

AM0111

Large-scale Methodology

Abatement of fluorinated greenhouse gases in semiconductor manufacturing

Version 01.0.0

Sectoral scope(s): 04 and 09



United Nations
Framework Convention on
Climate Change

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1. Introduction

1. The following table describes the key elements of the methodology:

Table 1. Methodology key elements

Typical project(s)	This methodology is for project activities that install an abatement system in existing semiconductor manufacturing facilities for the abatement of fluorinated greenhouse gases (F-GHGs) emitted from semiconductor etching processes
Type of GHG emissions mitigation action	GHG destruction. Destruction of various fluorinated greenhouse gasses

2. Scope, applicability, and entry into force

2.1. Scope

2. This methodology is for project activities that install an abatement system in existing semiconductor manufacturing facilities for the abatement of F-GHGs emitted from semiconductor etching processes.

2.2. Applicability

3. The methodology is applicable under the following conditions:
 - (a) The methodology only applies to existing production lines with at least three years of historical information on F-GHG consumption and production of semiconductor substrate. The crediting period is limited to the remaining lifetime of the production lines existing at the time of validation of the project activity, estimated according to the “Tool to determine the remaining lifetime of equipment”;
 - (b) The F-GHGs emitted from the production lines have not been abated and have been vented in the last three years prior to implementation of the project activity before January 2012, and existing production lines do not have F-GHG-specific abatement devices¹ installed;
 - (c) F-GHGs are not temporarily stored or consumed for subsequent abatement;
 - (d) No law or regulation which mandates decomposition, abatement, recycling or substitution of F-GHGs exist in the host country and also no law prohibits installation and operation of abatement system for F-GHG;

¹ As opposed to non-F-GHG-specific abatement devices designed for the purpose of destroying substances other than F-GHGs (i.e. substances such as volatile organic compounds and silicon containing compounds (e.g. SiF₄)), but which may destroy part of the F-GHGs. To prevent any change in any incidental F-GHG abatement at existing non-F-GHG-specific abatement devices, the project proponents are required to document the operating conditions of the existing abatement devices prior to implementation of the project activity and shall be required to monitor these operating conditions during the crediting periods to ensure that these operating conditions are not modified in a way that may affect any incidental F-GHG destruction removal efficiency.

- (e) The F-GHG abatement should occur at the same industrial site where the F-GHGs are used; and the F-GHGs to be abated are not imported from other facilities;
 - (f) The measurements with respect to determining F-GHG flow to the abatement system are taken immediately before the abatement system, without any other devices located in between which are capable of changing the F-GHG flow through reaction, dilution, or decomposition;
 - (g) The maximum maximal treatment capacity of the abatement system is sized for the application in correlation to observed historical flow. The maximum maximal flow entering the abatement system, from all etch tools combined, is below the maximum maximal abatement capacity of the abatement system and the total flow of effluents (F-GHGs plus all other by-products and diluents) does not exceed the total outlet flow capacity of the abatement system;
 - (h) The applicability conditions of US EPA Methods 1 and 2 are satisfied, (i.e. the flow is not cyclonic or swirling and the stack has a diameter greater than 0.3 m or a cross section greater than 0.071m^2).
4. In addition, the applicability conditions included in the tools referred to below apply.
5. Finally, this methodology is only applicable if the baseline scenario is the continuation of the current situation, which is the continuation of the same baseline technology as used in the most recent three years prior to the implementation of the project activity and the venting of the F-GHG without abatement.

2.3. Entry into force

6. The date of entry into force is the date of the publication of the EB 70 meeting report on the 23 November 2012.

3. Normative references

7. This baseline and monitoring methodology is based on elements from the latest versions of the following approved baseline and monitoring methodologies:
- (a) “AM0078 Version 1.1 - Point of Use abatement Device to Reduce SF₆ emissions in LCD Manufacturing Operations, prepared by Climate Change Capital, LG International Corp., and Transcarbon International Corp.”;
 - (b) “AM0092 Version 1.0.0 – Substitution of PFC gases for cleaning Chemical Vapour Deposition (CVD) reactors in the semiconductor industry, prepared by Climate Change Capital, Global Foundries Inc., and Transcarbon International Corp.”;
 - (c) “AM0096 Version 1.0.0. - CF₄ emission reduction from installation of an abatement system in a semiconductor manufacturing facility, prepared by Samsung Electronics Co. Ltd, Environmental Resources Management (ERM), and Korea Research Institute of Standard and Science (KRISS)”.

8. This methodology also refers to the latest approved versions of the following tools, methods and guidelines:
- (a) “Combined tool to identify the baseline scenario and demonstrate additionality”;
 - (b) “Tool to estimate the baseline, project and/or leakage emissions from electricity consumption”;
 - (c) “Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion”;
 - (d) “Tool to determine the remaining lifetime of equipment”;
 - (e) “Assessment of the validity of the original/current baseline and update of the baseline at the renewal of the crediting period”;
 - (f) “US EPA Method 1 – Sample and velocity traverses for stationary sources”;
 - (g) “US EPA Method 2 – Determination of stack gas velocity and volumetric flow rate”;
 - (h) “US EPA Method 4 – Determination of moisture content in stack gases”;
 - (i) “US EPA Method 301 – Field validation of pollutant measurement methods from various waste media”;
 - (j) “US EPA Method 320 - Measurement of vapor phase organic and inorganic emissions by extractive FTIR spectroscopy”;
 - (k) ISMI's Guideline for Environmental Characterization of Semiconductor Process Equipment <<http://www.semtech.org/docubase/document/4825beng.pdf>>.

4. Definitions

9. The definitions contained in the “Glossary of CDM terms” shall apply.
10. For the purpose of this methodology, the following definitions apply:
- (a) **Destruction Removal Efficiency (DRE)** - The percentage fraction representing the removal efficiency of a particular compound through an abatement device;
 - (b) **Etching process** - A process using fluorinated greenhouse (F-GHG) gases disassociated by means of plasma to generate reactive species to selectively remove materials from a wafer as part of semiconductor manufacturing;
 - (c) **Fluorinated greenhouse gases (F-GHGs)** - CF₄, C₂F₆, CHF₃, CH₃F, CH₂F₂, C₃F₈, c-C₄F₈, and SF₆ gases used as precursors for etching processes in the semiconductor industry. Other F-GHGs may be included in the project activity as they become eligible under the Kyoto Protocol;
 - (d) **Fourier transform infrared (FTIR) spectrometer** - an analytical system that employs a source of mid-infrared radiation, an interferometer, an enclosed sample cell of known absorption path length, an infrared detector, optical elements that transfer infrared radiation between components, and a computer system. The time-domain detector response (interferogram) is processed by a

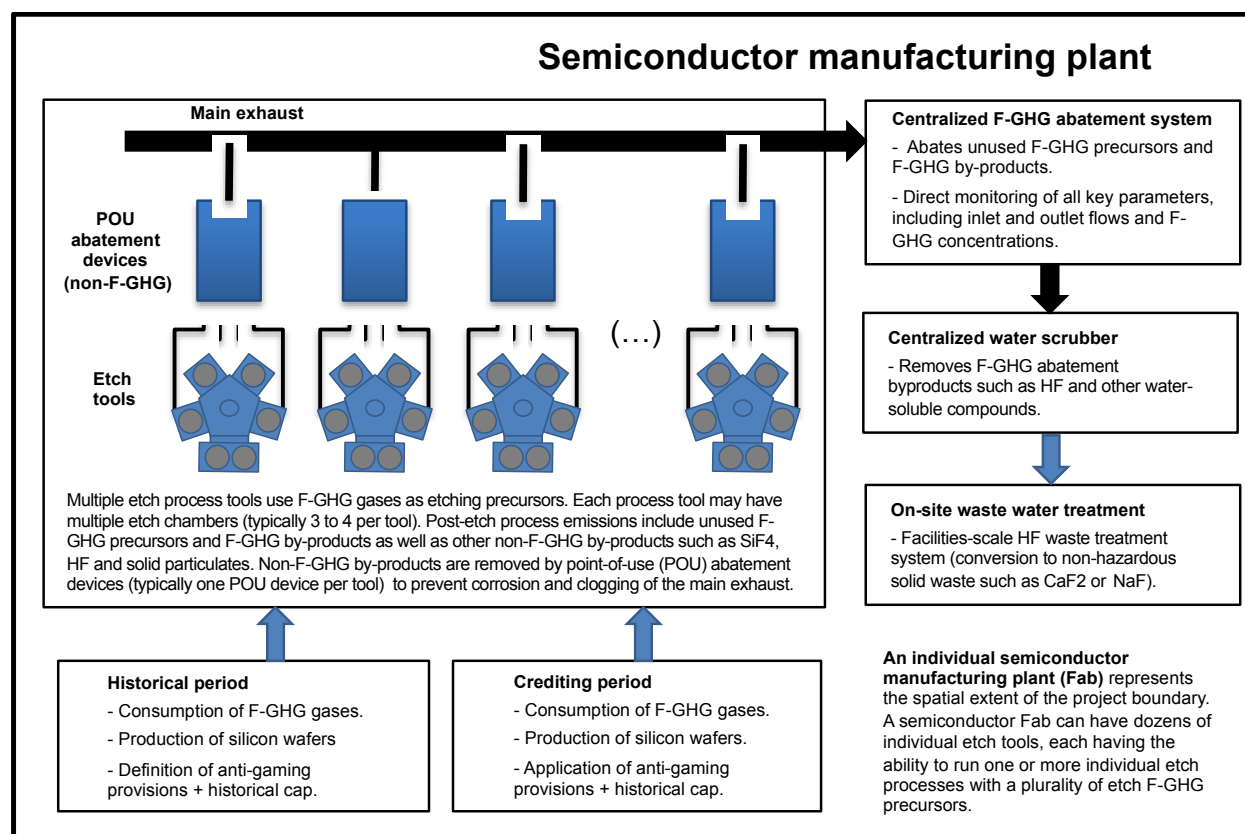
Fourier transform to yield a representation of the detector response vs. infrared frequency;

- (e) **Quadrupole Mass Spectrometer (QMS)** - An analytical system that ionizes the atoms or molecules to be quantified and separates these ionized species according to their mass to electrical charge ratio. After separation, the individual ionized species are collected using a Faraday cup or an electron multiplier.

