Approved baseline and monitoring methodology AM0078

"Point of Use Abatement Device to Reduce SF$_6$ emissions in LCD Manufacturing Operations"

I. SOURCE, DEFINITIONS AND APPLICABILITY

Sources

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

- NM0271 "Point of Use Abatement Device to Reduce SF$_6$ emissions in LCD Manufacturing Operations", prepared by Climate Change Capital, LG International Corp, and Transcarbon International Corp.

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

- Combined tool to identify the baseline scenario and demonstrate additionality;
- Tool to calculate baseline, project and/or leakage emissions from electricity consumption;
- Tool to calculate project or leakage CO$_2$ emissions from fossil fuel combustion.

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

This methodology also refers to the approved versions of the following US EPA Methods:

- US EPA Method 1 – Sample and velocity traverses for stationary sources;
- US EPA Method 2 – Determination of stack gas velocity and volumetric flow rate;
- US EPA Method 4 – Determination of moisture content in stack gases.

Selected approach from paragraph 48 of the CDM modalities and procedures

"Existing actual or historical emissions, as applicable".

Definitions

Liquid Crystal display (LCD). It is a type of display that utilizes two sheets of polarizing material with a liquid crystal solution between them.

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

Fourier transform infrared (FTIR) spectrometer. It is an analytical system that employs a source of mid-infrared radiation, an interferometer, an enclosed sample cell of known absorption path length, an infrared detector, optical elements that transfer infrared radiation between components, and a computer

system. The time-domain detector response (interferogram) is processed by a Fourier transform to yield a representation of the detector response vs. infrared frequency.

Applicability

This methodology applies to project activities that involve the installation of a combustion or thermal abatement device that is able to eliminate the SF_6 from an LCD <u>etching</u> plant, which currently is venting the SF_6 to the atmosphere.

The methodology is applicable under the following conditions:

- The methodology only applies to existing production lines with at least 3 years information of SF_6 purchase and consumption and production of LCD substrate by 31 January 2009. The crediting period is limited to the remaining lifetime of the production lines existing at the time of registration;
- The maximum treatment capacity of the abatement system is sized for the application in correlation to observed historical flow. The maximum SF6 flow entering the abatement device, from all chambers combined, is below the maximum SF6 abatement capacity of the abatement device and where the total flow of effluents (SF6 plus all other by-products and diluents) does not exceed the total flow capacity of the abatement device;
- No law or regulation which mandate decomposition, destruction, recycle or substitution of SF_6 or any component of exhaust gases containing SF_6 exist;
- The SF_6 destruction should occur at the same industrial site where the SF_6 is used, and SF_6 destroyed is not imported from other facilities;
- The measurement with respect to determining SF_6 flow to the abatement device are taken immediately before the abatement device, without any other devices located in between which is capable of changing the SF_6 flow through transformation or decomposition;
- Where the applicability conditions of US EPA Methods 1 and 2 are satisfied (i.e. the flow is not cyclonic or swirling and the stack has a circular cross section with a diameter greater than 0.3 meter);
- The facility has obtained necessary permits concerning safety and health in order to install and operate the abatement device and monitoring facilities;
- SF_6 is not temporarily stored for subsequent destruction;
- It is demonstrated by test data by the manufacturer or the project proponent that the abatement technology does not generate known non-CO_2 greenhouse gas such as fluorocompounds, including non-Kyoto gases, at detection levels.

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

This methodology in its present form is <u>not applicable</u> to Chemical Vapor Deposition (CVD) processes that use SF_6.

II. BASELINE METHODOLOGY PROCEDURE

Identification of the baseline scenario and additionality demonstration

Project participants shall apply the following steps to identify the baseline scenario:

This methodology proposes using the latest version of the Combined tool to identify the baseline scenario and demonstrate additionality ("Combined Tool").

Identification of Alternative Scenario

The potential alternatives to this project include:

(1) Undertaking this project, using an abatement device without CDM;

(2) Continuing the use of SF_6 without any abatement;

(3) Using a substitute gas for SF_6;

(4) Process modifications/optimization to minimize SF_6 consumption;

(5) SF_6 could be captured and recycled at the outlet of the vacuum pump.

After listing these alternatives (and others if appropriate), the project developers should analyze, according to Step 1b of the "Combined Tool", whether all of the alternatives are allowed under local laws. If the baseline scenario determination shows that two or more baseline scenarios are equally deemed 'most probable', then the scenario with the lowest level of emissions will be considered the most plausible baseline scenario. This methodology is only applicable to project activities where "*Continuing the use of SF_6 without any abatement*" is the most plausible baseline scenario.

In most foreseeable project activities, since the abatement device requires financial resources to purchase and operate and adds no value to the output of the plant, the financial additionality test will be applicable. The identification of the most plausible scenario, the determination of additionality and of the baseline emissions, project emissions and leakage effects, applied in the context of this proposed methodology, are outlined below.

The "Combined tool" outlines the various barriers (technical, first-of-a-kind, investment barriers, etc.). Depending on the scenario used, there could be a number of barriers, including:

- New abatement or destruction technologies not introduced into a market previously. This would, for example, be the case for many of the FC abatement devices, which are just beginning to be used in developed countries. As it is the common case, new technologies often face market-entry issues, with clients unwilling to invest capital in an untested alternative. The incentive of CDM could help bring in investors who could cover some of the additional capital costs and help reduce the perceived risk for the LCD manufacturer.

- Investment Barriers/Higher Operational Costs: All the abatement devices require a non-recoverable investment (without CDM) and are expensive to operate. There is little if any direct business reason to take on such an investment, take up valuable production space, and pay for maintenance costs. These additional expenses mean that the abatement device offers higher annual operation and maintenance costs for the LCD manufacturer (as per Step 3 of the "Combined tool").

This list can provide some potential examples of the barriers that SF6 abatement devices in the LCD manufacturing industry may face.

Project boundary

The spatial extent of the project boundary encompasses the particular LCD plant(s) that is having its SF6 emissions abated.

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

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

	Source	**Gas**	**Included?**	**Justification / Explanation**
Baseline	Use in etching process	CO_2	No	Not applicable
		SF_6	Yes	This is the primary gas, which will be abated in the project scenario
Project Activity	Unabated SF_6 and CO_2 emissions	CO_2	Yes	Resulting from electricity and fossil fuels used to operate the abatement technology
		SF_6	Yes	Some small percent typically less than 5% of the SF6 will not be abated via the project

Baseline emissions

Baseline emissions for a crediting year y are calculated on the basis of mass of SF_6 entering the abatement device during the year y. In order to prevent intentional increase in baseline emissions, baseline emissions are limited within a cap derived from historical consumption of SF_6. Furthermore, any increase in SF6 consumption per unit of surface area of LCD substrate processed will be discounted by incorporating an "SF_6 consumption factor".

The resulting baseline equation is as follows:

$$BE_{in,y} = k \cdot E_{SF6,y} \cdot GWP_{SF6} \tag{1}$$

Where:

$BE_{in,y}$ = Total baseline emissions in year y, (tonnes of CO_2)

k = SF_6 consumption factor, defined as the ratio of SF_6 consumption per unit surface area of LCD substrate processed (in m^2) in the project period with that of the baseline (dimensionless, see below)

$E_{SF6,y}$ = SF_6 baseline emissions in year y (tonnes SF_6), calculated as shown below

GWP_{SF6} =   Global warming potential of SF6 in tonnes CO2 per tonnes of SF6 [1]

$$E_{SF6,y} = \min\{E_{SF6,in,y}; 0.48 \times C_{SF6,y}; 0.48 \times C_{SF6,hist}\} \tag{2}$$

Where:

$E_{SF6,in,y}$ =   Mass of SF_6 gas entering the abatement device in year y (tonnes SF_6), which is the annual sum of the mass of SF_6 entering the abatement device per unit time ($E_{SF6,in}$ in grams per second)

$C_{SF6,y}$ =   Annual consumption of SF_6 during the project year y, defined as the total SF_6 purchased in a specific project year y, taking into account the change in inventory in the same year (tonnes SF_6)

$C_{SF6,hist}$ =   Historical SF_6 consumption, calculated as the three years maximum consumption prior the implementation of the project activity before January 31, 2009. Consumption is defined as the total SF_6 purchased in a year, taking into account the change in inventory in a specific year (tonnes SF_6)

0.48   =   Ratio of SF6 consumed but not destroyed or transformed in the process. This is derived from the IPCC 2006 Guideline's default factor on destruction / decomposition (0.4), and factoring in 20% uncertainty ((1-0.4) * 0.8 = 0.48)

