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THE GNCS FACTSHEETS

# Mitigating Emissions from PFCs

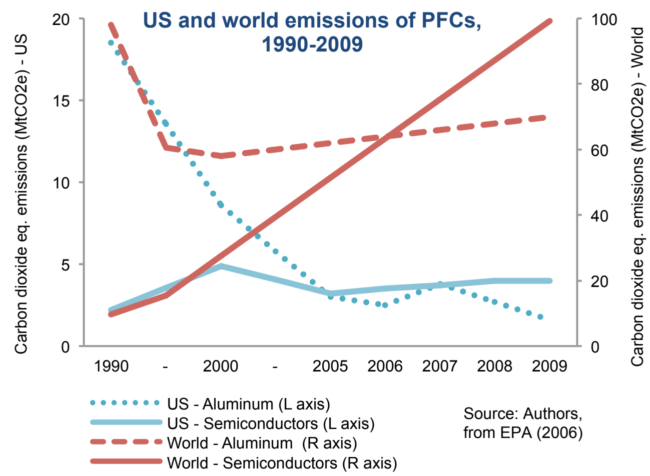
Emissions of perfluorocarbons (PFCs) constitute less than 0.25% of global greenhouse gas emissions.[1] However, they play a disproportionate role in climate change because they are extremely efficient at trapping heat, up to 9500 times more so than carbon dioxide ($CO_2$). With atmospheric residence times of up to 50,000 years, their contribution to global warming is irreversible on any relevant time scale.

PFCs are the most potent of a group of fluorinated compounds used in industry that are generally grouped together as “high global warming potential” non-$CO_2$ greenhouse gases.[2] PFCs are an attractive target for mitigation efforts because the impact per ton of abatement is far greater than for $CO_2$. Furthermore, they are less complex to approach than $CO_2$ because they come from a small number of easily identified sources.

## Sources of PFC Emissions

Globally, the largest source of PFC emissions is *aluminum production*. As these emissions result from production inefficiencies, the industry has had an economic incentive to reduce them. Thus, PFC emissions per ton of aluminum declined by 90% from 1990 to 2009.[3] However, the aluminum industry still accounted for around 60–70% of total PFC emissions in 2005.[4] These emissions can be almost entirely eliminated(see GNCS factsheet on Mitigating Emissions from Aluminum).

*Semiconductor manufacturing* – the fabrication of integrated circuits on silicon wafers – now accounts for around 25–30% of global PFC emissions. In some countries that have cut aluminum emissions, such as the US, the semiconductor industry has become the largest single source (see figure below). Total PFC emissions from the semiconductor industry were 27 million tons of $CO_2$ equivalent ($MtCO_2e$) in 2000, and despite industry efforts to reduce them are projected to rise to 28.3 $MtCO_2e$ in 2020.[5] PFCs are used in plasma etching and the cleaning of chemical vapor deposition (CVD) chambers. Anywhere from 10–80% of the gases used in these processes simply evaporate and are emitted as exhaust, entering the atmosphere unreacted. PFCs have been vital to the production of more advanced semi-conductors and are seen as critical to future innovation.[6]




Smaller amounts of PFCs are also used as *industrial solvents* in precision and electronics cleaning, as a substitute for ozone-depleting CFCs. Almost all the PFCs consumed as solvents end up being emitted to the atmosphere. In a business as usual (BAU) scenario, under existing policy measures in the US and EU, total solvent emissions (which include HFCs and HFEs as well as PFCs) are projected to decline by over 70% by 2020.[7]

## Abatement Options

Mitigation approaches for PFCs are industry-specific. For information on the efficiency improvements that have reduced emissions from *aluminum production*, see the GNCS factsheet on Mitigating Emissions from Aluminum.

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[1] Emissions inventories present aggregated data for the high GWP gases (HFCs, PFCs, SF6). This is an estimate.
[2] PFCs comprise $CF_4$, $C_2F_6$, $C_3F_8$, c-$C_4F_8$, $C_4F_{10}$, $C_5F_{12}$, $C_6F_{14}$, $C_7F_{16}$, of which $CF_4$ and $C_2F_6$ account for around 78% and 15% of emissions respectively. See: http://edgar.jrc.ec.europa.eu/part_PFC.php.
[3] IAI. (2010). *Results of the 2009 Anode Effect Survey: Report on the Aluminium Industry’s Global PFC Gases Emissions Reduction Programme*. International Aluminium Institute. 5 July 2010.
[4] See: http://edgar.jrc.ec.europa.eu/part_PFC.php.
[5] EPA. (2006). *Global Mitigation of Non-$CO_2$ Greenhouse Gases*. Washington D.C.: US Environmental Protection Agency.
[6] See: http://www.epa.gov/semiconductor-pfc/basic.html#two.
[7] EPA (2006).

