



Approved baseline and monitoring methodology AM0078

“Point of Use Abatement Device to Reduce SF₆ 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 SF₆ 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 CO₂ emissions from fossil fuel combustion”;
- “Assessment of the validity of the original/current baseline and to update of the baseline at the renewal of the crediting period”.

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). A type of display that utilizes two sheets of polarizing material with a liquid crystal solution between them.

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.

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 versus 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 SF₆ from an LCD etching plant, which currently is venting the SF₆ to the atmosphere.

The methodology is applicable under the following conditions:

- The methodology only applies to existing production lines with at least 3 years of historical data for the most recent calendar years prior to the implementation of the project activity of SF₆ 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 validation of the project activity;
- The maximum SF₆ abatement capacity of the abatement system shall be higher than the maximum historical flow of SF₆ and effluents (SF₆ and all other by-products and diluents) entering the abatement system over the most recent three calendar years prior to the implementation of the project activity;
- No law or regulation which mandates decomposition, destruction, recycle or substitution of SF₆ or any component of exhaust gases containing SF₆ exist;
- The SF₆ destruction shall occur at the same industrial site where the SF₆ is used, and the SF₆ to be destroyed is not imported from other facilities;
- The measurement with respect to determining SF₆ flow to the abatement device are taken immediately before the abatement device, without any other devices located in between which are capable of changing the SF₆ 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 all permits concerning safety and health in order to install and operate the abatement device and monitoring facilities as required by applicable national law;
- SF₆ is not temporarily stored for subsequent destruction;
- It is demonstrated by test data by the manufacturer or the project participants that the abatement technology does not generate known non-CO₂ 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 not applicable to Chemical Vapor Deposition (CVD) processes that use SF₆.

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 an Alternative Scenario

The potential alternatives to this project include:

- (1) Undertaking this project, using an abatement device without CDM;
- (2) Continuing the use of SF₆ without any abatement;
- (3) Using a substitute gas for SF₆;
- (4) Process modifications/optimization to minimize SF₆ consumption;
- (5) SF₆ could be captured and recycled at the outlet of the vacuum pump.

After listing these alternatives (and others if appropriate), the project participants 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 SF₆ without any abatement” is the most plausible baseline scenario.

In most foreseeable project activities, as 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 provides 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 SF ₆ will not be abated via the project |

Baseline emissions

Baseline emissions for a crediting year y are calculated on the basis of mass of SF₆ 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 SF₆. Furthermore, any increase in SF₆ consumption per unit of surface area of LCD substrate processed will be discounted by a factor (k).

Baseline emissions are calculated as follows:

$$BE_y = k \times E_{SF6,y} \times GWP_{SF6} \quad (1)$$

Where:

- BE_y = Total baseline emissions in year y , (tonnes of CO₂)
 k = Discount factor to prevent any intentional increase of SF₆ entering into the etching process
 $E_{SF6,y}$ = Amount of eligible SF₆ emitted in the baseline in year y (tonnes)
 GWP_{SF6} = Global warming potential of SF₆ valid for the first commitment period (tonnes CO₂ per tonnes of SF₆)

Determination of $E_{SF6,y}$

Amount of eligible SF₆ emitted in the baseline in year y is determined as the minimum among:

- Mass of SF₆ gas entering the abatement device in year y ;
- Theoretically estimated amount of SF₆ emitted in year y ; and
- Theoretically estimated amount of SF₆ emitted in historical years.



This avoids the possibility to overestimate the baseline emissions by intentional increase of the SF₆ consumption.

$$E_{SF6,y} = \min \{ E_{SF6,in,adj,y}; 0.432 \times C_{SF6,y}; 0.432 \times C_{SF6,hist} \} \quad (2)$$

Where:

- $E_{SF6,y}$ = Amount of eligible SF₆ emitted in the baseline in year y (tonnes)
- $E_{SF6,in,adj,y}$ = Adjusted mass of SF₆ gas entering the abatement device in year y (tonnes)
- $C_{SF6,y}$ = Annual consumption of SF₆ during the project year y , defined as the total SF₆ purchased in a specific project year y , taking into account the change in inventory in the same year (tonnes)
- $C_{SF6,hist}$ = Historical SF₆ consumption (tonnes)
- 0.432 = Fraction of SF₆ consumed but not destroyed or transformed in the process. This is derived from the 2006 IPCC Guidelines default factor on destruction / decomposition (0.4), and factoring in 20% uncertainty, and 0.10 of default value for the fraction of gas remaining in the shipping container ((1-0.4) x 0.8 x (1-0.10) = 0.432)

