2 Trends in Greenhouse Gas Emissions and Removals

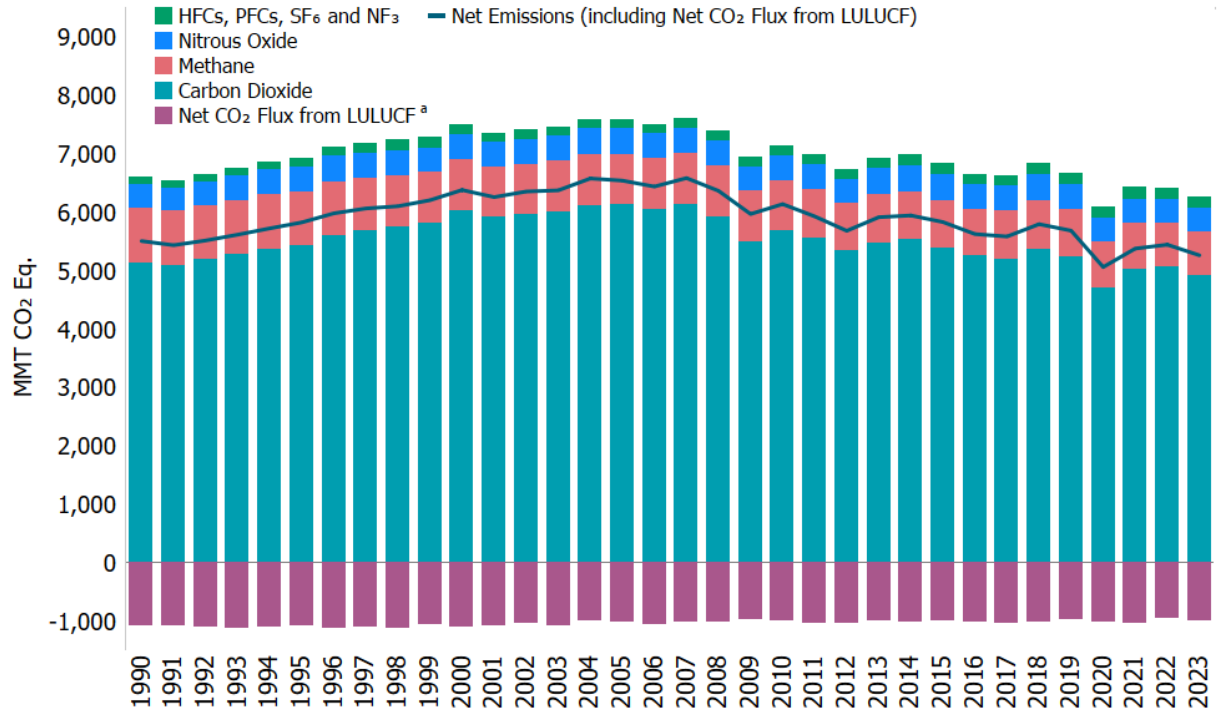
2.1 Overview of U.S. Greenhouse Gas Emissions and Sinks Trends

In 2023, total gross U.S. greenhouse gas emissions were 6,197.3 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq.). Total gross U.S. emissions, which exclude emissions and sinks from the land use, land use change and forestry (LULUCF) sector, decreased by 5.2 percent from 1990 to 2023, down from a high of 15.3 percent above 1990 levels in 2007. Gross emissions decreased from 2022 to 2023 by 2.3 percent (146.8 MMT CO_2 Eq.), driven largely by a decrease in CO_2 emissions from fossil fuel combustion. CO_2 emissions from fossil fuel combustion decreased by 3.0 percent in 2023 relative to 2022 and were 4.1 percent below 1990 emissions. Specifically, CO_2 emissions from coal consumption decreased by 18.3 percent (164.1 MMT CO_2 Eq.) from 2022 to 2023. CO_2 emissions from natural gas use increased by 1.0 percent (17.6 MMT CO_2 Eq.) and emissions from petroleum use increased by 0.2 percent (3.1 MMT CO_2 Eq.) from 2022 to 2023. The decrease in coal use and associated emissions from 2022 to 2023 is mainly due to reduced use in the electric power sector and is driving the overall reduction. The increase in natural gas consumption and associated emissions in 2023 is observed mostly in the electric power and industrial sectors, the increase in petroleum use is mainly in the transportation sector.

Net emissions, including emissions and sinks from the LULUCF sector were 5,257.4 MMT CO_2 Eq. in 2023. Overall, net emissions decreased by 3.3 percent from 2022 to 2023. Over the last 20 years, net emissions decreased nearly 20 percent. Trends in net emissions are illustrated in Table 2-1. Carbon sequestration in the LULUCF sector offset 16.1 percent of total gross emissions in 2023.

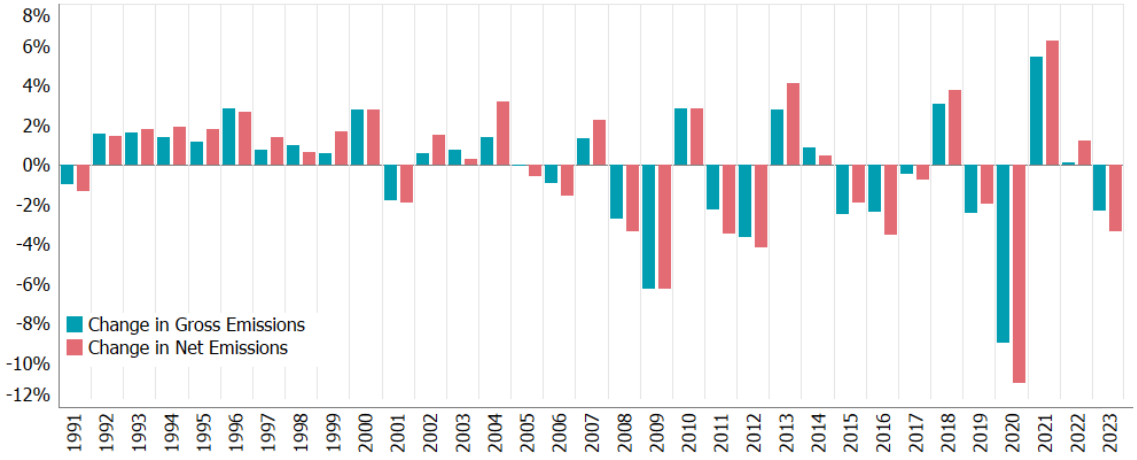
Figure 2-1 and Figure 2-2 illustrate the overall trend in total U.S. emissions and sinks since 1990, by gas and by annual percentage changes relative to the previous year.

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 Net and Gross U.S. Greenhouse Gas Emissions and Sinks Relative to the Previous Year

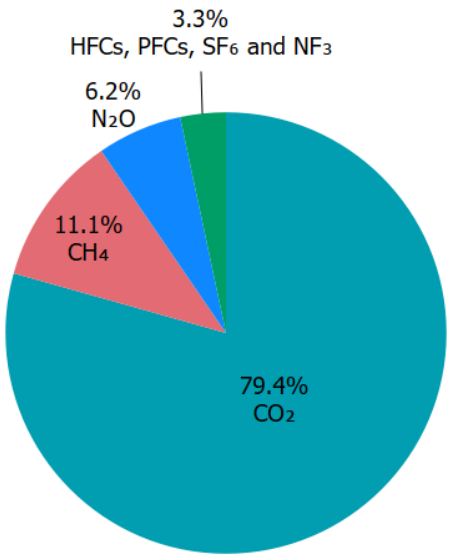


Emissions and Sinks by Gas

Figure 2-3 illustrates the relative contribution of each gas to total gross U.S. greenhouse gas emissions in 2023, 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 79.4 percent of total gross 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. N_2O accounts for an additional 6.2 percent of emissions. 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 fluorochemical production, electronics manufacturing, and primary aluminum production. Electrical equipment accounted for most sulfur hexafluoride (SF_6) emissions. The electronics industry and fluorochemical production are the only sources of NF_3 emissions.

Figure 2-3: 2023 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 2023, total gross emissions of CO_2 decreased by 4.2 percent (213.4 MMT CO_2 Eq.), total gross emissions of methane (CH_4) decreased by 21.4 percent (186.5 MMT CO_2 Eq.), and total gross emissions of nitrous oxide (N_2O) decreased by 5.1 percent (20.9 MMT CO_2 Eq.). During the same period, emissions of fluorinated gases including HFCs, PFCs, SF_6, and NF_3 rose by 63.5 percent (79.7 MMT CO_2 Eq.). Rapidly growing emissions of HFCs drove this trend, overwhelming decreases in emissions of PFCs and SF_6. Emissions of HFCs, PFCs, SF_6, and NF_3 are emitted in smaller quantities but 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 sequestration in managed forests, trees in urban areas, agricultural soils, landfilled yard

trimmings, and coastal wetlands. These were estimated to offset 16.1 percent (1,000.5 MMT CO_2 Eq.) of total gross emissions in 2023.

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 by Gas (MMT CO_2 Eq.)

Gas/Source	1990	2005	2019	2020	2021	2022	2023
CO_2	**5,131.8**	**6,126.9**	**5,235.9**	**4,690.0**	**5,020.1**	**5,055.4**	**4,918.4**
Fossil Fuel Combustion	4,752.2	5,744.1	4,852.6	4,342.3	4,654.6	4,702.8	4,559.4
Transportation	*1,468.9*	*1,858.6*	*1,816.6*	*1,573.0*	*1,753.5*	*1,753.6*	*1,776.5*
Electric Power Sector	*1,820.0*	*2,400.1*	*1,606.7*	*1,439.6*	*1,540.9*	*1,531.7*	*1,414.2*
Industrial	*876.5*	*847.6*	*809.8*	*763.4*	*780.5*	*799.7*	*792.6*
Residential	*338.6*	*358.9*	*342.9*	*314.8*	*318.0*	*335.2*	*307.1*
Commercial	*228.3*	*227.1*	*251.7*	*229.3*	*237.5*	*259.2*	*244.2*
U.S. Territories	*20.0*	*51.9*	*24.8*	*22.3*	*24.1*	*23.5*	*24.9*
Non-Energy Use of Fuels	99.1	125.0	106.5	97.9	111.7	101.7	107.1
Iron and Steel Production & Metallurgical Coke Production	104.7	70.1	46.8	40.7	47.2	45.2	46.2
Cement Production	33.5	46.2	40.9	40.7	41.3	41.9	40.6
Natural Gas Systems	32.5	26.3	38.7	36.8	35.7	36.4	37.7
Petrochemical Production	20.1	26.9	28.5	27.9	30.7	28.8	30.5
Petroleum Systems	9.6	10.2	45.4	28.9	24.1	22.1	23.3
Incineration of Waste	12.9	13.3	12.9	12.9	12.5	12.5	12.4
Ammonia Production	14.4	10.2	12.4	12.3	11.5	11.9	12.2
Lime Production	11.7	14.6	12.1	11.3	11.9	12.2	11.5
Other Process Uses of Carbonates	7.1	8.5	9.0	9.0	8.6	10.4	7.2
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	6.2	5.9	6.7	5.5	5.4
Liming	4.7	4.4	2.2	2.9	2.4	3.2	5.3
Urea Fertilization	2.4	3.5	4.9	5.0	5.1	5.2	5.3
Coal Mining	4.6	4.2	3.0	2.2	2.5	2.5	2.4
Non-EOR Carbon Dioxide Utilization	1.5	1.4	2.4	2.8	2.9	2.8	2.1
Glass Production	2.3	2.4	1.9	1.9	2.0	2.0	1.8
Soda Ash Production	1.4	1.7	1.8	1.5	1.7	1.7	1.7
Ferroalloy Production	2.2	1.4	1.6	1.4	1.4	1.3	1.2
Aluminum Production	6.8	4.1	1.9	1.7	1.5	1.4	1.2
Titanium Dioxide Production	1.2	1.8	1.3	1.3	1.5	1.5	1.2
Zinc Production	0.6	1.0	1.0	1.0	1.0	0.9	0.9
Phosphoric Acid Production	1.5	1.3	0.9	0.9	0.9	0.8	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5

Gas/Source	1990	2005	2019	2020	2021	2022	2023
Carbide Production and Consumption	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CO_2 Transport, Injection, and Geological Storage	0.0	0.0	+	+	0.1	0.1	0.1
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*	*332.0*	*294.7*	*302.0*	*304.4*	*300.5*
International Bunker Fuels[b]	*103.6*	*113.3*	*113.6*	*69.6*	*80.2*	*98.2*	*96.2*
CH_4[c]	**873.1**	**797.1**	**752.6**	**730.9**	**715.6**	**696.8**	**686.7**
Enteric Fermentation	183.1	188.2	197.3	196.3	196.5	192.6	187.1
Natural Gas Systems	219.6	210.7	189.0	180.1	174.6	172.8	162.4
Landfills	197.8	147.7	128.2	122.6	120.7	118.7	119.5
Manure Management	39.1	55.0	66.7	66.9	66.4	64.7	65.1
Coal Mining	108.1	71.5	53.0	46.2	44.7	43.6	45.4
Petroleum Systems	50.0	48.4	50.8	50.6	45.1	36.3	38.0
Wastewater Treatment	22.7	22.7	21.1	21.0	20.7	20.9	21.1
Rice Cultivation	18.9	20.6	15.6	18.6	18.5	18.0	18.7
Stationary Combustion	9.7	8.8	9.8	7.9	7.9	8.7	8.8
Abandoned Oil and Gas Wells	7.8	8.2	8.5	8.5	8.6	8.5	8.5
Abandoned Underground Coal Mines	8.1	7.4	6.6	6.5	6.2	6.1	6.1
Composting	0.4	2.1	2.5	2.6	2.6	2.6	2.6
Mobile Combustion	7.2	5.2	2.8	2.5	2.6	2.6	2.5
Field Burning of Agricultural Residues	0.5	0.6	0.7	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[c]	**407.8**	**424.8**	**416.4**	**391.4**	**398.4**	**387.5**	**387.0**
Agricultural Soil Management	289.1	294.7	316.4	293.0	298.9	291.8	296.3
Wastewater Treatment	14.8	18.1	21.1	21.8	21.3	21.1	20.8
Stationary Combustion	22.3	30.5	22.1	20.5	22.0	22.6	19.6
Manure Management	13.4	15.2	16.8	16.9	17.1	17.0	16.8
Mobile Combustion	37.8	42.0	18.7	16.0	16.8	16.6	16.2
Nitric Acid Production	10.8	10.1	8.9	8.3	7.9	8.6	8.3

Gas/Source	1990	2005	2019	2020	2021	2022	2023
N_2O from Product Uses	3.8	3.8	3.8	3.8	3.8	3.8	3.8
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	1.2	1.1	1.2	1.3	1.3
Adipic Acid Production	13.5	6.3	4.7	7.4	6.6	2.1	1.2
Incineration of Waste	0.4	0.3	0.4	0.3	0.4	0.3	0.3
Electronics Industry	+	0.1	0.2	0.3	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
Petroleum Systems	+	+	+	+	+	+	+
Natural Gas Systems	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.8*	*0.9*	*0.9*	*0.5*	*0.6*	*0.8*	*0.8*
HFCs	**47.8**	**125.0**	**175.8**	**177.8**	**184.3**	**189.5**	**191.0**
Substitution of Ozone Depleting Substances[d]	0.3	102.7	169.7	173.7	179.9	184.8	189.0
Fluorochemical Production	47.3	22.2	5.8	3.8	4.0	4.3	1.7
Electronics Industry	0.2	0.2	0.3	0.3	0.4	0.3	0.3
Magnesium Production and Processing	0.0	0.0	0.1	0.1	+	+	+
Other Product Manufacture and Use	0.0	0.0	0.0	+	0.0	0.0	0.0
PFCs	**39.7**	**10.3**	**7.3**	**6.6**	**6.3**	**6.5**	**5.8**
Fluorochemical Production	17.7	4.1	3.0	2.5	2.6	2.8	2.7
Electronics Industry	2.5	3.0	2.7	2.6	2.7	2.8	2.4
Aluminum Production	19.3	3.1	1.4	1.4	0.9	0.8	0.5
Other Product Manufacture and Use	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Substitution of Ozone Depleting Substances	0.0	+	+	+	+	+	+
Electrical Equipment	+	+	+	+	+	+	0.0
SF_6	**37.9**	**20.2**	**8.3**	**7.7**	**8.0**	**7.2**	**7.7**
Electrical Equipment	24.6	11.8	6.0	5.5	5.5	4.9	5.1
Magnesium Production and Processing	5.6	3.0	0.9	0.9	1.2	1.1	1.1
Other Product Manufacture and Use	1.3	1.3	0.6	0.5	0.4	0.5	0.8
Electronics Industry	0.5	0.8	0.8	0.8	0.9	0.8	0.7
Fluorochemical Production	5.8	3.3	+	+	+	+	+
NF_3	**0.2**	**1.0**	**1.1**	**1.3**	**1.1**	**1.1**	**0.8**
Electronics Industry	+	0.4	0.5	0.6	0.6	0.6	0.5
Fluorochemical Production	0.1	0.6	0.6	0.7	0.5	0.5	0.3
Other Product Manufacture and Use	+	+	+	+	+	+	0.0

Gas/Source	1990	2005	2019	2020	2021	2022	2023
Total Gross Emissions (Sources)	**6,538.3**	**7,505.3**	**6,597.4**	**6,005.7**	**6,333.8**	**6,344.1**	**6,197.3**
LULUCF Emissions[c]	**59.1**	**71.8**	**63.2**	**82.6**	**81.0**	**68.6**	**60.6**
CH_4	54.4	60.9	56.1	69.0	67.8	59.6	54.7
N_2O	4.7	10.9	7.0	13.7	13.1	9.0	5.9
LULUCF Carbon Stock Change[e]	**(1,096.9)**	**(1,040.7)**	**(982.6)**	**(1,034.2)**	**(1,043.8)**	**(973.9)**	**(1,000.5)**
LULUCF Sector Net Total[f]	**(1,037.9)**	**(968.9)**	**(919.4)**	**(951.6)**	**(962.9)**	**(905.3)**	**(939.9)**
Net Emissions (Sources and Sinks)	**5,500.4**	**6,536.4**	**5,678.0**	**5,054.2**	**5,371.0**	**5,438.7**	**5,257.4**

+ 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.

