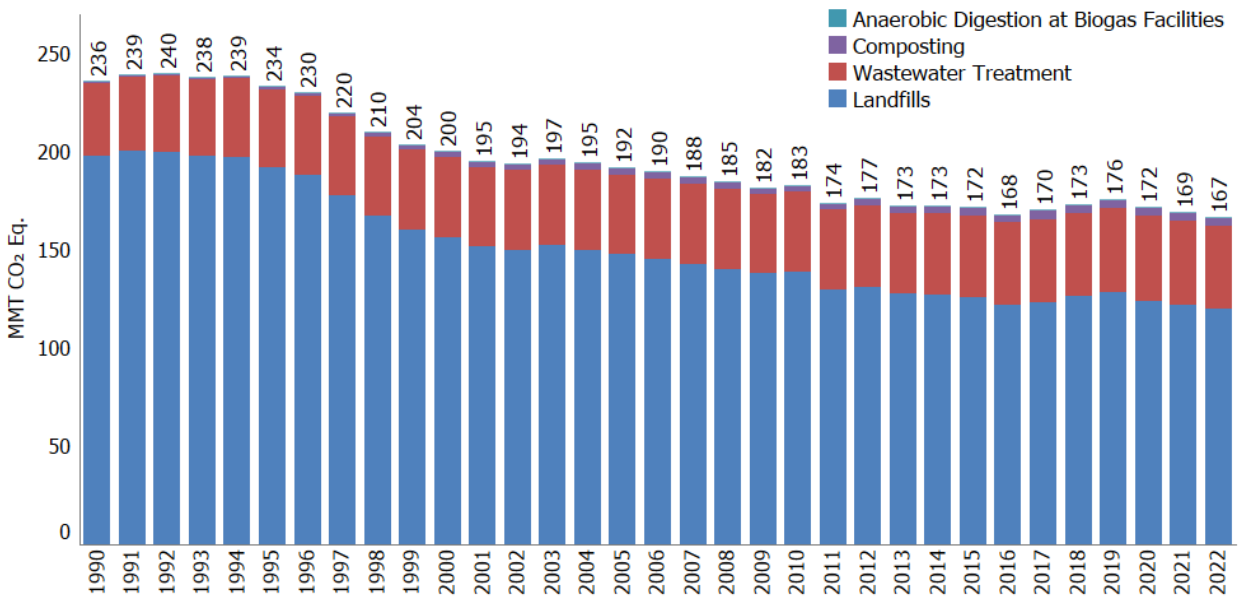


Table 2-9: Emissions from Waste (MMT CO_2 Eq.)

Gas/Source	1990	2005	2018	2019	2020	2021	2022
CH_4	**220.9**	**172.4**	**150.2**	**152.4**	**147.6**	**145.3**	**143.2**
Landfills	197.8	147.7	126.3	128.7	124.1	122.0	119.8
Wastewater Treatment	22.7	22.7	21.4	21.1	21.0	20.7	20.8
Composting	0.4	2.1	2.5	2.5	2.6	2.6	2.6
Anaerobic Digestion at Biogas Facilities	+	+	+	+	+	+	+
N_2O	**15.1**	**19.5**	**23.0**	**23.4**	**24.1**	**23.9**	**23.7**
Wastewater Treatment	14.8	18.1	21.2	21.6	22.3	22.1	21.9
Composting	0.3	1.5	1.8	1.8	1.8	1.8	1.8
Total	**235.9**	**192.0**	**173.2**	**175.8**	**171.7**	**169.2**	**166.9**

+ Does not exceed 0.05 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Waste sector emissions decreased by 1.4 percent since 2021 and 29.3 percent since 1990. Some notable trends in U.S. emissions from Waste source categories (Figure 2-12) over the 33-year period from 1990 through 2022 included the following:

- Net CH_4 emissions from landfills decreased by 78.0 MMT CO_2 Eq. (39.4 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.
- Methane and N_2O emissions from wastewater treatment decreased by 1.9 MMT CO_2 Eq. (8.4 percent) and increased by 7.1 MMT CO_2 Eq. (48.2 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. N_2O emissions from wastewater treatment processes gradually increased across the time series as a result of increasing U.S. population and protein consumption.

- Combined CH_4 and N_2O emissions from composting have increased by 3.7 MMT CO_2 Eq. since 19902, which represents more than a six-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) an increase in 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.

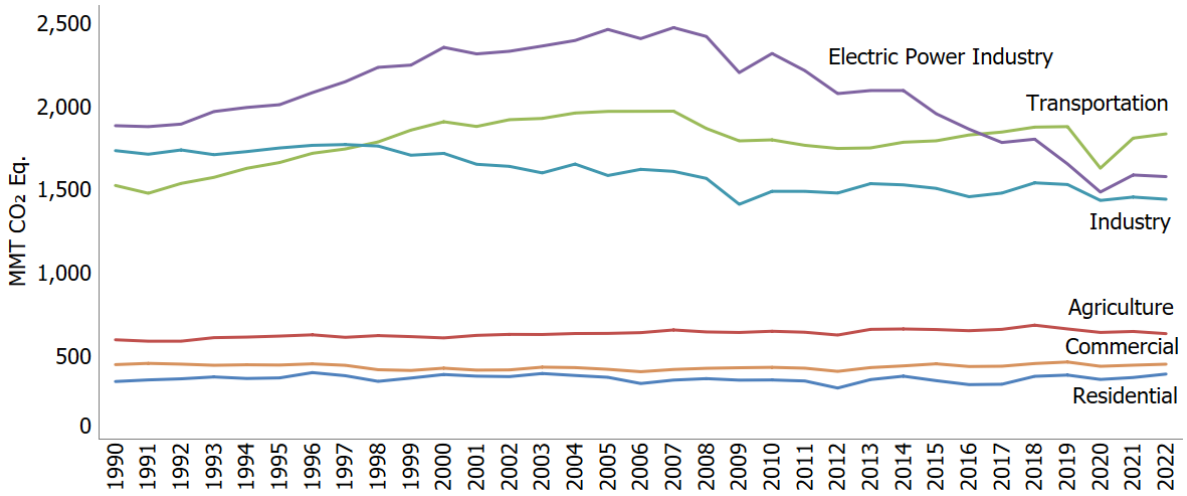
2.2 Emissions and Sinks by Economic Sector

In addition to the Paris Agreement and UNFCCC reporting sectors and methods defined by the IPCC, this report also characterizes 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 LULUCF sector, see Section 2.1.

