The 1997 U.S. Climate Action Report, Chapter 3,
submitted by the United States of America
Under the United Nations Framework
Convention on Climate Change.

Greenhouse Gas Inventory

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1997 U.S Climate Action Report, Chapter 3

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Greenhouse Gas Inventory

Central to any study of climate change is the development of an emission inventory that identifies and quantifies a country's primary sources and sinks of greenhouse gases (GHGs). This inventory provides both (1) a basis for the ongoing development of a comprehensive and detailed methodology for estimating sources and sinks of greenhouse gases, and (2) a common, consistent mechanism that enables all signatory countries to the United Nations' Framework Convention on Climate Change (FCCC) to estimate emissions and to compare the relative contribution of different emission sources and greenhouse gases to climate change. Moreover, systematically and consistently estimating national and international emissions is a prerequisite for evaluating the cost-effectiveness and feasibility of mitigation strategies and emission reduction technologies.

This chapter summarizes the latest information on U.S. greenhouse gas emission trends, from 1990 to 1995 , as presented in the draft EPA report, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1995. To ensure that the U.S. emissions inventory is comparable to those of other FCCC signatory countries, the estimates presented here were calculated using baseline methodologies similar to those recommended in Volumes 1-3 of the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC/OECD/IEA/UNEP 1995). For U.S. emission sources related to energy consumption, forest sinks, and some CH_4 sources, the IPCC default methodologies were expanded, resulting in a more comprehensive procedure for estimating U.S. emissions. Details on how these estimates were developed are available in the 1995 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1994 (U.S. EPA 1995) and in the upcoming edition.

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Recent Trends in U.S. Greenhouse Gas Emissions

Greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Chlorofluorocarbons (CFCs), a family of human-made compounds, and other compounds such as hydrofluorocarbons (HFCs) and perfluorinated carbons (PFCs) are also greenhouse gases.

Other nongreenhouse, radiatively important gases — such as carbon monoxide (CO), oxides of nitrogen (NO_x), and nonmethane volatile organic compounds (NMVOCs) — contribute indirectly to the greenhouse effect. These are commonly referred to as "tropospheric ozone precursors" because they influence the rate at which ozone and other gases are created and destroyed in the atmosphere. For convenience, all gases discussed in this chapter are generically referred to as "greenhouse gases" (unless otherwise noted).

Although CO_2, CH_4, and N_2O occur naturally in the atmosphere, their recent atmospheric buildup is largely the result of human activities. Since 1800, atmospheric concentrations of these greenhouse gases have increased by 30, 145, and 15 percent, respectively (IPCC 1996). This buildup has altered the composition of the earth's atmosphere, and may affect future global climate.

Beginning in the 1950's, the use of CFCs increased by nearly 10 percent a year, until the mid-1980's when international concern about ozone depletion led to the signing of the Montreal Protocol. Since then, the consumption of CFCs has rapidly declined as they are phased out. In contrast, use of CFC substitutes is expected to grow significantly.

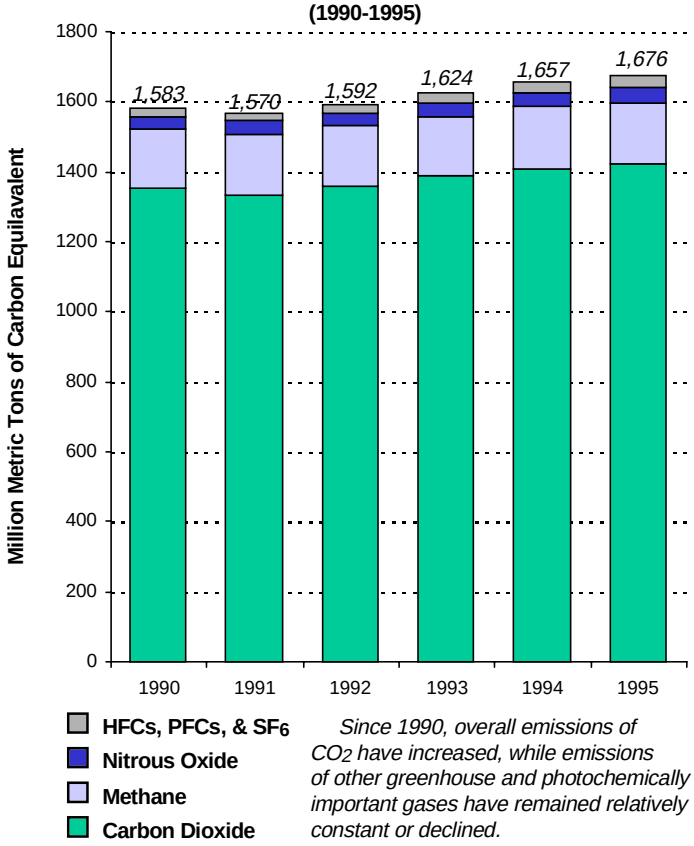
Figure 3-1 and Table 3-1 summarize the current U.S. greenhouse gas emissions inventory for 1990-95. They present the estimated sources and sinks in millions of metric tons of carbon equivalent (MMTCE), which accounts for the gases' global warming potentials.

The growth in U.S. greenhouse gas emissions has been erratic from 1990 to 1995. Emissions from anthropogenic sources in dropped in 1991, increased steadily through 1994, and then slowed down in 1995. Over the five-year period, greenhouse gas emissions rose by 5.9 percent, representing an average annual increase of just over one percent. This trend is largely attributable to changes in total energy consumption resulting from the economic slowdown in the early 1990s and the subsequent recovery. U.S. energy consumption increased at an average annual rate of 1.5 percent over the same period (DOE/EIA 1996a). The increase in emissions from 1993 through 1995 was also influenced by generally low energy prices, which increased demand for fossil fuels (DOE/EIA 1996b).

Among the inventory's greenhouse gases, changes in CO_2 emissions from fossil fuel consumption had the greatest impact during the five-year period. In most cases, emissions from methane, N_2O, HFCs, PFCs, and sulfur hexaflouride (SF_6) have remained relatively constant or have increased slightly. For example, methane emissions increased by just over 4 percent. The rise in HFC, PFC, and SF_6 emissions, although a small portion of the total, is significant because of their extremely high global warming potentials and, in the cases of PFCs and SF_6, their long atmospheric

Figure 3-1

Recent Trends in U.S. Greenhouse Gas Emissions (1990-1995)



Since 1990, overall emissions of CO_2 have increased, while emissions of other greenhouse and photochemically important gases have remained relatively constant or declined.