SF_6 Consumption ratio

Historical ratio of SF6 consumption versus LCD production based on previous three years (-1, -2 and -3) prior the implementation of the project activity before January 31, 2009.

$$SF_{6,ratio} = \min\left(C_{SF6,-1} \div SP_{-1}; C_{SF6,-2} \div SP_{-2}; C_{SF6,-3} \div SP_{-3}\right) \tag{3}$$

Where:

$SF_{6,ratio}$ =   Ratio of SF6 consumption to the surface area of LCD substrate processed (tonnes/m^2)

$C_{SF6,-i}$ =   Historical SF6 consumption in year i, where i =-1, -2, -3, previous to the implementation of the project activity before January, 31, 2009 (tonnes)

SP_{-i} =   Historical production of LCD substrate (in m^2) during year i (where i =-1, -2, -3) prior the implementation of the project activity before January, 31, 2009

SF_6 consumption factor

$$k = \begin{cases} 1 & ; SF_{6,ratio} \geq C_{SF6,y} \div SP_{project \cdot y} \\ \dfrac{SF_{6,ratio}}{C_{SF6,y} \div SP_{project \cdot y}} & ; SF_{6,ratio} < C_{SF6,y} \div SP_{project \cdot y} \end{cases} \tag{4}$$

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[1] 23.9 tonnes CO_2/kg SF_6 - see IPCC 4th assessment.

Where:

$SP_{project \cdot y}$ = Production of LCD substrate (in m^2) during the project year y

$C_{SF6,y}$ = Annual consumption of SF$_6$ during the project year y, defined as the total SF$_6$ purchased in a specific project year y, taking into account the change in inventory in the same year (tonnes SF$_6$)

$SF_{6,ratio}$ = Ratio of SF6 consumption to the surface area of LCD substrate processed (tonnes/m^2)

Provision in cases where there is an existing abatement device

In facilities where there already exists an abatement device, the following calculations must be carried out in order to remove the possibility of intentional increase of SF$_6$ abated while decreasing the abatement at the existing abatement device.

$$E_{SF6in,adj,y} = E_{SF6in,y} - CAP_{SF6,ex}$$ **(5)**

Where:

$E_{SF6in,adj,y}$ = Adjusted mass of SF$_6$ gas entering the abatement device in year y to be used in place of E$_{SF6,in,y}$ in equation (2) (tonnes SF$_6$)

$E_{SF6,in,y}$ = Mass of SF$_6$ gas entering the abatement device in year y (tonnes SF$_6$), which is the annual sum of the mass of SF$_6$ entering the abatement device per unit time (E$_{SF6,in}$ in grams per second (refer equation 14))

$CAP_{SF6,ex}$ = Design capacity of existing abatement device, based on the assumption that the existing abatement device is operating at full design capacity for the entire period of the year (i.e. 8760 hours) (tonnes SF$_6$)

Experimental setup for determination of the baseline and project emissions

Figure 1 depicts the experimental setup required for the measurement of the SF$_6$ concentrations and dilution through the abatement system, the monitoring of the inlet and outlet flows, and for the calculation of the SF$_6$ destruction removal efficiency of the abatement device (DRE). This experimental setup will be used during commissioning of the abatement system (initial evaluation period at project startup) and during annual surveillance tests.
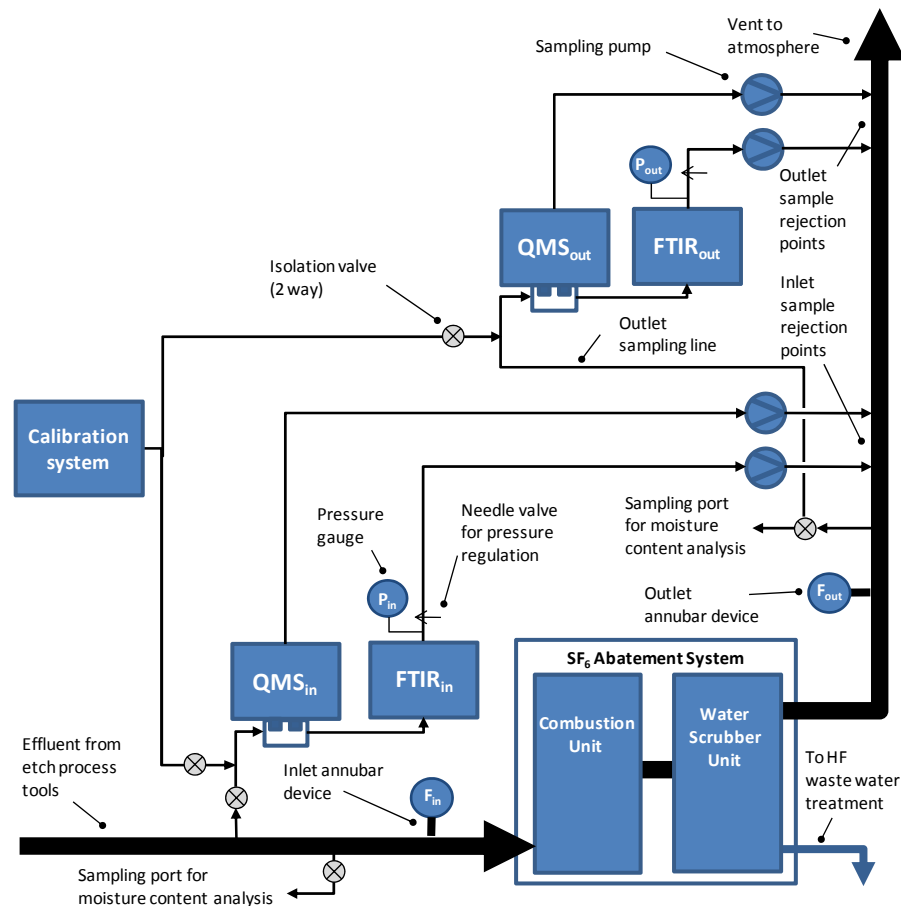
**Figure 1: Schematic of the experimental setup for determination of the
baseline and project emissions**

Calibration of the measuring devices and measurement of the mass of SF₆ entering and exiting the abatement system

Calibration of the annubar devices is required for the monitoring of gas velocity and calculation of the flows at the inlet and outlet of the abatement system. Annubar devices take multiple samples across the diameter of the stack, accounting for variations in flow across the section. In the following, the calculation of the flow follows the nomenclature of EPA Method 2. Other nationally- or internationally-recognized standards such as ISO 5167 may also be used for the measurement and calculation of the flow. Following the EPA methodology, the calculation of the averaged volumetric flow rates at the inlet and outlet of the abatement system is based on the measurement and averaging of the pressure differential measured for each gas velocity sampling point across the section of the inlet and outlet stacks. Annubar

devices should be used, provided they sample at least 80% of the fluid profile.[2] Method for the calibration and QA/QC procedures for the annubar devices is provided in Annex 1.b.

To convert the concentrations of SF_6 measured at the inlet and outlet of the abatement system into masses of SF_6 entering and exiting the abatement system, measurement of the gas mass densities and of the gas flows shall be conducted. The mass of SF_6 is proportional to the product of the SF_6 concentration and of the total flows at the inlet and outlet. The measurement of the total inlet and outlet flows is derived from a measurement of the inlet and outlet gas velocities, and from a determination of the gas mass densities, taking into account the dry molecular weight of the gases as well as their water content.

The proportion of water vapor in the inlet and outlet gas streams ($B_{ws,in}$ and $B_{ws,out}$) will be determined using US EPA Method 4 and measurement of the moisture content will be done on the basis of percentage volume fraction.

The molecular weight of the inlet gas, on a dry basis ($M_{d,in}$) will be determined by quantifying the averaged relative concentrations of SF_6, Ar, O_2, CO_2 and N_2 (mass fraction in percentage) measured by the QMS at the inlet of the abatement system during normal production conditions. The experimental sequence is as follows:

    (i)   Preliminary sampling of effluents using QMS to identify the effluent components (by determination of the m/e ratios and identification of the IR absorption bands);

    (ii)   Calibration of the QMS systems with gas standards corresponding to each of the components determined in Step 1 having a concentration of greater than 100ppmv;

    (iii)   Minimum 6 hours measurement period during standard manufacturing operation.

