2. Trends in Greenhouse Gas Emissions and Removals

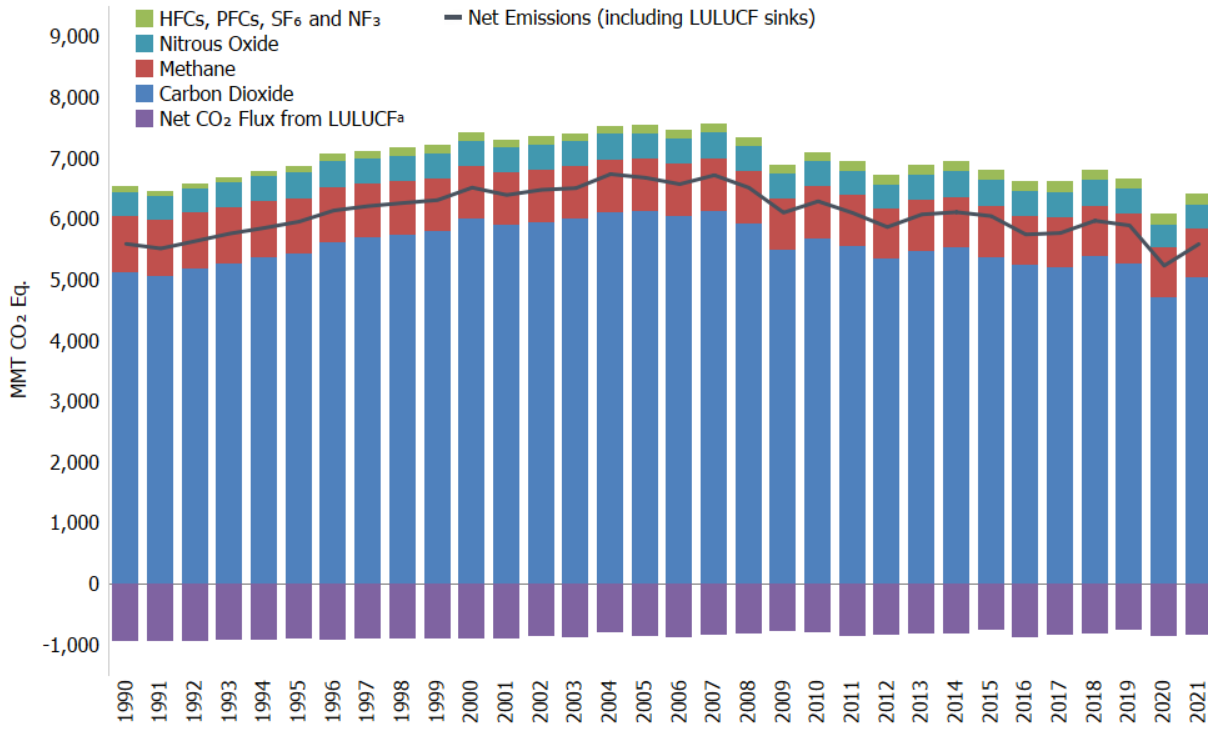
2.1 Overview of U.S. Greenhouse Gas Emissions and Sinks Trends

In 2021, total gross U.S. greenhouse gas emissions were 6,347.7 million metric tons of carbon dioxide equivalent (MMT CO_2 Eq).[1] Total U.S. emissions have decreased by 2.0 percent from 1990 to 2021, down from a high of 15.8 percent above 1990 levels in 2007. Emissions increased from 2020 to 2021 by 5.5 percent (333.2 MMT CO_2 Eq.). Net emissions (i.e., including sinks) were 5,593.5 MMT CO_2 Eq. in 2021. Overall, net emissions increased 6.8 percent from 2020 to 2021 and decreased 16.3 percent from 2005 levels, as shown in Table 2-1. Between 2020 and 2021, the increase in total greenhouse gas emissions was driven largely by an increase in CO_2 emissions from fossil fuel combustion due to economic activity rebounding after the COVID-19 pandemic. The CO_2 emissions from fossil fuel combustion increased by 7.0 percent from 2020 to 2021, including a 13.8 percent increase in transportation sector emissions and a 7.1 percent increase in the electric power sector emissions. The increase in electric power sector emissions was due to an increase in electricity demand of 2.1 percent since 2020, although the overall decrease in electric power sector emissions from 1990 through 2021 reflects the combined impacts of long-term trends in many factors, including population, economic growth, energy markets, technological changes including energy efficiency, and the carbon intensity of energy fuel choices. Between 2019 and 2021, there was still a decrease of 1.3 percent and 4.0 percent in CO_2 emissions from fossil fuel combustion from the transportation and electric power sectors, respectively.

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

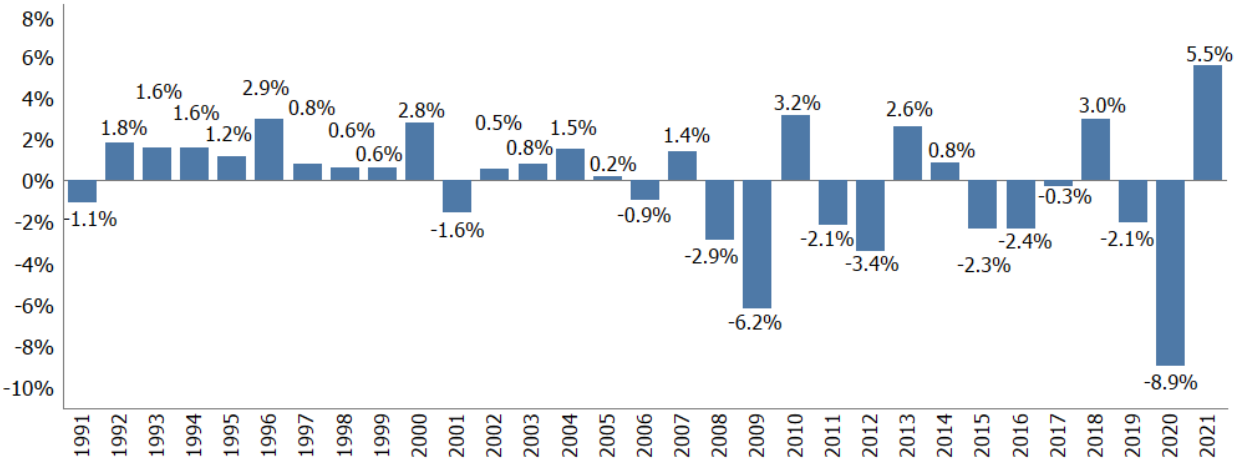
[1] The gross emissions total presented in this report for the United States excludes emissions and sinks from removals from Land Use, Land-Use Change, and Forestry (LULUCF). The net emissions total presented in this report for the United States includes emissions and sinks from removals from LULUCF.

Figure 2-1: 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 Percent Change in Gross U.S. Greenhouse Gas Emissions Relative to the Previous Year

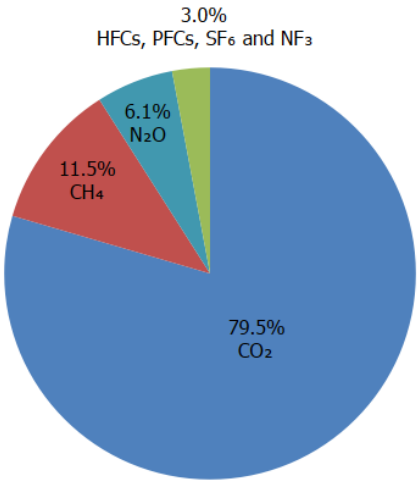


Emissions and Sinks by Gas

Figure 2-3 illustrates the relative contribution of the greenhouse gases to total gross U.S. emissions in 2021, 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 79.5 percent of total greenhouse gas emissions. The largest source of CO_2,

and of overall greenhouse gas emissions, is fossil fuel combustion primarily from transportation and power generation. Methane (CH_4) emissions account for 11.5 percent of emissions. The major sources of methane include enteric fermentation associated with domestic livestock, natural gas systems, and decomposition of wastes in landfills. Agricultural soil management, wastewater treatment, stationary sources of fuel combustion, and manure management are the major sources of N_2O emissions. Ozone depleting substance (ODS) substitute emissions were the primary contributor to aggregate hydrofluorocarbon (HFC) emissions. Perfluorocarbon (PFC) emissions were primarily attributable to electronics manufacturing and primary aluminum production. Electrical transmission and distribution systems accounted for most sulfur hexafluoride (SF_6) emissions. The electronics industry is the only source of nitrogen trifluoride (NF_3) emissions.

Figure 2-3: 2021 Gross Total U.S. Greenhouse Gas Emissions by Gas (Percentages based on MMT CO_2 Eq.)



Note: Emissions and removals from Land Use, Land-Use Change, and Forestry are excluded from figure above.

Overall from 1990 to 2021, total emissions of CO_2 decreased by 73.3 MMT CO_2 Eq. (1.4 percent), total emissions of methane (CH_4) decreased by 141.3 MMT CO_2 Eq. (16.3 percent), and total emissions of nitrous oxide (N_2O) decreased by 11.8 MMT CO_2 Eq. (3.0 percent). During the same period, emissions of fluorinated gases including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) rose by 95.9 MMT CO_2 Eq. (104.8 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, SF_6, and NF_3 are significant because many of them have extremely high global warming potentials (GWPs), and, in the cases of PFCs, SF_6, and NF_3, very long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by carbon (C) sequestration in managed forests, trees in urban areas, agricultural soils, landfilled yard trimmings, and coastal wetlands. These were estimated to offset 13.1 percent (832.0 MMT CO_2 Eq.) of total gross emissions in 2021.

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

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

Gas/Source	1990	2005	2017	2018	2019	2020	2021
CO_2	**5,121.4**	**6,132.4**	**5,212.1**	**5,378.0**	**5,259.8**	**4,714.4**	**5,048.2**
Fossil Fuel Combustion	4,728.2	5,747.3	4,852.5	4,989.8	4,853.4	4,344.8	4,651.0
Transportation	*1,468.9*	*1,858.6*	*1,780.1*	*1,812.9*	*1,813.9*	*1,572.5*	*1,789.4*
Electric Power Sector	*1,820.0*	*2,400.1*	*1,732.0*	*1,753.4*	*1,606.7*	*1,439.6*	*1,542.2*
Industrial	*852.4*	*850.8*	*789.0*	*813.5*	*815.9*	*767.9*	*762.4*

Residential	*338.6*	*358.9*	*293.4*	*338.2*	*341.4*	*313.2*	*310.1*
Commercial	*228.3*	*227.1*	*232.0*	*245.8*	*250.7*	*228.5*	*223.9*
U.S. Territories	*20.0*	*51.9*	*25.9*	*25.9*	*24.8*	*23.2*	*23.0*
Non-Energy Use of Fuels	112.4	128.9	112.8	129.4	127.6	119.2	143.2
Iron and Steel Production & Metallurgical Coke Production	104.7	70.1	40.8	42.9	43.1	37.7	42.0
Cement Production	33.5	46.2	40.3	39.0	40.9	40.7	41.3
Natural Gas Systems	32.4	25.2	31.8	33.0	38.7	36.3	36.8
Petrochemical Production	21.6	27.4	28.9	29.3	30.7	29.8	33.2
Petroleum Systems	9.5	10.2	24.5	36.1	46.9	29.1	24.7
Incineration of Waste	12.9	13.3	13.2	13.3	12.9	12.9	12.5
Ammonia Production	14.4	10.2	12.5	12.7	12.4	13.0	12.2
Lime Production	11.7	14.6	12.9	13.1	12.1	11.3	11.9
Other Process Uses of Carbonates	6.2	7.5	9.9	7.4	8.4	8.4	8.0
Urea Fertilization	2.4	3.5	4.9	4.9	5.0	5.1	5.2
Carbon Dioxide Consumption	1.5	1.4	4.6	4.1	4.9	5.0	5.0
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	5.2	6.1	6.2	5.8	5.0
Liming	4.7	4.4	3.1	2.2	2.2	2.9	3.0
Coal Mining	4.6	4.2	3.2	3.1	3.0	2.2	2.5
Glass Production	2.3	2.4	2.0	2.0	1.9	1.9	2.0
Soda Ash Production	1.4	1.7	1.8	1.7	1.8	1.5	1.7
Ferroalloy Production	2.2	1.4	2.0	2.1	1.6	1.4	1.6
Aluminum Production	6.8	4.1	1.2	1.5	1.9	1.7	1.5
Titanium Dioxide Production	1.2	1.8	1.7	1.5	1.5	1.2	1.5
Zinc Production	0.6	1.0	0.9	1.0	1.0	1.0	1.0
Phosphoric Acid Production	1.5	1.3	1.0	0.9	0.9	0.9	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.4
Carbide Production and Consumption	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Abandoned Oil and Gas Wells	+	+	+	+	+	+	+
Substitution of Ozone Depleting Substances	+	+	+	+	+	+	+
Magnesium Production and Processing	0.1	+	+	+	+	+	+
Biomass and Biofuel Consumption[a]	*237.9*	*245.4*	*328.9*	*336.0*	*333.1*	*305.6*	*313.3*
International Bunker Fuels[b]	*103.6*	*113.3*	*120.2*	*122.2*	*116.1*	*69.6*	*69.3*
CH_4[c]	**868.7**	**791.2**	**762.8**	**774.2**	**767.8**	**742.3**	**727.4**
Enteric Fermentation	183.1	188.2	195.9	196.8	197.3	196.2	194.9
Natural Gas Systems	215.1	203.4	186.4	194.4	193.6	185.4	181.4
Landfills	197.8	147.7	123.9	126.7	129.0	124.8	122.6
Manure Management	39.0	54.9	64.4	66.5	65.7	66.7	66.0
Petroleum Systems	51.3	50.9	61.9	60.6	59.9	54.5	50.2
Coal Mining	108.1	71.8	61.4	59.1	53.0	46.2	44.7
Wastewater Treatment	22.7	22.7	21.5	21.4	21.2	21.3	21.1
Rice Cultivation	17.9	20.2	16.7	17.4	16.9	17.6	16.8
Stationary Combustion	9.6	8.8	8.6	9.6	9.8	8.8	8.9
Abandoned Oil and Gas Wells	7.7	8.1	8.3	8.3	8.3	8.2	8.2
Abandoned Underground Coal Mines	8.1	7.4	7.2	6.9	6.6	6.5	6.4
Mobile Combustion	7.2	4.4	2.9	2.9	2.9	2.6	2.6
Composting	0.4	2.1	2.7	2.5	2.5	2.6	2.6
Field Burning of Agricultural Residues	0.4	0.5	0.5	0.5	0.5	0.5	0.5
Petrochemical Production	0.2	0.1	0.3	0.3	0.4	0.3	0.4

Anaerobic Digestion at Biogas Facilities	+	+	0.2	0.2	0.2	0.2	0.2
Ferroalloy Production	+	+	+	+	+	+	+
Carbide Production and Consumption	+	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O[c]	**396.7**	**405.1**	**402.8**	**418.5**	**399.1**	**377.7**	**384.8**
Agricultural Soil Management	278.4	280.8	298.7	312.1	298.2	279.3	285.2
Stationary Combustion	22.3	30.5	25.3	25.1	22.2	20.7	22.1
Wastewater Treatment	14.8	18.1	20.6	21.2	21.3	20.9	20.9
Manure Management	12.4	14.5	16.9	17.2	17.4	17.5	17.4
Mobile Combustion	38.4	37.0	18.5	17.5	19.0	16.1	17.1
Nitric Acid Production	10.8	10.1	8.3	8.5	8.9	8.3	7.9
Adipic Acid Production	13.5	6.3	6.6	9.3	4.7	7.4	6.6
N_2O from Product Uses	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Composting	0.3	1.5	1.9	1.8	1.8	1.8	1.8
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.5	1.9	1.3	1.3	1.2	1.2	1.2
Incineration of Waste	0.4	0.3	0.4	0.4	0.4	0.3	0.4
Electronics Industry	+	0.1	0.2	0.2	0.2	0.3	0.3
Field Burning of Agricultural Residues	0.1	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*	*1.0*	*0.9*	*0.5*	*0.5*
HFCs	**39.0**	**116.4**	**160.8**	**160.9**	**165.4**	**168.2**	**175.1**
Substitution of Ozone Depleting Substances[d]	0.3	99.4	156.1	157.7	161.9	166.1	172.4
HCFC-22 Production	38.6	16.8	4.3	2.7	3.1	1.8	2.2
Electronics Industry	0.2	0.2	0.3	0.3	0.3	0.3	0.4
Magnesium Production and Processing	NO	NO	0.1	0.1	0.1	0.1	+
PFCs	**21.8**	**6.1**	**3.8**	**4.3**	**4.0**	**3.9**	**3.5**
Electronics Industry	2.5	3.0	2.7	2.8	2.5	2.4	2.6
Aluminum Production	19.3	3.1	1.0	1.4	1.4	1.4	0.9
Substitution of Ozone Depleting Substances[d]	NO	+	+	+	+	+	+
Electrical Transmission and Distribution	NO	+	+	NO	+	+	+
SF_6	**30.5**	**15.5**	**7.2**	**7.1**	**7.8**	**7.5**	**8.0**
Electrical Transmission and Distribution	24.7	11.8	5.5	5.2	6.1	5.9	6.0
Magnesium Production and Processing	0.5	0.8	0.7	0.8	0.8	0.8	0.9
Electronics Industry	5.4	2.9	1.0	1.1	0.9	0.9	1.1
NF_3	**+**	**0.4**	**0.5**	**0.5**	**0.5**	**0.6**	**0.6**
Electronics Industry	+	0.4	0.5	0.5	0.5	0.6	0.6
Total Gross Emissions (Sources)	**6,478.3**	**7,466.9**	**6,550.0**	**6,743.4**	**6,604.4**	**6,014.5**	**6,347.7**
LULUCF Emissions[c]	**57.9**	**72.4**	**68.3**	**64.4**	**64.2**	**76.4**	**77.8**
CH_4	53.5	61.3	60.1	57.3	56.9	65.4	66.0
N_2O	4.4	11.1	8.3	7.0	7.3	11.0	11.8
LULUCF Carbon Stock Change[d]	**(938.9)**	**(853.5)**	**(842.5)**	**(829.5)**	**(768.2)**	**(852.5)**	**(832.0)**
LULUCF Sector Net Total[e]	**(881.0)**	**(781.1)**	**(774.2)**	**(765.1)**	**(704.0)**	**(776.2)**	**(754.2)**

Net Emissions (Sources and Sinks)	**5,597.3**	**6,685.8**	**5,775.8**	**5,978.3**	**5,900.3**	**5,238.3**	**5,593.5**

+ Does not exceed 0.05 MMT CO_2 Eq.

NO (Not Occurring)

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

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

[c] LULUCF emissions of CH_4 and N_2O are reported separately from gross emissions totals. LULUCF emissions include the CH_4 and N_2O emissions reported for Peatlands Remaining Peatlands, forest fires, drained organic soils, grassland fires, and Coastal Wetlands Remaining Coastal Wetlands; CH_4 emissions from Land Converted to Coastal Wetlands, Flooded Land Remaining Flooded Land, and Land Converted to Flooded Land; and N_2O emissions from forest soils and settlement soils. Refer to Table 2-8 for a breakout of emissions and removals for LULUCF by gas and source category.