Table 3-1

Recent Trends in U.S. Greenhouse Gas Emissions (1990-1995)
(MMTs of Carbon Equivalent)

Gas and Source	Emissions - Direct and Indirect Effects					
	1990	1991	1992	1993	1994	1995
Carbon Dioxide (CO_2)	**1,228**	**1,213**	**1,235**	**1,268**	**1,291**	**1,305**
Fossil Fuel Combustion	1,336	1,320	1,340	1,370	1,391	1,403
Industrial Processes and Other	17	16	17	18	19	19
Total	*1,353*	*1,336*	*1,357*	*1,388*	*1,410*	*1,422*
Forests (sink)*	(125)	(123)	(122)	(120)	(119)	(117)
Methane (CH_4)	**170**	**172**	**173**	**171**	**176**	**177**
Landfills	56	58	58	60	62	64
Agriculture	50	51	52	52	54	55
Coal Mining	24	23	22	20	21	20
Oil and Natural Gas Systems	33	33	34	33	33	33
Other	6	7	7	6	6	6
Nitrous Oxide (N_2O)	**36**	**37**	**37**	**38**	**39**	**40**
Agriculture	17	17	17	18	18	18
Fossil Fuel Consumption	11	11	12	12	12	12
Industrial Processes	8	8	8	8	9	9
HFCs	**12**	**12**	**13**	**14**	**17**	**21**
PFCs	**5**	**5**	**5**	**5**	**7**	**8**
SF_6	**7**	**7**	**8**	**8**	**8**	**8**
U.S. Emissions	**1,583**	**1,570**	**1,592**	**1,624**	**1,657**	**1,676**
Net U.S. Emissions	**1,458**	**1,447**	**1,470**	**1,504**	**1,538**	**1,559**

* These estimates for the conterminous US for 1990-91 and 1993-95 are interpolated from forest inventories in 1987 and 1992, and projections through 2040. The methodology reflects long-term averages rather than specific events in any given year.

Note: The totals presented in the summary tables in this chapter may not equal the sum of the individual source categories due to rounding.

lifetimes. Greenhouse gas emissions were partly offset by carbon sequestration in forests.

Figure 3-2 illustrates the relative contribution of the primary greenhouse gases to total U.S. emissions in 1995, with CO_2 emissions accounted for the largest share. The largest change in methane emission estimates compared to earlier inventories is in the natural gas sector, where emissions have been adjusted upward by more than 75 percent due to improved estimation methods; however, these revised emissions have not changed significantly during 1990-95. Larger landfills, expanded animal populations, and more widespread use of liquid manure management systems increased methane emissions from waste management and agricultural activities. In contrast, improved methane recovery and lower coal production from gassy mines have reduced methane emissions from coal mining.

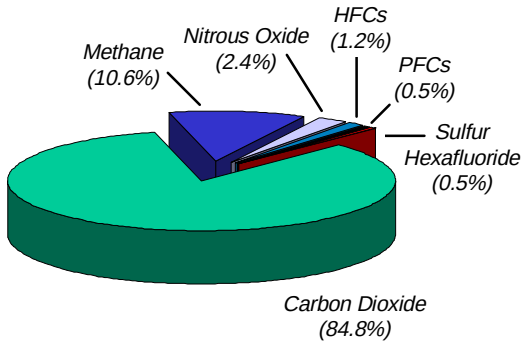
Nitrous oxide emissions rose by just under 10 percent during the period, primarily for two reasons. First, fertilizer use, which account for approximately 46 percent of total U.S. N_2O emissions, increased significantly during 1993-95 as farmers planted more acreage and worked to replace nutrients lost in the 1993 floods. And second, emissions from other categories grew slightly as the U.S. economy grew.

HFCs, PFCs, and SF_6 emissions are increasing, along with their expanded use as substitutes for CFCs and other ozone-depleting compounds being phased out under the terms of the *Montreal Protocol* and Clean Air Act Amendments (IPCC/OECD/IEA/UNEP 1995). Two major contributors to the rise in HFC emissions since 1990 are the use of HFC-134a for mobile air conditioners and the emission of HFC-23 during the production of the refrigerant HCFC-22.

The following sections present the anthropogenic sources of greenhouse gas emissions, briefly discuss emission pathways, summarize the emission estimates, and explain the relative importance of emissions from each source category.

Figure 3-2

Total 1995 U.S. Greenhouse Gas Emissions



Box 3-1

The Global Warming Potential Concept

Gases can contribute to the greenhouse effect both directly and indirectly. Direct effects occur when the gas itself is a greenhouse gas; indirect radiative forcing occurs when chemical transformations of the original gas produce a greenhouse gas, or when a gas influences the atmospheric lifetimes of other gases.

The concept of Global Warming Potential (GWP) has been developed to allow scientists and policy makers to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to another gas. CO_2 was chosen as the reference gas to be consistent with IPCC guidelines (IPCC/OECD/IEA/UNEP 1995).

All gases in this inventory are presented in units of million metric tonnes of carbon equivalent, or MMTCE. Carbon comprises 12/44 of carbon dioxide by weight. The following equation may be used to convert MMTs of emissions of greenhouse gas (GHG) x to MMTCE:

MMTCE=(MMT of GHGx)(GWP of GHGx)(12/44)

The GWP of a greenhouse gas is the ratio of global warming, or radiative forcing (both direct and indirect), from one kilogram of a greenhouse gas to one kilogram of CO_2 over a period of time. While any time period may be selected, this report uses the 100-year GWPs recommended by the IPCC and employed for U.S. policy making and reporting purposes (IPCC 1996).

The GWPs of some selected GHGs are shown here. GWPs are not provided for the photochemically important gases CO, Nox, NMVOCs, and SO_2 because there is no agreed-upon method to estimate their contributions to climate change, and they affect radiative forcing only indirectly (IPCC 1996).

Global Warming Potential

The higher global warming potential of lower emitting greenhouse gases significantly increases their contributions to the greenhouse effect. For example, over a 100-year time horizon, nitrous oxide is 310 times more effective than carbon dioxide at trapping heat in the atmosphere.

Gas	GWP (100 Years)
Carbon Dioxide	1
Methane	21
Nitrous Oxide	310
HFC-23	11,700
HFC-125	2,800
HFC-134a	1,300
HFC-143a	3,800
HFC-152a	140
HFC-227ea	2,900
HFC-43-10mme	1,300
CF_4	6,500
C_2F_6	9,200
C_4F_{10}	7,000
C_6F_{14}	7,400
PFCs/PFPEs	7,400
SF_6	23,900

Carbon Dioxide Emissions

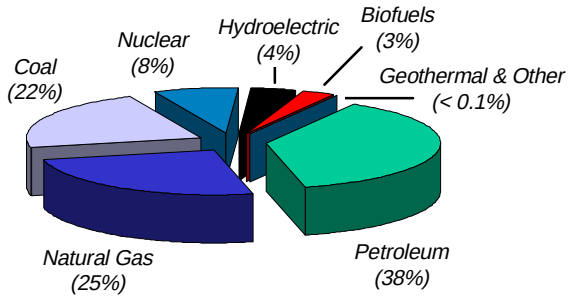
The global carbon cycle is made up of large carbon flows and reservoirs. Hundreds of billions of tons of carbon in the form of CO_2 are absorbed by the oceans or trees (sinks) or are emitted to the atmosphere annually through natural processes (sources). When in equilibrium, carbon fluxes among the various reservoirs are roughly balanced.