The project developer shall demonstrate that the molecular weight of the inlet stack gas does not vary by more than +/- 5% around the averaged mean value measured during the 6 hours period (using a 95% confidence interval)(if this is not fulfilled, measurement shall be taken again). As a conservative measure, the project developer shall record the inlet gas molecular weight ($M_{d,in}$) as the highest value recorded during the 6 hours period . $M_{d,in}$ shall be defined as the highest value of the gas molecular weight measured at the inlet during the 6 hours period, using equation 6 (gram/mole):

$$M_{d,in} = 1.460[SF_{6in}] + 0.44[CO_{2in}] + 0.399[Ar_{in}] + 0.320[O_{2in}] + 0.280[N_{2in}] \qquad \textbf{(6)}$$

Where:
$M_{d,in}$ =   Total inlet stack gas dry molecular weight (gram/mole)
$SF_{6in}, \ldots N_{2in}$ =   Average relative concentration of the gases (mass fraction in percentage)

If gases other than N_2, O_2, Ar, CO_2 and SF_6 are present at the inlet of the abatement system at concentrations of greater than 100ppmv, the project developer shall account for their contribution to the the total inlet gas dry molecular weight ($M_{d,in}$) by multiplying their relative concentrations by their individual molecular weights, and adding the result to equation 4. For example, if carbon monoxide (CO)

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[2] For such devices, the project developer should follow the manufacturer's recommendation for calibration, operation, and calculation of the flow.

is detected at a concentration of 200ppm at the inlet, the total inlet gas dry molecular weight will be calculated by adding 0.28x0.02=0.0056 to equation 6. The QMS will be calibrated for any gas detected at the inlet of the abatement device in concentrations greater than 100ppmv, in conformity with the calibration method described in Annex 1.a (replacing SF_6 by the relevant gas).

The molecular weight of the outlet stack gas, on a dry basis ($M_{d,out}$), will be determined by quantifying the relative concentrations of SF_6, Ar, O_2, N_2, CO, CO_2, F_2, HF, SO_2, SOF_2 and SO_2F_2 (mass fraction in percentage) measured by the QMS at the outlet of the abatement system while running in normal production conditions. This measurement will be performed for a minimum of 6 hours. The project developer shall demonstrate that the molecular weight of the outlet stack gas does not vary by more than +/- 5% around the averaged value measured during the 6 hours period (using a 95% confidence interval) (if this is not fulfilled, measurement shall be taken again). The outlet gas molecular weight ($M_{d,out}$) shall be recorded as the lowest value recorded during the 6 hours period. This is conservative because a low outlet gas molecular weight leads to an overestimation of the project emissions. Thus, $M_{d,out}$ will be defined as the lowest value of the gas mass molecular weight measured at the outlet during the 6 hours period, using equation 7 (gram/mole):

$$
\begin{aligned}
M_{d,out} = {} & 1.460[SF_{6out}] + 0.399[Ar_{out}] + 0.320[O_{2out}] + 0.280[N_{2out}] + 0.28[CO_{out}] \\
& + 0.44[CO_{2in}] + 0.380[F_{2out}] + 0.200[HF_{out}] + 0.641[SO_{2out}] + 0.861[SOF_{2out}] \quad \textbf{(7)} \\
& + 1.021[SO_2F_{2out}]
\end{aligned}
$$

Where:

$M_{d,out}$	=	Total outlet stack gas dry molecular weight (gram/mole)
$SF_{6out}, \ldots SO_2F_{2out}$	=	Average relative concentration of the gases (mass fraction in percentage)

If gases other than those listed above are present at the outlet of the abatement system at concentrations of greater than 100ppmv, the project developer will account for their contribution to the total outlet gas dry molecular weight ($M_{d,out}$) by multiplying their relative concentrations by their individual molecular weights, and adding the result to equation 7. For example, if carbonyl fluoride (COF_2) is detected at a concentration of 150ppm at the outlet, the total outlet gas dry molecular weight will be calculated by adding 0.66x0.015=0.0099 to equation 7.

The QMS will be calibrated for any gas detected at the outlet of the abatement device in concentrations greater than 100ppm, in conformance with the calibration method described in Annex 1.a (replacing SF_6 by the relevant gas).

Following US EPA Method 2, the total (wet) stack gas molecular weights at the inlet and outlet of the abatement system ($M_{s,in}$, $M_{s,out}$) will be calculated using equations 8 and 9:

$$ M_{s,in} = M_{d,in} \cdot (100 - B_{ws,in}) \div 100 + 0.18 \cdot B_{ws,in} \qquad \textbf{(8)} $$

$$ M_{s,out} = M_{d,out} \cdot (100 - B_{ws,out}) \div 100 + 0.18 \cdot B_{ws,out} \qquad \textbf{(9)} $$

Where:

$M_{d,in}$ and $M_{d,out}$	=	Total molecular weights of the inlet and outlet stack gases, dry basis (gram/mole)
$B_{ws,in}$ and $B_{ws,out}$	=	Water vapor in the inlet and outlet gas streams. (Percentage volume fraction)

Following US EPA Method 2, the averaged inlet and outlet stack gas velocity ($v_{s,in}$, $v_{s,out}$) will be calculated using following equations:

$$v_{s,in} = K_p \cdot C_{p,in} \sqrt{p_{avg,in}} \sqrt{\frac{T_{s,in}}{P_{s,in} \cdot M_{s,in}}} \qquad \textbf{(10)}$$

$$v_{s,out} = K_p \cdot C_{p,out} \sqrt{p_{avg,out}} \sqrt{\frac{T_{s,out}}{P_{s,out} \cdot M_{s,out}}} \qquad \textbf{(11)}$$

Where:

$v_{s,in}$ and $v_{s,out}$	=	Average inlet and outlet stack gas velocities (m/sec)
K_p	=	Velocity equation constant (=34.97)
$C_{p,in}$ and $C_{p,out}$	=	Inlet and outlet annubar device coefficients
$p_{avg,in}$ and $.p_{avg,in}$	=	Average inlet and outlet velocity head measurements b, measured across the annubar device (mmH_2O)
$T_{s,in}$ and $T_{s,out}$	=	Absolute inlet and outlet stack temperatures (K)
$P_{s,in}$ and $P_{s,out}$	=	Absolute inlet and outlet stack pressures (mmHg)
$M_{s,in}$ and $M_{s,out}$	=	Stack gas molecular weights at the inlet and outlet of the abatement system

Following US EPA Method 2, the averaged stack dry volumetric total flow rate at the inlet and outlet of the abatement device (Q_{in} and Q_{out} in standard cubic meters per second) will be calculated:

$$Q_{in} = \{(100 - B_{ws,in}) \div 100\} v_{s,in} A_{in} \left[\frac{T_{std} P_{s,in}}{T_{s,in} P_{std}} \right] \qquad \textbf{(12)}$$

$$Q_{out} = \{(100 - B_{ws,out}) \div 100\} v_{s,out} A_{out} \left[\frac{T_{std} P_{s,out}}{T_{s,out} P_{std}} \right] \qquad \textbf{(13)}$$

Where:

A_{in} and A_{out}	=	Cross-sectional areas of the inlet and outlet stacks (m^2)
T_{std}	=	Standard absolute temperature (293°K)
P_{std}	=	Standard absolute pressure (760 mm Hg)

The mass of SF_6 entering and exiting the abatement device per unit time ($E_{SF6,in}$ and $E_{SF6,out}$ in grams per second) will be calculated by multiplying the volumetric total flow rate (Q_{in} and Q_{out} in standard cubic meters per second) by the concentration of SF_6 at the inlet and outlet (in %) and by the SF_6 molar mass to molar volume ratio:[3]

$$E_{SF6in} = 65.18 Q_{in}[SF_{6in}]$$ **(14)**

$$E_{SF6out} = 65.18 Q_{out}[SF_{6out}]$$ **(15)**

Where:

SF_{6in} and SF_{6out} =   Concentration of SF_6 at the inlet and outlet (ppm)

Q_{in} and Q_{out} =   Inlet and Outlet volumetric flow rate (m^3/sec)

Project emissions

Project emissions include emissions due to the incomplete destruction of the SF_6 in the abatement unit and CO_2 emissions from electricity and/or fuel consumption in the abatement device along with any SF_6 entering the abatement device that is not operating within prescribed conditions.