Determination of $C_{SF6,hist}$

$$C_{SF6,hist} = \max(C_{SF6,-1}; C_{SF6,-2}; C_{SF6,-3}) \quad (3)$$

Where,

- $C_{SF6,hist}$ = Historical SF₆ consumption (tonnes)
- $C_{SF6,-1}, C_{SF6,-2}, C_{SF6,-3}$ = Historical SF₆ consumption during years prior the implementation of the project activity before 31 January 2009 (-1 is one year prior, -2 is two year prior and -3 is three year prior) (tonnes)

Determination of k

The value of k shall be determined as follows:

$$k = 1 \text{ if } SF_{6,ratio} \geq \frac{C_{SF6,y}}{SP_{project,y}} \quad (4)$$

otherwise,

$$k = \frac{SF_{6,ratio}}{C_{SF6,y} \div SP_{project,y}} \quad (5)$$

Where:

- k = Discount factor to prevent any intentional increase of SF₆ entering into the etching process
- $SP_{project,y}$ = Production of LCD substrate during the project year y (m²)
- $C_{SF6,y}$ = Annual consumption of SF₆ during the project year y , defined as the total SF₆ purchased in a specific project year y , taking into account the change in inventory in the same year (tonnes)
- $SF_{6,ratio}$ = Ratio of SF₆ consumption to the surface area of LCD substrate processed (tonnes/m²)

Determination of $SF_{6, ratio}$

$SF_{6, ratio}$ is determined as the historical ratio of SF_6 consumption to LCD production based on previous three years (-1, -2 and -3) prior the implementation of the project activity before 31 January 2009.

$$SF_{6, ratio} = \min \left(\frac{C_{SF6, -1}}{SP_{-1}}; \frac{C_{SF6, -2}}{SP_{-2}}; \frac{C_{SF6, -3}}{SP_{-3}}; 0.0002 \text{ t } SF_6 / m^2 \right) \quad (6)$$

Where:

- $SF_{6, ratio}$ = Ratio of SF_6 consumption to the surface area of LCD substrate processed (tonnes/ m^2)
- $C_{SF6, -1}, C_{SF6, -2}, C_{SF6, -3}$ = Historical SF_6 consumption in years prior to the implementation of the project activity before 31 January 2009 (-1 is one year prior, -2 is two year prior and -3 is three year prior) (tonnes)
- $SP_{-1}, SP_{-2}, SP_{-3}$ = Historical production of LCD substrate during years prior the implementation of the project activity before January, 31, 2009 (-1 is one year prior, -2 is two year prior and -3 is three year prior) (m^2)
- 0.0002 = 2006 IPCC Guidelines Tier 1 gas-specific emission factors for SF_6 emissions from semiconductor industry ($t \text{ } SF_6 / m^2$) ($0.2 \text{ kg-}SF_6 / m^2$ substrate)

Determination of $ESF_{6, in, adj, y}$

$ESF_{6, in, adj, y}$ is determined as:

$$E_{SF6, in, adj, y} = E_{SF6, in, y} - CAP_{SF6, ex} \quad (7)$$

Where:

- $E_{SF6, in, adj, y}$ = Adjusted mass of SF_6 gas entering the abatement device in year (tonnes)
- $E_{SF6, in, y}$ = Mass of SF_6 gas entering the abatement device in year y (tonnes)
- $CAP_{SF6, ex}$ = Design capacity of existing abatement device (only in cases where facilities have 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). In cases where facilities do not have existing abatement device, value of $CAP_{SF6, ex}$ is zero

Calibration of the measuring devices and measurement of the mass of SF_6 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.¹ The method for the calibration and QA/QC procedures for the annubar devices is provided in Annex 1.b.

To convert the concentrations of SF₆ measured at the inlet and outlet of the abatement system into masses of SF₆ entering and exiting the abatement system, measurement of the gas mass densities and of the gas flows shall be conducted. The mass of SF₆ is proportional to the product of the SF₆ 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}) shall be determined using US EPA Method 4 and measurement of the moisture content shall 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 SF₆, Ar, O₂, CO₂ and N₂ (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 hour measurement period during standard manufacturing operation.

The project participants shall demonstrate that the molecular weight of the inlet stack gas does not vary by more than +/- 5% around the mean value measured during the 6 hour period (if this is not fulfilled, the measurement shall be taken again). As a conservative measure, the project participants shall record the inlet gas molecular weight (M_{d,in}) as the highest value recorded during the 6 hour period. M_{d,in} shall be defined as the highest value of the gas molecular weight measured at the inlet during the 6 hour period, using equation 8:

$$M_{d,in} = 1.460 [SF_{6in}] + 0.44 [CO_{2in}] + 0.399 [Ar_{in}] + 0.320 [O_{2in}] + 0.280 [N_{2in}] \quad (8)$$

Where:

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

If gases other than N₂, O₂, Ar, CO₂ and SF₆ are present at the inlet of the abatement system at concentrations greater than 100ppmv, the project participants shall account for their contribution to 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 8. For example, if carbon monoxide (CO) 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 8. The QMS will be calibrated for any

¹ For such devices, the project participant should follow the manufacturer's recommendation for calibration, operation, and calculation of the flow.