Since the Industrial Revolution, this equilibrium has been increasingly compromised. Atmospheric concentrations of CO_2 have risen about 30 percent, principally because of fossil fuel combustion, which accounts for 99 percent of total U.S. CO_2 emissions (Seki 1995). Changes in land use and forestry activities can emit CO_2 (e.g., through conversion of forest land to agricultural or urban use) and can act as a sink for – or absorb — CO_2 (e.g., through improved forest management activities).

Table 3-2 summarizes U.S. sources and sinks of CO_2, while the remainder of this section discusses CO_2 emission trends in greater detail.

Figure 3-3

Sources of U.S. Energy Consumed in 1995



Source: U.S. DOE/EIA 1996b

The Energy Sector

Energy-related activities account for roughly 87 percent of annual U.S. greenhouse gas emissions. Of that share, approximately 85 percent is produced through fossil fuel combustion, and the remaining 15 percent comes from renewable or other energy sources, such as hydropower, biomass, and nuclear energy (Figure 3-3). Energy related activities other than fuel combustion also emit greenhouse gases (primarily methane), such as those associated with producing, transmitting, storing, and distributing fossil fuels.

Fossil Fuel Consumption

The amount of carbon in fossil fuels varies significantly by fuel type. For example, coal contains the highest amount of carbon per unit of energy, natural gas has about 45 percent less than coal, and petroleum has about 20 percent less.

Carbon dioxide is the most significant GHG emitted in the U.S. Currently, carbon dioxide makes up 85 percent of the total U.S. GHG emissions and the combustion of fossil fuels accounts for 99 percent of that portion. In 1995, U.S. fossil fuel combustion emitted 1,403 million metric tons of carbon equivalent (MMTCE). Total consumption of fossil fuels during 1990-95 increased at an average annual rate of 1.2 percent, primarily because of economic growth and generally low energy prices.

Table 3-2

U.S. Sources of Carbon Dioxide Emissions in 1995
(Millions of Metric Tons)

Sources and Sinks	CO2 Emissions (Molecular Basis)	CO2 Emissions (Carbon Equivalent)
Fossil Fuel Consumption	**5,144.6**	**1,403.1**
Residential	*994.7*	*271.3*
Commercial	*801.6*	*218.6*
Industrial	*1,708.7*	*466.0*
Transportation	*1,600.8*	*436.6*
U.S. Territories	*38.8*	*10.6*
Fuel Production and Processing	**6.2**	**1.7**
Cement Production	**38.5**	**10.5**
Lime Production	**13.6**	**3.7**
Limestone Consumption	**4.4**	**1.2**
Soda Ash Production and Consumption	**5.9**	**1.6**
Carbon Dioxide Manufacture	**1.5**	**0.4**
Sources -- Total Emissions	***5,214.6***	***1422.2***
Sinks -- Forestry and Land Use	***(428.0)***	***(117.0)***
Net Emissions	**4,786.6**	**1,305.2**

Note: The totals provided here do not reflect emissions from bunker fuels used in international transport activities. At its Ninth Session, the Intergovernmental Negotiating Committee instructed countries to report these emissions separately, and not include them in national totals. U.S. emissions from bunker fuels were approximately 22 MMTCE in 1995.

Overall, emissions from fossil fuel consumption have increased from 1990 to 1995. While emissions of CO_2 in 1991 were approximately 1.2 percent lower than the 1990 baseline level, in 1992 they increased by about 1.6 percent above the 1991 levels, thus returning emissions to slightly more than the 1990 baseline. By 1993, CO_2 emissions from fossil fuel combustion were approximately 2.5 percent greater than in 1990; in 1994, they were about 4.1 percent higher than 1990; and in 1995, they were about 5 percent higher. This trend is largely attributable to changes in total energy consumption resulting from the economic slowdown in the United States in the early 1990s and the subsequent recovery.

Despite the continued increase in natural gas and coal consumption in 1995, the total amount of petroleum used for energy production declined by about 0.2 percent, as somewhat higher prices for crude oil in 1995 led electric utilities and industry to decrease their consumption of petroleum by 32 and 1.9 percent, respectively, and to rely more heavily on natural gas, coal, nuclear electric power, and renewable energy. In contrast, consumption of petroleum increased 1.3 percent in the residential and commercial sectors, and about 1.6 percent in the transportation sector.

The energy related sources of CO_2 emissions included steam production for industrial processes, gasoline consumption for transportation, heating in residential and commercial buildings, and generation of electricity. Petroleum products across all sectors of the economy accounted for about 42 percent of total U.S. energy-related CO_2 emissions; coal, 36 percent; and natural gas, 22 percent.

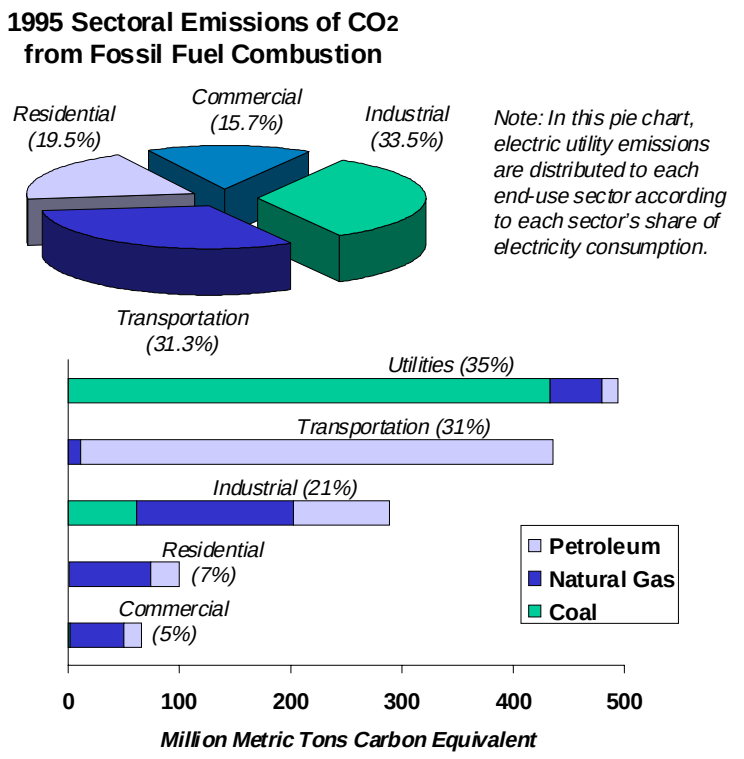
Industrial Sector. Industry accounts for the largest percentage of U.S. emissions from fossil fuel consumption (Figure 3-4). About two-thirds of these emissions result from producing steam and process heat, while the remaining third results from providing electricity for such uses as motors, electric furnaces, ovens, and lighting.

