Not All Greenhouse Gases are the Same

Biggest benefits come from ranking greenhouse gas reduction impact

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The world's largest semiconductor consumer, Apple, and similar silicon-hungry companies like Google and Microsoft, are driving suppliers to set ambitious carbon and greenhouse gas (GHG) emission goals. Sustainability compliance is becoming an important quality metric in quarterly scorecard reviews between suppliers. Not only is carbon and GHG emission reduction good for the planet, it's increasingly critical for business success. Lucrative contracts are being won and lost partly on how companies are performing to their sustainability goals, and hundreds of millions of dollars are at stake.

Scope 1-3 pollution classification

GHG emissions are classified into three categories:

- Scope 1: pollution from materials consumed and waste
- Scope 2: pollution from facilities and machinery i.e., energy input
- Scope 3: supplier and third-party pollution related to manufacturing

Scope 3 pollution is approximately 20% of the semiconductor manufacturing total and is generally about working with sustainable suppliers and making sustainable shipping and travel choices.

Scope 2 pollution is approximately 55% of the semiconductor manufacturing total. It's about energy input to facilities and process equipment tools. There has been significant focus on selecting sustainable energy solutions to reduce GHG emissions, and while there is more work to be done here, in general, the path forward to a sustainable solution, using renewable energy sources, is well understood.

Scope 1 pollution is approximately 35% of the semiconductor manufacturing total. Scope 1 pollution is about 80% process gas and materials related, and it is growing in percentage terms both as process complexity increases and the Scope 2 contribution switches increasingly to sustainable options. So how do semiconductor manufacturing companies start to control their growing Scope 1 emissions and set a path to reduce them over time?

Some simple fixes

Where to start on Scope 1 emissions? For many fab operators it's a daunting problem. Process chemistry is highly diverse, and materials and by-products are extremely difficult to recapture for reuse or recovery. Most waste is going to wet-burn abatement systems for destruction, using GHG-generating natural gas. Destruction rate efficiency (DRE) is not 100% and the percentage that is not destroyed and is vented to the atmosphere. As can be seen in figure 1 and figure 2 below, the relative impact of all greenhouse gases is not equal. When GHG potency relative to CO_2, years of atmospheric residency, and volume of gas used in semiconductor manufacturing are considered, the etch and clean gases namely NF_3 (Nitrogen Trifluoride) and SF_6 (Sulfur Hexafluoride) rise to the top of the list for attention.