Using this categorization, transportation activities accounted for the largest portion (28.9 percent) of total U.S. greenhouse gas emissions in 2022. Emissions from electric power accounted for the second largest portion (24.8 percent), while emissions from industry accounted for the third-largest portion (22.7 percent) of total U.S. greenhouse gas emissions in 2022. 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 23.6 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 10.0 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 carbon sequestration is assigned to the LULUCF sector rather than the agriculture economic sector. The commercial and residential sectors accounted for roughly 7.1 percent and 6.2 percent of greenhouse gas emissions, respectively, and U.S. Territories accounted for 0.4 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 carbon) 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 carbon 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 2022.

Figure 2-13: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors



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 2022)

Sector/Source	1990	2005	2018	2019	2020	2021	2022	Percent of Total Emissions[a]
Transportation	**1,521.4**	**1,965.9**	**1,871.6**	**1,874.6**	**1,625.3**	**1,805.5**	**1,830.9**	**28.9%**
CO_2 from Fossil Fuel Combustion	1,468.9	1,858.6	1,813.1	1,816.6	1,572.8	1,753.5	1,780.8	28.1%
Substitution of Ozone Depleting Substances	0.0	63.1	35.5	34.0	32.5	31.2	29.6	0.5%
Mobile Combustion[b]	40.6	34.1	13.7	15.1	12.2	12.7	12.2	0.2%
Non-Energy Use of Fuels	11.8	10.2	9.2	8.8	7.8	8.0	8.4	0.1%
Electric Power Industry	**1,880.2**	**2,457.4**	**1,799.2**	**1,650.8**	**1,482.2**	**1,584.4**	**1,574.7**	**24.8%**
CO_2 from Fossil Fuel Combustion	1,820.0	2,400.1	1,753.4	1,606.7	1,439.6	1,540.9	1,531.7	24.2%
Stationary Combustion[b]	18.7	27.7	23.1	20.2	18.9	20.4	20.1	0.3%
Incineration of Waste	13.3	13.6	13.7	13.3	13.3	12.8	12.7	0.2%
Other Process Uses of Carbonates	3.6	4.2	4.0	4.5	4.5	4.3	5.2	0.1%
Electrical Equipment	24.7	11.9	5.0	6.1	5.9	6.0	5.1	0.1%
Industry	**1,730.4**	**1,581.2**	**1,537.3**	**1,527.3**	**1,431.8**	**1,451.9**	**1,439.1**	**22.7%**
CO_2 from Fossil Fuel Combustion	827.8	792.7	765.4	758.5	710.4	729.0	737.8	11.6%
Natural Gas Systems	251.2	236.5	223.0	227.3	217.0	210.4	209.7	3.3%
Non-Energy Use of Fuels	88.3	108.2	112.3	106.9	100.1	112.8	107.5	1.7%
Petroleum Systems	59.0	58.4	93.8	97.8	82.3	72.8	61.6	1.0%
Coal Mining	112.7	75.6	62.2	56.0	48.3	47.1	46.1	0.7%
Cement Production	33.5	46.2	39.0	40.9	40.7	41.3	41.9	0.7%
Iron and Steel Production	104.8	70.1	42.9	43.1	37.7	41.9	40.7	0.6%
Substitution of Ozone Depleting Substances	+	8.0	31.9	33.1	33.9	32.2	33.4	0.5%

Petrochemical Production	21.6	27.4	27.2	28.5	27.9	30.7	28.8	0.5%
Landfills (Industrial)	12.2	16.1	18.7	18.8	18.9	18.9	18.9	0.3%
Ammonia Production	14.4	10.2	12.7	12.4	13.0	12.2	12.6	0.2%
Lime Production	11.7	14.6	13.1	12.1	11.3	11.9	12.2	0.2%
Nitric Acid Production	10.8	10.1	8.5	8.9	8.3	7.9	8.6	0.1%
Abandoned Oil and Gas Wells	7.8	8.2	8.4	8.5	8.5	8.6	8.5	0.1%
Wastewater Treatment	6.6	7.1	7.5	7.6	7.6	7.6	7.7	0.1%
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	6.1	6.2	5.8	6.6	7.1	0.1%
Abandoned Underground Coal Mines	8.1	7.4	6.9	6.6	6.5	6.4	6.4	0.1%
Mobile Combustion[b]	3.6	5.6	5.5	5.6	5.3	5.5	5.8	0.1%
Other Process Uses of Carbonates	3.6	4.2	4.0	4.5	4.5	4.3	5.2	0.1%
Fluorochemical Production	77.4	26.6	6.1	7.0	5.0	5.3	5.2	0.1%
Carbon Dioxide Consumption	1.5	1.4	4.1	4.9	5.0	5.0	5.0	0.1%
Electronics Industry	3.3	4.5	4.8	4.4	4.6	5.0	4.7	0.1%
N_2O from Product Uses	3.8	3.8	3.8	3.8	3.8	3.8	3.8	0.1%
Stationary Combustion	4.8	4.5	3.9	3.7	3.5	3.6	3.4	0.1%
Aluminum Production	26.1	7.2	2.9	3.3	3.2	2.5	2.2	+%
Adipic Acid Production	13.5	6.3	9.3	4.7	7.4	6.6	2.1	+%
Glass Production	2.3	2.4	2.0	1.9	1.9	2.0	2.0	+%
Soda Ash Production	1.4	1.7	1.7	1.8	1.5	1.7	1.7	+%
Titanium Dioxide Production	1.2	1.8	1.5	1.3	1.3	1.5	1.5	+%
Ferroalloy Production	2.2	1.4	2.1	1.6	1.4	1.6	1.3	+%
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.5	1.9	1.3	1.2	1.1	1.2	1.3	+%
Magnesium Production and Processing	5.7	3.0	1.1	1.0	0.9	1.2	1.2	+%
Zinc Production	0.6	1.0	1.0	1.0	1.0	1.0	0.9	+%
Phosphoric Acid Production	1.5	1.3	0.9	0.9	0.9	0.9	0.8	+%
SF_6 and PFCs from Other Product Use	1.5	1.5	1.0	0.8	0.7	0.5	0.8	+%
Lead Production	0.5	0.6	0.5	0.5	0.5	0.4	0.4	+%
Carbide Production and Consumption	0.3	0.2	0.2	0.2	0.2	0.2	0.2	+%
Agriculture	**595.9**	**634.3**	**683.5**	**661.0**	**640.0**	**645.9**	**632.7**	**10.0%**
N_2O from Agricultural Soil Management	288.8	294.1	333.4	315.6	292.1	298.0	290.8	4.6%
Enteric Fermentation	183.1	188.2	196.8	197.3	196.3	196.5	192.6	3.0%
Manure Management	52.5	70.2	84.3	83.5	83.8	83.6	81.7	1.3%
CO_2 from Fossil Fuel Combustion	43.4	50.8	39.8	39.7	39.1	39.8	38.0	0.6%
Rice Cultivation	18.9	20.6	19.9	15.6	18.6	18.3	18.9	0.3%
Urea Fertilization	2.4	3.5	4.9	5.0	5.1	5.2	5.3	0.1%
Liming	4.7	4.4	2.2	2.2	2.9	2.4	3.3	0.1%
Mobile Combustion[b]	1.4	1.6	1.2	1.2	1.2	1.2	1.2	+%