Transportation Sector. In the same league as the industrial sector, the transportation sector accounts for about 31 percent of U.S. CO_2 emissions from fossil fuel consumption. Virtually all of the energy consumed in this sector comes from petroleum-based products. Nearly two thirds of the emissions result from gasoline consumption in automobiles and other vehicles. The remaining emissions stem from meeting other transportation demands, including the combustion of diesel fuel for the trucking industry and jet fuel for aircraft.

Residential and Commercial Sectors. The residential and commercial sectors account for about 19 and 16 percent, respectively, of CO_2 emissions from fossil fuel consumption. Both sectors rely heavily on electricity for meeting energy needs, with about two-thirds to three-quarters of their emissions attributable to electricity consumption. End use applications include lighting, heating, cooling, and operating appliances. The remaining emissions are largely due to the consumption of natural gas and oil, primarily for meeting heating and cooking needs.

Electric Utilities. The United States relies on electricity to meet a significant portion of its energy requirements -- e.g., lighting, electric motors, and heating and air conditioning. As the largest consumers of U.S. energy (averaging 28 percent), electric utilities are collectively the largest producers (approximately 35 percent) of U.S. CO_2 emissions (Figure 3-5).

Figure 3-4 and 3-5



The type of energy electric utilities consume directly affects the volume of CO_2 emitted. For example, some of this electricity is generated with low-emitting technologies, such as nuclear energy, hydropower, or geothermal energy. However, electric utilities rely on coal for over half of their total energy requirements and account for about 87 percent of all coal consumed in the United States. Consequently, changes in electricity demand can significantly affect coal consumption and associated CO_2 emissions.

Fuel Production and Processing

Carbon dioxide is produced via flaring activities at natural gas systems and oil wells. The methane trapped in natural gas systems or oil wells is flared to relieve the rising pressure or to dispose of small quantities of gas that are not commercially marketable. As a result, the carbon contained in the methane becomes oxidized and forms CO_2. In 1995, flaring activities emitted approximately 2 MMTCE, or about 0.1 percent of total U.S. CO_2 emissions. Emissions trends from fuel production and processing are dictated by fossil fuel consumption.

Biomass and Biomass-Based Fuel Consumption

Biomass fuel is used primarily by the industrial sector in the form of fuel wood and wood waste, while the transportation sector dominates the use of biomass-based fuel, such as ethanol from corn or woody crops. Ethanol and ethanol blends, such as gasohol, are typically used to fuel public transport vehicles.

Although these fuels do emit CO_2, their emissions do not increase total atmospheric CO_2 because the biomass resources are consumed on a sustainable basis. For example, fuel wood burned one year but regrown the next only recycles carbon, rather than creating a net increase in total atmospheric carbon.

CO_2 emissions from biomass consumption were approximately 51 MMTCE, with the industrial sector accounting for 72 percent of the emissions, and the residential sector, 25 percent. CO_2 emissions from ethanol use in the United States have been rising in recent years due to a number of factors, including extension of federal tax exemptions for ethanol production, the Clean Air Act Amendments mandating the reduction of mobile source emissions, and the Energy Policy Act of 1992, which established incentives for increasing the use of alternative-fueled vehicles. In 1995, total U.S. CO_2 emissions from ethanol were 2 MMTCE.

Industrial Processes

Emissions are often produced as a by-product of various nonenergy-related activities. For example, in the industrial sector raw materials are often chemically transformed from one state to another. This transformation often releases such greenhouse gases as CO_2. The production processes that emit CO_2 include cement production, lime production, limestone consumption (e.g., in iron and steel making), soda ash production and use, and CO_2 manufacture. Total carbon dioxide emissions from these sources were approximately 17.4 MMTCE in 1995, accounting for about 1 percent of total U.S. CO_2 emissions. In 1995, emissions from these sources were approximately 10.5, 3.7, 1.2, 1.6, and 0.4 MMTCE, respectively, for a total of 17.4 MMTCE, or about one percent of total U.S. CO_2 emissions. Since 1990, emissions from cement, lime, and CO_2 manufacturing have increased slightly; emissions from limestone use have fluctuated; while emissions from soda ash production remained constant from 1990-1994 and increased in 1995.

Cement Production (10.5 MMTCE)

Carbon dioxide is produced primarily during the production of clinker, an intermediate product from which finished Portland and masonry cement are made. Specifically, carbon dioxide is created when calcium carbonate ($CaCO_3$) is heated in a cement kiln to form lime and CO_2. This lime combines with other materials to produce clinker, while the CO_2 is released into the atmosphere.

Lime Production (3.7 MMTCE)

Lime is used in steel making, construction, pulp and paper manufacturing, and water and sewage treatment. It is manufactured by heating limestone (mostly calcium carbonate — $CaCO_3$) in a kiln, creating calcium oxide (quicklime) and CO_2, which is normally emitted to the atmosphere.

Soda Ash Production and Consumption (1.6 MMTCE)

Commercial soda ash (sodium carbonate) is used in many consumer products, such as glass, soap and detergents, paper, textiles, and food. During the manufacturing of these products, natural sources of sodium carbonate are heated and transformed into a crude soda ash, in which CO_2 is generated as a by-product. In addition, CO_2 is released when the soda ash is consumed.

Limestone Consumption (1.2 MMTCE)

Limestone is a basic raw material used by a wide variety of industries, including the construction, agriculture, chemical, and metallurgical industries. For example, limestone can be used as a purifier in refining metals. In the case of iron ore, limestone heated in a blast furnace reacts with impurities in the iron ore and fuels, generating CO_2 as a by-product. Limestone is also used in flue gas desulfurization systems to remove sulfur dioxide from the exhaust gases.

Carbon Dioxide Manufacture (0.4 MMTCE)

Carbon dioxide is used in many segments of the economy, including food processing, beverage manufacturing, chemical processing, crude oil products, and a host of industrial and miscellaneous applications. For the most part, the CO_2 used in these applications will eventually be released into the atmosphere.

Changes in Forest Management and Land Use

How the Earth's land resources are managed can alter the natural balance of trace gas emissions. Everyday land-use decisions include clearing an area of forest to create cropland or pasture, restocking a logged forest, draining a wetland, or allowing a pasture to revert to a grassland or forest.

Forests, which cover about 295 million hectares (737 million acres) of U.S. land in the contiguous 48 states (USDA/USFS 1990), are also an important terrestrial sink for CO_2. Because approximately half the dry weight of wood is carbon, as trees add mass to trunks, limbs, and roots, carbon is stored in relatively long-lived biomass instead of being released to the atmosphere. Soils and vegetative cover also provide potential sinks for carbon emissions.

In the United States, improved forest-management practices and the regeneration of previously cleared forest areas have resulted in a net uptake (sequestration) of carbon in U.S. forest lands. This uptake is an ongoing result of land-use changes in previous decades. For example, because of improved agricultural productivity and the widespread use of tractors, the rate of clearing forest land for crop cultivation and pasture slowed greatly in the late 19th century, and by 1920 this practice had all but ceased. As farming expanded in the Midwest and West, large areas of previously cultivated land in the East were brought out of crop production, primarily between 1920 and 1950, and were allowed to revert to forest land or were actively reforested.