Determination of the SF_6 destruction removal efficiency (DRE) of the abatement device

The SF_6 DRE will be calculated as follows:

$$DRE_y = 1 - \frac{E_{SF6,out,y}}{E_{SF6,in,y}}$$ **(16)**

Where:

DRE_y =   Destruction removal efficiency of the abatement unit

$E_{SF6,in,y}$ =   Mass of SF_6 gas entering the abatement device in year y

$E_{SF6,out,y}$ =   Mass of SF_6 gas exiting the abatement device in year y

Project emissions are calculated as following:

$$PE_y = BE_y(1 - DRE_y) + C_{CO2,y}$$ **(17)**

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[3] Where the volumetric to mass conversion factor is obtained by dividing the molar mass of SF_6 (146g/mole) by its molar volume (22.4l/mole), at standard conditions. Hence, each cubic meter of SF_6 entering the abatement device corresponds to 6,518g of SF_6.

Where:

PE_y	=	Project emissions during year y
$C_{CO2,y}$	=	Amount of CO_2 produced in a year from the operation of the abatement machine from electricity and/or fuel combustion in year y, calculated using the latest version of the "Tool to calculate baseline, project and/or leakage emissions from electricity consumption" and the "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion"

Quality assurance and quality control (QA/QC) procedures

In addition to the calculation of the standard deviations and R^2 values determined during the calibration procedures for the FTIR and QMS systems (see Annex 1.a.), the project developer will ensure conformance to the following QA/QC procedures:

Step 1: QA/QC procedure for the calibration and maintenance of the Annubar devices

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

Step 2: QA/QC procedure for maintenance of abatement system

The project developer will follow the abatement device manufacturer's recommendations for maintaining the abatement device, including inspection and cleaning procedures and replacement of consumable parts.

Step 3: QA/QC procedure for maintenance of FTIR system

To detect eventual drifts in the FTIR systems' calibration due to coating of the FTIR windows, the operator will perform periodic calibrations of the FTIR systems using the procedure described in Annex 1.a. If a deviation in the slope of the calibration curve of greater than 5% is detected (compared to the reference calibration slope generated during the initial evaluation period), the project developer will be required to clean or replace the FTIR windows and to repeat the FTIR calibration procedure described in Annex 1.a. The minimum frequency for the cleaning or replacement of the FTIR windows will be recorded as a non-monitored parameter. Note that a coating of the FTIR windows at the inlet of the abatement device will lead to a decrease of the FTIR absorbance and an underestimation of the quantity of SF_6 abated, resulting in a conservative estimate of the emissions baseline. Recalibration of the FTIR devices will be required every time the abatement device is brought offline for maintenance or every time the FTIR devices themselves are brought offline for maintenance.

Step 4: Annual surveillance test

For the annual surveillance test, the project will use the guidelines provided in EN14181 (Quality assurance of automated measuring systems). To ensure that the measurement conditions at the inlet and outlet of the abatement system have not changed during the crediting period, the project developer will repeat the QMSs, FTIRs and Annubar devices calibration procedures described in Annex 1.a and 1.b on a yearly basis.

Leakage

No leakage is expected from this methodology.

While some small amount of solid waste is generated from the operation of the abatement device that may require transportation to a landfill site, it will simply be combined with existing solid waste stream for disposal and will not by itself cause a noticeable rise in disposal transportation related emissions.

Emission reductions

Emission reductions are calculated as follows:

$$ER_y = BE_y - PE_y \tag{18}$$

Where:
ER$_y$ = Emission reductions in year y (t CO$_2$e/yr)
BE$_y$ = Baseline emissions in year y (t CO$_2$e/yr)
PE$_y$ = Project emissions in year y (t CO$_2$/yr)

Data and parameters not monitored

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

ID Number:	1
Parameter:	GWP of SF$_6$
Data unit:	kgCO2eq/kg SF$_6$
Description:	Global warming potential of SF$_6$
Source of data:	IPCC
Measurement procedures (if any):	Project participants should keep track of any change by the CDM Executive Board in the assigned GWP of SF$_6$
Any comment:	

ID Number:	2
Parameter:	Design capacity for existing Abatement Device ($CAP_{SF6,ex}$)
Data unit:	tonnes / year
Description:	Design capacity should be based the maximum flow allowed for normal operation of abatement device, based on the assumption that the existing abatement device is operating at full design capacity for the entire period of the year (i.e. 8760 hours).
Source of data:	Manufacturers specifications
Measurement procedures (if any):	None
Any comment:	

ID Number:	3
Parameter:	Historical SF$_6$ consumption ($C_{SF6,hist}$)
Data unit:	tonnes
Description:	Historical SF$_6$ consumption, calculated as the three years maximum consumption prior the implementation of the project activity before 31 January 2009. Consumption is defined as the total SF$_6$ purchased in a year, taking into account the change in inventory in a specific year.
Source of data:	Record of purchase and inventory
Measurement procedures (if any):	Record of purchase and inventory
Any comment:	

ID Number:	4
Parameter:	Historical production of LCD substrate (**SP$_{-i}$**)
Data unit:	m2
Description:	Historical production of LCD substrate (m^2) during year i (where i =-1, -2, -3) prior the implementation of the project activity before January, 31, 2009
Source of data:	Production, sales and inventory records
Measurement procedures (if any):	None
Any comment:	

ID Number:	5
Parameter:	Maintenance schedule for abatement device
Data unit:	List of maintenance requirements
Description:	Complete maintenance schedule for the device
Source of data:	Manufacturers specifications
Measurement procedures (if any):	None
Any comment:	

ID Number:	6
Parameter:	Maintenance schedule for FTIR measurement devices
Data unit:	List of maintenance requirements
Description:	Complete maintenance schedule for the device
Source of data:	QA/QC procedure following baseline emission section Step 3 "QA/QC procedure for maintenance of FTIR system"
Measurement procedures (if any):	None
Any comment:	

ID Number:	7
Parameter:	Maintenance schedule for Annubar devices
Data unit:	List of maintenance requirements and time between manual cleanup
Description:	Complete maintenance schedule for the Annubar devices
Source of data:	QA/QC procedure Step 1 in the project emissions section
Measurement procedures (if any):	The Annubar devices' head velocity will be measured before and after back-purging the Annubar devices with pressurized air to clean them. If the before and after velocity measurements are within 5 percent, then the data is acceptable. If the back-purging methodology is insufficient to ensure the Annubar devices cleanliness, the project developer will determine a suitable maintenance frequency and procedure to manually clean the Annubar devices.
Any comment:	

ID Number:	8
Parameter:	$C_{p.in}$
Data unit:	coefficient of the inlet Annubar device (dimensionless)
Description:	US EPA Method 2 or similar nationally- or internationally-recognized standard, annubar device manufacturer's calibration procedure
Source of data:	Annubar device manufacturer
Measurement procedures (if any):	See US EPA Method 2, section 10.0
Any comment:	

ID Number:	9
Parameter:	$C_{p.out}$
Data unit:	coefficient of the outlet annubar device (dimensionless)
Description:	US EPA Method 2 or similar nationally- or internationally-recognized standard, annubar device manufacturer's calibration procedure
Source of data:	Annubar device manufacturer
Measurement procedures (if any):	See US EPA Method 2, section 10.0
Any comment:	

ID Number:	10
Parameter:	Cross sectional area of the inlet stack (A_{in})
Data unit:	m^2
Description:	The cross sectional of the circular inlet stack, which should be greater than 0.3 m in diameter
Source of data:	EPA Method 1 or similar nationally- or internationally-recognized standard
Measurement procedures (if any):	Measured prior to validation, during commissioning of the SF$_6$ abatement system.
Any comment:	

ID Number:	11
Parameter:	Cross sectional area of the outlet stack (A_{out})
Data unit:	m^2
Description:	The cross sectional of the circular outlet stack, which should be greater than 0.3 m in diameter
Source of data:	EPA Method 1 or similar nationally- or internationally-recognized standard
Measurement procedures (if any):	Measured prior to validation, during commissioning of the SF$_6$ abatement system.
Any comment:	

III. MONITORING METHODOLOGY

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

Project proponents have to provide in the CDM-PDD information concerning the system in place to ensure the quality of the data. It should include the actions to be undertaken to constitute and to maintain the needed measurement equipment to satisfy the requirements concerning the quality of the data:

- The inventory, identification and the description of the measurement equipment used;
- The description of the QA/QC procedures for monitoring;
- The organizational structure and the responsibilities;
- The calibration and verification of the measurement equipment;
- The connecting of standard equipment to data logging devices;
- The process of recording data entries.

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

The steps required for the monitoring of the baseline and project emissions as well as the measures required to quantify uncertainties, ensure data quality, and conservativeness are as follows:

Step 1: Experimental setup for the monitoring methodology

The monitoring methodology will require the project developer to continuously measure several parameters concerning the operation of the abatement tool and the measurement devices, the gas flow velocities at the inlet and outlet, and the concentration of SF_6 at the inlet and outlet of the SF_6 abatement device. A schematic description of the monitoring setup is provided in Figure 2.