Field Burning of Agricultural Residues	0.7	0.8	0.8	0.9	0.8	0.8	0.8	+%
Stationary Combustion[b]	0.1	+	0.1	0.1	0.1	0.1	0.1	+%
Commercial	**447.0**	**418.7**	**453.5**	**462.6**	**436.9**	**443.7**	**449.6**	**7.1%**
CO_2 from Fossil Fuel Combustion	228.3	227.0	246.3	251.7	229.3	237.5	244.7	3.9%
Landfills (Municipal)	185.5	131.6	107.7	109.9	105.2	103.1	100.9	1.6%
Substitution of Ozone Depleting Substances	+	21.4	58.5	59.8	60.8	61.9	62.9	1.0%
Wastewater Treatment	30.9	33.6	35.0	35.1	35.6	35.1	35.0	0.6%
Composting	0.7	3.6	4.3	4.3	4.4	4.4	4.4	0.1%
Stationary Combustion[b]	1.5	1.5	1.7	1.7	1.6	1.6	1.7	+%
Anaerobic Digestion at Biogas Facilities	+	+	+	+	+	+	+	+%
Residential	**345.6**	**370.9**	**376.8**	**384.2**	**358.0**	**369.6**	**390.3**	**6.2%**
CO_2 from Fossil Fuel Combustion	338.6	358.6	338.9	342.9	314.8	318.0	333.1	5.3%
Substitution of Ozone Depleting Substances	0.2	7.0	31.9	35.1	39.0	47.3	52.2	0.8%
Stationary Combustion[b]	6.8	5.3	6.0	6.2	4.2	4.2	5.0	0.1%
U.S. Territories	**23.4**	**59.7**	**26.3**	**25.1**	**23.4**	**23.9**	**23.9**	**0.4%**
CO_2 from Fossil Fuel Combustion	20.0	51.9	25.9	24.8	23.3	23.8	23.8	0.4%
Non-Energy Use of Fuels	3.4	7.6	0.2	0.2	0.1	0.1	0.1	+%
Stationary Combustion[b]	0.1	0.2	0.1	0.1	0.1	0.1	0.1	+%
Total Gross Emissions (Sources)	**6,544.0**	**7,488.2**	**6,748.2**	**6,585.6**	**5,997.6**	**6,324.9**	**6,341.2**	**100.0%**
LULUCF Sector Net Total[c]	**(976.7)**	**(907.6)**	**(915.5)**	**(863.6)**	**(904.4)**	**(910.5)**	**(854.3)**	**-13.5%**
Net Emissions (Sources and Sinks)	**5,567.3**	**6,580.5**	**5,832.7**	**5,722.0**	**5,093.2**	**5,414.4**	**5,487.0**	**86.5%**

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

[a] Percent of total (gross) emissions excluding emissions from LULUCF for 2022.

[b] Includes CH_4 and N_2O emissions from fuel combustion.

c The LULUCF sector net total is the net sum of all LULUCF CH_4 and N_2O emissions to the atmosphere plus LULUCF net carbon stock changes.

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

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 sectors common for reporting under the Paris Agreement and the UNFCCC. 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, CH_4 and N_2O emissions from the combustion of fossil fuels that are included in the EIA electric power sector. Carbon dioxide, CH_4, and N_2O emissions from waste incineration are included in the electric power economic sector, as the majority of MSW is combusted in plants that produce electricity. The electric power economic sector also includes SF_6 from electrical equipment, 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. Emissions of ODS substitutes 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. Emissions of ODS substitutes are apportioned based on their specific end-uses within the source category, with most emissions falling within the industry economic sector. Finally, CH_4 emissions from industrial landfills and CH_4 and N_2O from industrial wastewater treatment are included in 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 includes agriculture equipment in the industrial fuel-consuming sector. Agriculture fuel use estimates are obtained from U.S. Department of Agriculture survey data, in combination with EIA Fuel Oil and Kerosene Sales (FOKS) data (EIA 1991 through 2022). Agricultural operations are based on annual energy expense data from the Agricultural Resource Management Survey (ARMS) conducted by the National Agricultural Statistics Service (NASS) of the USDA. NASS collects information on farm production expenditures including expenditures on diesel fuel, gasoline, LP gas, natural gas, and electricity use on the farm with the annual ARMS. A USDA publication (USDA/NASS 2023) shows national totals, as well as selected States and ARMS production regions. These supplementary data are subtracted from the industrial fuel use reported by EIA to obtain agriculture fuel use. Carbon dioxide 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. Emissions of ODS substitutes are apportioned to the residential economic sector based on emissions from residential air-conditioning systems. N_2O 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. Emissions of ODS substitutes are apportioned to the commercial economic sector based on emissions from commercial refrigeration/air-conditioning systems. Public works sources, including direct CH_4 from municipal landfills, CH_4

from anaerobic digestion at biogas facilities, CH_4 and N_2O from domestic 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 24.8 percent of total U.S. greenhouse gas emissions in 2022. Electric power-related emissions decreased by 16.2 percent since 1990 mainly due to fuel switching in the electric power sector. From 2021 to 2022, electric power-related emissions decreased by 0.6 percent. Between 2021 and 2022, the consumption of natural gas and petroleum for electric power generation increased by 7.6 percent and 18.9 percent, respectively, while the consumption of coal decreased by 6.4 percent. Electric power-related emissions are still lower than pre-pandemic 2019 levels.