[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.

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

Gas/Source	1990	2005	2019	2020	2021	2022	2023
CO_2	**5,131,761**	**6,126,903**	**5,235,912**	**4,689,954**	**5,020,111**	**5,055,403**	**4,918,407**
Fossil Fuel Combustion	4,752,234	5,744,138	4,852,647	4,342,309	4,654,629	4,702,769	4,559,379
Transportation	*1,468,944*	*1,858,552*	*1,816,636*	*1,572,955*	*1,753,546*	*1,753,554*	*1,776,451*
Electric Power Sector	*1,819,951*	*2,400,057*	*1,606,721*	*1,439,566*	*1,540,933*	*1,531,678*	*1,414,177*
Industrial	*876,470*	*847,643*	*809,823*	*763,421*	*780,475*	*799,677*	*792,620*
Residential	*338,568*	*358,898*	*342,905*	*314,795*	*318,034*	*335,172*	*307,077*
Commercial	*228,293*	*227,130*	*251,749*	*229,264*	*237,528*	*259,182*	*244,161*
U.S. Territories	*20,010*	*51,857*	*24,813*	*22,308*	*24,114*	*23,506*	*24,893*
Non-Energy Use of Fuels	99,104	124,988	106,487	97,881	111,718	101,697	107,069
Iron and Steel Production & Metallurgical Coke Production	104,738	70,078	46,835	40,675	47,218	45,157	46,240
Cement Production	33,484	46,194	40,896	40,688	41,312	41,884	40,636
Natural Gas Systems	32,525	26,325	38,696	36,810	35,745	36,410	37,682
Petrochemical Production	20,075	26,882	28,483	27,926	30,656	28,788	30,540
Petroleum Systems	9,597	10,222	45,445	28,876	24,091	22,084	23,272
Incineration of Waste	12,900	13,254	12,948	12,921	12,476	12,484	12,425
Ammonia Production	14,404	10,234	12,388	12,335	11,458	11,945	12,211
Lime Production	11,700	14,552	12,112	11,299	11,870	12,208	11,548
Other Process Uses of Carbonates	7,103	8,472	8,973	9,012	8,583	10,383	7,163

Gas/Source	1990	2005	2019	2020	2021	2022	2023
Urea Consumption for Non-Agricultural Purposes	3,784	3,653	6,234	5,905	6,724	5,464	5,424
Liming	4,690	4,365	2,203	2,887	2,387	3,194	5,280
Urea Fertilization	2,417	3,504	4,950	5,031	5,105	5,193	5,258
Coal Mining	4,606	4,169	2,992	2,197	2,455	2,474	2,404
Non-EOR Carbon Dioxide Utilization	1,472	1,375	2,415	2,842	2,889	2,812	2,150
Glass Production	2,263	2,402	1,940	1,858	1,969	1,956	1,774
Soda Ash Production	1,431	1,655	1,792	1,461	1,714	1,704	1,723
Ferroalloy Production	2,152	1,392	1,598	1,377	1,426	1,327	1,245
Aluminum Production	6,831	4,142	1,880	1,748	1,541	1,446	1,237
Titanium Dioxide Production	1,195	1,755	1,340	1,340	1,541	1,541	1,233
Zinc Production	632	1,030	1,026	977	1,007	947	920
Phosphoric Acid Production	1,529	1,342	909	901	874	804	850
Lead Production	516	553	518	491	473	455	450
Carbide Production and Consumption	243	213	175	154	172	210	183
CO_2 Transport, Injection, and Geological Storage	0	0	18	39	65	53	98
Abandoned Oil and Gas Wells	7	7	8	8	8	8	8
Substitution of Ozone Depleting Substances	+	1	3	4	4	4	4
Magnesium Production and Processing	129	4	2	3	3	3	2
Biomass and Biodiesel Consumption[a]	*237,946*	*245,421*	*332,018*	*294,657*	*301,976*	*304,397*	*300,518*
International Bunker Fuels[b]	*103,634*	*113,328*	*113,632*	*69,638*	*80,180*	*98,241*	*96,160*
CH_4[c]	**31,183**	**28,468**	**26,877**	**26,102**	**25,558**	**24,884**	**24,524**
Enteric Fermentation	6,539	6,722	7,045	7,010	7,017	6,878	6,683
Natural Gas Systems	7,842	7,525	6,751	6,431	6,236	6,173	5,802
Landfills	7,063	5,275	4,578	4,379	4,310	4,238	4,266
Manure Management	1,398	1,964	2,382	2,390	2,373	2,312	2,326
Coal Mining	3,860	2,552	1,892	1,648	1,595	1,558	1,623
Petroleum Systems	1,787	1,730	1,813	1,807	1,611	1,295	1,358
Wastewater Treatment	811	809	755	748	738	747	755
Rice Cultivation	677	735	558	664	661	642	667
Stationary Combustion	345	313	349	282	284	312	313
Abandoned Oil and Gas Wells	279	294	302	303	306	303	303
Abandoned Underground Coal Mines	288	264	237	232	221	218	219
Composting	15	75	91	92	92	92	93
Mobile Combustion	258	187	101	90	91	92	91
Field Burning of Agricultural Residues	19	23	23	22	22	22	22
Anaerobic Digestion at Biogas Facilities	+	+	1	1	1	1	1
Carbide Production and Consumption	1	+	+	+	+	+	+

Gas/Source	1990	2005	2019	2020	2021	2022	2023
Ferroalloy Production	1	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	1	1	+	+	+	+	+
Petrochemical Production	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*7*	*5*	*4*	*3*	*3*	*3*	*3*
N_2O[c]	**1,539**	**1,603**	**1,571**	**1,477**	**1,503**	**1,462**	**1,460**
Agricultural Soil Management	1,091	1,112	1,194	1,106	1,128	1,101	1,118
Wastewater Treatment	56	68	80	82	80	80	79
Stationary Combustion	84	115	84	77	83	85	74
Manure Management	50	57	63	64	65	64	63
Mobile Combustion	143	158	71	60	64	63	61
Nitric Acid Production	41	38	34	31	30	33	32
N_2O from Product Uses	14	14	14	14	14	14	14
Composting	1	6	7	7	7	7	7
Caprolactam, Glyoxal, and Glyoxylic Acid Production	6	7	5	4	5	5	5
Adipic Acid Production	51	24	18	28	25	8	4
Incineration of Waste	2	1	1	1	1	1	1
Electronics Industry	+	+	1	1	1	1	1
Field Burning of Agricultural Residues	1	1	1	1	1	1	1
Petroleum Systems	+	+	+	+	+	+	+
Natural Gas Systems	+	+	+	+	+	+	+
International Bunker Fuels[b]	*3*	*3*	*3*	*2*	*2*	*3*	*3*
HFCs	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Substitution of Ozone Depleting Substances[d]	M	M	M	M	M	M	M
Fluorochemical Production	M	M	M	M	M	M	M
Electronics Industry	M	M	M	M	M	M	M
Magnesium Production and Processing	0	0	+	+	+	+	+
Other Product Manufacture and Use	0	0	0	+	0	0	0
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	M	M	M	M	M	M	M
Substitution of Ozone Depleting Substances	+	+	+	+	+	+	+
Electrical Equipment	+	+	+	+	+	+	0
SF_6	**1**	**1**	**+**	**+**	**+**	**+**	**+**
Electrical Equipment	1	1	+	+	+	+	+
Magnesium Production and Processing	+	+	+	+	+	+	+

Gas/Source	1990	2005	2019	2020	2021	2022	2023
SF_6 and PFCs from Other Product Use	+	+	+	+	+	+	+
Electronics Industry	+	+	+	+	+	+	+
Fluorochemical Production	+	+	+	+	+	+	+
NF_3	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Electronics Industry	+	+	+	+	+	+	+
Fluorochemical Production	+	+	+	+	+	+	+
Other Product Manufacture and Use	+	+	+	+	+	+	0

+ Does not exceed 0.5 kt.
M (Mixture of multiple gases)
[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 Inventory 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 national inventory 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 34-year period of 1990 to 2023, total emissions from the Energy and Waste sectors decreased by 6.2 percent (331.6 MMT CO_2 Eq.) and 29.7 percent (70.1 MMT CO_2 Eq.), respectively. Emissions from Industrial Processes and Product Use and Agriculture grew by 4.6 percent (16.8 MMT CO_2 Eq.) and 8.0 percent (43.9 MMT CO_2 Eq.), respectively. Over the same period, total carbon sequestration in the LULUCF sector decreased by 8.8 percent (96.4 MMT CO_2), and emissions from the LULUCF sector increased by 2.6 percent (1.5 MMT CO_2 Eq.). The overall net flux from LULUCF (i.e., the net sum of all CH_4 and N_2O emissions to the atmosphere plus LULUCF net carbon stock changes in units of MMT CO_2 Eq.) decreased by 9.4 percent (97.9 MMT CO_2 Eq.) from 1990 levels.

Figure 2-4: U.S. Greenhouse Gas Emissions and Removals by Inventory Sector

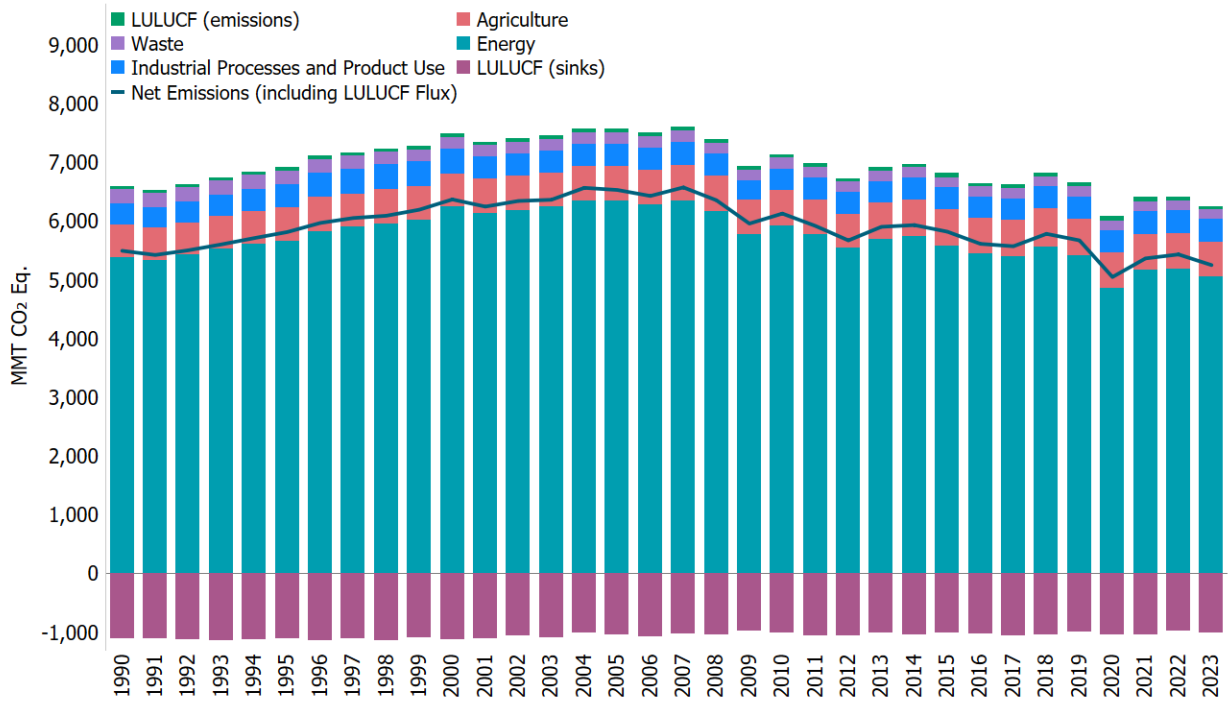


Table 2-3: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Inventory Sector/Category (MMT CO_2 Eq.)

Inventory Sector/Category	1990	2005	2019	2020	2021	2022	2023
Energy	**5,381.9**	**6,356.2**	**5,420.9**	**4,860.2**	**5,170.1**	**5,196.2**	**5,050.4**
Fossil Fuel Combustion	4,752.2	5,744.1	4,852.6	4,342.3	4,654.6	4,702.8	4,559.4
Natural Gas Systems	252.1	237.0	227.7	216.9	210.4	209.3	200.1
Non-Energy Use of Fuels	99.1	125.0	106.5	97.9	111.7	101.7	107.1
Petroleum Systems	59.6	58.7	96.2	79.5	69.2	58.4	61.3
Coal Mining	112.7	75.6	56.0	48.3	47.1	46.1	47.8
Stationary Combustion	32.0	39.3	31.9	28.4	30.0	31.3	28.3
Mobile Combustion	45.0	47.2	21.5	18.5	19.4	19.2	18.8
Incineration of Waste	13.3	13.6	13.3	13.3	12.8	12.8	12.8
Abandoned Oil and Gas Wells	7.8	8.2	8.5	8.5	8.6	8.5	8.5
Abandoned Underground Coal Mines	8.1	7.4	6.6	6.5	6.2	6.1	6.1
CO_2 Transport, Injection, and Geological Storage	0	0	+	+	0.1	0.1	0.1
Biomass and Biodiesel Consumption[b]	*237.9*	*245.4*	*332.0*	*294.7*	*302.0*	*304.4*	*300.5*
International Bunker Fuels[c]	*104.6*	*114.3*	*114.6*	*70.3*	*80.9*	*99.1*	*97.0*
Industrial Processes and Product Use	**368.9**	**374.7**	**380.8**	**375.3**	**390.9**	**389.6**	**385.7**
Substitution of Ozone Depleting Substances	0.3	102.7	169.7	173.7	179.9	184.9	189.0
Iron and Steel Production & Metallurgical Coke Production	104.8	70.1	46.8	40.7	47.2	45.2	46.2
Cement Production	33.5	46.2	40.9	40.7	41.3	41.9	40.6
Petrochemical Production	20.1	26.9	28.5	27.9	30.7	28.8	30.5
Ammonia Production	14.4	10.2	12.4	12.3	11.5	11.9	12.2

Inventory Sector/Category	1990	2005	2019	2020	2021	2022	2023
Lime Production	11.7	14.6	12.1	11.3	11.9	12.2	11.5
Nitric Acid Production	10.8	10.1	8.9	8.3	7.9	8.6	8.3
Other Process Uses of Carbonates	7.1	8.5	9.0	9.0	8.6	10.4	7.2
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	6.2	5.9	6.7	5.5	5.4
Electrical Equipment	24.6	11.8	6.0	5.5	5.5	4.9	5.1
Fluorochemical Production	71.0	30.0	9.3	7.0	7.1	7.6	4.7
Electronics Industry	3.3	4.5	4.5	4.5	4.9	4.8	4.2
N_2O from Product Uses	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Non-EOR Carbon Dioxide Utilization	1.5	1.4	2.4	2.8	2.9	2.8	2.1
Glass Production	2.3	2.4	1.9	1.9	2.0	2.0	1.8
Soda Ash Production	1.4	1.7	1.8	1.5	1.7	1.7	1.7
Aluminum Production	26.1	7.2	3.3	3.2	2.5	2.2	1.7
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.5	1.9	1.2	1.1	1.2	1.3	1.3
Ferroalloy Production	2.2	1.4	1.6	1.4	1.4	1.3	1.3
Titanium Dioxide Production	1.2	1.8	1.3	1.3	1.5	1.5	1.2
Adipic Acid Production	13.5	6.3	4.7	7.4	6.6	2.1	1.2
Magnesium Production and Processing	5.7	3.0	1.0	0.9	1.2	1.1	1.1
Other Product Manufacture and Use	1.5	1.5	0.8	0.7	0.5	0.6	1.0
Zinc Production	0.6	1.0	1.0	1.0	1.0	0.9	0.9
Phosphoric Acid Production	1.5	1.3	0.9	0.9	0.9	0.8	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5
Carbide Production and Consumption	0.3	0.2	0.2	0.2	0.2	0.2	0.2
Agriculture	**551.5**	**582.5**	**620.8**	**600.4**	**605.8**	**593.3**	**595.4**
Agricultural Soil Management	289.1	294.7	316.4	293.0	298.9	291.8	296.3
Enteric Fermentation	183.1	188.2	197.3	196.3	196.5	192.6	187.1
Manure Management	52.5	70.2	83.5	83.8	83.6	81.7	81.9
Rice Cultivation	18.9	20.6	15.6	18.6	18.5	18.0	18.7
Liming	4.7	4.4	2.2	2.9	2.4	3.2	5.3
Urea Fertilization	2.4	3.5	4.9	5.0	5.1	5.2	5.3
Field Burning of Agricultural Residues	0.7	0.8	0.9	0.8	0.8	0.8	0.8
Waste	**235.9**	**192.0**	**174.8**	**169.7**	**167.0**	**165.1**	**165.8**
Landfills	197.8	147.7	128.2	122.6	120.7	118.7	119.5
Wastewater Treatment	37.5	40.7	42.3	42.7	41.9	42.0	41.9
Composting	0.7	3.6	4.3	4.4	4.4	4.4	4.4
Anaerobic Digestion at Biogas Facilities	+	+	+	+	+	+	+
Total Gross Emissions[e] (Sources)	**6,538.3**	**7,505.3**	**6,597.4**	**6,005.7**	**6,333.8**	**6,344.1**	**6,197.3**
LULUCF Sector Net Total[f]	**(1,037.9)**	**(968.9)**	**(919.4)**	**(951.6)**	**(962.9)**	**(905.3)**	**(939.9)**
Forest land	(1,152.9)	(1,036.3)	(971.3)	(1,001.9)	(984.9)	(931.5)	(977.1)
Cropland	49.6	4.4	12.1	20.5	3.0	3.5	5.0
Grassland	59.8	46.4	49.4	40.9	31.1	34.6	43.6
Wetlands	45.3	42.8	40.4	40.4	40.3	40.4	40.4
Settlements	(39.5)	(26.2)	(50.0)	(51.4)	(52.4)	(52.3)	(51.9)
Net Emissions (Sources and Sinks)[g]	**5,500.4**	**6,536.4**	**5,678.0**	**5,054.2**	**5,371.0**	**5,438.7**	**5,257.4**