Relative Potency and Residency of Common Semiconductor Process Gases

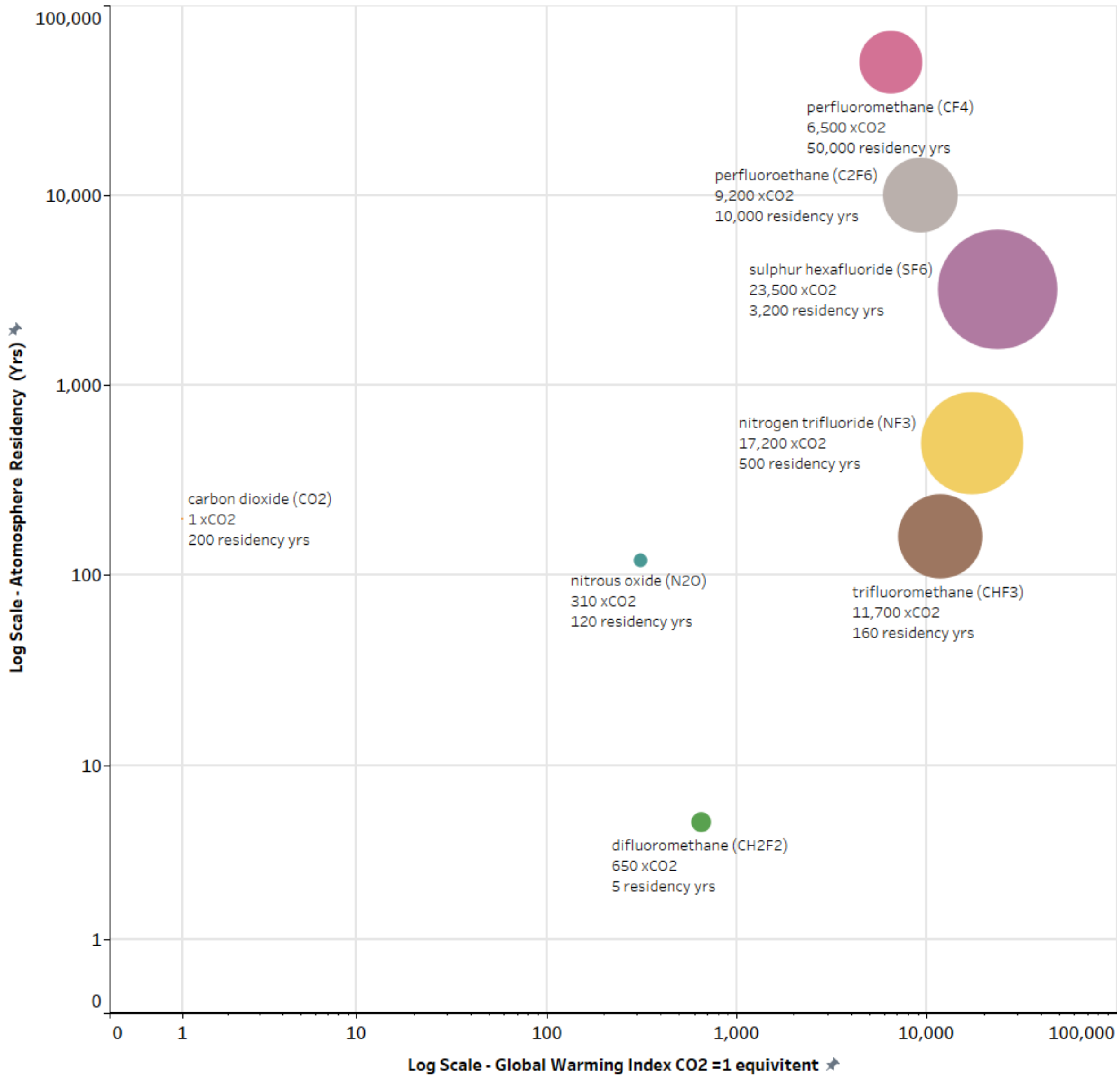
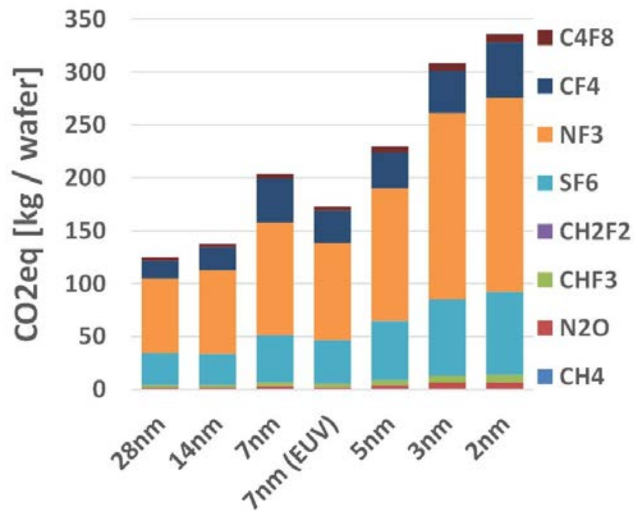


Figure 1 Relative potency of Green House Gases Used in semiconductor manufacturing.
Source: US Department of Energy

Some progress has been made with NF_3 (nitrogen trifluoride) replacing SF_6 (sulfur hexafluoride), especially in process chamber clean applications. As a greenhouse gas, NF_3 is about two-thirds as potent as SF_6. However, NF_3 is still over 17,200 times more potent as a greenhouse gas than CO_2 and its atmospheric concentrations (Figure 2) have almost doubled in the past five years especially in the industrialized northern hemisphere, where most of the semiconductor manufacturing takes place.