5. Baseline methodology

5.1. Project boundary

11. Figure 1 presents the spatial extent of the project boundary, which encompasses the physical boundary of the particular semiconductor plant that is having its F-GHG emissions abated. Typically, a semiconductor plant can have 50 to over 100 individual etch tools, each having one or multiple etch chambers. Each etch chamber (reactor) uses one or more F-GHG(s) to perform an etching process to selectively remove materials from a wafer. The etching process is based on a chemical reaction where an F-GHG is disassociated by means of plasma to generate fluorine radicals that will react with the solid materials (e.g. SiO_2 , SiN) at the surface of the wafer to form volatile by-products (e.g. SiF_4) that are pumped away from the process chamber. During the process, undesirable corrosive by-products such as HF and COF_2 are also generated and solid particles may be formed.
12. Depending on the type of material to be removed and the specific requirements of the integrated circuit being manufactured, a semiconductor facility can have several hundred etching “recipes,” each corresponding to a prescribed combination of relevant process parameters such as pressure, temperature, gas flow, or plasma power. Greenhouse gas emissions result from etching processes because of the limited utilization efficiency of the F-GHG precursor(s) inside the chamber, and because of the formation of F-GHG by-products. For example, when C_2F_6 is used as a precursor, the plasma decomposition process will form CF_4 as a by-product. Depending on the process conditions, the F-GHG utilization efficiency typically ranges from 30 to 90 per cent while 7 to 40 per cent of the precursor gas can be transformed into other F-GHG by-products on a mass basis.
13. The project activity consists of installing a centralized abatement system to remove the unreacted F-GHG precursors and F-GHG by-products from the effluent stream, instead of venting them to atmosphere. The abatement system can destroy F-GHGs through high-temperature combustion or catalytic reactions that will break down the F-GHGs and generate by-products such as CO_2 , COF_2 , and HF . The water-soluble by-products of the combustion or catalytic reaction are then removed using a conventional (centralized) water scrubber. The resulting waste is then treated with a fluoride waste treatment system where the aqueous fluoride compounds are converted into an inert solid by-product such as NaF or CaF_2 .
14. During crediting periods, project participants will monitor F-GHG consumption and wafer production data as well as continuously measure the mass of F-GHGs entering and exiting the F-GHG abatement device to determine the baseline and project emissions, and calculate the emissions reductions.

Figure 1. Project boundaries for baseline and project scenarios

15. The greenhouse gases included in or excluded from the project boundary are shown in Table 2. Note that not all F-GHGs included in the list of Table 2 may necessarily be used by all semiconductor facilities. In this case, the PDD shall specify which gas(es) are not included in any particular project.

Table 2. Emissions sources included in or excluded from the project boundary

Source		Gas	Included?	Justification/Explanation
Baseline	F-GHGs that are partially used during the etch process or that are emitted as by-products	CF ₄	Yes	Precursor gas partially used during the etch process or emitted as by-product of the etch reaction
		C ₂ F ₆	Yes	Precursor gas partially used during the etch process or emitted as by-product of the etch reaction.
		CHF ₃	Yes	Precursor gas partially used during the etch process
		CH ₃ F	Yes	Precursor gas partially used during the etch process
		CH ₂ F ₂	Yes	Precursor gas partially used during the etch process
		C ₃ F ₈	Yes	Precursor gas partially used during the etch process or emitted as by-product of the etch reaction
		c-C ₄ F ₈	Yes	Precursor gas partially used during the etch process

Source		Gas	Included?	Justification/Explanation
		SF ₆	Yes	Precursor gas partially used during the etch process
Project activity	Unabated F-GHGs and CO ₂ emissions from abatement process	CF ₄	Yes	Gas not destroyed by abatement system
		C ₂ F ₆	Yes	Gas not destroyed by abatement system
		CHF ₃	Yes	Gas not destroyed by abatement system
		CH ₃ F	Yes	Gas not destroyed by abatement system
		CH ₂ F ₂	Yes	Gas not destroyed by abatement system
		C ₃ F ₈	Yes	Gas not destroyed by abatement system
		c-C ₄ F ₈	Yes	Gas not destroyed by abatement system
		SF ₆	Yes	Gas not destroyed by abatement system
		CO ₂	Yes	CO ₂ is generated as by-product of F-GHG abatement
	Fossil fuel consumption due to project activity	CO ₂	Yes	Resulting from combustion of fossil fuel used to operate the abatement technology
		CH ₄	No	Excluded for simplification. This emission source is assumed to be very small
		N ₂ O	No	Excluded for simplification. This emission source is assumed to be very small
	Electricity consumption due to the project activity	CO ₂	Yes	Resulting from electricity used to operate the abatement technology
		CH ₄	No	Excluded for simplification. This emission source is assumed to be very small
		N ₂ O	No	Excluded for simplification. This emission source is assumed to be very small

5.2. Selection of the baseline scenario and demonstration of additionality

5.2.1. Identification of the alternative scenarios

16. The selection of the baseline scenario shall be conducted using Step 1 (Identification of the alternative scenarios) of the latest version of the “Combined tool to identify the baseline scenario and demonstrate additionality” (hereinafter referred to as the “Combined tool”). The following additional guidance should be used when applying the tool:
17. The project proponents will identify all alternative scenarios that: (a) are available to the project proponents; (b) cannot be implemented in parallel to the proposed project activity; and (c) provide outputs or services with comparable quality, properties and application areas as the proposed CDM project activity. The alternative scenarios shall include:
 - (a) Undertaking this project using an abatement device without being registered as a CDM project activity;
 - (b) The continued venting of F-GHGs without any abatement (continuation of the current situation);
 - (c) Using etch gases other than F-GHGs;
 - (d) Process modifications/optimization to which reduce F-GHG emissions;
 - (e) Capture and recycling of unused F-GHGs at the outlet of the process chambers.

18. After listing these alternatives (and others if appropriate), the project developers shall take into account, according to Step 1b of the “Combined tool” all relevant national and/or sectoral policies and circumstances, and determine whether all alternatives are allowed under local laws. If the baseline scenario determination shows that two or more baseline scenarios are equally deemed ‘most probable’, then the scenario with the lowest level of emissions shall be considered the most plausible baseline scenario. This methodology is only applicable to project activities where continuing the use of F-GHGs without abatement is the most plausible baseline scenario.

5.2.2. Additionality

19. The demonstration of additionality shall be conducted using Steps 2-4 of the latest version of the “Combined tool”. The following additional guidance should be used when applying the tool:
20. In applying Step 2 of the “Combined tool” (Barrier Analysis), project proponents will identify barriers that may prevent alternative scenarios to occur, including investment barriers, first-of-a-kind, and technological barriers, and will eliminate alternative scenarios that are prevented by the identified barriers.
21. In applying Step 3 of the “Combined tool” (Investment Analysis), project proponents will compare the economic or financial attractiveness of the alternative scenarios remaining after Step 2. Each scenario should include in the financial indicator a calculation of all relevant costs and possible benefits, if any. These should include:
- (a) Capital costs for new equipment or equipment retrofits required;
 - (b) Operational costs (e.g. cost maintenance, utilities consumption and cost, monitoring costs, cost of additional labour);
 - (c) Other costs and benefits (if any) of the proposed project activity, both directly and indirectly. For example benefits derived from monitoring of the exhaust gas composition as means for improving process efficiency.
22. As part of the financial analysis, the project proponents will include a sensitivity analysis to assess whether the conclusions regarding the financial attractiveness is robust to reasonable variations in the critical assumptions.
23. When applying Step 4 of the “Combined tool” (Common practice analysis), the project proponents shall demonstrate that the proposed project activity has not already diffused in the semiconductor industry in the relevant geographic area.

5.3. Baseline emissions

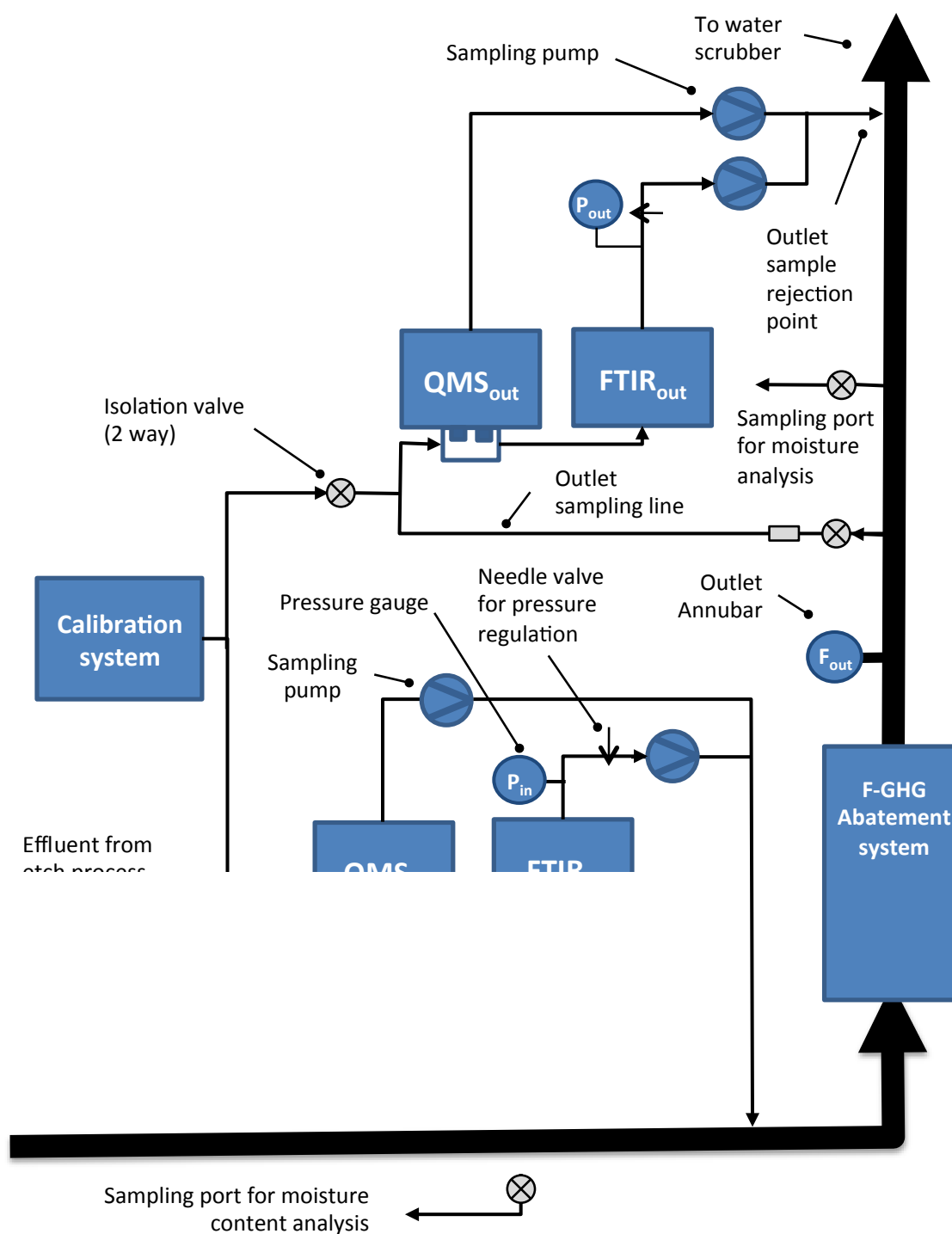
24. Prior to implementation of the project activity, participants will record the consumption of F-GHGs, the production of silicon wafers, and will estimate the plant’s CO₂-equivalent emissions using the IPCC Tier 2b methodology for the historical period, which is three calendar years prior to the beginning of the project. Participants will then calculate the historical emissions intensity of the manufacturing plant (in kgCO₂e per m² of wafers produced), which will serve as a cap to compensate for increases in emissions intensity during the crediting years. Further, the historical consumption of each F-GHG shall be used as a cap to prevent baseline emissions increase above the historical baseline.