Since the early 1950s, the managed growth of private forest land in the East has nearly doubled the biomass density there. The 1970s and 1980s saw a resurgence of federally sponsored tree-planting programs (e.g., the Forestry Incentive Program) and soil conservation programs (e.g., the Conservation Reserve Program), which have focused on reforesting previously harvested lands, improving timber-management, combating soil erosion, and converting marginal cropland to forests.

As a result of these activities, the net CO_2 flux in 1995 is estimated to have been an uptake of 117 MMTCE (which includes the carbon stored in the U.S. wood product pool and in landfills). This carbon uptake represents an offset of about 8 percent of the 1995 CO_2 emissions from fossil fuel combustion during this period. The amount of carbon sequestered through changes in U.S. forestry and land use practices continues to decline, as the expansion of eastern forest cover slows down.

Methane Emissions

Atmospheric methane (CH_4) is an integral component of the greenhouse effect, second only to CO_2 as an anthropogenic source. Methane's overall contribution to global warming is large because it is estimated to be twenty-one times more effective at trapping heat in the atmosphere than CO_2 over a 100-year time horizon (IPCC 1996). Over the last two centuries, methane's concentration in the atmosphere has more than doubled. Scientists believe these atmospheric increases are due largely to increasing emissions from anthropogenic sources, such as landfills, agricultural activities, fossil fuel combus-

Figure 3-6

U.S. Sources of Methane Emissions in 1995

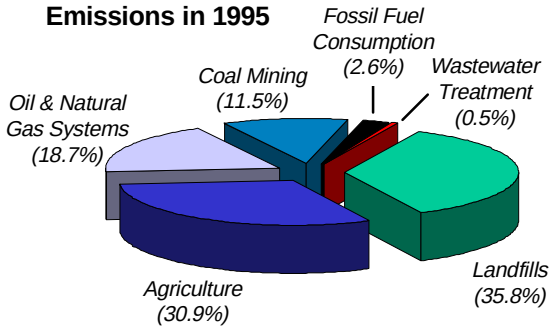


Table 3-3

U.S. Methane Emissions by Source in 1995

Sources	MMT	MMTCE
Landfills	11.1	63.5
Agriculture*	9.6	54.8
Coal Mining	3.6	20.4
Oil and Natural Gas Systems	5.8	33.2
Fossil Fuel Consumption	0.8	4.6
Wastewater Treatment	0.2	0.9
TOTAL EMISSIONS	31.0	177.3

Note: All methane emission estimates are preliminary.

* One-year data were used to estimate methane emissions from rice cultivation as part of the Agriculture sector. Corresponding values for the Agricultural sector using IPCC recommended three-year averages for rice cultivation are: 9.3 MMT and 53.2 MMTCE.

tion, coal mining, the production and processing of natural gas and oil, and wastewater treatment (Table 3-3 and Figure 3-6).

Landfills

Landfills are the largest single anthropogenic source of methane emissions in the United States. Of the estimated 3,000 methane-emitting landfills in the United States, 1,300 account for about half of the emissions.

In an environment where the oxygen content is low or nonexistent, organic materials, such as yard waste, household waste, food waste, and paper, are decomposed by bacteria to produce methane, CO_2, and stabilized organic materials (materials that cannot be decomposed further). Methane emissions from landfills are affected by such specific factors as waste composition, moisture, and landfill size.

Methane emissions from U.S. landfills in 1995 were 63.5 MMTCE, a slight increase over the 60 MMTCE reported in the previous inventory. Emissions from U.S. municipal solid waste landfills, which received over 59 percent of the total solid waste generated in the United States, accounted for about 90 to 95 percent of total landfill emissions, while industrial landfills accounted for the remaining 5 to 10 percent. Currently, almost 15 percent of the methane released is recovered for use as energy, compared to 10 percent reported in the last inventory.

A regulation promulgated in March 1996 requires the largest U.S. landfills to collect and combust their landfill gas to reduce emissions of nonmethane volatile organic compounds (VOCs). It is estimated that by the year 2000, this regulation will have reduced landfill methane emissions by more than 50 percent (6.2 million metric tons of methane, or 35.5 MMTCE).

Agriculture

The agricultural sector accounted for approximately 31 percent of total U.S. methane emissions in 1995, with enteric fermentation in domestic livestock (34.9 MMTCE) and manure management (17.1 MMTCE) together accounting for the majority (Figure 3-7). Other agricultural activities contributing directly to methane emissions include rice cultivation (2.8 MMTCE) and field burning of agricultural crop wastes (0.04 MMTCE).

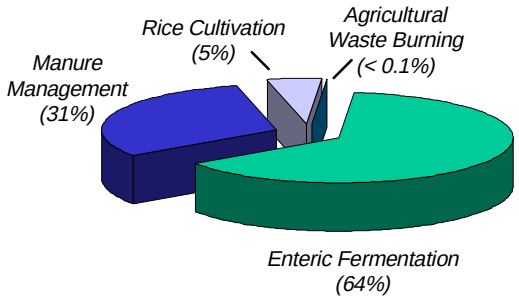
Between 1990 and 1995, methane emissions from domestic livestock enteric fermentation and manure management increased by about 7 percent and 15 percent, respectively. During this same time period, methane emissions from rice cultivation increased by about 10 percent, while emissions from field burning fluctuated. Several other agricultural activities, such as irrigation and tillage practices, may contribute to methane emissions. However, since emissions from these sources are uncertain and are believed to be small the United States has not included them in the current inventory. Details on the emission pathways included in the inventory follow.

Enteric Fermentation in Domestic Livestock
(34.9 MMTCE)

During animal digestion, methane is produced through a process referred to as enteric fermentation, in which microbes that reside in animal digestive systems break down the feed consumed by the animal. In 1995, enteric fermentation was the source of about 20 percent of total U.S. methane emissions, and about 64 percent of methane emissions from the

Figure 3-7

U.S. Sources of Agricultural Methane Emissions in 1995



agricultural sector. This estimate of 34.9 MMTCE is the same as that reported in the previous inventory.

Manure Management (17.1 MMTCE)

The decomposition of organic animal waste in an anaerobic environment produces methane. The most important factor affecting the amount of methane produced is how the manure is managed, since certain types of storage and treatment systems promote an oxygen-free environment. In particular, liquid systems tend to produce a significant quantity of methane, whereas solid waste management approaches produce little or no methane. Higher temperatures and moist climatic conditions also promote methane production.

Emissions from manure management were about 10 percent of total U.S. methane emissions in 1995, and about 31 percent of methane emissions from the agriculture sector. Liquid-based manure management systems accounted for over 80 percent of total emissions from animal wastes. The 17.1 MMTCE estimate reported here is slightly above the 13.7 MMTCE reported in the previous inventory because of larger U.S. farm animal populations and expanded use of liquid manure management systems.

