

Quick Facts

- High global warming potential (GWP) gases are mostly man-made gases used in industrial processes. They typically have much longer atmospheric lifetimes and much stronger radiative forcing properties than carbon dioxide.
- Currently, high GWP gases account for 2.1 percent of domestic greenhouse gas (GHG) emissions in terms of carbon dioxide equivalency (CO₂e). The EPA has created several voluntary programs aimed at lowering these emissions.
- Because of their immense contributions to climate change per molecule emitted, abatement of high GWP gases can be very cost-effective.

Background

This factsheet examines high GWP gases outside of methane and nitrous oxide. High global warming potential gases are gases that have a greater impact on climate change per molecule emitted than carbon dioxide (CO₂). GWP is a reporting mechanism developed by the IPCC to standardize the impact of GHGs on climate in units of carbon dioxide equivalency (abbreviated as CO₂e). Typically, these potentials are reported over a 100-year time horizon. Carbon dioxide is assigned a 100-year GWP of 1, and this is the standard used to determine the GWPs of other gases (i.e., a gas with a GWP of 50 has an impact on warming 50 times greater than that of CO₂ across a 100-year time span).

GHGs can be thought of as having three specific properties: they selectively absorb radiation—meaning they let shortwave radiation (solar radiation) pass through and absorb longwave radiation (infrared radiation) before it can exit the earth's atmosphere; they have long residency times in the atmosphere; and they are strong absorbers of longwave radiation. GWP is a function of these three properties. Thus, a gas that is a very strong absorber of longwave radiation and remains in the atmosphere for a long time will have a high GWP.

Description

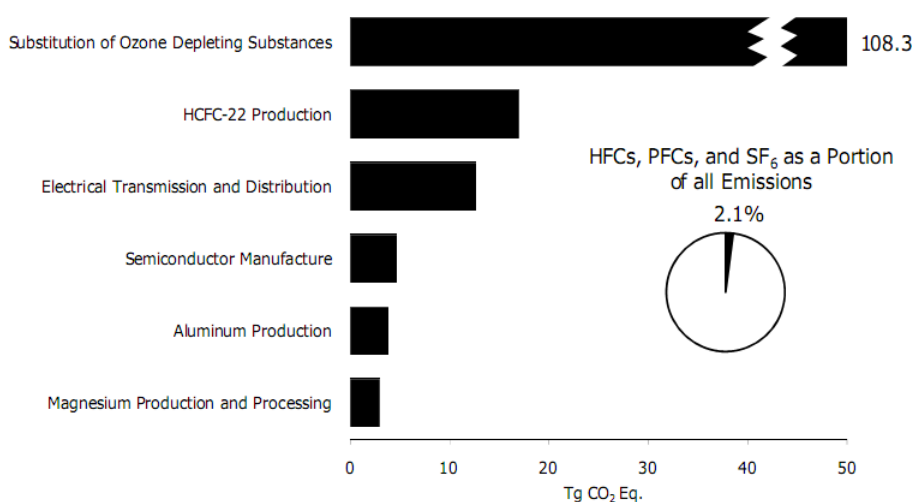
While two high GWP gases—methane (CH₄) and nitrous oxide (N₂O)—are accounted for in most GHG inventories, many other high GWP gases are not. Some of these GHGs have an extremely high GWP—e.g., sulfur hexafluoride (SF₆), which has a GWP 22,800 times that of CO₂. Industrial processes are responsible for the majority of high GWP GHG emissions. Many of these high GWP gases do not occur naturally; rather, they are man-made, industrial gases that have been manufactured for certain applications.¹