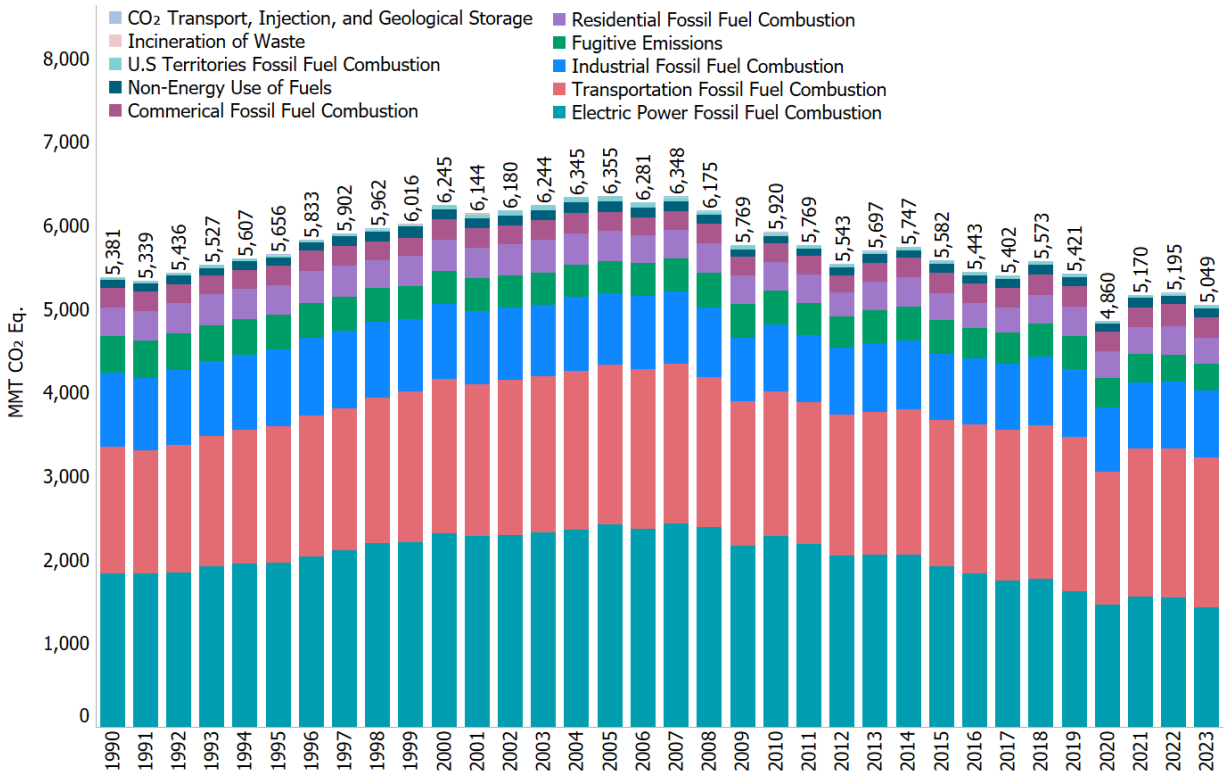
+ Does not exceed 0.05 MMT CO_2 Eq.

[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] SF_6 and PFCs from other product use category includes the use of HFCs and NF_3.
[e] Total emissions without LULUCF.
[f] 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.
[g] 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) emissions associated with fuel use (i.e., fossil fuel combustion, non-energy use of fossil fuels and waste incineration), 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 2023. 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).

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



In 2023, 82.6 percent of the energy used in the United States on a Btu basis was produced through the combustion of fossil fuels. The remaining 17.4 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 (39.6 percent and 9.3 percent of gross total U.S. emissions of each gas, respectively).[1] Table 2-4 presents greenhouse gas emissions from the Energy sector by source and gas.

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

Gas/Source	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
CO_2	**4,911.0**	**5,923.1**	**5,059.2**	**4,521.0**	**4,841.2**	**4,878.0**	**4,742.3**	**-3%**
Fossil Fuel Combustion	4,752.2	5,744.1	4,852.6	4,342.3	4,654.6	4,702.8	4,559.4	-4%
Transportation	*1,468.9*	*1,858.6*	*1,816.6*	*1,573.0*	*1,753.5*	*1,753.6*	*1,776.5*	*21%*
Electricity Generation	*1,820.0*	*2,400.1*	*1,606.7*	*1,439.6*	*1,540.9*	*1,531.7*	*1,414.2*	*-22%*
Industrial	*876.5*	*847.6*	*809.8*	*763.4*	*780.5*	*799.7*	*792.6*	*-10%*
Residential	*338.6*	*358.9*	*342.9*	*314.8*	*318.0*	*335.2*	*307.1*	*-9%*
Commercial	*228.3*	*227.1*	*251.7*	*229.3*	*237.5*	*259.2*	*244.2*	*7%*
U.S. Territories	*20.0*	*51.9*	*24.8*	*22.3*	*24.1*	*23.5*	*24.9*	*24%*
Non-Energy Use of Fuels	99.1	125.0	106.5	97.9	111.7	101.7	107.1	8%
Natural Gas Systems	32.5	26.3	38.7	36.8	35.7	36.4	37.7	16%
Petroleum Systems	9.6	10.2	45.4	28.9	24.1	22.1	23.3	142%
Incineration of Waste	12.9	13.3	12.9	12.9	12.5	12.5	12.4	-4%
Coal Mining	4.6	4.2	3.0	2.2	2.5	2.5	2.4	-48%
CO_2 Transport, Injection, and Geological Storage	0.0	0.0	+	+	0.1	0.1	0.1	100%
Abandoned Oil and Gas Wells	+	+	+	+	+	+	+	13%
Biomass-Wood[a]	*215.2*	*206.9*	*216.7*	*189.5*	*191.5*	*194.3*	*187.7*	*-13%*
International Bunker Fuels[a]	*103.6*	*113.3*	*113.6*	*69.6*	*80.2*	*98.2*	*96.2*	*-7%*
Biofuels-Ethanol[a]	*4.2*	*22.9*	*82.6*	*71.8*	*79.1*	*79.6*	*80.7*	*1,810%*
Biofuels-Biodiesel[a]	*0.0*	*0.9*	*17.1*	*17.7*	*16.1*	*15.6*	*18.2*	*100%*
Biofuels-MSW[a]	*18.5*	*14.7*	*15.7*	*15.6*	*15.3*	*14.9*	*13.9*	*-25%*
CH_4	**410.4**	**360.2**	**320.4**	**302.3**	**289.6**	**278.7**	**271.9**	**-34%**
Natural Gas Systems	219.6	210.7	189.0	180.1	174.6	172.8	162.4	-26%
Coal Mining	108.1	71.5	53.0	46.2	44.7	43.6	45.4	-58%
Petroleum Systems	50.0	48.4	50.8	50.6	45.1	36.3	38.0	-24%
Stationary Combustion	9.7	8.8	9.8	7.9	7.9	8.7	8.8	-9%
Abandoned Oil and Gas Wells	7.8	8.2	8.5	8.5	8.6	8.5	8.5	9%

[1] The contribution of energy non-CO_2 emissions is based on gross totals, so it 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 36.6 percent and 9.2 percent, respectively.

[2] The full time series data is in CSV format available at https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Gas/Source	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
Abandoned Underground Coal Mines	8.1	7.4	6.6	6.5	6.2	6.1	6.1	-24%
Mobile Combustion	7.2	5.2	2.8	2.5	2.6	2.6	2.5	-65%
Incineration of Waste	+	+	+	+	+	+	+	-19%
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*-55%*
N_2O	**60.53**	**72.87**	**41.26**	**36.91**	**39.25**	**39.55**	**36.17**	**-40%**
Stationary Combustion	22.3	30.5	22.1	20.5	22.0	22.6	19.6	-12%
Mobile Combustion	37.8	42.0	18.7	16.0	16.8	16.6	16.2	-57%
Incineration of Waste	0.4	0.3	0.4	0.3	0.4	0.3	0.3	-19%
Natural Gas Systems	+	+	+	+	+	+	+	57%
Petroleum Systems	+	+	+	+	+	+	+	73%
International Bunker Fuels[b]	*0.8*	*0.9*	*0.9*	*0.5*	*0.6*	*0.8*	*0.8*	*0%*
Total	**5,381.9**	**6,356.2**	**5,420.9**	**4,860.2**	**5,170.1**	**5,196.2**	**5,050.4**	**-6%**

+ 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* and the national inventory reporting guidelines.

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 73.6 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 2023. 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 4.1 percent (192.9 MMT CO_2 Eq.) from 1990 to 2023 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 20.6 percent (1,184.8 MMT CO_2 Eq.) since 2005. From 2022 to 2023, these emissions decreased by 3.0 percent (143.4 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-21 in Annex 2.1 for more detail on the carbon content coefficient of different fossil fuels).

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 (including bunker fuels) increased by 1.2 percent from 2022 to 2023. Fuel economy of light-duty vehicles is an important factor in transportation sector CO_2 emissions trends. 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 vehicle miles traveled (VMT) by light-duty vehicles grew only modestly for much of the period, slowing 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.[3]

- *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.)

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

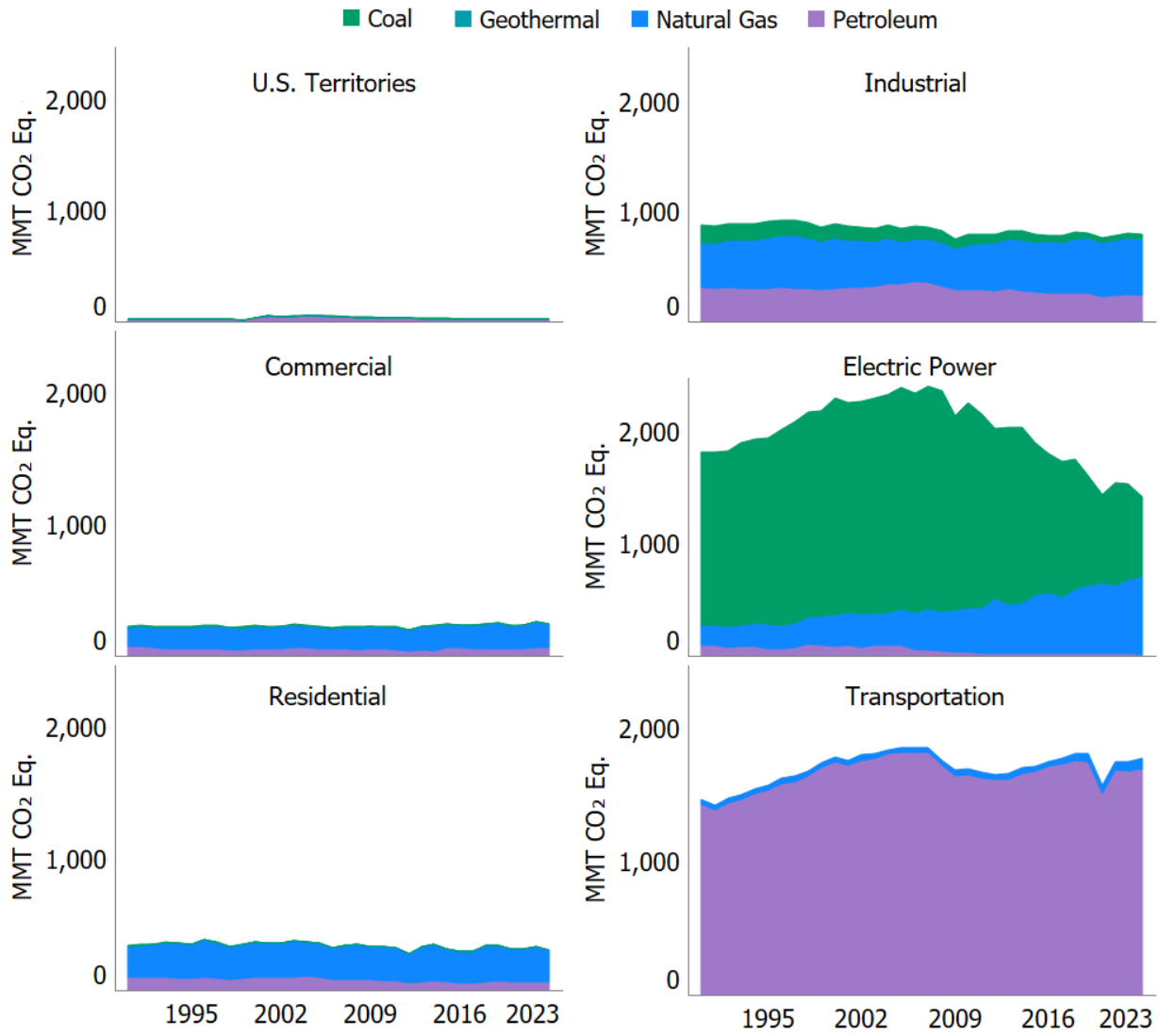
Table 2-5: CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector (MMT CO_2 Eq.)

End-Use Sector	1990	2005	2019	2020	2021	2022	2023
Transportation	**1,472.0**	**1,863.3**	**1,820.9**	**1,576.4**	**1,757.5**	**1,758.0**	**1,781.5**
Combustion	1,468.9	1,858.6	1,816.6	1,573.0	1,753.5	1,753.6	1,776.5
Electricity	3.0	4.7	4.2	3.5	4.0	4.5	5.0
Industrial	**1,562.9**	**1,584.0**	**1,275.3**	**1,173.1**	**1,225.7**	**1,236.9**	**1,197.1**
Combustion	876.5	847.6	809.8	763.4	780.5	799.7	792.6
Electricity	686.4	736.3	465.5	409.7	445.2	437.2	404.5
Residential	**931.3**	**1,214.9**	**927.1**	**860.7**	**891.1**	**901.6**	**815.6**
Combustion	338.6	358.9	342.9	314.8	318.0	335.2	307.1
Electricity	592.7	856.0	584.2	545.9	573.0	566.5	508.5
Commercial	**766.0**	**1,030.1**	**804.5**	**709.7**	**756.2**	**782.7**	**740.3**
Combustion	228.3	227.1	251.7	229.3	237.5	259.2	244.2
Electricity	537.7	803.0	552.7	480.5	518.7	523.5	496.1
U.S. Territories [a]	**20.0**	**51.9**	**24.8**	**22.3**	**24.1**	**23.5**	**24.9**
Total	**4,752.2**	**5,744.1**	**4,852.6**	**4,342.3**	**4,654.6**	**4,702.8**	**4,559.4**
Electric Power	**1,820.0**	**2,400.1**	**1,606.7**	**1,439.6**	**1,540.9**	**1,531.7**	**1,414.2**

[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.

