

**AM0092**

## Large-scale Methodology

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# Substitution of PFC gases for cleaning Chemical Vapour Deposition (CVD) reactors in the semiconductor industry

Version 02.0.0

Sectoral scope(s): 04 and 11



**United Nations**  
Framework Convention on  
Climate Change

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## 1. Introduction

- The following table describes the key elements of the methodology:

**Table 1. Methodology key elements**

<b>Typical projects</b>	Production of petro/renewable diesel by switching the feedstock of hydrodesulphurization process (HDS) unit from 100% gasoil to a mixture of gasoil and vegetable oil in an existing refinery, where the vegetable oil comes from oilseeds from plants that are cultivated on dedicated plantations established on lands that are degraded or degrading at the start of the project
<b>Type of GHG emissions mitigation action</b>	(a) Renewable energy; (b) Feedstock switch. Displacement of more-GHG-intensive feedstock for the production of diesel

## 2. Scope, applicability, and entry into force

### 2.1. Scope

- This methodology is applicable to projects activities that reduce PFC emissions through replacement of  $C_2F_6$  with  $c-C_4F_8$  (octa-fluoro-cyclo-butane) as a gas for in-situ cleaning of CVD reactors in the semiconductor industry.

### 2.2. Applicability

- The methodology is applicable under the following conditions:
  - Where production lines included in the project boundary started commercial operation before 1 January 2010 and have an operational history of at least three years prior to the implementation of the project activity, during which the original PFC gas was  $C_2F_6$ ;
  - Where the substitute PFC gas is not temporarily stored for subsequent destruction.
- The methodology does not apply to processes that have abatement devices specifically designed for the purpose of destroying PFCs.<sup>1</sup>
- In addition, the applicability conditions in the tools referred to above apply.
- Finally, this methodology is only applicable if the baseline scenario is the continuation of the current situation, that is the continuation of the same baseline technology as used in the most recent three years prior to the implementation of the project activity.

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<sup>1</sup> As opposed to abatement devices designed for the purpose of destroying other substances such as volatile organic carbons and silanes, which may destroy part of the PFCs.

### 2.3. Entry into force

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

## 3. Normative references

8. This baseline and monitoring methodology is based on elements from the following approved baseline and monitoring methodology and proposed new methodologies:
- (a) “NM0330: Substitution of PFC gases for cleaning Chemical Vapour Deposition (CVD) reactors in the semiconductor industry” prepared by Climate Change Capital, Global Foundries Inc, Transcarbon International Corp”;
  - (b) “AM0078 Point of Use Abatement Device to Reduce SF6 emission in LCD Manufacturing Operation” prepared by Climate Change Capital, LG International Corp., and Transcarbon International Corp”;
  - (c) “NM0303: PFC emissions reduction by gas replacement in the process of CVD cleaning in semiconductor production” prepared by Hynix Semiconductor Inc”.
9. This methodology also refers to the latest approved versions of the following documents:
- (a) “Combined tool to identify the baseline scenario and demonstrate additionality”;
  - (b) “Assessment of the validity of the original/current baseline and update of the baseline at the renewal of the crediting period”;
  - (c) “Tool to determine the remaining lifetime of equipment”;
  - (d) “IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3, Chapter 6, Electronics industry emissions”;
  - (e) “Guidelines for Environmental Characterization of Semiconductor Process Equipment, International Sematech Manufacturing Initiative Technology Transfer #06 124825A-ENG, 2006”;
  - (f) “US EPA's Protocol for Measuring Destruction or Removal Efficiency (DRE) of Fluorinated Greenhouse Gas Abatement Equipment in Electronics Manufacturing”;
  - (g) “International Standard ISO14956: Air quality - Evaluation of the suitability of a measurement procedure by comparison with a required measurement uncertainty”;
  - (h) “European Standard EN14181: Stationary source emissions - Quality assurance of automated measuring systems”;

- (i) "Mandatory Reporting of Greenhouse Gases: Additional Sources of Fluorinated GHGs. 40 CFR Part 98, Subpart I (Electronics Manufacturing). Published in Federal Register / Vol. 75, No. 69, April 12, 2010, p.18669";
  - (j) "Reduction of Perfluorocompound (PFC) Emissions: 2005 State-of-the-Technology Report. International SEMATECH Manufacturing Initiative, December 2, 2005".
10. For more information regarding the proposed new methodologies and the tools as well as their consideration by the Executive Board (hereinafter referred to as the Board) of the clean development mechanism (CDM) please refer to <<http://cdm.unfccc.int/goto/MPappmeth>>.

### 3.1. Selected approach from paragraph 48 of the CDM modalities and procedures

11. "Existing actual or historical emissions, as applicable".

## 4. Definitions

12. The definitions contained in the Glossary of CDM terms shall apply.
13. For the purpose of this methodology, the following definitions apply:
- (a) **Abatement device** - A device designed for the purpose of destroying substances other than PFCs, such as volatile organic carbons and silanes, which may destroy part of the PFCs during the abatement process;
  - (b) **Cleaning process** - A process to remove impurities from the CVD reactors optimized for a unique combination of the following three process/production components:
    - (i) CVD thin film deposition application;
    - (ii) Specific model of CVD tool; and
    - (iii) Specific abatement device;<sup>2</sup>
  - (c) **Baseline process *p*** - A process defined as the use of C<sub>2</sub>F<sub>6</sub> in a cleaning process;
  - (d) **Substitute process *p*** - A process defined as a c-C<sub>4</sub>F<sub>8</sub> cleaning process replacing a baseline process;
  - (e) **Clean run *k*** - A specific instance of performing a cleaning process using substitute process *p*. Because the thickness *t* of the film deposited prior to every

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<sup>2</sup> A cleaning process consists of a set of process steps with predetermined process parameters (gas flows, pressure, plasma power), optimized for a combination of hardware and film thickness. For example, a cleaning process can be defined as a process to clean the residues following the deposition of a film of undoped silicate glass (e.g. TEOS/O<sub>2</sub>-based) on an Applied Materials P5000 xL<sup>TM</sup> chamber equipped with a Guardian<sup>TM</sup> abatement device. Another example would be a cleaning process to clean residues from the deposition of a film of silicon nitride (e.g. SiH<sub>4</sub>/NH<sub>3</sub>-based) on a Novellus<sup>TM</sup> Sequel tool equipped with a CDO<sup>TM</sup> abatement device.

clean run can vary, the project participants will calculate emissions reductions based on each clean run (and thus every thickness);

- (f) **Original PFC gas** - The PFC used for the cleaning of CVD reactors prior to implementation of the project ( $C_2F_6$ );
- (g) **Substitute PFC gas** - The PFC gas replacing the original PFC gas after implementation of the project ( $c-C_4F_8$ );
- (h) **Dilution Factor (DF)** - The ratio of total outlet volume flow to the total inlet volume (pump or abatement device);
- (i) **Destruction Removal Efficiency (DRE)** - The percentage representing the removal efficiency of a particular compound through an abatement device.

## 5. Baseline methodology

### 5.1. Identification of the baseline scenario and demonstration of additionality

14. The latest version of the "Combined tool to identify the baseline scenario and demonstrate additionality" shall be applied to identify the baseline scenario and demonstrate additionality.
15. In applying Step 1 of the tool, the potential alternatives to this project should include, but not be limited to:
  - (a) Process optimisation to reduce consumption and emissions of the original PFC gas;<sup>3</sup>
  - (b) Reducing emissions through implementation of PFC-capable abatement devices;
  - (c) Use of PFC substitutes other than  $c-C_4F_8$  (e.g.  $C_3F_8$ );
  - (d) Use of a non-global-warming gas as a PFC replacement (e.g.  $COF_2$  or  $F_2$ );
  - (e) Replacement of existing CVD tools with CVD tools having  $NF_3$  remote clean technology;<sup>4</sup>
  - (f) Upgrade of existing CVD tools with  $NF_3$  remote clean technology;
  - (g) The proposed project activity not registered as a CDM project activity;
  - (h) Continuation of the current situation. Which is the use of  $C_2F_6$ .
16. Project participants shall follow the Step 3 of the "Combined tool to identify the baseline scenario and demonstrate additionality" to compare the alternatives remaining after Step 1 for projects applying this methodology and not the barrier analysis (Step 2). 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 baseline.

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<sup>3</sup> Project participants shall provide evidence demonstrating that the process is already optimized.

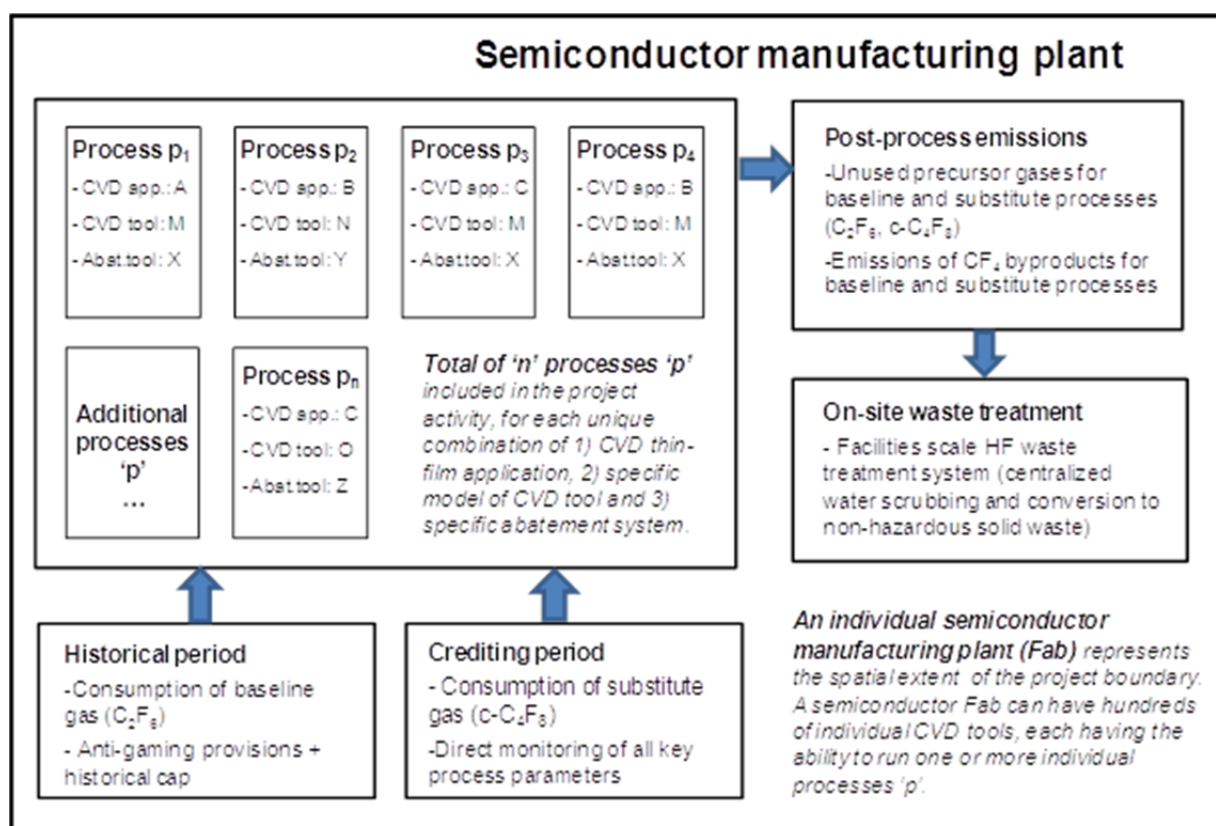
<sup>4</sup> It should be noted that switch to  $NF_3$  does not lead to increase in baseline emissions since  $NF_3$  is not a greenhouse gas.

17. In applying Step 3 of the tool, the project participants should consider the following:
- Operational costs (e.g. cost of clean gas, cost of maintenance, utilities consumption and cost, monitoring cost, etc.);
  - Capital for new equipment or equipment retrofits required;
  - Possible benefits of substitute PFC gas such as reduction in cleaning time and increase in productivity and other costs or savings as applicable;
  - Any other costs and benefits relevant for the financial feasibility.
18. A third party industry expert without conflict of interest at the time of validation shall confirm the accuracy of the financial analysis including reviewing any justification and expenditures for requalification (if needed).

## 5.2. Project boundary

19. The **spatial extent** of the project boundary encompasses the particular semiconductor production lines which qualify under this methodology and to which the substitute process is applied. Figure 1 presents the spatial extent of the project boundary.