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 SF₆ 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 SF₆, Ar, O₂, N₂, CO, CO₂, F₂, HF, SO₂, SOF₂ and SO₂F₂ (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 participants 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 hour 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 hour 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 hour period, using equation 9:

$$M_{d,out} = 1.460 [SF_{6out}] + 0.399 [Ar_{out}] + 0.320 [O_{2out}] + 0.280 [N_{2out}] + 0.28 [CO_{out}] \\ + 0.44 [CO_{2in}] + 0.380 [F_{2out}] + 0.200 [HF_{out}] + 0.641 [SO_{2out}] + 0.861 [SOF_{2out}] \\ + 1.021 [SO_2F_{2out}] \quad (9)$$

Where:

$M_{d,out}$ = Total outlet stack gas dry molecular weight (gram/mole)
 $SF_{6out}, \dots, SO_2F_{2out}$ = 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 participants 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 9. For example, if carbonyl fluoride (COF₂) 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 9.

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 SF₆ 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 10 and 11:

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

$$M_{s,out} = M_{d,out} \times \frac{100 - B_{ws,out}}{100} + 0.18 \times B_{ws,out} \quad (11)$$

Where:

$M_{s,in}$ and $M_{s,out}$ = Stack gas molecular weights at the inlet and outlet of the abatement system (gram/mole)
 $M_{d,in}$ 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:

$$v_{s,in} = K_p \times C_{p,in} \sqrt{p_{avg,in}} \sqrt{\frac{T_{s,in}}{P_{s,in} \times M_{s,in}}} \quad (12)$$

$$v_{s,out} = K_p \times C_{p,out} \sqrt{p_{avg,out}} \sqrt{\frac{T_{s,out}}{P_{s,out} \times M_{s,out}}} \quad (13)$$

Where:

- $v_{s,in}$ and $v_{s,out}$ = Average inlet and outlet stack gas velocities (m/sec)
- K_p = Velocity equation constant (=34.97 m/sec)
- $C_{p,in}$ and $C_{p,out}$ = Inlet and outlet annubar device coefficients (dimensionless)
- $p_{avg,in}$ and $p_{avg,out}$ = Average inlet and outlet velocity head measurements b, measured across the annubar device (mmH₂O)
- $T_{s,in}$ 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 (gram/mole)

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:

$$Q_{in} = \frac{100 - B_{ws,in}}{100} \times v_{s,in} \times A_{in} \times \left[\frac{T_{std} \times P_{s,in}}{T_{s,in} \times P_{std}} \right] \quad (14)$$

$$Q_{out} = \frac{100 - B_{ws,out}}{100} \times v_{s,out} \times A_{out} \times \left[\frac{T_{std} \times P_{s,out}}{T_{s,out} \times P_{std}} \right] \quad (15)$$

Where:

- Q_{in} and Q_{out} = Inlet and Outlet volumetric flow rate (m³/sec)
- $B_{ws,in}$ and $B_{ws,out}$ = Water vapor in the inlet and outlet gas streams (Percentage volume fraction)
- $v_{s,in}$ and $v_{s,out}$ = Average inlet and outlet stack gas velocities (m/sec)
- $T_{s,in}$ 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)
- A_{in} and A_{out} = Cross sectional areas of the circular inlet and outlet stacks, which should be greater than 0.3m in diameter (m²)
- T_{std} = Standard absolute temperature (293°K)
- P_{std} = Standard absolute pressure (760 mm Hg)



The mass of SF₆ 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 SF₆ at the inlet and outlet (in ppm) and by the SF₆ molar mass to molar volume ratio:²

$$E_{SF6,in} = 65.18 \times Q_{in} \times SF_{6in} \quad (16)$$

$$E_{SF6,out} = 65.18 \times Q_{out} \times SF_{6out} \quad (17)$$

Where:

| | |
|--------------------------------|---|
| $E_{SF6,in}$ and $E_{SF6,out}$ | = Emissions of SF ₆ gas measured at the inlet and outlet of the abatement system (grams/sec) |
| SF_{6in} and SF_{6out} | = Inlet and Outlet SF ₆ concentration (percentage volume fraction) |
| Q_{in} and Q_{out} | = Inlet and Outlet volumetric flow rate (m ³ /sec) |
| 65.18 | = Constant |

Project emissions

Project emissions include:

- (a) Emissions due to the incomplete destruction of the SF₆ in the abatement unit; and
- (b) CO₂ emissions from electricity and/or fuel consumption in the abatement device along with any SF₆ entering the abatement device that is not operating within prescribed conditions.