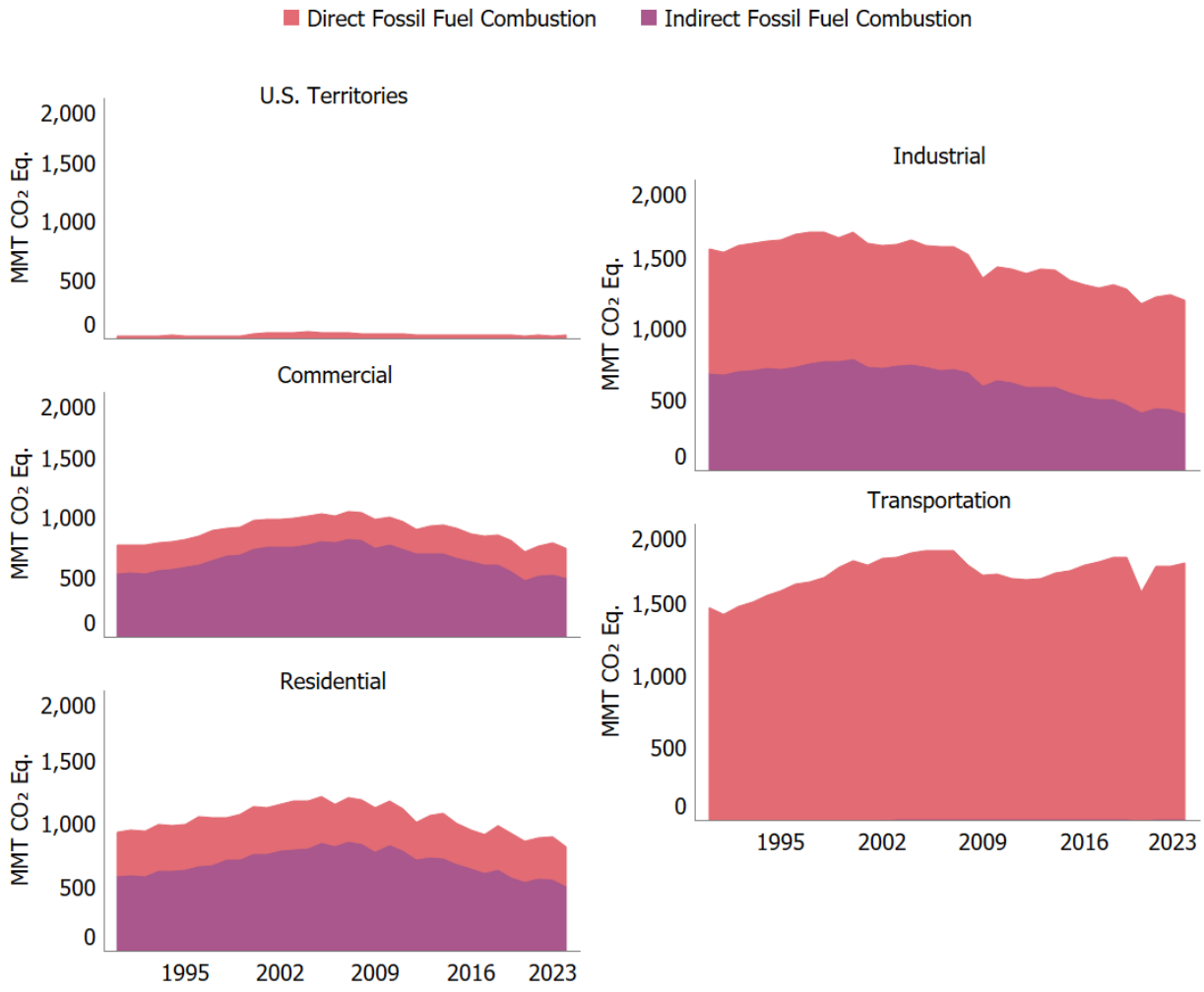
Notes: Combustion-related emissions from electric power are allocated based on aggregate national electricity use by each end-use sector. Totals may not sum due to independent rounding.

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



Notes: 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.

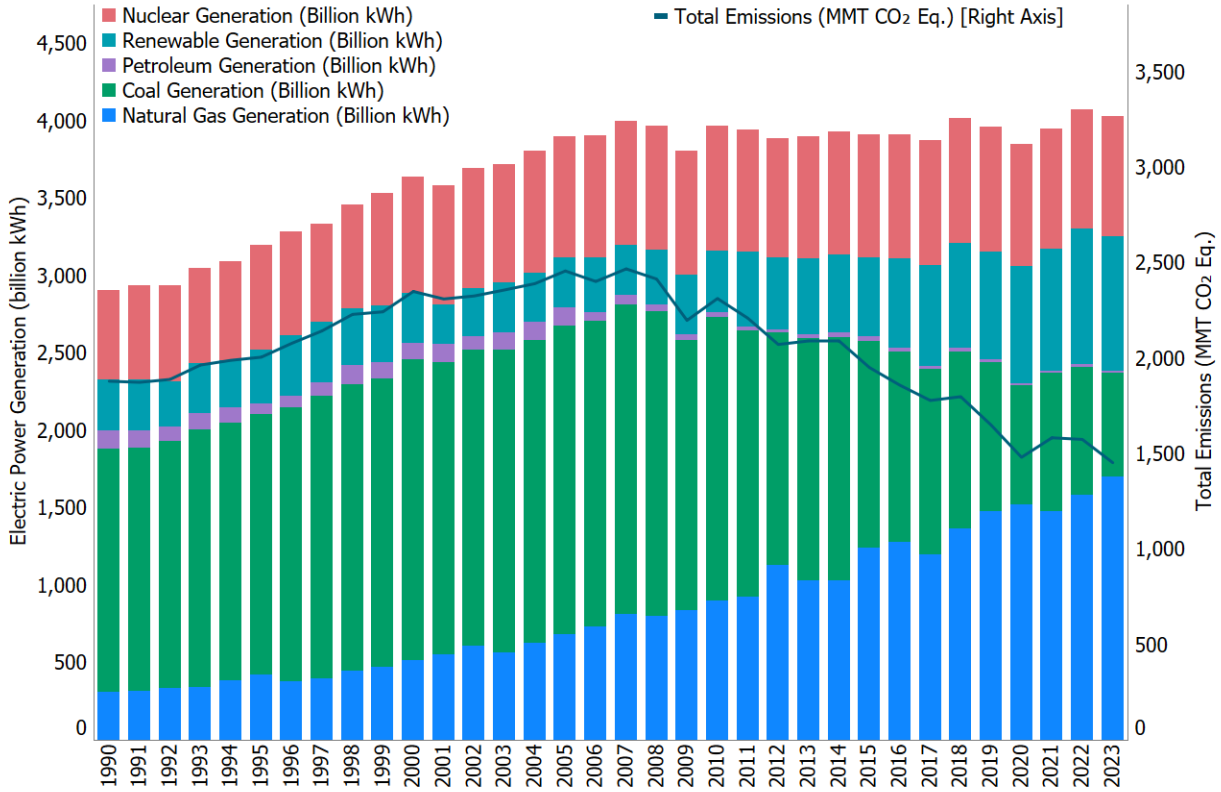
Figure 2-7: Trends in End-Use Sector Emissions of CO_2 from Fossil Fuel Combustion



Electric power was the second largest end-use emitter of CO_2 in 2023 (surpassed by transportation in 2017); electric power generators used 29.9 percent of U.S. energy from fossil fuels and emitted 31.0 percent of the CO_2 from fossil fuel combustion in 2023. CO_2 emissions from fossil fuel combustion in the electric power sector decreased by 7.7 percent between 2022 and 2023 due to changes in the mix of electric generation resources. Between 2022 and 2023 total electricity generation decreased by 1.1 percent, electricity generation from coal decreased by 18.8 percent, electricity generation from natural gas increased by 7.4 percent, and electricity generation from renewables decreased by 0.4 percent. 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 22.3 percent since 1990, and the carbon intensity of the electric power sector, in terms of CO_2 Eq. per QBtu input, has decreased by 21.8 percent during that same timeframe. This trend is shown below in Figure 2-8. Overall CO_2 emissions from electric power generation in 2023 decreased by 41 percent from a high in 2007 (see Figure 2-6, 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 for electric power generation gradually increased between 1990 and 2007, then began to decrease at a faster rate from 2008 to 2023. Carbon dioxide

emissions from natural gas combustion for electric power generation steadily increased between 1990 and 2023.

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 1,781.5 MMT CO_2 Eq. in 2023 or 39.1 percent of total CO_2 emissions from fossil fuel combustion, a 1.3 percent increase since 2022. The industrial end-use sector accounted for 26.3 percent of CO_2 emissions from fossil fuel combustion when including allocated electricity emissions, a decrease of 3.2 percent since 2022. From 2022 to 2023, total electricity use in the industrial sector decreased by 1.2 percent due to a decrease in total industrial production and manufacturing output. The residential and commercial end-use sectors accounted for 17.9 and 16.2 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 building-related energy needs, with electricity use for lighting, heating, air conditioning, and operating appliances contributing 62.3 and 67.0 percent of emissions from the residential and commercial end-use sectors, respectively. From 2022 to 2023, a decrease in heating degree days (10.4 percent) decreased energy demand for heating in the residential and commercial sectors; also, a 5.2 percent decrease in cooling degree days compared to 2022 decreased demand for air conditioning in the residential and commercial sectors. Total CO_2 emissions from the residential and commercial end-use sectors when including allocated electricity emissions decreased by 9.5 and 5.4 percent since 2022, respectively.

Other Energy Sector Trends

Energy sector emissions decreased by 2.8 percent since 2022 and decreased by 6.2 percent since 1990. Other notable trends in emissions from energy source categories (Figure 2-6 and Figure 2-7) over the 34-year period from 1990 through 2023 included the following:

- Emissions (CH_4, CO_2, and N_2O) from oil and gas systems decreased by 16.1 percent (50.3 MMT CO_2 Eq.) since 1990 and decreased by 2.3 percent (6.2 MMT CO_2 Eq.) from 2022 to 2023. Natural gas systems CH_4 emissions have decreased by 26.0 percent (57.1 MMT CO_2 Eq.) since 1990, due to a decrease in emissions from distribution, transmission and storage, and processing. 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 decreased due to increased gathering and boosting emissions. Between 2022 and 2023, methane emissions from natural gas systems decreased 6.0 percent, due to a decrease in emissions from production segment pneumatic controllers. Petroleum systems CH_4 emissions decreased by 24.0 percent (12.0 MMT CO_2 Eq.) since 1990 and increased 4.9 percent between 2022 and 2023. This increase 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 44.7 percent (18.8 MMT CO_2) from 1990 to 2023 and increased by 4.2 percent between 2022 and 2023. 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.
- Methane emissions from coal mining decreased by 58.0 percent (62.6 MMT CO_2 Eq.) from 1990 through 2023 primarily due to a decrease in the number of active mines and annual coal production over the time period. Methane emissions from coal mining increased 4.1 percent between 2022 and 2023. The number of mines increased, but overall coal production has decreased.
- Nitrous oxide emissions from mobile combustion decreased by 57.0 percent (21.5 MMT CO_2 Eq.) from 1990 through 2023 and by 2.1 percent (0.4 MMT CO_2 Eq.) between 2022 and 2023, 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 2023, accounting for 5.1 percent of N_2O emissions and 0.4 percent of total gross U.S. greenhouse gas emissions in 2023. Stationary combustion emissions peaked in 2007 and have steadily decreased since then.
- Carbon dioxide emissions from non-energy uses of fossil fuels increased by 8.0 percent (8.0 MMT CO_2 Eq.) from 1990 through 2023 and 5.3 percent (5.4 MMT CO_2 Eq.) between 2022 and 2023. Emissions from non-energy uses of fossil fuels were 107.1 MMT CO_2 Eq. in 2023, which constituted 2.2 percent of total national CO_2 emissions, approximately the same proportion as in 1990.

- Carbon dioxide emissions from incineration of waste decreased by 3.7 percent (0.5 MMT CO_2 Eq.) from 1990 through 2023, as the volume of scrap tires and other fossil carbon-containing materials in waste decreased.

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 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) sector accounted for 6.2 percent of U.S. greenhouse gas emissions in 2023. Emissions from the IPPU sector increased by 4.6 percent from 1990 to 2023. The use of HFCs as substitutes for ODS is the largest source of emissions in this sector, contributing 49.0 percent of IPPU emissions in 2023 and driving growth since 1990. From 2022 to 2023, total emissions from IPPU decreased 1.0 percent. Emissions from ferroalloy production decreased 6.2 percent, while emissions from electrical equipment and petrochemical production increased 4.5 percent and 6.1 percent, respectively. Zinc production emissions decreased by 2.9 percent, and electronics industry emissions decreased by 12.5 percent. 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

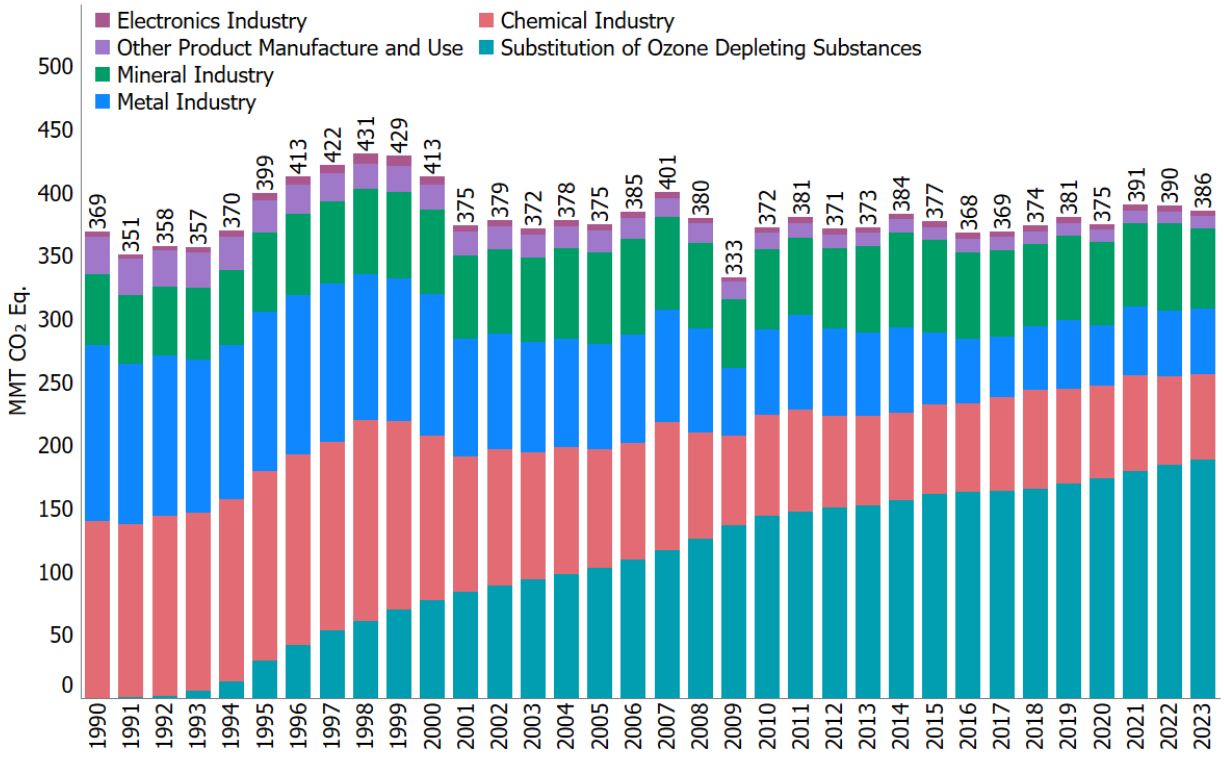


Table 2-6: Emissions from Industrial Processes and Product Use (MMT CO_2 Eq.)

	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
CO_2	**213.7**	**195.9**	**169.5**	**161.0**	**171.4**	**169.0**	**165.5**	**-22.5%**
Iron and Steel Production & Metallurgical Coke Production	104.7	70.1	46.8	40.7	47.2	45.2	46.2	-55.9%
Iron and Steel Production	*99.1*	*66.2*	*43.8*	*38.3*	*44.0*	*42.2*	*43.3*	*-56.4%*
Metallurgical Coke Production	*5.6*	*3.9*	*3.0*	*2.3*	*3.2*	*3.0*	*3.0*	*-46.7%*
Cement Production	33.5	46.2	40.9	40.7	41.3	41.9	40.6	21.4%
Petrochemical Production	20.1	26.9	28.5	27.9	30.7	28.8	30.5	52.1%
Ammonia Production	14.4	10.2	12.4	12.3	11.5	11.9	12.2	-15.2%
Lime Production	11.7	14.6	12.1	11.3	11.9	12.2	11.5	-1.3%
Other Process Uses of Carbonates	7.1	8.5	9.0	9.0	8.6	10.4	7.2	0.9%
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	6.2	5.9	6.7	5.5	5.4	43.3%
Non-EOR Carbon Dioxide Utilization	1.5	1.4	2.4	2.8	2.9	2.8	2.1	46.0%
Glass Production	2.3	2.4	1.9	1.9	2.0	2.0	1.8	-21.6%
Soda Ash Production	1.4	1.7	1.8	1.5	1.7	1.7	1.7	20.4%
Ferroalloy Production	2.2	1.4	1.6	1.4	1.4	1.3	1.2	-42.1%

	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
Aluminum Production	6.8	4.1	1.9	1.7	1.5	1.4	1.2	-81.9%
Titanium Dioxide Production	1.2	1.8	1.3	1.3	1.5	1.5	1.2	3.1%
Zinc Production	0.6	1.0	1.0	1.0	1.0	0.9	0.9	45.6%
Phosphoric Acid Production	1.5	1.3	0.9	0.9	0.9	0.8	0.9	-44.4%
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5	-12.8%
Carbide Production and Consumption	0.2	0.2	0.2	0.2	0.2	0.2	0.2	-24.7%
Substitution of Ozone Depleting Substances[a]	+	+	+	+	+	+	+	30,504.1%
Magnesium Production and Processing	0.1	+	+	+	+	+	+	-98.2%
CH_4	**0.1**	**+**	**+**	**+**	**+**	**+**	**+**	**-48.6%**
Carbide Production and Consumption	+	+	+	+	+	+	+	-38.5%
Ferroalloy Production	+	+	+	+	+	+	+	-48.6%
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+	-66.8%
Petrochemical Production	+	+	+	+	+	+	+	-11.9%
N_2O	**29.6**	**22.2**	**18.7**	**20.8**	**19.7**	**16.1**	**14.9**	**-49.8%**
Nitric Acid Production	10.8	10.1	8.9	8.3	7.9	8.6	8.3	-22.6%
N_2O from Product Uses	3.8	3.8	3.8	3.8	3.8	3.8	3.8	-0.4%
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.5	1.9	1.2	1.1	1.2	1.3	1.3	-10.5%
Adipic Acid Production	13.5	6.3	4.7	7.4	6.6	2.1	1.2	-91.5%
Electronics Industry	+	0.1	0.2	0.3	0.3	0.3	0.3	665.8%
HFCs	**47.8**	**125.0**	**175.8**	**177.8**	**184.3**	**189.5**	**191.0**	**299.8%**
Substitution of Ozone Depleting Substances[a]	0.3	102.7	169.7	173.7	179.9	184.8	189.0	74,673.9%
Fluorochemical Production	47.3	22.2	5.8	3.8	4.0	4.3	1.7	-96.5%
Electronics Industry	0.2	0.2	0.3	0.3	0.4	0.3	0.3	54.8%
Magnesium Production and Processing	0.0	0.0	0.1	0.1	+	+	+	100.0%
Other Product Manufacture and Use	0.0	0.0	0.0	+	0.0	0.0	0.0	0.0%
PFCs	**39.7**	**10.3**	**7.3**	**6.6**	**6.3**	**6.5**	**5.8**	**-85.5%**
Fluorochemical Production	17.7	4.1	3.0	2.5	2.6	2.8	2.7	-84.8%
Electronics Industry	2.5	3.0	2.7	2.6	2.7	2.8	2.4	-4.3%
Aluminum Production	19.3	3.1	1.4	1.4	0.9	0.8	0.5	-97.6%
Other Product Manufacture and Use	0.1	0.1	0.1	0.1	0.1	0.1	0.2	22.5%
Substitution of Ozone Depleting Substances	0.0	+	+	+	+	+	+	100.0%
Electrical Equipment	+	+	+	+	+	+	0.0	-100.0%

	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
SF_6	**37.9**	**20.2**	**8.3**	**7.7**	**8.0**	**7.2**	**7.7**	**-79.6%**
Electrical Equipment	24.6	11.8	6.0	5.5	5.5	4.9	5.1	-79.4%
Magnesium Production and Processing	5.6	3.0	0.9	0.9	1.2	1.1	1.1	-80.0%
Other Product Manufacture and Use	1.3	1.3	0.6	0.5	0.4	0.5	0.8	-38.3%
Electronics Industry	0.5	0.8	0.8	0.8	0.9	0.8	0.7	40.6%
Fluorochemical Production	5.8	3.3	+	+	+	+	+	-100.0%
NF_3	**0.2**	**1.0**	**1.1**	**1.3**	**1.1**	**1.1**	**0.8**	**335.8%**
Fluorochemical Production	0.1	0.6	0.6	0.7	0.5	0.5	0.3	117.6%
Electronics Industry	+	0.4	0.5	0.6	0.6	0.6	0.5	1,034.7%
Other Product Manufacture and Use	+	+	+	+	+	+	+	0.0%
Total	**368.9**	**374.7**	**380.8**	**375.3**	**390.9**	**389.6**	**385.7**	**4.6%**

+ Does not exceed 0.05 MMT CO_2 Eq.