5.3.1. Experimental setup for determination of emissions

The experimental setup used for the determination of the mass of F-GHGs emitted at the inlet and outlet of the abatement system is depicted in Figure 2. The setup includes both FTIR and QMS. While FTIR is used to measure the concentrations of F-GHGs at the inlet and outlet of the abatement system, QMS is used to identify the effluent components that are not detectable by FTIR² and to determine the molecular weight of the inlet and outlet effluents. Measurement of the molecular weights of the inlet and outlet gases is necessary for the calculation of the flows, which are derived from measurements of the gas velocities using annubar devices. Note that the setup of Figure 2 is only used during commissioning of the abatement system (initial evaluation period at project start-up) and during annual surveillance tests. A different setup (using only FTIR) is used for continuous monitoring purposes.

² Experimental setup used for commissioning of the F-GHG abatement system and during annual surveillance tests to determine emissions.

Figure 2. Experimental setup used for commissioning of the F-GHG abatement system and during annual surveillance tests to determine emissions



5.3.2. Calculation of baseline emissions

25. Baseline emissions are obtained by multiplying emissions of each eligible F-GHG i ($E_{i,in,y}$) by the appropriate global warming potential for that gas, and summing up emissions of each eligible F-GHG during crediting year y . A discount factor compensates for increase in the emissions intensity of the manufacturing plant:

$$BE_y = MS_q \times k \times \sum_i E_{i,in,y} \times GWP_i \quad \text{Equation (1)}$$

Where:

BE_y	=	Baseline emissions in year y (t CO ₂ e)
k	=	Discount factor to account for emissions intensity changes of the manufacturing plant (fraction)
$E_{i,in,y}$	=	Eligible mass of F-GHG i entering the abatement system in year y (tonnes)
GWP_i	=	Global warming potential of F-GHG i (t CO ₂ e per t of gas i)
MS_q	=	Market share of baseline technology (Uses of F-GHGs in etching processes) (Fraction)

5.3.3. Discount factor to account for emissions intensity changes of the manufacturing plant

26. Baseline emissions shall be discounted in case actual emission intensity of the plant would exceed the historical emissions intensity of the manufacturing plant during the crediting year. The historical emissions intensity of the manufacturing plant (E_{hist}), calculated as the average emissions intensity for the three calendar years preceding implementation of the project activity. To calculate the emission intensity of the plant, the CO₂-equivalent emissions of the plant shall be calculated during each historical year and divided by the surface area of 'good' wafers (i.e. not including scrap wafers) produced during the corresponding historical year. Emissions shall be estimated by multiplying the consumption of each F-GHG i included in the project boundary by the default emission factors of the IPCC Tier 2b methodology (factoring in a default heel of 10 per cent, and the default utilization efficiencies and by-products formation factors for each F-GHG i),³ and multiplying the result by the relevant GWP factors to convert emissions in CO₂-equivalent. The CO₂-e contribution of each unused F-GHG i and each F-GHG by-product will then be added to estimate the total CO₂-equivalent emissions of the plant. During the crediting period, the actual consumption of each GHG-G i and the actual production of good wafers during each crediting year shall be monitored. From this data, the actual emission intensity of the manufacturing plant during the year shall be calculated, using the same methodology used for the historical period (i.e. the IPCC Tier 2b methodology). If, during any crediting year, the emissions intensity of the plant exceeds its average historical emissions intensity, any emissions due to the increase in emissions intensity shall be discounted. Thus, the discount factor k shall be calculated as follows:

³ See Table 6.3 of the IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3, Chapter 6.

$$k = \min\{1; EI_{hist}/EI_y\} \quad \text{Equation (2)}$$

Where:

k	= Discount factor to account for emissions intensity changes of the manufacturing plant (fraction)
EI_{hist}	= Historical emissions intensity of manufacturing plant (kgCO ₂ e/m ²)
EI_y	= Emissions intensity of manufacturing plant in crediting year y (kgCO ₂ e/m ²)

$$EI_{hist} = 0.9 \times \frac{\sum_{i,hist} C_{i,hist} \times GWP_i \times EF_i}{SP_{hist}} \quad \text{Equation (3)}$$

Where:

EI_{hist}	= Historical emissions intensity of manufacturing plant (kgCO ₂ e/m ²)
GWP_i	= Global warming potential of F-GHG i (t CO ₂ e per t of F-GHG i)
$C_{i,hist}$	= Historical consumption of F-GHG i (kg)
EF_i	= Default emission factors of the IPCC Tier 2b methodology
SP_{hist}	= Historical production of semiconductor (m ²)
0.9	= Default heel factor

$$EI_y = \frac{\sum_i GWP_i \times E_{i,in,y}}{SP_y} \quad \text{Equation (4)}$$

Where:

EI_y	= Emissions intensity of manufacturing plant in crediting year y (kgCO ₂ e/m ²)
GWP_i	= Global warming potential of F-GHG i (t CO ₂ e per t of F-GHG i)
$E_{i,in,y}$	= Mass of F-GHG i exiting the abatement system in year y (t)
SP_y	= Production of semiconductor in crediting year y (m ²)

5.3.4. Calculation of eligible mass of F-GHG entering the abatement system during year y ($E_{i,in,y}$)

27. The mass of F-GHG i entering the abatement system in year y ($E_{i,in,y}$) is calculated by summing up emissions of that gas for each monitoring interval p . The monitoring interval is essentially driven by the response time of the FTIR systems, and represents the interval during which the concentration of F-GHGs and other relevant parameters (e.g. flow rate, temperature, pressure) are being measured. For example, if the FTIR provides one data point every minute, then the duration of each monitoring interval p equals 60 seconds, and therefore crediting year y consists of 525,600 monitoring intervals. For

an interval p to be counted as part of the baseline emissions, emissions must be eligible, subject to a cap in consumption for each F-GHG i in monitoring interval p ($CAP_{i,p}$):

$$E_{i,in,y} = \sum_p CAP_{i,p} \times E_{i,in,p} \times 10^{-6} \quad \text{Equation (5)}$$

Where:

$E_{i,in,y}$	= Eligible mass of F-GHG i entering the abatement system in year y (tonnes)
$CAP_{i,p}$	= Cap in baseline consumption of F-GHG i (0 or 1)
$E_{i,in,p}$	= Emissions of F-GHG i entering the abatement device during monitoring interval p (g)
p	= Monitoring interval in the crediting year y

5.3.5. Procedure to address the possibility of increase of baseline consumption

28. Baseline emissions are capped based on the historical consumption of each F-GHGs included in the project activity ($C_{i,hist}$), calculated as the average consumption of each F-GHG i during the three years preceding implementation of the project activity. During the project activity, the consumption of each F-GHG i used shall be monitored as precursor for the etch processes. If, at any point during a crediting year (i.e. for each monitoring interval p), the consumption of each F-GHG i exceeds the historical consumption, any emission reductions associated with F-GHG i above the baseline consumption shall be discounted from the calculation of emission reductions. Thus, the consumption cap factor $CAP_{i,p}$ shall be calculated as follows:

$$CAP_{i,p} = \begin{cases} 1 & \text{if } C_{i,p} \leq C_{i,hist} \times CF \\ 0 & \text{if } C_{i,p} > C_{i,hist} \times CF \end{cases} \quad \text{Equation (6)}$$

Where:

$CAP_{i,p}$	= Cap in baseline consumption of F-GHG i (0 or 1)
$C_{i,p}$	= Consumption of F-GHG i in monitoring interval p (g)
$C_{i,hist}$	= Historical consumption of F-GHG i (kg)
CF	= Consumption factor, adjusting from the length of historical data to the length of interval p ($s \cdot g \cdot s^{-1} \cdot kg^{-1}$)

29. If the lengths of the measured and the historical monitoring interval are not identical, $C_{i,hist}$ shall be adjusted accordingly.

5.3.6. Determination of emissions of F-GHG entering the abatement device

30. The mass of F-GHG i entering the abatement device during monitoring interval p is calculated as follows:

$$E_{i,in,p} = A_i \times Q_{in,p} \times [FGHG_{i,in,p}] \quad \text{Equation (7)}$$

Where:

$E_{i,in,p}$	= Emissions of F-GHG i entering the abatement device during monitoring interval p (g)
A_i	= Conversion factor to convert $\text{ppm-m}^3/\text{sec}$ to g for F-GHG i ⁴
$Q_{in,p}$	= Volumetric flow rate at the inlet of the abatement system during monitoring interval p (m^3/s)
$[FGHG_{i,in,p}]$	= Concentration of F-GHG i at the inlet of the abatement system during monitoring interval p (ppmv)

5.3.7. Determination of $[FGHG_{i,in,p}]$

31. The concentration of F-GHG i at the inlet of the abatement system ($[FGHG_{i,in,p}]$) is determined using FTIR spectroscopy. A method for the calibration of FTIR devices and for validating the measurement of $[FGHG_{i,in,p}]$ in accordance with US EPA Method 320 is described in the monitoring procedure. Note that $[FGHG_{i,in,p}]$ is measured continuously.