Figure 1. Project boundaries for baseline and project scenarios



20. The greenhouse gases included in or excluded from the project boundary are shown in Table 2.

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

Source		Gas	Included	Justification/Explanation
Baseline	Use of original PFC gas	C <sub>2</sub> F <sub>6</sub>	Yes	Emissions of C <sub>2</sub> F <sub>6</sub> unused during the CVD chamber cleaning process are included in the project boundary
	Emissions of FC by-products from use of original PFC gas	CF <sub>4</sub>	Yes	Emissions of CF <sub>4</sub> produced as a by-product of the C <sub>2</sub> F <sub>6</sub> CVD chamber cleaning process are included in the project boundary
	CO <sub>2</sub> emissions from fuel or electricity use	CO <sub>2</sub>	No	There is no significant difference between CO <sub>2</sub> emissions from fuel of electricity usage between the baseline and the project activity
Project activity	Use of substitute PFC gas	c-C <sub>4</sub> F <sub>8</sub>	Yes	Emissions of c-C <sub>4</sub> F <sub>8</sub> unused during the substitute CVD chamber cleaning process are included in the project boundary
	Emissions of FC by-products from use of substitute PFC gas	CF <sub>4</sub>	Yes	Emissions of CF <sub>4</sub> produced as a by-product of the c-C <sub>4</sub> F <sub>8</sub> CVD chamber cleaning process are included in the project boundary
		C <sub>2</sub> F <sub>6</sub>	No	Experimental evidence shows that C <sub>2</sub> F <sub>6</sub> is not produced as a by-product of the c-C <sub>4</sub> F <sub>8</sub> CVD chamber cleaning process
		C <sub>3</sub> F <sub>8</sub>	No	Experimental evidence shows that C <sub>3</sub> F <sub>8</sub> is not produced as a by-product of the c-C <sub>4</sub> F <sub>8</sub> CVD chamber cleaning process
	CO <sub>2</sub> emissions from fuel or electricity use	CO <sub>2</sub>	No	There is no significant difference between CO <sub>2</sub> emissions from fuel of electricity usage between the baseline and the project activity

### 5.3. Project emissions

#### 5.3.1. Step P1: Calculation of project emissions

21. The calculation of project emissions during a crediting year is based on the measurement of the consumption of substitute gas (c-C<sub>4</sub>F<sub>8</sub>) and the calculation of the emission factors. The following provides guidance on the approach for measurements:



- (a) Record the thickness  $t$  of the thin film deposited in the CVD chamber prior to the clean run for each clean run  $k$  of any cleaning process  $p$  performed during the crediting periods;
  - (b) Continuous recording of the consumption of c-C<sub>4</sub>F<sub>8</sub> substitute gas for each clean run  $k$  for any cleaning process  $p$ , and the thickness  $t$  of the thin film deposited in the CVD chamber prior to the clean run. For each clean run, the c-C<sub>4</sub>F<sub>8</sub> consumption should be measured by integrating the signal of the c-C<sub>4</sub>F<sub>8</sub> mass flow controllers over the clean run time;
  - (c) Continuous monitoring of all key process parameters (temperature, plasma power, pressure, flows) for every cleaning process  $p$  and for every thickness  $t$  to ensure that no drift from the center process occurs.
22. Thus, the following stepwise approach needs to be followed in order to calculate project emissions during crediting year  $y$ .
23. Actual project emissions ( $PE_{p,t,k}$ ) are calculated based on the emission factors ( $EF_{PJ,p,t}$ ) measured during the ex ante campaign and the measurement of the mass of substitute gas consumed during each CVD chamber cleaning run ( $C_{PJ,y,p,t,k}$ ) for each clean run  $k$ .
24. Total project emissions for the crediting period ( $PE_y$ ) are calculated by summing the project emissions for all cleaning processes  $p$  and all clean runs  $k$  included in the project activity.
25. For each cleaning process  $p$  included in the project activity, the project emissions for year  $y$  ( $PE_{p,y}$ ) should be calculated by summing up project emissions across all clean runs  $k$  performed during the year.
26. If there are  $p$  distinct cleaning processes included in the project, the project emissions for crediting year  $y$  should be calculated as follows:

$$PE_y = \sum_p \sum_k (C_{PJ,y,p,t,k} \times EF_{PJ,p,t}) \times 10^{-6} \quad \text{Equation (1)}$$

Where:

$PE_y$	= Project emissions for crediting year $y$ (t CO <sub>2</sub> e)
$C_{PJ,y,p,t,k}$	= Consumption of c-C <sub>4</sub> F <sub>8</sub> for clean run $k$ undertaken for substitute process $p$ with thickness $t$ for crediting year $y$ (g)
$EF_{PJ,p,t}$	= Emission factor for substitute process $p$ and thickness $t$ (gCO <sub>2</sub> e per g of c-C <sub>4</sub> F <sub>8</sub> consumed)
$p$	= Number of distinct cleaning processes included in the project activity
$t$	= Thickness of the thin film deposited in the CVD chamber during clean run $k$ (μm)
$k$	= Clean run number for cleaning process $p$

### 5.3.2. Step P2: Determination of project emission factors ( $EF_{PJ,p,t}$ )

27. The following approach for the measurement and calculations shall be applied in order to determine project emission factors:

- (a) A campaign using the IPCC Tier 3 methodology shall be conducted to measure the baseline and substitute processes' gas use rates ( $U_{BL,p,t}$ ,  $U_{PJ,p,t}$ ), as well as the amount of  $CF_4$  by product generated during the processes ( $B_{CF_4,BL,p,t}$ ,  $B_{CF_4,PJ,p,t}$ ) for each cleaning process 'p' to be included in the project activities and for a range of thicknesses  $t$ .

The verification of the design, implementation and results of the ex ante campaign shall be performed by an independent qualified expert with documented experience installing and undertaking measurements of gaseous emissions in semiconductor/LCD/PV operations. The credentials of the independent expert will be provided to the DOE during verification.

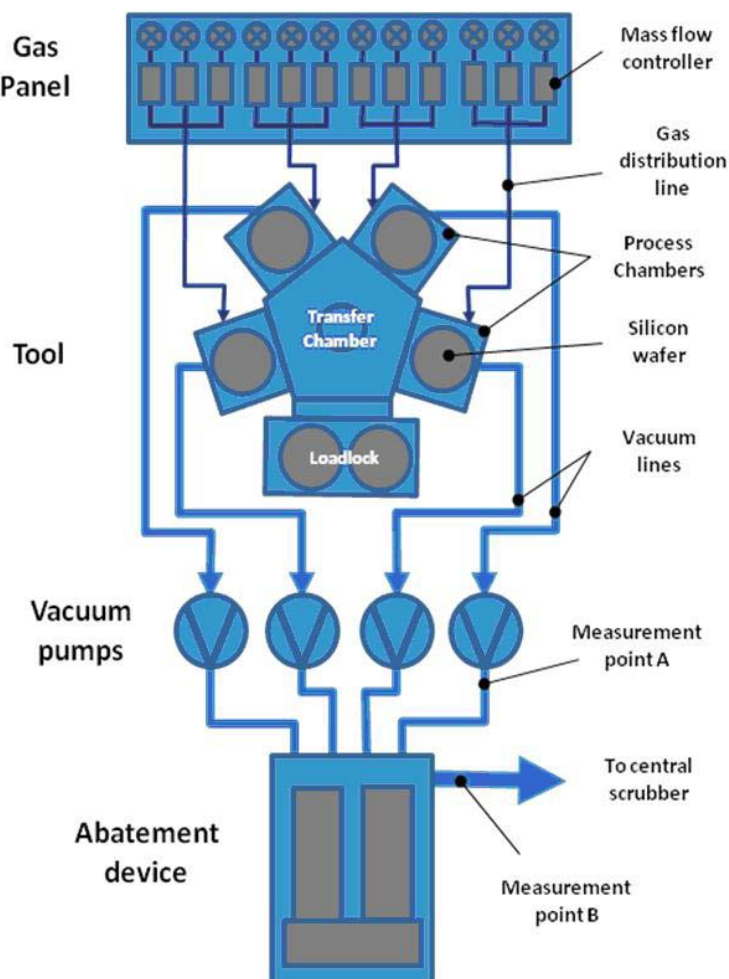
The ratios of baseline gas to substitute gas consumed for each cleaning process  $p$  and thickness  $t$  ( $C_{BL,p,t}/C_{PJ,p,t}$ ) shall be quantified. Such measurements should be conducted using Fourier transform infrared (FTIR) spectroscopy which quantifies emissions at the exhaust of the CVD chambers' vacuum pumps (pre-abatement measurement, point A of Figure 2);

- (b) If any abatement devices are included within the project boundary, the destruction removal efficiencies (DREs) of each gas  $i$  entering the abatement device during the baseline process ( $dBL,i,p$ ) and of each gas  $j$  entering the abatement devices during the substitute process ( $dPJ,j,p$ ) shall be measured. The DRE measurements should be based on FTIR and quadrupole mass spectroscopy (QMS) which quantifies emissions at the exhaust of the CVD chamber(s) vacuum pumps (pre-abatement measurement, point A of Figure 2) and at the exhaust of the abatement devices (post-abatement, point B of Figure 2).

The emission factors and the destruction removal efficiencies should be estimated conservatively by accounting for the CVD tools' configurations. A DRE of 99% is possible and would almost completely eliminate emissions from a given production process as the equations would demonstrate;

- (c) Based on the measurement obtained in Steps (a) and (b) above, the emission factors for each baseline and each substitute process  $p$  and thickness  $t$  ( $EF_{BL,p,t}$ ,  $EF_{PJ,p,t}$ ) are calculated. The emission factors should be estimated conservatively by accounting for experimental uncertainties.

**Figure 2. Schematic description of a CVD tool with four chambers connected to one abatement device**



### 5.3.3. Step P2.1: Determination of the c-C<sub>4</sub>F<sub>8</sub> use rate and CF<sub>4</sub> by product emission factors

28. For each substitute process  $p$  to be included in the project activity and thickness  $t$ , the mass of CF<sub>4</sub> and the mass of c-C<sub>4</sub>F<sub>8</sub> emitted during the substitute process at the exhaust of the CVD chamber vacuum pumps should be quantified. This measurement should be based on FTIR spectroscopy, repeating each measurement for a minimum of five deposition/clean cycles, and following the experimental procedures highlighted in the appendix.
29. The c-C<sub>4</sub>F<sub>8</sub> use rates ( $\dot{U}_{PJ,p,t}$ ) and the CF<sub>4</sub> by-product emission factors ( $\dot{B}_{CF_4,PJ,p,t}$ ) should then be calculated for each experimental point, as follows:

$$U_{PJ,n,p,t} = 1 - \frac{M_{c-C_4F_8,PJ,n,p,t}}{C_{PJ,n,p,t}} \quad \text{Equation (2)}$$

Where:

$U_{PJ,n,p,t}$	=	Use rate of c-C <sub>4</sub> F <sub>8</sub> cleaning gas during substitute process $p$ , with thickness $t$ (dimensionless)
$C_{PJ,n,p,t}$	=	Consumption of c-C <sub>4</sub> F <sub>8</sub> gas for substitute process $p$ , with thickness $t$ (g)
$M_{c-C_4F_8,PJ,n,p,t}$	=	Mass outflow of c-C <sub>4</sub> F <sub>8</sub> from CVD during substitute process $p$ , with thickness $t$ (g)
$n$	=	Number of individual measurements for each substitute process $p$ , with thickness $t$

$$B_{CF_4,PJ,n,p,t} = \frac{M_{CF_4,PJ,n,p,t}}{C_{PJ,n,p,t}} \quad \text{Equation (3)}$$

Where:

$B_{CF_4,PJ,n,p,t}$	=	CF <sub>4</sub> emission factor for substitute process $p$ and thickness $t$ (g CF <sub>4</sub> per g of c-C <sub>4</sub> F <sub>8</sub> cleaning gas used during substitute process)
$M_{CF_4,PJ,n,p,t}$	=	Mass outflow of CF <sub>4</sub> by-products from CVD during substitute process $p$ for thickness $t$ (g)
$C_{PJ,n,p,t}$	=	Consumption of c-C <sub>4</sub> F <sub>8</sub> for substitute process $p$ , with thickness $t$ (g)
$n$	=	Number of individual measurements for each substitute process $p$ , with thickness $t$

