Draft baseline and monitoring methodology AM00XX

"CF_4 emission reduction from installation of an abatement system in a semiconductor manufacturing facility"

I. SOURCE, DEFINITIONS AND APPLICABILITY

Sources

This baseline and monitoring methodology is based on elements from the following proposed new methodology:

- NM0332 "PFCs emission reduction from installation of an abatement device in a semiconductor manufacturing facility" prepared by Samsung Electronics Co., Ltd, Environmental Resources Management (ERM) and Korea Research Institute of Standard and Science (KRISS).

This methodology also refers to the latest approved versions of the following tools:

- Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion;
- Tool to calculate baseline, project and/or leakage emissions from electricity consumption;
- Combined tool to identify the baseline scenario and demonstrate additionality;
- Tool to assess the validity of the original/current baseline and to update the baseline at the renewal of a crediting period (This tool is an annex to the "Procedures for renewal of the crediting period of a registered CDM project activity").

For more information regarding the proposed new methodologies and the tools as well as their consideration by the Executive Board please refer to <http://cdm.unfccc.int/goto/MPappmeth>.

Selected approach from paragraph 48 of the CDM modalities and procedures

"Existing actual or historical emissions, as applicable".

Definitions

For the purpose of this methodology, the following definitions apply:

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. The resulting current is proportional to the concentration of detected species in an effluent sample. The QMS allows to identify the type of species present in an effluent stream and to analyze their time dependency, including the partial pressure of type of species presented.

Stable Chemical Species. A chemical species that has no interference with the reaction occurred and is indestructible inside the scrubber (For example, Helium and Krypton).

Etching process. A process in semiconductor manufacturing where thin film on wafers are removed. In semiconductor manufacturing, a process known as dry etching is commonly used, where fluorinated gases are used.

Applicability

This methodology applies to project activities that installs a catalytic oxidation unit (abatement system) in existing semiconductor manufacturing facility for the abatement of CF_4 from semiconductor etching process. This methodology is only applicable for abatement of CF_4. Any other use of etching gas is not allowed under this methodology.

The methodology is applicable under the following conditions:

- The methodology only applies to existing production lines with at least three years information of CF_4 purchased and inventory and production of semiconductor substrate by 31 January 2010. The crediting period is limited to the remaining lifetime of the production lines existing at the time of validation of the project activity;
- The CF_4 emitted from the production lines has not been abated in the last three years prior to implementation of the project activity, and existing production lines do not have CF_4 abatement device installed;
- CF_4 is not temporarily stored or consumed for subsequent abatement;
- The CF_4 emitted from the production lines was being vented to the atmosphere in the last three years prior to implementation of the project activity;
- No law or regulation which mandates decomposition, abatement, recycling or substitution of CF_4 or any component of exhaust gases containing CF_4 exist in the host country;
- The CF_4 abatement should occur at the same industrial site where the CF_4 is used; and CF_4 to be abated is not imported from other facilities;
- The measurements with respect to determining CF_4 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 CF_4 flow through reaction, dilution or decomposition;
- The maximum treatment capacity of the abatement system is sized for the application in correlation to observed historical flow. The maximum CF_4 flow entering the abatement system, from all chambers combined, is below the maximum CF_4 abatement capacity of the abatement system and the total flow of effluents (CF_4 plus all other by-products and diluents) does not exceed the total flow capacity of the abatement system;
- It is demonstrated by test data by the technology provider or the project participants that the abatement system does not generate known non-CO_2 greenhouse gas such as fluoro-compounds, including non-Kyoto-Protocol gases, at detection levels; and
- This methodology, in its present form, is not applicable to project activities which reduce emissions of PFCs from Chemical Vapour Deposition (CVD) processes.
- The facility has obtained necessary permits concerning health and safety in order to install and operate the abatement system and monitoring facilities;

In addition, the applicability conditions included in the tools referred to above apply.

Finally, this methodology is only applicable if the most plausible baseline scenario, as identified per the section “Selection of the baseline scenario and demonstration of additionality” hereunder, is B2: continuation of current practice (direct venting of waste CF_4).

II. BASELINE METHODOLOGY PROCEDURE

Project boundary

The **spatial extent** of the project boundary encompasses the semiconductor manufacturing facility where the CF_4 emission is to be abated. The project boundary is illustrated as below:

- The etching exhausting gas within the semiconductor manufacturing facility; and
- CF_4 abatement system.