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

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

[f] The LULUCF Sector Net Total is the net sum of all 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 (kt)

Gas/Source	1990	2005	2017	2018	2019	2020	2021
CO_2	**5,121,447**	**6,132,355**	**5,212,068**	**5,377,950**	**5,259,759**	**4,714,391**	**5,048,172**
Fossil Fuel Combustion	4,728,194	5,747,307	4,852,515	4,989,843	4,853,402	4,344,837	4,650,953
Transportation	*1,468,944*	*1,858,552*	*1,780,103*	*1,812,903*	*1,813,869*	*1,572,525*	*1,789,400*
Electric Power Sector	*1,819,951*	*2,400,057*	*1,732,033*	*1,753,432*	*1,606,721*	*1,439,563*	*1,542,206*
Industrial	*852,413*	*850,812*	*789,024*	*813,528*	*815,894*	*767,899*	*762,364*
Residential	*338,578*	*358,898*	*293,410*	*338,218*	*341,400*	*313,175*	*310,113*
Commercial	*228,298*	*227,130*	*231,999*	*245,838*	*250,703*	*228,463*	*223,854*
U.S. Territories	*20,011*	*51,858*	*25,947*	*25,924*	*24,815*	*23,211*	*23,016*
Non-Energy Use of Fuels	112,407	128,920	112,841	129,441	127,621	119,208	143,209
Iron and Steel Production & Metallurgical Coke Production	104,737	70,076	40,810	42,858	43,090	37,712	42,041
Cement Production	33,484	46,194	40,324	38,971	40,896	40,688	41,312
Natural Gas Systems	32,363	25,206	31,770	32,974	38,705	36,296	36,846
Petrochemical Production	21,611	27,383	28,890	29,314	30,702	29,780	33,170
Petroleum Systems	9,519	10,221	24,462	36,102	46,874	29,081	24,667
Incineration of Waste	12,900	13,254	13,161	13,339	12,948	12,921	12,476
Ammonia Production	14,404	10,234	12,481	12,669	12,401	13,006	12,207
Lime Production	11,700	14,552	12,882	13,106	12,112	11,299	11,870
Other Process Uses of Carbonates	6,233	7,459	9,869	7,351	8,422	8,399	7,951
Urea Fertilization	2,417	3,504	4,862	4,939	5,030	5,122	5,214
Carbon Dioxide Consumption	1,472	1,375	4,580	4,130	4,870	4,970	4,990
Urea Consumption for Non-Agricultural Purposes	3,784	3,653	5,161	6,111	6,154	5,814	4,989
Liming	4,690	4,351	3,069	2,240	2,203	2,915	3,047
Coal Mining	4,606	4,170	3,153	3,141	2,992	2,198	2,456
Glass Production	2,262	2,401	1,984	1,989	1,940	1,858	1,969
Soda Ash Production	1,431	1,655	1,753	1,714	1,792	1,461	1,714
Ferroalloy Production	2,152	1,392	1,975	2,063	1,598	1,377	1,567
Aluminum Production	6,831	4,142	1,205	1,455	1,880	1,748	1,541

Titanium Dioxide Production	1,195	1,755	1,688	1,541	1,474	1,193	1,474
Zinc Production	632	1,030	900	999	1,026	977	969
Phosphoric Acid Production	1,529	1,342	1,025	937	909	901	909
Lead Production	516	553	513	527	531	464	446
Carbide Production and Consumption	243	213	181	184	175	154	172
Abandoned Oil and Gas Wells	7	7	7	7	8	7	7
Substitution of Ozone Depleting Substances	+	1	3	3	3	4	4
Magnesium Production and Processing	128	3	3	2	2	3	3
Biomass and Biofuel[a]	*237,946*	*245,421*	*328,888*	*335,973*	*333,059*	*305,562*	*313,346*
International Bunker Fuels[b]	*103,634*	*113,328*	*120,192*	*122,179*	*116,132*	*69,638*	*69,280*
CH_4[c]	**31,025**	**28,255**	**27,243**	**27,649**	**27,421**	**26,509**	**25,980**
Enteric Fermentation	6,539	6,722	6,998	7,028	7,046	7,007	6,962
Natural Gas Systems	7,682	7,263	6,657	6,943	6,915	6,620	6,479
Landfills	7,063	5,275	4,424	4,525	4,607	4,456	4,379
Manure Management	1,394	1,960	2,300	2,375	2,348	2,383	2,358
Petroleum Systems	1,833	1,819	2,209	2,165	2,138	1,945	1,791
Coal Mining	3,860	2,566	2,192	2,110	1,893	1,648	1,595
Wastewater Treatment	811	809	770	763	755	761	753
Rice Cultivation	640	720	596	623	602	630	600
Stationary Combustion	344	313	307	344	351	313	316
Abandoned Oil and Gas Wells	274	289	295	296	297	295	295
Abandoned Underground Coal Mines	288	264	257	247	237	232	228
Mobile Combustion	258	158	105	102	103	92	94
Composting	15	75	98	90	91	92	92
Field Burning of Agricultural Residues	15	17	17	17	17	17	17
Petrochemical Production	9	3	10	12	13	12	15
Anaerobic Digestion at Biogas Facilities	1	2	6	6	6	6	6
Ferroalloy Production	1	+	1	1	+	+	+
Carbide Production and Consumption	1	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	1	1	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*7*	*5*	*4*	*4*	*4*	*3*	*3*
N_2O[c]	**1,497**	**1,529**	**1,520**	**1,579**	**1,506**	**1,425**	**1,452**
Agricultural Soil Management	1,050	1,060	1,127	1,178	1,125	1,054	1,076
Stationary Combustion	84	115	95	95	84	78	83
Wastewater Treatment	56	68	78	80	80	79	79
Manure Management	47	55	64	65	65	66	66
Mobile Combustion	145	140	70	66	72	61	65
Nitric Acid Production	41	38	31	32	34	31	30
Adipic Acid Production	51	24	25	35	18	28	25
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	5	5	4	5
Incineration of Waste	2	1	1	1	1	1	1
Electronics Industry	+	+	1	1	1	1	1

Field Burning of Agricultural Residues	1	1	1	1	1	1	1
Petroleum Systems	+	+	+	+	+	+	+
Natural Gas Systems	+	+	+	+	+	+	+
International Bunker Fuels[b]	*3*	*3*	*4*	*4*	*3*	*2*	*2*
HFCs	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Substitution of Ozone Depleting Substances	M	M	M	M	M	M	M
HCFC-22 Production	3	1	+	+	+	+	+
Electronics Industry	M	M	M	M	M	M	M
Magnesium Production and Processing	NO	NO	+	+	+	+	+
PFCs	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Electronics Industry	M	M	M	M	M	M	M
Aluminum Production	M	M	M	M	M	M	M
Substitution of Ozone Depleting Substances[d]	+	+	+	+	+	+	+
Electrical Transmission and Distribution	+	+	+	+	+	+	+
SF_6	**1**	**1**	**+**	**+**	**+**	**+**	**+**
Electrical Transmission and Distribution	1	1	+	+	+	+	+
Magnesium Production and Processing	+	+	+	+	+	+	+
Electronics Industry	+	+	+	+	+	+	+
NF_3	+	+	+	+	+	+	+
Electronics Industry	+	+	+	+	+	+	+
CO	**130,085**	**66,912**	**34,752**	**32,827**	**32,279**	**31,496**	**30,713**
NO_x	**21,700**	**17,176**	**8,285**	**7,726**	**7,176**	**6,719**	**6,424**
SO_2	**20,935**	**13,193**	**2,302**	**2,210**	**1,798**	**1,615**	**1,706**
NMVOCs	**20,923**	**13,310**	**9,483**	**9,173**	**8,751**	**8,650**	**8,549**

+ Does not exceed 0.5 kt.
M (Mixture of multiple gases)
NO (Not Occurring)
[a] Emissions from Biomass and Biofuel Consumption are not included specifically in Energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for LULUCF.
[b] Emissions from International Bunker Fuels are not included in totals.
[c] LULUCF emissions of LULUCF CH_4 and N_2O are reported separately from gross emissions totals. Refer to Table 2-8 for a breakout of emissions and removals for LULUCF by gas and source category.
[d] Small amounts of PFC emissions also result from this source.
Notes: Totals by gas may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

Emissions by IPCC Sector

Emissions and removals of all gases can be summed from each source and sink category into a set of five sectors defined by the UNFCCC Reporting Guidelines and methodological framework provided by the Intergovernmental Panel on Climate Change (IPCC). Figure 2-4 and Table 2-3 illustrate that over the thirty-two-year period of 1990 to 2021, total emissions from the Energy and Waste sectors decreased by 155.6 MMT CO_2 Eq. (2.9 percent) and 66.8 MMT CO_2 Eq. (28.3 percent), respectively. Emissions from Industrial Processes and Product Use and Agriculture grew by 41.1 MMT CO_2 Eq. (12.2 percent) and 50.8 MMT CO_2 Eq. (9.4 percent), respectively. Over the same period, total C sequestration in the Land Use, Land-Use Change, and Forestry (LULUCF) sector decreased by 106.8 MMT CO_2 (11.4 percent decrease in total C sequestration), and emissions from the LULUCF sector increased by 19.9 MMT CO_2 Eq. (34.4 percent).

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

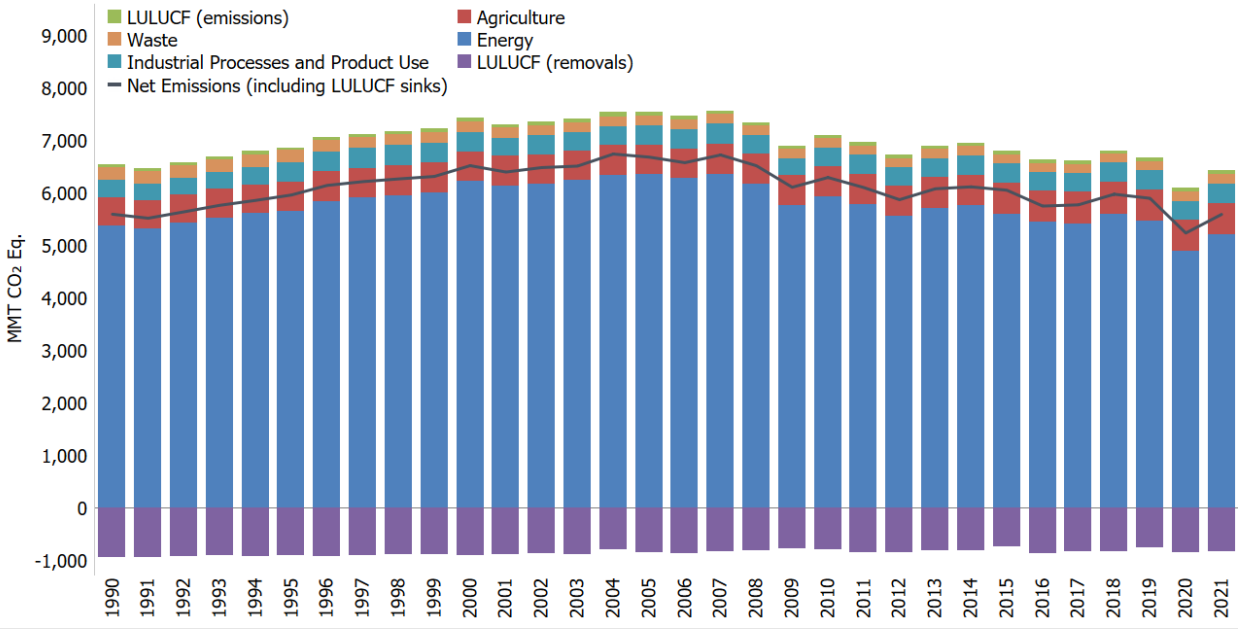


Table 2-3: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by IPCC Sector/Category (MMT CO_2 Eq.)

IPCC Sector/Category	1990	2005	2017	2018	2019	2020	2021
Energy	**5,368.2**	**6,351.8**	**5,418.8**	**5,589.7**	**5,458.3**	**4,893.8**	**5,212.5**
Fossil Fuel Combustion	4,728.2	5,747.3	4,852.5	4,989.8	4,853.4	4,344.8	4,651.0
Natural Gas Systems	247.5	228.6	218.2	227.4	232.3	221.7	218.3
Non-Energy Use of Fuels	112.4	128.9	112.8	129.4	127.6	119.2	143.2
Petroleum Systems	60.8	61.2	86.4	96.8	106.8	83.6	74.8
Coal Mining	112.7	76.0	64.5	62.2	56.0	48.3	47.1
Stationary Combustion[a]	31.9	39.3	33.9	34.7	32.0	29.4	30.9
Mobile Combustion[a]	45.6	41.4	21.5	20.4	21.9	18.7	19.8
Incineration of Waste	13.3	13.6	13.5	13.7	13.3	13.3	12.8
Abandoned Oil and Gas Wells	7.7	8.1	8.3	8.3	8.3	8.3	8.3
Abandoned Underground Coal Mines	8.1	7.4	7.2	6.9	6.6	6.5	6.4
Biomass and Biofuel Consumption[b]	*237.9*	*245.4*	*328.9*	*336.0*	*333.1*	*305.6*	*313.3*
International Bunker Fuels[c]	*104.6*	*114.3*	*121.2*	*123.2*	*117.1*	*70.3*	*69.9*
Industrial Processes and Product Use	**335.7**	**356.1**	**359.1**	**362.2**	**366.8**	**363.2**	**376.8**
Substitution of Ozone Depleting Substances	0.3	99.4	156.1	157.8	162.0	166.1	172.5
Iron and Steel Production & Metallurgical Coke Production	104.8	70.1	40.8	42.9	43.1	37.7	42.0
Cement Production	33.5	46.2	40.3	39.0	40.9	40.7	41.3
Petrochemical Production	21.9	27.5	29.2	29.7	31.1	30.1	33.6
Ammonia Production	14.4	10.2	12.5	12.7	12.4	13.0	12.2
Lime Production	11.7	14.6	12.9	13.1	12.1	11.3	11.9
Other Process Uses of Carbonates	6.2	7.5	9.9	7.4	8.4	8.4	8.0
Nitric Acid Production	10.8	10.1	8.3	8.5	8.9	8.3	7.9
Adipic Acid Production	13.5	6.3	6.6	9.3	4.7	7.4	6.6
Electrical Transmission and Distribution	24.7	11.8	5.5	5.2	6.1	5.9	6.0

Carbon Dioxide Consumption	1.5	1.4	4.6	4.1	4.9	5.0	5.0
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	5.2	6.1	6.2	5.8	5.0
Electronics Industry	3.3	4.5	4.6	4.7	4.3	4.4	4.8
N_2O from Product Uses	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Aluminum Production	26.1	7.2	2.2	2.9	3.3	3.2	2.5
HCFC-22 Production	38.6	16.8	4.3	2.7	3.1	1.8	2.2
Glass Production	2.3	2.4	2.0	2.0	1.9	1.9	2.0
Soda Ash Production	1.4	1.7	1.8	1.7	1.8	1.5	1.7
Ferroalloy Production	2.2	1.4	2.0	2.1	1.6	1.4	1.6
Titanium Dioxide Production	1.2	1.8	1.7	1.5	1.5	1.2	1.5
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.5	1.9	1.3	1.3	1.2	1.2	1.2
Magnesium Production and Processing	5.5	2.9	1.1	1.1	1.0	0.9	1.2
Zinc Production	0.6	1.0	0.9	1.0	1.0	1.0	1.0
Phosphoric Acid Production	1.5	1.3	1.0	0.9	0.9	0.9	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.4
Carbide Production and Consumption	0.3	0.2	0.2	0.2	0.2	0.2	0.2
Agriculture	**538.4**	**567.0**	**601.2**	**617.8**	**603.3**	**586.0**	**589.3**
Agricultural Soil Management	278.4	280.8	298.7	312.1	298.2	279.3	285.2
Enteric Fermentation	183.1	188.2	195.9	196.8	197.3	196.2	194.9
Manure Management	51.4	69.4	81.3	83.7	83.1	84.2	83.4
Rice Cultivation	17.9	20.2	16.7	17.4	16.9	17.6	16.8
Urea Fertilization	2.4	3.5	4.9	4.9	5.0	5.1	5.2
Liming	4.7	4.4	3.1	2.2	2.2	2.9	3.0
Field Burning of Agricultural Residues	0.6	0.7	0.7	0.6	0.6	0.6	0.6
Waste	**236.0**	**192.1**	**170.9**	**173.7**	**176.0**	**171.5**	**169.2**
Landfills	197.8	147.7	123.9	126.7	129.0	124.8	122.6
Wastewater Treatment	37.5	40.7	42.2	42.5	42.5	42.2	42.0
Composting	0.7	3.6	4.7	4.3	4.3	4.4	4.4
Anaerobic Digestion at Biogas Facilities	+	+	0.2	0.2	0.2	0.2	0.2
Total Gross Emissions[d] (Sources)	**6,478.3**	**7,466.9**	**6,550.0**	**6,743.4**	**6,604.4**	**6,014.5**	**6,347.7**
LULUCF Sector Net Total[e]	**(881.0)**	**(781.1)**	**(774.2)**	**(765.1)**	**(704.0)**	**(776.2)**	**(754.2)**
Forest Land	(914.2)	(793.9)	(793.5)	(791.2)	(736.3)	(782.2)	(768.7)
Cropland	31.6	25.6	34.3	39.7	41.7	33.4	37.6
Grassland	2.2	(28.4)	(12.9)	(12.3)	(8.7)	(19.3)	(14.0)
Wetlands	44.8	44.4	42.7	42.6	42.6	42.4	42.4
Settlements	(45.3)	(28.9)	(44.7)	(44.0)	(43.4)	(50.5)	(51.4)
Net Emission (Sources and Sinks)[f]	**5,597.3**	**6,685.8**	**5,775.8**	**5,978.3**	**5,900.3**	**5,238.3**	**5,593.5**

+ 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 Biodiesel Consumption are not included specifically in summing Energy sector totals. Net carbon fluxes from changes in biogenic carbon reservoirs are accounted for in the estimates for LULUCF.

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

[d] Total emissions without LULUCF.

[e] LULUCF emissions of CH_4 and N_2O are reported separately from gross emissions totals. LULUCF emissions include the CH_4 and N_2O emissions reported for Peatlands Remaining Peatlands, forest fires, drained organic soils, grassland fires, and Coastal Wetlands Remaining Coastal Wetlands; CH_4 emissions from Land Converted to Coastal Wetlands, Flooded Land Remaining Flooded Land, and Land Converted to Flooded Land; and N_2O emissions from forest soils and settlement soils. Refer to Table 2-8 for a breakout of emissions and removals for LULUCF by gas and source category.

[f] Net emissions with LULUCF.

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

Energy

Emissions from energy-related activities come from two main categories, including direct emissions associated with fuel use (i.e., fossil fuel combustion, non-energy use of fossil fuels and waste combustion) and 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 for the period of 1990 through 2021. Fossil fuel combustion is the largest source of energy-related emissions, with CO_2 being the primary gas emitted (see Figure 2-5). Due to their relative importance, fossil fuel combustion-related CO_2 emissions are considered in detail in the Energy chapter (see Chapter 3).