The US Environmental Protection Agency (EPA) estimates that by 2020, 43% of *semiconductor manufacturing* BAU emissions could be abated at breakeven cost.[8] There are two key abatement options:

(1) *Process optimization/ alternative processes.* Eighty percent of the PFCs used in the semiconductor industry are consumed in the cleaning of chemical vapor deposition chambers. These CVD chambers are used to produce thin films on the surface of semiconductor materials, and chemically cleaning the chambers is critical to avoiding contamination. PFCs are used as a source of fluorine, the key cleaning agent. Chamber cleaning emissions can be addressed by optimizing current processes or by developing new ones. Process optimization involves adjusting parameters such as chamber pressure, temperature, plasma power, cleaning gas flow rates, and gas ratios of mixtures. This approach offers potential reductions of 10-56% of baseline CVD emissions.[9] The next generation process for cleaning CVD chambers can reduce emissions by 95%: in "remote cleans", fluorine is obtained from $NF_3$ that is dissociated in remote plasma and then fed into the cleaning process chamber. Remote cleans convert fluorine at 90–95% efficiency, in contrast to 30% for the standard process. Emissions are correspondingly reduced by more than 90%.[10] The turnover of manufacturing facilities and equipment is high in the industry, so mitigation measures can penetrate quickly. For instance, facilities to fabricate state of the art semiconductor wafers (300 mm) are now being built with remote clean technologies.

(2) *Plasma etch emissions* are increasing with the surface area of semiconductor wafers. Reducing these emissions requires capture and recovery using scrubber systems. These have been successfully tested, but thus far adoption has been limited by cost. The EPA estimates that by 2020, methods to reduce plasma etch emissions will cost \$17–33/t$CO_2$e and could account for a reduction of around 7% of PFC emissions from the industry.[11]

The EPA estimates that by 2020, 49% of BAU emissions from *industrial solvents* can be abated for less than \$10/t$CO_2$e.[12] For solvents, there are three main abatement options:

(1) *Conversion to hydrofluoroether (HFE) solvents*. HFEs are effective substitutes for PFCs in many applications, and are much less potent greenhouse gases. Many end-users have already switched to HFEs in order to comply with the Montreal Protocol, and the EPA estimates that this conversion is cost-neutral. HFE substitution could abate around 25% of BAU solvent emissions by 2020.

(2) *Improved equipment and cleaning processes using existing solvents (no-clean)*. Process changes have been effective in reducing emissions from evaporation of solvents. Improved containment, good handling practices and design improvements have the potential to reduce emissions by 1% of BAU at a cost *saving* of \$50.75/t$CO_2$e in 2020.[13]

(3) *Aqueous and semi-aqueous alternative processes.* Water-based solvents in combination with detergents can also substitute for pernicious chemical solvents. They are applicable to all uses, and have been successfully adopted by many end-users already. They have essentially zero emissions. Use of these alternatives has the potential to reduce BAU emissions by 23.2% in 2020.

## Industry Coordination

The aluminum and semiconductor industries have been actively engaged in mitigation efforts. In 1999, the World Semiconductor Council (WSC) announced that its member associations, representing 90% of global production, would reduce PFC emissions by 10% below 1995 levels by 2010.[14] In the US, these efforts have been facilitated by a partnership with the EPA.[15] The industry accomplished these targets in 2009; given the industry's growth, without them PFC emissions from semiconductor manufacturing would have risen 700% since 1995.[16] Industry coordination related to solvents is lacking.

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Further resources are available at **www.theGNCS.org**

[8] EPA (2006), p. IV-182.
[9] Sematech. (2005). *Reduction of Perfluorocompound (PFC) Emissions: 2005 State of the Technology Report*. p. 4.
[10] *Ibid.* p. 4.
[11] EPA (2006), p. IV-182.
[12] *Ibid.* p. IV-72.
[13] *Ibid.* p. IV-70.
[14] WSC. (2010). *Joint Statement of the 14th Meeting of the World Semiconductor Council.* 27 May 2010, Seoul. p. 2.
[15] EPA. *PFC Reduction/Climate Partnership for the Semiconductor Industry* [website]. See: http://www.epa.gov/semiconductor-pfc/.
[16] WSC (2010), p. 11.