5.3.8. Determination of $Q_{in,p}$

32. The total flow of gas at the inlet of the abatement system during monitoring interval p ($Q_{in,p}$) is determined by measuring the gas velocity with the inlet annubar device. The calculation of the flow from the velocity measurements in equations 8-11 follows US EPA Methods 1, 2, and 4.⁵

$$Q_{in,p} = \left(\frac{100 - B_{w,in}}{100} \times v_{in,p} \times S_{in} \times \frac{T_{std} \times P_{in,p}}{T_{in,p} \times P_{std}} \right) \quad \text{Equation (8)}$$

Where:

$Q_{in,p}$	= Volumetric flow rate at the inlet of the abatement system during monitoring interval p (m^3/s)
$B_{w,in}$	= Water vapour in the inlet gas stream measured in accordance with US EPA Method 4 (percentage volume fraction)
$v_{in,p}$	= Inlet gas velocity during monitoring interval p (m/s)
S_{in}	= Cross-sectional area of the inlet stack (m^2)
T_{std}	= Standard absolute temperature (293K)

⁴ The conversion factor is obtained by dividing the molar mass of gas i (e.g. 88g/mole for CF_4 , 138g/mole for C_2F_6 , 146g/mol for SF_6) by its molar volume at zero degrees Celsius and one atmosphere (22.4 l/mole), and multiplying the result by 10^{-3} (e.g. $A_{\text{CF}_4} = 3.929 \times 10^{-3}$, $A_{\text{C}_2\text{F}_6} = 6.161 \times 10^{-3}$, $A_{\text{SF}_6} = 6.518 \times 10^{-3}$).

⁵ Project participants may propose revisions for the methodology to apply other nationally- or internationally-recognized standards such as ISO 5167.

P_{std}	=	Standard absolute pressure ($\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-2}$)
$P_{in,p}$	=	Absolute inlet stack pressure during monitoring interval p (mm Hg)
$T_{in,p}$	=	Absolute inlet stack temperature during monitoring interval p (K)

5.3.9. Determination of $v_{in,p}$

33. In accordance with US EPA Method 2, the inlet stack gas velocity during monitoring period p ($v_{in,p}$) are calculated as follows:

$$v_{in,p} = K \times C_{in} \times \sqrt{p_{in,p}} \times \sqrt{\frac{T_{in,p}}{P_{in,p} \times M_{w,in} \times 10^3}} \quad \text{Equation (9)}$$

Where:

$v_{in,p}$	=	Inlet gas velocity during monitoring interval p (m/s)
K	=	Velocity equation constant (=34.97)
C_{in}	=	Inlet annubar device coefficient (dimensionless)
$p_{in,p}$	=	Inlet velocity head measurement across the annubar device during monitoring interval p ($\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-2}$)
$T_{in,p}$	=	Absolute inlet stack temperature during monitoring interval p (K)
$P_{in,p}$	=	Absolute inlet stack pressure during monitoring interval p (mm Hg)
$M_{w,in}$	=	Total wet stack gas molecular weight at the inlet of the abatement system (kg/mole)

34. Note that $v_{in,p}$ is measured continuously.

5.3.10. Determination of $M_{w,in}$

35. The total (wet) stack gas molecular weight at the inlet of the abatement system ($M_{w,in}$) is calculated in accordance with US EPA Method 2.

$$M_{w,in} = M_{d,in} \times \frac{100 - B_{w,in}}{100} + 0.18 \times B_{w,in} \quad \text{Equation (10)}$$

Where:

$M_{w,in}$	=	Total wet stack gas molecular weight at the inlet of the abatement system (kg/mole)
$M_{d,in}$	=	Total dry stack gas molecular weight at the inlet of the abatement system (kg/mole)
$B_{w,in}$	=	Water vapour in the inlet gas stream measured in accordance with US EPA Method 4 (percentage volume fraction)

36. Note that the determination of $M_{w,in}$ is only done at commissioning of the abatement systems and during annual verification tests.

5.3.11. Determination of $M_{d,in}$

37. To determine the total dry stack molecular weight at the inlet of the abatement system, FTIR and QMS shall be used to identify the components (j) of the inlet stack gas.⁶ The determination of $M_{d,in}$ will only be done at commissioning of the abatement systems and during annual verification tests. The procedures for calibration of the FTIR and QMS system are presented below. The concentration of each gas component j shall be measured during a minimum of six hours and $M_{d,in}$ is calculated as follows:

$$M_{d,in} = \sum_j m_j \times [X_j] \quad \text{Equation (11)}$$

Where:

$M_{d,in}$	=	Total dry stack gas molecular weight at the inlet of the abatement system (g/mole)
m_j	=	Molecular weight of gas component j in the inlet stack (g/mole)
$[X_j]$	=	Concentration of gas component j in the inlet stack as determined by QMS (ppmv)

38. If inlet stack gas components j other than those listed in footnote 6 are present at the inlet of the abatement system at concentrations greater than 1,000ppmv, their contribution to the total inlet gas dry molecular weight shall be accounted for. If some of the stack gas components j listed above are not present in the exhaust at concentrations of greater than 1,000ppmv, then their contribution to the total inlet gas dry molecular weight may be ignored.
39. During the six hours measurement period, it shall be demonstrated that the molecular weight of the inlet stack gas does not vary by more than +/-5 per cent around the average value, using a 95 per cent confidence interval. As a conservative measure, the inlet gas molecular weight ($M_{d,in}$) shall be recorded as the highest value recorded during the six hours period. This is conservative because a high inlet gas molecular weight leads to an underestimation of the baseline emissions.

5.4. Project emissions

40. Project emissions include:
- (a) F-GHGs not destroyed by the abatement system;
 - (b) CO₂ generated as a by-product of the abatement of F-GHGs;

⁶ The following list of potential stack gas components shall be targeted: $j = \text{N}_2, \text{Ar}, \text{O}_2, \text{CO}, \text{CO}_2, \text{COF}_2, \text{SOF}_2, \text{SO}_2\text{F}_2, \text{SO}_2, \text{SiF}_4, \text{HF}, \text{F}_2, \text{OF}_2, \text{Cl}_2, \text{BCl}_3, \text{HCl}, \text{SiCl}_4, \text{CCl}_4, \text{CHCl}_3, \text{AlCl}_3, \text{Br}_2, \text{HBr}, \text{SiBr}_4, \text{CF}_4, \text{C}_2\text{F}_4, \text{C}_2\text{F}_6, \text{CHF}_3, \text{CH}_3\text{F}, \text{CH}_2\text{F}_2, \text{C}_3\text{F}_8, \text{c-C}_4\text{F}_8, \text{NF}_3, \text{SF}_6, \text{C}_4\text{F}_6, \text{C}_5\text{F}_8 \text{ and } \text{C}_4\text{F}_8\text{O}$ (Note: this list of potential gas components was derived from ISMI's Guideline for Environmental Characterization of Semiconductor Process Equipment – Revision 2 (Technology Transfer #06124825B-ENG, available at <www.semtech.org>).

- (c) CO₂ resulting from the combustion of fossil fuel in the abatement system;
 - (d) CO₂ resulting from electricity usage during operation of the abatement system.
41. Project emissions shall be evaluated for all greenhouse gasses and not only for those eligible under the Kyoto Protocol.
42. Project emissions are calculated as follows:

$$PE_y = \sum_i E_{i,out,y} \times GWP_i + PE_{CO_2,y} + PE_{FC,y} + PE_{EC,y} \quad \text{Equation (12)}$$

Where:

PE_y	=	Project emissions in year y (t CO ₂ e)
GWP_i	=	Global warming potential of F-GHG i (t CO ₂ e per t of F-GHG i)
$E_{i,out,y}$	=	Mass of F-GHG exiting the abatement system in year y (t)
$PE_{CO_2,y}$	=	Project emissions due to CO ₂ generated as a by-product of the abatement of F-GHGs in year y (t CO ₂ e)
$PE_{FC,y}$	=	Project emissions due to fossil fuel combustion in year y (t CO ₂ e)
$PE_{EC,y}$	=	Project emissions due to electricity consumption in year y (t CO ₂ e)

5.4.1. Calculation of mass of F-GHG exiting the abatement system during year y ($E_{i,out,y}$)

43. The mass of F-GHG i contributing to project emissions during year y is calculated by summing up the mass of F-GHG i emitted during each monitoring interval p :

$$E_{i,out,y} = \sum_p E_{i,out,p} \times 10^{-6} \quad \text{Equation (13)}$$

Where:

$E_{i,out,y}$	=	Mass of F-GHG i exiting the abatement system in year y (t)
$E_{i,out,p}$	=	Mass of F-GHG i exiting the abatement system in interval p (g)

44. Determination of emissions of F-GHG exiting the abatement device ($E_{i,out,p}$)
45. The mass of F-GHG i exiting the abatement device during monitoring interval p is calculated as follows:

$$E_{i,out,p} = A_i \times Q_{out,p} \times [FGHG_{i,out,p}] \quad \text{Equation (14)}$$

Where:

$E_{i,out,p}$	= Emissions of F-GHG i exiting the abatement device during monitoring interval p (g)
A_i	= Conversion factor to convert $\text{ppm}\cdot\text{m}^3/\text{sec}$ to g for F-GHG i ⁷
$Q_{out,p}$	= Volumetric flow rate at the outlet of the abatement system during monitoring interval p (m^3/s)
$[FGHG_{i,out,p}]$	= Concentration of F-GHG i at the outlet of the abatement system during monitoring interval p (ppmv)

5.4.2. Determination of $[FGHG_{i,out,p}]$

46. The concentration of F-GHG i at the outlet of the abatement system ($[FGHG_{i,out,p}]$) is determined using FTIR spectroscopy. A method for the calibration of FTIR devices and for validating the measurement of $[FGHG_{i,out,p}]$ in accordance with US EPA Method 320 is described in the monitoring procedure. Note that $[FGHG_{i,out,p}]$ is measured continuously.