In 2021, 79.3 percent of the energy used in the United States on a Btu basis was produced through the combustion of fossil fuels. The remaining 20.7 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 (41.6 percent and 10.3 percent of total U.S. emissions of each gas, respectively). Table 2-4 presents greenhouse gas emissions from the Energy chapter by source and gas.

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

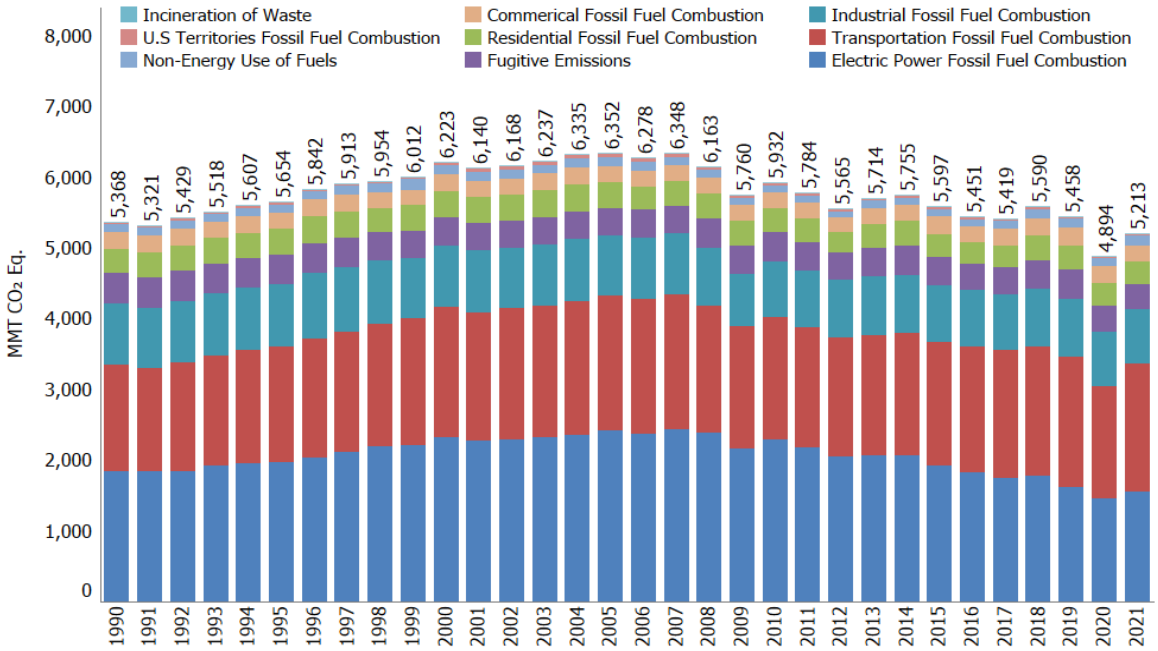


Table 2-4: Emissions from Energy (MMT CO_2 Eq.)[2]

Gas/Source	1990	2005	2017	2018	2019	2020	2021
CO_2	**4,900.0**	**5,929.1**	**5,037.9**	**5,204.8**	**5,082.5**	**4,544.5**	**4,870.6**
Fossil Fuel Combustion	4,728.2	5,747.3	4,852.5	4,989.8	4,853.4	4,344.8	4,651.0
Transportation	*1,468.9*	*1,858.6*	*1,780.1*	*1,812.9*	*1,813.9*	*1,572.5*	*1,789.4*
Electricity Generation	*1,820.0*	*2,400.1*	*1,732.0*	*1,753.4*	*1,606.7*	*1,439.6*	*1,542.2*
Industrial	*852.4*	*850.8*	*789.0*	*813.5*	*815.9*	*767.9*	*762.4*
Residential	*338.6*	*358.9*	*293.4*	*338.2*	*341.4*	*313.2*	*310.1*

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

Commercial	*228.3*	*227.1*	*232.0*	*245.8*	*250.7*	*228.5*	*223.9*
U.S. Territories	*20.0*	*51.9*	*25.9*	*25.9*	*24.8*	*23.2*	*23.0*
Non-Energy Use of Fuels	112.4	128.9	112.8	129.4	127.6	119.2	143.2
Natural Gas Systems	32.4	25.2	31.8	33.0	38.7	36.3	36.8
Petroleum Systems	9.5	10.2	24.5	36.1	46.9	29.1	24.7
Incineration of Waste	12.9	13.3	13.2	13.3	12.9	12.9	12.5
Coal Mining	4.6	4.2	3.2	3.1	3.0	2.2	2.5
Abandoned Oil and Gas Wells	+	+	+	+	+	+	+
Biomass-Wood [a]	*215.2*	*206.9*	*212.0*	*220.0*	*217.7*	*200.4*	*202.8*
Biofuels-Ethanol [a]	*4.2*	*22.9*	*82.1*	*81.9*	*82.6*	*71.8*	*79.1*
International Bunker Fuels[b]	*103.6*	*113.3*	*120.2*	*122.2*	*116.1*	*69.6*	*69.3*
Biofuels-Biodiesel [a]	*0.0*	*0.9*	*18.7*	*17.9*	*17.1*	*17.7*	*16.1*
Biofuels-MSW [a]	*18.5*	*14.7*	*16.1*	*16.1*	*15.7*	*15.6*	*15.3*
CH_4	**407.0**	**354.8**	**336.7**	**341.8**	**334.2**	**312.0**	**302.3**
Natural Gas Systems	215.1	203.4	186.4	194.4	193.6	185.4	181.4
Petroleum Systems	51.3	50.9	61.9	60.6	59.9	54.5	50.2
Coal Mining	108.1	71.8	61.4	59.1	53.0	46.2	44.7
Stationary Combustion	9.6	8.8	8.6	9.6	9.8	8.8	8.9
Abandoned Oil and Gas Wells	7.7	8.1	8.3	8.3	8.3	8.2	8.2
Abandoned Underground Coal Mines	8.1	7.4	7.2	6.9	6.6	6.5	6.4
Mobile Combustion	7.2	4.4	2.9	2.9	2.9	2.6	2.6
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O	**61.1**	**67.9**	**44.2**	**43.1**	**41.5**	**37.2**	**39.6**
Stationary Combustion	22.3	30.5	25.3	25.1	22.2	20.7	22.1
Mobile Combustion	38.4	37.0	18.5	17.5	19.0	16.1	17.1
Incineration of Waste	0.4	0.3	0.4	0.4	0.4	0.3	0.4
Petroleum Systems	+	+	+	+	+	+	+
Natural Gas Systems	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.8*	*0.9*	*0.9*	*1.0*	*0.9*	*0.5*	*0.5*
Total	**5,368.2**	**6,351.8**	**5,418.8**	**5,589.7**	**5,458.3**	**4,893.8**	**5,212.5**

+ Does not exceed 0.05 MMT CO_2 Eq.

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

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

Note: Totals may not sum due to independent rounding.

Fossil Fuel Combustion CO_2 Emissions

As the largest contributor to U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion has accounted for approximately 74.9 percent of CO_2-equivalent total gross emissions on average across the time series. Within the United States, fossil fuel combustion accounted for 92.1 percent of CO_2 emissions in 2021. Emissions from this source category include CO_2 associated with the combustion of fossil fuels (coal, natural gas, and petroleum) for energy use. Fossil fuel combustion CO_2 emissions decreased by 1.6 percent (77.2 MMT CO_2 Eq.) from 1990 to 2021 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 1,096.4 MMT CO_2 Eq. since 2005, representing a decrease of 19.1 percent. From 2020 to 2021, these emissions increased by 7.0 percent (306.1 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. Carbon dioxide emissions from coal combustion gradually increased between 1990 and 2007, then began to decrease at a faster rate from 2008 to

2021. Carbon dioxide emissions from natural gas combustion remained relatively constant, with a slight increase between 1990 and 2009, then began to consistently increase between 2010 and 2019. The replacement of coal combustion with natural gas combustion was largely driven by new discoveries of natural gas fields and advancements in drilling technologies, which led to more competitive natural gas prices. On an annual basis, the overall consumption and mix of fossil fuels in the United States fluctuates primarily in response to changes in general economic conditions, overall energy prices, the relative price of different fuels, weather, and the availability of non-fossil alternatives. For example, coal consumption for electric power is influenced by a number of factors, including the relative price of coal and alternative sources, the ability to switch fuels, and longer-term trends in coal markets. Between 2020 and 2021, coal consumption for electric power increased 15.4 percent, a reversal of the overall trend since 2008. However, this followed a 19.2 percent reduction in coal generation between 2019 and 2020 due in part to the COVID-19 pandemic reducing overall demand for fossil fuels across all sectors. There has been a 35.7 percent reduction in overall CO_2 emissions from electric power generation from 2005 to 2021 (see Figure 2-7), reflecting the continued shift in the share of electric power generation from coal to natural gas and renewables since 2005.

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 C content of natural gas (see Table 3-12 in Chapter 3 for more detail on electricity generation by source and see Table A-22 in Annex 2.1 for more detail on the C 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) have increased by 13.9 percent since 2020. This trend can be primarily attributed to a 11.2 percent increase in vehicle miles traveled (VMT) from 2020 to 2021 due to the gradual recovery from the COVID-19 pandemic, which limited travel in 2020. From 2019 to 2021, emissions from petroleum consumption for transportation (including bunker fuels) decreased by 1.7 percent following a decrease of 1.0 percent in VMT over that time period. Fuel economy of light-duty vehicles is another important factor. The decline in new light-duty vehicle fuel economy between 1990 and 2004 reflected the increasing market share of light-duty trucks, which grew from about 30 percent of new vehicle sales in 1990 to 48 percent in 2004. Starting in 2005, average new vehicle fuel economy began to increase while light-duty VMT grew only modestly for much of the period and has slowed the rate of increase of CO_2 emissions.

Overall, across all sectors, there was a 7.0 percent increase in total CO_2 emissions from fossil fuel combustion from 2020 to 2021.

Trends in CO_2 emissions from fossil fuel combustion, separated by end-use sector, are presented in Table 2-5 and Figure 2-6 based on the underlying U.S. energy consumer data collected by the U.S. Energy Information Administration (EIA). Figure 2-7 further describes trends in direct and indirect CO_2 emissions from fossil fuel combustion, separated by end-use sector. Estimates of CO_2 emissions from fossil fuel combustion are calculated from these EIA "end-use sectors" based on total fuel consumption and appropriate fuel properties described below. (Any additional analysis and refinement of the EIA data is further explained in the Energy chapter of this report.)

- *Transportation.* EIA's fuel consumption data for the transportation sector consists of all vehicles whose primary purpose is transporting people and/or goods from one physical location to another.
- *Electric Power.* EIA's fuel consumption data for the electric power sector are comprised of electricity-only and combined-heat-and-power (CHP) plants within the North American Industry Classification System (NAICS) 22 category whose primary business is to sell electricity, or electricity and heat, to the public. (Non-utility power producers are included in this sector as long as they meet the electric power sector definition.)
- *Industry.* EIA statistics for the industrial sector include fossil fuel consumption that occurs in the fields of manufacturing, agriculture, mining, and construction. EIA's fuel consumption data for the industrial sector consist of all facilities and equipment used for producing, processing, or assembling goods. (EIA includes

generators that produce electricity and/or useful thermal output primarily to support on-site industrial activities in this sector.)

- *Residential.* EIA's fuel consumption data for the residential sector consist of living quarters for private households.
- *Commercial.* EIA's fuel consumption data for the commercial sector consist of service-providing facilities and equipment from private and public organizations and businesses. (EIA includes generators that produce electricity and/or useful thermal output primarily to support the activities at commercial establishments in this sector.)

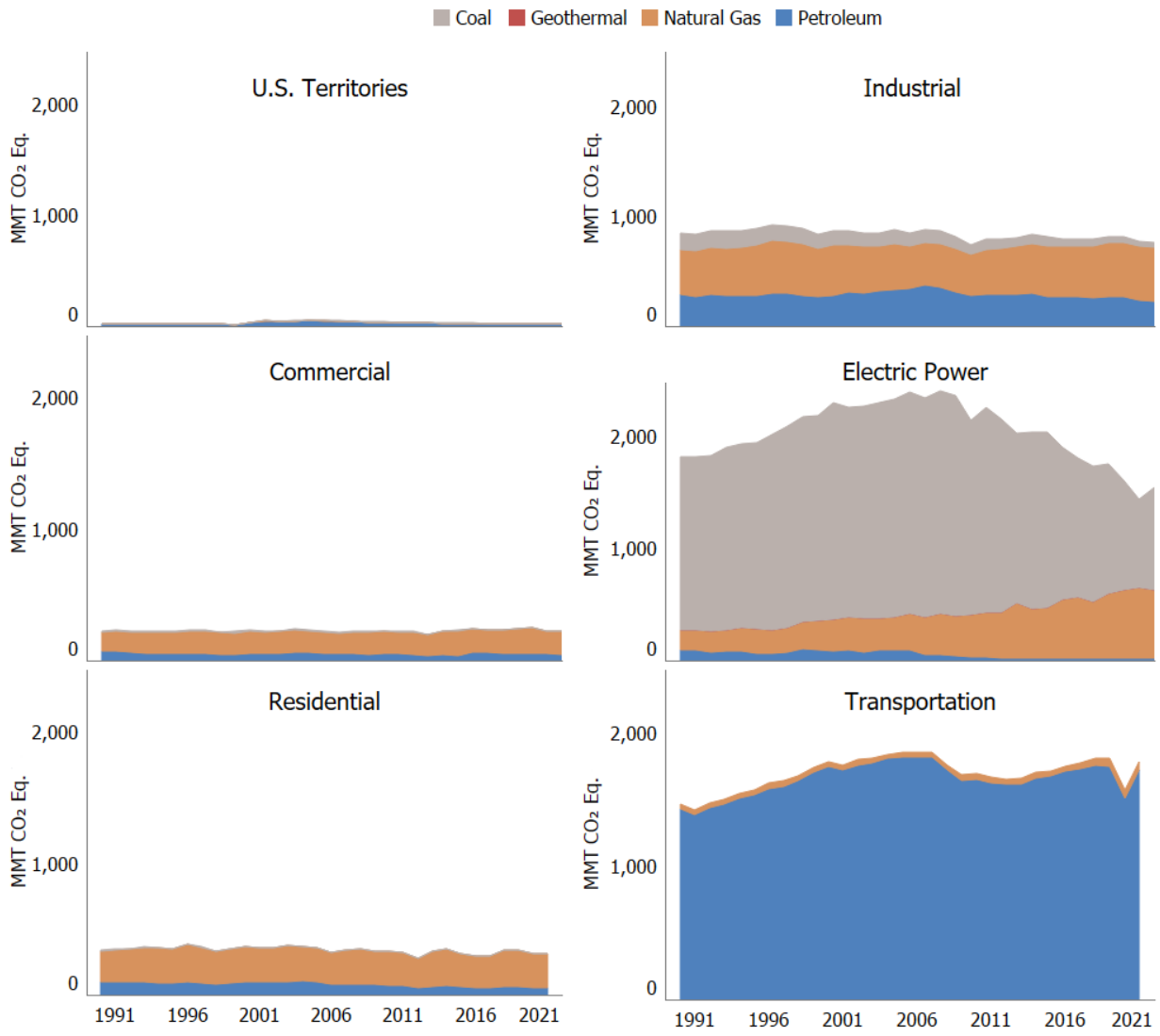
Table 2-5: CO_2 Emissions from Fossil Fuel Combustion by End-Use Sector (MMT CO_2 Eq.)

End-Use Sector	1990	2005	2017	2018	2019	2020	2021
Transportation	**1,472.0**	**1,863.3**	**1,784.4**	**1,817.7**	**1,818.7**	**1,576.6**	**1,794.5**
Combustion	1,468.9	1,858.6	1,780.1	1,812.9	1,813.9	1,572.5	1,789.4
Electricity	3.0	4.7	4.3	4.8	4.8	4.1	5.1
Industrial	**1,538.8**	**1,587.1**	**1,293.4**	**1,314.9**	**1,281.4**	**1,177.7**	**1,202.8**
Combustion	852.4	850.8	789.0	813.5	815.9	767.9	762.4
Electricity	686.4	736.3	504.4	501.3	465.5	409.8	440.5
Residential	**931.3**	**1,214.9**	**910.5**	**980.5**	**925.1**	**858.5**	**887.3**
Combustion	338.6	358.9	293.4	338.2	341.4	313.2	310.1
Electricity	592.7	856.0	617.1	642.3	583.7	545.3	577.2
Commercial	**766.0**	**1,030.1**	**838.2**	**850.9**	**803.4**	**708.8**	**743.3**
Combustion	228.3	227.1	232.0	245.8	250.7	228.5	223.9
Electricity	537.7	803.0	606.2	605.0	552.7	480.3	519.5
U.S. Territories[a]	**20.0**	**51.9**	**25.9**	**25.9**	**24.8**	**23.2**	**23.0**
Total	**4,728.2**	**5,747.3**	**4,852.5**	**4,989.8**	**4,853.4**	**4,344.8**	**4,651.0**
Electric Power	**1,820.0**	**2,400.1**	**1,732.0**	**1,753.4**	**1,606.7**	**1,439.6**	**1,542.2**

[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.

