

5. Other Gases: Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride

Overview

Total U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2004

Estimated 2004 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	155.9
Change Compared to 2003 (Million Metric Tons Carbon Dioxide Equivalent)	13.6
Change from 2003 (<i>Percent</i>)	9.6%
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	67.9
Change from 1990 (<i>Percent</i>)	77.1%

U.S. emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆) in 2004, according to the U.S. Environmental Protection Agency (EPA), totaled 155.9 million metric tons carbon dioxide equivalent (MMTCO₂e). Collectively, these “other gases” represented 2.2 percent of total U.S. greenhouse gas emissions. Their 2004 emissions were 9.6 percent (13.6 MMTCO₂e) above the 2003 level of 142.4 MMTCO₂e, an increase attributed primarily to a 12-percent (13.5 MMTCO₂e) increase in emissions of HFCs.

Table 31 at the end of this chapter shows U.S. emissions of HFCs, PFCs, and SF₆ from 1990 to 2004 in carbon dioxide equivalent units, and Table 32 shows their emissions in metric tons of native gas. U.S. emissions of HFCs, PFCs, and SF₆ were 77 percent (67.9 MMTCO₂e) higher in 2004 than in 1990 (88.1 MMTCO₂e). Revised EPA data for 1990-2003 and new estimates for 2004 show that annual emissions of HFCs have increased significantly since 1990; emissions of PFCs have declined by two-thirds; and SF₆ emissions have declined by about one-half since 1990 (Figure 4).

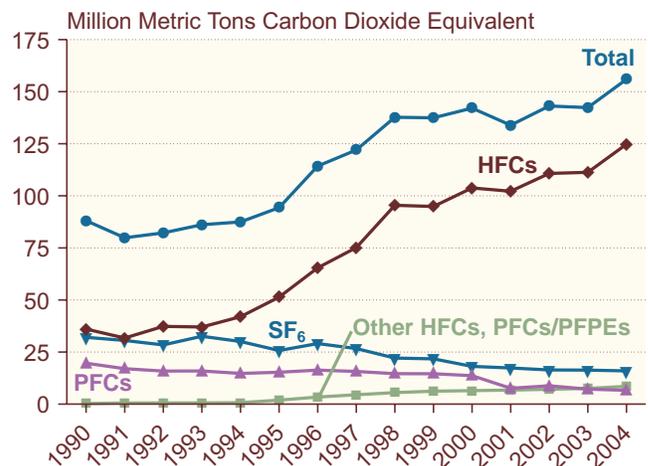
The increase in HFC emissions since the early 1990s reflects the use of HFCs as replacements for CFCs (chlorofluorocarbons), HCFCs (hydrochlorofluorocarbons), halons, and other ozone-depleting substances

(ODS) that are being phased out under the Montreal Protocol because they damage the Earth’s stratospheric ozone layer. ODS are used in a variety of applications, including refrigeration and air conditioning, solvents, foam production, fire extinguishers, aerosols, and sterilization.

PFC emissions have trended downward since 1990, largely as a result of reduced PFC emissions from the aluminum industry. SF₆ emissions have also declined since 1990, mainly due to reduced emissions from electricity transmission and distribution facilities in the electric power industry.

The emissions estimates in Table 31 are based on data provided by the EPA’s Office of Air and Radiation.⁸⁸ The EPA data, provided in units of native gas (thousand metric tons), were converted to carbon dioxide equivalent units by the Energy Information Administration (EIA), using values for the global warming potential (GWP) for each gas from the 2001 Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The estimates in Table 32 are taken directly from data supplied by the EPA’s Office of Air and Radiation. The 2004 preliminary estimates developed by the EPA and provided to EIA include some revisions to historical emissions estimates, based on recent runs of the EPA’s Vintaging Model (see boxes on

Figure 4. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2004



Source: Estimates presented in this chapter.

⁸⁸Preliminary data estimates received by EIA from the EPA’s Office of Air and Radiation, October 2005.

pages 69 and 70). Those revisions are reflected in the emissions estimates presented in this chapter.