Figure2. NF3 and SF6 are the major semiconductor process GHG contributors
Source: Mieke Van Bavel, imec



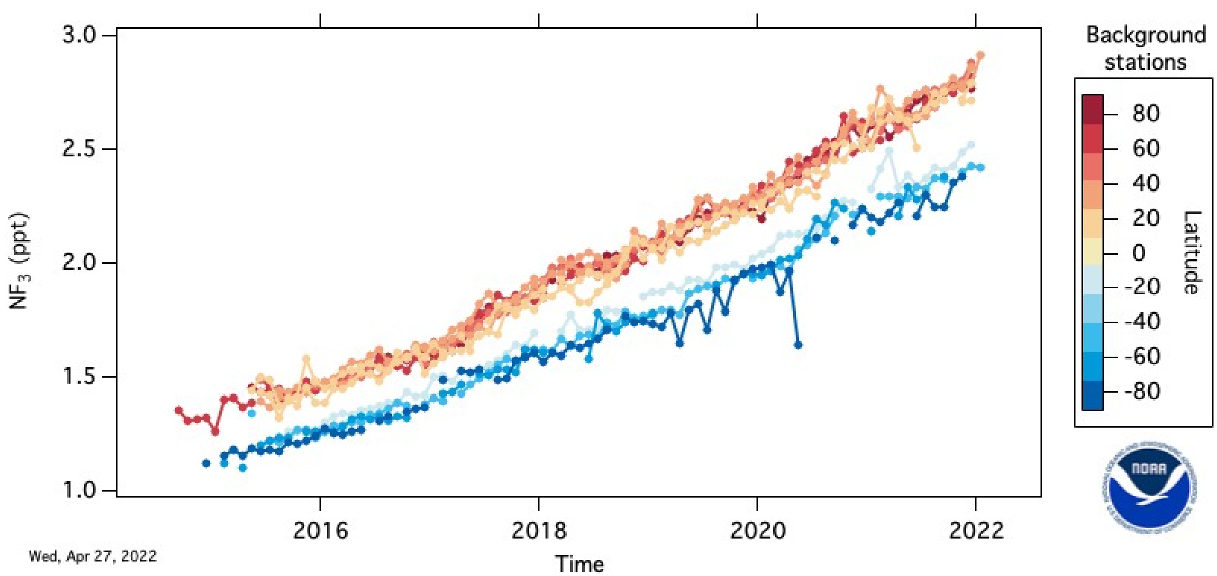


Figure 3. Atmospheric concentrations trend of NF3 since 2015
Source: NOAA Global Monitoring Laboratory https://gml.noaa.gov/hats/gases/NF3.html

NF_3 is used extensively in semiconductor manufacturing for cleaning process chambers, to remove the build-up of particulate and deposition matter for the chamber walls and surfaces. Chamber cleaning is required to ensure consistent manufacturing and to reduce yield loss from particulate defects depositing on the wafer surface. It is common for the clean process to happen as often as every five wafers, or five times for a standard 25 wafer processing lot during a typical process deposition step. Subsequently, process chambers may spend more than 20% of their useful time being cleaned with NF_3 or SF_6 during production processing.