From 2021 to 2022, electricity sales to the residential end-use sector increased by 2.6 percent. Electricity sales to the commercial end-use and industrial sectors increased by 4.7 percent and 2.0 percent, respectively. Overall, from 2021 to 2022, the amount of electricity retail sales (in kWh) increased by 3.2 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	2019	2020	2021	2021	2022
CO_2	**1,836.4**	**2,417.5**	**1,770.7**	**1,624.2**	**1,457.0**	**1,557.7**	**1,549.2**
Fossil Fuel Combustion	1,820.0	2,400.1	1,753.4	1,606.7	1,439.6	1,540.9	1,531.7
Coal	*1,546.5*	*1,982.8*	*1,152.9*	*973.5*	*788.2*	*910.1*	*851.5*
Natural Gas	*175.4*	*318.9*	*577.9*	*616.6*	*634.8*	*612.8*	*659.3*
Petroleum	*97.5*	*98.0*	*22.2*	*16.2*	*16.2*	*17.7*	*20.5*
Geothermal	*0.5*	*0.5*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
Incineration of Waste	12.9	13.3	13.3	12.9	12.9	12.5	12.4
Other Process Uses of Carbonates	3.6	4.2	4.0	4.5	4.5	4.3	5.2
CH_4	**0.5**	**1.0**	**1.4**	**1.4**	**1.4**	**1.4**	**1.5**
Stationary Sources[a]	0.5	1.0	1.4	1.4	1.4	1.4	1.5
Incineration of Waste	+	+	+	+	+	+	+
N_2O	**18.6**	**27.1**	**22.1**	**19.1**	**17.9**	**19.4**	**18.9**
Stationary Sources[a]	18.2	26.7	21.7	18.8	17.5	19.0	18.6
Incineration of Waste	0.4	0.3	0.4	0.4	0.3	0.4	0.3
SF_6	**24.7**	**11.8**	**5.0**	**6.1**	**5.9**	**6.0**	**5.1**
Electrical Equipment	24.7	11.8	5.0	6.1	5.9	6.0	5.1
PFCs	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Electrical Equipment	+	+	NO	+	+	+	+
Total	**1,880.2**	**2,457.4**	**1,799.2**	**1,650.8**	**1,482.2**	**1,584.4**	**1,574.7**

+ Does not exceed 0.05 MMT CO_2 Eq.

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

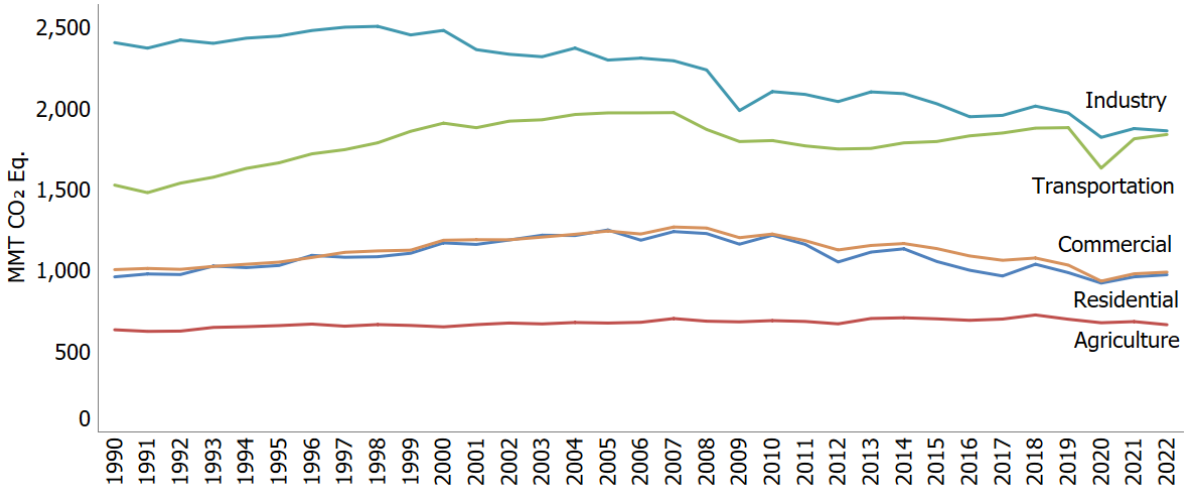
Note: Totals may not sum due to independent rounding.

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 2020b; USDA/NASS 2023). 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 equipment. Note that only 50 percent of the emissions from other process uses of carbonates were associated with electric power and

distributed as described; the remaining emissions from other process uses of carbonates were attributed to the industry economic end-use sector.[9]

When emissions from electricity use are distributed among these economic end-use sectors, 2022 emissions from industrial activities account for the largest share of total U.S. greenhouse gas emissions (29.3 percent), followed closely by emissions from transportation (29.0 percent). Emissions from the commercial and residential sectors also increase substantially when emissions from electricity are included (15.6 and 15.3 percent, respectively). In all economic end-use sectors except agriculture, CO_2 accounts for more than 78 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 2-14 shows the trend in these emissions by sector from 1990 to 2022.

Figure 2-14: U.S. Greenhouse Gas Emissions with Electricity-Related Emissions Distributed to Economic Sectors



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 2022

Sector/Gas	1990	2005	2018	2019	2020	2021	2022	Percent[a]
Industry	**2,404.4**	**2,296.8**	**2,012.6**	**1,970.3**	**1,819.3**	**1,873.8**	**1,859.7**	**29.3%**
Direct Emissions	**1,730.4**	**1,581.2**	**1,537.3**	**1,527.3**	**1,431.8**	**1,451.9**	**1,439.1**	**22.7%**
CO_2	1,174.4	1,133.8	1,108.8	1,116.1	1,034.6	1,068.7	1,070.0	16.9%
CH_4	413.3	371.2	352.2	337.7	323.3	311.4	299.9	4.7%
N_2O	37.1	31.3	31.3	26.8	28.3	27.3	24.3	0.4%
HFCs, PFCs, SF_6 and NF_3	105.6	45.0	45.1	46.7	45.6	44.4	44.9	0.7%
Electricity-Related	**674.0**	**715.6**	**475.3**	**443.0**	**387.6**	**421.9**	**420.6**	**6.6%**
CO_2	658.3	704.0	467.7	435.9	381.0	414.8	413.8	6.5%
CH_4	0.2	0.3	0.4	0.4	0.4	0.4	0.4	+%
N_2O	6.7	7.9	5.8	5.1	4.7	5.2	5.1	0.1%
SF_6	8.8	3.5	1.3	1.6	1.5	1.6	1.4	+%
Transportation	**1,524.6**	**1,970.8**	**1,876.5**	**1,879.5**	**1,629.5**	**1,810.7**	**1,837.2**	**29.0%**

[9] 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.