[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 decreased 1.0 percent since 2022 but have increased 4.6 percent since 1990. Some significant trends in U.S. emissions from IPPU source categories over the 34-year period from 1990 through 2023 included the following:

- HFC and PFC emissions resulting from the substitution of ODS (e.g., chlorofluorocarbons [CFCs]) increased from small amounts in 1990 to 189.0 MMT CO_2 Eq. in 2023 (an increase of 74,680 percent).
- Combined CO_2 and CH_4 emissions from iron and steel production and metallurgical coke production increased by 2.4 percent from 2022 to 2023 to 46.2 MMT CO_2 Eq. and declined by 55.9 percent (58.5 MMT CO_2 Eq.) from 1990 through 2023, 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 52.1 percent between 1990 and 2023, from 20.1 MMT CO_2 Eq. to 30.5 MMT CO_2 Eq. The increase in emissions is largely driven by the production of ethylene more than doubling over that period.
- Carbon dioxide emissions from ammonia production have decreased by 15.2 percent (2.2 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 21.4 percent (7.2 MMT CO_2 Eq.) from 1990 through 2023. Emissions 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 29.2 percent.
- HFC, PFC, SF_6, and NF_3 emissions from fluorochemical production decreased by 93.4 percent (66.4 MMT CO_2 Eq.) from 1990 to 2023 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 97.6 percent (18.8 MMT CO_2 Eq.) from 1990 to 2023, 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 2023 due to a sharp increase in the price of SF_6 during the 1990s and industry emission reduction efforts.
- HFC, PFC, SF_6, and NF_3 emissions from use in electronics increased 27.2 percent (0.9 MMT CO_2 Eq.) from 1990 to 2023. Industrial growth, increasing chip complexity, and the adoption of emissions reductions technologies contributed to the fluctuation in electronics industry emissions.

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.[4] Carbon stock changes from agricultural soils are included in the LULUCF sector.

In 2023, agricultural activities were responsible for emissions of 595.4 MMT CO_2 Eq., or 9.6 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 (49.8 percent) and were the largest source of U.S. N_2O emissions in 2023, accounting for 76.6 percent. Methane emissions from enteric fermentation and manure management represented 27.2 percent and 9.5 percent of total CH_4 emissions from anthropogenic activities, respectively, in 2023. Enteric fermentation is the largest anthropogenic source of CH_4 emissions, while manure management is the fourth largest anthropogenic source of CH_4 and N_2O emissions. 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. 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

[4] 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 48.3 percent, respectively.

croplands) are included in the LULUCF sector. Figure 2-10 and Table 2-7 illustrate agricultural greenhouse gas emissions by source and gas.

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

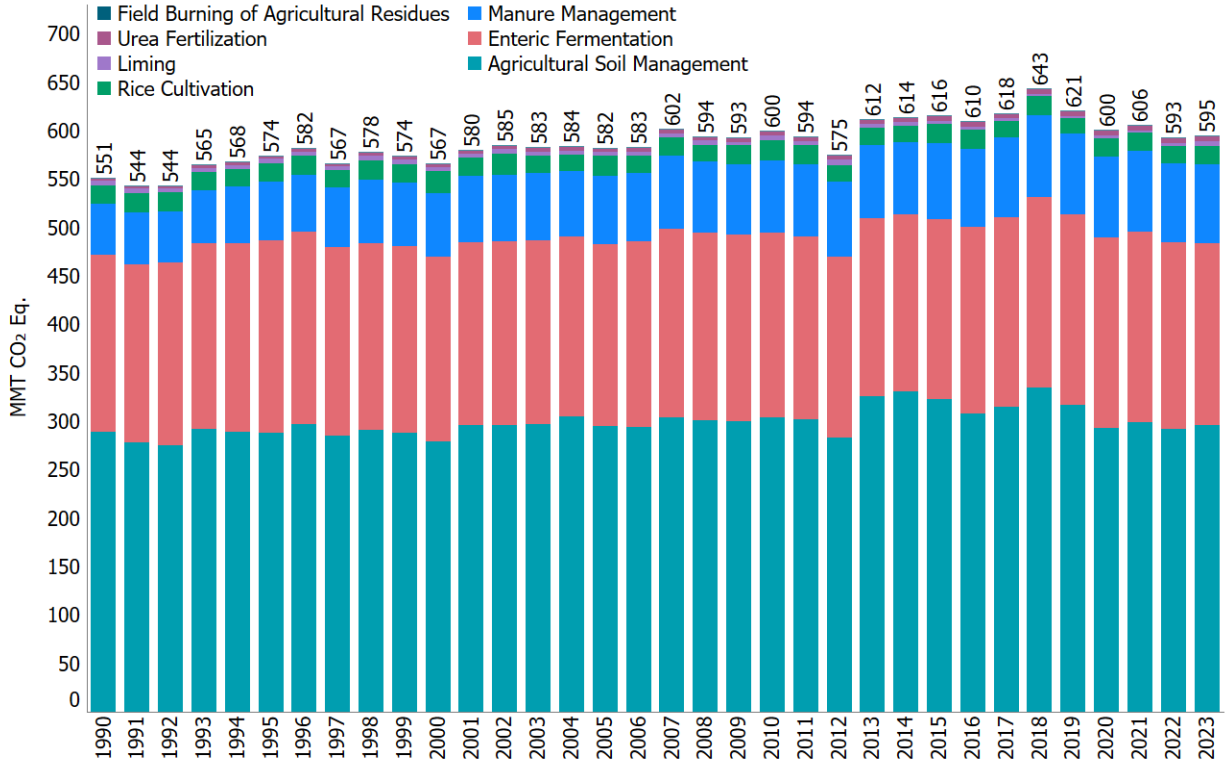


Table 2-7: Emissions from Agriculture (MMT CO_2 Eq.)

Gas/Source	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
CO_2	**7.1**	**7.9**	**7.2**	**7.9**	**7.5**	**8.4**	**10.5**	**48.3%**
Liming	4.7	4.4	2.2	2.9	2.4	3.2	5.3	12.6%
Urea Fertilization	2.4	3.5	4.9	5.0	5.1	5.2	5.3	117.5%
CH_4	**241.7**	**264.4**	**280.2**	**282.4**	**282.0**	**275.9**	**271.6**	**12.3%**
Enteric Fermentation	183.1	188.2	197.3	196.3	196.5	192.6	187.1	2.2%
Manure Management	39.1	55.0	66.7	66.9	66.4	64.7	65.1	66.4%
Rice Cultivation	18.9	20.6	15.6	18.6	18.5	18.0	18.7	-1.4%
Field Burning of Agricultural Residues	0.5	0.6	0.7	0.6	0.6	0.6	0.6	14.8%
N_2O	**302.7**	**310.2**	**333.4**	**310.1**	**316.3**	**309.0**	**313.3**	**3.5%**
Agricultural Soil Management	289.1	294.7	316.4	293.0	298.9	291.8	296.3	2.5%
Manure Management	13.4	15.2	16.8	16.9	17.1	17.0	16.8	25.5%
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2	15.8%
Total	**551.5**	**582.5**	**620.8**	**600.4**	**605.8**	**593.3**	**595.4**	**8.0%**

Note: Totals may not sum due to independent rounding.

Agriculture sector emissions increased by 0.4 percent since 2022 and increased by 8.0 percent since 1990. Some significant trends in U.S. emissions from Agriculture source categories (Figure 2-10) over the 34-year time series from 1990 through 2023 included the following:

- Annual N_2O emissions from agricultural soils fluctuated between 1990 and 2023, and overall emissions were 2.5 percent (7.2 MMT CO_2 Eq.) higher in 2023 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 emissions increased from 1990 to 2023, largely due to increasing cattle population. For example, emissions increased from 1990 to 1995 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 decreased again from 2008 to 2014 as beef cattle populations again decreased. Emissions increased from 2014 to 2023, consistent with an increase in beef cattle population over those same years. CH_4 emissions from enteric fermentation decreased by 2.9 percent (5.5 MMT CO_2 Eq.) from 2022 to 2023, however, largely driven by a decrease in beef cattle populations.
- Emissions from manure management decreased by 56.0 percent between 1990 and 2023. This includes an increase of 66.4 percent (26.0 MMT CO_2 Eq.) for CH_4 and an increase of 25.5 percent (3.4 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 39.8 and 109.1 percent, respectively, from 1990 to 2023. From 2022 to 2023, CH_4 emissions from manure management increase by 0.6 percent, mainly due to minor shifts in the animal populations and the resultant effects on manure management system allocations.
- Liming emissions increased by 65.3 percent relative to 2022 and increased by 12.6 percent (0.6 MMT CO_2 Eq.) relative to 1990, while urea fertilization emissions increased by 1.2 percent relative to 2022 and 117.5 percent (2.8 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 (i.e. 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 2023 resulted in a net increase in carbon stocks (i.e., net CO_2 removals) of 1,000.5 MMT CO_2 Eq. (Table 2-8).[5] This represents an offset of 16.1 percent of total (i.e., gross) greenhouse gas emissions in 2023. Emissions of CH_4 and N_2O from LULUCF activities in 2023 were 60.6 MMT CO_2 Eq. and represented 1.2 percent of net greenhouse gas emissions.[6] Between 1990 and 2023, total net carbon sequestration in the LULUCF sector decreased by 8.8 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. Total flux, accounting for both removals and emissions, was a net removal of 939.9 MMT CO_2 Eq., a 3.8 percent increase in removals from 2022.

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 2023, totaling 45.8 MMT CO_2 Eq. (1,635.9 kt of CH_4). Coastal wetland remaining coastal wetland was the second largest source of CH_4 emissions from LULUCF in 2023, totaling 4.3 MMT CO_2 Eq. (154.6 kt of CH_4). Settlement soils were the largest source of N_2O emissions from LULUCF in 2023, totaling 2.5 MMT CO_2 Eq. (9.6 kt of N_2O). Figure 2-11 and Table 2-8 illustrate LULUCF emissions and removals by land-use category and gas.

[5] 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.

[6] 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.

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

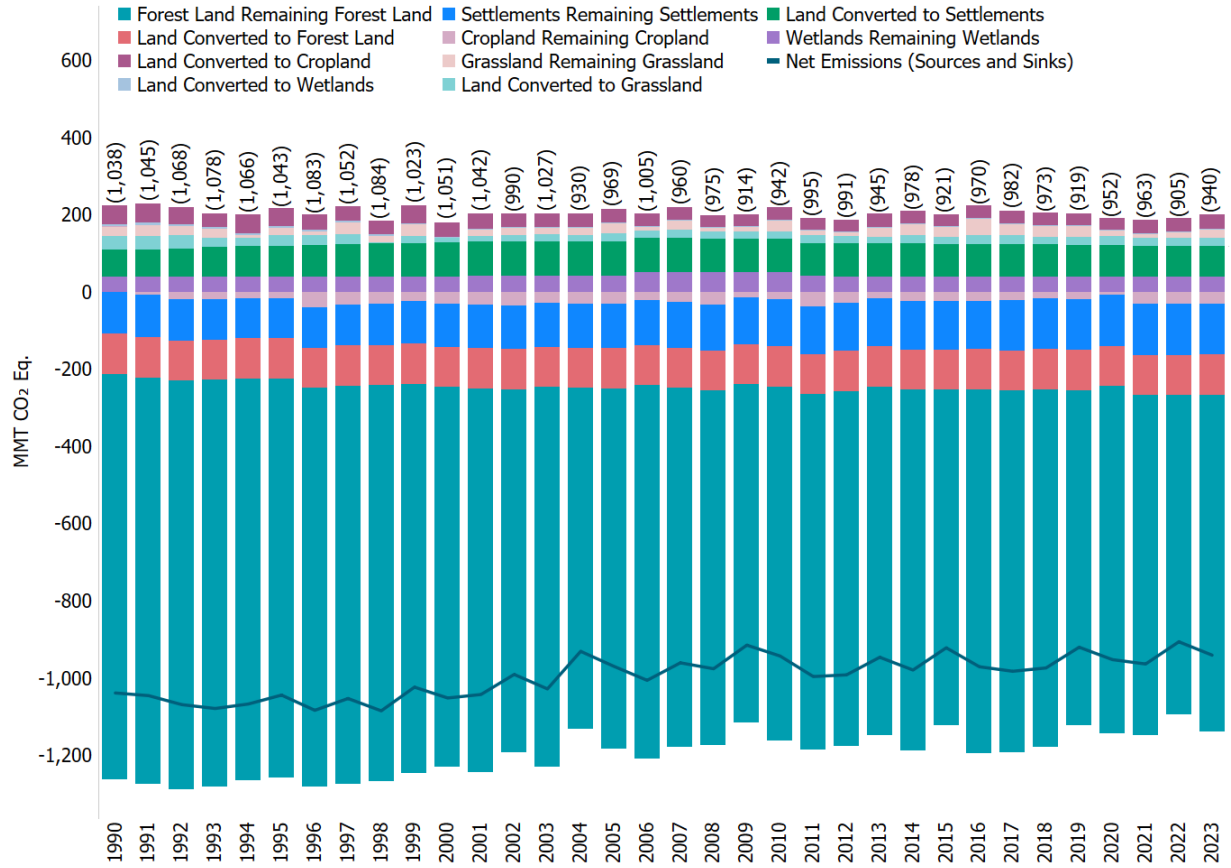


Table 2-8: U.S. Greenhouse Gas Emissions and Removals (Net Flux) from Land Use, Land-Use Change, and Forestry (MMT CO_2 Eq.)