Project emissions are calculated as following:

$$PE_y = PE_{SF6,y} + PE_{FC,y} + PE_{EC,y} \quad (18)$$

Where:

| | |
|--------------|---|
| PE_y | = Project emissions during year y (tonnes of CO ₂) |
| $PE_{SF6,y}$ | = Project emissions due to the incomplete destruction of the SF ₆ in the abatement unit in year y (tonnes of CO ₂) |
| $PE_{FC,y}$ | = Project emissions due to fossil fuel combustion in year y (tonnes of CO ₂) |
| $PE_{EC,y}$ | = Project emissions due to electricity consumption in year y (tonnes of CO ₂) |

Determination of project emissions due to the incomplete destruction of the SF₆ in the abatement unit

The emissions due to SF₆ emitted from the abatement system are estimated through the following equation:

$$PE_{SF6,y} = E_{SF6,out,y} \times GWP_{SF6} \quad (19)$$

² Where the volumetric to mass conversion factor is obtained by dividing the molar mass of SF₆ (146g/mole) by its molar volume (22.4l/mole), at standard conditions. Hence, each cubic meter of SF₆ entering the abatement device corresponds to 6,518g of SF₆.

Where:

- $PE_{SF_6,y}$ = Project emissions due to the incomplete destruction of the SF₆ in the abatement unit in year y (tonnes of CO₂)
- $E_{SF_6,out,y}$ = Mass of SF₆ gas exiting the abatement device in year y (tonnes)
- GWP_{SF_6} = Global warming potential of SF₆ (tonnes CO₂ per tonnes of SF₆)³

Determination of project emissions due to fossil fuel combustion

Project emissions from fossil fuel combustion in year y ($PE_{FC,y}$) are calculated using the latest approved version of the “Tool to calculate project or leakage CO₂ emissions from fossil fuel combustion”, where the sources j in the tool correspond to all sources of fossil fuel consumption by the project activity, including the abatement system. All emission sources should be documented transparently in the CDM-PDD.

Determination of project emissions due to electricity consumption

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

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 participants 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 participants 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 participants 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 participants will record the maintenance schedule as a non-monitored parameter.

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

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

³ 23.9 tonnes CO₂/kg SF₆ - see IPCC 4th assessment.

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 participants 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 SF₆ 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 participants 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:

$$ER_y = BE_y - PE_y \quad (20)$$

Where:

- ER_y = Emission reductions in year y (tonnes of CO₂)
- BE_y = Baseline emissions in year y (tonnes of CO₂)
- PE_y = Project emissions in year y (tonnes of CO₂)

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

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

**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.

| | |
|----------------------------------|--|
| Parameter: | GWP_{SF_6} |
| Data unit: | tonnes CO ₂ -e per tonnes of SF ₆ |
| Description: | Global warming potential of SF ₆ valid for the first commitment period |
| Source of data: | A value of 23,900 shall be applied Source: IPCC Second Assessment Report |
| 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: | |

| | |
|----------------------------------|---|
| Parameter: | $CAP_{SF_6,ex}$ |
| Data unit: | tonnes / year |
| Description: | 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) |
| Source of data: | Manufacturers specifications |
| Measurement procedures (if any): | None |
| Any comment: | |

| | |
|----------------------------------|---|
| Parameter: | $C_{SF_6,-1}, C_{SF_6,-2}, C_{SF_6,-3}$ |
| Data unit: | tonnes |
| Description: | Historical SF ₆ consumption in years prior to the implementation of the project activity before 31 January 2009 (-1 is one year prior, -2 is two year prior and -3 is three year prior). 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: | |

| | |
|----------------------------------|---|
| Parameter: | $SP_{-1}, SP_{-2}, SP_{-3}$ |
| Data unit: | m ² |
| Description: | Historical production of LCD substrate during years prior the implementation of the project activity before 31 January 2009 (-1 is one year prior, -2 is two year prior and -3 is three year prior) |
| Source of data: | Production, sales and inventory records |
| Measurement procedures (if any): | None |
| Any comment: | |



| | |
|----------------------------------|--|
| 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: | |

| | |
|----------------------------------|---|
| 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: | |

| | |
|----------------------------------|--|
| 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 participants will determine a suitable maintenance frequency and procedure to manually clean the Annubar devices |
| Any comment: | |

| | |
|----------------------------------|--|
| 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: | |

| | |
|----------------------------------|--|
| 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: | |



| | |
|---|--|
| Parameter: | A_{in} |
| Data unit: | m^2 |
| Description: | Cross-sectional area 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: | |

| | |
|---|---|
| Parameter: | A_{out} |
| Data unit: | m^2 |
| Description: | Cross-sectional area 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 participants 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 participants 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 SF₆ at the inlet and outlet of the SF₆ abatement device. A schematic description of the monitoring setup is provided in Figure 1.