#### 5.3.4. Step P2.2: Determination of the destruction removal efficiency of the abatement device (when an abatement device is existent)

30. If any abatement device is installed under the project activity, the concentration of each gas  $j$  ( $j$ = CF<sub>4</sub> emitted as byproduct and c-C<sub>4</sub>F<sub>8</sub>) present at the exhaust of the abatement devices should be measured during the substitute process. The abatement devices' dilution factors (DFs) should also be measured, using the experimental procedures highlighted in the appendix.
31. Based on these measurements and the pre-abatement measurements the destruction removal efficiency (DRE) of each gas  $j$  entering the abatement device during the substitute process should be defined. As a conservative measure, the DRE for the substitute processes should be measured in the worst case scenario (lowest project DRE measured for the highest substitute gas flow), when all CVD chambers on a given tool are running substitute processes. This will ensure that the DRE values used to calculate project emissions are lower than the actual destruction removal efficiencies of the substitute processes' by-products.
32. The calculation of the DREs for the substitute processes should be performed using the following equation:

$$d_{PJ,j,p} = 1 - \frac{c_{out,j,p} \times DF}{c_{in,j,p}} \quad \text{Equation (4)}$$

Where:

$d_{PJ,j,p}$	=	Destruction removal efficiency (DRE) of gas $j$ measured during substitute process $p$ (dimensionless)
$c_{in,j,p}$	=	Concentration of gas $j$ entering the abatement device during substitute process $p$ (ppmv)
$DF$	=	Abatement device dilution factor (dimensionless)
$c_{out,j,p}$	=	Concentration of gas $j$ exiting the abatement device during substitute process $p$ (ppmv)

### 5.3.5. Step P2.3: Calculation of the project emission factors

33. Based on the c-C<sub>4</sub>F<sub>8</sub> use rates and CF<sub>4</sub> emission factors measured in Step P2.1 and the DRE values measured in Step P2.2, the overall emission factors for each substitute process  $p$  and each thickness  $t$  can be determined.
34. For each experimental data point (individual measurement for each substitute process  $p$ , with thickness  $t$ ), the substitute emission factors should be calculated as follows:

$$EF_{PJ,n,p,t} = (1 - U_{PJ,n,p,t}) \times (1 - d_{c-C_4F_8,PJ,p}) \times GWP_{c-C_4F_8} + B_{CF_4,PJ,n,p,t} \times (1 - d_{CF_4,PJ,p}) \times GWP_{CF_4} \quad \text{Equation (5)}$$

Where:

$EF_{PJ,n,p,t}$	=	Emission factor of substitute process $p$ for thickness $t$ (gCO <sub>2</sub> E per g of c-C <sub>4</sub> F <sub>8</sub> gas consumed)
$U_{PJ,n,p,t}$	=	Use rate of substitute cleaning gas during substitute process $p$ , for thickness $t$ (dimensionless)
$d_{c-C_4F_8,PJ,p}$	=	DRE of c-C <sub>4</sub> F <sub>8</sub> measured for substitute process $p$ (dimensionless)
$GWP_{c-C_4F_8}$	=	Global warming potential of c-C <sub>4</sub> F <sub>8</sub> (gCO <sub>2</sub> E/g of c-C <sub>4</sub> F <sub>8</sub> )
$B_{CF_4,PJ,n,p,t}$	=	CF <sub>4</sub> emission factor for substitute process $p$ and thickness $t$ (g CF <sub>4</sub> created per g of c-C <sub>4</sub> F <sub>8</sub> cleaning gas used during substitute process)
$d_{CF_4,PJ,p}$	=	DRE of the CF <sub>4</sub> by-products generated from the use of the substitute PFC gas during substitute process $p$ (dimensionless)
$GWP_{CF_4}$	=	Global warming potential of CF <sub>4</sub> (gCO <sub>2</sub> E/g of CF <sub>4</sub> )
$n$	=	Number of individual measurements for each substitute process $p$ , with thickness $t$

35. The average and the standard deviation of the substitute processes emission factors are calculated based on the measurements conducted above, and the values calculated in Step P2.3.
36. If there are  $n$  individual measurements for each substitute process  $p$  and each thickness point  $t$ , the average and standard deviations should be calculated as follows:

$$EF_{AVG,PJ,p,t} = \frac{\sum_{n=1}^N EF_{PJ,n,p,t}}{N} \quad \text{Equation (6)}$$

Where:

- $EF_{AVG,PJ,p,t}$  = Average emission factor of substitute process  $p$  for thickness  $t$  (gCO<sub>2</sub>e per g of c-C<sub>4</sub>F<sub>8</sub> consumed)
- $EF_{PJ,n,p,t}$  = Emission factor of substitute process  $p$  for thickness  $t$  of the measurement  $n$  (gCO<sub>2</sub>e per g of c-C<sub>4</sub>F<sub>8</sub> consumed)
- $N$  = Amount of measurements (minimum five)

$$\sigma_{EF,PJ,p,t} = \sqrt{\frac{\sum_{n=1}^N (EF_{PJ,n,p,t} - EF_{AVG,PJ,p,t})^2}{N - 1}} \quad \text{Equation (7)}$$

Where:

- $\sigma_{EF,PJ,p,t}$  = Standard deviation of emission factor for substitute process  $p$  and thickness  $t$  based on  $N$  measurements (gCO<sub>2</sub>e per g of c-C<sub>4</sub>F<sub>8</sub> gas consumed)
- $EF_{AVG,PJ,p,t}$  = Average emission factor of substitute process  $p$  for thickness  $t$  (gCO<sub>2</sub>e per g of c-C<sub>4</sub>F<sub>8</sub> gas consumed)
- $EF_{PJ,n,p,t}$  = Emission factor of substitute process  $p$  for thickness  $t$  of the measurement  $n$  (gCO<sub>2</sub> per g of c-C<sub>4</sub>F<sub>8</sub> gas consumed)
- $n$  = Number of individual measurements for each substitute process  $p$ , with thickness  $t$
- $N$  = Amount of measurements (minimum five)

37. As a conservative measure, the project developer will add to each  $\overline{EF_{PJ,p,t}} EF_{AVG,PJ,p,t}$  value an amount equal to 2.77 times the standard deviation of the emission factor ( $\sigma_{EF_{PJ,p,t}} \sigma_{EF_{PJ,p,t}}$ ). The result of this conservative estimate of the substitute processes' emission factors ( $\overline{EF_{PJ,p,t}} EF_{PJ,p,t}$ ) will be used to calculate the project emissions for the crediting periods, and will ensure a 95% confidence that the calculated project emissions used to determine the emissions reduction are higher than actual project emissions.
38. Emission factor for substitute process  $p$  and thickness  $t$  should be conservatively calculated using the following equation:

$$EF_{PJ,p,t} = EF_{AVG,PJ,p,t} + 2.77\sigma_{EF_{PJ,p,t}} \quad \text{Equation (8)}$$

Where:

- $EF_{PJ,p,t}$  = Conservative estimate of emission factor for substitute process  $p$  and thickness  $t$  (gCO<sub>2</sub>e per g of c-C<sub>4</sub>F<sub>8</sub> gas consumed)
- $EF_{AVG,PJ,p,t}$  = Average emission factor measured for a minimum of five wafers for substitute process  $p$  for thickness  $t$  (gCO<sub>2</sub>e per g of c-C<sub>4</sub>F<sub>8</sub> consumed for thickness  $t$ )
- $\sigma_{EF_{PJ,p,t}}$  = Standard deviation of emission factors measured for a minimum of five wafers for Substitute process  $p$  for thickness  $t$  (gCO<sub>2</sub>e per g of c-C<sub>4</sub>F<sub>8</sub> consumed)
- $p$  = Number of distinct cleaning process included in the project activity

#### 5.4. Baseline emissions

39. Determination of the baseline emissions require quantification of emission factors for each baseline process  $p$  ( $EF_{BL,p}$ ), which the project proponent should measure during the ex ante measurement campaign conducted prior to the start of project activities. The verification of the design, implementation and results of the ex ante campaign shall be performed by an independent qualified expert with documented experience installing and undertaking measurements of gaseous emissions in semiconductor/LCD/PV operations. The credentials of the independent expert will be provided to the DOE during verification.
40. As part of the analysis to estimate the baseline, and prior to validation, project developers should apply an anti-gaming provision to ensure there was no irregular increase in the baseline during the three years preceding the implementation of the project. After validation and implementation of the project, baseline emissions during the crediting periods should be calculated using the emission factors measured during the ex ante campaign by estimating the emissions that would have occurred if C<sub>2</sub>F<sub>6</sub> had been used instead of c-C<sub>4</sub>F<sub>8</sub>.
41. The approach for the measurement and calculation please refer to the *preambles* of the project emission section. In addition to the steps under the project emissions the following steps are mandatory for the three years preceding the implementation of the project:
  - (a) Documentation of consumption of baseline gas during the three years preceding the implementation of the project ( $C_{BL,p,x}$ ,  $x = -1$  to  $-3$ ) for each cleaning process  $p$  and for every thickness  $t$  to be included in the project activities;
  - (b) Documentation of historical projects that may have affected emission factors or baseline emissions during the three years preceding the implementation of the project;
  - (c) Application of the anti-gaming provision to ensure that there was no irregular increase in the baseline during the three years preceding the implementation of the project.
42. The calculation of the baseline emissions for crediting year  $y$  involves the following steps:

#### 5.4.1. Step B1: Calculation of baseline emissions

43. The emissions that would have occurred during the crediting year if  $C_2F_6$  had been used instead of  $c-C_4F_8$  should be calculated for each baseline process  $p$  included in the project activity. Thus, the baseline emissions for baseline process  $p$  during crediting year  $y$  will be calculated by monitoring the baseline emissions across all clean runs  $k$  performed during the crediting period. The total baseline emissions for year  $y$  should be calculated by summing up the contribution from each baseline process  $p$ . The consumption of PFC gas should be capped by the value based on the historical consumption of the  $C_2F_6$  gas corresponding to the averaged historical thickness for each cleaning process ( $t_{AVG,p}$ ).
44. The minimum and the maximum film thickness should be defined for each cleaning process  $p$ , included in the project activity based on actual production conditions to be run during the crediting period. Consumption of the  $C_2F_6$  gas should be calculated for the average value of the thickness during the ex ante campaign. For example, if the range of thickness is between a minimum of  $0.5\ \mu m$  and a maximum of  $1.5\ \mu m$ , consumption should be calculated for  $1.0\ \mu m$ .