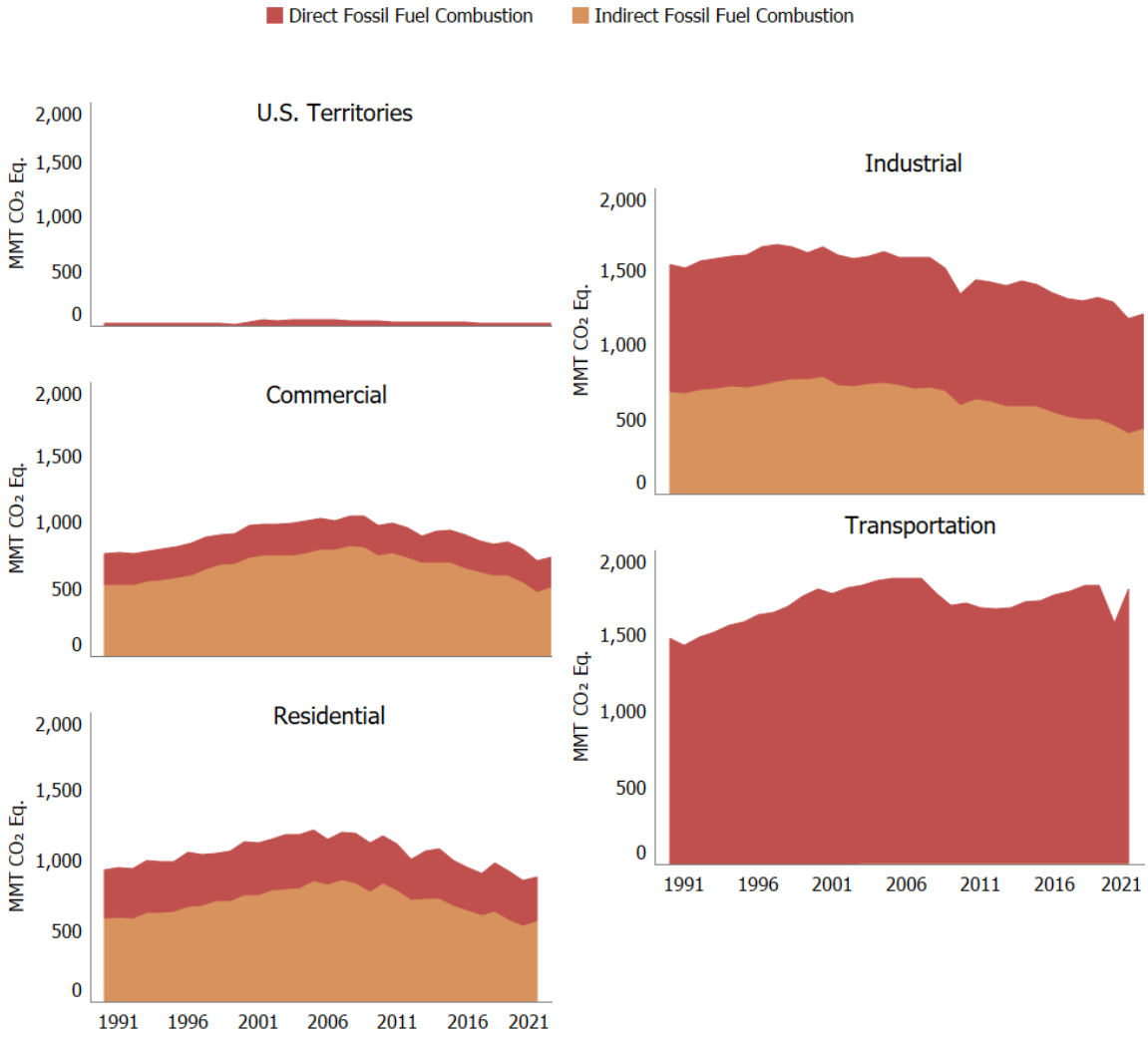
Notes: Combustion-related emissions from electric power are allocated based on aggregate national electricity use by each end-use sector. Totals may not sum due to independent rounding.

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



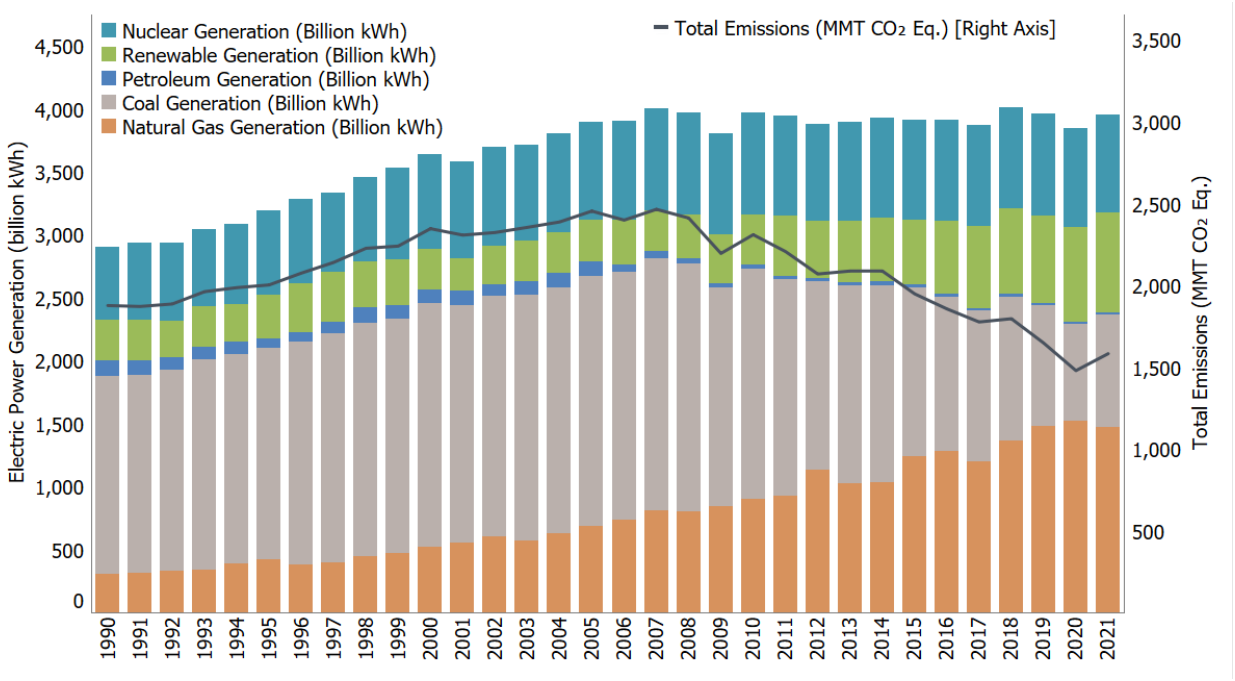
Note: Fossil Fuel Combustion for electric power also includes emissions of less than 0.5 MMT CO_2 Eq. from geothermal-based generation.

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



Electric power was the second largest emitter of CO_2 in 2021 (surpassed by transportation in 2017); electric power generators used 30.7 percent of U.S. energy from fossil fuels and emitted 33.2 percent of the CO_2 from fossil fuel combustion in 2021. Changes in electricity demand and the carbon intensity of fuels used for electric power generation have a significant impact on CO_2 emissions. Carbon dioxide emissions from fossil fuel combustion from the electric power sector have decreased by 15.3 percent since 1990, and the carbon intensity of the electric power sector, in terms of CO_2 Eq. per QBtu input, has significantly decreased by 24.9 percent during that same timeframe. This decoupling of electric power generation and the resulting CO_2 emissions is shown below in Figure 2-8.

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



Electric power CO_2 emissions can also be allocated to the end-use sectors that use electricity, as presented in Table 2-5. With electricity CO_2 emissions allocated to end-use sectors, the transportation end-use sector represents the largest source of fossil fuel combustion emissions accounting for 1,794.5 MMT CO_2 Eq. in 2021 or 38.6 percent of total CO_2 emissions from fossil fuel combustion. The industrial end-use sector accounted for 24.3 percent of CO_2 emissions from fossil fuel combustion when including allocated electricity emissions. The residential and commercial end-use sectors accounted for 19.1 and 16.0 percent, respectively, of CO_2 emissions from fossil fuel combustion when including allocated electricity emissions. Both of these end-use sectors were heavily reliant on electricity for meeting energy needs, with electricity use for lighting, heating, air conditioning, and operating appliances contributing 65.1 and 69.9 percent of emissions from the residential and commercial end-use sectors, respectively.

Other Significant Energy Sector Trends

Other significant trends in emissions from energy source categories (Figure 2-6 and Figure 2-7) over the thirty-two-year period from 1990 through 2021 included the following:

- Methane emissions from natural gas systems and petroleum systems (combined here) decreased 34.8 MMT CO_2 Eq. (13.1 percent) from 1990 to 2021, from 266.4 MMT CO_2 Eq. in 1990 to 231.6 MMT CO_2 Eq. in 2021. Natural gas systems CH_4 emissions have decreased by 33.7 MMT CO_2 Eq. (15.7 percent) since 1990, largely due to a decrease in emissions from distribution, transmission and storage, processing, and exploration. The decrease in distribution is largely due to decreased emissions from pipelines and distribution station leaks, and the decrease in transmission and storage emissions is largely due to reduced compressor station emissions (including emissions from compressors and leaks). At the same time, emissions from the natural gas production segment increased. Methane emissions from natural gas systems decreased 2.1 percent between 2020 and 2021. Petroleum systems CH_4 emissions decreased by 1.2 MMT CO_2 Eq. (or 2.2 percent) since 1990 and 7.9 percent between 2020 and 2021. This decrease is due primarily to decreases in emissions from offshore platforms, tanks, and pneumatic controllers. Carbon dioxide emissions from natural gas and petroleum systems increased by 19.6 MMT CO_2 Eq. (46.9 percent) from 1990 to 2021. This increase is due primarily to increases in the production segment, where

flaring emissions from associated gas flaring, tanks, and miscellaneous production flaring have increased over time.

- Methane emissions from coal mining decreased by 63.4 MMT CO_2 Eq. (58.7 percent) from 1990 through 2021 and by 3.2 percent between 2020 and 2021 primarily due to a decrease in the number of active mines and annual coal production over this time period.
- Nitrous oxide emissions from mobile combustion decreased by 21.3 MMT CO_2 Eq. (55.4 percent) from 1990 through 2021, primarily as a result of national vehicle criteria pollutant emissions standards and emission control technologies for on-road vehicles. Emissions increased by 1.0 MMT CO_2 Eq. (6.0 percent) between 2020 and 2021 due to a gradual rebound in travel activity since the reduced travel seen in 2020 due to the COVID-19 pandemic.
- Carbon dioxide emissions from non-energy uses of fossil fuels increased by 30.8 MMT CO_2 Eq. (27.4 percent) from 1990 through 2021, and 20 percent (24.0 MMT CO_2 Eq.) between 2020 and 2021.Emissions from non-energy uses of fossil fuels were 143.2 MMT CO_2 Eq. in 2021, which constituted 2.8 percent of total national CO_2 emissions, approximately the same proportion as in 1990.
- Carbon dioxide emissions from incineration of waste (12.5 MMT CO_2 Eq. in 2021) decreased slightly by 0.4 MMT CO_2 Eq. (3.3 percent) from 1990 through 2021, as the volume of scrap tires and other fossil C-containing materials in waste decreased. Emissions decreased 0.4 MMT CO_2 Eq. (3.3 percent) between 2020 and 2021, consistent with trends across the time series.

Industrial Processes and Product Use

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

Second, industrial manufacturing processes and use by end-consumers also release HFCs, PFCs, SF_6, and NF_3 and other man-made compounds. In addition to the use of HFCs and some PFCs as substitutes for ozone depleting substances (ODS), fluorinated compounds such as HFCs, PFCs, SF_6, NF_3, and others are also emitted through use by a number of other industrial sources in the United States. These industries include the electronics industry, electric power transmission and distribution, and magnesium metal production and processing. In addition, N_2O is used in and emitted by the electronics industry and anesthetic and aerosol applications, and CO_2 is consumed and emitted through various end-use applications.

Emission sources in the Industrial Processes and Product Use (IPPU) chapter accounted for 5.9 percent of U.S. greenhouse gas emissions in 2021. Emissions from the IPPU sector increased by 12.2 percent from 1990 to 2021. The use of HFCs and PFCs as substitutes for ODS is the largest source of emissions in this sector, contributing 45.8 percent of IPPU emissions in 2021. Total emissions from IPPU increased 3.7 percent between 2020 and 2021, reversing the emissions reduction trend in 2020 from reduced industrial activity due to the COVID-19 pandemic. Despite the sectoral increase in emissions, emissions from aluminum, ammonia, lead, zinc, adipic acid, and nitric acid production all decreased from 2020 to 2021, along with emissions from other process uses of carbonates and urea consumption. Figure 2-9 presents greenhouse gas emissions from IPPU by source category.

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

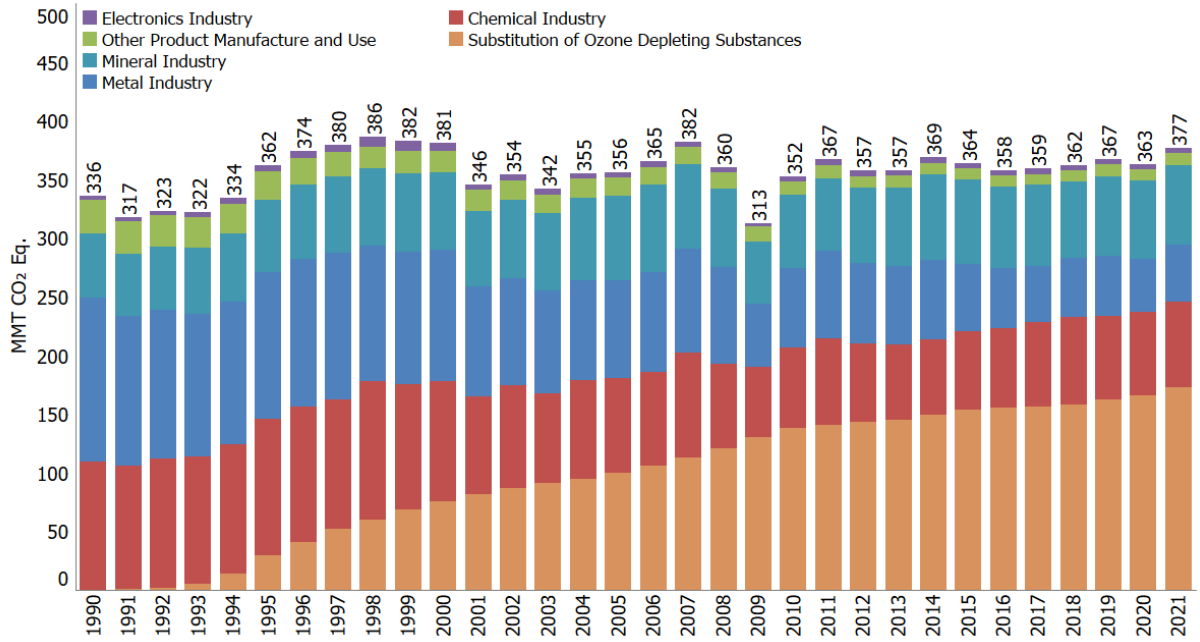


Table 2-6: Emissions from Industrial Processes and Product Use (MMT CO_2 Eq.)

Gas/Source	1990	2005	2017	2018	2019	2020	2021
CO_2	**214.3**	**195.4**	**166.2**	**165.9**	**170.0**	**161.8**	**169.3**
Iron and Steel Production & Metallurgical Coke Production	104.7	70.1	40.8	42.9	43.1	37.7	42.0
Iron and Steel Production	*99.1*	*66.2*	*38.8*	*41.6*	*40.1*	*35.4*	*38.8*
Metallurgical Coke Production	*5.6*	*3.9*	*2.0*	*1.3*	*3.0*	*2.3*	*3.2*
Cement Production	33.5	46.2	40.3	39.0	40.9	40.7	41.3
Petrochemical Production	21.6	27.4	28.9	29.3	30.7	29.8	33.2
Ammonia Production	14.4	10.2	12.5	12.7	12.4	13.0	12.2
Lime Production	11.7	14.6	12.9	13.1	12.1	11.3	11.9
Other Process Uses of Carbonates	6.2	7.5	9.9	7.4	8.4	8.4	8.0
Carbon Dioxide Consumption	1.5	1.4	4.6	4.1	4.9	5.0	5.0
Urea Consumption for Non-Agricultural Purposes	3.8	3.7	5.2	6.1	6.2	5.8	5.0
Glass Production	2.3	2.4	2.0	2.0	1.9	1.9	2.0
Soda Ash Production	1.4	1.7	1.8	1.7	1.8	1.5	1.7
Ferroalloy Production	2.2	1.4	2.0	2.1	1.6	1.4	1.6
Aluminum Production	6.8	4.1	1.2	1.5	1.9	1.7	1.5
Titanium Dioxide Production	1.2	1.8	1.7	1.5	1.5	1.2	1.5
Zinc Production	0.6	1.0	0.9	1.0	1.0	1.0	1.0
Phosphoric Acid Production	1.5	1.3	1.0	0.9	0.9	0.9	0.9
Lead Production	0.5	0.6	0.5	0.5	0.5	0.5	0.4
Carbide Production and Consumption	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Substitution of Ozone Depleting Substances	+	+	+	+	+	+	+
Magnesium Production and Processing	0.1	+	+	+	+	+	+
CH_4	**0.3**	**0.1**	**0.3**	**0.4**	**0.4**	**0.4**	**0.4**
Petrochemical Production	0.2	0.1	0.3	0.3	0.4	0.3	0.4
Ferroalloy Production	+	+	+	+	+	+	+
Carbide Production and Consumption	+	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+

Iron and Steel Production	+	+	+	+	+	+	+
Metallurgical Coke Production	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*
N_2O	**29.6**	**22.2**	**20.2**	**23.1**	**18.7**	**20.8**	**19.7**
Nitric Acid Production	10.8	10.1	8.3	8.5	8.9	8.3	7.9
Adipic Acid Production	13.5	6.3	6.6	9.3	4.7	7.4	6.6
N_2O from Product Uses	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.5	1.9	1.3	1.3	1.2	1.2	1.2
Electronics Industry	+	0.1	0.2	0.2	0.2	0.3	0.3
HFCs	**39.0**	**116.4**	**160.8**	**160.9**	**165.4**	**168.2**	**175.1**
Substitution of Ozone Depleting Substances[a]	0.3	99.4	156.1	157.7	161.9	166.1	172.4
HCFC-22 Production	38.6	16.8	4.3	2.7	3.1	1.8	2.2
Electronics Industry	0.2	0.2	0.3	0.3	0.3	0.3	0.4
Magnesium Production and Processing	NO	NO	0.1	0.1	0.1	0.1	+
PFCs	**21.8**	**6.1**	**3.8**	**4.3**	**4.0**	**3.9**	**3.5**
Electronics Industry	2.5	3.0	2.7	2.8	2.5	2.4	2.6
Aluminum Production	19.3	3.1	1.0	1.4	1.4	1.4	0.9
Substitution of Ozone Depleting Substances	NO	+	+	+	+	+	+
Electrical Transmission and Distribution	NO	+	+	NO	+	+	+
SF_6	**30.5**	**15.5**	**7.2**	**7.1**	**7.8**	**7.5**	**8.0**
Electrical Transmission and Distribution	24.7	11.8	5.5	5.2	6.1	5.9	6.0
Magnesium Production and Processing	5.4	2.9	1.0	1.1	0.9	0.9	1.1
Electronics Industry	0.5	0.8	0.7	0.8	0.8	0.8	0.9
NF_3	**+**	**0.4**	**0.5**	**0.5**	**0.5**	**0.6**	**0.6**
Electronics Industry	+	0.4	0.5	0.5	0.5	0.6	0.6
Total	**335.7**	**356.1**	**359.1**	**362.2**	**366.8**	**363.2**	**376.8**

+ Does not exceed 0.05 MMT CO_2 Eq.
NO (Not Occurring)
[a] Small amounts of PFC emissions also result from this source.
Note: Totals may not sum due to independent rounding.

Some significant trends in U.S. emissions from IPPU source categories over the thirty-two-year period from 1990 through 2021 included the following:

- HFC and PFC emissions resulting from the substitution of ODS (e.g., chlorofluorocarbons [CFCs]) have been increasing from small amounts in 1990 to 172.5 MMT CO_2 Eq. in 2021 (68,134.2 percent).
- Combined CO_2 and CH_4 emissions from iron and steel production and metallurgical coke production decreased by 11.5 percent from 2020 to 2021 to 42.0 MMT CO_2 Eq. and have declined overall by 62.7 MMT CO_2 Eq. (59.9 percent) from 1990 through 2021, due to restructuring of the industry. The trend in the United States has been a shift towards fewer integrated steel mills and more electric arc furnaces (EAFs). EAFs use scrap steel as their main input and generally have less on-site emissions.
- Carbon dioxide emissions from petrochemicals increased by 53.5 percent between 1990 and 2021 from 21.6 MMT CO_2 Eq. to 33.2 MMT CO_2 Eq. The increase in emissions is largely driven by a doubling of production of ethylene over that time period.
- Carbon dioxide emissions from ammonia production (12.2 MMT CO_2 Eq. in 2021) 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 23.4 percent (7.8 MMT CO_2 Eq.) from 1990 through 2021. They rose from 1990 through 2006 and then fell until 2009, due to a decrease in

demand for construction materials during the economic recession. Since 2010, CO_2 emissions from cement production have risen 31.4 percent (9.9 MMT CO_2 Eq.).