There are three key types of high GWP gases outside of methane and nitrous oxide. These are: sulfur hexafluoride (SF₆), other types of perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs). All of these gases contain fluorine, and fluorinated compounds are very potent GHGs because of their long lifetime in the atmosphere and high absorption potential. Over the past two decades, PFC and HFC usage has increased because these gases are good substitutes for chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and halons—all of which are ozone depleting substances² (ODSs) being phased out of production under the Montreal Protocol.³ HFCs and PFCs have replaced ODSs in many cases, as they are not ODSs; however, these gases do have high GWPs. Overall, replacement provides net-benefits because HCFCs and CFCs are potent greenhouse gases as well as ODSs. For example, CFC-11 is a common chlorofluorocarbon that depletes the ozone and has a 100-year GWP of approximately 4,750 CO₂e. HCFCs and CFCs were

excluded from the Kyoto Protocol, however, because the Montreal Protocol had already mandated reductions in these gases. Despite ozone benefits relative to the use of HCFCs, CFCs, and halons, HFCs and PFCs are powerful greenhouse gases. In order to achieve climate protection, it is important to increase the efficiency of their use, abate emissions, or find substitutes that are environmentally benign.⁴

High GWP gases only account for about 2.1 percent of U.S. greenhouse gas emissions in terms of CO₂e (carbon dioxide is the dominant greenhouse gas, accounting for 85 percent of domestic emissions).⁵ The chart below illustrates domestic sources of high GWP gas emissions and their relative contributions.

Figure 1: Relative Contributions of Domestic Sources of High GWP Gases



Source: [2009 U.S. Greenhouse Gas Inventory Report](#), EPA, 2009.

- **PFCs**

PFCs are very potent GHGs with 100-year GWPs between 7,390 to 17,700 CO₂e and atmospheric lifetimes in the range of 740 to 50,000 years. There are a few types of sources of PFC emissions in the United States at present. One source category is aluminum production. Aluminum production is a very electricity-intensive process during which alumina is electrolytically reduced into aluminum in a reaction cell.⁶ During this process, alumina concentrations may drop below a certain optimal threshold, and this causes a surge in voltage in the cell and switches the reduction reaction to carbon in the anode, called an “anode effect.” During an anode effect, carbon in the anode and fluorine present in the reaction cell are converted to PFCs.⁷

Solvents are also a source of PFC emissions. Many solvents used for electronics and metals cleaning contain PFCs. These solvents have low boiling points, so they convert easily to gas. Once in gaseous form, they can remain in the atmosphere for thousands of years.⁸

- **HFCs**

HFCs have a 100-year GWP range between 124 and 14,800 CO₂e and atmospheric lifetimes in the range of 1.4 to 270 years. They are emitted from a wide variety of industrial processes and are the most common of the high GWP gas types. The greatest source of HFCs, and the greatest source of any high GWP gas, is leakage from refrigeration, heat pumps and air conditioning equipment. They may leak from these units during operation, repair, or disposal at the end of a unit's useful life.⁹

Like PFCs, HFCs are also used in solvents designed for electronics and metals cleaning. HFCs are emitted when these solvents evaporate.¹⁰

The production of HCFC-22, commonly known as R-22, is another source of HFC emissions. HFC-23, a powerful greenhouse gas, is created as a byproduct in the production of R-22, which is currently used for a variety of applications.¹¹

HFCs are also used as blowing agents in the production of certain types of foams. HFCs will escape during the manufacture of the foam, and they will also gradually leak from the foam throughout its life, although a portion of the HFCs will remain trapped indefinitely.¹²

Many aerosols also contain HFCs. For example, metered dose inhalers used for various medical applications have recently switched from CFC-based propellants to HFC-based propellants. Many other consumer products, like aerosol computer dusting agents and emergency air horns, also contain HFCs.¹³

HFCs have now replaced halons in fire extinguishers as well. These HFCs are emitted when a fire extinguisher is discharged.¹⁴

- **Sulfur Hexafluoride**

Sulfur hexafluoride (SF₆) has a 100-year GWP potential of 22,800 CO₂e and an atmospheric lifetime of 3,200 years, making it an extremely potent GHG. It acts as an insulator in electric transmission and distribution equipment. A vast majority of SF₆, about 80 percent of all emissions, is emitted when such equipment is damaged or opened during repair or disposal.¹⁵