5.4.3. Determination of $Q_{out,p}$

47. The total flow of gas at the outlet of the abatement system during monitoring interval p ($Q_{out,p}$) is determined by measuring the gas velocity with the outlet annubar device. The calculation of the flow from the velocity measurements in equations 8-11 follows US EPA Methods 1, 2, and 4.⁸

$$Q_{out,p} = \left(\frac{100 - B_{w,out}}{100} \times v_{out,p} \times S_{out} \times \frac{T_{std} \times P_{out,p}}{T_{out,p} \times P_{std}} \right) \quad \text{Equation (15)}$$

Where:

$Q_{out,p}$	= Volumetric flow rate at the outlet of the abatement system during monitoring interval p (m^3/s)
$B_{w,out}$	= Water vapour in the outlet gas stream measured in accordance with US EPA Method 4 (percentage volume fraction)
$v_{out,p}$	= Outlet gas velocity during monitoring interval p (m/s)
S_{out}	= Cross-sectional area of the outlet stack (m^2)
T_{std}	= Standard absolute temperature (293K)
P_{std}	= Standard absolute pressure ($\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-2}$)

⁷ The conversion factor is obtained by dividing the molar mass of gas i (e.g. 88g/mole for CF_4 , 138g/mole for C_2F_6 , 146g/mole for SF_6) by its molar volume at zero degrees Celsius and one atmosphere (22.4 l/mole), and multiplying the result by 10^{-3} (e.g. $A_{\text{CF}_4} = 3.929 \times 10^{-3}$, $A_{\text{C}_2\text{F}_6} = 6.161 \times 10^{-3}$, $A_{\text{SF}_6} = 6.518 \times 10^{-3}$).

⁸ Project participants may propose revisions for the methodology to apply other nationally- or internationally-recognized standards such as ISO 5167.

$P_{out,p}$	=	Absolute outlet stack pressure during monitoring interval p (mm Hg)
$T_{out,p}$	=	Absolute outlet stack temperature during monitoring interval p (K)

5.4.4. Determination of $v_{out,p}$

48. In accordance with US EPA Method 2, the outlet stack gas velocity during monitoring period p ($v_{out,p}$) are calculated as follows:

$$v_{out,p} = K \times C_{out} \times \sqrt{p_{out,p}} \times \sqrt{\frac{T_{out,p}}{P_{out,p} \times M_{w,out} \times 10^3}} \quad \text{Equation (16)}$$

Where:

$v_{out,p}$	=	Outlet gas velocity during monitoring interval p (m/s)
K	=	Velocity equation constant (=34.97)
C_{out}	=	Outlet annubar device coefficient (dimensionless)
$p_{out,p}$	=	Out velocity head measurement across the annubar device during monitoring interval p ($\text{kg} \cdot \text{m}^{-1} \cdot \text{s}^{-2}$)
$T_{out,p}$	=	Absolute outlet stack temperature during monitoring interval p (K)
$P_{out,p}$	=	Absolute outlet stack pressure during monitoring interval p (mm Hg)
$M_{w,out}$	=	Total wet stack gas molecular weight at the outlet of the abatement system (kg/mole)

49. Note that $v_{out,p}$ is measured continuously.

5.4.5. Determination of $M_{w,out}$

50. The total (wet) stack gas molecular weight at the outlet of the abatement system ($M_{w,out}$) is calculated in accordance with US EPA Method 2:

$$M_{w,out} = M_{d,out} \times \frac{100 - B_{w,out}}{100} + 0.18 \times B_{w,out} \quad \text{Equation (17)}$$

Where:

$M_{w,out}$	=	Total wet stack gas molecular weight at the outlet of the abatement system (kg/mole)
$M_{d,out}$	=	Total dry stack gas molecular weight at the outlet of the abatement system (kg/mole)
$B_{w,out}$	=	Water vapour in the outlet gas stream measured in accordance with US EPA Method 4 (percentage volume fraction)

51. Note that the determination of $M_{w,out}$ is only done at commissioning of the abatement systems and during annual verification tests.

5.4.6. Determination of $M_{d,out}$

52. To determine the total dry stack molecular weight at the outlet of the abatement system, FTIR and QMS shall be used to identify the components (j) of the inlet stack gas.⁹ The determination of $M_{d,out}$ will only be done at commissioning of the abatement systems and during annual verification tests. The procedures for calibration of the FTIR and QMS system are presented below. The concentration of each gas component j shall be measured during a minimum of six hours and $M_{d,out}$ is calculated as follows:

$$M_{d,out} = \sum_{j'} m_{j'} \times [X_{j'}] \quad \text{Equation (18)}$$

Where:

$M_{d,out}$	=	Total dry stack gas molecular weight at the outlet of the abatement system (g/mole)
$m_{j'}$	=	Molecular weight of gas component j' in the outlet stack (g/mole)
$[X_{j'}]$	=	Concentration of gas component j' in the outlet stack as determined by QMS (ppmv)

53. If outlet stack gas components j' other than the listed ones are present at the inlet of the abatement system at concentrations greater than 1,000ppmv, their contribution to the total inlet gas dry molecular weight shall be accounted for. If some of the stack gas components j' listed are not present in the exhaust at concentrations of greater than 1,000ppmv, then their contribution to the total inlet gas dry molecular weight may be ignored.
54. During the six hours measurement period, it shall be demonstrated that the molecular weight of the outlet stack gas does not vary by more than +/-5 per cent around the average value, using a 95 per cent confidence interval. As a conservative measure, the outlet gas molecular weight ($M_{d,out}$) shall be recorded as the highest value recorded during the six hours period. This is conservative because a high outlet gas molecular weight leads to an underestimation of the baseline emissions.

5.4.7. Determination of project emissions due to CO₂ emitted as by-product of the abatement of F-GHGs ($PE_{CO_2,y}$)

55. The emissions of CO₂ generated as a by-product of the abatement process result from the conversion of $C_xF_yH_z$ molecules into CO, CO₂, COF₂, F₂, and HF. For simplification and conservativeness, it is assumed that all the carbon contained in the $C_xF_yH_z$ molecules is removed in the form of CO₂. The emissions of CO₂ generated as a by-product of the abatement process are calculated as follows:

⁹ The following list of potential stack gas components shall be targeted: $j = N_2, Ar, O_2, CO, CO_2, COF_2, SOF_2, SO_2F_2, SO_2, SiF_4, HF, F_2, OF_2, Cl_2, BCl_3, HCl, SiCl_4, CCl_4, CHCl_3, AlCl_3, Br_2, HBr, SiBr_4, CF_4, C_2F_4, C_2F_6, CHF_3, CH_3F, CH_2F_2, C_3F_8, c-C_4F_8, NF_3, SF_6, C_4F_6, C_5F_8$ and C_4F_8O (Note: this list of potential gas components was derived from ISMI's Guideline for Environmental Characterization of Semiconductor Process Equipment – Revision 2 (Technology Transfer #06124825B-ENG, available at <www.semtech.org>).

$$PE_{CO_2,y} = \sum_i \frac{(E_{i,in,y} - E_{i,out,y}) \times Z_i \times m_{CO_2}}{m_i} \quad \text{Equation (19)}$$

Where:

$PE_{CO_2,y}$	=	Project emissions due to CO ₂ generated as a by-product of the abatement of F-GHGs in year y (t CO ₂ e)
$E_{i,in,y}$	=	Mass of F-GHG i entering the abatement system in year y (t)
$E_{i,out,y}$	=	Mass of F-GHG i exiting the abatement system in year y (t)
Z_i	=	Number of carbon atoms in molecule of F-GHG i (integer)
m_{CO_2}	=	Molecular weight of carbon dioxide (44 g/mole)
m_i	=	Molecular weight of F-GHG i (g/mole)

5.4.8. Determination of project emissions due to fossil fuel combustion

56. Project emissions from fossil fuel combustion in the abatement system ($PE_{FC,y}$) shall be calculated using the latest approved version of the “Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion”. Consumption of fossil fuels by the abatement system shall be monitored continuously.

5.4.9. Determination of project emissions due to electricity consumption

57. Project emissions from electricity consumption by the abatement system ($PE_{EC,y}$) shall be calculated using the latest version of the “Tool to calculate baseline, project and/or leakage emissions from electricity consumption”. Consumption of electricity by the abatement system shall be monitored continuously.

5.5. Leakage

58. No leakage emissions are foreseen under the project activity.

5.6. Emission reductions

59. Emission reductions are calculated as follows:

$$ER_y = BE_y - PE_y \quad \text{Equation (20)}$$

Where:

ER_y	=	Emission reductions in year y (t CO ₂ e)
BE_y	=	Project emission in year y (t CO ₂ e)
PE_y	=	Project emissions in year y (t CO ₂ e)

5.7. Changes required for methodology implementation in 2nd and 3rd crediting periods

60. Refer to the latest approved version of the tool “Assessment of the validity of the original/current baseline and update of the baseline at the renewal of the crediting period”.

5.8. Data and parameters not monitored

61. In addition to the parameters listed here, the provisions on data and parameters not monitored in the tools referred to in this methodology apply.

Data / Parameter table 1.

Data / Parameter:	GWP_i
Data unit:	t CO ₂ e per t of F-GHG <i>i</i>
Description:	Global warming potentials of F-GHG <i>i</i>
Source of data:	IPCC
Measurement procedures (if any):	Project participants shall update GWPs according to the latest values approved by the COP/MOP
Any comment:	-

Data / Parameter table 2.

Data / Parameter:	S_{in}
Data unit:	m ²
Description:	Cross sectional area of the inlet stack
Source of data:	EPA Method 1 or similar nationally- or internationally-recognized standard
Measurement procedures (if any):	Measured prior to validation, during commissioning of the abatement system
Any comment:	Should be greater than 0.3 m in diameter or 0.071m ² for EPA Method 1 to apply

Data / Parameter table 3.

Data / Parameter:	S_{out}
Data unit:	m ²
Description:	Cross sectional area of the outlet stack
Source of data:	EPA Method 1 or similar nationally- or internationally-recognized standard
Measurement procedures (if any):	Measured prior to validation, during commissioning of the abatement system
Any comment:	Should be greater than 0.3 m in diameter or 0.071m ² for EPA Method 1 to apply

Data / Parameter table 4.

Data / Parameter:	OP_{abatement,hist}
Data unit:	List of operating conditions of any non-F-GHG-specific abatement system installed prior to implementation of the project activity
Description:	Temperature, utilities settings (water, fuel, electricity, purges), and flow conditions for any non-F-GHG-specific abatement device installed prior to implementation of the project activity
Source of data:	-
Measurement procedures (if any):	None
Any comment:	Should be greater than 0.3 m in diameter or 0.071m ² for EPA Method 1 to apply

Data / Parameter table 5.