- HFC-23 emissions from HCFC-22 production decreased by 36.4 MMT CO_2 Eq. (94.2 percent) from 1990 to 2021 due to a reduction in the HFC-23 emission rate (kg HFC-23 emitted/kg HCFC-22 produced).

- PFC emissions from aluminum production decreased by 18.4 MMT CO_2 Eq. (95.3 percent) from 1990 to 2021, due to both industry emission reduction efforts and lower domestic aluminum production.

- SF_6 emissions from electrical transmission and distribution decreased by 18.7 MMT CO_2 Eq. (75.7 percent) from 1990 to 2021 due to industry emission reduction efforts.

Agriculture

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

In 2021, agricultural activities were responsible for emissions of 589.3 MMT CO_2 Eq., or 9.3 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 (48.4 percent) and were the largest source of U.S. N_2O emissions in 2021, accounting for 74.1 percent. Methane emissions from enteric fermentation and manure management represented 26.8 percent and 9.1 percent of total CH_4 emissions from anthropogenic activities, respectively, in 2021. Carbon dioxide emissions from the application of crushed limestone and dolomite (i.e., soil liming) and urea fertilization represented 0.2 percent of total CO_2 emissions from anthropogenic activities. Figure 2-10 and Table 2-7 illustrate agricultural greenhouse gas emissions by source and gas.

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

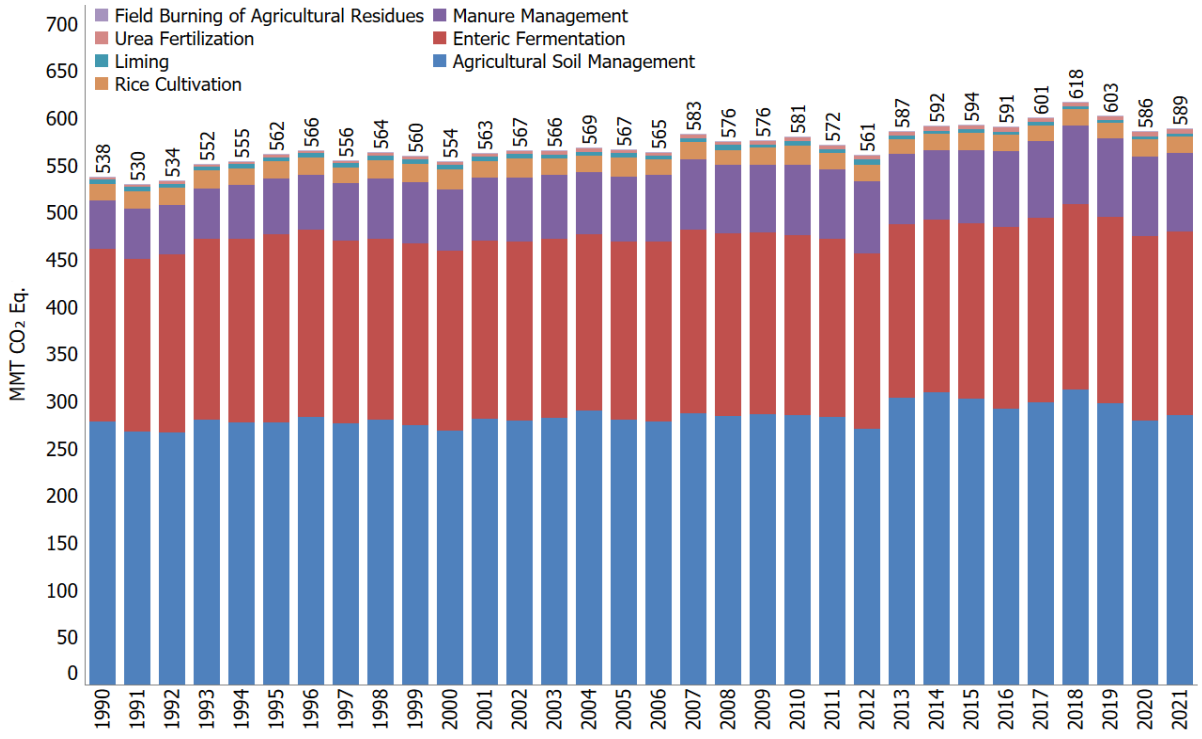


Table 2-7: Emissions from Agriculture (MMT CO_2 Eq.)

Gas/Source	1990	2005	2017	2018	2019	2020	2021
CO_2	**7.1**	**7.9**	**7.9**	**7.2**	**7.2**	**8.0**	**8.3**
Urea Fertilization	2.4	3.5	4.9	4.9	5.0	5.1	5.2
Liming	4.7	4.4	3.1	2.2	2.2	2.9	3.0
CH_4	**240.4**	**263.7**	**277.5**	**281.2**	**280.4**	**281.0**	**278.2**
Enteric Fermentation	183.1	188.2	195.9	196.8	197.3	196.2	194.9
Manure Management	39.0	54.9	64.4	66.5	65.7	66.7	66.0
Rice Cultivation	17.9	20.2	16.7	17.4	16.9	17.6	16.8
Field Burning of Agricultural Residues	0.4	0.5	0.5	0.5	0.5	0.5	0.5
N_2O	**290.9**	**295.4**	**315.7**	**329.4**	**315.7**	**297.0**	**302.8**
Agricultural Soil Management	278.4	280.8	298.7	312.1	298.2	279.3	285.2
Manure Management	12.4	14.5	16.9	17.2	17.4	17.5	17.4
Field Burning of Agricultural Residues	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Total	**538.4**	**567.0**	**601.2**	**617.8**	**603.3**	**586.0**	**589.3**

Note: Totals may not sum due to independent rounding.

Some significant trends in U.S. emissions from Agriculture source categories (Figure 2-10) over the thirty-two-year period from 1990 through 2021 included the following:

- Agricultural soils are the largest anthropogenic source of agriculture-related emissions and also N_2O emissions in the United States, accounting for 74.1 percent of N_2O emissions and 4.5 percent of total emissions in the United States in 2021. Estimated emissions from this source in 2021 were 285.2 MMT CO_2 Eq. Annual N_2O emissions from agricultural soils fluctuated between 1990 and 2021, and overall emissions were 6.8 MMT CO_2 Eq. or 2.5 percent higher in 2021 than in 1990. Year-to-year fluctuations are largely a reflection of annual variation in weather patterns, synthetic fertilizer use, and crop production.
- Enteric fermentation is the largest anthropogenic source of CH_4 emissions in the United States. In 2021, enteric fermentation CH_4 emissions were 26.8 percent of total CH_4 emissions (194.9 MMT CO_2 Eq.), which represents an increase of 11.9 MMT CO_2 Eq. (6.5 percent) since 1990. This increase in emissions from enteric fermentation from 1990 to 2021 generally follows the increasing trends in cattle populations. For example, from 1990 to 1995, emissions increased and then generally decreased from 1996 to 2004, mainly due to fluctuations in beef cattle populations and increased digestibility of feed for feedlot cattle. Emissions increased from 2005 to 2007, as both dairy and beef populations increased. Research indicates that the feed digestibility of dairy cow diets decreased during this period. Emissions decreased again from 2008 to 2014 as beef cattle populations again decreased. Emissions increased from 2014 to 2021, consistent with an increase in beef cattle population over those same years.
- Manure management emissions increased 62.3 percent between 1990 and 2021. This encompassed an increase of 69.2 percent for CH_4, from 39.0 MMT CO_2 Eq. in 1990 to 66.0 MMT CO_2 Eq. in 2021; and an increase of 40.5 percent for N_2O, from 12.4 MMT CO_2 Eq. in 1990 to 17.4 MMT CO_2 Eq. in 2021. The majority of the increase observed in CH_4 resulted from swine and dairy cattle manure, where emissions increased 38.3 and 124.3 percent, respectively, from 1990 to 2021. From 2020 to 2021, there was a 1.1 percent decrease in total CH_4 emissions from manure management, mainly due to minor shifts in the animal populations and the resultant effects on manure management system allocations.
- Liming and urea fertilization are the only sources of CO_2 emissions reported in the Agriculture sector. All other CO_2 emissions and removals (e.g., carbon stock changes from the management of croplands, etc.) are characterized in the LULUCF sector. Estimated emissions from these sources were 3.0 and 5.2 MMT CO_2 Eq., respectively. Liming emissions increased by 4.5 percent relative to 2020 and decreased 1.6 MMT CO_2 Eq. or 35.0 percent relative to 1990, while urea fertilization emissions increased by 1.8 percent relative to 2020 and 2.8 MMT CO_2 Eq. or 115.7 percent relative to 1990.

Land Use, Land-Use Change, and Forestry

When humans alter the terrestrial biosphere through land use, changes in land use, and land management practices, they also influence the carbon (C) stock fluxes on these lands and cause emissions of CH_4 and N_2O. Overall, managed land is a net sink for CO_2 (C sequestration) in the United States. The primary 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 C stocks in harvested wood pools. The net sequestration in Settlements Remaining Settlements, is driven primarily by C stock gains in urban forests (i.e., Settlement Trees) through net tree growth and increased urban area, as well as long-term accumulation of C in landfills from additions of yard trimmings and food scraps.

The LULUCF sector in 2021 resulted in a net increase in C stocks (i.e., net CO_2 removals) of 832.0 MMT CO_2 Eq. (Table 2-8).[3] This represents an offset of 13.1 percent of total (i.e., gross) greenhouse gas emissions in 2021. Emissions of CH_4 and N_2O from LULUCF activities in 2021 were 77.8 MMT CO_2 Eq. and represented 1.4 percent of net greenhouse gas emissions.[4] Between 1990 and 2021, total net C sequestration in the LULUCF sector decreased by 11.4 percent, primarily due to a decrease in the rate of net C accumulation in forests and Cropland Remaining Cropland, as well as an increase in CO_2 emissions from Land Converted to Settlements.

Flooded Land Remaining Flooded Land was the largest source of CH_4 emissions from LULUCF in 2021, totaling 45.4 MMT CO_2 Eq. (1,623 kt of CH_4). Forest fires were the second largest source of CH_4 emissions from LULUCF in 2021, totaling 15.5 MMT CO_2 Eq. (554 kt of CH_4). Coastal Wetlands Remaining Coastal Wetlands resulted in CH_4 emissions of 4.3 MMT CO_2 Eq. (154 kt of CH_4). Grassland fires resulted in CH_4 emissions of 0.3 MMT CO_2 Eq. (12 kt of CH_4). Land Converted to Wetlands, drained organic soils, and Peatlands Remaining Peatlands resulted in CH_4 emissions of less than 0.05 MMT CO_2 Eq. each.

Forest fires were the largest source of N_2O emissions from LULUCF in 2021, totaling 8.9 MMT CO_2 Eq. (34 kt of N_2O). Nitrous oxide emissions from fertilizer application to settlement soils in 2021 totaled to 2.1 MMT CO_2 Eq. (8 kt of N_2O). Additionally, the application of synthetic fertilizers to forest soils in 2021 resulted in N_2O emissions of 0.4 MMT CO_2 Eq. (2 kt of N_2O). Grassland fires resulted in N_2O emissions of 0.3 MMT CO_2 Eq. (1 kt of N_2O). Coastal Wetlands Remaining Coastal Wetlands and drained organic soils resulted in N_2O emissions of 0.5 MMT CO_2 Eq. each (0.5 kt of N_2O). Peatlands Remaining Peatlands resulted in N_2O emissions of less than 0.05 MMT CO_2 Eq. Figure 2-11 and Table 2-8 along with CH_4 and N_2O emissions (purple) for LULUCF source categories.

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

[4] 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 CO_2 Flux) from Land Use, Land-Use Change, and Forestry

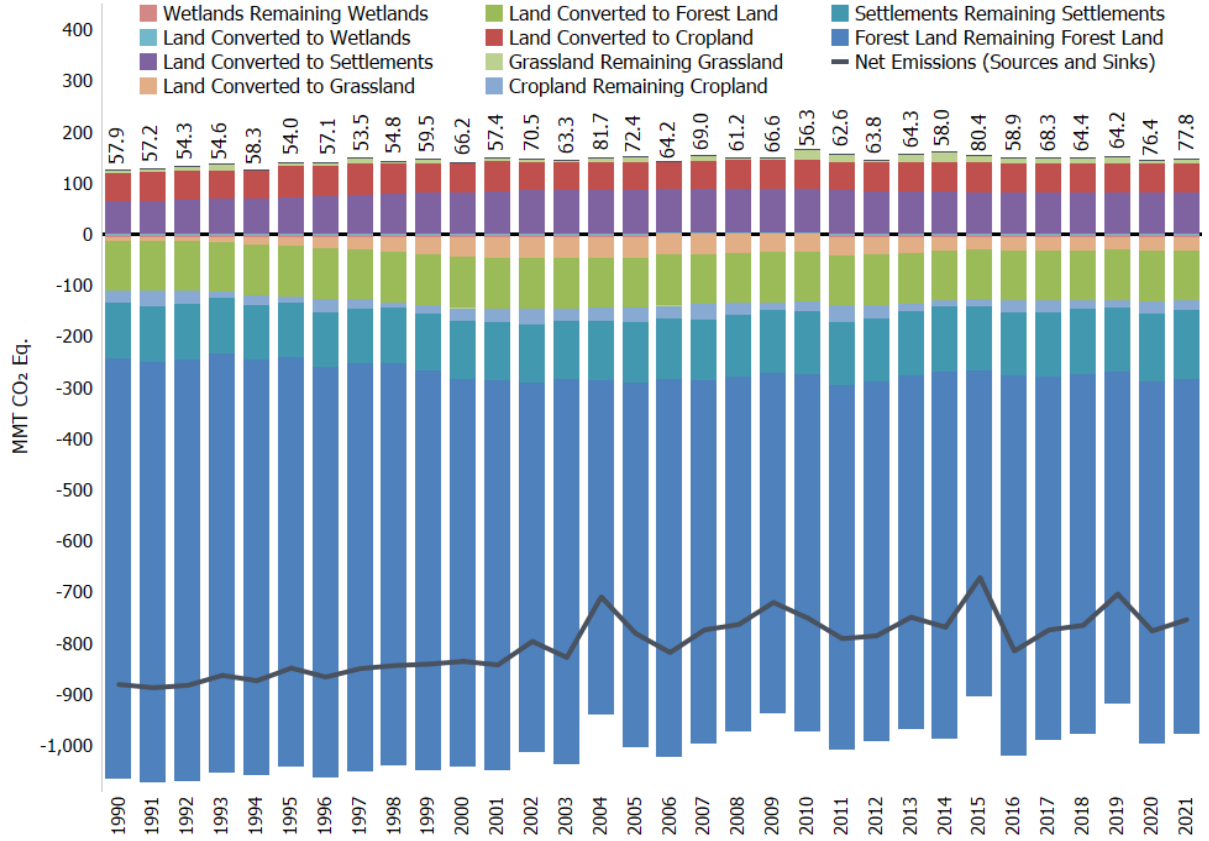


Table 2-8: U.S. Greenhouse Gas Emissions and Removals (Net Flux) from Land Use, Land-Use Change, and Forestry (MMT CO_2 Eq.)

Land-Use Category	1990	2005	2017	2018	2019	2020	2021
Forest Land Remaining Forest Land	**(815.8)**	**(695.4)**	**(695.2)**	**(692.9)**	**(638.1)**	**(684.0)**	**(670.5)**
Changes in Forest Carbon Stocks[a]	(821.4)	(714.2)	(710.7)	(704.4)	(649.3)	(707.4)	(695.4)
Non-CO_2 Emissions from Forest Fires[b]	5.5	18.3	15.0	11.0	10.8	23.0	24.4
N_2O Emissions from Forest Soils[c]	0.1	0.4	0.4	0.4	0.4	0.4	0.4
Non-CO_2 Emissions from Drained Organic Soils[d]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Land Converted to Forest Land	**(98.5)**	**(98.4)**	**(98.3)**	**(98.3)**	**(98.3)**	**(98.3)**	**(98.3)**
Changes in Forest Carbon Stocks[e]	(98.5)	(98.4)	(98.3)	(98.3)	(98.3)	(98.3)	(98.3)
Cropland Remaining Cropland	**(23.2)**	**(29.0)**	**(22.3)**	**(16.6)**	**(14.5)**	**(23.3)**	**(18.9)**
Changes in Mineral and Organic Soil Carbon Stocks	(23.2)	(29.0)	(22.3)	(16.6)	(14.5)	(23.3)	(18.9)
Land Converted to Cropland	**54.8**	**54.7**	**56.6**	**56.3**	**56.3**	**56.7**	**56.5**
Changes in all Ecosystem Carbon Stocks[f]	54.8	54.7	56.6	56.3	56.3	56.7	56.5
Grassland Remaining Grassland	**8.8**	**11.7**	**11.6**	**11.9**	**14.6**	**6.7**	**10.6**
Changes in Mineral and Organic Soil Carbon Stocks	8.7	11.0	10.9	11.3	14.0	6.0	10.0
Non-CO_2 Emissions from Grassland Fires[g]	0.2	0.7	0.6	0.6	0.6	0.6	0.6
Land Converted to Grassland	**(6.7)**	**(40.1)**	**(24.5)**	**(24.2)**	**(23.3)**	**(25.9)**	**(24.7)**
Changes in all Ecosystem Carbon Stocks[f]	(6.7)	(40.1)	(24.5)	(24.2)	(23.3)	(25.9)	(24.7)

Wetlands Remaining Wetlands	**41.5**	**43.1**	**41.8**	**41.8**	**41.8**	**41.8**	**41.8**
Changes in Organic Soil Carbon Stocks in Peatlands	1.1	1.1	0.8	0.8	0.8	0.7	0.7
Non-CO_2 Emissions from Peatlands Remaining Peatlands	+	+	+	+	+	+	+
Changes in Biomass, DOM, and Soil Carbon Stocks in Coastal Wetlands	(8.4)	(7.7)	(8.8)	(8.8)	(8.8)	(8.8)	(8.8)
CH_4 Emissions from Coastal Wetlands Remaining Coastal Wetlands	4.2	4.2	4.3	4.3	4.3	4.3	4.3
N_2O Emissions from Coastal Wetlands Remaining Coastal Wetlands	0.1	0.2	0.1	0.1	0.1	0.1	0.1
CH_4 Emissions from Flooded Land Remaining Flooded Land	44.6	45.3	45.4	45.4	45.4	45.4	45.4
Land Converted to Wetlands	**3.3**	**1.4**	**0.8**	**0.8**	**0.8**	**0.6**	**0.6**
Changes in Biomass, DOM, and Soil Carbon Stocks in Land Converted to Coastal Wetlands	0.5	0.5	(+)	(+)	(+)	(+)	(+)
CH_4 Emissions from Land Converted to Coastal Wetlands	0.3	0.3	0.2	0.2	0.2	0.2	0.2
Changes in Land Converted to Flooded Land	1.4	0.4	0.4	0.4	0.4	0.3	0.3
CH_4 Emissions from Land Converted to Flooded Land	1.1	0.3	0.3	0.3	0.3	0.2	0.2
Settlements Remaining Settlements	**(107.8)**	**(113.9)**	**(125.6)**	**(125.0)**	**(124.5)**	**(131.6)**	**(132.5)**
Changes in Organic Soil Carbon Stocks	11.3	12.2	16.0	15.9	15.9	15.9	15.9
Changes in Settlement Tree Carbon Stocks	(96.4)	(117.4)	(129.6)	(129.5)	(129.3)	(136.7)	(137.8)
N_2O Emissions from Settlement Soils[h]	1.8	2.8	1.9	2.0	2.0	2.0	2.1
Changes in Yard Trimming and Food Scrap Carbon Stocks in Landfills	(24.5)	(11.4)	(13.8)	(13.4)	(13.1)	(12.8)	(12.6)
Land Converted to Settlements	**62.5**	**85.0**	**80.9**	**81.0**	**81.1**	**81.0**	**81.0**
Changes in all Ecosystem Carbon Stocks[f]	62.5	85.0	80.9	81.0	81.1	81.0	81.0
LULUCF Emissions[i]	**57.9**	**72.4**	**68.3**	**64.4**	**64.2**	**76.4**	**77.8**
CH_4	53.5	61.3	60.1	57.3	56.9	65.4	66.0
N_2O	4.4	11.1	8.3	7.0	7.3	11.0	11.8
LULUCF Carbon Stock Change[j]	**(938.9)**	**(853.5)**	**(842.5)**	**(829.5)**	**(768.2)**	**(852.5)**	**(832.0)**
LULUCF Sector Net Total[k]	**(881.0)**	**(781.1)**	**(774.2)**	**(765.1)**	**(704.0)**	**(776.2)**	**(754.2)**

+ 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 C 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 C stock gains and losses from all land use and land-use conversion categories.