Direct Emissions	**1,521.4**	**1,965.9**	**1,871.6**	**1,874.6**	**1,625.3**	**1,805.5**	**1,830.9**	**28.9%**
CO_2	1,480.8	1,868.7	1,822.3	1,825.5	1,580.6	1,761.6	1,789.2	28.2%
CH_4	6.4	3.1	1.7	1.7	1.4	1.5	1.5	+%
N_2O	34.3	31.0	12.1	13.4	10.7	11.2	10.7	0.2%
HFCs[b]	+	63.1	35.5	34.0	32.5	31.2	29.6	0.5%
Electricity-Related	**3.1**	**4.8**	**4.9**	**4.9**	**4.2**	**5.2**	**6.3**	**0.1%**
CO_2	3.1	4.8	4.8	4.9	4.1	5.1	6.2	0.1%
CH_4	+	+	+	+	+	+	+	+%
N_2O	+	0.1	0.1	0.1	0.1	0.1	0.1	+%
SF_6	+	+	+	+	+	+	+	+%
Residential	**958.0**	**1,247.4**	**1,035.9**	**984.0**	**919.5**	**958.0**	**971.0**	**15.3%**
Direct Emissions	**345.6**	**370.9**	**376.8**	**384.2**	**358.0**	**369.6**	**390.3**	**6.2%**
CO_2	338.6	358.6	338.9	342.9	314.8	318.0	333.1	5.3%
CH_4	5.9	4.5	5.1	5.3	3.6	3.6	4.3	0.1%
N_2O	0.9	0.8	0.8	0.8	0.6	0.6	0.7	+%
SF_6	0.2	7.0	31.9	35.1	39.0	47.3	52.2	0.8%
Electricity-Related	**612.4**	**876.5**	**659.1**	**599.7**	**561.5**	**588.4**	**580.7**	**9.2%**
CO_2	598.1	862.2	648.6	590.1	551.9	578.5	571.3	9.0%
CH_4	0.2	0.3	0.5	0.5	0.5	0.5	0.5	+%
N_2O	6.1	9.7	8.1	6.9	6.8	7.2	7.0	0.1%
SF_6	8.0	4.2	1.8	2.2	2.2	2.2	1.9	+%
Commercial	**1,002.5**	**1,240.9**	**1,074.3**	**1,030.5**	**931.5**	**976.9**	**987.1**	**15.6%**
Direct Emissions	**447.0**	**418.7**	**453.5**	**462.6**	**436.9**	**443.7**	**449.6**	**7.1%**
CO_2	228.3	227.0	246.3	251.7	229.3	237.5	244.7	3.9%
CH_4	203.6	150.9	125.9	127.8	122.9	120.5	118.4	1.9%
N_2O	15.1	19.4	22.8	23.2	23.9	23.7	23.5	0.4%
HFCs	+	21.4	58.5	59.8	60.8	61.9	62.9	1.0%
Electricity-Related	**555.5**	**822.2**	**620.8**	**567.8**	**494.6**	**533.2**	**537.5**	**8.5%**
CO_2	542.6	808.9	611.0	558.7	486.2	524.2	528.8	8.3%
CH_4	0.1	0.3	0.5	0.5	0.5	0.5	0.5	+%
N_2O	5.5	9.1	7.6	6.6	6.0	6.5	6.5	0.1%
SF_6	7.3	4.0	1.7	2.1	2.0	2.0	1.7	+%
Agriculture	**631.1**	**672.6**	**722.7**	**696.2**	**674.4**	**681.6**	**662.3**	**10.4%**
Direct Emissions	**595.9**	**634.3**	**683.5**	**661.0**	**640.0**	**645.9**	**632.7**	**10.0%**
CO_2	50.5	58.7	47.0	46.9	47.1	47.4	46.6	0.7%
CH_4	241.9	264.6	285.2	280.4	282.6	282.0	277.0	4.4%
N_2O	303.5	311.0	351.3	333.7	310.3	316.4	309.1	4.9%
Electricity-Related	**35.2**	**38.3**	**39.2**	**35.2**	**34.4**	**35.7**	**29.6**	**0.5%**
CO_2	34.3	37.7	38.6	34.7	33.8	35.1	29.1	0.5%
CH_4	+	+	+	+	+	+	+	+%
N_2O	0.3	0.4	0.5	0.4	0.4	0.4	0.4	+%
SF_6	0.5	0.2	0.1	0.1	0.1	0.1	0.1	+%
U.S. Territories	**23.4**	**59.7**	**26.3**	**25.1**	**23.4**	**23.9**	**23.9**	**0.4%**
Total Gross Emissions (Sources)	**6,544.0**	**7,488.2**	**6,748.2**	**6,585.6**	**5,997.6**	**6,324.9**	**6,341.2**	**100.0%**
LULUCF Sector Net Total[c]	**(976.7)**	**(907.6)**	**(915.5)**	**(863.6)**	**(904.4)**	**(910.5)**	**(854.3)**	**-13.5%**
Net Emissions (Sources and Sinks)	**5,567.3**	**6,580.5**	**5,832.7**	**5,722.0**	**5,093.2**	**5,414.4**	**5,487.0**	**86.5%**

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

[a] Percent of total (gross) emissions excluding emissions from LULUCF for the year 2022.

[b] Includes primarily HFC-134a.

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

Notes: Total gross emissions are presented without LULUCF. Net emissions are 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.

Industry

The industry economic sector includes CO_2 emissions from fossil fuel combustion from all manufacturing facilities, in aggregate, and with the distribution of electricity-related emissions, accounted for 29.3 percent of U.S. greenhouse gas emissions in 2022. 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 and CO_2 emissions from coal mining, byproduct CO_2 emissions from cement production, and HFC, PFC, SF_6, and NF_3 byproduct emissions from the electronics industry, to name a few.

Since 1990, industry sector emissions have declined by 22.7 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., shifts from producing 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 29.0 percent of U.S. greenhouse gas emissions in 2022. The largest sources of transportation greenhouse gas emissions in 2022 were light-duty trucks, which include sport utility vehicles, pickup trucks, and minivans (36.7 percent); medium- and heavy-duty trucks (22.7 percent); passenger cars (20.6 percent); commercial aircraft (6.5 percent); other aircraft (2.7 percent); pipelines (3.8 percent); ships and boats (2.7 percent); and rail (1.9 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.

