

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

Overview

Total U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2003

Estimated 2003 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	143.4
Change Compared to 2002 (Million Metric Tons Carbon Dioxide Equivalent)	-0.4
Change from 2002 (Percent)	-0.3%
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	54.8
Change from 1990 (Percent)	62.0%

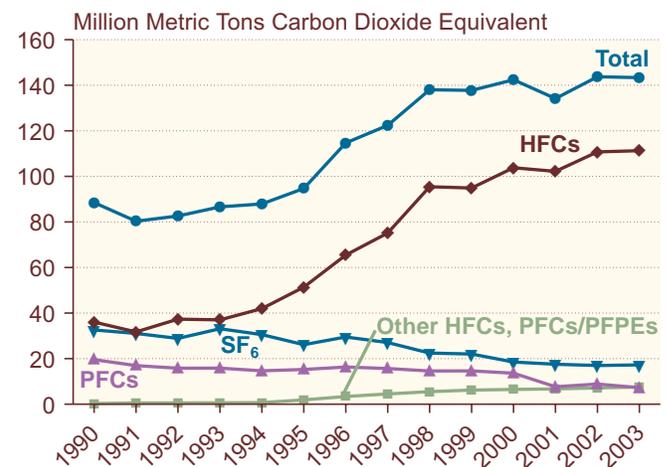
In addition to the three principal greenhouse gases (carbon dioxide, methane, and nitrous oxide), there are other gases that account for 2.1 percent of total U.S. greenhouse gas emissions when weighted by their 100-year global warming potentials (GWP).⁸⁰ The U.S. Environmental Protection Agency (EPA) estimates total emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆) in 2003 at 143.4 million metric tons carbon dioxide equivalent—a 0.3-percent decrease from 2002 emissions, but a 62.0-percent increase over 1990 emissions. Table 30 summarizes U.S. emissions of HFCs, PFCs, and SF₆ from 1990 to 2003, and Table 31 shows the corresponding emissions in metric tons carbon dioxide equivalent.

In summary, revised EPA data for 1990-2002 and new estimates for 2003 show that emissions of HFCs have risen significantly from their 1990 level; annual emissions of PFCs declined overall from 1990 through 2000 and then dropped more significantly since 2000; and SF₆ emissions have declined overall, falling to about one-half their 1990 level by 2002 (Figure 4). In the case of HFCs, the overall increase in emissions reflects the use

of HFCs as replacements for CFCs (chlorofluorocarbons), halons, and other ozone-depleting chemicals that are being phased out under the Montreal Protocol because they damage the Earth's stratospheric ozone layer. The upward trend in HFC emissions is expected to continue in the next decade as HCFCs (hydrochlorofluorocarbons) used as interim substitutes for CFCs are also phased out under the provisions of the Copenhagen Amendments to the Montreal Protocol. PFC emissions from the aluminum industry have been falling since 1990; however, the decrease is partially offset by increases in PFC emissions from the semiconductor industry. Emissions of SF₆ have declined overall in the magnesium and utility sectors since 1990, despite an increase in use in the semiconductor industry.

The small quantities of HFCs, PFCs, and SF₆ that are emitted have disproportionate effects on overall emissions because of their large GWPs. PFCs and SF₆ have particularly high GWPs because of their stability, strong infrared absorption in the atmosphere, and long atmospheric lifetimes.⁸¹ SF₆ is the most potent of the greenhouse gases, with a GWP of 22,200. PFCs, with

Figure 4. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990-2003



Source: Estimates presented in this chapter.

⁸⁰Preliminary data estimates received by EIA from the U.S. Environmental Protection Agency (EPA), Office of Air and Radiation, September 2004. Note that EIA calculates emissions in carbon dioxide equivalent units using the GWP values published by the Intergovernmental Panel on Climate Change (IPCC) in 2001 in its Third Assessment Report, whereas the EPA uses the GWP values from the IPCC's 1996 Second Assessment Report.