Hydrofluorocarbons (HFCs)

U.S. Emissions of Hydrofluorocarbons, 1990-2004

Estimated 2004 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	124.8

Change Compared to 2003 (Million Metric Tons Carbon Dioxide Equivalent)	13.5

Change from 2003 (Percent)	12.1%

Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	88.7

Change from 1990 (Percent)	246.1%

The EPA estimates U.S. emissions of HFCs in 2004 at 124.8 MMTCO₂e, equivalent to 1.8 percent of total U.S. greenhouse gas emissions.⁸⁹ HFC emissions in 2004 were 12 percent (13.5 MMTCO₂e) above the 2003 level of 111.3 MMTCO₂e (Table 31). The overall increase included increases in emissions of HFC-134a (5.2 MMTCO₂e), HFC-23 (3.4 MMTCO₂e), HFC-143a (3.0 MMTCO₂e), and HFC-125 (1.9 MMTCO₂e).

U.S. HFC emissions in 2004 were 246 percent (88.7 MMTCO₂e) above the 1990 level of 36.1 MMTCO₂e. Since 1990, HFC emissions have accounted for a growing share of total emissions of HFCs, PFCs, and SF₆ combined (80 percent in 2004, compared with 41 percent in 1990). By far the largest portion of HFC emissions, 87 percent, can be attributed to their use as replacements for ODS. Emissions of HFCs used as substitutes for ODS (HFC-125, HFC-134a, HFC-143a, and HFC-236fa) have grown from trace amounts in 1990 to 108.5 MMTCO₂e in 2004.

HFCs are compounds containing carbon, hydrogen, and fluorine. Although they do not destroy stratospheric ozone, they are powerful greenhouse gases. HFCs are used in many applications, such as solvents, domestic and commercial refrigerants, firefighting agents,

propellants for pharmaceutical and industrial aerosols, foam-blowing agents, and in blends for air conditioning refrigerants.

The market for HFCs is expanding. As CFCs and ODS are being phased out under the Montreal Protocol and the Clean Air Act, HFCs have been introduced into the market to fill the void in many key applications. For example, HFCs are used in fire protection applications to replace Halon 1301 and Halon 1211, which are no longer being produced in the United States.⁹⁰ HCFCs, now interim replacements for CFCs, will also be phased out. For example, HCFC-141b and HCFC-142b, which are used as blowing agents in insulation foams, will be replaced by HFCs for some uses.⁹¹

Trifluoromethane (HFC-23)

The EPA estimates 2004 emissions of HFC-23 at 16.3 MMTCO₂e.⁹² HFC-23 emissions, representing 13 percent of total HFC emissions in 2004, were 26 percent (3.4 MMTCO₂e) above their 2003 level of 13.0 MMTCO₂e—the first upturn in HFC-23 emissions since 1998—but still 55 percent (19.7 MMTCO₂e) below their 1990 level of 36.1 MMTCO₂e. Since 1990, annual HFC-23 emissions have fluctuated, peaking in 1998 at 41.7 MMTCO₂e and then falling steadily until the upturn in 2004.

As in 1998, the 2004 increase in HFC-23 emissions can be traced to an increase in the production of chlorodifluoromethane (HCFC-22). Nearly all HFC-23 emissions (98 percent) are created as a byproduct in the production of HCFC-22 and generally are vented to the atmosphere. In some cases the HFC-23 is captured for use in a limited number of applications. While production of HCFC-22 peaked in 2000, emissions of HFC-23 from this source declined from 1998 until 2004, because the HFC-23 emission rate (i.e., the amount of HFC-23 emitted per kilogram of HCFC-22 manufactured) decreased significantly.⁹³ Production of HCFC-22 also fell significantly between 2000 and 2004, resulting in further reductions in emissions.⁹⁴

HCFC-22 is used as a component of blowing agents for polyurethane foams and extruded polystyrene foams, and in the refrigerant market for stationary refrigeration and air conditioning (including chillers, room and household [central] air conditioners, and dehumidifiers). The EPA administers a voluntary program (the HFC-23 Emission Reduction Program) with HCFC-22

⁸⁹Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.

⁹⁰European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/applications/other_app/firefighting.html.