Land-Use Category	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
Forest Land Remaining Forest Land	**(1,049.3)**	**(932.8)**	**(867.4)**	**(898.0)**	**(881.0)**	**(827.6)**	**(873.3)**	**-16.8%**
Changes in Forest Carbon Stocks[a]	(1,054.9)	(950.0)	(877.1)	(926.5)	(907.9)	(842.4)	(880.0)	-16.6%
Non-CO_2 Emissions from Forest Fires[b]	5.4	16.7	9.3	28.0	26.4	14.3	6.2	14.8%
N_2O Emissions from Forest Soils[c]	0.1	0.4	0.4	0.4	0.4	0.4	0.4	455.1%
Non-CO_2 Emissions from Drained Organic Soils[d]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0%
Land Converted to Forest Land	**(103.6)**	**(103.6)**	**(103.9)**	**(103.8)**	**(103.8)**	**(103.8)**	**(103.8)**	**0.2%**
Changes in Forest Carbon Stocks[e]	(103.6)	(103.6)	(103.9)	(103.8)	(103.8)	(103.8)	(103.8)	0.2%
Cropland Remaining Cropland	**1.0**	**(31.0)**	**(19.3)**	**(8.7)**	**(31.9)**	**(31.6)**	**(30.5)**	**-3,036.6%**
Changes in Mineral and Organic Soil Carbon Stocks	1.0	(31.0)	(19.3)	(8.7)	(31.9)	(31.6)	(30.5)	-3,036.6%

Land-Use Category	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
Land Converted to Cropland	**48.5**	**35.5**	**31.4**	**29.2**	**34.9**	**35.0**	**35.6**	**-26.7%**
Changes in all Ecosystem Carbon Stocks[f]	48.5	35.5	31.4	29.2	34.9	35.0	35.6	-26.7%
Grassland Remaining Grassland	**24.2**	**24.5**	**28.5**	**16.8**	**11.2**	**13.7**	**22.7**	**-6.1%**
Changes in Mineral and Organic Soil Carbon Stocks	24.0	23.7	28.2	15.8	10.2	13.1	22.0	-8.2%
Non-CO_2 Emissions from Grassland Fires[g]	0.2	0.8	0.3	1.1	0.9	0.6	0.7	227.6%
Land Converted to Grassland	**35.6**	**21.9**	**20.9**	**24.1**	**19.9**	**20.9**	**20.9**	**-41.3%**
Changes in all Ecosystem Carbon Stocks[f]	35.6	21.9	20.9	24.1	19.9	20.9	20.9	-41.3%
Wetlands Remaining Wetlands	**38.5**	**40.9**	**39.7**	**39.7**	**39.7**	**39.7**	**39.7**	**3.3%**
Changes in Organic Soil Carbon Stocks in Peatlands	1.1	1.1	0.6	0.6	0.5	0.6	0.6	-42.7%
Non-CO_2 Emissions from Peatlands Remaining Peatlands	+	+	+	+	+	+	+	-44.4%
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)	2.9%
CH_4 Emissions from Coastal Wetlands Remaining Coastal Wetlands	4.2	4.2	4.3	4.3	4.3	4.3	4.3	3.6%
N_2O Emissions from Coastal Wetlands Remaining Coastal Wetlands	0.1	0.2	0.1	0.1	0.1	0.1	0.1	14.9%
CH_4 Emissions from Flooded Land Remaining Flooded Land	43.9	45.5	45.8	45.8	45.8	45.8	45.8	4.2%
Land Converted to Wetlands	**6.8**	**1.9**	**0.7**	**0.7**	**0.7**	**0.7**	**0.6**	**-90.6%**
Changes in Biomass, DOM, and Soil Carbon Stocks in Land Converted to Coastal Wetlands	0.5	0.5	(+)	(+)	(+)	(+)	(+)	-94.8%
CH_4 Emissions from Land Converted to Coastal Wetlands	0.3	0.3	0.2	0.2	0.2	0.2	0.2	-42.1%
Changes in Land Converted to Flooded Land	3.4	0.7	0.3	0.3	0.3	0.3	0.3	-92.1%
CH_4 Emissions from Land Converted to Flooded Land	2.7	0.5	0.2	0.2	0.2	0.2	0.2	-93.0%
Settlements Remaining Settlements	**(109.1)**	**(115.2)**	**(131.4)**	**(131.7)**	**(132.1)**	**(132.1)**	**(131.7)**	**20.8%**
Changes in Organic Soil Carbon Stocks	9.9	10.1	14.6	15.1	15.6	16.0	16.4	66.2%
Changes in Settlement Tree Carbon Stocks	(96.5)	(117.0)	(135.4)	(136.6)	(137.6)	(138.4)	(139.0)	44.0%
N_2O Emissions from Settlement Soils[h]	2.1	3.1	2.5	2.5	2.5	2.5	2.5	23.1%
Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills	(24.5)	(11.4)	(13.1)	(12.8)	(12.5)	(12.3)	(11.7)	-52.2%
Land Converted to Settlements	**69.5**	**89.0**	**81.4**	**80.3**	**79.7**	**79.8**	**79.8**	**14.9%**
Changes in all Ecosystem Carbon Stocks[f]	69.5	89.0	81.4	80.3	79.7	79.8	79.8	14.9%

Land-Use Category	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
LULUCF Emissions[j]	**59.1**	**71.8**	**63.2**	**82.6**	**81.0**	**68.6**	**60.6**	**2.6%**
CH_4	54.4	60.9	56.1	69.0	67.8	59.6	54.7	0.5%
N_2O	4.7	10.9	7.0	13.7	13.1	9.0	5.9	26.7%
LULUCF Carbon Stock Change[i]	**(1,096.9)**	**(1,040.7)**	**(982.6)**	**(1,034.2)**	**(1,043.8)**	**(973.9)**	**(1,000.5)**	**-8.8%**
LULUCF Sector Net Total[k]	**(1,037.9)**	**(968.9)**	**(919.4)**	**(951.6)**	**(962.9)**	**(905.3)**	**(939.9)**	**-9.4%**

+ 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 carbon stock change includes any carbon stock gains and losses from all land use and land-use conversion categories.

[j] 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.

[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 by 11.6 percent from 2022 and increased by 2.6 percent since 1990, while total net sequestration decreased by 8.8 percent since 1990 and increased 2.7 percent from 2022. Other trends from 1990 to 2023 in fluxes from LULUCF categories (Figure 2-11) over the 34-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 15.1 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 20.8 percent over the period from 1990 to 2023. This is primarily due to an increase in urbanized land area in the United States with tree growth.
- Annual emissions from land converted to settlements increased by 14.9 percent from 1990 to 2023 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 165.8 MMT CO_2 Eq., or 2.7 percent of total U.S. greenhouse gas emissions in 2023. In 2023, landfills were the largest source of waste emissions, accounting for 72.0 percent of waste-related emissions. Landfills are also the third-largest source of U.S. anthropogenic CH_4 emissions, generating 119.5 MMT CO_2 Eq. and accounting for 17.4 percent of total U.S. CH_4 emissions in 2023.[7] Additionally, wastewater treatment generated emissions of 41.9 MMT CO_2 Eq. and accounted for 25.3 percent of waste emissions, 3.1 percent of U.S. CH_4 emissions, and 5.4 percent of U.S. N_2O emissions in 2023. 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 1.6 and 1.1 percent of Waste sector emissions, respectively. Anaerobic digestion 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

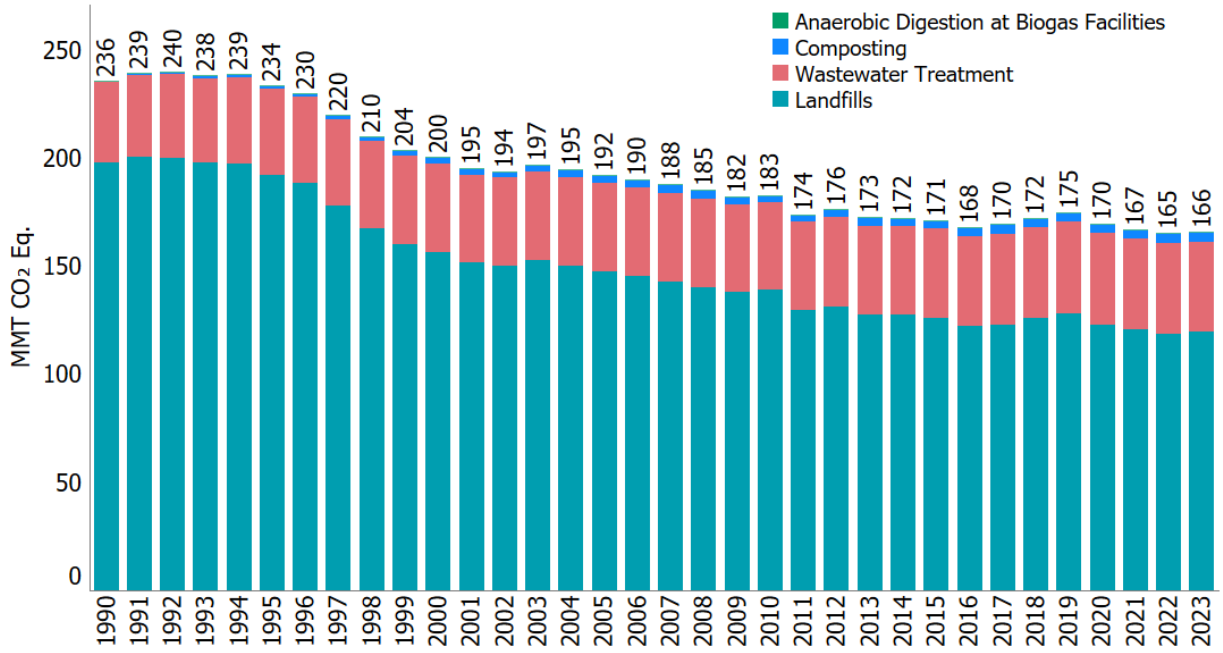


Table 2-9: Emissions from Waste (MMT CO_2 Eq.)

Gas/Source	1990	2005	2019	2020	2021	2022	2023	Percent Change Since 1990
CH_4	**220.9**	**172.4**	**151.9**	**146.1**	**143.9**	**142.2**	**143.2**	**-35.2%**
Landfills	197.8	147.7	128.2	122.6	120.7	118.7	119.5	-39.6%
Wastewater Treatment	22.7	22.7	21.1	21.0	20.7	20.9	21.1	-6.9%

[7] 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.

Composting	0.4	2.1	2.5	2.6	2.6	2.6	2.6	507.7%
Anaerobic Digestion at Biogas Facilities	+	+	+	+	+	+	+	1,427.9%
N_2O	**15.1**	**19.5**	**22.9**	**23.6**	**23.1**	**22.9**	**22.6**	**50.3%**
Wastewater Treatment	14.8	18.1	21.1	21.8	21.3	21.1	20.8	41.0%
Composting	0.3	1.5	1.8	1.8	1.8	1.8	1.8	507.7%
Total	**235.9**	**192.0**	**174.8**	**169.7**	**167.0**	**165.1**	**165.8**	**-29.7%**

+ Does not exceed 0.05 MMT CO_2 Eq.
Note: Totals may not sum due to independent rounding.

Waste sector emissions increased by 0.5 percent since 2022 and decreased by 29.7 percent since 1990. Some notable trends in U.S. emissions from Waste source categories (Figure 2-12) over the 34-year period from 1990 through 2023 included the following:

- Net CH_4 emissions from landfills decreased by 78.3 MMT CO_2 Eq. (39.6 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.
- CH_4 and N_2O emissions from wastewater treatment decreased by 6.9 percent (1.6 MMT CO_2 Eq.) and increased by 41.0 percent (6.0 MMT CO_2 Eq.), 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 commercial composting have increased by 507.7 percent (3.7 MMT CO_2 Eq.) since 1990. The growth in composting since the 1990s is largely due to growing legislation by state and local governments discouraging the disposal of yard trimmings and food waste in landfills and increased collection of yard trimmings.

2.2 Emissions and Sinks by Economic Sector

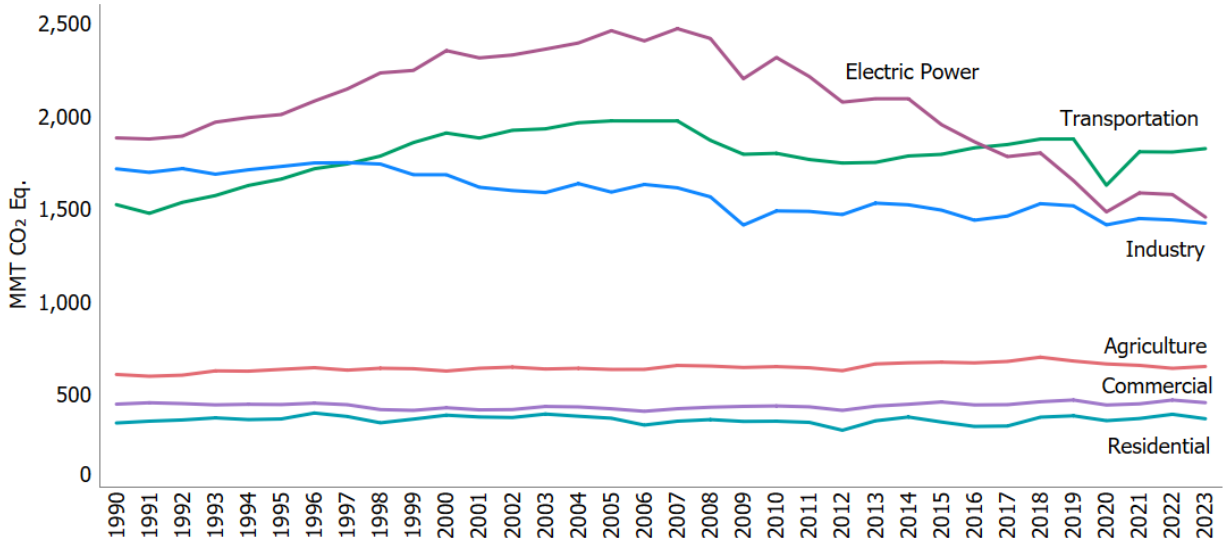
This report also characterizes gross emissions according to commonly used economic sector categories: residential, commercial, industry, transportation, electric power, and agriculture. All emissions from U.S. Territories are reported together as their own end-use sector in this characterization due to a lack of specific consumption data for the individual end-use sectors. 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 (29.4 percent) of total U.S. greenhouse gas emissions in 2023. Emissions from electric power accounted for the second largest portion (23.5 percent), while emissions from industry accounted for the third-largest portion (23.0 percent) of total U.S. greenhouse gas emissions in 2023. 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 24.2 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 10.5 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 7.3 percent and 5.9 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 2023.

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 the 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 2023)

Sector/Source	1990	2005	2019	2020	2021	2022	2023	Percent of Total Emissions[a]
Transportation	**1,520.8**	**1,971.8**	**1,874.2**	**1,625.3**	**1,805.5**	**1,804.0**	**1,822.5**	**29.4%**
CO_2 from Fossil Fuel Combustion	1,468.9	1,858.6	1,816.6	1,573.0	1,753.5	1,753.6	1,776.5	28.7%

Sector/Source	1990	2005	2019	2020	2021	2022	2023	Percent of Total Emissions[a]
Substitution of Ozone Depleting Substances	0.0	63.1	34.0	32.5	31.2	29.6	27.9	0.4%
Mobile Combustion[b]	40.0	40.0	14.7	12.0	12.7	12.2	11.6	0.2%
Non-Energy Use of Fuels	11.8	10.2	8.8	7.8	8.0	8.7	6.6	0.1%
Electric Power Industry	**1,880.2**	**2,457.4**	**1,650.7**	**1,481.8**	**1,584.0**	**1,575.5**	**1,453.7**	**23.5%**
CO_2 from Fossil Fuel Combustion	1,820.0	2,400.1	1,606.7	1,439.6	1,540.9	1,531.7	1,414.2	22.8%
Stationary Combustion[b]	18.7	27.7	20.2	18.9	20.4	20.9	18.1	0.3%
Incineration of Waste	13.3	13.6	13.3	13.3	12.8	12.8	12.8	0.2%
Electrical Equipment	24.6	11.8	6.0	5.5	5.5	4.9	5.1	0.1%
Other Process Uses of Carbonates	3.6	4.2	4.5	4.5	4.3	5.2	3.6	0.1%
Industry	**1,714.5**	**1,589.4**	**1,514.8**	**1,412.3**	**1,446.0**	**1,439.8**	**1,423.0**	**23.0%**
CO_2 from Fossil Fuel Combustion	822.6	798.1	752.8	701.9	731.9	754.5	739.7	11.9%
Natural Gas Systems	252.1	237.0	227.7	216.9	210.4	209.3	200.1	3.2%
Non-Energy Use of Fuels	83.9	107.2	97.4	89.9	103.5	92.9	100.4	1.6%
Petroleum Systems	59.6	58.7	96.2	79.5	69.2	58.4	61.3	1.0%
Coal Mining	112.7	75.6	56.0	48.3	47.1	46.1	47.8	0.8%
Iron and Steel Production	104.8	70.1	46.8	40.7	47.2	45.2	46.2	0.7%
Cement Production	33.5	46.2	40.9	40.7	41.3	41.9	40.6	0.7%
Substitution of Ozone Depleting Substances	+	8.0	33.1	33.9	32.2	33.4	35.1	0.6%
Petrochemical Production	20.1	26.9	28.5	27.9	30.7	28.8	30.5	0.5%
Landfills (Industrial)	12.2	16.1	18.8	18.9	18.9	18.9	18.9	0.3%
Ammonia Production	14.4	10.2	12.4	12.3	11.5	11.9	12.2	0.2%
Lime Production	11.7	14.6	12.1	11.3	11.9	12.2	11.5	0.2%
Abandoned Oil and Gas Wells	7.8	8.2	8.5	8.5	8.6	8.5	8.5	0.1%
Nitric Acid Production	10.8	10.1	8.9	8.3	7.9	8.6	8.3	0.1%
Wastewater Treatment	6.6	7.1	7.6	7.6	7.7	7.7	7.6	0.1%
Abandoned Underground Coal Mines	8.1	7.4	6.6	6.5	6.2	6.1	6.1	0.1%
Mobile Combustion	3.6	5.6	5.6	5.3	5.5	5.8	5.9	0.1%
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	6.2	5.9	6.7	5.5	5.4	0.1%
Fluorochemical Production	71.0	30.0	9.3	7.0	7.1	7.6	4.7	0.1%
Electronics Industry	3.3	4.5	4.5	4.5	4.9	4.8	4.2	0.1%
N_2O from Product Uses	3.8	3.8	3.8	3.8	3.8	3.8	3.8	0.1%
Other Process Uses of Carbonates	3.6	4.2	4.5	4.5	4.3	5.2	3.6	0.1%
Stationary Combustion	4.8	4.5	3.8	3.6	3.6	3.6	3.3	0.1%
Non-EOR Carbon Dioxide Utilization	1.5	1.4	2.4	2.8	2.9	2.8	2.1	0.0%
Glass Production	2.3	2.4	1.9	1.9	2.0	2.0	1.8	0.0%
Soda Ash Production	1.4	1.7	1.8	1.5	1.7	1.7	1.7	0.0%
Aluminum Production	26.1	7.2	3.3	3.2	2.5	2.2	1.7	0.0%
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.5	1.9	1.2	1.1	1.2	1.3	1.3	0.0%
Ferroalloy Production	2.2	1.4	1.6	1.4	1.4	1.3	1.3	0.0%