The effluents containing SF₆ and other byproducts (N₂, Ar, SiF₄, HF...) of the etch process are evacuated from the process chamber through vacuum pumps connected to each chamber. Water soluble toxic byproducts (HF, F₂, SiF₄...) are then removed from the effluent stream using point of use (POU) water scrubbers, such that only SF₆, N₂, Ar and oxygen are present at the inlet of the SF₆ abatement system. The POU water scrubbers do not remove SF₆, 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 SF₆ abatement system where SF₆ is destroyed by high-temperature combustion. The byproducts of the SF₆ combustion process (CO, CO₂, F₂, HF, SO₂, SOF₂, and SO₂F₂) are then passed through a final water scrubbing unit to remove the undesirable byproducts (in particular HF and F₂).

Under the monitoring procedure, two FTIR systems will be used to continuously monitor the concentration of SF₆ at the inlet and outlet of the SF₆ abatement system, while annubar devices will be used to continuously monitor the velocity of the gas entering and exiting the SF₆ 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 SF₆ entering and exiting the abatement device, and the inlet and outlet flows will be calculated on a continuous basis, according to equations 14, 15, 16, and 17. 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 hour initial evaluation period (at project start-up). The project participants will ensure that the abatement system’s fuel flow is regulated and will discount from the baseline any SF₆ 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.