The effluents containing SF_6 and other byproducts (N_2, Ar, SiF_4, HF…) of the etch process are evacuated from the process chamber through vacuum pumps connected to each chamber. Water soluble toxic byproducts (HF, F_2, SiF_4…) are then removed from the effluent stream using point of use (POU) water scrubbers, such that only SF_6, N_2, Ar and oxygen are present at the inlet of the SF_6 abatement system. The POU water scrubbers do not remove SF_6, which has very low water solubility. The existing POU water scrubber units will be operated in a manner identical to the situation in the baseline scenario. The effluents from the POU system are piped to the SF_6 abatement system were SF_6 is destroyed by high-temperature combustion. The byproducts of the SF_6 combustion process (CO, CO_2, F_2, HF, SO_2, SOF_2, and SO_2F_2) are then passed through a final water scrubbing unit to remove the undesirable byproducts (in particular HF and F_2).

Under the monitoring procedure, two FTIR systems will be used to continuously monitor the concentration of SF_6 at the inlet and outlet of the SF_6 abatement system, while annubar devices will be used to continuously monitor the velocity of the gas entering and exiting the SF_6 abatement system. A calibration system will be used periodically to ensure that the calibration of the FTIR systems has not drifted (see Step "QA/QC procedure for maintenance of FTIR system"), and to recalibrate the FTIR units whenever the abatement device is brought offline for maintenance or whenever the FTIR monitor itself is brought offline for maintenance (See procedure "QA/QC procedure for maintenance and calibration of the FTIR systems")

The mass of the SF_6 entering and exiting the abatement device, the SF_6 DRE and the inlet and outlet flows will be calculated on a continuous basis, according to equations 12,13,14,15,and 16. All other parameters necessary to calculate the emissions baseline and the project emissions (fuel and electricity usage) will be monitored on a continuous basis. Continuous monitoring of the fuel flow will be used to ensure that the SF6 combustion process conditions do not significantly vary during the monitoring period, and to ensure that the molecular weight of the outlet gas stream does not significantly change, compared to the molecular weight of the outlet gas measured during the 6 hours initial evaluation period (at project start-up). The project proponents will ensure that the abatement system's fuel flow is regulated and will discount from the baseline any SF_6 entering the abatement system if the fuel flow deviates by more than +/- 5%, compared to the nominal flow rate determined during the initial evaluation period.
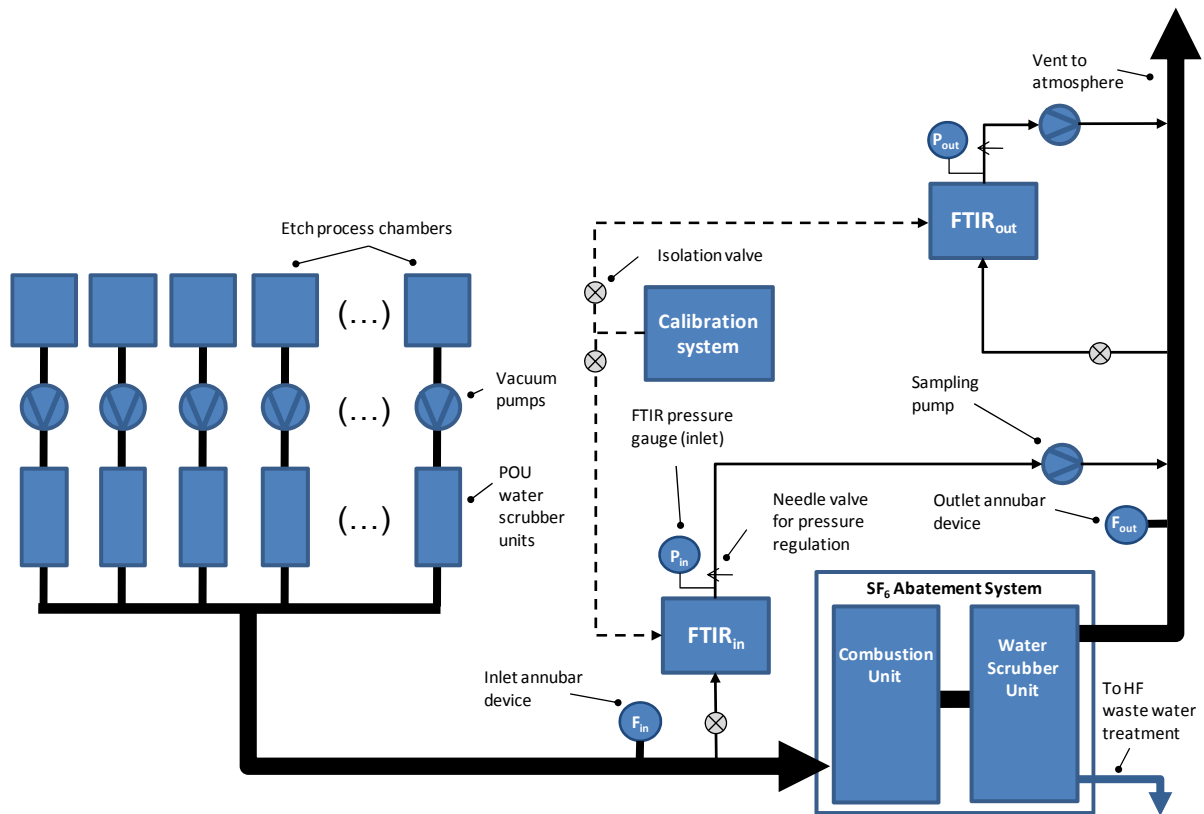
Figure 2: Schematic description of the treatment and monitoring setup

Step 2: Quality assurance, quality control, and conservativeness of the monitoring methodology

The proposed methodology relies on direct and continuous monitoring of all key parameters necessary to quantify the baseline and project emissions. As such, the method does not require projection of the baseline or of the project emissions and does not lead to an overestimation of emission reductions attributable to the project activity. In addition to following the QA/QC and uncertainty assessment procedures highlighted in the baseline section for the measurement of SF_6 concentration, and to following the QA/QC procedures of the US EPA Methods for measuring the flow, the project developer will ensure conformance to the following steps, throughout the entire monitoring period.

Step 2a: QA/QC procedure and conservativeness for monitoring of the inlet flow

The project developer will ensure that maintenance of the inlet annubar device is performed at least as frequently as determined in Step 1 of the baseline methodology procedure. By continuously monitoring the flow at the inlet of the abatement system ($Q_{,in}$), the project developer will ensure that the flow conditions at the inlet of the abatement system do not drift, compared to the measurement performed during determination of the baseline (i.e. .Q_{in} measured in Step 2.2.). As mentioned in Step 2.2, the

method provides a conservative measure to estimate the baseline emissions by taking the highest value of the gas molecular weight measured at the inlet to calculate the inlet flow. As an additional conservative measure, the project developer will discount from the crediting period any SF_6 emissions measured when the value of the gas flow measured at the inlet of the abatement system during the monitoring period decreases by more than 5%, compared to the baseline flow rate measured during Step 2.2 (i.e. if $.Q_{in, monitoring} < 0.95 .Q_{in, baseline}$). Indeed, a decrease of the total inlet flow would result in an increase in the SF_6 concentration, which could artificially increase the baseline if no flow compensation is accounted for. Should the gas flow measured at the inlet of the SF_6 abatement system drop below $0.95 . Q_{in, baseline}$, the project developer will identify the source of the issue (annubar device clogging or real decrease in inlet flow) and restore the nominal flow condition prior to resuming normal operation and measurements for emission reductions.

Step 2b: QA/QC procedure and conservativeness for monitoring of the outlet flow

The project developer will ensure that maintenance of the outlet annubar device is performed at least as frequently as determined in Step 1 of the baseline methodology procedure. By continuously monitoring the gas flow at the outlet of the abatement system ($Q_{,out}$), the project developer will ensure that the flow conditions at the outlet of the abatement system do not drift, compared to the measurement performed during determination of the baseline (i.e. $.Q_{out}$ measured in Step 2.2). As mentioned in Step 2.2, the method provides a conservative measure to estimate the project emissions by taking the lowest value of the gas molecular weight measured at the outlet to calculate the outlet flow. As an additional conservative measure, the project developer will discount from the crediting period any SF_6 emissions measured when the value of the gas flow measured at the outlet of the abatement system during the monitoring period increases by more than 5%, compared to the averaged velocity measured during Step 2.2 (i.e. if $.Q_{out,monitoring} > 1.05 .,Q_{out, baseline}$). Indeed, an increase in the total outlet flow would result in a decrease in the SF_6 concentration measured at the outlet, which could artificially increase the measurement of the DRE if no flow compensation is accounted for. Should the gas flow measured at the outlet of the SF_6 abatement system increase above $1.05 Q_{out, baseline}$, the project developer will identify the source of the issue (Annubar device clogging or real increase in inlet flow) and restore the nominal flow condition prior to resuming normal operation and measurements for emission reductions.