⁸¹See discussion of relative forcing effects of gases in Chapter 1.

atmospheric lifetimes in the thousands of years, have GWPs in the range of 7,000 to 9,000. HFC-23 is the most potent greenhouse gas of the HFCs, with a GWP of 12,000, while other HFCs have GWPs in the range of 100 to 10,000.⁸²

The emissions estimates in Table 30 are taken from data supplied by the EPA's Office of Air and Radiation.⁸³ The estimates in Table 31 are based on data provided by the EPA's Office of Air and Radiation in units of native gas (thousand metric tons), which were converted to carbon dioxide equivalent units by the Energy Information Administration (EIA), using GWP values from the IPCC's 2001 Third Assessment Report. The 2003 preliminary estimates were developed by the EPA and provided to EIA. They include some revisions to the historical emissions estimates, based on recent runs of the EPA's Vintaging Model (see boxes on pages 65 and 66). The revisions are reflected in the emissions estimates presented in this chapter.

Hydrofluorocarbons (HFCs)

U.S. Emissions of Hydrofluorocarbons, 1990-2003

Estimated 2003 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	111.3
Change Compared to 2002 (Million Metric Tons Carbon Dioxide Equivalent)	0.5
Change from 2002 (<i>Percent</i>)	0.5%
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	75.2
Change from 1990 (<i>Percent</i>)	208.6%

Since 1990, HFC emissions have accounted for a growing share (77.6 percent in 2003) of total carbon dioxide equivalent emissions of HFCs, PFCs, and SF₆ combined.

The EPA estimates U.S. emissions of all HFCs in 2003 at 111.3 million metric tons carbon dioxide equivalent, a 0.5-percent increase from 2002 emissions and a 208.6-percent increase from 1990.⁸⁴ By far the largest portion of HFC emissions, 88.5 percent, is attributed to their use as replacements for ozone-depleting substances, which have grown from trace amounts in 1990 to 98.4 million metric tons carbon dioxide equivalent in 2003.

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 other ozone-depleting substances 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.⁸⁵ 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.⁸⁶

Trifluoromethane (HFC-23)

The EPA estimates 2003 emissions of HFC-23 at 1,080 metric tons of gas.⁸⁷ Annual emissions have fluctuated since 1990, showing an overall decline of 64.0 percent by 2003. Although emissions of HFC-23 are relatively small, its high GWP (12,000)⁸⁸ gives it a substantial potential climatic effect. Nearly all HFC-23 emissions (97.6 percent) are created as a byproduct in the production of chlorodifluoromethane (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 have declined since 1998,

⁸²Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

⁸³Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004.

⁸⁴Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004. 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.

⁸⁵European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/frame.htm?applications/others/firefighting/main_appli/main.htm.

⁸⁶European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/frame.htm?applications/insulation/main_appli/main.htm.

⁸⁷Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004.

⁸⁸Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001).

EPA Revises Emissions Estimation Methodology

The primary source for the emission estimates presented in this chapter is data obtained from the U.S. Environmental Protection Agency (EPA), Office of Air and Radiation, which also prepares an annual inventory of greenhouse gas emissions.^a The data supporting the EPA inventory include emissions estimates through 2003, incorporating a number of revisions to the estimates of HFC, PFC, and SF₆ emissions for 2002 and earlier years. Those changes are reflected in the estimates presented in this chapter.

The changes to the historical emission estimates are the result of revisions to the data and estimation methodologies used by the EPA:

- *Electrical Transmission and Distribution.* The changes in calculations of emissions from electricity transmission and distribution include both a revised methodology and updated activity data for 1990 through 1998. The revised methodology accounts for the quantity of SF₆ that is recaptured and/or released from operating electrical equipment, rather than assuming all SF₆ was released at the time of its initial installation into the equipment. The methodology assumes that only 22.5 percent of the SF₆ is emitted at the time of its installation and the remaining 77.5 percent is emitted over a 30-year period. The activity data were updated in two ways: first, with the results of a survey of SF₆ manufacturers conducted in 2002 by the RAND Corporation;^b and second, with revised data received from participants in the EPA's SF₆ Emission Reduction Partnership for Electric Power Systems, which led to updated regression equations and extrapolations to non-reporting partners. These revisions resulted in a decrease in estimated SF₆ emissions from electric power systems of 9.0 percent for 1990, 18.2 percent for 1998, and 3.3 percent for 2001; and an increase in estimated emissions of 1.4 percent in 2000.