Data / Parameter:	SP_{hist}
Data unit:	m ²
Description:	Historical production of semiconductor
Source of data:	Production and inventory records
Measurement procedures (if any):	Production based on calendar year
Any comment:	-

6. Monitoring methodology

6.1. Archival of monitoring information

62. All data collected as part of monitoring should be archived electronically and be kept at least for two years after the end of the last crediting period. One hundred per cent of the data should be monitored if not indicated otherwise in the tables below.

6.2. Monitoring and QA/QC information

63. In the CDM-PDD, project proponents have to provide information concerning the system in place to ensure the quality of the data. It should include the actions to be undertaken to constitute and to maintain the needed measurement equipment to satisfy the requirements concerning the quality of the data:
- (a) The inventory, identification and the description of the measurement equipment used;
 - (b) The description of the QA/QC procedures for monitoring;
 - (c) The organizational structure and the responsibilities;
 - (d) The calibration and verification of the measurement equipment;

- (e) The connecting of standard equipment to data logging devices;
- (f) The process of recording data entries.

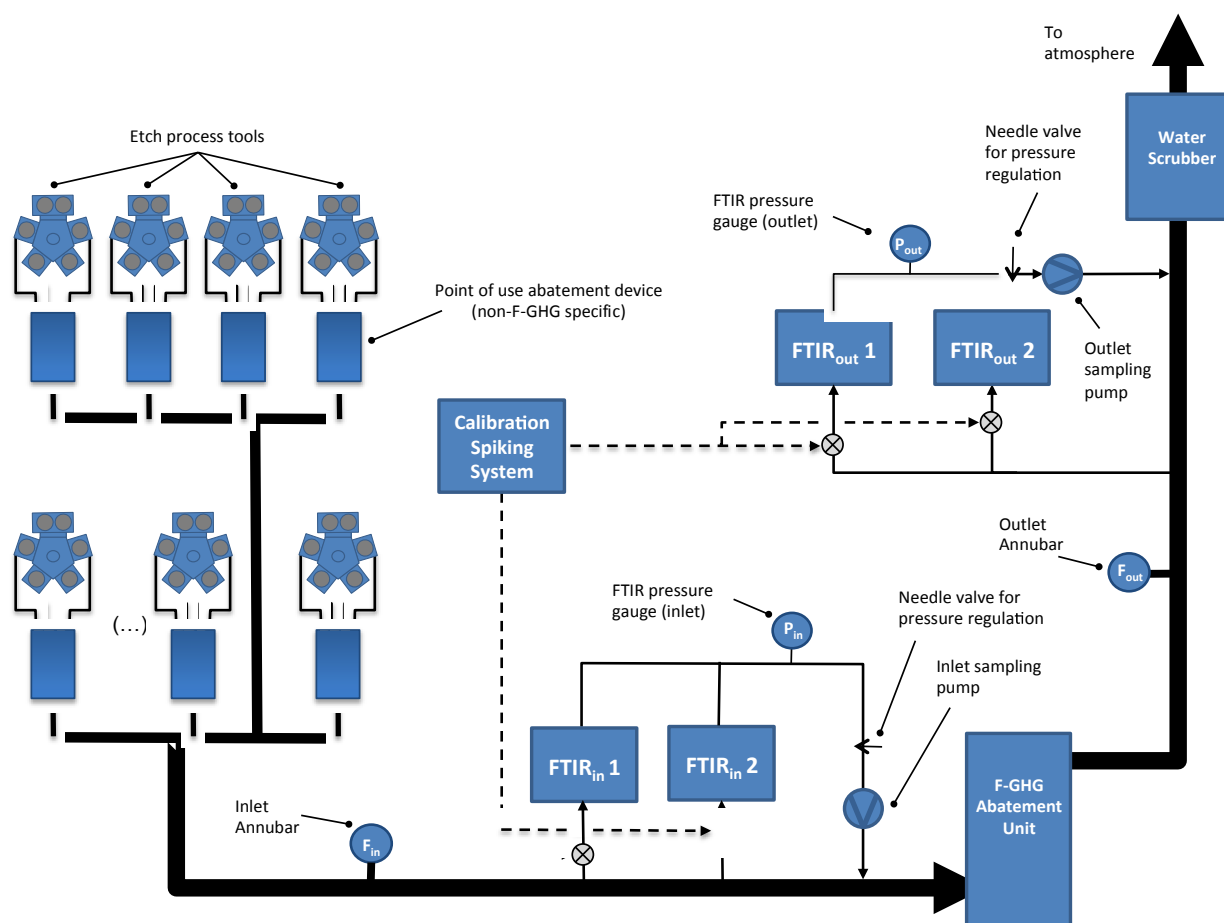
6.3. Monitoring provisions in the CDM tools

64. The monitoring provisions in the tools referred to in this methodology apply.

6.4. Experimental setup for the monitoring methodology

65. The monitoring methodology will require the project developer to continuously measure all key parameters concerning the operation of the abatement tool and measurement of the baseline and project emissions. A schematic description of the monitoring setup is provided in Figure 3.

Figure 3. Schematic description of the treatment and monitoring setup



66. Under the monitoring procedure, one (of optionally two) FTIR system(s) shall be used to continuously monitor the concentration of F-GHGs at the inlet of the abatement system, while an annubar device shall be used to monitor the inlet gas velocity. One (of optionally two) other FTIR system(s) and one separate annubar device shall be used to continuously monitor the concentration of F-GHGs at the outlet. Using two FTIR units at

the inlet and two at the outlet is recommended due to the dynamic nature of the effluents and for redundancy, in particular during maintenance and calibration activities. When using redundant FTIRs (two at the inlet and two at the outlet), one of the two shall be used for the measurement and deemed 'primary' while the other shall be in standby and deemed 'secondary.' Upon occurrence of an event requiring maintenance of the primary FTIR, the secondary unit shall be switched to operational mode to become the primary unit. A detailed description of the experimental protocol and of the calibration and method validation procedures is provided.

67. The mass of each F-GHG entering and exiting the abatement device, and the inlet and outlet flows shall be calculated continuously (for each monitoring interval p), according to equations 7, 14, 8, and 15 respectively. All other parameters necessary to calculate the emissions baseline and the project emissions (fuel and electricity usage) shall be monitored on a continuous basis. All measurements should be conducted with calibrated measurement equipment according to relevant industry standards, or as described further below.

6.4.1. Commissioning and annual verification tests

68. Note that the experimental setup described in Figure 3 is different from the experimental setup described in Figure 2. While the setup of Figure 3 is used for continuous monitoring of the inlet and outlet gas flows and for continuous measurement of the inlet and outlet F-GHG concentrations during crediting periods, the setup described in Figure 2 is only used for commissioning of the abatement system and during annual surveillance tests. Thus, the setup of Figure 2 is only used once a year to characterize and verify the measurement of the inlet and outlet gas molecular weights through the use of the QMS systems.

6.4.2. Calibration of the FTIR systems

69. A calibration system shall be used periodically to ensure that the calibration of the FTIR systems has not drifted. Two types of calibration procedures shall be used to calibrate the FTIR units: (1) a "full range" calibration followed by a validation procedure done in accordance with EPA Method 320 shall be used at commissioning of the abatement system and during annual verification tests to calibrate the FTIR systems over the entire range of F-GHG concentrations to be measured at the inlet and the outlet of the abatement system, and (2) a "spiked" calibration, also performed in accordance with US EPA Method 320, shall be used to recalibrate the FTIR units whenever the abatement device is brought offline for maintenance or whenever the FTIR units themselves are brought offline for maintenance during a crediting period. A detailed description of the FTIR calibration and measurement validation procedures is provided.

6.4.3. Calibration of the annubar devices

70. Following US EPA Methods 1 and 2, the project developer should document for the validator the selection of sampling ports and traverse points at which sampling for F-GHGs will occur in the inlet and outlet stacks, ensuring that the flow at the inlet and outlet of the abatement system is not cyclonic or swirling. Additionally, the project developer should document for the validator the use of equipment and testing methods required by US EPA Methods 1 and 2: annubar devices should be used to measure the inlet and outlet flow velocities; two differential pressure gauges should be used to measure the static and the impact pressures in the inlet and outlet stacks; two

temperature sensors should be used to compensate for deviation from standard temperature conditions; and a barometer should be used as a reference to measure actual atmospheric pressure.

6.5. General QA/QC, maintenance and repair provision

71. The project participants shall ensure that the QA/QC, maintenance, and repair procedures of the monitoring and abatement equipment are followed at least as often as the manufacturer's recommendation or as prescribed in this methodology. The project participants shall document and present the maintenance requirements of the monitoring and abatement equipment to the validator and shall ensure that they have been followed in at least as rigorous a manner as required. Further, the project proponent should record any failure or maintenance procedures that might affect the calculation of the baseline and project emissions. For example, any failures or maintenance activities resulting in downtime (or bypassing) of the abatement device shall be recorded, and the mass of F-GHG entering and exiting the abatement system during such failures or maintenance activities shall be discounted from the calculation of emissions reduction. In the case monitoring systems are redundant (e.g. FTIR units), the project participants will still be required to record any failure or maintenance of any of the redundant systems, but discounting of emissions reduction during maintenance or repair of one of the systems is not required unless both systems fail.

6.5.1. QA/QC procedure for the maintenance of the FTIR systems

72. To detect eventual drifts in the FTIR systems' calibration due to coating of the FTIR windows, the project participants will perform periodic calibrations of the FTIR systems using the "spiked" calibration procedure described below. If a deviation in calibration of greater than 5 per cent is detected (compared to the previous calibration), the project participant shall be required to clean or replace the FTIR windows and to repeat the spiked calibration procedure to ensure that the calibration performed during the commissioning or annual verification test is still valid. The minimum frequency for the cleaning or replacement of the FTIR windows shall be recorded as a non-monitored parameter.