Rice Cultivation (2.8 MMTCE)

Most of the world's rice, and all of the rice in the United States, is grown on flooded fields. The soil's organic matter decomposes under the anaerobic conditions created by the flooding, releasing methane to the atmosphere, primarily through the rice plants.

In 1995, rice cultivation was the source of less than 2 percent of total U.S. methane emissions, and about 5 percent of U.S. methane emissions from agricultural sources. Emissions estimates from this source have not changed significantly since 1990.

Field Burning of Agricultural Wastes (0.04 MMTCE)

Farming systems produce large quantities of agricultural crop wastes. Disposal systems for these wastes include plowing them back into the field; composting, landfilling, or burning them in the field; using them as a biomass fuel; or selling them in supplemental feed markets.

Burning crop residues releases a number of greenhouse gases, including CO_2, methane, carbon monoxide, nitrous oxide, and oxides of nitrogen. Field burning is not considered to be a net source of carbon dioxide emissions because the CO_2 released during burning is reabsorbed by crop regrowth during the next growing season. However, this practice is a net source of emissions for the other gases, since their emissions would not have occurred had the wastes not been combusted.

Because field burning is not common in the United States, it was responsible for only 0.02 percent of total U.S. methane emissions in 1995, and 0.07 percent of emissions from the agricultural sector. Estimates of emissions from this source have dropped significantly since the last inventory as a result of new research indicating that a smaller fraction of U.S. crop wastes is burned than previously assumed.

Oil and Natural Gas Production and Processing

Methane emissions vary greatly from facility to facility. In 1995, an estimated 31.2 MMTCE (or approximately 18 percent) of U.S. methane emissions were due to leaks, disruptions, etc., in the operation and maintenance of equipment in the U.S. natural gas system. This figure is significantly higher than previous estimates because of revised estimation methods that improved activity factors (i.e., equipment counts) and emission factors. As a result, natural gas systems are now ranked as the third largest source of U.S. methane emissions.

Natural gas is often found in conjunction with oil exploration. Methane is also released during the production, refinement, transportation, and storage of crude oil. During 1995, oil and gas production facilities released 2.0 MMTCE of methane to the atmosphere, representing about one percent of total U.S. methane emissions.

Coal Mining

Produced millions of years ago during the formation of coal, methane is trapped within coal seams and surrounding rock strata. The volume of methane released to the atmosphere during coal-mining operations depends primarily upon the depth and type of coal being mined.

Methane from surface mines is emitted directly to the atmosphere as the rock strata overlying the coal seam are removed. Because methane in underground mines is explosive at concentrations of 5 to 15 percent in air, most active underground mines are required to circulate large quantities of air and vent the air into the atmosphere. At some mines, methane-recovery systems may supplement these ventilation

systems to ensure mine safety. U.S. recovery of methane has been increasing in recent years. During 1995, coal mining, processing, transportation, and consumption activities produced an estimated 20.4 MMTCE of methane, or 12 percent of total U.S. methane emissions. This lower estimate is the result of improved mine-specific information and expanded methane recovery.

Other Sources

Methane is also produced from several other sources in the United States, including energy-related combustion activities, wastewater treatment, industrial processes, and changes in land use. The sources included in the U.S. inventory are fuel combustion and wastewater treatment, which accounted for approximately 4.6 and 0.9 MMTCE, respectively, in 1995. These emissions represent about 3 percent of total U.S. methane emissions. Additional U.S. anthropogenic sources of methane -- such as ammonia, coke, iron, steel production, and land-use changes -- are not included because little information on methane emissions from these sources is currently available.

Nitrous Oxide Emissions

Nitrous oxide (N_2O) is a chemically and radiatively active greenhouse gas that is produced naturally from a wide variety of biological sources in soil and water. While N_2O emissions of are much lower than CO_2 emissions, N_2O is approximately 310 times more powerful than CO_2 at trapping heat in the atmosphere over a 100-year time horizon (IPCC 1996).

During the past two centuries, human activities have raised atmospheric concentrations of N_2O by approximately 8 percent (Figure 3-8, Table 3-4). The main anthropogenic activities producing N_2O are soil management and fertilizer use for agriculture, fossil fuel combustion, adipic acid production, and nitric acid production (see *Table 3-4* and *Figure 3-8*). While emissions from soil management and fertilizers remained relatively constant during 1990-93, they increased during 1994-95 because of intensified fertilizer applications to speed recovery of nutrients lost to the 1993 floods. N_2O emissions from all other sources showed no significant changes.

Agricultural Soil Management and Fertilizer Use

In 1995, U.S. consumption of synthetic nitrogen and organic fertilizers accounted for 18.4 MMTCE, or approximately 46 percent of total U.S. N_2O emissions. Other agricultural soil management practices, such as irrigation, tillage practices, or laying fallow the land, can also affect N_2O fluxes to and from the soil. However, because there is much uncertainty about the direction and magnitude of the effects of these other practices, only the emissions from fertilizer use and field burning of agricultural wastes are included in the U.S. inventory at this time.

Fossil Fuel Combustion

N_2O is a product of the reaction that occurs between nitrogen and oxygen during fossil fuel combustion. Both mobile and stationary sources emit N_2O, and the volume emitted varies according to the type of fuel, technology, or pollution control device used, as well as maintenance and operation practices.

For example, catalytic converters installed to reduce vehicular pollutants have unintentionally promoted the formation of N_2O. As the number of catalytic converter-equipped vehicles has risen in the U.S. motor vehicle fleet, so have emissions of N_2O from this source (DOE/EIA, 1993b).

In 1995, N_2O emissions from mobile sources totaled 9.2 MMTCE (or 23 percent of total N_2O emissions), and total N_2O emissions from stationary sources were 3.0 MMTCE.

Adipic Acid Production

The vast majority of all adipic acid produced in the United States is used to manufacture nylon 6,6. N_2O is also used to produce some low-temperature lubricants, and to add a “tangy” flavor to foods.

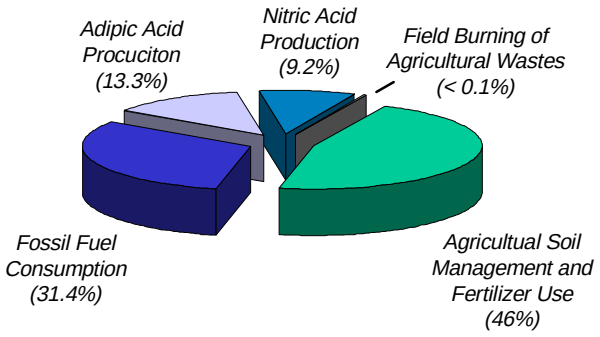
Table 3-4

U.S. Nitrous Oxide Emissions by Source in 1995

Sources	MMT	MMTCE
Agricultural Soil Management and Fertilizer Use	0.21	18.4
Fossil Fuel Consumption	0.15	12.3
Adipic Acid Production	0.06	5.2
Nitric Acid Production	0.04	3.6
Agricultural Waste Burning	< 0.01	< 0.1
TOTAL EMISSIONS	**0.47**	**39.5**

Figure 3-8

U.S. Sources of Nitrous Oxide Emissions in 1995



In 1995, U.S. adipic acid production generated 5.2 MMTCE of nitrous oxide, or 13 percent of total U.S. N_2O emissions. By 1996, all adipic acid production plants in the United States are expected to have N_2O controls in place that will reduce emissions up to 98 percent, compared to uncontrolled levels. (One-half of the plants had these controls in place and operating in 1995.)