^aThe information presented in this text box was obtained from U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-004 (Washington, DC, April 2004), web site <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html>.

^bK.D. Smythe, RAND Corporation, RAND Environmental Science and Policy Center, "Production and Distribution of SF₆ by End-Use Application," International Conference on SF₆ and the Environment: Emission Reduction Strategies (San Diego, CA, November 21-22, 2002).

- *Magnesium Production and Processing.* The emissions estimates in this report were revised to reflect new historical data supplied by participants in EPA's SF₆ Emission Reduction Partnership for the Magnesium Industry. This change resulted in a decrease of about 0.5 percent in estimated SF₆ emissions for 2001.
- *Semiconductor Manufacture.* The EPA updated activity data provided by participants in EPA's PFC Reduction/Climate Partnership for the Semiconductor Industry, as well as its PFC Emissions Vintaging Model (PEVM), which estimates emissions from entities that do not participate in the partnership program. The EPA also revised its methodology for estimating the historical distribution of emissions among HFCs, PFCs, and SF₆, by incorporating market information on sales volumes that was obtained in surveys. These updates resulted in an average decrease of 9 percent in estimates of emissions from semiconductor manufacture for 1995 through 2001.
- *Substitution of Ozone-Depleting Substances.* The EPA updated assumptions for its Vintaging Model pertaining to market trends in chemicals and chemical substitutes. These changes resulted in an average annual increase of 9.1 percent in HFC and PFC emissions for the period 1990 through 2001.
- *Aluminum Production.* In cooperation with the EPA's Voluntary Aluminum Industrial Partnership program, participants provided additional smelter-specific information on aluminum production and emission factors. The new information resulted in a decrease in PFC emissions of 1.0 percent for 1990 through 1994, 4.0 percent for 2001; and an increase of 12.0 percent for 2000.

because the emission rate of HFC-23 (i.e., the amount of HFC-23 emitted per kilogram of HCFC-22 manufactured) has decreased significantly. Production of HCFC-22 has also fallen significantly between 2000 and 2002, resulting in further reductions in emissions.⁸⁹

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

⁸⁹U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-004 (Washington, DC, April 2004), web site <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.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

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 is consistently making improvements to the model to use more accurate data from the industries and to reduce uncertainty. 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.

^aU.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-004 (Washington, DC, April 2004), web site <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html>.

dehumidifiers). The EPA administers a voluntary program with HCFC-22 producers to reduce HFC-23 emissions, which has helped to offset the rising demand for HCFC-22 in the short term. 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, its production for use as a feedstock in the production of other chemicals (fluorinated polymers) will be allowed to continue indefinitely and is anticipated to grow.⁹⁰

Tetrafluoroethane (HFC-134a)

According to EPA estimates, emissions of HFC-134a, which has a GWP of 1,300,⁹¹ were 46,559 metric tons in 2003.⁹² HFC-134a accounts for the largest share of all HFC emissions (54.4 percent in terms of carbon dioxide equivalent), and the single largest share of any one gas for all HFC, PFC, and SF₆ emissions combined (42.2 percent). The 2003 estimate is 6.3 percent higher than that for 2002.

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 and has low toxicity. It is also used for domestic refrigeration and freezing, as a propellant for industrial and pharmaceutical aerosols, as a solvent, and as a blowing agent for extruded polystyrene foams.

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.