Sector/Source	1990	2005	2019	2020	2021	2022	2023	Percent of Total Emissions[a]
Titanium Dioxide Production	1.2	1.8	1.3	1.3	1.5	1.5	1.2	0.0%
Adipic Acid Production	13.5	6.3	4.7	7.4	6.6	2.1	1.2	0.0%
Magnesium Production and Processing	5.7	3.0	1.0	0.9	1.2	1.1	1.1	0.0%
Other Product Manufacture and Use	1.5	1.5	0.8	0.7	0.5	0.6	1.0	0.0%
Zinc Production	0.6	1.0	1.0	1.0	1.0	0.9	0.9	0.0%
Phosphoric Acid Production	1.5	1.3	0.9	0.9	0.9	0.8	0.9	0.0%
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.0%
Carbide Production and Consumption	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.0%
CO_2 Transport, Injection, and Geological Storage	0.0	0.0	+	+	0.1	0.1	0.1	0.0%
Agriculture	**606.8**	**633.7**	**679.2**	**663.3**	**655.7**	**639.8**	**649.6**	**10.5%**
N_2O from Agricultural Soil Management	289.1	294.7	316.4	293.0	298.9	291.8	296.3	4.8%
Enteric Fermentation	183.1	188.2	197.3	196.3	196.5	192.6	187.1	3.0%
Manure Management	52.5	70.2	83.5	83.8	83.6	81.7	81.9	1.3%
CO_2 from Fossil Fuel Combustion	53.9	49.6	57.1	61.6	48.6	45.2	52.9	0.9%
Rice Cultivation	18.9	20.6	15.6	18.6	18.5	18.0	18.7	0.3%
Liming	4.7	4.4	2.2	2.9	2.4	3.2	5.3	0.1%
Urea Fertilization	2.4	3.5	4.9	5.0	5.1	5.2	5.3	0.1%
Mobile Combustion[b]	1.4	1.6	1.2	1.2	1.2	1.2	1.225	0.0%
Field Burning of Agricultural Residues	0.7	0.8	0.9	0.8	0.8	0.8	0.8	0.0%
Stationary Combustion[b]	0.1	+	0.1	0.1	0.1	0.1	0.1	0.0%
Commercial	**447.0**	**422.1**	**469.2**	**442.3**	**448.6**	**469.0**	**455.1**	**7.3%**
CO_2 from Fossil Fuel Combustion	228.3	227.1	251.7	229.3	237.5	259.2	244.2	3.9%
Landfills (Municipal)	185.5	131.6	109.4	103.7	101.8	99.8	100.6	1.6%
Substitution of Ozone Depleting Substances	+	24.7	67.4	68.3	69.1	69.6	70.0	1.1%
Wastewater Treatment	30.9	33.6	34.7	35.1	34.3	34.3	34.3	0.6%
Composting	0.7	3.6	4.3	4.4	4.4	4.4	4.4	0.1%
Stationary Combustion[b]	1.5	1.5	1.6	1.5	1.6	1.7	1.6	0.0%
Anaerobic Digestion at Biogas Facilities	+	+	+	+	+	+	+	0.0%
Residential	**345.6**	**371.2**	**384.2**	**358.0**	**369.6**	**392.4**	**368.3**	**5.9%**
CO_2 from Fossil Fuel Combustion	338.6	358.9	342.9	314.8	318.0	335.2	307.1	5.0%
Substitution of Ozone Depleting Substances	0.2	7.0	35.1	39.0	47.3	52.2	56.1	0.9%
Stationary Combustion[b]	6.8	5.3	6.2	4.2	4.2	5.0	5.2	0.1%
U.S. Territories	**23.4**	**59.7**	**25.1**	**22.6**	**24.4**	**23.7**	**25.1**	**0.4%**
CO_2 from Fossil Fuel Combustion	20.0	51.9	24.8	22.3	24.1	23.5	24.9	0.4%
Non-Energy Use of Fuels	3.4	7.6	0.2	0.2	0.2	0.1	0.1	0.0%
Stationary Combustion[b]	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.0%

Sector/Source	1990	2005	2019	2020	2021	2022	2023	Percent of Total Emissions[a]
Total Gross Emissions (Sources)	**6,538.3**	**7,505.3**	**6,597.4**	**6,005.7**	**6,333.8**	**6,344.1**	**6,197.3**	**100.0%**
LULUCF Sector Net Total[c]	**(1,037.9)**	**(968.9)**	**(919.4)**	**(951.6)**	**(962.9)**	**(905.3)**	**(939.9)**	**-15.2%**
Net Emissions (Sources and Sinks)	**5,500.4**	**6,536.4**	**5,678.0**	**5,054.2**	**5,371.0**	**5,438.7**	**5,257.4**	**84.8%**

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

[a] Percent of total (gross) emissions excluding emissions from LULUCF for 2023.

[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

This report also characterizes emissions according to following economic sector categories. 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 2020). 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 2024) 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 the electric power sector are allocated to the economic end-use sectors in which the electricity is used). For example, greenhouse

gas emissions from some economic sectors, e.g., commercial, residential and industry, increase substantially when indirect emissions from electricity end-use are included, due to the relatively large share of electricity use by buildings (75 percent of the electricity generated in the United States for heating, ventilation, and air conditioning; lighting; and appliances, etc.)[8] and use of electricity for powering industrial machinery.

The generation, transmission, and distribution of electricity directly accounted for 23.5 percent of total U.S. greenhouse gas emissions in 2023. Electric power-related emissions decreased by 22.7 percent since 1990 mainly due to fuel switching. From 2022 to 2023, electric power-related emissions decreased by 7.7 percent. Between 2022 and 2023, the consumption of natural gas for electric power generation increased by 6.9 percent, while consumption of petroleum and coal decreased by 28.3 percent and 18.4 percent, respectively. Electric power-related emissions in 2023 are still lower than pre-pandemic 2019 levels. Table 2-11 provides a detailed summary of emissions from electric power-related activities.

From 2022 to 2023, electricity sales to the residential end-use sector and commercial end-use sector decreased by 3.9 percent and increased 1.2 percent, respectively. Electricity sales to the industrial sectors decreased by 1.1 percent. Overall, from 2022 to 2023, the amount of electricity retail sales (in kWh) decreased by 1.3 percent.

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

Gas/Fuel Type or Source	1990	2005	2019	2020	2021	2022	2023
CO_2	**1,836.4**	**2,417.5**	**1,624.2**	**1,457.0**	**1,557.7**	**1,549.4**	**1,430.2**
Fossil Fuel Combustion	1,820.0	2,400.1	1,606.7	1,439.6	1,540.9	1,531.7	1,414.2
Coal	1,546.5	1,982.8	973.5	788.2	910.1	851.5	694.6
Natural Gas	175.4	318.9	616.6	634.8	612.8	659.3	704.5
Petroleum	97.5	98.0	16.2	16.2	17.7	20.5	14.7
Geothermal	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Incineration of Waste	12.9	13.3	12.9	12.9	12.5	12.5	12.4
Other Process Uses of Carbonates	3.6	4.2	4.5	4.5	4.3	5.2	3.6
CH_4	**0.5**	**1.0**	**1.4**	**1.4**	**1.4**	**1.5**	**1.5**
Stationary Sources[a]	0.5	1.0	1.4	1.4	1.4	1.5	1.5
Incineration of Waste	+	+	+	+	+	+	+
N_2O	**18.6**	**27.1**	**19.1**	**17.9**	**19.4**	**19.8**	**16.9**
Stationary Sources[a]	18.2	26.7	18.8	17.5	19.0	19.4	16.6
Incineration of Waste	0.4	0.3	0.4	0.3	0.4	0.3	0.3
SF_6	**24.6**	**11.8**	**6.0**	**5.5**	**5.5**	**4.9**	**5.1**
Electrical Equipment	24.6	11.8	6.0	5.5	5.5	4.9	5.1
CF_4	**+**	**+**	**+**	**+**	**+**	**+**	**0.0**
Electrical Equipment	+	+	+	+	+	+	0.0
Total	**1,880.2**	**2,457.4**	**1,650.7**	**1,481.8**	**1,584.0**	**1,575.5**	**1,453.7**

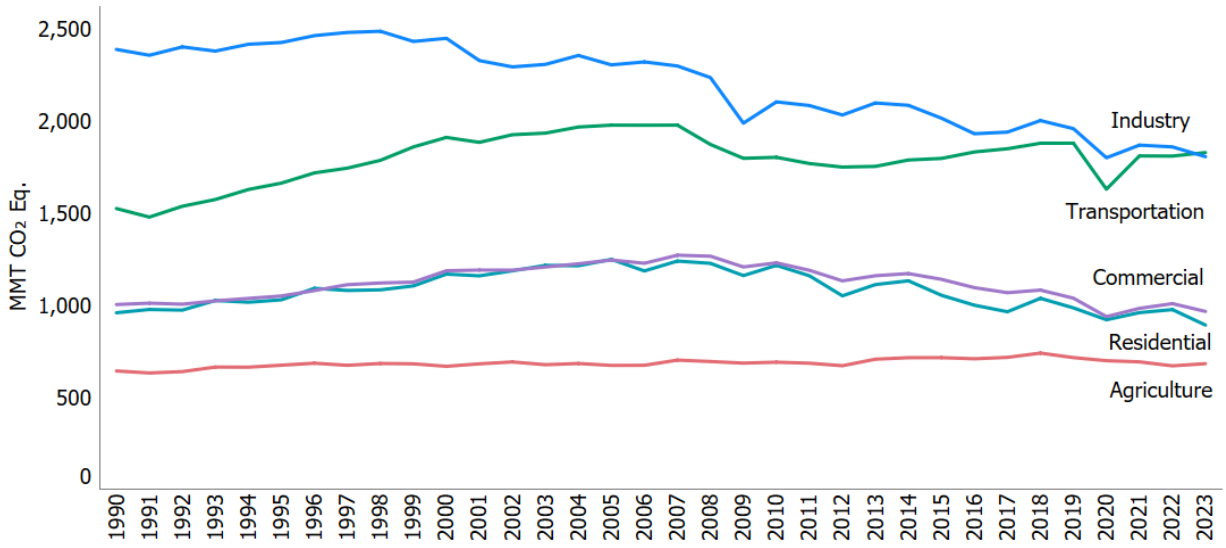
+ Does not exceed 0.05 MMT CO_2 Eq.
[a] Includes only stationary combustion emissions related to the generation of electricity.
Note: Totals may not sum due to independent rounding.

[8] See https://www.nrel.gov/news/features/2023/nrel-researchers-reveal-how-buildings-across-the-united-states-do-and-could-use-energy.html.

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 2020; USDA/NASS 2024). 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 to these economic end-use sectors, 2023 emissions from transportation account for the largest share of total U.S. greenhouse gas emissions (29.5 percent), followed closely by emissions from industrial activities (29.2 percent). The relative share of emissions from the commercial and residential sectors also increased substantially when emissions from electricity are included (15.6 and 14.4 percent, respectively). In all economic end-use sectors except agriculture, CO_2 accounts for more than 77.3 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 2023.

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 the 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 2023

[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.

Emissions by Gas	1990	2005	2019	2020	2021	2022	2023	Percent[a]
Transportation	**1,523.9**	**1,976.6**	**1,878.5**	**1,628.9**	**1,809.5**	**1,808.6**	**1,827.7**	**29.5%**
Direct Emissions	1,520.8	1,971.8	1,874.2	1,625.3	1,805.5	1,804.0	1,822.5	29.4%
CO_2	1,480.8	1,868.7	1,825.5	1,580.7	1,761.6	1,762.3	1,783.0	28.8%
CH_4	6.4	4.0	1.6	1.4	1.5	1.5	1.4	0.0%
N_2O	33.6	35.9	13.0	10.6	11.2	10.7	10.2	0.2%
HFCs[b]	0.0	63.1	34.0	32.5	31.2	29.6	27.86	0.4%
Electricity-Related	3.1	4.8	4.3	3.6	4.1	4.6	5.1	0.1%
CO_2	3.1	4.8	4.3	3.5	4.0	4.5	5.1	0.1%
CH_4	+	+	+	+	+	+	+	0.0%
N_2O	+	0.1	0.1	+	+	0.1	0.1	0.0%
SF_6	+	+	+	+	+	+	+	0.0%
Industry	**2,388.5**	**2,305.0**	**1,957.8**	**1,799.7**	**1,868.0**	**1,859.6**	**1,806.9**	**29.2%**
Direct Emissions	1,714.5	1,589.4	1,514.8	1,412.3	1,446.0	1,439.8	1,423.0	23.0%
CO_2	1,163.4	1,137.7	1,102.4	1,016.2	1,064.9	1,072.2	1,065.5	17.2%
CH_4	414.8	371.9	336.5	320.4	307.8	296.0	289.0	4.7%
N_2O	35.7	29.8	26.0	27.6	26.8	23.4	22.2	0.4%
HFCs, PFCs, SF_6 and NF_3	100.7	50.0	49.9	48.2	46.5	48.1	46.3	0.7%
Electricity-Related	674.0	715.6	443.0	387.4	422.0	419.8	383.9	6.2%
CO_2	658.3	704.0	435.9	380.9	415.0	412.8	377.7	6.1%
CH_4	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.0%
N_2O	6.7	7.9	5.1	4.7	5.2	5.3	4.5	0.1%
SF_6	8.8	3.4	1.6	1.4	1.5	1.3	1.3	0.0%
Residential	**957.9**	**1,247.7**	**984.4**	**919.9**	**958.7**	**975.0**	**891.1**	**14.4%**
Direct Emissions	345.6	371.2	384.2	358.0	369.6	392.4	368.3	5.9%
CO_2	338.6	358.9	342.9	314.8	318.0	335.2	307.1	5.0%
CH_4	5.9	4.5	5.3	3.6	3.6	4.3	4.5	0.1%
N_2O	0.9	0.8	0.8	0.6	0.6	0.7	0.7	0.0%
SF_6	0.2	7.0	35.1	39.0	47.3	52.2	56.1	0.9%
Electricity-Related	612.4	876.5	600.2	561.9	589.1	582.7	522.7	8.4%
CO_2	598.1	862.2	590.6	552.5	579.3	573.0	514.3	8.3%
CH_4	0.2	0.3	0.5	0.5	0.5	0.5	0.5	0.0%
N_2O	6.1	9.7	7.0	6.8	7.2	7.3	6.1	0.1%
SF_6	8.0	4.2	2.2	2.1	2.1	1.8	1.8	0.0%
Commercial	**1,002.5**	**1,244.3**	**1,037.1**	**936.9**	**981.8**	**1,007.5**	**965.1**	**15.6%**
Direct Emissions	447.0	422.1	469.2	442.3	448.6	469.0	455.1	7.3%
CO_2	228.3	227.1	251.7	229.3	237.5	259.2	244.2	3.9%
CH_4	203.6	150.9	127.3	121.4	119.1	117.4	118.5	1.9%
N_2O	15.1	19.4	22.8	23.4	22.9	22.8	22.5	0.4%
HFCs	+	24.7	67.4	68.3	69.1	69.6	70.0	1.1%
Electricity-Related	555.5	822.2	567.9	494.6	533.2	538.5	510.0	8.2%
CO_2	542.6	808.9	558.7	486.3	524.3	529.6	501.8	8.1%
CH_4	0.1	0.3	0.5	0.5	0.5	0.5	0.5	0.0%

Emissions by Gas	1990	2005	2019	2020	2021	2022	2023	Percent[a]
N_2O	5.5	9.1	6.6	6.0	6.5	6.8	5.9	0.1%
SF_6	7.3	4.0	2.1	1.8	1.9	1.7	1.8	0.0%
Agriculture	**641.9**	**672.0**	**714.4**	**697.7**	**691.4**	**669.6**	**681.5**	**11.0%**
Direct Emissions	606.8	633.7	679.2	663.3	655.7	639.8	649.6	10.5%
CO_2	61.0	57.4	64.2	69.5	56.1	53.6	63.5	1.0%
CH_4	241.9	264.6	280.4	282.6	282.2	276.1	271.7	4.4%
N_2O	303.9	311.6	334.5	311.2	317.4	310.1	314.4	5.1%
Electricity-Related	35.2	38.3	35.2	34.4	35.7	29.9	31.9	0.5%
CO_2	34.3	37.7	34.7	33.8	35.1	29.4	31.4	0.5%
CH_4	+	+	+	+	+	+	+	0.0%
N_2O	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.0%
SF_6	0.5	0.2	0.1	0.1	0.1	0.1	0.1	0.0%
U.S. Territories	**23.4**	**59.7**	**25.1**	**22.6**	**24.4**	**23.7**	**25.1**	**0.4%**
Total Gross Emissions (Sources)	**6,538.3**	**7,505.3**	**6,597.4**	**6,005.7**	**6,333.8**	**6,344.1**	**6,197.3**	**100.0%**
LULUCF Sector Net Total[c]	**(1,037.9)**	**(968.9)**	**(919.4)**	**(951.6)**	**(962.9)**	**(905.3)**	**(939.9)**	**-15.2%**
Net Emissions (Sources and Sinks)	**5,500.4**	**6,536.4**	**5,678.0**	**5,054.2**	**5,371.0**	**5,438.7**	**5,257.4**	**84.8%**

+ 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 2023.