Magnesium production and casting have also become sources of SF₆ emissions. SF₆ has replaced sulfur dioxide (SO₂) in magnesium production as an inhibitor of violent molten magnesium oxidation.¹⁶ Its use in this process generates GHG emissions.¹⁷

- **Semiconductor manufacture**

Several high GWP gases—including HFCs, PFCs, and SF₆—are used in the manufacture of semiconductors. These gases are largely used for plasma etching and the cleaning of semiconductor production equipment.¹⁸

Environmental Benefit/Emission Reduction Potential

As there are many different sources of high GWP gas emissions, there are also many different potential options for emission reduction.

- **PFCs**

PFC emissions result from sub-optimal concentrations of alumina, in the form of anode effects. Thus, improving control of alumina concentrations could mitigate PFC emissions. At present, computerization of the smelting process or capital additions, such as point feeders,¹⁹ provide means to better control alumina concentrations in the production process. There are two gases emitted from anode effects, CF₄ and C₂F₆, with GWPs of 7,390 and 12,200 CO₂e, respectively. In 2001, the EPA estimated that these technologies could reduce 2010 emissions by between 17 and 30 percent, depending on the technologies used and the degree to which they are employed.²⁰

Reductions in PFC emissions from solvents can be achieved several ways: through improvements to cleaning equipment and properties; through improvements in the efficiency of solvent usage and recycling; and through improvements in solvent technology and the development of alternative solvents. These GHGs have GWPs upwards of 7,400 CO₂e. Reductions will vary by technology used—with greater reductions occurring from displacement of PFC solvents and smaller reductions coming from process improvements. In 2001, the EPA estimated overall emissions reduction potential to be between 31 and 35 percent in the year 2010 depending on the technologies employed.²¹

- **HFCs**

Refrigeration, cooling units, and heat pumps are the greatest sources of HFC emissions. Thus, finding ways to improve the handling and operation of such units will decrease fugitive HFC emissions. In many cases, this may be as simple as providing routine maintenance to units and performing leakage tests. In addition, ensuring that refrigeration units are properly disposed of will prevent HFC leakage at landfills. The EPA requires the recovery of refrigerant from retired equipment, but the degree to which this actually occurs is unknown. Design and performance improvements aimed at emission reductions for future units, and upgrades to existing units, can also be implemented. Non-HFC refrigeration systems that do not contribute to climate change, such as ammonia or hydrocarbon-based refrigeration systems, could be deployed at scale, but there are flammability and toxicity issues that must be addressed with many of these systems before they can be fully commercialized. Finally, alternative cooling technologies, like geothermal cooling—where the relatively constant temperature present in subterranean environments can be used as a heat sink—could be employed. These geothermal systems would have to employ HFC-free heat pump systems or water based systems in order to be emissions-free. Overall, these non-or-low-HFC technologies limit emissions from leakage, and they may also limit emissions from electricity production, as some use significantly less energy than conventional refrigeration and cooling systems. As refrigeration and air conditioning are the greatest contributors to high GWP emissions, significant potential for reduction exists. In 2001, the EPA estimated that reductions between 4 and 12 percent could be achieved in 2010.²²

HFC-23 emissions from R-22 production will remain problematic in the short-term. However, as part of the Montreal Protocol, R-22 is to be gradually phased out of production and usage in the United States by 2020.²³ Until then, measures that improve the efficiency of R-22 production will limit diffuse emissions of HFC-23. Additionally, HFC-23 emissions can be thermally oxidized, thereby

decreasing their GWP by converting them to carbon dioxide, hydrogen fluoride, and water. Thermal oxidation has the potential to eliminate over 99 percent of HFC-23 emissions.²⁴

Like PFCs, HFCs are also present in solvents. Reduction options for HFCs in solvents mirror those for PFCs, and the EPA estimated reduction potential is the same, as HFCs are part of these reductions, at about 31 to 35 percent.²⁵