[j] 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, and Land Converted to Flooded Land, and Land Converted to Coastal Wetlands; and N_2O emissions from forest soils and settlement soils.

[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.

Other significant trends from 1990 to 2021 in emissions from LULUCF categories (Figure 2-11) over the thirty-two-year period included the following:

- Annual carbon (C) sequestration by forest land (i.e., annual C stock accumulation in the five ecosystem C pools and harvested wood products for Forest Land Remaining Forest Land and Land Converted to Forest Land) has decreased by 13.7 percent since 1990. This is primarily due to decreased C stock gains in Land Converted to Forest Land and the harvested wood products pools within Forest Land Remaining Forest Land.
- Annual C sequestration from Settlements Remaining Settlements (which includes organic soils, settlement trees, and landfilled yard trimmings and food scraps) has increased by 22.8 percent over the period from 1990 to 2021. This is primarily due to an increase in urbanized land area in the United States with trees growing on it.
- Annual emissions from Land Converted to Settlements increased by 29.7 percent from 1990 to 2021 due primarily to C stock losses from Forest Land Converted to Settlements and mineral soils C stocks from Grassland Converted to Settlements.

Waste

Waste management and treatment activities are sources of CH_4 and N_2O emissions (see Figure 2-12 and Table 2-9). In 2021, landfills were the largest source of waste emissions, accounting for 72.5 percent of waste-related emissions. Landfills are also the third-largest source of U.S. anthropogenic CH_4 emissions, generating 122.6 MMT CO_2 Eq. and accounting for 16.9 percent of total U.S. CH_4 emissions in 2021.[5] Additionally, wastewater treatment generated emissions of 42.0 MMT CO_2 Eq. and accounted for 24.8 percent of waste emissions, 2.9 percent of U.S. CH_4 emissions, and 5.4 percent of U.S. N_2O emissions in 2021. 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., respectively. Anaerobic digestion at biogas facilities generated CH_4 emissions of 0.2 MMT CO_2 Eq., accounting for 0.1 percent of emissions from the Waste sector. Overall, emission sources accounted for in the Waste chapter generated 169.2 MMT CO_2 Eq., or 2.7 percent of total U.S. greenhouse gas emissions in 2021.

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

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

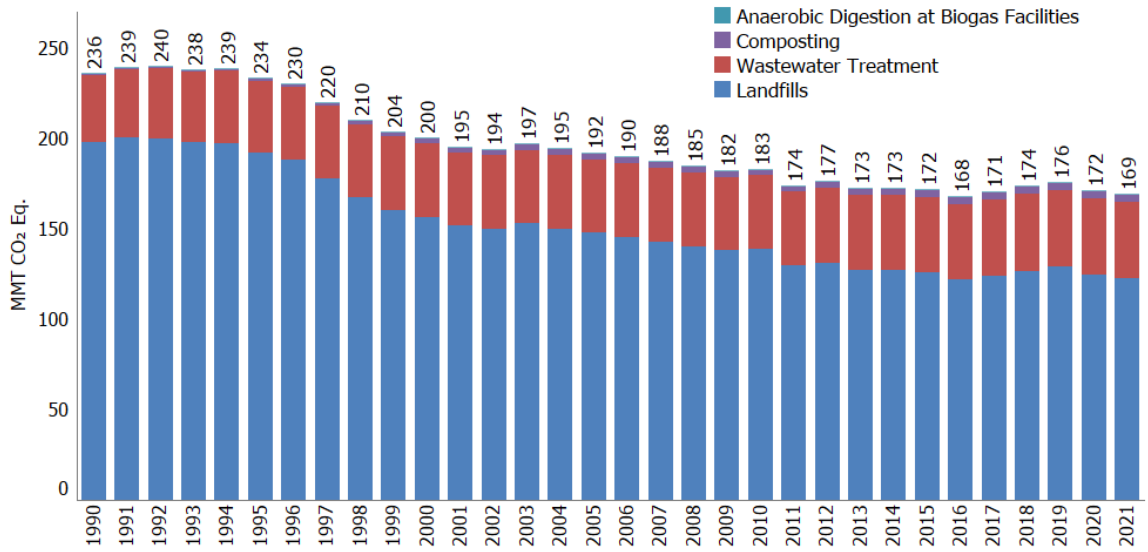


Table 2-9: Emissions from Waste (MMT CO_2 Eq.)

Gas/Source	1990	2005	2017	2018	2019	2020	2021
CH_4	**220.9**	**172.5**	**148.3**	**150.8**	**152.9**	**148.8**	**146.4**
Landfills	197.8	147.7	123.9	126.7	129.0	124.8	122.6
Wastewater Treatment	22.7	22.7	21.5	21.4	21.2	21.3	21.1
Composting	0.4	2.1	2.7	2.5	2.5	2.6	2.6
Anaerobic Digestion at Biogas Facilities	+	+	0.2	0.2	0.2	0.2	0.2
N_2O	**15.1**	**19.5**	**22.6**	**22.9**	**23.1**	**22.7**	**22.7**
Wastewater Treatment	14.8	18.1	20.6	21.2	21.3	20.9	20.9
Composting	0.3	1.5	1.9	1.8	1.8	1.8	1.8
Total	**236.0**	**192.1**	**170.9**	**173.7**	**176.0**	**171.5**	**169.2**

+ Does not exceed 0.05 MMT CO_2 Eq.

Note: Totals may not sum due to independent rounding.

Some significant trends in U.S. emissions from waste source categories (Figure 2-12) over the thirty-two-year period from 1990 through 2021 included the following:

- Net CH_4 emissions from landfills decreased by 75.1 MMT CO_2 Eq. (38.0 percent), with small increases occurring in interim years. This downward trend in emissions coincided with increased landfill gas collection and control systems, and a reduction of decomposable materials (i.e., paper and paperboard, food scraps, and yard trimmings) discarded in municipal solid waste (MSW) landfills over the time series.
- Methane and N_2O emissions from wastewater treatment decreased by 1.6 MMT CO_2 Eq. (7.2 percent) and increased by 6.1 MMT CO_2 Eq. (41.6 percent), respectively. Methane emissions from domestic wastewater treatment have decreased since 1999 due to decreasing percentages of wastewater being treated in anaerobic systems, including reduced use of on-site septic systems and central anaerobic treatment systems. Nitrous oxide emissions from wastewater treatment processes gradually increased across the time series as a result of increasing U.S. population and protein consumption.
- Combined CH_4 and N_2O emissions from composting have increased by 3.7 MMT CO_2 Eq. since 1990, from 0.7 MMT CO_2 Eq. to 4.4 MMT CO_2 Eq. in 2021, which represents more than a six-fold increase over the time series. The growth in composting since the 1990s is attributable to primarily four factors: (1) the enactment of legislation by state and local governments that discouraged the disposal of yard trimmings

and food waste in landfills; (2) an increase in yard trimming collection and yard trimming drop off sites provided by local solid waste management districts; (3) an increased awareness of the environmental benefits of composting; and (4) loans or grant programs to establish or expand composting infrastructure.

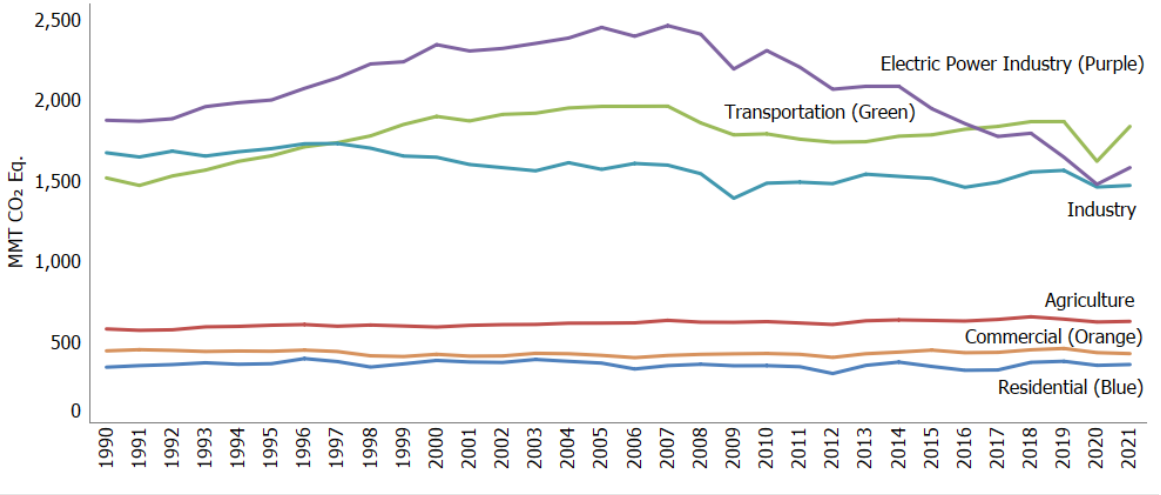
2.2 Emissions by Economic Sector

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

Using this categorization, transportation activities accounted for the largest portion (29.0 percent) of total U.S. greenhouse gas emissions in 2021. Emissions from electric power accounted for the second largest portion (25.0 percent), while emissions from industry accounted for the third largest portion (23.2 percent) of total U.S. greenhouse gas emissions in 2021. Emissions from industry have in general declined over the past decade due to a number of factors, including structural changes in the U.S. economy (i.e., shifts from a manufacturing-based to a service-based economy), fuel switching, and efficiency improvements.

The remaining 22.8 percent of U.S. greenhouse gas emissions were contributed by, in order of magnitude, the agriculture, commercial, and residential sectors, plus emissions from U.S. Territories. Activities related to agriculture accounted for roughly 9.9 percent of emissions; unlike other economic sectors, agricultural sector emissions were dominated by N_2O emissions from agricultural soil management and CH_4 emissions from enteric fermentation, rather than CO_2 from fossil fuel combustion. An increasing amount of carbon is stored in agricultural soils each year, but this C sequestration is assigned to the LULUCF sector rather than the agriculture economic sector. The commercial and residential sectors accounted for roughly 6.8 percent and 5.7 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 C) by a variety of activities related to forest management practices, tree planting in urban areas, the management of agricultural soils, landfilling of yard trimmings, and changes in C stocks in coastal wetlands. Table 2-10 presents a detailed breakdown of emissions from each of these economic sectors by source category, as they are defined in this report. Figure 2-13 shows the trend in emissions by sector from 1990 to 2021.

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



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

Table 2-10: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (MMT CO_2 Eq. and Percent of Total in 2021)

Sector/Source	1990	2005	2017	2018	2019	2020	2021	Percent[a]
Transportation	**1,521.4**	**1,966.0**	**1,841.6**	**1,871.3**	**1,871.7**	**1,624.9**	**1,841.7**	**29.0%**
CO_2 from Fossil Fuel Combustion	1,468.9	1,858.6	1,780.1	1,812.9	1,813.9	1,572.5	1,789.4	28.2%
Substitution of Ozone Depleting Substances	+	63.1	37.0	35.5	34.0	32.5	31.2	0.5%
Mobile Combustion[b]	40.6	34.2	14.9	13.6	15.0	12.1	13.0	0.2%
Non-Energy Use of Fuels	11.8	10.2	9.6	9.2	8.8	7.8	8.0	0.1%
Electric Power Industry	**1,879.7**	**2,456.9**	**1,779.2**	**1,799.1**	**1,650.5**	**1,481.8**	**1,585.4**	**25.0%**
CO_2 from Fossil Fuel Combustion	1,820.0	2,400.1	1,732.0	1,753.4	1,606.7	1,439.6	1,542.2	24.3%
Stationary Combustion[b]	18.7	27.7	23.2	23.1	20.2	18.9	20.4	0.3%
Incineration of Waste	13.3	13.6	13.5	13.7	13.3	13.3	12.8	0.2%
Electrical Transmission and Distribution	24.7	11.8	5.5	5.2	6.1	5.9	6.0	0.1%
Other Process Uses of Carbonates	3.1	3.7	4.9	3.7	4.2	4.2	4.0	0.1%
Industry	**1,677.8**	**1,574.7**	**1,494.7**	**1,558.3**	**1,568.4**	**1,464.9**	**1,474.9**	**23.2%**
CO_2 from Fossil Fuel Combustion	809.0	800.0	749.2	773.7	776.2	728.8	722.7	11.4%
Natural Gas Systems	247.5	228.6	218.2	227.4	232.3	221.7	218.3	3.4%
Non-Energy Use of Fuels	97.2	111.2	103.1	120.0	118.5	111.2	135.0	2.1%
Petroleum Systems	60.8	61.2	86.4	96.8	106.8	83.6	74.8	1.2%
Coal Mining	112.7	76.0	64.5	62.2	56.0	48.3	47.1	0.7%
Iron and Steel Production	104.8	70.1	40.8	42.9	43.1	37.7	42.0	0.7%
Cement Production	33.5	46.2	40.3	39.0	40.9	40.7	41.3	0.7%
Petrochemical Production	21.9	27.5	29.2	29.7	31.1	30.1	33.6	0.5%
Substitution of Ozone Depleting Substances	+	7.9	30.2	32.1	33.3	34.1	32.4	0.5%
Landfills (Industrial)	12.2	16.1	18.4	18.5	18.6	18.8	18.9	0.3%
Ammonia Production	14.4	10.2	12.5	12.7	12.4	13.0	12.2	0.2%
Lime Production	11.7	14.6	12.9	13.1	12.1	11.3	11.9	0.2%
Abandoned Oil and Gas Wells	7.7	8.1	8.3	8.3	8.3	8.3	8.3	0.1%
Nitric Acid Production	10.8	10.1	8.3	8.5	8.9	8.3	7.9	0.1%
Wastewater Treatment	6.6	7.1	7.4	7.5	7.6	7.6	7.6	0.1%
Adipic Acid Production	6.5	6.8	6.9	6.9	6.9	7.0	6.9	0.1%
Abandoned Underground Coal Mines	3.8	3.7	5.3	5.2	6.0	6.0	6.0	0.1%
Mobile Combustion[b]	7.2	6.6	6.7	6.4	6.2	5.9	5.8	0.1%
Carbon Dioxide Consumption	3.9	6.1	5.6	5.8	6.0	6.1	5.7	0.1%
Urea Consumption for Non-Agricultural Purposes	1.5	1.4	4.6	4.6	4.1	4.9	5.0	0.1%
Electronics Industry	3.1	3.7	5.4	4.9	3.7	4.9	4.9	0.1%
Other Process Uses of Carbonates	3.6	4.8	5.0	4.9	5.1	4.7	4.7	0.1%
N_2O from Product Uses	4.2	4.2	4.2	4.2	4.2	4.2	4.2	0.1%
Stationary Combustion[b]	4.9	4.7	4.2	4.1	4.0	4.0	3.7	+%
Aluminum Production	28.3	7.6	2.7	2.3	3.1	3.6	3.4	0.1%
HCFC-22 Production	46.1	20.0	2.8	5.2	3.3	3.7	2.1	0.1%
Glass Production	2.3	2.4	2.1	2.0	2.0	1.9	1.9	+%
Soda Ash Production	1.4	1.7	1.7	1.8	1.7	1.8	1.5	+%
Ferroalloy Production	2.2	1.4	1.8	2.0	2.1	1.6	1.4	+%
Titanium Dioxide Production	1.2	1.8	1.7	1.7	1.5	1.5	1.3	+%

Caprolactam, Glyoxal, and Glyoxylic Acid Production	1.7	2.1	1.7	1.5	1.4	1.4	1.2	+%
Magnesium Production and Processing	0.6	1.0	0.8	0.9	1.0	1.0	1.0	+%
Zinc Production	1.5	1.3	1.0	1.0	0.9	0.9	0.9	+%
Phosphoric Acid Production	5.3	2.7	1.2	1.1	1.1	0.9	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	**583.2**	**619.5**	**642.3**	**658.9**	**644.2**	**626.3**	**630.2**	**9.9%**
N_2O from Agricultural Soil Management	278.4	280.8	298.7	312.1	298.2	279.3	285.2	4.5%
Enteric Fermentation	183.1	188.2	195.9	196.8	197.3	196.2	194.9	3.1%
Manure Management	51.4	69.4	81.3	83.7	83.1	84.2	83.4	1.3%
CO_2 from Fossil Fuel Combustion	43.4	50.8	39.8	39.8	39.7	39.1	39.7	0.6%
Rice Cultivation	17.9	20.2	16.7	17.4	16.9	17.6	16.8	0.3%
Urea Fertilization	2.4	3.5	4.9	4.9	5.0	5.1	5.2	0.1%
Liming	4.7	4.4	3.1	2.2	2.2	2.9	3.0	+%
Mobile Combustion[b]	1.4	1.6	1.2	1.2	1.2	1.2	1.2	+%
Field Burning of Agricultural Residues	0.6	0.7	0.7	0.6	0.6	0.6	0.6	+%
Stationary Combustion[b]	+	+	+	+	+	+	+	+%
Commercial	**447.0**	**418.9**	**437.6**	**453.7**	**462.0**	**436.0**	**429.9**	**6.8%**
CO_2 from Fossil Fuel Combustion	228.3	227.1	232.0	245.8	250.7	228.5	223.9	3.5%
Landfills (Municipal)	185.5	131.6	105.5	108.2	110.4	106.0	103.7	1.6%
Substitution of Ozone Depleting Substances	+	21.4	58.9	58.5	59.8	60.8	61.9	1.0%
Wastewater Treatment	30.9	33.6	34.7	35.0	34.8	34.6	34.3	0.5%
Composting	0.7	3.6	4.7	4.3	4.3	4.4	4.4	0.1%
Stationary Combustion[b]	1.5	1.5	1.6	1.7	1.7	1.6	1.6	+%
Anaerobic Digestion at Biogas Facilities	+	+	0.2	0.2	0.2	0.2	0.2	+%
Residential	**345.6**	**371.2**	**328.4**	**375.8**	**382.4**	**356.9**	**362.3**	**5.7%**
CO_2 from Fossil Fuel Combustion	338.6	358.9	293.4	338.2	341.4	313.2	310.1	4.9%
Substitution of Ozone Depleting Substances	0.2	7.0	30.0	31.7	34.8	38.7	46.9	0.7%
Stationary Combustion[b]	6.8	5.3	4.9	5.9	6.2	5.1	5.3	0.1%
U.S. Territories	**23.4**	**59.7**	**26.3**	**26.3**	**25.1**	**23.5**	**23.3**	**0.4%**
CO_2 from Fossil Fuel Combustion	20.0	51.9	25.9	25.9	24.8	23.2	23.0	0.4%
Non-Energy Use of Fuels	3.4	7.6	0.2	0.2	0.2	0.2	0.2	+%
Stationary Combustion[b]	0.1	0.2	0.1	0.1	0.1	0.1	0.1	+%
Total Gross Emissions (Sources)	**6,478.3**	**7,466.9**	**6,550.0**	**6,743.4**	**6,604.4**	**6,014.5**	**6,347.7**	**100.0%**
LULUCF Sector Net Total[c]	**(881.0)**	**(781.1)**	**(774.2)**	**(765.1)**	**(704.0)**	**(776.2)**	**(754.2)**	**(11.9%)**
Net Emissions (Sources and Sinks)	**5,597.3**	**6,685.8**	**5,775.8**	**5,978.3**	**5,900.3**	**5,238.3**	**5,593.5**	**88.1%**

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

[a] Percent of total (gross) emissions excluding emissions from LULUCF for 2021.