6.5.2. QA/QC procedure for the maintenance of the annubar devices

73. The project developer will follow the QA/QC procedures highlighted in US EPA Methods 1, 2, and 4, including adequate proof that the openings of the annubar devices have not plugged up during the measurement period. This can be accomplished by comparing the velocity measurement before and after back-purging the annubar devices with pressurized air to clean them. If the before and after velocity measurements are within 5 per cent, then the data is acceptable. If the back-purging methodology is insufficient to ensure the annubar devices cleanliness (measurements are not within 5 per cent), the project developer will determine a minimum maintenance frequency and procedure to manually clean the annubar devices. For the avoidance of doubt, the minimum manual maintenance frequency shall be determined to ensure that the before and after purge velocities measured at the inlet and outlet annubar devices do not drop by more than 5 per cent between the annubar devices cleaning procedures. The project developer will record the maintenance schedule as a non-monitored parameter.

6.6. Data and parameters monitored

6.6.1. Project emissions

Data / Parameter table 6.

Data / Parameter:	$B_{w,in}$
Data unit:	Percentage volume fraction
Description:	Water vapour in the inlet gas stream measured in accordance with US EPA Method 4
Source of data:	-
Measurement procedures (if any):	EPA Method 4, as determined by measurement of volume or mass. This measurement shall be done for a minimum of six hours during normal manufacturing conditions
Monitoring frequency:	Annual
QA/QC procedures:	See EPA Method 4
Any comment:	-

Data / Parameter table 7.

Data / Parameter:	$[FGHG_{i,in,p}]$
Data unit:	ppmv
Description:	Concentration of F-GHG i at the inlet of the abatement system during monitoring interval p
Source of data:	Inlet FTIR system
Measurement procedures (if any):	Conversion of FTIR absorbance to concentration based on calibration results.
Monitoring frequency:	Continuous
QA/QC procedures:	-
Any comment:	-

Data / Parameter table 8.

Data / Parameter:	$p_{in,p}$
Data unit:	$kg \cdot m^{-1} \cdot s^{-2}$
Description:	Inlet velocity head measurement across the annubar device during monitoring interval p
Source of data:	Annubar device
Measurement procedures (if any):	See EPA Method 2 or similar nationally – or internationally-recognized standard

Monitoring frequency:	Continuous
QA/QC procedures:	-
Any comment:	-

Data / Parameter table 9.

Data / Parameter:	P_{in,p}
Data unit:	mmHg
Description:	Absolute inlet stack pressure during monitoring interval <i>p</i>
Source of data:	Pressure gauge
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	See EPA Method 2 or similar nationally- or internationally-recognized standard. The inlet pressure gauge shall be calibrated and maintained per the manufacturer's instructions
Any comment:	-

Data / Parameter table 10.

Data / Parameter:	T_{in,p}
Data unit:	K
Description:	Absolute inlet stack temperature during monitoring interval <i>p</i>
Source of data:	Thermocouple
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	See EPA Method 2. The inlet temperature gauge shall be calibrated and maintained per the manufacturer's instructions
Any comment:	-

Data / Parameter table 11.

Data / Parameter:	B_{w,out}
Data unit:	Water vapour in the outlet gas stream measured in accordance with US EPA Method 4
Description:	Water vapour in the outlet gas stream
Source of data:	-
Measurement procedures (if any):	EPA Method 4, as determined by measurement of volume or mass. This measurement shall be done for a minimum of six hours during normal manufacturing conditions

Monitoring frequency:	Annual
QA/QC procedures:	See EPA Method 4
Any comment:	-

Data / Parameter table 12.

Data / Parameter:	Z_i
Data unit:	Integer
Description:	Number of carbon atoms in molecule of F-GHG i
Source of data:	Type of F-GHG i included in the project activity
Measurement procedures (if any):	None
Monitoring frequency:	Annual
QA/QC procedures:	Cross-check with gas purchase records
Any comment:	-

Data / Parameter table 13.

Data / Parameter:	$[FGHG_{i,out,p}]$
Data unit:	ppmv
Description:	Concentration of F-GHG i at the outlet of the abatement system during monitoring interval p
Source of data:	Outlet FTIR system
Measurement procedures (if any):	Conversion of FTIR absorbance to concentration based on calibration results.
Monitoring frequency:	Continuous
QA/QC procedures:	-
Any comment:	-

Data / Parameter table 14.

Data / Parameter:	$p_{out,p}$
Data unit:	$kg \cdot m^{-1} \cdot s^{-2}$
Description:	Outlet velocity head measurement across the annubar device during monitoring interval p
Source of data:	Annubar device
Measurement procedures (if any):	See EPA Method 2 or similar nationally – or internationally-recognized standard

Monitoring frequency:	Continuous
QA/QC procedures:	-
Any comment:	-

Data / Parameter table 15.

Data / Parameter:	P_{out,p}
Data unit:	mmHg
Description:	Absolute outlet stack pressure during monitoring interval <i>p</i>
Source of data:	Pressure gauge
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	-
Any comment:	-

Data / Parameter table 16.

Data / Parameter:	T_{out,p}
Data unit:	K
Description:	Absolute outlet stack temperature during monitoring interval <i>p</i>
Source of data:	Thermocouple
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	See EPA Method 2. The inlet temperature gauge shall be calibrated and maintained per the manufacturer's instructions
Any comment:	-

Data / Parameter table 17.

Data / Parameter:	OP_{abatement,y}
Data unit:	List of operating conditions of any non-F-GHG-specific abatement system operated during year <i>y</i>
Description:	Temperature, utilities settings (water, fuel, electricity, purges), and flow conditions for any non-F-GHG-specific abatement device installed prior to implementation of the project activity and operated during year <i>y</i>
Source of data:	Abatement system actual settings during year <i>y</i>
Measurement procedures (if any):	None

Monitoring frequency:	-
QA/QC procedures:	-
Any comment:	-

Data / Parameter table 18.

Data / Parameter:	SP_y
Data unit:	m ²
Description:	Production of semiconductor product in crediting year y
Source of data:	Production records
Measurement procedures (if any):	None
Monitoring frequency:	Annual
QA/QC procedures:	Cross-check with inventory records
Any comment:	-

Data / Parameter table 19.

Data / Parameter:	MS_q
Data unit:	Ratio (Fraction)
Description:	Market share of baseline technology (Uses of gases in semiconductor industries)
Source of data:	Independent publications or survey
Measurement procedures (if any):	<p>Semiconductor plants within the applicable geographic area, as identified according to the “Combined tool” and with a comparable capacity from 50 per cent to 150 per cent of semiconductors produced (surface area of substrate produced in m²) shall be evaluated for the technology (uses of gases like C₂F₆ etc.). This will be done based on the latest available data on every 7th year and 14th year for the project activities which have applied for renewable of crediting period. The parameter shall be the fraction of semiconductor plants which are using the gases (C₂F₆ etc.); which are used in the baseline of registered project activity, excluding activities implemented as a CDM project activity to the total semiconductor plants in the relevant geographical area</p> <p>1. The maximum values of MS_q should be used: 7th year onwards: (MS_q value from 7th year market survey; 0.6) 14th year onward: (MS_q value from 14th year market survey; 0.2)</p>

Monitoring frequency:	-
QA/QC procedures:	The maximum values of MS_q should be used
Any comment:	-

74. Note: in addition to the monitored parameters listed above, the data and parameters necessary to calculate the project's CO₂ emissions from fossil fuel combustion and to calculate project's emissions due to consumption of electricity by the abatement system will also be monitored. Please see the "Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion," and the "Tool to calculate baseline, project and/or leakage emissions from electricity consumption" for more details.

Appendix 1. Experimental protocols

1. Introduction

1. This appendix further specifies the experimental protocols and guides the project participants in the measurements of the baseline and project emissions. In particular, this appendix describes the experimental procedures for the sampling of effluents, the calibration of the FTIR (Fourier Transform Infrared) and QMS (Quadrupole Mass Spectrometer) equipment, the validation of EPA Method 320, and the maintenance and QA/QC procedures. Project participants should refer to the various tools and methods mentioned in section I of the methodology (Sources), but when a provision of these methods conflict with the present methodology, the latter prevails.

2. Safety

2. The measurement of effluents involves handling of toxic and hazardous gases, liquids and solid materials, and other electrical and mechanical hazards. It is the responsibility of the project participants to ensure that all experimental conditions meet the local safety standards, codes, and regulations. In particular, all sampling lines, fittings, and equipment should be tested for leaks. Proper personal protection equipment (PPE) should be worn at all times.

3. Experimental setup, effluents sampling and conditioning

3. Figures 2 and 3 of the methodology depict the experimental setups for the measurement of the effluents. The setup of Figure 2 is used during commissioning of the abatement system and during annual surveillance tests. The setup of Figure 3 is used during the crediting periods to characterize the project emissions continuously. The primary difference between the two setups is that Quadrupole Mass Spectroscopy is required for commissioning and annual verification to measure the inlet and outlet gas molecular weight, while QMS is not required during regular monitoring.
4. The sampling lines used to draw a small portion of the inlet/outlet effluents should include a micron-size filter between the sampling point and the analytical systems to ensure that solid particles emitted from the process do not coat the FTIR windows or the QMS sampling train. In cases where the etch deposition chemistry leads to formation of vapour-phase solid by-products, such reaction may coat the windows of the FTIR system and lead to attenuation of the measurement signal or background interferences. Minor background interferences can be corrected by collecting a new background, but instances where deviations greater than ± 5 per cent in an analytical region are unacceptable (see EPA Method 320 section 3.10). When such greater than ± 5 per cent deviations are encountered the project developer will be required to clean or replace the FTIR windows and to repeat the "spiked" calibration procedure described in this appendix. Recalibration of the FTIR devices will also be required every time the abatement device is brought offline for maintenance or every time the FTIR devices themselves are brought offline for maintenance. The minimum frequency for the cleaning or replacement of the FTIR windows will be recorded as a non-monitored parameter.

5. Flow meters (not shown on Figure 2 and 3) should be used to measure the flow of gas in the sampling lines, which should be maintained at a minimum of 1 slm. The pressure in the effluent lines and FTIR cells should be regulated using a needle valve - or preferably an automated throttle valve - at approximately 700 Torrs (93.326 kPa), or slightly below atmospheric pressure. The base pressure in the QMS' quadrupole sections shall be able to reach a minimum of 10^{-6} Torrs (1.3×10^{-4} kPa). The temperature of the FTIR cells and of the QMS inlets should be maintained at a regulated temperature of 110C or above to prevent water vapour condensation. The FTIR systems should be operated at 1 cm^{-1} resolution or better and proper cell lengths should be used to ensure that the absorbance signals fall between 0.1 and 1.