For HFC emissions related to foam and foam blowing, the best mitigation option is substituting other blowing agents that have lower GWPs than HFCs. For example, hydrofluoroolefin (HFO) and hydrocarbon-based blowing agents offer viable alternatives to HFC blowing agents. Concerns about flammability exist with the use of some hydrocarbons. In addition, performance issues and other obstacles may need to be overcome with the use of certain blowing agents, but alternative blowing agents present promising options. In 2001, the EPA estimated that emissions reductions between 35 and 37 would occur.²⁶

CFC use in aerosols has largely been replaced by the use of HFCs. As of December 31, 2008, all metered dose inhalers (MDIs) have switched to a hydrofluoroalkane (HFA) propellant from a CFC based propellant (inhalers were the last consumer product in the United States to use a CFC propellant).²⁷ The GWP of the HFA propellant is nearly six times less than that of the CFC propellant, and almost 30 percent less propellant is required per dose. Tire inflators and air horns are other types of equipment that utilize HFCs. There are several options for mitigation, such as transitioning to dry powder-based inhalers that do not require propellants in the case of MDIs and finding lower GWP alternatives for other types of equipment. Performance and safety issues, particularly issues with flammability, will have to be overcome for certain alternatives, but the EPA estimates that alternative propellants could reduce emissions by up to 20 percent by 2010. When combined with other options, like non-propellant based alternatives and the use of hydrocarbon based propellants, up to 37 percent reductions could occur by 2010.²⁸

For portable and installed fire extinguishers with HFCs, water mist systems and inert gas systems present lower GWP alternatives. In addition, technologies that impede the spread of fires or allow for early detection and quick extinguishment may cut down on emissions because they will allow extinguishing systems to use smaller amounts of chemicals to put out fires. In 2001, the EPA estimated that water mist systems could reduce emissions by 3 percent and inert gas systems could reduce emissions by 25 percent by 2010.²⁹

- **Sulfur Hexafluoride**

SF₆ emissions from electricity transmission and distribution equipment can be reduced by:

- ensuring that equipment is properly disposed of and that SF₆ is recycled whenever possible; the EPA estimates that this could reduce emissions by 10 percent;
- installing new equipment that is easier to service, uses SF₆ and has greater structural integrity, which could reduce SF₆ emissions by up to 50 percent;
- developing alternative insulating gases, with lower GWP than SF₆, as an alternative;
- and installing leak detection systems that will inform operators of leakage, which could reduce emissions by up to 20 percent.³⁰

SF₆ emissions from magnesium production can be reduced by:

- replacing SF₆ with lower GWP cover gases;
- improving the efficiency of SF₆ usage and implementing measures to reduce leakage;

- installing alternative production and casting systems that limit the need for cover gases.³¹

- **Semiconductors**

Several technologies have been employed that improve the efficiency of and reduce emissions from etching and production operations. Some of these technologies involve capturing emissions and subsequently destroying them through thermal or catalytic processes. Emissions reductions can be anywhere between 50 to 98 percent or greater, depending on the technology used. While there are currently no alternatives to the use of fluorinated GHGs (F-GHGs) in semiconductor manufacture, some processes are amenable to substitution by F-GHGs that have lower GWPs and/or are more efficiently reacted, thus lowering CO₂e emissions.³²

Cost

As there are numerous sources of high GWP emissions, costs of emission reductions vary widely depending on the source of emissions and the available mitigation technologies. Typically, costs will be lower for reductions achieved through efficiency improvements or lower GWP gas substitutes—these options may even generate a net savings. The installation of new capital or additions to existing capital designed to mitigate emissions are generally more costly options across all emission sources because of the large upfront expenditures required for such projects.