Step 2c: QA/QC procedure for maintenance and calibration of the FTIR systems

The project developer will ensure that the maintenance procedures of the FTIR systems are followed at least as often as the manufacturer's recommendation. The project developer will document very clearly to the DOE what the maintenance requirements of the FTIR devices are and will ensure that they have been followed in at least as rigorous a manner as required. The project developer will also ensure that the FTIR systems windows are maintained in conformance with the maintenance procedure determined in Step 3 "QA/QC procedure for maintenance of FTIR system" of the project emission section Recalibration of the FTIR devices will be required every time the abatement device is brought offline for maintenance or every time the FTIR devices themselves are brought offline for maintenance, following the calibration procedure. Obviously, the project developer will discount from the crediting period any emissions of SF_6 that could occur while any FTIR system is being maintained or calibrated.

Step 2d: QA/QC procedure for the maintenance of the abatement system

The project developer will ensure that the maintenance procedures of the SF_6 abatement system are followed at least as often as the manufacturer's recommendation. The project developer will document very clearly to the DOE what the maintenance requirements of the abatement device are and will ensure that they have been followed in at least as rigorous a manner as required.

Data and parameters monitored

Data / Parameter:	$E_{SF6,in,y}$
Data unit:	tonnes
Description:	Mass of SF_6 gas entering the abatement device in year y
Source of data:	From inlet FTIR and inlet Annubar devices
Measurement procedures (if any):	Annual sum of the mass of SF_6 entering the abatement device per unit time ($E_{SF6,in}$ in grams per second)
Monitoring frequency:	Annual
QA/QC procedures:	All of the manufacturer's maintenance and calibration procedures and timetables will be followed
Any comment:	To convert the concentration of SF_6 measured at the inlet of the abatement system into the mass of SF_6 entering the abatement system, the project developer will use the conservative measurement of the inlet gas molecular weight, and calculate the inlet gas flow from the measurement of the inlet gas velocity. This calculation will be done automatically by the control system and will provide the data unit as described above to be recorded on a continuous basis

Data / Parameter:	$C_{SF6,y}$
Data unit:	tonnes
Description:	Annual consumption of SF_6 during the project year y, defined as the total SF_6 purchased in a specific project year y taking into account the change in inventory in the same year
Source of data:	Record of purchase and inventory
Measurement procedures (if any):	Record of purchase and inventory
Monitoring frequency:	Annual
QA/QC procedures:	Cross check with purchase records
Any comment:	

Data / Parameter:	$SP_{project,y}$
Data unit:	m^2
Description:	Production of LCD substrate during the project year y
Source of data:	Production, sales and inventory records
Measurement procedures (if any):	Check production, sales and inventory records
Monitoring frequency:	Annual
QA/QC procedures:	Check production, sales and inventory records
Any comment:	

Data / Parameter:	$E_{SF6,in}$
Data unit:	Gram / second
Description:	Emissions of SF_6 gas measured at the inlet of the SF_6 abatement system
Source of data:	From inlet QMS, FTIR and outlet Annubar devices
Measurement procedures (if any):	Calculated by multiplying the volumetric total flow rate by the concentration of SF_6 at the inlet (in %) and by the SF_6 molar mass to molar volume ratio (6,518 gram / standard cubic meter).
Monitoring frequency:	Continuous
QA/QC procedures:	All of the manufacturer's maintenance and calibration procedures and timetables will be followed
Any comment:	See relevant provisions of the methodology. Only the values obtained when QMS, FTIR systems, Annubar devices or calibration are operating within required parameters are taken into account for the purpose of calculating $E_{SF6,in,y}$

Data / Parameter:	$E_{SF6,out}$
Data unit:	Gram / second
Description:	Emissions of SF_6 gas measured at the outlet of the SF_6 abatement system
Source of data:	From outlet FTIR and outlet Annubar devices
Measurement procedures (if any):	Calculated by multiplying the volumetric total flow rate by the concentration of SF_6 at the outlet (in %) and by the SF_6 molar mass to molar volume ratio (6,518 gram / standard cubic meter)
Monitoring frequency:	Continuous
QA/QC procedures:	All of the manufacturer's maintenance and calibration procedures and timetables will be followed.
Any comment:	See relevant provisions of the methodology. Only the values obtained when FTIR systems, Annubar devices or calibration are operating within required parameters are taken into account for the purpose of calculating $E_{SF6,out,y}$

Data / Parameter:	$M_{d,in}$
Data unit:	Gram / mole
Description:	Total dry molecular weight of inlet stack gas
Source of data:	QMS data
Measurement procedures (if any):	Quantifying the averaged relative concentrations of SF_6, Ar, O_2, CO_2 and N_2 (percentage mass fraction) measured by the QMS at the inlet of the abatement system during normal production conditions. $M_{d,in}$ shall be defined as the highest value of the gas molecular weight measured at the inlet during the 6 hours period per year, using equation 6
Monitoring frequency:	Once per year
QA/QC procedures:	Annex 1.a.
Any comment:	

Data / Parameter:	$M_{d,out}$
Data unit:	Gram / mole
Description:	Total dry molecular weight of outlet stack gas
Source of data:	QMS data
Measurement procedures (if any):	Quantifying the averaged relative concentrations of SF_6, Ar, O_2, N_2, CO, CO_2, F_2, HF, SO_2, SOF_2, and SO_2F_2 (percentage mass fraction) measured by the QMS at the outlet of the abatement system during normal production conditions. $M_{d,out}$ shall be defined as the highest value of the gas molecular weight measured at the inlet during the 6 hours period per year, using equation 7
Monitoring frequency:	Once per year
QA/QC procedures:	Annex 1.a.
Any comment:	

Data / Parameter:	$B_{ws,in}$
Data unit:	dimensionless (percentage volume fraction)
Description:	The proportion of water in the inlet gas stream measured using EPA Method 4, and used to calculate the inlet gas molecular weight.
Source of data:	EPA Method 4, as determined by measurement of volume or mass.
Measurement procedures (if any):	This measurement will be done for a minimum of 6 hours during normal manufacturing conditions. The averaged proportion of water during the 6 hours period will be used to calculate the inlet gas stream-total (wet) molecular weight (equation 8)
Monitoring frequency:	Once per year
QA/QC procedures:	Annex 1.a.
Any comment:	

Data / Parameter:	$B_{ws,out}$
Data unit:	dimensionless (percentage volume fraction)
Description:	The proportion of water in the outlet gas stream measured using EPA Method 4, and used to calculate the inlet gas molecular weight
Source of data:	EPA Method 4, as determined by measurement of volume or mass.
Measurement procedures (if any):	This measurement will be done for a minimum of 6 hours during normal manufacturing conditions. The averaged proportion of water during the 6 hours period will be used to calculate the inlet gas stream total (wet) molecular weight (equation 9)
Monitoring frequency:	Once per year
QA/QC procedures:	Annex 1.a.
Any comment:	

Data / Parameter:	$P_{s,in}$
Data unit:	mmHg
Description:	The inlet stack pressure measured during manufacturing operations
Source of data:	Pressure gauge
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	See EPA Method 2 or similar nationally- or internationally-recognized standard.; The inlet pressure gauge will be calibrated and maintained per the manufacturer's instructions

Data / Parameter:	$P_{s,out}$
Data unit:	mmHg
Description:	The outlet stack pressure measured during manufacturing operations
Source of data:	Pressure gauge
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	See EPA Method 2 or similar nationally- or internationally-recognized standard.; The inlet pressure gauge will be calibrated and maintained per the manufacturer's instructions

Data / Parameter:	$T_{s,in}$
Data unit:	K
Description:	The inlet stack temperature measured during manufacturing operations
Source of data:	Thermocouple
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	See EPA Method 2; The inlet temperature gauge will be calibrated and maintained per the manufacturer's instructions