##### 5.4.1.1. Determination of $rp,t$

45. The ratio of mass of  $C_2F_6$  gas consumed to the mass of  $c-C_4F_8$  gas consumed for the project activity ( $C_{BL,p,t}/C_{PJ,p,t}$ ) measured during the development of the  $c-C_4F_8$  cleaning recipes shall be quantified for each cleaning process  $p$  and range of thickness  $t$  included in the project activity. Please refer to the appendix for determination of the proper thickness range and thickness points.
46. The baseline emissions should be adjusted for the cases when production is falling by introduction of the cap: When production in any given crediting year  $y$  is less than during any of the three years preceding the implementation of the project ( $M2PT_y < \min(M2PT_{(x,-1,x,-2,x,-3)})$ ) then 'BE' should be discounted by the ratio of production in the project year divided by the production in the lowest of the three years preceding the implementation of the project. For example, if in project year  $y$   $10,000\ m^2$  of product were produced and the lowest historical year production was found in  $x-3$  at  $12,000\ m^2$  then emission reduction would be multiplied by  $10,000/12,000$  to determine the actual cap for the year  $y$ .
47. If there are  $n$  distinct baseline processes  $p$  included in the project, the baseline emissions for crediting year  $y$  should be calculated as the minimum of baseline emissions reconstructed from consumption of substitute gas, historical consumption, and historical consumption per area of substrate multiplied by the production of substrate in the year  $y$ :



$$\begin{aligned}
 & BE_y \\
 & = \min \left[ \sum_p \sum_k (C_{PJ,y,p,t,k} \right. \\
 & \quad \times r_{p,t}), C_{BL,cap}, \min \left( \frac{C_{BL,x-1}}{M2TP_{x-1}}, \frac{C_{BL,x-2}}{M2TP_{x-2}}, \frac{C_{BL,x-3}}{M2TP_{x-3}}, \sum_y \frac{\sum_p \sum_k C_{PJ,y,p,t,k}}{M2TP_y} \right. \\
 & \quad \left. \left. \times r_{p,t} \right) \times M2TP_y \right] \times EF_{BL,p,t} \times 10^{-6}
 \end{aligned}
 \tag{Equation (9)}$$

With

$$r_{p,t} = \frac{C_{BL,p,t}}{C_{PJ,p,t}} \tag{Equation (10)}$$

And

Where:

$BE_y$	= Baseline emissions for crediting year $y$ (t CO <sub>2</sub> e)
$C_{PJ,y,p,t,k}$	= Consumption of c-C <sub>4</sub> F <sub>8</sub> for clean run $k$ undertaken for substitute process $p$ with thickness $t$ for crediting year $y$ (g )
$r$	= Ratio of mass of C <sub>2</sub> F <sub>6</sub> gas consumed for baseline process $p$ to mass of c-C <sub>4</sub> F <sub>8</sub> gas consumed for substitute process $p$ , for thickness $t$ (dimensionless)
$C_{BL,p,t}$	= Mass of C <sub>2</sub> F <sub>6</sub> gas consumed for baseline process $p$ , for thickness $t$
$C_{PJ,p,t}$	= Mass of c-C <sub>4</sub> F <sub>8</sub> gas consumed for substitute process $p$ , for thickness $t$
$C_{BL,cap}$	= Capped mass of C <sub>2</sub> F <sub>6</sub> gas consumed, defined as the average consumption of C <sub>2</sub> F <sub>6</sub> in the historical three years
$C_{BL,x-1,x-2,x-3}$	= Mass of C <sub>2</sub> F <sub>6</sub> gas consumed, during historical year $x$ ( $x = -3$ to $-1$ )

$EF_{BL,p,t}$	=	Conservative estimate of emission factor for baseline process $p$ and thickness $t$ (gCO <sub>2</sub> e per g of C <sub>2</sub> F <sub>6</sub> gas consumed)
$p$	=	Number of distinct cleaning process included in the project activity (integer)
$t$	=	Thickness of the thin film deposited in the CVD chamber during clean run $k$ (μm)
$k$	=	Clean run number for cleaning process $p$
$M2TP_y$	=	Surface area of substrate produced during the crediting year $y$ (m <sup>2</sup> )
$M2TP_{(x-1,x-2,x-3)}$	=	Surface area of substrate produced during historical year $x$ ( $x = -3$ to $-1$ ), (m <sup>2</sup> )

#### 5.4.2. Step B2: Determination of baseline emission factors ( $EF_{BL,p,t}$ )

48. The approach for the measurement and calculations please refer to the preamble of the corresponding section of project emissions.

##### 5.4.2.1. Step B2.1: Determination of the C<sub>2</sub>F<sub>6</sub> use rate and CF<sub>4</sub> by product emission factors

49. The mass of CF<sub>4</sub> and the mass of C<sub>2</sub>F<sub>6</sub> emitted during the baseline process at the exhaust of the CVD chamber vacuum pumps should be quantified for each baseline process  $p$  and thickness  $t$  to be included in the project activity. This measurement should be based on FTIR spectroscopy, repeating each measurement for a minimum of five deposition/clean cycles, and following the experimental procedures highlighted in the appendix. The consumption of C<sub>2</sub>F<sub>6</sub> for each baseline process  $p$  and thickness  $t$  should also be measured.
50. The C<sub>2</sub>F<sub>6</sub> use rates ( $\dot{U}_{BS,p,t}$ ) and the CF<sub>4</sub> by-product emission factors ( $\dot{B}_{CF_4,BS,p,t}$ ) for each experimental point should be calculated, using equations below:

$$U_{BL,n,p,t} = 1 - \frac{M_{C_2F_6,BL,n,p,t}}{C_{BL,n,p,t}} \quad \text{Equation (11)}$$

Where:

$U_{BL,n,p,t}$	=	Use rate of C <sub>2</sub> F <sub>6</sub> cleaning gas during baseline process $p$ , with thickness $t$ (dimensionless)
$C_{BL,n,p,t}$	=	Consumption of C <sub>2</sub> F <sub>6</sub> for baseline process $p$ with thickness $t$ (g)
$M_{C_2F_6,BL,n,p,t}$	=	Mass outflow of C <sub>2</sub> F <sub>6</sub> during baseline process $p$ , with thickness $t$ (g)
$n$	=	Number of individual measurement for each baseline process $p$ , with thickness $t$

$$B_{CF_4,BL,n,p,t} = \frac{M_{CF_4,BL,n,p,t}}{C_{BL,n,p,t}} \quad \text{Equation (12)}$$

Where:

$B_{CF_4,BL,n,p,t}$	=	CF <sub>4</sub> emission factor for baseline process $p$ and thickness $t$ (g CF <sub>4</sub> per g of C <sub>2</sub> F <sub>6</sub> cleaning gas used during baseline process)
$M_{CF_4,BL,n,p,t}$	=	Mass outflow of CF <sub>4</sub> by-products during baseline process $p$ for thickness $t$ (g)
$C_{BL,n,p,t}$	=	Consumption of C <sub>2</sub> F <sub>6</sub> for baseline process $p$ with thickness $t$ (g)
$n$	=	Number of individual measurement for each baseline process $p$ , with thickness $t$

#### 5.4.2.2. Step B2.2: Determination of the destruction removal efficiency of the abatement device (when an abatement device is existent)

51. If any abatement device is installed under the project activity, the concentration of each gas  $i$  ( $i = \text{CF}_4$  and  $\text{C}_2\text{F}_6$ ) present at the exhaust of the abatement devices should be measured during the baseline process. The abatement devices' dilution factors (DFs) should also be measured, using the experimental procedures highlighted in the appendix. Based on these measurements and the pre-abatement measurements taken in Step B.2.1, the destruction removal efficiency (DRE) of each gas  $i$  entering abatement device during the baseline process should be defined. As a conservative measure, the DRE for the baseline process for each process 'p' should be measured in the best case scenario (highest baseline DRE measured for the lowest baseline gas flow), when only one CVD chamber on a given tool is running a cleaning process (the other chambers being kept idle). This will ensure that the DRE values used to calculate baseline emissions are higher than the actual destruction removal efficiencies of the baseline processes' by-products.
52. The calculation of the DREs for the baseline processes should be performed using equation 13 below:

$$d_{BL,i,p} = 1 - \frac{c_{out,i,p} \times DF}{c_{in,i,p}} \quad \text{Equation (13)}$$

Where:

$d_{BL,i,p}$	=	Destruction removal efficiency (DRE) of gas $i$ measured during baseline process $p$ (dimensionless)
$c_{in,i,p}$	=	Concentration of gas $i$ entering the abatement device during baseline process $p$ (ppmv)
$DF$	=	Abatement device dilution factor (dimensionless)
$c_{out,i,p}$	=	Concentration of gas $i$ exiting the abatement device during baseline process $p$ (ppmv)

### 5.4.2.3. Step B2.3: Calculation of the baseline emission factors

53. Based on the  $C_2F_6$  use rates and  $CF_4$  emission factors measured in Step B2.1 and the DRE values measured in Step B2.2, the emission factors for the baseline processes, for each baseline process  $p$  and each thickness  $t$  should be determined. Essentially, these baseline emission factors will allow to account for the global warming potentials of all FC gases contained at the exhaust of the abatement device during the baseline process, and to calculate  $CO_2$ -equivalent emissions per unit mass of  $C_2F_6$  gas consumed.
54. For each experimental data point (individual measurement for each substitute process  $p$ , with thickness  $t$ ), baseline emission factors should be calculated using the following equation:

$$EF_{BL,n,p,t} = (1 - U_{BL,n,p,t}) \times (1 - d_{C_2F_6,BL,p}) \times GWP_{C_2F_6} + B_{CF_4,BL,n,p,t} \times (1 - d_{CF_4,BL,p}) \times GWP_{CF_4} \quad \text{Equation (14)}$$

Where:

$EF_{BL,n,p,t}$	=	Emission factor of baseline process $p$ for thickness $t$ (gCO <sub>2</sub> e per g of $C_2F_6$ gas consumed)
$U_{BL,n,p,t}$	=	Use rate of $C_2F_6$ cleaning gas during baseline process $p$ , for thickness $t$ (dimensionless)
$d_{C_2F_6,BL,p}$	=	DRE of $C_2F_6$ measured for baseline process $p$ (dimensionless)
$GWP_{C_2F_6}$	=	Global warming potential of $C_2F_6$ (gCO <sub>2</sub> e/g of $C_2F_6$ )
$B_{CF_4,BL,n,p,t}$	=	$CF_4$ emission factor for baseline process $p$ and thickness $t$ (g $CF_4$ created per g of $C_2F_6$ cleaning gas used during baseline process)
$d_{CF_4,BL,p}$	=	DRE of the $CF_4$ by-products generated from the use of the baseline PFC gas during baseline process $p$ (dimensionless)
$GWP_{CF_4}$	=	Global warming potential of $CF_4$ (gCO <sub>2</sub> e/g of $CF_4$ )
$n$	=	Number of individual measurements for each substitute process $p$ , with thickness $t$

55. Based on the measurements and the values calculated in the equation above, the average and the standard deviation of the baseline processes emission factors should be calculated.
56. If there are  $n$  individual measurements for each baseline process  $p$  and each thickness point  $t$ , the average and standard deviations will be calculated as follows:

$$EF_{AVG,BL,p,t} = \frac{\sum_{n=1}^N EF_{BL,n,p,t}}{N} \quad \text{Equation (15)}$$

Where:

$EF_{AVG,BL,p,t}$  = Average emission factor of baseline process  $p$  for thickness  $t$  (gCO<sub>2</sub>e per g of C<sub>2</sub>F<sub>6</sub> gas consumed)

$EF_{BL,n,p,t}$  = Emission factor of baseline process  $p$  for thickness  $t$  of the measurement  $n$  (gCO<sub>2</sub>e per g of C<sub>2</sub>F<sub>6</sub> gas consumed)

$$\sigma_{EF_{BL,p,t}} = \sqrt{\frac{\sum_{n=1}^N (EF_{BL,n,p,t} - EF_{AVG,BL,p,t})^2}{N-1}} \quad \text{Equation (16)}$$

Where:

$\sigma_{EF_{BL,p,t}}$  = Standard deviation of emission factor for baseline process  $p$  and thickness  $t$  based on  $N$  measurements (gCO<sub>2</sub>e per g of C<sub>2</sub>F<sub>6</sub> gas consumed)

$EF_{AVG,BL,p,t}$  = Average emission factor of baseline process  $p$  for thickness  $t$  (gCO<sub>2</sub>e per g of C<sub>2</sub>F<sub>6</sub> gas consumed)

$EF_{BL,n,p,t}$  = Emission factor of baseline process  $p$  for thickness  $t$  of the measurement  $n$  (gCO<sub>2</sub>e per g of C<sub>2</sub>F<sub>6</sub> gas consumed)

$n$  = Number of individual measurements for each substitute process  $p$ , with thickness  $t$

$N$  = Amount of measurements (minimum five)

57. As a conservative measure, the project developer will subtract from each  $EF_{AVG,BL,p,t}$  value an amount equal to 2.77 times the standard deviation of the emission factor ( $\sigma_{EF_{BL,p,t}}$ ). The result of this conservative estimate of the baseline processes' emission factors ( $EF_{AVG,BL,p,t} - 2.77 \sigma_{EF_{BL,p,t}}$ ) will be used to calculate the baseline emissions for the historical period and the baseline emissions for the crediting periods, and will ensure a 95% confidence that the estimated baseline emissions are lower than the actual baseline emissions.
58. As a conservative measure, the project developer will subtract from each  $EF_{AVG,BL,p,t}$  value an amount equal to 2.77 times the standard deviation of the emission factor ( $\sigma_{EF_{BL,p,t}}$ ). The result of this conservative estimate of the baseline processes' emission factors ( $EF_{AVG,BL,p,t} - 2.77 \sigma_{EF_{BL,p,t}}$ ) will be used to calculate the baseline emissions for the historical period and the baseline emissions for the crediting periods, and will ensure a 95% confidence that the estimated baseline emissions are higher than the actual baseline emissions.
59. As a conservative measure, the project developer will subtract from each  $EF_{AVG,BL,p,t}$  value an amount equal to 2.77 times the standard deviation of the emission

factor ( $\sigma_{EF_{BL,p,t}}$ ). The result of this conservative estimate of the baseline processes' emission factors ( $EF_{BL,p,t}$ ) will be used to calculate the baseline emissions for the historical period and the baseline emissions for the crediting periods, and will ensure a 95% confidence that the estimated baseline emissions are higher than the actual baseline emissions.