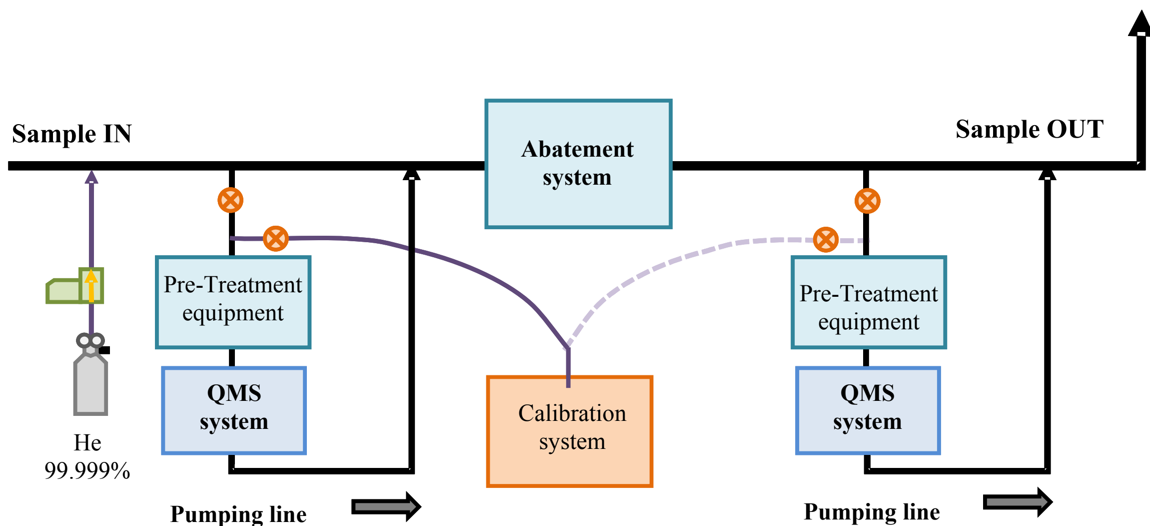

Figure 1: Project Boundary

The project boundary will cover from the effluent waste gas coming out of the etching process (sample in) to the outlet gas coming out of the abatement facility (sample out) as shown in figure 1.

In the etching process, the dry etch process uses etching gases such as Cl_2, BCl_3, CF_4, CHF_3, NF_3, SF_6, CH_3F, C_4F_6 to etch away a selective previous webbing (i.e. Si, SiO_2, Si_3N_4). Etching gases are supplied from cylinders located in a designated gas storage and supply area to a production line.

CF_4 is purchased in metal cylinders and transported into the designated area where they are connected to the gas supply pipelines to the etch process chambers. The pressure of the CF_4 gas is continuously monitored by the automatic gas supply system. Once the amount of gas in the cylinder reaches 10% (according to IPCC Guideline) of the original amount, the solenoid valve of the supply pipeline connected to the cylinder is automatically closed and the solenoid valve connected to the new cylinder is opened.

There are currently hundreds of etch process chambers for one production line. Exposure time for CF_4 gas varies by the product type, substrate type as well as the manufacturers of the etch process chambers.

When a semiconductor substrate needs a certain period of exposure time to CF_4 gas, the semiconductor substrate will be put into the chamber by a robot and the solenoid valve installed for each chamber will be opened to allow the CF_4 gas to flow in. The radio frequency (RF) power inside the etch process chamber will be turned on to transform the CF_4 gas into a plasma state to allow the etching process to take place. Once the desired exposure time is reached, the mass flow controller (MFC) will be closed to stop exposure to the CF_4 gas and the semiconductor substrate is moved outside of the etch process chamber by a robot.

The wasted etchant gas will be entered to the abatement system for the destruction process. A sample of such gas, together with the selected inert gas, will be captured to measure the concentration. The amount of CF_4 that is not being destroyed by the abatement system will be fed out from the system.

The greenhouse gases included in or excluded from the project boundary are shown in Table 1.

Table 1: Emissions sources included in or excluded from the project boundary

Source		Gas	Included?	Justification / Explanation
Baseline	Gases that are not destroyed or transformed in the etching process and vented out directly to the atmosphere	CF_4	Yes	This is the primary gas which will be abated in the project scenario
Project activity	Unabated CF_4 and CO_2 emissions	CO_2	Yes	Resulting from Electricity and other fuels used to in the abatement technology, together with CO_2 generated from oxidation of CF_4 within the abatement system ($CF_4 + 2H_2O \text{-->} CO_2 + 4HF$)
		CF_4	Yes	Amount of CF_4 not destroyed by the abatement system
	Electricity consumption due to the project activity	CO_2	Yes	May be an important emission source
		CH_4	No	Excluded for simplification. This emission source is assumed to be very small
		N_2O	No	Excluded for simplification. This emission source is assumed to be very small
	Fossil fuel consumption due to the project activity	CO_2	Yes	May be an important emission source
		CH_4	No	Excluded for simplification. This emission source is assumed to be very small
		N_2O	No	Excluded for simplification. This emission source is assumed to be very small

Selection of the baseline scenario and demonstration of additionality

The selection of the baseline scenario and the demonstration of additionality should be conducted using the latest version of the “Combined tool to identify the baseline scenario and demonstrate additionality”. The following additional guidance should be used when applying the tool.

When applying “Sub-step 1a” of the tool, alternative scenarios should include all realistic and credible alternatives to the project activity that are consistent with current laws and regulations of the host country.

The following likely scenarios shall be assessed, *inter alia*:

B1: Abatement through catalytic oxidation system (the proposed project activity), undertaken without being registered as a CDM project activity;

B2: Continuation of current practice (direct venting of waste CF_4);

B3: Abatement through other technologies such as fuelled burner-scrubber unit, electrically heated thermal-scrubber unit or atmospheric / compact plasma unit;

B4: Process optimisation (monitoring and minimising the use of CF_4 consumption in the process);

B5: Alternative etch chemistries (replacement of high-GWP gases with lower or non-GWP gases used in the process);

B6: Capture/recovery of the CF_4 emitted from the process.