HFCs make attractive solvents because of their nonflammability, thermal and chemical stability, excellent dielectric properties, high material compatibility, low surface tension and viscosity, and high liquid density. HFC-134a, in particular, is used in special extraction processes to produce important natural active pharmaceuticals, such as TAXOL[®] for breast cancer treatment,

⁹⁰U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-004 (Washington, DC, April 2004), web site <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html>.

⁹¹Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

⁹²Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004.

nutraceuticals, flavors, and fragrances.⁹³ 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 159,319 metric tons of gas in 2002.⁹⁴

Other HFCs

Other HFCs with considerable radiative forcing potential include HFC-125, HFC-143a, and HFC-236fa, with 100-year GWPs of 3,400, 4,300, and 9,400, respectively.⁹⁵ The EPA estimates emissions of HFC-125 (pentafluoroethane) at 213 metric tons of gas in 1992, increasing to 5,247 metric tons in 2003.⁹⁶ The estimate for 2003 is 9.8 percent higher than the estimate for 2002. 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 phase-out of HCFC-22 begins to gain momentum, producers expect a rapid increase in the demand for R-410A.⁹⁷ HFC-125 can also be used as a firefighting agent.

The EPA estimates 1993 emissions of HFC-143a (trifluoroethane) at 29 metric tons of gas, increasing to 3,834 metric tons in 2003.⁹⁸ The estimate for 2003 is 19.7 percent higher than the estimate for 2002. 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 will 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.

The EPA estimates 1997 emissions of HFC-236fa (hexafluoropropane) at 9 metric tons of gas, increasing to 369 metric tons in 2003.⁹⁹ The estimate for 2003 is 8.1 percent higher than the estimate for 2002. HFC-236fa is also used as a refrigerant, in particular by the U.S. Navy for shipboard applications.¹⁰⁰ In another application, HFC-236fa is used as a firefighting agent.

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, with 100-year GWPs of 120, 3,500, 950, and 1,500, respectively.¹⁰¹ The EPA estimates total emissions of this group of "other HFCs" at 7.6 million metric tons carbon dioxide equivalent in 2003, representing 5.3 percent of all emissions of HFCs, PFCs, and SF₆ reported.¹⁰² 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 5.9 percent in 2003 compared with 2002.

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.¹⁰³

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, HFC-245fa (pentafluoropropane) appears to be the strongest contender.¹⁰⁴

⁹³European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/frame.htm?applications/solvents/main_appli/main.htm.

⁹⁴Alternative Fluorocarbons Environmental Acceptability Study, Production, Sales and Atmospheric Release, web site www.afeas.org/prodsales_download.html.

⁹⁵Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

⁹⁶Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004.

⁹⁷J. Ouellette, "Fluorocarbon Market Is Poised To Grow," *Chemical Market Reporter* (June 19, 2000).

⁹⁸Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004.

⁹⁹Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004.

¹⁰⁰E-mail correspondence with the Office of Policy, U.S. Department of Energy, October 18, 2000.

¹⁰¹Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 388.

¹⁰²Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004. 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.

¹⁰³C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).

¹⁰⁴C. Boswell, "Hydrofluorocarbons Build with Transition Away from CFCs," *Chemical Market Reporter* (September 13, 1999).

Perfluorocarbons (PFCs)

U.S. Emissions of Perfluorocarbons, 1990-2003

Estimated 2003 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	7.3
Change Compared to 2002 (Million Metric Tons Carbon Dioxide Equivalent)	-1.6
Change from 2002 (Percent)	-18.0%
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	-12.3
Change from 1990 (Percent)	-62.9%

The EPA estimates 2003 emissions of PFCs at 7.3 million metric tons carbon dioxide equivalent, accounting for 5.1 percent of all emissions of HFCs, PFCs, and SF₆ combined. The estimate for 2003 is 18.0 percent lower than the estimate for 2002 and 62.9 percent lower than 1990 emissions (Table 31).¹⁰⁵ The overall decrease is the result of improvements in the aluminum industry, which creates PFCs as byproducts, as well as decreases in domestic aluminum production; a small increase in PFC emissions is seen in industrial applications, such as in semiconductor manufacturing.