$$EF_{BL,p,t} = (EF_{AVG,BL,p,t} - 2.77 \times \sigma_{EF_{BL,p,t}}) \times MS_q \quad \text{Equation (17)}$$

Where:

$EF_{BL,p,t}$	=	Conservative estimate of emission factor for baseline process $p$ and thickness $t$ (gCO <sub>2</sub> e per g of C <sub>2</sub> F <sub>6</sub> gas consumed)
$EF_{AVG,BL,p,t}$	=	Average emission factor measured for a minimum of five wafers for baseline process $p$ for thickness $t$ (gCO <sub>2</sub> e per g of C <sub>2</sub> F <sub>6</sub> gas consumed)
$\sigma_{EF_{BL,p,t}}$	=	Standard deviation of emission factor for baseline process $p$ and thickness $t$ based on a minimum of five measurements (gCO <sub>2</sub> e per g of C <sub>2</sub> F <sub>6</sub> gas consumed)
$p$	=	Number of distinct cleaning process included in the project activity
$t$	=	Thickness of the thin film deposited in the CVD chamber (μm)
$MS_q$	=	Market share of baseline technology (Uses of gases in semiconductor industries) (Fraction)

#### 5.4.3. Step B3: Application of anti-gaming provision

60. Upon completion of the ex ante measurement campaign, the project developers should quantify the consumption of baseline PFC gas for every cleaning process  $p$  during the three years preceding the start of the project (historical period). Developers should document any process changes that may have affected the baseline during the historical period, and is required to demonstrate that there was no increase in the baseline. The steps to applying the anti-gaming provision are as follows:
- Documentation of the consumption of C<sub>2</sub>F<sub>6</sub> baseline gas for the three years preceding the implementation of the project ( $C_{BL,p,x}$ ,  $x = -3$  to  $-1$ ) for every cleaning process  $p$  to be included in the project activity;
  - Documentation of historical projects such as process changes that may have affected emission factors ( $EF_{BL,p,x}$ ,  $x = -3$  to  $-1$ ) for every cleaning process  $p$  to be included in the project activity, during the historical period or historical projects that might otherwise affect the methodology's applicability conditions;
  - Provision of evidence that, for each cleaning process  $p$  included in the project activity, there was no increase in the baseline during the three years preceding the implementation of the project. Specifically, it shall be shown that there was no increase in the historical emission factors ( $EF_{BL,p,x}$ ) for any particular cleaning process  $p$ , that is any unique combination of: (i) CVD thin film deposition application; (ii) specific model of CVD tool; and (iii) specific model of abatement device;

- (i) To demonstrate that a cleaning process was not altered to increase  $EF_{BL,p,x}$  during the historical period, the project proponent may rely on: (i) direct experimental evidence; (ii) clear and convincing evidence from the scientific literature showing that specific changes to substantially similar cleaning processes do indeed lead to decreased emissions; or, (iii) the IPCC Tier 2b or Tier 3 methodologies;
- (ii) In the absence of direct experimental evidence, the most conservative baseline estimate available from either the scientific literature or the Tier 2b method shall be adopted;
- (d) When it cannot be demonstrated that emission factors related to a particular baseline process  $p$  did not increase during the historical period, that particular baseline process shall be disqualified from the project (i.e. no credits will be allowed for that particular baseline process);
  - (i) This provision does not apply to cleaning process changes where it can be demonstrated that historical projects led to a decrease in baseline emissions for a specific cleaning process  $p$ . For example, the anti-gaming provision does not apply when historical process changes led to a reduction in emissions through optimization of processes, implementation of alternative chemistries providing reduced overall CO<sub>2</sub>-equivalent emissions, or other legitimate improvement activities;
  - (ii) This approach is conservative as a reduction in the baseline as a result of process optimization in the historical years would be fully captured in the calculations.

## 5.5. Leakage

61. No leakage is expected from this methodology.

## 5.6. Emission reductions

62. For each crediting year, emission reductions will be calculated as the CO<sub>2</sub>-equivalent difference between actual project emissions (emissions resulting from the use of the substitute PFC gas, c-C<sub>4</sub>F<sub>8</sub>) and the emissions that would have occurred if the baseline (C<sub>2</sub>F<sub>6</sub>) PFC gas would have been used.
63. Thus, emission reductions for crediting year  $y$  shall be calculated as follows:

$$ER_y = (BE_y - PE_y) \quad \text{Equation (18)}$$

Where:

- $ER_y$  = Emission reductions in year  $y$  (t CO<sub>2</sub>e)
- $BE_y$  = Baseline emissions in year  $y$  (t CO<sub>2</sub>e)
- $PE_y$  = Project emissions in year  $y$  (t CO<sub>2</sub>e)

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

64. 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”.

### 5.6.2. Data and parameters not monitored

65. In addition to the parameters listed in section 5.6.2 below, the provisions on data and parameters not monitored in the tools referred to in this methodology apply.

**Data / Parameter table 1.**

<b>Data / Parameter:</b>	$GWP_i$
Data unit:	t CO <sub>2</sub> /tFC <sub>i</sub>
Description:	Global warming potential of FC gas <i>i</i> valid for the first commitment period
Source of data:	IPCC
Measurement procedures (if any):	-
Value to be applied:	Project participants shall update GWPs according to the most recent COP/MOP approved IPCC report. For the first commitment period: $GWP_{CF4}=7,390$ $GWP_{C2F6}=12,200$ $GWP_{C3F8}=8,830$ $GWP_{C-C4F8}=10,300$
Any comment:	These values apply for the calculation of the baseline and project emissions

**Data / Parameter table 2.**

<b>Data / Parameter:</b>	$M2TP_{(x-1,x-2,x-3)}$
Data unit:	m <sup>2</sup>
Description:	Surface area of substrate produced in historical years 'x' (x= -3 to -1)
Source of data:	Production records
Measurement procedures (if any):	-
Any comment:	-



**Data / Parameter table 3.**

<b>Data / Parameter:</b>	$M_{C_2F_6,BL,n,p,t}$
Data unit:	G
Description:	Mass outflow of $C_2F_6$ during baseline process $p$ , with thickness $t$
Source of data:	Ex ante measurement campaign
Measurement procedures (if any):	Measured using FTIR spectrometer for a minimum of five wafers
Any comment:	-

**Data / Parameter table 4.**

<b>Data / Parameter:</b>	$C_{BL,n,p,t}$
Data unit:	G
Description:	Consumption of $C_2F_6$ for baseline process $p$ with thickness $t$
Source of data:	Ex ante measurement campaign
Measurement procedures (if any):	Measured through CVD tool mass flow controller (MFC) by integrating its signal over time. Project participants will follow the MFC manufacturers' calibration and maintenance procedures
Any comment:	See appendix for details

**Data / Parameter table 5.**

<b>Data / Parameter:</b>	$M_{CF_4,BL,n,p,t}$
Data unit:	G
Description:	Mass outflow of $CF_4$ by-products during baseline process $p$ for thickness $t$
Source of data:	Ex ante measurement campaign
Measurement procedures (if any):	Measured using FTIR spectrometer for a minimum of five wafers
Any comment:	-

**Data / Parameter table 6.**

<b>Data / Parameter:</b>	$c_{in,i,p}$
Data unit:	Ppmv
Description:	Concentration of gas $i$ entering the abatement device during baseline process $p$

Source of data:	Ex ante measurement campaign
Measurement procedures (if any):	Measured per EPA protocol using Fourier Transform Infrared (FTIR) spectrometer
Any comment:	-

**Data / Parameter table 7.**

<b>Data / Parameter:</b>	$C_{out,i,p}$
Data unit:	Ppmv
Description:	Concentration of gas $i$ exiting the abatement device during baseline process $p$
Source of data:	Ex ante measurement campaign
Measurement procedures (if any):	Measured per EPA protocol using Fourier Transform Infrared (FTIR) spectrometer
Any comment:	-

**Data / Parameter table 8.**

<b>Data / Parameter:</b>	$C_{BL,x-1,x-2,x-3}$
Data unit:	G
Description:	Mass of $C_2F_6$ gas consumed, during historical year $x$ ( $x = -3$ to $-1$ )
Source of data:	Historical record of consumption
Measurement procedures (if any):	Inventories, taking into account fraction of gas remaining in shipping container after use (heel), with a default of 0.10 according to IPCC 2006 Guidelines vol.3 ch.6
Any comment:	-

## 6. Monitoring methodology

### 6.1. Direct monitoring of key parameters

66. During each crediting year, the project proponent should directly monitor all key parameters related to estimation of the baseline and project emissions. The project proponent should continuously monitor the consumption of  $c-C_4F_8$  substitute gas, and all key cleaning process parameters (flow, plasma power, pressure, thickness and temperature) to ensure that there is no drift in the cleaning process set-points. In addition, the project proponent should implement an annual verification plan to ensure that the emission factors measured during the ex ante campaign have not drifted and to verify that the calculation of the project emissions is accurate.
67. As part of the monitoring methodology, project participants should also be required to record any process changes to any cleaning process  $p$ , and to document and follow proper maintenance procedures. The project proponent is also 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:

- (a) All data collected as part of monitoring should be archived electronically and kept for at least 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 of section "Data and parameters monitored". All measurements should be conducted with calibrated measurement equipment according to relevant industry standards;
- (b) The monitoring provisions in the tools referred to in this methodology apply;
- (c) Project emissions should be calculated based on the continuous monitoring of the consumption of substitute cleaning gas ( $C_{PJ,p,t,k}$ ) for each substitute CVD chamber cleaning run. The measurement of the substitute FC gas consumed will be provided by the CVD tools' mass flow controllers (MFCs), which signal will be integrated over time to calculate the consumption in real time;
- (d) All key process parameters for all substitute processes (pressure, temperature, plasma power, flows) should be continuously monitored to ensure that the relevant emission factors (utilization efficiencies, by-products emissions factors, DRE) do not drift from the center-point processes determined during the ex ante measurement campaigns;
- (e) The project developer should follow the quality assurance and quality control (QA/QC) procedures contained in the list of monitored parameters, the QA/QC procedures highlighted in the appendix for the measurement of the emission factors and the measurement of the DRE.

## 6.2. Verification of emissions factors

68. At the beginning of each crediting year, the DOE should systematically select a number of substitute processes representing 20% of the total number of substitute processes and range of thickness combinations implemented as part of the project (excluding processes verified in preceding years) and verify the accuracy of the emission factors measured during the ex ante measurement campaign. For the avoidance of doubt, the validation DOE will pick the first 20% of processes to include in the first campaign and the verification DOE will choose all subsequent processes for further campaigns.
- (a) For avoidance of doubt, if there are  $m=100$  distinct substitute processes and range of thickness combinations (i.e. 100 distinct processes and thickness range) implemented as part of the project, the project developer should, every crediting year, randomly select twenty of the processes and their thickness range not verified in previous years and repeat the measurement of the emission factors ( $EF_{PJ,p,t}$ ) performed during the ex ante campaign, following the same experimental protocol as the one used during the ex ante campaign.
  - (b) The selection should be done before the beginning of the crediting year in the first year during the validation visit and in subsequent years during the verification visit. In case the total number of process 'p' does not divide evenly by 20, the number will be rounded up conservatively (i.e. if  $n=95$  processes, the number of processes verified every year will be rounded up to twenty).

69. For each verified cleaning process, the project developer shall ensure that a deviation of no more than  $\pm 2.5\%$  between the verified and the ex ante emission factors has occurred.
- (a) If no deviation greater than  $\pm 2.5\%$  is found in the sample, then it can be assumed that all processes fall within the specified conditions;
  - (b) If a deviation of greater than  $\pm 2.5\%$  is found in the sample, then the project participants can either:
    - (i) Discount emission reductions that represent the proportion of production by the process identified to be in the deviation;
    - (ii) Use newly measured emission factors fully discounted by the newly measured standard deviation.

### **6.3. Verification of the lifetime of the production lines**

70. At the beginning of each crediting year, the project developer should apply the “Tool to determine the remaining lifetime of equipment” to each project line included in the project boundaries. In case remaining lifetime of any project line will be less than one year line that line should be excluded from the project activity.