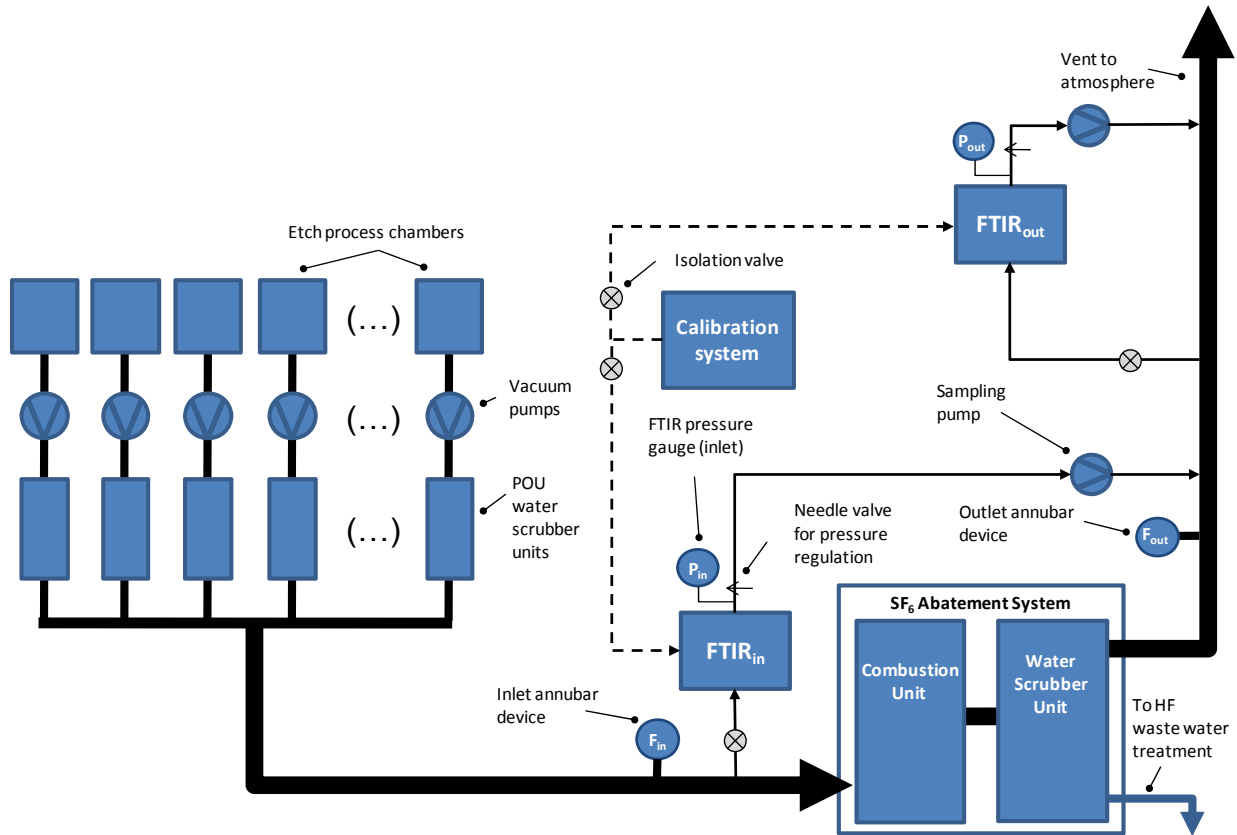


Figure 1: Schematic description of the treatment and monitoring setup

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 SF₆ concentration, and to following the QA/QC procedures of the US EPA Methods for measuring the flow, the project participants 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 participants 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 participants 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 participants will discount from the crediting period any SF₆ 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 $Q_{in, monitoring} < 0.95 \cdot Q_{in, baseline}$). Indeed, a decrease of the total inlet flow would result in an increase in the SF₆ concentration, which could artificially increase the baseline if no flow compensation is accounted for. Should the gas flow measured at the inlet of the SF₆ abatement system drop below $0.95 \cdot Q_{in, baseline}$, the project participants 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 participants 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 participants 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 participants will discount from the crediting period any SF₆ 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 $Q_{out, monitoring} > 1.05 \cdot Q_{out, baseline}$). Should the gas flow measured at the outlet of the SF₆ abatement system increase above $1.05 \cdot Q_{out, baseline}$, the project participants 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 participants will ensure that the maintenance procedures of the FTIR systems are followed at least as often as the manufacturer's recommendation. The project participants will document 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 participants 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. The project participants will discount from the crediting period any emissions of SF₆ 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 participants will ensure that the maintenance procedures of the SF₆ abatement system are followed at least as often as the manufacturer's recommendation. The project participants 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: | $E_{SF_6, in, y}$ |
| 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 ($E_{SF_6, in}$ 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 participants 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: | $E_{SF_6, out, y}$ |
| Data unit: | tonnes |
| Description: | Mass of SF ₆ gas exiting the abatement device in year y |
| Source of data: | From outlet FTIR and outlet Annubar devices |
| Measurement procedures (if any): | Annual sum of the mass of SF ₆ exiting the abatement device per unit time ($E_{SF_6, out}$ 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 outlet of the abatement system into the mass of SF ₆ existing the abatement system, the project participants will use the conservative measurement of the outlet gas molecular weight, and calculate the outlet gas flow from the measurement of the outlet 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: | $C_{SF_6, y}$ |
| 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: | $SP_{\text{project},y}$ |
| 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: | $E_{\text{SF}_6,\text{in}}$ |
| 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 $E_{\text{SF}_6,\text{in},y}$ |

| | |
|----------------------------------|--|
| Data / Parameter: | $E_{\text{SF}_6,\text{out}}$ |
| 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 $E_{\text{SF}_6,\text{out},y}$ |

| | |
|--------------------------|--|
| Data / Parameter: | $M_{\text{d},\text{in}}$ |
| Data unit: | Gram / mole |
| Description: | Total dry molecular weight of the inlet stack gases, dry basis |
| 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 hour period per year, using equation 8 |
| 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 the outlet stack gases, dry basis |
| 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 ₂ F 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 hour period per year, using equation 9 |
| Monitoring frequency: | Once per year |
| QA/QC procedures: | Annex 1.a. |
| Any comment: | |

| | |
|----------------------------------|--|
| Data / Parameter: | $B_{ws,in}$ |
| Data unit: | Percentage volume fraction |
| Description: | Water vapor in the inlet gas streams |
| 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 hour period will be used to calculate the inlet gas stream total (wet) molecular weight (equation 10) |
| Monitoring frequency: | Once per year |
| QA/QC procedures: | Annex 1.a. |
| Any comment: | |

| | |
|----------------------------------|--|
| Data / Parameter: | $B_{ws,out}$ |
| Data unit: | Percentage volume fraction |
| Description: | Water vapor in the outlet gas streams |
| 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 hour period will be used to calculate the inlet gas stream total (wet) molecular weight (equation 11) |
| Monitoring frequency: | Once per year |
| QA/QC procedures: | Annex 1.a. |
| Any comment: | |



| | |
|----------------------------------|---|
| Data / Parameter: | $P_{s,in}$ |
| Data unit: | mmHg |
| Description: | Absolute inlet stack pressures |
| 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: | Absolute outlet stack pressures |
| 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: | Absolute inlet stack temperatures |
| 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: | Absolute outlet stack temperatures |
| 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 ₂ O |
| Description: | Average inlet velocity head measurements b, measured across the annubar device |
| 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 participants 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: | Average outlet velocity head measurements b, measured across the annubar device |
| 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 participants 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: | Average inlet stack gas velocities |
| 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: | Average outlet stack gas velocities |
| 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: | SF_{6in} |
| Data unit: | ppm |
| Description: | Inlet SF_6 concentration |
| 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: | SF_{6out} |
| Data unit: | ppm |
| Description: | Outlet SF_6 concentration |
| 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 versus infrared frequency. There are numerous manufacturers of FTIR and the device provides highly accurate results.