⁹¹European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/applications/insulation_foams.html.

⁹²Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005.

⁹³Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005.

⁹⁴Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005.

Revisions in EPA Emissions Estimation Methodology

The primary source for the emissions estimates presented in this chapter is data obtained from the U.S. Environmental Protection Agency (EPA), Office of Air and Radiation. The Office of Air and Radiation also prepares an annual inventory of greenhouse gas emissions, which is published pursuant to U.S. commitments under the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC encourages parties to revise methods regularly and to recalculate emissions affected by the revisions. The data supporting the EPA inventory, including the emissions estimates for 2004, incorporate a number of revisions to the data and estimation methodologies used for hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆) in its most recent emissions inventory.^a Those changes are reflected in the EPA's historical emissions estimates, as described below:

- *Electricity Transmission and Distribution.* The changes in calculations of emissions from electricity transmission and distribution are the result of incorporating more up-to-date transmission mileage data and the inclusion of additional historical partner data in the EPA's SF₆ Emissions Reduction Partnership for Electric Power Systems for 2000, 2001, and 2002. Previously, the 2001 Utility Data Institute (UDI) Directory of Electric Power Producers and Distributors was used by the EPA to estimate SF₆ emissions for 2001 and 2002. Those numbers have been revised to account for increases in transmission mileage during 2001 and 2002, primarily as a result of growth in the U.S. transmission system. Accordingly, estimates of non-partner and non-reporting partner emissions have been recalculated in the non-reporting partner regression equations.

Because transmission miles are highly correlated with SF₆ emissions, the EPA has used these regression equations to calculate emissions from non-partners and non-reporting partners in the SF₆ emissions reduction partnership. In addition to transmission mileage revisions, the electric power system emission estimates have also been recalculated, based on additional historical partner data. Specifically, the regression equations for each respective year of the historical partner

submissions have been updated, resulting in new extrapolations to non-reporting partners as well. These revisions resulted in an average annual decrease in estimated SF₆ emissions from electric power systems of 0.2 percent, or less than 0.1 million metric tons carbon dioxide equivalent (MMTCO₂e) for the 2000-2002 period.

- *Magnesium Production and Processing.* The emissions estimates in this report have been revised to reflect new historical data supplied by the U.S. Geological Survey and participants in the EPA's SF₆ Emission Reduction Partnership for the Magnesium Industry. This change resulted in an average annual increase in estimated SF₆ emissions from magnesium production and processing of less than 0.1 MMTCO₂e (4.1 percent) for the 2000-2002 period.
- *Substitution of Ozone-Depleting Substances.* The EPA has updated assumptions for its Vintaging Model pertaining to market trends in chemicals and chemical substitutes. These changes resulted in an average annual net increase in estimated HFC and PFC emissions of less than 0.1 MMTCO₂e (4.1 percent) for the 1990-2002 period.
- *Aluminum Production.* As the result of an EPA-funded study, facility-specific slope coefficients for three U.S. aluminum smelters have been reestimated. The new coefficients have been used by the EPA in place of the IPCC defaults for revising the appropriate smelter-specific emission factors. The EPA provided the revised data to EIA, along with additional recently reported data concerning smelter operating parameters by participants in the EPA's Voluntary Aluminum Industrial Partnership Program. These changes resulted in an average annual increase of less than 0.1 MMTCO₂e (0.2 percent) for the 1990-2002 period.
- *HCFC-22 Production.* Based on conversations with the Alliance for Responsible Atmospheric Policy, the EPA has adjusted the historical time series for HFC emissions from HCFC-22 production. These changes resulted in an average annual decrease in HFC emissions from HCFC-22 production of less than 0.1 MMTCO₂e (0.01 percent) for the 1990-2002 period.

^aU.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003*, EPA-430-R-05-003 (Washington, DC, April 2005), web site http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHG_EmissionsUSEmissionsInventory2005.html.