### **6.4. Verification of the type of PFC gas used**

71. As a part of verification process, the DOE should check that no cleaning gas other than the substitute PFC gas was used in the CVD reactors within the project boundary during the crediting year  $y$ .

### **6.5. Changes in emission factors**

72. The project proponent should record any process changes that might affect the calculation of the baseline and project emissions. Any change in key process parameters (flow, plasma power, pressure, thickness range and temperature) will disqualify the process from capturing credits. However, the project developer can re-qualify the process, using the same qualification procedure as for the ex ante campaign.

### **6.6. Maintenance and repairs, calibrations and QA/QC procedures**

73. The project proponent should record any maintenance procedures that might affect the calculation of the baseline and project emissions. For example; MFC calibration or other CVD chambers' maintenance procedures resulting in flowing of the substitute gas without a plasma being struck in the CVD chamber shall be recorded, and the mass of substitute gas consumed during such procedures shall be discounted from the project emissions calculation. Similarly, any failures or maintenance activities resulting in abatement devices' downtime (or bypassing) shall be recorded, and the mass of substitute gas consumed during such failures or maintenance activities shall be discounted from the project emissions.
74. Periodic calibration and maintenance of the measurement devices should be performed in accordance with the equipment supplier's recommendations and in accordance with the procedures outlined in this methodology.

75. For quality assurance of automated measurement systems the project developer should in principle follow the guidelines of EN 14181 or other similar national or international standard.
76. For quality assurance of measurement procedures the project developer should in principle follow the guidelines of ISO 14956 or other similar national or international standard.
77. In addition, the monitoring provisions in the tools referred to in this methodology apply.

## 6.7. Data and parameters monitored

Data / Parameter table 9.

Data / Parameter:	$C_{PJ,y,p,t,k}$
Data unit:	g
Description:	Consumption of c-C <sub>4</sub> F <sub>8</sub> for clean run $k$ undertaken for substitute process $p$ with thickness $t$ for crediting year $y$
Source of data:	CVD tool controller
Measurement procedures (if any):	The mass of substitute PFC gas consumed will be calculated from the CVD tool mass flow controller by integrating its signal over time
Monitoring frequency:	Continuous
QA/QC procedures:	Project participants will follow the MFC manufacturers' calibration and maintenance procedures
Any comment:	-

Data / Parameter table 10.

Data / Parameter:	$M2TP_y$
Data unit:	m <sup>2</sup>
Description:	Surface area of substrate produced in year $y$
Source of data:	Production records
Measurement procedures (if any):	-
Monitoring frequency:	Once per year
QA/QC procedures:	-
Any comment:	-

**Data / Parameter table 11.**

<b>Data / Parameter:</b>	$M_{c-C_4F_8,PJ,n,p,t}$
Data unit:	G
Description:	Mass outflow of c-C <sub>4</sub> F <sub>8</sub> from CVD during substitute process <i>p</i> , with thickness <i>t</i>
Source of data:	Verification of emission factor
Measurement procedures (if any):	Measured using FTIR spectrometer for a minimum of five wafers
Monitoring frequency:	Once per year
QA/QC procedures:	See section “Monitoring methodology” for the details
Any comment:	-

**Data / Parameter table 12.**

<b>Data / Parameter:</b>	$C_{PJ,n,p,t}$
Data unit:	G
Description:	Consumption of c-C <sub>4</sub> F <sub>8</sub> gas for substitute process <i>p</i> , with thickness <i>t</i>
Source of data:	Verification of emission factor
Measurement procedures (if any):	Measured through CVD tool mass flow controller (MFC) by integrating its signal over time. Project participants will follow the MFC manufacturers’ calibration and maintenance procedures
Monitoring frequency:	Once per year
QA/QC procedures:	See section “Monitoring methodology” for the details
Any comment:	-

**Data / Parameter table 13.**

<b>Data / Parameter:</b>	$M_{CF_4,PJ,n,p,t}$
Data unit:	G
Description:	Mass outflow of CF <sub>4</sub> by-products from CVD during substitute process <i>p</i> for thickness <i>t</i>
Source of data:	Verification of emission factor
Measurement procedures (if any):	Measured using FTIR spectrometer for a minimum of five wafers
Monitoring frequency:	Once per year
QA/QC procedures:	See section “Monitoring methodology” for the details
Any comment:	-

**Data / Parameter table 14.**

<b>Data / Parameter:</b>	$C_{in,j,p}$
Data unit:	ppmv
Description:	Concentration of gas $i$ entering the abatement device during substitute process $p$
Source of data:	Verification of emission factor
Measurement procedures (if any):	Measured per EPA protocol using Fourier Transform Infrared (FTIR) spectrometer
Monitoring frequency:	Once per year
QA/QC procedures:	See section “Monitoring methodology” for the details
Any comment:	-

**Data / Parameter table 15.**

<b>Data / Parameter:</b>	$C_{out,j,p}$
Data unit:	ppmv
Description:	Concentration of gas $i$ exiting the abatement device during substitute process $p$
Source of data:	Verification of emission factor
Measurement procedures (if any):	Measured per EPA protocol using Fourier Transform Infrared (FTIR) spectrometer
Monitoring frequency:	Once per year
QA/QC procedures:	See section “Monitoring methodology” for the details
Any comment:	-

**Data / Parameter table 16.**

<b>Data / Parameter:</b>	$MS_q$
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 industries within the applicable geographic area, as identified according to the “Combined tool to identify the baseline scenario and demonstrate additionality” and with a comparable capacity from 50% to 150% of semiconductors produced (surface area of substrate produced in m<sup>2</sup>) shall be evaluated for the technology (uses of gases like C<sub>2</sub>F<sub>6</sub> etc.). This will be done based on the latest available data on every 7<sup>th</sup> year and 14<sup>th</sup> year for the project activities which have applied for renewable crediting period. The parameter shall be the fraction of semiconductor industries which are using the gases (C<sub>2</sub>F<sub>6</sub> etc.) 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>The maximum values of MS<sub>q</sub> should be used:  7<sup>th</sup> year onwards: (MS<sub>q</sub> value from 7<sup>th</sup> year market survey; 0.6)  14<sup>th</sup> year onward: (MS<sub>q</sub> value from 14<sup>th</sup> year market survey; 0.2)</p>
Monitoring frequency:	7 <sup>th</sup> year and 14 <sup>th</sup> year for the project activities applying for renewable of crediting period. During the first and fixed crediting period MS <sub>q</sub> will be considered as 1
QA/QC procedures:	-
Any comment:	-



## Appendix 1. Experimental protocols

### 1. Introduction

1. The Sematech guidelines and the EPA protocols specified above should be followed for the quantification of effluents. 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 necessary and mandatory for the sampling of effluents, the calibration of the FTIR (Fourier Transform Infrared) and QMS (Quadrupole Mass Spectrometer) equipment, the measurements of the pumps' and abatement dilution factors, the calculation of emission factors, and maintenance and QA/QC procedures.

### 2. Safety

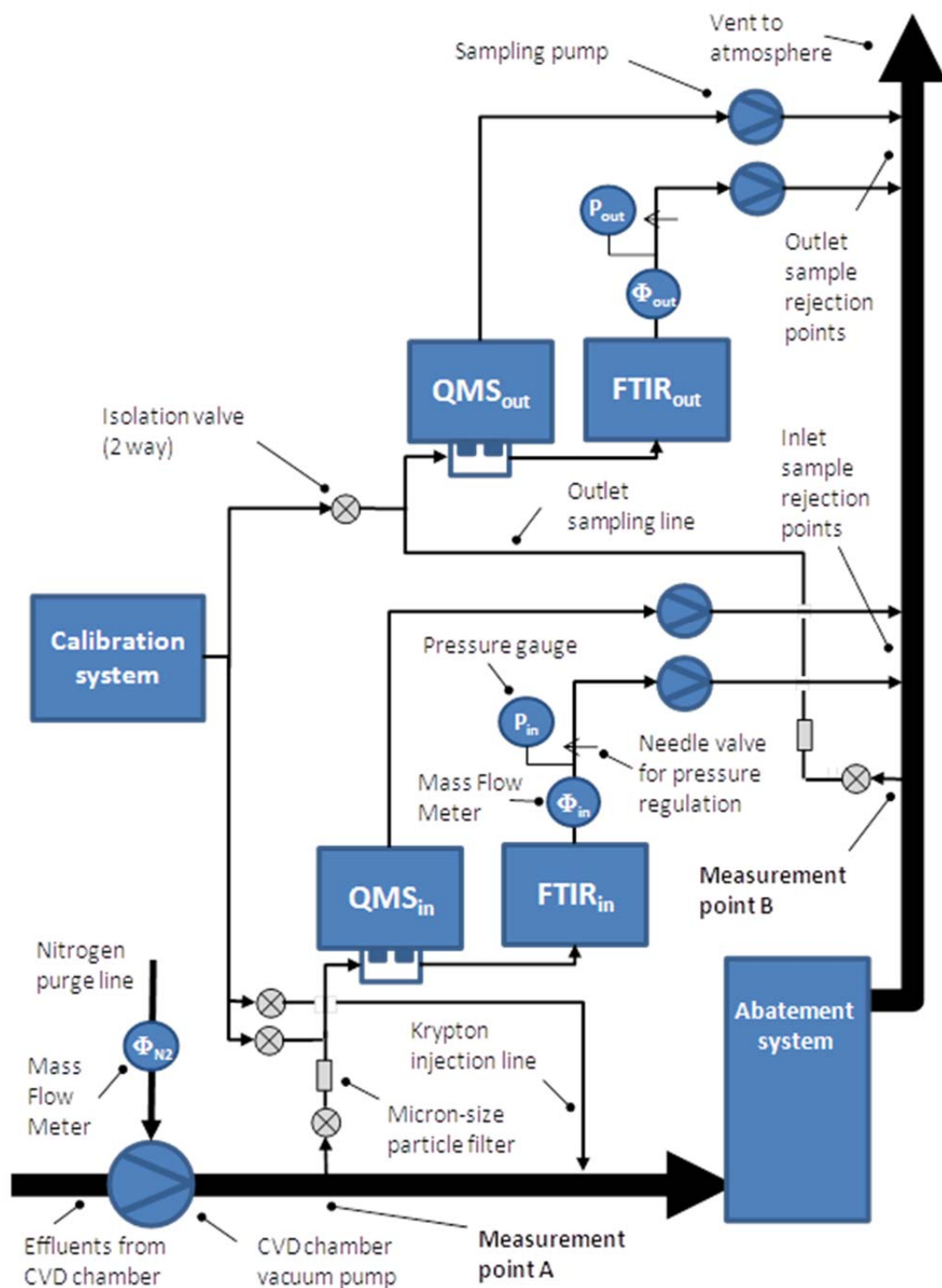
2. The measurement of effluents involves handling of toxic and hazardous gases, liquids and solid materials, and other electrical and mechanical hazards. It is the responsibility of the project participants to ensure that all experimental conditions meet the local safety standards, codes, and regulations. 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. Figure 1 depicts the experimental setup for the measurement of the effluents at the exhaust of the CVD chamber vacuum pump (measurement point A) and at the exhaust of the abatement device (measurement point B). The sampling lines should include a micron-size filter between the sampling point and the analytical systems to ensure that solid particles from the deposition process do not coat the FTIR windows or the QMS sampling train. In cases where the CVD deposition chemistry leads to formation of vapour-phase solid by-products, such reaction may coat the windows of the FTIR system or otherwise lead to detrimental experimental effects (e.g. trace amounts of deposition vapors leading to FTIR or QMS line interferences during the cleaning process). In such as case, one option is to close the sampling valve (measurement point A) during the deposition cycle. However, proper purging and timing of the valve opening and closing should be devised to ensure that the entire clean cycle is recorded.
4. Flow meters ( $\Phi_{in}$ ,  $\Phi_{out}$ ) should be used to measure the flow of gas in the sampling lines, which should be maintained at approximately 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 Torr (93.326 kPa) (or slightly below atmospheric pressure). The base pressure in the QMS' quadrupole sections shall be able to reach a minimum of  $10^{-6}$  Torr ( $1.3 \times 10^{-4}$  kPa). The temperature of the FTIR cells and of the QMS inlets should be maintained at a regulated temperature of 110°C or above to prevent water vapor condensation. The FTIR systems should be operated at  $0.5 \text{ cm}^{-1}$  resolution and proper cell lengths should be used to ensure that the absorbance signals fall between 0.1 and 1. The sampling frequency for the FTIR and the QMS systems should be less than three seconds.