From 1990 to 2022, total transportation emissions from fossil fuel combustion increased by 18.8 percent. From 2021 to 2022, emissions increased by 1.5 percent. The increase in transportation emissions from 1990 to 2022 was due, in large part, to increased demand for travel. Vehicle miles traveled (VMT) by light-duty motor vehicles (passenger cars and light-duty trucks) increased 45.4 percent from 1990 to 2022 as a result of a confluence of factors including population growth, economic growth, urban sprawl, and periods of low fuel prices. The primary driver of transportation-related emissions was fossil fuel combustion of CO_2, which increased by 21.4 percent from 1990 to 2022 when including electricity. This rise in CO_2 emissions, combined with an increase in HFCs from close to zero emissions in 1990 to 29.6 MMT CO_2 Eq. in 2022, led to an increase in overall greenhouse gas emissions from transportation activities of 20.5 percent.

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 approximately 29.6 percent of new vehicle sales in 1990 to 48.0 percent in 2004. Starting in 2005, average new vehicle fuel economy began to increase while light-duty VMT grew only modestly between 2005 and 2013. Light-duty VMT grew by less than one percent or declined each year between 2005 and 2013, 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 one percent or less each year. Average new vehicle fuel economy has increased almost every year since 2005, while light-duty truck market share decreased to 33.0 percent in 2009 and has since varied from year to year between 35.6 and 63.1 percent. Light-duty truck market share was about 63.1 percent of new vehicles in model year 2022 (EPA 2023b).

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. Despite this increase, 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. For a more detailed breakout of emissions by fuel type by vehicle see Table A-93 in Annex 3.

Figure 2-15: Trends in Transportation-Related Greenhouse Gas Emissions

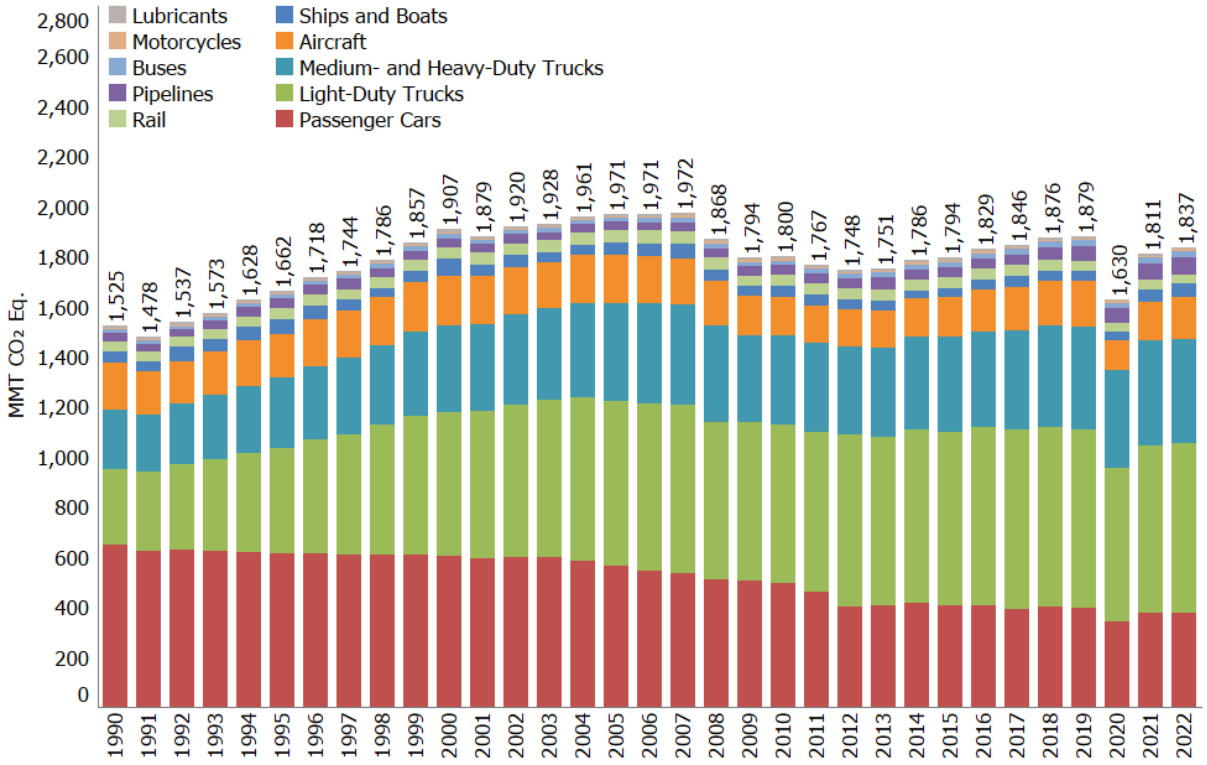


Table 2-13: Transportation-Related Greenhouse Gas Emissions (MMT CO_2 Eq.)

Gas/Vehicle	1990	2005	2018	2019	2020	2021	2022
Passenger Cars	**648.4**	**564.4**	**398.7**	**395.5**	**341.7**	**374.2**	**377.6**
CO_2	622.2	521.1	386.5	384.2	331.9	365.0	369.1
CH_4	3.8	1.2	0.3	0.3	0.3	0.3	0.2
N_2O	22.5	13.3	2.5	2.6	2.0	1.9	1.6
HFCs	0.0	28.8	9.4	8.4	7.6	7.0	6.6
Light-Duty Trucks	**302.4**	**659.3**	**720.6**	**711.7**	**615.3**	**671.8**	**674.3**
CO_2	292.1	614.0	699.0	690.1	596.2	654.0	658.6
CH_4	1.5	1.0	0.6	0.6	0.5	0.5	0.5
N_2O	8.7	14.0	4.6	5.6	4.4	4.2	3.8
HFCs	0.0	30.2	16.4	15.4	14.2	13.0	11.4
Medium- and Heavy-Duty Trucks	**234.5**	**391.0**	**406.5**	**409.3**	**386.7**	**417.0**	**417.2**
CO_2	233.1	386.2	397.9	400.3	377.8	407.7	407.7
CH_4	0.5	0.2	0.1	0.1	0.1	0.1	0.1
N_2O	1.0	1.5	2.8	3.0	2.7	3.0	3.1
HFCs	0.0	3.2	5.6	5.8	6.1	6.3	6.3
Buses	**13.3**	**17.8**	**24.9**	**25.3**	**24.0**	**26.1**	**26.5**
CO_2	13.2	17.5	24.3	24.7	23.4	25.6	26.0
CH_4	+	+	+	+	+	+	+
N_2O	0.1	0.1	0.2	0.2	0.2	0.2	0.2
HFCs	0.0	0.2	0.4	0.4	0.4	0.4	0.4