PFCs are compounds composed of carbon and fluorine that have relatively high GWPs (5,700 for perfluoromethane [CF₄] and 11,900 for perfluoroethane [C₂F₆]).¹⁰⁶ PFCs are also characterized by long atmospheric lifetimes (up to 50,000 years); hence, unlike most HFCs, they are essentially permanent additions to the atmosphere.

The principal quantifiable source of PFCs is as a byproduct of aluminum smelting created during periods of process inefficiency and disruption. The amount created depends on the frequency and duration of the events. The EPA estimates U.S. emissions from aluminum

production at 504 metric tons of perfluoromethane and 56 metric tons of perfluoroethane in 2003.¹⁰⁷ Reductions in primary aluminum production and efficiency improvements to reduce anode effects leading to process inefficiency have contributed to reductions in emissions of perfluoromethane and perfluoroethane from this source by 79.6 percent and 77.0 percent, respectively, since 1990.

Aluminum smelting companies that participate in EPA's Voluntary Aluminum Industry Partnership (VAIP) program 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, domestic primary aluminum production decreased significantly between the years 1998 and 2001 and remained steady in 2002. The decline in production resulted from cutbacks in smelter production, which in turn were caused by increased energy costs in various parts of the country.¹⁰⁸

Another source of PFC emissions is semiconductor manufacturing. For 2003, the EPA estimates emissions of perfluoromethane and perfluoroethane from semiconductor manufacturing at 162 metric tons of perfluoromethane and 228 metric tons of perfluoroethane, respectively.¹⁰⁹ Both estimates reflect the rapid growth of the semiconductor industry in the 1990s, which resulted in increases of 40.6 percent and 42.6 percent in emissions of perfluoromethane and perfluoroethane, respectively, since 1990. Perfluoromethane and perfluoroethane are used as plasma etchants and cleaning agents 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 (C₃F₈, with a GWP of 8,600), perfluorobutane (C₄F₁₀, GWP 8,600), perfluorohexane (C₆F₁₄, GWP 9,000), and nitrogen trifluoride (NF₃).¹¹⁰ Although continued expansion of the worldwide semiconductor market may lead to increased PFC use and emissions, emissions of PFCs from this source have been falling since their peak

¹⁰⁵Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004. 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.

¹⁰⁶Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 389.

¹⁰⁷Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004.

¹⁰⁸U.S. Department of the Interior, U.S. Geological Survey, *Mineral Commodity Summaries 2003*, web site <http://minerals.usgs.gov/minerals/pubs/mcs/2003/mcs2003.pdf>.

¹⁰⁹Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004.

¹¹⁰Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (Cambridge, UK: Cambridge University Press, 2001), p. 389.

in 1999 as a result of drops in semiconductor production (and silicon consumption) and voluntary industry efforts to curb emissions through new methods, such as process optimization.¹¹¹

Sulfur Hexafluoride (SF₆)

U.S. Emissions of Sulfur Hexafluoride, 1990-2003

Estimated 2003 Emissions (Million Metric Tons Carbon Dioxide Equivalent)	17.3
Change Compared to 2002 (Million Metric Tons Carbon Dioxide Equivalent)	0.3
Change from 2002 (Percent)	1.6%
Change Compared to 1990 (Million Metric Tons Carbon Dioxide Equivalent)	-15.4
Change from 1990 (Percent)	-47.1%

The EPA estimates 2003 emissions of SF₆ at 777 metric tons of gas, accounting for 12.0 percent of all HFC, PFC, and SF₆ emissions combined in 2003.¹¹² The estimate for 2003 is 47.1 percent lower than the estimate for 1990. The decrease 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 62.0 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 non-corrosive.¹¹³ In electrical 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.¹¹⁴

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 2001.¹¹⁵ 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.¹¹⁶ 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, loud speakers, lasers, and as a cover gas or fluxing and degassing agent for specialized casting operations in the aluminum industry.¹¹⁷

¹¹¹U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-004 (Washington, DC, April 2004), web site <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html>.