5. FTIR spectroscopy should be used to measure fluorine-containing compounds such as  $\text{CF}_4$ ,  $\text{C}_2\text{F}_6$ ,  $\text{C}_3\text{F}_8$ ,  $\text{c-C}_4\text{F}_8$ ,  $\text{SiF}_4$ , HF and  $\text{COF}_2$ . The principal purpose of the QMS measurement is to measure dilution through the abatement device using Krypton as a tracer gas. However, QMS may also be used to quantify emissions of fluorine ( $\text{F}_2$  – which cannot be detected by FTIR) when this gas is present at the exhaust of the pump and when the fluoride volume balance cannot be closed to better than 90 per cent.

**Figure 1. Schematic description of the experimental setup for the measurement of effluents**



#### 4. Pump purge dilution measurements

6. A mass flow meter (MFM) will be installed upstream of the N<sub>2</sub> vacuum pumps purge connections to measure the N<sub>2</sub> flow from all pumps installed on the tool. When applicable, measurement of other purges (e.g. vacuum line purge) is also necessary to determine the total flow of gases exiting the pumps.

#### 5. FTIR systems calibration

7. The calibration of the FTIR systems should 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 ( $c_{\min}$  to  $c_{\max}$ ) that can be expected at the exhaust of the pumps and of the abatement device. For each gas to be quantified, a range of concentrations will be generated by mixing a gas standard (e.g. 1% CF<sub>4</sub> in N<sub>2</sub> ballast) with nitrogen.
8. For each gas  $i$  to be quantified, the project participants will generate a calibration curve with a minimum of five distinct calibration points and plot the FTIR absorbance as a function of the gas concentration (see Figure 3).
9. For each calibration point, the operator should ensure that the FTIR signal has reached a steady state for a minimum of two minutes. For the mid-range concentration point ( $c_{\text{mid}}=(c_{\min}+c_{\max})/2$ ), the experiment should be repeated at least five times by turning the calibration gas' mass flow controller ON and OFF.
10. The operator should calculate the standard deviation associated with the FTIR absorbance, and ensure that it is below 5%.
11. The standard deviations ( $\sigma$ ) 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 ( $n \geq 5$ ) |
12. 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<sup>2</sup> 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 the CVD process chambers are idle, 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 from the tool). For each fitting curve, the R<sup>2</sup> values are calculated as follows:

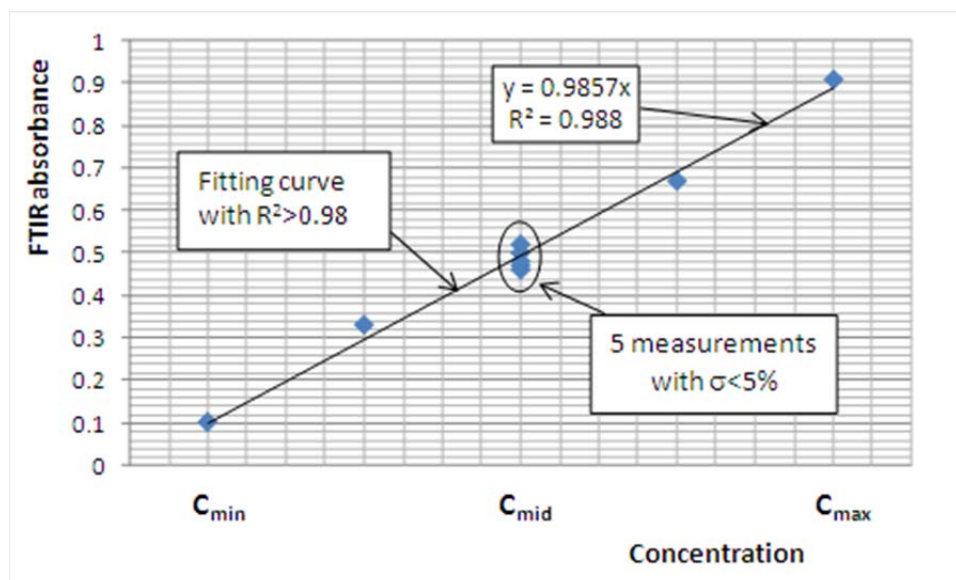
$$R^2 = \left( \frac{\sum_{j=0}^n (x_j - \bar{x})(y_j - \bar{y})}{\sqrt{\sum_{j=0}^n (x_j - \bar{x})^2 \sum_{j=0}^n (y_j - \bar{y})^2}} \right)^2 \quad \text{Equation (2)}$$

Where:

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

13. An example of an FTIR calibration curve is given in Figure 2 below:

**Figure 2. Example of FTIR calibration curve**



## 6. QMS calibration

14. Calibration of the QMS systems should be performed for both mass locations and response to analytes.
15. A calibration mixture of 1% 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 (or the F2 standard if F2 emissions shall be quantified) shall be diluted with nitrogen to generate a

concentration range falling within the range of concentrations that can be expected at the measurement point.

16. The project participants should generate a calibration curve with a minimum of five (5) 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.
17. The operator should calculate the standard deviation associated with the QMS signal intensity, and ensure that it is below 5%.
18. Following the calibration procedure, the project proponent should plot a calibration curve similar to Figure 2 (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.

## 7. Abatement device's dilution measurements

19. To measure the dilution through the abatement device, the project participants should inject known flows of Krypton at the inlet of the abatement device and measure the Kr concentration at the outlet of the abatement device. The project participants should inject at least 5 different Kr flow rates and calculate the dilution factor by averaging the dilution factor for each flow condition.
20. The determination of the dilution factor first involves the determination of the total volume flow entering the abatement device ( $TVF_{in}$ ), as follows:

$$TVF_{in} = \frac{s_{in}}{C_{in} \times 10^{-6}} \quad \text{Equation (3)}$$

Where:

$TVF_{in}$	=	Total inlet volume flow (slm)
$s_{in}$	=	Kr gas flow into the abatement device (slm)
$C_{in}$	=	Concentration of Kr at the inlet of the abatement device (ppmv)

21. Alternatively, the project participants can calculate the total inlet volume flow ( $TVF_{in}$ ) by summing up the flows from the pumps dilution and adding the flow of Kr for each experimental point.

22. The second necessary step for the measurement of the dilution factor involves the determination of the total volume flow at the outlet of the abatement device ( $TVF_{out}$ ), as follows:

$$TVF_{out} = \frac{s_{in}}{C_{out} \times 10^{-6}} \quad \text{Equation (4)}$$

Where:

$TVF_{out}$  = Total outlet volume flow (slm)  
 $s_{in}$  = Kr gas flow into the abatement device (slm)  
 $C_{out}$  = Concentration of Kr at the outlet of the abatement device (ppmv)

23. Finally, the project participants will calculate the dilution factor (DF) as the ratio of total outlet volume flow to the total inlet volume flow:

$$DF = \frac{TVF_{out}}{TVF_{in}} \quad \text{Equation (5)}$$

Where:

$DF$  = Abatement device dilution factor (dimensionless)  
 $TVF_{out}$  = Total outlet volume flow (slm)  
 $TVF_{in}$  = Total inlet volume flow (slm)

## 8. Integration of FTIR signals

24. When measuring the emission factors, the concentration of gas at the exhausts of the pumps and of the abatement device varies over time (as a function of the deposition / clean cycles), and cannot be assumed to be at steady state. Therefore, the total volume of process gas entering and exiting the abatement device shall be estimated by integrating the FTIR signal over time. These absorbance signals should be converted to concentrations (ppmv) using the calibration curves, prior to integration.<sup>1</sup> After integration of the concentration curves (ppmv.s) and accounting for the pump dilution, the final emission values will be expressed in grams per clean process.

## 9. Production conditions and minimum number of measurements per experimental data point

25. For the measurement of the emission factors, the CVD chamber shall be running in real production conditions. That is, the project participants should run the experiments with the same recipes used for production conditions (same recipe parameter set-points, same number of recipe steps, same duration). Running with blank wafers (i.e. wafers on which no integrated circuit is built or partially built) is acceptable.

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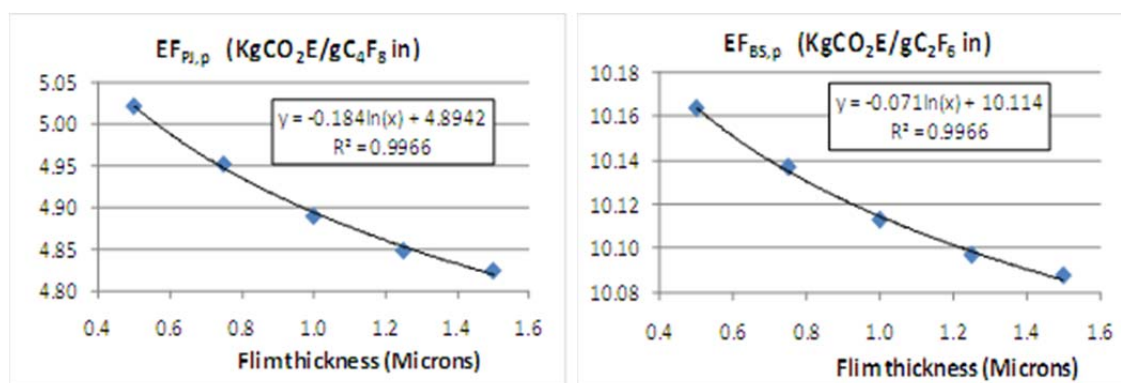
<sup>1</sup> See EPA protocol section 2.3.2.2.1 for more details.

26. For each process  $p$  and each thickness point  $t$ , the quantification of the emission factors will be based on the measurement of a minimum of five deposition/clean cycles, for both the baseline ( $C_2F_6$ ) and the substitute ( $c-C_4F_8$ ) processes.

# 10. Selection of thickness range and determination of emission factors as a function of thickness

27. The minimum and the maximum film thickness based on actual production conditions to be run during the crediting period should be defined for each cleaning process  $p$ . Emission factors for these minimum and maximum values of the thickness should be measured, as well as for three additional thickness values substantially equally spaced between the minimum and maximum thickness values. For example, if the range of thickness is between a minimum of  $0.5\ \mu m$  and a maximum of  $1.5\ \mu m$ , the project participants shall measure the emission factors for  $0.5, 0.75, 1.0, 1.25$  and  $1.5\ \mu m$  which will result in two curves depicting the dependence of the baseline and project emission factors as a function of the film thickness for each cleaning process ' $p$ '. Examples of such curves are depicted below for typical  $C_2F_6$  (left) and  $c-C_4F_8$  processes (right).

**Figure 3.** Variation of emission factors ( $EF_{BS,p}(t)$  and  $EF_{PJ,p}(t)$  respectively) as a function of the thickness of the film deposited in the CVD reactor prior to the clean run



28. After measurement of the emission factors as a function of thickness, the project participants will fit the experimental data with a logarithmic function, ensuring that the goodness of fit provides an  $R^2$  value of greater than 0.95. During the crediting period, the project proponent will keep track of the thickness ( $t$ ) of each clean run and will apply the baseline and substitute emission factors to the actual thickness for every clean run, using the equations derived from the fitting functions. For the avoidance of production represented by points higher and lower than the original maximum and minimum thickness, those points will be excluded from the calculations for emission reductions.
29. Thus, in the specific example provided in the Figure 3 above, the emission factors for the baseline and project emissions will be calculated as a function of the thickness ( $t$ ):

$$EF_{BS,p}(t) = -0.07 \ln(t) + 10.114$$

Equation (6)



$$EF_{PJ,p}(t) = -0.184 \ln(t) + 4.8942 \quad \text{Equation (7)}$$

Where:

$EF_{BS,p}(t)$  = Emission factor for baseline process  $p$  as a function of thickness

$EF_{PJ,p}(t)$  = Emission factor for substitute process  $p$  as a function of thickness

## 11. DRE measurements

30. To measure the abatement devices' DREs, the project participants will follow the EPA protocol. However, to ensure conservativeness, the DREs for the baseline process for each process 'p' will be measured in the best case scenario (highest baseline DRE measured for the lowest baseline gas flow), when *only one* CVD chamber on a given tool is running a cleaning process (the other chambers being kept idle). This will ensure that the DRE values used to calculate baseline emissions are higher than the actual destruction removal efficiencies of the baseline processes' by-products. For the substitute process, the DRE will be measured in the worst case scenario (lowest project DRE measured for the highest substitute gas flow), when *all* CVD chambers on a given tool are running substitute cleaning processes. This will ensure that the DRE values used to calculate project emissions are lower than the actual destruction removal efficiencies of the substitute processes' by-products.
31. For the DRE measurement, the radio-frequency (RF) power shall be turned ON in the CVD chambers, but it is not necessary to run deposition recipes prior to running the clean processes (this is also conservative since the utilization efficiency of FC gases is lower when the chamber is clean). It is also acceptable to measure the DREs using clean recipes with extended clean times (e.g. 10 minutes-long clean recipes) to ensure that enough data points are recorded while all chambers are running at the same time, and to make sure that the tool is running in steady state during the experiment.
32. Please refer to the EPA protocol for the determination of the standard deviations and relative error, and QA/QC procedures relating to the measurement of the DRE.