When applying "Step 3" of the tool (Investment Analysis), the following guidance should be followed:

Each scenario should include in the financial indicator a calculation of all relevant cost and possible benefits, if any. These should include, if relevant (but are not limited to):

- Cost paid for the equipment installed additionally;
- Additional labour cost invested for the project in the minimum estimation;
- Cost paid using gas for the implementation of experiments;
- Current cost and expected future cost (variable costs) of etchant gas after the beginning of the project activity;

  (Note: Currently, the prices of CF_4 gases used for the project are estimated by public or official publication from public institutions or intergovernmental public entities. Another way is to use the prices[1] offered by CF_4 gas supplier. It may be assumed that future prices of the etchant gas are the same as the current price.).
- Monetized benefits from the project activity.

Include a sensitivity analysis to assess whether the conclusion regarding the financial attractiveness is robust to reasonable variations in the critical assumptions.

When applying "Step 4" of the tool, following additional guidance should be followed:

Demonstrate that the project activity is not common practice in the semiconductor industry in the relevant geographical area (as described in the prevailing practice barrier analysis).

Baseline emissions

Baseline emissions are calculated as follows:

$$BE_y = E_{CF4,y} \times k \times GWP_{CF4} \quad \textbf{(1)}$$

Where:

BE_y	=	Baseline emissions in year y (t CO_2e)
$E_{CF4,y}$	=	Amount of eligible CF_4 emitted in the baseline in year y (t CF_4)

[1] The estimated price of substitute gas after the beginning of the project activity shall be examined by a DOE in terms of appropriateness. Any changes in the prices should not exceed the range of ±15 %($/kg) from the estimated prices.

k = Discount factor to prevent any intentional increase of CF_4 entering into the etching process
GWP_{CF4} = Global Warming potential of CF_4 (t CO_2e/t CF_4)

Determination of $E_{CF4,y}$

Amount of eligible CF_4 emitted in the baseline in year *y* is determined as the minimum among:

(a) Amount of CF_4 entering the abatement system in year *y*;

(b) Theoretically estimated amount of CF_4 emitted after the etching process in year *y*; and

(c) Theoretically estimated amount of CF_4 emitted after the etching process in historical years.

This avoids the possibility to overestimate the baseline emissions by intentional increase of the CF_4 consumption.

$$E_{CF4,y} = \min\left\{E_{CF4,in,y};\left(X_{CF4,y} \times 0.252\right);\left(X_{CF4,hist} \times 0.252\right)\right\} \quad \textbf{(2)}$$

Where:
$E_{CF4,y}$ = Amount of eligible CF_4 emitted in the baseline in year *y* (t CF_4)
$E_{CF4,in,y}$ = Amount of CF_4 entering the abatement system in year *y* (t CF_4)
$X_{CF4,y}$ = Amount of CF_4 consumed in year *y* (t CF_4)
$X_{CF4,hist}$ = Amount of CF_4 consumed historically (prior to the implementation of the project activity) (t CF_4)
0.252 = Ratio of CF_4 that is not destroyed or transformed in the process. This is derived from the IPCC 2006 Guideline's default factor on destruction / decomposition (0.3), factoring in 60% uncertainty, and 0.10 of default value for the fraction of gas remaining in the shipping container ((1-0.3) x 0.4 x (1-0.10) = 0.252)

Determination of $E_{CF4,in,y}$

Amount of CF_4 entering the abatement system in year *y* ($E_{CF4,in,y}$) shall be calculated by multiplying the volumetric total flow rate by concentration of CF_4 at the inlet as follow:

$$E_{CF_4,in,y} = \frac{123.9}{1000} \times \sum_p \left(Q_{in,p} \times C_{CF4,in,p} \times \frac{273.15}{\mathrm{T_p}} \right) \quad \textbf{(3)}^{2}$$

Where,
$E_{CF4,in,y}$ = Amount of CF_4 entering the abatement system in year *y* (t CF_4)
$C_{CF4,in,p}$ = Concentration of CF_4 in the gas entering the abatement system during monitoring interval *p* (ppm)
$Q_{in,p}$ = Volumetric flow rate of gas entering the abatement system during monitoring interval *p* (m^3/sec)
123.9[3] = Conversion factor to convert ppm-m^3/sec to kg/yr
T_p = Temperature at MFC during period *p* (K)
p = Measurement interval (15 mins)

[2] Mass flow controller for adding Helium to duct should be calibrated periodically at the standard condition, 273.15 K and 1 atm.
[3] (1 ppm-m^3/sec) x ($10^{-6}m^3$/ppm) / (22.4 L/mol) x (0.088 kg/mol) x (3600 sec/hr) x (8760 hr/yr) = 123.9 kg/yr.

Determination of $Q_{in,p}$

$Q_{in,p}$ (volumetric flow rate of gas entering the abatement system) is measured following the EPA "Protocol for Measuring Destruction or Removal Efficiency (DRE) of Fluorinated Greenhouse Gas Abatement Equipment in Electronics Manufacturing", as applied by Lee et al. 2007 where the flow rate is measured by adding a stable chemical species as internal reference in the process line and estimated by measuring partial pressure of that stable chemical species, as shown in Figure 1 above. It should be noted that the stable chemical species must have no interference with the analyses and be indestructible inside the process. The stable chemical species are, for example, Helium (He) and Krypton (Kr).