¹¹²Preliminary data estimates received by EIA from the EPA's Office of Air and Radiation, September 2004. 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.

¹¹³European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/frame.htm?chfamilies/SF6/prod_main/prod.htm.

¹¹⁴U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-004 (Washington, DC, April 2004), web site <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html>.

¹¹⁵U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2002*, EPA-430-R-04-004 (Washington, DC, April 2004), web site <http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html>.

¹¹⁶European Fluorocarbon Technical Committee, web site www.fluorocarbons.org/frame.htm?applications/electri_appli/main_appli/main.htm.

¹¹⁷Historically, 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 30. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990 and 1995-2003
(Thousand Metric Tons of Gas)

Gas	1990	1995	1996	1997	1998	1999	2000	2001	2002	P2003
Hydrofluorocarbons										
HFC-23	3.0	2.3	2.7	2.6	3.5	2.6	2.6	1.7	1.7	1.1
HFC-125	0.0	1.3	1.9	2.5	3.1	3.6	4.0	4.4	4.8	5.2
HFC-134a	0.0	13.9	18.9	24.1	28.2	32.5	36.9	40.5	43.8	46.6
HFC-143a	0.0	0.2	0.5	0.9	1.4	1.7	2.2	2.6	3.2	3.8
HFC-236fa	0.0	0.0	0.0	*	0.1	0.1	0.2	0.3	0.3	0.4
Perfluorocarbons										
CF ₄	2.6	1.8	1.9	1.8	1.5	1.5	1.5	0.7	0.9	0.7
C ₂ F ₆	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.3	0.3	0.3
PFCs/PFPEs	W	W	W	W	W	W	W	W	W	W
Other HFCs, PFCs/PFPEs	M									
Sulfur Hexafluoride	1.5	1.2	1.3	1.2	1.0	1.0	0.8	0.8	0.8	0.8

*Less than 50 metric tons of gas.

P = preliminary data. M = mixture of gases. W = withheld to avoid disclosure of confidential 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 2004).

Table 31. U.S. Emissions of Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride, 1990 and 1995-2003
(Million Metric Tons Carbon Dioxide Equivalent)

Gas	1990	1995	1996	1997	1998	1999	2000	2001	2002	P2003
Hydrofluorocarbons										
HFC-23	36.1	28.0	32.3	31.2	41.7	31.7	30.9	20.6	20.6	13.0
HFC-125	0.0	4.4	6.3	8.6	10.7	12.1	13.6	14.9	16.2	17.8
HFC-134a	0.0	18.0	24.5	31.4	36.7	42.2	48.0	52.7	56.9	60.5
HFC-143a	0.0	0.9	2.3	4.0	5.9	7.5	9.3	11.4	13.8	16.5
HFC-236fa	0.0	0.0	0.0	0.1	0.6	1.3	2.0	2.6	3.2	3.5
Total HFCs	36.1	51.4	65.5	75.1	95.5	94.9	103.8	102.2	110.7	111.3
Perfluorocarbons										
CF ₄	14.7	10.3	11.0	10.0	8.7	8.7	8.6	4.3	5.1	3.9
C ₂ F ₆	4.8	4.9	5.3	5.6	5.9	6.0	5.0	3.4	3.8	3.4
Total PFCs	19.6	15.3	16.3	15.7	14.6	14.6	13.6	7.7	8.9	7.3
Other HFCs, PFCs/PFPEs	0.3	1.9	3.4	4.5	5.5	6.2	6.5	6.7	7.1	7.6
Sulfur Hexafluoride	32.6	26.1	29.5	27.1	22.4	22.0	18.5	17.5	17.0	17.3
Total Emissions	88.5	94.7	114.7	122.4	138.0	137.8	142.4	134.2	143.7	143.4

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 2004).