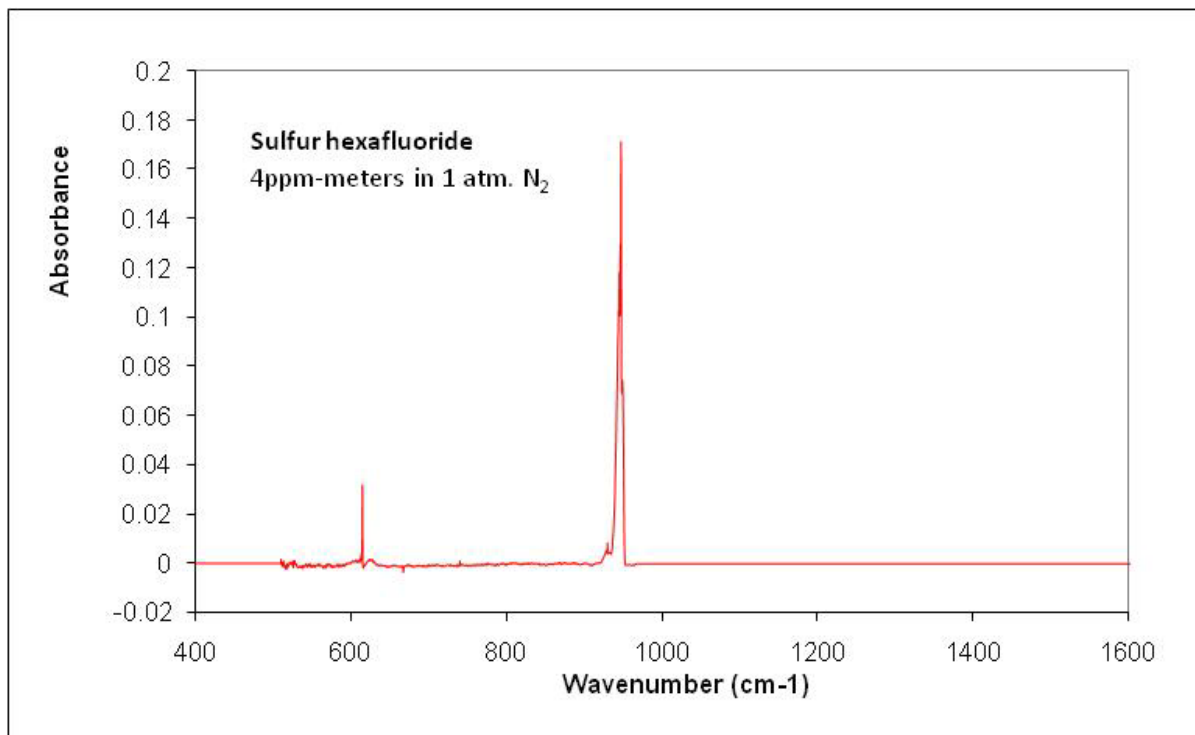


Chart 1: FTIR Spectrum of SF₆

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, N₂, O₂, F₂ but may have limited ability to analyze molecules with high molar weight.

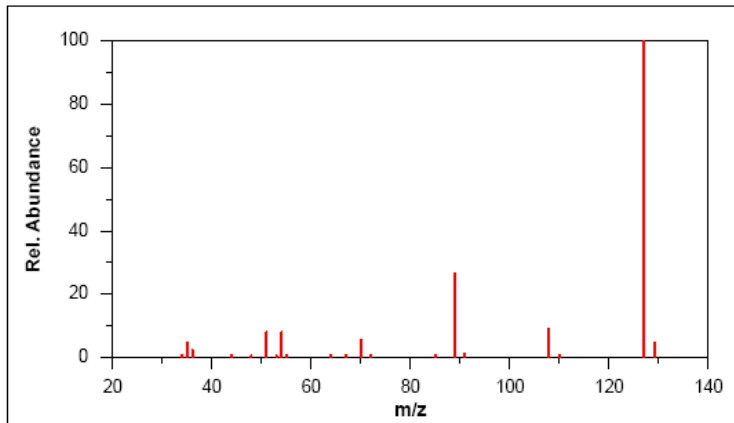


Chart 2: QMS spectrum of SF₆

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 SF₆ concentrations will be generated by mixing an SF₆ standard (e.g. 1% SF₆ in N₂ 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 (~700Torr) 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 SF₆ concentration. For each FTIR system, the operator will record a calibration curve and plot the FTIR absorbance as a function of the SF₆ 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 SF₆ concentrations (SF_{6min} to SF_{6max}), as measured during normal production of the etch process tools at the inlet and the outlet of the SF₆ abatement device (there will therefore be two separate ranges of SF₆ 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}) SF₆ 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 SF₆ concentration points (SF_{6mid}=(SF_{6max}+SF_{6min})/2), the experiment will be repeated at least 5 times by turning the SF₆ 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 SF₆ 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:

$$\sigma = \sqrt{\frac{\sum_{i=0}^n (I_i - \bar{I})^2}{(n-1)}} \quad (1)$$

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 ($\text{SF}_{6\text{mid}}$), and by turning the SF_6 MFC ON and OFF between each recording ($n \geq 5$).