These stable chemical species will be added with a calibrated and fixed flow rate ($Q_{He,p}$) into the duct before entering the abatement system. This, together with the effluent gas from the Etching process, will be collected to the by-pass duct as a sample gas. This sample gas will be fed to the QMS to obtain the mole fraction of CF_4 and helium gas and then pumped out to the main duct and entered to the abatement system. It should be noted that Inert gas flow must be measured continuously and it must be a monitored parameter with the highest accuracy. It is also necessary that the detection limit of QMS with signal to noise ratio 2 (S/N = 2) should be less than one tenth of the mole fraction of helium. Moreover, every volumetric data or parameter must refer to a pressure and a temperature and for calculation; all must be in the same basis (101,325 kPa and 273.15 K as reference conditions to perform calculations).

The volumetric flow rate of the gas entering the abatement system, therefore, is determined as follows:

$$Q_{in,p} = \left(\frac{Q_{He,p} \times \left(100 - C_{He,bg-in.p}\right)}{C_{He,in,p} - C_{He,bg-in,p}} \right) \times \frac{1}{100} \quad \textbf{(4)}$$

Where:

$Q_{in,p}$	=	Volumetric flow rate of gas entering the abatement system during monitoring interval p (m^3/sec)
$Q_{He,p}$	=	Calibrated flow rate of He gas added to duct before entering to the abatement system during monitoring interval p (m^3/sec)
$C_{He,bg-in,p}$	=	Helium concentration in the effluent gas from the Etching process entering to the abatement system during monitoring interval p which can be directly measured using QMS without injection of calibrated He (%mol/mol)
$C_{He,in,p}$	=	Helium concentration entering to the abatement system during monitoring interval p which can be directly measured using QMS after adding He with calibrated flow (%mol/mol)

Determination of $X_{CF4,hist}$

$$X_{CF4,hist} = \max\left(X_{CF4,-1}; X_{CF4,-2}; X_{CF4,-3}\right) \quad \textbf{(5)}$$

Where:

$X_{CF4,hist}$	=	Amount of CF_4 consumed historically (prior to the implementation of the project activity) (t CF_4)
$X_{CF4,-1}$, $X_{CF4,-2}$, $X_{CF4,-3}$	=	Amount of CF_4 consumed in years prior to the implementation of the project activity (-1 is one year prior, -2 is two year prior and -3 is three year prior) (t CF_4)

Determination of k

The value of k shall be determined as below:

$$k = 1 \text{ if } R_{CF4,hist} \geq R_{CF4,y} \quad \textbf{(6)}$$

or else,

$$k = \frac{R_{CF4,hist}}{R_{CF4,y}} \quad \textbf{(7)}$$

Where:

k	=	Discount factor to prevent any intentional increase of CF_4 entering into the etching process (fraction)
$R_{CF4,hist}$	=	Historical ratio of consumption of CF_4 to the surface area of semiconductor substrate processed (t CF_4/m^2)
$R_{CF4,y}$	=	Ratio of consumption of CF_4 to the surface area of semiconductor substrate processed in year *y* (t CF_4/m^2)

Determination of $R_{CF4,hist}$

Historical ratio of consumption of CF_4 to the surface area of semiconductor substrate processed ($R_{CF4,hist}$) is determined as follows:

$$R_{CF4,hist} = \min\left\{\left(\frac{X_{CF4,-1}}{SP_{-1}}\right);\left(\frac{X_{CF4,-2}}{SP_{-2}}\right);\left(\frac{X_{CF4,-3}}{SP_{-3}}\right);0.0009\right\} \quad \textbf{(8)}$$

Where:

$R_{CF4,hist}$	=	Historical ratio of consumption of CF_4 to the surface area of semiconductor substrate processed (t CF_4/m^2)
$X_{CF4,-1}$, $X_{CF4,-2}$, $X_{CF4,-3}$	=	Amount of CF_4 consumed in years prior to the implementation of the project activity (-1 is one year prior, -2 is two year prior and -3 is three year prior) (t CF_4)
SP_{-1}, SP_{-2}, SP_{-3}	=	Amount of semiconductor substrate produced in years prior to the implementation of the project activity (-1 is one year prior, -2 is two year prior and -3 is three year prior) (m^2)
0.0009	=	IPCC 2006 Guidelines Tier 1 gas-specific emission factors for CF_4 emissions from semiconductor industry (t CF_4/m^2) (0.9 kg-CF_4/m^2 substrate)

Determination of $R_{CF4,y}$

$$R_{CF4,y} = \frac{X_{CF4,y}}{SP_y} \quad \textbf{(9)}$$

Where:

$R_{CF4,y}$	=	Ratio of consumption of CF_4 to the surface area of semiconductor substrate processed in year *y* (t CF_4/m^2)
$X_{CF4,y}$	=	Amount of CF_4 consumed in year *y* (t CF_4)
SP_y	=	Amount of semiconductor substrate produced in year *y* (m^2)

Project emissions

Project emissions include:

(a) The not abated CF_4 emitted from the abatement system;

(b) CO_2 emissions from the fossil fuel or electricity by the project activity including operation of the abatement system; and

(c) CO_2 emitted as by-product from abatement system (by conversion of CF_4 to CO_2 during the abatement process).