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

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

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

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

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

The Electric Power economic sector includes CO_2, 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 municipal solid waste is combusted in plants that produce electricity. The Electric Power economic sector also includes SF_6 from Electrical Transmission and Distribution, and a portion of CO_2 from Other Process Uses of Carbonates (from pollution control equipment installed in electric power plants).

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

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

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

The Agriculture economic sector includes CO_2 emissions from the combustion of fossil fuels that are based on supplementary sources of agriculture fuel use data, because EIA includes agriculture equipment in the industrial fuel-consuming sector. Agriculture fuel use estimates are obtained from U.S. Department of Agriculture survey data, in combination with EIA Fuel Oil and Kerosene Sales (FOKS) data (EIA 1991 through 2021). 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 2020) shows national totals, as well as select 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. Substitution of Ozone Depleting Substances are apportioned to the Residential economic sector based on emissions from residential air-conditioning systems. Nitrous oxide emissions from the application of fertilizers to developed land (termed "settlements" by the IPCC) are also included in the Residential economic sector.

The Commercial economic sector includes CO_2 emissions from the combustion of fossil fuels that are included in the EIA commercial fuel-consuming sector. Emissions of CH_4 and N_2O from mobile combustion are also apportioned to the Commercial economic sector based on the EIA commercial fuel-consuming sector. Substitution of Ozone Depleting Substances emissions are apportioned to the Commercial economic sector based on emissions from commercial refrigeration/air-conditioning systems. Public works sources, including direct CH_4 from municipal landfills, CH_4 from anaerobic digestion at biogas facilities, CH_4 and N_2O from domestic wastewater treatment, and composting, are also included in the Commercial economic sector.

Emissions with Electricity Distributed to Economic Sectors

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

The generation, transmission, and distribution of electricity accounted for 25.0 percent of total U.S. greenhouse gas emissions in 2021. Electric power-related emissions decreased by 15.7 percent since 1990 mainly due to fuel switching in the electric power sector. From 2020 to 2021, electric power-related emissions increased by 7.0 percent due to in part to electricity use rebounding after the COVID-19 pandemic. Between 2020 to 2021, the consumption of natural gas for electric power generation decreased by 3.1 percent, while the consumption of coal and petroleum increased by 15.4 and 6.8 percent, respectively. However, even with the increase in 2021, electric power-related emissions are still lower than pre-pandemic 2019 levels.

From 2020 to 2021, electricity sales to the residential end-use sector increased by 0.8 percent. Electricity sales to the commercial end-use and industrial sectors both increased by 2.9. Overall, from 2020 to 2021, the amount of electricity retail sales (in kWh) increased by 2.1 percent. Table 2-11 provides a detailed summary of emissions from electric power-related activities.

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

Gas/Fuel Type or Source	1990	2005	2017	2018	2019	2020	2021
CO_2	**1,836.0**	**2,417.0**	**1,750.1**	**1,770.4**	**1,623.9**	**1,456.7**	**1,558.7**
Fossil Fuel Combustion	1,820.0	2,400.1	1,732.0	1,753.4	1,606.7	1,439.6	1,542.2
Coal	1,546.5	1,982.8	1,207.1	1,152.9	973.5	788.2	909.7
Natural Gas	175.4	318.9	505.6	577.9	616.6	634.8	615.1
Petroleum	97.5	98.0	18.9	22.2	16.2	16.2	17.1
Geothermal	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Incineration of Waste	12.9	13.3	13.2	13.3	12.9	12.9	12.5
Other Process Uses of Carbonates	3.1	3.7	4.9	3.7	4.2	4.2	4.0
CH_4	**0.5**	**1.0**	**1.2**	**1.4**	**1.4**	**1.4**	**1.4**
Stationary Sources[a]	0.5	1.0	1.2	1.4	1.4	1.4	1.4
Incineration of Waste	+	+	+	+	+	+	+
N_2O	**18.6**	**27.1**	**22.4**	**22.1**	**19.1**	**17.9**	**19.4**
Stationary Sources[a]	18.2	26.7	22.0	21.7	18.8	17.5	19.0
Incineration of Waste	0.4	0.3	0.4	0.4	0.4	0.3	0.4
SF_6	**24.7**	**11.8**	**5.5**	**5.2**	**6.1**	**5.9**	**6.0**
Electrical Transmission and Distribution	24.7	11.8	5.5	5.2	6.1	5.9	6.0
PFCs	**+**	**+**	**+**	**+**	**+**	**+**	**+**
Electrical Transmission and Distribution	+	+	+	+	+	+	+
Total	**1,879.7**	**2,456.9**	**1,779.2**	**1,799.1**	**1,650.5**	**1,481.8**	**1,585.4**

+ Does not exceed 0.05 MMT CO_2 Eq.

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

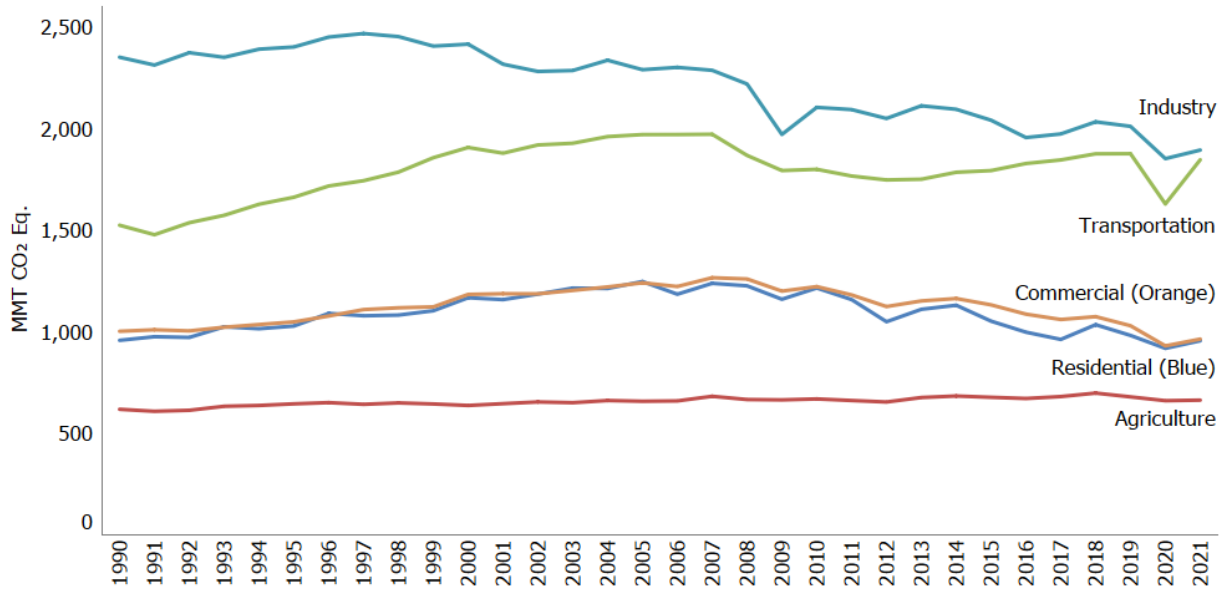
Note: Totals may not sum due to independent rounding.

To distribute electricity emissions among economic end-use sectors, emissions from the source categories assigned to the electric power sector were allocated to the residential, commercial, industry, transportation, and agriculture economic sectors according to each economic sector's share of retail sales of electricity (EIA 2020b; USDA/NASS 2020). These source categories include CO_2 from Fossil Fuel Combustion, CH_4 and N_2O from Stationary Combustion, Incineration of Waste, Other Process Uses of Carbonates, and SF_6 from Electrical Transmission and Distribution Systems. Note that only 50 percent of the Other Process Uses of Carbonates emissions were associated with electric power and distributed as described; the remainder of Other Process Uses of Carbonates emissions were attributed to the industry economic end-use sector.[6]

When emissions from electricity use are distributed among these economic end-use sectors, emissions from industrial activities account for the largest share of total U.S. greenhouse gas emissions (29.8 percent), followed closely by emissions from transportation (29.1 percent). Emissions from the commercial and residential sectors also increase substantially when emissions from electricity are included (15.2 and 15.1 percent, respectively). In all economic end-use sectors except agriculture, CO_2 accounts for more than 75 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 2021.

[6] 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.

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



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

Table 2-12: U.S. Greenhouse Gas Emissions by Economic Sector and Gas with Electricity-Related Emissions Distributed (MMT CO_2 Eq.) and Percent of Total in 2021

Sector/Gas	1990	2005	2017	2018	2019	2020	2021	Percent[a]
Industry	**2,351.6**	**2,290.2**	**1,974.0**	**2,033.6**	**2,011.4**	**1,852.4**	**1,894.5**	**29.8%**
Direct Emissions	**1,677.8**	**1,574.7**	**1,494.7**	**1,558.3**	**1,568.4**	**1,464.9**	**1,474.9**	**23.2%**
CO_2	1,164.0	1,142.4	1,072.9	1,128.2	1,149.1	1,065.2	1,087.0	17.1%
CH_4	411.7	367.4	353.5	358.0	350.4	329.6	319.9	5.0%
N_2O	35.6	29.9	27.3	30.3	26.0	27.8	26.8	0.4%
HFCs, PFCs, SF_6 and NF_3	66.5	35.0	40.9	41.8	42.9	42.3	41.3	0.7%
Electricity-Related	**673.8**	**715.5**	**479.3**	**475.2**	**442.9**	**387.5**	**419.7**	**6.6%**
CO_2	658.1	703.8	471.5	467.7	435.8	380.9	412.6	6.5%
CH_4	0.2	0.3	0.3	0.4	0.4	0.4	0.4	+%
N_2O	6.7	7.9	6.0	5.8	5.1	4.7	5.1	0.1%
SF_6	8.8	3.4	1.5	1.4	1.6	1.5	1.6	+%
Transportation	**1,524.6**	**1,970.9**	**1,846.0**	**1,876.2**	**1,876.7**	**1,629.2**	**1,846.9**	**29.1%**
Direct Emissions	**1,521.4**	**1,966.0**	**1,841.6**	**1,871.3**	**1,871.7**	**1,624.9**	**1,841.7**	**29.0%**
CO_2	1,480.8	1,868.7	1,789.7	1,822.1	1,822.7	1,580.3	1,797.4	28.3%
CH_4	6.4	3.2	1.8	1.7	1.7	1.5	1.6	+%
N_2O	34.3	31.0	13.1	11.9	13.3	10.7	11.5	0.2%
HFCs[b]	+	63.1	37.0	35.5	34.0	32.5	31.2	0.5%
Electricity-Related	**3.1**	**4.8**	**4.4**	**4.9**	**5.0**	**4.2**	**5.2**	**0.1%**
CO_2	3.1	4.8	4.4	4.8	4.9	4.2	5.1	0.1%
CH_4	+	+	+	+	+	+	+	+%
N_2O	+	0.1	0.1	0.1	0.1	0.1	0.1	+%
SF_6	+	+	+	+	+	+	+	+%
Residential	**957.8**	**1,247.5**	**962.3**	**1,034.9**	**982.0**	**918.3**	**955.7**	**15.1%**
Direct Emissions	**345.6**	**371.2**	**328.4**	**375.8**	**382.4**	**356.9**	**362.3**	**5.7%**
CO_2	338.6	358.9	293.4	338.2	341.4	313.2	310.1	4.9%
CH_4	5.9	4.5	4.2	5.1	5.3	4.4	4.6	0.1%
N_2O	0.9	0.8	0.7	0.8	0.8	0.7	0.7	+%

SF_6	0.2	7.0	30.0	31.7	34.8	38.7	46.9	0.7%
Electricity-Related	**612.2**	**876.3**	**633.9**	**659.0**	**599.6**	**561.3**	**593.4**	**9.3%**
CO_2	598.0	862.1	623.6	648.5	590.0	551.8	583.4	9.2%
CH_4	0.2	0.3	0.4	0.5	0.5	0.5	0.5	+%
N_2O	6.1	9.7	8.0	8.1	6.9	6.8	7.3	0.1%
SF_6	8.0	4.2	2.0	1.9	2.2	2.2	2.2	+%
Commercial	**1,002.4**	**1,241.0**	**1,060.4**	**1,074.5**	**1,029.7**	**930.5**	**963.9**	**15.2%**
Direct Emissions	**447.0**	**418.9**	**437.6**	**453.7**	**462.0**	**436.0**	**429.9**	**6.8%**
CO_2	228.3	227.1	232.0	245.8	250.7	228.5	223.9	3.5%
CH_4	203.7	150.9	124.3	126.6	128.5	124.2	121.6	1.9%
N_2O	15.1	19.4	22.4	22.8	23.0	22.5	22.5	0.4%
HFCs	+	21.4	58.9	58.5	59.8	60.8	61.9	1.0%
Electricity-Related	**555.4**	**822.0**	**622.8**	**620.8**	**567.7**	**494.5**	**534.0**	**8.4%**
CO_2	542.5	808.7	612.6	610.9	558.6	486.1	525.0	8.3%
CH_4	0.1	0.3	0.4	0.5	0.5	0.5	0.5	+%
N_2O	5.5	9.1	7.8	7.6	6.6	6.0	6.5	0.1%
SF_6	7.3	4.0	1.9	1.8	2.1	2.0	2.0	+%
Agriculture	**618.4**	**657.8**	**681.0**	**698.1**	**679.4**	**660.7**	**663.4**	**10.5%**
Direct Emissions	**583.2**	**619.5**	**642.3**	**658.9**	**644.2**	**626.3**	**630.2**	**9.9%**
CO_2	50.5	58.7	47.8	47.0	46.9	47.1	48.0	0.8%
CH_4	240.6	263.9	277.7	281.4	280.5	281.2	278.4	4.4%
N_2O	292.1	296.9	316.9	330.5	316.8	298.0	303.9	4.8%
Electricity-Related	**35.2**	**38.3**	**38.7**	**39.2**	**35.2**	**34.4**	**33.1**	**0.5%**
CO_2	34.3	37.7	38.1	38.5	34.6	33.8	32.6	0.5%
CH_4	+	+	+	+	+	+	+	+%
N_2O	0.3	0.4	0.5	0.5	0.4	0.4	0.4	+%
SF_6	0.5	0.2	0.1	0.1	0.1	0.1	0.1	+%
U.S. Territories	**23.4**	**59.7**	**26.3**	**26.3**	**25.1**	**23.5**	**23.3**	**0.4%**
Total Gross Emissions (Sources)	**6,478.3**	**7,466.9**	**6,550.0**	**6,743.4**	**6,604.4**	**6,014.5**	**6,347.7**	**100.0%**
LULUCF Sector Net Total[c]	**(881.0)**	**(781.1)**	**(774.2)**	**(765.1)**	**(704.0)**	**(776.2)**	**(754.2)**	**(11.9%)**
Net Emissions (Sources and Sinks)	**5,597.3**	**6,685.8**	**5,775.8**	**5,978.3**	**5,900.3**	**5,238.3**	**5,593.5**	**88.1%**

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

[a] Percent of total (gross) emissions excluding emissions from LULUCF for year 2021.

[b] Includes primarily HFC-134a.

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

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

Industry

The industry end-use sector includes CO_2 emissions from fossil fuel combustion from all manufacturing facilities, in aggregate, and with the distribution of electricity-related emissions, accounts for 29.8 percent of U.S. greenhouse gas emissions in 2021. This end-use sector also includes emissions that are produced as a byproduct of the non-energy-related industrial process activities. The variety of activities producing these non-energy-related emissions includes CH_4 emissions from petroleum and natural gas systems, fugitive CH_4 and CO_2 emissions from coal mining, byproduct CO_2 emissions from cement manufacture, and HFC, PFC, SF_6, and NF_3 byproduct emissions from the electronics industry, to name a few.

Since 1990, industrial sector emissions have declined by 22.6 percent. The decline has occurred both in direct emissions and indirect emissions associated with electricity use. Structural changes within the U.S. economy that led to shifts in industrial output away from energy-intensive manufacturing products to less energy-intensive products (e.g., from steel to computer equipment) have had a significant effect on industrial emissions.

Transportation

When electricity-related emissions are distributed to economic end-use sectors, transportation activities accounted for 29.1 percent of U.S. greenhouse gas emissions in 2021. The largest sources of transportation greenhouse gas emissions in 2021 were light-duty trucks, which include sport utility vehicles, pickup trucks, and minivans (36.8 percent); medium- and heavy-duty trucks (23.3 percent); passenger cars (20.5 percent); commercial aircraft (5.0 percent); other aircraft (4.0 percent); pipelines (3.5 percent); ships and boats (2.7 percent); and rail (1.9 percent). These figures include direct CO_2, CH_4, and N_2O emissions from fossil fuel combustion used in transportation, indirect emissions from electricity use, and emissions from non-energy use (i.e., lubricants) used in transportation, as well as HFC emissions from mobile air conditioners and refrigerated transport allocated to these vehicle types.