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 SF_6 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 R^2 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:

$$R^2 = \left(\frac{\sum_{i=0}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=0}^n (x_i - \bar{x})^2 \sum_{i=0}^n (y_i - \bar{y})^2}} \right)^2 \quad (2)$$

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.

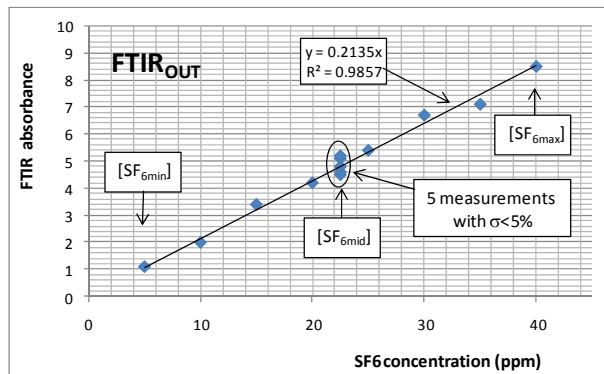
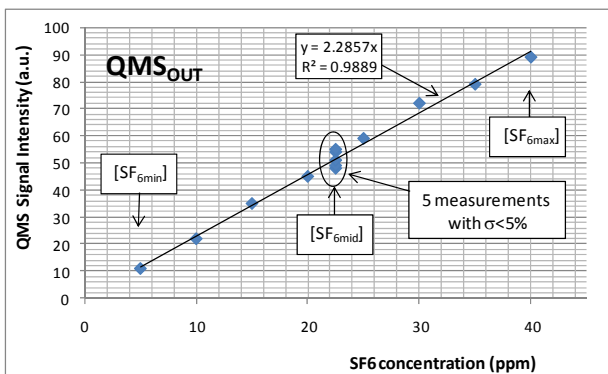
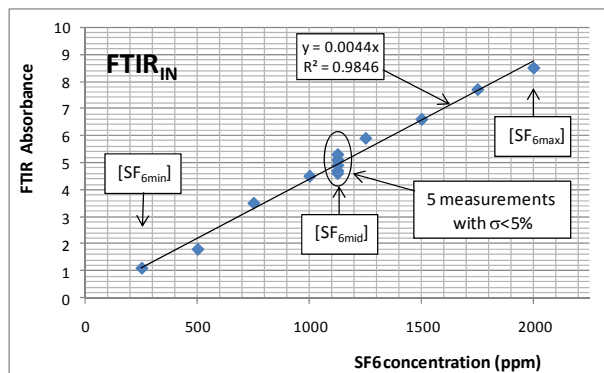
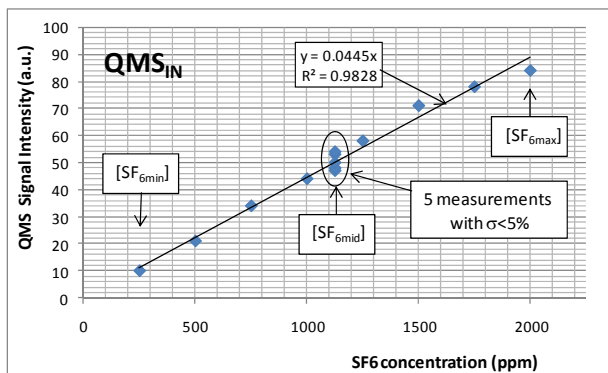


Chart 3: Examples of calibration curves for the inlet and outlet QMS and FTIR systems

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

Following US EPA Methods 1 and 2, the project participants should document for the validator the selection of sampling ports and traverse points at which sampling for SF₆ 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 participants 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.

- - - - -

History of the document

| Version | Date | Nature of revision(s) |
|--|------------------------------------|---|
| 02.0.0 | EB 66, Annex 34 2 March 2012 | Revision to: <ul style="list-style-type: none"> • Improve and reorganize the procedure to determine the amount of eligible SF₆ that would be emitted in the baseline; • Change the default value of the fraction of SF₆ consumed but not destroyed or transformed in the process to account for the fraction of gas remaining in the shipping container; • Include a cap for the ratio of SF₆ consumption to the surface area of LCD substrate processed, based on the Tier 1 emission factor provided in the 2006 IPCC Guidelines; • Revise the procedure to calculate project emissions to directly monitor SF₆ emissions from the abatement device; • Improve the clarity of the language; and • Add reference to methodological tool "Assessment of the validity of the original/current baseline and to update of the baseline at the renewal of the crediting period" and include requirements at the renewal of the crediting periods. |
| 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. |
| Decision Class: Regulatory Document Type: Standard Business Function: Methodology | | |