Nitric Acid Production

Nitric acid production is another industrial source of N_2O emissions. Used primarily to make synthetic commercial fertilizer, this raw material is also a major component in the production of adipic acid and explosives.

Virtually all of the nitric acid that is manufactured commercially in the United States is produced by the oxidation of ammonia, during which N_2O is formed and emitted to the atmosphere. In 1995, about 3.6 MMTCE of N_2O were emitted from nitric acid production, accounting for 9 percent of total U.S. N_2O emissions.

Other Sources of N_2O

Other N_2O-emitting activities include the burning of agricultural crop residues and changes in land use. In 1995, agricultural burning contributed approximately 0.01 MMTCE of N_2O emissions to the atmosphere.

The U.S. inventory does not account for several land-use changes because of uncertainties in their effects on fluxes in N_2O and trace gases, as well as poorly quantified statistics on them. These changes include forest activity, reclamation of freshwater wetland areas, conversion of grasslands to pasture and cropland, and conversion of managed lands to grasslands.

Emissions from HFCs, PFCs and SF_6

Hydrofluorocarbons (HFCs) and perfluorinated compounds (PFCs) have been introduced as alternatives to the ozone depleting substances being phased out under the *Montreal Protocol* and Clean Air Act Amendments of 1990. Because HFCs and PFCs are not directly harmful to the stratospheric ozone layer, they are not controlled by the *Montreal Protocol*.

However, these compounds, along with sulfur hexafluoride (SF_6), are powerful greenhouse gases. Therefore, they are considered under the United Nations' Framework Convention on Climate Change

Table 3-5

1995 Emissions of HFCs, PFCs, and SF6

HFCs, PFCs, and SF6 are powerful greenhouse gases. In addition to having high global warming potentials, SF6 and most PFCs have extremely long atmospheric lifetimes, resulting in their irreversible accumulation in the atmosphere.

Compound	MMT of Gas	Atmospheric Lifetime (yrs)	GWP Value	MMTCE
HFCs	**0.02071**			**20.92**
HFC-23	0.00426	264	11,700	13.61
HFC-125	0.00227	33	2,800	1.74
HFC-134a	0.01086	15	1,300	3.85
HFC-143a	0.00004	48	3,800	0.05
HFC-152a	0.00091	2	140	0.03
HFC-227	0.00186	37	2,900	1.47
HFC-4310	0.00051	17	1,300	0.18
PFCs	**0.00410**			**7.93**
CF_4	0.00250	50,000	6,500	4.43
C_2F_6	0.00057	10,000	9,200	1.42
C_4F_{10}	0.00001	2,600	7,000	0.02
C_6F_{14}	< 0.00001	3,200	7,400	< 0.01
PFCs/PFPEs*	0.00102		7,400	2.05
SF_6	**0.00129**	**3,200**	**23,900**	**8.40**

*PFC/PFPEs are a proxy for many diverse PFCs and perfluoropolyethers (PFPEs) which are beginning to be employed in solvent applications. GWP and lifetime values are based upon C_6F_{14}.

Box 3-2

Emissions of CFCs and Related Compounds

Chlorofluorocarbons (CFCs)and other halogenated compounds were first emitted into the atmosphere this century. This family of human-made compounds includes CFCs, halons, methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These substances are used in a variety of industrial applications, including foam production, refrigeration, air conditioning, solvent cleaning, sterilization, fire extinguishing, paints, coatings, other chemical intermediates, and miscellaneous uses (e.g., aerosols and propellants).

Because these compounds have been shown to deplete stratospheric ozone, they are typically referred to as ozone-depleting substances (ODSs). In addition, they are important greenhouse gases because they block infrared radiation that would otherwise escape into space (IPCC 1996).

Recognizing the harmful effects of these compounds on the atmosphere, in 1987 many governments signed the Montreal Protocol on Substances that Deplete the Ozone Layer to limit the production and consumption of a number of them. As of April 1997, 155 countries have signed the Montreal Protocol. The United States furthered its commitment to phase out these substances by signing and ratifying the Copenhagen Amendments to the Montreal Protocol in 1992. Under these amendments, the U.S. committed to eliminating the production of halons by January 1, 1994, and CFCs by January 1, 1996.

The IPCC Guidelines do not include reporting instructions for emissions of ODSs because their use is being phased out under the Montreal Protocol. Nevertheless, because the United States believes that no inventory is complete without these emissions, estimates for emissions from several Class I and Class II ODSs are provided here. Compounds are classified according to their ozone-depleting potential and must adhere to a strict set of phase-out requirements under the Montreal Protocol.

Class I compounds are the primary ODSs; Class II compounds include partially halogenated chlorine compounds (HCFCs), some of which were developed as interim replacements for CFCs. Because these HCFC compounds are only partially halogenated, their hydrogen-carbon bonds are more vulnerable to oxidation in the troposphere and, therefore, pose only about one-tenth to one-hundredth the threat to stratospheric ozone, compared to CFCs.

Also, the effects of these compounds on radiative forcing are not provided here. Although CFCs and related compounds have large direct global warming potentials, their indirect effects are believed to be negative and, therefore could significantly reduce the magnitude of their direct effects (IPCC 1992). Given the uncertainties surrounding the net effect of these gases, they are reported here on a full molecular weight basis only.

U.S. Emissions of Ozone-Depleting Substances and Related Compounds
(Millions of Metric Tons in 1997)

Compound	Emissions
Class I Compounds	
CFC-11	0.036
CFC-12	0.052
CFC-113	0.017
CFC-114	0.002
CFC-115	0.003
Carbon Tetrachloride	0.005
Methyl Chloroform	0.046
Halon-1211	0.001
Halon-1301	0.002
Class II Compounds	
HCFC-22	0.092
HCFC-123	0.002
HCFC-124	0.005
HCFC-141b	0.019
HCFC-142b	0.020

(FCCC). In addition to having high global warming potentials, SF_6 and most PFCs have extremely long atmospheric lifetimes, resulting in their essentially irreversible accumulation in the atmosphere.

From 1990 to 1993, U.S. emissions of HFCs and PFCs remained relatively constant, while SF_6 emissions increased slightly. Since 1993, the use and emissions of HFC substitutes have grown largely from an increase in the use of HFC-134a in mobile air conditioners. HFC and PFC emissions also result as by-product emissions from other production processes. For example, HFC-23 is a by-product emitted during the production of HCFC-22, and PFCs (CF_4 and C_2F_6) are emitted during aluminum smelting.