Overall, those high GWP gases that are point source emissions—meaning they come from a fixed, identifiable source—present more cost-effective mitigation options than other diffuse emissions sources, like fugitive emissions from electricity transmission lines, because they only require improvements to single sources rather than large-scale improvements to expansive systems. Some reductions in certain high GWP gases could be spill-over effects from other actions taken to reduce GHG emissions. For example, electricity efficiency measures aimed at reducing CO₂ emissions could also be responsible for indirect reductions in fugitive SF₆ emissions by cutting down on the amount of electricity transmission and distribution equipment needed. These indirect benefits may not be accounted for when estimating the cost of mitigation projects.³³

Finally, it is important to note that several economic studies have concluded that the inclusion of high GWP gases—including methane and nitrous oxide—in measures designed to reduce GHG emissions creates greater GHG reductions at lower costs than just targeting CO₂ alone. For example, a Pew Center on Global Climate Change report completed in 2003 estimated that meeting Kyoto Protocol targets with a multi-gas mitigation system would be about 30 percent cheaper and would allow for about 5 percent greater reductions than a CO₂-only system. Because these gases are far stronger than CO₂, emissions reductions per dollar expended tend to be much higher in many cases, making them very cost-effective options relative to CO₂.³⁴

Current Status of High GWP Gas Mitigation

As noted before, the Montreal Protocol has called for the phase out of ODSs—which are also potent GHGs. Class I ODSs, of which CFCs are a part, are no longer used or produced in the United States.³⁵ Class II ODSs, of which HCFCs are part, will be completely phased out by January 1, 2030.³⁶ As the Montreal Protocol is an international treaty, gradual phase out can be expected on a global level, and this will have a significant impact on reducing high GWP gases not included in the Kyoto Protocol. In fact, a decision to accelerate the

phase out of HCFCs made by parties to the Montreal Protocol in 2007 will avoid emissions of approximately 16 gigatons CO₂e.³⁷

The EPA has established several voluntary programs aimed at reducing high GWP emissions. It estimates that these voluntary programs will be responsible for reductions of approximately 90 million metric tons CO₂e for the year 2010 when compared to business as usual estimates, about a 300 percent reduction.³⁸ These voluntary programs are as follows:

- SF₆ Emission Reduction Partnership for Electric Power Systems
 - The electric power systems partnership focuses on reducing emissions of SF₆ emissions from electric transmission and distribution equipment. Partners agree to keep an inventory of SF₆ emissions and implement measures to reduce them. About 45 percent of the industry now participates in the program, and Partners were collectively responsible for 4 million metric tons carbon equivalent (MMTCE) reduction in 2006 alone.³⁹
- The Voluntary Aluminum Partnership (VAIP)
 - VAIP was established in 1995 with the goal of reducing PFC emissions from aluminum production through the mitigation of anode effects. It represents 98 percent of U.S. aluminum production capacity. VAIP's efforts have reduced PFC emissions per ton of aluminum produced by 77 percent from 1990 levels.⁴⁰
- SF₆ Emission Reduction Partnership for the magnesium Industry
 - Established in 1999, this partnership between the EPA and the magnesium industry focuses on reducing the SF₆ emissions associated with the production and casting of magnesium. It was responsible for emissions reductions of 40 percent per ton of magnesium produced between 1999 and 2002. The program has a goal of eliminating SF₆ emissions from this industry entirely by 2010.⁴¹
- PFC Reduction/Climate Partnership for the Semiconductor Industry
 - Established in 1996, this partnership focuses on reducing a wide variety of high GWP emissions from semiconductor manufacturing through efficiency and capital improvements. The program has a goal of reducing emissions 10 percent below a 1995 baseline, and the EPA estimates that it will mitigate 10 MMTCE in the year 2010 alone.⁴²

The EPA also maintains a regulatory program called the Significant New Alternatives Policy Program. Under this program, the EPA may evaluate and control substitutes to ODSs so as to ensure that they are more environmentally benign than the substances they seek to replace.