Data / Parameter:	$T_{s,out}$
Data unit:	K
Description:	The outlet stack temperature measured during manufacturing operations
Source of data:	Thermocouple
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard; The outlet temperature gauge will be calibrated and maintained per the manufacturer's instructions.
Monitoring frequency:	Continuous
QA/QC procedures:	See EPA Method 2 or similar nationally- or internationally-recognized standard

Data / Parameter:	$p_{avg,in}$
Data unit:	mmH_2O
Description:	The averaged velocity head measurement used to calculate the inlet gas velocity in equation 10
Source of data:	Differential pressure gauge
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	The project proponents will completely discount from the baseline any SF_6 emitted during periods of times where the gas velocity measured at the inlet decreases by more than 5%, compared to the averaged velocity. See also EPA Method 2's QA/QC procedures

Data / Parameter:	$p_{avg,out}$
Data unit:	mmH$_2$O
Description:	The averaged velocity head measurement used to calculate the inlet gas velocity in equation 11
Source of data:	Differential pressure gauge
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	The project proponents will completely discount from the baseline any SF$_6$ emitted during period of times where the gas velocity measured at the outlet increases by more than 5%, compared to the averaged velocity. See also EPA Method 2's QA/QC procedures

Data / Parameter:	$v_{s,in}$
Data unit:	m/sec
Description:	Inlet gas velocity calculated using equation 10
Source of data:	Measurement of inlet gas velocity corrected for pressure and temperature variations
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	See EPA Method 2

Data / Parameter:	$v_{s,out}$
Data unit:	m/sec
Description:	Outlet gas velocity
Source of data:	Measurement of outlet gas velocity corrected for pressure and temperature variations
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	See EPA Method 2

Data / Parameter:	Q_{in}
Data unit:	m^3/s
Description:	Inlet volumetric flow rate
Source of data:	Measurement of inlet gas velocity corrected for pressure and temperature variations
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	See EPA Method 2 or similar nationally- or internationally-recognized standard

Data / Parameter:	Q_{out}
Data unit:	m^3/sec
Description:	Outlet volumetric flow rate
Source of data:	Measurement of outlet gas velocity corrected for pressure and temperature variations
Measurement procedures (if any):	See EPA Method 2 or similar nationally- or internationally-recognized standard
Monitoring frequency:	Continuous
QA/QC procedures:	See EPA Method 2 or similar nationally- or internationally-recognized standard

Data / Parameter:	Inlet SF_6 concentration
Data unit:	ppm
Description:	Inlet SF_6 concentration measured by FTIR
Source of data:	Inlet FTIR system
Measurement procedures (if any):	Conversion of FTIR absorbance measurement into concentration
Monitoring frequency:	Continuous
QA/QC procedures:	See Annex 1.a.: The inlet FTIR unit will be calibrated and maintained per the manufacturer's instructions

Data / Parameter:	Outlet SF_6 concentration
Data unit:	ppm
Description:	Outlet SF_6 concentration measured by FTIR
Source of data:	Outlet FTIR system
Measurement procedures (if any):	Conversion of FTIR absorbance measurement into concentration
Monitoring frequency:	Continuous
QA/QC procedures:	See Annex 1.a.; The outlet FTIR unit will be calibrated and maintained per the manufacturer's instructions

IV. REFERENCES AND ANY OTHER INFORMATION

2006 IPCC Guidelines for National Greenhouse Gas Inventories Vol. 3 Chapter 6, Electronics Industry Emissions
Guideline for Environmental Characterization of Semiconductor Process Equipment, International SEMATECH Manufacturing Initiative Technology Transfer #06124825A-ENG, 2006.
Protocol for Equipment Leak Emission Estimates, EPA-453/R-95-017, 1995, chapter 4.
EN14181- European Standards in English- Stationary source emissions. Quality assurance of automated measuring systems
US EPA Method 1 – Sample and velocity traverses for stationary sources.
<http://www.epa.gov/ttn/emc/promgate/m-01.pdf>
US EPA Method 2 – Determination of stack gas velocity and volumetric flow rate
<http://www.epa.gov/ttn/emc/promgate/m-02.pdf>
US EPA Method 4 – Determination of moisture content in stack gases
<http://www.epa.gov/ttn/emc/promgate/m-04.pdf>

Annex 1.a. Calibration of FTIR and QMS systems

Fourier transform infrared (FTIR) spectrometer - an analytical system that employs a source of mid-infrared radiation, an interferometer, an enclosed sample cell of known absorption path length, an infrared detector, optical elements that transfer infrared radiation between components, and a computer system. The time-domain detector response (interferogram) is processed by a Fourier transform to yield a representation of the detector response vs. infrared frequency. There are numerous manufacturers of FTIR and the device provides highly accurate results.
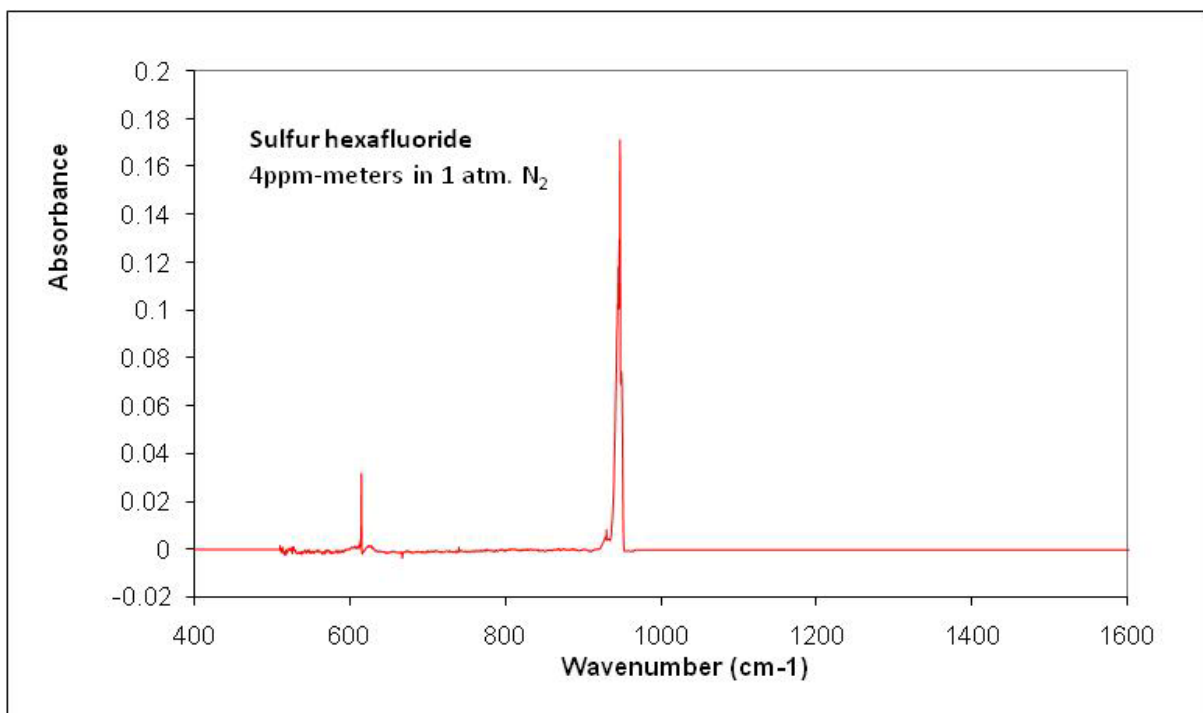

Chart 1: FTIR Spectrum of SF$_6$

Quadrupole Mass Spectrometer (QMS) – an analytical system that ionizes the atoms or molecules to be quantified and separates these ionized species according to their mass to electrical charge ratio. After separation, the individual ionized species are collected using a Faraday cup or an electron multiplier. The resulting current is proportional to the concentration of detected species in an effluent sample. The QMS allows to identify the type of species present in an effluent stream and to analyze their concentration and time dependency. Unlike FTIR, QMS is also sensitive to mono and diatomic species such as Ar, Kr, N$_2$, O$_2$, F$_2$ but may have limited ability to analyze molecules with high molar weight.
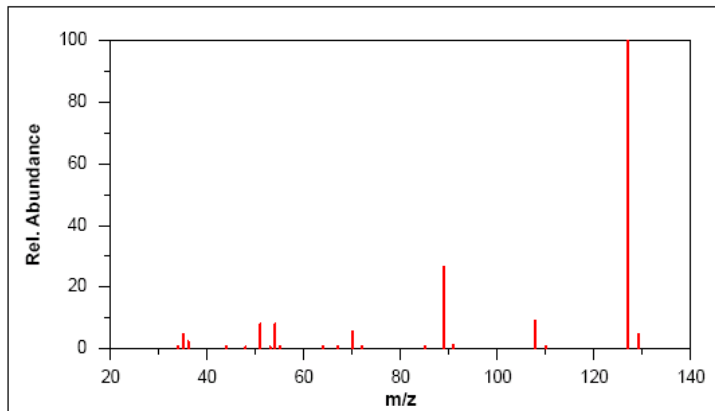
Chart 2: QMS spectrum of SF$_6$

The calibration of the FTIR and QMS systems will be performed using a standalone dynamic dilution calibration system equipped with at least two calibrated mass flow controllers (MFCs). A range of SF$_6$ concentrations will be generated by mixing an SF$_6$ standard (e.g. 1% SF$_6$ in N$_2$ ballast) with nitrogen, using two mass flow controllers. The pressure in the inlet and outlet sampling lines will be measured and maintained constant at slightly below atmospheric pressure (~700Torrs) using a pressure gauge and a needle valve to adjust the flow. The calibration system should be able to provide a flow of about 1slm (standard liters per minute).