The EPA Vintaging Model: Estimation Methods and Uncertainty

The U.S. Environmental Protection Agency (EPA) uses a detailed Vintaging Model for equipment and products containing ozone-depleting substances (ODS) and ODS substitutes to estimate actual versus potential emissions of various ODS substitutes, including hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The model estimates the quantities of equipment and products sold each year that contain ODS and ODS substitutes, and the amounts of chemicals required for their manufacture and/or maintenance over time. Emissions from more than 40 different end uses are estimated by applying annual leak rates and release profiles, which account for the lag in emissions from equipment as it leaks over time.

For most products (refrigerators, air conditioners, fire extinguishers, etc.), emissions calculations are split

^aU.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003*, EPA-430-R-05-003 (Washington, DC, April 2005), web site <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html>.

into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses plus emissions from manufacture; and disposal emissions, which occur when the equipment is discarded. By aggregating the data over different end uses, the model produces estimates of annual use and emissions of each compound.^a

The EPA periodically attempts to improve the model and reduce the uncertainty of emissions estimates by using more accurate data from emitting industries. The level of detail incorporated in the EPA Vintaging Model is higher than that of the default methodology used by the Intergovernmental Panel on Climate Change, although there still is some uncertainty about some of the model inputs, such as equipment characteristics and sales figures.

producers to reduce HFC-23 emissions, which has helped to moderate HFC-23 emissions during periods of rising demand for HCFC-22. In the long term, domestic production of HCFC-22 for non-feedstock uses will be phased out by 2020 under the U.S. Clean Air Act, pursuant to U.S. agreements under the Copenhagen Amendments to the Montreal Protocol. However, HCFC-22 production for use as a feedstock in the production of other chemicals (fluorinated polymers) will be allowed to continue indefinitely.⁹⁵

Tetrafluoroethane (HFC-134a)

The EPA estimates 2004 U.S. emissions of HFC-134a at 65.8 MMTCO₂e.⁹⁶ HFC-134a accounts for the largest share of total HFC emissions (53 percent). The 2004 emissions level is 8.7 percent (5.2 MMTCO₂e) higher than the 2003 level of 60.5 MMTCO₂e. The increase can be attributed primarily to the continued use of HFC-134a as a substitute for CFCs in motor vehicle air conditioning systems.

Annual HFC-134a emissions have grown dramatically from their estimated 1992 level of 0.7 MMTCO₂e. Since 1994, HFC-134a has been the transportation industry standard for replacing CFCs in air conditioners for

passenger cars, trucks, trains, and buses, because it is nonflammable, has low toxicity, and is not an ODS.

HFC-134a is also used in refrigerant blends (e.g., R-404A) in most new commercial refrigeration equipment built in the United States and in commercial chillers, but leakage from these sources is much less than from automotive air conditioners. Leakage occurs primarily during the servicing of the units rather than during normal operation. Short-term uses of HFC-134a, on the other hand, are becoming an important source of emissions. Such uses include aerosols and open-cell foam blowing, which are denoted as short-term uses because most of the HFC-134a used will be emitted to the atmosphere within a short period of time. According to the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), worldwide sales of HFC-134a jumped more than fourfold between 1992 and 1993, doubled again in 1994, and continued growing steadily to 166,899 metric tons of gas in 2003.⁹⁷

Pentafluoroethane (HFC-125)

The EPA estimates U.S. emissions of HFC-125 in 2004 at 19.7 MMTCO₂e, equivalent to 16 percent of total HFC emissions.⁹⁸ The 2004 emissions level is 10 percent (1.9

⁹⁵U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003*, EPA-430-R-05-003 (Washington, DC, April 2005), web site <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2005.html>.

⁹⁶Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005.

⁹⁷Alternative Fluorocarbons Environmental Acceptability Study, Production, Sales and Atmospheric Release, web site www.afeas.org/2003/html/hfc-134a.html.

⁹⁸Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005.

MMTCO₂e) higher than the 2003 level of 17.8 MMTCO₂e. Emissions of HFC-125 have increased steadily from 0.7 MMTCO₂e in 1992 because of its use as a refrigerant blending agent.