Project emissions are calculated as follows:

$$PE_y = PE_{CF4,y} + PE_{FC,y} + PE_{EC,y} + PE_{CO_2,y} \quad \textbf{(10)}$$

Where:

PE_y	=	Project emissions in year *y* (t CO_2e)
$PE_{CF4,y}$	=	Project emissions due to CF_4 emitted from the abatement system in year *y* (t CO_2e)
$PE_{FC,y}$	=	Project emissions due to fossil fuel combustion in year *y* (t CO_2e)
$PE_{EC,y}$	=	Project emissions due to electricity consumption in year *y* (t CO_2e)
$PE_{CO2,y}$	=	Project emissions due to CO_2 emitted as by-product from abatement system in year *y* (t CO_2e)

Step 1: Determination of project emissions due to CF_4 emitted from the abatement system

The emission from CF_4 emitted from the abatement system is estimated through the following equation:

$$PE_{CF4,y} = E_{CF4,out,y} \cdot GWP_{CF4} \quad \textbf{(11)}$$

Where:

$PE_{CF4,y}$	=	Project emissions due to CF_4 emitted from the abatement system in year *y* (t CO_2e)
$E_{CF4,out,y}$	=	Amount of CF_4 leaving the abatement system in year *y* (t CF_4)
GWP_{CF4}	=	Global Warming potential of CF_4 (t CO_2e/t CF_4)

Determination of $E_{CF4,out,y}$

The amount of CF_4 leaving the abatement system in year *y* ($E_{CF4,out,y}$) shall be determined as follows:

$$E_{CF_4,out,y} = \frac{123.9}{1000} \times \sum_q \left(Q_{out,q} \times C_{CF4,out,q} \times \frac{273.15}{T_q} \right) \quad \textbf{(12)}$$

Where,

$E_{CF4,out,y}$	=	Amount of CF_4 leaving the abatement system in year *y* (t CF_4)
$C_{CF4,out,q}$	=	Concentration of CF_4 in the gas leaving the abatement system during monitoring interval *q* (ppm)
$Q_{out,q}$	=	The volumetric flow rate of gas leaving the abatement system during monitoring interval *q* (m^3/sec)
T_q	=	Temperature at MFC during period *q* (K)
q	=	Measurement interval (15 mins)

Determination of $Q_{out,q}$

An approach similar to above (determination of $Q_{in,p}$) applies to the estimation of flow rate of gas outlet mixtures out of the abatement system ($Q_{out,q}$).

$$Q_{out,q} = \left(\frac{Q_{He,p} \times (100 - C_{He,bg-out,q})}{C_{He,out,q} - C_{He,bg-out,q}} \right) \times \frac{1}{100} \quad \textbf{(13)}$$

Where:

$Q_{out,q}$	=	The volumetric flow rate of gas leaving the abatement system during monitoring interval *q* (m^3/sec)
$Q_{He,p}$	=	Calibrated flow rate of He gas added to duct before entering to the abatement system during monitoring interval *p* (m^3/sec)
$C_{He,bg-out,q}$	=	Helium concentration of gas outlet mixtures out of the abatement system during monitoring interval *q* which can be directly measured using QMS without injection of calibrated He (%mol/mol)
$C_{He,out,q}$	=	Helium concentration out of the abatement system during monitoring interval *q* which can be directly measured using QMS after adding He with calibrated flow (%mol/mol)

Step 2: Determination of project emissions due to fossil fuel combustion

Project emissions from fossil fuel combustion in year *y* ($PE_{FC,y}$) are calculated using the latest approved version of the "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion", where the sources *j* in the tool correspond to all sources of fossil fuel consumption by the project activity, including the abatement system. All emission sources should be documented transparently in the CDM-PDD.

Step 3: Determination of project emissions due to electricity consumption

Project emissions from electricity consumption in year *y* ($PE_{EC,y}$) are calculated using the latest version of the "Tool to calculate baseline, project or leakage emissions from electricity consumption" where the electricity consumption sources *j* in the tool corresponds to all electricity consumption sources by the project activity, including the abatement system. All emission sources should be documented transparently in the CDM-PDD.

Step 4: Determination of project emissions due to CO_2 emitted as by-product from abatement system

The emission from CO_2 by-product from abatement system (by conversion of destroyed CF_4 to CO_2) is calculated as follows:

$$PE_{CO_2,y} = \frac{E_{CF_4,in,y} - E_{CF_4,out,y}}{MW_{CF4}} \times MW_{CO_2} \quad \textbf{(14)}$$ [4]

[4] This equation is developed based on the chemical reaction of $CF_4 + 2H_2O \text{-->} CO_2 + 4HF$. This shows that 1 mole of CF_4 that is abated in the abatement system results in 1 mole of CO_2 out of the abatement system.

Where:

$PE_{CO2,y}$	=	Project emissions due to CO_2 emitted as by-product from abatement system in year *y* (t CO_2e)
$E_{CF4,in,y}$	=	Amount of CF_4 entering the abatement system in year *y* (t CF_4)
$E_{CF4,out,y}$	=	Amount of CF_4 leaving the abatement system in year *y* (t CF_4)
MW_{CF4}	=	Molecular weight of CF_4 (88.003 gram per mole)
MW_{CO2}	=	Molecular weight of CO_2 (44.009 gram per mole)

Leakage

No leakage is considered.