Obstacles to Further Development or Deployment of High GWP Emissions Controls

- **Cost**

High GWP gas mitigation has increasing marginal costs, meaning that smaller emissions reductions achieved by substituting gases or implementing marginal efficiency improvements may be cheap, but large reductions—which require new capital or alternative processes—will have much higher costs in the form of R&D or expenditures on new equipment. Thus, attaining high levels of reductions may be very costly, and some technologies still remain prohibitively expensive.

- **Diffuse emissions**

Many high GWP emissions come from diffuse sources, such as electricity transmission equipment, that are more difficult to monitor and control. Mitigation options for diffuse emission will be systemic in scope. In most cases, this will make their implementation longer and more difficult than mitigation measures for point sources.

Policy Options to Help Promote High GWP Emissions Reductions

- **Price on greenhouse gases**

A price on greenhouse gases, as would exist, for example, under a greenhouse gas cap-and-trade program, would incentivize high GWP emissions reductions so long as they were included in the cap. If they were not included in the cap, inclusion in an offsets program— where high GWP gas-emitting firms could still earn emission reduction credits that they could sell to covered firms—would incentivize reductions.

- **Mandates or incentives**

The Montreal Protocol has contributed to significant emissions reductions in ODSs, which are also high GWP gases. A similar mandate targeting industrial high GWP gases, or a program that incentivizes or subsidizes their reduction, could effectively reduce emissions. However, this approach is limited by the availability of technically acceptable and cost-effective alternatives.

Related Business Environmental Leadership Council (BELC) Company Activities

- [ABB](#)
- [Alcoa Inc.](#)
- [American Electric Power](#)
- [Cummins Inc.](#)
- [Duke Energy](#)
- [Dupont](#)
- [Exelon](#)
- [IBM](#)
- [PG&E](#)
- [Rio Tinto](#)
- [Wisconsin Energy Corporation](#)

Related Pew Center Resources

[*Multi-Gas Contributors to Global Climate Change: Climate Impacts and Mitigation Costs of Non-CO₂ Gases*, 2003.](#)

Further Reading/Additional Resources

U.S. Environmental Protection Agency (EPA)

- [Final Report on U.S. High Global Warming Potential \(High GWP\) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions](#)

¹ Reilly, John M., Jacoby, Henry D. and Prinn, Ronald G. *Multi-gas contributors to global climate change 2003*. Arlington, VA : Pew Center on Global Climate Change, 2003.

² ODSs are chemicals that deplete the stratospheric ozone layer in the earth's atmosphere. The ozone layer absorbs ultraviolet radiation; its depletion allows more ultraviolet radiation to reach earth's surface, and this has negative impacts on public health and agricultural productivity. The Montreal Protocol, an international treaty that called for a reduction in the use of ODSs, was ratified in 1987. Since then, the United States and many other nations have sought to phase out the usage of ODSs.

³ Phasing Out Ozone Depleting Substances and Safeguarding the Global Climate. *UNDP-Environment and Energy*. [Online] United Nations . [Cited: July 15, 2009.] <http://www.undp.org/chemicals/montrealprotocol.htm>.

⁴ Final Report on U.S. High Global Warming Potential (High GWP) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions. *EPA High Global Warming Potential Gases*. [Online] June 2001. [Cited: July 18, 2009.] <http://www.epa.gov/highgwp/projections.html>.

⁵ 2009 U.S. Greenhouse Gas Inventory Report. *Climate Change - Greenhouse Gas Emissions*. [Online] EPA, 2009. [Cited: July 15, 2009.] <http://www.epa.gov/climatechange/emissions/usinventoryreport.html>.

⁶ Production. *International Aluminum Institute*. [Online] International Aluminum Institute, 2009. [Cited: July 17, 2009.] <http://www.world-aluminium.org/About+Aluminium/Production>.

⁷ Cost and Emission Reduction Analysis of PFC Emissions from Aluminum Smelters in the United States . *Final Report on U.S. High Global Warming Potential (High GWP) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions*. [Online] EPA, June 2001. [Cited: July 17, 2009.] http://www.epa.gov/highgwp/pdfs/chap5_alum.pdf.