HFC-125 is used in the blend R-410A, which is designed to replace HCFC-22 as the refrigerant of choice for stationary commercial refrigeration and air conditioning applications, as well as in the blends R-404A and R-507A. Some manufacturers have already introduced air conditioners that use R-410A, but as yet the product has captured only a small percentage of the market. As the phaseout of HCFC-22 begins to gain momentum, producers expect a rapid increase in demand for R-410A.⁹⁹ HFC-125 can also be used as a firefighting agent.

Trifluoroethane (HFC-143a)

The EPA estimates U.S. emissions of HFC-143a in 2004 at 19.5 MMTCO₂e, equivalent to 16 percent of total HFC emissions.¹⁰⁰ The 2004 emissions level is 18 percent (3.0 MMTCO₂e) higher than the 2003 level of 16.5 MMTCO₂e. HFC-143a emissions have increased rapidly from 0.1 MMTCO₂e in 1993, as demand for HFC-143a as a refrigerant blending agent has increased.

HFC-143a is a halocarbon used in blends for commercial refrigeration and air conditioning, such as R-404A and R-507A. HFC-143a, like other HFCs, is used as a substitute because it contains neither chlorine nor bromine and does not emit ozone-depleting halogen radicals into the stratosphere. Like other halocarbons, HFC-143a does make a positive contribution to atmospheric warming; however, the GWPs of R-404A and R-507A are lower than those of the gases it replaces, such as CFC-12 with a GWP of 10,600.

Hexafluoropropane (HFC-236fa)

The EPA estimates U.S. emissions of HFC-236fa in 2004 at 3.5 MMTCO₂e, equivalent to 2.8 percent of total HFC emissions.¹⁰¹ The 2004 emissions level is essentially unchanged from the 2003 level of 3.5 MMTCO₂e. Emissions of HFC-236fa have increased from 0.1 MMTCO₂e in 1997 because of its use as a refrigerant, in particular by the U.S. Navy for shipboard applications.¹⁰² In another application, HFC-236fa is used as a firefighting agent.

Perfluorocarbons (PFCs)

U.S. Emissions of Perfluorocarbons, 1990-2004

Estimated 2004 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	6.7
Change Compared to 2003 (Million Metric Tons Carbon Dioxide Equivalent)	-0.5
Change from 2003 (<i>Percent</i>)	-7.5%
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	-13.0
Change from 1990 (<i>Percent</i>)	-66.1%

The EPA estimates 2004 emissions of PFCs at 6.7 MMTCO₂e, accounting for 4.3 percent of all emissions of HFCs, PFCs, and SF₆ combined. The estimate for 2004 is 7.5 percent (0.5 MMTCO₂e) lower than the estimate for 2003 (7.2 MMTCO₂e) and 66 percent (13.0 MMTCO₂e) lower than the 1990 emissions level of 19.6 MMTCO₂e.¹⁰³ The downward trend in emissions is largely the result of decreases in domestic aluminum production, which creates PFCs as byproducts, as well as process efficiency improvements in the aluminum industry. Moderating the decrease in PFC emissions from aluminum manufacture have been periodic increases in PFC emissions from semiconductor manufacture. The two PFCs emitted by these industries are perfluoromethane (CF₄) and perfluoroethane (C₂F₆).

Perfluoromethane (CF₄)

The EPA estimates U.S. emissions of CF₄ in 2004 at 3.2 MMTCO₂e, equivalent to 48 percent of total PFC emissions.¹⁰⁴ The 2004 emissions level is 16 percent (0.6 MMTCO₂e) lower than the 2003 level of 3.8 MMTCO₂e. CF₄ emissions have dropped by a total of 79 percent (11.7 MMTCO₂e) from their 1990 level of 14.8 MMTCO₂e.

⁹⁹J. Ouellette, "Fluorocarbon Market Is Poised To Grow," *Chemical Market Reporter* (June 19, 2000).

¹⁰⁰Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005.

¹⁰¹Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005.

¹⁰²E-mail correspondence with the Office of Policy, U.S. Department of Energy, October 18, 2000.

¹⁰³Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.

¹⁰⁴Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005.