[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.

Transportation

When electricity-related emissions are distributed to economic end-use sectors, transportation activities accounted for 29.5 percent of U.S. greenhouse gas emissions in 2023. The largest sources of transportation greenhouse gas emissions in 2023 were light-duty trucks, which include sport utility vehicles, pickup trucks, and minivans (39.7 percent); medium- and heavy-duty trucks (23.4 percent); passenger cars (16.6 percent); commercial aircraft (7.2 percent); pipelines (3.9 percent); ships and boats (2.4 percent); and other aircraft (2.8 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 2023, total transportation emissions from fossil fuel combustion increased by 20.9 percent due, in large part, to increased demand for travel. From 2022 to 2023, emissions increased by 1.3 percent. VMT by light-duty vehicles (passenger cars and light-duty trucks) increased by 48.6 percent from 1990 to 2023 as a result of a confluence of factors including population growth, economic growth, urban sprawl, and periods of low fuel prices. The rise in transportation-related CO_2 emissions, combined with an increase in HFCs from close to zero emissions in 1990 to 27.9 MMT CO_2 Eq. in 2023,

led to an increase in overall greenhouse gas emissions from transportation activities of 19.9 percent from 1990 to 2023.

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 vehicle VMT grew only modestly between 2005 and 2013. Light-duty vehicle 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). Between 2016 and 2022 the rate of light-duty vehicle VMT growth slowed to one percent or less each year. From 2022 to 2023, light-duty vehicle VMT increased by 2.3 percent. 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 33.0 and 63.1 percent. Light-duty truck market share was about 62.5 percent of new passenger vehicle sales in model year 2023 (EPA 2023).

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 electric vehicles. Despite this increase, almost all of the energy used for transportation was supplied by petroleum-based products, with more than half 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. Indirect emissions from electricity are less than 1 percent of direct emissions in the transportation sector. 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

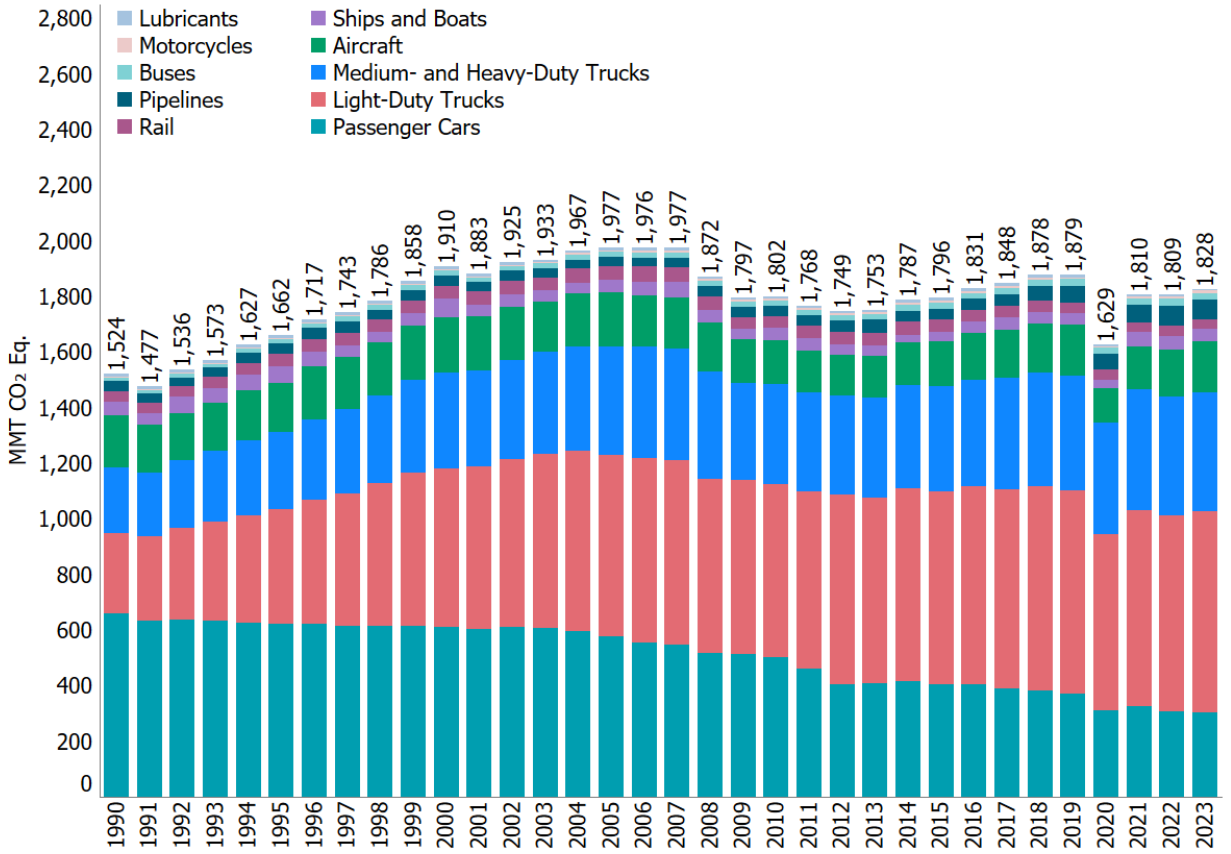


Table 2-13: Transportation-Related Greenhouse Gas Emissions (MMT CO_2 Eq.)

Gas/Vehicle Type	1990	2005	2019	2020	2021	2022	2023
Passenger Cars	**658.7**	**576.1**	**372.7**	**309.6**	**325.4**	**307.3**	**303.3**
CO_2	632.6	529.1	361.3	299.8	316.3	298.9	296.0
CH_4	3.8	1.8	0.3	0.2	0.2	0.2	0.2
N_2O	22.3	16.4	2.7	2.0	1.9	1.6	1.4
HFCs	0.0	28.8	8.4	7.6	7.0	6.6	5.705
Light-Duty Trucks	**289.7**	**653.8**	**729.8**	**636.9**	**705.8**	**704.5**	**726.2**
CO_2	280.0	606.4	708.3	618.0	688.0	688.8	711.9
CH_4	1.4	1.3	0.6	0.5	0.5	0.5	0.5
N_2O	8.2	15.8	5.5	4.3	4.2	3.8	3.4
HFCs	0.0	30.2	15.4	14.2	13.0	11.4	10.4
Medium- and Heavy-Duty Trucks	**236.6**	**390.8**	**413.8**	**400.3**	**434.6**	**430.2**	**427.5**
CO_2	235.1	386.0	405.2	391.3	425.1	420.6	418.1
CH_4	0.5	0.2	0.1	0.1	0.1	0.1	0.1
N_2O	1.0	1.5	2.7	2.8	3.1	3.2	3.2
HFCs	0.0	3.2	5.8	6.1	6.3	6.3	6.1
Buses	**13.1**	**18.0**	**24.8**	**20.2**	**22.3**	**24.4**	**24.4**
CO_2	12.9	17.6	24.2	19.7	21.8	23.8	23.8

Gas/Vehicle Type	1990	2005	2019	2020	2021	2022	2023
CH_4	0.1	+	+	+	+	+	+
N_2O	0.1	0.1	0.2	0.1	0.2	0.2	0.2
HFCs	0.0	0.2	0.4	0.4	0.4	0.4	0.4
Motorcycles	**3.3**	**4.8**	**6.8**	**6.2**	**7.0**	**8.3**	**8.7**
CO_2	3.3	4.7	6.7	6.1	6.9	8.2	8.6
CH_4	+	+	+	+	+	+	+
N_2O	+	+	0.1	0.1	0.1	0.1	0.1
Commercial Aircraft [a]	**110.8**	**133.8**	**137.8**	**92.0**	**120.0**	**130.8**	**130.8**
CO_2	109.9	132.7	136.7	91.3	119.0	129.7	129.7
CH_4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N_2O	0.9	1.1	1.1	0.7	1.0	1.1	1.1
Other Aircraft [b]	**78.0**	**59.5**	**45.6**	**31.0**	**35.5**	**37.0**	**51.1**
CO_2	77.3	59.0	45.2	30.7	35.1	36.7	50.7
CH_4	0.1	0.1	+	+	+	+	+
N_2O	0.6	0.5	0.4	0.2	0.3	0.3	0.4
Ships and Boats [c]	**47.0**	**45.5**	**40.0**	**32.2**	**50.7**	**49.9**	**43.8**
CO_2	46.3	44.3	35.5	27.5	45.4	44.4	38.0
CH_4	0.4	0.5	0.4	0.4	0.5	0.5	0.5
N_2O	0.2	0.2	0.2	0.1	0.3	0.3	0.2
HFCs	0.0	0.5	3.9	4.2	4.5	4.8	5.1
Rail	**39.0**	**51.4**	**39.7**	**34.2**	**35.5**	**35.6**	**33.9**
CO_2	38.5	50.8	39.1	33.7	34.9	35.0	33.4
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	0.115
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**	**58.5**	**58.5**	**64.9**	**72.0**	**71.3**
CO_2	36.0	32.8	58.5	58.5	64.9	72.0	71.3
Lubricants	**11.8**	**10.2**	**8.8**	**7.8**	**8.0**	**8.7**	**6.6**
CO_2	11.8	10.2	8.8	7.8	8.0	8.7	6.6
Total Transportation	**1,523.9**	**1,976.6**	**1,878.5**	**1,628.9**	**1,809.5**	**1,808.6**	**1,827.7**
International Bunker Fuels [f]	54.7	44.6	26.2	22.7	22.7	25.3	23.5
Ethanol CO_2 [g]	4.1	21.6	78.7	68.1	75.4	75.0	76.4
Biodiesel CO_2 [g]	0.0	0.9	17.1	17.7	16.1	15.6	18.2

+ 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, 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.

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 (e.g., powering industrial machinery), accounted for 29.2 percent of U.S. greenhouse gas emissions in 2023. This end-use sector also includes emissions that are produced as a byproduct of the non-energy-related industrial process activities. Various activities produce these non-energy-related emissions, including 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.

Since 1990, industry sector emissions have declined by 24.4 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.

Commercial

The commercial end-use sector, including electricity-related emissions, accounted for 15.6 percent of U.S. greenhouse gas emissions in 2023. Like the residential sector it is heavily reliant on electricity for meeting energy needs, with electricity use for building-related activities like 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.

Residential

The residential end-use sector, including electricity-related emissions, accounted for 14.4 percent of U.S. greenhouse gas emissions in 2023. This sector is heavily reliant on electricity for meeting energy needs, with electricity use for building-related activities like 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.

Agriculture

The agriculture end-use sector accounted for 11.0 percent of U.S. greenhouse gas emissions in 2023 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 2023, 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. Indirect emissions from electricity use in agricultural activities (e.g., powering buildings and equipment) are about 5 percent of direct emissions.

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.

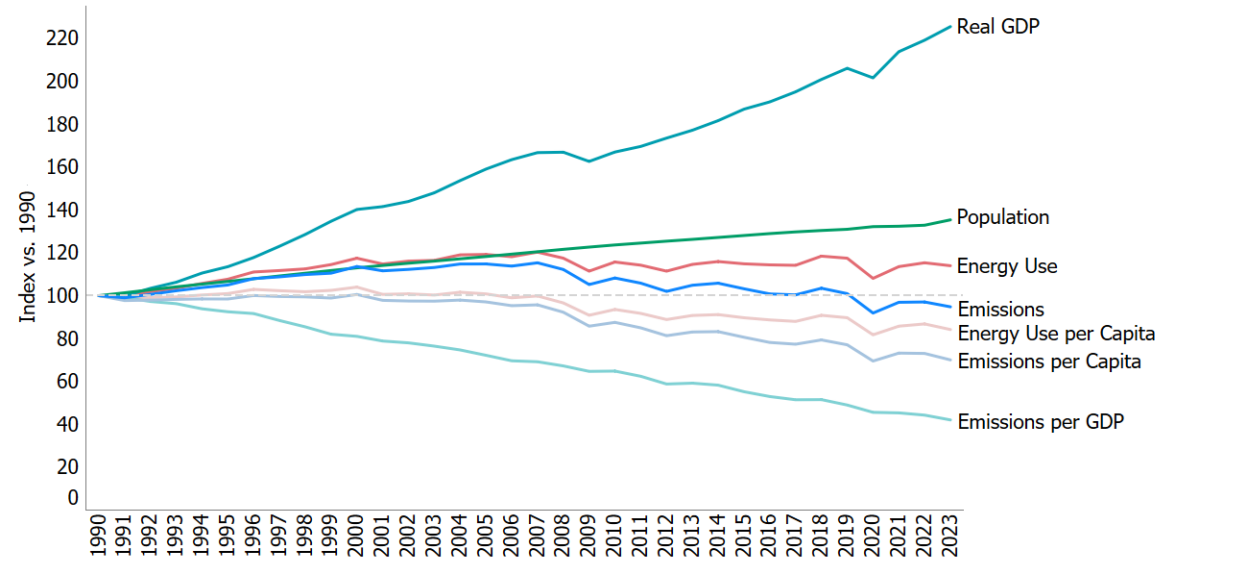
Table 2-14 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. These values represent the relative change in each statistic since 1990. Greenhouse gas emissions in the United States have decreased at an average annual rate of 0.1 percent 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 1.0 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	2019	2020	2021	2022	2023	Avg. Annual Change Since 1990[a]	Avg. Annual Change Since 2005[a]
Greenhouse Gas Emissions[b]	100	115	101	92	97	97	95	-0.1%	-1.0%
Energy Use[c]	100	119	117	107	113	115	113	0.4%	-0.2%
GDP[d]	100	159	206	202	214	219	225	2.5%	2.0%
Population[e]	100	118	131	132	132	133	135	0.9%	0.8%

[a] Average annual growth rate.
[b] Gross total GWP-weighted values.
[c] Energy-content-weighted values (EIA 2025).
[d] GDP in chained 2017 dollars (BEA 2024).
[e] U.S. Census Bureau (2025).

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



Source: BEA (2024), U.S. Census Bureau (2025), and net estimates in this report.

2.3 Precursor Greenhouse Gas Emissions

This section summarizes emissions of compounds that are precursors to greenhouse gases, which include carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), ammonia (NH_3), and sulfur dioxide (SO_2). These gases are not 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. Primary sources of ammonia (NH_3) are livestock waste and fertilizer application, and additional contributions come from industrial processes and on-road vehicles. 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, NH_3, and SO_2 (EPA 2024), 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.[10] Precursor emission estimates for this report for 1990 through 2023 were obtained from data published on EPA's National Emissions Inventory (NEI) Air Pollutants Emissions Trends Data website (EPA 2024). For Table 2-15, NEI-reported emissions of CO, NO_x, SO_2, NH_3, and NMVOCs are recategorized from NEI Emissions Inventory System (EIS) source categories to those more closely aligned with reporting sectors and categories in this report, 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 (2024).

Table 2-15: Emissions of NO_x, CO, NMVOCs, NH_3, and SO_2 (kt)

Gas/Activity	1990	2005	2019	2020	2021	2022	2023
NO_x	**22,898**	**19,903**	**7,841**	**7,141**	**7,178**	**6,879**	**6,531**
Energy	21,966	18,863	7,048	6,237	6,300	6,103	5,823
IPPU	774	672	440	391	402	390	389
Agriculture	21	159	192	180	163	156	148
LULUCF	53	158	89	257	237	137	80
Waste	84	51	73	76	76	75	74
CO	**133,263**	**84,345**	**47,186**	**53,144**	**52,559**	**46,803**	**41,849**
Energy	124,712	64,455	30,349	28,430	28,820	28,004	27,475
IPPU	4,096	1,701	1,011	852	899	885	882
Agriculture	407	7,393	9,431	8,665	8,257	8,853	8,638
LULUCF	3,069	9,618	5,214	13,855	13,241	7,721	3,513
Waste	979	1,178	1,181	1,342	1,343	1,340	1,340
NMVOCs	**20,975**	**14,372**	**10,893**	**10,891**	**10,999**	**10,858**	**10,772**
Energy	13,067	8,694	5,444	5,305	5,561	5,403	5,342
IPPU	6,982	3,668	2,996	3,364	3,505	3,403	3,403
Agriculture	57	1,858	2,297	2,048	1,761	1,881	1,856
LULUCF	NA	NA	NA	NA	NA	NA	NA
Waste	870	152	156	173	172	171	171

[10] 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/.

Gas/Activity	1990	2005	2019	2020	2021	2022	2023
NH_3	**511**	**2,763**	**2,935**	**3,021**	**3,190**	**2,839**	**2,834**
Energy	229	219	179	180	267	271	268
IPPU	193	117	65	57	56	56	56
Agriculture	16	2,408	2,672	2,700	2,783	2,429	2,427
LULUCF	NA	NA	NA	NA	NA	NA	NA
Waste	73	18	19	84	84	83	83
SO_2	**20,924**	**13,174**	**1,759**	**1,546**	**1,706**	**1,718**	**1,524**
Energy	19,398	12,312	1,344	1,173	1,315	1,341	1,151
IPPU	1,490	776	309	265	273	261	260
Agriculture	+	65	83	75	85	84	82
LULUCF	NA	NA	NA	NA	NA	NA	NA
Waste	36	20	23	33	32	31	31

+ Does not exceed 0.5 kt.
NA (Not Available)
Note: Totals by gas may not sum due to independent rounding.
Source: (EPA 2024) except for estimates from forest fires, grassland fires, and field burning of agricultural residues. Emission categories from EPA (2024) are aggregated into sectors and categories reported under Table ES-3.