From 1990 to 2021, total transportation emissions from fossil fuel combustion increased by approximately 21.8 percent. From 2020 to 2021, emissions increased by 13.8 percent, which followed a decline of 13.3 percent from 2019 to 2020 due to reduced travel demand during the COVID-19 pandemic. The increase in transportation emissions from 1990 to 2021 was due, in large part, to increased demand for travel. The number of VMT by light-duty motor vehicles (passenger cars and light-duty trucks) increased 48.4 percent from 1990 to 2021 as a result of a confluence of factors including population growth, economic growth, urban sprawl, and periods of low fuel prices.

The decline in new light-duty vehicle fuel economy between 1990 and 2004 reflected the increasing market share of light-duty trucks, which grew from approximately 29.6 percent of new vehicle sales in 1990 to 48.0 percent in 2004. Starting in 2005, average new vehicle fuel economy began to increase while light-duty VMT grew only modestly for much of the period. Light-duty VMT grew by less than one percent or declined each year between 2005 and 2013, then grew at a faster rate until 2016 (2.6 percent from 2014 to 2015, and 2.5 percent from 2015 to 2016). Since 2016, the rate of light-duty VMT growth has slowed to at or less than one percent each year. Average new vehicle fuel economy has increased almost every year since 2005, while light-duty truck market share decreased to 33.0 percent in 2009 and has since varied from year to year between 35.6 and 62.9 percent. Light-duty truck market share was about 62.9 percent of new vehicles in model year 2021 (EPA 2022b).

Table 2-13 provides a detailed summary of greenhouse gas emissions from transportation-related activities with electricity-related emissions included in the totals. Historically, the majority of electricity use in the transportation sector was for rail transport. However, more recently there has been increased electricity use in on-road electric and plug-in hybrid vehicles. For a more detailed breakout of emissions by fuel type by vehicle see Table A-99 in Annex 3.

Almost all of the energy used for transportation was supplied by petroleum-based products, with more than half being related to gasoline consumption in automobiles and other highway vehicles. Other fuel uses, especially diesel fuel for freight trucks and jet fuel for aircraft, accounted for the remainder. The primary driver of transportation-related emissions was CO_2 from fossil fuel combustion, which increased by 21.9 percent from 1990 to 2021. This rise in CO_2 emissions, combined with an increase in HFCs from close to zero emissions in 1990 to 31.2 MMT CO_2 Eq. in 2021, led to an increase in overall greenhouse gas emissions from transportation activities of 21.1 percent.

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

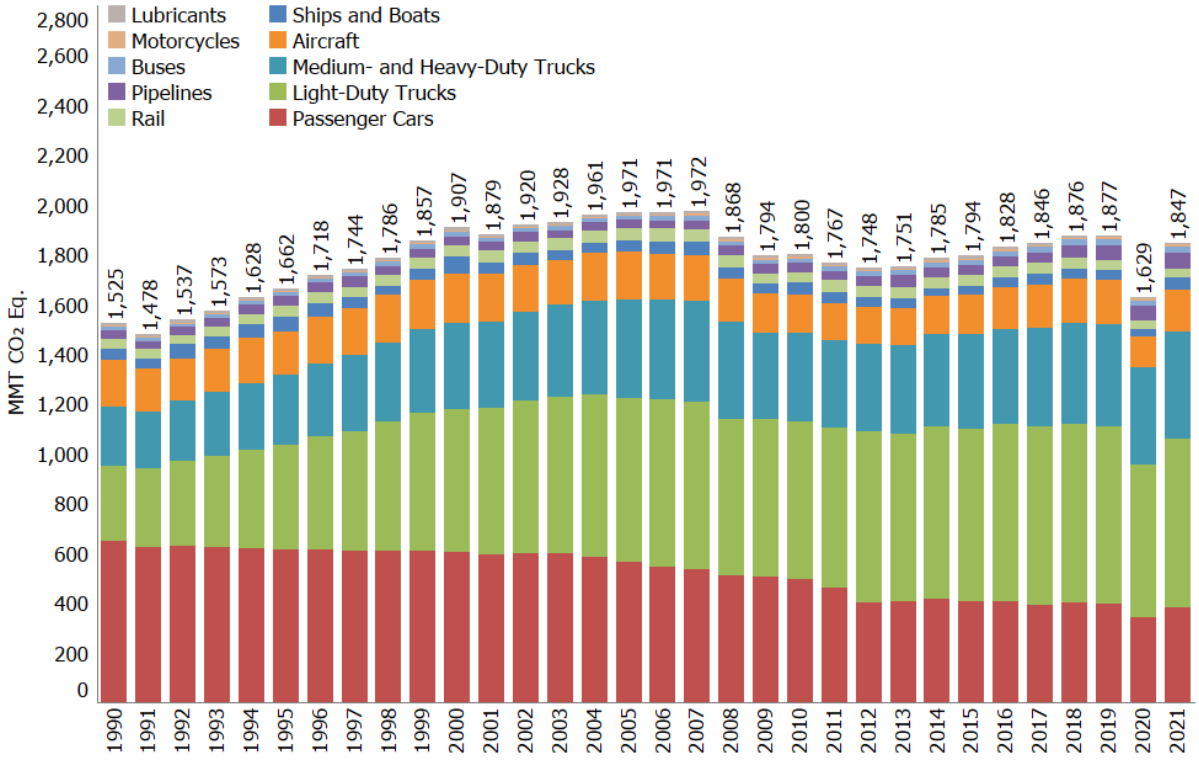


Table 2-13: Transportation-Related Greenhouse Gas Emissions (MMT CO_2 Eq.)

Gas/Vehicle	1990	2005	2017	2018	2019	2020	2021
Passenger Cars	**648.4**	**564.4**	**392.7**	**398.7**	**395.5**	**341.7**	**378.5**
CO_2	622.2	521.1	379.0	386.5	384.2	331.9	369.2
CH_4	3.8	1.2	0.3	0.3	0.3	0.3	0.3
N_2O	22.5	13.3	3.0	2.5	2.6	2.0	2.0
HFCs	0.0	28.8	10.4	9.4	8.4	7.6	7.0
Light-Duty Trucks	**302.5**	**659.5**	**716.2**	**720.6**	**711.8**	**615.4**	**680.1**
CO_2	292.2	614.2	692.7	699.1	690.2	596.3	662.2
CH_4	1.5	1.0	0.6	0.6	0.6	0.5	0.6
N_2O	8.7	14.0	5.4	4.6	5.6	4.4	4.3
HFCs	0.0	30.2	17.5	16.4	15.4	14.2	13.0
Medium- and Heavy-Duty Trucks	**234.3**	**391.3**	**395.6**	**406.7**	**409.5**	**386.7**	**430.1**
CO_2	232.8	386.5	387.5	398.2	400.6	377.9	420.7
CH_4	0.5	0.2	0.1	0.1	0.1	0.1	0.1
N_2O	1.0	1.5	2.6	2.7	3.0	2.7	3.0
HFCs	0.0	3.2	5.4	5.6	5.8	6.1	6.3
Buses	**13.4**	**17.7**	**23.4**	**24.4**	**24.8**	**23.6**	**26.5**
CO_2	13.3	17.2	22.8	23.7	24.2	23.0	25.9
CH_4	+	0.1	0.1	0.1	0.1	+	+
N_2O	+	0.1	0.2	0.2	0.2	0.2	0.2
HFCs	0.0	0.2	0.4	0.4	0.4	0.4	0.4
Motorcycles	**3.4**	**5.0**	**7.2**	**7.4**	**7.5**	**6.7**	**7.6**
CO_2	3.4	4.9	7.0	7.3	7.4	6.6	7.5
CH_4	+	+	+	+	+	+	+
N_2O	+	+	0.1	0.1	0.1	0.1	0.1
Commercial Aircraft[a]	**110.8**	**133.8**	**129.0**	**130.7**	**135.3**	**92.0**	**92.0**

CO_2	109.9	132.7	128.0	129.6	134.2	91.3	91.3
CH_4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N_2O	0.9	1.1	1.0	1.1	1.1	0.7	0.7
Other Aircraft[b]	**78.0**	**59.5**	**45.5**	**44.6**	**45.6**	**31.0**	**74.7**
CO_2	77.3	59.0	45.1	44.2	45.2	30.7	74.1
CH_4	0.1	0.1	+	+	+	+	+
N_2O	0.6	0.5	0.4	0.4	0.4	0.2	0.6
Ships and Boats[c]	**47.0**	**45.5**	**43.8**	**41.1**	**40.0**	**32.4**	**50.0**
CO_2	46.3	44.3	39.9	36.9	35.5	27.6	44.8
CH_4	0.4	0.5	0.5	0.5	0.4	0.4	0.5
N_2O	0.2	0.2	0.2	0.2	0.2	0.1	0.3
HFCs	0.0	0.5	3.2	3.6	3.9	4.2	4.5
Rail	**39.0**	**51.4**	**41.3**	**42.5**	**39.7**	**34.0**	**35.2**
CO_2	38.5	50.8	40.7	41.9	39.1	33.5	34.6
CH_4	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N_2O	0.3	0.4	0.3	0.3	0.3	0.3	0.3
HFCs	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Other Emissions from Electric Power[d]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipelines[e]	**36.0**	**32.6**	**41.6**	**50.2**	**58.2**	**57.9**	**64.2**
CO_2	36.0	32.6	41.6	50.2	58.2	57.9	64.2
Lubricants	**11.8**	**10.2**	**9.6**	**9.2**	**8.8**	**7.8**	**8.0**
CO_2	11.8	10.2	9.6	9.2	8.8	7.8	8.0
Total Transportation	**1,524.6**	**1,970.9**	**1,846.0**	**1,876.2**	**1,876.7**	**1,629.2**	**1,846.9**
International Bunker Fuels[f]	*54.7*	*44.6*	*34.5*	*32.4*	*26.3*	*22.7*	*22.6*
Ethanol CO_2[g]	*4.1*	*21.6*	*77.7*	*78.6*	*78.7*	*68.1*	*76.3*
Biodiesel CO_2[g]	*0.0*	*0.9*	*18.7*	*17.9*	*17.1*	*17.7*	*16.1*

+ Does not exceed 0.05 MMT CO_2 Eq.

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

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

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

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

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

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

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

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

Residential

The residential end-use sector, with electricity-related emissions distributed, accounts for 15.1 percent of U.S. greenhouse gas emissions in 2021 and similarly, is heavily reliant on electricity for meeting energy needs, with electricity use for lighting, heating, air conditioning, and operating appliances. The remaining emissions were largely due to the direct consumption of natural gas and petroleum products, primarily for heating and cooking needs. Emissions from the residential sector have generally been increasing since 1990, and annual variations are often correlated with short-term fluctuations in energy use caused by weather conditions, rather than prevailing

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

Commercial

The commercial end-use sector, with electricity-related emissions distributed, accounts for 15.2 percent of U.S. greenhouse gas emissions in 2021 and is heavily reliant on electricity for meeting energy needs, with electricity use for lighting, heating, air conditioning, and operating appliances. The remaining emissions were largely due to the direct consumption of natural gas and petroleum products, primarily for heating and cooking needs. Energy-related emissions from the commercial sector have generally been increasing since 1990, and annual variations are often correlated with short-term fluctuations in energy use caused by weather conditions, rather than prevailing economic conditions. Decreases in energy-related emissions in the commercial sector in recent years can be largely attributed to an overall reduction in energy use driven by a reduction in heating degree days and increases in energy efficiency.

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

Agriculture

The agriculture end-use sector accounts for 10.5 percent of U.S. greenhouse gas emissions in 2021 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 2021, agricultural soil management was the largest source of N_2O emissions, and enteric fermentation was the largest source of CH_4 emissions in the United States. This sector also includes small amounts of CO_2 emissions from fossil fuel combustion by motorized farm equipment such as tractors.

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

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

Table 2-14 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. These values represent the relative change in each statistic since 1990. Greenhouse gas emissions in the United States have decreased at an average annual rate of 0.02 percent since 1990, although changes from year to year have been significantly larger. This growth rate is slightly slower than that for total energy use, overall gross domestic product (GDP) and national population (see Table 2-14 and Figure 2-16). The direction of these trends started to change after 2005, when greenhouse gas emissions, total energy use and associated fossil fuel consumption began to peak. Greenhouse gas emissions in the United States have decreased at an average annual rate of 0.9 percent since 2005. Fossil fuel consumption has also decreased at a slower rate than emissions since 2005, while total energy use, GDP, and national population, generally continued to increase, 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	2017	2018	2019	2020	2021	Avg. Annual Change	Avg. Annual Change
Greenhouse Gas Emissions[b]	100	115	101	104	102	93	98	(+)%	-0.9%
Energy Use[c]	100	119	116	120	119	109	115	0.5%	-0.1%

GDP[d]	100		159		193	199	203	198	209	2.4%	1.8%
Population[e]	100		118		130	130	131	133	134	0.9%	0.8%

+ Absolute value does not exceed 0.05 percent.

[a] Average annual growth rate.

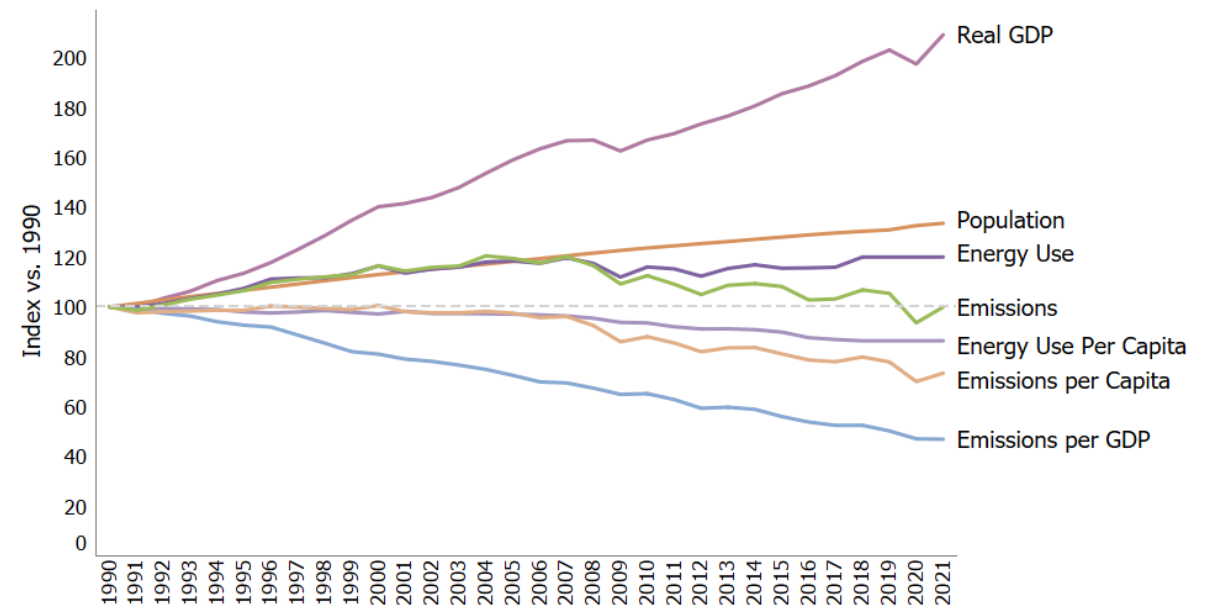
[b] Gross total GWP-weighted values.

[c] Energy-content-weighted values (EIA 2022).

[d] GDP in chained 2009 dollars (BEA 2022).

[e] U.S. Census Bureau (2021).

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



Source: BEA (2022), U.S. Census Bureau (2021), and gross emission estimates in this report.

2.3 Precursor Greenhouse Gas Emissions (CO, NO_x, NMVOCs, and SO_2) – TO BE UPDATED FOR FINAL INVENTORY REPORT

The reporting requirements of the UNFCCC[7] request that information be provided on emissions of compounds that are precursors to greenhouse gases, which include carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), and sulfur dioxide (SO_2). These gases are not 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

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

process) and agricultural burning. Anthropogenic sources of NMVOCs, which include hundreds of organic compounds that participate in atmospheric chemical reactions (i.e., propane, butane, xylene, toluene, ethane, and many others)—are emitted primarily from transportation, industrial processes, oil and natural gas production, waste practices, agricultural burning, and non-industrial consumption of organic solvents. In the United States, SO_2 is primarily emitted from coal combustion for electric power generation and the metals industry.

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

Since 1970, the United States has published triennial estimates of emissions of CO, NO_x, NMVOCs, and SO_2 (EPA 2021b), 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.[8] Precursor emission estimates for this report for 1990 through 2021 were obtained from data published on EPA's National Emissions Inventory (NEI) Air Pollutants Emissions Trends Data website (EPA 2021b). For Table 2-15, NEI-reported emissions of CO, NO_x, SO_2, and NMVOCs are recategorized from NEI Tier 1/Tier 2 source categories to those more closely aligned with IPCC categories, based on EPA (2022a) and detailed in Annex 6. 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 (2021b); see Sections 5.7, 6.2, and 6.6.

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

Gas/Activity	1990	2005	2017	2018	2019	2020	2021
NO_x	**21,764**	**17,333**	**8,792**	**8,483**	**8,008**	**7,425**	**7,128**
Energy	21,106	16,602	8,268	7,883	7,456	6,962	6,471
IPPU	592	572	402	397	397	397	397
LULUCF	52	142	107	188	139	50	244
Agriculture	13	15	14	14	14	14	14
Waste	+	2	1	1	1	1	1
CO	**132,759**	**74,553**	**39,981**	**43,688**	**39,531**	**34,170**	**43,799**
Energy	125,640	64,985	34,461	33,401	32,392	31,384	30,376
LULUCF	2,673	7,642	4,099	8,936	5,789	1,436	12,074
IPPU	4,129	1,557	1,075	1,007	1,007	1,007	1,007
Agriculture	315	363	340	339	338	337	336
Waste	1	7	6	5	5	5	5
NMVOCs	**20,923**	**13,309**	**9,855**	**9,483**	**9,310**	**9,136**	**8,963**
Energy	12,612	7,345	6,022	5,664	5,491	5,318	5,145
IPPU	7,638	5,849	3,776	3,767	3,767	3,767	3,767
Waste	673	114	57	52	52	52	52
Agriculture	NA	NA	NA	NA	NA	NA	NA
LULUCF	NA	NA	NA	NA	NA	NA	NA

[8] 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/.

SO_2	**20,935**	**13,196**	**2,906**	**2,303**	**2,211**	**1,943**	**1,780**
Energy	19,628	12,364	2,439	1,794	1,701	1,433	1,270
IPPU	1,307	831	466	509	509	509	509
Waste	+	1	1	1	1	1	1
Agriculture	NA	NA	NA	NA	NA	NA	NA
LULUCF	NA	NA	NA	NA	NA	NA	NA

+ Does not exceed 0.5 kt.
NA (Not Available)
Note: Totals by gas may not sum due to independent rounding.
Source: (EPA 2021b) except for estimates from forest fires, grassland fires, and Field Burning of Agricultural Residues. Emission categories from EPA (2021b) are aggregated into IPCC categories following as shown in Table ES-3.

1