Emission reductions

Emission reductions are calculated as follows:

$$ER_y = BE_y - PE_y \quad \textbf{(15)}$$

Where:

ER_y	=	Emission reductions in year *y* (t CO_2e)
BE_y	=	Baseline emissions in year *y* (t CO_2e)
PE_y	=	Project emissions in year *y* (t CO_2e)

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

Refer to the “Tool to assess the validity of the original/current baseline and to update the baseline at the renewal of a crediting period” (Annex 1 of the “Procedures for renewal of the crediting period of a registered CDM project activity”).[5]

Data and parameters not monitored

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

Data / Parameter:	GWP_{CF4}
Data unit:	t CO_2e/t CF_4
Description:	Global warming potential of CF_4
Source of data:	A value of 6,500 shall be applied. Sourced from the 2nd Assessment Report Climate Change 1995, at 100 years time horizon
Measurement procedures (if any):	-
Any comment:	-

[5] <https://cdm.unfccc.int/Reference/Procedures/reg_proc04.pdf>.

Data / Parameter:	$X_{CF4,-1;}$ $X_{CF4,-2;}$ $X_{CF4,-3}$
Data unit:	t CF_4
Description:	Amount of CF_4 consumed in years prior to the implementation of the project activity (-1 is one year prior, -2 is two year prior and -3 is three year prior)
Source of data:	Project participants, based on record of purchase and inventory
Measurement procedures (if any):	-
Any comment:	Consumption is defined as the total CF_4 purchased in a year, taking into account the change in inventory of CF_4 in the same year

Data / Parameter:	$SP_{-1;}$ $SP_{-2;}$ SP_{-3}
Data unit:	m^2
Description:	Amount of semiconductor substrate produced in years prior to the implementation of the project activity (-1 is one year prior, -2 is two year prior and -3 is three year prior)
Source of data:	Project participants, based on record of production and inventory
Measurement procedures (if any):	-
Any comment:	-

III. MONITORING METHODOLOGY

During each crediting year, the project participants will directly monitor all key parameters related to estimation of the baseline and project emissions. The project participants will continuously monitor the consumption of CF_4, and all key process parameters (volumetric flow rate and concentration of CF_4 and He, temperature) to ensure that there is no drift in the process set-points. As part of the monitoring methodology, project participants will also be required to record any significant changes and to document and follow proper maintenance procedures. The project participants will also be required to discount from the emission reductions any emissions resulting from calibration of equipment, or from equipment malfunction or other repair activities that might affect the calculation of the project emissions. The elements of the monitoring methodology are as follows:

All data collected as part of monitoring should be archived electronically and kept for at least 2 years after the end of the last crediting period. 100% of the data should be monitored if not indicated otherwise in the monitoring tables. All measurements should be conducted with calibrated measurement equipment according to relevant industry standards.

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

The conversion of signal intensity (Ion current) of QMS system into a mass of CF_4

Firstly, the default value of each chemical based on standard gas is calculated. Standard gases for CF_4 and He will be injected to the QMS system respectively with a certain pressure. “He” sensitivity is necessary to estimate the flow rate, which is explained later. These standard gases will be used to identify the sensitivity of CF_4 and He which will be then used to estimate the concentration of the CF_4 of online gas samples in the following equation. The QMS will directly measure the Ion current of the standard gas. Together with the known concentration of standard gas, the sensitivity is calculated as follow:

$$Sen_{CF4} = \frac{I_{std-CF4}}{P_{std-CF4} \times C_{std-CF4}} \tag{16}$$

$$Sen_{He} = \frac{I_{std-He}}{P_{std-He} \times C_{std-He}} \quad \textbf{(17)}$$

Where:

Sen_{CF4}	=	Sensitivity of the CF_4 peak (Amp/(mbar·%mol/mol)
Sen_{He}	=	Sensitivity of the He peak (Amp/(mbar·%mol/mol)
$I_{std-CF4}$	=	Ion Current of CF_4 peak (Amp) which is the signal intensity obtained from QMS by injection of CF_4 standard gas
I_{std-He}	=	Ion Current of He peak (Amp) which is the signal intensity obtained from QMS by injection of He standard gas
$P_{std-CF4}$	=	Injection pressure of the CF_4 standard gas which is obtained from the direct measurement by Barton gauge (mbar) in inlet system
P_{std-He}	=	Injection pressure of the He standard gas which is obtained from the direct measurement by Barton gauge (mbar) in inlet system
$C_{std-CF4}$	=	Concentration of CF_4 gas in a standard gas mixture (%mol/mol)
C_{std-He}	=	Concentration of He gas in a standard gas mixture (%mol/mol)

The value of the sensitivity of each chemical ($Sen_{std-CF4}$ and Sen_{std-He}) will be checked periodically. During the operation of the abatement system, QMS will measure the value of Ion Current (I) continuously. Together with the injection pressure of the inlet system front of QMS which is directly measured (as the pressure of the total gas inlet) and the Ion Current of the CF_4 will be applied to estimate the concentration of the CF_4 , using the following equation:

$$\frac{I_{CF_4}}{Sen_{CF4}} \times \frac{1}{P_{inlet}} \times 100 = C_{CF_4} \quad \textbf{(18)}$$

Where:

I_{CF4}	=	Ion Current of CF_4 peak (Amp) which is the signal intensity obtained from QMS
P_{inlet}	=	Injection pressure of the gas inlet, can be obtained from the direct measurement by Barton gauge (mbar)
C_{CF4}	=	concentration of a CF_4 in a gas inlet (%mol/mol)
Sen_{CF4}	=	Sensitivity of the CF_4 peak (Amp/(mbar·%mol/mol)

Please note that this conversion of partial pressure of PFCs substances to concentration approach (eq 16, 17, and 18) will be performed automatically which is explained later in the monitoring methodology session.