Motorcycles	**3.4**	**5.0**	**7.4**	**7.5**	**6.7**	**7.5**	**7.7**
CO_2	3.4	4.9	7.3	7.4	6.6	7.4	7.6
CH_4	+	+	+	+	+	+	+
N_2O	+	+	0.1	0.1	0.1	0.1	0.1
Commercial Aircraft[a]	**110.8**	**133.8**	**130.7**	**137.8**	**92.0**	**120.0**	**120.0**
CO_2	109.9	132.7	129.6	136.7	91.3	119.0	119.0
CH_4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N_2O	0.9	1.1	1.1	1.1	0.7	1.0	1.0
Other Aircraft[b]	**78.0**	**59.5**	**44.6**	**45.6**	**31.0**	**35.5**	**50.5**
CO_2	77.3	59.0	44.2	45.2	30.7	35.1	50.0
CH_4	0.1	0.1	+	+	+	+	+
N_2O	0.6	0.5	0.4	0.4	0.2	0.3	0.4
Ships and Boats[c]	**47.0**	**45.5**	**41.1**	**40.0**	**32.2**	**50.7**	**49.9**
CO_2	46.3	44.3	36.9	35.5	27.5	45.4	44.4
CH_4	0.4	0.5	0.5	0.4	0.4	0.5	0.5
N_2O	0.2	0.2	0.2	0.2	0.1	0.3	0.3
HFCs	0.0	0.5	3.6	3.9	4.2	4.5	4.8
Rail	**39.0**	**51.4**	**42.5**	**39.7**	**34.2**	**35.5**	**35.6**
CO_2	38.5	50.8	41.9	39.1	33.7	34.9	35.0
CH_4	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N_2O	0.3	0.4	0.3	0.3	0.3	0.3	0.3
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	0.1	0.1	0.1	0.1
Pipelines[e]	**36.0**	**32.8**	**50.3**	**58.3**	**58.0**	**64.4**	**69.3**
CO_2	36.0	32.8	50.3	58.3	58.0	64.4	69.3
Lubricants	**11.8**	**10.2**	**9.2**	**8.8**	**7.8**	**8.0**	**8.4**
CO_2	11.8	10.2	9.2	8.8	7.8	8.0	8.4
Total Transportation	**1,524.6**	**1,970.8**	**1,876.5**	**1,879.5**	**1,629.5**	**1,810.7**	**1,837.2**
International Bunker Fuels[f]	*104.6*	*114.3*	*125.3*	*114.6*	*70.3*	*80.9*	*83.2*
Ethanol CO_2[g]	*4.1*	*21.6*	*78.6*	*78.7*	*68.1*	*75.4*	*76.7*
Biodiesel CO_2[g]	*0.0*	*0.9*	*17.9*	*17.1*	*17.7*	*16.1*	*15.6*

+ 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 MSW is combusted in "trash-to-steam" electric power plants), electrical equipment, 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 LULUCF (see Chapter 6), in line with IPCC methodological guidance and reporting obligations under the Paris Agreement and the UNFCCC, 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.

Residential

The residential end-use sector, including electricity-related emissions, accounted for 15.3 percent of U.S. greenhouse gas emissions in 2022. This sector 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.

Commercial

The commercial end-use sector, including electricity-related emissions, accounted for 15.6 percent of U.S. greenhouse gas emissions in 2022. Like the residential sector it 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.

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

Agriculture

The agriculture end-use sector accounted for 9.4 percent of U.S. greenhouse gas emissions in 2022 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 2022, 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: Trends in Various U.S. Greenhouse Gas Emissions-Related Data

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

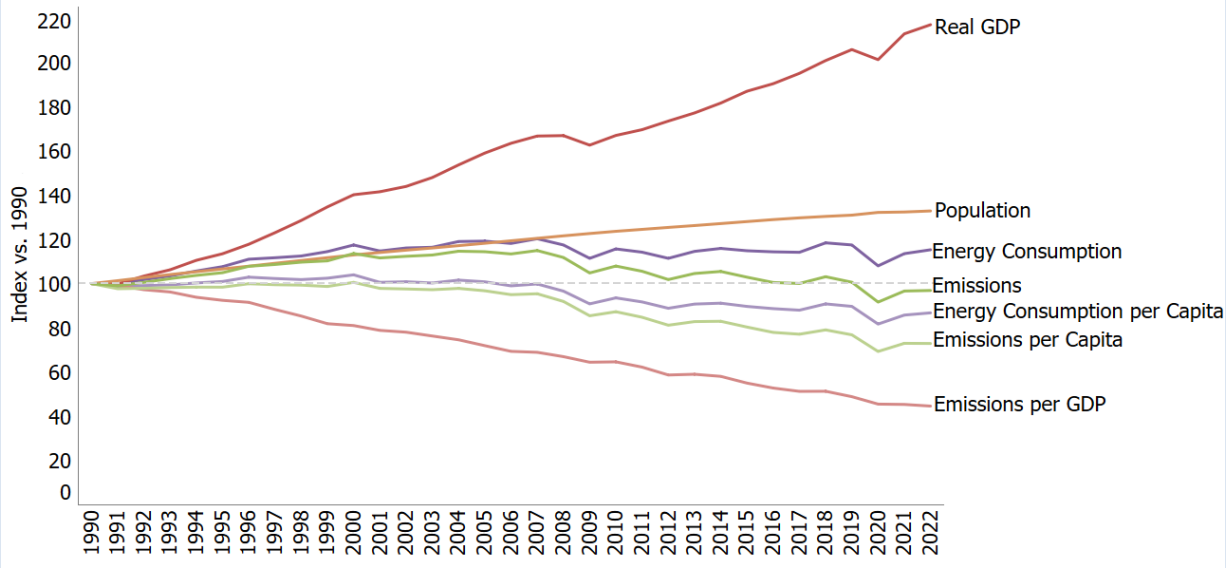
Table 2-14 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. These values represent the relative change in each statistic since 1990. Greenhouse gas emissions in the United States have decreased at an average annual rate of 0.1 percent 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 2-16). 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 0.9 percent since 2005. Since 2005, GDP, and national population, generally continued to increase, and energy use has decreased slightly, noting 2020 was impacted by the COVID-19 pandemic.

