Semiconductor Production Greenhouse Gases
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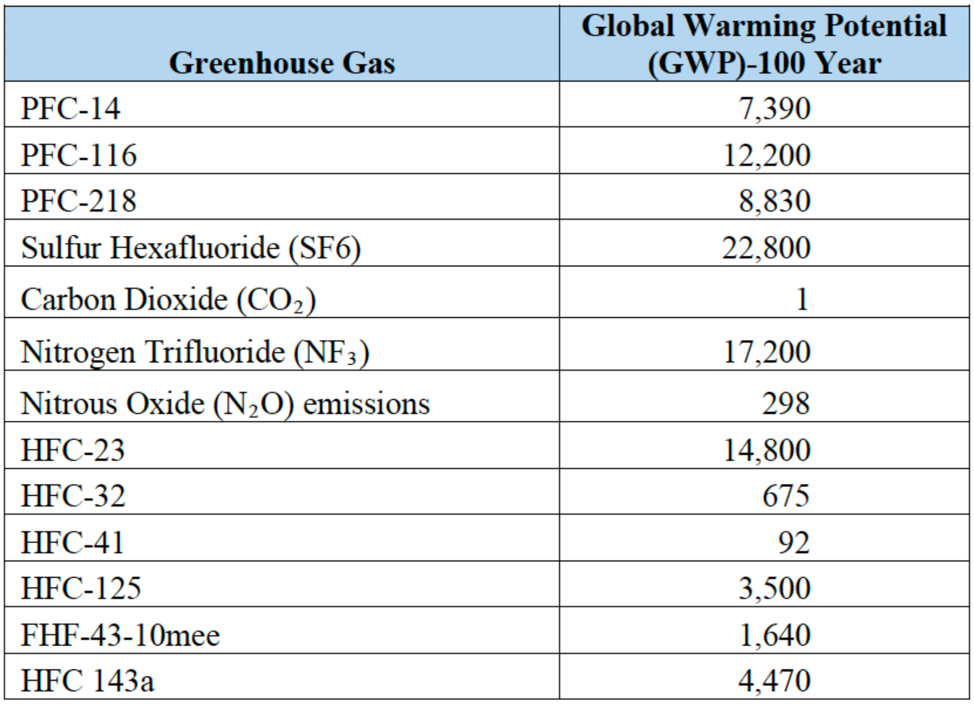
The CHIPS Program Office has identified the use and release of fluorinated gases as the principal source of greenhouse gases (GHGs) from semiconductor production:

"Most of the GHG emissions from semiconductor fabrication facilities are fluorinated gases such as PFCs and SF_6. The use of fluorinated gases did not begin in the semiconductor industry until the late 1980's. Under normal operating conditions, EPA estimates that 10 to 80 percent of these gases pass through the manufacturing process unreacted and are released into the atmosphere. Once released, the lifetime of these chemical compounds in the atmosphere can range from 270 to 50,000 years (EPA, 2023e). Global warming potential (GWP) is a measure of how much energy the emission of 1 ton of a gas will absorb over a given period of time (in this case, 100 years), relative to the emission of 1 ton of carbon dioxide (CO_2) (EPA, 2023f). **Table 3.4-1** shows the 100-year GWP of select GHGs associated with semiconductor manufacturing." (See the draft Programmatic Environmental Assessment [dPEA] at https://www.nist.gov/system/files/documents/2023/12/26/CHIPS%20Modernization%20Draft%20PEA.pdf (p. 34 of PDF)

Table 3.4-1. 100-Year Global Warming Potential of Select Greenhouse Gases



Greenhouse Gas	Global Warming Potential (GWP)-100 Year
PFC-14	7,390
PFC-116	12,200
PFC-218	8,830
Sulfur Hexafluoride (SF6)	22,800
Carbon Dioxide (CO_2)	1
Nitrogen Trifluoride (NF_3)	17,200
Nitrous Oxide (N_2O) emissions	298
HFC-23	14,800
HFC-32	675
HFC-41	92
HFC-125	3,500
FHF-43-10mee	1,640
HFC 143a	4,470

Source: 40 CFR Part 98 Subpart A, Table A-1

Industry seems to be working to reduce its climate impact, but technical challenges and increased production are making that difficult. The dPEA adds, “Although GHG emissions could increase as a result of improving and expanding production capacities associated with modernization, CHIPS Act funding represents an opportunity for facilities to modernize their tools and change processes to minimize direct emissions from semiconductor manufacturing processes.” (p. 36 of PDF)

A new industry paper summarizes those efforts. (See https://www.spiedigitallibrary.org/conference-proceedings-of-spie/12958/3013226/An-overview-of-semiconductor-industry-efforts-to-reduce-PFAS-use/10.1117/12.3013226.short . Unfortunately, this paper is behind a paywall.) The authors identify the problem:

“So, what is the concern? The fluorinated greenhouse gases used in plasma processes are the most potent greenhouse gases measured. They absorb infrared (IR) at wavelengths that CO2 does not and they are potent - 1 kg of SF6 has the global warming impact of >25,000 kg of CO2. They also have the longest atmospheric lifetime of any of the greenhouse gases, up to 50,000 years. F-GHGs are anthropogenic and their concentrations in the atmosphere are increasing. Once released to the atmosphere, they will remain for longer than human civilization has existed.” (p. 2)

They explain the challenges of reducing fluorinated gas releases:

“F-gas reductions have been achieved through:

“1) Process optimization and alternative processing. Examples include the use of endpoint detection to reduce clean times;

“2) Alternative chemistries that pose no or reduced long-term environmental threat and controllable safety and health impacts. Alternatives must reduce or eliminate GHG emissions – although an alternative input gas may not be a GHG does not mean potent GHGs are not formed as byproducts from the plasma process;

“3) Capture and/or recovery technologies that reuse or recycle input gases. SEMATECH evaluated several different capture recovery technologies including membrane separation, cryogenic recovery, and pressure swing adsorption/desorption. In all of these evaluations, cost of ownership (COO) was found to be excessive due to low F-GHG concentrations in the exhaust coupled with many process byproducts that required pretreatment; and

“4) Abatement that destroys PFCs so that they are not released to the atmosphere. Abatement devices can break PFCs into smaller chemical byproducts but may have high COO and create criteria air pollutants such as SOx, NOx, CO and hazardous and toxic air pollutants such as F2 COF2, and HF, that require additional abatement.

“Application of reduction technologies varies depending on fab age, manufacturing space, manufacturing technology, and available infrastructure. Bay-and-chaise 150mm fabs may not have the space or the utilities to allow for installation of abatement; however, if process equipment is being replaced or upgraded, it should utilize more efficient chamber clean technology and should include abatement." (p. 3)

A more detailed analysis is found in the Semiconductor PFAS Consortium's June, 2023 technical paper. (Consortium papers may be downloaded from https://www.semiconductors.org/pfas/ .). It shows substantial "reductions in the ratio of gases emitted to gases used from 2000 to 2020." (p. 5-6 of PDF) This document explains further:

"The abatement of fluorinated GHG (F-GHG) air emissions from semiconductor processes poses these challenges:

"• The C-F bond is difficult to break.

"• Etch and plasma CVD processes occur under a vacuum, with F-GHG flow rates tens to hundreds of standard cubic centimeters per minute in etch processes (Hong and Uhm 2003) and several liters per minute in chamber cleans (ISMI 2005). Vacuum pumps use nitrogen as a purge gas; thus, post-pump emissions are diluted and require significant energy input to convert F-GHGs into water-scrubbable byproducts. F-GHG emissions continue to be further diluted as they move downstream of the process chamber into central exhaust ducts. Because of dilution, semiconductor F-GHG abatement technologies cannot demonstrate very high destruction or removal efficiency (DRE), such as the 99.99% removal specified for concentrated F-GHG emissions from other industries (United Nations 2016).

"• Abatement systems require space and infrastructure (such as natural gas fuel lines, which may not be installed in an existing fab); moreover, the products of abatement (HF, COF2) require further treatment such as water scrubbing, fluoride removal or elementary neutralization, which may not have capacity for the increased waste streams. If a fab is not initially designed with F-GHG abatement systems, retrofitting may be infeasible.

"As described in the Objectives and Transition from PFCs to NF3 sections, the semiconductor industry has undertaken extensive efforts to develop and evaluate F-GHG emissions reductions technologies, including alternative chemistries and processing (where feasible), process optimization to reduce gas consumption, recovery and recycling, and abatement. (Mocella 1996); (Beu 2005); (Illuzzi and Thewissen 2010). Although not the only practice in driving HFC and PFC emissions reductions, abatement plays a key role in voluntary industry efforts to reduce emissions. (p. 19)"

The Consortium working group added, "Abatement manufacturers continue to develop new and improved abatement technologies and, as such, it is possible to demonstrate efficacy in specific semiconductor applications with experimental data. Each POU abatement technology has additional utility use, space, cost, operation, safety, air and wastewater considerations that require application-specific evaluations (Beu 2005)."

In summary, largely driven by regulation, the global semiconductor industry is attempting to reduce its releases of fluorinated gases and other greenhouse gases used in production, but it is difficult. Government money that is dedicated to the semiconductor industry should support research and development on alternative chemistries and abatement, and new and expanded plants should be designed to accept the installation of environmentally friendly technologies as they are proven.