Monitoring the abatement system

Maintenance Schedule

A drop in abatement performance could also occur if the abatement system is not properly maintained.

The project participants shall ensure that the maintenance procedures are followed at least as often as the manufacturer's recommendation. The project participants shall document and present the maintenance requirements of the abatement system to the DOE and shall ensure that they have been followed in at least as rigorous manner as required.

Ongoing calibration of QMS device

Calibration of the QMS device will be required every time the abatement system is brought offline for maintenance or whenever the QMS device itself is brought offline for maintenance (e.g. when cleaning of the QMS ionization part). The ongoing calibration of the QMS device will be performed using a standalone dynamic dilution calibration system with certified reference gas mixtures, such as the one described in section II, in the baseline emission session. An ongoing calibration can be done offline, by isolating the QMS from the inlet of the abatement system and connecting the QMS to the standalone calibration system. In such a way, the ongoing calibration of the QMS device can be done while the process tools run in production condition, avoiding to have to shut down the tool for a routine calibration procedure. Certainly, emissions occurring while the QMS device is put offline will be discounted from the crediting period for conservativeness. When using the standalone calibration system, the operator will ensure that a minimum of 5 calibration points are generated and that the calibration points cover the proper range of CF_4 being emitted during normal operation of the tools (range = CF_4 min to CF_4 max). For each calibration point, the operator will ensure that the QMS signals have reached a stable intensity. For the mid-range CF_4 concentration point (CF_4 mid=(CF_4 max+ CF_4 min)/2), the experiment will be repeated 5 times by turning the MFCs flows ON and OFF.

Calculation of uncertainty, drifts and estimation of measurement errors

For the calibration point corresponding to the middle of the CF_4 flow range or concentration being characterized (CF_4 mid = (CF_4 max + CF_4 min)/2, which is repeated at least five times, the operator will calculate the standard deviation associated with the signal intensity. The standard deviation should be below 5%. If the abatement system can reduce the concentration of CF_4 to below 100 µmol/mol, the measurement uncertainty of the signal intensity from QMS is likely to be higher than 5%. This is a natural phenomenon for a measurement by an instrument at a low concentration level. In this case, the standard deviation associated with the signal intensity should be below 10 %.

The standard deviation is calculated as follows:

$$\sigma = \sqrt{\frac{\Sigma_{i=0}^{n}\left(I_i - \overline{I}\right)^2}{(n-1)}} \quad \textbf{(19)}$$

Where:

I_i	=	The QMS signal intensity recorded for the CF_4 flow or concentration corresponding to the middle of the flow or concentration range being characterized for each experiment i
n	=	The total number of experimental points
σ	=	Standard deviation

After completion of the experimental calibration procedure, the operator will fit the experimental data points of CF_4 flow or concentration versus signal intensity with a linear curve (or other suitable fitting curve) and to ensure that an R2 value of greater than 0.98 is obtained between the fitting curve and the experimental points. Calibration should be done in accordance to the recommendation from the manufacturer. The R2 value is calculated as follows:

$$R^2 = \left(\frac{\Sigma_{i=0}^{n}\left(x_i - \overline{x}\right)\left(y_i - \overline{y}\right)}{\sqrt{\Sigma_{i=0}^{n}\left(x_i - \overline{x}\right)^2 \Sigma_{i=0}^{n}\left(y_i - \overline{y}\right)^2}}\right)^2 \quad \textbf{(20)}$$

Where:

x	=	The sum of the flows or the concentration of CF_4 indicated by the chamber(s) MFCs or the standalone dilution system for each point i of the calibration curve
y	=	The QMS signal intensities recorded for each point i of the calibration curve
n	=	The total number of calibration points

Note that a source of error in estimating the quantity of CF_4 abated can originate from the contamination of the QMS ionization part with residues from the Etching process. In such a case, the coating of the windows will lead to a decrease of the QMS signal intensity and an underestimation of the quantity of CF_4 abated, resulting in a conservative estimate. This phenomenon will provide an incentive to perform regular inspection and maintenance of the QMS monitoring device.

Calculation of CF_4 use/m^2 of substrate to prevent gaming

To prevent potential activities to intentionally raise CF_4 emissions in the baseline, the project developer will collect historical data of the amount of CF_4 purchased by the semiconductor manufacturing plant and calculate the ratio of CF_4 purchased versus the surface area (in m^2) of semiconductor substrates processed. The historical data should cover at least three years period prior to implementation of the CDM project. Any increase in CF_4 emissions above the historical baseline, as measured in kilograms of CF_4 per square millimetre of substrate processed will be discounted from the crediting period.

In addition, the monitoring provisions in the tools referred to in this methodology apply.

Data and parameters monitored

Data / Parameter:	$X_{CF4,y}$
Data unit:	t CF_4
Description:	Amount of CF_4 consumed in year *y*
Source of data:	Project participants, based on record of purchase and inventory
Measurement procedures (if any):	-
Monitoring frequency:	Annually
QA/QC procedures:	Check against record of purchase
Any comment:	Consumption is defined as the total CF_4 purchased in year y, taking into account the change in inventory of CF_4 in the same year

Data / Parameter:	SP_y
Data unit:	m^2
Description:	Amount of semiconductor substrate produced in year *y*
Source of data:	Project participants, based on record of production, sales and inventory
Measurement procedures (if any):	-
Monitoring frequency:	Annually
QA/QC procedures:	Cross-check production, wafer purchase or inventory records
Any comment:	-

Data / Parameter:	$Q_{He,p}$
Data unit:	m^3/sec
Description:	Calibrated flow rate of He gas added to duct before entering to the abatement system during monitoring interval *p*
Source of data:	Direct measurement
Measurement procedures (if any):	Mass flow controller
Monitoring frequency:	Continuously – every 15 mins
QA/QC procedures:	-
Any comment:	The flow rate of Helium entering the abatement system must be constant (i.e. 0.0001 m^3/sec) every time that the sample gas is taken and analysed.