The two principal sources of CF_4 , as well as C_2F_6 , are as a byproduct of aluminum smelting created during periods of process inefficiency and disruption, and in the manufacture of semiconductors. The EPA estimates U.S. CF_4 emissions in 2004 from aluminum production at 2.1 MMT CO_2e and from semiconductor manufacture at 1.1 MMT CO_2e .¹⁰⁵ With reductions in primary aluminum production and improvements that reduce anode effects leading to process inefficiency, CF_4 emissions from aluminum smelting have been reduced by 85 percent (12.1 MMT CO_2e) from their 1990 level of 14.2 MMT CO_2e .

Aluminum smelting companies that participate in the EPA's Voluntary Aluminum Industry Partnership (VAIP) have achieved efficiency improvements through voluntary actions. Reductions in primary aluminum production have also played a role in reducing PFC emissions. According to data from the U.S. Geological Survey (USGS), domestic primary aluminum production decreased significantly between the years 2000 and 2003 and, according to preliminary USGS estimates, fell again in 2004. The decline in production resulted from cutbacks in smelter production in response to higher costs of energy and alumina. Most of the production cutbacks took place in the Pacific Northwest.¹⁰⁶

Another source of CF_4 emissions is semiconductor manufacturing. Emissions from this source peaked in 2000 at just over 1.6 MMT CO_2e and have since declined by 34 percent (0.6 MMT CO_2e) to their 2004 level of 1.1 MMT CO_2e .¹⁰⁷ This estimate reflects the rapid growth of the semiconductor industry in the 1990s, which has resulted in a 61-percent increase in emissions (0.4 MMT CO_2e) from their 1990 level of 0.7 MMT CO_2e . CF_4 , like C_2F_6 , is used as a plasma etchant and cleaning agent in semiconductor manufacturing; some of the gas used in those processes does not react with the materials and, unless abated, is emitted to the atmosphere. A variety of other perfluorinated compounds are used in the semiconductor industry, including perfluoropropane (C_3F_8 , with a GWP of 8,600), perfluorobutane (C_4F_{10} , GWP 8,600), perfluorohexane (C_6F_{14} , GWP 9,000), and nitrogen trifluoride (NF_3).¹⁰⁸

Perfluoroethane (C_2F_6)

The EPA estimates U.S. emissions of C_2F_6 in 2004 at 3.5 MMT CO_2e , equivalent to 52 percent of total PFC emissions.¹⁰⁹ The 2004 emissions level is 2.4 percent (0.1 MMT CO_2e) above the 2003 level of 3.4 MMT CO_2e . Emissions of C_2F_6 have dropped by 28 percent (1.3 MMT CO_2e) from their 1990 level of 4.8 MMT CO_2e .

C_2F_6 emissions originate from the aluminum and semiconductor industries. Thus, C_2F_6 , like CF_4 , has had two countervailing trends bearing on its emissions levels. On one side, decreasing aluminum production and increased efficiency in the aluminum industry have tended to lower emissions. C_2F_6 emissions in the aluminum industry fell from 2.9 MMT CO_2e in 1990 to 0.6 MMT CO_2e in 2004, or by 81 percent (2.3 MMT CO_2e). On the other side, increased semiconductor production has tended to increase emissions. C_2F_6 emissions in the semiconductor industry, estimated by the EPA at 2.9 MMT CO_2e in 2004, have increased by 53 percent (1.0 MMT CO_2e) from their 1990 level of 1.9 MMT CO_2e . The net effect has been a 28-percent overall reduction in emissions of C_2F_6 since 1990.

Other HFCs and PFCs/PFPEs

There is a group of other HFCs and PFCs/PFPEs for which the EPA withholds individual emissions data, because the data are considered confidential and could compromise business practices. This group includes HFC-152a, HFC-227ea, HFC-245fa, and HFC-4310mee.¹¹⁰ The EPA estimates total emissions of this group of "other HFCs" at 8.6 MMT CO_2e in 2004, representing 5.5 percent of all emissions of HFCs, PFCs, and SF₆ reported.¹¹¹ Emissions of these HFCs are small but growing rapidly, as they continue to find applications as substitutes for CFCs and HCFCs. Emissions of "other HFCs" increased by 13 percent (1.0 MMT CO_2e) in 2004 compared with 2003 (7.6 MMT CO_2e).