⁸ Cost and Emission Reduction Analysis of HFC and PFC/PFPEs Emissions from Solvents in the United States . *Final Report on U.S. High Global Warming Potential (High GWP) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions*. [Online] EPA, June 2001. [Cited: July 17, 2009.] http://www.epa.gov/highgwp/pdfs/chap8_solv.pdf.

⁹ Cost and Emission Reduction Analysis of HFC Emissions from Refrigeration and Air Conditioning in the United States. *Final Report on U.S. High Global Warming Potential (High GWP) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions*. [Online] EPA, June 2001. [Cited: July 17, 2009.]

¹⁰ Cost and Emission Reduction Analysis of PFC Emissions from Aluminum Smelters in the United States, 2001.

¹¹ Cost and Emission Reduction Analysis of HCFC-22 Production in the United States, 2001.

¹² Cost and Emission Reduction Analysis of HFC Emissions from Foams in the United States, 2001.

¹³ Cost and Emission Reduction Analysis of HFC Emissions from Aerosols in the United States. *Final Report on U.S. High Global Warming Potential (High GWP) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions*. [Online] EPA, June 2001. [Cited: July 17, 2009.] http://www.epa.gov/highgwp/pdfs/chap10_aero.pdf.

¹⁴ Cost and Emission Reduction Analysis of HFC and PFC Emissions from Fire Extinguishing in the United States . *Final Report on U.S. High Global Warming Potential (High GWP) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions*. [Online] EPA, June 2001. [Cited: July 17, 2009.] http://www.epa.gov/highgwp/pdfs/chap11_fire.pdf.