Data / Parameter:	$C_{He,in,p}$
Data unit:	%mol/mol
Description:	Helium concentration entering to the abatement system during monitoring interval *p* which can be directly measured using QMS after adding He with calibrated flow
Source of data:	QMS
Measurement procedures (if any):	Conversion of QMS signal to concentration
Monitoring frequency:	Continuously – every 15 mins
QA/QC procedures:	The QMS will be calibrated and maintained as per manufacturing's instruction
Any comment:	-

Data / Parameter:	$C_{He,out,q}$
Data unit:	% mol/mol
Description:	Helium concentration out of the abatement system during monitoring interval *q* which can be directly measured using QMS after adding He with calibrated flow
Source of data:	QMS
Measurement procedures (if any):	Conversion of QMS signal to concentration
Monitoring frequency:	Continuously – every 15 mins
QA/QC procedures:	The QMS will be calibrated and maintained as per manufacturing's instruction
Any comment:	-

Data / Parameter:	$C_{He,bg-in,p}$
Data unit:	% mol/mol
Description:	Helium concentration in the effluent gas from the Etching process entering to the abatement system during monitoring interval *p* which can be directly measured using QMS without injection of calibrated He
Source of data:	QMS
Measurement procedures (if any):	Conversion of QMS signal to concentration
Monitoring frequency:	Continuously – every 15 mins
QA/QC procedures:	The QMS will be calibrated and maintained as per manufacturing's instruction
Any comment:	-

Data / Parameter:	$C_{He,bg-out,q}$
Data unit:	% mol/mol
Description:	Helium concentration of gas outlet mixtures out of the abatement system during monitoring interval *q* which can be directly measured using QMS without injection of calibrated He
Source of data:	QMS
Measurement procedures (if any):	Conversion of QMS signal to concentration
Monitoring frequency:	Continuously – every 15 mins
QA/QC procedures:	The QMS will be calibrated and maintained as per manufacturing's instruction
Any comment:	-

Data / Parameter:	$C_{CF4,in,p}$
Data unit:	ppm
Description:	Concentration of CF_4 in the gas entering the abatement system during monitoring interval *p*
Source of data:	QMS
Measurement procedures (if any):	Conversion of QMS signal to concentration (see previous section "The conversion of signal intensity (Ion current) of QMS system into a mass of CF_4)"
Monitoring frequency:	Continuously – every 15 minutes
QA/QC procedures:	See section III, ongoing calibration of QMS device. The QMS will be calibrated and maintained as per manufacturing's instruction
Any comment:	-

Data / Parameter:	$C_{CF4,out,q}$
Data unit:	ppm
Description:	Concentration of CF_4 in the gas leaving the abatement system during monitoring interval *q*
Source of data:	QMS
Measurement procedures (if any):	Conversion of QMS signal to concentration (see previous section “The conversion of signal intensity (Ion current) of QMS system into a mass of CF_4)”
Monitoring frequency:	Continuously – every 15 minutes
QA/QC procedures:	See section III, ongoing calibration of QMS device. The QMS will be calibrated and maintained as per manufacturing’s instruction
Any comment:	-

Data / Parameter:	T_p
Data unit:	K
Description:	Temperature at MFC during period *p*
Source of data:	Thermocouple
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuously – every 15 minutes
QA/QC procedures:	See EPA Method 2 or similar nationally- or internationally-recognized standard
Any comment:	-

Data / Parameter:	T_q
Data unit:	K
Description:	Temperature at MFC during period *q*
Source of data:	Thermocouple
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuously – every 15 minutes
QA/QC procedures:	See EPA Method 2 or similar nationally- or internationally-recognized standard
Any comment:	-

IV. REFERENCES AND ANY OTHER INFORMATION

(1) 2006 IPCC Guidelines for National Greenhouse Gas Inventories Vol. 3 Chapter 6, Electronics Industry Emissions;

(2) Guideline for Environmental Characterization of Semiconductor Process Equipment – Revision 2, International SEMATECH Manufacturing Initiative, December 9, 2009;

(3) Technical Support Document for Process Emissions from electronics manufacture: Proposed Rule for Mandatory Reporting of Greenhouse Gases by U.S. Environmental Protection Agency (EPA), January 29, 2009;

(4) Evaluation Method on Destruction and Removal Efficiency of Perfluorocompounds from Semiconductor and Display Manufacturing, Bulletin of the Korean Chemical Society, Vol. 28, No.8, August 20, 2007, Page 1383-1388;

(5) US EPA Method 2 – Determination of stack gas velocity and volumetric flow rate http://www.epa.gov/ttn/emc/promgate/m-02.pdf;

(6) US EPA Method 2a – Direct measurement of gas volume through pipes and small ducts http://www.epa.gov/ttn/emc/promgate/m-02a.pdf.

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History of the document

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