¹⁰⁵Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005.

¹⁰⁶U.S. Department of the Interior, U.S. Geological Survey, *Mineral Commodity Summaries 2003*, web site <http://minerals.usgs.gov/minerals/pubs/mcs/2005/mcs2005.pdf>.

¹⁰⁷Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005.

¹⁰⁸Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 389.

¹⁰⁹Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005.

¹¹⁰Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

¹¹¹Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the IPCC in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.

Other HFCs and HFC blends are also likely to gain market share as a result of the phaseout of CFCs and HCFCs, because no single product is suited for all applications. For example, each potential replacement product has an optimal operating temperature range; hence, the refrigerant best suited for use in ice cream freezers will differ from the best choice for milk coolers.¹¹²

In addition to replacing HCFC-22 in stationary air conditioning and refrigeration applications, other HFCs are expected to gain new markets as foam-blowing agents. CFCs have already been phased out of this market, having been replaced by HCFCs (primarily HCFC-141b). Among the potential replacements for HCFCs, HFC-245fa (pentafluoropropane) appears to be the strongest contender.¹¹³

Sulfur Hexafluoride (SF₆)

U.S. Emissions of Sulfur Hexafluoride, 1990-2004

Estimated 2004 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	16.0
Change Compared to 2003 (Million Metric Tons Carbon Dioxide Equivalent)	-0.4
Change from 2003 (Percent)	-2.2%
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	-16.1
Change from 1990 (Percent)	-50.2%

The EPA estimates 2004 emissions of SF₆ at 16.0 MMTCO₂e, accounting for 10 percent of all HFC, PFC, and SF₆ emissions combined in 2004.¹¹⁴ Emissions in 2004 were 2.2 percent (0.4 MMTCO₂e) lower than in 2003 (16.3 MMTCO₂e) and 50 percent (16.1 MMTCO₂e) lower

than the estimate for 1990 (32.1 MMTCO₂e). The downward trend in SF₆ emissions since 1990 is the result of industry efforts to reduce emissions from electrical power systems, as well as the rising cost of SF₆. In contrast, emissions of SF₆ from uses in the semiconductor manufacturing industry have increased overall by 76 percent since 1990.

SF₆ is used primarily in electrical applications, in which it is an excellent dielectric gas for high-voltage applications, because it is chemically inert, gaseous at low temperatures, nonflammable, nontoxic, and noncorrosive.¹¹⁵ In electricity transmission and distribution systems, SF₆ acts as an insulator and arc interrupter for circuit breakers, switch gear, and other electrical equipment; however, it can escape through seals, especially in older equipment. Emissions also occur during equipment installation, servicing, and disposal.¹¹⁶

Other applications that produce SF₆ emissions include magnesium metal casting processes that employ SF₆ to replace toxic and corrosive materials, such as salt fluxes and sulfur dioxide (SO₂). Another use of SF₆ is as a cover gas during magnesium production and processing to prevent excessive oxidation of molten magnesium in the presence of air, although emissions from this source have declined due to a decrease in the quantity of magnesium die casting, process optimizations by industry participants in EPA's SF₆ Emission Reduction Partnership for the Magnesium Industry, and the closure of primary magnesium processing facilities in the United States in 2001.¹¹⁷ Pre-treating aluminum melt with SF₆ (or an inert gas mixture) prevents porosity and therefore weakening of the metal. It also removes oxides and solid impurities. In addition, mixtures of SF₆ and O₂ are used as feed gases for plasma etching of semiconductor devices.¹¹⁸ Because of its extremely low atmospheric concentration, SF₆ is also useful as an atmospheric tracer gas for a variety of experimental purposes. Other minor applications include leak detection, loudspeakers, lasers, and as a cover gas or fluxing and degassing agent for specialized casting operations in the aluminum industry.¹¹⁹

¹¹²C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).

¹¹³C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).

¹¹⁴Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, October 2005. In compiling its estimates, the EPA receives data from participants in the SF₆ Emission Reduction Partnership for Electric Power Systems and the SF₆ Emission Reduction Partnership for the Magnesium Industry.

¹¹⁵European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/families/sf6/main_app.html.