## 12. Fluorine volume closure

33. The Equivalent Fluoride Inlet (EFI) and the Equivalent Fluoride Outlet (EFO) values are calculated using the following equations:

$$EFI = \sum_i V_{I,i} \times (\text{number of fluorine atoms in gas } i) \quad \text{Equation (8)}$$

$$EFO = \sum_i V_{O,i} \times (\text{number of fluorine atoms in gas } i) \quad \text{Equation (9)}$$

Where:

$EFI$  = Equivalent fluoride inlet (volume fluorine equivalent – liters)

$EFO$  = Equivalent fluoride outlet (volume fluorine equivalent – liters)

- $i$  = Any gas containing fluorine at the inlet or outlet of the abatement device ( $\text{CF}_4$ ,  $\text{C}_2\text{F}_6$ ,  $\text{c-C}_4\text{F}_8$ ,  $\text{SiF}_4$ ,  $\text{HF}$ ,  $\text{COF}_2$ ...)
- $V_{I,i}$  = Volume of gas  $i$  at the inlet of the abatement device (liters)
- $V_{O,i}$  = Volume of gas  $i$  at the outlet of the abatement device (liters)

34. The fluorine volume closure (FVC) is defined as:

$$FVC = \frac{EFO}{EFI} \quad \text{Equation (10)}$$

Where:

- $FVC$  = Fluorine volume closure (dimensionless)
- $EFI$  = Equivalent fluoride inlet (volume fluorine equivalent – liters)
- $EFO$  = Equivalent fluoride outlet (volume fluorine equivalent – liters)
35. As a quality assurance and control measure, the project participants are required to demonstrate that, in accordance with the Sematech guidelines, the fluorine volume closure is greater than 90%. This goal is meant to ensure that greater than 90% of the fluorine-containing gas effluents are accounted for.
36. If the FVC is less than 90%, the project participants are required to provide evidence that the missing fluorine is linked to the formation of solid by-products during the CVD process, and that no other fluorine-containing compounds with a global warming potential of greater than zero is present in the exhaust stream.

### 13. Data and parameters of the experimental protocols

37. Parameters presented below used in the experimental protocols. Protocols mandatory to perform for the sampling of effluents, the calibration of the FTIR (Fourrier Transform Infrared) and QMS (Quadrupole Mass Spectrometer) equipment, the measurements of the pumps' and abatement dilution factors, the calculation of emission factors, and maintenance and QA/QC procedures.

**Data / Parameter table 1.**

<b>Data / Parameter:</b>	<i>DF</i>
Data unit:	Dmnls
Description:	Abatement device's dilution factor
Source of data:	Ex ante measurement campaign
Measurement procedures (if any):	Measured per EPA protocol using Kr dilution method
Any comment:	-

**Data / Parameter table 2.**

<b>Data / Parameter:</b>	$P_{BS,p}$
Data unit:	Pa
Description:	Pressure setpoint during baseline process $p$
Source of data:	Baseline recipe
Measurement procedures (if any):	None
Any comment:	-

**Data / Parameter table 3.**

<b>Data / Parameter:</b>	$T_{BS,p}$
Data unit:	Degrees Celsius
Description:	Setpoint for CVD reactor temperature (substrate holder temperature) for baseline process $p$
Source of data:	Baseline recipe
Measurement procedures (if any):	None
Any comment:	-

**Data / Parameter table 4.**

<b>Data / Parameter:</b>	$W_{BS,p}$
Data unit:	W
Description:	Setpoint for CVD reactor plasma power during baseline process $p$
Source of data:	Baseline recipe
Measurement procedures (if any):	None
Any comment:	-

**Data / Parameter table 5.**

<b>Data / Parameter:</b>	$F_{BS,p}$
Data unit:	Standard liters per minute
Description:	Setpoint for $C_2F_6$ flow of baseline cleaning gas
Source of data:	Baseline recipe
Measurement procedures (if any):	None
Any comment:	-

**Data / Parameter table 6.**

<b>Data / Parameter:</b>	$P_{PJ,p}$
Data unit:	Pa
Description:	Pressure setpoint during substitute process $p$
Source of data:	Substitute recipe
Measurement procedures (if any):	None
Any comment:	-

**Data / Parameter table 7.**

<b>Data / Parameter:</b>	$T_{PJ,p}$
Data unit:	Degrees Celsius
Description:	Setpoint for CVD reactor temperature (substrate holder temperature) for substitute process $p$
Source of data:	Substitute recipe
Measurement procedures (if any):	None
Any comment:	-

**Data / Parameter table 8.**

<b>Data / Parameter:</b>	$W_{PJ,p}$
Data unit:	W
Description:	Setpoint for CVD reactor plasma power during substitute process $p$
Source of data:	Substitute recipe
Measurement procedures (if any):	None
Any comment:	-

**Data / Parameter table 9.**

<b>Data / Parameter:</b>	$F_{PJ,p}$
Data unit:	Standard liters per minute
Description:	Setpoint for c-C <sub>4</sub> F <sub>8</sub> flow for substitute process $p$
Source of data:	Substitute recipe
Measurement procedures (if any):	None
Any comment:	-

**Data / Parameter table 10.**

<b>Data / Parameter:</b>	$P_p$
Data unit:	Pa
Description:	Pressure setpoint in CVD reactors during cleaning process $p$
Source of data:	CVD tool controller
Measurement procedures (if any):	The pressure will be measured using the CVD chamber pressure gauge
Monitoring frequency:	Continuous
QA/QC procedures:	Project participants will follow the pressure gauge manufacturers' calibration and maintenance procedures
Any comment:	-

**Data / Parameter table 11.**

<b>Data / Parameter:</b>	$T_p$
Data unit:	Degrees Celsius
Description:	CVD reactor temperature setpoint (substrate holder temperature)
Source of data:	CVD tool controller
Measurement procedures (if any):	The temperature will be measured using the CVD chamber temperature gauge
Monitoring frequency:	Continuous
QA/QC procedures:	Project participants will follow the temperature gauge manufacturers' calibration and maintenance procedures
Any comment:	-

**Data / Parameter table 12.**

<b>Data / Parameter:</b>	$W_p$
Data unit:	W
Description:	CVD reactor plasma power setpoint during substitute cleaning process $p$
Source of data:	CVD tool controller
Measurement procedures (if any):	The plasma power will be measured by monitoring the CVD reactor's RF power supply
Monitoring frequency:	Continuous
QA/QC procedures:	Project participants will follow the RF power supply manufacturers' calibration and maintenance procedures
Any comment:	-

**Data / Parameter table 13.**

<b>Data / Parameter:</b>	$F_p$
Data unit:	Standard liters per minute
Description:	Flow of substitute cleaning gas setpoint
Source of data:	CVD tool controller
Measurement procedures (if any):	The flow will be measured by the CVD tool mass flow controller
Monitoring frequency:	Continuous
QA/QC procedures:	Project participants will follow the MFC manufacturers' calibration and maintenance procedures
Any comment:	-

**Data / Parameter table 14.**

<b>Data / Parameter:</b>	$t_{p,min}$
Data unit:	$\mu\text{m}$
Description:	Thickness of production in relation to each cleaning process $p$ for each process run $k$
Source of data:	Process tool control system
Measurement procedures (if any):	-
Monitoring frequency:	Continuous determination of the thickness of each cleaning process $p$ for each process run $k$
QA/QC procedures:	-
Any comment:	Each process run $k$ has a specific thickness while each $p$ may have varying thicknesses

**Data / Parameter table 15.**

<b>Data / Parameter:</b>	$t_{p,max}$
Data unit:	$\mu\text{m}$
Description:	Thickness of production in relation to each cleaning process $p$ for each process run $k$
Source of data:	Process tool control system
Measurement procedures (if any):	-
Monitoring frequency:	Continuous determination of the thickness of each cleaning process $p$ for each process run $k$
QA/QC procedures:	-
Any comment:	Each process run $k$ has a specific thickness while each $p$ may have varying thicknesses

**Data / Parameter table 16.**

<b>Data / Parameter:</b>	$N$
Data unit:	Integer
Description:	Number of substitute processes implemented as part of the project
Source of data:	Ex ante measurement campaign
Measurement procedures (if any):	-
Monitoring frequency:	Annual
QA/QC procedures:	-
Any comment:	-

**Data / Parameter table 17.**

<b>Data / Parameter:</b>	$\Phi_{in}$
Data unit:	Standard liters per minute (slm)
Description:	Flow into the sampling lines during the ex ante measurement campaign
Source of data:	Flow meter used in ex ante measurement campaign
Measurement procedures (if any):	Ensure that flow is approximately 1 slm during the measurements
Monitoring frequency:	Once during the ex ante campaign
QA/QC procedures:	-
Any comment:	-

**Data / Parameter table 18.**

<b>Data / Parameter:</b>	$\Phi_{out}$
Data unit:	Standard liters per minute (slm)
Description:	Flow out of the sampling lines during the ex ante measurement campaign
Source of data:	Flow meter used in ex ante measurement campaign
Measurement procedures (if any):	Ensure that flow is approximately 1 slm during the measurements
Monitoring frequency:	Once during the ex ante campaign
QA/QC procedures:	-
Any comment:	-

**Data / Parameter table 19.**

<b>Data / Parameter:</b>	$S_{in}$
Data unit:	Standard liters per minute (slm)
Description:	Kr gas flow into the abatement device
Source of data:	Flow meter used in ex ante measurement campaign
Measurement procedures (if any):	-
Monitoring frequency:	Once during the ex ante campaign
QA/QC procedures:	Flow meter will be calibrated before the ex ante campaign as per manufacturer's instructions
Any comment:	-

**Data / Parameter table 20.**

<b>Data / Parameter:</b>	$TVF_{out}$
Data unit:	Standard liters per minute (slm)
Description:	Total outlet volume flow
Source of data:	Flow out is calculated by injecting a known amount of krypton at the inlet and measuring the concentration at the outlet
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	-
Any comment:	-

**Data / Parameter table 21.**

<b>Data / Parameter:</b>	$TVF_{in}$
Data unit:	Standard liters per minute (slm)
Description:	Total inlet volume flow
Source of data:	Measured using Mass Flow Controllers (MFCs) measuring the pump dilution
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	Project participants will follow the MFC manufacturers' calibration and maintenance procedures
Any comment:	-



**Data / Parameter table 22.**

<b>Data / Parameter:</b>	<b>C<sub>in</sub></b>
Data unit:	Ppmv
Description:	Concentration of Kr at the inlet of the abatement device
Source of data:	QMS
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	QMS will be calibrated as per manufacturer's instructions
Any comment:	

**Data / Parameter table 23.**

<b>Data / Parameter:</b>	<b>C<sub>out</sub></b>
Data unit:	Ppmv
Description:	Concentration of Kr at the outlet of the abatement device
Source of data:	QMS
Measurement procedures (if any):	-
Monitoring frequency:	-
QA/QC procedures:	QMS will be calibrated as per manufacturer's instructions
Any comment:	-

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### Document information

<i>Version</i>	<i>Date</i>	<i>Description</i>
02.0.0	23 November 2012	EB 70, Annex 19 Revised to: (i) fix an error in the calculation of the use rates of different PFC gases (equation 2); (ii) remove the reference to a fixed crediting period; and (iii) introduce provisions and guidance for project proponents for the renewal of the crediting period.
01.0.0	15 July 2011	EB 62, Annex 2 Initial adoption.

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