4. "Full range" FTIR systems calibration

6. A "full range" calibration of the FTIR systems should be performed at commissioning of the abatement and monitoring systems and once a year during the annual verification test. This procedure will be performed using a standalone dynamic dilution calibration system equipped with at least two calibrated mass flow controllers (MFCs). The project participants should ensure that the calibration range encompasses the entire range of concentrations (cmin to cmax) for each gas 'i' that can be expected at the inlet and at the outlet of the abatement device (two separate ranges).
7. Preferably, project proponents should use calibration standards accurate to within +/-2 per cent, but chemical standards may be prepared by diluting certified commercially prepared chemical gases or pure analytes with ultra-pure carrier grade nitrogen (see EPA method 320, FTIR protocol section 4.6.2.2). For each gas to be quantified, a range of concentrations will be generated by mixing the gas standard with ultra-pure nitrogen for each gas included in the project boundary. Rather than using gas standards with a single gas mixed with nitrogen, it is also possible to use gas mixtures (i.e. a specially manufactured gas standard with a mix of CF_4 , C_2F_6 , SF_6 ... of known concentrations).
8. For each gas 'i' to be quantified and each measurement point (before and after the abatement system), the project participants will generate a calibration curve with a minimum of five (5) distinct calibration points and plot the FTIR absorbance as a function of the gas concentration (see Figure 1). For each calibration point, the operator should ensure that the FTIR signal has reached a steady state. For the mid-range concentration point ($c_{\text{mid}} = (c_{\text{min}} + c_{\text{max}})/2$), the experiment should be repeated at least five times by turning the calibration gas' mass flow controller ON and OFF.
9. The operator should calculate the standard deviation associated with the FTIR absorbance, and ensure that it is below 5 per cent.
10. The standard deviations (σ) should be calculated as follows:

$$\sigma = \sqrt{\frac{\sum_{j=0}^n (I_j - \bar{I})^2}{(n - 1)}} \quad \text{Equation (1)}$$

Where:

- I_j = The FTIR absorbance recorded for the mid-range concentration point (absorbance unit)
- n = The total number of experimental points being recorded by flowing the gas at constant concentration (mid concentration value), and by turning the MFC ON and OFF between each recording ($n \geq 5$)

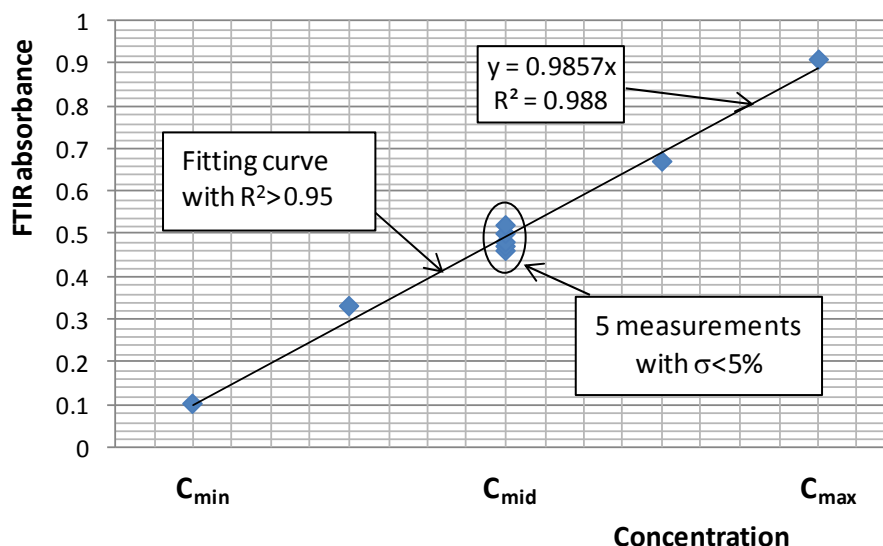
11. After completion of the calibration procedure, the operator should fit the experimental data points of FTIR absorbance versus gas concentrations with linear curves (or other suitable fitting curves). The fitting procedure should use the least squares method to determine the best fit between the experimental data and the calibration curve. Specifically, the sum of the squared residuals should be minimized, the residuals being defined as the difference between an observed value and the value given by the model. The operator should ensure that an R^2 value of greater than 0.95 is obtained between the fitting curve and the experimental points. To ensure that no gas flow or concentration is recorded when no F-GHG is present at the measurement point, the calibration curves' intercept will be forced to zero (i.e. the calibration curve should provide an intensity reading of zero when no gas is flown in or out of the abatement device). For each fitting curve, the R^2 values are calculated as follows:

$$R^2 = \left(\frac{\sum_{j=0}^n (x_j - \bar{x})(y_j - \bar{y})}{\sqrt{\sum_{j=0}^n (x_j - \bar{x})^2 \sum_{j=0}^n (y_j - \bar{y})^2}} \right)^2 \quad \text{Equation (2)}$$

Where:

- x_j = Concentration of gas generated for each point (j) of the calibration curve (ppmv)
- y_j = FTIR absorbance signal intensity recorded for each point (j) of the calibration curve (absorbance unit)
- n = Total number of calibration points

12. An example of an FTIR calibration curve is given in Figure 1 below:

Figure 1. Example of FTIR calibration curve

5. EPA Method 320 validation procedure

13. In addition to the “full range” calibration procedure described above, project participants shall validate the measurement system according to EPA method 320 during commissioning of the abatement and measurement system and during annual verification tests. A validation run consists of at least 24 measurements of independent samples, half spiked and half not spiked. Independent spiked samples are defined as two samples separated by at least 5 FTIR cell volumes. A validation test shall be performed for each F-GHG ‘i’ included as part of the project activity, and for the median concentration determined in the full range calibration procedure.
14. Under the validation procedure, the spike gas is introduced at the back of FTIR sample probes at a continuous and constant flow rate while the probes sample the native analytes (i.e. the effluents at the inlet and outlet of the abatement sample), under flow conditions identical to those used during continuous monitoring. The spike flow shall be less than 10 per cent of the total native analyte flow. Both the sample and the spike flows shall be measured using flow meters (not shown on figures 2 or 3) having a precision of at least ± 2 per cent. For the validation procedure, it is desirable to use two FTIR systems to perform synchronized measurements of spiked and unspiked samples, particularly for analytes that vary rapidly over time (otherwise, it may be difficult to meet the validation performance requirements).
15. The analyte concentrations in the spiked samples shall be compared to the expected spike concentration, calculated from the measurement of the spiked flow and of the sample flow. Since the concentration of the spike is known, this procedure can be used to determine if the sampling system is removing the spiked analytes from the sample stream. Also, it is possible to calculate if any bias is introduced by the method. Project participants shall calculate the value of the bias according to EPA Method 301 (section 6.3.2) using the following equation:

$$B = S_m - M_m - CS \quad \text{Equation (3)}$$

Where:

B	=	Bias at the spike level
S_m	=	Mean of the spiked samples
M_m	=	Mean of the unspiked samples
CS	=	Calculated value of the spiked level

16. If it is determined that the bias is significant according to section 6.3.2.2 of EPA Method 301, then project participant shall use section 6.3.3 of Method 301 to calculate a correction factor (CF) using the following equation:

$$CF = \frac{1}{1 + \frac{B}{CS}} \quad \text{Equation (4)}$$

Where:

F	=	Correction factor
B	=	Bias at the spike level
CS	=	Calculated value of the spiked level

17. If CF is outside the range of 0.70 to 1.30, the data and method are considered unacceptable, and the project participants should evaluate the sampling system, instrument configuration, and analytical system to determine if improper setup or malfunction was the cause. If so, the project participants shall repair the system and repeat the validation. For correction factors within the range, all analytical results obtained for each gas i from application of the calibration curves determined under the full range calibration should be multiplied by the correction factor.

6. “Spiked” FTIR systems calibration

18. A “spiked” calibration shall be performed every time after the abatement system or the FTIR units are brought offline for maintenance or any other reason. The purpose of the spiked calibration is for quality assurance to ensure that calibration of the FTIR units has not drifted over time, and to ensure that the applicability conditions of EPA method 320 are met, without having to repeat the lengthy full range calibration and validation procedures. The spiked calibration shall be done using a CF_4 standard¹⁰ where the spike gas is introduced in the same manner as for the validation test discussed above, at the median concentration value determined in the full range calibration procedure.
19. Spectra of at least three independent spiked samples shall be recorded. The analyte concentrations in the spiked samples shall be compared to the expected spike

¹⁰ CF_4 was chosen for spiked calibrations because it lies in the middle of the IR spectral range where other F-GHGs also absorb infrared radiations and because it is the main by-product of the decomposition of most F-GHG precursors.

concentration, calculated from the measurement of the spiked flow and of the sample flow. Since the concentration of the spike is known, this procedure can be used to determine if the sampling system is removing the spiked analytes from the sample stream. If the average spiked concentration is within ± 5 per cent of the mid-range concentration determined in the validation test, then the measurement system is deemed calibrated and the calibration curves determined during commissioning or the annual verification tests may be used, corrected by the correction factor as necessary. If not, a full range calibration and validation test shall be redone.

7. QMS calibration

20. Calibration of the QMS systems should be performed for both mass locations and response to analytes.
21. A calibration mixture of 1 per cent He, Ar, Kr and Xe can be used to ensure calibration of the QMS for both low and high atomic mass numbers. The calibration mixture shall be diluted with nitrogen to generate a concentration range falling within the range of concentrations that can be expected at the measurement point.
22. The project participants should generate a calibration curve with a minimum of five distinct calibration points and plot the QMS signal intensity as a function of the gas concentration. For each calibration point, the operator should ensure that the QMS signal has reached a steady state for a minimum of two minutes. For the mid-range concentration point ($c_{mid} = (c_{min} + c_{max})/2$), the experiment should be repeated at least five times by turning the calibration gas' mass flow controller ON and OFF.
23. The operator should calculate the standard deviation associated with the QMS signal intensity, and ensure that it is below 5 per cent.
24. Following the calibration procedure, the project proponent should plot a calibration curve similar to Figure 1 (replacing the FTIR absorbance by the QMS signal intensity) and fit the experimental points with a linear curve (or other suitable curve) using the least square method, setting the intercept to zero and ensuring that the R^2 value is greater than 0.95.

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