- ¹⁵ Cost and Emission Reduction Analysis of SF₆ Emissions from Electric Utilities in the United States . *Final Report on U.S. High Global Warming Potential (High GWP) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions*. [Online] EPA, June 2001. [Cited: July 17, 2009.] http://www.epa.gov/highgwp/pdfs/chap3_elec.pdf.
- ¹⁶ Magnesium is a highly flammable metal that reacts violently with oxidizing or extinguishing agents. This may result in excessive oxidation which is dangerous and results in losses of the metal during production. SF₆ is used as a cover gas, a gas that helps stabilize the magnesium production process by inhibiting ignition violent oxidation.
- ¹⁷ Cost and Emission Reduction Analysis of SF₆ Emissions from Magnesium Production and Parts Casting in the United States. *Final Report on U.S. High Global Warming Potential (High GWP) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions*. [Online] EPA, June 2001. [Cited: July 17, 2009.] http://www.epa.gov/highgwp/pdfs/chap4_mag.pdf.
- ¹⁸ Cost and Emission Reduction Analysis of PFC, HFC, and SF₆ Emissions from Semiconductor Manufacturing in the United States. *Final Report on U.S. High Global Warming Potential (High GWP) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions*. [Online] EPA, June 2001. [Cited: July 17, 2009.] http://www.epa.gov/highgwp/pdfs/chap6_semi.pdf.
- ¹⁹ Point feeders are alumina distribution devices that allow for greater control and precision in the administration of alumina in the reaction cell. By incrementally adding alumina into the reaction cell, they help maintain optimal reaction conditions and cut down on anode effects.
- ²⁰ Cost and Emission Reduction Analysis of PFC Emissions from Aluminum Smelters in the United States, 2001.
- ²¹ Cost and Emission Reduction Analysis of HFC and PFC/PFPEs Emissions from Solvents in the United States, 2001.
- ²² Cost and Emission Reduction Analysis of HFC Emissions from Refrigeration and Air Conditioning in the United States, 2001.
- ²³ Phaseout of HCFC-22 and HCFC-142b in the United States. *Ozone Layer Depletion - Regulatory Programs*. [Online] EPA, 2009. <http://www.epa.gov/Ozone/title6/phaseout/hcfcfaqs.html>
- ²⁴ Cost and Emission Reduction Analysis of HCFC-22 Production in the United States, 2001.
- ²⁵ Cost and Emission Reduction Analysis of HFC and PFC/PFPEs Emissions from Solvents in the United States, 2001.
- ²⁶ Cost and Emission Reduction Analysis of HFC Emissions from Foams in the United States, 2001.
- ²⁷ CFC-Free Inhalers: Time to Make the Switch. *American Lung Association*. [Online] American Lung Association. [Cited: July 15, 2009.] <http://www.lungusa.org/site/c.dvLUK900E/b.2222599/>.
- ²⁸ Dalby, Richard. Introduction to Pharmaceutical Aerosols. *University of Maryland*. [Online] [Cited: July 15, 2009.] <http://www.pharmacy.umaryland.edu/faculty/rdalby/TeachingWebPages/Introduction%20to%20Pressurized%20Formulations.pdf.pdf>.
- ²⁹ Cost and Emission Reduction Analysis of HFC and PFC Emissions from Fire Extinguishing in the United States, 2001.
- ³⁰ Cost and Emission Reduction Analysis of SF₆ Emissions from Electric Utilities in the United States, 2001.
- ³¹ Cost and Emission Reduction Analysis of SF₆ Emissions from Magnesium Production and Parts Casting in the United States, 2001.
- ³² Cost and Emission Reduction Analysis of PFC, HFC, and SF₆ Emissions from Semiconductor Manufacturing in the United States. *Final Report on U.S. High Global Warming Potential (High GWP) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions*. [Online] EPA, June 2001. [Cited: July 17, 2009.] http://www.epa.gov/highgwp/pdfs/chap6_semi.pdf.
- ³³ Final Report on U.S. High Global Warming Potential (High GWP) Emissions 1990-2010: Inventories, Projections, and Opportunities for Reductions, 2001.
- ³⁴ Reilly, 2003.
- ³⁵ Phase Out of Class I Ozone Depleting Substances. *Ozone Layer Depletion-Regulatory Programs*. [Online] EPA, June 2001. [Cited: July 17, 2009.] <http://www.epa.gov/ozone/title6/phaseout/classone.html>.
- ³⁶ Phaseout of HCFC-22 and HCFC-142b in the United States. *Ozone Layer Depletion - Regulatory Programs*. [Online] EPA, June 2001. [Cited: July 17, 2009.] <http://www.epa.gov/Ozone/title6/phaseout/hcfcfaqs.html>.
- ³⁷ Phasing Out Ozone Depleting Substances and Safeguarding the Global Climate, 2009.
- ³⁸ High Global Warming Potential Gases. *EPA*. [Online] EPA, October 2006. [Cited: July 16, 2009.] <http://www.epa.gov/highgwp/projections.html>.
- ³⁹ SF₆ Emission Reduction Partnership for Electric Power Systems. *EPA* . [Online] EPA, February 2009. [Cited: July 15, 2009.] <http://www.epa.gov/highgwp/electricpower-sf6/index.html>.
- ⁴⁰ Voluntary Aluminum Industrial Partnership (VAIP). *Voluntary Aluminum Industrial Partnership (VAIP)*. [Online] EPA, March 2008. [Cited: July 15, 2009.] <http://www.epa.gov/highgwp/aluminum-pfc/index.html>.

⁴¹ SF6 Emission Reduction Partnership for the Magnesium Industry. *SF6 Emission Reduction Partnership for the Magnesium Industry*. [Online] EPA, March 2008. [Cited: July 15, 2009.] <http://www.epa.gov/highgwp/magnesium-sf6/index.html>.

⁴² PFC Reduction/Climate Partnership for the Semiconductor Industry . *PFC Reduction/Climate Partnership for the Semiconductor Industry* . [Online] EPA, March 2008. [Cited: July 15, 2009.] <http://www.epa.gov/highgwp/semiconductor-pfc/index.html>.