Sulfur hexafluoride (SF_6) is the most potent greenhouse gas the IPCC has ever evaluated. About 80 percent of the worldwide use of SF_6 is as an insulator in electrical transmission and distribution systems. SF_6 is also used as a protective atmosphere for the casting of molten magnesium.

Table 3-5 presents emission estimates for these gases. In 1995, U.S. emissions of HFCs and PFCs were estimated to be 29 MMTCE, and SF_6 emissions, approximately 8 MMTCE.

Emissions of Criteria Pollutants

In the United States, carbon monoxide (CO), nitrogen oxides (NO_x), nonmethane volatile organic compounds (NMVOCs), and sulfur dioxide (SO_2) are commonly referred to as "criteria pollutants." CO is produced when carbon containing fuels are burned incompletely. Oxides of nitrogen (NO and NO_2) are created by lightening, fires, fossil fuel combustion, and in the stratosphere from nitrous oxide. NMVOCs -- which include such compounds as propane, butane, and ethane -- are emitted primarily from transportation and industrial processes, as well as forest wildfires and nonindustrial consumption of organic solvents. And SO_2 can result from the combustion of fossil fuels, industrial processing (particularly in the metals industry), waste incineration, and biomass burning (U.S. EPA 1996).

Because of their contribution to the formation of urban smog (and acid rain in the case of SO_2), criteria pollutants are regulated under the 1970 Clean Air Act and its successive amendments. These gases also effect global climate, although their impact is limited because their radiative effects are indirect. That is, they do not directly act as greenhouse gases but react with other chemical compounds in the atmosphere to form compounds that are greenhouse gases. Unlike other criteria pollutants, SO_2 emitted into the atmosphere affects the Earth's radiative budget negatively; therefore, it is discussed separately from the other criteria pollutants in this section.

The most important of the indirect effects of criteria pollutants is their role as precursors of tropospheric ozone. In this role, they contribute to ozone formation and alter the atmospheric lifetimes of other greenhouse gases. For example, CO interacts with the hydroxyl radical (OH) -- the major atmospheric sink for methane emissions -- to form CO_2. Therefore, increased atmospheric concentrations of CO limit the number of OH compounds available to destroy methane, thus increasing the atmospheric lifetime of methane.

Since 1970, the United States has published estimates of annual emissions of criteria pollutants. Table 3-6 shows that fuel consumption accounts for the majority of emissions of these gases. In fact, motor vehicles that burn fossil fuels contributed approximately 81 percent of all U.S. CO emissions in 1995. Motor vehicles also emit more than a third of total U.S. NO_x and NMVOC emissions. Industrial processes -- such as the manufacture of chemical and allied products, metals processing, and industrial uses of solvents -- are also major sources of CO, NO_x, and NMVOCs.

Table 3-6

1995 Emissions of CO, NOx, NMVOCs, and SO 2

(Million Metric Tonnes)

Sources	MMT	NOx	MMTCE	SO2
Fossil Fuel Combustion	70.95	18.75	8.22	14.73
Industrial Processes	5.15	0.71	4.13	1.83
Solvent Use	< 0.01	< 0.01	5.80	< 0.01
Waste Disposal and Recycling	1.60	0.01	2.19	0.03
Other Combustion	5.86	0.21	0.41	0.01
TOTAL	**83.55**	**19.75**	**20.74**	**16.60**

Box 3-3

Sources and Effects of Sulfur Dioxide

Emitted into the atmosphere through natural and human processes, SO_2 affects the Earth's radiative budget through photochemical transformation into sulfate particles that (1) scatter sunlight back to space, thereby reducing the radiation reaching the Earth's surface; (2) possibly increase the number of cloud condensation nuclei, thereby potentially altering the physical characteristics of clouds; and (3) affect atmospheric chemical composition -- e.g., atmospheric ozone -- by providing surfaces for heterogeneous chemical processes. As a result of these activities, the effect of these SO_2 emissions on radiative forcing is likely negative (IPCC 1996), although the distribution is not uniform.

SO_2 is also a major contributor to the mix of urban air pollution, which can significantly increase acute and chronic respiratory diseases. Once SO_2 is emitted, it is chemically transformed in the atmosphere and returns to the Earth as the primary source of acid rain. Because of these harmful effects, the United States has regulated SO_2 emissions in the Clean Air Act of 1970 and its subsequent 1990 amendments.

Electric utilities are the largest source of SO_2 emissions in the United States, accounting for about 66 percent of total SO_2 emissions in 1995. Coal combustion contributes approximately 96 percent of those emissions. SO_2 emissions have significantly decreased in recent years, as electric utilities have increasingly switched to lower-sulfur coal and natural gas. The second largest source is fuel combustion for metal smelting and other industrial processes, which produced about 20 percent of 1995 SO_2 emissions (U.S. EPA/OAQPS).

REFERENCES

United States Department of Energy/Energy Information Administration (DOE/EIA). 1993. *Emissions of Greenhouse Gases in the United States: 1985 - 1990*. U.S. DOE, Washington, D.C. DOE/EIA-0573.

DOE/EIA. 1996a. *Emissions of Greenhouse Gases in the United States 1995*; Energy Information Administration, U.S. Department of Energy, Washington, D.C.

DOE/EIA. 1996b. *Annual Energy Review 1995;* Energy Information Administration, U.S. Department of Energy, Washington, D.C.

IPCC. 1992. *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment.* University Press, Cambridge, England.

IPCC. 1994. *Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios*; J.T. Houghton, L.G. Meira Filho, J. Bruce, Hoesung Lee, B.A. Callander, E. Haites, N. Harris, and K. Maskell, Eds.; Intergovernmental Panel on Climate Change: Cambridge; pp. 1-34.

IPCC. 1996. *Climate Change 1995: The Science of Climate Change*; J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell, Eds.; Cambridge University Press. Cambridge, U.K.

IPCC/OECD/IEA/UNEP. 1995. *IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 3, Reference Manual*; Intergovernmental Panel on Climate Change, Organization for Economic Co-Operation and Development, International Energy Agency, United Nations Environment Program: Brecknell, UK; pp. Preface 1-Overview 7.

U.S. EPA. 1995. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1994*; Office of Policy, Planning and Evaluation, Washington, D.C.

U.S. EPA. 1996. *National Air Pollutant Emission Trends, 1995*, Office of Air Quality Planning and Standards, Washington, D.C.

U.S. EPA. 1997. draft of *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1995*; Office of Policy, Planning and Evaluation, Washington, D.C.

United States Forest Service (USFS). 1990. *An Analysis of the Timber Situation in the United States: 1989 - 2040: A Technical Document Supporting the 1989 USDA Forest Service RPA Assessment.* Forest Service, United States Department of Agriculture. General Technical Report RM-199.

Seki, M., Christ, R. 1995. *African Regional Workshop on Greenhouse Gas Emission Inventories and Emission Mitigation Options: Forestry, Land-use Change and Agriculture*; UNEP.