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

Variable	1990	2005	2018	2019	2020	2021	2022	Avg. Annual Change Since 1990[a]	Avg. Annual Change Since 2005[a]
Greenhouse Gas Emissions[b]	100	114	103	101	92	97	97	-0.1%	-0.9%
Energy Use[c]	100	119	118	117	107	113	115	0.5%	-0.2%
GDP[d]	100	159	201	206	201	213	217	2.5%	1.9%
Population[e]	100	118	130	131	132	132	133	0.9%	0.7%

[a] Average annual growth rate.
[b] Gross total GWP-weighted values.
[c] Energy-content-weighted values (EIA 2023).
[d] GDP in chained 2012 dollars (BEA 2023).
[e] U.S. Census Bureau (2023).

Figure 2-16: U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product



Source: BEA (2023), U.S. Census Bureau (2023), and gross emission estimates in this report.

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

The reporting requirements of the Paris Agreement and the UNFCCC[10] request that information be provided on emissions of compounds that are precursors to greenhouse gases, which include carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), and sulfur dioxide (SO_2). These gases are not

[10] See paragraph 51 of Annex to 18/CMA.1 available online at: https://unfccc.int/sites/default/files/resource/CMA2018_03a02E.pdf.

direct greenhouse gases, but can indirectly impact Earth's radiative balance, by altering the concentrations of other greenhouse gases (e.g., tropospheric ozone) and atmospheric aerosol (e.g., particulate sulfate). Carbon monoxide is produced when carbon-containing fuels are combusted incompletely in energy, transportation, and industrial processes, and is also emitted from practices such as agricultural burning and waste disposal and treatment. Anthropogenic sources of nitrogen oxides (i.e., NO and NO_2) are primarily fossil fuel combustion (for energy, transportation, industrial process) and agricultural burning. Anthropogenic sources of NMVOCs, which include hundreds of organic compounds that participate in atmospheric chemical reactions (propane, butane, xylene, toluene, ethane, and many others)—are emitted primarily from transportation, industrial processes, oil and natural gas production, waste practices, agricultural burning, 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.

As noted above and summarized in Chapter 6 of IPCC (2021), these compounds can have important indirect effects on Earth's radiative balance. For example, reactions between NMVOCs and NO_x in the presence of sunlight lead to formation of tropospheric ozone, a greenhouse gas. Concentrations of NMVOCs, NO_x, and CO can also impact the abundance and lifetime of primary greenhouse gases. This largely occurs by altering the atmospheric concentrations of the hydroxyl radical (OH), which is the main sink for atmospheric CH_4. For example, NO_x emissions can lead to increases in O_3 concentrations and subsequent OH production, which will increase the amount of OH molecules that are available to destroy CH_4. In contrast, NMVOCs and CO can both react directly with OH, leading to lower OH concentrations, a longer atmospheric lifetime of CH_4, and a decrease in CO_2 production (i.e., CO+OH→ CO_2). Changes in atmospheric CH_4 can also feedback on background concentrations of tropospheric O_3. Other indirect impacts include the formation of sulfate and nitrate aerosol from emissions of NO_x and SO_2, both of which have a net negative impact on radiative forcing.

Since 1970, the United States has published triennial estimates of emissions of CO, NO_x, NMVOCs, and SO_2 (EPA 2023a), which are regulated under the Clean Air Act. Emissions of each of these precursor greenhouse gases has decreased significantly since 1990 as a result of implementation of Clean Air Act programs, as well as technological improvements.[11] Precursor emission estimates for this report for 1990 through 2022 were obtained from data published on EPA's National Emissions Inventory (NEI) Air Pollutants Emissions Trends Data website (EPA 2023a). For Table 2-15, NEI-reported emissions of CO, NO_x, SO_2, and NMVOCs are recategorized from NEI Emissions Inventory System (EIS) source categories to those more closely aligned with reporting sectors and categories under the Paris Agreement and the UNFCCC, based on the crosswalk detailed in Annex 6.3. Table 2-15 shows that fuel combustion accounts for the majority of emissions of these precursors. 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. Precursor emissions from Agriculture and LULUCF categories are estimated separately and therefore are not taken from EPA (2023a).

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

Gas/Activity	1990	2005	2018	2019	2020	2021	2022
NO_x	**22,896**	**19,754**	**8,064**	**7,639**	**6,879**	**6,968**	**6,686**
Energy	21,966	18,863	7,384	7,048	6,235	6,289	6,056
IPPU	774	672	461	440	393	394	393
Agriculture	16	18	17	18	17	18	19
LULUCF	56	149	130	61	158	190	142
Waste	84	51	73	73	76	76	76
CO	**133,549**	**76,691**	**38,656**	**36,234**	**38,911**	**42,095**	**39,198**
Energy	124,713	64,455	30,760	30,349	28,427	29,311	28,560
IPPU	4,099	1,701	1,022	1,011	855	855	855
Agriculture	407	480	433	468	446	480	501
LULUCF	3,301	8,877	5,259	3,224	7,841	10,107	7,939

[11] More information is available online at: https://www.epa.gov/clean-air-act-overview/progress-cleaning-air-and-improving-peoples-health and https://gispub.epa.gov/neireport/2017/.

Waste	1,028	1,178	1,182	1,182	1,342	1,342	1,342
NMVOCs	**20,918**	**12,708**	**8,987**	**8,804**	**9,040**	**9,037**	**8,974**
Energy	13,067	8,694	5,506	5,444	5,306	5,302	5,239
IPPU	6,982	3,668	3,119	2,996	3,366	3,366	3,366
Agriculture	+	194	206	208	196	196	196
LULUCF	NA	NA	NA	NA	NA	NA	NA
Waste	870	152	156	157	173	173	173
SO_2	**20,924**	**13,108**	**2,001**	**1,676**	**1,471**	**1,628**	**1,552**
Energy	19,400	12,312	1,643	1,344	1,173	1,330	1,253
IPPU	1,488	776	335	309	266	266	265
Agriculture	+	0	0	0	+	+	+
LULUCF	NA	NA	NA	NA	NA	NA	NA
Waste	36	20	23	23	33	33	33

+ Does not exceed 0.5 kt.

NA (Not Available)

Note: Totals by gas may not sum due to independent rounding.

Source: (EPA 2023a) except for estimates from forest fires, grassland fires, and field burning of agricultural residues. Emission categories from EPA (2023a) are aggregated into sectors and categories reported under the Paris Agreement and the UNFCCC as shown in Table ES-3.

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