For each QMS system, the operator will record a calibration curve and plot the QMS signal intensity (Faraday cup or electron amplifier current) as a function of the SF$_6$ concentration. For each FTIR system, the operator will record a calibration curve and plot the FTIR absorbance as a function of the SF$_6$ concentration. The operator will ensure that a minimum of 8 calibration points are generated for calibration of the inlet QMS and FTIR systems, and 8 separate calibration points for the outlet QMS and FTIR systems. The operator will ensure that the calibration points cover the proper range of SF$_6$ concentrations (SF$_{6min}$ to SF$_{6max}$), as measured during normal production of the etch process tools at the inlet and the outlet of the SF$_6$ abatement device (there will therefore be two separate ranges of SF$_6$ concentrations, one for the inlet and one for the outlet). The operator will ensure that each 8 concentration point is substantially equally spaced between the minimum (SF$_{6min}$) and the maximum (SF$_{6max}$) SF$_6$ concentrations expected during normal production conditions. For each calibration point, the operator will ensure that the FTIR and/or QMS signals have reached a stable intensity for at least two minutes. For the mid-range SF$_6$ concentration points (SF$_{6mid}$=(SF$_{6max}$+SF$_{6min}$)/2), the experiment will be repeated at least 5 times by turning the SF$_6$ MFC flow ON and OFF. Examples of the four calibration curves generated for each QMS and FTIR systems are depicted in chart 3 below.

For the calibration points corresponding to the middle of the SF$_6$ concentration being characterized (SF$_{6mid}$=(SF$_{6max}$+SF$_{6min}$)/2), which was repeated at least five time, the operator will calculate the standard deviation associated with the FTIR absorbance or QMS signal intensity. The standard deviation should be below 5%. For each FTIR and each QMS, the standard deviations are calculated as follows:

$$\sigma = \sqrt{\dfrac{\sum\limits_{i=0}^{n}(I_i - \bar{I})^2}{(n-1)}} \tag{1}$$

Where:

- I_i is the FTIR absorbance or QMS signal intensity recorded for the SF_6 concentration corresponding to the middle of the flow or concentration range being characterized for each experiment (i);
- n is the total number of experimental points being recorded by flowing SF_6 at constant concentration (SF_{6mid}), and by turning the SF_6 MFC ON and OFF between each recording (n≥5).

After completion of the experimental calibration procedure, the operator will fit the experimental data points of SF_6 FTIR absorbance or QMS signal intensity versus SF6 concentrations with linear curves (or other suitable fitting curves). The fitting procedure will 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 will be minimized, the residuals being defined as the difference between an observed value and the value given by the model. The operator will ensure that an R2 value of greater than 0.98 is obtained between the fitting curve and the experimental points. To ensure that no SF_6 flow or concentration is recorded when the etch 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 SF_6 is flown from the tool or the standalone calibration system). For each fitting curve, the R^2 values are calculated as follows:

$$R^2 = \left(\dfrac{\sum\limits_{i=0}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum\limits_{i=0}^{n}(x_i - \bar{x})^2 \sum\limits_{i=0}^{n}(y_i - \bar{y})^2}} \right)^2 \tag{2}$$

Where:

- x_i is the concentration of SF_6 generated by the dilution system for each point (i) of the calibration curve;
- y_i is the FTIR absorbance or QMS signal intensity recorded for each point (i) of the calibration curve;
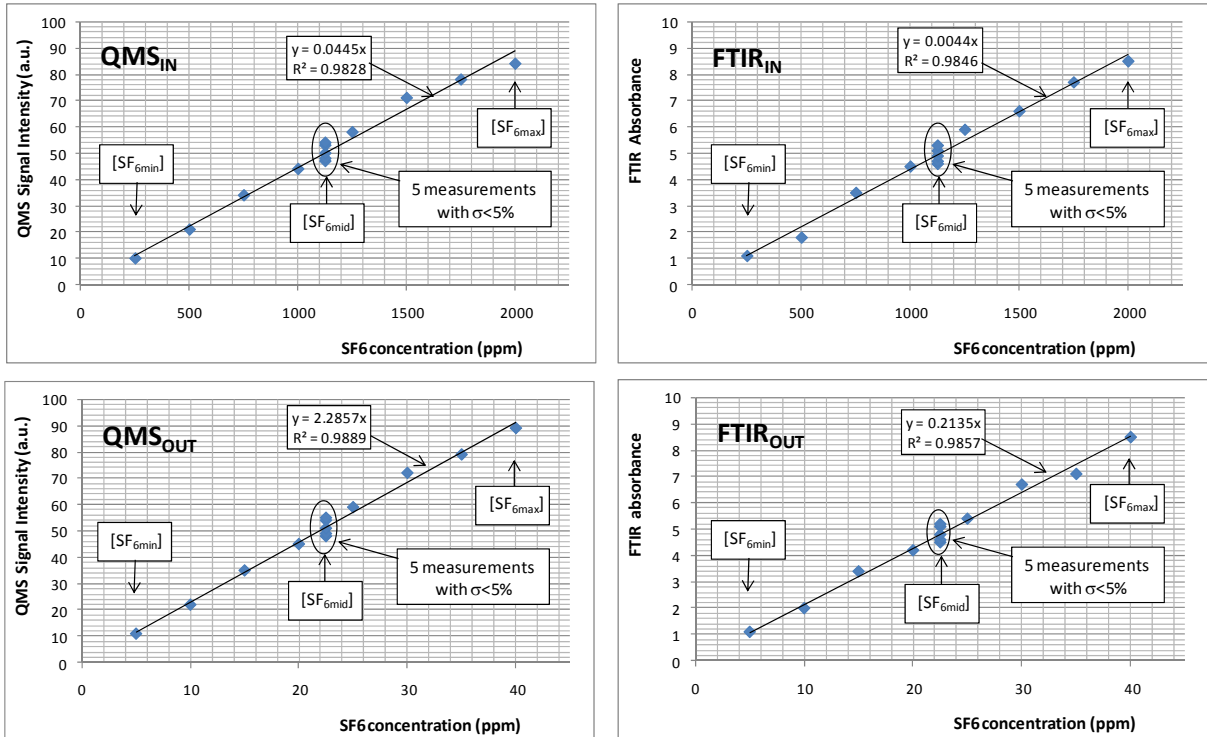- n is the total number of calibration points.

Chart 3: Examples of calibration curves for the inlet and outlet QMS and FTIR systems

Annex 1.b. Calibration of inlet and outlet Annubar Devices

Following US EPA Methods 1 and 2, the project developer should document for the validator the selection of sampling ports and traverse points at which sampling for SF_6 will occur in the inlet and outlet stacks, ensuring that the flow at the inlet and outlet of the abatement system is not cyclonic or swirling. Additionally, the project developer should document for the validator the use of equipment and testing methods required by US EPA Methods 1 and 2: the annubar device should be used to measure the inlet and outlet flow velocity; two differential pressure gauges should be used to measure the static and the impact pressures in the inlet and outlet stacks; two temperature sensors should be used to compensate for deviation from standard temperature conditions; and a barometer should be used as a reference to measure actual atmospheric pressure, during the measurement.

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History of the document

Version	Date	Nature of revision(s)
01.1	EB 47, Annex 5 28 May 2009	Editorial revision to clarify the applicability conditions.
01	EB 45, Annex 5 13 February 2009	Initial adoption.