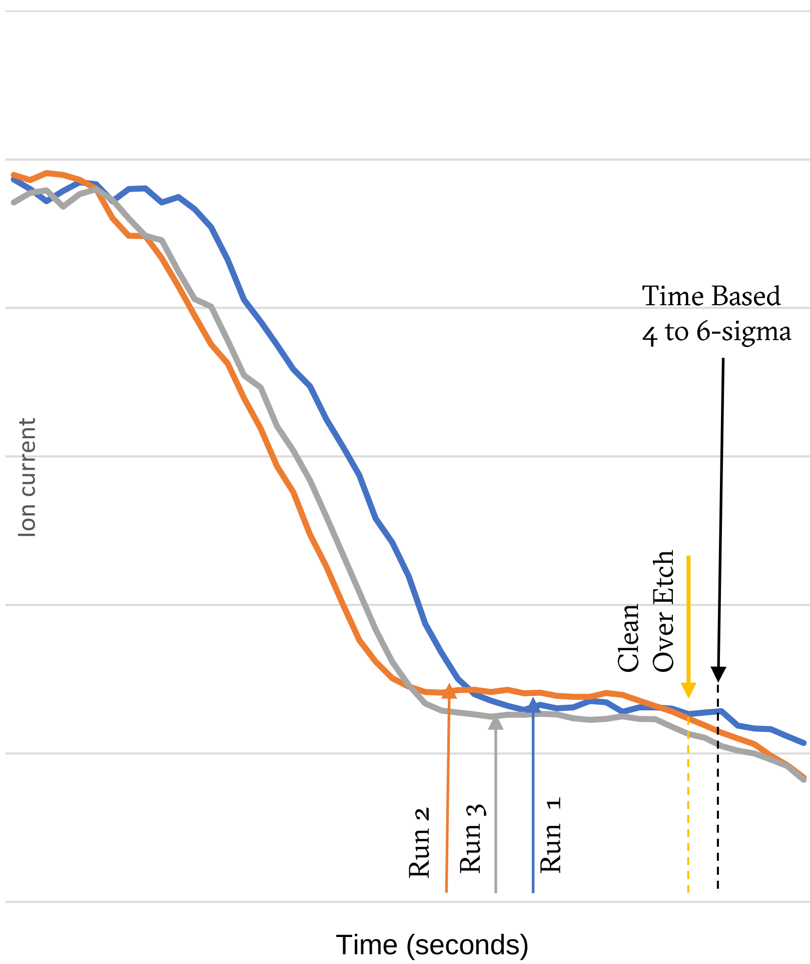
Most chamber cleans are fixed timed processes with defined periods, and this is where a simple fix could make a significant difference to NF_3 gas emission reduction. Atonarp's Aston mass spectrometer has been used successfully by a number of semiconductor fab operators to dramatically reduce NF_3 based clean cycles. Instead of fixed time based cleans, Aston's *in-situ,* actionable metrology is used to precisely detect the end point of the clean process.

The chemically-specific endpoint detection changes dynamically from chamber to chamber and run to run, based on how dirty the chamber was to start with.

The benefits for the semiconductor fabs were multi-faceted:

- Higher process throughput from reduced clean time
- Less NF_3 consumed saving on materials and enabling a significantly more sustainable process
- Reduced abatement requirements from the reduced clean gasses used.

Cleaning to end point also resulted in less post-clean chamber re-seasoning, thus further increasing process efficiency and throughput, and making the GHG contribution of the overall process significantly lower.



Less is More

When using Aston Plasma for end point detection, clients saw a reduction in clean times of up to 75%, thus resulting in a unit process throughput increase of over 15%. Unlike legacy residual gas analyzers that use a hot wire electron impact ionization source, the unique feature of Aston's plasma-based ionization allows the robust Aston solution to work with the harsh NF_3 (and other) process gases without filament corrosion.

Benefits or reduced clean time using end point detection extend beyond environmental impact to cost savings or increase profits from higher throughput. A 30% reduction in clean time represents an ~6% increase in overall throughput for a typical memory deposition process. That 6% throughput increase equals >$1M in incremental profit a year for FAB operators for just one constrained deposition tool cell before materials and energy savings from lower abatement demands from running less clean gas.

Silicon oxide and nitride deposition processes are very common in all aspects of silicon memory and logic manufacturing. These deposition processes are used in most all process nodes and both 200- and 300-mm wafer manufacturing. It is estimated that as many as 15% of the 150,000+ processing chambers in production are dedicated to silicon oxide and nitride deposition processes.

Converting the clean cycle of this process chamber to end point detection clean (from the more common fixed time clean) is a simple change, that the silicon industry can take today to reduce NF_3 clean gas emissions and increase process throughput. A win-win for sustainability and long-term cost savings for fab operators.