¹¹⁶U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2003*, EPA-430-R-05-003 (Washington, DC, April 2005), web site <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2005.html>.

¹¹⁷U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-0-00 (Washington, DC, April 2004), web site <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUS EmissionsInventory2004.html>.

¹¹⁸European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/en/families/sf6/main_app.html#c.

¹¹⁹Historically, emissions of SF₆ from the aluminum industry have been omitted from global estimates, because any emissions are expected to be insignificant. The EPA does not estimate emissions from this source due to uncertainties about the quantities used and the amounts destroyed in the applications.

Table 31. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990 and 1996-2004
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1996	1997	1998	1999	2000	2001	2002	2003	P2004
Hydrofluorocarbons										
HFC-23	36.1	32.3	31.2	41.7	31.7	30.9	20.6	20.6	13.0	16.3
HFC-125	0.0	6.3	8.6	10.7	12.1	13.6	14.9	16.2	17.8	19.7
HFC-134a	0.0	24.5	31.4	36.7	42.2	48.0	52.7	56.9	60.5	65.8
HFC-143a	0.0	2.3	4.0	5.9	7.5	9.3	11.4	13.8	16.5	19.5
HFC-236fa	0.0	0.0	0.1	0.6	1.3	2.0	2.6	3.2	3.5	3.5
Total HFCs	36.1	65.5	75.1	95.5	94.9	103.8	102.2	110.7	111.3	124.8
Perfluorocarbons										
CF ₄	14.8	11.0	10.1	8.7	8.6	8.7	4.2	5.0	3.8	3.2
C ₂ F ₆	4.8	5.4	5.6	5.9	6.0	5.0	3.4	3.8	3.4	3.5
Total PFCs	19.6	16.4	15.7	14.6	14.6	13.7	7.6	8.8	7.2	6.7
Other HFCs, PFCs/PFPEs	0.3	3.4	4.5	5.5	6.2	6.5	6.7	7.1	7.6	8.6
Sulfur Hexafluoride	32.1	29.1	26.7	22.1	21.7	18.1	17.4	16.4	16.3	16.0
Total Emissions	88.1	114.3	122.0	137.7	137.4	142.1	133.9	143.1	142.4	155.9

P = preliminary data.

Notes: Other HFCs, PFCs/PFPEs include HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and a variety of PFCs and perfluoropolyethers (PFPEs). They are grouped together to protect confidential data. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, September 2005).

Table 32. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990 and 1996-2004
(Thousand Metric Tons of Gas)

Gas	1990	1996	1997	1998	1999	2000	2001	2002	2003	P2004
Hydrofluorocarbons										
HFC-23	3.0	2.7	2.6	3.5	2.6	2.6	1.7	1.7	1.1	1.4
HFC-125	0.0	1.9	2.5	3.1	3.6	4.0	4.4	4.8	5.2	5.8
HFC-134a	0.0	18.9	24.1	28.2	32.5	36.9	40.5	43.8	46.6	50.6
HFC-143a	0.0	0.5	0.9	1.4	1.7	2.2	2.6	3.2	3.8	4.5
HFC-236fa	0.0	0.0	*	0.1	0.1	0.2	0.3	0.3	0.4	0.4
Perfluorocarbons										
CF ₄	2.6	1.9	1.8	1.5	1.5	1.5	0.7	0.9	0.7	0.6
C ₂ F ₆	0.4	0.4	0.5	0.5	0.5	0.4	0.3	0.3	0.3	0.3
Other HFCs, PFCs/PFPEs	M									
Sulfur Hexafluoride	1.4	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.7	0.7

*Less than 50 metric tons of gas.

P = preliminary data. M = mixture of gases.

Notes: Other HFCs, PFCs/PFPEs include HFC-152a, HFC-227ea, HFC-245fa, HFC-4310mee, and a variety of PFCs and perfluoropolyethers (PFPEs). They are grouped together to protect confidential data. Totals may not equal sum of components due to independent rounding.

Source: U.S. Environmental Protection Agency, Office of Air and Radiation, web site www.epa.gov/globalwarming/ (preliminary estimates, September 2005).